ВАК 2024 MODERN ASTRONOMY: FROM THE EARLY UNIVERSE TO EXOPLANETS AND BLACK HOLES
300 years Russian Academy of Sciences

Determination of the dwarf novae parameters and their temporal changes

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Abstract. We present the development of a method for determining dwarf novae parameters and their temporal changes from the analysis of observations for several times. Using the modeling method of H I lines in the optical spectra of dwarf novae with high-temperature white dwarfs leads to large errors in the measured parameters. Therefore, the idea of using observations for several times was proposed, which will allow to determine the parameters of the system with greater accuracy. The dwarf novae FL Psc, which belongs to the WZ Sge type, was chosen as a test object. Its spectroscopic observations were carried out in 2021 and 2023 years by the 6-m BTA telescope. According to the light curve from the ZTF archive, in 2021 FL Psc was in a quiescent state, and in 2023 observations were made at the final stage FL Psc of relaxation to the pre-outburst level. The values of white dwarf temperature in both times of observations were obtained using the requirement of the invariability of the gravity value on its surface. However, similar temperature values in both times of observations differ from the literature predictions on the temperature increase of a white dwarf after a superoutburst.

Keywords: methods: numerical; stars: dwarf novae, fundamental parameters; individual: FL Psc

DOI: 10.26119/VAK2024.072

1 Introduction

Cataclysmic variables are close binary systems consisting of a white dwarf and a low–mass main sequence star that fills its Roche lobe. Dwarf novae belong to cataclysmic variables with a disk form of accretion. SU UMa-type systems are a subclass of dwarf novae that demonstrate ordinary outbursts with the brightness amplitudes of $\Delta m = 2^{\mathrm{m}}$–$5^{\mathrm{m}}$ and the durations of a few days, as well as superoutbursts with the amplitudes of $\Delta m > 8^{\mathrm{m}}$ (Smith 2006). A junior subclass of SU UMa-type dwarf novae are WZ Sge-type dwarf novae, which exhibit only superoutbursts with the amplitudes up to $\Delta m = 9^{\mathrm{m}}$ with a long relaxation period to the quiescence (Kato 2015). Determining the parameters of white dwarfs which are a part of cataclysmic variables gets complicated by the predominance of radiation from the accretion disk and flowing matter from the secondary in the optical spectrum. Therefore, it is impossible to apply standard methods for determining the effective temperature and surface gravity of a white dwarf based on modeling of H I profiles. Mitrofanova et al. (2014) analysed the optical spectra of a dwarf novae of WZ Sge-type GSC 02197-00886. In this paper it was shown that the system in quiescence exhibits an optically thin accretion disc and the continuum is dominated by white dwarf radiation. Therefore, the authors made an assumption about the possibility of directly determining the parameters of white dwarfs using the H I absorption line modeling method. The method was implemented in the work of Dudnik et al. (2023), in which a model analysis of the optical spectra of three dwarf novae was performed. The described approach allows us to obtain the most correct assessment of the accuracy of the obtained parameters. According to the results of Dudnik et al. (2023), the method most optimally describes the observed spectra of dwarf novae with the medium-temperature white dwarfs. If the system contained a high-temperature white dwarf, then the error range was large. Therefore, to solve the described problem, the idea of performing the specified model spectrum analysis for several times of observations was put forward. Using this approach will significantly improve the accuracy of determining the obtained parameters of the observed systems.

2 Observations

FL Psc was discovered in the Automatic Sky Survey (ASAS) as a variable object called ASAS 002511+1217.2. Based on the spectrometric and photometric studies, FL Psc was assigned as a dwarf star of the WZ Sge-type, and the orbital period of the system was estimated as $P_{\mathrm{orb}} = 81.59 \pm 0.05$ min (Templeton et al. 2006). The brightness increase during the superoutburst was $\Delta m = 7^{\mathrm{m}}$, and the maximum interval between the superoutbursts was estimated to be 66 years. The current study used the observational data that were obtained at the 6-m BTA telescope by the SCORPIO-1 (Afanasiev & Moiseev 2005) on the nights of August 16–17, 2021 and October 21–22, 2023. According to the type of observed spectra FL Psc can be attributed to dwarf novae in a quiescence with a predominance of continuous radiation from a white dwarf and emission lines of an optically thin accretion disk superimposed on its continuum. The normalisation was carried out iteratively by comparing the observed spectrum with the model spectrum of the white dwarf with the parameters obtained from the previous analysis, taking into account the mask, excluding the regions distorted by emissions. Varying the mask boundaries allowed us to establish the optimal parameters of the mask boundaries, which ensured the stability of the determined parameters over the widest possible range of the analyzed spectrum (Fig. 1). The mask parameters were the same for the 2021 and 2023 observations.

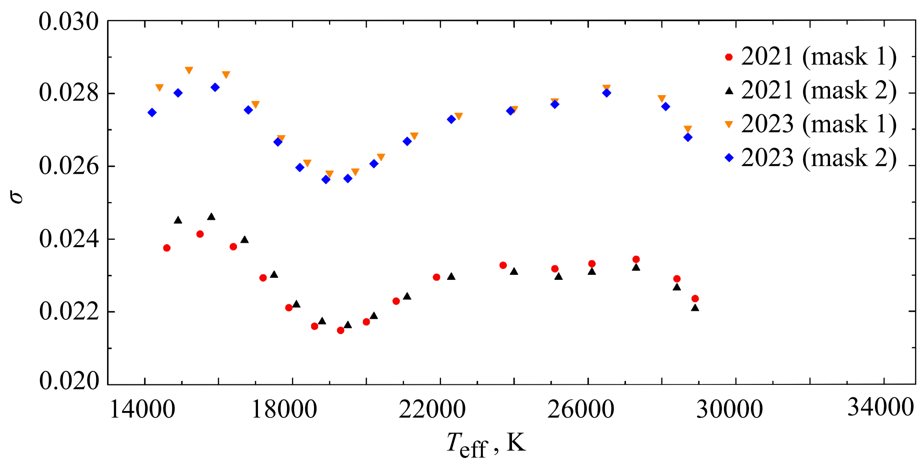

Fig. 1. $\sigma(T_{\rm eff})$ distributions at fixed $\log g$ for FL Psc observations in 2021 and 2023 with different masks.

3 Modeling of optical spectra and determination of white dwarfs atmospheric parameters

Dwarf novae FL Psc turned out to be a good choice for the object: according to the ZTF (Masci et al. 2019) data during the observation period in August 2021, the system was in a quiescence, in May 2023, there was an outburst in the system with the amplitude of $\Delta m \approx 3^{\rm m}$, and at the time of observations in October 2023, the system was at the stage of medium or late relaxation. The method of automatic analysis and determination of fundamental parameters performed for observations in 2021 and 2023 is completely identical to the method implemented in the work of Dudnik et al. (2023). When analysing the distributions obtained for the 2021 and 2023 observation time, numerical parameters of the atmospheric models of white dwarfs $T_{\rm eff}$ and $\log g$ were obtained, which corresponded to the global minima of the distributions σ (Fig. 1). In the current work, the errors $\log g$ are set as the difference between the obtained optimal values for the observation times of 2021 and 2023. Errors in all other parameters are calculated from the $\log g$ error defined in the specified way. To estimate the mass M_1 and radius R_1 of a white dwarf, a dependence of temperature–mass–radius was used for white dwarfs with a predominance of various chemical elements in the core, taken from the work of Panei et al. (2000). To find the fundamental parameters of the secondary, we simultaneously used the theoretical mass–radius relations for brown (Baraffe et al. 2003) and red (Girardi et al. 2000) dwarfs and the equation from Eggleton (1983). The calculations also used the assumption of Kolbin et al. (2022) about the excess of the radius of the Roche lobe of a cold star over its model radius at the level of 5%, which is due to various factors. The resulting parameters are presented in Table 1. The comparison of the observed spectra with the theoretical ones is shown in Fig. 2.

Table 1. The final values of the parameters. The 2013 data were obtained in the work of Dudnik et al. (2023) and are given for comparison.

Observation	2021	2023	2013
$T_{\rm eff}$, K	19200 ± 1900	19100 ± 2000	22300 ± 1800
$\log g$	8.09 ± 0.25	8.14 ± 0.27	8.14 ± 0.14
M_1, $M_\odot$	0.67 ± 0.16	0.69 ± 0.17	0.70 ± 0.07
R_1, $R_\odot$	0.0122 ± 0.0019	0.0117 ± 0.0021	0.0118 ± 0.0010
M_2, $M_\odot$	0.132 ± 0.010	0.132 ± 0.010	0.114 ± 0.005
R_2, $R_\odot$	0.152 ± 0.011	0.152 ± 0.011	0.132 ± 0.005
A, $R_\odot$	0.575 ± 0.004	0.581 ± 0.005	0.587 ± 0.004
q	0.199 ± 0.014	0.191 ± 0.022	0.158 ± 0.010

4 Discussion

From the obtained results we can conclude that the condition of constancy of the surface gravity $\log g$ is fulfilled. However, comparing the values of the effective temperature $T_{\rm eff}$ requires a separate discussion. The obtained $T_{\rm eff}$ for the observation times of 2021 and 2023 coincide, which causes a discrepancy with the literature data. After a superoutburst, an increase in the temperature of a white dwarf (up to

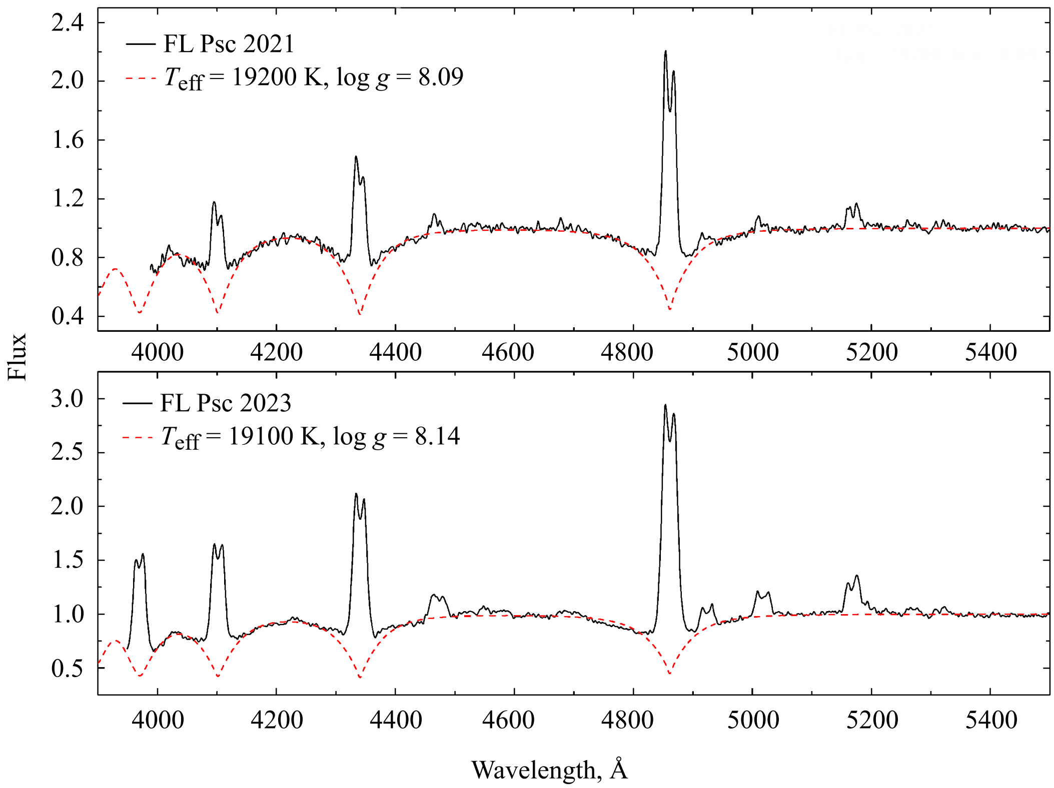

Fig. 2. Observed FL Psc spectra (solid lines) and model spectra (dashed lines) for two observation times.

35 000 K) is always recorded, and the process of its further cooling occurs on a time scale from one year to several years (Long et al. 2004; Godon et al. 2006). According to the light curve obtained from the ZTF data (Masci et al. 2019), it cannot be definitely stated that the dwarf nova FL Psc experienced a superoutburst in May 2023, since its observations at the beginning and maximum of the outburst are absent (amplitude $\Delta m \approx 2\overset{\rm m}{.}5$ in the zr-band). For a typical outburst, the brightness decay time is several days, which also does not correspond to the observed light curve, for which the relaxation time is more than $90^{\rm d}$. It is possible that the excess luminosity can be explained by additional radiation from the accretion disk in the emission lines and optical continuum. Brightness in 2023 is about $0\overset{\rm m}{.}5$ higher than in 2021. Measurements of the integral intensity of the lines in the two spectra showed that radiation in the emission lines can provide no more than 6.1% of the excess luminosity in the V-band, which is at odds with the observations. Therefore, the question

remains open about the contribution of radiation from an optically thin accretion disc to the continuous spectrum in the relaxation-to-quiet phases.

5 Summary

In this paper, we implement a method for determining the parameters of dwarf novae and their temporal changes from the analysis of observations over several times. The idea of this method is to expand the observed series under the study and take into account the requirement of constancy of gravity. The specified requirements were met and the values obtained within the error limits coincided with the measurements made in Dudnik et al. (2023). A comparison of the obtained values of the white dwarf temperatures is presented for discussion: according to the light curve, the system was at the stage of the middle or late relaxation during the observation period of 2023, and the obtained values indicate no temperature change. This contradicts the published data on the increase in the white dwarf temperature after the superoutburst.

Acknowledgements. The study was supported by the grant of the Russian Science Foundation No. 22-72-10064 (https://rscf.ru/project/22-72-10064/). The work on the observational data reduction and modeling the stellar spectra was supported by the grant No. 075-15-2022-262 of the Ministry of Sciences and Higher Education of the Russian Federation (13.MNPMU.21.0003).

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