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Model atmosphere parameters of the binary system 41Dra

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Abstract.
Model atmospheres were built for the individual components of the system 41Dra using the grid of the Kurucz (1994) blanketed models and the entire spectral energy distribution of the system. The fundamental parameters of the system components were derived as: $T^a_{eff} = 6100\,K$, $T^b_{eff} = 6100\,K$, $\lg g_a$=3.86, $\lg g_b$=4.01, $R_a = 2.15R_\odot$, $R_b = 1.76R_\odot$, $M_a = 1.24M_\odot$, $M_b = 1.18M_\odot$ and the spectral types F8 for both components.
The formation and evolution of the system were discussed depending on the filament fragmentation process.

Key words: stars: spectrophotometry — stars: binary stars — binaries: individual: 41Dra — stars: atmospheric modeling

1. Introduction

The visual double star ADS11061 was known to be a quadruple hierarchical system consisting of two double-lined spectroscopic binaries separated by 19″, these are: ADS11061A(= 41Dra = Hip88136 = HR6810 = HD166866) and ADS11061B (= 40Dra = Hip88127 = HR6809 = HD166865). Table 1 contains the Bright Star Catalogue's data of the system (Hoffleit & Jachek 1982), and Table 2 contains the data from Hipparcos and Tycho Catalogues (ESA, 1997).

Tokovinin (1995) estimated the physical and geometrical elements of the system (Table 3), and by his work he raised the importance of studying such system in solving the problem of multiple-star system formation.

The system was resolved by speckle interferometry for the first time in 1993 (Balega et al. 1994), and it was designated as BAG 6 in WDS catalogue. Its preliminary interferometric orbit was computed by Balega et al. (1997).

Balega et al. (2001) show that the magnitude difference of the system components is practically constant over a wide range of wavelengths, with the average value of $\Delta m = 0.426 \pm 0.028$. It points to the fact that the two components have very similar effective temperatures and different radii.

High-resolution spectroscopy revealed that the system has a slight (+0.2 dex) overabundance of iron as compared to the Sun (Balega et al. 2003). The X-ray flux measured by Pizzolato et al. (2000) seems to be normal for F7V dwarfs.

Table 1: *Data from BS Catalogue*

	ADS11061A
α_{2000}	$18^h00^m09^s$
δ_{2000}	$+80°00'15''$
HR	6810.41Dra
HD	166866
V	$5^m_.68$
$B-V$	$0^m.50$
$U-B$	$-0^m_.01$
Spectral type	F7

Table 2: *Data from Hipparcos and Tycho Catalogues*

	ADS11061A
$V_J(Hipp)$	$5^m_.74$
$(B-V)_J(Hipp)$	$0^m_.516$
B_T	$6^m_.274$
V_T	$5^m_.731$
$V_J(Tycho)$	$5^m_.68$
$(B-V)_J(Tycho)$	$0^m_.505$

The importance of such contribution arises from the need of an accurate determination of the fundamental parameters of each of the components of the system, since there was a large difference in spectral type determination between Tokovinin (1995) who es-

Table 3: *Spectroscopic elements of orbits and physical parameters of the system estimated by Tokovinin (1995)*

Parameter	41Dra
P, days	1247.2
T, JDH	49571.047
e	0.9754
$\omega,^\circ$	127.6
K_1, km s^{-1}	44.79
K_2, km s^{-1}	0.17
γ, km s^{-1}	5.84
χ^2, N	62.5 82
$\sigma_1 2$, km s^{-1}	1.06
$q = M_2/M_1$	0.912
$(M_1 + M_2)\sin^3 i, M_\odot$	1.100
i	50°
a, AU	3.040
$\alpha,''$	0.085
$a(1-e)$, AU	0.0748

timated F7V for each of the components and the Hipparcos Input Catalogue which gives K2V (Turon et al. 1992).

Another important point of such work arises from the need of understanding the nature of formation and evolution of highly eccentric orbit binary systems, where dynamical interaction can be changed following the state of the components on the orbit. So, 41Dra forms a unique case of such systems.

2. Observational results

The spectral energy distribution of the system, its B, V, R magnitudes and $B - V$ colour index were taken from Al-Wardat (2002) (Fig. 1 and Table 2). 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.

Table 4: *B, V, and R magnitudes and B-V colour indices of the system as taken from Al-Wardat (2002)*

	41Dra
B	$6^m_.25 \pm 0.06$
V	$5^m_.73 \pm 0.06$
R	$5^m_.45 \pm 0.07$
$B-V$	$0^m_.52 \pm 0.08$

2.1. Model atmospheres

The spectrophotometric results showed that $B - V = 0.52$. This refers to F7 or F8 spectral type and effective temperature between 6100K and 6400K. Hereafter we will adopt the average of these estimations $T_{eff} = 6250$K as a preliminary input for atmospheric modeling of the system. The second input is the magnitude difference between the components of the system, this is given by speckle results as $\Delta m = 0^m_.426 \pm 0.028$ (Balega et al. 2001), and it has been assured as $\Delta m = 0^m_.42 \pm 0.02$ by measuring the relative residual intensity of lines of the components from high resolution spectra (Fig. 2). The distance to the system is 43.276 ± 3pc (Balega et al. 1997). This gives luminosities of the components as: $L_a = 5.096 \pm 0.687 L_\odot$ and $L_b = 3.376 \pm 0.456 L_\odot$. In the first approximation these values along with $T^{ab}_{eff} = 6250$K, permit estimation of the radii:

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

as: $R_a = 1.93 R_\odot$ and $R_b = 1.57 R_\odot$. These values together with the masses $M_a = 1.24 \pm 0.23\, M_\odot$ and $M_b = 1.17 \pm 0.22\, M_\odot$ 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, $\lg g_a$=3.95 and $\lg g_b$=4.10, 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 41Dra is created from the net luminosity of the components Ba and Bb located at a distance d from the Earth. So we can write:

$$F_\lambda \cdot d^2 = H^a_\lambda \cdot R^2_{Ba} + H^b_\lambda \cdot R^2_{Bb},$$

from which

$$F_\lambda = (R^2_{Ba}/d)^2 (H^a_\lambda + H^b_\lambda \cdot (R_{Bb}/R_{Ba})^2),$$

where H^a_λ and H^b_λ are the fluxes from a unit surface of the corresponding component. There was no good agreement between the observed flux and that computed using the previous parameters:

$$T^a_{eff} = 6250\mathrm{K}, T^b_{eff} = 6250\mathrm{K},$$

$$\lg g_a = 3.95, \lg g_b = 4.10,$$

$$R_a = 1.93 R_\odot, R_b = 1.57 R_\odot,$$

and $d = 43.276$pc (Fig. 3). While a good agreement found using the following parameters:

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

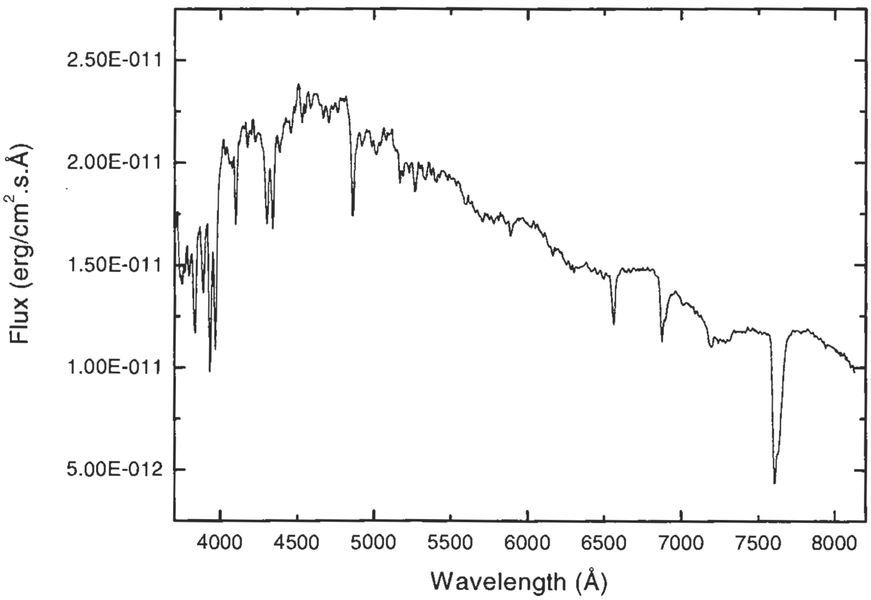

Figure 1: *Spectral energy distribution of 41Dra(Al-Wardat 2002).*

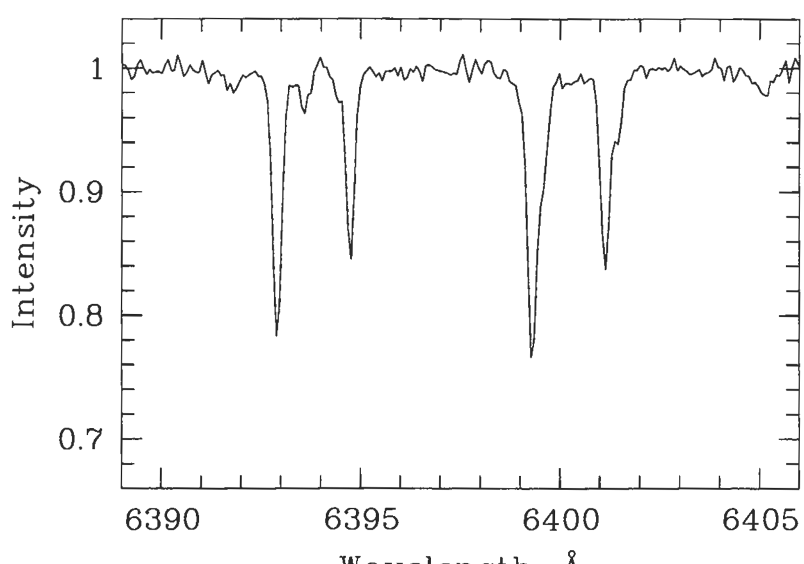

Figure 2: *A part of the high resolution (echelle) spectrum of 41Dra taken on the 1st of July 2001.*

$$\lg g_a = 3.86, \lg g_b = 4.01,$$

$$R_a = 2.15R_\odot, R_b = 1.76R_\odot,$$

and $d = 43.276$ pc was taken as a postulate (Fig. 4). Thus the luminosities and masses follow as: $L_a = 5.72 \pm 0.69L_\odot$, $L_b = 3.83 \pm 0.46L_\odot$, $M_a = 1.24 \pm 0.16M_\odot$ and $M_b = 1.18 \pm 0.15M_\odot$.

These elements represent adequately enough the parameters of 41Dra components and give new spectral types for the components of the system as F8V, which is consistent with observational estimations.

The estimated masses correspond to the mass sum estimation of Tokovinin (1995), Table 3, and to those estimated by Balega et al. (1997) as $M_a = 1.26M_\odot$ and $M_b = 1.18M_\odot$. The spectral types differ slightly from the earlier estimations of Tokovinin (1995) and those given by the BS catalogue as F7 (Table 1), while they contradict those given by the Hipparcos input catalogue as K2.

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

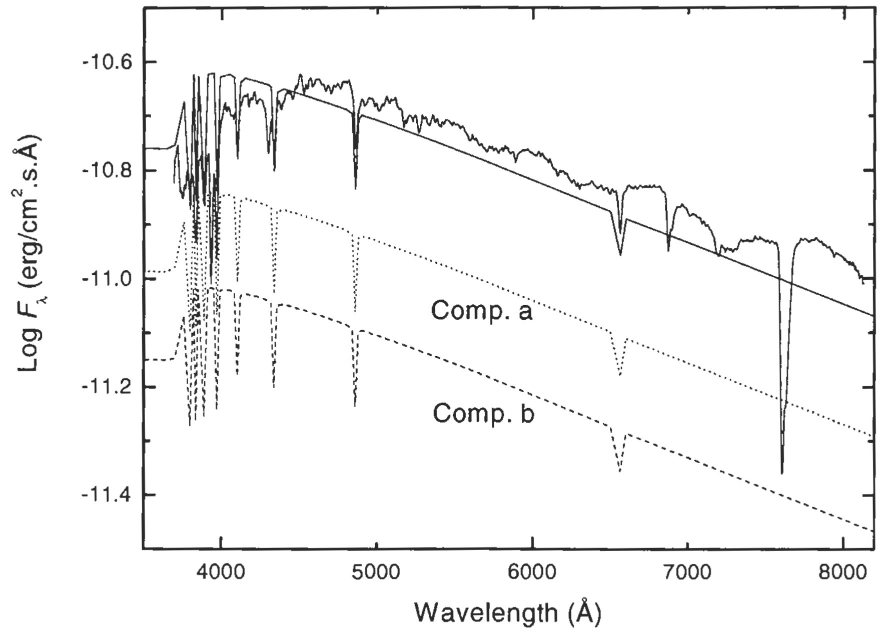

Figure 3: *The observed energy distribution in the continuous spectrum of 41Dra at the level of the Earth's atmosphere along with the computed ones using the following parameters:* $T^a_{eff} = 6250\mathrm{K}, T^b_{eff} = 6250\mathrm{K}, \lg g_a = 3.95, \lg g_b = 4.10, R_a = 1.93R_\odot, R_b = 1.57R_\odot$, *and* $d = 43.276\,pc$.

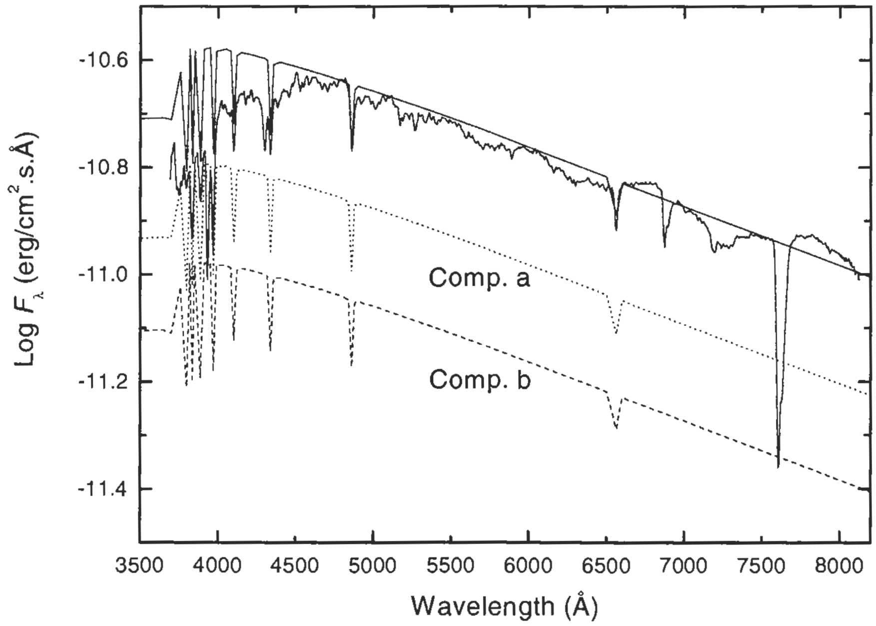

Figure 4: *The observed energy distribution in the continuous spectrum of 41Dra at the level of the Earth's atmosphere along with the computed ones. The solid line represents the total computed flux of the two components, the dots represent the computed flux of the first component with* $T_{eff} = 6100\,K$, $log\ g = 3.86$, $R = 2.15R_\odot$, *the dashes represent the computed flux of the second component with* $T_{eff} = 6100\,K$, $log\ g = 4.01$, $R = 1.76R_\odot$.

2.2. Formation and evolution of the system

The final parameters of the system show a good agreement between the components of the systems as a whole. This along with the highly eccentric orbit lead us to adopt the filament fragmentation process for the formation of such a hierarchical system, where Zinnecher (1989, 2001) pointed out that tumbling filaments, rotating end over end, would tend to fragment into binaries with high eccentricity, and this has also been confirmed by Bonnell and Bastien (1992) using numerical simulations.

Table 5: *Estimated parameters of the system 41Dra*

Component	a	b
Mass, $M_\odot$	1.24 ± 0.16	1.18 ± 0.15
Sp. Type	F8	F8
T_{eff}	6100 ± 100	6100 ± 100
Luminosity, $L_\odot$	5.72 ± 0.69	3.83 ± 0.46
Radius, $R_\odot$	2.15 ± 0.17	1.76 ± 0.14
log g	3.86 ± 0.39	4.01 ± 0.40

3. Conclusions

On the basis of atmospheric modeling of the system, the following main conclusions can be drawn.

1. Model atmospheres for the system have been built and the parameters of its components have been derived as: $T^a_{eff} = 6100\,\mathrm{K}$, $T^b_{eff} = 6100\,\mathrm{K}$, $\lg g_a$=3.86, lg g_b=4.01, $R_a = 2.15 R_\odot$, $R_b = 1.76 R_\odot$, $M_a = 1.24 M_\odot$, $M_b = 1.18 M_\odot$ and the spectral types as F8 for both components. The masses correspond to the mass sum estimation of Tokovinin (1995) Table 3, and to those estimated by Balega et al. (1997) as $M_a = 1.26 M_\odot$ and $M_b = 1.18 M_\odot$. The spectral types differ slightly from the earlier estimations of Tokovinin (1995) and those given by the BS catalogue as F7 (Table 1), while they contradict those given by the Hipparcos input catalogue as K2.

2. Filament fragmentation was proposed as the most likely process for the formation and evolution of the system.

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