ABSTRACT

dissertations for the degree of "Doctor of Philosophy" (PhD) in the specialty "6D061100 - Physics and Astronomy"

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ACCRETION DISKS IN CATACLYSMIC VARIABLES AFTER CROSSING THE ORBITAL PERIOD MINIMUM

This work is devoted to determining the fundamental parameters and studying the accretion structure in the cataclysmic variable (CV) EZ Lyn, a candidate for the so-called “bounce-back” systems that, in the course of their evolution, have passed a minimum for the orbital periods of close binary systems consisting of a white dwarf as an accretor and a donor main sequence star.

In the work, new photometric and spectral observations of the object were obtained at the observatories of Mexico (San Pedro Martir), the Crimean Astrophysical Observatory, and also at the Roque de los Muchachos observatory on the island of Palma (Canary Islands, Spain). Additionally, there were used data available in public archives of astronomical data.

Based on the updated distance to the object, obtained from the data of the GAIA space telescope and the modeling of optical photometric data using the program code "CVLab", the fundamental parameters of this system were determined: the mass of the white dwarf $M_{wd} = 0.85 \pm 0.01\ M_{\odot}$, its effective temperature $T_{eff} = 11250 \pm 50$ K, the brown dwarf has a mass of $0.042 \pm 0.014\ M_{\odot}$, and a spectral type of L2. The falling matter in the system forms an accretion disk whose radius reaches the maximum possible radius, limited by the tidal influence of the donor star. The tilt angle of the system plane with respect to the observer is $79^{\circ}.0 \pm 0.2$.

Based on the results of the study of the structure of the accretion disk in the cataclysmic variable EZ Lyn, it was shown that the system has an optically thin hot T~10000 -15000K medium that forms emission lines and occupies the entire volume of the disk from the white dwarf surface up to the outer edge of the disk. An optical continuum with a low effective temperature (~2000 K) of radiation is formed in the outer part of the disk along the radius.

Additionally, based on a joint analysis of Doppler tomography built on the basis of phase-resolved spectra of the Hα emission line and photometry data, it was shown that the accretion disk in the EZ Lyn system has a complex structure: the disk shape is asymmetric, spiral density arms are formed in the disk due to the presence of 2:1 resonance in the system.

The latter are responsible for the observed double-hump shape of the system's light curve convoluted with its orbital period.

Relevance of the topic

It is currently assumed that cataclysmic variable stars evolve from long (~5-8 hours) orbital periods to short ones (~1 hour). After reaching a minimum (~80 minutes) for the orbital periods of close binary systems (CBS) with a white dwarf and a main sequence star as components of the system, the orbital period begins to increase and the system passes into the class of the close binaries that have passed the minimum of the orbital period or "bounce-back" systems. Due to the fact that in the process of evolution the donor (secondary) star loses thermal equilibrium, a partial degeneration of matter occurs, and as a result, at a certain moment, the radius of the secondary ceases to decrease despite the ongoing mass loss. This leads to the fact that the size of the system and, accordingly, its orbital period begin to increase.

The theory predicts that cataclysmic variables, which have already passed the minimum of the orbital period, should account for about 70% of all of the number of all systems in the Galaxy. Nevertheless, due to the selection effect associated with the low accretion rate and the weakness of the intrinsic radiation of white and brown dwarfs, only about two dozen candidates for such systems have so far been found. Confirmation of the nature of these objects, determination of their fundamental parameters and the physics of the accretion structure in them, the nature of the viscosity in the disk, and the features of flare activity and behavior in a quiescent state is an urgent task of studying the physics of close binary systems.

Due to the low rate of mass transfer between the components, these objects are weak sources of radiation and, consecutively, are still poorly understood at the moment. As a rule, candidates for such objects are found among objects of the WZ Sge type, which are short-period CVs showing superoutburst with characteristic times of tens of years between outburst. Some of these objects are still on the branch of systems evolving towards the minimum of the orbital period, but others may have already passed into the category of “bounce-back” systems. Accurate determination of the fundamental parameters of the system, such as masses, effective temperatures of the components, the rate of transfer of matter in the system,

Aim of this work is to study the structure of the accretion disk at quiescence in the EZ Lyn close binary, which is a candidate for a bounce-back system.

Research objectives:

1 Analysis of the phase-resolved photometric and spectral observational data of the EZ Lyn system obtained in the system's low-light state.

2 Determination of the fundamental parameters of the system based on the simulation of its light curve using the computer code “CVLab”.

3 Determination of the characteristics of the white dwarf, radiation of the accretion disk structure, its evolution with time in the system's low-light state.

4 Modeling the Balmer Hα emission line profiles to determine the properties of the plasma where they form.

Object of study:

The accretion disk of the bounce-back system EZ Lyn.

Research methods:

1. Time-resolved photometric and spectral observations used to analyze the behavior of a system in quiescence.

2. Reduction and analysis of the obtained observational data based on the IRAF astrophysical data processing package.

3. Computer simulation by the CVLab program of the obtained light curves of the EZ Lyn system.

4. Simulation of period-averaged spectra of a system using a combination of theoretical spectra of white dwarfs and an accretion disk.

5. Study of the structure of the accretion disk using Doppler tomography.

Main provisions to be defended

1 Based on the distance to the EZ Lyn system obtained from the GAIA space observatory data and modeling of optical photometric data, the fundamental parameters are defined of the EZ Lyn system were determined: the mass of the white dwarf M_{wd} = 0.85 ± 0.01 $M_{\odot}$, its effective temperature $T_{эфф}$=11250 ± 50 K, brown dwarf temperature T_{eff} $\leq 1900\,^{+400}_{-1000}$ K, brown dwarf mass M_{bd} = 0.042 ± 0.014 $M_{\odot}$, mass accretion rate $\dot{M} \approx 0.3 - 3.0 \times 10^{-12}$ $M_{\odot}$/year, inclination of the system plane with respect to observer $79^{o}.0 \pm 0.2$, as well as the radius of the accretion disk, which reaches the maximum possible radius (R_{OUT}=0.35$R_{\odot}$) limited by the tidal influence of the donor star.

2 A joint analysis of Doppler tomography constructed on the basis of phase-resolved spectra of the Hα emission line and photometric data shows that the accretion disk in the EZ Lyn system has a complex structure: the disk shape is asymmetric, spiral density arms are formed in the disk, which are responsible for the observed two-hump shape of the curve the brightness of the system convoluted with its orbital period.

3 In the EZ Lyn system, the region of formation of Balmer lines covers the entire disk, from the surface of the white dwarf up to the outer edge of the disk, while the optical continuum is formed only in the outer parts of the disk with a radius $R_{in} > 0.2R_{\odot}$

Scientific novelty of the work is in the fact that for the first time the following facts were shown:

1 Based on the analysis of photometric data and using the latest results on the distance to the EZ Lyn system, the fundamental parameters of the system were determined; it was shown that the disk in such systems does not change its size either during superflares or at rest.

2 The presence of asymmetry in the structure of the accretion disk was shown, and observational evidence was obtained for the presence of a spiral structure in the disk, which manifests itself in spectroscopic and photometric data.

3 The complex structure of the accretion disk is determined: the region of formation of Balmer lines covers the entire disk, from the surface of the white dwarf to the outer edge of the disk, while the continuum is formed only in the outer parts of the disk.

Theoretical and practical significance of the work

The results obtained in this work are necessary for studying the physics and evolution of accretion structures in short-period cataclysmic variable systems.

Author's personal contribution

The author of the dissertation took part in obtaining photometric data in Mexico (Observatory Astronomical Nacional San Pedro Martir, Baja California).

The results of the analysis were obtained personally by the author. The setting of tasks and discussion of the results were carried out jointly with scientific consultants.

Reliability of results

The reliability of the scientific conclusion of the work is confirmed by consistency with theoretical models and with conclusions about the nature of similar objects obtained by other authors.

Approbation of work

The results obtained in the dissertation work were reported and discussed:

– at the International Scientific Conference of Students and Young Scientists "Farabi Alemi" (2021 Almaty, Kazakhstan);

– at the Kazakh-Uzbek seminar on the topic: “ Accretion disks in cataclysmic variables after crossing the orbital period minimum”.

Based on the materials of the dissertation, 4 publications were published:

Articles with a high impact factor in the Thomson Reuters database or in publications included in the international scientific database Scopus:

– Amantayeva A., Zharikov S., Page K. L., Pavlenko E., Sosnovskij A., Khokhlov S., Ibraimov M. Period Bouncer Cataclysmic Variable EZ Lyn in Quiescence //The Astrophysical Journal. – 2021. – Vol. 918. – №. 2. – P. 58.

Publications in collections of abstracts:

1. Amantaeva A.E., Perdebaeva M. Application of the Doppler tomography method to the study of the short-period variable star SDSS0804// Materials of the international conference of students and young scientists "Farabi world". - Almaty, 2019. - S. 248

2. Amantaeva A.E., Junus A. Study of the short-period cataclysmic variable ASAS J002511+1217.2 using the Doppler tomography method// Materials of the international conference of students and young scientists "Farabi world". - Almaty, 2020. - S. 268

3. Amantaeva A.E. Modeling the brightness curve of EZ Lyn star// Proceedings of international conference of students and young students "Farabi world". - Almaty, 2021. - S. 177

The connection of the dissertation topic with the plans of scientific work

The dissertation work was carried out in accordance with the plans of fundamental research works of the Committee of Science of the Ministry of Education and Science of the Republic of Kazakhstan "Grant funding of scientific research" on

the topic: "AP08856419 - Observational manifestations of accretion flows in close binary star systems and their analysis by computer simulation methods."

The structure and scope of the dissertation

The dissertation consists of an introduction, four sections, a conclusion, a bibliography and contains two appendices. The work is presented on 90 pages of typewritten text, illustrated with 38 figures, 38 formulas, 9 tables, the list of references contains 138 items.