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Mass ejection by the symbiotic binary Z And during its 2000–2002 outburst⋆

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Abstract. Broad-band *UBVJHKLM* data have been obtained at the time of the quiescent orbital photometric maximum of the classical symbiotic binary system Z And and at some epochs of its 2000–2002 active phase. The data of the active phase are related to the time of the optical maximum and after it when the star was returning to quiescence. Broad-band quiescent *RI* photometry from the literature was also used to obtain the parameters of the cool component of this binary. All of these data suggest that the hot compact component has undergone a major expansion and the emission measure of the circumbinary nebula has also increased. Some mechanisms for interpretation of the outburst are reviewed.

Key words. stars: binaries: symbiotic – stars: activity – stars: individual: Z And – stars: mass-loss – techniques: photometric

1. Introduction

Symbiotic stars are a group of interacting binary systems whose photometric behaviour is characterized by an alternance of quiescent periods and phases of eruptive activity. The eruptions lead in some cases to loss of mass of the accreting star in the form of single discreet shells and in the other ones to high velocity gas flow (stellar wind). The energy distribution of the ejected shells changes and leads often to strong increase of the optical flux. Z And is considered as a prototype of the symbiotic class. It consists of a normal cool giant of spectral type M 4.5 (Mürset & Schmid 1999) and a hot compact object with temperature higher than 10^5 K (Fernandez-Castro et al. 1988). The third component of the system is an extended nebula formed by the wind of the giant partly photoionized by the hot component. The orbital period of this binary is $758\overset{\mathrm{d}}{.}8$, which is based on both photometric (Formiggini & Leibowitz 1994) and radial velocity (Mikolajewska & Kenyon 1996) data.

The light curve of Z And is characterized by phases of activity alternating with periods of quiescence. The quiescent optical light displays an orbital modulation with amplitudes of about 0.5 mag in the *BV* region and 1 mag in *U*. A 28-min oscillation of the *B* light was also detected during quiescence and the small 1997 outburst as well with an amplitude of 2–5 mmag, which is supposed to arise from the rotation of an accreting magnetic white dwarf (Sokoloski & Bildsten 1999).

The Z And system has spent much of its time in phases of increased activity (after 1915, 1939, 1960, 1984 and 2000) characterized by several brightenings, whose amplitudes reach up to 2–3 mag. During the major outburst in 1939 its visual magnitude reached about 8^{m} and the only spectrum which was observed was that of the P Cyg type expanding shell with emission lines corresponding to an A star. The spectrum of the M giant and the circumbinary nebula were not visible (Swings & Struve 1941). The optical spectrum of Z And during its time of activity after 1960 was observed by Boyarchuk (1967b). The data suggest continuum flux redistribution caused by expansion and cooling of the hot component when the light rises. Fernandez-Castro et al. (1995) analysed radio and UV low and high resolution spectral data of Z And taken during its 1984–1985 active phase. They obtained that the rise in the visual emission coincides closely with a minimum in the UV and radio. The anticorrelation between visual and UV was explained as extinction of the hot star radiation by a false photosphere produced by the ejection of a shell of dense material.

Z And entered its last active phase at the end of August 2000 (Skopal et al. 2000) and reached the maximum of its optical light in December, when the *V* magnitude was about $8\overset{\mathrm{m}}{.}9$. During the time of the light maximum the 28-min oscillation disappeared, indicating probably a blocking of the flux from the white dwarf by an optically thick shell (Sokoloski et al. 2002).

The visual light of the hot stellar component of the system increases strongly during the phases of activity dominant to the emission of the giant and the circumbinary nebula. We derived observational data in a number of broad-band photometric

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⋆ Based on observations collected at the National Astronomical Observatory Rozhen, Bulgaria and the Crimean Station of the Sternberg Astronomical Institute, Ukraine.

systems selected in accordance with the spectral energy distribution of the components of Z And. An additional set of data was derived in the quiescence. These data give us possibility, based on the continuum radiation, to obtain some of the component's parameters, which will shed light on their behaviour during the active phase.

2. Observations and reduction

Broad-band five colour *JHKLM* photometry of Z And was obtained on 1 Oct. 1999 (JD 2 451 453.498), 20 Nov. 2000 (JD 2 451 869.337), 24 Dec. 2000 (JD 2 451 903.241) and 4 Feb. 2002 (JD 2 452 310.197) with the InSb photometer attached to the 125-cm telescope of the Crimean Station of the Sternberg Astronomical Institute. The star BS 8860 having $J = 1\overset{m}{.}46$, $H = 0\overset{m}{.}62$, $K = 0\overset{m}{.}37$, $L = 0\overset{m}{.}25$ and $M = 0\overset{m}{.}67$ (Johnson et al. 1966) was used as a comparison star. The H magnitude was estimated from the spectral type of this star using the data of Koorneef (1983).

In addition, three colour *UBV* photometry was obtained on 15 Sept. 1999 (JD 2 451 437.383), 6 Dec. 2000 (JD 2 451 885.229) and 27 Jan. 2002 (JD 2 452 302.224) with the single channel photoelectric photometer, mounted at the Cassegrain focus of the 60 cm, $F/12.5$ telescope of the National Astronomical Observatory Rozhen. The star BD+48°4090 having $V = 9\overset{m}{.}01$, $B - V = 0\overset{m}{.}48$ and $U - B = -0\overset{m}{.}06$ (Belyakina 1970) was used as a comparison star, which was checked by the star BD+47°4192.

The collection of the visual and infrared photometric data provides the possibility to analyse the light in a broad spectral region. The data taken in 1999 are related to close epochs during the system's quiescence and can be collected. The data from December 2000 were derived during the time of light maximum at close epochs too and can be also collected. Our *UBV* estimate is in very good agreement with the photometry of Skopal et al. (2002) taken at that time and for the aim of this consideration we used an averaged value as presented in Table 1. Our November 2000 *UBV* photometry was of poor quality because of unfavourable atmospheric conditions, but the star was also observed by Skopal et al. (2002). Thus their *UBV* magnitudes taken on 22 November were added to our IR ones. The data from 2002 are also at close epochs and can be collected. In this way we collected *UBVJHKLM* data (Table 1), relating to four epochs, one of them being in the quiescent stage of the star and the others during the outburst (see Fig. 1). The data were related to the times of obtaining the *UBV* magnitudes since the IR ones were less changed.

The stellar magnitudes were converted into continuum fluxes using the calibration from the book of Mihailov (1973) (Table 2). The U flux was corrected for the energy distribution of Z And in the region of the Balmer jump. The continuum on its long wavelength-side is weaker, which leads to a reduction of the flux at 3650 Å. The correction of the quiescent U flux was made by means of the optical spectrum of Fernandez-Castro et al. (1995), taken on 12 July 1986 at orbital phase 0.22 (see below), when the star was returning to quiescence after its 1985 outburst. The flux on the long wavelength-side of the Balmer jump at that time was smaller by a factor of 2 than that

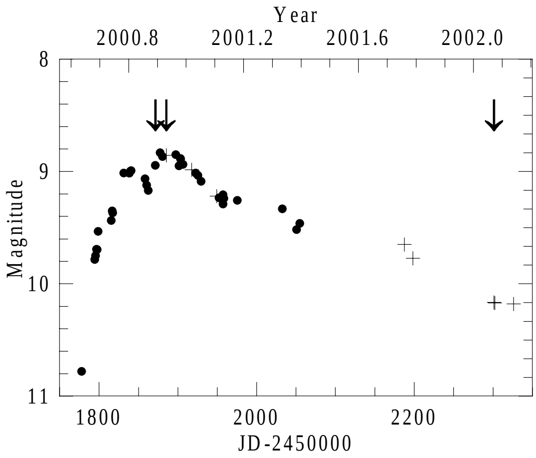

Fig. 1. The V light curve of Z And during its 2000–2002 outburst. The dots indicate the data of Skopal et al. (2002) and the crosses our unpublished data. The arrows indicate the epochs of obtaining our multicolour data.

on the short wavelength-side, which caused a reduction of 25% of the real flux at 3650 Å. This amount was added to the observed U flux.

We were not able to find in the literature any spectrum of Z And taken during its 2000–2002 active phase in the region of the Balmer jump. To obtain at least an approximate estimate of the ratio of the fluxes on its two sides, when the star's light was at its maximum, we compared our quiescent Hγ spectral data (Tomov et al. 2003), taken at orbital phase 0.228 (see below) with those taken simultaneously to the photometry during the outburst. At wavelengths greater than 3650 Å the spectrum of the stars with strong hydrogen emission is formed by an apparent continuum produced by the blending of the Balmer lines with high numbers (see Sect. 3). Even though the Balmer decrement possibly changes, the height of these lines compared to the Pashen continuum varies practicaly in the ratio close to that of the Hγ line. The spectral data taken during the outburst showed that the height of Hγ was decreased by a factor of about 3.4 (in the same time, its flux increased by a factor of up to 2.7). If we suppose that the Balmer jump is changed in the same ratio, the flux on its long wavelength-side is obtained to be by a factor of 1.59 smaller than the flux on its short wavelength-side. This depression in the spectrum leads to a reduction of 18.7% of the real flux at 3650 Å. The amount of 18.7% was added to the observed U flux. At the epoch of our last data taken in the end of the active phase, we used the correction based on the spectrum of Fernandez-Castro et al. (1995) again, since the star was at the same evolutionary stage, namely return to quiescence.

The Z And system has strong emission lines in its visual spectrum and the analysis of its continuum will give more confident results if the *UBV* fluxes are corrected for the emission lines. This cannot be realized using our high resolution spectra (Tomov & Tomova 2003) since they do not cover the whole *UBV* region. Mikolajewska & Kenyon (1996) have derived both *UBV* photometric data and fluxes of almost all of the emission lines in this region at the same time. We obtained that the light emitted in the lines is equal to 3%, 9% and 1% of

Table 1. The collected multicolour photometry.

Date	JD–2 451 000	Phase	*U*	*B*	*V*	*R*[a]	*I*[a]	*J*	*H*	*K*	*L*	*M*
1999 Sept. 15	437.383	0.560	10.81	11.53	10.43	8.80	7.20	6.23	5.28	4.97	4.76	4.99
Quiescent			±0.03	±0.02	±0.03	±0.02	±0.01	±0.02	±0.03	±0.01	±0.03	±0.08
2000 Nov. 22	871.313	0.131	8.60	9.41	8.94			6.05[b]	5.22[b]	4.90[b]	4.64	4.91
Active			±0.01	±0.01	±0.01						±0.01	±0.02
2000 Dec. 06	885.229	0.150	8.40	9.30	8.86			6.02[b]	5.20[b]	4.86[b]	4.61	4.93
Active			±0.01	±0.01	±0.01						±0.01	±0.02
2002 Jan. 27	1302.224	0.699	10.01	10.93	10.17			6.21	5.31	4.98[b]	4.76	5.03
Active			±0.03	±0.02	±0.03			±0.02	±0.01		±0.01	±0.03

[a] Data of Belyakina (1992).
[b] The inner uncertainty is of about $0\overset{\rm m}{.}001$.

Table 2. The continuum fluxes of the system's components in units 10^{-12} erg cm^{-2} s^{-1} Å^{-1}. The uncertainties of the observed values are in the same units.

Date	SC[a]	*U*	*B*	*V*	*R*	*I*	*J*	*H*	*K*	*L*	*M*
1999 Sept. 15	Cool	0.020	0.160	0.376	0.710	1.755	1.343	0.856	0.439	0.113	0.034
Quiescent	Hot	0.030	0.014								
	Neb.	1.012	0.293	0.257	0.195	0.157	0.056	0.032	0.020		
	TF	1.062	0.467	0.633	0.905	1.912	1.399	0.888	0.459	0.113	0.034
	OF	0.988	0.497	0.625	1.093	1.870	1.347	0.877	0.432	0.105	0.023
		±0.022	±0.010	±0.017	±0.020	±0.017	±0.025	±0.023	±0.004	±0.003	±0.001
	r	7	−6	1	−17	2	4	1	6	8	48
2000 Nov. 22	Cool	0.020	0.160	0.376	0.710	1.755	1.343	0.856	0.439	0.113	0.034
Active	Hot	5.537	2.934	1.336	0.730	0.340	0.063	0.022	0.007		
	Neb.	1.983	0.717	0.631	0.547	0.432	0.147	0.081	0.051	0.020	
	TF	7.540	3.811	2.343	1.987	2.527	1.553	0.959	0.497	0.133	0.034
	OF	7.205	3.848	2.492			1.591	0.927	0.461	0.117	0.024
		±0.054	±0.036	±0.022			±0.002	±0.001	±0.001	±0.001	±0.001
	r	5	−1	−6			−2	3	8	14	42
2000 Dec. 06	Cool	0.020	0.160	0.376	0.710	1.755	1.343	0.856	0.439	0.113	0.034
Active	Hot	6.257	3.315	1.510	0.826	0.384	0.071	0.024	0.008		
	Neb.	2.382	0.861	0.758	0.657	0.519	0.176	0.098	0.061	0.024	
	TF	8.659	4.336	2.644	2.192	2.658	1.590	0.978	0.508	0.137	0.034
	OF	8.662	4.257	2.682			1.635	0.944	0.478	0.120	0.024
		±0.064	±0.039	±0.023			±0.001	±0.001	±0.001	±0.001	±0.001
	r	0	2	−1			−4	4	6	14	42
2002 Jan. 27	Cool	0.020	0.160	0.376	0.710	1.755	1.343	0.856	0.439	0.113	0.034
Active	Hot	1.247	0.629	0.274	0.146	0.066	0.012				
	Neb.	0.622	0.140	0.123	0.107	0.084	0.029	0.016	0.010	0.004	
	TF	1.889	0.929	0.773	0.963	1.905	1.384	0.872	0.449	0.117	0.034
	OF	2.067	0.863	0.795			1.372	0.853	0.428	0.105	0.022
		±0.044	±0.018	±0.022			±0.025	±0.007	±0.001	±0.001	±0.001
	r	−9	8	−3			1	2	5	11	54

[a] The system's components, TF = Cool + Hot + Nebular: total flux; OF: observed flux; r = (TF − OF)/OF in %.

their *UBV* fluxes at phases close to the orbital maximum during quiescence and at the time JD 2 446 723, when the system was returning to quiescence after its 1984–1986 stage of activity.

Belyakina (1970) calculated the mean corrections for the emission lines for the epochs of the spectral data taken during the time of activity of the system from 1964–1965. The mean magnitudes at these epochs are $U = 10\overset{\rm m}{.}4$, $B = 11\overset{\rm m}{.}2$ and $V = 10\overset{\rm m}{.}3$. In this case the light emitted in the lines is found to be 20%, 12% and 2% from the corresponding *UBV* fluxes. However, in our view, the correction of the *U* flux is too great and must not exceed that of the *B* flux since the emission lines of the *U* spectral region of Z And are weak compared to those of its *B* region. We used the corrections based on the data of Mikolajewska & Kenyon (1996) for our first and last *UBV* estimates.

Our spectral data (Tomov & Tomova 2003) show that the height of the emission lines of all elements considerably decreases during the time of the optical maximum of the

2000−2002 active phase. For this reason we concluded that the correction related to this phase can be regarded as negligible.

Finally, the fluxes were corrected for the interstellar reddening $E(B-V)$. This quantity was rectified many times and the different authors propose relatively close values. Viotti et al. (1982) obtained 0.35, Kenyon & Webbink (1984) – 0.27-0.29, Mürset et al. (1991) – 0.30, Mikolajewska & Kenyon (1996) – about 0.3, Birriel et al. (1998) – 0.24 and Birriel et al. (2000) – 0.24 as well. We adopted the value 0.30. The fluxes were corrected according to the approaches in the papers of Seaton (1979) and Johnson (1966).

For our consideration we used the ephemeris Min(vis) = JD 2 442 666$^{\rm d}$ + 758$\overset{\rm d}{.}$8 $\times E$, 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 (Formiggini & Leibowitz 1994; Mikolajewska & Kenyon 1996; Fekel et al. 2000).

3. Analysis of the energy distribution

The main aim of our photometric study is to obtain the parameters of the hot stellar component and the circumbinary nebula during the active phase. These parameters can be determined from their continuum emission, which, from its side, requires having the photometric fluxes of each component of the system. The fluxes of the cool giant can be calculated from our IR data, taken during quiescence, when it is the only source of radiation. The quiescent visual fluxes of the hot component can be found from its UV emission and temperature estimate supposing that it radiates as a blackbody. The availability of the stellar fluxes gives us possibility to obtain the emission of the circumbinary nebula and on its basis – the quiescent electron temperature and the emission measure.

During the active phase we can determine the continuum fluxes of each component of the system using only our data and the circumstance that only two components of the system have emission in some photometric bands and the emission of one of them is known. For example only the cool giant and the circumbinary nebula have a contribution in the observed continuum at the position of the L band and the flux of the former is already known.

3.1. The quiescent phase

The Z And system has been observed photometrically in the IR spectral region by Eiroa et al. (1982), Munari et al. (1992), Kamath & Ashok (1999) and Taranova (2000). Taranova (2000) has obtained mean estimates in the period 1978–1999 which are $J = 6\overset{\rm m}{.}34$, $H = 5\overset{\rm m}{.}29$, $K = 5\overset{\rm m}{.}06$, $L = 4\overset{\rm m}{.}62$ and $M = 4\overset{\rm m}{.}85$. The data from the work of Munari et al. (1992) have also been obtained by Taranova and contribute to these mean estimates. Our quiescent IR data are very close to those of Eiroa et al. (1982). However they differ from the mean estimates of Taranova by an amount greater than our observational error. They differ also from some of the JHK estimates of Kamath & Ashok (1999). The study of the quiescent variability of Z And is not a task for our consideration. To decrease the influence of the quiescent variability over the parameters of its hot stellar component and circumbinary nebula during the active phase 2000–2002, we used only our IR estimates, but not the mean ones based on all published data.

For the continuum analysis during quiescence and calculation of the parameters of the cool component we need photometric data in R and I in addition to ours. At the wavelengths of the R and I bands the emission of the Z And undergoes an orbital variation (Belyakina 1992) caused by an occultation of the circumbinary nebula (Mikolajewska & Kenyon 1996). We used the data of Belyakina (1992) taken at the orbital phase of our observation near the light maximum of JD 2 447 598 when the UBV emission was the same.

The effective temperature of the cool giant of Z And was determined from its spectral type (Mürset & Schmid 1999) and the recent calibration for normal giants as published by Belle et al. (1999). An M4.5 spectral type with a m.s. error of 0.2 yields an effective temperature of 3400 ± 50 K. The V magnitude of the giant was calculated from the dereddened quiescent magnitude in the K photometric band, where it is the only source of emission and the dereddened colour index $V-K = 5\overset{\rm m}{.}15$ of the M4 III star HD 5316 (Fluks et al. 1994), which according to Belle et al. (1999) has the same effective temperature of 3400 K. This V magnitude was transformed into light flux (Table 2). The U, B, R and I fluxes of the giant were obtained from its V emission and the ratios of the dereddened fluxes of the same star HD 5316 based on data of SIMBAD and Kharitonov et al. (1988). The quiescent $JHKLM$ fluxes of Z And were fitted with a Planck function with a temperature of 3100 K and we suppose that they are emitted only by its cool giant, whose colour temperature in the $J-M$ spectral region is the same.

The next step of our consideration is to derive the observed bolometric flux of the giant. Its flux in the $J-M$ region was taken as an integral of a Planck function with temperature of 3100 K. In the visual region, however, the giant does not radiate as a blackbody and moreover, at wavelengths different from those of the $UBVRI$ photometric bands, we do not know its fluxes because of the light of the other components of the system. That is why we calculated its visual emission via linear interpolation of the $UBVRI$ fluxes. This part of the emission was added to the IR one and an observed bolometric flux of $2.221 \pm 0.048 \times 10^{-8}$ erg cm^{-2} s^{-1} was obtained. The uncertainty is based on those of the observational data.

The radius of the giant was derived from the bolometric flux and the effective temperature using the relation $R = d(F^{\rm bol}/\sigma T_{\rm eff}^4)^{1/2}$ and a distance to the system of 1.12 kpc according to Fernandez-Castro et al. (1988, 1995). This radius amounts to $85 \pm 4\,(d/1.12\ {\rm kpc})\ R_\odot$.

The UBV continuum of the system is formed by the emission of their three components (Nussbaumer & Vogel 1989; Fernandez-Castro et al. 1995). The quiescent UBV fluxes of the hot star were determined supposing that it radiates as a blackbody and using the ratios of the fluxes at λ 1270 Å and the positions of the UBV bands of a blackbody with the same temperature and the observed flux at λ 1270 Å, where the emission of the nebula can be regarded as negligible. The UV flux at λ 1270 Å was taken as an arithmetical mean of its values obtained during the time of quiescence 1978–1982 of Z And and listed in Table 2A of the paper of Fernandez-Castro et al. (1995). It was corrected for the interstellar reddening as described in Sect. 2 and was found to be equal to $1.552 \pm 0.108 \times 10^{-12}$ erg cm^{-2} s^{-1} Å^{-1}, whose uncertainty is the m.s. error. The temperature of the hot component during the quiescent stage of the system was determined in several works. Fernandez-Castro et al. (1988) estimated this parameter with the Zanstra method assuming that the nebula is optically thick to the stellar continuum shortward of 912 Å and that the hot component radiates as a blackbody. They concluded that it is equal to or greater than 100 000 K. According to Nussbaumer & Vogel (1989) there is an appreciable uncertainty in this Zanstra temperature which ranges probably from 100 000 to 200 000 K. Comparing the nebular recombination line He II 1640 with the underlying continuum, Mürset et al. (1991) obtained a Zanstra temperature of 105 000–110 000 K. For our calculations we adopted a value of 150 000 K. The quiescent *UBV* fluxes of the hot component derived on the basis of these data are presented in Table 2. The temperature and the UV flux used by us lead also to a radius of this star of about 0.06 (d/1.12 kpc) $R_\odot$ (Table 3). Its uncertainty based on that of the flux is less than 0.01 $R_\odot$.

The *UBV* fluxes of the circumbinary nebula can be obtained after subtraction of the stellar fluxes from the observed ones. The continuum fit to the nebular fluxes gives us the electron temperature and the emission measure of the nebula. To make this fit we need to know the state of ionization of helium. We calculated the ratio of the emission measures of the neutral and ionized helium using the fluxes of the He I 4471 and He II 4686 lines from the high resolution optical spectra of the star, taken at orbital phase 0.228 during its quiescent state (Tomov & Tomova 2003). It was obtained that doubly ionized helium is dominant in the nebula during the quiescent state and we supposed that the nebular emission in this case is mostly continuum emission of hydrogen and ionized helium (see also the work of Nussbaumer & Vogel 1989). It is also necessary to have the quantities γ_ν related to the emission coefficients of these elements at the positions of the photometric bands determined by recombinations and free-free transitions. The position of the *U* band is close to the Balmer limit. The symbiotic systems with strong hydrogen emission spectrum (AG Peg, AG Dra) have an apparent continuum which on the long wavelength-side of the Balmer limit has the same flux as on the short wavelength-side (see for example Tomov et al. 1998; Tomova & Tomov 1999) because of the blending of the Balmer lines with high numbers. We supposed, that the Z And system has the same characteristics since its Balmer lines are strong and are seen in emission up to H_{32} (Boyarchuk 1967a) and took the value of the hydrogen coefficient on the short wavelength-side (Osterbrock 1974).

The emission coefficients result from the fitting of the nebular continuum. Initially we determined the quantities γ_ν at the positions of the photometric bands and the corresponding electron temperature. Having these quantities and the nebular fluxes we obtained the emission measure. The parameters γ_ν in the infrared in units 10^{-40} erg cm^3 s^{-1} Hz^{-1} were used as follows: $\gamma_J(\mathrm{H^o}) = 5.63$, $\gamma_H(\mathrm{H^o}) = 5.49$, $\gamma_K(\mathrm{H^o}) = 6.29$, $\gamma_L(\mathrm{H^o}) = 6.42$, $\gamma_J(\mathrm{He^+}) = 20.7$, $\gamma_H(\mathrm{He^+}) = 21.7$, $\gamma_K(\mathrm{He^+}) = 23.0$ and $\gamma_L(\mathrm{He^+}) = 24.3$ (see Sect. 3.2). We adopted also helium abundance of 0.1 (Nussbaumer & Vogel 1989). The relation between the light flux F_λ and the emission measure $n_e^2 V$ was used

$$F_\lambda = \frac{1 + 2a(\mathrm{He})}{4\pi d^2} \left[\gamma_\nu(\mathrm{H^o}, T_e) + a(\mathrm{He})\gamma_\nu(\mathrm{He^+}, T_e)\right] \times n_e^2 V \frac{c}{\lambda^2} 10^{-8}. \quad (1)$$

The best fit for the quiescent nebular emission of the star at the wavelength positions of the *UBVRI* bands turned out to be continuum of gas with an electron temperature of $20\,000 \pm 1000$ K and an emission measure of $4.7 \pm 0.3 \times 10^{59} (d/1.12\ \mathrm{kpc})^2$ cm^{-3} (Fig. 2, Table 3). The uncertainties are determined from those of the observational data. The quiescent nebular fluxes in Table 2 are related to these parameters.

3.2. The active phase

The energy distribution of the hot component underwent drastic change during the active phase and its emission reached the infrared. At the time of the optical maximum only the region of the *LM* bands was free of the hot emission. The circumbinary nebula has a contribution in the *L* band continuum. We initially obtained an approximate emission measure using the quiescent electron temperature and only the *L* flux, which was reduced by the flux of the giant. Then these parameters were corrected by the use of all photometric data.

At the epoch of our last observation the *HKL* fluxes reached their typical quiescent values, which means that only the cool giant radiated at the wavelengths of these photometric bands (Table 2). The *UBV* fluxes, however, were still great compared with the quiescent ones. The *J* flux was above its quiescent value too and we assumed that the additional emission probably belongs only to the circumbinary nebula. Using this emission we obtained an approximate emission measure, which was later corrected according to the *UBV* data. The best fit parameters for each epoch during the outburst of the star are presented in Table 3. The electron temperature was 20 000 K again, although the dominant helium ionization state changed.

We determined the state of ionization of helium with use of the same lines (Tomov & Tomova 2003) as in the quiescent phase of the system, but observed on 17 Nov. and 6 Dec. when our photometric observations were carried out. It was obtained that singly ionized helium was dominant in the nebula and we supposed that its continuum is formed by hydrogen and neutral helium.

When calculating the quiescent nebular *U* flux we used the value of the hydrogen continuum coefficient on the short wavelength-side of the Balmer limit because of the blending of the Balmer lines with high numbers. In this way we proceeded when treating our last observation too. The situation about the *U* flux taken at the time of the optical maximum was different. At that time the width of the Hγ line was decreased (Tomov et al. 2003), which probably means that the width of the Balmer lines with higher numbers decreased too. The blending of the lines whose position is close to the Balmer jump can be changed for this reason, which can lead to decrease

Table 3. Parameters of the hot stellar and the nebular components based on the observations.

Date	Component of the system	$T_{\rm eff}$ (K)	$R(d/1.12$ kpc) ($R_\odot$)	$T_{\rm e}$ (K)	$n_{\rm e}^2 V(d/1.12$ kpc$)^2$ $\times 10^{59}$ (cm^{-3})
1999 Sept. 15	Hot	150 000[a]	0.06[a]		
Quiescent	Nebular			20 000 ± 1000	4.7 ± 0.3
2000 Nov. 22	Hot	35 000 ± 1000	2.22 ± 0.06		
Active	Nebular			20 000 ± 1000	17.4 ± 0.6
2000 Dec. 06	Hot	35 000 ± 1000	2.36 ± 0.07		
Active	Nebular			20 000 ± 1000	20.9 ± 0.5
2002 Jan. 27	Hot	58 000 + 2000/−3000	0.72 + 0.04/−0.03		
Active	Nebular			20 000 ± 2000	3.4 ± 0.4

[a] Based on UV data (Nussbaumer & Vogel 1989; Fernandez-Castro et al. 1988, 1995).

of the flux at 3650 Å. That is why we took the arithmetical mean of the values of the hydrogen coefficient on both sides of the Balmer limit (Osterbrock 1974).

The IR continuum emission coefficients of H^o, He^o and He^+ were calculated by us for the wavelengths of the photometric bands $JHKL$. When the abundance of helium is 0.1 and it is mostly doubly ionized, its contribution to the continuum is comparable to that of hydrogen. However, when helium is mostly singly ionized, its contribution is only about 10% of that of hydrogen. In the ordinary optical region the free-bound continuum is stronger, but in the infrared the free-free continua dominate (Osterbrock 1974). That is why for the time of the active phase when He^+ was the dominant ionization state in the nebula and the basic contribution to the continuum was that of He^o, we calculated its IR emission coefficient determined only by free-free transitions and used it as a total emission coefficient. This leads to an error not greater than about 5% of the calculated nebular fluxes. We used the equations from the papers of Brown & Mathews (1970) and Skopal (2001) and obtained quantities that were practicaly the same as those derived via linear interpolation of the data from the Tables 1 and 2 of the paper of Ferland (1980). The parameters of He^o in units 10^{-40} erg cm^3 s^{-1} Hz^{-1} were used as follows: $\gamma_{\rm J}({\rm He^o}) = 3.64$, $\gamma_{\rm H}({\rm He^o}) = 4.18$, $\gamma_{\rm K}({\rm He^o}) = 4.67$ and $\gamma_{\rm L}({\rm He^o}) = 5.27$.

The emission measure at the time of the optical maximum turned out to be increased by a factor of about 4.4 compared with its quiescent value at a phase close to this one of the orbital photometric maximum (Table 3).

The $UBVJHK$ fluxes of the hot component during the active phase were derived when the emission of the giant and the nebula was subtracted from the observed one. The fluxes of the hot component at each epoch were fitted with a blackbody continuum of a star whose temperature and radius are presented in Table 3. The data in Table 2 suggest a drastic increase of the stellar radius compared with its quiescent value.

The hot component parameters could be determined with better confidence by including the recent UV continuum fluxes at wavelengths 1059 Å and 1104 Å (Sokoloski et al. 2002) where it is the only source of radiation. The dereddened values of these fluxes are equal to 36.2×10^{-12} erg cm^{-2} s^{-1} Å^{-1} and 34.5×10^{-12} erg cm^{-2} s^{-1} Å^{-1}. However they are by a factor of 3 smaller than the fluxes of a blackbody with a temperature of 35 000 K and a radius of 2.36 $R_\odot$ (Fig. 2). It means that the visual–infrared data on one hand and UV data on the other hand cannot be fitted with the same parameters. At the time of the optical maximum the system has been at orbital phase 0.150 where the hot component is behind the giant. This inconsistency then could be explained with the supposition of Rayleigh scattering of the hot radiation by neutral hydrogen in the extended atmosphere of the cool giant as was suggested by Fernandez-Castro et al. (1995). Z And, however, is not an eclipsing system (Mikolajewska & Kenyon 1996) and Rayleigh scattering has only been detected in its spectra taken in 1984 and 1985 outbursts (Fernandez-Castro et al. 1995). This can be due to the expansion (see Sect. 4) of the hot component during the active phase, when some part of its radiation passes through the more dense layers of the cool giant atmosphere.

4. Discussion and conclusions

Our photometric data suggest strong flux redistribution in the observed region of the spectrum during the rise to the optical maximum – behaviour typical of system containing hot luminous star, not an accretion disk (Mikolajewska & Kenyon 1992). Mikolajewska & Kenyon (1996) concluded that the hot component of Z And expands in radius by a factor of up to 100 during the active phases as its effective temperature declines. The radius, which we obtained for the epoch of the light maximum, indicates an expansion by a factor of about 40 and is probably related to an ejected shell with photospheric characteristics.

The radius and the temperature of the hot component at the time of the optical maximum lead to an appreciable bolometric luminosity of 7500 $L_\odot$. However, a smaller radius will not be in agreement with the spectral data (Tomov et al. 2003), indicating absorption components of the $\lambda\lambda$ 4471 Å and 4713 Å helium triplet lines, when our observed fluxes are used. The residual intensity of the He I 4471 line was 0.46 in November and 0.60 in December. Since the continuum of the cool giant at the same time was about 0.07–0.08 of the total continuum of the system at the wavelengths of these lines, their appearance can be related to the hot component. In such a case the depth

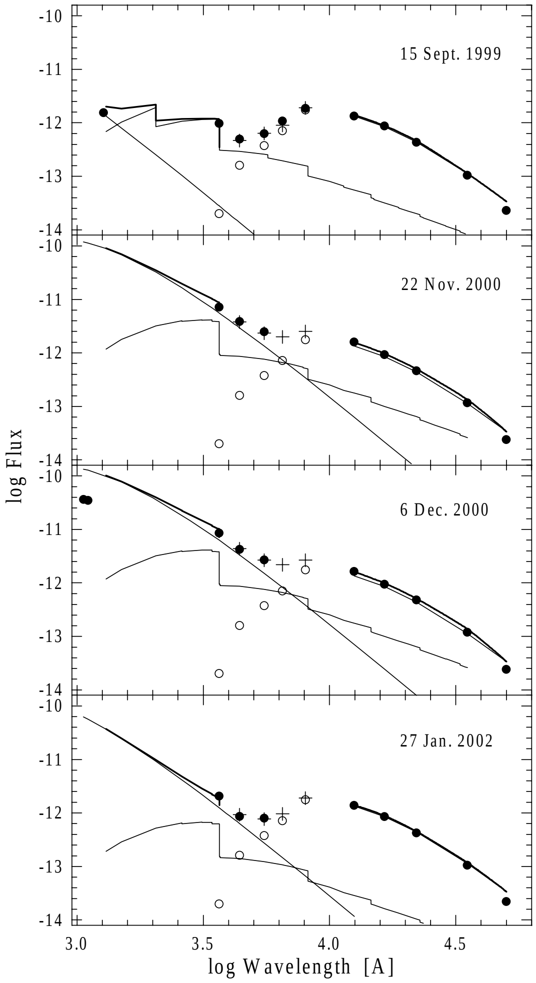

Fig. 2. The spectral energy distribution of Z And during quiescence and different epochs of its 2000–2002 active phase. The points indicate the observed fluxes. The thin lines represent the continua of the system's components. The circles represent the *UBVRI* fluxes of the giant. The thick line represents the resulting continuum. In the region of the *BVRI* photometric bands the resulting continuum is represented by crosses, placed only at their positions, since the giant does not radiate as a blackbody in this region and its continuum has not been known at the other wavelengths. The UV flux of Fernandez-Castro et al. (1995) and the *RI* fluxes of Belyakina (1992) are displayed at the panel of 15 Sept. 1999. The UV fluxes of Sokoloski et al. (2002) are displayed at the panel of 6 Dec. 2000. Flux units are erg cm^{-2} s^{-1} Å^{-1}.

of the He I 4471 line should be smaller than its continuum flux, determining the stellar radius.

The bolometric luminosity depends also on the temperature. If we suppose that the temperature of the hot component during the active phase was lower than the typical one of the O stars (~30 000 ÷ 40 000), it would be difficult to explain the strong emission line He II 4686 (Tomov et al. 2003) in the spectrum of Z And (see also Mikolajewska & Kenyon 1996). The blackbody temperature, which is suggested by the observed energy distribution, is indirectly confirmed also by the interpretation of the absorption features of some other lines of Z And. The presence only of absorption helium triplet lines in the spectrum was observed in some O stars, having $T_{\rm eff} \gtrsim 40\,000$ K and $\log g \sim 3.5 \div 3.8$ and is due to blocking of the UV flux in the region 228–912 Å by their metal lines and the reduced absorption of the flux in the singlet helium lines (Herrero 2000). It was assumed that the same mechanism is responsible for the presence only of the absorption triplet lines in the spectrum of Z And (Tomov et al. 2003).

Having our observed fluxes, we cannot allow that the radius of the hot component is smaller than the obtained one because it would be in disagreement with the depth of the absorption lines. The supposition for the considerably lower temperature, on the other hand, meets difficulties with the presence of some lines in the spectrum. The observed fluxes, however, depend on the interstellar reddening. For this reason we conclude that because of uncertainty in this parameter, our luminosity estimate is uncertain by a factor of about 2.

The quiescent temperature and radius adopted by us lead to bolometric luminosity of 1700 $L_\odot$. Nussbaumer & Vogel (1989), however, find that there is an appreciable uncertainty in the temperature, which ranges probably from 100 000 K to 200 000 K. The quiescent temperature of the hot component of Z And can be higher compared to some other symbiotic systems (AG Peg, AG Dra), being really about 200 000 K, as far as the dominant helium ionization state in the circumbinary nebula of this system is He^{++}, but not He^{+} as in AG Peg and AG Dra. Using a temperature of 200 000 K and an observed UV flux at 1270 Å of 1.552×10^{-12} erg cm^{-2} s^{-1} Å^{-1} we obtain a bolometric luminosity of 3700 $L_\odot$. The two values of the luminosity – the quiescent one and that related to the outburst – represent the possibility of evolution at roughly constant bolometric luminosity. However it can be concluded in principle only with use of UV data taken at both states.

The fitting of our last data proposes a radius of the hot component considerably exceeding its typical quiescent radius and an effective temperature considerably lower than the quiescent one. These parameters can be also related to one false photosphere, which gives us a reason to suppose that a mass flow from the outbursting star was still being realised at that time. This flow must have an optical depth of unity in the continuum at a distance equal to the radius obtained.

It was suggested that hydrogen burning on the surface of an accreting degenerate dwarf is stationary within a narrow range of accretion rates (Paczynski & Zytkow 1978; Fujimoto 1982). Small variations in the accretion rate can lead the accretor to expand at approximately constant bolometric luminosity (Mikolajewska & Kenyon 1992), which was assumed to be the most probable scenario for the optical outbursts of Z And (Fernandez-Castro et al. 1995).

Bisikalo et al. (2002) have modelled the evolution of the gas flow in the vicinity of the hot compact component of Z And, which accretes matter of the wind of the cool giant. They have considered the dependence of the accretion rate on the wind velocity. One of their results is that an accretion disk surrounding the compact component exists when the velocity takes some lower values. When the velocity takes higher, but close values, the gas environment is different – the disk does not exist and the accretion in this case is from the infalling flow. There is a velocity range where the accretion is changed – the disk is destroyed and its mass is accreted in a typical time less than

0.1 of the orbital period of Z And after the epoch of the velocity increase. As a result the accretion rate increases by a factor of about 20–30. It is supposed that the growth of the accretion rate accompanied by change of the burning regime can lead to ejection of mass by the accretor. Explanation of the present photometric data could be searched for in the light of these theoretical considerations.

We summarize the main results of our analysis as follows:

1. An effective temperature of the cool component of Z And binary system of 3400 K was obtained on the basis of its spectral type M 4.5 (Mürset & Schmid 1999) and the calibration of Belle et al. (1999) for normal giants. Its observed bolometric flux of 2.221×10^{-8} erg cm^{-2} s^{-1} was also obtained from multicolour $UBVRIJHKLM$ data. These parameters provide a radius of the star of $85\,(d/1.12$ kpc$)\,R_{\odot}$.
2. The quiescent electron temperature of the circumbinary nebula and its emission measure at the phase of the orbital photometric maximum were estimated to be 20 000 K and $4.7 \times 10^{59}(d/1.12$ kpc$)^2$ cm^{-3}.
3. At the time of the light maximum of the 2000 outburst of Z And the emission measure was increased by a factor of about 4.4, being $20.9 \times 10^{59}(d/1.12$ kpc$)^2$ cm^{-3}. The best fit of our data, however, did not show change of the electron temperature of the nebula, which was obtained to be 20 000 K again.
4. During the increase of the light the hot stellar component of the system expanded in radius by a factor of about 40, reaching a value of $2.36\,(d/1.12$ kpc$)\,R_{\odot}$ at the epoch of the light maximum. We suppose that this radius is related to an ejected shell with photospheric (pseudophotospheric) characteristics. The blackbody temperature at the same epoch was estimated to be about 35 000 K.

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