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The Pisa pre-main sequence database.

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Abstract. In recent years new observational data of pre-main sequence stars (pre-MS) with metallicity lower than solar have been made available; the study of the star formation regions requires comparison between theoretical models and observational data to assign masses and ages to the stars. However, the calculations of pre-MS models, mainly for low and very low masses, are particularly challenging because they require an accurate treatment of the microphysics associated with relatively cold matter. We present a large database of pre-MS tracks and isochrones for a wide range of chemical compositions (Z = 0.0002 ÷ 0.03), masses (M=0.2 ÷ 6.0M$_\odot$) and ages (1 ÷ 100 Myr) for a solar calibrated mixing length parameter, α = 1.9. For each chemical composition additional models have been computed with α = 1.5, and with two different initial deuterium abundances. Models are computed with a standard stellar evolutionary code adopting the most recent physical ingredients.

Key words. stars: evolutionary tracks – stars: isochrones – stars: pre-main sequence – stars: stellar evolution – stars: low-mass stars

1. Introduction

In the recent years a growing amount of accurate data of young stellar systems is being gathered (e.g. Gouliermis et al. 2006; Panagia et al. 2006; Delgado et al. 2007) which prompt a renewed interest in the computation of updated pre-MS models. As already shown by several authors (see e.g., D'Antona & Mazzitelli 1997; Baraffe et al. 1998) for the theoretical predictions of pre-MS stars a crucial role is played by the equation of state (EOS), the radiative opacity (mainly molecular opacity) and the boundary conditions. The uncertainties due to these quantities progressively increase as the stellar mass decreases, especially for low-mass stars M < 0.5 M$_\odot$. Thus, to compute models as accurate as possible, it is mandatory to include the most recent updates for the above quoted physical inputs. In this paper we present a large database of theoretical tracks and isochrones for pre-MS stars computed relying on the most recent physical inputs.

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2. The models

Present models are computed with an updated version of stellar evolutionary code FRANEC. A more detailed description of the code is given in Tognelli et al. (2009); here we briefly summarize the updates that mainly affects pre-MS evolution.

- **Equation of state**. We use the OPAL EOS[1] in the version released in 2006 (Rogers & Nayfonov 2002). By means of the OPAL EOS we can follow the pre-MS evolution of a star greater than 0.25 $M_\odot$. To extend the OPAL EOS to lower temperature required for the integration of the outer layers of very low-mass stars ($\sim$ 0.2 $M_\odot$), we use the FreeEOS tables[2] in the most recent version (2008).
- **Radiative Opacity**. We use the OPAL radiative opacities[3] released in 2006 (Iglesias & Rogers 1996) for log T > 4.2 and the Ferguson et al. (2005) (F05) ones for lower temperatures.
- **Boundary conditions**. Boundary conditions are obtained from realistic atmosphere models by Brott et al. (2005) for effective temperature in the range 3000 K $< T_{eff} <$ 10000 K, and Castelli & Kurucz (2003) for higher effective temperature, $T_{eff} \geq$ 10000 K.
- **Convection**. We adopt the Mixing Length Theory formalism (MLT, Böhm-Vitense 1958) for the convection in the outer envelope of stars.

Models are evolved from an hydrostatic spherical completely formed initial structure along the Hayashi track to the ZAMS.

3. Comparison with different authors

Present theoretical tracks and isochrones have been compared to pre-MS stars computed in recent years by other groups by means of different evolutionary codes (Lebreton & Michel (2008), CESAM08; Dotter et al. (2008), DSEP08; D'Antona & Mazzitelli (1997), DM97; Siess et al. (2000), SD00; Baraffe et al. (1998), BCAH98). Comparisons, for different metallicities, are described in a forthcoming paper (Tognelli et al. 2009). Here we briefly discuss the comparison for solar metallicity Z = 0.02 shown in figure 1. Since the models are computed adopting different physical ingredients, discrepancies among the theoretical predictions are present.

One of the crucial differences between the models relies on the assumption on the boundary conditions. CESAM08 and DM97 use a simplified $T(\tau)$ relation to specify the conditions at the surface, while DSEP08, SD00 and BCAH98 adopt realistic atmosphere models. As already noted (see e.g., Baraffe et al. 1998) the choice of the boundary condition deeply affects the low-mass stars, for which the formation of molecules and grains in the atmosphere becomes important. Such an effect changes the effective temperature of the star as it evolves in the pre-MS phase. Further discrepancies between different theoretical models can also be ascribed to the chosen low-temperature radiative opacity. With the exception of DSEP08 all the other codes adopt the old version of the low temperature radiative opacities by Alexander & Ferguson (1994) (AF94). The improved treatment of the absorption and the inclusion of additional molecular lines in the new radiative opacity tables (F05) produce structures colder and less luminous than the ones computed by adopting the AF94 opacity.

It is also worth noticing the role of the equation of state for low-mass stars. It is well known that the outer envelope of low-mass stars becomes progressively more adiabatic as the mass decreases. In these regimes the effective temperature is weakly affected by a change of the mixing-length parameter, since the required superadiabaticity is small and the convection develops in an almost adiabatic environment. On the other hand, in this mass range the effective temperature depends on the adiabatic gradient and thus on the adopted EOS. We expect that for low-mass stars, besides the discussed effects of opacity and boundary conditions, also the choice of a different EOS will play a crucial role.

There are two other points that deserve to be mentioned; the uncertainties on the convection model, and the initial deuterium abundance. Regarding the convection, since a significative fraction of the pre-MS evolutionary phase is characterized by the presence of an extended convective envelope, the treat-

[1] http://opalopacity.llnl.gov/EOS_2005/
[2] http://freeeos.sourceforge.net/
[3] http://opalopacity.llnl.gov/new.html

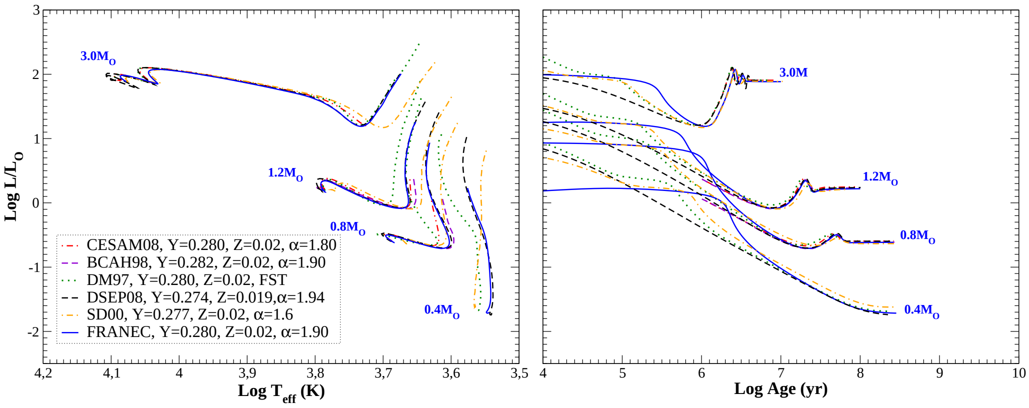

Fig. 1. Comparisons between theoretical models from different authors (see text), for Z = 0.02 in the theoretical plane (log T_{eff}, log L/L$_\odot$), *left panel*, and in the plane (log age (yr), log L/L$_\odot$), *right panel*.

ment of the super-adiabatic convective transport plays a crucial role. With the exception of the models by DM97, which follows the Canuto-Mazzitelli formalism for a turbulent description of the convective flux (FST, Canuto & Mazzitelli 1991), all the models adopt the ML theory. As already noted (D'Antona & Mazzitelli 1997) the models computed adopting the FST formalism are generally hotter than the others computed by a solar-calibrated mixing length when stars develop thick convective envelopes. However the discrepancies in the tracks become progressively smaller as the models approach the ZAMS. The early phases of pre-MS evolution are deeply affected also by the initial deuterium abundance. The models which do not take into account D-burning evolve more quickly in the initial pre-MS phase; this explain the large discrepancy in the (log age, log L/L$_\odot$) plane between the DSEP08 models and the others, differences that decrease as the stars approach the ZAMS. All the other models, except DM97 follow the D-burning adopting an initial fractional abundance in mass of deuterium $X_D \sim 2 \cdot 10^{-5}$, which is about one half of the value assumed in our computations. Our models and the DM97 ones adopt the same $X_D = 4 \cdot 10^{-5}$, but their D-burning phase is faster than our. Such a difference could be ascribed to the treatment of super-adiabatic convective mixing which affects the temperature profile inside the whole structure; an higher temperature causes an increase of the efficiency of the D-burning, and so a more rapid destruction of deuterium.

4. The database

Present models have been computed for 12 values of metallicity Z, from Z= 0.0002, representative of the metal deficient stars, to the supersolar value Z= 0.03. For each Z value we computed models for three different initial helium abundances Y. Y has been evaluated following, as usual, a linear relation $Y = Y_p + Z \cdot \Delta Y/\Delta Z$ where Y_p represents the cosmological ^{4}He abundance and $\Delta Y/\Delta Z$ is the galactic helium-to-metal enrichment ratio, that is the ratio of helium supplied by stars to the interstellar medium relative to their supply of heavy elements. For the cosmological value of Y_p we used both the recent WMAP estimations, Y_p= 0.2485 (Steigman 2006; Peimbert et al. 2007) and an old estimate Y_p= 0.230 (see e.g., Olive et al. 1991), usually referred as canonical Y_p in several stellar isochrones database. The estimated value for helium to metal enrichment is affected by several uncertainties, thus, we decided to chose both the typical value $\Delta Y/\Delta Z = 2$ and an higher value, $\Delta Y/\Delta Z = 5$, which seems to be the upper extreme (Pagel & Portinari 1998; Flynn 2004; Gennaro 2008). For each value of Y_p, $\Delta Y/\Delta Z$ and Z we computed models in the mass range 0.2÷6.0 M$_\odot$.

The models have been computed adopting two different values of the mixing length parameter α, namely 1.9 (solar calibrated) and 1.5, as suggested by the comparisons between theoretical models and observational data on the surface abundance of lithium in young galactic clusters (Ventura et al. 1998; D'Antona & Montalbán 2003; Tognelli 2008). All models adopt an initial deuterium abundance $X_D = 4.0 \cdot 10^{-5}$ which is good estimate at least for population II stars, while for population I star observations suggest a lower deuterium abundance (see e.g., Pettini et al. 2008); thus we computed models adopting $X_D = 2.0 \cdot 10^{-5}$ too. Young isochrones for ages from 1 Myr to 100 Myr are also available in the database. Thus for each chemical composition 41 evolutionary tracks, in the mass range $0.2 \div 6$ $M_{\odot}$, and 28 isochrones, in the range $1 \div 100$ Myr, have been made available.

5. Conclusions

We present a new set of pre-MS tracks and isochrones, which relies on the state of the art of the main input physics in order to provide the astronomical community with a versatile theoretical tool for the interpretation of observational data. The models have been computed for a very large and fine grid of chemical compositions and masses.

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