METAL ABUNDANCES OF ONE HUNDRED HIPPARCOS DWARFS

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ABSTRACT

Abundances for Fe, O, and the $\alpha-$elements (Mg, Si, Ca, and Ti) have been derived from high resolution spectra of a sample of about one hundred dwarfs with high precision parallaxes measured by Hipparcos. The stars have metal abundances in the range $-2.5 <$[Fe/H]< 0.2. The observational data set consists of high dispersion ($20\,000 < R < 70\,000$), high S/N (> 200) spectra collected at the Asiago and McDonald Observatories. The abundance analysis followed the same precepts used by Gratton et al. (1997a) for $\sim$ 300 field stars and for giants in 24 globular clusters (Carretta & Gratton 1997), and includes corrections for departures from LTE in the formation of O lines. Our main results are: (1) that the equilibrium of ionization of Fe is well satisfied in late F – early K dwarfs; (2) O and $\alpha-$elements are overabundant by $\sim$ 0.3 dex. This large homogeneous data set was used in the derivation of accurate ages for globular clusters (Gratton et al., this volume).

Key words: Stars: chemical abundances - Stars: basic parameters.

1. INTRODUCTION

Hipparcos has provided parallaxes with accuracies of $\sim$ 1 mas for several hundreds dwarfs. We had access to data for about 100 dwarfs with metal abundances in the range $-2.5 <$[Fe/H]< 0.2 and have used them in a thorough revision of the ages of the oldest globular clusters derived by Main Sequence (MS) fitting technique. A crucial step in the derivation of ages via this method is the assumption that the nearby subdwarfs have the same chemical composition of the globular cluster main sequence stars. This assumption was verified through a careful abundance analysis of the vast majority of nearby dwarfs with Hipparcos parallaxes available to us.

Our data set and the Hipparcos parallaxes were also used to test whether an appreciable Fe overionization occurred in the atmosphere of late F – early K dwarfs (Bikmaev et al. 1990; Magain & Zhao 1996). This was done by comparing abundances provided by neutral and singly ionized lines, once the surface gravity of each program star had be derived from its mass, temperature and luminosity rather then from the equilibrium of ionization of Fe.

Finally, our abundances are fully consistent with those presented by Gratton et al. (1997a) for about 300 field dwarfs. A large, homogenous data base of high accuracy (errors $\sim$ 0.07 dex) abundances computed with the Kurucz (1993) model atmospheres is now available and can be used to recalibrate photometric and low S/N spectroscopic abundances.

2. BASIC DATA FOR SUBDWARFS

Average V magnitudes and colors (Johnson $B-V$ and $V-K$, and Strömgren $b-y$, m_1 and c_1) for the programme stars were obtained from a careful discussion of the literature data. We used also the Tycho V magnitudes and $B-V$ colors, after correcting them for the very small systematic difference with ground-based data.

Absolute magnitudes M_V were derived combining apparent V magnitudes and Hipparcos parallaxes. No Lutz-Kelker corrections were applied. Lutz-Kelker corrections (Lutz & Kelker 1973) take into account that stars with parallaxes measured too high are more likely to be included in a sample if the sample selection criteria are based on the parallaxes themselves. Since our sample was selected before the Hipparcos parallaxes were known; Lutz-Kelker corrections should not be applied when the whole sample is considered, as we do when comparing the abundances obtained from Fe I and Fe II lines.

Multiple high precision radial velocity observations exist for a large fraction of our objects (80 out of 99). Twenty stars in the sample are known and four are suspected spectroscopic binaries. Two further stars display very broad lines in our spectra, possibly due to fast rotation. They were discarded. A few other stars display some IR excess, which also may be a signature of binarity. No evidence for binarity disturbing the present analysis exists for the remainder. Sixty-eight out of the 99 stars of our sample are included in Carney et al. (1994) catalogue. Reddening estimates are given for 58 of them. All but two have zero values. We have thus assumed a zero reddening for all the programme stars.

3. OBSERVATIONS AND REDUCTIONS

High dispersion spectra for about two thirds of the programme stars were acquired using the 2D-coudè spectrograph of the 2.7 m telescope at McDonald Observatory and the REOSC echelle spectrograph at the 1.8 m telescope at Cima Ekar (Asiago). McDonald spectra have a resolution $R = 70\,000$, $S/N \sim 200$, and spectral coverage from about 4000 to 9000 Å; they are available for 21 stars (most with [Fe/H]< -0.8). Cima Ekar telescope provided spectra with resolution $R = 15\,000$, $S/N \sim 200$, and two spectral ranges ($4500< \lambda <7000$ and $5500 < \lambda <8000$ Å) for 65 stars.

Equivalent widths of the lines were measured by means of a gaussian fitting routine applied to the core of the lines; appropriate average corrections were included to take into account the contribution of the damping wings. Only lines with $\log(\mathrm{EW}/\lambda) < -4.7$ were used in the final analysis (corrections to the equivalent widths for these lines are ≤ 7 mÅ, that is well below 10 per cent). The large overlap between the two samples (14 stars) allowed us to tie the Asiago equivalent widths to the McDonald ones.

External checks on our equivalent widths are possible with Edvardsson et al. (1993: hereinafter E93) and Tomkin et al. (1992: hereinafter TLLS). Comparisons performed using McDonald equivalent widths alone show that they have errors of ±4 mÅ. From the rms scatter, σ, between Asiago and McDonald equivalent widths, we estimate that the former have errors of ±6.7 mÅ. When Asiago and McDonald equivalent widths are considered together, we find average residuals (us-others) of -0.2 ± 1.0 mÅ (39 lines, $\sigma = 6.1$ mÅ) and $+0.8 \pm 1.0$ mÅ (36 lines, $\sigma = 5.9$ mÅ) with E93 and TLLS, respectively.

4. ANALYSIS

4.1. Atmospheric Parameters

The abundance derivation followed precepts very similar to the reanalysis of ~ 300 field and ~ 150 globular cluster stars described in Gratton et al. (1997a) and Carretta & Gratton (1997). The same line parameters were adopted. The effective temperatures were derived from $B-V$, $b-y$, and $V-K$ colours using the iterative procedure outlined in Gratton et al. (1997a). Atmospheric parameters are derived as follows:

1. we assume as input values $\log g = 4.5$ and the metal abundance derived from the *uvby* photometry using the calibration of Schuster & Nissen (1989);
2. $T_{\rm eff}$ is then derived from the colours, using the empirical calibration of Gratton et al. (1997a) for population I stars (assumed to be valid for [Fe/H]=0), and the abundance dependence given by Kurucz (1993) models;
3. a first iteration value of $\log g$ is then derived from the absolute bolometric magnitude (derived from the apparent V magnitude, parallaxes from Hipparcos, and bolometric corrections from Kurucz 1993), and masses obtained by interpolation in $T_{\rm eff}$ and [A/H] within the Bertelli et al. (1997) isochrones;
4. steps 2 and 3 are iterated until a consistent set of values is obtained for $T_{\rm eff}$, $\log g$, and [A/H];
5. the equivalent widths are then analyzed, providing new values for $v_{\rm t}$ and [A/H] (assumed to be equal to [Fe/H] obtained from neutral lines);
6. the procedure is iterated until a new consistent set of parameters is obtained.

4.2. Error Analysis

Random errors in $T_{\rm eff}$ (±45 K) were obtained by comparing temperatures derived from different colours. Systematic errors may be larger; the $T_{\rm eff}$-scale used in this paper is discussed in detail in Gratton et al. (1997a). We assume that systematic errors in the adopted $T_{\rm eff}$'s are ≤ 100 K.

Random errors in the gravities (±0.09 dex) are estimated from the errors in the masses (1.2 per cent), M_V's (0.18 mag), and in the $T_{\rm eff}$'s (0.8 per cent), neglecting the small contribution due to bolometric corrections. Systematic errors (±0.04 dex) are mainly due to errors in the $T_{\rm eff}$ scale and in the solar M_V value.

Random errors in the microturbulent velocities can be estimated from the residuals around the fitting relation in $T_{\rm eff}$ and $\log g$. We obtain values of 0.47 and 0.17 km s^{-1} for the Asiago and McDonald spectra, respectively.

Random errors in the equivalent widths and the line parameters significantly affect the abundances when few lines are measured for a given specie. Errors should scale as $\sigma/\sqrt{n}$ where σ is the typical error in the abundance from a single line (0.14 dex for the Asiago spectra, and 0.11 dex for the McDonald ones) and n is the number of lines used in the analysis. However, errors may be larger if all lines for a given element are in a small spectral range. Furthermore, undetected blends may contribute significantly to errors when the spectra are very crowded (mainly Asiago spectra of cool, metal-rich stars).

Random errors in the model metal abundance are obtained by summing up quadratically the errors due to the other sources. Systematic errors can be due to non-solar abundance ratios. They can be as large as ~ 0.2 dex in the metal-poor stars ([Fe/H]< -0.5), where O and the other $\alpha-$elements are overabundant by ~ 0.3 dex.

Random errors in the Fe abundances are ~ 0.07 and ~ 0.04 dex for abundances derived from Asiago and McDonald spectra, respectively. Systematic errors (~ 0.08 dex) are mainly due to the $T_{\rm eff}$ scale.

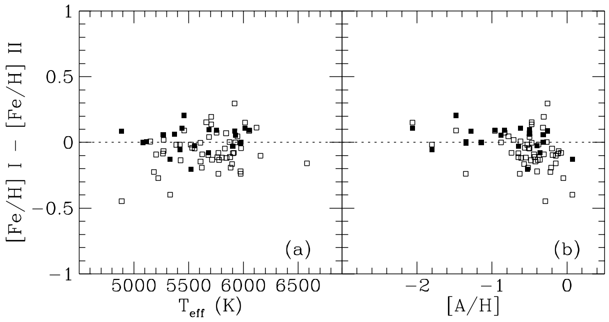

Figure 1. Run of the difference between the abundances derived from neutral and singly ionized Fe lines as a function of temperature (panel a) and overall metal abundance (panel b). Open squares are abundances obtained from the Asiago spectra; filled squares are abundances obtained from the McDonald spectra.

4.3. Comparison with Other Abundances

On average, differences (Asiago−McDonald) in the Fe abundances are -0.01 ± 0.02 dex (12 stars, $\sigma = 0.07$ dex). Analogous differences for the [O/Fe] and [α/Fe] ratios are $+0.02 \pm 0.08$ dex (5 stars, $\sigma = 0.17$ dex), and $+0.01 \pm 0.03$ dex (12 stars, $\sigma = 0.10$ dex).

E93 measured abundances for ∼ 200 dwarfs; six stars are in common with our sample. Abundance residuals (our analysis−E93) are $+0.08 \pm 0.03$, -0.02 ± 0.03, and $+0.02 \pm 0.02$ dex for [Fe/H], [O/Fe], and [α/Fe], respectively. Residual differences are mainly due to our use of a higher temperature scale (our $T_{\rm eff}$'s are larger by 63 ± 12 K). We have six stars in common with TLLS, which used a restricted wavelength range. Average differences (ours−TLLS) are: $+0.34 \pm 0.04$ and -0.31 ± 0.07 dex for [Fe/H] and [O/Fe], respectively. They are due to different assumption in the analysis: (i) our temperature scale is higher; (ii) TLLS used a different solar model; (iii) our non-LTE corrections to the O abundances are slightly larger. Finally, Gratton et al. (1997a) made a homogenous reanalysis of the original equivalent widths for ∼ 300 metal-poor field stars. On average, the present Fe abundances are larger by 0.02 ± 0.02 dex (11 stars, $\sigma = 0.06$ dex). Since the same analysis procedure is adopted, these differences are entirely due to random errors in the equivalent widths and in the adopted colours. In the following, we assume that Gratton et al. abundances are on the same scale of the present analysis.

4.4. Fe Abundances

Since gravities are derived from masses and luminosities rather than from the equilibrium of ionization for Fe, we may test if predictions based on LTE are satisfied for the program stars.

In Figure 1 we plot the difference between abundances of Fe obtained from neutral and singly ionized lines against effective temperature and metal abundance. Different symbols refer to results obtained from McDonald and Asiago spectra, respectively. McDonald spectra have a higher weight because the higher resolution allowed us to measure a larger number of Fe II lines (10 ∼ 20), and errors in the equivalent widths are smaller; very few Fe II lines could be measured in the crowded spectra of cool and/or metal-rich stars observed from Asiago. Average differences between abundances given by Fe I and II lines are 0.025 ± 0.020 (21 stars, $\sigma = 0.093$ dex) for the Mc Donald spectra, and -0.063 ± 0.019 (52 stars, $\sigma = 0.140$ dex) for the Asiago spectra. The scatter obtained for McDonald spectra agrees quite well with the expected random error of 0.085 dex. The average value is consistent with LTE if the adopted $T_{\rm eff}$ scale is too high by ∼ 20 K, well within the quoted error bar of ±100 K. The lower mean difference obtained for the Asiago spectra is due to a few cool metal-rich stars which have very crowded spectra. Very few Fe II lines could be measured in these spectra and the line-to-line comparison with the superior McDonald data suggests that even these lines may be affected by blends.

We conclude that the equilibrium of ionization for Fe is well satisfied in the late F – K dwarfs of any metallicity in our sample. This result depends on the adopted temperature scale.

Our empirical result agrees very well with the extensive statistical equilibrium calculations for Fe by Gratton et al. (1997b). In that paper, the uncertain collisional cross sections were normalized in order to reproduce the observations of the RR Lyraes, where overionization is expected to be much larger than in late F – K dwarfs. The lower limit to collisional cross sections given by the absence of detectable overionization in RR Lyrae spectra (Clementini et al. 1995) implies that LTE is a very good approximation for the formation of Fe lines in dwarfs.

4.5. O and α−element Abundances

O abundances were derived from the permitted IR triplet, and include non-LTE corrections computed for each line in each star following the precepts of Gratton et al. (1997b). We find that O and the other α−elements are overabundant in stars with [Fe/H]<-0.5 (see Figure 2):

$$[{\rm O/Fe}] = 0.38 \pm 0.13$$

$$[\alpha/{\rm Fe}] = 0.26 \pm 0.08$$

(error bars are the rms scatter of individual values around the mean). The moderate O excess derived from the IR permitted lines is a consequence of the rather high temperature scale adopted. When this adoption is made, abundances from permitted OI lines agree with those determined from the forbidden [OI] and the OH lines.

The present abundances agree very well with those derived in Gratton et al. (1997c). Note also that the overabundance of O and $\alpha-$ elements found for the field subdwarfs is similar to the excesses found for globular cluster giants (apart from those stars affected by the O-Na anticorrelation, see Kraft 1994).

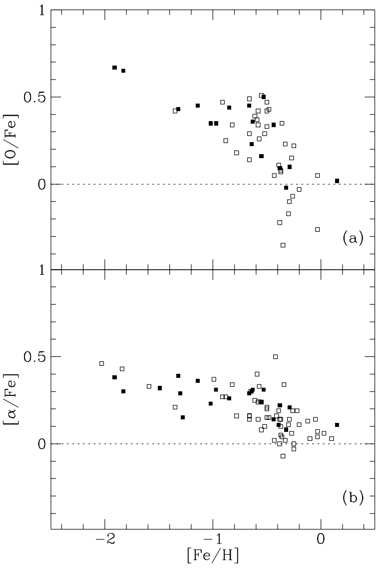

Figure 2. Runs of the overabundances of O (panel a) and α− elements (panel b) as a function of [Fe/H] for the programme subdwarfs. Filled squares are abundances from McDonald spectra; open squares are abundances from Asiago spectra.

5. CALIBRATION OF PHOTOMETRIC ABUNDANCES

Once combined with the abundances obtained by Gratton et al. (1997a), the sample of late F to early K-type field stars with homogenous and accurate high dispersion abundances adds up to nearly 400 stars. Schuster & Nissen (1989) have shown that rather accurate metal abundances for late F to early K-type can be obtained using Strömgren *uvby* photometry (available for a considerable fraction of the Hipparcos stars). Furthermore, the extensive binary search by Carney et al. (1994) has provided a large number of metal abundances derived from an empirical calibration of the cross correlation dips for metal-poor dwarfs.

We have recalibrated these abundance scales. Schuster & Nissen (1989) abundances only differs for a zero-point offset (see panel *a* of Figure 3); the mean difference is:

$$[\mathrm{Fe/H}]_{\mathrm{us}} = [\mathrm{Fe/H}]_{\mathrm{SN}} + (0.102 \pm 0.012) \qquad (1)$$

based on 152 stars (the rms scatter for a single star is 0.151 dex).

In the case of Carney et al. (1994, panel *b* of Figure 3), a small linear term is also required. The best fit line (66 stars) is:

$$[\mathrm{Fe/H}]_{\mathrm{us}} = (0.94 \pm 0.03)[\mathrm{Fe/H}]_{\mathrm{C94}} + (0.18 \pm 0.17) \quad (2)$$

The offsets between the high dispersion abundances and those provided by Schuster & Nissen (1989) and Carney et al. (1994) are mainly due to different assumptions about the solar abundances in the high dispersion analyses originally used in the calibrations of Schuster & Nissen (1989) and Carney et al. (1994).

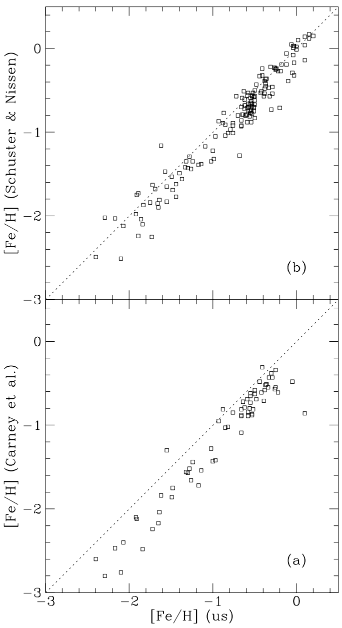

Figure 3. Comparison between the abundances obtained from high dispersion spectra (present analysis or Gratton et al. 1997), and those provided by the original calibration of Schuster & Nissen (1989, panel a) and Carney et al. (1994, panel b).

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