THE ACTIVITY OF THE SYMBIOTIC BINARY Z AND AT THE END OF 2002

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Abstract

Broad-band UBVRJHKLM photometric data taken at the time of the optical maximum of the symbiotic binary Z And during its small-amplitude brightening in the end of 2002 are analyzed. The spectral energy distribution of each component of the binary has been obtained. The analysis shows that the energy distribution of the compact companion was changed very small, it was remained a hot object emitting mostly in UV as in the quiescent state of the system. On the basis of this result the brightening is supposed to be due to a slow expansion to about two times its quiescent size as a result of an accretion rate increase.

Introduction

The symbiotic system Z And consists of a normal cool giant of spectral type M4.5 [1], a hot compact component with temperature higher than 10^5 K [2] and an extended circumbinary nebula formed by the wind of the giant and partly photoionized by the hot component.

The last major brightening of Z And began in the end of August 2000, the optical light reached maximum in December and gradually decreased to its typical quiescent value till the summer of 2002 [3, 4, 5]. In August 2002 there was not any indication of activity of the system and the light was in a deep minimum determined by an eclipse of the hot component [5]. After that time the light increased again and reached maximum in November, but the *UBV* amplitudes were not great ~1^m. In the same time, however, the IR emission was heavily enhanced - to the level close to that in December 2000. The star underwent an outburst again, but it was differing from the major outbursts when the visual emission of the hot companion predominates over the other components in its typical energy distribution – a weak *UBV* emission and relatively strong *JHKLM* one. Our study is devoted to an analysis of the continuum energy emitted in these regions of the spectrum of Z And. The aim is to obtain the basic parameters of the hot stellar component and the surrounding nebula at the time of the light maximum.

Observations and reduction

Broad-band *JHKLM* photometry of Z And was obtained on 11 Dec. 2002 (JD 2452620.262) with the InSb photometer attached to the 125cm telescope of the Crimean Station of the Sternberg Astronomical Institute. Broad-band *UBV* photometry was obtained on 12 Nov. 2002 (JD 2452591.308) with the single channel photoelectric photometer, attached to the 60 cm telescope of the National Astronomical Observatory Rozhen. The comparison stars used were described in the work of Tomov et al. [6].

The light curves of Skopal [5] and Skopal et al. [7] show that our *UBV* estimate of November 2002 was obtained at the maximum of the light during the outburst at the end of the year 2002 (Fig. 1). For our considerations we used average *UBV* magnitudes from the photometry of Skopal and our data at that time. The collection of the data taken in eight photometric bands provides the possibility to analyse the light in a broad spectral region. Since the IR estimates were less changed they were related to the times of obtaining the *UBV* magnitudes. We also used *R* photometric data from the light curve of Skopal [5] at the epoch of our observation from November 2002. The stellar magnitudes were converted into continuum fluxes.

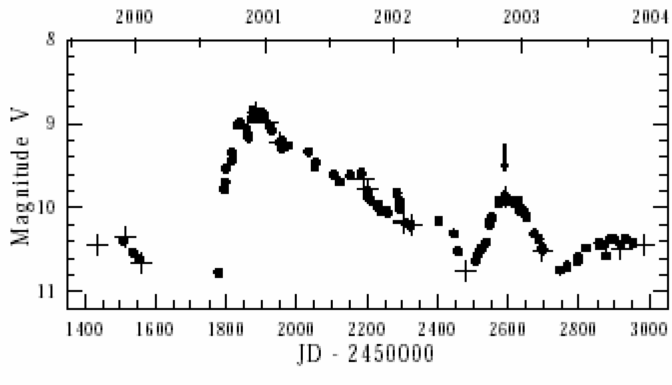

Fig. 1. The V light curve of Z And during its phase of activity after the summer of 2000. The dots indicate the data of Skopal et al. [4, 7] and the crosses our unpublished data. The arrow indicates the epoch during which we obtained our multicolour *UBVRJHKLM* data.

All fluxes were corrected for the interstellar reddening. We used the value E(B-V)=0.30 and proceeded according to the approaches of Seaton [8] and Johnson [9].

Continuum energy distribution

The basic parameters of the components of the binary can be obtained from their continuum emission. It turned out, however, that the hot component has radiated comparatively little in the region of the photometric bands used by us and mainly at the shorter wavelengths. That is why its parameters were determined also by means of some suppositions in addition to the analysis of the observed continuum.

When analyzing our data we proceeded in the following way. The giant was not variable during the time of activity after the year 2000. That is why initially we subtracted its fluxes according to the work of Tomov et al. [6] from the observed fluxes. It turned out that the rest of the emission is fitted very well by a nebular continuum in the region of the *RJHK* bands. Then we assumed that the same continuum is probably present also in the *UBV* region. In this region, however, an additional emission of a third component is present as well.

On the basis of our spectral data it was obtained that doubly ionized helium is dominant in the circumbinary nebula and we assumed that its continuum is formed by the emission of hydrogen and ionized helium.

The best fit at the wavelength positions of the *UBVRJHKL* bands for the nebular emission turned out to be continuum of gas with an electron temperature of 20000 ± 1000 K and an emission measure of $(11.7\pm0.3)\times10^{59}(d/1.12\ \mathrm{kpc})^2\ \mathrm{cm}^{-3}$ (Fig. 2, Table 1).

This result showed that the increase of the light of Z And at the time of its optical maximum was mainly due to the nebular emission and the energy distribution of its secondary stellar component was typical of a hot object radiating predominantly in the UV region, as in the quiescent state. In this case it would not be correct to determine its parameters on the basis only of visual data. Thus, we obtained these parameters from both the *UBV* fluxes and the companion's Lyman luminosity. It was necessary for this luminosity also to be estimated. Using the quiescent radius and effective temperature adopted in the work of Tomov et al. [6], we obtained a Lyman photon luminosity of 9.43×10^{46} phot s^{-1}. We supposed that the Lyman luminosity has increased in the same ratio of 2.5±0.2 as the emission measure of the nebula and in this case obtained $(2.36\pm0.19)\times10^{47}$ phot s^{-1}.

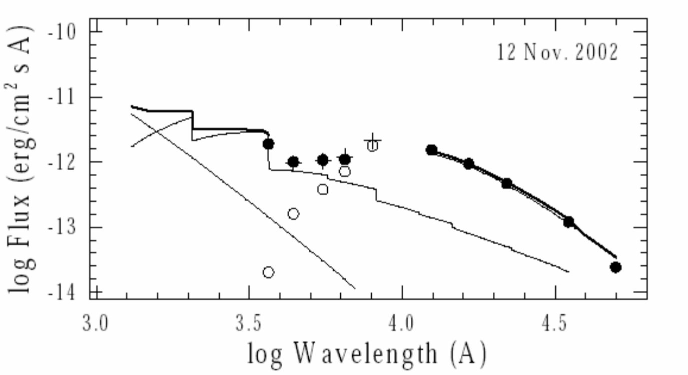

Fig. 2. The spectral energy distribution of Z And at the time of its optical maximum in November 2002. The points indicate the observed fluxes. The thin lines represent the continua of the system's components. The circles represent the *UBVRI* fluxes of the giant. The thick line represents the resulting 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 is not known at the other wavelengths.

Using this value and the observed *UBV* fluxes, for the radius and the effective temperature at the time of the optical maximum we derived 0.13±0.01 $R_\odot$ and 125000±3000 K. The uncertainties are determined from our observed fluxes. These parameters are given in Table 1 and the fluxes of the hot component were calculated on their basis.

DATE	15.09.1999 QUIESCENT	12.11.2002 ACTIVE
Hot stellar		
T_{eff} (K)	150000 (UV data)	125000 ± 3000
R (d/1.12 kpc) $R_\odot$	0.06 (UV data)	0.13 ±0.01
Nebular		
T_e (K)	20000 ± 1000	20000 ± 1000
n_e^2 V (d/1.12 kpc)^2×10^{59} (cm^{-3})	4.7 ± 0.3	11.7 ± 0.3

Table 1. Parameters of the hot stellar and the nebular components based on the observations. The parameters for the quiescent state are from the work of Tomov et al. [6].

Discussion and Conclusions

The commonly accepted view is that hydrogen steady-state burning is realized at the surface of the secondary component of Z And in its quiescent state [10]. This component is a high temperature compact object. Its expansion could then be due to an accumulation of matter not included in the burning process as a result of the growth of the accretion rate. The expansion occurs at constant bolometric luminosity [11]. The quiescent parameters used by us and the assumed increase of the Lyman luminosity by a factor of 2.5 lead to an increase of the bolometric luminosity of this hot object by a factor of about 2, which however, makes the interpretation difficult for an expansion at constant bolometric luminosity. Though, we will use the relation between the velocity of the expansion and the accretion rate of an accreting white dwarf with hydrogen burning at its surface to obtain at least a most crude estimate of the increase of the accretion rate during the active phase. This velocity is given by

$$dR / dt = R\,(d \ln R / d \ln\Delta M_1) \times ((\mathrm{Mdot} - \mathrm{Mdot}_{RG}) / \Delta M_1)$$

$$\approx 8\ \mathrm{m/s}\ ((\mathrm{Mdot} - \mathrm{Mdot}_{RG}) / 10^{-6}\ M_{\odot}/\mathrm{yr}) \times (\Delta M_1 / 10^{-5}\ M_{\odot})^{-1}\ , \quad (1)$$

where $d \ln R / d \ln\Delta M_1 = 3.1\sim4.1$ at $R=1R_{\odot}$ [11]. Mdot is the accretion rate necessary to trigger the expansion and ΔM_1 is the mass of the accreted envelope. Mdot $_{RG}$ is the upper limit of the region of the accretion rates, where the accretion rate is equal to the burning rate; when the accretion rate is greater than this limit the envelope expands as a result of accumulation of mass. Using this relation we can obtain an estimate of the mean accretion rate needed for expansion of the hot component of Z And for the time of the light increase from the mean velocity of the increase of the star's radius. The typical time of the growth of the light is 100^d [5]. In this case the mean velocity of the increase of the radius from 0.06 $R_{\odot}$ to 0.13 $R_{\odot}$ is obtained to be 5.6 m s^{-1}. At a mass of the hot component of 0.6 $M_{\odot}$ [2, 12] the mass of the accreted envelope for burning in thermal equilibrium is 5.01×10^{-5} $M_{\odot}$. The upper limit of the accretion rate is 1.77×10^{-7} $M_{\odot}$ yr^{-1} [11]. Then using the relation (1), we derived 3.2×10^{-7} $M_{\odot}$ yr^{-1} for the accretion rate providing the expansion. According to Fernandez-Castro et al. [2] the quiescent accretion rate of the hot component of the Z And system is equal to 4.5×10^{-9} $M_{\odot}$ yr^{-1}. In this case the ratio of the two values is about 70.

We present the results of broad-band *UBVRJHKLM* observations of the symbiotic binary Z And taken during its outburst at the end of 2002. The data show that the hot component of this system was a compact object emitting mostly in UV during this time, as in quiescence. The increase of the emission of the circumbinary nebula indicates an increase of the flux of the ionizing photons from this component. We assumed that its Lyman luminosity increases in the same ratio as the emission measure of the nebula. On the basis of the Lyman luminosity estimate and the *UBV* fluxes we calculated its effective temperature and radius. The result shows that it expands to about two times its quiescent size. We also obtained a crude estimate of the mean accretion rate during the active phase.

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