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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

PHOTOMETRIC AND SPECTRAL PROPERTIES OF THE CH CYG SYMBIOTIC STAR

Speciality: 2108.01 – Astrophysics and stellar astronomy

Field of Science: Astronomy

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GENERAL DESCRIPTION OF WORK

Relevance and development of the research work. Symbiotic stars are spectrally identifiable binary star systems consisting of a cool red giant and a white dwarf, both interacting with each other and surrounded by a nebula.

Currently, around 300 symbiotic stars are known. In such systems, a strong mass transfer occurs from the cool star via stellar wind, leading to the formation of an accretion disk around the hot compact star. Symbiotic stars may represent a transitional stage in the evolution of several types of binary systems in which there is intense mass transfer from a more massive star to a less massive one.

Among symbiotic stars, the CH Cyg symbiotic star is of particular interest and has been the focal point of many researchers up to the present day[1]. Its unique characteristics continue to draw the attention of researchers. These characteristics are as follows:

1. The CH Cyg symbiotic star is considered one of the most dramatic sources of galactic jets. In CH Cyg, both optical and radio regions exhibit directed jet-like bipolar ejections. This feature is also common in young stars in symbiotic systems, binary X-ray stars, and the nuclei of active galaxies. The CH Cyg symbiotic star serves as an optimal laboratory to understand these phenomena and determine their origins.
2. Observations of the CH Cyg symbiotic system reveal flickering (small variations) in the optical and ultraviolet regions. These flickerings are attributed to the accretion disk formed around the hot component. The disappearance of these flickerings after an outburst is explained by the disintegration of the disk. If this is the case, the CH Cyg symbiotic star could represent the stage of disk formation in binary systems.
3. The cool red giant in the CH Cyg symbiotic system pulsates periodically. As a result, the accretion mode changes, and the

[1] Skopal A., Shugarov S., Vanko M., et al., Recent photometry of symbiotic stars // Astronomische Nachrichten, Berlin: –2012, Vol. 333, –p. 242-255.

system exhibits more complex variations. Additionally, this system, with its various short and long orbital periods, stands out from other symbiotic stars. Studying the evolution of this system is of great cosmological significance.

4. The CH Cyg star is classified as an S-type (Star) symbiotic, but it also shows characteristics typical of the D-type (Dust) symbiotics. This indicates the formation of a dust shell around the star after an outburst, making the study of CH Cyg particularly interesting.
5. Recently, evidence suggesting the presence of a third component in the CH Cyg symbiotic system has emerged. Many researchers consider it a system of three stars. However, the debate on whether the CH Cyg symbiotic star consists of two or three stars continues.
6. The CH Cyg symbiotic star also differs significantly from other symbiotic stars due to its prolonged activity dynamics. After a long period of quiescence, an active phase began in 1963. Following a major outburst in 1977, this activity has continued to the present day.

High-dispersion spectral observations are of great importance for studying the nature of the CH Cyg symbiotic star. Precise determination of the radial velocities and equivalent widths of emission and absorption lines during both active and quiescent states of the star allows for the clarification of detected periodic variations and the study of the system's morphology. Despite the intense photometric and spectral observations carried out since the onset of the activity period in 1963 to the present day, the following questions about the nature of the star remain unresolved:

1. The reason for the long-term persistence of the activity period.
2. The interaction of the components within the CH Cyg symbiotic system, the mechanism of mass exchange between them, and their evolutionary characteristics.
3. The causes of the accretion process, the characteristics of changes in accretion rate and speed.
4. The reasons for the formation of jet − like high-velocity absorption components and the mechanism of their occurrence.
5. Whether the CH Cyg symbiotic system is a binary system or consists of three stars − if it is a three-star system, is the internal or

external system eclipsing, and what is the role of the participating components in the overall radiation of the system?

The aim and objectives of the research. Among the various methods for analyzing radiation from space, photometric and spectral studies hold a special place. In astronomy, photometry is used to measure the flux or intensity of light from astronomical objects. The methods used to conduct photometric measurements depend on the wavelength being studied. Standard sets of filters have been established to ensure precise comparison of observations.

A comparative analysis of photometric and spectral observations allows for a more comprehensive understanding of the star. Special spectral devices and light detectors are used for conducting spectral studies. With their help, it is possible to study absorption and emission spectra. The study of the spectrum provides complete information about the physical processes occurring in the environment (radiation source) and the characteristics of the medium through which the radiation is transmitted.

The main objective of this dissertation is to detect photometric and spectral variability in the CH Cyg star, search for possible periods in the star, and regularly obtain high-resolution spectra of the CH Cyg symbiotic star using the Shamakhy Fiber Echelle Spectrograph (ShAFES) at the cassegrain focus of a 2-meter telescope equipped with a CCD light detector. This includes processing, analyzing, and comparing the obtained spectra with the light curve of the determined spectrophotometric parameters. The following tasks have been completed to achieve this:

1. Collection and compilation of photometric observation data.
2. Processing and analysis of photometric observation data using the MaxIm_DL software for investigating variability in the brightness of the CH Cyg symbiotic star.
3. Construction of the light curve of the CH Cyg symbiotic star based on the AAVSO (American Association of Variable Star Observers) database, searching for possible periodic variations, and comparative analysis of the spectrophotometric parameters determined from the spectra with the light curve.

4. Obtaining spectra of the CH Cyg symbiotic star with the 2-meter telescope at the Shamakhy Astrophysical Observatory.
5. Processing and analysis of spectrometric parameters using the Dech30 software.
6. Construction and examination of the profiles of selected spectral lines (H_α, H_β, HeI λ5876Å, NaI D1, and NaI D2), and determination of the spectrometric parameters of the CH Cyg symbiotic star.

Research object and subject. The main object of the research is the CH Cyg symbiotic star and the standard stars in its vicinity. The primary subject of the research is the study of the photometric and spectral characteristics of the CH Cyg symbiotic star.

Applied methods. Photometric observations of the CH Cyg symbiotic star were conducted using a CCD photometer installed on the Zeiss 600 telescope at the Shamakhy Astrophysical Observatory (ShAO) named after N. Tusi of the Ministry of Science and Education of the Republic of Azerbaijan. Spectral observation materials were obtained using devices connected to the cassegrain focus of the 2-meter telescope at the ShAO (2 m Telescope + Shamakhy Fiber Echelle Spectrograph + CCD light detector).

Photometric observation data were processed using the MaxIm_DL software, while spectral observation data were processed using the DECH software. The Scargle method was used to search for periodic variations in the star.

The main provisions of the defense:

1. Detection of photometric and spectral variability in the observations of the CH Cyg symbiotic star.
2. Presence of periodic variations of approximately ~750 and 95 days in the radiation velocities and light curve of the CH Cyg symbiotic star.
3. Detection of phase shifts between the light and radiation velocity curves of the CH Cyg symbiotic star.
4. Observation of high-velocity, broad, and deep absorption jets in the CH Cyg symbiotic star based on echelle spectra with a resolution of R=28000.

5. Red wing parameters of the NaI D1 and D2 lines of the CH Cyg symbiotic star show an anti-correlation with the V-band light curve based on CCD echelle spectra.

Scientific novelty of the research:

1. Development of a method for cleaning hot pixels. This involves removing the background from the object (object-background) or, for better cleaning, first removing dark frames from both the object and background (object-dark, background-dark) and then removing the background from the object (object-background).
2. Analysis of observations conducted over 17 nights between 06.07.2018 and 16.09.2018 (72 days) revealed the following key results: During the observation period, the brightness of the CH Cyg symbiotic star increased by up to 2 magnitudes, rising from 8.5^m to 6.5^m. Continuous observations showed that in observations longer than 15 minutes, the star exhibited variability of 0.2^m to 0.45^m in magnitude. This variability is explained by the acceleration of the material flow from the red giant to the white dwarf when the white dwarf is near periastron, or by the instability of the accretion disk around the white dwarf. Periodic variations of 67, 65, and 12 minutes in the star's brightness were detected on different nights.
3. The ~95-day periodic variation found in the brightness of CH Cyg (for the period 1998-2019) closely matches values found by various researchers. The ~95-day periodic brightness variations are explained by the radial pulsations of the red giant, the primary star of the symbiotic system.
4. Spectral observations on 15-07-2015 revealed spectral variability, with the central intensity and equivalent width of the HeI λ5876Å line correlating positively with the parameters of the violet emission component of the H_α line. The correlation coefficients were 0.92 for intensity and 0.70 for equivalent width. The spectral variations observed in the CH Cyg symbiotic star are related to the optical brightness variability characteristic of the active phase of the system.
5. High-resolution (R=28000) echelle spectra from 2017 revealed high-velocity, broad, and deep absorption jets in the hydrogen (H_β,

H_γ, H_δ) and helium (HeI λ 5876Å) lines of the CH Cyg symbiotic star. The absorption jets' velocities reached -3000 km/s in the violet wing, with widths of 800-1000 km/s and depths ranging from 0.2 to 0.6 Å. These high-velocity absorption jets are likely caused by strong material outflows from the equatorial region of the red giant to the white dwarf.

6. In 2018, the spectrophotometric parameters of the H_β emission line – the equivalent width, and the intensities of the violet and red components – showed anti-phase variations with the light curve in the V band. Both components of the NaI D1 and D2 lines exhibited a paired structure, with changes in the intensities of the red components perfectly matching the variation characteristics of the light curve in the V band.
7. In 2018, a sharp change and complete disappearance of emission in the HeI λ 5876Å line were observed.
8. In 2018, absorption jets with speeds reaching -800 km/s in the violet wing of the H_β and HeI λ5876Å lines were observed.
9. Periodic variations of 750.8 days based on AAVSO photometric data (1963-2021) and 751.8 days based on radiation velocities were detected in the light curve of the CH Cyg symbiotic star. The comparison of phase diagrams showed that the radiation velocity curve leads the light curve by approximately 0.3 phases.

Theoretical and practical significance of the research. The results obtained from the photometric and spectral studies of the CH Cyg symbiotic star in this work can be used to explain the mechanisms of physical processes occurring in obscured binary and multiple star systems as follows:

1. Explanation of the pulsation mechanism in binary star systems.
2. Study of the morphology and dynamics of binary star systems showing multiple periodic variations.
3. Explanation of the mechanism of material transfer from a giant star to a hot dwarf star in binary systems.
4. Explanation of the formation mechanism of strong jet-like material ejections - absorption jets.
5. Results from homogeneous observational data can be used in the theoretical modeling of symbiotic-type stars like CH Cyg.

Important parameters of the profiles of H_α, H_β, He, and Na emission and absorption lines can be used in theoretical calculations of hydrogen and other line profiles in stars under various physical conditions.

6. The cleaning method proposed in the dissertation for cleaning astronomical images obtained on cooled electron CCDs from traces of hot pixels and other distortions may be useful for observing astronomers.

Reliability of the dissertation work. The photometric observational data in this work were obtained using the FLI (Finger Likes İnstrumentation) CCD camera on the 60 cm telescope at the ShAO. The data processing was performed using the MaxIm_DL software package. Spectral observations were conducted with the ShaFES fiber-optic spectrometer on the 2 m telescope at ShAO, using a modern CCD matrix with high quantum efficiency. The processing of these spectral data was carried out using the DECH software package.

In addition to the photometric and spectral data obtained at the ShAO, the author utilized observations from the AAVSO to investigate possible periods in the spectral and photometric parameters of the CH Cyg symbiotic star.

The observations and measurements were conducted using the latest devices and software. The results have been presented at several national and international scientific conferences and published in the respective conference proceedings. These factors ensure the accuracy and reliability of the obtained results.

Publications. A total of 25 scientific papers have been published on the dissertation topic. Of these, 13 articles appeared in peer-reviewed journals, and 12 were published in conference materials and proceedings.

Approval and application of the work. The main results of the dissertation have been presented at scientific seminars of the Batabat Astrophysical Observatory and the ShAO, both under the Ministry of Science and Education of the Republic of Azerbaijan, as well as at the following national and international conferences:

1. III International Scientific Conference of Young Researchers, Baku Engineering University, Baku, April 29-30, 2019.
2. Physics of Stars and Planets: Atmospheres, Activity, Magnetic Fields, International Conference, ANAS Nasiraddin Tusi ShAO, Shamakhy, September 16-20, 2019.
3. IV National Scientific-Practical Conference of Young Scientists, Ganja State University, Ganja, October 25-26, 2019.
4. V National Scientific Conference of Future Scientists, Baku State University, Baku, May 12-13, 2020.
5. IV International Scientific Conference of Young Researchers, Baku Engineering University, Baku, June 5, 2020.
6. V International Scientific Conference of Young Researchers, Baku Engineering University, Baku, April 29-30, 2021.
7. "Lütfi Zade-100" National Conference, Shamakhy Astrophysical Observatory named after N. Tusi of the ANAS, Shamakhy, August 4, 2021.
8. "Modern Problems in Physics and Astronomy" National Scientific Conference, Nakhchivan State University, Nakhchivan, November 3, 2021.
9. VI International Scientific Conference of Young Researchers, Baku Engineering University, Baku, April 29-30, 2022.
10. Proceedings of the XXI International Multidisciplinary Conference "Prospects and Key Tendencies of Science in Contemporary World", Bubok Publishing S.L., Madrid, Spain, July 21, 2022.

Institution where the dissertation was conducted: The dissertation work was carried out at the Batabat Astrophysical Observatory under the Ministry of Science and Education of the Republic of Azerbaijan.

Author's personal contribution. In the list of published scientific works on the dissertation topic, as provided in the author's abstract the articles numbered 9, 12, 14, and 16-25 were co-authored. The contributions to these articles in terms of problem formulation, calculations, theoretical interpretation, results acquisition, analysis, and text composition are shared equally between the author and co-authors. In the articles numbered 1-8, 10-11, 13, and 15 the author is

solely responsible for the problem formulation, calculations, theoretical interpretation, results acquisition, analysis, and text composition.

Structure and volume of the dissertation. The dissertation consists of an introduction, three chapters, conclusions, and a bibliography with a total of 185 references. The dissertation includes 65 figures and 9 tables. The total volume of the dissertation is 158 pages, with 138 pages dedicated to the main text, excluding the bibliography.

Overall volume of the dissertation in characters: 229216 characters. Title page – 801 characters. Table of contents – 6442 characters. Introduction – 20336 characters. Main content of the dissertation (chapters, paragraphs, sections) – 162758 characters. Conclusion – 3924 characters. List of references – 34239 characters. List of abbreviations and symbols – 716 characters.

MAIN CONTENT OF THE DISSERTATION

The dissertation consists of an introduction, three chapters, conclusions, and a list of references. The introduction provides the relevance of the topic, the research objectives, and the issues addressed. The research methods used are described. Scientific innovations are substantiated, the main theses defended are outlined, and a list of reports presented at national and international conferences where the dissertation results were discussed is provided. The practical and theoretical significance of the scientific results obtained is demonstrated.

In the **first** paragraph of the **chapter I**, the devices and equipment used for photometric observation materials are described. It is noted that the combination of Telescope + Photometer + CCD Camera + Computer constitutes and ensures the completeness of the photometric measurement system. Information about the devices and equipment included in the measurement system at the ShAO is provided.

It was noted in the **second** paragraph of **chapter I** states that the process of photometric observations and data processing was carried out using the MaxIm_DL software.

Photometric observation data used in the dissertation were obtained following the sequence below:

1. **Bias** frame acquisition. At least 3 frames were taken in each filter. Bias frames were obtained with an exposure time of 0 seconds.
2. **Flat** frame acquisition. Images of the clear sky during civil twilight were taken through various filters (at least 3–5 frames per filter). The exposure time of these frames should match that of the object frames.
3. **Dark** frame acquisition. At least 3 frames were obtained for each filter used for both flat and object frames. The exposure time of the dark frames must be identical to that of the corresponding object and flat frames.
4. Imaging of the **object** and **standard** stars in the same frame. This step was performed with at least 3 frames.

In the **third** paragraph of the **chapter I**, it is mentioned that in addition to the photometric observations of the CH Cyg symbiotic star carried out at the ShAO, photometric observation data from the AAVSO database were also used. The sequence of downloading photometric data from the AAVSO database is provided.

In the f**ourth** paragraph of the **chapter I**, the devices and equipment used for spectral observation materials in the dissertation work are described. For obtaining spectral observation materials, the ShaFES device, positioned at the Cassegrain focus of the 2-meter telescope at the ShAO, and a CCD photometer were used. The methodology for acquiring and processing spectral observation materials of the CH Cyg symbiotic star is extensively discussed in sections 1.4.1-1.4.7 The DECH software folder was used for obtaining spectra and processing observational materials.

In the **fifth** paragraph of the **chapter I**, the method for removing cosmic particle trails and hot pixels from astronomical CCD images is described.

Electron-cooled CCDs can also be used for spectral and photometric observations and for long exposures. When acquiring spectra of objects, the following conditions must be met:

1. Three images each of the object, background, and dark must be taken with the same exposure time (to remove cosmic radiation and also to reduce noise). Especially when acquiring spectra of extended objects, it is important to obtain the background spectrum.

2. To use observing time efficiently, dark images can be taken after the observation (with the same characteristics as the CCD).

3. To remove hot pixels, the background is subtracted from the object (object-background). For better cleaning, dark images are first subtracted from both the object and the background (object-dark, background-dark), and then the background is subtracted from the object (object-background).

In order to obtain clean and undistorted information from CCD frames-especially from spectra-it is essential to acquire additional calibration frames such as dark, flat-field, and background frames. It is important to note that if hot pixels are not removed from spectral images, they may be mistakenly interpreted as false emission components in the spectral lines. Similarly, if hot pixels are not corrected in photometric images, the accuracy of photometric measurements may be questioned.

Chapter II is primarily dedicated to the photometric study of the CH Cyg symbiotic star. In the **first** paragraph of this chapter, a comprehensive summary of symbiotic stars is provided. The summary describes the main characteristics that define symbiotic stars, their photometric and spectral properties, and the primary research problems associated with them. One of the key characteristics of symbiotic stars is that their brightness can increase by 3–4 magnitudes over the course of several months and then gradually return to its original luminosity level.

In the **second** paragraph, several widely accepted models that aim to explain symbiotic systems and characterize symbiotic stars are presented and analyzed.

In the **third** and **fourth** paragraphs of **chapter II**, respectively, the characteristics that distinguish the CH Cyg symbiotic star from other

symbiotic stars, the results obtained from photometric observations conducted by various researchers at different times, and the photometric map of the star are presented. It is noted that before starting the observations, the photometric map of the star to be studied is taken from the literature, and the observation target and standard stars are specially marked on the map.

In the **fifth** paragraph of **chapter II**, the photometry of the CH Cyg symbiotic star based on AAVSO observations is discussed. This paragraph presents the visual light curve of the CH Cyg symbiotic star over a 60-year period (1959-2019) based on AAVSO observations[2]. The study of the light curve shows that the activity that started in 1963 resumed in 1965 after a one-year hiatus and exhibited various magnitudes and scales of outbursts during the active periods of 1967-1970, 1977-1984, 1992-1994, 1998-1999, 2011-2012, and 2017-2018. The light curve indicates that there were variations with a period of approximately 2 years between 1963 and 1976. In 1983-1984, the star was even visible to the naked eye, reaching a magnitude of 5.4^m. Since 1986, the star's brightness has continued to decrease, reaching its deepest minimum in mid-1996, with a magnitude of 10.5^m in the V filter.

In the **sixth** paragraph of **chapter II**, it is noted that the Scargle program was used in the dissertation to investigate the periodicity of the CH Cyg symbiotic star. The sequence of using the Scargle Fourier program to determine the period is illustrated with images.

In the **seventh** paragraph of **chapter II**, titled “Photometric Variations in the CH Cyg Symbiotic Star”, the results of photometric observations carried out at the ShAO are presented. It is noted that the photometric observation materials related to the star studied in the dissertation were collected by the applicant using the 'Zeiss-600' telescope at the ShAO over 17 nights during the period from July 6, 2018, to September 16, 2018 (72 days), and on 4 nights in 2019 (08-07-2019, 11-07-2019, 20-07-2019 and 18-08-2019). The telescope was equipped with a photometer and a light receiver with a useful field

[2] https://www.aavso.org/LCGv2/

of view of 17 arcminutes[3]. The comparison star chosen was TYC 3551-1725-1, and the check star was V2365 Cyg (SAO 31628). To investigate the nature of faster short-term variations, continuous observations with high temporal resolution were carried out using only one filter (V) over several nights.

As mentioned above, the MaxIm_DL software was used for acquiring and processing photometric images (the methodology is provided in Chapter I). To increase measurement accuracy and clean frames from cosmic particle trails, 3 to 5 frames were averaged in some cases. Several comparison stars, including the binary star SAO 31628, were used as checks. Table 1 presents information on the photometric observations of the CH Cyg star carried out with the 60 cm telescope. The table includes the observation date, number of frames and exposure time, duration of the observation, and the average ($\mathbf{V_{avg}}$), minimum ($\mathbf{V_{min}}$), and maximum ($\mathbf{V_{max}}$) brightness values, as well as the maximum variation ($\mathbf{\Delta V = V_{max} - V_{min}}$).

Photometric variations in the symbiotic star CH Cyg were first discovered by Cester and Wallerstein[4,5].

During the observation period, CH Cyg was active, with its brightness varying by 1.1 magnitudes, increasing from 7.56^m to 6.47^m. The observations carried out by the claimant also coincided with the ignition time of the symbiotic star CH Cyg. Continuous observations conducted over 17 nights have shown that the symbiotic star CH Cyg exhibits small-amplitude brightness variations lasting a few minutes.

Over the course of several nights, brightness variations were observed in the symbiotic star CH Cyg in the V filter.

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[3] Abdullaev B.I., Alekberov I.A., Gulmaliyev N.I., Medjidova S.O., Mikailov Kh.M., Rustamov B.N., A new photometer-polarimeter coupled with CCD // Azerbaijani Astronomical Journal, Baku: –2012. No. 4, –pp. 39-49.

[4] Cester B., CH Cygni // Information Bulletin on Variable Stars, Budapesht: 1968, № 291, 1. –p. 123-128.

[5] Wallerstein G., Photoelectric observations of rapid variations of CH Cygni // Annals of Harvard College Observatory, Cambridge: –1968, Vol. 88, –p. 111-112.

Table 1.

Photometric observations of the CH Cyg star using a 60 cm telescope.

Observation date	Number of frames and exposure time	Duration of the observation (minutes)	V_{ave}	V_{min}	V_{max}	ΔV
06.07.2018	5x10s	1.16	7.579	7.591	7.568	0.023
09.07.2018	15x5s	2.51	7.488	7.507	7.466	0.041
10.07.2018	59x3s	10	7.463	7.546	7.379	0.167
11.07.2018	79x3s	9+3*	7.301	7.388	7.269	0.119
14.07.2018	10x3s	2.36	7.187	7.211	7.17	0.041
18.07.2018	60x2s,15x3s	13	7.145	7.275	7.056	0.219
19.07.2018	700x3s,30x5s	148	7.012	7.143	6.846	0.297
06.08.2018	450x1s,15x2s, 11x3s	79	6.574	6.714	6.411	0.303
07.08.2018	120x2s	20.5	6.564	6.61	6.493	0.117
16.08.2018	174x1.5s, 150x2s	37+42*	6.623	6.796	6.424	0.372
22.08.2018	50x2s, 15x3s	10	6.669	6.727	6.589	0.138
30.08.2018	60x2s	8	6.777	6.808	6.74	0.068
03.09.2018	70x2s	17	6.471	6.626	6.358	0.268
06.09.2018	20x1.5s, 130x1s, 200x1s	43+27*	6.674	6.91	6.447	0.463
07.09.2018	160x1s	24	6.889	6.961	6.828	0.133
15.09.2018	100x1s	14	7.214	7.336	7.082	0.254
16.09.2018	950x2s, 500x2s	87+79*	7.199	7.336	7.087	0.249
08.07.2019	265x4s,150x5s, 125x6s	109.25	7.668	7.806	7.531	0.275
11.07.2019	505x5s	116.67	7.486	7.649	7.324	0.325
20.07.2019	480x7s	120.65	7.872	7.965	7.780	0.185
18.08.2019	285x3s	52.38	8.388	8.475	8.302	0.173

***-** observations were carried out in two consecutive time intervals.

Fluctuations with amplitudes of 0.05^m–0.06^m were recorded on short timescales of 10–30 seconds, while larger variations of 0.1^m–0.45^m were detected over longer timescales ranging from 1 to 30 minutes. Subsequently, the results of the photometric observations of the studied star were analyzed. Since the observations of the symbiotic star CH Cyg by the claimant, with a few exceptions, do not cover a

sufficiently broad time interval, it is difficult to investigate the periodicity of the fluctuations in CH Cyg. The Scargle program was used to search for periodic changes.

The main results obtained from the analysis of observations conducted with the "Zeiss-600" telescope at the ShAO are as follows:

1. During the observation period, the star's brightness increased by approximately 2 magnitudes, rising from 8.5 to 6.5.
2. Continuous observations have shown that the star exhibits short-term variations in brightness ranging from 0.2 to 0.45 magnitudes. These variations can be explained by an increase in the flow rate of material from the red giant to the surface of the white dwarf during the white dwarf's periastron passage.
3. Periodic variations in the brightness of 67, 65, and 12 minutes were detected on different nights.

The mechanism behind the flickering in the symbiotic star CH Cyg is discussed in the following paragraph.

It is noted that the source of flickering in symbiotic stars is considered to be the accretion disk. Short-term variability is related to the activity of the accretion disk. Since 2014, the increase in flickering activity in the CH Cyg symbiotic system can be linked to the enhanced mass transfer from the red giant during the periastron passage of the white dwarf, which accelerates processes within the disk. The years 2015 and 2018 were the most active years for the CH Cyg symbiotic star.

In the **8th** paragraph of **chapter II**, a light curve graph for the symbiotic star CH Cyg in the V filter was plotted based on the AAVSO database for the period from 1988 to 2020. In this graph, short-period variations of the star were searched for, and it was found that during its relatively quiet state, the star exhibited periodic variations with a period of approximately 95 days (figure 1). The star's V filter magnitudes were obtained from the AAVSO observation database and are conventionally calculated starting from phase 1998 (with the JD date 2450815), which corresponds to the beginning of the observation season.

Using the Scargle method, the ~95 day period found in the brightness variations of the CH Cyg symbiotic star closely matches the periods identified by various researchers[6,7] at different times.

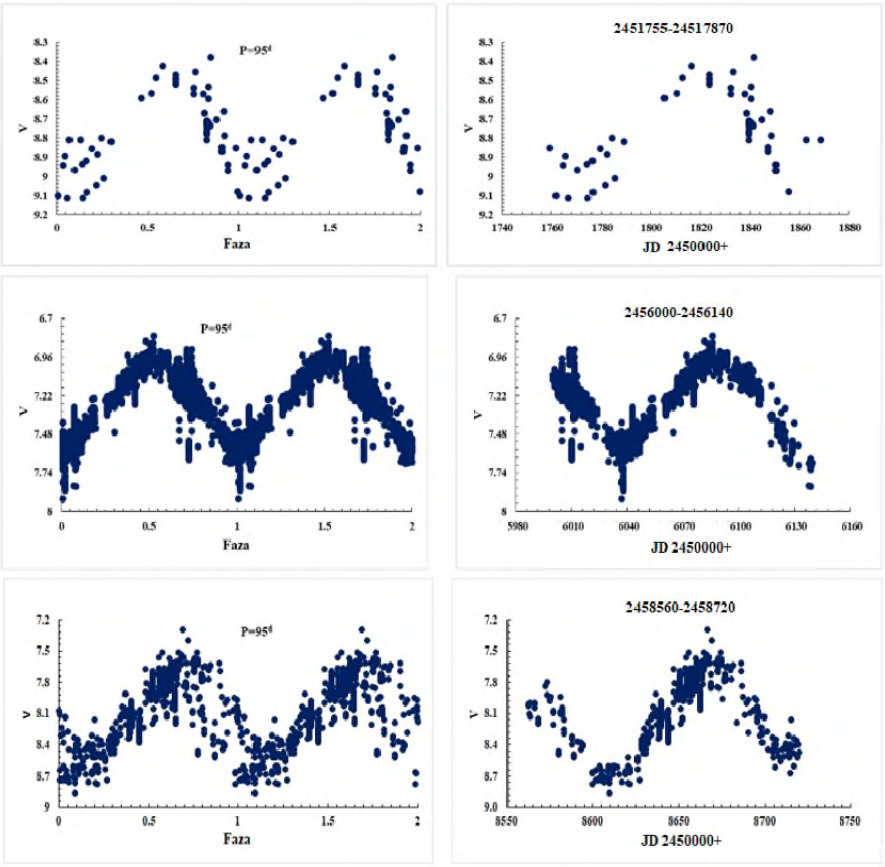

Fig. 1. Demonstration of short-period (P=95[d]) variations in the light curve of the CH Cyg symbiotic star from 1998 to 2019.

[6] Shugarov S., Kolotilov E., Komissarova, G., Skopal, A., & Zemko, P., Photometric Activity of the Symbiotic Star CH Cyg during 2008–2011 // Baltic Astronomy, – Vilnius: 2012, Vol. 21, –p.184-188.

[7] Wallerstein G., Munari U., Siviero A., Dallaporta S., Dalmeri I., The Spectrum and Light Curve of CH Cygni during its Recent Broad Minimum // Publications of the Astronomical Society of the Pacific, Chicago: –2010, Vol. 122, Iss. 887, –p. 12-16.

The short-term variations observed in the symbiotic star CH Cyg can be attributed to the instability of the accretion disk around the hot component, the white dwarf star. The ~95 day periodic variations discovered in the dissertation work can be explained by the radial pulsations of the primary star in the symbiotic system, the red giant.

Chapter III is dedicated to the spectral study of the symbiotic star CH Cyg. The first paragraph of chapter III provides detailed information about the history of the star's spectral observations. The importance of spectral observation is discussed.

It is noted that the CH Cyg symbiotic star is one of the most extensively studied yet least understood objects. Therefore, high-dispersion spectral observations with time resolution are of great importance for investigating the nature of the CH Cyg symbiotic system.

In the **second** paragraph of **chapter III**, the results of spectral observations of the CH Cyg symbiotic star conducted on July 15, 2015, with the 2-meter telescope of the ShAO are discussed. The rapid spectral variations observed in the HeI λ5876Å and NaI doublet D1 and D2 lines are presented, along with a comparative analysis of these variations with the H_α and H_β lines in the spectra.

Based on the available spectra, the profiles of the HeI λ5876Å and NaI D1 and D2 doublet lines were constructed, and the equivalent widths and radial velocities of the lines were calculated from these profiles.

Observations were conducted continuously for 6 hours with 20-minute exposures, resulting in a total of 14 echelle spectra. The spectra were processed using the DECH-20 program[8]. It was found that there is a significant correlation between the profile parameters of the violet component of the H_α line and the parameters of the HeI λ5876Å line. The correlation coefficients between the intensities and equivalent widths of these lines are 0.92 and 0.70, respectively (figure 2).

[8]http://www.gazinur.com/DECH-software.html.

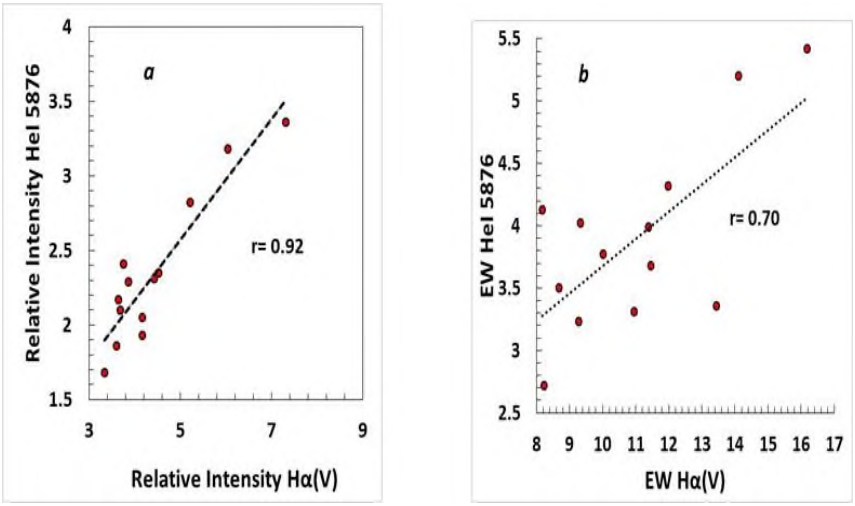

Fig. 2. The correlation between the HeI λ5876Å line and the V component of the H_α line: *a*) – intensities and *b*) – equivalent widths.

During the observations, the hot component of the CH Cyg system was located almost at periastron. The maximum approach of the system's components leads to an intensification of mass transfer, which is accompanied by certain spectral variations.

In the **third** paragraph of **chapter III**, the results of both photometric and spectral observations conducted on the same night on July 10, 2018, at the ShAO are discussed. The duration of the photometric observation was 12 minutes. During this time, approximately 100 frames were taken with an exposure time of 5 seconds.

To reveal spectral variations, 9 consecutive spectra of the CH Cyg symbiotic star were obtained with a 2-meter telescope, each with an exposure time of 300 seconds.

The analysis revealed that as the brightness of the star decreases, the equivalent widths of the hydrogen lines also decrease, with this effect being more pronounced in the H_α line. Additionally, the comparison of photometric and spectral observations shows that short-term variability in brightness is also reflected in the spectral parameters.

In the **fourth** paragraph of **chapter III**, it is noted that the CH Cyg symbiotic star is one of the most dramatic galactic jet sources among symbiotics. Astrophysical jets are observed in almost all types of accreting binary systems. In symbiotic stars, jets are primarily associated with outbursts in the optical band. CH Cyg is one of the most dramatic galactic jet sources among symbiotic stars. Its optical monitoring can play a significant role in clarifying jet structure. Furthermore, this paragraph presents the analysis of spectral observations conducted with the 2-meter telescope at the ShAO from may to november 2017. A total of 80 echelle spectra of CH Cyg were obtained over 36 nights. The dissertation focuses on 14 spectra from 6 nights, which show strong and rapid absorption components.

The spectral resolution was $R=\lambda/\Delta\lambda=28000$, and the spectral range was 3900-8000Å. The chip size was 4096x4096 pixels, with each pixel measuring 15x15 μm. Wavelength calibration was performed using Sky and ThAr spectra. The spectral processing was carried out in accordance with standard procedures using the new version of the program folder. All spectra were extracted using the IRAF mask.

Absorption jets were observed in the spectra obtained in 2017 and used in this study.

The hot star was at periastron in 2015. Since the star's orbital period is close to 16 years, it could not have moved far from periastron in just 2 years. Therefore, it can be concluded that the ongoing high-velocity mass ejections are related to the hot star's proximity to periastron.

In 2017, based on echelle spectra obtained with a resolution of R=28000 using the ShAFES on the 2-meter telescope, high-velocity, broad, and deep absorption components were observed in the H_β, H_γ, H_δ, and HeI λ5876Å lines of the CH Cyg symbiotic star. The radial velocities of the absorption components in the violet wing reached up to -3000 km/s. The width was 800-1000 km/s, and the depth ranged from 0.2 to 0.6 Å. It is suggested that the formation of these high-velocity absorptions is due to strong mass ejections from the equatorial region of the white dwarf[9].

[9] Mikailov Kh. M., Mammadov R. T., Alakbarov I.A., Khalilov O.V., High velocity absorption in the spectra of CH Cyg in 2017 // Astronomıcal Journal of Azerbaıjan, Baku: –2020, Vol. 15, № 2, –p. 82-90.

In the fifth paragraph of **chapter III**, a comparative analysis of the spectral parameters of the H_α, H_β, HeI λ5876Å, and NaI doublet D1 and D2 lines with the V-band light curve of the CH Cyg symbiotic star, based on spectra obtained in 2018 with the 2-meter telescope at the ShAO, is presented. All the echelle spectra analyzed were obtained over 31 nights from may to december 2018 at the ShAO 2-meter telescope. The observation period lasted 223 days, during which up to 100 echelle spectra were obtained. Spectra were taken almost continuously for 119 days, with the last two spectra being acquired approximately 100 days later. To remove telluric lines from the spectra of the CH Cyg symbiotic star, spectra of α Lyr and 51 Draconis were used. For the removal of the spectrum of a cold red giant, spectra of HD 148783 (G Her, M6 III) were obtained on certain nights under similar conditions. Wavelength calibration was also performed using Sky and ThAr spectra. The spectra were processed using the new version of the DECH program folder, following standard procedures such as (dark subtraction and flat-field) correction. All spectra extractions were carried out using the IRAF mask.

Based on the photometric observations we conducted at the Shamakhi Astrophysical Observatory and data from the AAVSO database, a light curve in the V filter was constructed for the period during which spectral observations of the symbiotic star CH Cyg were carried out. It was determined that the star was active during this period, and its brightness decreased by about 1.5 magnitudes over a few days — from 6.5^m to 8^m — and returned to its previous brightness level over approximately the following month. Coincidentally, the period of spectral observations fully encompassed this dramatic phase of the star.

In the dissertation, attention was focused on the Hα and Hβ lines of the hydrogen atom's Balmer series, the HeI λ5876Å line of the helium atom, and the NaI D1, D2 doublet lines of the sodium atom.

A comparison between the equivalent widths of the Hα and Hβ lines and the light curve shows a characteristic feature typical for symbiotic stars — an increase in equivalent width as the brightness decreases.

However, during the star's dramatic phase (a short-term brightness drop), this trend was disrupted in the Hα line.

From the analysis of CCD echelle spectra of the CH Cyg symbiotic star obtained in 2018, the following results were obtained for the first time:

1. The spectrophotometric parameters of the H_β emission line – the line's equivalent width, and the intensities of the violet and red components – show variations that are of the same character as the V-band light curve but are out of phase.
2. Both NaI doublet D1 and D2 lines exhibit a composite component structure, and the changes in the intensities of the red components of both lines match perfectly with the variation pattern of the V-band light curve.
3. A sharp variation and complete disappearance of emission in the HeI λ5876Å line were observed.
4. Absorption jets with speeds reaching -800 km/s were observed in the violet wing of the H_β and HeI λ5876Å lines.

In the sixth paragraph of **chapter III**, a light curve and the radial velocity curve of the absorption lines of the red giant for approximately a 60-year period (1963-2021) based on AAVSO photometric data for the CH Cyg symbiotic star are presented, and the issue of period evaluation is discussed.

To better observe the periodic variations in the light curve, the graph was divided into two parts: the first part covered the period from 1963 to 1988, and the second part covered the period from 1988 to 2021.

To assess the periodicity of brightness changes in the CH Cyg symbiotic star, a relatively quiescent state of the star was selected, and two different periods (1966-1976 and 2000-2005) were examined (figure 3).

To investigate periodicity, statistical spectral Fourier analysis was applied using the Scargle method, and periodicity was evaluated for both periods.

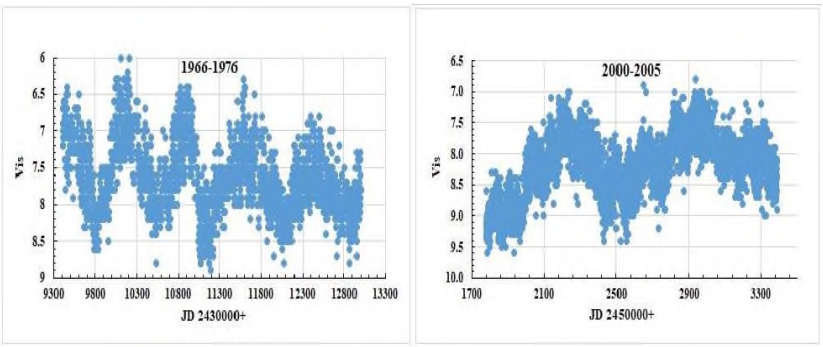

Fig. 3. Light curves of the CH Cyg symbiotic star for the periods 1966-1976 and 2000-2005 (based on AAVSO observations[10]).

Subsequently, in this paragraph, the time-dependence curve of the radial velocities of the absorption lines of the CH Cyg symbiotic star was constructed based on literature data[11,12,13,14] (fig. 4). Certain analyses were performed, and using the Scargle program again, the period was evaluated based on the radial velocity curves of the absorption lines. As a result, a period of 750.8 days was obtained for the light curve and a period of 751.8 days was obtained for the radial velocity curve. It can be said that both values almost coincide. The minimum of the wavy curve was taken as the zero phase. JD = 2439400 + 751.8×E, where E is the number of cycles. In figure 5, the phase diagrams of brightness and beam velocities are presented. (a) Vis-1 refers to the 1960s, (b) Vis-2 refers to the 2000s, (c) V-filter corresponds to the period 1999-2005, and (d) refers to the absorption

[10] https://www.aavso.org/LCGv2/

[11] Hinkle K.H., Fekel F.C., Joyce R., Infrared Spectroscopy of Symbiotic Stars. VII. Binary Orbit and Long Secondary Period Variability of CH Cygni // The Astrophysical Journal, Washington: –2009, № 692, –p.1360-1372.

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[13] Iijima T., Naito H. and Narusawa S., High-velocity equatorial mass ejections and some other spectroscopic phenomena of the symbiotic star CH Cygni in an active stage//Astronomy & Astrophysics, ESO-Munchen: –2018, Vol. 622, A45, –p. 2-15.

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lines of beam velocities. Despite covering different periods, the minima and maxima in the light curve (figure 5 a, b, c) coincide perfectly. The radial velocity curve (figure 5 d) leads the light curve by about 0.3 in phase. It is still difficult to determine whether this is a result of the red giant's pulsation or the presence of a third component.

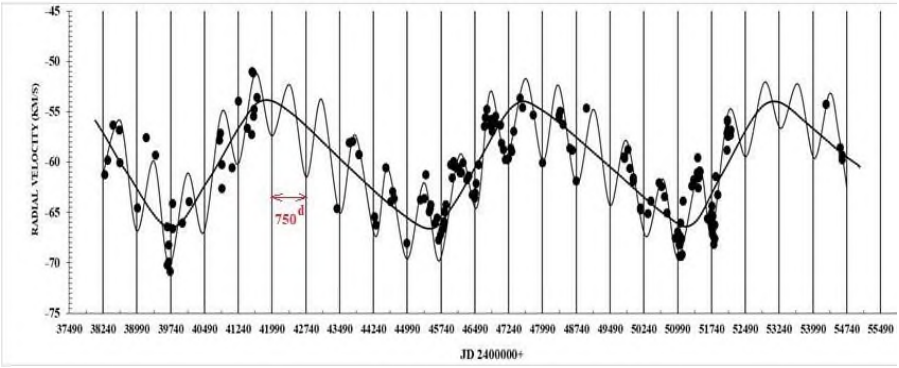

Fig. 4. General view of the dependence curve of the radial velocities of the absorption lines of the CH Cyg star on JD.

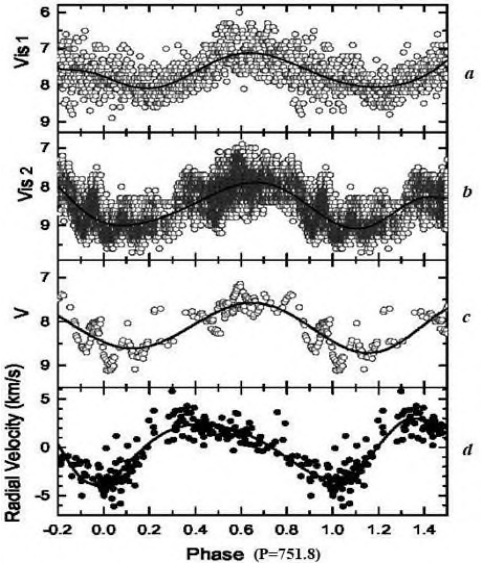

Fig. 5. Phase diagram of the star's magnitude and the radial velocities of the absorption lines (P = 751.8 days).

As a result, comparison of the phase diagrams revealed that the radial velocity curve precedes the light curve by a phase of 0.3.

MAIN RESULTS OBTAINED IN THE DISSERTATION

1. A method for cleaning hot pixels has been developed.
2. From the analysis of observations of the CH Cyg symbiotic star conducted over 17 nights between 06.07.2018 and 16.09.2018 (72 days), it has been determined that a flare occurred during this period, causing the star's brightness to increase by approximately 2 magnitudes, from 8.5^m to 6.5^m. It was found that the star experiences short-term fluctuations of 0.2^m to 0.45^m, with periodic variations of 67, 65, and 12 minutes. These fluctuations are explained by the increased rate of mass flow from the red giant to the surface of the white dwarf during the white dwarf's periastron passage.
3. Periodic variations of approximately ~95 days were detected in the brightness of the CH Cyg symbiotic star over the interval of 1998-2019. These variations are explained by the radial pulsations of the red giant, the primary star in the symbiotic system.
4. Spectral observations conducted on 15-07-2015 revealed spectral fluctuations. It was found that there is a direct correlation between the central intensity and equivalent width of the HeI λ5876Å line and the corresponding parameters of the violet emission component of the H_α line, with correlation coefficients of 0.92 for intensity and 0.70 for equivalent width. The spectral changes observed in the CH Cyg symbiotic star's spectrum are related to the optical brightness fluctuations characteristic of the star's active phase in the system.
5. From the analysis of spectra obtained in 2017, it was found that high-speed, broad, and deep absorption components (features) are observed in the hydrogen (H_β, H_γ, H_δ) and helium (HeI λ5876Å) lines of the CH Cyg symbiotic star. The radial velocities of the absorption components in the violet wing reached up to -3000 km/s, with widths of 800-1000 km/s and depths in the range of 0.2-0.6 Å. The analysis of spectra obtained in 2018 also revealed that

absorption features are observed in the violet wings of the H_β and HeI λ5876Å lines, with the speeds of the absorption features being approximately 3.75 times lower (-800 km/s) than in 2017. It is hypothesized that the high-speed absorptions are caused by strong mass outflows from the white dwarf.

6. For the first time, from the analysis of spectra obtained over 31 nights in 2018, it was determined that the spectrophotometric parameters of the H_β emission line equivalent width, violet and red component intensities exhibit changes that are characteristic of the star's V-filter light curve but in opposite phases. It was also found from the spectra obtained in 2018 that the profiles of both lines of the NaI doublet show a double-component structure, and the changes in the intensities of the red components of both lines completely coincide with the changes in the V-filter light curve.
7. From the analysis of spectra obtained in 2018, it was determined that the equivalent width of the HeI λ5876Å line varies in the range of 0-3.5Å, and the emission line completely disappears. The disappearance of the emission line can be explained by changes in the temperature regime of the symbiotic system.
8. A light curve for a period of 60 years and a radial velocity curve of absorption lines of the red giant were constructed based on the AAVSO photometric data for the CH Cyg symbiotic star. Periods of 750.8 days from the light curve and 751.8 days from the radial velocity curve were identified. Comparison of the phase diagrams showed that the radial velocity curve leads the light curve by approximately 0.3 in phase.

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