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The eclipsing binary system AB Cas: binarity and pulsation

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Abstract. This paper presents *uvby* light curves for the Algol-type binary system AB Cas, in which the primary component is a δ Sct-type pulsating star. Additional Crawford H_β data were also obtained. A detailed photometric analysis based on these observations is presented for both binarity and pulsation. The Wilson-Devinney code was used as the most appropriate for modelling the binary light curve whereas the pulsation of the primary component is analysed using the Fourier Transform and classical O-C methods. The pulsation analysis suggests the hotter component as monoperiodic with a period P_p=0.^{d}05828741 oscillating in the fundamental radial mode. It is also shown that binarity, in this case, has no special effect on the pulsation.

Key words: techniques: photometric – stars: oscillations – stars: individual: AB Cas – stars: variables: δ Sct – stars: binaries: eclipsing

1. Introduction

Only a few short-period regularly pulsating stars are known to belong to eclipsing binary systems. AB Cas is a very good example where the light curves show simultaneously, and clearly, both types of variability: binarity and pulsation. In this case, AB Cas (A3V+KV) is an Algol-type binary system discovered by Hoffmeister (1929), with a period P_b=1.^{d}3668 and eclipse depths in the primary and secondary minima of about ΔV$\sim$1.^{m}6 and 0.^{m}1, respectively. In this system, the primary component is a pulsating star type δ Sct with P_p=0.^{d}0583 and ΔV$\sim$0.^{m}05 (Rodríguez et al. 1994). Its first photoelectric photometry, using Johnson V photometry, was made by Tempesti (1971) who discovered the pulsational nature of the hotter component. New photometric observations were collected by Irkaev et al. (1978), Ando (1980) and Frolov et al. (1982). The last authors obtained a large number of times of maxima for the pulsating component and determined a period P_p=0.^{d}0582874.

In this paper, we present for the first time simultaneous observations in the four *uvby* filters of the Strömgren photometric system together with some additional Crawford H_β data collected for this system. The observations are described in Sect. 2. A detailed analysis based on these observations is presented for both binarity and pulsation in Sects. 3 and 4, respectively. Finally, some conclusions are summarized in Sect. 5.

2. Observations

The observations were carried out during the years 1987 and 1988 using the 75 cm telescope at Sierra Nevada Observatory, Spain. The photometer attached to this telescope was a six-channel *uvby*β spectrograph photometer for simultaneous measurements in *uvby* or in the narrow and wide H_β channels, respectively, using uncooled EMI photomultipliers type 9789 QA (Nielsen 1983). Five nights were devoted to measuring AB Cas using only the four *uvby* filters and two other nights using both *uvby* and H_β.

In these observations, BD+70°00188 was used as the main comparison star and BD+70°00186 and SAO 4710 as check stars. A circular diaphragm of 28" was used throughout. The sequence was, generally, C1,C2,C3,V,C1,V. Sky measurements were made every 2 or 3 cycles. Each integration consisted of 60 s in *uvby* and 80 s in H_β for the variable and C1 or 40 s and 60 s in *uvby* and H_β for C2 and C3. 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 C1 and C2 kept constant brightness, C3 was discovered to be a pulsating variable type δ Sct with a period of 0.^{d}058 and an amplitude of luminosity variation of 0.^{m}04 (from peak to peak) in the *v* filter (Sedano et al. 1987). This star has been catalogued as V663 Cas in the GCVS.

Tables 1 and 2 list the *uvby* and H_β data obtained as magnitude differences variable minus BD+70°00188 in the instrumental system versus Heliocentric Julian Day. These tables are available via *ftp* at the CDS and can also be requested from the authors. Because of an instrumental problem 82 points in the *b* channel (during the last observational night, JD2447483) had to be rejected, corresponding to a portion of the primary eclipse. To transform our data into the standard *uvby*β system, a set of 37 standard stars were also observed from the lists of Crawford & Mander (1966) and Crawford & Barnes (1970). The instrumental system was found to be stable during the observing period,

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* Tables 1 and 2 will be accessible only in electronic form at the CDS

Table 3. Transformation coefficients. K is the coefficient for β

B	D	F	J	H	I	K
0.036	1.029	0.902	0.020	1.021	0.121	1.357
± 10	± 8	± 43	± 11	± 6	± 11	± 14

Table 4. Data for AB Cas (photometry at phase 0.25) and the comparison stars

	Variable	Comp. 1	Comp. 2
HD no.	-	-	15592
SAO no.	-	-	4681
BD no.	+70°00193	+70°00188	+70°00186
α_{1950}	$2^h32^m55^s$	$2^h30^m53^s$	$2^h30^m\ 2^s$
δ_{1950}	71° 5'30"	71°20' 5"	71°19'12"
l	131°	130°	131°
b	10°	10°	10°
Sp. type	A3V+KV	A	A
V	$10.^m173$	$10.^m068$	$9.^m052$
	±14	±9	±8
b-y	$0.^m252$	$0.^m152$	$0.^m088$
	±7	±6	±6
m_1	$0.^m137$	$0.^m134$	$0.^m096$
	±8	±7	±6
c_1	$0.^m789$	$1.^m074$	$0.^m866$
	±15	±8	±9
β	$2.^m829$	$2.^m891$	-
	±15	±9	-

and mean coefficients for transformation to the standard system are given in Table 3. The terminology for the coefficients is that of Giménez et al. (1990). The typical deviations obtained with these transformation equations were: $0.^m010$, $0.^m008$, $0.^m009$, $0.^m010$ and $0.^m008$ for V, b-y, m_1, c_1 and β, respectively. Standard *uvby*β indices for AB Cas and the two comparison stars C1 and C2 are given in Table 4 together with relevant catalogue information for these stars.

3. Binarity and evolutionary status

One time of light primary minimum was obtained at $2447483.^d4980$ (±0.0005) using the method described in Rodríguez et al. (1990) where each minimum is determined as the average over the four *uvby* bands. Assuming a linear ephemeris with T_{0b}=$2447483.^d4980$ and P_b=$1.^d3668783$ (Frolov et al. 1982), our data were phased and plotted in Fig. 1 where we can see clearly, and directly, the pulsational behaviour of the primary component in all phases of the binary period, except during the primary eclipse (as we will see later, it is only due to the very large and rapid variation of luminosity taking place during this event). The bottom panels in each graph show the corresponding magnitude differences of C2-C1 at the same scale that Var-C1.

In order to investigate the pulsational properties of the primary component of AB Cas, the orbital light variations due to binarity have to be previously removed from the observed light curve. The shape of the underlying binary curve corresponds to that of an Algol-type eclipsing binary system. Hence, we choose the Wilson-Devinney code (Wilson & Devinney 1971; Wilson 1983) as the most appropriate for modelling the curve of such semi-detached system and for determining its photometric elements.

Table 5. WD solutions for AB Cas

parameter	u	v	b	y	adopted
i	85.95	85.88	85.30	85.80	85.70
					±0.15
T_1(K)					8000
T_2(K)	4590	4450	4420	4380	4460
					±80
Ω_1	4.193	4.251	4.258	4.250	4.238
					±0.15
Ω_2					2.2828
Phase shift	−0.0008	−0.0008	−0.0022	−0.0007	−0.0008
q					0.22
L_1	0.962	0.957	0.933	0.906	
L_2	0.037	0.043	0.067	0.093	
l_3					0.000
e					0.000
x_1	0.610	0.695	0.670	0.590	
x_2	1.000	0.950	0.870	0.780	
g_1					1.00
g_2					0.32
Max. mag.	0.107	0.299	0.201	0.095	
rms mag.	0.0285	0.0312	0.0367	0.0258	
r_1 pole	0.250	0.248	0.248	0.248	0.249
					±1
r_1 point	0.254	0.252	0.253	0.252	0.253
					±1
r_1 side	0.253	0.250	0.251	0.251	0.251
					±1
r_1 back	0.254	0.251	0.252	0.252	0.251
					±1
r_2 pole					0.239
r_2 point					0.350
r_2 side					0.249
r_2 back					0.281

After some preliminary tests, we assumed that the secondary component fills its Roche lobe (MODE 5), the orbit is circular and a mass ratio of 0.22 (Ando 1980). The effective temperature adopted for the primary component (8000 K) was derived from the colour indices and the calibration by Moon & Dworetsky (1985). Usual values for the gravity-darkening exponents (1.0 for the primary and 0.32 for the secondary) were adopted, while theoretical calculations for the limb-darkening coefficients (Díaz-Cordovés et al. 1995) were used. We also assume that there is no third light (l_3=0.0). The final elements obtained after analysing the light curve in each colour separately, together with the remaining adopted parameters are given in Table 5. Moreover, we have derived the masses of the components as 1.78 and 0.39 $M_{\odot}$. Please note that the adopted phase shift was −0.0008 cycles as an average over the three *uvy* bands.

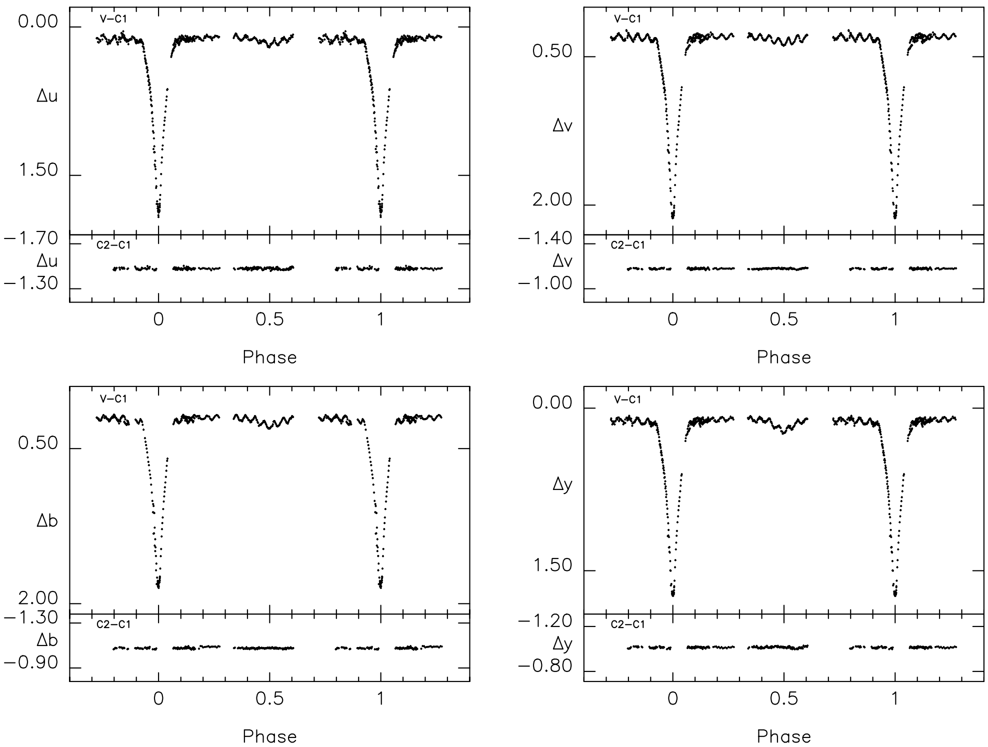

Fig. 1. *uvby* light curves of AB Cas relative to C1=+70°00188. The bottom panels in each graph show the corresponding light curves of C2-C1

The *b* filter was not considered for the average because of the instrumental problem, in this filter, mentioned in Sect. 2.

As it is well known, the components of an Algol-type binary are affected by the mass exchange and mass loss processes that certainly took place in the system, moving them away from the normal evolution of a single star. Due to the distorted configuration of the secondary component we have made use of the equivalent radius to compute its log g. Within this approximation we derive log g_2=3.49 whereas a value of log g_1=4.24 is found for the primary component. Additionally, luminosities of $M_{bol1}=2.^m2$ and $M_{bol2}=4.^m5$ can be obtained for the two components. These results are in very good agreement with those which we can obtain using the evolutionary tracks from Claret (1995) with: X=0.70, Z=0.02 as chemical composition; 1.52 as mixing-length parameter; d/H_p=0.20 to characterize a moderate amount of core overshooting for the more massive component. Then, the agreement between models and the observed dimensions is good for both components. However, the ages inferred for each star are very different as expected for Algol-type systems due to mass transfer.

In Fig. 2 we plot the *y*, b-y and u-b observed curves of AB Cas-C1 along the binary cycle together with the synthetic light curve in the filter *y* and the corresponding residuals. Now, the pulsation is also shown during the primary eclipse. From the different panels of this figure we can see as the effective temperature of the full system decrease during the primary minimum and increase during the secondary one.

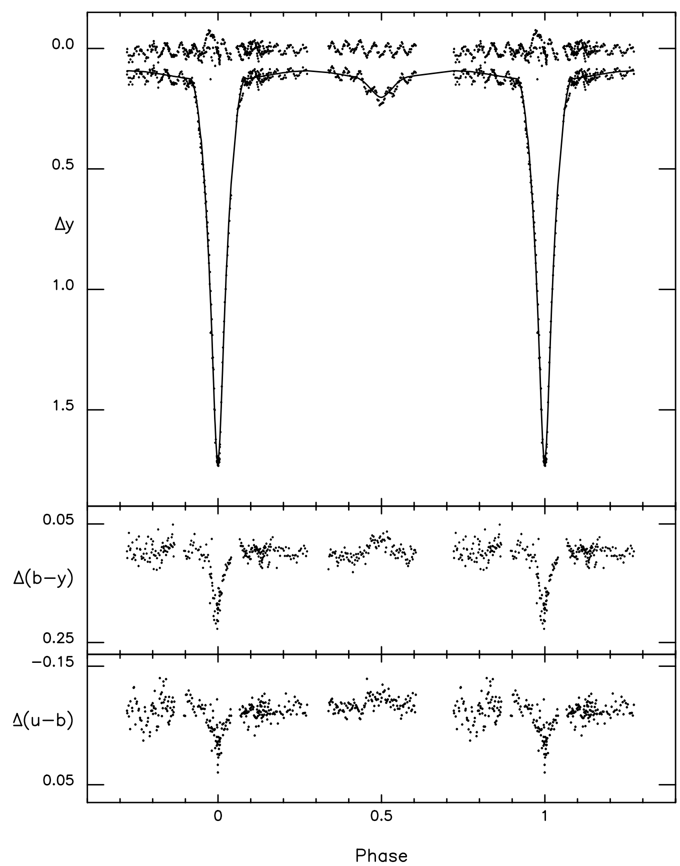

Fig. 2. *y* light curve and (b-y) and (u-b) colour curves of AB Cas-C1 together with the calculated *y* light curve and residuals

4. Pulsation

After removing the corresponding computed binary light curve in each filter, the pulsation of the primary component can be analysed in order to investigate the frequency content. The analysis of frequencies was carried out using the Discrete Fourier Transform method, as described in López de Coca et al. (1984). The *v* filter was the first analysed because both amplitude and intensity are, commonly in δ Sct variables, larger in this band than in all the other three. The periodograms showed a principal peak at ν=17.1563 cd^{-1}, very close to that frequency of 17.15637 cd^{-1} derived by Frolov et al. (1982). After prewhitening for this frequency, the resulting periodogram did not show any trace of another peak suggesting a monoperiodic nature for this star above 0.^{m}004. The residual spectrum is flat but the noise level seems to be slightly higher than expected. We assume this high level as due to the extraction of the binary light curve before analysing the pulsation, by comparing the very large variation as consequence of the binarity with the relative small pulsational amplitude. Nevertheless, the existence of secondary frequencies with very small amplitudes must not be ruled out. The same analysis was performed for the other three *uby* filters and the results were consistent in the sense that the frequency found was always the same within 0.0005 cd^{-1}. Again, after prewhitening for the main peak, it seems that there are not remaining periodicities in the light curves.

Fig. 3 shows the observed light curves in the *v* band with the Fourier fitting versus Heliocentric Julian Day. As can be seen, the synthetic light curves seem to reproduce the data satisfactorily except in some places which correspond to phases around the primary eclipse where an increase of the pulsation amplitude seems to be presents. However, this increase is fictitious. This might be produced by systematic errors in obtaining the magnitude differences Var-C1 and/or in subtracting the binarity from the observed light curves. At first sight, one could think that this increase of amplitude could be related to the fact that an oscillating surface is being hidden by another constant one. However, if the primary is pulsating in a radial mode then one should expect just the opposite, that is, a decreasing amplitude during the primary minimum and an increasing during the secondary one. In the particular case of AB Cas, these corrections are of a very few thousandths of magnitude. On the other hand, if the hotter component is oscillating in a nonradial mode then, for the inclination of the system and synchronization between both components, a change in the pulsation phase has to be expected during the primary eclipse as observed in some white dwarfs. However no phase change is observed giving an extra argument favoring radial pulsation as we will see later. Thus, we think that the apparent increase in the pulsation amplitude is mainly induced by the interpolation necessary to remove the binary light curve.

Assuming the pulsating component of AB Cas as a monoperiodic pulsator, the classical O-C method can be applied to our data. Twenty times of light maxima (listed in Table 6) were obtained as averages over the three *vby* bands using the method described in Rodríguez et al. (1990). The *u* band was not considered for the averages since the times of maxima in this filter are shifted with respect to the other three by about 0.036 cycles (0.033, 0.032 and 0.043 cycles with respect to the *v*, *b* and *y* bands, respectively; see Table 8), in good agreement with other δ Sct-type pulsators (Rodríguez et al. 1995 and references therein). We adopted as initial epoch T_{0p}=2447117.^{d}3555 (our first light maximum) and P_p=0.^{d}0582874 (Frolov et al. 1982). A least squares fit of a linear ephemeris leads to the following elements: T_{1p}=2447117.^{d}3556 ($\pm$0.0003) and P_p=0.^{d}05828741 ($\pm$0.00000012) in very good agreement with the results of Frolov et al. (1982). Resulting cycles E_i and residuals O-C are listed in the third and fourth column of Table 6. The standard deviation of the fit is of 0.^{d}0013. This value seems to be well within the error bars of the observed times of maxima.

Table 6. Times of maxima for the pulsation in the primary companion of AB Cas with the resulting cycles E_i and residuals O-C from the linear ephemeris determined in the text

i	T_i(HJD) 2400000.+	E_i (cycles)	(O–C) (days)
1	47117.3555	0	−0.0001
2	47117.4142	1	0.0003
3	47117.4751	2	0.0029
4	47117.5328	3	0.0023
5	47118.6942	23	−0.0021
6	47120.3871	52	0.0005
7	47120.4457	53	0.0008
8	47120.5031	54	−0.0001
9	47120.5614	55	−0.0001
10	47120.6201	56	0.0004
11	47120.6775	57	−0.0005
12	47122.4251	87	−0.0015
13	47122.5413	89	−0.0019
14	47122.6006	90	−0.0009
15	47219.3572	1750	−0.0014
16	47219.4181	1751	0.0012
17	47412.5812	5065	0.0005
18	47483.3424	6279	0.0001
19	47483.3992	6280	−0.0014
20	47483.6346	6284	0.0009

The pulsational phases of all individual observations were calculated according to the above derived linear ephemeris. Fig. 4 shows the resulting light and colour index variations of the pulsating component of AB Cas along the pulsation cycle after removing the points corresponding to phases around the primary eclipse. Table 7 lists the results of the Fourier fitting applied to our *uvby* data, with the amplitudes, phases, mean values and residuals calculated for the four *uvby* filters together with the b-y and c_1 indices. The initial time, T_{or}, corresponds to the phase 0.0.

Due to only one frequency being found in the light curve of the pulsating component of AB Cas, methods based on period ratios or frequency differences are excluded in order to identify the pulsation mode of this star. However, the method based on the phase shifts and amplitude ratios between the observed

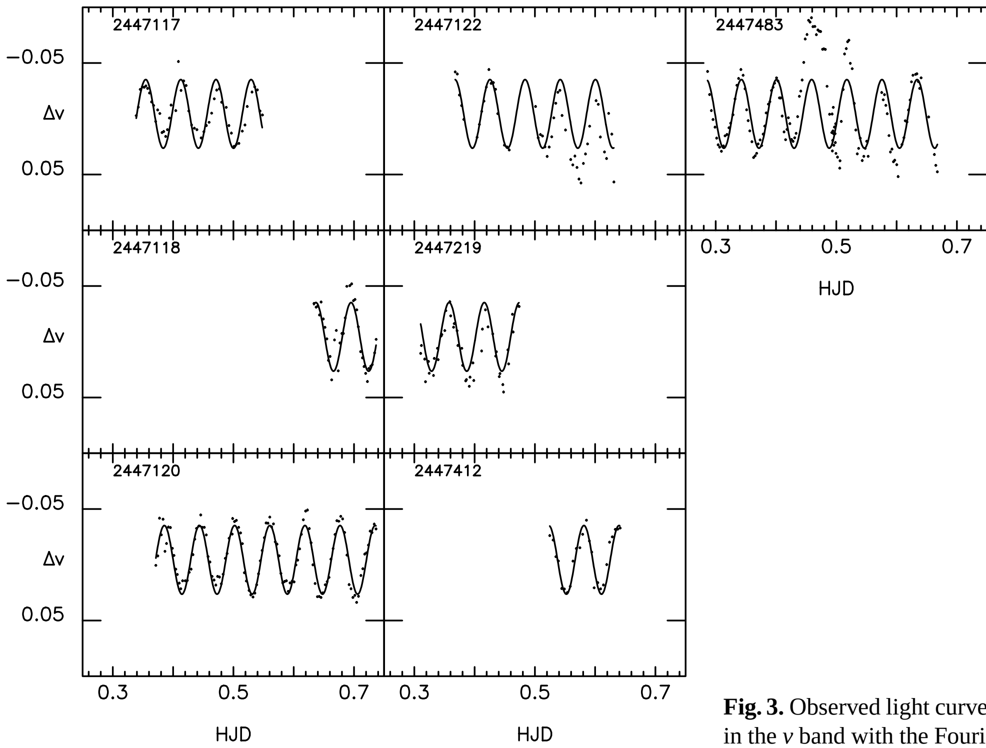

Fig. 3. Observed light curves of the pulsating companion of AB Cas in the *v* band with the Fourier fitting versus Heliocentric Julian Day

Table 7. Results from Fourier analysis

	u		*v*		*b*		V		b–y		c_1	
H	A (mag)	φ (rad)	A (mag)	φ (rad)	A (mag)	φ (rad)	A (mag)	φ (rad)	A (mag)	φ (rad)	A (mag)	φ (rad)
ν	0.0243	5.002	0.0295	4.795	0.0260	4.800	0.0219	4.730	0.0045	5.155	0.0106	1.147
	13	53	8	27	7	28	9	40	8	189	17	165
mean value (mag)	0.0021		−0.0053		−0.0015		0.0048		−0.0063		0.0112	
	9		6		5		6		6		12	
residuals (mag)	0.0153		0.0096		0.0086		0.0103		0.0101		0.0209	
T_{or}(Phase)	0.0											

Table 8. Observed phase shifts and amplitude ratios

u-y (°)	v-y (°)	b-y (°)	(b-y)-y (°)	c_1-y (°)
15.6	3.7	4.0	24.3	−25.3
5.3	3.8	3.8	13.1	11.7
u/y	v/y	b/y	(b-y)/y	c_1/y
1.11	1.35	1.19	0.20	0.48
10	9	8	5	10

light and colour variations, in *uvby* (Garrido et al. 1990), can be used. This way, Table 8 lists the phase shifts, in degrees, and amplitude ratios between the different bands and colour indices, derived from Table 7. We can see that the phase shifts of both *v*, *b* with respect to the *y* band are positive, that is, the light maximum in the *y* band occurs later than both in *v* and *b*. This is also true for the pair (b-y,y). These phase shifts suggest radial pulsation for this star by comparing with the "amplitude ratios versus phase shifts" diagrams of Garrido et al. (1990). On the other hand, following the procedure described in that paper we find a phase lag of Ψ^T=130° (±2) and an adiabatic parameter R=0.31 (±0.02). As shown also in that paper these values are independent of the radial or nonradial nature of the mode. Taking the above calculated values and using the formula (1) of Garrido et al (1990) we can predict theoretical values for phase differences and amplitude ratios between different photometric colours and bands for the lowest, and hence visible, *l*-values. Table 9 lists these results for the Strömgren colours. It is to note that the only acceptable *l*-value for these observations is that corresponding to a radial pulsation although some observed amplitude ratios seem to be slightly small. However,

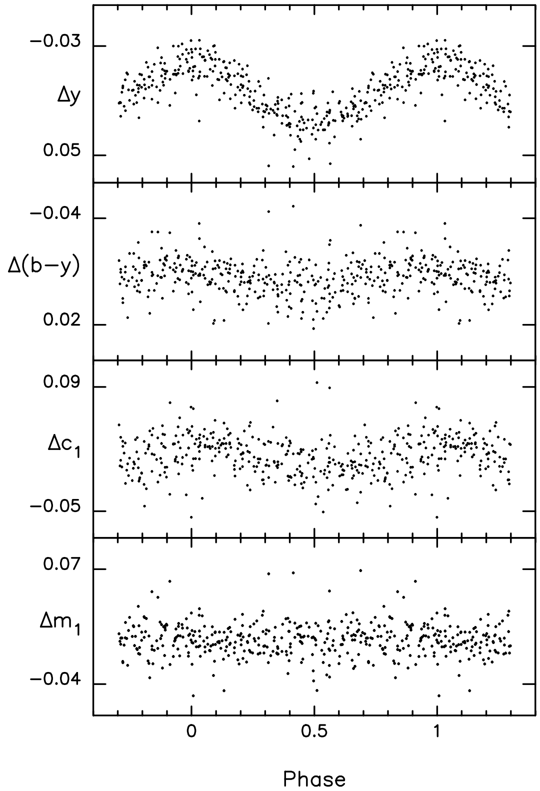

Fig. 4. Light curve and colour index variations of the pulsating companion of AB Cas along the pulsation cycle

we consider this disagreement to be minor, since the amplitude ratios (but not the phase shifts) are sensitive to the adopted atmospheric parameters. Any other nonradial value gives a very discrepant phase difference, specially between (b-y) and *y*, as expected when comparing a temperature indicator with a luminosity one. Another indication of radial pulsation come from the fact that the pulsation phase is constant along the primary minimum. A nonradial mode should show a change in the phase as long as the oscillation surface is being hidden.

Assuming for the hotter component the following values of log T_{eff}=3.903, log g=4.24 and $M_{bol}=2.^m2$ (derived in Sect. 3) together with the pulsation period P_p (obtained in this section), a value of Q=$0.^d036$ (±0.006) (Breger 1990) is found for the pulsation constant using the relation by Petersen & Jørgensen (1972). This suggests pulsation in the fundamental mode. Theoretical models predict that the primary component of AB Cas could be a typical δ Sct variable. From this point of view there is nothing special in the physical behaviour of this star, even isolated this star should be variable, the observed blue border of the instability strip is a little bit hotter than the primary component of AB Cas. Furthermore, looking at the ratio between the pulsation and binary periods one can realise that no resonance is possible because P_b/P_p=23.4507 (±0.0002). Then, there are not low integer values involved in this ratio, within the observational errors, as expected if some resonance is present.

Table 9. Theoretical phase shifts and amplitude ratios for *l*=0,1,2. The phase shifts are in degrees

u-y u/y	v-y v/y	b-y b/y	(b-y)-y (b-y)/y	c_1-y c_1/y	*l*
15	2	2	8	−32	0
1.19	1.43	1.26	0.26	0.50	
9	−3	−1	−8	−47	1
1.24	1.37	1.22	0.22	0.39	
4	−5	−3	−18	−54	2
1.20	1.26	1.17	0.17	0.25	

5. Conclusions

In this paper we report, for the first time, simultaneous *uvby* light curves for the Algol-type binary system AB Cas, in which the primary component is a δ Sct-type pulsating star. Additional Crawford H_β data were also collected. A detailed photometric analysis based on these observations is presented for both binarity and pulsation.

The WD code was used as the most appropriate for modelling the curve of such semi-detached system. After several preliminary tests, we assume that the secondary fills its Roche lobe and the orbit is circular. We have estimated the masses of the components as 1.78 and 0.39 $M_\odot$ (adopted mass ratio q=0.22). The effective temperature of the primary, deduced from the colour indices, was fixed in T_1=8000 K. From the WD solutions, the effective temperature of the secondary component was found to be of T_2=4460 K.

After subtracting the binary light curve, the pulsation of the primary component is analysed using the Fourier Transform and classical O-C methods. Only one frequency is found from the pulsating light curves of this star whereas a more accurate pulsation period of $P_p=0.^d05828741$ is found by using the O-C method, in very good agreement with earlier determinations from other authors. In addition, the analysis of the phase shifts and amplitude ratios between observed light and colour variations suggests that the pulsating component of this binary system is a radial pulsator. This fact is supported by the observations collected during the primary eclipse. Furthermore, a value of $0.^d036$ is obtained for the pulsation constant suggesting pulsation in the fundamental mode. We think that binarity has no influence in the pulsation of the hotter component of AB Cas in the sense that the star shows variability because lies into the instability strip and pulsates in its natural fundamental radial period, which is not significatively changed by the presence of a companion. According to García & Giménez (1990) we can say that even from the pulsational point of view the primary is a “normal” star and binarity has not altered its internal structure at least as radial oscillation periods are concerned.

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