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A new database of evolutionary models for low- and intermediate-mass stellar structures

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Abstract. We present a new database of stellar evolutionary models for a quite large range of star mass and chemical compositions, based on an up-to-date theoretical framework. We briefly discuss the adopted physical inputs and assumptions in computing the models. Some preliminary comparisons between observational evidences and theoretical predictions are also provided. Being such project still in progress, we mention the extension and improvements of present work, we plan to realize in the next future.

Key words. CM diagram – H burning – He burning stars – Isochrone fitting

1. Introduction

Theoretical iscochrones are the most powerful tool for measuring the ages of stellar clusters, and thanks to the numerous revent improvements in the physical inputs, we may now claim to know the age of galactic stellar systems, such as the globular clusters, better than ever before. Nevertheless, this does not mean that the present theoretical framework provides 'exact' results. In fact, as one can easily verify by reading the most recent litterature, significant improvements in this field have been achieved just in these last years. Therefore, stellar evolutionary models have to be updated when significant improvements are made in the physics. In recent times, new sets of stellar models have been computed (Straniero et al. 1997; Girardi et al. 2000; Yi et al. 2001; Vandenberg et al. 2000; Salaris & Weiss 1998). These stellar models databases represent a huge improvement with respect to previously available sets of models, being based on a most updated physics. This notwithstanding, also these databases show some evident limitation:

- sometimes they do not properly cover all the relevant evolutionary phases, such as the central and shell He-burning;
- in some cases, not all the physical inputs have been updated.
- in some cases, they do not provide a self-consistent evolutionary scenario for both low- and intermediate mass stars;

Because of the need for a comprehensive set of stellar models and isochrones for current and

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future-planned researches in the stellar poulations field and aware of the above quoted limitations in the presently available databases, we have started a long term project aimed to build a new database of stellar evolutionary models, covering a quite large stellar mass range and bases on up-to-date imput physics and parameters. The outline of this paper is as follows: in the next section we briefly discuss the physical inputs adopted for computing the models and show some results, in section 3 we present some preliminary comparisons with observational data. A discussion on the future developments of our work will close the paper.

2. The theoretical framework

The whole database of models has been computed by using a recent version of the FRANEC evolutionary code, updated in many aspects concerning both the numerical scheme adopted for treating the nuclear burnings and the accuracy of the numerics. Almost all the adopted physical inputs have been updated as well. In particular, the radiative opacity tables are obtained from the OPAL tables (Iglesias & Rogers 1996) for temperature larger than 10^4 K, and from Alexander & Ferguson (1994) for lower temperatures. Thermal conduction is accounted for following the prescriptions by Potekhin (1999). We have updated the energy loss rates from plasma-neutrino processes using the most recent and accurate results provided by Haft et al. (1994). For all other processes we still rely on the same prescriptions adopted by Cassisi & Salaris (1997). The nuclear reaction rates have been updated by using the NACRE database (Angulo et al. 1999), with the exception of the $^{12}C(\alpha,\gamma)^{16}O$ reaction. For this reaction we employ the more accurate recent determination by Kunz et al. (2002). The updated Equation of State (EOS) by A. Irwin (Irwin et al. 2003; Cassisi, Salaris & Irwin 2003). It is important to notice that this EOS, whose accuracy and reliability is similar to the OPAL EOS (Rogers, Swenson & Iglesias 1996), allows us to compute self-consistent stellar models in all relevant evolutionary phases. In the standard models, the extension of the convective zones is fixed by means of the classical Schwarzschild criterion. Induced overshooting and semiconvection during the He-central burning phase are accounted for following the prescriptions given by Castellani et al. (1985). The thermal gradient in the superadiabatic regions is determined according to the mixing length theory, whose free parameter has been evaluated by computing a solar standard model. For the present set of models. we adopt a scaled-solar heavy element mixture (Grevesse & Noels 1993). As for the initial He-abundance, we rely on the estimate ($Y = 0.245$) recently provided by Cassisi et al. (2003) on the basis of the R parameter analysis in a large sample of GGCs. In order to reproduce the calibrated solar He-abundance we adopt an Helium enrichment ratio equal to $dY/dZ \approx 1.4$ (Pietrinferni et al. 2003). The models have been computed for metallicity values in the range: $10^{-4} \leq Z \leq 0.04$. For each fixed chemical composition, we have computed models in the mass range $0.5 \leq M/M_{\odot} \leq 10$ with a very fine mass grid. A more detailed discussion on this topic can be found in Pietrinferni, Cassisi & Salaris (2003). In order to provide an hint about the new available database of isochrones in Fig. 1, we show a set of isochrones for the labeled chemical compostions and age range.

3. Comparison with observations

The comparison between theory and observations is a fundamental step in order to assess the reliability of the adopted theoretical scenario and its capability to properly reproduce real stars. This work of comparison is still in progress and a detailed discussion of the results will be presented in Pietrinferni et al. (2003). Here we wish only to provide an hint about the reliability of current models in matching the observations. For such aim in Fig. 2 (left panel) we show the comparison between empirical measurements for the quantity $\Delta F555W_{HB}^{bump}$, i.e. the magnitude difference in the HST F555W filter between the RGB bump and the Horizontal Branch (HB), for a large sample of galactic GCs and our theoretical predictions. One can notice that a largely satisfactory agreement does exist be-

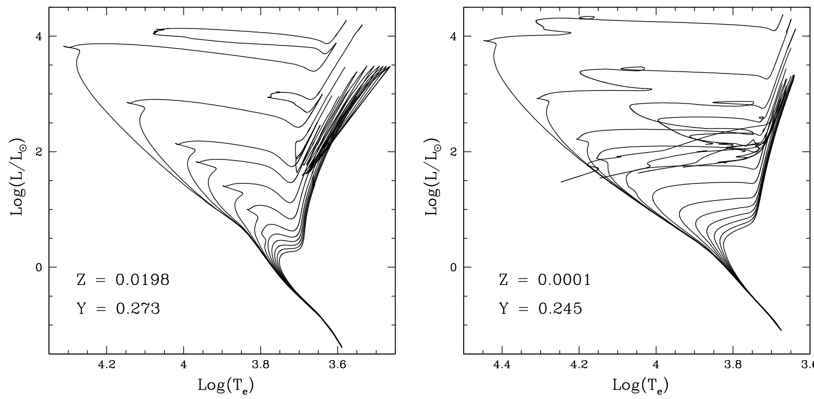

Fig. 1. Left panel: Theoretical isochrones in the age range: 25 Myr-14 Gyr, and for a chemical composition Z=0.0001 and Y=0.245. Right panel: as left panel but for the solar composition, i.e. Z=0.0198 and Y=0.273.

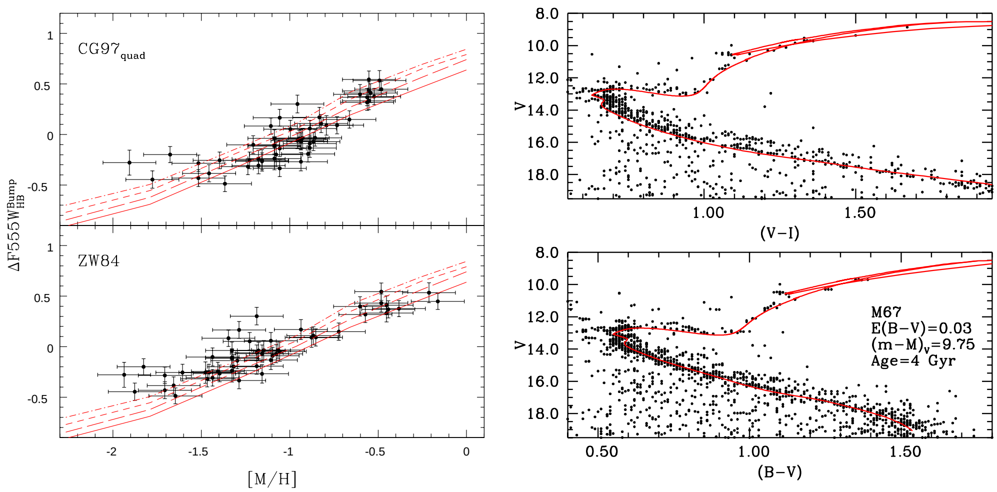

Fig. 2. Left panel: comparison between theoretical and empirical values of $\Delta F555W_{HB}^{bump}$ as a function of the global metallicity for a large sample of galactic GCs. Bottom and upper panels show respectively the empirical data plotted according to the Zinn & West (1984) and Carretta & Gratton (1997) metallicity scales. The theoretical prediction for four different ages are shown: 10 Gyr (solid line), 12 Gyr (long dash), 14 Gyr (short dash) and 16 Gyr (dot - short dash). Right panel: the best fit between the CMD of M67 and a theoretical isochron for the labeled assumptions about the cluster age, distance and chemical composition.

tween theory and observations (Riello et al. 2003). In the right panel of the same figure, it is disclosed the comparison between the Color-Magnitude diagram (CMD) of the open cluster M67 (Montgomery et al. 1993) with a theoretical isochron for a suitable choice about the age and chemical composition. It is worthwhile to notice how good is the capability of the isochron to properly match all the relevant evolutionary sequences in the CMD.

4. Future developments

Our aim is to provide to the scientific community a very large database of stellar tracks, isochrones and luminosity function for a large range of ages and chemical compositions. The computations of canonical stellar models for a solar scaled heavy elements mixture has been already completed. The next steps of our work are:

- to compute stellar models accounting for overshooting at the border of canonical convective core during the H central-burning phase;
- to develop the same theoretical framework but for an $\alpha-$elements enhanced mixture;
- to extend the mass range to the very low-mass stars regime and to structures more massive than $10M_{\odot}$, and to more advanced evolutionary phases such as the white dwarfs cooling sequence;
- to compute stellar models for low-mass stars accounting for atomic diffusion of both He and heavy elements.

In the meantime, we are currently working in order to make available this theoretical database on WEB. We plan to create an interactive WEB interface, which could allow to the user to compute isochron for any specified age, synthetic CMD and to retrieve all relevant data on stellar models.

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