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STRÖMGREN $uvby - \beta$ PHOTOELECTRIC PHOTOMETRY OF THE VARIABLE STARS RU PSC, SS PSC AND TU UMA[1]

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RESUMEN

Se reporta fotometría $uvby - \beta$ de Strömgren para las estrellas RU y SS Piscium y TU UMa.

ABSTRACT

Strömgren $uvby - \beta$ photoelectric photometry of the stars RU Piscium, SS Piscium and TU UMa is reported.

Key Words: stars: individual (RU Piscium, SS Piscium, TU Uma) — stars: variables: RR Lyrae — techniques: photometry

1. INTRODUCTION

In continuation of a project (see Peña et al. 2009, and references therein) to determine the physical characteristics of field RR Lyrae stars through $uvby - \beta$ photometry, we present an analysis of the variable stars RU and SS in Piscium and TU in UMa (Peña et al. 2008). This goal can be attained from the V magnitude variation and the relationships that have been developed by Kovacz & Jurcsik in several papers (see Kovacz & Walker 2001 for references) through the correlation between the Fourier parameters derived from the light curves and the physical parameters of the RR Lyrae stars. As stated by Kovács & Walker (2001) in their review paper, this method is purely empirical and is based on the assumption that the period and the shape of the light curve are directly correlated with physical parameters such as the absolute magnitude M_v, the intrinsic color $(B - V)_0$ and the metal abundance [Fe/H].

Furthermore, since we have simultaneously obtained $uvby - \beta$ photoelectric photometry, the precise variation along the cycle for each star can also be determined.

2. OBSERVATIONAL MATERIAL AND REDUCTIONS

All observations were carried with the 1.5 m telescope of the Observatorio Astronómico Nacional in San Pedro Mártir (OAN-SPM), Mexico. The 1.5 m telescope is equipped with a multichannel spectrophotometer that simultaneously observes the Strömgren $uvby$ bands and almost simultaneously the two filters that define Hβ. This instrument has been described in detailed by Schuster & Nissen (1988). The observing seasons were several, as listed in Table 1. Column 1 indicates the star considered; Columns 2 and 3 the initial and final observing times in HJD; Column 4, the date and the last column the number of observed point on each night.

2.1. *Data acquisition*

In each season the same observing routine was employed: a multiple series of integrations was performed, often five 10-s integrations of the star, to the average of which a 10-s integration of the nearby sky was subtracted. All the data reductions were performed using the `NABAPHOT` package (Arellano Ferro & Parrao 1988). A series of standard stars was also observed on each night to transform the data into the standard system. The chosen system was that defined by the standard values of Olsen (1983). The final results of the transformation into the standard system, grouped by season, were obtained, reduced, and published elsewhere (Peña & Peniche 1994; Peña et al. 2005). Two seasons that have not been reported before are those of 2008 and September, 1995, which had a malfunction in the u filter, making the

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TABLE 1

LOG OF THE OBSERVING SEASONS

Star	Initial HJD	Final HJD	Date	Points
Ru Psc	2447834.64547	2447834.87717	1989/11/4	118
	2447835.63637	2447835.86060	1989/11/5	89
	2448896.81319	2448896.95996	1992/10/1	16
	2449975.80147	2449975.83466	1995/9/15	4
	2449976.81785	2449976.95828	1995/9/16	5
	2449977.78820	2449977.87645	1995/9/17	4
	2449978.79232	2449978.89046	1995/9/18	7
	2449979.77929	2449979.85061	1995/9/19	4
	2449980.75842	2449981.00158	1995/9/20	28
	2449981.75020	2449981.93370	1995/9/21	26
		Nights=10	Total data=	301
SS Psc	2448891.91449	2448891.91449	1992/9/26	1
	2448892.72776	2448892.72776	1992/9/27	1
	2448896.70922	2448896.99775	1992/10/1	59
	2449975.80688	2449975.83047	1995/9/15	3
	2449976.80558	2449976.96451	1995/9/16	5
	2449977.79835	2449977.88459	1995/9/17	7
	2449978.80481	2449978.88634	1995/9/18	5
	2449979.78510	2449979.85824	1995/9/19	6
	2449980.76145	2449980.99916	1995/9/20	28
	2449981.75329	2449981.93952	1995/9/21	25
		Nights=10	Total data=	140
TU UMa	2453102.87946	2453102.87946	2004/4/7	1
	2453103.87146	2453103.87146	2004/4/8	1
	2453104.81966	2453104.89100	2004/4/9	4
	2453106.81838	2453106.82435	2004/4/11	2
	2453439.82621	2453439.82621	2005/3/10	1
	2453440.81179	2453440.81179	2005/3/11	1
	2453441.82312	2453441.82312	2005/3/12	1
	2453442.88012	2453442.88012	2005/3/13	1
	2453444.74651	2453444.74651	2005/3/15	1
	2453445.79603	2453445.79603	2005/3/16	1
	2454550.83534	2454550.96729	2008/3/25	5
	2454551.72411	2454551.93289	2008/3/26	4
	2454552.74327	2454552.96792	2008/3/27	8
	2454553.70350	2454553.93219	2008/3/28	8
	2454881.80524	2454881.94009	2009/2/19	11
		Nights=15	Total data=	50

determination of c_1 unreliable. In 1995, no Hβ was observed. A recent season, that of 2008, was devoted to several RR stars, TU UMa among them. The seasonal transformation coefficients are reported in Table 2. The indicated coefficients are obtained for the equations defined by Grönbech, Olsen, & Strömgren (1976).

The values of the slopes for the various observing seasons are summarized in Table 2. The transformation coefficients for this season are listed in Ta-

TABLE 2

TRANSFORMATION COEFFICIENTS FOR EACH SEASON

Season	B	D	F	G	I	J	L
Oct-Nov, 1989	+0.010	1.001	0.940	0.013	1.006	0.078	1.258
Sep-Oct, 1992	−0.010	0.993	0.949	0.024	0.988	0.068	
Sep, 1995	−0.078	0.964	1.054	0.027	1.020	0.127	
Apr, 2004	+0.021	0.990	1.074	0.017	1.035	0.125	
Mar, 2005	−0.078	0.964	1.054	0.027	1.020	0.127	
Mar, 2008	−0.041	0.974	0.936	0.043	0.919	−0.052	−1.316
Jan, 2009	−0.030	0.987	1.055	0.040	0.928	−0.084	

TABLE 3

STRÖMGREN $UVBY-\beta$ PHOTOELECTRIC PHOTOMETRY DATA
FOR THE STARS SS PISCIUM, RR PISCIUM AND TU UMA

Id	V	$(b-y)$	m_1	c_1	HJD ($uvby$)	β	HJD (Hβ)
RU Psc	10.293	0.258	0.075	0.928	2447834.64547	2.672	2447834.64606
RU Psc	10.313	0.254	0.070	0.948	2447834.64978	2.662	2447834.65007
:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:
SS Psc	11.154	0.244	0.159	0.920	2448891.91449	2.711	2448891.91385
SS Psc	11.065	0.222	0.142	1.010	2448892.72776	2.719	2448892.72701
:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:
TU UMa	10.152	0.302	0.117	0.700	2453102.87946	—-	—-
TU UMa	10.075	0.322	0.067	0.660	2453103.87146	—-	—-
:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:

ble 2 and the mean uncertainties, calculated from the differences of the obtained values of the standard stars from those values of the literature are the following: $(V, b-y, m_1, c_1, \beta)$ = (0.028, 0.014, 0.022, 0.031, 0.008 mag.). The final photometric values are available online in the *Simbad* database in the format presented in Table 3 where Column 1 is the star considered, Columns 2–5 are V, $(b-y)$, m_1 and c_1 respectively, Column 6 is the time in HJD when V, $(b-y)$, m_1 and m_1 were taken, Column 7 is β and Column 8 is the time in HJD when β was taken.

The uncertainties of our measurements have two different sources: the first one arises from the manner in which the data were acquired; the second from the transformation of the data into the standard system.

To evaluate the first, we consider the number of counts for each star since they were obtained in different seasons as can be seen in Table 4. Although the procedure was almost the same, small differences have to be considered with respect to the integration times and the number of times that they were measured. Table 4 lists the compilation of these values for each season and for each star (Columns 1 and 2 of the table). In each case care was taken so that enough counts were obtained to reach accuracies of the order of hundredths, as can be seen in the table. Columns 3 to 6 list the net counts obtained in the u, v, b, and y filters. Column 7 lists both the integration time and the number of times they were measured. Column 8 lists the night from which the counts were obtained, although, because of the similar procedure followed in each season, all nights show the same values. Finally, Columns 9 to 12 list the accuracy considering the customary relation $\sqrt{N}/N$.

TABLE 4

UNCERTAINTIES IN THE DATA

Year	Star	u	b	v	y	Method	Night	du	db	dv	dy
1989	RU Psc	89018	313757	292637	139428	20s-3times	Nov-04	0.003	0.002	0.002	0.003
1992	RU Psc	140097	247541	310559	153770	10s-5times	Oct-01	0.003	0.002	0.002	0.003
1992	SS Psc	40888	13883	19361	10139	10s-5times	Oct-01	0.005	0.008	0.007	0.010
1995	RU Psc	176948	235506	80505	169561	10s-5times	Sep-19	0.002	0.002	0.004	0.002
1995	SS Psc	96847	146840	52391	101762	10s-5times	Sep-19	0.003	0.003	0.004	0.003
2004	TU UMa	83564	423607	583078	202386	10s-6times	apr-09	0.003	0.002	0.001	0.002
2005	TU UMa	92940	354868	412787	139101	10s-4times	Mar-11	0.003	0.002	0.002	0.003
2008	TU UMa	139924	632414	765045	243307	10s-5times	Mar-26	0.003	0.001	0.001	0.002
2009	TU UMa	40853	168946	193785	57948	10s-6times	Feb-19	0.005	0.002	0.002	0.004

The uncertainties due to star counts are negligible for the stars considered.

The second source of error arises from the transformation of the data into the standard system. Table 2 presents the transformation coefficients obtained, as defined by Grönbech et al. (1976). D, F, I, and L are the slope coefficients for $(b-y)$, m_1, c_1 and β respectively; B, G, and J are the color term coefficients of V, m_1 and c_1 of the transformation equations. An estimate of the accuracy was done comparing the indexes with those of the standard stars considered. The uncertainties were evaluated in the following manner: the average differences (present data minus standard data) were evaluated and provide an error bar for the transformation of the season.

3. SAMPLE STARS

RU Psc (=BD+23° 159=HIP 5803). This is an RRc type RR Lyrae star with spectral type ranging between A7–F3. The star has an amplitude of variation of about 0.5 mag in the V band. Its reported pulsation period is 0.390385 d (Kholopov 1987). One of the most thorough studies on RU Psc is that of Mendes de Oliveira & Nemec (1988). They stated that RU Psc is known for having irregular cycle-to-cycle brightness variations and a possible 28 d Blazhko period. With an analysis of more than 1100 photometric observations they concluded that the peculiarities seen in the photometry of RU Psc are due primarily to rapid and irregular period changes and not due to low-amplitude oscillations caused by a secondary period.

In the RR Lyrae data base of GEOS[7] (2012) one can find a list of 122 times of maxima and the analysis of the O-C residuals calculated with the ephemerides 2440143.40270 + 0.3903850000 E of Kholopov (1987). These times of maxima span 1934-2012. From our observations we were able to determine two new epochs of maximae V light at HJD 2447835.6660 d and HJD 2448896.8778 d. An analysis of the times of maximum light could provide information on the pulsational nature of the star.

SS Psc (=HIP 006301). This star is classified as an RRc type RR Lyrae star (`http://www.upv.es/geos`) with a spectral type range between A7 and F2, an amplitude of variation of about 0.4 mag in the V band, and a period of 0.28779276 d (Kholopov 1987). This star has also being listed as a δ Scuti in the catalogue of Rodríguez et al. (1994).

The time span of our observations of this star is not as extense as in the case of RU Psc (2150 d.) because it was not a target in 1989. Hence, our data consisted of 140 data points covering a time span of 1090 days in the interval of JD 2448891 and 2449981.

TU UMa (=BD +30° 2162=HIP 056088). This is a RRab star with a V amplitude of about 0.9 mag. and a period of 0.5576587 d (Kholopov 1987). A detailed analysis of the times of maximum light recorded between 1914 and 1999 was carried out by Wade et al. (1999). These authors have shown that the O-C residuals display an oscillatory variation that is interpreted as being due to light time effects in an orbital motion. They also show convincing evidence that the center-of-mass velocities for TU UMa can be reproduced by orbital solutions, and conclude that TU UMa is a member of a binary system with a period of about 23 yr, an eccentricity of 0.79 and a mass for the companion star of 0.4 $M_{\odot}$. Our data for this star include four seasons: 2004, 2005, 2008 and 2009, with 50 data points between JD 2453102 and 2454881.

[7]`http://www.upv.es/geos`.

4. CONCLUSIONS

From data collected in several photometric campaigns we have obtained $uvby-\beta$ photometry over a relatively large time span that adequately covers the pulsation cycle. This could serve to calculate, through Fourier analysis, coefficients that could be used in the determination of the physical parameters of each star. Reddening could be estimated by considering different main sequence objects in the same direction. Once reddening is fixed, the unrreddened Strömgren indexes along the cycle could be employed to determine the variation of effective temperature and surface gravity along the cycle.

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