ABSTRACT

Dissertation submitted for the degree of Philosophy Doctor (PhD) in the educational program «8D05307 – Physics and Astronomy»

BAKYTKYZY AIGERIM

EVOLUTIONARY STATUS OF AS314: A COMPARATIVE STUDY WITH LUMINOUS BLUE VARIABLES AND POST-AGB STARS

General characteristics of the work

The study of stellar evolution is one of the key directions in modern astrophysics. A star's mass, luminosity, and chemical composition determine its evolutionary path, while the structure of its atmosphere and the properties of its stellar wind change significantly during evolution. One of the objects whose nature remains controversial is the star AS314. In the literature, it has been classified either as a low-mass post-AGB star or as an object exhibiting properties typical of luminous blue variables (LBVs). This contradiction necessitated a comprehensive investigation of the evolutionary status of AS314.

In this work, a comprehensive analysis of photometric and spectroscopic observational data of AS314 was carried out. The study utilized long-term photometric data from the ASAS-SN and ASAS-3 surveys, photometric results from the Gaia EDR3 and WISE space missions, as well as infrared observations from the AKARI, MSX, and IRAS missions. In addition, high-resolution spectra obtained at several observatories were analyzed. Data reduction and processing were performed using the IRAF package and modern spectral analysis tools, allowing a detailed study of the star's spectral features and diffuse interstellar bands.

To determine the main physical parameters, the spectral energy distribution was modeled using Castelli – Kurucz stellar atmosphere models and the DUSTY radiative transfer code. This approach enabled the estimation of the photospheric parameters as well as the temperature and optical depth of the circumstellar dust shell. The position of the star on the Hertzsprung – Russell diagram was determined and compared with the evolutionary tracks of post-AGB and LBV stars.

As a result, the fundamental physical parameters of AS314 – luminosity, mass, radius, distance, and interstellar extinction were determined. The activity of the stellar wind, the dynamics of spectral line profiles, and the possibility of a binary component were also investigated. The performed analysis allowed us to clarify the physical nature and evolutionary status of the star.

The combination of photometric, spectroscopic, and modeling approaches provided a comprehensive understanding of the nature of AS314 and its evolutionary position.

Relevance of the topic

Accurate classification of stars is one of the fundamental tasks of modern astrophysics, as determining the evolutionary status of a star makes it possible to understand stellar life cycles, matter circulation within the Galaxy, and its chemical

evolution. According to current estimates, approximately 70–80% of stars at advanced evolutionary stages belong to binary or multiple systems. In such systems, complex processes such as mass transfer and the redistribution of gas and dust occur, leading to the formation of circumstellar dust shells that enrich the interstellar medium.

Post-AGB stars and luminous blue variables (LBVs) represent important examples of objects at advanced evolutionary stages. Post-AGB stars are low-mass objects that have lost a significant fraction of their mass and outer envelope and are evolving toward white dwarfs or central stars of planetary nebulae. LBVs, in contrast, are extremely luminous and unstable massive stars undergoing intense mass loss and potentially evolving into Wolf – Rayet stars or ending their lives as supernovae. Both types play a crucial role in enriching the interstellar medium with heavy elements and contribute significantly to galactic chemical evolution.

However, distinguishing between these two classes remains a challenging problem in astrophysics. Their spectral and photometric properties often overlap: both exhibit prominent Balmer lines and other characteristic spectral features, and both may be surrounded by circumstellar dust shells or disk-like structures. Their temperature ranges can also overlap, further complicating the determination of their evolutionary status.

The evolutionary connection between LBV and post-AGB stars has not yet been fully established. Some objects display properties characteristic of both classes. AS314 is one such rare intermediate-type object, and a comprehensive study of this star may help clarify the evolutionary boundary between these two groups.

In previous studies, AS314 has been interpreted either as a low-mass post-AGB star or as a luminous blue variable. This contradiction may be related to its photometric stability, complex spectral line profiles, and the presence of a pronounced circumstellar dust shell.

Studying objects such as AS314 is important not only for determining the evolutionary nature of a single star but also for understanding the physical processes occurring in massive stars at advanced evolutionary stages. Such stars play a major role in galactic chemical evolution by injecting heavy elements and dust into the interstellar medium.

The Gaia mission currently provides high-precision measurements of stellar distances, enabling improved estimates of luminosities and evolutionary positions on the Hertzsprung–Russell diagram. Nevertheless, for objects with complex spectral properties like AS314, Gaia data may require careful interpretation, since interstellar extinction, dust effects, complex atmospheric geometry, and strong emission lines can lead to underestimated luminosity values.

Therefore, determining the nature of AS314 is not merely the study of an individual object but also an important step toward understanding the evolutionary connection between post-AGB and LBV stars, as well as the mechanisms of mass loss and galactic chemical evolution.

Aim of the work

The main objective of this work is to conduct a comprehensive investigation of the evolutionary nature of the star AS314. For this purpose, photometric data obtained in different wavelength ranges and optical spectroscopic observations were analyzed.

The study focused on determining the fundamental physical parameters of the star, identifying distinctive spectral features, estimating interstellar extinction, and examining the surrounding circumstellar dust shell. By comparing the obtained results with the properties of LBV and post-AGB objects, the evolutionary nature of AS314 was interpreted.

Main tasks of the research

– Analysis of the spectral and photometric data of AS314 and modeling of its spectral energy distribution using Castelli – Kurucz atmospheric models and the DUSTY radiative transfer code to determine its fundamental physical parameters and the structure of the circumstellar dust shell.

– Determination of the luminosity, radius, and mass of AS314, construction of its position on the Hertzsprung – Russell diagram, and estimation of the distance using the Bayestar2019 map, followed by comparison with LBV and post-AGB objects to clarify its evolutionary status.

– Analysis of the light curve and spectral line profiles to investigate the atmospheric dynamics of the star and to test for the presence of orbital motion and a possible binary component.

Object of research: AS314.

Subject of the study: The spectral and photometric properties of the star AS314, its evolutionary nature, fundamental parameters (effective temperature, luminosity, radius, mass, distance, interstellar extinction), spectral energy distribution, stellar wind dynamics, and orbital motion.

Research methods

– Collection and analysis of photometric and high-resolution spectroscopic data of AS314, and modeling of its spectral energy distribution using Castelli –Kurucz stellar atmosphere models and the DUSTY radiative transfer code.

– Construction of the Hertzsprung – Russell diagram, estimation of the distance using the Bayestar2019 dust map, calculation of the physical parameters of AS314, and comparative analysis with LBV and post-AGB type stars.

– Application of cross-correlation analysis to photometric and high-resolution spectroscopic data, construction of the light curve, determination of radial velocities, and investigation of atmospheric dynamics and orbital motion using the Doppler effect.

Basic statements submitted for defense. The following statements are submitted for defense

1. Spectral energy distribution modeling shows that the effective temperature of AS314 is 10 000 K, and the star is surrounded by an optically thin circumstellar dust shell with an optical depth of $\tau \approx 0.1$.

2. Based on its physical parameters and spectral characteristics, AS314 exhibits properties typical of LBV stars, and its luminosity is approximately 50 times higher than that of typical post-AGB stars.

3. Variations in the light curve and shifts in spectral line profiles are not caused by a binarity but are due to the dynamics of a variable stellar wind with velocities of 100–200 km/s.

Research Results

1. Spectral energy distribution modeling has shown that the effective temperature of AS314 is approximately 10000 K. The presence of an optically thin graphite–silicate dust shell with an optical depth of $\tau \approx 0.1$ has been determined.

2. A comparative analysis of the spectral, photometric, and physical parameters of AS314 (luminosity $\log(L/L_{\odot}) \approx 5.2$, radius $R \approx 130R_{\odot}$, mass $M \approx 60M_{\odot}$, distance $d \approx 10$kpc) with LBV and post-AGB type stars has established that its luminosity and mass are approximately 50 times higher than those of typical post-AGB stars ($\log(L/L_{\odot}) \approx 3.5$). It has been demonstrated that the physical characteristics of AS314 are consistent with luminous LBV-type stars.

3. The analysis of the light curve and temporal variations of radial velocities has shown the absence of a stable periodicity. From Doppler shifts of the Balmer lines H_{α}, H_{β}, and H_{γ}, the stellar wind velocity toward the observer has been determined to be 100–200 km/s. It has been demonstrated that these variations are not caused by orbital motion but by the dynamics of a variable stellar wind, confirming the single-star nature of AS314.

Scientific novelty of the work

1. For the first time, the spectral energy distribution of AS314 was modeled using Castelli–Kurucz stellar atmosphere models and the DUSTY radiative transfer code, allowing the determination of its effective temperature, interstellar extinction, and the structure of its circumstellar dust shell.

2. The obtained results were compared for the first time with LBV and post-AGB type stars, enabling the determination of the star's physical parameters and providing scientific justification for classifying AS314 as a luminous LBV-type object.

3. For the first time, a comprehensive analysis of high-resolution spectroscopic and photometric data covering the last 25 years was carried out, the light curve was constructed, and radial velocity variations were investigated using the cross-correlation method, allowing the study of atmospheric dynamics and orbital motion.

Theoretical significance of the work

This study refines the evolutionary nature of AS314 and contributes to the understanding of mass-loss processes, stellar wind dynamics, and dust formation in massive stars. The applied methods of spectral analysis, cross-correlation techniques, and spectral energy distribution modeling provide an effective methodological framework for distinguishing LBV and post-AGB stars and for determining their physical parameters.

Practical significance of the work From a practical perspective, the work demonstrates a complete algorithm for processing modern astronomical data and performing modeling, and it illustrates the possibility of conducting independent studies of similar objects using open-access data. The results can be incorporated into the educational process as a specialized course or practical training module and may serve as a foundation for state-funded research projects focused on massive stars.

Personal contribution of the author

All analyses and results were obtained by the author. The research objectives and methods were formulated together with the scientific supervisors, and the results were independently interpreted and discussed by the author.

Reliability of results

The reliability of the study is confirmed by the use of validated methods, consistent observational data, and agreement with independent analyses of similar objects.

Approbation of the work

Research results were presented at international and national scientific conferences and published in journals indexed in Thomson Reuters and Scopus databases:

1. Bakhytkyzy A., Miroshnichenko A. S., Klochkova V. G., Panchuk V. E., Zharikov S. V., Mahy L., Van Winckel H., Agishev A. T., Khokhlov S. A. AS 314: A Massive Dusty Hypergiant or a Low-Mass Post-Asymptotic Giant Branch Object? //Galaxies. – 2025. – Vol. 13. – №. 2. – P. 17. Web of Science: Impact Factor 3.8, Q2. Scopus: CiteScore 6.3, Percentile 74%. https://doi.org/10.3390/galaxies13020017

Publications in journals recommended by the Kazakhstan Ministry of Science and Higher Education:

1. Gyuchtash A., Nurmakhametova S., Vaidman N., Khokhlov S., Agishev A., Bakhytkyzy A. (2025). A method for determining the physical parameters of hot supergiants based on spectral energy distribution analysis. //Physical Sciences and Technology. – 2025. – Vol. 12. – №. 1-2. – P. 45-56. Web of Science: Impact Factor 0.25, Q4. Scopus: CiteScore 0.7, Percentile 24%. https://doi.org/10.26577/phst20251215

Project funding

This dissertation was carried out within the framework of project No. AP23484898 «Development of a modern technique for determining the fundamental parameters of Galactic hot supergiants» funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (2024-2026).

Structure and volume of the dissertation

The dissertation consists of an introduction, four main chapters, a conclusion, a list of references, and two appendices. The total length of the work is 120 pages, including 35 figures, 7 tables, and 79 references.