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Galactic helium-to-metals enrichment ratio ($\Delta Y/\Delta Z$) from the analysis of local main sequence stars observed by HIPPARCOS

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Abstract. We discuss the reliability of one of the most used method to determine the *Helium-to-metals enrichment ratio*, $\Delta Y/\Delta Z$, i.e. the photometric comparison of a selected data set of local disk low Main Sequence (MS) stars observed by *HIPPARCOS* and a new grid of stellar models with up-to-date input physics. Most of the attention has been devoted to evaluate the effects on the final results of different sources of uncertainty (observational errors, evolutionary effects, selection criteria, systematic uncertainties of the models, numerical errors). As a check of the result the procedure has been repeated using another, independent, data set: the low-MS of the Hyades cluster. The obtained of $\Delta Y/\Delta Z$ for the Hyades, together with spectroscopic determinations of [Fe/H] ratio, have been used to obtain the Y and Z values for the cluster. Isochrones have been calculated with the estimated chemical composition, obtaining a very good agreement between the predicted position of the Hyades MS and the observational data in the Color - Magnitude Diagram (CMD).

Key words. Stars: abundances – Stars: low-mass Galaxy: solar neighbourhood – Galaxy: evolution – Galaxy: abundances

1. Introduction

The helium abundance, Y, is one of the fundamental parameters that influences stellar evolution and consequently the evolution of galaxies as a whole. Unfortunately, as well known, Y cannot be determined spectroscopically, at least in most cases, and so it remains one of the most important sources of uncertainty in many applications of stellar physics. Usually the helium abundance of stellar models is estimated by assuming a linear relation between Y and Z:

$$Y = Y_P + \frac{\Delta Y}{\Delta Z} \times Z \qquad (1)$$

while Z is directly related to the observed value of [Fe/H] (once a solar mixture is assumed):

$$Z = \frac{1 - Y_P}{1 + \frac{\Delta Y}{\Delta Z} + \frac{1}{(Z/X)_\odot} \times 10^{-[Fe/H]}} \qquad (2)$$

and so using a value for Y_P, the primordial helium content, Y is directly related to $\Delta Y/\Delta Z$, then the problem is shifted to the evaluation

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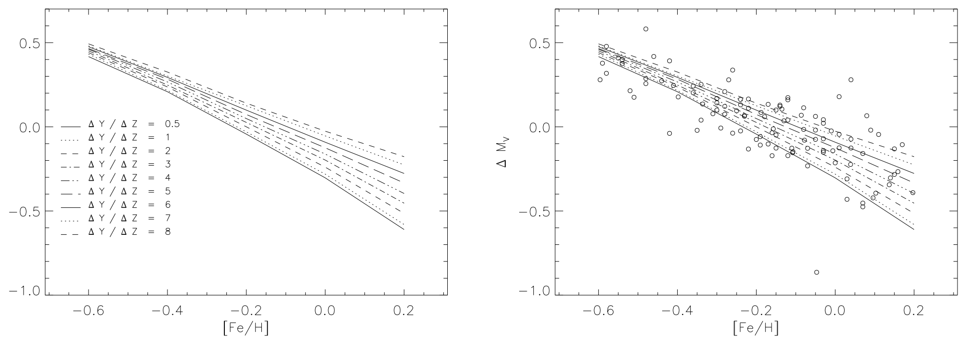

Fig. 1. Left: Differences in magnitude between models and the reference ZAMS for different values of $\Delta Y/\Delta Z$. Right: The same but with superimposed the differences between the data and the same reference ZAMS.

of a reliable value for this ratio. In Eq. 2 $(Z/X)_\odot$ indicates the solar metals-to-hydrogen ratio. The value we used for Y_P is 0.248, from Peimbert et al. (2007) and Izotov et al. (2007).

As well known, the initial helium content influences the position of stars in the CMD but this position also depends on age. This problem can be overcome by selecting a sample of low MS stars, which are supposed to be still near the ZAMS so that their position in the diagram depends mainly on chemical composition. The general procedure of this work is to calculate ZAMS models for different $\Delta Y/\Delta Z$ and to compare them with observed low MS stars to determine the value of $\Delta Y/\Delta Z$ which better reproduces the observations.

2. The data set

The stars of our sample have been selected among the HIPPARCOS (ESA 1997) stars with relative error on the parallax less than 5%. B and V photometry is also taken from HIPPARCOS data set. Then our sample has been restricted only to those stars with $M_V \geq 6$ mag to minimize evolutionary effects; [Fe/H] determinations are taken from the Geneva-Copenhagen survey catalog (Nordström et al. 2004) and the catalog by Taylor (2006). Our sample is made of 110 stars with tipical errors given by: $\sigma(M_V) \simeq 0.1$ mag, $\sigma(B-V) \simeq 0.03$ mag and $\sigma([Fe/H]) \simeq 0.1$ dex.

3. The models

Stellar models have been calculated for 9 $\Delta Y/\Delta Z$ values (0.5, 1, 2 ... 8) and 5 [Fe/H] values (from −0.6 to +0.2 in steps of 0.2 dex). For each of these 45 combinations we calculated evolutionary tracks for 11 stellar masses (from 0.5 to 1.0 $M_\odot$ in steps of 0.05 $M_\odot$) in order to realize ZAMS curves that cover the whole HR region corresponding to our data set. Models have been calculated using an updated version of the `FRANEC` evolutionary code (Chieffi & Straniero 1989; Degl'Innocenti et al. 2007). The equation of state and high temperature opacities are calculated from the OPAL website[1] while low temperature opacities are those from Ferguson et al. (2005). All the opacities are calculated for the solar mixture by Asplund et al. (2005). The value of the Mixing Length parameter $\alpha_{MLT} = 1.97$ is that of our latest Standard Solar Model, with the same input physics as above. Theoretical models have been transformed from the $(\log T_{eff}, \log L/L_\odot)$ to the $(B-V, M_V)$ diagram by means of synthetic photometry using the spectra database GAIA v2.6.1 calculated from PHOENIX model atmospheres (Brott & Hauschildt 2005).

[1] www-phys.llnl.gov/Research/OPAL/opal.html

4. Outlines of the method

The comparison between models and data is not directly made in the CMD, but in a diagram such as those of Fig. 1. After choosing a reference ZAMS, *theoretical* differences in magnitude, ΔM_V, between that ZAMS and the other ZAMS are measured at a fixed value of the color index $B - V$. We checked that, even if these differences are slightly dependent on the choice of both the reference ZAMS and the color index value, the final result for $\Delta Y/\Delta Z$ is unchanged when different choices are adopted; this because observational errors in the data set are more important and completely mask this dependence. The differences ΔM_V obviously depend on the chemical composition, i.e. on both $\Delta Y/\Delta Z$ and [Fe/H], as is clearly visible in Fig. 1 (left panel). *Observational* differences between the data set and the same reference ZAMS are also measured and are plotted in Fig. 1 (right panel) as a function of [Fe/H].

The method consists in determining the theoretical curve which minimizes the quantity:

$$\mathcal{D}_j = \sum_i \left[\frac{\Delta M_{V,i} - \Delta M_{V,j}([Fe/H]_i)}{\sigma(\Delta M_{V,i})} \right]^2 \qquad (3)$$

where j runs over the curves (i.e. over different $\Delta Y/\Delta Z$ values) and i over the data. To take into account observational errors we assign to each star errors in the three observational quantities M_V, $B - V$ and [Fe/H]. The errors in M_V and $B - V$ are assigned in the CMD, i.e. *before* the calculation of the differences ΔM_V; then the error in [Fe/H] is assigned in the (ΔM_V, [Fe/H]) diagram. In this way a new data set, including the "error effects" is created from the original one. The procedure is iterated in order to estimate the "best value" of $\Delta Y/\Delta Z$ and the uncertainty on the obtained value due to the observational errors. In Fig. 2 it is possible to see the histogram of occurrences for a Monte Carlo simulation with a total of 20000 iterations.

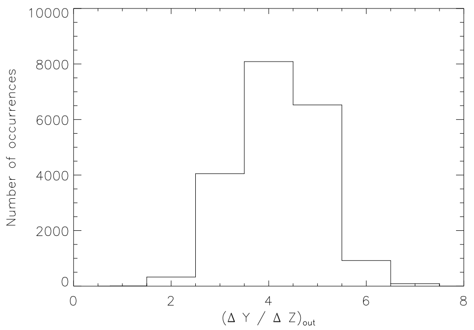

Fig. 2. Results for a Monte Carlo simulation of 20000 runs.

4.1. Artificial data set

To check the reliability of the procedure and to evaluate the effects of the contribution of the various possible sources of uncertainty, we applied our method to a number of artificial data set with controlled input parameters. This sets have been created by interpolation in our grid of models. We found that our recovery method is not affected in an important way by observational errors. On the other hand, we surprisingly found that, even selecting high magnitude stars, evolutionary effects can play an important role and they can introduce a *bias* in the final result. In fact, by creating an artificial data set of stars with $(\Delta Y/\Delta Z)_{in} = 4$ but a spread in age from 0 to 8 Gyr (a reliable estimate for the age of the disk), so that stars are not *really* on their ZAMS position, we found an output value of our recovery method of $(\Delta Y/\Delta Z)_{out} = 3$. Thus evolution, by shifting isochrones towards the redder part of the CMD, "mimics" a lower value of $\Delta Y/\Delta Z$.

It means that even if our *observational* data set has been selected with a very strict cutoff of $M_V = 6$, evolutionary effects can still play an important role, and the stars of the sample cannot be really considered as if they are on their ZAMS position. So our final result of $\Delta Y/\Delta Z = 4 \pm 1$ is probably biased and should be reasonably shifted by ~ 1 towards higher values. The uncertainty we quote here is just the 1σ confidence level of the simulation, and so it is connected only to observational errors, and of course not to systematics.

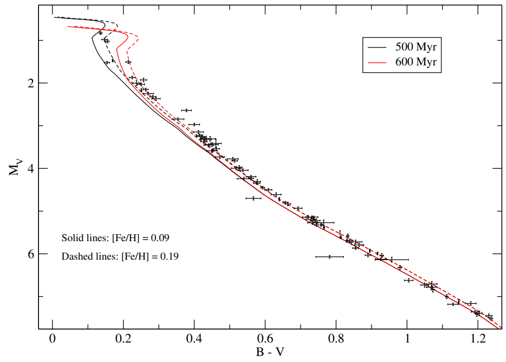

Fig. 3. CMD for the Hyades (data from Madsen et al. 2002) with isochrones calculated with $\Delta Y/\Delta Z = 5$ for two different values of the age and for the extreme values of [Fe/H] from Perryman et al. (1998).

5. The Hyades low Main Sequence

To avoid the possible bias due to evolution, we applied our recovery method to a set of stars which can be safely considered unevolved: the stars of the lowest part ($M_V \geq 5.2$) of the Hyades Main Sequence. For this cluster an age of about $500 \div 600$ Myr is generally estimated so that low luminosity stars which correspond to masses lower than about $0.9 M_{\odot}$, are really on or at least very close to their ZAMS position. Moreover, data for this cluster are even more precise than those of our local disk data set; using the data from Madsen et al. (2002) the tipical errors are $\sigma(M_V) \simeq 0.05$ mag and $\sigma(B-V) \simeq 0.02$ mag. The metallicity value is taken from Perryman et al. (1998): [Fe/H] $= 0.14 \pm 0.05$ dex. The maximum occurrence value we found with our Monte Carlo procedure is $\Delta Y/\Delta Z = 5$, in very good agreement with what we found using local main sequence stars and taking into account the evolutionary bias. To check the consistency of this final result, we calculated isochrones with this value of $\Delta Y/\Delta Z$ together with the extreme values of our [Fe/H] interval, i.e. 0.09 and 0.19. The agreement between our models and the Hyades data is very good (see Fig. 3), making us confident about the adopted procedure.

6. Conclusions

The principal aim of this work has been to test the reliability of the determination of $\Delta Y/\Delta Z$ by the comparison of low MS stars and theoretical ZAMS models. We adopted a given set of models, both for the interior and the atmosphere, in particular we used a fixed value of α_{MLT} and a unique set of color transformation. We found that the inferred value of $\Delta Y/\Delta Z$ is extremely sensitive to the age of the sample of stars, even if we restricted the data set to low luminosity stars; the lack of an accurate age estimate of low mass field stars leads to an underestimate of the inferred $\Delta Y/\Delta Z$ of ~ 1. On the contrary the method firmly recovers the $\Delta Y/\Delta Z$ value for not evolved sample of stars such as the Hyades low MS. The systematic uncertainties on the ZAMS positions introduced by the assumption in the models will be discussed in a forthcoming paper (Gennaro et al. 2008).

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References

Asplund, M., Grevesse, N. & Sauval, A. J., 2005, ASP Conf. Ser. 336, 25
Brott, I. & Hauschildt, P. H. 2005, ESA Special Publication, 576, 565
Chieffi, A. & Straniero, O. 1989, ApJS, 71, 47
Degl'Innocenti, et al. 2007, Ap&SS, tmp, 291
ESA, 1997, VizieR Online Data Catalog, 1239
Ferguson, J. W., et al. 2005, ApJ, 623, 585
Gennaro, M., Prada Moroni, P. G. & Degl'Innocenti, S., 2008, *in preparation*
Izotov, Y. I., Thuan, T. X. & Stasińska, G., 2007, 662, 15
Madsen, S., Dravins, D. & Lindegren, L., 2002, A&A, 381, 446
Nordström, B., et al. 2004, VizieR Online Data Catalog, 5117
Peimbert, M. et al. 2007, Astronomical Society of the Pacific Conference Series, 374, 81
Perryman, M. A. C., et al. 1998, A&A, 331, 81
Taylor, B. J., 2006, VizieR Online Data Catalog, 216