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Secondary standard stars for *uvbyβ* CCD photometry[⋆,⋆⋆]

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Abstract. Accurate standard *uvby* indices are presented for 73 southern B, A, F and G stars in the V magnitude range 8.2 to 10.9. They cover all three transformation regions of the *uvby* system (Olsen 1983) well. Standard β indices are included for the 55 B, A, and F stars in the sample. Our results provide a useful set of secondary standards for *uvbyβ* CCD photometry with southern hemisphere $1-2$ m class telescopes. A critical comparison with published photometry, in general based on fewer observations, is given.

Key words: Strömgren photometry — astronomical data bases: miscellaneous — stars: fundamental parameters — stars: general

1. Introduction

The Strömgren *uvbyβ* photometric system is widely accepted as one of the astrophysically most well calibrated photometric systems available. Numerous $T_{\rm e}$, $\log g$, [Me/H], microturbulence and interstellar reddening calibrations have been published through the years, covering all together wide ranges in spectral type and luminosity class. Its carefully selected narrow-intermediate wavelength bands make the system suitable for detailed investigations of single stars, including variables, binaries and clusters, as well as for studies of the structure and evolution of the Milky Way and nearby galaxies.

With present days extended use of CCD's accurate photometry can be obtained for quite faint objects, but one of the new challenges is to bring the data to the standard system through reliable transformations based on CCD observations of a sufficient number of carefully selected standard stars. In the case of the *uvbyβ* system the situation unfortunately is that the primary standard stars (Crawford & Mander 1966; Crawford & Barnes 1970; Grønbech et al. 1976; Olsen 1983; Perry et al. 1987; Olsen 1993) are too bright for most CCD observations, and a complete enough sample of fainter secondary standards, as available for *UBVRI* photometry (Landolt 1992), has furthermore not yet been established. Lists of candidates, often created for a specific project, are available (see e.g. Sect. 2), but for various reasons they often turn out to be insufficient for other investigations. This was the case for an ongoing project on eclipsing binaries and population studies in the Magellanic Clouds (MC). We have therefore decided, as an integrated part of the project, to establish new accurate standard *uvbyβ* indices for a wide grid of stars which could serve as secondary standard stars. They were observed together with numerous primary standards, and our results are presented in Table 5. Selection and observation of the candidates, transformation to the standard system, and a comparison with published photometry is presented in the following sections.

2. Selection of secondary standards

As the CCD *uvbyβ* observations for the MC projects mentioned above are carried out at the Danish 1.5 m telescope at La Silla, it was decided to establish the set of secondary standards through simultaneous observations at the small fully automatic Danish 50 cm photometric telescope (Strömgren Automatic Telescope or SAT), also located at La Silla. The procedure has the additional advantage of saving observing time at the 1.5 m telescope, since the nightly extinction can be measured both more accurately and easier at SAT. For our telescope combination stars in the magnitude interval $8.5-11$ are optimal

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[⋆] Based on observations made at the European Southern Observatory, La Silla, Chile.

[⋆⋆] Tables 3, 4, 5 are also available 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

Table 1. Extinction coefficients

JD	$k(y)$	m.e.	$k(b-y)$	m.e.	$k(m_1)$	m.e.	$k(c_1)$	m.e.	$k(b)$	m.e.	$k(v)$	m.e.	$k(u)$	m.e.
2449316	0.149	12	0.046	4	0.058	4	0.127	9	0.194	13	0.298	15	0.529	19
2449317	0.137	5	0.054	3	0.052	4	0.128	5	0.190	4	0.296	5	0.529	7
2449318	0.138	7	0.054	3	0.047	3	0.140	6	0.192	9	0.294	11	0.535	12
2449319	0.124	8	0.061	4	0.047	4	0.126	6	0.185	8	0.294	8	0.529	9
2449320	0.142	6	0.055	3	0.051	4	0.128	8	0.197	6	0.304	7	0.538	8
2449630	0.135	32	0.072	7	0.045	4	0.146	7	0.207	35	0.324	42	0.588	50
2449631	0.133	5	0.062	3	0.050	4	0.136	7	0.195	6	0.307	8	0.555	14
2449632	0.125	11	0.060	3	0.047	5	0.138	4	0.185	10	0.293	12	0.537	11
2449633	0.120	15	0.059	4	0.052	6	0.129	7	0.179	16	0.289	17	0.528	18
2449634	0.130	5	0.061	3	0.046	4	0.125	6	0.190	4	0.297	5	0.529	9
2449637	0.171	9	0.051	5	0.069	10	0.123	15	0.222	10	0.342	15	0.585	20
2449638	0.132	12	0.046	3	0.068	6	0.130	13	0.178	13	0.291	16	0.534	23
2449650	0.138	16	0.046	5	0.071	5	0.118	7	0.184	18	0.301	21	0.536	24
2450030	0.135	6	0.042	3	0.076	5	0.117	7	0.177	6	0.295	7	0.529	10
2450031	0.141	4	0.046	3	0.077	6	0.101	6	0.187	4	0.310	5	0.535	8
2450032	0.138	6	0.040	4	0.074	6	0.117	6	0.178	8	0.292	9	0.523	11
2450033	0.116	7	0.050	3	0.064	6	0.110	6	0.165	7	0.279	9	0.502	14
2450034	0.129	11	0.040	3	0.079	5	0.114	7	0.169	11	0.289	10	0.522	12
2450035	0.117	6	0.044	3	0.075	8	0.111	7	0.161	9	0.281	8	0.512	9
2450036	0.136	5	0.051	2	0.061	2	0.133	20	0.187	5	0.299	6	0.544	18
2450037	0.131	6	0.047	5	0.073	10	0.122	10	0.178	8	0.298	6	0.540	11
2450038	0.129	7	0.047	4	0.067	10	0.129	10	0.176	8	0.290	9	0.533	15
2450039	0.138	5	0.053	3	0.063	5	0.121	5	0.191	5	0.306	6	0.542	7
2450040	0.160	11	0.055	5	0.065	7	0.124	8	0.215	15	0.335	15	0.580	18

Table 2. Transformation coefficients. Mean values of scale and colour term $(b-y)$ coefficients are given; see Grønbech et al. (1976) for the notation. Zero points were determined independently for each night. K is the coefficient to β_{inst} in the linear β transformations. N_{std} is the number of standard stars observed during each period

uvby	1993(BAF)	1994(BAF)	1995(BAF)	1995(GK V)	1995(GK III)
B	0.019	0.018	0.046	0.046	0.046
D	1.019	1.022	0.956	0.926	1.003
F	0.957	0.955	1.102	1.059	0.896
H	1.014	1.026	1.096	1.065	0.832
I	0.133	0.139	0.252	0.229	0.320
J	0.005	0.002	0.005	0.038	0.039
N_{std}	38	31	10	20	8
β	1993(B)	1993(A)	1994(B)	1994(A)	
K	1.256	1.305	1.240	1.341	
N_{std}	16	22	11	20	

as secondary standards; see also Jønch-Sørensen (1993) for further comments.

In order to cover a wide range of the HR diagram we have select candidates from several lists of stars with published *uvbyβ* indices. The number of previous observations per stars is often low, and as different transformation procedure have furthermore been applied, it was decided to re-observe all candidates together with an extensive net of primary standards, and thereby both increase the internal accuracy and also secure homogeneity in the transformations.

B stars were selected mainly from Knude (1992), who presented *uvbyβ* photometry for 528 stars in the V range 8 to 9 based on at least two (but always few) observations per object. Knude used B, A, F and G standards for the transformation without any separation in groups like those defined by Olsen (1983).

A and F stars were selected from the partly overlapping studies of E-region stars by Jønch-Sørensen (1993), which includes *uvbyβ* results for 64 stars, and by Kilkenny & Laing (1992), which contains *uvby* data for 201 stars. E-region G and K giants were taken also from

Table 3. Catalogue of transformed *uvby* indices for the observed primary standard stars. T is the *uvby* transformation region: A (BAF), D (GKV), G (GKIII). N is the number of observations; the internal rms errors of one observation (m.e.) are given. The last four colums give the differences d = standard value - transformed value in units of 0.001 mag

HD	T	N	V	m.e.	$b-y$	m.e.	m_1	m.e.	c_1	m.e.	$d(V)$	$d(b-y)$	$d(m_1)$	$d(c_1)$
2262	A	23	3.946	0.006	0.091	0.003	0.202	0.003	0.916	0.007	−6	12	−8	−9
4628	D	28	5.727	0.005	0.514	0.003	0.415	0.006	0.255	0.006	3	−5	8	1
10476	D	24	5.241	0.006	0.491	0.003	0.366	0.007	0.300	0.005	−1	1	−2	−6
11171	A	12	4.658	0.010	0.205	0.003	0.192	0.004	0.640	0.008	2	7	−6	0
14214	A	33	5.600	0.004	0.371	0.003	0.182	0.005	0.410	0.006	0	−3	8	−5
16160	D	19	5.792	0.003	0.550	0.004	0.518	0.008	0.261	0.005	−2	2	−3	10
17081	A	16	4.248	0.004	−0.051	0.002	0.106	0.003	0.597	0.006	2	6	−8	2
17094	A	31	4.273	0.010	0.183	0.003	0.193	0.003	0.751	0.008	−3	6	−6	11
17326	A	46	6.244	0.005	0.354	0.004	0.148	0.005	0.418	0.007	−4	2	−11	10
20165	D	28	7.812	0.006	0.503	0.004	0.408	0.009	0.290	0.006	−2	0	−4	6
21019	D	20	6.204	0.007	0.447	0.003	0.202	0.006	0.300	0.006	−4	4	−2	−2
21120	G	19	3.614	0.005	0.549	0.003	0.323	0.005	0.433	0.005	−14	−2	12	−9
21197	D	20	7.841	0.005	0.649	0.003	0.727	0.007	0.147	0.008	−1	−4	2	2
24587	A	16	4.638	0.008	−0.057	0.002	0.113	0.003	0.504	0.006	12	3	−4	−5
26462	A	24	5.708	0.010	0.230	0.004	0.165	0.004	0.595	0.008	2	1	−2	−3
27371	G	15	3.653	0.003	0.597	0.005	0.435	0.008	0.377	0.006	−3	−1	−8	11
28305	G	17	3.535	0.005	0.617	0.004	0.454	0.007	0.402	0.006	5	−1	−6	20
28307	G	15	3.841	0.004	0.580	0.004	0.389	0.006	0.387	0.007	9	0	1	2
30836	A	30	3.683	0.007	−0.055	0.002	0.075	0.002	0.128	0.004	−3	0	−5	3
32147	D	19	6.203	0.005	0.598	0.003	0.636	0.005	0.230	0.006	7	0	1	1
32923	D	16	4.912	0.005	0.411	0.005	0.195	0.011	0.335	0.008	−2	4	2	−3
33021	D	10	6.161	0.007	0.399	0.003	0.183	0.007	0.348	0.006	9	−2	3	1
34816	A	15	4.294	0.005	−0.103	0.002	0.068	0.003	−0.067	0.003	−4	−6	6	−2
36003	D	18	7.619	0.004	0.626	0.003	0.657	0.006	0.192	0.007	1	1	−2	−4
39764	A	10	4.876	0.015	−0.066	0.003	0.109	0.004	0.410	0.011	−6	−7	14	−10
40494	A	13	4.372	0.004	−0.070	0.002	0.089	0.004	0.362	0.005	−12	−3	5	−7
43318	A	14	5.622	0.004	0.323	0.003	0.152	0.004	0.448	0.006	−2	−2	3	−1
43358	A	13	6.362	0.005	0.300	0.005	0.144	0.006	0.482	0.007	8	−4	7	−6
43587	A	12	5.706	0.004	0.386	0.002	0.181	0.004	0.353	0.007	4	−1	6	−4
45067	A	35	5.875	0.004	0.362	0.003	0.163	0.005	0.401	0.006	−5	−2	8	−7
45610	D	15	7.177	0.003	0.522	0.003	0.180	0.006	0.322	0.008	3	4	−9	11
51199	A	18	4.663	0.004	0.238	0.002	0.159	0.004	0.636	0.006	−3	13	−7	5
52265	A	14	6.290	0.003	0.363	0.002	0.181	0.004	0.411	0.008	10	−5	13	−10
53244	A	12	4.112	0.004	−0.044	0.002	0.099	0.002	0.552	0.003	8	2	−0	0
59881	A	16	5.248	0.007	0.128	0.003	0.169	0.005	1.203	0.010	2	3	4	0
59984	A	19	5.924	0.005	0.357	0.004	0.124	0.006	0.336	0.008	6	−2	1	−1
61064	A	28	5.129	0.004	0.285	0.004	0.173	0.007	0.642	0.006	−9	4	−4	11
61831	A	12	4.840	0.009	−0.078	0.002	0.097	0.004	0.300	0.006	10	−1	5	−4
63077	A	11	5.360	0.005	0.378	0.003	0.132	0.005	0.279	0.010	0	−1	0	−2
69267	G	16	3.528	0.006	0.910	0.002	0.759	0.004	0.375	0.006	2	1	6	−8
70110	A	31	6.174	0.005	0.384	0.003	0.185	0.006	0.414	0.008	6	−3	0	−3
70958	A	8	5.596	0.007	0.311	0.002	0.137	0.004	0.398	0.006	4	0	2	0
71155	A	9	3.898	0.002	−0.015	0.003	0.161	0.004	1.027	0.009	2	10	−3	−3
74280	A	10	4.296	0.004	−0.083	0.003	0.090	0.003	0.240	0.005	4	−5	2	0
74395	G	7	4.628	0.005	0.513	0.004	0.295	0.004	0.492	0.004	2	6	−6	−16
76151	D	6	6.005	0.002	0.413	0.005	0.234	0.009	0.330	0.007	−5	5	−7	−2
76932	A	3	5.808	0.011	0.360	0.004	0.121	0.004	0.293	0.009	12	0	−4	10
81997	A	9	4.591	0.004	0.302	0.002	0.150	0.003	0.459	0.004	19	−6	14	−11
83754	A	5	5.065	0.005	−0.063	0.005	0.100	0.009	0.411	0.008	5	−6	7	−6
83944	A	3	4.504	0.003	−0.035	0.003	0.139	0.003	0.813	0.002	16	−4	6	−3

Table 3. continued

HD	T	N	V	m.e.	$b-y$	m.e.	m_1	m.e.	c_1	m.e.	$d(V)$	$d(b-y)$	$d(m_1)$	$d(c_1)$
105382	A	4	4.459	0.008	−0.070	0.003	0.099	0.004	0.254	0.007	11	−6	5	2
184915	A	9	4.963	0.010	0.093	0.004	−0.016	0.003	−0.040	0.006	−3	−14	2	18
195943	A	8	5.399	0.007	0.017	0.002	0.203	0.002	0.983	0.004	1	6	4	1
196378	A	8	5.119	0.006	0.358	0.006	0.137	0.005	0.384	0.003	1	−2	0	−2
200499	A	8	4.860	0.006	0.087	0.004	0.191	0.004	0.953	0.007	−20	4	−3	−12
200779	D	7	8.267	0.003	0.689	0.003	0.747	0.003	0.122	0.012	3	1	0	−7
202575	D	13	7.894	0.009	0.579	0.007	0.571	0.014	0.206	0.015	6	0	−3	0
203608	A	9	4.228	0.004	0.343	0.004	0.109	0.005	0.321	0.006	−8	−19	17	−6
204848	D	17	7.419	0.005	0.525	0.003	0.230	0.004	0.306	0.007	1	−1	2	−1
206859	G	10	4.340	0.008	0.708	0.004	0.485	0.008	0.361	0.009	0	1	−17	−7
210049	A	16	4.505	0.007	0.025	0.003	0.172	0.002	1.070	0.004	−5	2	2	6
210460	D	10	6.188	0.006	0.448	0.003	0.205	0.007	0.333	0.005	−8	−2	−3	−7
211998	D	18	5.280	0.003	0.451	0.003	0.114	0.007	0.233	0.006	0	2	−4	0
212943	G	10	4.794	0.004	0.639	0.002	0.414	0.005	0.431	0.007	6	−1	12	−7
214846	A	14	4.142	0.009	0.116	0.004	0.199	0.004	0.904	0.009	8	−3	1	−4
217014	D	15	5.452	0.007	0.419	0.004	0.225	0.009	0.375	0.007	−2	−3	7	−11
217987	D	19	7.333	0.003	0.938	0.003	0.507	0.006	0.144	0.007	−3	1	−2	3
221950	A	18	5.686	0.008	0.307	0.004	0.122	0.006	0.395	0.005	4	−1	0	−11
224617	A	31	4.031	0.006	0.267	0.003	0.162	0.003	0.623	0.007	−1	−1	−12	7
224686	A	17	4.501	0.005	−0.021	0.003	0.101	0.003	0.874	0.002	−1	−8	5	12
224930	D	14	5.750	0.006	0.434	0.005	0.176	0.010	0.221	0.011	0	−6	13	−6

Jønch-Sørensen (1993). 28 stars are included in both lists, and although different approaches have been applied in the transformation of the observations to the standard system, the *uvby* results are reported to agree well (Jønch-Sørensen 1993).

Finally a limited number of G and K dwarfs were selected from the extensive catalogues by Olsen (1993, 1994a).

3. Observation

As mentioned above the photoelectric observations were carried out with the fully automatic Danish 50 cm telescope (SAT) at La Silla (Florentin Nielsen et al. 1987; Sterken & Manfroid 1991; Sterken 1991). This telescope is permanently equipped with a six-channel spectrograph photometer and photon counting system for simultaneous measurements in *uvby* or β, respectively (Florentin Nielsen 1987). The pre-programmed observing procedure includes accurate centring at a target before (and often also between) the $2-3$ individual $10-120$ seconds integrations. Sky measurements of adequate duration, calculated from the angular distance to the Moon and from its phase, were included near each object. All data were obtained through a circular diaphragm of $17''$ diameter. Except for the u measurements of the faintest and reddest stars the photon shot noise (statistics of star plus sky) was kept at or below 0.5% per measurement.

The observations were carried out during November 1993, October 1994 and November 1995 (see Table 1). The 1993 and 1994 periods were devoted to *uvby* and β observations of B, A and F stars covering the $b-y$ range from -0.08 to 0.40 and the β range $2.58-2.90$, thereby providing secondary standards for the *uvby* "BAF region" (Olsen 1983) and the β "B and A regions" (Grønbech & Olsen 1977). In 1995 additional *uvby* photometry, but no β measurements, were obtained for some F stars in the $b-y$ range $0.25-0.40$, but the main effort was placed on the two transformation regions for G and K dwarfs and giants, respectively (Olsen 1983). This procedure was chosen in order to be able to include a large number of primary standards (and extinctions stars) for the relevant transformation regions every night. Typically $50-70$ observations of primary standards were done per night compared to about $40-50$ measurements on program star. The primary standard stars were selected from the references mentioned in Sect. 1.

4. Reduction and transformation

Individual extinction coefficients determined from a nights repeated observations of several primary standards passing through a wide airmass interval were used for the reduction of nearly all the data; well established mean values were used for the remaining $3-4$ nights. The coefficients are listed in Table 1 and may well be useful for other projects carried out at La Silla during the three observing periods; see also Burki et al. (1995) and references therein. When needed correction for drift through a night from temperature changes (uncooled photomultipliers) or gradually changing transparency was applied.

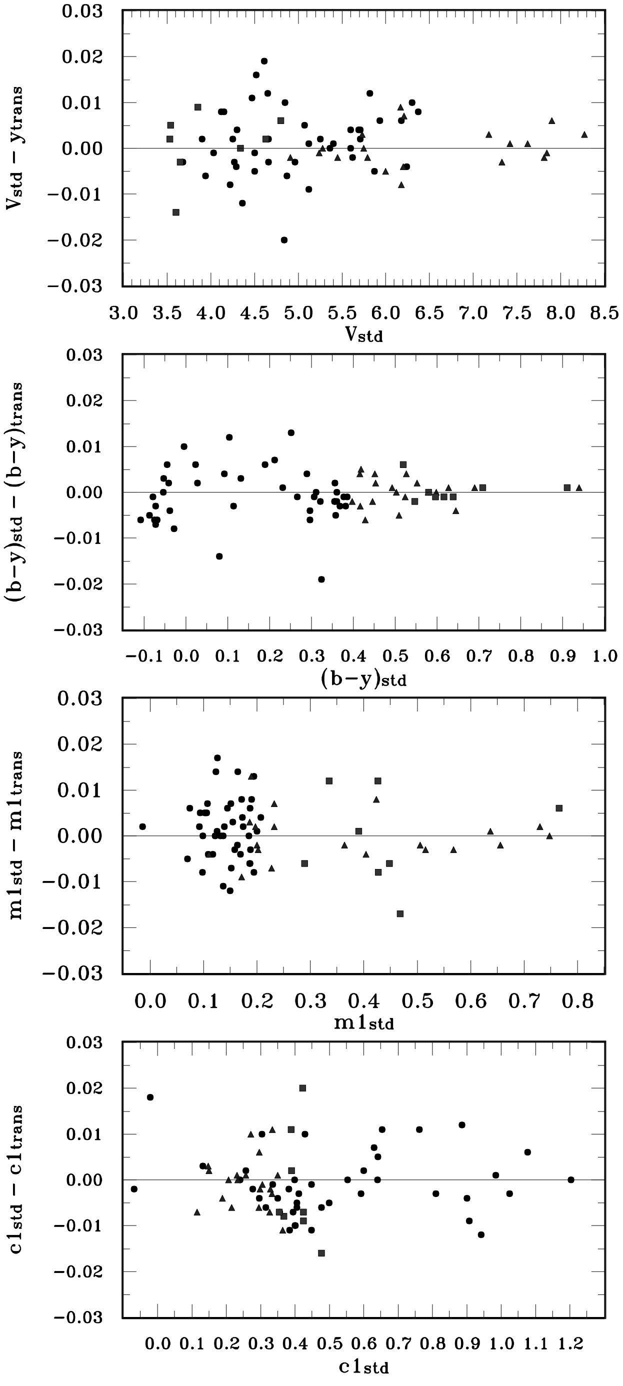

Fig. 1. Residuals (*uvby*) for the primary standard stars. The transformation regions are indicated by circles (BAF), triangles (GK V) and boxes (GK III), respectively

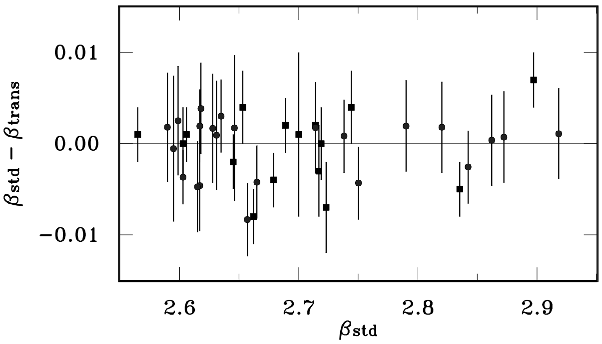

Fig. 2. Residuals (β) for the primary standard stars with error bars indicating the rms errors of one observation. The transformation regions are shown as circles (A) and boxes (B), respectively

For the transformation to the standard system we have adopted the three *uvby* regions defined by Olsen (1983) and the two β regions defined by Grønbech & Olsen (1977). Mean scale and colour coefficients, derived for each of the three observing periods, were used in combination with individual nightly zero points. The scale and colour coefficients are listed in Table 2, adopting the notation by Grønbech et al. (1976) and Grønbech & Olsen (1977). The alternative approach of using individual nightly transformations, i.e. both zero points and scale and colour coefficients, was tested. As expected this approach leads to nearly identical standard indices, since a complete set of primary standards was observed on (almost) every night.

The *uvby* transformations may be compared with those determined by Olsen (1993, Table 7) for observations 1985-1987 with the same instrumentation as used here. In general the scale and colour terms agree well. Slight differences are noticed for the 1995 BAF transformation. This is probably due to the fact that only standards with $b - y > 0.25$ were used during this period; we will return to this matter later. Jønch-Sørensen (1993) also used SAT but arrived at *uvby* transformations somewhat different from ours.

The scale coefficients of the β transformations agree well with those obtained for SAT 1991-92 by Jønch-Sørensen (1993) except for the 1993 coefficient for the late group (A) which appears slightly low. Gray & Olsen (1991) determined coefficients of 1.226 (B) and 1.298 (A) from observations with SAT 1987-88. Olsen (private communication) reports 1.316 (A) from 1988-89 data.

For each observing period the mean of the transformed indices for the primary standard stars have been compared with their standard values, and residual plots generally show that the transformations listed in Table 2 do in fact bring the data on the standard system. A few comments on the $b - y$ transformations are, however,

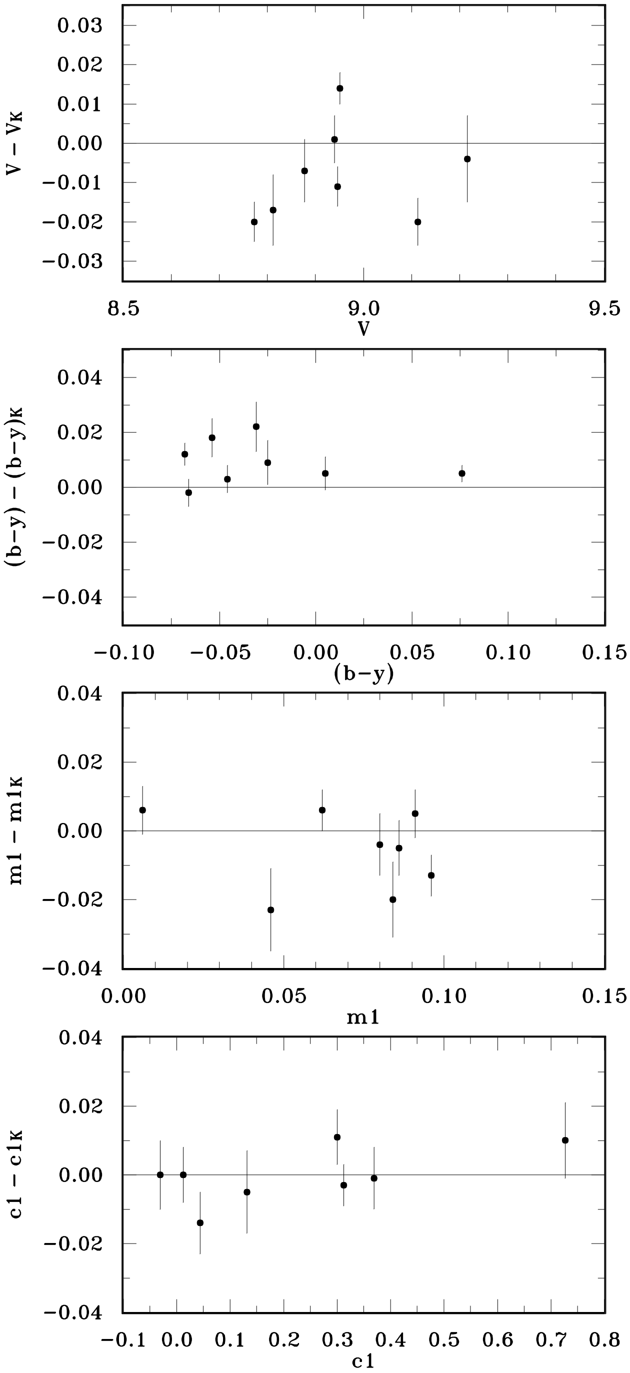

Fig. 3. Comparison (*uvby*) with the photometry of Knude (1992). The error bars indicate the rms errors of one observation (this paper)

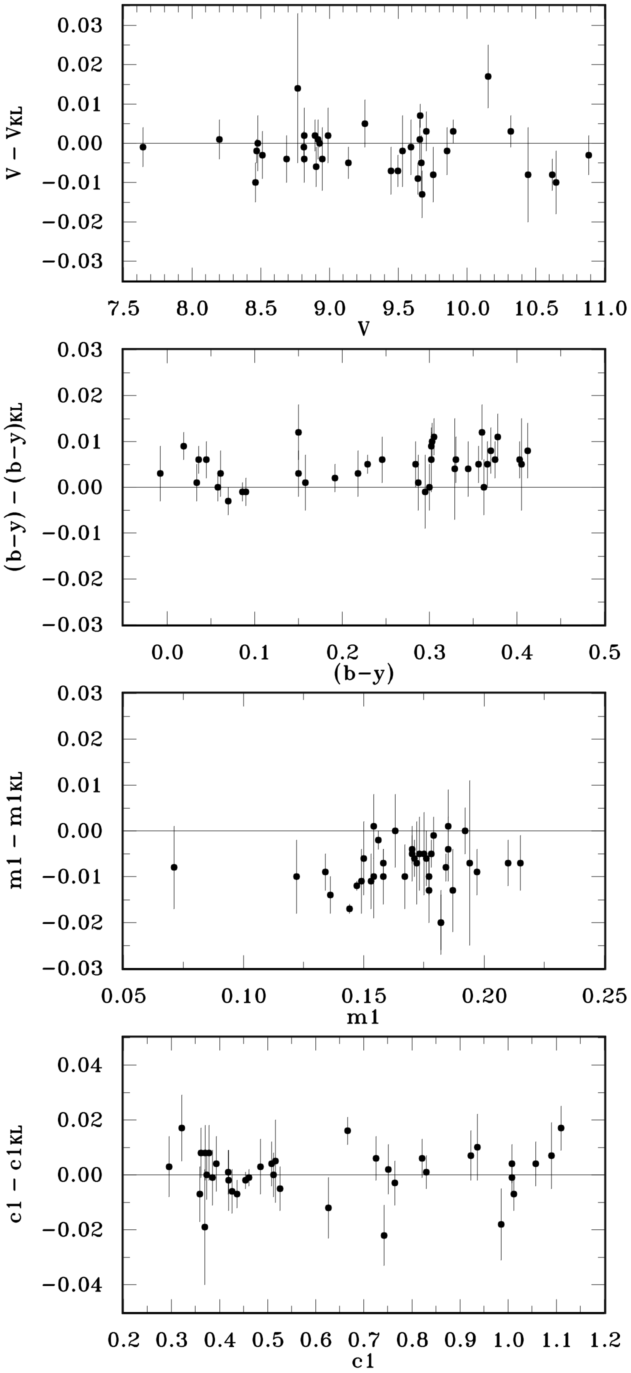

Fig. 4. Comparison (*uvby*) with the photometry of Kilkenny & Laing (1992). The error bars indicate the rms errors of one observation (this paper)

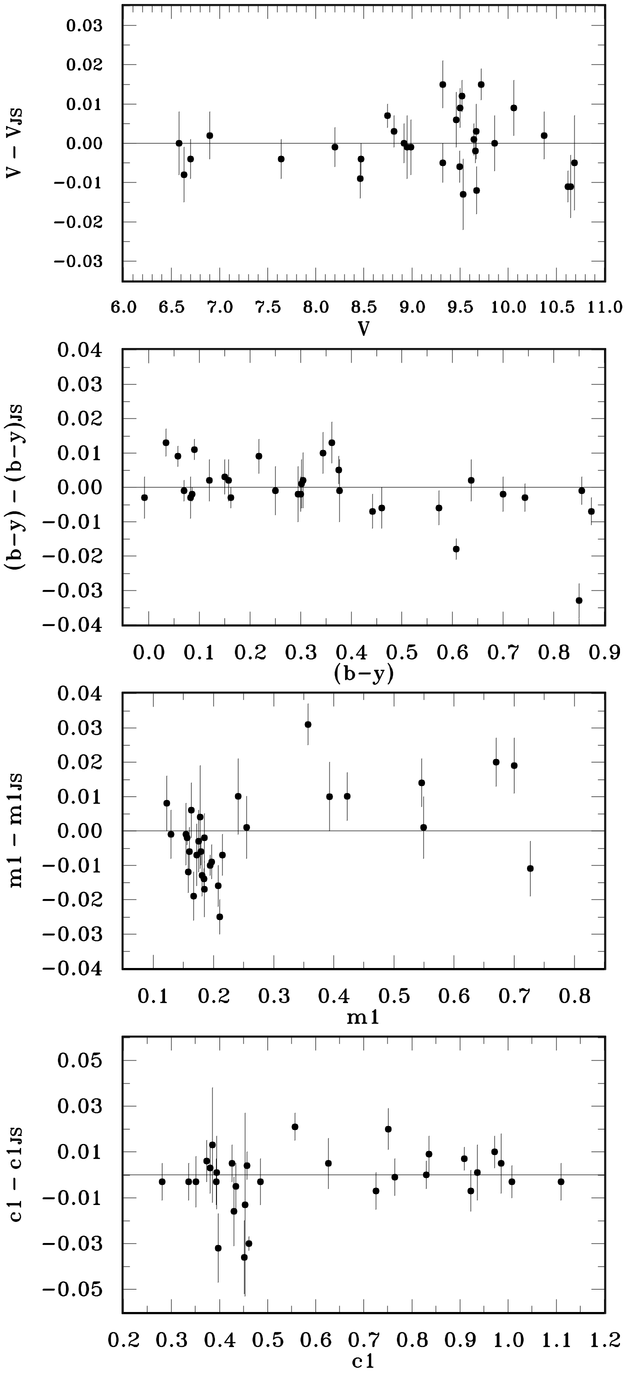

Fig. 5. Comparison (*uvby*) with the photometry of Jønch-Sørensen (1993). The error bars indicate the rms errors of one observation (this paper)

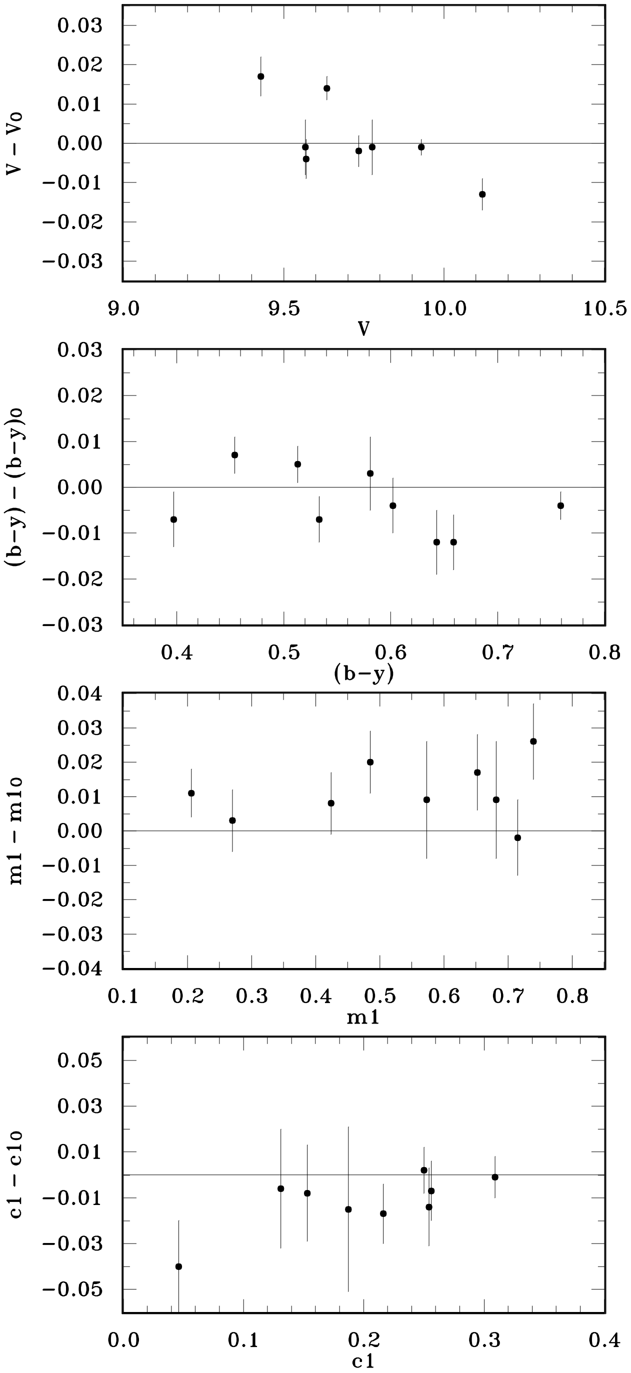

Fig. 6. Comparison (*uvby*) with the photometry of Olsen (1993, 1994). The error bars indicate the rms errors of one observation (this paper)

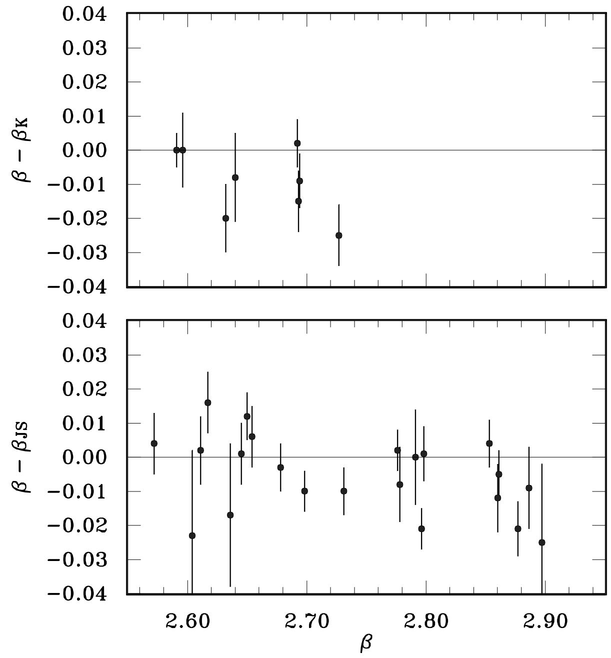

Fig. 7. Comparison (β) with the photometry of Knude (1992) (upper) and Jønch-Sørensen (1993) (lower). The error bars indicate the rms errors of one observation (this paper)

relevant. Some indication of small systematic trends is noticed in $b-y$ for the 1993 and 1994 BAF transformations, which cover the interval -0.08 to 0.40, but not for the 1995 transformations where the blue end below 0.25 was not included. Briefly the transformed $b-y$ for stars below -0.05 are in average about 0.005 larger than their standard values, and between about 0.10 and 0.20 they are about 0.005 smaller. A second order correction of $(b-y)_{\rm std} = 0.000 + 1.05 \cdot (b-y)_{\rm trans} - 0.16 \cdot (b-y)^2_{\rm trans}$ would lead to a more random distribution of the residuals through the $b-y$ interval, but the improvement is marginal. We have noticed a similar effect for the BAF group in the much larger observing program carried out at SAT by Olsen (1993, Table 8), who included standard stars from this region although his catalogue contains only G5-type type HD stars outside the $b-y$ range discussed here.

The reason for the small systematic trends is not clear, and in order not to introduce a correction which might be artificial, we have decided not to adjust the two $b-y$ transformations. In case a future detailed study confirms that a second order term is needed in $b-y$ for transformation from the SAT instrumental system to the standard system our results can easily be adjusted through the approximation given above.

Mean values of the transformed $uvby\beta$ indices for the primary standards observed 1993-1995 are listed in Tables 3 and 4, and compared with the standard indices in Figs. 1 and 2.

Table 4. Catalogue of transformed β indices for the observed primary standard stars. T_β is the transformation region, N is the number of observations; m.e. is the internal rms errors of one observation. The last colum gives the differences d = standard value - transformed value in units of 0.001 mag

HD	T_β	N	β	m.e.	$d(\beta)$
2262	A	32	2.845	0.004	−3
11171	A	15	2.737	0.004	1
14214	A	19	2.622	0.005	5
17081	B	22	2.719	0.004	0
17094	A	45	2.754	0.004	−4
17326	A	22	2.620	0.005	−5
24587	B	23	2.740	0.004	4
26462	A	30	2.712	0.005	2
30836	B	40	2.605	0.003	1
34816	B	22	2.603	0.004	0
39764	B	15	2.720	0.005	−3
40494	B	18	2.647	0.003	−2
43318	A	16	2.630	0.006	1
43358	A	16	2.644	0.008	2
43587	A	16	2.607	0.003	−4
45067	A	15	2.614	0.005	4
52265	A	19	2.626	0.006	2
53244	B	16	2.687	0.003	2
59881	A	22	2.788	0.005	2
59984	A	14	2.596	0.006	3
61064	A	8	2.666	0.004	−8
61831	B	15	2.670	0.003	−8
63077	A	13	2.588	0.006	2
70110	A	9	2.615	0.004	2
70958	A	8	2.632	0.004	3
71155	B	11	2.890	0.003	7
74280	B	12	2.649	0.004	4
76932	A	3	2.595	0.008	−1
83754	B	6	2.699	0.009	1
83944	B	4	2.840	0.003	−5
105382	B	4	2.683	0.003	−4
184915	B	14	2.564	0.003	1
195943	A	16	2.917	0.005	1
200499	A	13	2.862	0.005	0
210049	A	23	2.872	0.005	1
214846	A	17	2.818	0.005	2
224617	A	47	2.669	0.004	−4
224686	B	21	2.730	0.005	−7
224990	B	22	2.712	0.004	2

5. The secondary standards

The transformed $uvby$ and β results for the program stars are presented in Table 5. For each of these potential secondary standards mean values of the indices are given together with their rms errors and the total number of observations. A few stars still have not quite enough observations and/or their rms errors are slightly high; they are easily identified from the information given in Table 5. In Figs. 3-7 the indices given in Table 5 (with errors) have been compared with results published in the lists from which the candidates were selected.

Of the 10 B stars selected from Knude (1992) 8 are shown in Figs. 3 and 7. In average 8 observations per star have been obtained. Small systematic differences are noticed; our $b-y$ results are typically slightly larger whereas m_1 and β are typically slightly lower than obtained by Knude (1992). The $b-y$ discrepancy might be partly removed if the adjustment described in Sect. 4 is applied on our data. For the two stars not shown in the figures (HD 60993 = SAO 153144 and HD 68572 = SAO 198913) our results disagree completely. Simbad information (mainly V) support our results for HD 68572, which has probably been misidentified by Knude. For HD 60993 the situation is less obvious; note that the very low β value, indicating emission, is outside the range covered by our primary standards.

Figure 4 shows a comparison with the *uvby* indices of Kilkenny & Laing (1992) for 38 E-region stars, all belonging to the BAF transformation category . Again our $b-y$ results are generally slightly larger and m_1 lower. If the adjustment of our $b-y$ results mentioned in Sect. 4 is added the discrepancy becomes slightly larger in the $0.00-0.30$ $b-y$ interval and remains nearly unchanged between 0.30 and 0.40. We have no reason at all to suspect our m_1 results which are based on a large number of primary standards (Table 2) for which the standard indices are nicely reproduced (Fig. 1).

In Figs. 5 and 7 our results are compared with those published by Jønch-Sørensen (1993) for 31 E-region stars. 21 belong to the BAF transformation region, and the comments given above to the comparison with Kilkenny & Laing (1992) can basically be repeated. With respect to β our results are in average slightly lower than obtained by Jønch-Sørensen (1993), supporting the indication given in his paper that the β values might be about 0.006 too high. The remaining 10 stars are G and K giants, and here our m_1 results are typically 0.01 higher than obtained by Jønch-Sørensen. Considering the rather small number of primary standards available (we have used 8, Jønch-Sørensen 5) such differences are difficult to avoid and illustrate the transformation problems for this category of stars. Again the standard indices for the primary standard stars are, however, nicely reproduced by our transformations (Fig. 1).

Results for 9 G and K dwarfs are compared with those by Olsen (1993, 1994a, 1994b) in Fig. 6. HD 219057 is not shown in the V panel (upper) since our V magnitude, which is based on 10 observations, is significantly brighter than the average obtained by Olsen (private communication); Olsen (1993) gives $V = 9.589$ and Olsen (1994b) gives $V = 10.008$, but both results have weight 0 in the catalogues. The star HD 66020 which shows the largest discrepancy in c_1 (Fig. 6, lower panel) lies slightly outside the c_1 interval covered by the primary standards we have used. With these comments two noticeable differences remain; our m_1 results are systematically about 0.01 higher than obtained by Olsen, and our c_1 results are typically about 0.01 lower. We have no clear explanation in hand; in neither of the studies the transformed m_1 and c_1 indices of the primary standards deviate systematically from their standard values (see Fig. 1).

6. Conclusions

Standard *uvby* indices have been obtained for 73 southern B, A, F and G stars in the V magnitude range 8.2 to 10.9. Standard β indices have been obtained for the 55 B, A and F stars in the sample. The results presented in Table 5 are based on many individual measurements per star ($3-28$, typically 8) and firmly tied to the standard system through observation of $40-50$ primary standards per night. As a wide range of the HR diagram is covered the stars provide a useful set of secondary standards for *uvbyβ* CCD photometry with southern $1-2$ m class telescopes. They are presently used in a project on eclipsing binaries and population studies in the Magellanic Clouds.

As described in Sect. 5 small systematic differences between our indices and those published in various lists are noticed. They may be due to slight zero-point shifts introduced by the different subsets of primary standards used, but in general the reason is not clear. In all cases observations, reduction and transformation seem to have been done carefully.

The situation illustrates the need for a large-scale project providing accurate *uvbyβ* photometry for stars within a grid of typical CCD size fields (e.g. along the celestial equator) based on intensive observations through several years.

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Table 5. Catalogue of observed secondary standard stars. The ID column gives the E-region identification (Cousins & Stoy 1962), T indicates the *uvby* (A, D, G) and β (A, B) transformation regions. N_V, N and N_β indicate the number of observations in V, *uvby* indices and β respectively; m.e. are the rms errors of one observation

HD/CPD	ID	T	N_V	N	N_β	V	m.e.	$b-y$	m.e.	m_1	m.e.	c_1	m.e.	β	m.e.
8147	E103	AA	6	7	10	9.656	0.005	0.045	0.004	0.177	0.004	1.057	0.008	2.896	0.009
7040	E105	AA	21	21	9	9.447	0.006	0.246	0.005	0.149	0.007	0.526	0.008	2.693	0.010
7533	E108	AA	18	19	10	8.901	0.005	0.284	0.005	0.153	0.006	0.512	0.008	2.657	0.008
8340	E116	AA	19	20	7	9.753	0.007	0.378	0.005	0.187	0.009	0.378	0.010	2.617	0.011
8962	E117	AA	18	18	7	9.856	0.006	0.370	0.005	0.170	0.006	0.359	0.010	2.607	0.010
8501	E120	G	10	10		9.857	0.007	0.460	0.006	0.241	0.011	0.351	0.011		
8362	E135	G	10	10		9.461	0.007	0.874	0.004	0.700	0.008	0.453	0.040		
−45°155	E144	AA	9	10	6	10.886	0.005	0.405	0.010	0.194	0.018	0.369	0.021	2.610	0.022
9932	E175	AA	4	5	8	9.705	0.005	0.150	0.006	0.182	0.007	0.821	0.007	2.805	0.010
25714	E201	AA	7	8	10	8.813	0.004	0.058	0.003	0.210	0.005	1.008	0.007	2.891	0.012
25843	E202	AA	8	9	11	7.642	0.005	0.090	0.003	0.215	0.006	0.922	0.009	2.856	0.007
26273	E203	AA	9	10	11	9.667	0.007	0.158	0.006	0.172	0.009	0.830	0.006	2.776	0.011
25653	E204	AA	9	10	12	8.198	0.005	0.070	0.003	0.179	0.004	1.110	0.008	2.864	0.007
26375	E207	AA	8	8	11	8.948	0.008	0.218	0.005	0.167	0.007	0.751	0.009	2.729	0.007
25842	E218	DA	27	28	11	8.471	0.004	0.442	0.005	0.255	0.009	0.281	0.008	2.577	0.009
−44°427	E220	AA	18	19	8	9.497	0.004	0.375	0.004	0.185	0.007	0.393	0.010	2.614	0.010
26744	E221	AA	19	20	10	9.672	0.006	0.362	0.006	0.185	0.008	0.373	0.009	2.619	0.009
24392	E234	G	12	12		8.746	0.003	0.607	0.003	0.422	0.007	0.434	0.010		
24500	E239	AA	5	5	5	6.700	0.005	0.162	0.003	0.194	0.003	0.835	0.008	2.775	0.006
24805	E241	AA	5	5	6	6.898	0.006	0.083	0.006	0.208	0.006	0.909	0.005	2.863	0.010
25860	E242	AA	4	4	5	6.631	0.007	0.120	0.006	0.181	0.006	0.972	0.007	2.795	0.006
26413	E243	AA	5	5	6	6.579	0.008	0.250	0.007	0.160	0.007	0.557	0.006	2.696	0.006
	E274	G	12	12		9.321	0.006	0.850	0.005	0.727	0.008	0.394	0.016		
47445	E309	AB	9	10	12	8.917	0.005	−0.008	0.006	0.122	0.008	0.725	0.008	2.798	0.008
49754	E312	AA	6	7	8	9.658	0.003	0.086	0.002	0.184	0.003	0.936	0.012	2.881	0.008
48464	E319	AA	7	8	10	8.989	0.007	0.150	0.005	0.197	0.005	0.764	0.008	2.790	0.014
47720	E322	AA	21	22	8	8.461	0.005	0.300	0.005	0.163	0.008	0.426	0.008	2.654	0.009
48384	E323	AA	19	20	7	9.642	0.004	0.302	0.007	0.154	0.009	0.485	0.010	2.650	0.007
48730	E326	AA	5	5	6	9.531	0.009	0.295	0.008	0.175	0.009	0.626	0.011	2.677	0.007
−45°1002	E333	G	8	8		10.057	0.007	0.700	0.005	0.549	0.009	0.385	0.025		
−44°1030	E334	G	7	7		9.721	0.004	0.573	0.005	0.357	0.006	0.397	0.015		
48855	E355	AB	3	3	3	10.647	0.008	0.034	0.004	0.156	0.002	0.985	0.013	2.897	0.023
189226	E803	AB	3	4	6	8.768	0.019	0.019	0.003	0.158	0.003	1.012	0.006	2.898	0.002
189834	E804	AA	3	4	7	9.256	0.006	0.036	0.003	0.178	0.003	1.008	0.005	2.920	0.012
187442	E807	AA	3	4	6	9.899	0.003	0.061	0.005	0.171	0.004	1.090	0.012	2.908	0.025
190709	E816	AA	3	4	6	8.478	0.007	0.302	0.003	0.147	0.001	0.419	0.011	2.655	0.008
189121	E817	AA	3	4	5	9.136	0.004	0.305	0.004	0.136	0.004	0.508	0.008	2.652	0.007
189933	E818	AA	2	3	6	9.321	0.005	0.305	0.008	0.129	0.007	0.457	0.006	2.645	0.009
188392	E821	AA	3	4	5	8.816	0.006	0.366	0.005	0.173	0.008	0.516	0.015	2.636	0.014
	E824	AA	3	4	4	10.318	0.004	0.287	0.006	0.154	0.007	0.454	0.003	2.657	0.017
−45°9672	E847	AA	3	4	4	10.621	0.004	0.344	0.006	0.158	0.006	0.461	0.003	2.637	0.021
188031	E864	AA	3	4	5	10.153	0.008	0.329	0.011	0.071	0.009	0.321	0.012	2.606	0.004
−45°9872	E873	AA	2	3	5	10.443	0.012	0.412	0.006	0.182	0.006	0.295	0.011	2.589	0.022
214509	E904	AA	2	3	7	8.927	0.001	0.229	0.002	0.144	0.001	0.666	0.005	2.702	0.012
214728	E906	AA	3	4	6	8.895	0.004	0.192	0.003	0.170	0.003	0.742	0.011	2.743	0.007
215788	E912	AA	10	11	6	8.687	0.006	0.303	0.004	0.134	0.004	0.436	0.005	2.639	0.006
216098	E915	AA	12	13	6	9.591	0.007	0.360	0.006	0.177	0.007	0.370	0.010	2.614	0.017
215877	E919	AA	11	12	6	8.511	0.006	0.403	0.004	0.192	0.005	0.361	0.009	2.610	0.009
215628	E921	AA	12	13	7	8.817	0.007	0.356	0.004	0.176	0.006	0.385	0.010	2.635	0.009
215105	E927	G	9	9		9.498	0.005	0.743	0.004	0.546	0.007	0.380	0.011		
−45°10328	E928	G	7	7		10.372	0.006	0.637	0.006	0.393	0.010	0.430	0.015		
215756	E938	G	7	7		9.520	0.004	0.855	0.004	0.670	0.007	0.451	0.016		
	E947	AA	8	9	3	10.690	0.012	0.377	0.009	0.178	0.015	0.336	0.008	2.607	0.025
216667	E950	AA	11	12	7	8.470	0.003	0.330	0.005	0.150	0.008	0.418	0.008	2.634	0.009

Table 5. continued

HD/CPD	ID	T	N_V	N	N_β	V	m.e.	$b-y$	m.e.	m_1	m.e.	c_1	m.e.	β	m.e.
22610		D	13	13		9.428	0.005	0.513	0.004	0.424	0.009	0.256	0.013		
24558		D	12	12		9.570	0.005	0.454	0.004	0.270	0.009	0.250	0.010		
25357		D	12	12		9.568	0.007	0.533	0.005	0.485	0.009	0.254	0.017		
50154		AB	8	8	8	8.939	0.006	−0.066	0.005	0.091	0.007	0.312	0.006	2.694	0.008
51036		AB	6	6	7	8.772	0.005	−0.068	0.004	0.096	0.006	0.131	0.012	2.640	0.013
51038		AB	8	8	8	9.112	0.006	−0.054	0.007	0.084	0.011	0.300	0.008	2.692	0.007
57503		AB	5	5	5	8.877	0.008	−0.046	0.005	0.062	0.006	0.044	0.009	2.632	0.010
57568		D	3	3		9.929	0.002	0.581	0.008	0.573	0.017	0.187	0.036		
58489		D	8	8		9.734	0.004	0.602	0.006	0.652	0.011	0.216	0.013		
59756		AB	6	6	7	8.945	0.005	0.076	0.003	0.006	0.007	−0.031	0.010	2.591	0.005
59882		AB	9	9	9	8.811	0.009	−0.031	0.009	0.046	0.012	0.012	0.008	2.596	0.011
60993		AB	9	9	9	8.880	0.013	0.047	0.009	0.020	0.010	−0.015	0.008	2.460	0.011
−27°1408		AB	9	9	9	9.215	0.011	−0.025	0.008	0.080	0.009	0.369	0.009	2.693	0.009
66020		D	8	8		9.635	0.003	0.759	0.003	0.715	0.011	0.046	0.020		
68572		AB	4	4	4	8.197	0.004	0.094	0.003	0.019	0.006	0.005	0.004	2.616	0.007
167321		AB	2	3	5	8.950	0.004	0.005	0.006	0.086	0.008	0.727	0.011	2.727	0.009
219057		D	10	10		9.595	0.004	0.397	0.006	0.206	0.007	0.309	0.009		
285947		D	5	5		10.119	0.004	0.643	0.007	0.681	0.017	0.153	0.021		
286770		D	10	10		9.776	0.007	0.659	0.006	0.739	0.011	0.131	0.026		

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