

PHOTOMETRIC DETERMINATION OF SURFACE GRAVITIES FOR G- AND K-TYPE GIANTS OF DIFFERENT METALLICITY

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Abstract. A new semi-empirical surface gravity calibration of the intrinsic colour indices $U-P$ and $U-X$ of the Vilnius photometric system is presented. It is applicable for giants of all metallicities with temperatures from 4200 K to 5500 K and $\log g$ from 0.5 dex to 3.0 dex. The standard deviation of the observed minus predicted $\log g$ residuals is about ± 0.3 dex. The $U-P$ colour index is found to be a very good surface gravity indicator, and it can be used for $\log g$ determination even when other atmospheric parameters (temperature and metallicity) are poorly known. The main atmospheric parameters for 93 red metal-deficient giants are determined from colour indices of the Vilnius system and compared with the evolutionary isochrones.

Key words: Vilnius photometric system–metal-deficient giants–surface gravities

1. Introduction

Photometric determination of the main atmospheric parameters of stars is a convenient method, since it makes possible to investigate faint stars in our Galaxy or nearby galaxies. Nowadays, photometric estimation of the effective temperatures T_e and metallicities $[\text{Fe}/\text{H}]$ has already reached a rather high accuracy, but determination of the surface gravities g is still far from being satisfactory, especially when interstellar reddening is present.

The Vilnius photometric system offers many possibilities in determination of these parameters. For low temperature giants, their effective temperatures can be determined from the $(Y-V)_0$, T_e relation calibrated by Straizys and Bartkevičius (1982) for solar metallicity giants and by Tautvaišienė (1987) for metal-deficient giants. Metallicities can be determined using the methods described by Straizys and Bartkevičius (1982) and Bartkevičius and Sperauskas (1983). For determination of surface gravity of the solar composition giants, reddening-free Q, Q diagrams of the Vilnius photometric system calibrated in terms of T_e and $\log g$ by Straizys et al. (1982) can be used. That calibration is based on the values of $\log g$ for different MK spectral and luminosity classes determined from the evolutionary tracks. The error of $\log g$ originating from the photometric errors of colour indices has been estimated to be of the order of ± 0.1 – 0.2 dex. However, the authors emphasize that systematic errors in the calibration can be larger. To check the above method, we have determined $\log g$ values for 21 giant stars of the solar chemical composition having spectroscopic $\log g$ estimations in the Cayrel de Strobel et al. (1992) catalogue. The stars were of $+0.20 \leq [\text{Fe}/\text{H}] \leq -0.43$, $4100 \text{ K} \leq T_e \leq 5040 \text{ K}$ and $1.5 \leq \log g \leq 3.1$. There was a rather good agreement for stars with $2.5 \leq \log g \leq 3.1$, while for lower surface gravity the photometric $\log g$ values were systematically too large. This may mean that one of these sources of $\log g$ is erroneous.

For metal-poor G and K giants, the first attempt to calibrate the Vilnius photometric system in terms of surface gravities has been made by Tautvaišienė (1987). The intrinsic colour indices $U-P$ and $U-X$ were semiempirically calibrated in terms of $\log g$, T_e and $[\text{Fe}/\text{H}]$. Members of the correlation equations were selected according to sensibility of the theoretical colour indices to the model atmosphere parameters. The coefficients were calculated for the empirical parameters collected from high dispersion spectroscopic studies. Nevertheless, the limited sample of stars available for the calibration, as well as errors of their physical parameters, allowed the author to reach the internal accuracy of $\log g$ estimation only of the order of ± 0.5 dex.

Here a new surface gravity calibration of the intrinsic colour indices $U-P$ and $U-X$ is presented. It is applicable for the giants with metallicities ranging from the solar value down to extreme metal-deficiency, with temperatures from 4200 K to 5500 K and $\log g$ from 0.5 dex to 3.0 dex.

2. Method of calibration and the data sample

We were searching for a correlation of the same general form as that used by Tautvaišienė (1987), i. e.,

$$\begin{aligned}
 Y = & b_0 + b_1 \cdot T_e + b_2 \cdot \log g + b_3 \cdot [\text{Fe}/\text{H}] + b_{11} \cdot T_e^2 \\
 & + b_{22} \cdot (\log g)^2 + b_{33} \cdot [\text{Fe}/\text{H}]^2 + b_{12} \cdot T_e \cdot \log g \\
 & + b_{13} \cdot T_e \cdot [\text{Fe}/\text{H}] + b_{23} \cdot \log g \cdot [\text{Fe}/\text{H}].
 \end{aligned}$$

Here Y is a gravity-sensitive colour index.

It is known that synthetic colour indices of the Vilnius system computed for the cool Kurucz (1991) models do not fit exactly to the observed colour indices in the short wavelength region. Therefore, we decided to choose the necessary members of the equation not only theoretically, as it was done by Tautvaišienė (1987), but also empirically, using the observational data for testing the higher order cross terms. T-ratios, i.e. the ratios between the coefficients and their standard errors, were used to eliminate the non-significant terms. The solutions were iterated; at each step the term with the smallest T-ratio was omitted until all terms were significant. In our final solution for the $U-P$ colour index, all terms have T-ratios with the absolute values ≥ 4.17 , the squared correlation coefficient being 0.90. For the $U-X$ colour index, two terms having lower T-ratios were left: $[\text{Fe}/\text{H}]$ having T-ratio equal to 0.78 was left from the theoretical point of view, and $T_e \cdot [\text{Fe}/\text{H}]$ having T-ratio 1.34 was left in order to reproduce better the stars with the limiting values of atmospheric parameters. All other members have T-ratios ≥ 5.16 , the squared correlation coefficient being 0.94. For calibration which is presented here, only the stars with atmospheric parameters from the detailed analyses of high dispersion spectra have been used. The atmospheric parameters of F, G and K giants were taken from the Cayrel de Strobel et al. (1992) compilation. Some additional data were added from Cottrell and Sneden (1986), Gratton and Sneden (1987) and Tautvaišienė and Straizys (1989). The Vilnius colour indices were taken from the general catalogue by Straizys and Kazlauskas (1993). The solar metallicity stars were dereddened using the program prepared by Vansevičius and Bridžius (1993). The intrinsic colour indices of metal-deficient stars were taken from Bartkevičius and Sperauskas (1983) or, for a few stars, were obtained in the same way as in their paper. In mathematical regressions and iterations the stars with residuals $\geq 3\sigma$, where σ is the standard

deviation of the solution, were omitted from the sample. The remaining 74 stars fall into the following colour index and parameter limits:

$$\begin{aligned} 0.5 &\leq (U - P)_0 \leq 1.0, \\ 0.9 &\leq (U - X)_0 \leq 2.2, \\ 4100 \text{ K} &\leq T_e \leq 5400 \text{ K}, \\ 0.2 &\leq \log g \leq 3.2, \\ -2.8 &\leq [\text{Fe}/\text{H}] \leq 0.3. \end{aligned}$$

Fig. 1 displays histograms of a number of stars with different values of $\log g$, T_e and $[\text{Fe}/\text{H}]$.

3. Results

The final equations are the following:

$$\log g = \{(U - P)_0 + b_0 + b_2 \cdot T_e + b_3 \cdot [\text{Fe}/\text{H}] + b_{22} \cdot T_e^2 + b_{23} \cdot T_e \cdot [\text{Fe}/\text{H}]\} / b_1 \quad (1)$$

$$\log g = \{(U - X)_0 + b_0 + b_2 \cdot T_e + b_3 \cdot [\text{Fe}/\text{H}] + b_{22} \cdot T_e^2 + b_{33} \cdot [\text{Fe}/\text{H}]^2 + b_{23} \cdot T_e \cdot [\text{Fe}/\text{H}]\} / b_1 \quad (2)$$

their coefficients being given in Table 1.

The standard deviation of $\log g$ is ± 0.34 dex and ± 0.38 dex for the equations using the $U-P$ and $U-X$ colour indices, respectively.

It is rather surprising, but almost the same standard deviation of ± 0.30 dex is obtained when calculating $\log g$ values by the equation

$$\log g = 5.163 - 4.915 \cdot (U - P)_0, \quad (3)$$

where dependence of $(U - P)_0$ on all other atmospheric parameters is neglected.

Table 1. Values of coefficients of the calibration Equations (1) and (2)

Coefficient	Equation (1)	Equation (2)
b_0	-6.261419	-15.458748
b_1	0.114894	0.168869
b_2	0.002272	0.005241
b_3	0.411309	-0.132378
b_{22}	$-2.388849 \cdot 10^{-7}$	$-5.080546 \cdot 10^{-7}$
b_{33}	-	0.065519
b_{23}	-0.000085	-0.000046

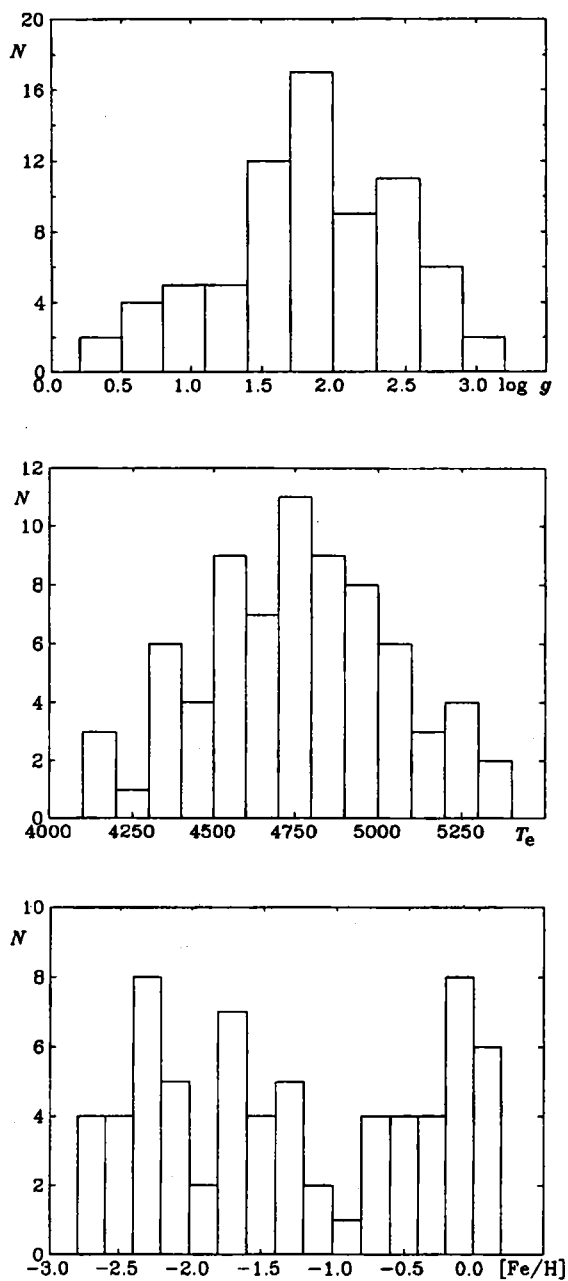


Fig. 1. The histograms giving distribution of the used sample of stars in $\log g$, T_e and $[\text{Fe}/\text{H}]$.

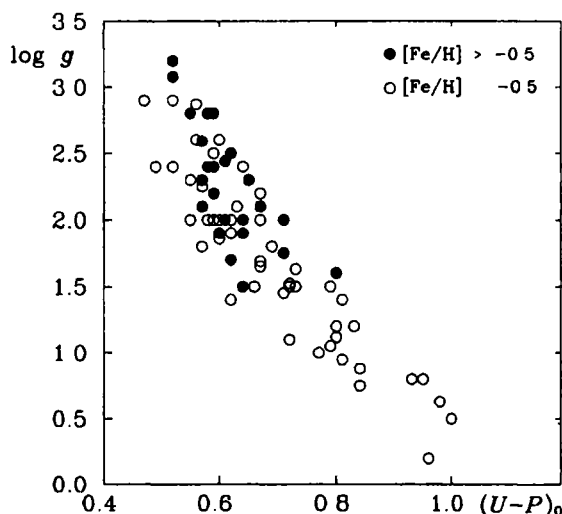


Fig. 2. Dependence of $\log g$ on the intrinsic colour indices $(U-P)_0$.

The relationship between $(U-P)_0$ and $\log g$ (Fig. 2) is rather tight, the correlation coefficient being 0.81. Thus, this index can be used for the surface gravity evaluation when other atmospheric parameters are poorly known.

4. Evaluation of the accuracy

Possible errors of the derived surface gravities due to uncertainties in the photometric index and atmospheric parameters may be estimated from Table 2. The influence of the parameter errors is greater for stars having $T_e < 4500$ K, and is rather small for stars at $T_e = 5000 \pm 200$ K.

Here we present the mean square residuals from intercomparison of the surface gravities determined by using Equations (1), (2) and (3):

$$\begin{aligned}
 \langle \log g(1) - \log g(2) \rangle &= \pm 0.31, \\
 \langle \log g(1) - \log g(3) \rangle &= \pm 0.26, \\
 \langle \log g(2) - \log g(3) \rangle &= \pm 0.37, \\
 \langle \log g(1, 2, 3) - \log g(1) \rangle &= \pm 0.14, \\
 \langle \log g(1, 2, 3) - \log g(2) \rangle &= \pm 0.21, \\
 \langle \log g(1, 2, 3) - \log g(3) \rangle &= \pm 0.19.
 \end{aligned}$$

Table 2. Possible changes in $\log g$ due to variation of colour indices and atmospheric parameters

Changes of parameters	Equations		
	(1)	(2)	(3)
$\Delta \text{Index} = +0.02$	$+0.17 \pm 0.02$	$+0.11 \pm 0.02$	$+0.10 \pm 0.002$
-0.02	-0.17 ± 0.02	-0.11 ± 0.02	-0.10 ± 0.002
$\Delta T_e = +100 \text{ K}$	$+0.08 \pm 0.25$	$+0.23 \pm 0.33$	–
-100 K	-0.12 ± 0.25	-0.29 ± 0.33	–
$\Delta [\text{Fe}/\text{H}] = +0.2$	$+0.01 \pm 0.08$	-0.22 ± 0.16	–
-0.2	-0.01 ± 0.08	$+0.19 \pm 0.16$	–

Comparison of the mean $\log g$ obtained from the three relations with the observed $\log g$ shows the residuals:

$$\langle \log g(1, 2, 3) - \log g(\text{observed}) \rangle = \pm 0.28,$$

without any systematic dependence on the atmospheric parameters of stars. The obtained scatter is completely compatible with the expected errors. Fig. 3 shows the comparison of $\log g$ observed and predicted using Equations (1), (2) and (3).

Consequently, in comparison with our earlier calibrations, the new calibration allows one to improve the accuracy of $\log g$ determination for stars of lower temperature, lower surface gravity and higher metallicity.

5. Comparison with surface gravities derived from M_V

Our surface gravity calibration was based on the spectroscopic surface gravities. Surface gravities also can be evaluated from the absolute visual magnitudes of stars M_V :

$$\log g = \log(M/M_\odot) + 4 \cdot \log T_e + 0.4 \cdot M_V + 0.4 \cdot \text{B.C.} - 12.49.$$

For the comparison we used only stars with $[\text{Fe}/\text{H}] \leq -1.0$, therefore, the typical stellar mass $M/M_\odot = 0.8$ has been assumed. The bolometric corrections tabulated by Buser and Kurucz (1992) were adopted taking into account the temperatures, metallicities and surface gravities obtained from our calibration. The absolute visual magnitudes were taken from the literature which included (1) determinations based on comparison with globular cluster diagrams $M_{V,(B-V)_0}$; (2) spectroscopic M_V determinations mainly based

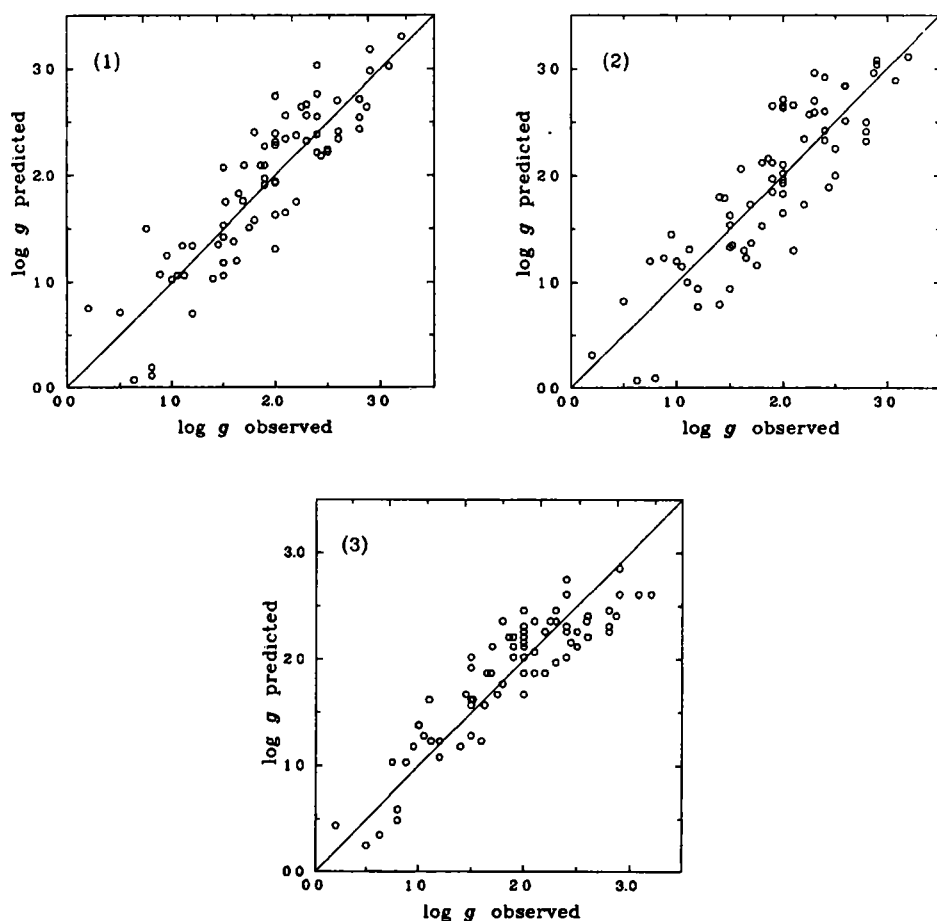


Fig. 3. Comparison of the observed $\log g$ and those predicted by Equations (1), (2) and (3).

on the width of the Ca II K line emission core; (3) M_V determinations in different photometric systems; (4) M_V determinations for Eggen's moving group members; (5) M_V determined using statistical parallaxes. Individual M_V values were averaged using statistical weights based on errors of M_V determinations. Deviating values, for which the difference between the maximum and minimum M_V values was more than 2 mag, were excluded. Using these M_V values, the

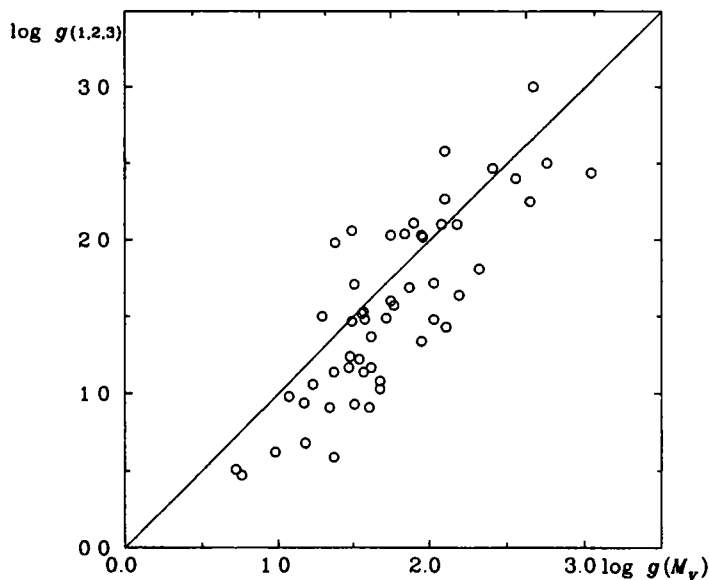


Fig. 4. Comparison of the surface gravities determined by Equations (1), (2) and (3) and the surface gravities determined from M_V

$\log g$ values were obtained for 53 metal-deficient giants and compared in Fig. 4 with $\log g$ values predicted using Equations (1),(2) and (3). We find $\langle \log g(1, 2, 3) - \log g(M_V) \rangle = -0.19 \pm 0.33$. The systematic difference obtained in the comparison is too small to be important, bearing in mind possible errors of $\log g$ determinations.

Consequently, the surface gravities determined by the calibration presented in this paper are in satisfactory agreement with the surface gravities calculated from M_V values. Some systematic difference can be observed for the low gravity stars.

6. Metal-deficient giants in $\log g$, $\log T_e$ diagram

Using the new calibrations, we determined $\log g$ values for 93 metal-deficient giants selected from the General Photometric Catalogue of Stars Observed in the Vilnius system (Straižys and Kazlauskas, 1993). Their intrinsic colour indices and metallicities were taken from Bartkevičius and Sperauskas (1983) or were estimated by us using the same method. The effective temperatures

for giants with moderate metal-deficiency ($-0.5 \leq [\text{Fe}/\text{H}] < -1.0$) were obtained from intrinsic colour indices $(Y-V)_0$ using both the calibration for normal stars by Straižys and Bartkevičius (1982) and the calibration for metal-deficient stars by Tauvaišienė (1987). The T_e values obtained with both these calibrations were averaged. For stars of lower metallicity ($[\text{Fe}/\text{H}] \leq -1.0$), only the second calibration was used.

The derived effective temperatures and surface gravities are compared in Fig. 5 with the evolutionary isochrones by Bergbush and Vandenberg (1992) for 14 Gyr age and different metallicities. The agreement between sequences of stars of different metallicities and the corresponding isochrones is sufficiently good.

7. Concluding remarks

The Vilnius photometric system is extremely effective for determination of the main atmospheric parameters for both normal and metal-deficient red giants. Colour index $U-P$ can be used for surface gravity determination even in the case when stellar temperatures and metallicities are poorly known. Surface gravities predicted using our calibration agree rather well with gravities following from the absolute magnitudes of stars. The new surface gravity calibration is applicable for giants with temperatures from 4200 K to 5500 K, $\log g$ from 0.5 dex to 3.0 dex and for all metallicities.

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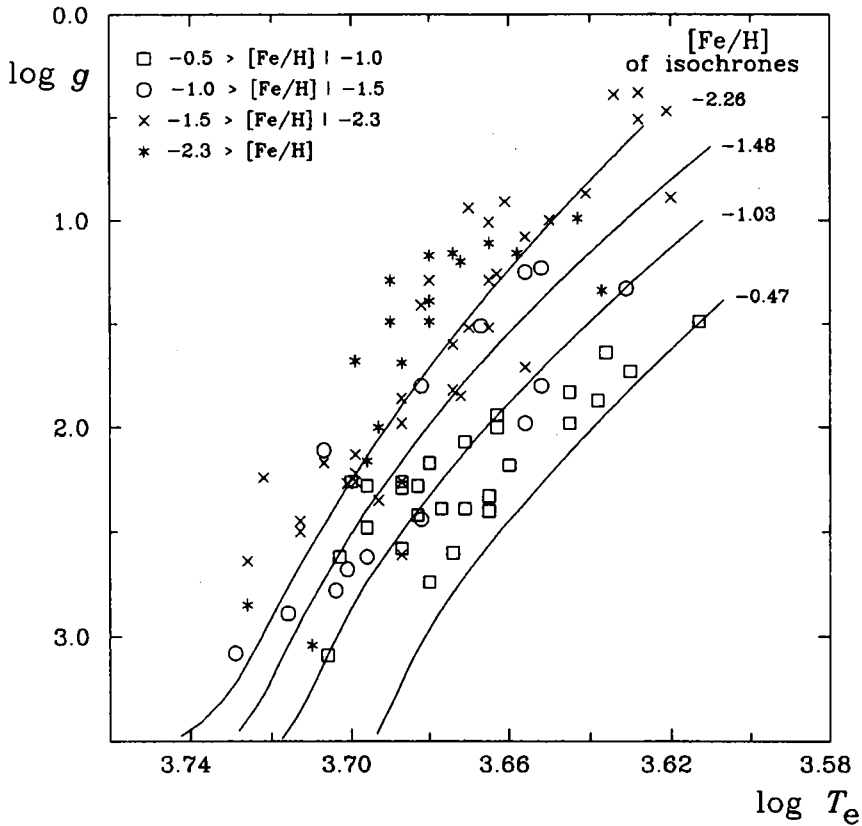


Fig. 5. Location of metal-deficient giants compared with the evolutionary isochrones by Bergbush and Vandenberg (1992) for 14 Gyr age and $[\text{Fe}/\text{H}] = -0.47; -1.03; -1.48$ and -2.26 .

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