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Strömgren and Hβ photometry of O and B type stars in star-forming regions

I. Canis Major – Puppis – Vela*,**

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Abstract. Strömgren and Hβ photometry of OB-stars generally brighter than 9.5 mag in the Canis Major - Puppis - Vela region of Milky Way is reported. The observations are based on the Milky Way luminous-star (LS) identifications and are designed to create a complete, magnitude-limited sample of LS for this field. We present new $uvby$ photometry for 127 LS and Hβ photometry for 25 of them. These observations are part of an ongoing effort to improve the completeness of the existing $uvby\beta$ data-base for the bright OB-type stars in the Milky Way, with the aim to investigate the structure of selected star-forming regions.

Key words: stars: early-type

1. Introduction

In the context of star formation, a detailed examination of the stellar content and structure of Galactic star-forming regions allows fundamental issues to be discussed. The Strömgren and Hβ photometry has always been an excellent tool in obtaining the colour excess and distance for the individual stars, revealing the associations' membership. The vast majority of studies concerning the existence and parameters of young Galactic stellar groups are based on the Q-method or spectroscopic parallaxes, with different absolute magnitude and intrinsic colours adopted. Problems regarding these approaches have been recently emphasized by several authors (Jaschek et al. 1996, Harries & Hilditch 1998, Massey et al. 1995). As a consequence, a large number of studies exist, varying widely in terms of the limiting magnitude, and the positions and dimensions of the fields chosen, and resulting in controversial conclusions.

After completion of the Hipparcos and Tycho Catalogues (ESA 1997), the knowledge about the distance scale and nearby young stellar groups has considerably improved. The OB-associations up to 650 pc have changed their appearance compared to the classical membership lists (de Zeeuw et al. 1999). However, according to their study, the astrometric evidence for moving groups in many fields where OB-associations do exist, is inconclusive. The majority of Galactic OB-associations are beyond 500 pc, where the Hipparcos parallaxes are of limited use, or the groups have unfavorable kinematics and can not be separated from the field stars in the Galactic disk. On the other hand, the Hipparcos data allow the reliability of the photometric and spectroscopic distance calibrations to be examined. The $uvby\beta$ photometric system provides reliable distance calibrations for O and B type stars (Kaltcheva & Knude 1998), which allow the structure of the star-forming regions to be studied.

In this context, a complete and homogeneous photometric $uvby\beta$ survey of O and B type stars, and in particular of intrinsically luminous OB stars, is a necessary step in the further study of the Galactic spiral structure. In general, the brightest LS delineate the most prominent young apparent stellar structures and are expected beyond 500 pc, i.e. beyond the limit of the Hipparcos survey. It is surprising how little has been done so far regarding the completeness of the $uvby\beta$ observations even for the brightest OB-stars. As pointed out by Reed (1996), of 5132 stars in the Stephenson-Sanduleak catalog (1971), only 817 have $uvby$ colours and magnitudes available and about 600 have both $uvby$ and β data.

In this paper, we present Strömgren and Hβ photometry of OB-luminous stars generally brighter than 9.5 mag in the Canis Major - Puppis - Vela region of the Milky Way. New $uvby$ photometry for 127 LS and Hβ photometry for 25 of them is obtained, utilizing for the purpose Stephenson & Sanduleak (1971) luminous-star and Northern Milky Way luminous-star identifications (see Reed 1998). The observations were performed with the Strömgren Automatic Telescope (SAT) of the Copenhagen Astronomical Observatory at La Silla and are the first part of an extensive program of $uvby\beta$ photometry of O and B type stars in the Milky Way, including the Carina Spiral Feature and the star-forming regions in the third Galactic quadrant. In its fully-automatic mode, the SAT is a very effective and appropriate instrument for this program.

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* Based on data from the Strömgren Automatic Telescope of the Copenhagen Astronomical Observatory, La Silla.

** Tables 3 and 4 are only available in electronic form at the CDS via anonymous ftp to 130.79.128.5 or via http://cdsweb.u-strasbg.fr/Abstract.html

Table 1. Catalogue of 53 standard stars (primary and secondary) on the Crawford-Barnes standard $uvby$ system. Secondary standard stars are marked by an asterisk. Column 2 gives the y_i photometry transformed to the standard Johnson V magnitude. The internal rms errors of one observation (weight 1) are given in Cols. 3, 5, 7, and 9, respectively, for V, $b-y$, m_1, and c_1. NN is the number of nights on which the star was observed. W is the weight of the four-colour indices, and VW the weight of the V magnitude. The last four columns give the differences D = transformed value - standard value. Units: 1 mag.

HD	V	m.e.	b-y	m.e.	m_1	m.e.	c_1	m.e.	VW	W	NN	D(V)	D(b-y)	D(m_1)	D(c_1)
16908	4.678	0.011	-0.055	0.003	0.092	0.002	0.339	0.005	18	18	14	0.008	-0.003	-0.005	0.006
17081	4.256	0.008	-0.052	0.002	0.098	0.003	0.596	0.004	31	31	20	0.006	-0.007	0.000	-0.003
23288	5.480	0.009	-0.002	0.003	0.105	0.004	0.648	0.005	21	21	13	0.020	-0.001	0.000	0.001
23324	5.676	0.008	-0.027	0.003	0.110	0.007	0.641	0.005	26	26	16	0.016	-0.005	0.001	0.004
24587 *	4.642	0.011	-0.063	0.002	0.118	0.003	0.500	0.006	33	33	18	-0.008	-0.009	0.009	0.001
34816 *	4.295	0.007	-0.101	0.002	0.058	0.003	-0.059	0.005	34	34	19	0.005	0.008	-0.016	0.010
36591AB	5.345	0.006	-0.071	0.002	0.071	0.002	-0.005	0.004	39	39	21	-0.005	0.006	-0.003	-0.003
39764	4.882	0.009	-0.072	0.002	0.119	0.003	0.405	0.007	35	35	19	0.012	0.001	-0.004	0.005
40494A	4.345	0.005	-0.070	0.002	0.088	0.003	0.360	0.005	39	39	21	-0.015	0.003	-0.006	0.005
48434 *	5.885	0.005	0.070	0.002	0.005	0.004	-0.077	0.007	8	8	8	0.025	-0.003	0.003	0.001
50820 *	6.161	0.006	0.438	0.004	-0.041	0.007	-0.025	0.008	13	13	13	0.001	0.000	0.015	0.000
51283 *	5.313	0.007	-0.054	0.002	0.073	0.003	0.159	0.003	12	12	12	-0.007	0.000	-0.002	0.006
52382 *	6.485	0.012	0.224	0.003	-0.034	0.004	-0.035	0.007	10	10	10	-0.015	0.000	0.012	-0.014
53244	4.119	0.008	-0.041	0.003	0.087	0.004	0.554	0.005	54	54	20	-0.001	0.001	-0.012	0.002
53975 *	6.495	0.006	-0.004	0.003	0.042	0.004	-0.134	0.006	11	11	11	-0.005	-0.006	0.004	0.008
54662 *	6.232	0.007	0.096	0.004	-0.005	0.006	-0.109	0.007	11	11	11	0.002	-0.007	0.001	0.002
54764A *	6.052	0.008	0.105	0.003	0.009	0.005	0.004	0.007	11	11	11	0.002	-0.002	-0.010	0.016
55879 *	6.017	0.006	-0.039	0.002	0.041	0.003	-0.098	0.003	12	12	12	-0.003	0.000	-0.005	0.010
60325 *	6.217	0.008	0.031	0.003	0.047	0.005	0.146	0.007	13	13	13	0.007	0.003	-0.009	0.002
61831	4.841	0.005	-0.084	0.002	0.105	0.002	0.298	0.004	38	38	21	-0.009	-0.005	0.003	0.002
70839 *	5.964	0.006	-0.002	0.002	0.070	0.004	0.047	0.005	14	14	14	-0.006	-0.001	0.007	0.000
74280	4.297	0.008	-0.082	0.004	0.082	0.005	0.241	0.005	61	61	22	-0.003	0.006	-0.010	0.001
74753 *	5.151	0.006	-0.060	0.002	0.051	0.003	-0.108	0.003	13	13	13	0.001	-0.006	0.011	-0.008
83754	5.069	0.008	-0.072	0.002	0.112	0.003	0.403	0.006	35	35	19	-0.001	-0.003	0.005	-0.002
83944	4.508	0.006	-0.040	0.003	0.148	0.004	0.810	0.003	35	35	20	-0.012	-0.001	0.003	0.000
84567 *	6.442	0.007	-0.004	0.004	0.034	0.007	-0.089	0.007	14	14	14	-0.008	0.004	-0.007	0.005
86606 *	6.346	0.009	0.006	0.003	0.040	0.004	-0.040	0.006	20	20	19	-0.004	0.001	-0.007	0.012
90994	5.076	0.007	-0.065	0.003	0.117	0.003	0.471	0.004	29	29	16	-0.004	-0.001	0.001	0.005
100600AB	5.943	0.008	-0.078	0.004	0.118	0.007	0.311	0.006	19	19	15	-0.007	-0.008	0.014	-0.008
105071 *	6.312	0.008	0.195	0.003	0.018	0.006	0.378	0.006	15	15	15	0.012	-0.008	0.025	-0.004
105382	4.461	0.010	-0.076	0.003	0.108	0.005	0.248	0.005	24	24	18	-0.009	0.000	0.004	-0.008
106068 *	5.948	0.012	0.264	0.003	0.006	0.004	0.407	0.006	14	14	14	0.018	-0.004	-0.005	0.005
111973 *	5.926	0.015	0.247	0.003	-0.024	0.005	0.126	0.008	12	12	12	0.016	-0.001	0.023	-0.008
115842 *	6.013	0.017	0.303	0.003	-0.076	0.004	-0.071	0.006	13	13	13	-0.017	-0.001	-0.014	0.010
116084 *	5.850	0.019	0.151	0.003	0.006	0.004	0.045	0.005	12	12	12	0.010	0.004	-0.003	-0.011
119159 *	5.997	0.006	0.022	0.003	0.035	0.005	-0.048	0.004	11	11	11	-0.003	0.007	-0.001	-0.005
122980	4.355	0.006	-0.091	0.002	0.099	0.002	0.160	0.001	5	5	5	-0.005	0.001	0.008	-0.008
133955AB	4.057	0.002	-0.074	0.002	0.098	0.004	0.263	0.002	5	5	5	0.007	0.003	-0.003	-0.011
141637	4.644	0.007	0.011	0.002	0.069	0.003	0.123	0.005	19	19	12	-0.006	0.003	-0.001	0.004
144470	3.937	0.008	0.046	0.003	0.033	0.004	0.007	0.005	1	1	1	-0.003	0.013	-0.008	-0.015
145502AB	3.999	0.008	0.082	0.003	0.049	0.004	0.144	0.005	1	1	1	-0.011	0.007	-0.012	0.002
146624 *	4.786	0.002	-0.005	0.002	0.188	0.002	0.969	0.003	3	3	3	0.016	-0.012	0.014	0.004
148379 *	5.335	0.008	0.493	0.003	-0.115	0.004	0.028	0.005	1	1	1	-0.025	0.001	-0.035	0.011
148605	4.784	0.006	-0.044	0.002	0.090	0.002	0.192	0.006	2	2	2	-0.006	0.002	0.005	-0.010
148688AB *	5.293	0.008	0.350	0.003	-0.099	0.004	-0.042	0.005	1	1	1	0.003	-0.003	0.001	-0.007
149404 *	5.478	0.008	0.344	0.003	-0.033	0.004	-0.116	0.005	1	1	1	0.028	-0.001	0.005	-0.003
150136AB *	5.625	0.008	0.199	0.003	-0.021	0.004	-0.116	0.005	1	1	1	-0.025	0.004	0.020	0.006
152236 *	4.755	0.019	0.458	0.003	-0.122	0.005	-0.042	0.004	4	4	4	0.025	0.015	-0.045	0.012
152249 *	6.472	0.008	0.230	0.003	-0.024	0.004	-0.111	0.005	1	1	1	0.002	0.011	-0.005	-0.004
154090A *	4.852	0.038	0.273	0.001	-0.060	0.003	-0.030	0.009	3	3	3	0.012	0.012	-0.032	0.001
155450A *	5.983	0.008	0.140	0.003	-0.029	0.004	0.008	0.005	1	1	1	-0.017	0.004	-0.004	-0.007
224686	4.510	0.005	-0.025	0.003	0.099	0.005	0.881	0.005	8	8	8	0.010	0.004	-0.007	-0.005
224990AB	5.051	0.006	-0.067	0.004	0.107	0.004	0.448	0.004	21	21	15	0.011	-0.003	-0.002	-0.005

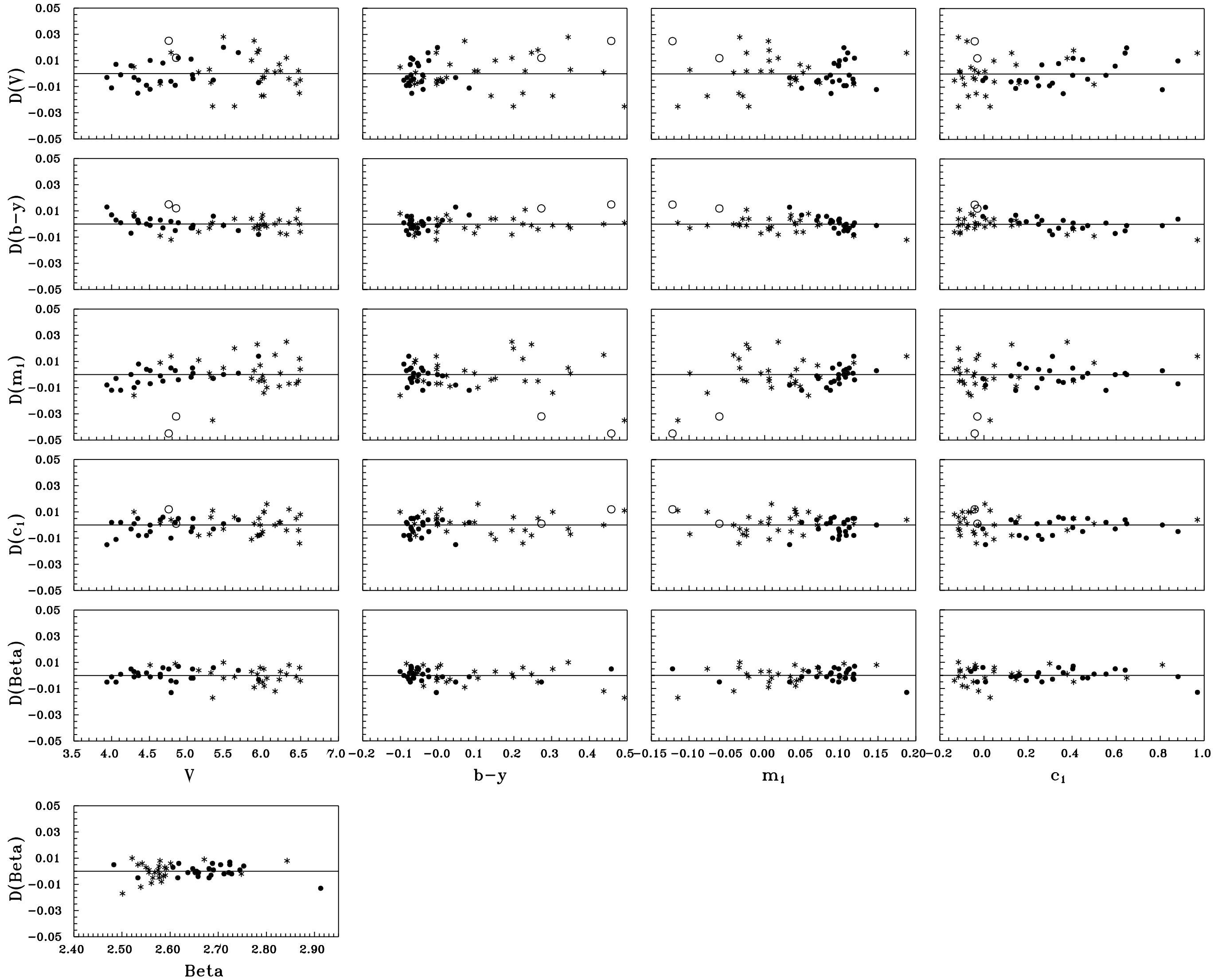

Fig. 1. D-residuals for the standard stars as functions of indices. The primary standards are marked with filled symbols and the secondary with asterisks. The two excluded standard stars are marked with open symbols.

2. Observing program

The catalogue of Stephenson & Sanduleak (1971), the data-base of Reed (1996) on luminous stars, and the $uvby\beta$ compilation of Hauck & Mermilliod (1998) were used in selecting the targets. The observations were designed to extend the existing $uvby\beta$ data of LS brighter than 9.5 mag in the field implicitly defined by LS catalogues from $l = 215^\circ$ to $l = 275^\circ$ and brought its completeness to about 98%.

The standard stars were chosen as follows. 1) From Crawford & Barnes (1970), 23 primary $uvby$ standards on the hot side of the Balmer maximum were selected. Most of these stars are also primary β standards (cf. Crawford & Mander 1966). 2) Since most of the primary standards show only moderate amounts of reddening, secondary $uvby$ standards with a larger range in reddening must be added. Another equally important consideration was the range of β covered by the primary standards. There are only a few with $\beta < 2.6$ (indicating e.g. Balmer line emission). From a compilation of major $uvby\beta$ catalogues (cf. Olsen 1988), 30 secondary standards were chosen to deal with both problems.

3. Observations and reductions

3.1. Observing procedures

All observations in the present catalogue were made by the SAT in its fully-automatic mode during ten nights in December 1997 – January 1998. Details about the spectrometer, the observing procedure, and the fully-automatic mode are given by Olsen (1993, 1994).

A circular diaphragm of 17″ was used. The number of photoelectrons counted was 100,000 in the y-channel and 70,000 in the $\beta_{\rm narrow}$-channel, except for a few of the faintest stars. The background was measured at each program star at a fixed offset.

Table 2. Catalogue of 50 standard stars (primary and secondary) on the Crawford-Mander standard β system. Secondary standard stars are marked by an asterisk. Column 3 gives the internal rms error of one observation (weight 1). NN, W, and D as in Table 1. Units: 1 mag.

HD	β	m.e.	W	NN	D(β)
16908	2.688	0.004	8	6	0.006
17081	2.724	0.004	7	7	0.005
23288 *	2.748	0.006	19	11	-0.002
23324	2.753	0.007	16	9	0.004
24587	2.745	0.004	20	12	0.001
34816	2.606	0.003	23	12	0.003
36591AB	2.618	0.005	24	12	0.006
39764	2.724	0.005	24	12	0.007
40494A	2.647	0.003	23	12	0.002
48434 *	2.561	0.002	6	6	-0.009
50820 *	2.539	0.008	6	6	-0.012
51283 *	2.592	0.004	6	6	0.002
52382 *	2.542	0.005	5	5	0.006
53244	2.690	0.004	11	11	0.001
53975 *	2.586	0.007	6	6	-0.004
54662 *	2.589	0.008	6	6	0.003
54764A *	2.578	0.007	6	6	-0.002
55879 *	2.582	0.003	5	5	-0.008
60325 *	2.590	0.009	6	6	-0.003
61831 *	2.671	0.004	24	12	0.009
70839 *	2.601	0.005	7	7	0.006
74280	2.652	0.004	24	13	-0.001
74753 *	2.577	0.003	7	7	0.004
83754	2.705	0.005	24	13	0.005
83944 *	2.843	0.004	23	12	0.008
84567 *	2.556	0.007	7	7	-0.001
86606 *	2.579	0.007	11	11	0.008
90994	2.728	0.004	10	10	-0.002
100600AB	2.685	0.006	14	10	-0.003
105071 *	2.575	0.009	8	8	0.001
105382	2.681	0.004	19	13	0.002
106068 *	2.564	0.008	8	8	-0.005
111973 *	2.556	0.007	7	7	0.001
115842 *	2.533	0.007	6	6	0.005
116084 *	2.550	0.007	6	6	0.003
119159 *	2.577	0.007	6	6	-0.005
122980	2.655	0.001	3	3	0.000
133955AB	2.681	0.003	3	3	-0.005
141637	2.637	0.006	5	5	-0.001
144470	2.616	0.005	1	1	-0.005
145502AB	2.659	0.005	1	1	-0.001
146624	2.913	0.001	2	2	-0.013
148379 *	2.501	0.005	1	1	-0.017
148605	2.658	0.004	2	2	-0.004
149404 *	2.521	0.005	1	1	0.010
150136AB *	2.568	0.005	1	1	-0.001
152236	2.483	0.006	3	3	0.005
154090A	2.533	0.000	2	2	-0.005
224686	2.722	0.003	4	4	-0.001
224990AB	2.712	0.004	6	6	-0.002

Table 5. Overall internal rms errors of one observation (weight 1) in both the instrumental systems (i-sys) and standard systems (s-sys). Results are given for both standard stars and program stars and are based on all 22 $uvby$ and 13 β nights mentioned above. Unit: 0.001 magnitudes. n is the number of residuals included in the computation. A few observations deviating more than 4 times the rms error or with airmass larger than 1.8 were excluded.

		V	n(V)	$b-y$	m_1	c_1	n($uvby$)	β	n(β)
i-sys	st.stars	7.9	789	2.5	3.8	4.8	790	3.8	463
	pr.stars	9.2	1262	4.4	6.6	7.6	1272	5.9	323
s-sys	st.stars	7.9	789	2.6	4.0	5.0	790	4.9	463
	pr.stars	9.2	1262	4.6	6.9	8.0	1275	7.5	323

3.2. *Instrumental systems*

Before reductions, several sky measurements from a small area of the sky, and contiguous in time, were combined and then used on all stars in the area. Sky measurements contaminated by faint stars were eliminated in this process.

The instrumental systems of the SAT were computed, following the procedure outlined by Olsen (1993). The $uvby$ system is based on 22 nights and the β system is based on 13 nights in the period mentioned above. For all nights, second-order night corrections have been applied.

3.3. *Transformations to the standard systems*

For the 30 secondary standards, the photometry from the sources referred to by Olsen (1988) was adopted as standard, i.e. it essentially defines the $uvby$ system for reddened OB-stars and the β system for β values below 2.6.

Olsen (1983) discussed a probable systematic error in the photometry of the so-called SH stars among the primary $uvby$ standards. He suggested certain small corrections to this subset of the primary standards. Most of the 30 secondary standards used here have photometry from Crawford et al. (1971) and probably suffer from the same systematic error. Therefore, the corrections suggested by Olsen (1983) were also applied to the photometry of these stars.

Two of the secondary standards (HD 152236 and 154090A) were only used as β standards (cf. their D residuals in Table 1).

All standard stars were given equal weights in the least-squares solutions, which determine the following transformation equations:

$$\begin{array}{rrrll}
V = & 16.456 & +0.053 & (b-y) + y_{\rm i}, & \sigma = 0.012 \\
 & \pm 2 & \pm 11 & & \\
b-y = & 1.036 & +1.033 & (b-y)_{\rm i}, & \sigma = 0.0050 \\
 & \pm 1 & \pm 5 & & \\
m_1 = & -0.691 & +1.031 & m_{\rm i} - 0.039 \;\; (b-y), & \sigma = 0.0102 \\
 & \pm 4 & \pm 48 & \;\;\;\;\;\; \pm 20 & \\
c_1 = & -0.647 & +1.010 & c_{\rm i} + 0.158 \;\;\; (b-y), & \sigma = 0.0073 \\
 & \pm 1 & \pm 4 & \;\;\;\;\;\; \pm 7 & \\
\beta = & 2.521 & +1.274 & \beta_{\rm i}, & \sigma = 0.0047, \\
 & \pm 20 & \pm 8 & &
\end{array}$$

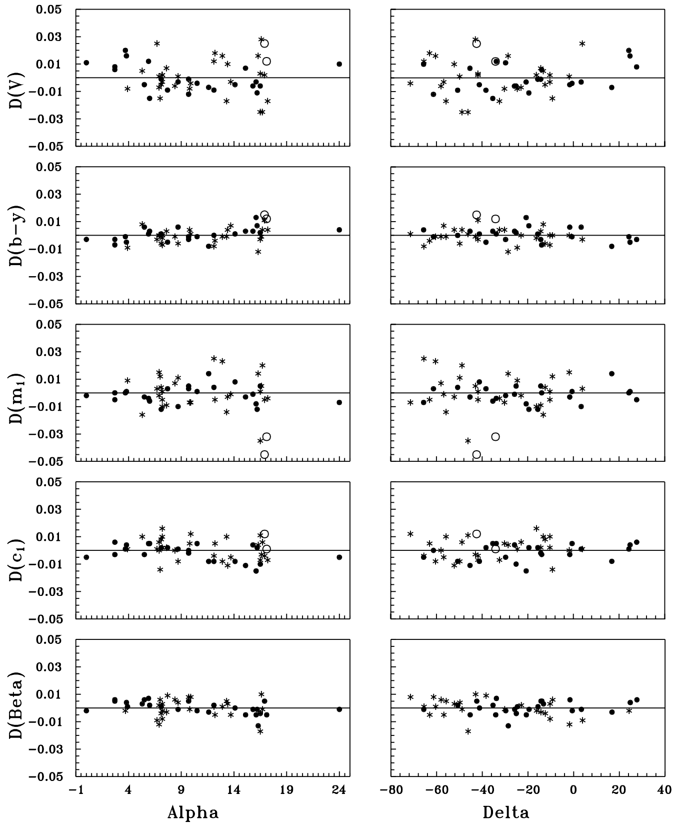

Fig. 2. D-residuals for the standard stars as functions of the coordinates α and δ. The symbols are the same as in Fig. 1.

where subscript i refers to the instrumental systems and σ is the standard deviation. A comparison with the transformation coefficients determined earlier for B, A, and F-type main-sequence stars (Olsen 1993, Table 7) shows several significant differences. This is not surprising, considering the luminous and partly reddened nature of the OB standards used here.

4. Results

The catalogue of $uvby$ standard stars transformed to the standard system is given in Table l. Five supergiant B-stars and one O-star are possible variables (HD 106068, 111973, 115842, 116084, 152236, and 154090A). Table 2 gives the catalogue of Hβ standards transformed to the standard system. Figs. 1 and 2 present the D-residuals from Tables 1 and 2 as functions of indices and coordinates α and δ. From these figures, we conclude that there are no systematic trends in the residuals, and that the photometry is indeed on the standard systems.

In Table 3, the catalogue of Strömgren $uvby$ photometry for 127 program stars is given. Table 4 presents Hβ photometry for 25 program stars. The $uvby$ indices are extrapolated for 10 program stars: LS 591 (spectral type sd:O), 145, LS VI -07 3 (HD 54024), 239, 721, 1172, 1212, 1216, 1230 and 1268. LS 617 and 343 have extrapolated β indices. Table 5 gives a summary of the overall internal rms errors of the photometry.

The data presented here are discussed elsewhere (Kaltcheva & Hilditch 1999).

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