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Comparison of Metallicities Adopted for the Synthetic UBV Photometry with Those Evaluated by Means of RGU Photometry

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Abstract

Comparison of metallicities adopted for synthetic UBV photometry with those evaluated by means of RGU photometry for 92 stars is presented. The agreement is only for zero metallicity. The discrepancy increases to low metallicities which cover Intermediate Population II and Population II main-sequence stars. U-G and G-R colour indices are transformed from UBV synthetic data and do not include any observational error. Therefore, the disagreement may originate from a systematic error in the metallicity calibration of relatively metal-poor stars in RGU photometry.
Key Words: photometry - stars : abundances - metal-poor.

1. Introduction

Metallicity plays an important role in the investigation of Galactic structure and gives us information on the early history and chemical evolution of the Galaxy. Despite a substantial number of investigations, [Sandage [1], Trefzger [2], Hartkopf and Yoss [3], Gilmore and Wyse [4], Carney et al. [5], Cayrel et al. [6], Croswell et al. [7], and Majewski [8,9] the available data on stellar metallicities are still limited. The existence of Intermediate Population II (Thick Disk) which was introduced into the literature by Gilmore and Reid [10] in 1983 is no longer controversial. However, its discreteness from Population I (Thin Disk) is still very controversial. It is accepted that the new population is a very important component of our Galaxy with larger z distance, up to 3500 pc. or even larger (Majewski [9]); and with lower metal-abundance, than previously assumed, down to [Fe/H] = -1.6 (Majewski [9], Morrison et al. [11], Flynn and Röser [12]), i.e. :

$z \sim 2500$ pc. and [Fe/H]$\sim$-0.6 to -0.8 (Gilmore and Wyse [4], Carney et al. [5], Buser and Fenkart [13]) but, with the original scale height approximately 1000 to 1500 pc., although estimates vary greatly. However, different methods are used for the determination of metallicity and unfortunately there are disagreements between their results as stated in the work of Karaali [14]. The conflict may originate from different sources, including observational data. So, we thought to limit our work with a comparison of the [M/H] metallicities adopted for synthetic UBV photometry with those evaluated by means of RGU photometry, where R, G, and U magnitudes are transformed from the synthetic U, B and V magnitudes via the transformation formulae of Buser and Güngör [15] which do not include any systematic observational error. These formulae had been obtained using Buser's method [16, 17, 18] and the original synthetic RGU data had been corrected to reproduced Buser's [18] results, as explained in the Appendix. Hence, the transformation formulae of Buser and Güngör [15] are free of any systematic error. Finally, we wish to quote the recent paper by the Twarogs [19] which gives an example of the problem in the DDO metallicity scale for supposedly metal-poor Intermediate Population II stars.

2. The data and comparison

The synthetic UBV data and the [M/H] metallicities are taken from Buser and Kurucz [20]. Among 234 stars, 104 of them have $\log g$ values of 3.75, 4.50, or 5.25 and are therefore main-sequence stars for which grids of Buser and Fenkart [13] are available for metallicity determination, 12 of these have G-R colour-indices larger than mag 1.80 for which Figure 4 of Buser and Fenkart [13] is not calibrated. The U-B and B-V colour-indices for these stars have been transformed to the U-G and G-R colour-indices by means of the transformation formulae of Buser and Güngör [15] which are available for six different metal abundances, i.e. : [M/H] = +0.50, 0.00, -0.50, -1.00, -2.00, and -3.00 (Table 1). The two-colour diagram for 92 stars for which [M/H] metallicities are evaluated by means of the method of Buser and Fenkart [13] is given in Figure 1. The original and evaluated metal abundances, i.e. : $[M/H]_{std}$ and $[M/H]_{ev}$, respectively, where std = standard (input) and ev = evaluated, are compared in Table 1 and Figure 2. The agreement is only for the metal abundance [M/H] = 0.00. The $[M/H]_{ev}$ values are less than those of $[M/H]_{std}$ for positive metallicities and it is the inverse for negative ones, except for eight stars (Nos : 194, 220, 225, 226, 227, 232, 233, and 234). The difference between $[M/H]_{std}$ and $[M/H]_{ev}$ increases from 0.30 to 1.25 dex as one goes from $[M/H]_{std}$=-0.50 to -3.0 dex indicating that the disagreement between two set of data is most severe for stars with low metallicities, i.e. : for Intermediate Population II and Population II stars.

The differences between $[M/H]_{ev}$ and $[M/H]_{std}$ for 92 main-sequence stars are plotted versus $[M/H]_{std}$ for three different log g values, i.e. : 3.75, 4.50, and 5.25 in Figure 3a,b, and c respectively. The general aspect is that the disagreement between two sets of metallicities is not a function of log g. Also, this disagreement is neither a function of the (G-R) nor (U-G) colour-indices as seen in Figure 4a-b. However, both

Figures reveal that about 2/3 of total stars have absolute Δ[M/H] differences less than 0.20 with a mean of $< \Delta[M/H] > = +0.03$, whereas the remaining ones have larger Δ[M/H] differences up to +1.25. The second set of stars have U-G colour-indices less than 2.20 mag. (Figure 4b) and occupy the narrow and discrete G-R intervals (0.95, 1.00), (1.20, 1.35), (1.45, 1.50), and (1.75, 1.80) in Figure 4a. However, this discreteness may be attributed to an artifact of sampling and may not be real. Also, these stars (with a few exceptions) occupy the region in the (U-G, G-R) two-colour diagram which is calibrated for relatively low metallicity main-sequence stars, i.e.: Intermediate Population II and Population II (Figure 1).

Table 1. Synthetic UBV data and transformed U-G and G-R colour-indices with adopted $[M/H]_{std}$ and evaluated $[M/H]_{ev}$ metallicities. The last column includes the $\Delta[M/H]=[M/H]_{ev}$-$[M/H]_{std}$ metal-abundance differences. Also, log g is given in the second column. The number of stars in the first column are those of Buser and Kurucz [20]

No	$\log g$	$[M/H]_{std}$	(U-B)	(B-V)	(U-G)	(G-R)	$[M/H]_{ev}$	Δ[M/H]
34	3.75	0.50	1.697	1.313	3.50	2.02	-	-
36	3.75	0.00	1.402	1.279	3.07	1.89	+0.50	+0.50
38	3.75	-0.50	1.143	1.246	2.71	1.83	-	-
39	3.75	-1.00	0.960	1.214	2.47	1.80	-0.88	0.12
40	3.75	-2.00	0.750	1.160	2.23	1.78	-1.88	0.12
41	3.75	-3.00	0.653	1.156	2.13	1.80	-2.60	0.40
42	4.50	0.50	1.563	1.309	3.33	2.00	-	-
44	4.50	0.00	1.303	1.296	2.95	1.92	-	-
46	4.50	-0.50	1.107	1.269	2.67	1.82	-	-
47	4.50	-1.00	0.960	1.238	2.47	1.82	-	-
48	4.50	-2.00	0.747	1.167	2.23	1.78	-1.88	0.12
49	4.50	-3.00	0.629	1.139	2.10	1.78	-2.60	0.40
50	5.25	0.50	1.368	1.314	3.09	2.00	-	-
52	5.25	0.00	1.192	1.294	2.82	1.92	-	-
54	5.25	-0.50	1.062	1.262	2.62	1.85	-	-
55	5.25	-1.00	0.975	1.242	2.49	1.83	-	-
56	5.25	-2.00	0.782	1.176	2.27	1.80	-1.78	0.22
57	5.25	-3.00	0.610	1.126	2.08	1.76	-2.60	0.40
58	3.75	0.50	1.504	1.202	3.25	1.88	-	-
60	3.75	0.00	1.173	1.155	2.78	1.74	0.15	0.15
62	3.75	-0.50	0.895	1.097	2.40	1.66	-0.45	0.05
63	3.75	-1.00	0.705	1.044	2.16	1.61	-0.88	0.12
64	3.75	-2.00	0.515	1.006	1.94	1.59	-1.53	0.47
65	4.50	0.50	1.470	1.194	3.21	1.87	-	-
67	4.50	0.00	1.193	1.163	2.80	1.75	0.15	0.15
69	4.50	-0.50	0.918	1.115	2.43	1.68	-0.45	0.05

Table 1. Cont.

No	$\log g$	$[M/H]_{std}$	(U-B)	(B-V)	(U-G)	(G-R)	$[M/H]_{ev}$	Δ[M/H]
70	5.25	0.00	1.118	1.181	2.72	1.78	0.00	0.00
91	3.75	0.50	1.260	1.089	2.94	1.73	0.50	0.00
93	3.75	0.00	0.918	1.034	2.46	1.60	0.08	0.08
95	3.75	-0.50	0.656	0.974	2.11	1.52	-0.52	-0.02
96	3.75	-1.00	0.482	0.920	1.89	1.46	-0.75	0.25
97	3.75	-2.00	0.308	0.877	1.69	1.44	-1.40	0.60
98	3.75	-3.00	0.211	0.890	1.58	1.47	-2.15	0.85
99	4.50	0.50	1.270	1.088	2.95	1.73	0.50	0.00
101	4.50	0.00	0.974	1.046	2.53	1.61	0.05	0.05
103	4.50	-0.50	0.699	0.980	2.16	1.53	-0.45	0.05
104	4.50	-1.00	0.526	0.940	1.95	1.48	-0.70	0.30
105	4.50	-2.00	0.326	0.904	1.71	1.47	-1.55	0.45
106	4.50	-3.00	0.211	0.900	1.58	1.48	-2.25	0.75
107	5.25	0.50	1.266	1.092	2.95	1.74	0.50	0.00
109	5.25	0.00	0.989	1.059	2.55	1.63	0.03	0.03
111	5.25	-0.50	0.715	1.000	2.19	1.55	-0.48	0.02
112	5.25	-1.00	0.552	0.969	1.98	1.51	-0.90	0.10
113	5.25	-2.00	0.330	0.918	1.72	1.48	-1.60	0.40
114	5.25	-3.00	0.214	0.903	1.59	1.49	-2.28	0.72
115	3.75	0.50	0.999	0.981	2.61	1.59	0.25	-0.25
117	3.75	0.00	0.677	0.923	2.17	1.47	-0.08	-0.08
119	3.75	-0.50	0.449	0.866	1.86	1.39	-0.35	0.15
120	3.75	-1.00	0.297	0.817	1.67	1.33	-0.60	0.40
121	3.75	-2.00	0.141	0.778	1.48	1.32	-1.25	0.75
122	4.50	0.00	0.744	0.938	2.25	1.49	-0.05	-0.05
123	5.25	0.00	0.793	0.948	2.30	1.50	0.03	0.03
139	3.75	0.50	0.755	0.881	2.30	1.46	0.25	-0.25
141	3.75	0.00	0.471	0.824	1.91	1.35	-0.05	-0.05
143	3.75	-0.50	0.277	0.770	1.65	1.28	-0.43	0.07
144	3.75	-1.00	0.148	0.727	1.49	1.23	-0.57	0.43
145	3.75	-2.00	0.005	0.691	1.31	1.22	-1.32	0.68
146	3.75	-3.00	-0.071	0.677	1.23	1.22	-1.75	1.25
147	4.50	0.50	0.815	0.887	2.37	1.47	0.35	-0.15
149	4.50	0.00	0.537	0.840	1.99	1.37	0.08	0.08
151	4.50	-0.50	0.315	0.781	1.70	1.30	-0.32	0.18
152	4.50	-1.00	0.18	0.742	1.52	1.25	-0.60	0.40
153	4.50	-2.00	0.025	0.710	1.34	1.24	-1.32	0.68
154	4.50	-3.00	-0.063	0.698	1.24	1.24	-1.75	1.25

Table 1. Cont.

No	$\log g$	$[M/H]_{std}$	(U-B)	(B-V)	(U-G)	(G-R)	$[M/H]_{ev}$	Δ[M/H]
155	5.25	0.50	0.855	0.897	2.42	1.49	0.35	-0.15
157	5.25	0.00	0.595	0.854	2.06	1.39	0.15	0.15
159	5.25	-0.50	0.358	0.789	1.75	1.31	-0.20	0.30
160	5.25	-1.00	0.217	0.755	1.57	1.27	-0.55	0.45
161	5.25	-2.00	0.043	0.729	1.36	1.26	-1.32	0.68
162	5.25	-3.00	-0.048	0.718	1.26	1.26	-1.95	1.05
163	3.75	0.00	0.304	0.736	1.70	1.25	0.00	0.00
164	4.50	0.00	0.357	0.752	1.77	1.27	0.10	0.10
165	5.25	0.00	0.415	0.767	1.84	1.28	0.20	0.20
181	3.75	0.50	0.372	0.708	1.81	1.24	0.40	-0.10
183	3.75	0.00	0.178	0.658	1.54	1.16	0.00	0.00
185	3.75	-0.50	0.046	0.612	1.37	1.10	-0.35	0.15
186	3.75	-1.00	-0.048	0.579	1.25	1.07	-0.72	0.28
187	3.75	-2.00	-0.168	0.539	1.10	1.05	-1.90	0.10
188	4.50	0.50	0.421	0.717	1.87	1.25	0.45	-0.05
190	4.50	0.00	0.209	0.672	1.58	1.17	0.08	0.08
192	4.50	-0.50	0.055	0.627	1.38	1.12	-0.42	0.08
193	4.50	-1.00	-0.047	0.596	1.25	1.08	-0.90	0.10
194	4.50	-2.00	-0.173	0.560	1.09	1.07	-2.25	-0.25
195	5.25	0.50	0.480	0.732	1.94	1.28	0.50	0.00
197	5.25	0.00	0.259	0.689	1.64	1.19	0.15	0.15
199	5.25	-0.50	0.085	0.641	1.42	1.13	-0.35	0.15
200	5.25	-1.00	-0.023	0.913	1.28	1.10	-0.85	0.15
201	5.25	-2.00	-0.164	0.581	1.11	1.09	-1.85	0.15
202	4.44	0.00	0.082	0.593	1.42	1.08	-0.05	-0.05
214	3.75	0.50	0.154	0.570	1.52	1.07	0.38	-0.12
216	3.75	0.00	0.034	0.526	1.35	0.99	0.00	0.00
218	3.75	-0.50	-0.054	0.488	1.24	0.96	-0.40	0.10
219	3.75	-1.00	-0.123	0.459	1.15	0.95	-0.92	0.08
220	3.75	-2.00	-0.209	0.425	1.05	0.94	-2.05	-0.05
221	4.50	0.50	0.156	0.579	1.53	1.08	0.38	-0.12
223	4.50	0.00	0.014	0.540	1.33	1.01	-0.15	-0.15
225	4.50	-0.50	-0.091	0.503	1.20	0.97	-0.65	-0.15
226	4.50	-1.00	-0.169	0.476	1.10	0.96	-1.50	-0.50
227	4.50	-2.00	-0.264	0.443	0.98	0.94	-4.00	-2.00
228	5.25	0.50	0.193	0.596	1.58	1.10	0.45	-0.05
230	5.25	0.00	0.028	0.558	1.35	1.03	-0.10	-0.10
232	5.25	-0.50	-0.098	0.519	1.19	0.99	-0.80	-0.30

Table 1. Cont.

No	$\log g$	$[M/H]_{std}$	(U-B)	(B-V)	(U-G)	(G-R)	$[M/H]_{ev}$	Δ[M/H]
233	5.25	-1.00	-0.183	0.495	1.08	0.97	-1.75	-0.75
234	5.25	-2.00	-0.285	0.464	0.96	0.96	-4.00	-2.00

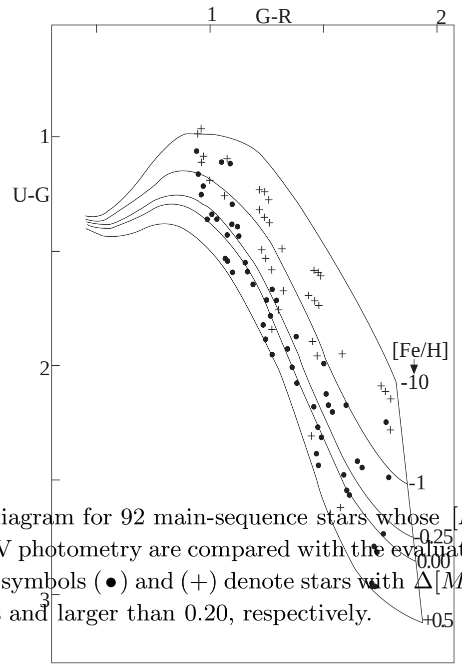


Figure 1. Two-colour diagram for 92 main-sequence stars whose $[M/H]_{std}$ metal-abundances adopted for synthetic UBV photometry are compared with the evaluated $[M/H]_{ev}$ ones by means of RGU photometry. The symbols ($\bullet$) and (+) denote stars with $\Delta[M/H] = [M/H]_{ev} - [M/H]_{std}$ differences absolutely less and larger than 0.20, respectively.

3. Conclusions

In the present study, comparison of metallicities adopted for synthetic UBV photometry with those evaluated by means of RGU photometry, where U-G and G-R colour-indices are transformed from these synthetic data, is presented. The agreement is only for zero metallicity. The discrepancy increases to low metallicities that cover Intermediate Population II and Population II main-sequence stars. Our data are independent from observations, hence they do not include any observational error. Therefore, the disagreement may originate from a systematic error in the metallicity calibration of relatively metal-poor stars in RGU photometry.

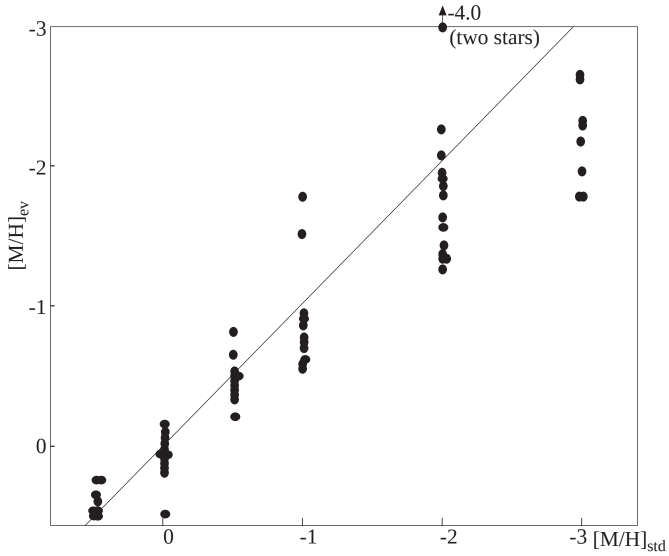
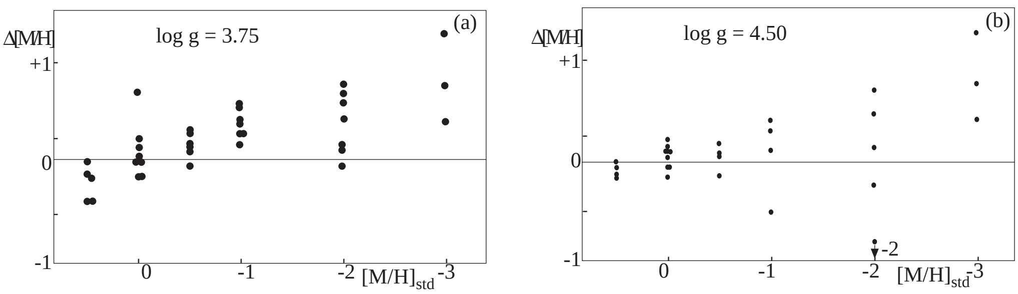


Figure 2. Comparison of $[M/H]_{std}$ metal-abundances adopted for synthetic UBV photometry with the $[M/H]_{ev}$ evaluated ones by means of RGU photometry. The agreement is only for zero metallicities. The discrepancy increases to low metallicities.



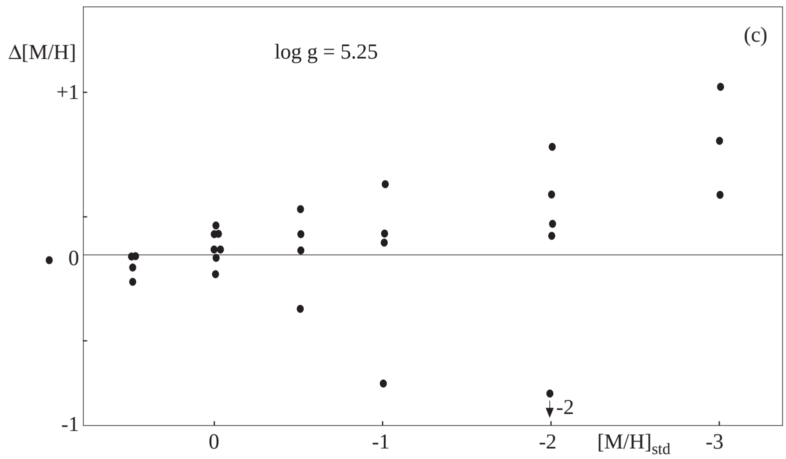


Figure 3a-c. $\Delta[M/H]$ differences versus $[M/H]_{\rm std}$ for three different $\log g$: (a) $\log g = 3.75$, (b) $\log g = 4.50$, and (c) $\log g = 5.25$. The discrepancy between two sets of metallicities is valid for each $\log g$.

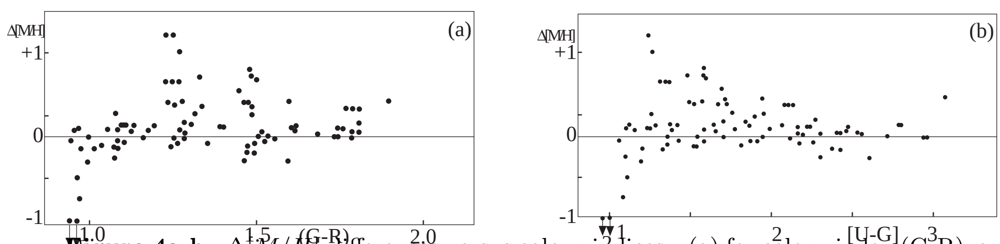


Figure 4a-b. $\Delta[M/H]$ differences versus colour-indices : (a) for colour-index (G-R), and (b) for colour-index (U-G). The discrepancy between two sets of metallicities is not a function of colour-index.

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Appendix : Transformation formulae of Buser and Güngör

The transformation formulae of Buser and Güngör [15] are a part of the doctorate thesis of Güngör and are based on the method used by Buser in 1978 and 1988. Buser used the model stellar atmospheres for zero metallicity, i.e. :[M/H]=0.00, and for main-sequence stars. He had derived the following photometric transformations from UBV to RGU [17], where the coefficients for these formulae are given in Table A.1 :

$$\begin{aligned} U - G &= a_1(U - B) + b_1(B - V) + c_1 \\ G - R &= a_2(U - B) + b_2(B - V) + c_2 \\ G - V &= a_3(U - B) + b_3(B - V) + c_3 \end{aligned} \quad (A.1)$$

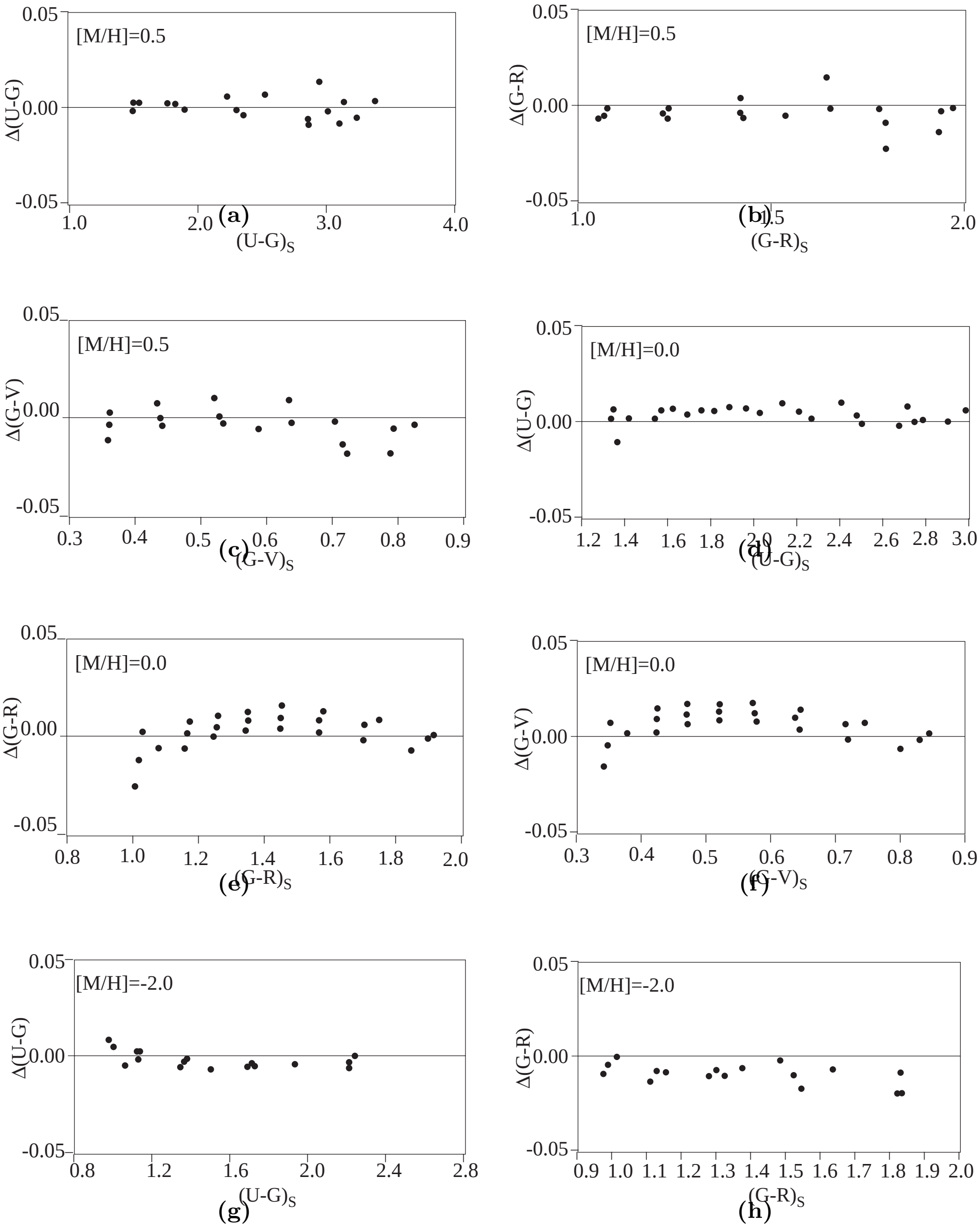
Table A1. Coefficients for the transformation formulae from UBV to RGU of Buser [17] for zero metallicity dwarfs

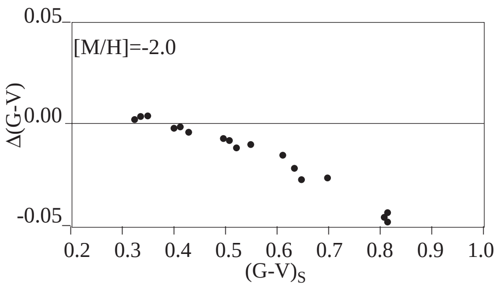
a_1	b_1	c_1
1.17	0.15	1.31
a_2	b_2	c_2
-0.04	1.27	0.34
a_3	b_3	c_3
-0.01	0.63	0.00

Buser used scanes of real stars to evaluate the UBV and RGU data in 1988 and improved his formulae by adding zero metallicity giants to his sampling. The coefficients of Busers transformation formulae for O-K and M dwarfs, and A-K and M giants are given in Table A.2.

Table A2. Coefficients for the transformation formulae from UBV to RGU of Buser [18] for zero metallicity dwarfs and gaints

	a_1	b_1	c_1	**Standard Deviation**
O-K dwarfs	1.17	0.15	1.21	± 0.013
M dwarfs	1.21	0.23	1.05	± 0.024
A-K gaints	1.12	0.15	1.24	± 0.008
M gaints	1.36	-0.29	1.47	± 0.018
	a_2	b_2	c_2	
O-K dwarfs	-0.04	1.27	0.32	± 0.022
M dwarfs	-0.99	1.13	1.76	± 0.039
A-K gaints	-0.09	1.22	0.33	± 0.021
M gaints	-0.93	2.36	0.31	± 0.060
	a_3	b_3	c_3	
O-K dwarfs	-0.01	0.63	-0.01	± 0.011
M dwarfs	-0.46	0.88	0.24	± 0.039
A-K gaints	-0.02	0.65	-0.01	± 0.012
M gaints	-0.52	1.36	-0.12	± 0.022


[M/H]=0.5
Δ(U-G)
(U-G)S
(a)
[M/H]=0.5
Δ(G-R)
(G-R)S
(b)
[M/H]=0.5
Δ(G-V)
(G-V)S
(c)
[M/H]=0.0
Δ(U-G)
(U-G)S
(d)
[M/H]=0.0
Δ(G-R)
(G-R)S
(e)
[M/H]=0.0
Δ(G-V)
(G-V)S
(f)
[M/H]=-2.0
Δ(U-G)
(U-G)S
(g)
[M/H]=-2.0
Δ(G-R)
(G-R)S
(h)



(i)

Figure A1a-i. Differences between evaluated and original synthetic colour-indices versus original synthetic colour-indices. The systematic error appeared here was corrected before derivation of the new transformation formulae as a function of metallicity.

The (U-G, G-R) two-colour diagrams obtained by his two set of formulae stated above are discussed by the author in his papers [17, 18] and they are consistent with the observational data for stars with zero metallicity, i.e. : [M/H] = 0.00.

Finally, Buser and Güngör used model stellar atmospheres of Buser and Kurucz [20] not only for zero metallicity, but also for five additional [M/H] values, i.e. : +0.5, -0.5, -1.0, -2.0, and -3.0 for dwarfs, and four values for giants, i.e. : -0.5, -1.0, -2.0, and -3.0. A sample of these data for different metallicities but only for one log g value (3.75) and two different effective temperatures ($T_e = 4000^{\circ}$K and 5000 $^{\circ}$K) are given in Table A.3. The columns are explained at the top of the table.

The differences between the original RGU synthetic data and those derived by means of the new transformation formulae, based on the synthetic UBV and RGU data, revealed a systematic difference between two sets of data for all metallicities. This can be seen in nine samples for different metallicities given in Figure A.1a-i. The colour-indices in abscissa axis refer to the original synthetic data whereas those in the ordinate axis are the differences between evaluated and original colour-indices. As the UBV synthetic data are well established, the source of error was assumed to be in the RGU synthetic data and the necessary correction had been carried out as follows :

The differences between the U-G, G-R, and G-V colour-indices evaluated via formulae of Buser [18] which are based on scanes of real stars, as mentioned above, and those evaluated by the new formulae which are not given here, was given in Güngör's doctorate thesis as a function of synthetic U-B and B-V colour-indices, i.e. :

$$\begin{aligned} \Delta(U-G) &= \alpha_1(U-B) + \beta_1(B-V) + \gamma_1 \\ \Delta(G-R) &= \alpha_2(U-B) + \beta_2(B-V) + \gamma_2 \qquad (A.2) \\ \Delta(G-V) &= \alpha_3(U-B) + \beta_3(B-V) + \gamma_3 \end{aligned}$$

Table A3. A sample of original UBV and RGU synthetic data, and the corrected U-G, G-R, and G-V colour-indices for different metallicities but only for log g = 3.75 and effective temperatures $T_e = 4000°$ K and $5000°$ K. The columns give : (1) and (2) : adopted and evaluated colour-excesses in UBV; (3), (4), (5), (6), and (7) : original synthetic colour- indices U-B, B-V, U-G, G-R, and G-V; (8) : EUBV = E(U-B)/E(B-V); (9) : RUBV = A(V)/E(B-V); (10) : ERGU = E(U-G)/E(G-R); (11) : RRGU = A(G)/E(G-R); (12), (13), and (14) : corrected (U-G)$_c$, (G-R)$_c$, and (G-V)$_c$ colour-indices, respectively. A(V) and A(G) refers to the total absorptions in the UBV and RGU systems, respectively

		[M/H]=0.00			$\log g$ = 3.75		T_e= 4000°K						
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	11)	(12)	(13)	(14)
E*(B-V)	E(B-V)	U-B	B-V	U-G	G-R	G-V	EUBV	RUBV	ERGU	RRGU	(U-G)$_c$	(G-R)$_c$	(G-V)$_c$
0.000	0.000	1.698	1.313	3.379	1.922	0.790	0.00	0.00	0.00	0.00	3.500	2.027	0.822
0.100	0.084	1.784	1.397	3.483	2.051	0.862	1.02	3.66	0.80	2.95	3.617	2.124	0.878
0.200	0.168	1.870	1.481	3.587	2.180	0.935	1.02	3.66	0.80	2.95	3.728	2.223	0.928
0.300	0.251	1.957	1.564	3.691	2.308	1.009	1.03	3.67	0.81	2.95	3.844	2.323	0.979
0.400	0.334	2.044	1.647	3.794	2.436	1.082	1.03	3.67	0.81	2.96	3.957	2.424	1.030
0.500	0.417	2.132	1.730	3.898	2.564	1.156	1.04	3.67	0.81	2.96	4.072	2.524	1.080
0.600	0.500	2.220	1.813	4.002	2.692	1.231	1.04	3.67	0.81	2.96	4.188	2.622	1.131
0.700	0.582	2.309	1.895	4.106	2.819	1.305	1.05	3.68	0.81	2.96	4.305	2.722	1.181
0.800	0.664	2.398	1.977	4.209	2.945	1.380	1.05	3.68	0.81	2.96	4.421	2.819	1.231
1.000	0.827	2.579	2.141	4.417	3.198	1.531	1.06	3.68	0.81	2.97	4.655	3.015	1.330

		[M/H]=0.00			$\log g$ = 3.75		T_e= 5000°K						
E*(B-V)	E(B-V)	U-B	B-V	U-G	G-R	G-V	EUBV	RUBV	ERGU	RRGU	(U-G)$_c$	(G-R)$_c$	(G-V)$_c$
0.000	0.000	0.756	0.881	2.225	1.418	0.537	0.00	0.00	0.00	0.00	2.292	1.465	0.542
0.100	0.090	0.835	0.971	2.326	1.550	0.610	0.88	3.45	0.77	2.91	2.402	1.569	0.604
0.200	0.180	0.915	1.061	2.427	1.681	0.683	0.88	3.45	0.77	2.91	2.508	1.677	0.658
0.300	0.269	0.995	1.150	2.528	1.812	0.756	0.89	3.46	0.77	2.92	2.616	1.785	0.712
0.400	0.358	1.076	1.239	2.629	1.943	0.830	0.90	3.46	0.77	2.92	2.724	1.894	0.767
0.500	0.446	1.158	1.327	2.731	2.073	0.904	0.90	3.47	0.77	2.92	2.833	2.002	0.822
0.600	0.534	1.241	1.415	2.832	2.203	0.978	0.91	3.47	0.77	2.92	2.942	2.108	0.876
0.700	0.622	1.324	1.503	2.934	2.333	1.052	0.91	3.47	0.78	2.93	3.053	2.215	0.929
0.800	0.709	1.408	1.590	3.035	2.462	1.127	0.92	3.48	0.78	2.93	3.163	2.321	0.983
1.000	0.883	1.578	1.764	3.239	2.719	1.277	0.93	3.48	0.78	2.93	3.387	2.531	1.089

		[M/H]=0.00		$\log g$ = 3.75			T_e= 4000°K						
E*(B-V)	E(B-V)	U-B	B-V	U-G	G-R	G-V	EUBV	RUBV	ERGU	RRGU	$(U-G)_c$	$(G-R)_c$	$(G-V)_c$
0.000	0.000	1.403	1.279	2.979	1.849	0.796	0.00	0.00	0.00	0.00	3.067	1.907	0.788
0.100	0.085	1.491	1.364	3.086	1.979	0.868	1.04	3.64	0.83	2.94	3.187	2.007	0.846
0.200	0.169	1.580	1.448	3.193	2.108	0.941	1.05	3.65	0.83	2.95	3.303	2.110	0.898
0.300	0.253	1.669	1.532	3.300	2.237	1.014	1.05	3.65	0.83	2.95	3.421	2.213	0.950
0.400	0.337	1.759	1.616	3.407	2.365	1.087	1.06	3.65	0.83	2.95	3.538	2.316	1.002
0.500	0.420	1.849	1.699	3.515	2.493	1.161	1.06	3.66	0.83	2.95	3.658	2.418	1.054
0.600	0.503	1.940	1.782	3.622	2.621	1.235	1.07	3.66	0.83	2.96	3.777	2.519	1.105
0.700	0.586	2.032	1.865	3.729	2.748	1.309	1.07	3.66	0.83	2.96	3.896	2.620	1.157
0.800	0.668	2.124	1.947	3.836	2.875	1.383	1.08	3.67	0.84	2.96	4.016	2.721	1.207
1.000	0.832	2.309	2.111	4.050	3.128	1.533	1.09	3.67	0.84	2.96	4.258	2.921	1.308

		[M/H]=0.00		$\log g$ = 3.75			T_e= 5000°K						
E*(B-V)	E(B-V)	U-B	B-V	U-G	G-R	G-V	EUBV	RUBV	ERGU	RRGU	$(U-G)_c$	$(G-R)_c$	$(G-V)_c$
0.000	0.000	0.471	0.825	1.867	1.345	0.522	0.00	0.00	0.00	0.00	1.906	1.353	0.496
0.100	0.091	0.551	0.916	1.969	1.477	0.595	0.88	3.43	0.77	2.90	2.017	1.459	0.559
0.200	0.181	0.631	1.006	2.072	1.609	0.668	0.88	3.43	0.78	2.91	2.126	1.571	0.615
0.300	0.271	0.713	1.096	2.174	1.740	0.741	0.89	3.43	0.78	2.91	2.234	1.681	0.671
0.400	0.361	0.794	1.186	2.277	1.871	0.814	0.90	3.44	0.78	2.91	2.343	1.792	0.726
0.500	0.450	0.877	1.275	2.379	2.002	0.888	0.90	3.44	0.78	2.92	2.452	1.902	0.782
0.600	0.539	0.960	1.364	2.482	2.132	0.962	0.91	3.45	0.78	2.92	2.563	2.011	0.837
0.700	0.627	1.044	1.452	2.585	2.262	1.036	0.91	3.45	0.78	2.92	2.674	2.120	0.892
0.800	0.715	1.128	1.540	2.688	2.391	1.110	0.92	3.46	0.78	2.92	2.786	2.228	0.946
1.000	0.889	1.300	1.714	2.894	2.649	1.259	0.93	3.47	0.79	2.93	3.012	2.443	1.054

		[M/H]=-0.50			$\log g = 3.75$		T_e= 4000°K						
E*(B-V)	E(B-V)	U-B	B-V	U-G	G-R	G-V	EUBV	RUBV	ERGU	RRGU	$(U\text{-}G)_c$	$(G\text{-}R)_c$	$(G\text{-}V)_c$
0.000	0.000	1.144	1.247	2.642	1.813	0.799	0.00	0.00	0.00	0.00	2.701	1.831	0.757
0.100	0.086	1.234	1.332	2.751	1.943	0.871	1.05	3.61	0.84	2.94	2.824	1.932	0.817
0.200	0.171	1.324	1.417	2.860	2.072	0.944	1.05	3.62	0.84	2.94	2.943	2.038	0.870
0.300	0.255	1.415	1.502	2.969	2.201	1.017	1.06	3.62	0.84	2.94	3.062	2.143	0.924
0.400	0.340	1.506	1.587	3.077	2.330	1.090	1.07	3.63	0.84	2.95	3.181	2.248	0.976
0.500	0.424	1.598	1.671	3.186	2.458	1.163	1.07	3.63	0.84	2.95	3.301	2.351	1.029
0.600	0.507	1.691	1.754	3.295	2.586	1.237	1.08	3.63	0.84	2.95	3.422	2.456	1.082
0.700	0.591	1.784	1.837	3.404	2.714	1.311	1.08	3.64	0.85	2.95	3.543	2.559	1.133
0.800	0.674	1.878	1.920	3.513	2.841	1.385	1.09	3.64	0.85	2.96	3.665	2.662	1.186
1.000	0.838	2.067	2.085	3.731	3.095	1.534	1.10	3.65	0.85	2.96	3.911	2.866	1.288

		[M/H]=-0.50			$\log g = 3.75$		T_e= 5000°K						
E*(B-V)	E(B-V)	U-B	B-V	U-G	G-R	G-V	EUBV	RUBV	ERGU	RRGU	$(U\text{-}G)_c$	$(G\text{-}R)_c$	$(G\text{-}V)_c$
0.000	0.000	0.277	0.770	1.629	1.293	0.500	0.00	0.00	0.00	0.00	1.652	1.280	0.458
0.100	0.092	0.357	0.862	1.732	1.425	0.573	0.87	3.40	0.77	2.90	1.764	1.386	0.522
0.200	0.183	0.437	0.953	1.834	1.557	0.645	0.87	3.40	0.77	2.90	1.871	1.500	0.578
0.300	0.274	0.517	1.044	1.937	1.689	0.719	0.88	3.41	0.78	2.90	1.979	1.613	0.636
0.400	0.364	0.599	1.135	2.040	1.821	0.792	0.88	3.41	0.78	2.91	2.088	1.725	0.692
0.500	0.454	0.681	1.225	2.142	1.951	0.865	0.89	3.42	0.78	2.91	2.197	1.835	0.747
0.600	0.544	0.764	1.314	2.245	2.082	0.939	0.89	3.42	0.78	2.91	2.307	1.947	0.804
0.700	0.633	0.847	1.403	2.348	2.212	1.013	0.90	3.43	0.78	2.92	2.418	2.056	0.859
0.800	0.722	0.931	1.492	2.452	2.342	1.087	0.91	3.43	0.78	2.92	2.530	2.166	0.914
1.000	0.897	1.102	1.668	2.658	2.600	1.236	0.92	3.44	0.79	2.92	2.756	2.384	1.023

		[M/H]=-1.00		$\log g = 3.75$			T_e= 4000°K						
E*(B-V)	E(B-V)	U-B	B-V	U-G	G-R	G-V	EUBV	RUBV	ERGU	RRGU	$(U-G)_c$	$(G-R)_c$	$(G-V)_c$
0.000	0.000	0.960	1.214	2.427	1.807	0.802	0.00	0.00	0.00	0.00	2.468	1.799	0.739
0.100	0.087	1.048	1.301	2.534	1.937	0.875	1.01	3.57	0.83	2.93	2.588	1.901	0.800
0.200	0.173	1.137	1.387	2.642	2.067	0.948	1.02	3.57	0.83	2.93	2.706	2.009	0.854
0.300	0.259	1.226	1.473	2.750	2.196	1.021	1.03	3.57	0.83	2.94	2.823	2.115	0.908
0.400	0.344	1.316	1.559	2.857	2.325	1.094	1.03	3.58	0.83	2.94	2.940	2.220	0.961
0.500	0.429	1.406	1.644	2.965	2.454	1.167	1.04	3.58	0.83	2.94	3.059	2.325	1.014
0.600	0.514	1.497	1.729	3.073	2.582	1.241	1.04	3.59	0.83	2.95	3.179	2.430	1.067
0.700	0.598	1.589	1.813	3.181	2.710	1.315	1.05	3.59	0.83	2.95	3.297	2.534	1.118
0.800	0.682	1.681	1.897	3.289	2.838	1.390	1.06	3.60	0.84	2.95	3.419	2.639	1.172
1.000	0.849	1.868	2.063	3.505	3.092	1.539	1.07	3.61	0.84	2.96	3.663	2.846	1.275

		[M/H]=-1.00		$\log g = 3.75$			T_e= 5000°K						
E*(B-V)	E(B-V)	U-B	B-V	U-G	G-R	G-V	EUBV	RUBV	ERGU	RRGU	$(U-G)_c$	$(G-R)_c$	$(G-V)_c$
0.000	0.000	0.148	0.728	1.477	1.262	0.483	0.00	0.00	0.00	0.00	1.490	1.236	0.432
0.100	0.093	0.226	0.820	1.579	1.395	0.556	0.85	3.37	0.77	2.89	1.600	1.344	0.497
0.200	0.185	0.305	0.913	1.681	1.528	0.629	0.85	3.38	0.77	2.90	1.708	1.460	0.554
0.300	0.276	0.385	1.004	1.783	1.660	0.702	0.86	3.38	0.77	2.90	1.814	1.573	0.611
0.400	0.367	0.465	1.095	1.885	1.792	0.775	0.86	3.38	0.77	2.90	1.922	1.686	0.668
0.500	0.458	0.546	1.186	1.987	1.923	0.849	0.87	3.39	0.77	2.91	2.030	1.797	0.725
0.600	0.549	0.628	1.276	2.089	2.054	0.923	0.88	3.39	0.77	2.91	2.139	1.910	0.781
0.700	0.638	0.711	1.366	2.192	2.184	0.997	0.88	3.40	0.78	2.91	2.248	2.020	0.836
0.800	0.728	0.794	1.456	2.295	2.314	1.071	0.89	3.40	0.78	2.91	2.360	2.131	0.892
1.000	0.905	0.963	1.633	2.500	2.573	1.220	0.90	3.41	0.78	2.92	2.584	2.350	1.002

		[M/H]=-2.00		$\log g = 3.75$			T_e= 4000°K						
E*(B-V)	E(B-V)	U-B	B-V	U-G	G-R	G-V	EUBV	RUBV	ERGU	RRGU	$(U-G)_c$	$(G-R)_c$	$(G-V)_c$
0.000	0.000	0.751	1.160	2.211	1.813	0.801	0.00	0.00	0.00	0.00	2.233	1.781	0.719
0.100	0.089	0.833	1.249	2.314	1.944	0.875	0.93	3.48	0.79	2.92	2.348	1.883	0.781
0.200	0.177	0.917	1.337	2.417	2.074	0.948	0.94	3.49	0.79	2.93	2.461	1.992	0.835
0.300	0.265	1.001	1.425	2.521	2.204	1.021	0.94	3.49	0.79	2.93	2.572	2.099	0.889
0.400	0.353	1.086	1.513	2.624	2.333	1.095	0.95	3.50	0.79	2.93	2.685	2.204	0.942
0.500	0.440	1.171	1.600	2.728	2.462	1.169	0.96	3.50	0.80	2.94	2.798	2.309	0.996
0.600	0.526	1.258	1.686	2.832	2.591	1.243	0.96	3.51	0.80	2.94	2.913	2.417	1.050
0.700	0.612	1.345	1.773	2.936	2.719	1.317	0.97	3.51	0.80	2.94	3.026	2.520	1.100
0.800	0.698	1.433	1.858	3.040	2.847	1.392	0.98	3.52	0.80	2.94	3.143	2.626	1.154
1.000	0.868	1.611	2.028	3.248	3.102	1.542	0.99	3.53	0.80	2.95	3.377	2.835	1.258

		[M/H]=-2.00		$\log g = 3.75$			T_e= 5000°K						
E*(B-V)	E(B-V)	U-B	B-V	U-G	G-R	G-V	EUBV	RUBV	ERGU	RRGU	$(U-G)_c$	$(G-R)_c$	$(G-V)_c$
0.000	0.000	0.006	0.691	1.320	1.261	0.481	0.00	0.00	0.00	0.00	1.320	1.219	0.418
0.100	0.094	0.081	0.785	1.420	1.394	0.554	0.81	3.33	0.75	2.89	1.428	1.326	0.482
0.200	0.187	0.158	0.878	1.520	1.527	0.627	0.81	3.33	0.75	2.89	1.533	1.443	0.540
0.300	0.280	0.235	0.971	1.620	1.659	0.701	0.82	3.34	0.75	2.90	1.636	1.556	0.598
0.400	0.372	0.313	1.063	1.721	1.791	0.774	0.83	3.34	0.76	2.90	1.743	1.669	0.654
0.500	0.464	0.392	1.155	1.821	1.922	0.848	0.83	3.35	0.76	2.90	1.848	1.781	0.711
0.600	0.556	0.471	1.247	1.922	2.053	0.922	0.84	3.35	0.76	2.90	1.956	1.895	0.768
0.700	0.647	0.552	1.338	2.023	2.184	0.996	0.84	3.36	0.76	2.91	2.062	2.006	0.823
0.800	0.737	0.633	1.428	2.124	2.314	1.070	0.85	3.36	0.76	2.91	2.172	2.118	0.879
1.000	0.916	0.798	1.608	2.326	2.573	1.220	0.86	3.37	0.77	2.92	2.392	2.338	0.990

		[M/H]=-3.00		$\log g$ = 3.75			T_e= 4000°K						
E*(B-V)	E(B-V)	U-B	B-V	U-G	G-R	G-V	EUBV	RUBV	ERGU	RRGU	$(U-G)_c$	$(G-R)_c$	$(G-V)_c$
0.000	0.000	0.654	1.156	2.127	1.848	0.821	0.00	0.00	0.00	0.00	2.137	1.799	0.724
0.100	0.090	0.733	1.246	2.227	1.979	0.894	0.89	3.44	0.77	2.92	2.249	1.900	0.784
0.200	0.179	0.814	1.335	2.328	2.110	0.968	0.89	3.45	0.77	2.93	2.359	2.010	0.839
0.300	0.268	0.895	1.424	2.428	2.240	1.041	0.90	3.45	0.77	2.93	2.465	2.118	0.893
0.400	0.356	0.977	1.512	2.529	2.369	1.115	0.91	3.46	0.77	2.93	2.576	2.222	0.946
0.500	0.444	1.060	1.600	2.630	2.498	1.189	0.91	3.46	0.77	2.93	2.686	2.327	1.000
0.600	0.532	1.143	1.688	2.731	2.627	1.264	0.92	3.47	0.78	2.94	2.797	2.435	1.053
0.700	0.619	1.228	1.775	2.832	2.756	1.338	0.93	3.47	0.78	2.94	2.906	2.540	1.103
0.800	0.705	1.313	1.861	2.933	2.884	1.413	0.94	3.48	0.78	2.94	3.021	2.645	1.157
1.000	0.877	1.486	2.033	3.136	3.138	1.564	0.95	3.49	0.78	2.95	3.250	2.854	1.262

		[M/H]=-3.00		$\log g$ = 3.75			T_e= 5000°K						
E*(B-V)	E(B-V)	U-B	B-V	U-G	G-R	G-V	EUBV	RUBV	ERGU	RRGU	$(U-G)_c$	$(G-R)_c$	$(G-V)_c$
0.000	0.000	0.071	0.678	1.236	1.272	0.489	0.00	0.00	0.00	0.00	1.228	1.219	0.417
0.100	0.095	0.003	0.772	1.335	1.405	0.562	0.79	3.30	0.74	2.89	1.335	1.327	0.481
0.200	0.189	0.078	0.866	1.434	1.538	0.635	0.79	3.31	0.74	2.89	1.439	1.443	0.539
0.300	0.282	0.154	0.960	1.533	1.670	0.708	0.80	3.31	0.75	2.89	1.540	1.557	0.596
0.400	0.375	0.231	1.053	1.633	1.802	0.782	0.80	3.32	0.75	2.90	1.646	1.670	0.653
0.500	0.468	0.308	1.145	1.732	1.934	0.856	0.81	3.32	0.75	2.90	1.750	1.783	0.711
0.600	0.560	0.387	1.237	1.832	2.065	0.930	0.82	3.33	0.75	2.90	1.856	1.898	0.768
0.700	0.652	0.466	1.329	1.932	2.196	1.004	0.82	3.33	0.75	2.91	1.961	2.008	0.822
0.800	0.743	0.546	1.420	2.032	2.326	1.078	0.83	3.34	0.76	2.91	2.070	2.120	0.878
1.000	0.923	0.708	1.601	2.233	2.585	1.228	0.84	3.35	0.76	2.91	2.289	2.341	0.989

Thus, a correction matrix M could be obtained by means of the least square method, i.e. :

$$M = \begin{pmatrix} 0.13 & -0.16 & 0.11 \\ 0.19 & -0.28 & 0.15 \\ 0.17 & -0.31 & 0.15 \end{pmatrix} \quad (A.3)$$

and the original RGU synthetic data were corrected, assuming that the source of error in the original RGU synthetic data was not a function of metallicity.

Finally, putting together the corrected U-G, G-R, and G-V colour-indices and the original U-B and B-V synthetic colour-indices in equations (A.1) for each metallicity individually and applying the least square method, the coefficients given in Table A.4 were obtained.

So, the corrected RGU data and the well known least squares method were used for derivation the new coefficients for transformation UBV to RGU. This methodology diminishes the probability of including any systematic error for the transformation formulae and corrected RGU data. Hence, the remaining source for such an error is probably due to the calibration of metallicity for the RGU system (Figures 3 and 4 of Buser and Fenkart [13].

Table A4. Coefficients for the transformation formulae from UBV to RGU of Buser and Güngör [15] for dwarfs and giants with different metallicities.

[M/H] (Dwarfs)	a_1	b_1	c_1	**Standard Deviation**
0.5	1.26	0.04	1.31	± 0.005
0.0	1.17	0.15	1.24	± 0.007
-0.5	1.13	0.15	1.22	± 0.010
-1.0	1.21	0.01	1.30	± 0.007
-2.0	1.20	0.04	1.28	± 0.005
-3.0	1.13	0.18	1.18	± 0.006
(Giants)				
0.0	1.14	0.15	1.24	± 0.010
-0.5	1.16	0.10	1.26	± 0.017
-1.0	1.18	0.10	1.25	± 0.022
-2.0	1.16	0.20	1.19	± 0.019
-3.0	1.15	0.24	1.18	± 0.013

[M/H]	a_2	b_2	c_2	**Standard Deviation**
(Dwarfs)				
0.5	0.06	1.15	0.40	± 0.008
0.0	-0.04	1.28	0.32	± 0.009
-0.5	0.00	1.15	0.39	± 0.015
-1.0	0.19	0.85	0.59	± 0.012
-2.0	0.17	0.92	0.58	± 0.005
-3.0	0.06	1.12	0.47	± 0.007
(Giants)				
0.0	-0.07	1.23	0.33	± 0.008
-0.5	-0.01	1.11	0.41	± 0.007
-1.0	-0.01	1.12	0.43	± 0.010
-2.0	-0.02	1.16	0.43	± 0.008
-3.0	-0.04	1.23	0.41	± 0.009

[M/H]	a_3	b_3	c_3	**Standard Deviation**
(Dwarfs)				
0.5	0.02	0.57	0.02	± 0.009
0.0	-0.01	0.63	-0.01	± 0.010
-0.5	0.07	0.49	0.06	± 0.011
-1.0	0.21	0.28	0.20	± 0.009
-2.0	0.19	0.32	0.19	± 0.009
-3.0	0.11	0.47	0.11	± 0.004
(Giants)				
0.0	0.00	0.64	-0.02	± 0.004
-0.5	0.03	0.60	0.01	± 0.004
-1.0	0.04	0.60	0.01	± 0.009
-2.0	0.04	0.64	0.01	± 0.007
-3.0	0.03	0.68	0.00	± 0.004