Hα observations of the symbiotic binary system Z And during its 2006 outburst ⋆

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Abstract. High resolution data in the region of the line Hα have been obtained at the time of the light maximum and after it of the 2006 optical outburst of the symbiotic binary Z And. A blue-shifted absorption component indicating outflow velocity of about 1400 $\mathrm{km\,s^{-1}}$ as well as additional emission components with similar velocities, situated on the two sides of the main peak of the line were observed during that time. It is suggested that all of them are spectral signature of bipolar outflow, observed for the first time in the optical spectrum of this binary.
Key words: binaries: symbiotic - stars: mass-loss - stars: winds, outflows - stars: individual: Z And

Hα наблюдения на симбиотичната двойна система Z And по време на избухването й през 2006 г.

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Получени са данни с високо разрешение в областта на линията Hα от спектъра на симбиотичната двойна система Z And по време на избухването й през 2006 г. Наблюдаван е абсорбционен компонент на линията, показващ скорост на изтичане около 1400 $\mathrm{km\,s^{-1}}$, както и допълнителни емисионни компоненти с подобни скорости, разположени от двете страни на централния пик. Предполага се, че тези компоненти се дължат на двуполюсно изтичане, наблюдавано за първи път в оптическия спектър на системата.

Introduction

Symbiotic stars are interpreted as interacting binaries consisting of a cool visual primary and a compact secondary component accreting matter from the atmosphere of its companion. As a result of accretion the compact object undergoes multiple outbursts accompanied with intensive mass ejection in the form of optically thick shells, stellar wind, single discreet ejections (blobs) as well as collimated bipolar jets. The system Z And is considered as a prototype of the classical symbiotic stars. It consists of a normal cool giant of spectral type M 4.5 (Mürset & Schmid 1999), a hot compact component with a temperature of 1.5×10^5 K (Sokoloski et al. 2006) and an extended circumstellar nebula formed by the winds of the stellar components and partly photoionized by the compact object.

Z And has underwent several active phases (after 1915, 1939, 1960, 1984 and 2000) characterized by repeated optical brightenings, partly realized as a result of a strong redistribution of the energy of the compact object. The energy redistribution was caused by intensive loss of mass (Swings & Struve 1941; Boyarchuk 1967; Fernandez-Castro et al. 1995; Tomov et al. 2003a; Sokoloski et al. 2006; Skopal et al. 2006). The last active phase of Z And began in the end of 2000 August and continues up to the present time. The system underwent four consecutive optical brightenings, whose maxima were in 2000 December ($V\sim 8.8$ mag), 2002 November ($V\sim 9.8$ mag), 2004 September ($V\sim 9.1$ mag) and 2006 July ($V\sim 8.6$ mag) (Skopal & Pribulla 2006, and our UBV data). Spectral indications for intensive loss of mass were obtained during three of them, whose maxima were in 2000, 2002 and 2006. The UV line P V λ 1117 had a variable P Cyg profile containing one or two absorption components indicating velocities of 0–300 $\mathrm{km\,s^{-1}}$ in 2000 November and December. In all cases, however, the absorption reached its maximal depth in the velocity interval 0–50 $\mathrm{km\,s^{-1}}$ (Sokoloski et al. 2006). During the same time the profiles of the lines He I were of type P Cyg too and

⋆ Based on observations collected at the Rozhen National Astronomical Observatory, Bulgaria the absorption component indicated moderate velocities of the flow of 50–100 $\mathrm{km\,s^{-1}}$ (Tomov et al. 2003b; Skopal et al. 2006). During the period 2002 September – November the He II λ 4686 line, from its side, had a two-component emission profile consisting of a central narrow component and a broad component indicating stellar wind with a velocity of 1100–1200 $\mathrm{km\,s^{-1}}$ (Tomov et al. 2005). Skopal et al. (2006) concluded, by analyzing the wings of the Hα line, that there was intensive loss of mass by the compact object at that time too.

Our data show that the lines of H I and He I had P Cyg profile with absorption component indicating moderate velocity during the period 2006 July – September. In some cases the components were more than one. In July, however, these lines had additional absorption component with a high velocity of about 1400 $\mathrm{km\,s^{-1}}$ as well. Moreover, during the period July – September the Hα line had additional emission components, located either side of its central peak and having velocities of 1200–1500 $\mathrm{km\,s^{-1}}$. The appearance of the Hβ line was similar. The additional emission line components of Z And were already reported by Skopal & Pribulla (2006) and Skopal & Wolf (2006), which consider them as indications of bipolar jets. We suppose that all components indicating high velocities appear in bipolar outflow from the outbursting hot object. The 2006 outburst of Z And is a first one, when optical bipolar outflow from this system was observed. Our talk is devoted to this phenomenon, where preliminary results of one study of the Hα line are treated.

1 Observations and reduction

The region of the line Hα was observed on eight nights in July, August and September 2006 with the Photometrics CCD camera mounted on the Coude spectrograph of the 2m RCC telescope of the Rozhen National Astronomical Observatory. During the last of these nights besides the region of the line Hα, that of Hβ was also observed. The spectral resolution was 0.2 $\mathrm{\AA\,px^{-1}}$ on all occasions. Some of the exposures were comparatively long to obtain better ratio signal to noise of the continuum although the central emission component of the Hα line was saturated in some cases (Table 1). Ever when we made more than one exposure per night, the spectra were added with the aim to improve the signal to noise ratio. The IRAF package was used for data reduction. The additional emission components were fitted with a Gaussian to measure their radial velocity and equivalent width. It was done only for those spectra that were strong enough (Table 2). The uncertainty of the equivalent width in these cases is not more than 50 per cent. The Hα flux was obtained using the equivalent width and the $R_{\rm c}$ flux supposing that it is practically equal to the continuum flux at the position of this line. For this aim we used the $R_{\rm c}$ magnitudes of Skopal & Pribulla (2006) and Skopal & Wolf (2006) taken very close to the time of our observations. The uncertainty of the continuum flux is not more than 10 per cent and that of the line flux – not more than 50 per cent. The fluxes were corrected for an interstellar extinction of $E(B-V) = 0.30$ according to the approach of Cardelli et al. (1989). It was used the ephemeris Min(vis) = JD $2\,442\,666^{\rm d} + 758\overset{\rm d}{.}8 \times {\rm E}$, where the orbital period is based on both photometric and spectral data (Formiggini & Leibowitz 1994; Mikolajewska & Kenyon 1996; Fekel et al. 2000).

2 Analysis and discussion

In our spectra the line Hα had a strong central component located around the reference wavelength, broad component and additional absorption and emission features on both sides of the central component (Fig. 1). The central component was single-peaked having shoulder(s) on its short-wavelengths side, which was not visible only on the spectra taken in September. A weak peak component on the short-wavelengths side of the central component is seen on the spectrum of August 8 and the dip feature between them indicates a moderate velocity of about 100 $\mathrm{km\,s^{-1}}$ like the P Cyg absorption of

Table 1. Journal of observations.

Date	JD− 2 453 000	Orb. phase	Exp. Time (min)
Jul 8	924.544	0.837	15+5
Jul 9	926.431	0.840	10+20
Jul 14	931.464	0.846	10+20
Jul 19	935.575	0.852	10
Aug 8	956.392	0.879	5+20+10
Aug 12	960.455	0.885	10+20+20+5
Sept 7	985.594	0.918	10+20
Sept 8	986.510	0.919	20

the He lines. That is why this dip feature can be determined by an outflow too, but it does not dispose below the level of the continuum probably because of filling in by the emission.

The broad component was not located around the reference wavelength during the whole period of the observations and in July its red wing was appreciably stronger than the blue one. In our treatment, however, we will concentrate on the other additional components of the Hα line, which appeared during the period of our observations.

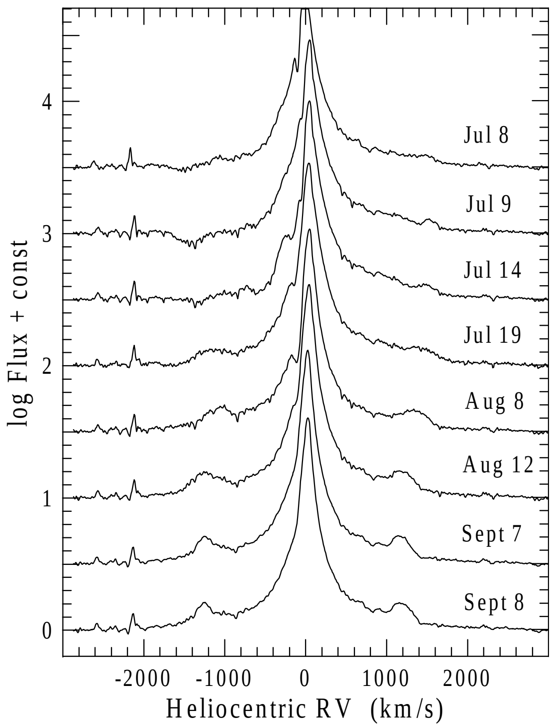

Fig. 1. Time evolution of the Hα line.

Table 2. Radial velocities, equivalent widths and line fluxes of the outflow components of the Hα line.

Date	Blue			Red		
	RV ($\mathrm{km\,s^{-1}}$)	EW (Å)	F$\times10^{-12}$ ($\mathrm{erg\,cm^{-2}\,s^{-1}}$)	RV ($\mathrm{km\,s^{-1}}$)	EW (Å)	F$\times10^{-12}$ ($\mathrm{erg\,cm^{-2}\,s^{-1}}$)
Jul 19	−1196	0.8	1.754	1445	0.9	1.813
Aug 8	−1087	1.5	2.912	1346	1.8	3.442
Aug 12	−1260	2.5	4.828	1201	2.0	3.846
Sept 7	−1245	1.8	3.109	1178	2.0	3.362
Sept 8	−1262	1.7	2.881	1196	2.1	3.534

The first spectra in July (Fig. 1) show a pronounced absorption with a velocity of -1400 $\mathrm{km\,s^{-1}}$ on the short-wavelengths side of the central Hα component and only a weak emission feature with irregular form and a velocity of about 1500 $\mathrm{km\,s^{-1}}$ on its long-wavelengths side. We will consider the absorption first supposing that it is due to mass flow from the compact object in the system. In this case the outflowing material generates an observed photosphere (pseudophotosphere, shell) whose optical depth in the continuum is close to unity. If we assume that the mass flow has spherical symmetry and a constant velocity, this photosphere will be a spherical layer with an internal boundary R equal to the radius of the star and an external boundary of infinity. In this case the density is a function of the distance to the center and is expressed via the continuity equation. The column density N is expressed as

$$N = \int_R^{\infty} n(r)\,\mathrm{d}r = \frac{\dot{M}}{4\pi\mu m_{\mathrm{H}} v R}\ ,$$

where $\mu = 1.4$ is a parameter determining the mean molecular weight μm_{H} in the wind (Nussbaumer & Vogel 1987) and the other quantities have their commonly accepted meaning. The optical depth of the layer is $\tau = \kappa N$, where κ is the continuum absorption coefficient (opacity). The mass-loss rate is

$$\dot{M} = \frac{4\pi\mu m_{\mathrm{H}} v R \tau}{\kappa}\ .$$

Let us calculate the mass-loss rate. The opacity κ per one atom is determined from the opacity $\mathrm{k_R}$ per unit mass by means of the relation $\kappa = \mathrm{k_R}\mu m_{\mathrm{H}}$. We used a value of 0.5 $\mathrm{cm^2\,g^{-1}}$ of the Rosseland mean opacity in the visual region from Table 4 of Seaton et al. (1994). In this case $\kappa = 1.2 \times 10^{-24}$ $\mathrm{cm^2}$ is obtained. However, we have no estimate of the size of the observed photosphere of the hot component of Z And at the time of our spectral observations. A radius of the hot component of 2.4(d/1.12 kpc) $\mathrm{R_\odot}$ was obtained in the work of Tomov et al. (2003a) from analysis of the continuum energy distribution of the system at the time of the light maximum of its 2000 outburst. As a result of the analysis of the spectral energy distribution too, Skopal et al. (2006) obtained a radius of 3.1(d/1.5kpc) $\mathrm{R_\odot}$. The correction of the data of Tomov et al. (2003a) for a distance to the system of 1.5 kpc leads to value of 3.2 $\mathrm{R_\odot}$ and is in very good agreement with the result of Skopal et al. (2006). For the need of our approximate calculation we will use the value of 3.5 $\mathrm{R_\odot}$, as according to our *UBV* data the 2006 outburst is more luminous than the 2000 one, when the increase of the light was due mostly to the expansion of the hot component (Tomov et al. 2003a). Having all of these quantities, for the mass-loss rate we obtain $\dot{M}$=1.33×10^{-5} $\mathcal{M}_\odot\,\mathrm{yr^{-1}}$.

This value is too great compared with the observed mass-loss rate of the hot compact component of the symbiotic systems during their active phases, which is most

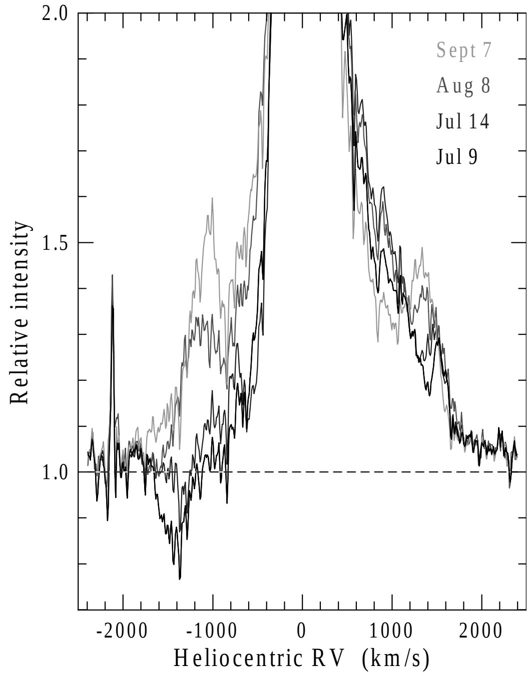

Fig. 2. Transition from the absorption feature to emission one indicating the front stream. The level of the local continuum is marked with a dashed line.

frequently about 10^{-9}– 10^{-7} $\mathcal{M}_\odot\,\mathrm{yr}^{-1}$ (Vogel & Nussbaumer 1994; Altamore & Cassatella 1997; Guoliang et al. 2006). The great value follows from our assumption for spherical symmetry of the outflowing material and the observed high velocity. It can be in reasonable limits if the material does not flow in all directions, but only in some of them, related to areas with small angular sizes. Thus the blue shifted absorption indicates motion probably in the front part of the wind which is projected on the stellar disc. Then we can suppose that the weak emission feature with a velocity of 1500 $\mathrm{km\,s^{-1}}$ appears in the nonocculted part of the back component of the wind.

As it is seen from the evolution of the spectrum in Figs. 1 and 2 the blueshifted absorption component disappears and an emission appears. Thus two emission components on the two sides of the central peak form in July. The disappearance of the blueshifted absorption and the appearance of emission are most probably due to decrease of the flow rate and/or increase of the number of emitting atoms in that part of the wind which does not project on to the stellar disc. If the absorption is related to the inner part of the wind and the emission – to its outer one, not projecting on the stellar disc, the evolution of the spectrum shows that the velocity in the front wind component (stream) decreases with the distance to the star.

It is seen in Fig. 1 that the emission on the long-wavelengths side of the central peak increases compared to the continuum. It is seen also in the figure that the velocity of the line decreases from about 1500 $\mathrm{km\,s^{-1}}$ to about 1200 $\mathrm{km\,s^{-1}}$. Taking into account the fact that the distance covered by the emitting gas increases with time it can be concluded that the velocity in the back stream decreases with the distance to the star too.

The Hβ line had similar emission components, as it is seen on the unique frame taken in its region in September.

The line flux is listed in Table 2. These data propose that the ejected matter increases until August 12 and after that decreases, which is probably due to decrease of the flow rate.

Conclusions

We present results of high resolution spectral observations carried out in the region of the line Hα of the spectrum of the symbiotic binary Z And close to the light maximum of its 2006 optical brightening. The line Hα had a blue-shifted absorption component with a velocity of about 1400 $\mathrm{km\,s^{-1}}$ at the time of maximal light in July. This line had also additional emission components placed at 1200–1500 $\mathrm{km\,s^{-1}}$ on the two sides of its central peak in July, August and September. The line Hβ had similar components as far as it is seen on its unique frame. It is supposed that both the absorption and the emission components are signature of bipolar wind outflow from the hot compact object in this system. The different velocities observed at different spectra indicate probably the decrease of the flow velocity.

The energy flux of the outflow components of the Hα line was calculated on the basis of R_c photometric data from the literature taken during the time of the spectral observations. This quantity increased until August 12 and after that decreased, which is probably due to diminution of the flow rate.

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