# The hydrogen and helium lines of the symbiotic binary Z And during its brightening at the end of 2002 \*

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High resolution observations in the region of the lines H $\alpha$ , He II  $\lambda$  4686 and H $\gamma$ of the spectrum of the symbiotic binary Z And were performed during its smallamplitude brightening at the end of 2002. The profiles of the hydrogen lines were double-peaked. These profiles give a reason to suppose that the lines can be emitted mainly by an optically thin accretion disc. The H $\alpha$  line is strongly contaminated by the emission of the envelope, therefore for consideration of accretion disc properties we use the H $\gamma$  line. The H $\alpha$  line had broad wings which are supposed to be determined mostly from radiation damping but high velocity stellar wind from the compact object in the system can also contribute to their appearance. The  $H\gamma$  line had a broad emission component which is assumed to be emitted mainly from the inner part of the accretion disc. The line He II  $\lambda$  4686 had a broad emission component too, but it is supposed to appear in a region of a high velocity stellar wind. The outer radius of the accretion disc can be calculated from the shift between the peaks. Assuming, that the orbit inclination can ranges from 47° to 76° we estimate the outer radius as  $20-50~{\rm R}_{\odot}$ . The behaviour of the observed lines can be considered in the framework of the model proposed for interpretation of the line spectrum during the major 2000 – 2002 brightening of this binary.

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<sup>\*</sup> Based on observations collected at the National Astronomical Observatory Rozhen, Bulgaria

### 1. INTRODUCTION

Symbiotic stars are interpreted as interacting binaries consisting of a cool giant of luminosity type III - II and a compact component accreting matter from the atmosphere of the giant. As a result of accretion the compact object undergoes multiple eruptions accompanied by intensive loss of mass. Symbiotic stars provide a good opportunity to study the processes of accretion and loss of mass which are spectroscopically observed and form multicomponent profiles of their spectral lines. The system Z And consists of a normal cool giant of spectral type M4.5 [1], hot compact component with temperature higher than 10<sup>5</sup> K [2, 3] and extended circum-binary nebula formed by the winds of two components. The orbital period of this binary is 758.8<sup>d</sup>, derived from both photometric [4] and radial velocity [5] data.

Z And has undergone several active phases (after 1915, 1939, 1960, 1984 and 2000) consisting of repeated optical brightenings with amplitudes up to 2–3 mag which are characterized by intensive loss of mass [3, 6–12]. The last active phase of Z And began at the end of August 2000 [13] and includes five optical brightenings. The second of them developed after August 2002, when the light began to rise after a deep minimum. The light reached its maximum in November and after that gradually decreased reaching its quiescent value in the middle of 2003. Skopal et al. [10] analyzed the wings of the H $\alpha$  line and concluded on this base that there was intensive loss of mass by the compact object during that brightening.

In our previous work [14] we analyzed the continuum emission of Z And during its 2002 brightening using multicolour photometric data. We concluded that the increase of the fluxes in the region UBVRJHKL was mainly due to the nebular emission. The energy distribution of the secondary component changed little (but not negligible), it remained a hot compact object as in the quiescent state of the system. To explain the line spectrum of the system during the major 2000 - 2002 brightening a gas dynamic model was proposed where the high-velocity stellar wind of the compact object having appeared at that time collides with the accretion disc and an optically thick disc-like shell forms [11]. The two velocity mass outflow as well as the behavior of the line He II  $\lambda$  4686 during that brightening were interpreted in the framework of this model. An emission detail of the quiescent profile

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Table 1	. List	of the	observations	and '	the $H\alpha$	flux in	units	$10^{-12}$	${\rm ergcm^{-1}}$	$^{2}  \mathrm{s}^{-1}$	
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Date	JD-	Orb.	$H\alpha$	
	2452000	phase	flux	
Sept. 25	543.35	0.017	173.494	
Oct. 20	568.37	0.050	255.255	
Nov. 12	591.20	0.080	292.098	

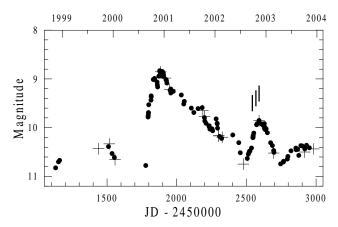
of the line  $H\gamma$  was interpreted as a component emitted by the accretion disc in the system.

During the growth of the light in the period September – November 2002 the emission line spectrum of the system had various features. The H $\alpha$  and H $\gamma$  lines had double-peaked profile. The H $\alpha$  line had broad wings extended to not less than  $\pm 2000 \text{ km s}^{-1}$  from its center. The lines H $\gamma$  and He II  $\lambda$  4686 had a broad emission component with a low intensity which indicated velocities up to more than 1000 km s<sup>-1</sup>. This paper is devoted to an analysis of the line profiles of Z And during its brightening at the end of 2002. Our aim is to evaluate the parameters of the accretion disc, to conclude about the possible nature of the nebular formations surrounding the hot compact component at that time, and to examine the possibility the emission line spectrum to be explained in the framework of the same gas dynamic model.

# 2. OBSERVATIONS AND REDUCTION

High resolution data in the regions of the lines H $\alpha$ , He II  $\lambda$  4686 and H $\gamma$  of the spectrum of the Z And system were obtained in 2002 with a Photometrics CCD camera mounted on the Coude spectrograph of the 2m RCC telescope of the National Astronomical Observatory Rozhen (Table 1, Fig. 1). The spectral resolution was 0.2 Å px<sup>-1</sup> on all occasions.

The initial data reduction and calculation of the line fluxes was described in our previous work [11]. The continuum flux at the wavelength position of the H $\alpha$  line was calculated using linear extrapolation of the V and R photometric fluxes taken on the same night or close nights. To calculate the fluxes of the spectra from September and October we used photometric data of Skopal et al. [16]. The fluxes of the spectra obtained in November were calculated on the basis of the photometric data for November 12, 2002 from our work Tomov et al. [14].



**Figure 1.** The V light curve of Z And where the first two brightenings of its last active phase are seen. The dots indicate the data of Skopal et al. [15, 16] and the crosses – our data. The vertical lines indicate the epochs of the spectral observations.

The BV fluxes were corrected for the strong emission lines of Z And in the same way as the quiescent data in the work Tomov et al. [9] because of the fact that the heights of these lines during the active phase were practically the same as those in the quiescence.

All the fluxes were corrected for the interstellar reddening of E(B-V) = 0.30 using the extinction law of Seaton [17].

As in our previous papers on Z And [9, 11, 14] we used an ephemeris  $Min(vis) = JD \ 2442666^d + 758.8^d \times E$ , where the orbital period is based on both photometric and spectral data and the epoch of the orbital photometric minimum coincides with that of the spectral conjunction [4, 5, 18].

# 3. ANALYSIS OF THE EMISSION LINE SPECTRUM

### 3.1. The Balmer lines

### 3.1.1. The $H\alpha$ line

In the quiescent state of the system the line H $\alpha$  was of the nebular type, but had, in addition, broad wings extended to not less than  $\pm 2000 \text{ km s}^{-1}$  from its center. It exceeded the local continuum by a factor of more than 100 at orbital phases close to 0.5 [11]. The width (FWHM) of the line was about 100–120 km s<sup>-1</sup> and only occasionally went beyond this value. The width remained the same during the 2000 – 2002 optical brightening too

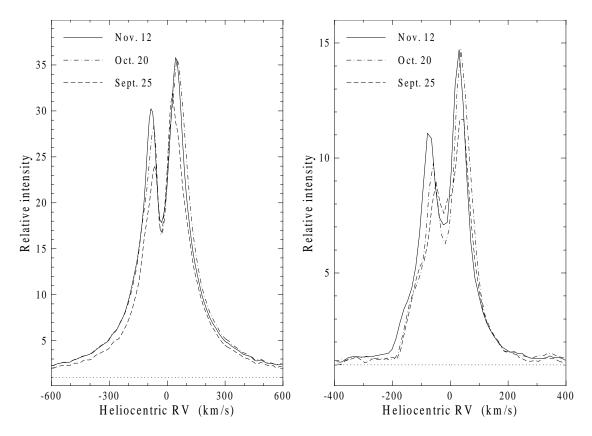


Figure 2. The profiles of the H $\alpha$  (left panel) and H $\gamma$  (right panel) lines. The level of the local continuum is marked with a doted line.

[11]. The view that the broad wings of the line in the quiescent state of the system are due to Raman scattering of Ly $\beta$  photons by atomic hydrogen is widely accepted [11, 19, 20]. Lee [19], though, considered other theoretical possibilities for their appearance too. He noted that Raman scattering and radiation damping depend on the wavelength in the same way, and the latter also cannot be excluded.

During the growth of the light at the end of 2002 the line was double (Fig. 2), it exceeded the local continuum by a factor of about 30 and its width increased by a factor of two. The dip between the two peaks had the same radial velocity at all times of observation.

Let us compare the H $\alpha$  flux in December 2000 at the time of the light maximum of the first brightening [11] and in the light maximum in November 2002 (Table 1). The two maxima are at close orbital phases – 0.15 and 0.08. During the first brightening the emission measure of the circum-binary nebula was greater by a factor of two compared with the second brightening [9, 14], which means that the quantity of the emitting gas has been greater by a factor of about two. We suppose close physical conditions in the nebula during these brightenings because, in the first place, the same mean electron temperature of 20 000

K[9, 14] was obtained. Moreover, the mean electron density during the first brightening will be higher only by a factor of  $\sqrt{2}$  if the nebula has the same volume.

If all H $\alpha$  photons left the nebula, the H $\alpha$  flux during the first brightening would be greater by a factor at least of two. The H $\alpha$  flux however, was approximately the same – about  $(270 - 290) \times 10^{-12} \,\mathrm{erg}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$  in the two light maxima. This means that during the first brightening the optical depth in this line has been greater. When all photons leave the emission region of one nebular line its profile is very close to Gaussian. The more photons are absorbed, the more the line profile will differ from the Gaussian function and can become a double-peaked one. If we suppose that the double-peaked profile during the second brightening is due only to the optical depth it must be greater than the depth during the first one when the profile was not double-peaked. The contradiction can be removed if we suppose that the double-peaked profile is mainly due to kinematics of the gas – one possibility is an emission of an accretion disc. The same conclusion is obtained when treating the line H $\gamma$ .

If we suppose that the H $\alpha$  line is emitted mainly by an accretion disc we must expect that the intensity of this line greatly increases during the brightening. The H $\alpha$  emission in this case is a sum of the emission of the circum-binary nebula and the disc. The emission of the nebula can increase or at least will not decrease during the brightening. At the same time disc's emission must predominate over that of the nebula to determine the profile. To examine it we will compare the H $\alpha$  flux with its quiescent value.

The intensity of the Balmer emission lines of Z And varies with the orbital phase [5, 11] and their flux during the brightening must be compared with the quiescent one at the same phase. We were not able to find in the literature Balmer fluxes at orbital phase close to 0 in the quiescent state of Z And. Mikolajewska & Kenyon [5] have obtained the H $\alpha$  flux at phases 0.16-0.34 where it increases from  $40 \times 10^{-12}$  to  $103 \times 10^{-12}$  erg cm<sup>-2</sup> s<sup>-1</sup>. Schwank et al. [21] have shown that the Balmer emission lines of symbiotic stars in their quiescent state are predominantly formed in the recombination zone which separates the H $^{\circ}$  from the H $^{+}$  region of the cool giant's wind since the density of this zone is the highest one. These authors have shown also that the Balmer lines are always self-absorbed emission lines. These theoretical considerations show that the absorption will be maximal at phase 0 where the giant is in its inferior conjunction because of the highest density of the absorbing particles. Then the line flux will have minimal value at this phase and in the case of Z And the H $\alpha$ 

flux will be probably less than  $40 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$ . The comparison of this flux with fluxes  $(170 \div 290) \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$  (Table 1) shows that it is strongly increased during the brightening, which can be due to addition of a new component in the line, possibly from an accretion disc. The same conclusion is obtained for the line H $\gamma$  too. The data of Mikolajewska & Kenyon [5] show that its flux at the orbital phase 0 is less than  $2.1 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$  and the flux of the narrow component during the outburst is  $(16 \div 29) \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$  (Table 2).

Let us calculate the outer radius of the line emission region in the disc from the shift between the two peaks. The shift was equal to  $2.8 \pm 0.2 \text{ Å}$  on November 12, 2002 at the time of the maximal light. To calculate the outer radius the orbit inclination is needed. There are several observational evidences supporting a high orbit inclination of the system Z And. Rayleigh scattering of the hot radiation was detected in the spectrum of this system during its 1984 and 1985 outbursts [8]. According to Skopal [22] the far UV continuum is attenuated by Rayleigh scattering at orbital phases close to 0 even in the quiescent state and an inclination of 76° was proposed on this base. The two-temperature type of the UV spectrum observed during the 2000 – 2002 outburst can be interpreted supposing that the orbit inclination is rather high [10]. On the other hand Schmid & Schild [23] came to the conclusion that the inclination is rather low proposing  $47^{\circ} \pm 12^{\circ}$  obtained from their polarimetric orbit. Both points of view are motivated and we cannot reject either of them. We suppose also that the inclination can range from 47° to 76°. The results of our consideration do not depend strongly on this quantity and we will perform our calculations with both of its values keeping in mind that the actual inclination can be also inside their range. At a mass of the hot component of 0.6  $M_{\odot}$  [2, 23] for the outer radius of the emission region we obtain from 15  $\pm$  2 R $_{\odot}$  to 26  $\pm$  4 R $_{\odot}$  for orbit inclination of 47° – 76°. This result supports our supposition, as it is in agreement with the theoretical models of discs resulted from accretion of the stellar wind [24].

The intensity of the H $\alpha$  wings increased during the growth of the light at the end of 2002. Skopal [25] obtained synthetic profiles arising from an optically thin bipolar stellar wind from the hot components of the symbiotic stars and was able to make a fit of the observed H $\alpha$  wings of a sample of ten symbiotic stars. According to him, however, the profile formed in the stellar wind is approximated by a function of the same type as that arising from Raman scattering. For this reason he concluded that it is not possible to distinguish between these

two processes directly. Ikeda et al. [26] noted that the polarization profile of the H $\alpha$  line of Z And does not agree with that of its Raman  $\lambda$  6830 Å line on October 25, 2002, i.e. during the brightening considered by us. Based on the data of Ikeda et al. [26] we suppose that the extended H $\alpha$  wings of Z And during this brightening are probably not due to Raman scattered Ly $_{\beta}$  photons. Attention, however, should be paid to the fact that the FWZI of the H $\alpha$  wings of Z And does not practically change during the active phase after the year 2000 and keeps its quiescent value of 4000 km s<sup>-1</sup>. This fact gives us some reason to suppose that during the 2002 brightening the FWZI was determined mainly from radiation damping and the stellar wind can have some contribution in the wings at smaller distances from the centre of the line. The problem about the nature of these wings during active phase needs to be considered further.

# 3.1.2. The $H\gamma$ line

The quiescent H $\gamma$  line of the system Z And was of nebular type and had an additional blue emission component with low intensity. Its width was about 80–90 km s<sup>-1</sup> and occasionally exceeded this value. The width remained the same during the 2000 – 2002 brightening like the for line H $\alpha$  [11].

During the growth of the light at the end of 2002 an additional broad emission exceeding the local continuum by a factor of 1.3 and with a full width at zero intensity (FWZI) of about 2000 km s<sup>-1</sup> appeared together with the nebular component of the line (Figs. 2, 3). In this way the H $\gamma$  line consisted of a narrow component of a nebular type and a broad component. At the same time behavior of the narrow component closely followed that of the H $\alpha$  line. Its profile was double-peaked and the width increased by a factor of two compared with its quiescent value. The dip between two peaks of the line had the same radial velocity at all times of observations, which was close to the velocity of the dip of the H $\alpha$  line (Fig. 4).

Let us calculate the outer radius of the emission region of the line in the disc using the shift between the two peaks. This shift was equal to  $1.4 \pm 0.1$  Å on November 12 and with use of the parameters of the system adopted by us it gives an outer radius from  $26 \pm 3$  R<sub> $\odot$ </sub> to  $46 \pm 6$  R<sub> $\odot$ </sub> for orbit inclination of  $47^{\circ} - 76^{\circ}$ . This radius is in agreement with the theory of discs formed as a result of wind accretion like the size of the H $\alpha$  region [24]. We obtained that the outer radius of the emission region of the H $\gamma$  line is greater than that of

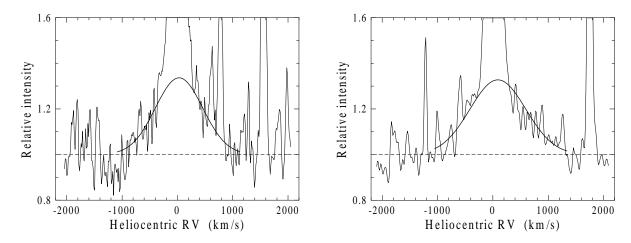


Figure 3. The H $\gamma$  (left panel) and He II  $\lambda$  4686 (right panel) broad components. The level of the local continuum is marked with a dashed line.

 $H\alpha$  but when atoms are excited as a result of recombination and the density decreases with the distance from the star, the region of the  $H\alpha$  line is expected to be located outward from that of  $H\gamma$ . Our result follows from the greater separation of the peaks of the line  $H\alpha$ .

The data propose not only greater peaks' separation, but also greater width of this line. If the emitting region is fully transparent in Balmer lines their width will be the same. The Balmer lines of symbiotic stars, however, are always self-absorbed emission lines. The reason for the greater width and peaks' separation of  $H\alpha$  of Z And can be its higher optical depth compared to  $H\gamma$ . Then for the size of the line emission region in the disc we will prefer mostly the results based on the  $H\gamma$  data.

There is, however, an other possibility for the greater separation of the peaks of the line  $H\alpha$  more, which follows from the flow structure. This line is possible to be emitted at greater distance from the orbital plane, but more close to the axis of the disc, where the rotational velocity is greater. In this way it can be strongly contaminated by emission of the disc-like envelope surrounding the accretion disc. This envelope forms from the material ejected during the previous outburst and fallen back after its finish. The conservation of the angular momentum of the ejected material is responsible for its formation. Close to the axis of rotation the velocity is large enough to explain the greater width of the line  $H\alpha$  and the greater separation of its peaks compared to the line  $H\gamma$ .

The broad component of the H $\gamma$  line was measured in the following way. The observed spectrum was corrected through removing several weak emission lines of Fe II, O II and N III as well as the most intensive absorption lines of the giant. After that it was analyzed by

FWHM(N) FWHM(B) Date Flux(N)FWZI(B) Flux(B)  $H\gamma$  HeII  $H\gamma$ Неп  $H\gamma$  $H\gamma$  He II He II  $H\gamma$  HeII HeII  $15.718 \ 46.319 \ 1014 \pm 100 \ 1091 \pm 92 \ 1900 \ 2113 \ 1050 \ 3.193 \ 3.713$ Sept. 25 166 87  $22.796\ 59.782\ |\ 1073\ \pm\ 78\ 1170\ \pm\ 101\ |\ 2100\ 2201\ |\ 1100\ |\ 4.885\ 5.234$ Oct. 20 165 92  $28.800 \ 70.110 \ | 1010 \pm 70 \ 1192 \pm 56 \ | 2030 \ 2416 \ | 1200 \ | 5.236 \ 6.658$ Nov. 12 171 105

**Table 2.** The data of the lines H $\gamma$  and He II  $\lambda$  4686. N and B denote narrow and broad component respectively. The flux is in units  $10^{-12}$  erg cm<sup>-2</sup> s<sup>-1</sup> and the other quantities are in units km s<sup>-1</sup>.

fitting with a Gaussian function (Fig. 3) and its parameters obtained with this procedure are listed in Table 2. The error of the equivalent width is not greater than 20 per cent depending on the noise of the different spectra.

To conclude about the nature of the gaseous environment where the broad component appeared we will treat different mechanisms of line broadening. One of them is the electron scattering. The total flux of the line, which is a sum of the fluxes of two components, is  $(19-34)\times10^{-12}~{\rm erg\,cm^{-2}\,s^{-1}}$  (Table 2). This gives emission measures of  $(1-2)\times10^{59}$  $(d/1.12 \text{ kpc})^2 \text{ cm}^{-3}$ . To calculate the radius of a spherical emitting volume, having this emission measure, the mean electron density is needed. Fernandez-Castro et al. [2] obtained a mean quiescent electron density of  $10^{10}~{\rm cm}^{-3}$  in the nebula of Z And. We assume that the mean electron density in the close vicinity of the compact object during the brightening is close to the quiescent electron density and will perform our calculations with the value  $10^{10}$  cm<sup>-3</sup>. We come to the same conclusion, however, if we use lower densities too. We obtain a radius of  $(6-8) \times 10^{12} (d/1.12 \text{ kpc})^{2/3}$  cm of the spherical emitting volume. If the broad component appeared due only to the electron scattering it would be risen in region with optical thickness of 0.17-0.19. Using these values and a density of  $10^{10}~{\rm cm}^{-3}$ , we derive the radius of almost  $3 \times 10^{13} \; (d/1.12 \; \mathrm{kpc})^{2/3} \; \mathrm{cm}$ , corresponding to an enormous emission measure of  $10^{61}$  (d/1.12 kpc)<sup>2</sup> cm<sup>-3</sup>. This result differs from the previous one and we conclude that the broad component is probably not produced by electron scattering.

An other possible mechanism the broad component to appear is to be emitted by an optically thin Keplerian accretion disc. The half width at zero intensity of the broad component on November 12 at the time of the light maximum was about 1020 km s<sup>-1</sup> (Table 2). The velocity, derived from the width at zero intensity of the line, is related to the movement at the inner boundary of the disc. This velocity, however, is on the line of sight. Taking into

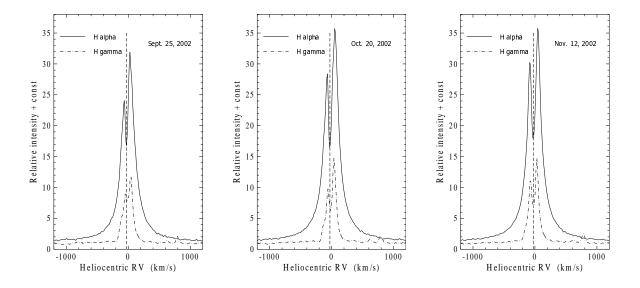


Figure 4. The lines  $H\alpha$  and  $H\gamma$  in each time of observation. The dips of the two lines have close velocity positions.

consideration the orbit inclination of  $47^{\circ} - 76^{\circ}$ , the obtained velocity at the inner boundary is  $1400 - 1050 \, \mathrm{km \, s^{-1}}$ . With the mass of the compact object adopted by us  $M_{wd} = 0.6 M_{\odot}$  we obtain an inner radius of the disc of  $0.06 \div 0.10 \, \mathrm{R_{\odot}}$ . This estimate is smaller than the upper limit of the radius of this object at the time of the maximal light ( $\sim 0.13 \, (\mathrm{d/1.12 \, kpc}) \, \mathrm{R_{\odot}}$  evaluated by Tomov et al. [14]). The estimate of the disc radius, however, has an appreciable uncertainty due to the velocity, which depends from the level of the local continuum. Our data take small range of 200 Å which leads to additional difficulty in determining continuum level. Its uncertainty can reach up to 5 per cent. Variation of 5 per cent can lead to reduction of 20 per cent of the velocity which is based on the FWZI of the line. So, a velocity of 800 km s<sup>-1</sup> gives us an inner radius of the disc of  $0.09 \div 0.17 \, \mathrm{R_{\odot}}$ . Then we can think that the inner radius is about  $0.1 \div 0.2 \, \mathrm{R_{\odot}}$  for the range of orbit inclination treated by us and is in satisfactory agreement with the upper limit of the radius of the compact object of  $0.13(\mathrm{d/1.12 \, kpc})\mathrm{R_{\odot}}$ . That is why we will suppose that the emission of an optically thin accretion disc can be possible reason for the broad  $\mathrm{H}\gamma$  component.

### 3.2. The HeII $\lambda$ 4686 line

During the rise of the light the He II  $\lambda$  4686 line (Fig. 5) consisted of two emission components – a narrow central component with a width of about 90 – 100 km s<sup>-1</sup> and a broad

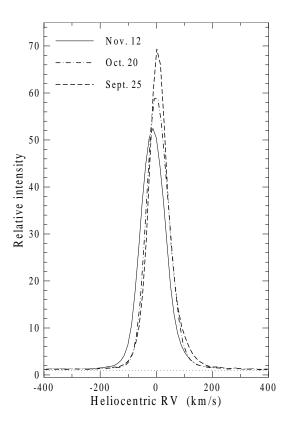


Figure 5. The profile of the He II  $\lambda$  4686 line. The level of the local continuum is marked with a doted line.

component whose width was much greater (Fig. 3). The broad component was analyzed in the following way.

The observed spectrum was corrected with removal of several weak emission lines of O II and the strongest absorption lines of the giant. Then it was fitted with a Gaussian function. The parameters obtained with this procedure are presented in Table 2. The error of the equivalent width ranges from 11 to 19 per cent depending on the noise of the individual spectrum.

The narrow central component of the line He II  $\lambda$  4686 was probably emitted in the ionized portion of the giant's wind and in that part of the disc's corona where the high velocity wind does not propagate as well.

As in the case of the line H $\gamma$  we must examine the possibility the broad component to be formed by electron scattering. The total flux of the line is  $(50 - 77) \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$  (Table 2) which leads to emission measures of about  $2 \times 10^{59} \text{ (d/1.12 kpc)}^2 \text{ cm}^{-3}$ . Using the mean density of  $10^{10} \text{ cm}^{-3}$  [2] we obtain the radius of  $(6 - 8) \times 10^{12} \text{ (d/1.12 kpc)}^{2/3} \text{ cm}$  of the spherical emitting volume. If the broad component was determined only by electron

scattering the optical thickness of its emission region would be 0.08 - 0.09. These values and the density of  $10^{10}$  cm<sup>-3</sup> give the radius of more than  $10^{13}$  (d/1.12 kpc)<sup>2/3</sup> cm, corresponding to great emission measures of  $(6 - 10) \times 10^{59}$  (d/1.12 kpc)<sup>2</sup> cm<sup>-3</sup>. This result differs from the previous one and we conclude on this base that the broad component is probably not determined by the electron scattering.

The red wing of the HeII  $\lambda$  4686 broad component at all spectra is more extended than the blue one causing one general asymmetry in this line, which however, is absent in the H $\gamma$  broad component (see Fig. 3). This asymmetry give us a reason to suppose that the line HeII  $\lambda$  4686 does not appear in an accretion disc but rather – in a region of a high velocity stellar wind. It is seen in Table 2 that the FWZI of the H $\gamma$  broad component is always smaller than that of the HeII  $\lambda$  4686 broad component. These data propose that the line H $\gamma$  is not emitted in the wind region of the HeII  $\lambda$  4686 line. If the line H $\gamma$  was emitted in more outer region of the wind, its FWZI would not be smaller than that of the HeII  $\lambda$  4686 line, since the velocity in this region is not smaller than in the HeII  $\lambda$  4686 region. Consequently the line H $\gamma$  is not emitted in the wind. Then these two lines are emitted probably in different regions of the binary system – H $\gamma$  in the accretion disc and HeII  $\lambda$  4686 in the stellar wind.

# 4. MASS-LOSS RATE

The mass-loss rate of the hot compact companion was calculated with use of the energy flux of the broad component of the line He II  $\lambda$  4686 in the same way as in our previous work Tomov et al. [11]. It was supposed that the outflow has a spherical symmetry and a constant velocity. In our calculations we used a wind velocity based on the half width at zero intensity of the line from Table 2. This velocity is actually an arithmetical mean of the velocities of the two wings. It was also supposed that the wind is fully transparent in this line. We adopted an electron temperature of 30 000 K in the wind and a distance to the system d = 1.12 kpc [2, 8] as in the case of the major brightening. The line is supposed to be emitted by a spherical layer and the radii of integration are need. The inner radius is the stellar radius. We calculated the mass-loss rate for the time November 12 at the light maximum since we had data for the stellar radius only for that time. We used the upper limit of the radius of 0.13 (d/1.12kpc)  $R_{\odot}$  from the work of Tomov et al. [14] and so we can obtain the upper limit of the mass-loss rate. The outer radius of integration is equal to

infinity. A recombination coefficient for case B [27] corresponding to temperature of 30 000 K and the density at the level of the photosphere was used. An upper limit of the rate of 1.8  $\times$  10<sup>-7</sup> (d/1.12 kpc)<sup>3/2</sup> M<sub> $\odot$ </sub> yr<sup>-1</sup> was derived with an uncertainty of about 30 per cent due to the observational data. The real uncertainty, however, is determined from use of a model with a constant velocity of the wind too and can be higher. We obtained in this way that the mass-loss rate at the time of the light maximum is close to that of 2.4  $\times$  10<sup>-7</sup> (d/1.12 kpc)<sup>3/2</sup> M<sub> $\odot$ </sub> yr<sup>-1</sup> at the time of the light maximum of the major 2000 – 2002 brightening.

# 5. DISCUSSION

An optically thin accretion disc which can give rise to the double-peaked Balmer profiles, could appear at the final stage of the major 2000 – 2002 brightening. At that time the residual accretion disc still existed in the system. In addition some part of the ejected mass was in the potential well of the compact object. After the discontinuation of the flow the accretion of this material began again which led to a strong increase of the accretion rate. That part of the ejected mass which has had orbital angular momentum great enough, formed the disc itself and a disk-like envelope. An accretion disc of such a type is possible to exist in the system during all brightenings following the major ones.

The growth of the optical light of the system during the small-amplitude brightening was mainly due to the nebular emission [14]. If the accretion disc is mainly responsible for the Balmer lines its contribution in the nebular continuum of the system will be the greatest one and its emission will determine the optical maximum. The disc emission increases not only as a result of an additional input of mass but probably because of the growth of the Lyman luminosity of the ionizing source too. The supposition for a growth of this luminosity is supported by the following observational fact. The emission measure of the nebula increased by a factor of  $2.5 \pm 0.2$  comparing to the quiescent state of the system [14] which means that the number of recombinating ions has increased in the same ratio. This is probably due not only to the collisional ionization but to the radiative one too. The increase of the radiative ionization is determined by change of the Lyman luminosity of the ionizing star.

The double-peaked profiles of the hydrogen lines give a reason to suppose that the lines can be emitted mainly by an optically thin accretion disc. Using the H $\gamma$  line we estimated the outer radius of the accretion disc as  $26 \pm 3 \div 46 \pm 6$  R $_{\odot}$  for the orbit inclination angle in

a range from 47° to 76°. We tryed to obtain one approximate estimate of the inner radius of the disc too, which amounts to about  $0.1 \div 0.2 R_{\odot}$  and does not contradict to the supposition of Sokoloski & Bildsten [28] for magnetosphere of the white dwarf in Z And.

Our supposition for the presence of an accretion disc and a high velocity stellar wind in the system gives a reason to assume that its visual line emission spectrum can be explained in the framework of the model for the interpretation of the spectral behavior during the major 2000 - 2002 brightening [11]. This model provides an explanation of the observed two-velocity regime of the mass outflow when a P Cyg wind with a low-velocity was observed together with the high-velocity optically thin wind. The low-velocity of the P Cyg absorption component was interpreted with slowing down the wind because of its collision with the disc. A P Cyg absorption component was absent in the spectrum during the brightening – subject of research in this paper. To observe component of such a type the column density of the absorbing gas needs to be high enough and the gas to be projected on the observed photosphere as well. During the small-amplitude brightening the column density in the wind was close to that during the major brightening. Then the possible reason can be that the gas, outflowing after the collision is not projected on the observed photosphere.

# 6. CONCLUSION

We present results of high-resolution observations of the Balmer lines  $H\alpha$  and  $H\gamma$  as well as the line He II  $\lambda$  4686 of the symbiotic binary Z And during the rise of the light of its small-amplitude brightening at the end of 2002. The width of the Balmer lines was greater by a factor of two than in the quiescent state of the system and their profiles were double-peaked.

We compared the emission measure of the circum-binary nebula of the system and fluxes of the two Balmer lines at the times of the light maxima in December 2000 and November 2002 which were at close orbital phases. We assumed close physical conditions in the nebula at those times. It was concluded on this base that the optical depth in the lines was greater in December 2000. This conclusion proposes that the double-peaked profile during the 2002 brightening can be explained not only with the self-absorption, but mainly with the velocity distribution of the emitting particles. The most probable reason can be the rotation of the accretion disc with the outer radius lying in a range  $26 \pm 3 \div 46 \pm 6 \text{ R}_{\odot}$  for orbit inclination angle from  $47^{\circ}$  to  $76^{\circ}$ .

The H $\gamma$  line had a broad emission component showing a velocity of about 1000 km s<sup>-1</sup>. Assuming that it is emitted in the inner part of the accretion disc we estimated roughly the inner radius which amounts to  $0.1 \div 0.2 R_{\odot}$  for the same orbit inclination.

The line He II  $\lambda$  4686 had a broad emission component whose FWZI was always greater than that of the line H $\gamma$ . This component was assumed to be due to high velocity stellar wind from the hot compact component of the system.

We suppose that an optically thin accretion disc, giving rise to double-peaked profile existed in the system during the brightening observed by us (and possibly many other brightenings following the major ones) since there were good conditions for its formation. At the final stage of the major 2000–2002 brightening some part of the ejected mass was in the potential well of the compact object. After the discontinuation of the flow the accretion of this material began again. This part of the ejected mass which had orbital angular momentum great enough, formed the disc.

The H $\alpha$  line had broad wings extended to not less than 2000 km s<sup>-1</sup> from its center. We supposed that they were determined mainly from radiation damping but stellar wind could contribute to their emission at smaller distance from the centre of the line.

Assuming that the broad component of the line He II  $\lambda 4686$  is due to a high velocity stellar wind we estimate the upper limit of the mass-loss rate of the companion resulting from this wind as  $\sim 1.8 \times 10^{-7} \; (d/1.12 \; \rm kpc)^{3/2} \; M_{\odot} \, \rm yr^{-1}$ .

Based on this interpretation we conclude that the behavior of the spectral lines can be explained in the framework of a model of the system proposed for its major 2000 – 2002 brightening where the high velocity stellar wind of the compact object collides with the accretion disc [11].

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