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On the width of the theoretical lower main sequence

Consequences for the determination of the $\Delta Y/\Delta Z$ ratio in the solar neighbourhood

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Abstract. We discuss the relation between the main sequence thickness and chemical composition variations. With the help of theoretical zero–age main sequence models between 0.7 and 1.0 $M_\odot$, computed with an advanced physical description of the stellar interiors, in a range of metallicities typical from Population I stars ($0.008 \leq Z \leq 0.034$), we establish a theoretical relation between the relative helium to metal enrichment, $\Delta Y/\Delta Z$, and the main-sequence broadening, represented in this work by ΔM_{bol}.

The locus in the Hertzsprung-Russell diagram of 69 low mass stars closer than 25 pc is analyzed, taking into account the present available metallicities for 25 of them.

Models show that $\Delta Y/\Delta Z$ should be *higher* than 2.0 in the *solar neighbourhood* to account for the observational main sequence width. As a consequence an helium abundance lower limit of Y=0:246 is found in the solar neighbourhood.

This value is presently loosely constrained by the observational uncertainties. A new step towards the $\Delta Y/\Delta Z$ determination is expected in the very near future, when accurate values of the stellar luminosities as determined by Hipparcos will permit more definite conclusions.

Key words: Galaxy: solar neighbourhood – stars: abundances – stars: low mass – stars: HR diagram – Galaxy: abundances

1. Introduction

It has long been suggested, by both observational and theoretical works, that the helium abundance Y, is correlated with the heavy elements abundance Z, by the relation,

$$Y = (\Delta Y/\Delta Z)Z + Y_p \qquad (1)$$

where $\Delta Y/\Delta Z$ is the relative helium to heavier elements enrichment and Y_p, the primordial helium abundance.

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Many observational and theoretical attempts have been made to determine these two parameters.

The Y_p-value is determined by the correlation between oxygen and helium abundances in extragalactic HII regions. Recent determinations of the initial helium abundance are in excellent agreement: Pagel et al. (1992) found $Y_p = 0.228 \pm 0.005$ while Balges et al. (1993) gave $Y_p = 0.227 \pm 0.006$.

The $\Delta Y/\Delta Z$-value is more difficult to estimate. Faulkner (1967) applied homology relations to extreme field subdwarf data and found $\Delta Y/\Delta Z$=3.5. Perrin et al. (1977), using theoretical HR diagrams (see later), proposed $\Delta Y/\Delta Z$=5 in the solar neighbourhood. Renzini (1994) determined the helium abundance of the metal rich stars in the Galactic Bulge and found $2 \leq \Delta Y/\Delta Z \leq 3$.

On the other hand theoretical nucleosynthesis predictions give much lower values: $\Delta Y/\Delta Z \simeq 1$ with a maximum value of about 2 when stellar winds are included. Assuming that products of nucleosynthesis are swallowed by black holes originating from progenitors of masses above 20–25 $M_\odot$, then $\Delta Y/\Delta Z$ can reach 5 (Maeder, 1992). Recently Pagel et al. (1992) derived $3 \leq \Delta Y/\Delta Z \leq 6$ with preferred values between 4 and 5 from observations of low-metallicity extragalactic HII regions. As discussed by Pagel (1995) (see also Traat, 1995), $\Delta Y/\Delta Z \geq 5$ is perhaps overestimated due to a combination of reasons as, for instance, the contamination by WR stars and dust absorption. Torres-Peimbert et al. (1995) determine $\Delta Y/\Delta Z$=2.4, from observations in uncontaminated HII regions in the Galaxy and nearby dwarfs.

The study of individual stars can also provide information. For the Sun, the metallicity is derived from observations and the helium abundance is obtained from the constraint that a solar model must yield the solar luminosity at the solar age. Recent solar models using the Livermore radiative opacities (Iglesias et al., 1992) lead to values of Y between 0.275 and 0.289 and $\Delta Y/\Delta Z$ between 2.3 and 3.1 (Charbonnel & Lebreton, 1993; Berthomieu et al., 1993; Guenther et al., 1992). Similar calibrations are also possible for binary stars of well-known masses and luminosities (Noels et al., 1991). Recent results give: $\Delta Y/\Delta Z \leq 2.5$ for α Centauri (Fernandes & Neuforge; 1995; Neuforge, 1993a; Lydon et al., 1993) and $\Delta Y/\Delta Z \approx 2.2$ for η Cassiopeiae (Fernandes et al., 1995).

Z is quite accurately known from observations while Y is fixed by physics. Models show that the solar initial helium content is reduced if one includes in the equation of state the Coulomb corrections to the pressure as is done for instance in the MHD equation of state (Mihalas et al., 1988). Consequently $\Delta Y/\Delta Z$ is also decreased (Charbonnel & Lebreton, 1993).

All these results show that the question of the helium and metals enrichment is complicated. The $\Delta Y/\Delta Z$ value has been estimated in various sites and different conditions. Thus direct comparisons of the results cannot be done without care and the non-universality of $\Delta Y/\Delta Z$ cannot be excluded.

In this paper we quantify the relation between $\Delta Y/\Delta Z$ and the main sequence broadening and we reexamine the determination of $\Delta Y/\Delta Z$ in the solar neighbourhood, as discussed 20 years ago by Perrin et al. (1977). They studied 138 F, G, and K stars in the solar neighbourhood and showed that the position in the HR diagram of the best stars of their sample can be reasonably fitted with a unique zero-age main sequence (ZAMS). Using the results of models available at that time (Hejlesen, 1975), they concluded that $\Delta Y/\Delta Z \approx 5 \pm 3$ in the solar neighbourhood. However the most recent HR diagrams for nearby stars show an evident thickness of the main-sequence for the whole range of masses covered (Jahreiss, 1992). Moreover the stellar physical description of stellar interiors has considerably changed since then, in particular the opacities calculations. In this work, we use modern stellar models to go beyond the study of Perrin et al. (1977), on the dependence between the main-sequence width in the solar neighbourhood and the chemical composition variations.

Several effects can be responsible for the observed main-sequence broadening: chemical composition, binarity, evolution, rotation and also observational errors. Chemical composition is the main factor of enlargement in the region corresponding to stars less massive than about one solar mass. We focus here on masses between 0.7 and $1.0M_\odot$ and compare the theoretical width with the most accurate available data.

In Sect. 2 we present the input physics entering the stellar models. We calculate ZAMS models for low-mass stars from 0.7 to $1.0M_\odot$ in a metallicity range typical of Population I. We establish a theoretical relation giving the ZAMS broadening as a function of $\Delta Y/\Delta Z$ in Sect. 3. In Sect. 4, we choose a stellar sample with criteria allowing to isolate the chemical composition from the other effects and determine the $\Delta Y/\Delta Z$ value corresponding to the solar neighbourhood, taking into account the present main sequence width given by observations. The different sources of uncertainties are also discussed. Future improvements to this work expected from the Hipparcos mission (Gomez & Luri, 1992) are mentioned.

2. Input physics for the stellar models

The stellar models are calculated with the CESAM evolutionary code (Morel, 1995; Berthomieu et al., 1993; Morel, 1992). The nuclear reaction rates are from Caughlan & Fowler (1988). The equation of state is described by Eggleton et al. (1973), hereafter EFF. This simple representation is sufficient for our purpose. In fact, Lebreton & Däppen (1988) examined the effect of different equations of state on the position of the ZAMS in the HR diagram and found that the position of the ZAMS calculated with EFF and with a more realistic equation of state as MHD is approximately the same for masses between $0.7M_\odot$ and $1.0M_\odot$.

We used the OPAL radiative opacities (Iglesias et al., 1992) complemented at low temperatures (T$\leq$ 10 000 K) by atomic and molecular opacity tables from Neuforge (1993b) using a smoothing analytical formula between them (Neuforge et al., 1994). The opacities were calculated with the solar mixture of Grevesse (1991) corresponding to a solar metallicity Z=0.0190. The present main uncertainties in stellar models for the range of mass considered, come from the treatment of convection. We use the classical mixing-length theory (Böhm-Vitense, 1958) for the convection description. All the models presented here are made using the solar mixing-length parameter. We will not discuss here the possibility of the variation of α with mass (Fernandes & Neuforge, 1995), which could change the ZAMS slope. Nevertheless we checked that an increase of α of 0.2 on the model of $1.0M_\odot$ produces an increase of the main-sequence broadening which is smaller than 0.05 mag. Moreover the T_{eff} sensitivity with α decreases with decreasing mass. The atmosphere is obtained with an Eddington T(τ, T_{eff}) law, where τ is the mean optical depth and T_{eff} the effective temperature. With these inputs the solar luminosity and radius are obtained at the solar age with an initial helium abundance $Y_\odot$=0.28, and a mixing length parameter for convection $\alpha_\odot = 1.70H_p$ where H_p is the pressure scale-height. This leads to $\Delta Y/\Delta Z$=2.6.

3. The correlation between chemical composition, $\Delta Y/\Delta Z$, and the main-sequence broadening, ΔM_{bol}

It is well-known that in a stellar model an increase of Y, keeping Z constant induces an increase of luminosity and effective temperature. On the other hand a Z-increase at fixed Y leads to an opposite effect, i.e. luminosity and effective temperature decrease. This behavior due to opacity and to mean molecular weight effects is easily explained in the framework of homology theory which also predicts that chemical composition differences in stars induce an enlargement of the main sequence, the value of which is dependent both on Z and on $\Delta Y/\Delta Z$. Our purpose here is to establish a more precise relation between the enlargement and the values of Z and $\Delta Y/\Delta Z$ using realistic updated models.

The ZAMS slope is quasi-constant between 0.7 and 1.0 $M_\odot$ and the effects of evolution and rotation are not very important (see Sect. 4.2.3 and Sect. 4.2.4). So, this domain of mass is well suited to study the dependence of the ZAMS thickness

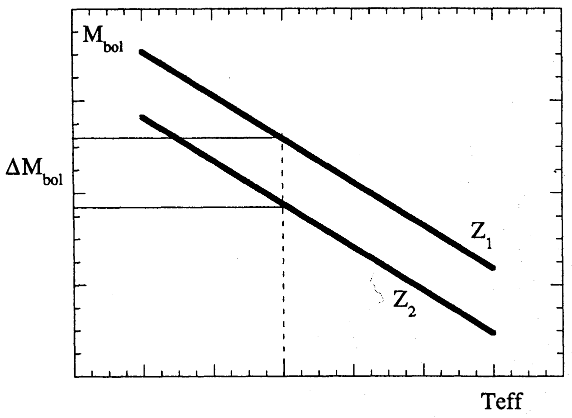

Fig. 1. ZAMS broadening ΔM_{bol} for a given T_{eff} value and two extreme ZAMS with metallicities Z1 and Z2 and the same value of $\Delta Y/\Delta Z$

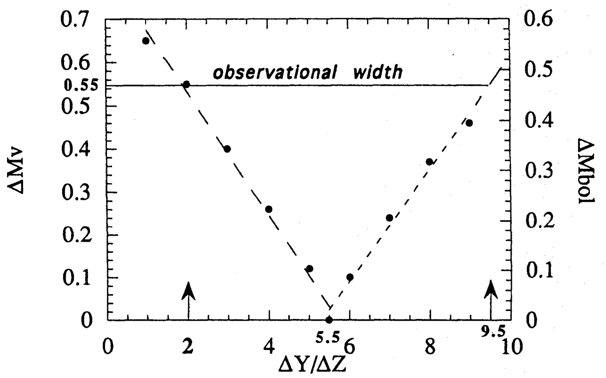

Fig. 2. ΔM_{bol} (right yy axis) and ΔM_v (left yy axis) as a function of $\Delta Y/\Delta Z$. The dashed lines represent the linear plot fit defined by Eqs. 2 and 3 respectively. The observational width (solid line), ΔM_v=0.55, is accounted for with $\Delta Y/\Delta Z \approx 2$ or with $\Delta Y/\Delta Z \approx 9.5$. For $\Delta Y/\Delta Z = 5.5$, ΔM_v=0.

with chemical composition. We therefore calculate ZAMS stellar models of 0.7 and 1.0 $M_\odot$ with metallicities corresponding to Population I, i.e., $0.008 \le Z \le 0.034$ (see Sect. 4.1) the helium abundance Y is derived from relation (1) with Y_p=0.23 and a large range of $\Delta Y/\Delta Z$ values, between 1. and 9. For a given value of $\Delta Y/\Delta Z$, the ZAMS broadening, ΔM_{bol}, is determined at a given T_{eff}, from the two extreme ZAMS, with metallicities Z1 and Z2 (Fig. 1). This gives a relation between ΔM_{bol} and $\Delta Y/\Delta Z$, independent of T_{eff}, which is represented in Fig. 2 and can be approximated linearly by the Eqs. (2a) and (2b),

$$\Delta M_{bol} = -0.12(\Delta Y/\Delta Z - 5.5) \Leftarrow \Delta Y/\Delta Z \le 5.5 \qquad (2a)$$

$$\Delta M_{bol} = 0.10(\Delta Y/\Delta Z - 5.5) \Leftarrow \Delta Y/\Delta Z \ge 5.5 \qquad (2b)$$

This results can be understood by the following:
a) If $\Delta Y/\Delta Z$ = 5.5 no broadening occurs (i.e. ΔM_{bol} = 0). So no dispersion is expected for the position in the HR diagram between metal-poor and metal rich stellar models. This result is very close to the value quoted in Perrin et al. (1977), $\Delta Y/\Delta Z$=5.3, obtained with an old generation of stellar models (Hejlesen, 1975). It means that this particular result is not very dependent on the improvements in the description of the physics of the stellar models. This can be easily understood by an homology analysis (see Appendix A)
b) If $\Delta Y/\Delta Z \le 5.5$, the ZAMS broadening decreases with increasing $\Delta Y/\Delta Z$. In this case, in the HR diagram, the poor metallicity ZAMS, i.e. Z=0.008, is below the metal rich one, Z=0.034. So metal-poor and metal rich stellar models define two distinct regions in the HR diagram. Metal poor stellar models preferentially occupy a position below that of metal rich ones;
c) If $\Delta Y/\Delta Z \ge 5.5$, it goes in the opposite way: the ZAMS broadening increases with increasing $\Delta Y/\Delta Z$ and the ZAMS at Z=0.008 is above the ZAMS at Z=0.034. So the situation is similar to case b), but metal poor models are under metal rich ones.

4. The present observational stellar sample and the $\Delta Y/\Delta Z$ value in the solar neighbourhood

4.1. Choosing the stellar sample

We select an observational sample composed of stars in the solar neighbourhood from the catalogue of Gliese & Jahreiss (1991) with the following criteria: expected single stars (see Sect. 4.2.2.); closer than 25pc; V-class luminosity; visual magnitude range between $4.6 \le M_v \le 6.6$. The stars correspond to an interval of masses between $0.7 M_\odot$ and $1.0 M_\odot$ estimated through the mass-luminosity relation from Schmidt-Kaler (1982).

According to Nissen & Schuster (1991), 98% of the stars in the solar neighbourhood belong to the thin disk, the metallicity range is $-0.37 \le [Fe/H] \le 0.25$, ($\approx 0.008 \le Z \le 0.034$) (Cayrel de Strobel, 1992a) and more than 80% of the nearby stars are low–mass stars and belong to V-Class luminosity. Among the stars for which metallicity measurements are available, we examine in detail those which have an uncertainty less than 0.20 dex. We take the $[Fe/H]$ values from Taylor (1994) and Cayrel de Strobel et al. (1992b), which are in very good agreement, for the stars of our sample. In one particular case, the metallicity is from Edvardsson et al. (1993). When metallicity data are not available in these catalogues, we estimate it from Tokovinin (1990), who establishes an analytical relation for $[Fe/H]$ as a function of the (B–V) color index and of the equivalent width of the metal lines.

Table 1 gives the observational parameters for the 25 stars with available metallicities. Each star is identified by the HD number, the spectral type (Gliese & Jahreiss, 1991) and the fundamental parameters, M_v, (B2–V1) and $[Fe/H]$ with their respective errors. In the last column we give the references for $[Fe/H]$ values. The numbers represented have the same nomenclature as in Cayrel de Strobel et al. (1992b) and Taylor (1994).

The HR diagram for the 69 selected stars is given in Fig. 3. Full lines represent the main-sequence observational broadening which is approximately constant throughout the mass range considered: for a given (B2–V1) value, $\Delta M_v \approx 0.55$ (see also

Table 1. Observational parameters for the 25 stars of our sample with available metallicities

HD	Spectral Type	$M_v \pm \sigma$	$(B2-V1) \pm \sigma$	$[Fe/H] \pm \sigma$	Source
1581	F9 V	$4.94 \pm b$	$0.329 \pm B$	-0.14 ± 0.07	476,540
4628	K2 V	$6.41 \pm a$	$0.551 \pm A$	-0.24 ± 0.07	552
10476	K1 V	$5.73 \pm b$	$0.524 \pm B$	-0.12 ± 0.13	421
10780	K0 V	$5.57 \pm b$	$0.492 \pm B$	-0.13 ± 0.20	Tokovinin 90
18803	G8 V	$4.74 \pm c$	$0.416 \pm B$	-0.06 ± 0.20	Tokovinin 90
20766	G2 V	$5.40 \pm c$	$0.391 \pm A$	-0.07 ± 0.07	571,476
20807	G1 V	$4.95 \pm c$	$0.356 \pm A$	-0.18 ± 0.05	C10
22049	K2 V	$6.16 \pm a$	$0.526 \pm A$	-0.20 ± 0.06	61,419,540
32147	K3 V	$6.44 \pm a$	$0.661 \pm B$	$+0.16 \pm 0.20$	Tokovinin 90
43834	G5 V	$5.37 \pm b$	$0.443 \pm B$	-0.14 ± 0.13	250
72905	G1 V	$4.93 \pm c$	$0.361 \pm A$	-0.07 ± 0.06	61,561
76151	G3 V	$5.74 \pm c$	$0.402 \pm C$	$+0.03 \pm 0.04$	Edvardsson et al. 93
114710	G0 V	$4.65 \pm b$	$0.334 \pm A$	$+0.14 \pm 0.06$	C26
115617	G6 V	$4.99 \pm c$	$0.433 \pm A$	$+0.03 \pm 0.05$	970,524
122742	G8 V	$5.39 \pm c$	$0.458 \pm A$	-0.06 ± 0.20	Tokovinin 90
128165	K3 V	$6.45 \pm c$	$0.621 \pm A$	$+0.03 \pm 0.05$	970,524
130948	G2 V	$5.07 \pm c$	$0.337 \pm C$	$+0.16 \pm 0.20$	Tokovinin 90
147584	G0 V	$4.74 \pm c$	$0.319 \pm A$	-0.16 ± 0.13	540
160346	K3 V	$6.06 \pm c$	$0.601 \pm A$	-0.28 ± 0.20	Tokovinin 90
166620	K2 V	$6.14 \pm a$	$0.548 \pm A$	-0.11 ± 0.13	150
185144	K0 V	$5.93 \pm a$	$0.495 \pm B$	-0.05 ± 0.09	62,151,952
187923	G0 V	$4.67 \pm c$	$0.398 \pm A$	-0.24 ± 0.09	3,951
189567	G2 V	$4.70 \pm c$	$0.393 \pm A$	-0.15 ± 0.09	86,548
192310	K0 V	$5.91 \pm c$	$0.561 \pm B$	$+0.13 \pm 0.06$	150,476
193664	G5 V	$5.24 \pm c$	$0.344 \pm A$	-0.06 ± 0.14	62

Legend : **C10** = 208, 476, 571, 951, 998 and **C26** = 3, 37, 62, 74, 949, 952
Errors on M_v and (B2-V1) :
a: $\sigma_{M_v} \leq 0.10$ and A: $\sigma_{(B2-V1)} \leq 0.003$
b: $0.11 \leq \sigma_{M_v} \leq 0.20$ and B: $\sigma_{(B2-V1)} = 0.004$
c: $0.21 \leq \sigma_{M_v} \leq 0.30$ and C: $\sigma_{(B2-V1)} = 0.005$

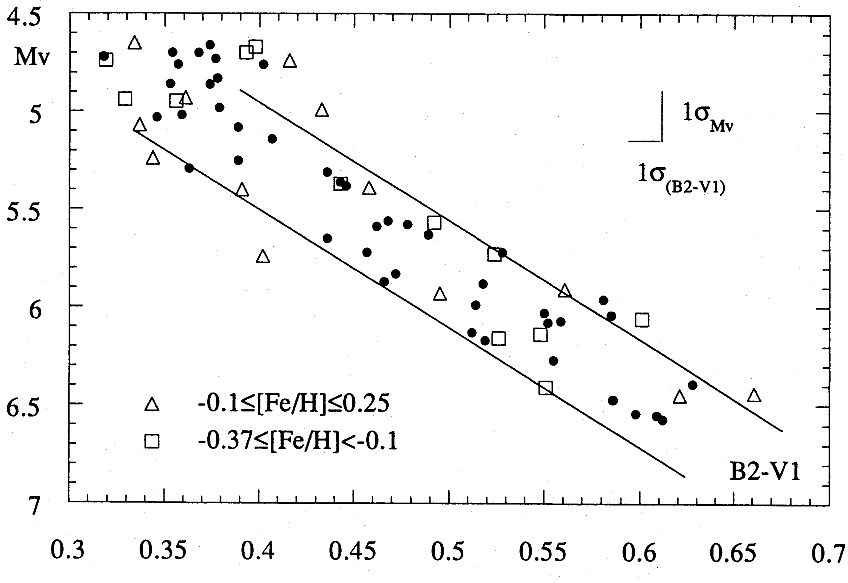

Fig. 3. HR diagram for the solar neighbourhood (see text). The squares represent the metal-poor stars ($-0.37 \leq [Fe/H] <$-0.1) and the triangles the metal rich ones (-0.1$\leq [Fe/H] \leq$0.25). Stars without available measures of metallicity are represented by black dottes. The full lines represent the observational main-sequence width, $\Delta M_v \approx$0.55.

Jahreiss, 1992). The stars with available metallicities are represented by open symbols. The total error box is also shown(see Sect. 4.2.1.c.).

4.2. The other broadening effects

We quantified in Sect. 3. the main sequence broadening due to chemical composition variations. Here we review the other broadening mechanisms.

4.2.1. Observational errors

a.) Absolute visual magnitude: $\bar{\sigma}(M_v)$.
The maximum observational uncertainty on M_v for the sample presented in Fig. 3 is 0.3 mag. Taking the M_v error quality classification from Gliese & Jahreiss (1991), our sample has the following error distribution: 6 stars with "a" quality code (i.e. $\sigma(M_v) \leq 0.10$); 17 stars with "b" code ($0.11 \leq \sigma(M_v) \leq 0.20$) and 46 stars with "c" code ($0.21 \leq \sigma(M_v) \leq 0.30$). This gives a weighted mean error of $\bar{\sigma}(M_v) \approx 0.21$. However the main contribution to $\bar{\sigma}(M_v)$ comes from uncertainties on dis-

tance. Preliminary results from the Hipparcos mission, seem to indicate that the observational broadening remains of the same order (Perryman et al., 1995) which is in favor of a minor role of the distance inaccuracies. After Hipparcos, the accuracy expected for our sample, is $\sigma(M_v) \approx 0.09$ mag (Gomez & Luri, 1992).

b.) Effective temperature photometric indice B2-V1: $\bar{\sigma}(B2 - V1)$

According to the Geneva system (Rufener, 1988), the maximum error, $\sigma(B2 - V1)$, for our sample is 0".006 mag, with the following distribution: 25 stars with $\sigma(B2 - V1) \leq$0".002 ; 12 stars with $\sigma(B2 - V1)$ =0".003; 26 stars with $\sigma(B2 - V1)$ =0".004; 5 stars with $\sigma(B2 - V1)$ =0".005 and 1 star with $\sigma(B2 - V1)$ =0".006 mag. This gives a weighted mean error of $\bar{\sigma}(B2 - V1) \approx$ 0".003.

c.) Metallicity: $\sigma([Fe/H])$.

We derive $\sigma([Fe/H]) \approx 0.11$ dex for weighted mean error on $[Fe/H]$, from the stars presented in Table 1. Using theoretical stellar models, with different Z values we estimate that the error produced by this uncertainty in the HR diagram variables is $\sigma(M_v) \approx$0.13 and $\sigma(B2 - V1) \approx$0.020.

d.) The total observational error.

The error box in Fig. 3, represents the total deviation on $[\bar{\sigma}(M_v)]_{total}$ and $[\bar{\sigma}(B2 - V1)]_{total}$, taking into account the different sources of errors. So,

$$[\bar{\sigma}(M_v)]_{total} = \sqrt{[\sigma(M_v)]_{obs}{}^2 + [\sigma(M_v)]_{[Fe/H]}{}^2} \approx 0.25$$

Similarly,

$$[\bar{\sigma}(B2 - V1)]_{total} \approx 0.02$$

where the subscripts "obs" and "$[Fe/H]$" represent the contributions to the total error from the direct observations of M_v and (B2-V1) (as computed in a. and b.) and from metallicity (as computed in c.).

We note that after Hipparcos $[\bar{\sigma}(M_v)]_{total}$ will be reduced, to at least, ≈ 0.16.

4.2.2. Binarity

Unresolved binary systems may produce a maximum error on M_v of 0.75 when the luminosities of both components are equal. This clearly appears on the HR diagram of clusters for which no chemical composition broadening is expected showing a concentration of objects on a line parallel to and above the lower main sequence of single stars. However theoretical and observational works about open clusters show that the number of unresolved binaries is small compared to the total number of stars: Monte-Carlo simulations of synthetic open clusters predicts 20% of unresolved spectroscopic binaries (Maeder, 1974); the observed HR diagram for Preasepe shows $\approx$ 10% of unresolved binaries (Arribas & Martines Roger, 1988). Even if we assume that the 8 stars ($\approx$ 10%) of our sample, that occupy the region close to the upper line, are spectroscopic binaries and consequently their M_v position is over-estimated (Fig. 3), the resulting observational broadening measured without these stars, will only decrease by $\approx$ 0.05 mag.

Moreover no evident parallel line of over-luminous stars is seen in our sample, which is a good argument to say that the possible existence of unresolved binaries does not affect our results significantly (see Appendix B).

4.2.3. Evolution

A small group of stars, located above our broadening delimitation, in the hottest part, $M_v \sim 4.7$, B2–V1$\sim$ 0.36-0.38, Fig. 3, appears to be stars already off the main sequence.

For a M_v higher than, say, 5.3 the observational broadening seems to be constant, which indicates a weak evolution broadening effect. On the other hand, we have calculated the evolution of masses from 0.7 to 1.0 $M_\odot$ in the range of metallicity considered and up to an age corresponding to the age of the thin disk. We have found that the M_v-limit of 5.3 is reached at this age by stars of masses lower than 0.9 $M_\odot$, for which the broadening due to evolution goes from 0.0 to 0.1 magnitude, and represents at most 20% of the observational broadening. This confirms that for the sample considered the evolution broadening effects are negligible.

4.2.4. Rotation

Rotation changes the HR position of the stellar models with respect to the non rotating ones (Maeder & Peytremann, 1972). But, as estimated by Zorec (1992) and Maeder & Peytremann (1972), the rotational effect is negligible for stellar masses lower than 1.4 $M_\odot$.

4.3. $\Delta Y/\Delta Z$ in the solar neighbourhood

In order to apply the theoretical approach derived in Sect. 3. to an observational sample we now have to relate the theoretical variables in the HR diagram, M_{bol} and T_{eff} to the observed ones: we choose M_v and (B2–V1). M_v is computed through M_{bol} using the bolometric corrections from Schmidt-Kaler (1982), with $M_{bol\odot}$=4.64 . Since accurate values of T_{eff} are not available for all the stars, we use the color index (B2–V1) from the Geneva catalogue (Rufener, 1988) which is a good T_{eff} indicator in this range of temperature and which is available for all the objects of the set. According to Hauck (1985), the photometric indice (B2–V1) determines the T_{eff} with a precision of 100 K. Moreover, Cayrel de Strobel (1992a) gives a list for 29 F, G, K nearby stars in the thin disk, where T_{eff} and [Fe/H] are determined by detailed spectroscopic analysis. We checked that the main conclusions of this work remain quasi-unchanged if the data of Cayrel de Strobel (1992a) are used.

So the relation $[\Delta M_{bol},(\Delta Y/\Delta Z)]$ becomes $[\Delta M_v,(\Delta Y/\Delta Z)]$, (also plotted in Fig. 2) represented by the Eqs. (3a) and (3b),

$$\Delta M_v = -0.15(\Delta Y/\Delta Z - 5.5) \Leftarrow \Delta Y/\Delta Z \leq 5.5 \quad (3a)$$

$$\Delta M_v = 0.13(\Delta Y/\Delta Z - 5.5) \Leftarrow \Delta Y/\Delta Z \geq 5.5 \quad (3b)$$

In fact, Eq. (3) are Eq. (2) corrected for the bolometric correction, BC. In the particular range of (B2–V1) (or T_{eff})

and $[Fe/H]$ considered in this work, the BC, varies quasi-linearly with (B2–V1) (or T_{eff}) and the correction to BC due to metal variation is lower than 0.01 mag for the metallicity range considered (Schmidt-Kaler 1982). So, we consider that $[\Delta M_v,(\Delta Y/\Delta Z)]$ is, in first approximation, also independent of (B2–V1).

The relations between (B2-V1) and T_{eff} obtained by Hauck (1985), are valid for stars on the main sequence with solar chemical composition. For metal-deficient stars ($[Fe/H] \leq$ -0.20, Z$\leq$0.012) and (B2-V1)$\geq$ 0.23, the relation $[(B2-V1), T_{eff}]$ must be corrected for the blanketing effect (Hauck, 1973). This correction produces a decrease of the (B2-V1) values for the metal-deficient ZAMS but this would change the main-sequence broadening by less than 0.15 mag. To analyse the blanketing influence, we measured the observational broadening in the $[M_v, (B-V)]$ and $[M_v, (R-I)]$ HR diagrams and we did not find significant differences with respect to $[M_v, (B2-V1)]$ HR diagram. Moreover the blanketing effects have a large contribution in cold stars, but for our sample (Fig. 3) the observational broadening is nearly constant with (B2-V1) and no differential spread is seen in the lowest part of the diagram.

This confirms the negligible influence of the blanketing in this metallicity range.

So taking into account that the chemical composition is the dominant broadening effect in the selected sample (the estimate of the other broadening effects seems to indicate that), the present observational width $\Delta M_v \approx 0.55$ (Fig. 3) can be accounted for if $\Delta Y/\Delta Z \geq 2.0$ or if $\Delta Y/\Delta Z \leq 9.5$. On the other hand Fig. 3 does not show any clear correlation between the position in the HR diagram and the stellar metal content. This indicates that a given position in the HR diagram could be occupied by metal rich or metal poor stars with different values of $\Delta Y/\Delta Z$ (see also Cayrel de Strobel & Crifo, 1995). This means that, according to the theoretical discussion made in Sect. 3. concerning Eqs. (2a) and (2b) and in order to account for the observational broadening given by the present observations it is not possible to distinguish between $\Delta Y/\Delta Z \in [2.0, 5.5]$, $\Delta Y/\Delta Z \in [5.5, 9.5]$ or even $\Delta Y/\Delta Z \in [2.0, 9.5]$. So up to now this method (i.e. the $\Delta Y/\Delta Z$ determination using relation between main sequence broadening and chemical composition variations) does not put severe constraints on $\Delta Y/\Delta Z$. The present width of the main sequence is compatible with any value of $\Delta Y/\Delta Z \in [2.0, 9.5]$. As a consequence, according to (1), the corresponding range of helium abundance is $0.25 \leq Y \leq 0.55$. (This upper limit looks somewhat exotic for the solar neighbourhood !)

5. Conclusion

We establish a theoretical quasi-linear function relating M_{bol} to $\Delta Y/\Delta Z$, which extends and confirm the 20 years old results of Perrin et al. (1977) that for $\Delta Y/\Delta Z \approx 5.$, $\Delta M_{bol} \approx 0$. This relation allows to bracket the $\Delta Y/\Delta Z$ ratio in the solar neighbourhood.

The observational width, $\Delta M_v \approx 0.55$, can be represented by models having $\Delta Y/\Delta Z \geq 2.0$ in the metallicity range $0.008 \leq Z \leq 0.034$. We estimated the other main sequence mechanisms (evolution, binarity and rotation). Their contributions are clearly lower than the chemical composition one. The value $\Delta Y/\Delta Z$ = 2.0 ($\pm$1.6, $\pm$1.0 after Hipparcos), has to be understood as a $\Delta Y/\Delta Z$ *lower limit* associated to the maximum main sequence broadening explained by the chemical composition variations in the solar neighbourhood.

It implies, in the solar neighbourhood, a lower limit of the helium abundance of about 0.246.

So, we suggest that the helium to metal enrichment ratio is not necessarily a constant in the solar neighbourhood. This result is consistent with recent stellar calibrations of the Sun and nearby visual binary stars α Centauri and η Cassiopeiae.

If the present observations of stellar metallicity were to be confirmed, i. e. if the metal rich and metal poor stars are really mixed throughout the main sequence band, it would mean that $\Delta Y/\Delta Z$ spaces an important fraction of the [2.0, 9.5] interval.

The main sources of errors come from the uncertainties on M_v. Hipparcos results will produce two important improvements: a better accuracy in stellar distances which means a large reduction of the error bar on stellar magnitude and a better definition for the binary systems. Hipparcos will also increase the possibility of discriminating between binaries and single objects at larger distances. This effect will better constrain the $\Delta Y/\Delta Z$ range, provided that progress is also made on the determination of $[Fe/H]$, bolometric corrections and T_{eff}.

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Appendix A: approach with the homology theory

The results expressed in Fig. 2, concerning the relation between the ZAMS broadening and $\Delta Y/\Delta Z$, can be qualitatively understood with the help of the homologous stellar transformations.

We take the following quasi-homology relation (Cox & Giuli, 1968):

$$L = {\epsilon_0}^{-0.077}{\kappa_0}^{-1.077}\mu^{7.769}M^{5.462} \quad (A1)$$

$$T_{eff} = {\epsilon_0}^{-0.096}{\kappa_0}^{-0.346}\mu^{2.211}M^{1.327} \quad (A2)$$

where $\mu = (2X + 0.75Y + 0.5Z)^{-1}$, is the mean molecular weight, ϵ the nuclear energy generation rate, κ the opacity and M the stellar mass.

Eliminating M by combinating (A1) and (A2) and supposing that the gas is perfect ; that the nuclear reactions are due to the pp chain with $\epsilon_0 \sim X^2$; that the opacity is dominated by the bound-free and free-free transitions with $\kappa_0 \sim (1+X)(100Z+1)$, gives

$$LogL = Log\mathbf{F}(\epsilon_0, \kappa_0, \mu) + 4.116 \times LogTeff \quad (A3)$$

where 4.116 represents the ZAMS slope and $Log\mathbf{F}(\epsilon_0, \kappa_0, \mu)$ the ZAMS broadening function which only depends on chemical composition: a variation of the chemical composition will translate the ZAMS.

Taking into account (1) $\mathbf{F}(\epsilon_0, \kappa_0, \mu)$ can be written as,

$$\mathbf{F}(\Delta Y/\Delta Z, Z) = [1.77 - Z(1+\Delta Y/\Delta Z)]^{0.348} \times$$
$$\times [1+100Z]^{0.348} \times [0.77 - Z(1+\Delta Y/\Delta Z)]^{0.638} \times$$
$$\times [1.71 - Z(1.5 - 1.25\Delta Y/\Delta Z)]^{1.333} \qquad (A4)$$

In the range of metallicity considered ($0.008 \leq Z \leq 0.034$) the ZAMS will not be enlarged if:

$$[\frac{\partial F(\Delta Y/\Delta Z, Z)}{\partial Z}]_{\Delta Y/\Delta Z} = 0 \Longleftrightarrow \Delta Y/\Delta Z \approx 4.5 \qquad (A5)$$

We find qualitative results similar to what is given by the detailed stellar model calculation presented in Fig. 2.

Appendix B: binary simulation

We take a sample of 1000 stars distributed uniformly in metallicity in the range $0.008 \leq Z \leq 0.034$. The helium abundance is derived from relation (1) and $\Delta Y/\Delta Z = 2.0$. We take the mass function of Salpeter (1955), $N(M) \sim M^{-2.5}$.

The stellar position in the HR diagram is generated using the relations (A1) and (A2). See Fig. B1 (black dots). We use $M_{bol\odot} = 4.64$ (Schmidt-Kaler, 1982) in order to change L to M_{bol}.

We consider that for a non-resolved binary system the observed luminosity is $L_{bin} = L_1 + L_2$, where L_1 and L_2 are respectively the real luminosity of the primary and of the second binary component.

In order to simulate the binary effects due to the non-resolved binaries, we suppose that the probability for the existence of a binary with $L_1 \approx L_2$ is lower than that of having $L_1 \gg L_2$.

So the real luminosity of a non-resolved binary can be written as

$$L_{bin} = L_1 + L_2 = L_1 + L_1 \times e^{-(L_1 - L_1 \times \Delta L)} \qquad (B1)$$

where ΔL is a random variable for which $0 \leq \Delta L \leq 1$.

We consider that 20% of our sample stars are non-resolved binaries. We also plot them in Fig. B1, where they are represented by open dots.

Fig. B1 shows an over-luminous stellar band near 2L ($\Delta M_{bol} = 0.75$). This result is similar to the Monte-Carlo calculations concerning the binary simulations in synthetic open clusters (Maeder, 1974).

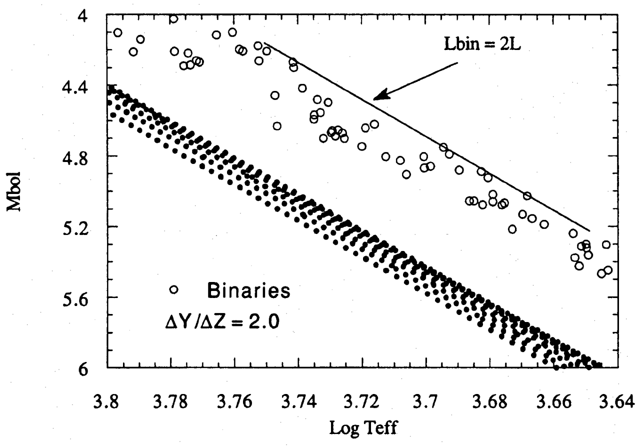

Fig. B1. Main sequence simulation for 1000 points (black dots) with $\Delta Y/\Delta Z = 2.0$ and taking 20% of non-resolved binaries (open dots)

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