THE ASTRONOMICAL JOURNAL VOLUME 95, NUMBER 5 MAY 1988

Hβ PHOTOMETRY FOR *uvby* STANDARD STARS

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Received 8 October 1987; revised 22 December 1987

ABSTRACT

From 1984 to 1986, we made several observational campaigns at Calar Alto and La Palma Observatories using the *uvby* and β photometric systems to monitor a selected sample of late-type variable stars. In this paper we present the β values for 38 *uvby* standard stars to contribute to the *uvby*–β calibration works on late-type stars. In the final discussion, the β computed values are plotted against the Strömgren $b-y$, m_1, and c_1 indices.

I. INTRODUCTION

The use of the *uvby* and β systems defined by Strömgren (1966) and Crawford-Mander (1966) has been a common and powerful method of photometric analysis used to investigate the nature of early- and intermediate-type stars.

The initial calibrations of Crawford (1975) for F and early G stars shows that the combined use of both systems is one of the most suitable photometric methods to determine temperatures, metal contents, luminosity class, and other stellar parameters of astrophysical interest.

In more recent papers, many authors have made attempts to extend the calibrations of the *uvby* and β systems to later spectral types. Since the first works of Olson (1974), the preliminary calibrations for main-sequence stars given by Olsen (1984) and Ardeberg and Lindgren (1985) for giants opened new perspectives in the use of the *uvby* and β systems for late-type stars.

From 1984 to 1986, we carried out several observational campaigns to investigate the behavior of a selected sample of active stars of the RS CVn (Hall 1972), BY Dra (Bopp *et al.* 1981), and Ca II variables (Wilson 1978) types, using the *uvby* and β systems at Calar Alto and La Palma Observatories, with results partially published at this moment (Reglero *et al.* 1986a,b and 1987a).

Due to the extensive nature of these surveys, with stars of spectral types ranging from F to M, we have made an effort to include a large number of *uvby* standards to be able to compute accurately the color dependences on the standard transformations (Grønbech *et al.* 1976; Reglero *et al.* 1987a,b). Simultaneous to the *uvby* photometry, β measurements were made for the complete set of *uvby* standard stars.

In this paper, we present the β results for the 38 *uvby* standards that are not β standard, to contribute to the *uvby*–β calibration efforts for late-type stars. A description of the observational techniques, reduction procedures, and data accuracy are reported. In a final discussion, the β computed values are plotted against the Strömgren $b-y$, m_1, and c_1 indices.

II. OBSERVATIONS AND β STANDARD TRANSFORMATIONS

The observations were made during six runs from 1984 to 1986. Three runs in May 1985, November 1985, and March 1986 at the Observatory of Roque de los Muchachos (La Palma, Canary Islands, Spain), located at 2369 m above sea level, were made in the framework of an all-sky *uvby*–β photometric program for RS CVn stars. The photometric equipment used was the People's two-channel photoelectric photometer, attached to the $f/15$ Cassegrain focus of the 1.0 m Jacobus Kapteyn telescope.

The three other runs were done in July 1984, 1985, and 1986 at the Observatory of Calar Alto (Almeria, Spain), located at 2168 m above sea level, in a program of differential *uvby*–β photometry for BY Dra (Bopp *et al.* 1981) and Ca II variable stars (Wilson 1978). The equipment used was the multipurpose *UBVRI* one-channel photoelectric photometer, attached to the Cassegrain focus of the 1.5 m telescope operated by the Observatorio Astronomico Nacional.

For each observational period, a selected sample of nights with good atmospheric conditions was used to obtain the standard transformation coefficients for the *uvby* system. A more detailed description of the equipment and observational techniques can be found in previous papers (Reglero *et al.* 1987a,b).

For the six runs, simultaneous observations were made with each of the Crawford narrow and wide filters centered on the Hβ line (Crawford and Mander 1966), for the main program and *uvby* standard stars.

The β measurements were reduced using the procedure described by Crawford and Mander (1966). Previously, the observed β'' values were tested, plotting β'' against airmass and time, to check for short-period changes in the equipment, or positional or atmospheric dependences.

TABLE I. Night corrections $n(i)$ Dates in JD − 2440000 and $n(i)$ in magnitudes.

Calar Alto, July 1984		La Palma, May 1985	
5904	−0.003	6214	0.007
5905	0.004	6215	0.001
5906	0.002	6216	0.001
5907	−0.001	6217	0.001
5908	0.002	6218	−0.002
5909	0.000	6219	−0.002
5910	−0.004	6220	0.001
σ	0.003	σ	0.003
Calar Alto, July 1985		**La Palma, November 1985**	
6268	0.000	6372	0.001
6269	−0.012	6373	0.011
6270	0.007	6374	−0.006
6271	0.008		
6272	−0.003		
6273	0.008		
6274	−0.005		
6275	−0.002		
6277	0.001		
σ	0.006	σ	0.007
Calar Alto, July 1986		**La Palma, March 1986**	
6634	0.004	6516	0.000
6637	0.001	6518	0.000
6638	−0.005	6519	−0.001
6639	0.000	6520	0.002
6640	0.003	6521	0.003
6641	0.000		
6642	0.000		
6643	−0.001		
σ	0.003	σ	0.001

After that, the observed β'' values were transformed to the natural system β' by means of a night correction $n(i)$, $\beta' = B'' + n(i)$. The computed $n(i)$ values are given in Table I, where the first and second columns are the Julian Day − 2440000 and the night correction, respectively. For both observatories, a common value of 0.004 mag is computed for the rms standard deviation, showing a remarkable stability of the instrumental systems over the six periods throughout the three years considered.

The natural system was then transformed to yield a standard system by means of a linear equation of the form $\beta = a + b\beta'$. For each observing run, the transformation was independently computed. The individual values, mean, and rms dispersions for both observatories are reported in Table II, following the suggestion by the compilers of the *uvby–β* catalog (Lindemann and Hauck 1973).

The transformed values in the Crawford–Mander system for the 21 β standard used are given in Table III. We also list

TABLE II. Standard β transformation coefficients.

Calar Alto	a	b	La Palma	a	b
July 1984	0.419	1.287	May 1985	0.276	1.144
July 1985	0.401	1.289	November 1985	0.269	1.141
July 1986	0.436	1.285	March 1986	0.289	1.137
Mean	0.419	1.287	Mean	0.278	1.140
σ	0.018	0.002	σ	0.008	0.003

the mean error of one observation for individual stars (σ) and the differences D between the standard and computed values. N is the number of star measurements and LP (La Palma) and CA (Calar Alto) indicate the site of the observations. The computed mean standard deviation for the β standard measurements is 0.004 mag.

III. THE β RESULTS AND CONCLUSIONS

Final β results for the *uvby* standards are presented in Table IV. Column (1) is the HR number, and (2), (3), (4), and (5) are the computed β values, rms dispersion, number of star measurements, and observatory, respectively.

For the complete set of *uvby* standards, there are no indications of variability (2σ) over the timescales considered. For HR 68, the small number of measurements (4) is not sufficient to determine the behavior of this star.

If we take the 31 stars in common with the *uvbyβ* Photoelectric Photometric Catalog (Hauck and Mermilliod 1980) and compute the differences, cataloged minus computed values, we find a mean value of 0.000 ± 0.008 mag. Some stars show deviations over the 2σ level, as is the case with HR 493, HR 7560, HR 8085, HR 8086, HR 2886, and HR 8313. The first four are Wilson's Ca II variables (Noyes *et al.* 1984) with chromospheric induced emission, and the two others are suspected variables, NSV 3642 and NSV 13864, respectively (Kholopov *et al.* 1982).

Finally, we have plotted the β computed values against the Strömgren $b - y$, m_1, and c_1 indices in Figs. 1–3. To show the ZAMS, we have used the Crawford (1975) calibrations for A to G2 stars and the preliminary values given by Olsen (1984) for main-sequence stars from G2 to M2.

The $(b - y, \beta)$ plane is shown in Fig. 1, where the crosses represent luminosity class V, the squares class IV, and the triangles class III stars. There is a good correlation between the β computed values and class V standard calibration. De-

TABLE III. Catalog of 21 β standard stars observed at La Palma and Calar Alto Observatories and transformed to the Crawford–Mander β standard system. Unit 1 mag.

HR	β	σ	D	N	Obs	HR	β	σ	D	N	Obs
63	2.887	0.001	−0.008	4	LP	5447	2.681	0.006	0.000	34	LP
458	2.631	0.001	−0.002	6	LP	5868	2.607	0.005	−0.004	14	LP
2918	2.611	0.003	0.002	8	LP	5933	2.635	0.004	−0.002	26	LP
3538	2.601	0.003	0.004	4	LP	6355	2.879	0.004	−0.001	35	LP,CA
3893	2.651	0.005	−0.005	8	LP	6467	2.652	0.008	0.004	27	CA
3974	2.838	0.003	−0.002	18	LP	7069	2.900	0.004	0.003	26	CA
4515	2.860	0.003	−0.007	6	LP	8494	2.763	0.006	−0.006	2	CA
4931	2.704	0.008	0.004	8	LP	8826	2.822	0.008	−0.005	15	LP,CA
5011	2.618	0.003	−0.003	10	LP	8969	2.630	0.007	−0.008	6	LP,CA
5062	2.846	0.008	0.001	14	LP	9088	2.570	0.002	−0.007	4	LP
5270	2.538	0.005	0.002	14	LP						

TABLE IV. Catalog of 38 *uvby* standard stars observed at La Palma and Calar Alto and transformed to the Crawford–Mander β standard system. Unit 1 mag. Stars marked with * have β values in the Hauck and Mermilliod Catalog.

HR	β	σ	N	Obs	HR	β	σ	N	Obs
68	2.905	0.014	4	LP,*	5936	2.712	0.007	34	LP,CA,*
493	2.560	0.005	2	LP,*	5947	2.563	0.005	26	LP
660	2.586	0.003	6	LP,*	5968	2.594	0.006	36	LP,CA,*
1346	2.573	0.006	4	LP	6458	2.594	0.004	15	CA,*
1373	2.576	0.006	4	LP	7061	2.654	0.008	11	CA
2857	2.876	0.008	18	LP,*	7462	2.568	0.006	7	CA
2880	2.788	0.002	10	LP,*	7503	2.609	0.006	30	CA,*
2886	2.842	0.003	16	LP,*	7504	2.599	0.006	30	CA,*
3003	2.551	0.003	8	LP,*	7534	2.652	0.007	43	CA,*
3555	2.856	0.003	20	LP,*	7560	2.640	0.004	8	Ca,*
3771	2.574	0.004	6	LP,*	7858	2.924	0.004	8	CA,*
3815	2.592	0.004	8	LP	8085	2.505	0.006	24	CA,*
3881	2.616	0.004	6	LP,*	8086	2.502	0.005	22	CA,*
3951	2.606	0.005	6	LP,*	8267	2.728	0.004	4	LP,*
4090	2.787	0.004	4	LP,*	8313	2.603	0.005	46	CA,*
4277	2.605	0.006	4	LP,*	8430	2.656	0.001	8	LP,*
4501	2.635	0.005	4	LP,*	8551	2.550	0.006	6	LP,CA,*
4753	2.676	0.004	14	LP	8729	2.603	0.008	8	LP,CA,*
5634	2.666	0.004	40	LP,*	8830	2.751	0.007	2	CA,*

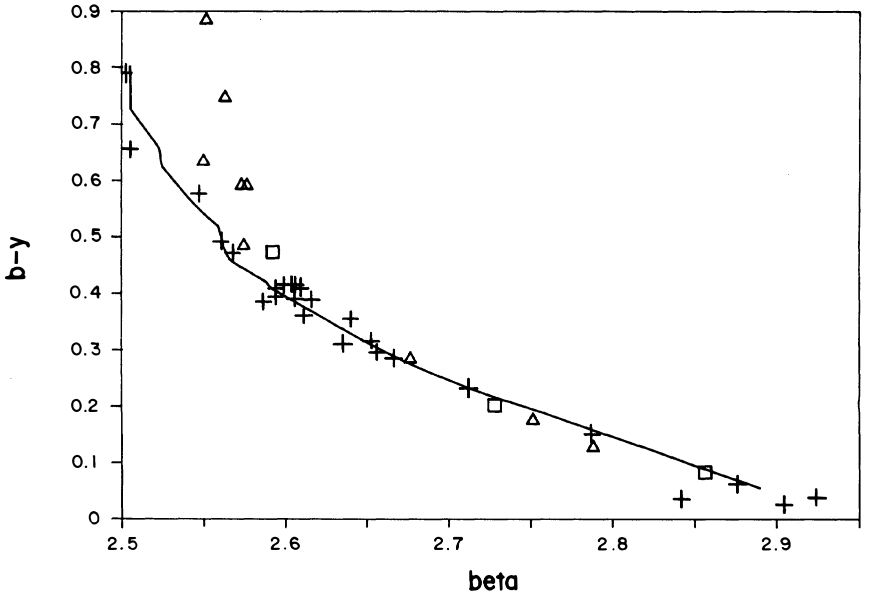

FIG. 1. $(b-y)$–β diagram. Stars of luminosity class V are plotted as crosses. Squares and triangles represent luminosity class IV and III stars. The curve is the standard Crawford (1975) relation for F–G stars and the preliminary calibration for G–M stars done by Olsen (1984).

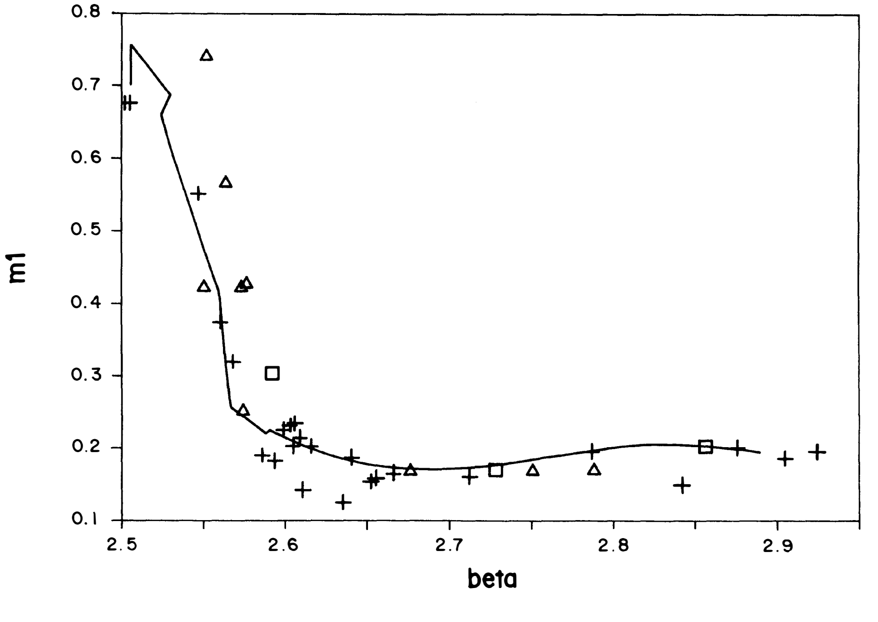

FIG. 2. m_1–β plane. Symbols and curve as in Fig. 1.

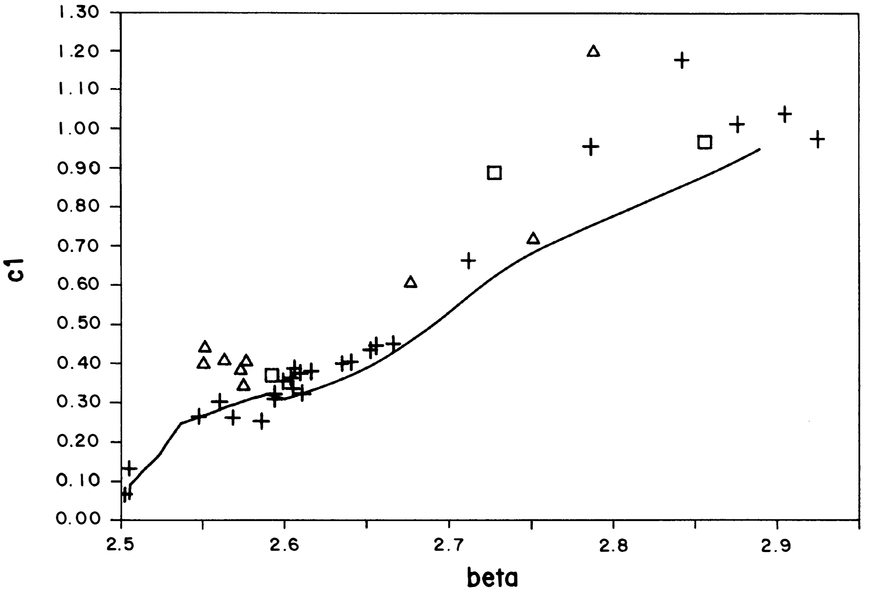

FIG. 3. c_1–β plane. Symbols and curve as in Fig. 1.

viations can be seen for late-type luminosity class III stars.

The (m_1,β) plane is shown in Fig. 2. The good agreement between the calibration lines and computed values have as exceptions the positions of HR 2886 and HR 4501, which show a m_1 value smaller than expected taking into account the β value. Deviations for giant stars are clearly seen.

The (c_1,β) plane from Fig. 3 shows clearly the discrimination between the stars of luminosity classes V (crosses) and III (triangles). As in the (m_1,β) figure, the position of HR 2886 is anomalous. The position of HR 4090 suggests a luminosity class IV rather than the class V assigned catalog value.

As a conclusion, the behavior of the 38 *uvby* standard stars is consistent with their expected values given by the *uvby*–β calibrations. Only HR 2886 shows systematic deviations; this may be related to its spectral type A1 V (A star problem, Crawford (1979)).

The JKT on the island of La Palma and the 1.5 m Telescope at Calar Alto are operated, respectively, by the Royal Greenwich Observatory at the Spanish Roque de los Muchachos Observatory (Instituto de Astrofísica de Canarias), and Observatorio Astronómico Nacional at the Spanish Calar Alto Observatory (Almería). We want to express our gratitude to the staffs of the observatories for their help during the observational campaigns. This work has been supported by the Spanish Comisión Asesora de Investigación Cientifica y Técnica (CAICYT No. 2254/83 and No. 3455/83).

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