The heavy elements mixture and the stellar cluster age

S. Degl’Innocenti 1,2, P.G. Prada Moroni1,2, B. Ricci3,4
1 Dipartimento di Fisica, Università di Pisa, Largo B. Pontecorvo 3, 56126 Pisa, Italy
2 INFN Sezione di Pisa, Largo B. Pontecorvo 3, 56126 Pisa, Italy
3Istituto Nazionale di Fisica Nucleare, Sezione di Ferrara, via Paradiso 12, I-44100 Ferrara, Italy,
4Dipartimento di Fisica dell’Università di Ferrara, via Paradiso 12, I-44100 Ferrara, Italy

Abstract

Recent analyses of solar spectroscopic data (see Asplund, Grevesse & Sauval 2004 and references therein) suggest a significative variation of the heavy elements abundance. The change of heavy mixture might affect the determination of the clusters age for two different reasons: the change of theoretical isochrones at fixed metallicity and the variation of the inferred cluster metallicity from the observed [Fe/H]. The first point is analyzed discussing the effects of updating the metal distribution on theoretical evolutionary tracks and isochrones for metallicities suitable for the galactic globular and open clusters and for the bulk population of the Large Magellanic Clouds. The maximum variation of the estimated age ($\approx 0.5$ Gyr), although not negligible, is still within the present uncertainty. The second point is addressed by comparing present theoretical predictions with the very precise observational data of the Hyades cluster from the Hypparcos satellite.

I. INTRODUCTION

Through the years the knowledges in stellar physics have been continuously improved thanks to the progress in the determination of the physical inputs for the stellar models (nuclear reaction rates, equation of state, opacity coefficients, microscopic diffusion etc..) and in the observational capabilities. Now the general scenario is well defined and confirmed by an huge amount of observational data of the Sun and of the field and cluster stars in our Galaxy. However several problems are still not completely solved (e.g. the precise treatment of external convection, the overshooting and diffusion efficiency, the discrepancy between theory and observation for the light elements surface abundance etc..).

Recent analyses of spectroscopic data using three dimensional hydrodynamic atmospheric models (see Asplund et al. 2004 and references therein) have reduced the derived abundances of CNO and other heavy elements with respect to previous estimates (Grevesse & Sauval 1998, hereafter GS98). Thus the Z/X solar value decreases from the GS98 value $(Z/X)_\odot=0.0230$ to $(Z/X)_\odot=0.0165$. GS98 already improved the mixture by Grevesse & Noels (1993, hereafter GN93), widely adopted in the literature, mainly revising the CNO
and Ne abundance and confirming the very good agreement between the new photospheric and meteoric results for iron.

Several works analyzed the effects of the last update of the composition on the solar characteristics pointing out a disagreement between the observed and the predicted sound speed (see e.g. Bahcall et al. 2005, Basu & Antia 2004). However, further investigations are needed because the still present uncertainties on the physical inputs adopted in the models prevent the reaching of a firm conclusion.

The change of heavy mixture might affect also the determination of the clusters age for two different reasons: 1) the change of theoretical isochrones at fixed metallicity; 2) the variation of the inferred cluster metallicity from the observed [Fe/H].

In the first part of the paper we will analyse the former point, while the last section is devoted to the comparison with Hipparcos observational data for the Hyades cluster. We point out that our aim is not to generally discuss the effects of a variation of the heavy elements abundance, as already done by several authors for Population II stars (see e.g. Simoda & Iben 1968, 1970, Renzini 1977, Castellani & Tornambè 1977, Rood 1981, Rood & Crocker 1985, VandenBerg 1985, Chaboyer, Sarajedini & Demarque 1992, Chieffi, Straniero & Salaris 1991, Salaris, Chieffi & Straniero 1993, VandenBerg 1992, VandenBerg & Bell 2001 and references therein) but to quantitatively analyse the effect of the quoted very recent specific solar mixture variation on Pop.II and Pop.I stellar cluster age determination.

To our knowledge all the extended sets of evolutionary tracks and isochrones available in the literature (see e.g. Pietrinferni et al. 2004, Cariulo, Degl’Innocenti, Castellani 2004, Castellani et al. 2003, VandenBerg et al. 2001, Yi et al. 2001, Salasnich et al. 2000, Maeder & Zahn, 1998 and references therein) adopt a heavy element mixture older than Asplund et al. 2004.

In this work we calculated evolutionary tracks and stellar isochrones for different mixtures with chemical compositions typical respectively of globular clusters (Z=0.0002, Z=0.001, Y=0.23) and open clusters (Z=0.02 Y=0.27) in our Galaxy and of the bulk of the population of the Large Magellanic Clouds (Z=0.008 Y=0.25). The results for other chemical compositions can be extrapolated from the previous results. Calculations are presented in Sect.II while the theoretical results are discussed in Sect.III for globulars and in Sect.IV for intermediate age clusters. In Sect. V theoretical predictions for the Hyades cluster are compared with observations.

II. THE MODELS AND THE PHYSICAL INPUTS

The models in this study have been computed with an updated version of the FRANEC evolutionary code (see e.g. Chieffi & Straniero 1989) adopting the radiative opacity by the Livermore group (Iglesias & Rogers 1996) and updated nuclear cross sections (for more details see Cariulo, Degl’Innocenti, Castellani 2004). Element diffusion has been included (Ciacio, Degl’Innocenti, Ricci 1997, with diffusion coefficients from Thoul, Bahcall & Loeb 1994). Radiative acceleration (see e.g. Richer et al. 1998, Richard et al. 2002) has not been implemented. For convective mixing, we adopt the Schwarzschild criterion to define regions in which convection elements are accelerated (see the description in Brocato & Castellani 1993).
With these choices we have already shown that theoretical predictions for the color-magnitude diagram (CMD) of the nearby open clusters Hyades, Pleiades and Ursa Major appear in good agreement with the observations for which precise parallaxes are available from the Hipparcos satellite (Castellani, Degl’Innocenti, Prada Moroni 2001, Castellani et al. 2002).

In the present models we adopted the EOS 2001 by OPAL 1 and the conductive opacity by Potekhin 1999, see also Potekhin et al. 1999.

The change of the solar mixture affects age determination. For globular clusters a widely used age indicator, independent of the cluster distance, is the difference in visual magnitude between the Turn-Off and the Zero Age Horizontal Branch at the RR Lyrae region (ΔM_V(ZAHB-TO)). For clusters up to about 6 Gyr, a useful age indicator is the difference in visual magnitude between the He clump and the main sequence termination, MT, (ΔM_V(clump-MT)). MT is evaluated at the maximum luminosity reached just after the overall contraction (H exhaustion) whereas the clump magnitude at the minimum luminosity of the He clump region.

In principle a mixture variation influences the evolution of a star on both the burning (which is affected by the total CNO abundance) and the opacity, as noted in studies of the effects of the enhancement of α elements in globular cluster stars (see e.g. Simoda & Iben 1970, VandenBerg 1985, Chaboyer, Sarajedini & Demarque 1992, Salaris, Chieffi, Straniero, 1993, Salaris & Weiss, 1998). To account for both aspects we calculated the opacities for the Asplund et al. (2004) mixture (URL: http://www-phys.llnl.gov/Research/OPAL/new.html).

We point out that low temperature opacities are not available for the Asplund et al. (2004) mixture; in particular the Alexander & Ferguson (1994) opacities, adopted in this work for T≤12000 oK, are available only for the Grevesse (1991) mixture. This is not a problem because it has already been demonstrated by several authors (e.g. Rood 1981, Bazzano et al. 1982, Salaris et al. 1993) that the main characteristics of population II stars are not influenced by the low temperature opacities. We also notice that model atmospheres with the Asplund et al. (2004) solar composition are still not available thus for our calculations we must adopt color transformations for the old solar mixture (Castelli 1999, see also Castelli, Gratton & Kurucz 1997). However preliminary calculations of stellar fluxes with the Asplund et al. composition show a change of the stellar colors, with respect to the ones calculated for the GN93 composition, within the observational errors (Aufdenberg, private communication).

As firstly predicted by Simoda & Iben (1968,1970) and Renzini (1977) and confirmed by several authors (see e.g. Rood 1981, Bazzano et al. 1982, Salaris et al. 1993) the TO characteristics and the mass of the He core at the central helium ignition are mainly influenced by the burning and thus by the CNO global abundances.

The computed evolutionary models for intermediate age clusters cover with a fine grid the mass range 0.7 to 8 M☉ for the adopted chemical compositions Z=0.008 Y=0.250, Z=0.02 Y=0.27, where the amount of original helium has been evaluated by assuming a primordial helium abundance Y_P = 0.23 and ΔY/ΔZ ~2.5 (see e.g. Pagel & Portinari 1998, Castellani, 1

1http://www-phys.llnl.gov/Research/OPAL/Download/
Degl’Innocenti, Marconi 1999); the related isochrones have been calculated from 100 Myr to 6 Gyr to properly cover the range of ages for the Galactic open clusters. For globular cluster models we calculated masses from 0.6 to 1.0 \( M_\odot \) for \( Z=0.0002 \) \( Y=0.23 \) and \( Z=0.001 \) \( Y=0.232 \) and isochrones in the age range 8÷15 Gyr. To select only the effects of the CNO abundance on the H burning we calculated models of different masses (0.8 \( M_\odot \), 1.2 \( M_\odot \), 3.0 \( M_\odot \), 5.0 \( M_\odot \)) for each of the selected chemical compositions with the same physical inputs, included radiative opacity table for the Grevesse & Noels (1993) solar mixture, but the C, N, O abundances of Asplund et al. (2004). We found that in all cases models with the new CNO abundance are quite identical with the old ones; the variation of the total CNO abundance (of the order of 7\%) is perhaps too small to be relevant for the burning.

III. RESULTS FOR GLOBULAR CLUSTERS

We analyzed isochrones for \( Z=0.0002 \) and \( Z=0.001 \) and ages from 8 to 15 Gyr. The change of the heavy element mixture (both in the CNO abundance and in the opacity calculations) does not affect neither the TO luminosity (see Fig. 1) nor the ZAHB luminosity level.

It’s worth clarifying a point: several observational works demonstrate that in halo stars the \( \alpha \) elements (e.g. O, Ne, Mg, Si, S, Ca, Ti etc..) are enhanced by about the same amount with respect to iron in comparison with the solar composition (see e.g. Gratton et al. 2003, Gratton et al. 2000) and this may seem to be an additional problem in our analysis of the dependence of the globular cluster age on the heavy elements mixture. Luckily this is not the case; Salaris et al. (1993) suggested, for the first time (see also e.g. Weiss, Peletier, Matteucci 1995, Salaris & Weiss, 1998), that for globular cluster stars, instead of calculating models with the \( \alpha \) enhanced mixture for \( Z_0 \), a good approximation can be obtained with standard solar mixture isochrones of the metallicity \( Z_{\text{tot}} \) given by \( Z_{\text{tot}}=Z_0(a_{\alpha} + b) \) with \( f_\alpha=10^{[\alpha/\text{Fe}]} \). The values of the coefficients \( a \) and \( b \) depend on the heavy-elements distribution; Salaris et al. 1993 give \( a=0.638 \) and \( b=0.364 \), while with the Asplund et al. (2004) composition they become respectively 0.659 and 0.341. Thus also for globular cluster stars it’s a right procedure to restrict our analysis to the effects of the latest solar mixture changes at fixed metallicity.

IV. RESULTS FOR OPEN CLUSTERS

We adopt as age indicator the \( \Delta M_V(\text{clump-MT}) \). The updating of the heavy element mixture has, as for the globular cluster stars, no effect on the MT luminosity and age. Figure 2 shows the comparison of \( \Delta M_V(\text{clump-MT}) \) as a function of age for \( Z=0.008 \) and \( Z=0.02 \) and the labeled heavy mixtures. The difference in the inferred age, which is thus only due to the difference in the clump luminosity, increases with age and the total metallicity reaching a maximum of the order of 0.5 Gyr in the present range of ages. Although not negligible, this discrepancy is still within the uncertainty on the age determination with the adopted method, which can be estimated of the order of \( \approx 2 \) Gyr (see e.g. Cassisi et al. 1999, Castellani & Degl’Innocenti 1999). The change of the He burning evolutionary times due to the mixture updating is negligible.
V. COMPARISON WITH THE HYADES

As mentioned in the introduction, the variation in the solar heavy-element mixture affects not only the theoretical tracks and isochrones for a given global metallicity $Z$, but also the conversion of the spectroscopically determined value of $[\text{Fe/H}]$ to the total metallicity $Z$ of the observed stars. This is a quite tricky point because for computing stellar models one needs the total metallicity $Z$ and not only the iron abundance, but to obtain the former from the latter is necessary specifying the distribution of the element abundances. Unless explicitly stated, it is usually assumed a solar mixture. Thus a revision of the photospheric abundance of the Sun directly implies a variation of the inferred total metallicity from the observed $[\text{Fe/H}]$. For solar-like stars, the $[\text{Fe/H}]$ is often estimated by means of relative measures, that is by the comparison of the iron lines of the star and those of the Sun. In such a case, the numerical value of $[\text{Fe/H}]$ remains unaffected by a change of the solar mixture and the updated global metallicity of the star can be easily derived by adopting the new value for $(Z/X)_{\odot}$. In practice:

$$\log \left( \frac{Z}{X} \right)_* = [\text{Fe/H}] + \log \left( \frac{Z}{X} \right)_{\odot}.$$

As a consequence of the new value of $(Z/X)_{\odot}=0.0165$, the estimated metallicity of the open clusters in the solar neighborhood has significantly decreased. To analyse the effects of this change we need very precise observational data. To this aim we will focus our attention on the Hyades cluster, for which very accurate Hipparcos observational data for the distances (and thus for the absolute visual magnitude of the stars) are available (see e.g. Dravins et al. 1997, Madsen, Dravins, & Lindegren 2002). Moreover, for this cluster, there is negligible reddening (see e.g. Perryman et al. 1998). Clusters with higher uncertainties on the distance modulus and the reddening are not suitable, in our opinion, for this analysis because the quoted uncertainties make the discussion of the results much less clear.

We adopted for this cluster $[\text{Fe/H}]= 0.14 \pm 0.05$ (see the discussion in Perryman et al. 1998) in agreement with Paulson, Sneden & Cochran 2003 too. Some years ago we already found a very good agreement with the Hyades observations for a 520 Myr isochrone by adopting a metallicity of $Z=0.024$, a value directly obtained from $[\text{Fe/H}]= 0.14$ and $(Z/X)_{\odot}$ by Grevesse & Noels 1993 (Castellani, Degl’Innocenti & Prada Moroni 2001, Castellani et al. 2002) in agreement with the results of other authors (see e.g. Perryman et al. 1998, Lebreton 2000, de Bruijne, Hoogerwerf, & de Zeeuw 2001, VendenBerg & Clem 2003). However, the updated $(Z/X)_{\odot}$, reduces the global metallicity to $Z=0.016$. This quite large decrease of the metallicity has a much greater effect on the fit of the cluster than the change in the heavy element mixture adopted in the computation of the models. In fact, by varying the solar mixture at fixed metallicity the MS color remains almost the same with a maximum variation lower than two hundredth of magnitude while the lowering of the metallicity from $Z=0.024$ to 0.016 blue shifts the MS by about 0.05 mag.

Figure 3 shows the color-magnitude diagram of the Hyades with superimposed the theoretical isochrones with $Z=0.016$ $Y=0.27$ and the labeled ages. As one can easily see, the model now disagrees with data. This result is particularly relevant for the upper $(B-V < 0.4)$ part of the MS, where, due to the radiative envelope of the stars, the color is indepen-
dent on the chosen mixing length parameter (see e.g. Fig.2 of Castellani et al. 2001). Figure 3 also shows that changing the assumed age does not remove the disagreement.

The independence of the mixing length parameter also holds in the lower part (B-V > 1.2) of the MS, where envelope convection is adiabatic; however in this region the obtained results are less firm because, as well known, at low temperatures a careful treatment of equation of state and molecular opacities is needed.

A reasonable reduction of the helium abundance doesn’t solve the problem; to have an estimate of the shift of the MS position as a function of the helium abundance see e.g. Castellani, Degl’Innocenti & Marconi (1999).

In order to reach a reasonable, although not perfect, match of the Hyades we have to increase the metallicity at least to Z=0.02, corresponding to [Fe/H]= 0.23.

Let us recall that we adopt color transformations and bolometric corrections computed by adopting the Grevesse & Noels 1993 solar mixture. For a precise and self-consistent comparison one should use the same distribution of elements both for the interior and for the atmosphere, but, at present, the color transformations and the bolometric corrections have not yet been updated. On the other hand, preliminary model atmosphere computations (Aufdenberg 2005, private communication) showed a minor effect.

We also note that conclusions based on the MS position in the color-magnitude diagram must be taken with caution because this is influenced at some level by the still present uncertainties on the physical inputs adopted in the calculations and on the color transformations (see e.g. Castellani et al. 2001, Sekiguchi & Fukugita 2000).

ACKNOWLEDGMENTS

We are extremely grateful to V. Castellani G. Fiorentini and S. Shore for useful discussions and for a careful reading of the paper. We warmly thank J. Aufdenberg for his preliminary analysis of the stellar fluxes with the Asplund et al. 2004 composition. Financial support for this work was provided by the Ministero dell’Istruzione, dell’Università e della Ricerca (MIUR) under the scientific project “Continuity and discontinuity in the Galaxy formation” (P.I.: R. Gratton).
REFERENCES

[1] Alexander D.R. & Ferguson J.W., 1994, ApJ 437, 879
[2] Asplund M., Grevesse N., Sauval A. J., 2004, in “Cosmic Abundances as Records of Stellar Evolution and Nucleosynthesis”, F.N. Bash and T.G. Barnes (editors), astro-ph/0410214
[3] Bahcall J.N., Basu S., Pinsonneault M., Serenelli A.M., 2005, ApJ, 618, 1049
[4] Basu S. & Antia H.M., 2004, ApJ, 606L, 85
[5] Bazzano A., Caputo F., Sestili M., Castellani V., 1982, A&A, 111, 312
[6] Brocato E. & Castellani V., 1993, ApJ 410, 99
[7] Cariulo P., Degl’Innocenti S., Castellani V., 2004, A&A, 424, 927
[8] Cassisi S., Castellani V., Degl’Innocenti S., Salaris M. et al., 1999, A&AS 134 103
[9] Castellani V. & Degl’Innocenti S., 1999, A&A 344, 97
[10] Castellani V. & Tornambè A., 1977, A&A 61, 427
[11] Castellani V., Degl’Innocenti S., Marconi M., Prada Moroni P. G., Sestito P., 2003, A&A, 404, 645
[12] Castellani V., Degl’Innocenti S., Marconi M., 1999, A&A 349, 834
[13] Castellani V., Degl’Innocenti S., Prada Moroni P.G., 2001, MNRAS 320, 66
[14] Castellani V., Degl’Innocenti S., Prada Moroni P.G., Tordiglione V., 2002, MNRAS 334, 193
[15] Castelli F., Gratton R. G., Kurucz R. L., 1997, A&A, 318, 841
[16] Castelli F., 1999, A&A, 346, 564
[17] Chaboyer B., Sarajedini A., Demarque P., 1992, ApJ, 394, 515
[18] Chieffi A., & Straniero O., 1989, ApJS, 71, 47
[19] Chieffi A., Straniero O., Salaris M., 1991, in ASP Conf. Ser. 13, “The Formation and Evolution of Star Clusters”, ed. K. Janes (San Francisco: ASP), 219
[20] Ciacio F., Degl’Innocenti S., Ricci B., 1997, A&AS, 123, 449
[21] Degl’Innocenti, S., Dziembowski W.A, Fiorentini G., Ricci B., 1997, Astrop. Phys. 7, 77
[22] de Bruijne J. H. J., Hoogerwerf R., de Zeeuw P., 2001, A&A 367, 111
[23] Dravins D., Lindegren L., Madsen S., Holmberg J., 1997, ESA, SP-402, p. 733
[24] Gratton R. G., Carretta E., Desidera S., Lucatello S., Mazzei P., Barbieri M., 2003, A&A, 406, 131
[25] Gratton R. G., Carretta E., Matteucci F., Sneden C., 2000, A&A, 358, 671
[26] Gratton R.G., Carretta E., Desidera S., Lucatello S., Mazzei P., Barbieri M., 2003, A&A, 406, 131
[27] Grevesse N., 1991, in “Evolution of Stars: the Photospheric Abundance Connection”, Proceedings of the 145th Symposium of the International Astronomical Union, held in Zlatni Piasaci (Golden Sands), Bulgaria, August 27-31, 1990. Edited by G. Michaud and A. V. Tutukov. IAU Symposium no. 145, Kluwer Academic Publishers, Dordrecht, 1991., p.63
[28] Grevesse N. & Noels A., 1993 in “Origin and Evolution of the elements”, ed. N. Prantzos, E. Vangioni-Flam, M. Cassel(Cambridge Univ. Press, Cambridge), p.15.
[29] Grevesse N. & Sauval A. J., 1998, Space Science Reviews, 85, 161
[30] Iglesias C.A. & Rogers F.J., 1996, ApJ 464, 943
[31] Lebreton Y., 2000, ARA&A 38, 35
[32] Madsen S., Dravins D., Lindegren L., 2002, A&A, 381, 446
[33] Madsen S., Lindegren L., Dravins D., 2000, in ASP Conf. Ser. 198, Stellar Cluster and
Associations, ed. R. Pallavicini, G. Micela, S. Sciortino, 137
[34] Maeder, A. & Zahn, J.P., 1998, A&A, 334, 1000
[35] Pagel, B.E.J. & Portinari, L., 1998, MNRAS, 298, 747
[36] Paulson D. B., Sneden C. C., William D., 2003, AJ 125, 3185
[37] Perryman M.A.C. et al., 1998, A&A 331, 81
[38] Pietrinferni A., Cassisi S., Salaris M., Castelli F., 2004, ApJ, 612, 168
[39] Potekhin, A. Y., 1999, A&A, 351, 787
[40] Potekhin A. Y., Baiko D. A., Haensel P., Yakovlev D. G., 1999, A&A, 346, 345
[41] Renzini A., 1977, in “Advanced Stages in Stellar Evolution”, ed. P. Bouvier & A. Maeder
(Geneva: Geneva Obs.), 151
[42] Rood R.T. & Crocker D.A., 1985, in “Production and Distribution of C, N, O Elements”,
ESO, Garching bei Mnchen, p. 61, eds. Danziger I.J. Matteucci F., Kjr K.
[43] Richard O., Michaud G., Richer J., et al., 2002, ApJ 568, 979
[44] Richer J., Michaud G., Rogers F., et al., 1998, ApJ, 492, 833
[45] Rood R. T., 1981, in “Physical processes in red giants”; Proceedings of the Second
Workshop, Erice, Italy, September 3-13, 1980. Dordrecht, D. Reidel Publishing Co.,
1981, p. 51-54.
[46] Salaris M., Chieffi, A., Straniero O., 1993, ApJ, 414, 580
[47] Salaris M. & Weiss A., 1998, A&A, 335, 943
[48] Salasnich B., Girardi L., Weiss A., Chiosi C., 2000, A&A, 361, 1023
[49] Sekiguchi M. & Fukugita M., 2000, AJ 120, 1072
[50] Simoda M. & Iben I. Jr., 1968, ApJ, 152, 509
[51] Simoda M. & Iben I. Jr., 1970, ApJS, 22, 81
[52] Straniero O., 1988, AAS, 76, 157
[53] Thoul A., Bahcall J., Loeb A., 1994, ApJ, 421, 828
[54] Yi S., Demarque P., Kim Y-C., et al., 2001, ApJ, 533, 670
[55] VandenBerg D.A., 1985 in “Production and Distribution of C, N, O Elements”, ESO,
Garching bei Mnchen, p. 61, Danziger I.J. Matteucci F., Kjr K. eds.
[56] VandenBerg D. A., 1992, ApJ 391, 685
[57] VandenBerg D. A., Swenson F. J., Rogers F. J., Iglesias C. A., Alexander D. R., 2000,
ApJ 532, 430
[58] VandenBerg D.A. & Bell R.A., 2001, New Astron. Rev. 45, 577
[59] VandenBerg, D. A. & Clem, J. L., 2003, AJ 126, 778
[60] Weiss A., Peletier R. F., Matteucci F., 1995, A&A, 296, 73
FIG. 1. The TO absolute visual magnitude, $M_V(\text{TO})$, as a function of the cluster age for the labeled assumptions about the original chemical composition and the heavy element mixture.
FIG. 2. The $\Delta M_V(\text{clump-MT})$ as a function of the cluster age for the labeled assumptions about the original chemical composition and the heavy element mixture.
FIG. 3. The CMD for the Hyades, using the parallax values from Madsen et al. (2002). Visual, spectroscopical and suspected binaries are excluded, see also Madsen et al. (2000). Error bars indicate observational errors as given by Madsen et al. (2002) for the parallax and by the Hipparcos catalog (at the node http://astro.estec.esa.nl/Hipparcos/HIPcataloguesearch.html) for the colors. Observational data are compared with present theoretical isochrones for $Z=0.016$ $Y=0.27$ $\alpha=1.9$. Color transformations and bolometric corrections from Castelli (1999).