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

II. Monoceros OB2, Canis Major OB1 and Collinder 121*,**

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Abstract. Strömgren and Hβ photometry of O and B type stars, generally brighter than 10 mag is presented for the fields of the galactic OB associations Monoceros OB2, Canis Major OB1 and Collinder 121. The observations are based on the PPM catalogue identifications and are designed to improve the completeness of the existing $uvby\beta$ data for the bright early-type stars in these fields. We present new $uvby$ photometry for 343 stars and Hβ photometry for 213 of them. These observations are part of our effort to study the structure of selected star-forming regions in the Milky Way, utilizing $uvby\beta$ photometry.

Key words: stars: early-type – Galaxy: open clusters and associations: individual: Mon OB2, CMa OB1, Col 121

1. Introduction

The present paper is part of a long-term project of studying the structure of selected star-forming regions and the stellar content of the related young stellar groups. The first results were given by Kaltcheva & Olsen (1999, Paper I). Here we include three fields, centered at the galactic OB associations Mon OB2, CMa OB1 and Col 121. The coordinates of the fields observed are given below:

Field	Mon OB2	CMa OB1	Col 121
l°	202 to 211	219 to 229	231 to 240
b°	2.5 to -6.7	3.6 to -6	-5.6 to -14.8
$\alpha(h:m)$	6:12 to 6:50	6:48 to 7:26	6:33 to 7:15
$\delta(^\circ)$	0 to 9	-5.4 to -14.4	-20 to -29

Both CMa OB1 and Col 121 were studied by de Zeeuw et al. (1999) on the basis of the Hipparcos catalogue (ESA 1997). The field of Mon OB2, observed here, is partly overlapping with the field of Mon OB1, discussed by the same authors.

According to the Hipparcos data, the OB association Col 121 has completely changed its appearance compared to the classical membership list. On the other hand, the young stars in the direction of CMa OB1 are beyond the Hipparcos limits and the astrometric evidence for moving groups there is inconclusive (de Zeeuw et al. 1999). The OB association Mon OB2 is also apparently beyond the Hipparcos limits and the field is not astrometrically investigated.

The observations presented in this paper were performed with the Strömgren Automatic Telescope (SAT) of the Copenhagen Astronomical Observatory at La Silla during 23 nights in November - December 1998. The aim of our efforts is to collect as much photometry as possible for the early-type stars in these fields for further investigation of their structure and stellar content.

2. Observations and reductions

The selection of the targets is based on the PPM catalogue (Bastian & Röser 1993, Röser & Bastian 1988), including all stars of spectral types O and B in the fields. The stars with $uvby\beta$ data in the compilation of Hauck & Mermilliod (1998) were excluded from the list of targets. In this way, 343 stars without $uvby$ photometry and 213 without Hβ photometry were selected.

For the field of Mon OB2, our sample consists of 112 stars for $uvby$ and 88 for Hβ photometry.

The field of CMa OB1 was observed earlier (cf. Paper I), utilizing for the purpose the catalogue of Stephenson & Sanduleak (1971) and the data-base of Reed (1996) on luminous stars. Here, 123 additional stars for $uvby$ and 54 for Hβ are included, mainly in the spectral range of mid-B subtypes.

In the field of Col 121, 108 stars for $uvby$ photometry and 74 stars for Hβ photometry were selected. According to de Zeeuw et al. (1999), 87 O and B-type astrometric members of Col 121 are recognized, and two subgroups at $(l,b) = (233^\circ, -9^\circ)$ and $(l,b) = (238^\circ, -9^\circ)$ are suggested on the basis of the Hipparcos proper motions. We obtained $uvby$ photometry of 25 Hipparcos members and Hβ photometry of 12 of them. With the photometry available in the Hauck & Mermilliod (1998) compilation, the $uvby\beta$ data for the Hipparcos O and B-type members of the

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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 36 standard stars 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	4.663	0.006	-0.053	0.003	0.099	0.006	0.342	0.004	18	18	10	-0.007	-0.001	0.002	0.009
17081	4.252	0.003	-0.046	0.002	0.093	0.003	0.601	0.004	23	23	13	0.002	-0.001	-0.005	0.002
23288	5.471	0.005	-0.006	0.002	0.120	0.004	0.643	0.003	20	20	10	0.011	-0.005	0.015	-0.004
23324	5.667	0.005	-0.030	0.002	0.129	0.005	0.635	0.004	20	20	10	0.007	-0.008	0.020	-0.002
24587 *	4.639	0.007	-0.061	0.002	0.119	0.003	0.503	0.005	26	26	15	-0.011	-0.007	0.010	0.004
34816 *	4.296	0.003	-0.097	0.001	0.049	0.003	-0.056	0.003	28	28	15	0.006	0.012	-0.025	0.013
36591AB	5.341	0.004	-0.073	0.002	0.079	0.002	-0.009	0.003	28	28	15	-0.009	0.004	0.005	-0.007
39764	4.889	0.008	-0.071	0.001	0.123	0.002	0.409	0.005	23	23	12	0.019	0.002	-0.000	0.009
40494A	4.361	0.004	-0.065	0.001	0.079	0.002	0.362	0.002	27	27	14	0.001	0.008	-0.015	0.007
48434 *	5.873	0.006	0.068	0.003	0.007	0.004	-0.081	0.003	12	12	12	0.013	-0.005	0.005	-0.003
50820 *	6.163	0.003	0.439	0.003	-0.051	0.007	-0.013	0.006	11	11	11	0.003	0.001	0.005	0.012
51283 *	5.309	0.004	-0.056	0.001	0.078	0.002	0.153	0.002	11	11	11	-0.011	-0.002	0.003	-0.000
52382 *	6.497	0.006	0.224	0.003	-0.041	0.007	-0.036	0.009	5	5	5	-0.003	0.000	0.005	-0.015
53244	4.117	0.003	-0.034	0.002	0.073	0.003	0.561	0.003	37	37	15	-0.003	0.008	-0.026	0.009
53975 *	6.494	0.002	-0.008	0.004	0.048	0.006	-0.140	0.003	11	11	11	-0.006	-0.010	0.010	0.002
54662 *	6.227	0.002	0.092	0.002	-0.002	0.004	-0.114	0.003	11	11	11	-0.003	-0.011	0.004	-0.003
54764A *	6.044	0.006	0.103	0.001	0.009	0.003	-0.002	0.003	11	11	11	-0.006	-0.004	-0.010	0.010
55879 *	6.020	0.003	-0.043	0.002	0.050	0.003	-0.106	0.003	11	11	11	-0.000	-0.004	0.004	0.002
60325 *	6.217	0.004	0.028	0.002	0.053	0.003	0.140	0.002	11	11	11	0.007	-0.000	-0.003	-0.004
61831	4.842	0.004	-0.084	0.001	0.110	0.004	0.292	0.004	26	26	14	-0.008	-0.005	0.008	-0.004
70839 *	5.965	0.003	-0.003	0.002	0.075	0.003	0.041	0.003	12	12	12	-0.005	-0.002	0.012	-0.006
74280	4.299	0.003	-0.077	0.002	0.076	0.004	0.243	0.003	41	41	14	-0.001	0.011	-0.016	0.003
74753 *	5.153	0.003	-0.060	0.001	0.049	0.002	-0.112	0.002	12	12	12	0.003	-0.006	0.009	-0.012
83754	5.072	0.005	-0.072	0.001	0.120	0.002	0.397	0.005	22	22	14	0.002	-0.003	0.013	-0.008
83944	4.513	0.002	-0.036	0.001	0.147	0.003	0.809	0.002	25	25	14	-0.007	0.003	0.002	-0.001
84567 *	6.448	0.007	-0.008	0.003	0.039	0.006	-0.097	0.005	11	11	11	-0.002	0.000	-0.002	-0.003
86606 *	6.349	0.005	0.003	0.003	0.045	0.004	-0.050	0.004	14	14	14	-0.001	-0.002	-0.002	0.002
90994	5.080	0.006	-0.064	0.002	0.124	0.004	0.469	0.004	22	22	13	0.000	0.000	0.008	0.003
100600AB	5.964	0.004	-0.076	0.002	0.125	0.003	0.302	0.004	1	1	1	0.014	-0.006	0.021	-0.017
105071 *	6.287	0.010	0.202	0.003	0.000	0.005	0.376	0.005	6	6	6	-0.013	-0.001	0.007	-0.006
105382	4.476	0.006	-0.068	0.001	0.096	0.002	0.255	0.004	15	15	14	0.006	0.008	-0.008	-0.001
106068 *	5.937	0.005	0.273	0.003	-0.015	0.003	0.405	0.006	4	4	4	0.007	0.005	-0.026	0.003
111973 *	5.970	0.004	0.258	0.002	-0.049	0.003	0.131	0.004	1	1	1	0.000	0.010	-0.002	-0.003
133955AB	4.061	0.004	-0.059	0.002	0.074	0.003	0.271	0.004	1	1	1	0.011	0.018	-0.027	-0.003
224686	4.508	0.004	-0.020	0.002	0.095	0.004	0.881	0.003	8	8	8	0.008	0.009	-0.011	-0.005
224990AB	5.041	0.006	-0.066	0.002	0.115	0.003	0.448	0.002	23	23	13	0.001	-0.002	0.006	-0.005

two subgroups is complete, except for four stars belonging to the PPM catalogue supplement (Röser et al. 1994).

The selection of standard stars was described in detail in Paper I. Only a subsample of the standards were used for this paper.

2.1. Observing procedures

All observations in the present catalogue were made by the SAT in its fully-automatic mode. 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.

2.2. 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 15 nights and the β system is based on 14 nights in the period mentioned above. For all nights, second-order night corrections have been applied.

Table 2. Catalogue of 35 standard stars 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	2.680	0.002	20	11	-0.002
17081	2.722	0.003	10	10	0.003
23288 *	2.739	0.003	22	11	-0.011
23324	2.742	0.004	22	11	-0.007
23850AB	2.696	0.000	2	2	-0.001
24587	2.744	0.002	26	14	-0.000
34816	2.606	0.002	29	14	0.003
36591AB	2.617	0.003	29	14	0.005
39764	2.721	0.003	26	12	0.004
40494A	2.649	0.002	28	13	0.004
48434 *	2.562	0.006	5	5	-0.008
50820 *	2.537	0.004	4	4	-0.014
51283 *	2.589	0.002	4	4	-0.001
52382 *	2.532	0.006	4	4	-0.004
53244	2.691	0.002	13	12	0.002
53975 *	2.588	0.001	4	4	-0.002
54662 *	2.588	0.004	4	4	0.002
54764A *	2.574	0.003	4	4	-0.006
55879 *	2.583	0.003	4	4	-0.007
60325 *	2.593	0.005	4	4	-0.000
61831 *	2.673	0.002	26	13	0.011
70839 *	2.605	0.003	5	5	0.010
74280	2.652	0.002	22	12	-0.001
74753 *	2.582	0.003	5	5	0.009
83754	2.704	0.002	18	12	0.004
83944 *	2.840	0.003	22	13	0.005
84567 *	2.560	0.005	5	5	0.003
86606 *	2.580	0.004	14	13	0.009
90994	2.726	0.002	6	6	-0.004
100600AB	2.684	0.001	4	2	-0.004
105382	2.682	0.002	17	12	0.003
122980	2.655	0.003	1	1	0.000
133955AB	2.681	0.003	1	1	-0.005
224686	2.725	0.002	11	10	0.002
224990AB	2.710	0.002	13	12	-0.004

2.3. Transformations to the standard systems

For the 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 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 primary standards (HD 100600AB and 133955AB) were only used as β standards since they have only one $uvby$ observation each (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:

$$
\begin{aligned}
V &= 17.330 \pm 1 + 0.035 \pm 10\ (b-y) + y_{\rm i}, && \sigma = 0.0074\\
b-y &= 1.082 \pm 1 + 1.051 \pm 8\ (b-y)_{\rm i}, && \sigma = 0.0058\\
m_1 &= -0.735 \pm 5 + 1.129 \pm 64\ m_{\rm i} - 0.072 \pm 27\ (b-y), && \sigma = 0.0102\\
c_1 &= -0.633 \pm 2 + 1.009 \pm 4\ c_{\rm i} + 0.168 \pm 9\ (b-y), && \sigma = 0.0065\\
\beta &= 2.520 \pm 30 + 1.230 \pm 11\ \beta_{\rm i}, && \sigma = 0.0048,
\end{aligned}
$$

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. A comparison with the coefficients determined in Paper I, valid also for OB stars, but referring to the SAT one year earlier, shows little change in the transformations, except for m_1. However, the two m_1 transformations show the highest rms errors in the coefficients and within these errors they agree. (The large change in zero-point for the V transformation is due to a re-aluminization of the primary mirror.)

As in Paper I, the residuals were investigated as functions of indices and coordinates. A few marginal systematic trends may be present, but since the set of standards used here is a subset of the standards used in Paper I, where no systematic trends were present, these marginal trends have been deemed insignificant.

3. Results

The catalogue of $uvby$ standard stars, transformed to the standard system is given in Table l. Two supergiant B stars, HD 52382 and 106068, are possibly variable. For these two stars, six observations showing 0.02–0.04 mag residuals in V have been deleted. The standard V value for HD 111973 was arbitrarily changed by 0.06 mag to match our observation. It is probably also variable. One observation of the secondary standard star HD 115842 deviates appreciably from the photometry reported in Paper I and was deleted. Table 2 gives the catalogue of β standards transformed to the standard system.

In Table 3, the catalogue of Strömgren $uvby$ photometry for 343 program stars is given. Eleven program stars are redder than the reddest standard star at b-y=0.438, and their data are based on extrapolation of the transformations. Similarly, one star is bluer than the bluest standard star at b-y = -0.109.

Table 4 gives Hβ photometry for 213 program stars. Two program stars have data extrapolated below β=2.5 and 21 are extrapolated above β=2.84.

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 15 $uvby$ and 14 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	4.5	519	1.7	2.8	3.5	518	2.1	421
	pr.stars	4.9	834	3.4	5.2	6.0	857	5.1	512
s-sys	st.stars	4.5	519	1.8	3.3	3.6	518	2.6	421
	pr.stars	4.8	834	3.6	6.1	6.1	857	6.2	512

A summary of the overall internal rms errors of the photometry is presented in Table 5. They are much smaller than the same errors given in Paper I for the previous season with the SAT on Cerro La Silla, Chile. Since the number of photo-electrons counted per observation was the same, the large improvement in quality is probably due more to the cessation of El Niño activity than to the re-aluminization of the primary mirror.

The data presented here will be discussed in forthcoming papers.

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