INVESTIGATION OF THE PRE-CATACLYSMIC VARIABLE NSVS 14256825

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In this work, we studied the features of the formation of radiation from the young pre-cataclysmic variable NSVS 14256825. The theoretical phase light curves of the system are matched taking into account the effects of reflection and non-sphericity of the components with those observed in the BVR bands. From the analysis of moderate-resolution spectra, a radial velocity curve of the sdB sub-dwarf was constructed and estimates of its amplitude were found. The integrated spectra of the system were simulated and the weakness of the effects of reflection on the deformation of the radial velocity curve of the sdB – sub-dwarf was theoretically shown. Based on a comprehensive analysis of observational data, the fundamental parameters of NSVS 14256825 are determined.

Keywords: observations: spectra – stars: parameters –modeling: reflection effects – stars: individual – V1828 Aql

1. INTRODUCTION

Close binary systems (CBS) of the HW Vir type belong to one of the groups of pre-cataclysmic variables (PV), first sorted out by their observational characteristics in the mid-90 of the last century. The main components of these systems are low-mass (M = 0.47 ± 0.02 $M_{\odot}$) sdB sub-dwarfs, shrinking to the state of cooling down white dwarfs, and the secondary components are low-mass red and brown dwarfs of the Main Sequence. According to the evolutionary status, such HW Vir stars occupy an intermediate position between systems with a common envelope, where the main component is on the horizontal branch of the Hertzsprung-Russell

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diagram, and cataclysmic binaries. The high effective temperature (Teff = 20000-45000 K) and luminosity ($M_V = 3^m - 4^m$) of sdB sub-dwarfs, combined with the proximity of cold satellites, lead to powerful ultraviolet irradiation of their surface, its heating, and energy reemission in the optical range. As a result, reflection effects are formed in HW Vir-type systems. Their amplitude is mainly determined by the temperature of the sdB sub-dwarf, the radius of the cold star, and the size of the semimajor axis of the system.

The group of young pre-cataclysmic variables with sdB sub-dwarfs remained poorly studied by the beginning of the 21st century due to the technical difficulties of their detection and subsequent analysis. However, the development of specialized methods for their identification has led to a rapid increase in the abundance of this group and currently it has about 40 objects. For a significant fraction of stars of the HW Vir type, numerical analysis of light curves and optical spectra was carried out with the determination of part of their fundamental parameters. However, in these works, mainly the modeling of light curves in the blackbody approximation was applied, which did not take into account the real physics of the interaction of radiation with matter and led to the appearance of additional errors. The results presented by us below are obtained using models of irradiated stars in close binary systems and are free from such drawbacks.

2. OBSERVATIONS

Spectroscopic observations were carried out at the Large Azimuth Telescope of the SAO RAS using the SCORPIO [1] primary focus aperture reducer in the spectroscopy mode with a long slit. In our analysis, we used the data obtained during observations with VPHG1200g grism (1200 lines / mm) and an EEV 42-40 CCD receiver (2048 × 2048 pixels, size 13.5 × 13.5 μm), providing spectral resolution $\Delta\lambda = 5.0$ Åin the studied wavelength range $\lambda\lambda$ 4050-5850 Å. The signal-to-noise ratio averaged 127.

Photometric observations were carried out on the Zeiss-1000 telescope of the SAO RAS using an EEV 42-40 CCD with dimensions of 2048×2048 pixels in a strip alternating mode. We have processed three-color photometric observations of the CBS NSVS 14256825 in the BVR photometric system. All observations were made under good astroclimatic conditions. For processing the observations, the Maxim DL computer package was used. All received images are calibrated (displacement currents of the device (bias) are subtracted). A comparison of the stars' brightness in the matrix field showed that the differential photometry errors of NSVS 14256825 were Δm $\approx$ 0.02m in bands B and V, and Δm $\approx$ 0.01m in band R.

3. MODELING AND ANALYSIS OF LIGHT CURVES AND SPECTRA

Theoretical modeling of spectra and light curves was carried out taking into account the effects of reflection and non-sphericity of the CBS components according to the technique implemented in the SPECTR [2] software package.

In the model analysis of the observed light curves, it was taken into account that the amplitude of the reflection effects is primarily affected by the radius of the secondary component, and the depth of the main eclipse is affected by radii of both components and the angle of inclination of the orbit. In this case, the values of the effective temperature and radius of the sdB sub-dwarf were considered fixed. They were found in advance from modeling the spectra of NSVS 14256825 in the phases of minimum brightness, when reflection effects do not have a noticeable effect on them. The value of the surface gravity of the sdB sub-dwarf obtained from the description of the observed spectra was used to determine its radius at a fixed mass value.The final set of parametrs obtained from this analysis was as follows: $i = 83°30'$, R1=0.166 $R_{\odot}$, R_2 =0.125 $R_{\odot}$, L1 / L_2 =17636. As a result, the ratio of the luminosity of the sdB sub-dwarf to the luminosity of the red dwarf L1 / L2 decreased by 43% compared with the results from [3].

The chemical composition of the atmosphere of the main component of NSVS 14256825 was obtained simultaneously with the values of its parameters from the modeling of spectra using the SPECTR software package [4, 5]. It shows a helium deficiency ([He / H] = -1.47) and a non-solar distribution of the contents of the remaining elements, expressed in a strong carbon deficiency ([C / H] = -1.6) and moderate ([X / H] = (-0.6) - (-1.0)) deficits of nitrogen, oxygen, silicon and sulfur. In general, the found chemical composition of the sdB sub-dwarf is consistent with the literature data and the chemical composition of other objects of this type, reflecting the effects of stratification in the hydrostatic atmosphere of the star.

4. ANALYSIS OF RADIAL VELOCITIES AND DETERMINATION OF SYSTEM PARAMETERS

The radial velocities of the sdB sub-dwarf were measured from the $H_\delta, H_\gamma, HeI, HeII, H_\beta$ lines using the cross-correlation method in single-band and multi-band versions.

The obtained sets of radial velocities were approximated for a circular orbit model with a calculation of their amplitudes. Numerical simulation of the spectra showed that the reflection effects in NSVS 14256825 significantly distort the observed radial velocity curves, changing the amplitudes by about 10%. Therefore, the analysis of radial velocity curves of this system with the determination of its parameters requires taking into account corrections for the reflection effects. At the same time, we found a weak effect of reflection on the shape of these curves, which does not allow us to obtain an estimate of the mass ratio of components from their model analysis. Therefore, we fixed the mass value of the main component at $R_1 = 0.47 \pm 0.01 R_\odot$, which is characteristic of all single sdB sub-dwarfs [7].

Table 1 presents a set of fundamental parameters NSVS 14256825 from [3] and the set of parameters we obtained. Compared with the data of [3], found by us mass of the main component increased by 12%, and the radius decreased by 12%, the mass of the secondary component decreased by 9% with a decrease in its radius by 23%. In general, the set of parameters NSVS 14256825 that we obtained is significantly different from that adopted previously and is characterized by a much lower mass ratio of the q components. The main reason for these changes is obviously the accounting in our work of the effects of reflection on the measured radial velocities of the sdB sub-dwarf. Simultaneously, modeling of light curves using model of atmospheres method in our work and using the blackbody approximation in the study of Almeida et al. [3] leads to slightly different estimates of the component radii, which also affects the final set of parameters. In general, we can conclude that it is desirable to analyze the radiation of HW Vir-type systems only on the basis of a numerical simulation of its optical radiation.

Table 1. Fundamental parameters of NSVS 14256825.

Parameter	Our results	Almeida et al
i	83.5°	$82.5^\odot \pm 0.3$
R_1 , $R_\odot$	0.166 ± 0.000	0.188 ± 0.010
$R2, R_\odot$	0.125 ± 0.000	0.162 ± 0.008
$a, R_\odot$	0.802 ± 0.002	0.800 ± 0.04
R_1/a	0.2080	0.2350
R_2/a	0.1566	0.2025
$logg$	5.75	5.51 ± 0.11
T_1,	K 40000	42000 ± 400
T_2	, K 4000	2550 ± 500
$M_2, M_\odot$	0.099 ± 0.003	0.109 ± 0.023

5. CONCLUSION AND ANALYSIS OF THE RESULTS

Preliminary modeling of the reflection effects in the light curves made it possible to find the mass ratio from the analysis of radial velocity curves, which at a known angle of inclination of the system ensured the determination of their masses. Analyzing the conditions of applicability of the new method, Shimanskii et al. [6], suggested that it is effective for systems with main component temperatures above Teff = 32000 K, which ensures the appearance of HI emission lines.

However, our analysis of the spectra of NSVS 14256825, the main component of which meets the above condition in excess, showed the limited application of the proposed methodology.

As a result, the use of additional evolutionary assumptions is required to determine the complete set of NSVS 14256825 parameters. We propose using, as an additional assumption, a fixed mass value of the main component M1 = 0.47 $M_{\odot}$, found for most single sdB sub-dwarfs [7].

Thus, from the analysis with modeling of optical radiation, we redefined the complete set of fundamental parameters of NSVS 14256825. We estimated the angle of inclination of the orbit, the semimajor axis, masses and radii of both components. Compared with the data from article [3], the parameters have shifted significantly. It is worth noting that the secondary component by weight is located on the border of red and brown dwarfs.

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