THE DETERMINATION OF ABSOLUTE PARAMETERS AND ABUNDANCE OF COMPONENTS BINARY SYSTEMS: THE SPECIFICITY AND PROBLEMS

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ABSTRACT. Spectroscopic binaries remain a laboratory for testing the stellar atmospher and the stellar evolution theories. It's considering problems determination of parameters of components and their errous for example two spectroscopic binaries with the main-sequence components BW Boo and OU Gem.

Key words: Spectroscopic:absolute parameters: spectroscopic binary; stars: individual: BW Boo,OU Gem

1. Introduction

Spectroscopic binaries, for which we can determine masses and radii of their components based on their orbiting, are still good sites to test the modern stellar atmosphere and stellar evolution theories, as well as to estimate the effect of duplicity on the variation in the internal structure of binaries and, consequently, on the divergence of the model parameters of such binaries from those of single stars of the given mass. It is difficult to determine the abundance of spectroscopic binaries as it is necessary to concordantly solve the problem of simulation of atmospheres for two stars at once. The selection of spectral lines to determine the abundance is also complicated as those lines should not be blended either with other lines of the star nor with the lines of the companion star. For two spectroscopic binaries with the main-sequence components we determined absolute parameters of the components by the radial velocity curves, the light curves of the binaries, as well as the rotat

ional velocities of their components, measured using the LSD-profiles. The age of binary was estimated by the presence of its components' rotation, synchronised with their orbiting, and the orbital eccentricity. Those parameters are applied to compute the models of atmospheres of the binary components, to obtain the total synthetic spectrum and to calculate the chemical abundances of elements, the lines of which are reliably identified in the observed spectrum. However, the binary parameters determined by different methods are not in good agreement.

2. Eclipsing and spectroscopic binary BW Boo

BW Boo (HD128661) is a poorly studied bright eclipsing binary (V=7.14^m) with the orbital period of 3.33^d. The spectral and photometric orbital elements, projected rotational velocities of the components were estimated and the absolute parameters of the binary components and the age of the binary system of 2 10^7 years (Table 1) were determined by two spectra, obtained with the 2.7-meter telescope of the McDonald Observatory with resolving power R=60000 and S/N=300 at the wavelength range 5000 − 6500 Å, as well as by the light curves reported in the literature (Glazunova 2011). The position of the primary on the Hertzsprung−Russell diagram correlates well with the determined mass and age (Fig. 1). According to the age of a star with mass of $1.1M_\odot$ and high lithium abundance in its atmosphere ($lg\,Li/H = 3.0$ dex), the secondary has not yet reached the main sequence.

Table 1: The absolute parameters.

Parameters	A	B
T_eff (K)	8900	5550
M ($M_\odot$)	2.0 ±0.1	1.1
R ($R_\odot$)	1.9 ±0.4	1.2
a ($R_\odot$)	13.67	
L ($L_\odot$)	21.62	1.24
v_{spin} (/)	2 ±0.5	17 ±2
v_{psyn} (/)	37	24
F(v_{psyn}/v_{spin})	18	1.4

The atmospheric parameters of the primary (see Table 2 where the rotational velocity was measured using the LSD-profiles of the lines, and the relative contributions of the components to the total luminosity were

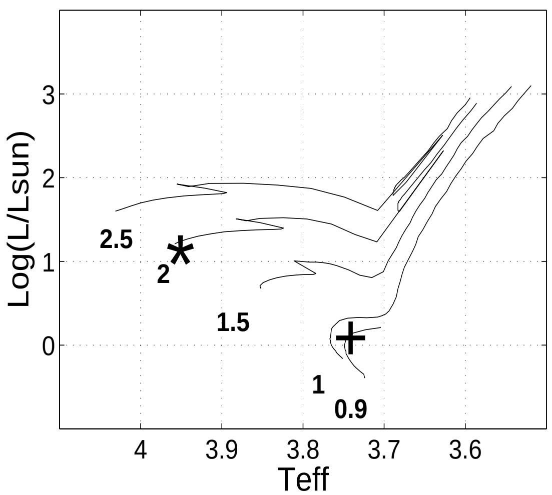

Figure 1: Evolutionary tracks for stars from 0.9 to 2.5 $M_\odot$ (Schaller et all. 1992). The primary and the secondary are marked by asterisk.

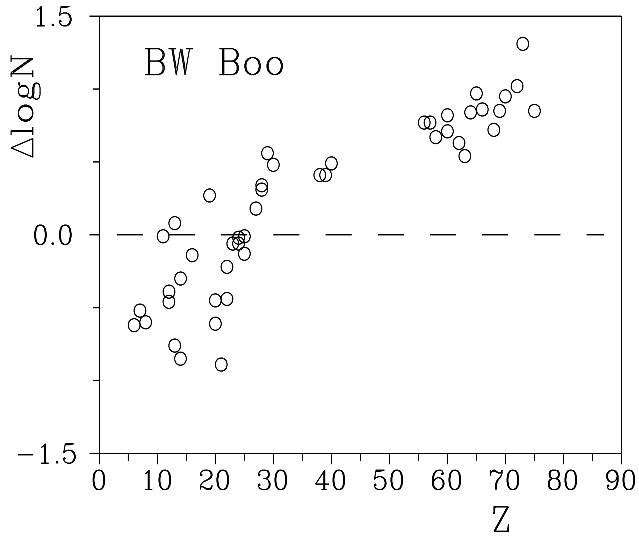

Figure 2: Elemental abundances by atomic number the primary of BW Boo.

determined from the light-curve solution) were determined by 114 neutral iron lines and 64 ionized iron lines, applying the method described by Yushchenko et al. (1999). The initial chemical composition was supposed to be similar to the solar one. The abundances of 38 chemical elements, including those with $Z > 60$ (Fig. 2) were estimated. The abundance is typical for an Am star with the iron abundance [Fe/H]=0.15±0.08 dex. About 100 lines were identified for the secondary, but with the component luminosity ratio of 23 those are lines with large equivalent widths, so they are unsuitable for the abundance estimation. However, it can be said that those lines are well specified by the given model parameters (within the error of 20% for weak lines). The results of comparison of the observed lines with the synthetic spectrum of the selected model are not contrary to the solar chemical composition.

Table 2: Atmospheric parameters

Parameters	A comp	B comp
$T_{eff}K$	8900±100	5500
lg g	4.1 ±0.1	4.3
v_{micr} (km/s)	1.3	2
v_{rot}(km/s)	2±1	17
L_{rel}	0.96	0.04

2. Problems in estimation of the parameters of the close binary BW Boo components

Determination of effective temperature and surface gravity by different methods (by the colour indices, the neutron and ionized iron lines, the evolutionary model) results in a wide scatter of values (Table 3). As is seen in Table 3, the closer towards the red end of the spectrum region is used to estimate the temperature, the lower that temperature is. According to the binary galactic coordinates ($l = 61, b = 66$), the interstellar absorption should be very low $0.1^m - 0.15^m$. The same is confirmed by determination of the interstellar absorption by the colour excesses in U–B=0.04 and B–V=0.12 as such A_V=0.2. The colour indices U–B=0.04 (for the model with a mass of 2 $M_\odot$ – 0.043), B–V=0.13 (0.058), V–J=0.34 (0.051), V–K=0.44 (0.067) for red emission do not correspond to those of a star with mass 2 $M_\odot$ and normal solar abundance. Apparently, such a wide scatter in the temperature and surface gravity determinations for the given star is associated with the metallicity of the star's atmosphere and, subsequently, the variation in energy distribution in its spectrum. With the component luminosity ratio of 23 the secondary contribution affects the composite spectrum just slightly. The absolute magnitude of the primary can be determined by the parallax and interstellar absorption: the parallax is 8.1 ± 0.6, $M_V = m_V + 5 - 5\,lg\,r - A_V$, M_V=1.68−0.2±0.16. What is the most astounding about BW Boo binary is the rotational velocity of its primary component, which is 18 times slower than the pseudo-synchronous rotational velocity for that component, and that ensures the Am star effect. It follows from the theory on circularisation and synchronisation in the close binaries that the binary components with the orbital periods less than 5 days should be synchronised as early as at the stage before the main sequence. According to that theory, the time of synchronisation for the BW Boo binary components is 2.6 10^5 years (Taussol 1988), and the time of circularisation is 5 10^8 years. Such asynchrony can be explained by a sharp decline in the binary period that is possible only in the presence of the protostellar disc, from which the binary system was originated or a multiple system was broken down. However, both alternatives require that the binary system is located in the star-forming high-density regions in the interstellar medium with high stellar density. As can be seen from the above, more accurate definition of the absolute parameters of the binary components allowed of selecting the model parameters of their atmospheres, which are in good agreement with each other.

Table 3: Determination of the temperature and surface of gravity by different methods.

Method	Magnitude	Reference	Teff K	lg g
B	7.258			
V	7.138			
J	6.788	2003yCat.2246	7850	3.5
H	6.726	OC		
K	6.692			
V	7.14	Guetter et all,		
B-V	0.12	PASP,96,44, 1984	8250	4.5
b-y	0.079	Hill et all,		
c1	1.175	Mem.R. astr. Soc.,	8500	3.65
m1	0.170	79,131,1975		
FeI/FeII		this paper	8900	4.1
as singel			8700	3.7
star				
M_A/t_{age}		this paper	9000	4.3

3. The BY Dra type spectroscopic binary OU Gem

OU Gem (HD 45088) is a BY Dra type bright spectroscopic binary with $m_v = 6.79^m$ and $P = 6.99^d$ with components of close spectral types $K3V + K5V$ that is located at a distance of 14.7 pc. OU Gem may belong to the UMa moving group, the estimated age of which is 300 Myr (Montes et al. 2000a). The binary light curve does not exhibit eclipses, but shows a smooth variation in brightness with an amplitude within the range of $0.02^m - 0.05^m$ and period, which is a little bit longer than the orbital one $P = 7.36^d$. The spectral elements of the binary orbit were redetermined by Mishenina et al. (2010). Strong emission in the CaII H&K lines is observed in both components of OU Gem binary just as in many other BY Dra type stars. With the components' contributions L_A/L_B=0.7/0.3 the equivalent widths of the component emission are estimated of 1.08/1.71 Åfor the K line and 1.02/1.51 Åfor the H line of the calcium (Montes et al. 1996, 2000b). As is seen from these estimations, the second ary, which is less massive, has higher chromospheric activity.

10 spectra with the resolving power R=75000 and S/N within the high signal-to-noise in the range of $71 - 173$ were obtained by T. Mishenina with the fiber-fed echelle spectrograph SOPHIE at the 1.93-m telescope of the Observatoire de Haute-Provence (France) in 2009, 2010 and 2011. The spectra processing was performed using the DECH20 software package. The total spectrum of the binary was analysed with the URAN code by Yushchenko (1998). The component temperatures were determined by the ratio of depths of specially selected lines applying the methods, described by V. Kovtyukh (2003). The computations of the component temperatures and abundances of chemical elements in their spectra were conducted by V. Kovtyukh.

Some spectral characteristics of the binary components at different spectral and photometric orbital phase given in Table 4. The spectral elements of the binary orbit, which allow of estimating the minimum masses of its components, were computed by the radial velocities of the binary components (Mishenina et al. 2010); but to estimate the absolute parameters of the binary, it is necessary to determine the orbital inclination to the plane of projection i and radii of the binary components. To do that, the luminosities of the components should be determined. To determine the absolute magnitude of the binary, we used the binary parallax value of 68.20 ± 1.10 mms that makes up r=14.7 pc (Hipparcos 1997).

Thus, $M_V = m_V + 5 - 5\,lg\,r = 5.89^m \pm 0.03$. Having made the bolometric correction for T_{eff}=5025 K ($lg\,T_{eff}$=3.70) and B–V=0.92, obtained by the calibration by Flower et al. (1996), BC=–0.295, we get the absolute bolometric magnitude $M_{bol} = 5.595^m \pm 0.03$ and $lg\,L/L_\odot = -0.306 \pm 0.002$. The binary luminosity will be equal to 0.496 $L_\odot$. Assuming that the luminosity contribution averages to 0.75($lg\,L_A/L_\odot$=-0.429) for the primary component and 0.25 ($lg\,L_B/L_\odot$=–0.907) for the secondary component, the luminosity and then the radius of each component could be determined. Therefore, the primary component mass is 0.78 ± 0.02 $M_\odot$, and the mass of the secondary component is $0.66 \pm 0.02 M_\odot$. The orbital inclination to the plane of projection is i=$76^o \pm 1$. Such an angle is consistent with the absence of eclipses in the binary, which are likely to occur at $i > 85^o$ for the given radii of the components. That is how the absolute parameters of the OU Gem binary components were obtained (Table 5).

The pseudo-synchronous velocities of the binary components for the determined radii are 7.5 ($v_{ps}\,sin\,i = 7.3km/s$) and 6.3 ($v_{ps}\,sin\,i = 6.2km/s$). The observed rotational velocity of the primary is 22% slower than its pseudo-synchronous one; and the rotational velocity of the secondary is close to its pseudo-synchronous ve-

Table 4: Determination of the temperature and surface of gravity by different methods .

JD 24+	$T_{eff\,A}$	$T_{eff\,B}$	$Fe(L_A/L_B)$	L_A/L_B	$v_A\ sin\,i$	$v_B\ sin\,i$	New sp. phase	New ph. phase
54898.313 (a)	5044±22	4693±67	0.74/0.26	0.71/0.29	6.14	6.57	0.74	0.65
54899.293(b)	5013±15	4486±50	0.78±0.02/0.22	0.74/0.26	5.2	5.30	0.88	0.78
54900.280(c)	4881±13						0.02	0.91
54901.395(d)	5025±10	44538±18	0.75±0.03/0/25	0.74/0.26	6.17	6.94	0.18	0.07
55128.695	5027±13	4559±39	0.73±0.03/0.27	0.72/0.28	5.94	6.53	0.69	0.95
55130.627	4985±13	4275±29	0.75±0.02/0.25	0.73/0.27	5.97	6.14	0.96	0.21
55131.623	5036±12	4498±35	0.76/0.24	0.74/0.26	5.89	6.29	0.11	0.21
55132.622	5058±10	4578±38	0.76/0.24	0.74/0.26	5.93	6.24	0.25	0.48
55835.685	5027±14	4459±37	0.78/0.22	0.70/0.30	5.94	6.93	0.80	0.01
55836.684	5010±11	4484±30	0.72/0.28	0.71/0.29	6.48	7.43	0.95	0.14
Average values	5025±13	4508±38	0.75/0.25	0.73/0.27	5.96±0.3	6.49±0.6		

locity. If a period of 7.36^d corresponds to the rotation period of the secondary at the latitude of the existing spot, then its rotational velocity at that latitude should equal to 4.4 km/s. The difference between the rotational velocities, measured using the LSD-profile of the secondary, and that one, obtained by the photometric period, can be explained by the differential rotation of that component. The synchronization and circularization time for the binary components for the given parameters, which was calculated with the formulas by Taussol (1988), is t_{synA}=2 10^5 years, $t_{cir\,A}$=5 10^8 years (with N=8); and by Zahn 1977 – $t_{syn\,A}$=3 10^7 years, $t_{cir\,A}$=3 10^{10} years.

Table 5: Atmospheric parameters

Parameters	A comp	B comp
$lg\,L/L_\odot$	–0.46±0.02	–0.83
M ($M_\odot$)	0.78±0.02	0.66
R($R_\odot$)	0.76±0.03	0.64
lg g	4.57±0.04	4.65

Using the URAN code the non-blended lines of the primary and secondary were identified in the spectra at different phases of the orbital period; their equivalent widths were measured and subsequently parted in relative luminosities of the components accounting for the change in their contributions at different wavelengths according to the ratio of radiation flux of the components. The abundances of different chemical elements in the atmospheres of the binary components were determined by the reduced equivalent widths. The surface gravity $lg\,g_A = 4.3 \pm 0.1$ and $lg\,g_B = 4.5$, as well as the microturbulent velocities 1.3 ± 0.2 and 1.5 km/s, which were used in the models, were determined on the base of the ionization-equilibrium neutral and ionized iron lines (220 and 9 lines, respectively). The abundances of 22 elements were estimated in the primary (with accuracy of 0.11 dex by the iron lines) and those of 14 elements were estimated in the spectrum of the secondary (with accuracy of 0.2 dex by the iron lines). The same iron abundances in the atmospheres of the binary components are reached at the luminosities L_A=0.78 and L_B=0.22 (Fig. 3).

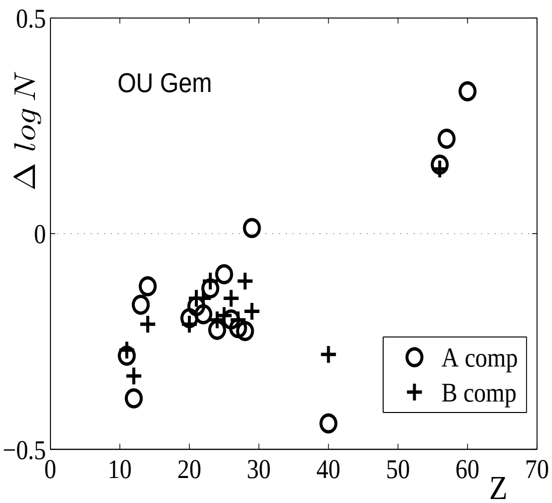

Figure 3: Elemental abundances by atomic number of components of OU Gem.

The abundances of most elements are lower relative to those solar ones (–0.18 dex for Fe). The heaviest elements are slightly overabundant. The binary age of 3 10^8 years is in good agreement with the absence of the Li I 6707 Åline in the spectra of both components. According to the studies of the lithium abundance in the Hyades cluster stars with age of 7 10^8 years (Cayrel et al. 1984), the lithium abundances in the stars with the given mass correspond to the equivalent width of the Li I 6707Å line less than 5 mÅ, and that is consistent with our measurements.

4. Peculiarities and contradictions

The ratio of the components' luminosities (table 4) does not correspond to the main-sequence stars with the mass ratio q=0.85 (for the given masses the models result in the ratio of fluxes of 3.5 by 5000 Å $F_A/F_B < 2$ in the observed spectra). The surface gravity, determined in the ionization equilibrium (4.3 ± 0.1 and 4.5), does not correlate with that one, determined by the mass and radius (4.57±0.04 and 4.65), as well as by the luminosity and effective temperature. An alternative explanation of such a difference is given in the paper by Tsantaki et al.(2013). The secondary component seldom exhibits sharp changes in effective temperature, which significantly exceed the method errors in its determination (see the table 4). The most common used formulae for estimation of the synchronization and circularization time in binary systems ($t_{syn\,A}$=2 10^5 years, $t_{cir\,A}$=5 10^8 years by Taussol 1988) do not expound the rotational velocities of the components or the orbital eccentricity.

5. Conclusion

The indicated method errors are just the technical errors as the accuracy errors of determination of effective temperature, surface gravity, metallicity and rotational velocity projection even by spectra with very high resolution are much larger ($> 2-3$ %, 0.3 dex,$>$ 0.2 dex, $>$ 2 km/s).

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