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Spectral energy distributions and model atmosphere parameters of the binary systems COU1289 and COU1291

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Abstract. The spectral energy distribution between λ 3700 Å and λ 8100 Å of the binary systems COU1289 and COU1291 is presented with a description of the methodology of getting their spectrum on Carl-Zeiss-Jena 1 m telescope of the Special Astrophysical Observatory. Their B, V, R magnitudes and $B - V$ colour indices were computed and compared with earlier results. Model atmospheres of both systems were constructed using the grid of the Kurucz blanketed models, and their energy distributions in the continuous spectrum were computed and compared with the observational ones. The model atmosphere parameters for the components of COU1289 were derived as: $T^a_{eff} = 7100$ K, $T^b_{eff} = 6300$ K, lg g_a=4.27, lg g_b=4.22, $R_a = 1.50R_\odot$, $R_b = 1.40R_\odot$, and for the components of COU1291 as: $T^a_{eff} = 6400$ K, $T^b_{eff} = 6100$ K, lg g_a=4.20, lg g_b=4.35, $R_a = 1.47R_\odot$, $R_b = 1.12R_\odot$. The spectral types of both components of the system COU1289 were approved as F1 and F7, and of the system COU1291 as F6 and F9. Finally the formation and evolution of the systems were discussed.

Key words: stars: spectrophotometry – stars: atmospheric modeling – stars: individual: COU1289, COU1291

1. Introduction

Binary stars play an important role in determining several key stellar parameters. The determination of these parameters is more complicated in case of close visual binaries. The application of speckle interferometry has greatly improved the situation, for now hundreds of binary systems with periods in the order of 10 years or less are routinely observed by different groups around the world. But this is not sufficient to determine the individual physical parameters of the system components. So, spectrophotometry and atmosphere modeling come with a complementary solution for this problem by giving an accurate determination of the effective temperature, radius, spectral type and luminosity class for each component in a binary.

The binary systems COU1289 and COU1291 are well known speckle interferometric systems and very good examples for this application, and consequently for studying the formation and evolution of binary stars. Table 1 contains the SIMBAD data of the systems, and Table 2 contains the data from Hipparcos and Tycho Catalogues (ESA, 1997).

Table 1: *Data from SIMBAD*

	COU1289	COU1291
α_{2000}	$16^h58^m22\overset{s}{.}864$	$17^h07^m29\overset{s}{.}99$
δ_{2000}	$+39°42'35\overset{''}{.}779$	$+38°10'20\overset{''}{.}64$
HD	153527	155039
HIP	83064	83791
Spectral type	G0	G5

2. Observations and data analysis

The spectra were obtained using a low resolution grating (325/4° grooves/mm, 6 Å/px reciprocal dispersion) within the UAGS spectrograph at the Cassegrain focus of the Carl Zeiss Jena (Zeiss-1000) 1 m telescope of SAO during the photometrical night May 26, 2002. The seeing was around $1\overset{''}{.}2$. The spectrograph has an ISD015 Å 530×580 px CCD detector. A 0.5 mm slit width was used to encompass all light from the star, and it was rotated (by changing the angle of the instrument's table) to a suitable direction to prevent the effect of nearby stars.

Two positional angles for the grating were used to

Table 2: *Data from Hipparcos and Tycho Catalogues*

	COU1289 Hip 83064	COU1291 Hip 83791
$V_J(Hipp)$	$8^m.09$	$8^m.57$
$(B-V)_J(Hipp)$	$0^m.583$	$0^m.545$
B_T	$8^m.770$	$9^m.209$
V_T	$8^m.149$	$8^m.626$
$V_J(Tycho)$	$8^m.09$	$8^m.57$
$(B-V)_J(Tycho)$	$0^m.567$	$0^m.536$
Trig. Parallax (mas)	8.43	8.80

cover the spectral range between 3700Å and 8100Å, 29° for the blue part and 30°40′ for the red part. This was done for two reasons; first, because of small dimensions of the detector which does not cover this spectral range, and second, in order to overcome the falling sensitivity of the detector in the blue part of the spectrum by applying longer integration times in this part, and there were at least 500 Å of overlap between the two regions, allowing us further checks on our internal agreement.

Standards from Massey et al. (1988), Oke (1990) and Hamuy et al. (1992, 1994) were used for the calibration of the system. The spectra were sky subtracted and wavelength calibrated. Then the spectral sensitivity curve of the CCD derived from the standard stars' spectra for each angle, was used for flux calibration of the object spectra. All steps were made using ESO-MIDAS[1] routines. The wavelength calibration was performed by means of He-Ne-Ar lamp emission spectra.

The spectra were averaged separately for angles of the grating. Then by averaging the resulting individual spectra in the overlap region, we obtained a single 4400 Å band spectrum.

The standard deviation of B and V magnitudes is typically better than $0^m.06$, and for the R band is better than $0^m.07$. The error bars are the lowest in the central part of the spectrum where the blue and red spectra overlap.

3. Observational results

Figs. 1 and 2 show the final results of the spectral energy distributions of COU1289 and COU1291, respectively. Note that some of the strong lines and depressions, especially in the red part of the spectrum (around λ6867Å, λ7200Å, and λ7605Å), are H_2O and O_2 telluric lines and depressions.

B, V, and R magnitudes were computed using *UBVRI* Bessel (1990) passbands, then normalized to

[1] Munich Image Data Analysis System, developed, maintained and distributed by the European Southern Observatory.

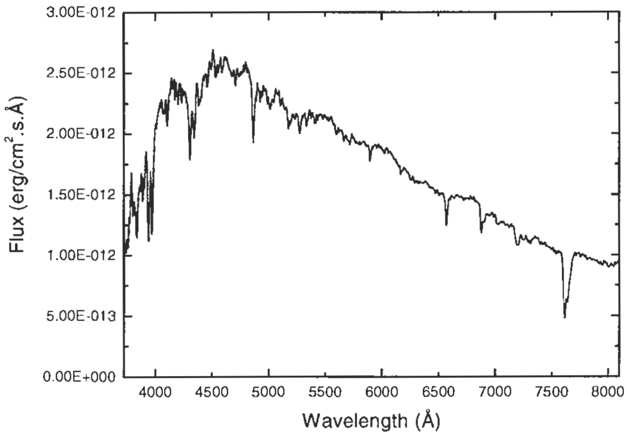

Figure 1: *Spectral energy distribution of COU1289.*

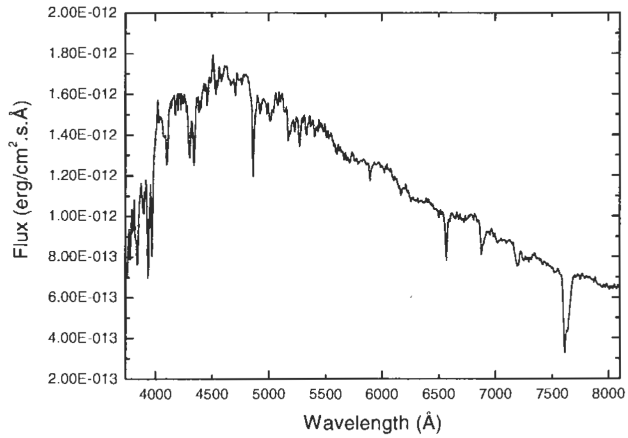

Figure 2: *Spectral energy distribution of COU1291.*

Vega. In practice we computed the integrals (for more information see Al-Wardat, 2002):

$$X = -2.5 \lg \frac{\int S_x(\lambda) F_\lambda d\lambda}{\int S_x(\lambda) d\lambda},$$

where $S_x(\lambda)$ is the transmission function for passband X, after interpolating $S_x(\lambda)$ to the wavelength spacing of F_λ which is 6 Å. Within the error values, the results (Table 3) show a good correspondence with Hipparcos and Tycho catalogues (Table 2).

Table 3: *B, V, and R magnitudes and B-V colour indices*

	COU1289	COU1291
B	$8^m.64 \pm 0.06$	$9^m.09 \pm 0.06$
V	$8^m.13 \pm 0.06$	$8^m.56 \pm 0.06$
R	$7^m.90 \pm 0.07$	$8^m.33 \pm 0.07$
$B-V$	$0^m.52 \pm 0.08$	$0^m.53 \pm 0.08$

4. Atmospheric modeling and discussion

4.1. Model atmosphere parameters of the system COU1289

Using $m_v = 8^m.13$ from the previous results and $\Delta m = 0^m.74 \pm 0.04$ from the speckle interferometric results (Balega et al. 2002), we can calculate the individual m_v for each component. This along with the distance to the star from Hipparcos catalogue ($d = 118.624pc$) and bolometric corrections from Lang (1992) give individual bolometric magnitudes as: $M_{bol} = 3^m.10$ for the first component and $M_{bol} = 3^m.78$ for the second one. Hence the individual luminosities are: $L_a = 4.55 \pm 0.59 L_\odot$ and $L_b = 2.44 \pm 0.32 L_\odot$.

To calculate the radii and gravity acceleration ($\lg g$) of the components, we need their effective temperatures and masses. These were derived from the empirical $T_{eff} - M_{bol}$ and $Sp - M$ relations for main sequence stars (Lang 1992) as:

$$T^a_{eff} = 7000\,\mathrm{K},\ T^b_{eff} = 6200\,\mathrm{K},$$
$$M_a = 1.55 M_\odot,\ M_b = 1.26 M_\odot.$$

Hence, the radii can be calculated using the relation:

$$\lg(R/R_\odot) = 0.5 \lg(L/L_\odot) - 2\lg(T/T_\odot),$$

as: $R_a = 1.46 R_\odot$ and $R_b = 1.36 R_\odot$. These values together with the masses enable obtaining the gravity acceleration at the surface of the components:

$$\lg g = \lg(M/M_\odot) - 2\lg(R/R_\odot) + 4.43.$$

The derived values $\lg g_a$=4.29 and $\lg g_b$=4.24 along with the effective temperatures allow construction of the model atmospheres of the components using the grid of the Kurucz (1994) blanketed models. Then, using the programme Sam1 modified for the programme KONTUR (Leushin & Topilskaya 1985), the energy distributions in the continuous spectrum H^a_λ and H^b_λ were computed.

The energy flux from the star is created from the net luminosity of the components a and b located at a distance d from the Earth. So we can write:

$$F_\lambda \cdot d^2 = H^a_\lambda \cdot R^2_a + H^b_\lambda \cdot R^2_b,$$

from which

$$F_\lambda = (R^2_a/d)^2 (H^a_\lambda + H^b_\lambda \cdot (R_b/R_a)^2),$$

where H^a_λ and H^b_λ are the fluxes from a unit surface of the corresponding component.

Fig. 3 shows the observed flux, the total computed flux, and the individual flux of each component using the previous estimated parameters:

$$T^a_{eff} = 7000\mathrm{K}, T^b_{eff} = 6200\mathrm{K},$$
$$\lg g_a = 4.29, \lg g_b = 4.24,$$
$$R_a = 1.46 R_\odot, R_b = 1.36 R_\odot,$$

and d = 118.624pc. Many attempts were made to achieve a better fitting between the observed flux and the total computed one using different set of parameters, the best fitting was found using the following set (Fig. 4):

$$T^a_{eff} = 7100\mathrm{K}, T^b_{eff} = 6300\mathrm{K},$$
$$\lg g_a = 4.27, \lg g_b = 4.22,$$
$$R_a = 1.50 R_\odot, R_b = 1.40 R_\odot,$$

and d = 118.624pc was taken as a postulate. Thus the luminosities follow as: $L_a = 5.12 L_\odot$ and $L_b = 2.77 L_\odot$, which lie within the errors of those calculated above.

The values of the best fitting represent adequately enough the parameters of COU1289 components. And using Lang (1992) $Sp - T_{eff}$ empirical relation, new spectral types for the components of the system can be derived as F1 for component a and F7 for component b.

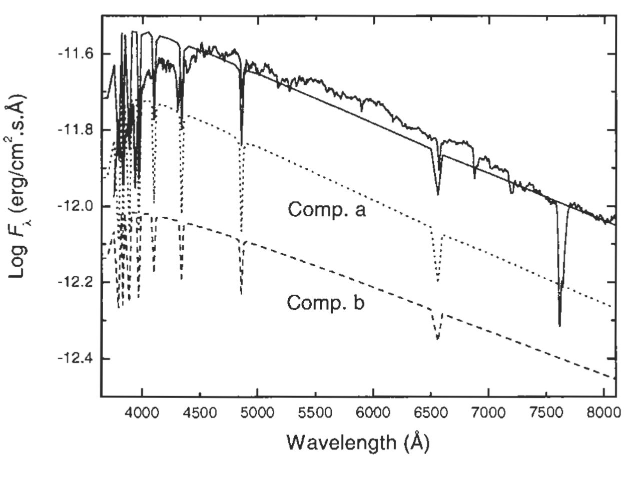

Figure 3: *The observed energy distribution in the continuous spectrum of COU1289 at the level of the Earth's atmosphere with the computed ones using the following parameters:* $T^a_{eff} = 7000\mathrm{K}, T^b_{eff} = 6200\mathrm{K}, \lg g_a = 4.29, \lg g_b = 4.24, R_a = 1.457 R_\odot, R_b = 1.358 R_\odot$, *and* $d = 118.624\,pc$.

4.2. Model atmosphere parameters of the system COU1291

Following the same procedures and calculations described above, and starting from $m_v = 8^m.13$ (from our observational previous results), $\Delta m = 0^m.74 \pm 0.04$ (from speckle interferometric results of Balega et al. 2002), d = 118.624 pc (from Hipparcos catalogue), and the bolometric corrections (from Lang 1992), the

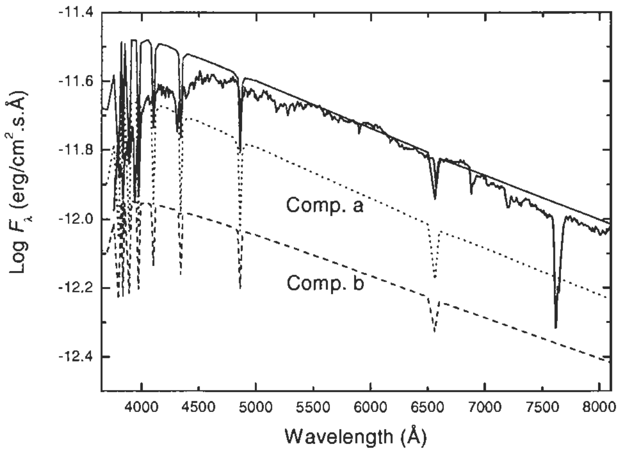

Figure 4: *The observed energy distribution in the continuous spectrum of COU1289 at the level of the Earth's atmosphere along with the computed ones. Solid line represents the total computed flux of the two components, dots represent the computed flux of the first component with $T_{eff} = 7100\,K$, $lg\ g = 4.27, R = 1.50R_\odot$, dashes represent the computed flux of the second component with $T_{eff} = 6300\,K$, $lg\ g = 4.22, R = 1.40R_\odot$, and $d = 118.624\,pc$.*

individual bolometric magnitudes were calculated as: $M^a_{bol} = 3\overset{m}{.}54$ and $M^b_{bol} = 4\overset{m}{.}35$. Hence the individual luminosities follows as: $L_a = 3.04 \pm 0.40L_\odot$ and $L_b = 1.44 \pm 0.19L_\odot$.

The effective temperatures and masses were derived using the same empirical relations mentioned in the previous subsection as:

$$T^a_{eff} = 6300\,\mathrm{K}, T^b_{eff} = 6000\,\mathrm{K},$$

$$M_a = 1.33M_\odot, M_b = 1.13M_\odot.$$

The radii and the gravity acceleration at the surface of each component (using relations in the previous subsection) were:

$$R_a = 1.47R_\odot, R_b = 1.12R_\odot,$$

$$\lg g_a = 4.20, \lg g_b = 4.35.$$

These values were used to build model atmospheres for the components and to compute the energy distributions in the continuous spectrum H^a_λ and H^b_λ and the total energy flux from the whole star F_λ. Comparison of the results with the observed flux yields a good fitting (Fig. 5), but the best fitting was achieved using the following set of parameters (Fig. 6):

$$T^a_{eff} = 6400\mathrm{K}, T^b_{eff} = 6100\mathrm{K},$$

$$\lg g_a = 4.20, \lg g_b = 4.35,$$

$$R_a = 1.47R_\odot, R_b = 1.12R_\odot,$$

and $d = 113.636\,\mathrm{pc}$ was taken as a postulate. The luminosities follow as: $L_a = 3.24L_\odot$ and $L_b = 1.55L_\odot$, which also lie within the errors of the calculated ones. Thus the spectral types of the components of the system can be derived as F6 for component a and F9 for component b.

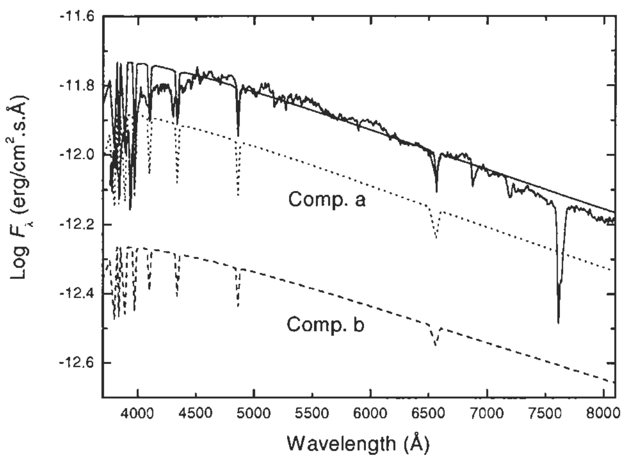

Figure 5: *The observed energy distribution in the continuous spectrum of COU1291 at the level of the Earth's atmosphere with the computed ones using the following parameters: $T^a_{eff} = 6300\mathrm{K}, T^b_{eff} = 6000\mathrm{K}, \lg g_a = 4.20, \lg g_b = 4.35, R_a = 1.47R_\odot, R_b = 1.12R_\odot$, and $d = 113.636\,pc$.*

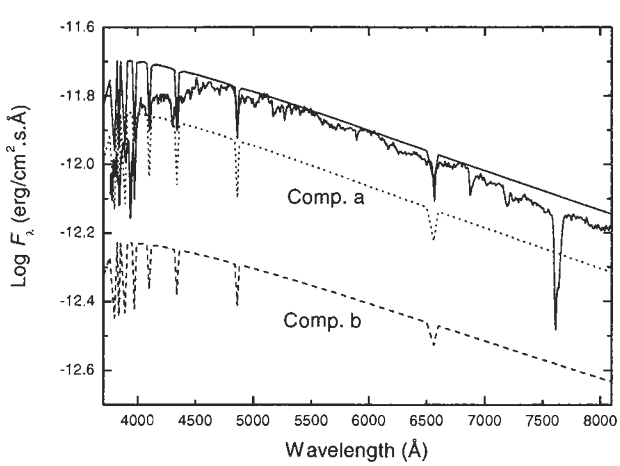

Figure 6: *The observed energy distribution in the continuous spectrum of COU1291 at the level of the Earth's atmosphere along with the computed ones. Solid line represents the total computed flux of the two components, dots represent the computed flux of the first component with $T^a_{eff} = 6400\,K$, $lg\ g_a = 4.20, R_a = 1.47R_\odot$, dashes represent the computed flux of the second component with $T^b_{eff} = 6100\,K$, $lg\ g_b = 4.35, R_b = 1.12R_\odot$, and $d = 113.636\,pc$.*

However, it should be noted that the models are highly dependent on the precision of observations and consistent with observations within the errors.

4.3. Formation and evolution of the systems

Fig. 7 shows the positions of the components on the isochrones of Girardi et al. (2000) and Table 4 lists the final parameters of the two systems. They show a good agreement between the components of each system. The age of the two systems can be established almost as 2 Gy, except for the component COU 1289a which seems little bit younger. This leads us to adopt the fragmentation process for the formation of such systems, where Bonnell (1994) concludes that fragmentation of rotating disk around an incipient central protostar is possible, as long as there is continuing infall, and Zinnecher (2001) pointed out that hierarchical fragmentation during rotational collapse has been invoked to produce binaries and multiple systems.

Table 4: *Parameters of the components of the systems COU1289 and COU1291.*

System	COU1289		COU1291	
Component	*a*	*b*	*a*	*b*
Mass, $M_{\odot}$	1.55	1.26	1.33	1.13
Sp. Type	F1	F7	F6	F9
T_{eff}	7100	6300	6400	6100
Radius, $R_{\odot}$	1.50	1.40	1.47	1.12
lg g	4.27	4.22	4.20	4.35

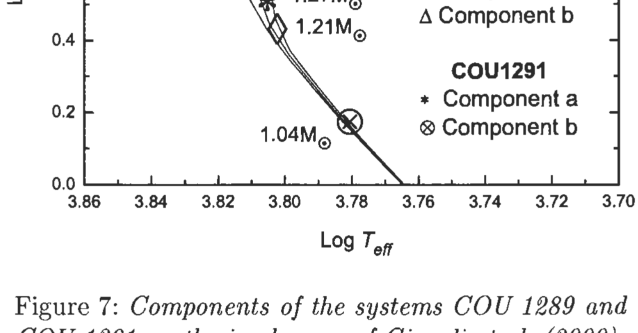

Figure 7: *Components of the systems COU 1289 and COU 1291 on the isochrones of Girardi et al. (2000).*

5. Conclusions

On the basis of the spectrophotometric study and atmospheric modeling of COU1289 and COU1291, the following main conclusions can be drawn.

1. The spectral energy distributions in the region between λ 3700 Å and λ 8100 Å of both systems were introduced.

2. The BVR magnitudes and $B-V$ colour indices of both systems were calculated, and they showed a good agreement with Hipparcos and Tycho catalogues.

3. The parameters of the systems' components were subtracted depending on the best fitting between the observational SED's and theoretical ones built using model atmospheres.

4. The spectral types of both components of the system COU1289 were approved as F1 and F7.

5. The spectral types of both components of the system COU1291 were approved as F6 and F9.

6. Finally, fragmentation was proposed as the most likely process for the formation and evolution of both systems.

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