CSIRO PUBLISHING

www.publish.csiro.au/journals/pasa *Publications of the Astronomical Society of Australia*, 2003, **20**, 165–172

New Metallicity Calibration Down to [Fe/H] = −2.75 dex

S. Karaali, S. Bilir, Y. Karataş and S. G. Ak

Department of Astronomy and Space Sciences, Science Faculty, Istanbul University, 34452 Istanbul, Turkey
karsa@istanbul.edu.tr

Received 2002 August 29, accepted 2003 February 1

Abstract: We have taken 88 dwarfs, covering the colour-index interval $0.37 \leq (B-V)_0 \leq 1.07$ mag, with metallicities $-2.70 \leq$ [Fe/H] $\leq +0.26$ dex, from three different sources for new metallicity calibration. The catalogue of Cayrel de Strobel et al. (2001), which includes 65% of the stars in our sample, supplies detailed information on abundances for stars with determination based on high-resolution spectroscopy. In constructing the new calibration we have used as '*corner stones*' 77 stars which supply at least one of the following conditions: (i) the parallax is larger than 10 mas (distance relative to the Sun less than 100 pc) and the galactic latitude is absolutely higher than 30°; (ii) the parallax is rather large, if the galactic latitude is absolutely low and vice versa. Contrary to previous investigations, a third-degree polynomial is fitted for the new calibration: [Fe/H] $= 0.10 - 2.76\delta - 24.04\delta^2 + 30.00\delta^3$. The coefficients were evaluated by the least-squares method, without regard to the metallicity of Hyades. However, the constant term is in the range of metallicity determined for this cluster, i.e. $0.08 \leq$ [Fe/H] ≤ 0.11 dex. The mean deviation and the mean error in our work are equal to those of Carney (1979), for [Fe/H] ≥ -1.75 dex where Carney's calibration is valid

Keywords: stars: abundances — stars: metallicity calibration — stars: metal-poor

1 Introduction

Metallicity plays an important role in Galactic structure. Although mean metal-abundances were attributed to three main Galactic components, i.e.: Population I (Thin Disk), Intermediate Population II (Thick Disk) and Extreme Population II (Halo) (cf. Norris 1996), recent works show that the metallicity distributions for these populations may well be multimodal (Norris 1996, Carney 2000, Karaali et al. 2000). More important is the metallicity gradient cited either for populations individually or for a region of the Galaxy. Examples can be found in Reid & Majewski (1993) and Chiba & Yoshii (1998). The importance is related to the formation of the Galaxy as explained here. The existence of a metallicity gradient for any component of the Galaxy means that it formed by dissipative collapse. The proponents of this suggestion are Eggen, Lynden-Bell & Sandage (1962, ELS). Discussion of the current status of this model is provided by Gilmore, Wyse & Kuijken (1989). Later analyses followed (e.g. Yoshii & Saio 1979; Norris, Bessel & Pickles 1985; Norris 1986; Sandage & Fouts 1987; Carney, Latham & Laird 1990; Norris & Ryan 1991; and Beers & Sommer-Larsen 1995). From their studies, an alternative picture emerged, suggesting that the collapse of the Galaxy occurred slowly. This picture was postulated largely on a supposed wide age range in the globular cluster system (Searle & Zinn (1978, SZ), Schuster & Nissen (1989). SZ especially argued that the Galactic halo was not formed as a result of collapse but from the merger or accretion of numerous fragments such as dwarf-type galaxies. Such a scenario indicates either no metallicity gradient or younger and even more metal-rich objects at the outermost part of the Galaxy. The globular cluster age range supposition has been disproved by recent analyses (Rosenberg et al. 1999) while the number of young field halo stars has been shown to be extremely small, inconsistent with this model by Unavane, Wyse & Gilmore (1996), Preston & Sneden (2000) and Gilmore (2000).

A clear metallicity gradient is highly dependent on the precise metallicity determination. The ultraviolet excess provides metallicities for large field surveys in many photometries such as uvby-β (Strömgren 1966), VBLUW (Walraven & Walraven 1960, Trefzger et al. 1995), RGU (Buser & Fenkart 1990) and UBV (Carney 1979). There are many calibrations between the normalised ultraviolet excess $(\delta_{\mathrm{U-B}})_{0.6}$ and the metal abundance [Fe/H] for the last system which deviate from each other considerably. Figure 15 of Buser & Kurucz (1992) compares these calibrations based on empirical data (Cameron 1985, Carney 1979) or theoretical models (Buser & Kurucz 1978, 1985, and Vandenberg & Bell 1985). The reason for these differences originates from the UBV data as well as from the atmospheric parameters. Cayrel de Strobel et al. (2001) state the following discrepancies even for high quality observations and careful analysis:

(1) The [Fe/H] determinations are usually solar scaled however it changes logarithmically from author to author by 0.20.
(2) The difference in temperature proposed by different authors for a star may be as large as 400 K which results ≅0.80 dex in metallicity as in the case of the metal-poor halo sub-giant HD 140283.
(3) The great metal deficiency in the atmosphere of a very evolved Population II star results in misclassification of spectral type. The MK spectrum of such stars mimics the MK spectrum of a hotter unevolved star.

10.1071/AS02028 1323-3580/03/02165

(4) It was shown by Hipparcos data that spectroscopic gravities, based on ionisation equilibrium are in error for very metal-poor stars.

We aimed to derive a new metallicity calibration for stars with a large [Fe/H] scale making use of the updated UBV and [Fe/H] data and keeping in mind the reservations mentioned above. Thus we had to investigate the metallicity distribution of metal-poor stars at different distances from the galactic plane and contribute to the implications for the Galactic formation and evolution. The first application (Karaali et al. 2003) based on CCD data for stars in an intermediate latitude field is promising. The data are presented in Section 2. The new metallicity calibration is given in Section 3 and finally a short discussion is presented in Section 4.

2 The Data

The data given in Table 1 were taken from three different sources. (1) 57 of them with $\log g \geq 4.5$ are from Cayrel de Strobel et al. (2001). This catalogue supplies detailed information on abundances for stars with determination based on high-resolution spectroscopy. Also it contains the errors in atmospheric parameters, i.e. $T_{\rm eff}$, $\log g$, and [Fe/H] when available. However, we did not include such stars in the statistics of our work. Additionally the spectral types of the stars are available in the catalogue. (2) 11 high mass stars were taken from a different catalogue of the same authors (Cayrel de Strobel et al. 1997). This catalogue has the advantage of including metal-poor stars down to $[{\rm Fe/H}] = -2.70$ dex with smaller surface gravity, i.e. $\log g \geq 4.0$. (3) We selected 20 dwarfs from the catalogue of Carney (1979). Although Table 5 of Carney includes a large sample of dwarfs we had to eliminate eight of them which are common in the catalogues of Cayrel de Strobel et al. (1997, 2001) and 12 of them which turned out to be variable stars according to the SIMBAD database. $T_{\rm eff}$ and $\log g$ parameters not given in the table of Carney are from the authors cited in the 'remarks' column.

We consulted the specialised catalogues which are included in the General Catalogue of Photometric Data[1] (Mermilliod et al. 1997) for the UBV magnitudes and colours in these catalogues. The data in columns 11 and 12 (the parallax and the galactic latitude in Table 1) are provided from the SIMBAD database.

The selection of a total 88 stars from the catalogues mentioned above was carried out as follows; most of the 57 and 20 stars taken from Cayrel de Strobel et al. (2001) and Carney (1979) respectively have parallaxes larger than 10 mas and galactic latitude absolutely higher than 30°. Such intermediate or high latitude stars which are at distances less than 100 pc can be adopted as free of interstellar extinction hence their UBV data need no reduction. However there are a few stars which do not satisfy both of these conditions though they can be adopted as un-reddened stars. BD +36 2165 ($\pi = 8.11$ mas, $b = 67^\circ.35$) and HD 39587 ($\pi = 115.43$ mas, $b = -2^\circ.73$) can be given as two examples for such stars, the galactic latitude of the first star is high and the second star is at a distance of only $r = 8.7$ pc relative to the Sun. 77 stars selected from the two catalogues cited above have been used as '*corner stones*' for the metallicity calibration. Then, 11 stars taken from the catalogue of Cayrel de Strobel et al. (1997) were selected such as to be close to the stars called '*corner stones*' or to obey the curvature determined by these stars, in the $(\delta_{\rm U-B})_{0.6}$–[Fe/H] plane. Thus the calibration could be extended down to [Fe/H] = -2.75 dex. No reduction for interstellar extinction was necessary for the UBV data for five stars in this catalogue which have either large parallaxes or galactic latitudes with $|b| \geq 23^\circ$. Whereas the UBV data for six absolutely very low latitude stars have been de-reddened by the following procedure (Bahcall & Soneira 1980).

$$A_d(b) = A_\infty(b)\left[1 - \exp\left(d\frac{-\sin b}{H}\right)\right] \qquad (1)$$

Here b and d are the galactic latitude and the distance of the star (evaluated by means of its parallax) respectively. H is the scale-height for the interstellar dust which is adopted as 100 pc and $A_\infty(b)$ and $A_d(b)$ are the total absorptions for the model and for the distance to the star respectively. $A_\infty(b)$ can be evaluated by means of Equation (2)

$$A_\infty(b) = 3.1E_\infty(B-V) \qquad (2)$$

where $E_\infty(B-V)$ is the colour excess for the model taken from the NASA Extragalactic Database. Then, $E_{\rm d}(B-V)$, i.e. the colour excess for the corresponding star at the distance d can be evaluated by Equation (2) adopted for distance d

$$E_d(B-V) = A(d)/3.1 \qquad (3)$$

and can be used for the colour excess $E_d(U-B)$ evaluation:

$$E_d(U-B) = 0.72E_d(B-V) + 0.05E_d^2(B-V) \qquad (4)$$

Finally, the de-reddened colour indices are:

$$(B-V)_0 = (B-V) - E_d(B-V) \quad \text{and}$$
$$(U-B)_0 = (U-B) - E_d(U-B) \qquad (5)$$

3 The Method

We adopted the procedure of Carney (1979) for the calibration of the normalized ultraviolet excess relative to Hyades cluster, $(\delta_{\rm U-B})_{0.6}$ and the solar scaled metal abundance [Fe/H], with small modifications. Our sample covers a large range of the B–V colour index, i.e. $0.37 \leq (B-V)_0 \leq 1.07$ mag, however 80% of the stars have colour-indices between 0.40 and 0.70 mag. The normalized ultraviolet excess and the metal abundance cover a large interval, i.e. $-0.09 \leq (\delta_{\rm U-B})_{0.6} \leq +0.38$ mag and $-2.70 \leq$ [Fe/H] $\leq +0.26$ dex, respectively. We divided the interval $-0.09 \leq (\delta_{\rm U-B})_{0.6} \leq +0.38$ mag into 17 scans and adopted the centroid of each scan as a locus point

---

[1] http://obswww.unige.ch/gcpd/cgi-bin/photoSysHtml.cgi?0

Table 1. Dwarfs used for metallicity calibration

The columns give: BD, HD or G (Giclas) number, Hipparcos (Hip) number, spectral type, T_{eff}, log g, the UBV data, the standardised ultraviolet excess ($\delta_{0.6}$), [Fe/H], parallax π, galactic latitude b and remarks. The figures (1), (2) or (3) in the last column refer to as Cayrel de Strobel et al. (2001), Cayrel de Strobel et al. (1997), and Carney (1979), respectively. The words ‘corrected’ or ‘uncorrected’ denote that UBV data are de-reddened or not (see text). T_{eff} and log g parameters not given in the table of Carney, are from the authors cited in the ‘remarks’ column

No	Hip No	Spec.	T_{eff}	log g	V	B–V	U–B	$\delta_{0.6}$	[Fe/H]	π	b	Remarks
BD +02 0375	86443	A5	5793	4.00	9.820	0.420	−0.260	0.36	−2.50	8.35	17.03	(2), corrected
BD +09 0352	12529	F2	5860	4.50	10.180	0.440	−0.250	0.30	−2.20	5.22	−44.51	(1)
BD +29 0366	10140	F8V	5760	4.56	8.760	0.590	−0.100	0.18	−0.99	17.66	−30.01	(2), uncorrected
BD +36 2165	54772	G0	6349	4.79	9.770	0.430	−0.190	0.22	−1.15	8.11	67.35	(1)
BD +38 4955	114661	F6	5125	4.50	11.015	0.665	−0.155	0.38	−2.69	14.09	−19.66	(1)
BD +41 3931	103269	G5	5560	4.77	10.170	0.590	−0.130	0.25	−1.60	14.24	−1.82	(2), corrected
BD +42 2667	78640	F5	5929	4.00	9.870	0.460	−0.200	0.23	−1.67	8.03	48.41	(3), Rebolo (1988)
BD +66 0268	16404	G0	5250	4.98	9.820	0.640	−0.110	0.29	−2.11	17.58	8.59	(2), corrected
BD −06 0855	19814	G	5419	4.50	10.600	0.690	0.115	0.13	−0.70	24.27	−37.12	(1)
CD −45 03283	36818	G8V−VI	5672	4.57	10.470	0.610	−0.020	0.16	−0.83	15.32	−11.98	(1)
G 88−10	34630	A:	5900	4.00	11.710	0.390	−0.280	0.35	−2.70	4.00	14.77	(2), corrected
HD 001581	1599	F9V	6009	4.52	4.220	0.580	0.010	0.09	−0.26	116.38	−51.92	(1)
HD 003765	3206	K2V	5091	4.64	7.360	0.940	0.700	−0.01	−0.06	57.90	−22.64	(2), uncorrected
HD 006582	5336	G5Vb	5305	4.61	5.170	0.700	−0.100	0.16	−0.71	132.42	−7.87	(2), uncorrected
HD 008673	6702	F7V	6380	4.50	6.330	0.460	−0.010	0.02	0.16	26.14	−27.75	(1)
HD 010700	8102	G8V	5500	4.32	3.500	0.720	0.210	0.08	−0.36	274.18	−73.44	(3), Mallik (1998)
HD 013555	10306	F5V	6358	4.07	5.290	0.420	−0.070	0.09	−0.40	33.19	−37.81	(3), Edvardsson (1993)
HD 020766	15330	G2.5V	5860	4.50	5.520	0.630	0.080	0.08	−0.20	82.51	−47.21	(1)
HD 022879	17147	F9V	5926	4.57	6.700	0.540	−0.080	0.15	−0.76	41.07	−43.12	(1)
HD 028946	21272	K0	5288	4.55	7.930	0.770	0.360	0.02	−0.03	37.33	−27.24	(1)
HD 030495	22263	G3V	6000	4.50	5.470	0.600	0.140	−0.01	0.10	75.10	−34.81	(1)
HD 030649	22596	G1V−VI	5727	4.31	6.970	0.590	0.020	0.11	−0.32	33.44	1.02	(3), Thevenin (1999)
HD 039587	27913	G0V	5929	4.50	4.410	0.590	0.080	0.03	−0.05	115.43	−2.73	(1)
HD 052298	33495	F5/F6V	6072	4.60	6.940	0.460	−0.110	0.14	−0.84	27.38	−20.34	(1)
HD 056513	35377	G2V	5659	4.50	8.030	0.630	0.050	0.11	−0.38	28.19	17.57	(1)
HD 063077	37853	G0V	5820	4.42	5.360	0.570	−0.070	0.17	−0.80	65.79	−4.81	(3), Castro (1999)
HD 064090	38541	sdG2	5370	4.00	8.260	0.610	−0.120	0.26	−1.73	35.29	25.93	(3), Mishenina (2000)
HD 064090	38541	sdG2	5340	4.75	8.320	0.620	−0.140	0.28	−1.86	35.29	25.93	(2), uncorrected
HD 064606	38625	G8V	5206	4.57	7.440	0.730	0.160	0.17	−0.93	52.01	13.34	(1)

Continued

Table 1. *Continued*

No	Hip No	Spec.	$T_{\rm eff}$	log g	V	B–V	U–B	$\delta_{0.6}$	[Fe/H]	π	b	Remarks
HD 065907	38908	G0V	6072	4.50	5.610	0.570	−0.010	0.10	−0.36	61.76	−15.68	(1)
HD 072905	42438	G1.5Vb	6030	4.66	5.640	0.620	0.070	0.08	−0.27	70.07	35.70	(3), Gray (2001)
HD 074000	42592	sdF6	6072	4.20	9.620	0.430	−0.230	0.28	−2.05	7.26	15.31	(3), Hartmann (1988)
HD 074000	42592	sdF6	6072	4.20	9.580	0.390	−0.270	0.31	−2.06	7.26	15.31	(2), corrected
HD 076151	43726	G2V	5727	4.50	6.000	0.670	0.220	0.00	0.07	58.50	24.16	(1)
HD 084937	48152	sdF5	6222	4.00	8.320	0.370	−0.200	0.27	−2.19	12.44	45.47	(3), Peterson (1981)
HD 089125	50384	F8Vbw	6143	4.54	5.820	0.500	−0.050	0.09	−0.38	44.01	55.00	(1)
HD 090508	51248	F9V	5802	4.35	6.420	0.600	0.050	0.08	−0.23	42.45	54.92	(3), Fuhrmann (2000)
HD 094028	53070	F4V	6060	4.54	8.240	0.470	−0.170	0.21	−1.38	19.23	61.77	(1)
HD 101501	56997	G8V	5538	4.69	5.310	0.720	0.280	0.01	0.03	104.81	73.32	(1)
HD 106516	59750	F5V	6222	4.50	6.100	0.480	−0.110	0.15	−0.82	44.34	51.54	(1)
HD 108177	60632	sdF5	6200	4.40	9.670	0.430	−0.220	0.26	−1.70	10.95	63.42	(3), Fulbright (2000)
HD 110897	62207	G0V	5860	4.41	5.950	0.550	−0.030	0.11	−0.31	57.57	77.78	(3), Thevenin (1999)
HD 113083	63559	F9V	5750	4.50	8.050	0.550	−0.110	0.19	−0.93	18.51	35.44	(1)
HD 114710	64394	F9.5V	6146	4.52	4.260	0.580	0.080	0.02	0.06	109.23	85.41	(1)
HD 114762	64426	F9V	5928	4.18	7.300	0.520	−0.080	0.14	−0.64	24.65	79.25	(3), Clementini (1999)
HD 115617	64924	G5V	5600	4.50	4.753	0.697	0.261	0.00	−0.02	117.30	44.09	(1)
HD 125072	69972	K3V	4941	4.50	6.640	1.040	0.950	−0.06	0.26	84.50	1.61	(1)
HD 126681	70681	G3V	5500	4.63	9.300	0.600	−0.100	0.23	−1.45	19.16	38.86	(1)
HD 128620	71683	G2V	5793	4.50	0.020	0.657	0.230	−0.03	0.20	742.24	−0.68	(1)
HD 128621	71681	K1V	5305	4.50	1.390	0.871	0.590	−0.01	0.14	742.22	−0.68	(1)
HD 131653	72998	G5	5356	4.65	9.520	0.720	0.160	0.15	−0.63	20.29	42.99	(1)
HD 132142	73005	K1V	5091	4.50	7.760	0.790	0.330	0.10	−0.55	41.83	55.04	(1)
HD 134439	74235	K0/K1V	5106	4.74	9.090	0.760	0.180	0.22	−1.30	34.14	34.99	(1)
HD 136352	75181	G4V	5478	4.18	5.660	0.640	0.060	0.12	−0.49	68.70	7.38	(3), Francois (1986)
HD 148816	80837	F8V	5923	4.16	7.280	0.530	−0.070	0.14	−0.63	24.34	33.05	(3), Clementini (1999)
HD 151044	81800	F8V	6146	4.50	6.470	0.540	0.020	0.04	−0.01	34.00	40.89	(1)
HD 152792	82636	G0V	5647	4.12	6.810	0.650	0.080	0.11	−0.38	21.13	39.13	(3), Gorgas (1999)
HD 157089	84905	F9V	5885	4.00	6.970	0.560	−0.010	0.10	−0.54	25.88	20.68	(3), Friel (1992)
HD 165908	88745	F7V	6001	4.21	5.050	0.520	−0.080	0.13	−0.46	63.88	22.30	(3), Gratton (1996)
HD 166913	89554	F6:Vw	6175	4.61	8.200	0.460	−0.200	0.24	−1.44	16.09	−18.88	(1)
HD 181743	95333	F3/F5w	5929	4.25	9.660	0.460	−0.250	0.31	−2.04	11.31	−24.27	(2), uncorrected
HD 184960	96258	F7V	6222	4.50	5.740	0.480	0.000	0.02	−0.13	39.08	14.59	(1)

Continued

Table 1. ***Continued***

No	Hip No	Spec.	$T_{\rm eff}$	log g	V	B–V	U–B	$\delta_{0.6}$	[Fe/H]	π	b	Remarks
HD 186185	97063	F5V	6462	4.50	5.490	0.465	0.025	−0.02	0.02	27.26	−18.36	(1)
HD 186427	96901	G3V	5860	4.50	6.220	0.660	0.200	0.00	0.08	46.70	13.20	(1)
HD 188510	98020	G5Vw	5628	5.16	8.830	0.600	−0.090	0.22	−1.37	25.32	−8.92	(1)
HD 191195	99026	F5V	6632	4.50	5.820	0.415	−0.030	0.04	0.02	27.43	11.18	(1)
HD 191408	99461	K3V	4893	4.50	5.310	0.850	0.430	0.14	−0.58	165.27	−30.92	(1)
HD 192985	99889	F5V:	6545	4.50	5.870	0.400	−0.040	0.05	−0.05	28.97	5.80	(1)
HD 193901	100568	F7V	5810	4.83	8.650	0.540	−0.130	0.20	−1.22	22.88	−29.38	(1)
HD 194598	100792	F7V−VI	5950	4.64	8.800	0.470	−0.140	0.17	−0.99	17.94	−16.13	(2), corrected
HD 197039	102029	F5	6545	4.50	6.740	0.445	0.025	−0.02	0.15	14.36	−15.66	(1)
HD 197373	102011	F6IV	6462	4.50	5.990	0.420	−0.040	0.05	−0.03	30.12	11.33	(1)
HD 197692	102485	F5V	6632	4.50	4.138	0.427	0.010	−0.01	−0.11	68.16	−35.50	(1)
HD 197963	102531	F7V	6300	4.50	5.140	0.490	0.080	−0.06	0.12	31.69	−16.58	(1)
HD 199289	103498	F5V	5936	4.71	8.290	0.520	−0.130	0.19	−0.99	18.94	−40.65	(1)
HD 201891	104659	F8V−VI	5867	4.46	7.370	0.510	−0.160	0.21	−1.42	28.26	−20.43	(3), Edvardsson (1993)
HD 202628	105184	G2V	5771	4.52	6.740	0.630	0.130	0.03	−0.14	42.04	−44.45	(1)
HD 204121	105864	F5V	6545	4.50	6.120	0.450	−0.010	0.02	0.08	20.89	−33.25	(1)
HD 210752	109646	G0	5958	4.59	7.400	0.520	−0.080	0.14	−0.59	26.57	−47.05	(1)
HD 212698	110778	G3V	5915	4.50	5.540	0.610	0.060	0.08	−0.13	49.80	−54.98	(1)
HD 212754	110785	F7V	6146	4.50	5.760	0.515	0.030	0.01	−0.04	25.34	−42.93	(1)
HD 213042	110996	K5V	4760	4.58	7.670	1.070	1.000	−0.09	0.25	64.74	−58.77	(1)
HD 217014	113357	G2.5IVa	5669	4.06	5.500	0.670	0.200	0.01	0.12	65.10	−34.73	(3), Gratton (1996)
HD 217877	113896	F8V	6000	4.50	6.680	0.580	0.060	0.04	−0.10	32.50	−56.02	(1)
HD 218235	114081	F6Vs	6462	4.50	6.160	0.445	0.020	−0.01	0.25	23.16	−37.72	(1)
HD 218261	114096	F7V	6146	4.50	6.450	0.540	0.020	0.04	0.09	35.32	−36.54	(1)
HD 218470	114210	F5V	6545	4.50	5.600	0.405	−0.035	0.04	−0.17	29.33	−10.16	(1)
HD 222451	116824	F1V	6632	4.50	6.250	0.400	−0.010	0.01	0.09	22.63	−24.02	(1)

Table 2. **Locus points and the number of stars associated with them (last column). The other columns give the current number, $\delta_{0.6}$, [Fe/H] and mean errors for the $\delta_{0.6}$ and [Fe/H], respectively.**

No	$\delta_{0.6}$	[Fe/H]	$\Delta\delta_{0.6}$	Δ[Fe/H]	*N*
01	−0.07	+0.21	0.01	0.04	3
02	−0.02	+0.09	0.00	0.04	8
03	+0.01	+0.05	0.00	0.02	7
04	+0.02	+0.01	0.00	0.04	7
05	+0.04	−0.04	0.00	0.03	7
06	+0.08	−0.28	0.00	0.03	8
07	+0.11	−0.41	0.00	0.03	7
08	+0.14	−0.62	0.00	0.04	8
09	+0.15	−0.75	0.00	0.03	5
10	+0.17	−0.93	0.00	0.04	4
11	+0.19	−1.05	0.00	0.07	3
12	+0.22	−1.32	0.00	0.04	5
13	+0.23	−1.52	0.00	0.06	3
14	+0.26	−1.68	0.00	0.03	3
15	+0.28	−2.05	0.00	0.06	4
16	+0.31	−2.10	0.00	0.04	3
17	+0.36	−2.60	0.01	0.05	3

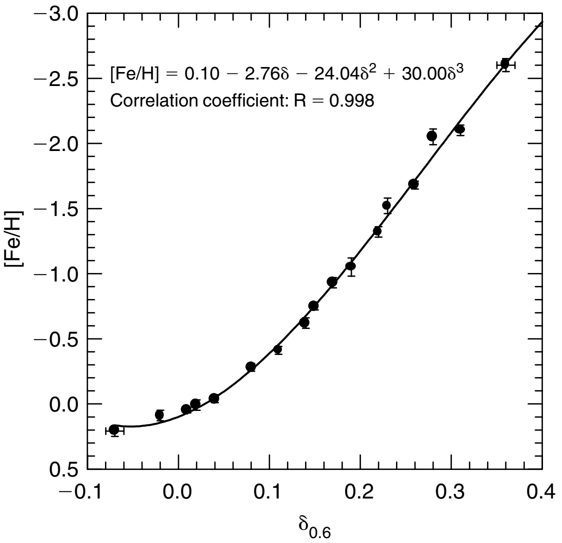

Figure 1 The third-degree polynomial curve through 17 locus-points and the correlation coefficient. The bars show the mean errors.

to fit the couple ($(\delta_{\text{U-B}})_{0.6}$, [Fe/H]). Table 2 gives the locus points and the number of associated stars. It is clear from this table that the number of metal-poor stars is small, resulting in a relatively larger scale both in $(\delta_{\text{U-B}})_{0.6}$ and [Fe/H] encompassing enough stars in this end of the calibration.

A third-degree polynomial is adopted for the locus points (Fig. 1). Although the constant term in the equation given by Carney, i.e. $[\text{Fe/H}] = 0.11 - 2.90\delta - 18.68\delta^2$ was assumed to represent the metallicity of Hyades and was fixed by 0.11 in the evaluation of the coefficients of other terms, we left it as a free parameter in our calculations. The constant term in the third-degree polynomial resulting by the least-squares method is $a_0 = 0.10$, which is rather close to the metal abundance given by Carney (1979) and 2% larger than the value of Cameron (1985), i.e. [Fe/H] = 0.08 dex. The full equation of the polynomial is $[\text{Fe/H}] = 0.10 - 2.76\delta - 24.04\delta^2 + 30.00\delta^3$. Here δ is replaced for the normalized ultraviolet excess $(\delta_{\text{U-B}})_{0.6}$. The curve of this equation is given in Fig. 2 together with the data for all stars in three catalogues cited above. Stars used for the metallicity calibration are marked by a different symbol. The deviations of the evaluated metal abundances from the original ones are given in Fig. 3. The mean deviation is almost zero, i.e. $<[\text{Fe/H}]> = 0.002$ dex and the corresponding mean error is ±0.01 dex.

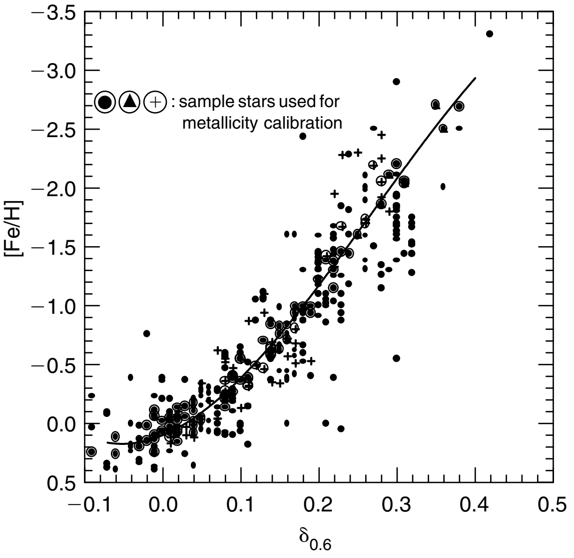

Figure 2 The third-degree polynomial curve evaluated by means of 17 locus points of 88 dwarfs, selected from three catalogues defined by the criteria explained in the text, and the position of stars which do not satisfy the mentioned criteria (see the text). The symbols give: (●) dwarfs with log $g \geq 4.5$ from Cayrel de Strobel et al. (2001), (▲) dwarfs with log $g \geq 4.0$ from Cayrel de Strobel et al. (1997), and (+) dwarfs from Carney (1979). A circled star belongs to the sample of 88 stars.

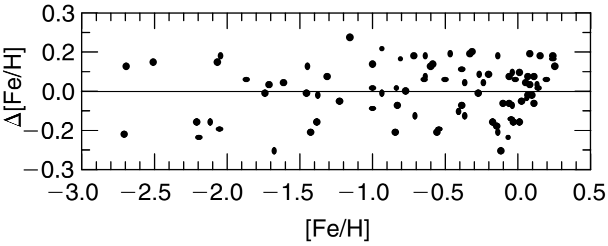

Figure 3 Deviation of evaluated metallicities from original ones versus original metallicity. The mean deviation and the mean error for this distribution are $<[\text{Fe/H}]> = 0.00$ and $(m.e.) = \pm 0.01$ dex, respectively.

4 Discussion

88 dwarfs with solar scaled metallicities $-2.70 \leq [\text{Fe/H}] \leq +0.26$ dex have been taken from three different sources for a new metallicity calibration. In particular, the catalogue of Cayrel de Strobel et al. (2001) provides

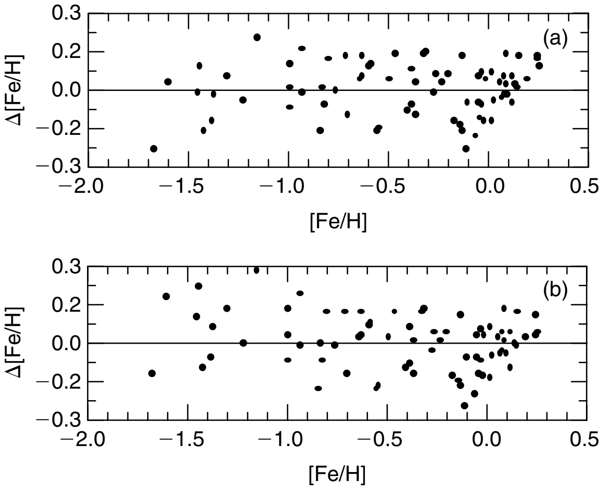

Figure 4 Comparison of the deviations in our (a) and Carney's (b) work for [Fe/H] ≥ −1.75 dex where Carney's calibration is valid. There is no discrepancy between two distributions; the mean deviations and the mean errors in these works are also equal.

us with 57 stars for this purpose and supplies detailed information on abundances for stars with determination based on high-resolution spectroscopy. The selection of these and 20 other stars from the catalogue of Carney (1979) (total 77) ensure freedom from interstellar extinction. These stars satisfy at least one of the following conditions: (i) the parallax is larger than 10 mas (distance relative to the Sun less than 100 pc) and the galactic latitude is absolutely higher than 30°, (ii) the parallax is rather large if the galactic latitude is absolutely low and vice versa. The remaining 11 stars were selected from Cayrel de Strobel et al. (1997) by means of a different criterion, i.e. their metallicities and normalised ultraviolet excesses are in good agreement with the data of 77 stars and their position in the $(\delta_{U-B})_{0.6}$–[Fe/H] plane obey the curvature determined from 77 stars. Five out of eleven stars could be adopted as free of interstellar extinction whereas the UBV data of the remaining six stars have to be de-reddened. The last sample extends the metallicity calibration down to [Fe/H] = −2.75 dex.

We compared our results with the ones of Carney (1979). Figure 4 shows the deviations in two works which are evaluated only for the metallicities [Fe/H] ≥ −1.75 dex where the calibration of Carney is valid. There is no discrepancy between the two distributions. The mean deviations and mean errors are equal ($<$[Fe/H]$>$ = 0.00 dex, ($m.e.$) = ± 0.01 dex). An additional comparison is carried out for 89 metal-poor stars, i.e. −2.50 ≤ [Fe/H] < −1.75 dex, taken from Carney et al. (1994). The catalogue of these authors contains a larger sample of stars with these metallicities, however many of them are peculiar stars, such as variable stars, binary stars, etc. We restricted our sample to a smaller number of stars to avoid any probable error. We used the UBV and $E(B{-}V)$ data for these stars and evaluated the metallicities by means of new calibration and we compared them with the original ones of Carney et al. Figure 5a shows the deviation relative to the original metallicities. There is a flat and symmetrical distribution relative to the mean deviation, $<\Delta$[Fe/H]$>$ = 0.21 dex. Contrary to expectation, the mean deviation is not zero. But this is also the case for the metal rich stars (Fig. 5b), where the mean deviation for metallicity interval −1.75 ≤ [Fe/H] < 0.20 dex is $<\Delta$[Fe/H]$>$= 0.19 dex, indicating a zero point difference between two sets of data. The mean error for the metal-poor stars, ±0.05 dex, is at the level of expectation. Hence the new calibration provides metallicities with the accuracy of Carney's (1979) calibration but it has the advantage of covering the extreme metal-poor stars.

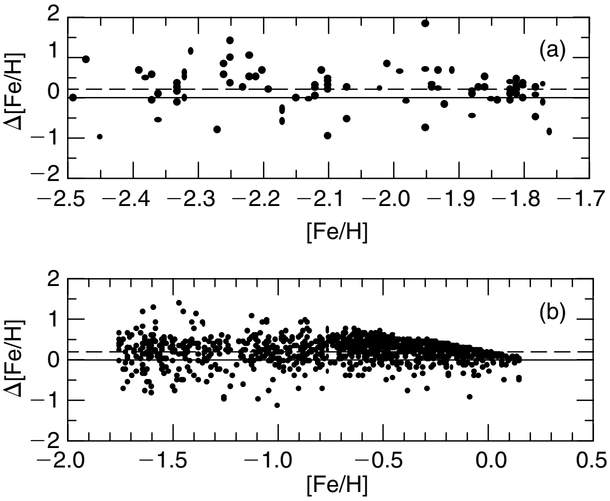

Figure 5 Deviations of the evaluated metallicities relative to the original ones, taken from Carney et al. (1994). For metallicities (a) −2.50 ≤ [Fe/H] < −1.75 dex and (b) −1.75 ≤ [Fe/H] < 0.20 dex. The mean deviations, different than zero (- - -), are due to different zero points in two systems.

Acknowledgement

We thank Prof. Esat Hamzaoğlu for editing the manuscript, and the anonymous referee for his/her comments.

References

Beers, T. C., & Sommer-Larsen, J. 1995, ApJS, 96, 175

Bahcall, J. N., & Soneira, R. M. 1980, ApJS, 44, 73

Buser, R., & Kurucz, R. L. 1978, A&A, 70, 555

Buser, R., & Kurucz, R. L. 1985, in: Hyades D. S., Pasinetti, L. E., Philip, A.G. Davis. Eds. Calibration of Fundamental Stellar Quantities. IAU Symp. 111, Reidel, Dordrecht, p. 513

Buser, R., & Fenkart, R. P. 1990, A&A, 239, 243

Buser, R., & Kurucz, R. L. 1992, A&A, 264, 557

Cameron, L. M. 1985, A&A, 146, 59

Carney, B. W. 1979, ApJ, 233, 211

Carney, B. W., Latham, D. W., & Laird, J. B. 1990, AJ, 99, 572

Carney, B. W., Latham, D. W., Laird, J. B. & Aguilar, L. A. 1994, AJ, 107, 2240

Carney, B. W. 2000, 35th Liège Int. Astrophys. Coll., Eds. Noels, A., Magain, P., Caro, D., Jehin, E., Parmentier, G. & Thoul, A. A., p. 287

Castro, S., Porto De Mello, G. F., & Da Silva, L. 1999, MNRAS, 305, 693

Cayrel de Strobel, G., Soubiran, C., Friel, E. D., Ralite, N., & Francois, P. 1997, A&AS, 124, 299

Cayrel de Strobel, G., Soubiran, C., & Ralite, N. 2001, A&A, 373, 159

Chiba, M., & Yoshii, Y. 1998, AJ, 115, 168

Clementini, G., Gratton, R. G., Carretta, E., & Sneden, C. 1999, MNRAS, 302, 22

Edvardsson, B., Andersen, J., Gustafsson, B., Lambert, D. L., Nissen, P. E., & Tomkin, J. 1993, 275, 101

Eggen, O. J., Lynden-Bell, D., & Sandage, A. R. 1962, ApJ, 136, 748 (ELS)

Francois, P. 1986, A&A, 160, 264

Friel, E. D., & Boesgaard, A. M. 1992, ApJ, 387, 170

Fuhrmann, L. 2000, private communication.

Fulbright, J. P. 2000, AJ, 120, 1841

Gorgas, J., Cardiel, N., Pedraz, S., & Gonzalez, J. J. 1999, A&AS, 139, 29

Gilmore, G., & Wyse, R. F. G. 1985, AJ, 90, 2015

Gilmore, G., Wyse, R. F. G., & Kuijken, K. 1989, ARA&A, 27, 555

Gilmore, G. 2000, JBAA, 110, 42

Gratton R. G., Carretta, E., & Castelli, F. 1996, A&A, 314 191

Gray, R. O., Napier, M. G., & Winkler, L. I. 2001, AJ, 121, 2148

Hartmann, K., & Gehren, T. 1988, A&A 199, 269

Karaali, S., Karataş, Y., Bilir, S., Ak, S. G., & Gilmore, G. F. 2000, 35th Liège Int. Astrophys. Coll., Eds Noels, A., Magain, P., Caro, D., Jehin, E., Parmentier, G. & Thoul, A. A., p. 353–358

Karaali, S., Ak, S. G., Bilir, S., Karataş, Y., & Gilmore, G. F. 2003, MNRAS, submitted

Laird, J. B., Carney, B. W., & Latham, D. W. 1988, AJ, 95, 1843 (LCL)

Majewski, S. R. 1993, ARA&A, 31, 575

Mallik, S. V. 1998, A&A, 338, 623

Mermilliod, J. C., Mermilliod, M., & Hauck, B. 1997, A&AS, 124, 349

Mishenina, T.V., Korotin, S. A., Klochkova, V. G., & Panchuk, V. E. 2000, A&A, 357, 978

Norris, J. E., Bessell, M. S., & Pickles, A. J. 1985, ApJS, 58, 463 (NBP)

Norris, J. E. 1986, ApJS, 61, 667

Norris, J. E., & Ryan, S. G. 1991, ApJ, 380, 403

Norris, J. E. 1996, ASP Conf. Ser. Vol. 92, p.14, Eds. Morrison, H. L., & Sarajedini, A.

Peterson, R. C. 1981, ApJS, 45, 421

Preston, G. W., & Sneden, C., 2000 AJ, 120, 1014

Rebolo, R., Crivellari, L., Castelli, F., Foing, B., & Beckman, J. E. 1986, A&A, 166, 195

Reid, N., & Majewski, S. R. 1993, ApJ, 409, 635

Rosenberg, A., Saviane, I., Piotto, G., & Aparicio, A. 1999, AJ, 118, 2306

Sandage, A., & Fouts, G. 1987, AJ, 93, 74

Schuster, W. J., & Nissen, P. E. 1989, A&A, 222, 69

Searle, L., & Zinn, R. 1978, ApJ, 225, 357 (SZ)

Stromgren, B. 1966, ARA&A, 4, 433

Thevenin, F., & Idiart, T. P. 1999, ApJ, 521, 753

Trefzger, Ch. F., Pel, J. W., & Gabi, S. 1995, A&A, 304, 381

Unavane, M., Wyse, R.F. G., & Gilmore, G. 1996, MNRAS, 278, 727

Yoshii, Y., & Saio, H. 1979, PASJ, 31, 334

VandenBerg, D. A., & Bell, R. A. 1985, ApJS, 58, 561

Walraven, Th., & Walraven, J. H. 1960, BAN, 15, 67