

# SPECTRAL INVESTIGATIONS OF THE SYMBIOTIC STAR CH CYGNI IN 2018

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The paper presents the results of a comparative analysis of the star's light curve with the spectrophotometric parameters of the  $H\alpha$ ,  $H\beta$ ,  $\text{Nal}$  doublets lines of the D1, D2 and  $\text{Hel } 5876$  measured on the basis of highly resolved echelle spectra of the symbiotic star CH Cyg obtained in the 2018th ShAO telescope in 2018 using a modern light receiver. The results of the analysis showed that the equivalent width and intensity of the  $H\alpha$ ,  $H\beta$  and  $\text{Hel } 5876$  emission lines increase with decreasing star brightness. Even at maximum brightness, the  $\text{Hel } 5876$  line disappears. Changes in the values of equivalent width and intensities of the components of the  $H\beta$  line and the light curve V show the same character with the opposite phase. High-velocity wide absorption components with a velocity of up to 800 km/s were found in the  $H\beta$  and  $\text{Hel } 5876$  lines. The  $\text{Nal}$  doublets absorption line profiles show a two-component structure, and the change in depth  $(1 - I/I_0)$  of the red components of the D1 and D2 lines indicates exactly the same feature as the brightness change V.

**Keywords:** CH Cyg, Symbiotic star–CDD Photometry–echelle spectra..

## 1. INTRODUCTION

CH Cyg is very complex and mysterious variable comprehensively studied in a very large spectral scale. CHCyg symbiotic star was revealed in 80<sup>th</sup> years of 19<sup>th</sup> century. Photometric observation history for more than 130 years period is available for this star [1]. This is the brightest the closest one among symbiotics. The distance to this symbiotic star is about 244 parsec according to data of Hipparcos [2]. Its visual star size is  $V=6.0^m$  in maximum and  $10.5^m$  in minimum, it is

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brighter in infrared ray and star size in  $2\mu\text{m}$  wave length is  $K=-1^m$ . First useful spectra of CH Cyg have been achieved by Joy in 1924 and 1927 [3]. According to 100 days period of well disseminated 5 spectra the spectral type of the star has been determined M6 and radial velocity has been determined  $-52.5$  km/s. There is no information available about emission lines. In 1952 Gaposkin classified the CH Cyg as M6-M7 spectral class varying in 90-100 days period in 1m amplitude by analyzing the Harvard patrol observation materials. It was even accepted as a standard star because these alterations were non noticeable in the spectrum. This classification was accepted true until 1963. For the first time Deutsch revealed a strong alteration in the spectrum of the star on September 1963 [5]. In the spectrum of the star hot blue continuum and emission lines of HI, HeI, [FeII] CaII were observed along with absorption lines of neutral metal, which is the sign of a cold star. It repeated in 1965 again. Since that time the star attracted attentions and was accepted as a symbiotic star.

Periodic photometric, infrared, spectral and radio observations have been conducted thanks to convenient location of the star – in the north hemisphere at  $(+50)$  degree. Observations show that repetitive active processes occur in the star in various periods. Composition of the star has not been fully identified yet: binary and triple star system models have been proposed [6].

Nowadays, CH Cyg is one of the most researched and the least understood objects [7]. It is accepted that the activeness of CH Cyg this star is generated from the energy released as a result of accretion of the red giant's wind by the hot component. The amount of accreting substance is dependent on pulsation of the giant and also on orbital movement of the star, of course if the orbit is elliptic. Several possible commonly accepted models have been proposed to explain the CH Cyg symbiotic system. Magnetic rotator model [8], according to this model the CH Cyg is a binary star system comprising of a pulsating red giant and white dwarf with a powerful magnetic field mowing in 5700 days period in an elliptic orbit. Hinkle and some others [9] identified  $756^d$  days period of periodic alterations of ray velocities in the ray spectrum of CH Cyg. They explained it with existence of the third G-dwarf in the inner orbit with a short period ( $P = 756^d$ ) within the long period ( $P = 5300^d$ ) of binary system. Later, after several observations and precisions, Hinkle refused from the 3 stars model and proposed binary symbiotic system for the CH Cyg [10].

By proposing a long period 5650d in [11] 1998-2001 Mikailov and others, based on spectra achieved in 1995-2004 Lijima and others identified that 756d period in ray velocities exists in optic region too for the photo spectrum lines of the red giant [12]. These results confirmed that CH Cyg symbiotic system consists of 3 stars.

We CH Cyg symbiotic star introduce the comparison of the spectral parameters of  $H\alpha$ ,  $H\beta$ , HeI 5876 and NaI doublets lines V light curve of the star based on spectra achieved on Shamakhy observatory in 2018.

## 2. OBSERVATIONS AND DATA REDUCTION.

All echelle spectra discussed in this paper have been managed in 2meters telescope of Shamakhy Astrophysical Observatory in 2018 between May÷December, during 31 nights. The telescope is fitted with ShAFES - Shamakhy Fibre Echelle Spectrograph and CCD camera cooled by liquid nitrogen [13]. Spectral identification  $R=\lambda/\Delta\lambda=28000$ , spectral diapason 3900-7700Å, Chip 4096x4096 pixel, pixel size  $15\times 15\mu\text{m}$ . All spectra have been achieved in SLW regime of CCD, gain=1.27 e-/ADU, Read Out Noise (RON) =3.74. All calibration screens have been achieved for each night: Sky, ThAr, Flat and Darks. The interval of the observation period was 223 days and in this period nearly 100 echellespectrum have been achieved. All spectra have been achieved within 119 days in sequence, just 2 spectr have been achieved after about  $\sim 100$  days.

Spectra of the stars a Lyr and 51 Dracon have been achieved in the same conditions for processing of the telluric lines in the spectra of CH Cyg symbiotic star and spectra of HD148783 (G Her, M6III) have been achieved in some nights for processing of the cold star M spectra.

Wavelength calibration achieved with Sky and a Th – Ar hollow cathode comparison. The spectra were reduced using the software package new version of DECH [14] following the standard procedures. Extraction of all spectra have been managed by using IRAF mask.

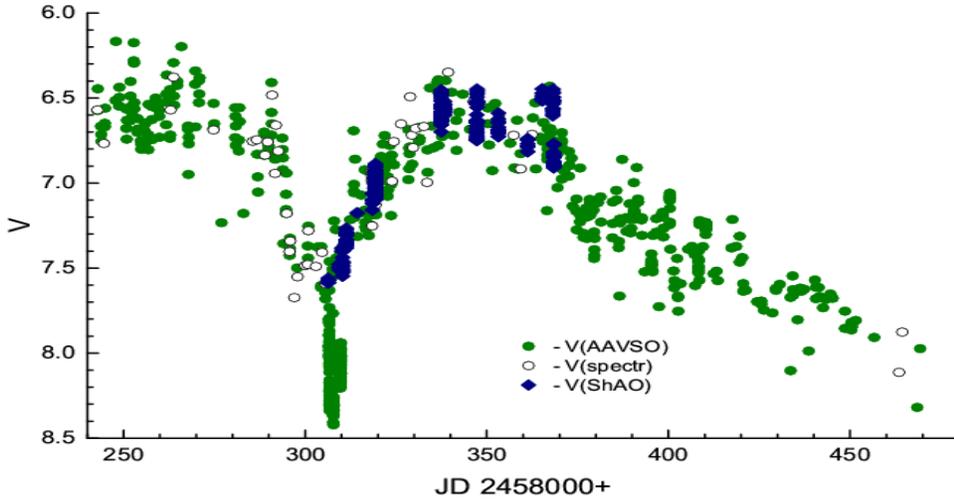
Observation history is given in the table-1. Catalogue list of the spectra and date of achievement, universal time, exposition time and number of spectra achieved within a night have been given in the table.

## 3. PHOTOMETRICS OF CH CYG.

17 nights of photometric observations of CHCyg have been carried out in ZEISS-600 telescope of Shamakhy Astrophysics Observatory in 2018 July-September. The telescope was fitted with  $4096\times 4096$  pixel (1 pix = 9 mic) size CCD type of light receiver and photometer with effective fields of view are of 17 arcmin [15].

Light curve in V filter for the period of spectral observations of CH Cyg symbiotic star was composed based on our observations and AAVSO [16] database (Fig.1). In the figure1 empty circles match with the dates of observations. As it

is seen from the figure, the star as active during observations and within several days it got weakened by  $1.5^m$  and reduced from  $6.5^m$  to  $8^m$ . It got its previous brightness after about 1 month. Fortunately, our spectral observations coincided with that period and covered that dramatic phase of the star. **Results of mea-**

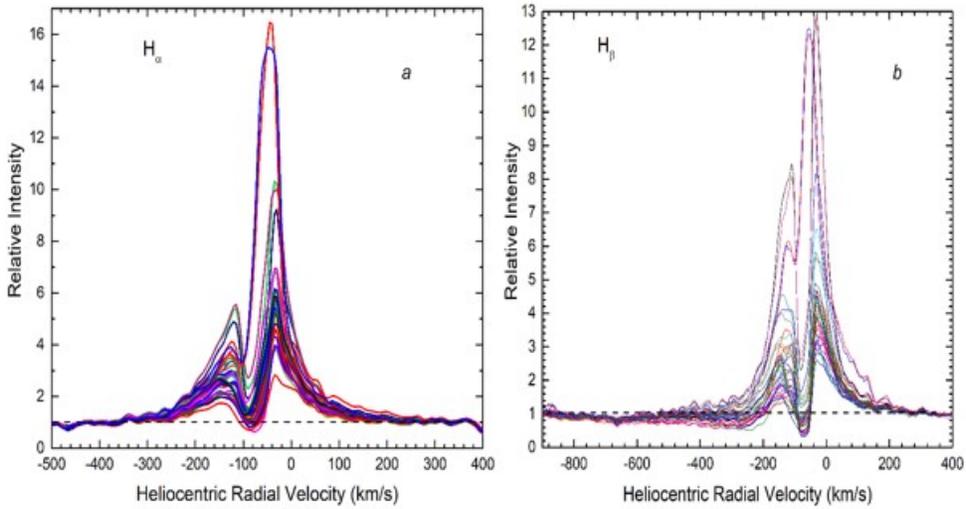


**Fig. 1.** Light curve of the CH Cyg symbiotic star in V filter. ●- AAVSO, ◆- ShAO data, ○- dates of spectral observations.

**surements.** In this paper we only worked with  $H\alpha$  and  $H\beta$  lines of Balmer series of the Hydrogen atom, HeI 5876 line of Helium atom, doublets lines of NaI D1 and D2 lines of Natrium atom. In the next studies it is planned to work with the other spectral and continue researches.  $H\alpha$  and  $H\beta$  lines are very bright and intense as radiation lines, hence it is possible to identify the structure of their profiles with high definition.

**$H\alpha$  and  $H\beta$  hydrogen lines.** Profiles of  $H\alpha$  and  $H\beta$  lines are given in the figure1. As it is seen from the figure,  $H\alpha$  and  $H\beta$  lines gave profiles with intensive alteration, centric absorption and with binary V and R components during period of observations. In all the spectra red component was more intensive than blue component, e.g.:  $V/R < 1$ . It indicates that all time through observations continuous flow of substance occurred. In some profiles the central absorption reduces, even lower than continuum. Large absorption components with high velocity have been observed in the blue side of  $H\beta$  line. Velocity in the blue side of absorption components varies between  $-660 \div -900$  km/s.

Spectral parameters (ray velocity, intensity, equivalent widths) of  $H\alpha$  and  $H\beta$  have been given in the table-2 and 3. Ray velocity of R component of  $H\alpha$  line was almost in close value in all the dates:  $RV = -31 \div -33$  km/s. Only in the



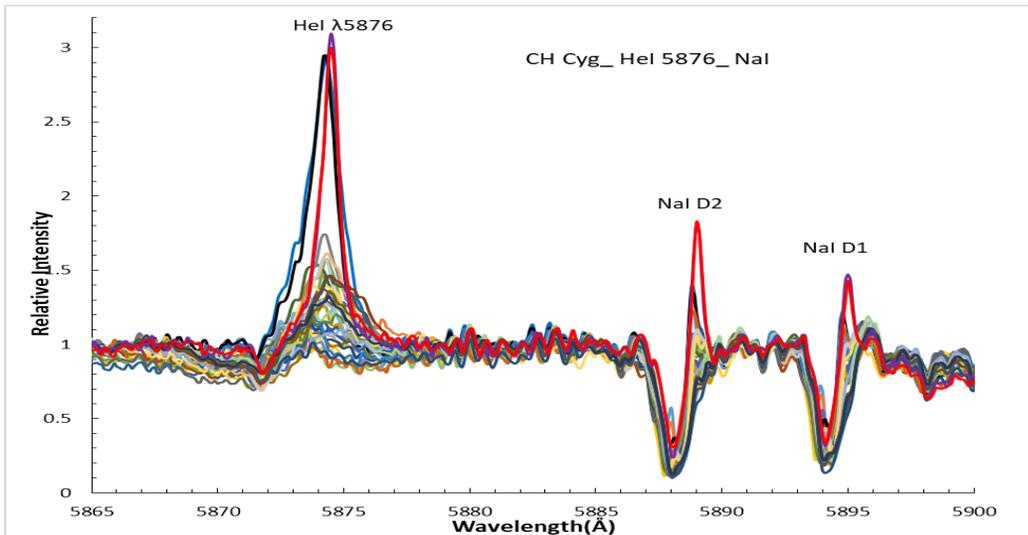
**Fig. 2.** Profiles of Hydrogen lines. a –  $H\alpha$  line, b –  $H\beta$  line. Continuum is indicated with dash line.

last two dates – 11<sup>th</sup> and 12<sup>th</sup> of December it slides towards to the blue side in about in 10 km/s and was  $RV = -43 \div -45$  km/s. Ray velocity of V component was changed in  $-116 \div -130$  km/s, and central absorption was changed in  $-75 \div -103$  km/s. Alterations in ray velocity is perhaps connected with alterations of intensity of V and R components. Ray velocity of the second component of the V component is measured  $-145 \div -150$  km/s. As it is seen from the table 2, intensity and equivalent widths of components of  $H\alpha$  line changes in about -5 times during the period of observations. Intensity of R component gets values in  $2.8 \div 16.4$  interval, and intensity of V component is gets values in  $1.73 \div 5.56$  interval. While measuring the equivalent widths of  $H\alpha$  and  $H\beta$  components the deepest point of the central absorption was taken as a border. That's why values of equivalent widths of components should be considered as conditional. Equivalent widths in  $H\alpha$  lines got values in the  $4.81 \div 29.2$  Å interval. The minimum value was recorded in 26-08-2018 and in that date HeI line disappeared.

$H\beta$  line's R component's ray velocity alters more than  $H\alpha$  during observation period:  $RV = -7.4 \div -33$  km/s, and it got  $RV = -52 \div -54$  km/s by sliding towards to the blue side on 11<sup>th</sup> and 12<sup>th</sup> of December by  $\div 30$  km/s. Most probably alteration in the velocity is due to sharp change in intensity of R component. Ray velocity of the  $H\beta$  line R component was  $-104 \div -153$  km/s, and ray velocity of the central absorption was close to  $H\alpha$ :  $-70 \div -100$  km/s. Alteration of ray velocity perhaps is due to changes in intensity of R and V components.

As it is seen from table-3, intensity and equivalent changes rapidly at the same observation period. Intensity of R component gets value of  $2.2 \div 12.84$  and intensity of V component gets value of  $1.63 \div 8.47$ . Increase of intensity of V component was 1.7 times more in  $H\beta$  line than in  $H\alpha$  line. Equivalent widths of  $H\beta$  line got value in  $3.05 \div 23.94 \text{ \AA}$ . Minimum and maximum proportion of values of equivalent widths of  $H\alpha$  and  $H\beta$  line were 6 and 8 respectively.

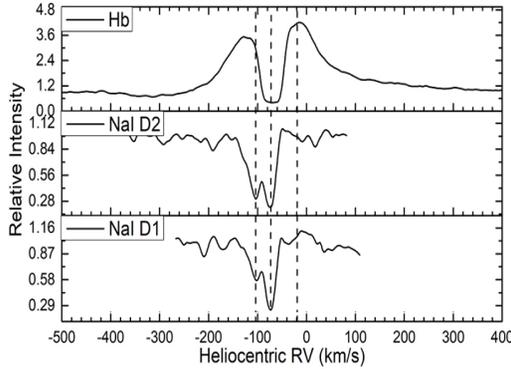
**HeI 5876 and NaI doublet lines.** HeI  $\lambda 5876$  and NaI doublet lines are the most visible lines after Balmer series lines of Hydrogen in the CH Cyg symbiotic star spectrum. HeI  $\lambda 5876$  is generated in the adjacent cover around the hot star in the star wind. NaI doublet lines are indicators of star surrounding cover and neutral material zone. Study of these lines will allow to characterize the afore mentioned environments. HeI 5876 and NaI doublet lines profiles are given in the Figure 3. As it is clear from the figure, HeI 5876 and NaI doublet lines changed rapidly during observation season. In parallel with strengthening of HeI 5876 line (increasing of the intensity), strong emission lines appear in the red wing of the NaI doublet lines and it converts to P Cyg type of profile. Both of the doublet lines of NaI demonstrate binary structure comprising of deep absorption especially in the bright period of the star. HeI 5876 line almost disappears in maximum brightness and even large absorption is observed.



**Fig. 3.** Profiles of HeI  $\lambda 5876$  and NaI D1, D2 lines.

In the table 4 the results of spectrophotometric measurements of HeI 5876 and NaI doublet lines have been introduced. Ray velocities of each component of the NaI doublet lines demonstrates very close values. Ray velocities of the R components of D1 and D2 lines are varying in  $-73 \div -85 \text{ km/s}$  interval and ray

velocity of the V component is varying in  $-97 \div -103$  km/s interval. R-red component demonstrates the same radial velocity with neutral hydrogen zone, i.e., the central absorption of Hydrogen lines (Fig4). It is assumed that the R absorption components of lines NaI, D1 and D2 arise are in the neutral absorption region. Deepness of R and V components of NaI D1 line change in  $0.59 \div 0.81$  and  $0.40$

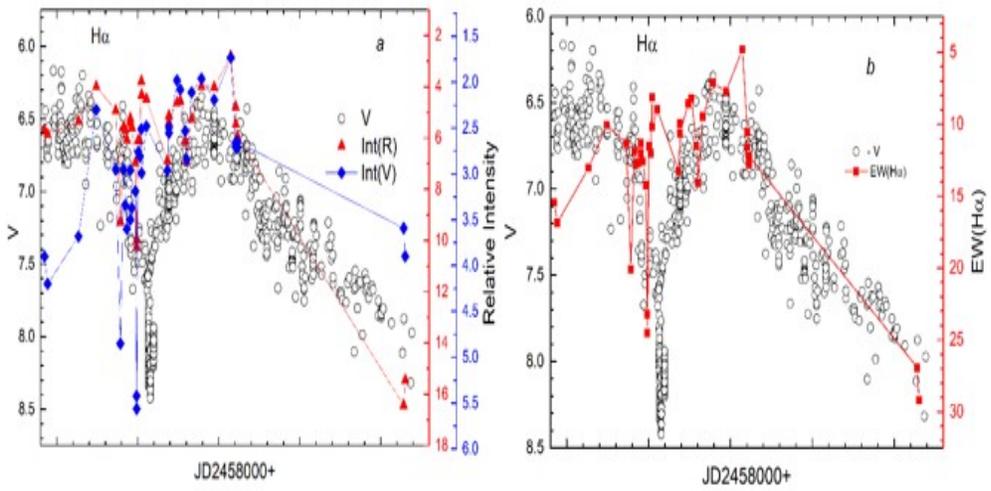


**Fig. 4.** Profiles of  $H\beta$  and NaI D1 and D2 lines.

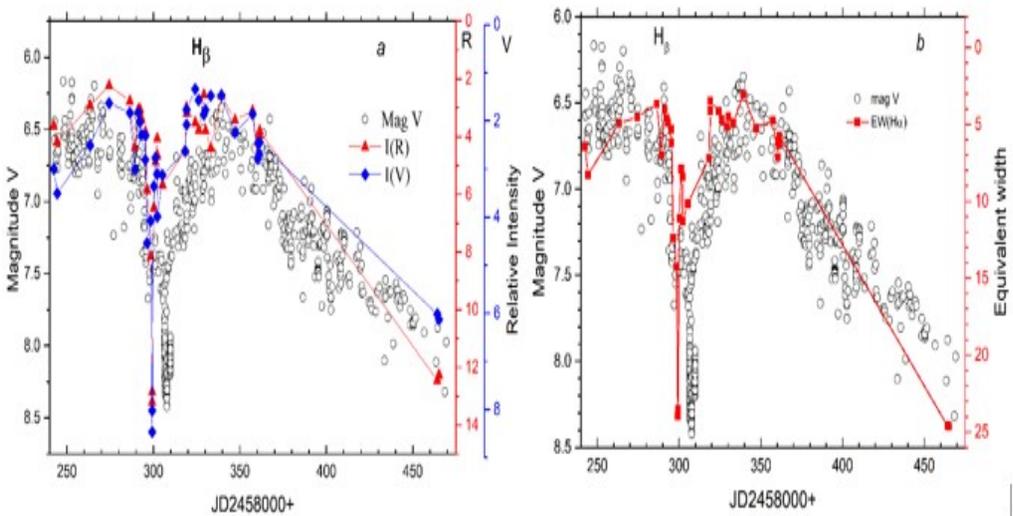
$\div 0.86$  interval respectively. Deepness of R and V components of NaI D2 line change in  $0.64 \div 0.85$  and  $0.64 \div 0.90$  interval respectively. Equivalent widths of D1 and D2 doublet lines of NaI takes value in  $0.60 \div 1.37$  interval for D1,  $0.59 \div 1.14$  for D2.

**Analysis of parameters of  $H\alpha$  and  $H\beta$  lines by using the light curve.** V Light curve's comparison of equivalent widths and components' intensity of  $H\alpha$  and  $H\beta$  lines in the spectrum of CH Cyg symbiotic star have been introduced in the figure 5 and 6 respectively. In the figures the right axes are in the increasing order towards to down. Comparison of equivalent widths of  $H\alpha$  and  $H\beta$  lines with light curve shows that, the typical feature for symbiotic stars – increase in equivalent widths with decrease in brightness – is observed here. This principle failed in  $H\alpha$  line in the dramatic phase (short term change in brightness) of the star. As it is seen from the figure, character of changes in components' intensity and equivalent widths of  $H\beta$  line during the observation period fully coincide with changes of brightness in V filter. It makes opposite correlation, it means, equivalent widths and intensity of the line increases as the brightness decreases.

Analysis of NaI doublet and HeI 5876 lines by using the light curve. In the Fig7 it is given the comparison of intensity of R components of NaI doublet lines with V light curve. As it is seen from the figure, changes of intensity of red components of D1 and D2 absorption lines are the same for both lines and it demonstrates identical character with changes in light curve in V filter. Decrease

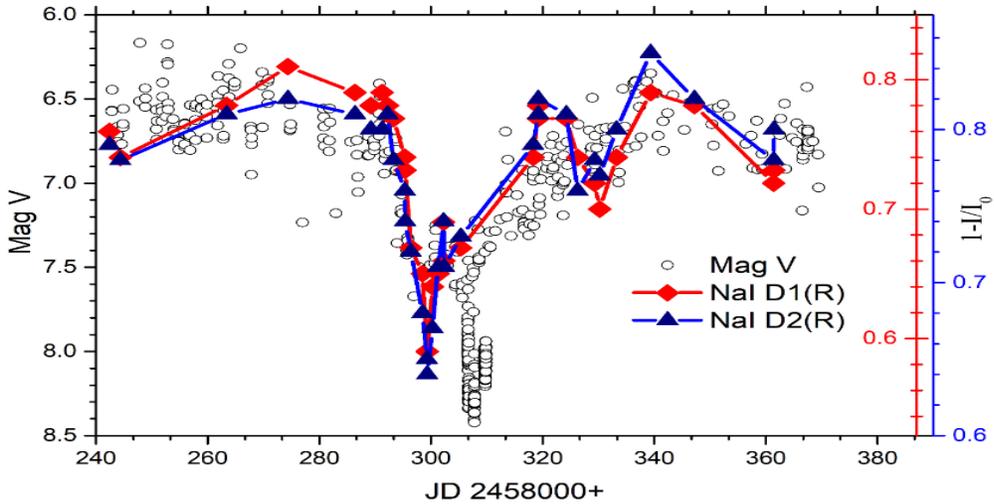


**Fig. 5.** Time changes of V light curve of CH Cyg symbiotic star and spectrophotometric parameters of H $\alpha$  line. a – changes in intensities, b – changes in equivalent widths, o – V filter light curve,  $\blacktriangle$ - intensity of R component,  $\blacklozenge$  - intensity of V component,  $\blacksquare$  - equivalent widths.



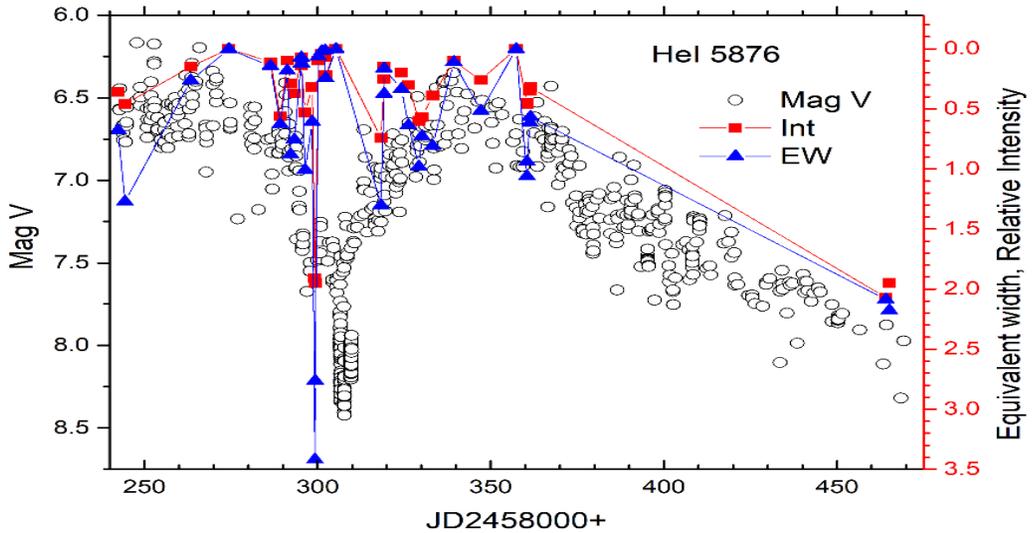
**Fig. 6.** Time changes of V light curve of CH Cyg symbiotic star and spectrophotometric parameters of H $\beta$  line. a – changes in intensities, b – changes in equivalent widths, o – V filter light curve,  $\blacktriangle$ - intensity of R component,  $\blacklozenge$  - intensity of V component,  $\blacksquare$  - equivalent widths.

in the deepness of the line is observed by decrease in brightness. **Analysis of**



**Fig. 7.** Timely changes of V light curve of CHCyg symbiotic star and deepness of red components of NaI doublet lines of D1 and D2.  $\circ$  – V filter light curve,  $\blacklozenge$  and  $\blacktriangle$  – deepness of D1 and D2 lines respectively.

**HeI 5876 line with V light curve.** V light curve comparison of HeI 5876 line intensity and equivalent widths has been introduced in the Fig8. As it is seen from the figure, convenience is observed in the character of changes of graphs if we do not consider the dramatic phase of the star. Values of equivalent widths and intensity increases with decrease in the value of brightness. Usually, line's intensity and equivalent widths decreases down to seamless spectrum level as the brightness increases. Even it was observed that HeI 5876 line disappeared for 3 days in the maximum of brightness. **Analysis and discussion of changes in CHCyg symbiotic star.** In some of our spectra V component of the H $\alpha$  and H $\beta$  lines and HeI 5876 line was found with complex structure and multiple components. As we already know, the emission lines are formed in the cloud around the hot star and enlargement of the surrounding cloud can lead to formation of several components. Existence of adsorbing substance around the star in the visual direction causes formation of the central absorption in the profile of the emission lines. In most cases central absorption gets a very close velocity to the mass center velocity (-60 km/s). But if we don't consider the spectra achieved in the last two dates of our observation, the central absorption slides towards the blue side of the spectrum in about 20 – 25 km/s and demonstrates the velocity of  $\sim$  -70 km/s, -85 km/s. This is because the velocity of the wind of the adsorbing particles in the neutral hydrogen region is greater than the velocity of wind of



**Fig. 8.** Time based change of intensity and equivalent widths of Hel 5876 and V filter light curve of CH Cyg symbiotic star. O – brightness in the V filter, ■ – intensity, ▲ – equivalent widths.

released particles in the ionized region. Absorption particles arrive in sooner than released particles. Deepness of the adsorbing component shows the density of the star wind [17].

Also, if we consider that,  $H\alpha$  and  $H\beta$  lines form in the disc around the star, formation of binary component profile can be explained by this factor. Rapid destruction of binary component profile and especially decreasing the intensity of V component are explained by destruction of the disc [17]. V/R proportion's being always less than 1 in our observations shows that continuous substance flow exists from the hot star.

Short term rapid changes in the star can be explained with the fact that, being in proximity for some years gives its effect when the hot star of the symbiotic system gets closer to the giant star, i. e., when the star moves through the periastron (Because the period is very long in CH Cyg star – 15 years). In this period intensity and amount of flow of substance from the giant star increases. As a result of that, stability of the disc around the hot star spoils and jet of substances are observed from the hot star and this is followed by rapid changes in  $H\alpha$  and  $H\beta$  lines [18].

Emission lines with high ionization potential, including HeI 5876 are formed in the region near the hot star. Rapid changes in the HeI 5876, getting disappeared of the line and formation can be related to changes of ultraviolet rays emitting from the hot star. Photometric rapid changes prove that firmly.

The fact of ray velocities of NaI D1 and D2 doublet lines red components and central absorption of H $\alpha$  and H $\beta$  getting the same value confirms that they have been formed in the same environment and in the neutral region around the star. Increase in the deepness of red component of D1 and D2 lines of NaI with increase of brightness of the star can be estimated a result of enrichment of the neutral region with Na atoms and vice versa. The other approach is also possible. Decrease in the brightness of the star after the active phase of the symbiotic star CH Cyg can be explained with screening too. Strong release of substance in the active period results in getting the gas-dust cloud denser around the star. As a result of that, the star becomes screened and brightness decreases. Formation of a strong emission in the red wing of the NaI doublet lines and at the same time reinforcement of the emission lines  $\lambda 6548 \text{ \AA}$  and  $\lambda 6584 \text{ \AA}$  of [NII] which is the main indicator of the gas-dust cloud once again proves that. The same time increase in the equivalent widths and intensity of H $\alpha$ , H $\beta$  and HeI 5876 lines in several times while rapid collapse decreasing of brightness can be explained with changes in the density of the surrounding cover. **The main results:** Following results have been summarized from the analysis of the CCD echelle spectra of CH Cyg symbiotic system achieved in 2018 for the first time.

1. Spectrophotometric parameters of H $\beta$  emission line such as equivalent widths, intensity of the red and blue components provide alteration with the same character and opposite phase changes with light curve in V filter.

2. Profiles of both D1 and D2 doublet lines of NaI represents binary component structure and changes in the intensity of both lines' red component match with the character of changes in V light curve.

3. Rapid alteration of HeI  $\lambda 5876 \text{ \AA}$  line and full disappearing of emission have been observed.

4. Absorption jets with the velocity of -800 km/s have been observed in the blue wing of H $\beta$  and HeI  $\lambda 5876$  lines.

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