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HD 163151: a new W UMa type system*

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Abstract. HD 163151 is discovered to be a new variable as a part of a W UMa system. In this paper we present complete *uvby* light curves. Additional Crawford H_β and Johnson BV data are also obtained. A detailed photometric analysis based on these observations is presented using the WD code. Several tests have been carried out concerning mass ratio and effective temperatures. The best fitting was achieved with q = 0.27 and T_1=6450 K (fixed) and T_2 = 6130 K. Moreover, the light curves show evidences of spots in one of the components.

Key words: binaries: visual – stars: individual: HD 163151 – stars: fundamental parameters – techniques: photometric

1. Introduction

During the course of a photometric and multicolor multisite campaign on the γ Dor variable HD 164615, the star HD 163151 (HR 6676, BD +11°3283) was used as a check star, but its differential photometry was discovered to be variable showing light curves similar to those of close binary systems, in particular a W UMa system, with a period of about $0.^d8$ and luminosity variation in the primary minimum of about $0.^m3$.

In this paper we present a preliminary investigation of such a star. As spectroscopic observations are not yet available we have used the Wilson-Devinney code to estimate the photometric elements. Sect. 2 is dedicated to describe the observations itself while Sect. 3 is devoted to analyze the light curves.

2. Observations

The multisite campaign was carried out during 1995, May to July, from 6 observatories in three continents. Photometric measurements in Johnson B and V, Strömgren *uvby* and Crawford's H_β colours were obtained covering a baseline of 43 days. The following telescopes were used: Rodríguez, Garrido and Martín (hereinafter RGM) collected *uvby*β photometry using the six-channel Strömgren photometer attached to the 90 cm telescope of the Sierra Nevada Observatory, Spain; Akan and his group (EGE) collected Johnson BV and Strömgren *uvby* photometry with a single channel photometer and the 50 cm telescope at the Ege University Observatory, Turkey; Paparó and Nuspl (PN) obtained BV data at Piszkésteto mountain station, Konkoly Observatory, Hungary using a single channel photometer and 50 cm telescope; Zerbi (FMZ), Luedeke (LUE) and Krisciunas (KK) collected Johnson V data using single channel photometers and telescopes of 50 cm, 30 cm and 15 cm, respectively, at Merate Observatory (Italy), Albuqerque (New Mexico, USA) and Mauna Kea (Hawaii, USA).

Besides HD 163151, two others comparison stars were used: C1=HD 166095 as main comparison star and C2=HD 166976 as check star. In some cases, HD 165760 was also used as additional check star. The extinction corrections were based on nightly coefficients determined from the main comparison star. Then, magnitude differences of each object with respect to C1 were calculated by means of linear interpolation. The observations showed that, while the comparison stars kept constant brightness, HD 163151 presented an undoubted photometric variability in all the filters during every night as part of an eclipsing binary system (not pulsation), because only very small variations were observed in the corresponding colour indices. Contributions from each observatory provided different precisions in the measurements but, during the observations reported here, neither of the comparison stars showed any sign of variability within the observational accuracy throughout the observing period. The best contribution was that obtained by RGM, where simultaneous measurements in *uvby* or in the narrow and wide H_β channels were collected. In this case, the standard deviations of C2-C1 were found to be of $0.^m0080$, $0.^m0045$, $0.^m0048$ and $0.^m0046$ for *u*, *v*, *b* and *y*, respectively.

To transform the RGM data into the standard *uvby*β system we have used the same procedure described in Rodríguez et al.

* Tables 2 to 5 will be accessible only in electronic form at the CDS

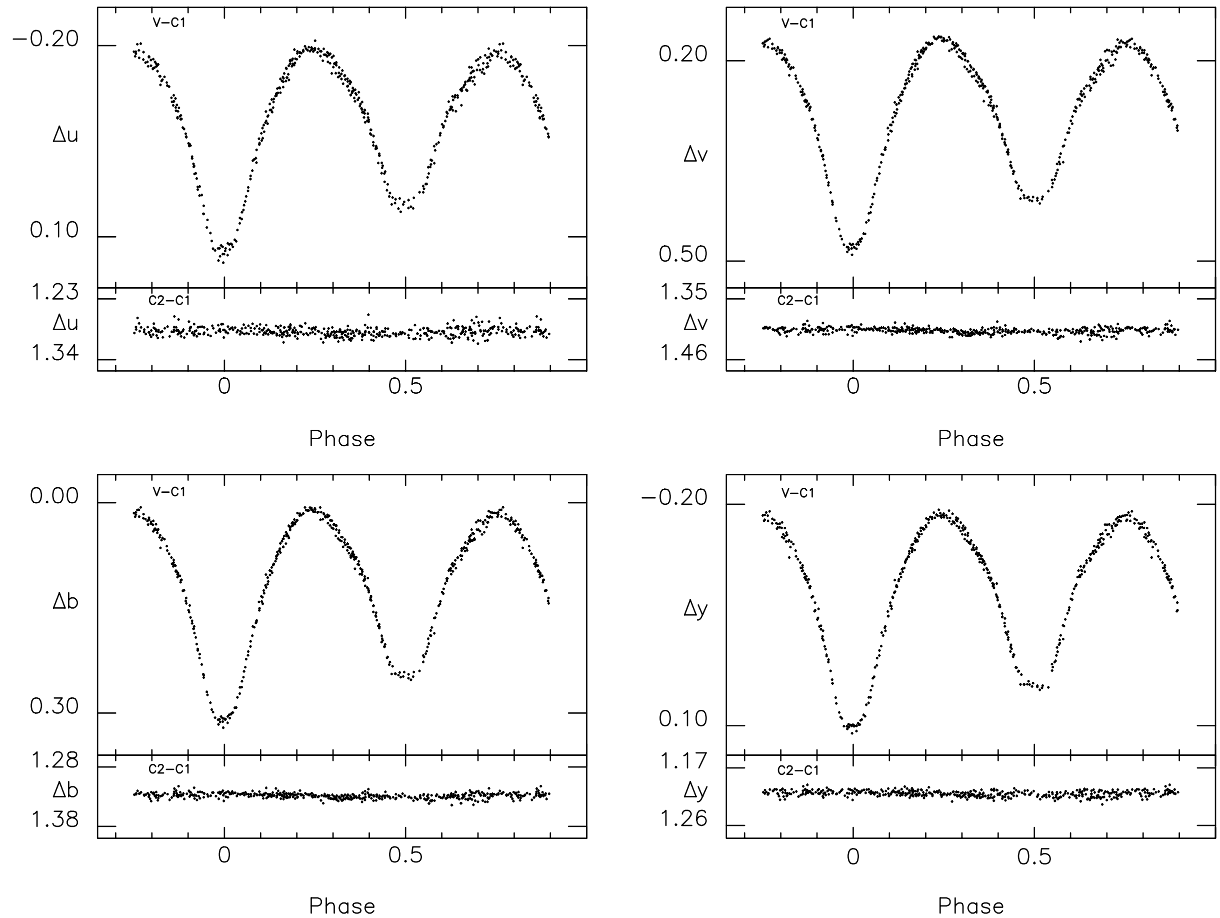

Fig. 1. *uvby* light curves of HD 163151 relative to C1=HD 166095. The bottom panels in each graph show the corresponding light curves of C2-C1

(1997). Then the other contributions were transformed to the standard system using the corresponding alignments including colour index terms in the equations. Standard *uvby*β indices for HD 163151 and the two main comparison stars are given in Table 1 together with relevant catalogue information for these stars. These obtained Strömgren values are in very good agreement with those found in the bibliography (e.g. Hauck & Mermilliod 1990). Table 2 lists the *uvby* data obtained as magnitude differences variable minus C1 in the standard system versus Heliocentric Julian Day. Tables 3, 4 and 5 are similar to Table 2 for H_β, Johnson B and V values, respectively. These tables are available via *ftp* at the CDS and can also be requested from the authors.

Table 1. Data for HD 163151 (photometry at phase 0.25) and the comparison stars

	Variable	Comp. 1	Comp. 2
HD no.	163151	166095	166976
HR no.	6676	6784	-
α_{1950}	$17^h51^m54^s$	$18^h06^m17^s$	$18^h10^m17^s$
δ_{1950}	11°08'28"	14°16'31"	12°22'46"
l	37°	41°	40°
b	18°	16°	14°
Sp. type	F5Vn	A5m	F0
V	$6.^m172$	$6.^m352$	$7.^m562$
	±7	±4	±5
b-y	$0.^m288$	$0.^m091$	$0.^m209$
	±3	±3	±3
m_1	$0.^m175$	$0.^m214$	$0.^m175$
	±2	±3	±4
c_1	$0.^m546$	$1.^m066$	$0.^m868$
	±5	±6	±5
β	$2.^m660$	$2.^m867$	$2.^m762$
	±8	±5	±9

3. Analysis of the light curves

3.1. Period

To determine the period of HD 163151, frequency analysis of our data was carried out using the Discrete Fourier Transform method, as described in López de Coca et al. (1984). When the Fourier analysis was applied to the RGM data in the *b* filter, the periodograms showed peaks at ν=1.24639 cd^{-1} (that is, a period of P=$0.^d8023$), 2ν, 3ν,... with the main peak located at 2ν, corresponding to half a period. After subtracting the frequency ν and its harmonics, the resulting periodograms

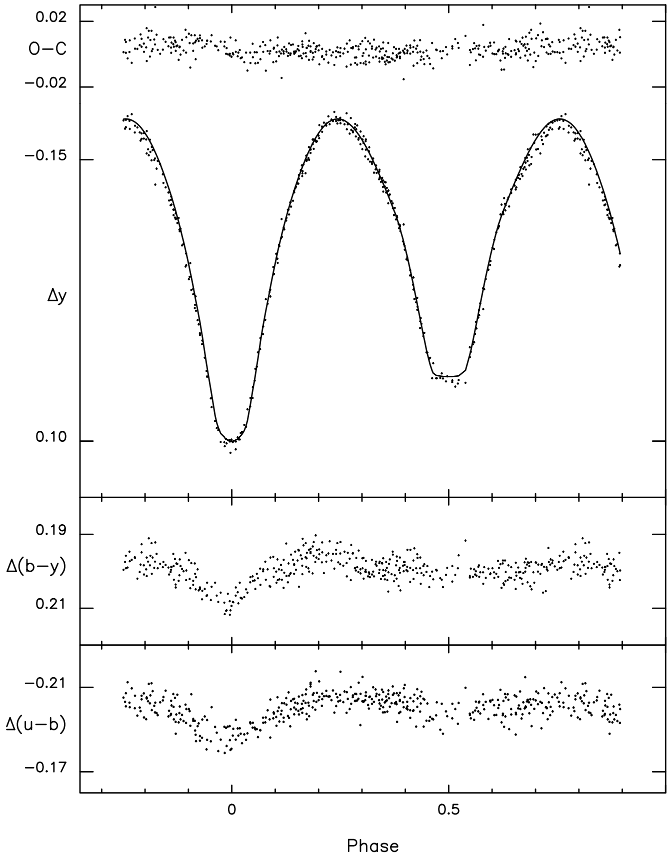

Fig. 2. *y* light curve and (b-y) and (u-b) colour index variations of HD 163151-C1 together with the synthetic *y* light curve and residuals using the adopted photometric elements (Table 6)

Table 6. Photometric elements for HD 163151

parameter	u	v	b	y	adopted
i	84.0	83.7	83.4	84.4	83.9 ±0.4
T_1(K)					6450
T_2(K)	6117	6136	6131	6130	6130 ±40
Ω_1=Ω_2	2.316	2.316	2.315	2.313	2.315 ±2
Phase shift	-0.0004	-0.0006	-0.0007	-0.0005	
q					0.27
L_1	0.808	0.798	0.794	0.790	
L_2	0.182	0.202	0.206	0.210	
l_3	0.410	0.417	0.420	0.425	
e					0.000
x_1	0.78	0.74	0.68	0.60	
x_2	0.78	0.74	0.68	0.60	
g_1					0.32
g_2					0.32
A_1					0.5
A_2					0.5
Max. mag.	-0.193	0.170	0.010	-0.186	
rms mag.	0.0088	0.0072	0.0074	0.0056	
r_1 pole	0.4824	0.4825	0.4827	0.4831	0.483 ±1
r_1 point	0.6309	0.6309	0.6309	0.6309	0.631 ±1
r_1 side	0.5259	0.5261	0.5263	0.5269	0.526 ±1
r_1 back	0.5571	0.5572	0.5575	0.5583	0.557 ±1
r_2 pole	0.2737	0.2738	2.2740	0.2745	0.274 ±1
r_2 point	0.3691	0.3691	0.3691	0.3691	0.369 ±1
r_2 side	0.2880	0.2882	0.2884	0.2890	0.288 ±1
r_2 back	0.3419	0.3422	0.3426	0.3440	0.342 ±1

did not show any trace of another peak, only white noise was present in the residuals. Hence, it seems that there are no remaining periodicities in the light curves of HD 163151 or C1. The same analysis was performed for the other filters and the results were consistent in the sense that the frequency found was always the same within 0.0001 cd^{-1}. The period, spectral type and the continuous light variations outside eclipses indicate that we are dealing with a W UMa eclipsing binary system. Three times of light minima were obtained for the primary minimum at 2449878.^{d}4682, 2449886.^{d}4919 and 2449890.^{d}5045 using the method described in Rodríguez et al. (1990) where each light minimum is determined as average of the four *uvby* bands. Assuming a linear ephemeris with T_0=2449890.^{d}5045 and P=0.^{d}8023, the RGM *uvby* data were phased and plotted in Fig. 1. All phases were covered at least twice. The bottom panels in each graph of Fig. 1 show the corresponding magnitude differences of C2-C1.

3.2. Synthetic light curves

The continuous light variations outside eclipses in HD163151 are characteristic of a binary system which components are appreciably distorted. In order to obtain the photometric elements, we decided to use the Wilson-Devinney code (Wilson & Devinney 1971, Wilson 1983) as the most geometrically realistic model. HD163151 is part of a visual binary (Fin 381) which orbital period is of about 9 years (Baize 1992), being the companion 0.2 mag fainter and 0.”1 distant. The companion has thus been included in the diaphragm for all photoelectric observations. Due to the lack of spectroscopic information, the difficulty in seeking for a photometric solution with the Wilson-Devinney method lies, mainly, in a reliable determination of the mass ratio q. Instead of utilizing the Wilson-Devinney differential correction code with q as an adjustable parameter, we have tried a set of discrete values of q. The value finally adopted corresponds to the minimum appearing in the (q, Σ Wt×res^2) plane. After some test runs with other configurations, we assumed that both components are in contact (MODE 3). We adopted an effective temperature for star 1 (star eclipsed at min I) of 6450 K as estimated from the standard colour indices given by Hauck & Mermilliod (1990) and using calibrations by Pe-

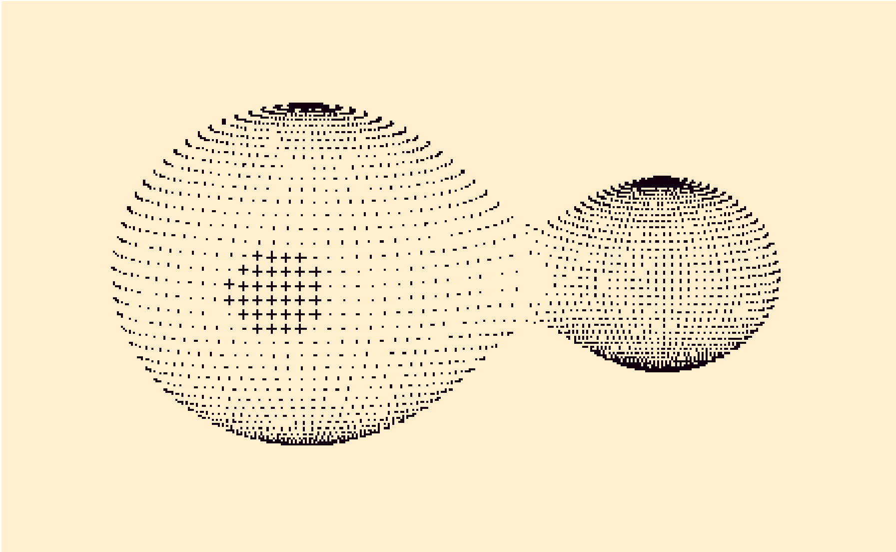

Fig. 3. Tri-dimensional representation of the binary system at phase 0.25 showing a hot spot (+) on the equator of the primary component, with a longitude of 100° and a spot radius of 15°

tersen & Jorgensen (1972) and Code et al. (1976). Theoretical limb-darkening coefficients (x) derived by Díaz-Cordovés et al. (1995) have been adopted for the primary component. In MODE 3, limb-darkening coefficients of both components are forced to be equal. The bolometric albedos and gravity-darkening exponents assumed are those appropriate for convective envelopes. (A_1=A_2=0.5 and g_1=g_2=0.32). In all solutions a circular orbit was assumed. The light curves in each colour were analysed separately by using all individual observations instead of making use of normal points. Several values of q (0.1, 0.15, 0.2, 0.26, 0.28, 0.30, 0.35, 0.42, 0.5, 0.55, 0.6 and 0.65) were tested, the adjustable parameters employed being: the phase shift, the inclination (i), the temperature of star 2 (T_2), the potential Ω_1, the luminosity of star 1 (L_1) and the third light (l_3).

Third light parameter was allowed to vary with the only, initial, restriction of being < 0.578 (*y*) as derived from the light at minima. Results are simply summarised: a minimum for the sum of squared light residuals was found around q=0.27 in all colours. The values of the other non-wavelength dependent parameters obtained at different colours, agree reasonably well. The value of third light in *y* solution converges towards l_3=0.425, which is consistent with the magnitude difference Δm=0.2 mag reported in the Bright Star Catalogue (1982) for the visual companion. Parameters for this contact configuration are listed in Table 6.

Fig. 2 shows the observed and calculated light curves in *y* filter, corresponding to that photometric solution, together with the residuals O-C and the observed b-y and u-b variations along the binary cycle. Some trends become apparent in the O-C plot around phase 0.75. The observed light level at second quadrature is slightly lower than at the first one. This effect is not unusual in light curves of this kind and is attributed to the presence of star spots on the surface of one or both components (Bradstreet 1985, Corcoran et al. 1991). We have made a first attempt to model the asymmetry by introducing a spot into the Wilson-Devinney code input. The bottom of the secondary eclipse seems to be not completely flat but showing a slightly negative slope. This would locate the origin of the asymmetry on the larger star since the eclipse is total. The observed differences between both quadratures could then be reproduced by assuming either a cool spot on the trailing side (lower flux at phase 0.75) or a hot spot on the leading side (higher flux at phase 0.25) of this larger component. Obviously, with no other information than the light curves presented here, multiple combinations of location, size and intensity of the spot, can lead to equally acceptable solutions. After several tests, we found that the observed asymmetry is reasonably matched in all filters by assuming a hot spot (T_{spot}/T_1=1.03) located on the equator of the primary component, with a longitude of about 100° and a spot radius of 15°. Although the calculated light curve, including this spot on the primary component, reproduces better both the asymmetry of the secondary eclipse and the observed difference in the height of the maxima, the solution is far from unique and should be considered as rather uncertain. Fig. 3 is a 3-D view of the binary system obtained with the Binary Maker program by Bradstreet (1991) at phase 0.25 showing the hot spot on the primary component.

A very rough estimation for the absolute dimensions of the system can be made if we combine the photometric solution given in Table 6 with a mass for the primary component assumed from a typical mass-spectrum law. The physical and geometrical parameters obtained for each component in this way are compatible with the expected location for the primary and secondary components of a W UMa A-type system on the H-R diagram. Further improvement in our understanding of HD163151 can be obtained from spectroscopic observations, in particular from the radial velocity curve. That would permit to verify the solution given here and to calculate the absolute dimensions of the system.

4. Conclusions

The discovery of a new W UMa binary system (HD 163151) is reported and complete *uvby* light curves are presented. Crawford

H_β and Johnson BV data were also obtained. A preliminary analysis of the photometric elements was carried out by using the WD code. The best fitting was achieved with q = 0.27 and T_1=6450 K (fixed) and T_2 = 6130 K. The light curves show evidences of spots in one of the components. We have explored some possibilities on temperature and location of such spots although a more reliable conclusion only will be possible when spectroscopic observations would be available.

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