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Four colour photometry of late-type binary systems

I. First $uvby\beta$ light curves of ZZ Ursae Majoris*,**

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Abstract. This paper presents first complete *uvby* light curves of the late-type detached eclipsing binary ZZ UMa (G0V + G8V, $P = 2\stackrel{\mathrm{d}}{.}2993$). This binary system has been observed during eight campaigns at the Calar Alto Observatory (Almeria, Spain)and at the Sierra Nevada Observatory (Granada, Spain). 294 points distributed over the binary period and covering both eclipses are given. The comparison stars used to calculate the differential light curves (SAO 15242 and SAO 15251) were confirmed as being good reference stars with constant flux. These observations are part of a 6 year *uvby* and Hβ monitoring program of low mass eclipsing binaries whose main objective is to provide accurate absolute astrophysical parameters for late-type main sequence stars. Details about the standardisation process and accuracy of the photometry are also given. The internal accuracy of the standard photometry measured as the mean RMS of the differences between standard and observed values for the standard stars observed along the program is only a few millimagnitudes. Detailed analysis of ZZ UMa, based on these light curves, will be published separately.

Key words: stars: binaries: eclipsing — stars: late-type — stars: individual: ZZ UMa — stars: fundamental parameters

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* Based on observations collected with the Spanish 1.5 m telescope at Calar Alto, Almería, Spain, and the Spanish 1 m telescope at Sierra Nevada, Granada, Spain.
** Tables 2 and 3 will be accessible only in electronic form at the CDS via anonymous ftp to
cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr//Abstract.html

1. Introduction

New and more accurate observational determinations of masses, radii, temperatures and abundances are needed in order to improve the mass-luminosity relationship at the end of the Main Sequence. The recently developed families of evolutionary models also need new observational constraints in order to test their predictions. Masses, radii, temperatures and abundances can be derived only for double-lined eclipsing binaries with accurate light and radial velocity curves, (Popper 1980; Andersen 1991). In spite of a large observing effort done up to now, those quantities are poorly defined in the low mass range where only a few stars have astrophysical parameters calculated with the required accuracy for a detailed evolutionary modelling. With this aim, we have performed a 6 year photometric monitoring program of several late-type candidates, in order to obtain precise photometric *uvby* and Hβ light curves.

The candidates for our study were selected by using the following criteria:

1. late-type (late F's and G's),
2. detached systems, in order to minimise interaction problems like mass transfer.
3. orbital inclination close to 90°, to be able to get precise magnitudes for both stars within the systems.
4. orbital period of a few days, so that the light curves could be covered in a reasonable period of time
5. sufficiently luminous to allow accurate photometry and spectroscopy.

The six systems selected were ZZ UMa, BH Vir, TY Tau, V530 Ori, V1061 Cyg and CR Cas. Particular attention has been paid to ZZ UMa for wich radial velocity curves are recently being obtained (Popper 1995) and good quality light curves were needed (Popper 1993).

ZZ UMa ($V = 9.850, G0V + G8V, P = 2^{\rm d}_{\cdot}2993$), is a detached, main sequence, late type, double line eclipsing binary. This system was classified as an eclipsing binary by Kippenhahn in 1955 (Geyer et al. 1955). The photographic light curve of Döppner (1962) is of Algol type, the time of minima and period are $2447237.400 + 2.2993\ E$. Lavrona & Lavrov (1988) found little reflection and elipticity effects in the light curves. The secondary star was classified as a G6-G8 by Janiashvili & Lavrov (1989), which is in agreement with our preliminary analysis (Clement et al. 1993).

In this paper we present the first accurate and complete photoelectric *uvby* and Hβ light curves for ZZ UMa, whose light curve has been fully covered along eight different epochs. We also give details of the photometric reduction procedure and an estimation of the accuracy of the photometry, as well as the absolute photometry of the standard stars used. A complete analysis of ZZ UMa based on these data will be published separately.

Light curves of BH Vir and CR Cas were also completly covered (Clement et al. 1996, 1997a,b).

The other three systems selected were partially covered. Their light curves and analysis will be published elsewere.

2. The observations

To carry out our programe we performed 18 observing campaings, between March 1990 and May 1996 at three different observatories. A large fraction of the data were collected at The Calar Alto Observatory (Almeria, Spain). The telescope used was the 1.5 m reflector equipped with either a multipurpose one-channel photoelectric photometer or, alternately, with a four-channel $uvby-$Hβ spectrograph photometer, both using narrow and wide Hβ filters. Two photometric campaigns were carried out at The European Southern Observatory (La Silla, Chile) using the 0.5 m Danish telescope equipped with a $uvby-$Hβ four-channel photometer, with Strömgren *uvby* filters as well as Crawford's narrow and wide Hβ filters, identical to the one used at Calar Alto. Finally one complementary campaign was performed at the Sierra Nevada Observatory (Granada, Spain) using the 1 m telescope with the same one-channel photoelectric photometer used at Calar Alto.

The 294 measurements of ZZ UMa were obtained in the Strömgren *uvby* system during eight of the observing campaigns, using the 1.5 m telescope of the Observatorio Astronómico Nacional at The Calar Alto Observatory at Almeria, Spain, except for the seventh campaign that was carried out using the 1 m telescope of the Instituto de Astrofísica de Andalucía at the Sierra Nevada Observatory, Granada, Spain.

1. Six nights in March 1990 using the mono-channel $UBVuvby$Hβ photometer, (MO), mounted on the 1.5 m telescope.
2. One night in January 1991 with the same MO photometer.
3. Six nights in January 1992 using the four-channel $uvby$Hβ photometer, (MU).
4. Two nights in January 1993 with the MU photometer.
5. Three nights in April 1994 using the MO photometer.
6. Three nights in June 1995 using the MO photometer.
7. Three nights in December 1995 using the same multichannel photometer, MU, mounted on the 1 m telescope at Sierra Nevada.
8. One night in May 1996 with the MO photometer.

Details about the instrumental configuration for each telescope used can be found in Lahulla & Pensado (1981), Grønbech et al. (1976) and Nielsen (1983).

Average standard magnitudes and colour indices for ZZ UMa and the comparison stars are given in Table 1. See next section.

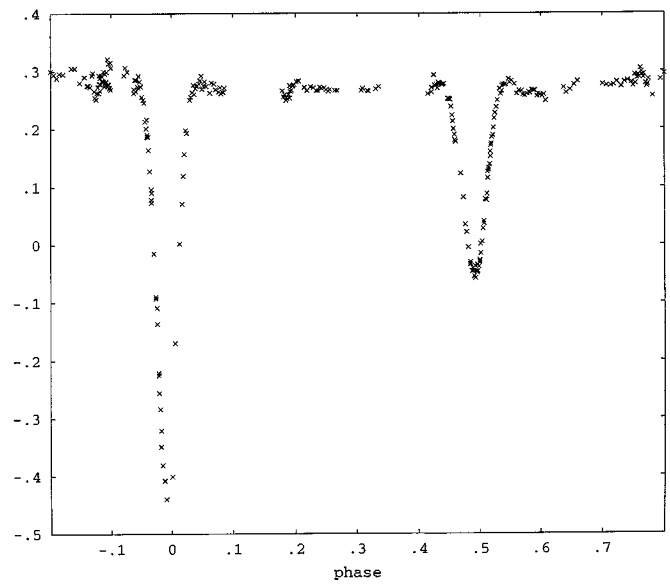

Fig. 1. ZZ UMa differential light curve. *y* filter

3. Standard transformation. Photometric accuracy

What follows refers to the 18 observing campaigns carried out to obtain the light curves of the six binary systems selected, including the eight runs in which we observed ZZ UMa.

First of all, atmospheric extinction coefficients were computed for each night by the "Bouguer method" (Hardie 1962), using the comparison stars as well as the photometric standards observed several times during the night, covering a typical range in air masses from 1 to 2.

Following the method described by Grønbech et al. (1976), after extinction correction, we determined night corrections for each observing period, in order to define magnitudes in the instrumental system.

For the observing periods at Calar Alto, the mean extinction coefficients obtained were: 0.142, 0.061, 0.051, 0.148 with RMS of 0.021, 0.010, 0.012, 0.021 for V, $(b-y)$, m_1 and c_1 respectively. We can appreciate their stability over the 5 years of observations. These results are in good agreement with previously published ones, Fabregat et al. (1991).

The extinction coefficients obtained for the two runs performed at La Silla are also very stable, with mean values of 0.161, 0.056, 0.051, 0.132 and RMS of 0.017, 0.006, 0.003, 0.003 for V, $(b-y)$, m_1 and c_1 respectively for the 24 nights in the two periods.

Next we transformed the observations to the *uvby* and Hβ standard systems, (Strömgren 1966; Crawford & Barnes 1970), following the procedure described by Fabregat & Reglero (1990). For that purpose a set of 38 standard stars from the compilation of Olsen (1991), was observed on selected nights with good atmospheric conditions. For each period independent transformation coefficients were computed and used to transform the magnitudes of the comparisons and program objects to the standard system.

For the campaigns where the number and type of standard stars measured allowed it, we computed the transformation coefficients separately for stars with $(b-y) < 0.410$ (A-F "blue" stars) and $(b-y) > 0.410$ (G-K "red" stars), in order to take into account the difference in colours for these stars in the transformation of the indices m_1 and c_1. The colour effect is not seen in the y and $(b-y)$ transformations, Fabregat (1989).

Hβ photometry has been transformed following the method described by Crawford & Mander (1966). The mean transformation cofficients obtained for the monochannel photometer used at the 1.5 m telescope at Calar Alto were:

B	D	F	H	I	J	a	b
-0.002	0.960	1.076	1.074	0.097	0.040	0.586	1.223
34	38	83	47	83	57	62	41

for the multi-channel photometer at Calar Alto:

B	D	F	H	I	J	a	b
-0.020	0.988	1.081	1.081	0.190	0.036	2.296	1.404
15	22	61	90	59	92	44	175

and for the multi-channel photometer at La Silla:

B	D	F	H	I	J	a	b
0.041	1.015	1.036	1.051	0.161	0.058	2.508	1.351
14	1	13	4	9	2	32	3

These values and their dispersions reflect the stability of the equipment during the 6 years of observations and its closeness to the standard system, as seen by scale transformation coefficients very close to unity.

In Table 2 we list the mean magnitudes and indices obtained for the 38 standards used, indicating the number of campaigns in which they were observed, the number of points averaged, and the difference between standard values and observed values. Only HD 143107A shows residuals on the m_1 and c_1 indices that clearly deviate from the mean values. HD 81997A also deviates on the Hβ index.

Table 1. standard photometry for ZZ UMa and the comparisons

	ZZ UMa	Comp. 1	Comp. 2
SAO no.	SAO15198	SAO15242	SAO15251
α_{2000}	$10^h30^m03^s$	$10^h38^m10^s$	$10^h39^m29^1$
δ_{2000}	61° 48′ 41″	61° 46′ 27″	61° 49′ 06″
Sp. type	G0V+G8V	G0	G2
V (0.25)	9.856	10.126	9.999
	5	13	12
V (0.00)	10.542		
	17		
V (0.50)	10.170		
	7		
$(b-y)$ (0.25)	0.407	0.368	0.396
	6	5	5
$(b-y)$ (0.00)	0.442		
	10		
$(b-y)$ (0.50)	0.377		
	5		
m_1 (0.25)	0.192	0.176	0.227
	11	10	14
m_1 (0.00)	0.193		
	23		
m_1 (0.50)	0.190		
	10		
c_1 (0.25)	0.317	0.307	0.325
	11	21	21
c_1 (0.00)	0.303		
	13		
c_1 (0.50)	0.331		
	16		
β (0.25)	2.598	2.597	2.598
	7	14	17
β (0.00)	2.536		
	2		
β (0.50)	2.605		
	11		

An estimation of the internal error of the photometry can be made by using the RMS dispersion of the differences between the standard value and the computed value for the standard set observed.

The average dispersions for the 11 photometric periods in which we could calculate the transformation were: 0.009 and 0.004 in V magnitude and $(b-y)$ colour, and 0.005, 0.006, 0.005 in the m_1, c_1 and Hβ indices.

These values are in good agreement with the mean RMS dispersions for the whole standard set of 0.010, 0.005, 0.005, 0.006, 0.005 magnitudes for V, $(b-y)$, m_1, c_1 and Hβ respectively.

We assume as an error of our photometry the larger of these two estimations, namely: 0.010 mag in V, 0.005 mag in $(b-y)$, and 0.005, 0.006, 0.005 in m_1, c_1 and Hβ indices.

SAO 15242, ($V = 10.13, G0V$) and SAO 15251 ($V = 10.00, G2V$), were used as comparison and check stars for ZZ UMa, their magnitudes and spectral types being similar to ZZ UMa itself.

The constancy of the comparison star was checked every night. The internal RMS error for the 135 differences (SAO 15242−SAO 15251) 0.007, 0.007, 0.014, 0.021, 0.019 in magnitude for V, $(b-y)$, m_1, c_1 and β respectively, is of the same order of that obtained for main-program stars.

Average standard magnitudes and colour indices for the comparisons of ZZ UMa are given in Table 1 with an indication of their accuracy measured through the RMS dispersion of the observed values. In Table 1 are also given averaged magnitudes and colour indices for the binary system in the eclipses and first quadrature.

Figure 1 presents the ZZ UMa differential light curve in the y filter. The light curve including the eclipses has been covered in eight different epochs, from March 1990 to May 1996. The apparent scatter of the light curve outside eclipses is mainly induced by activity. The 294 differential magnitude (ZZ UMa − SAO 15242) values in the standard system are given in Table 3. The analysis of this binary, including activity effects, will be published soon.

4. Conclusions

We have performed a photometric observational program to obtain precise *uvby* and Hβ light curves of late-type main-sequence detached binary systems. The accuracy of the photometry, evaluated as the dispersion of the discrepancies in the magnitudes and indices for the standard stars, is estimated at a few millimagnitudes.

In this paper we have presented the first complete *uvby*β photometric light curves for ZZ UMa. The comparison stars used showed no variability.

We have presented also *uvby* and Hβ photometry for the standard stars observed in the program, and details about the standard transformation procedure.

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