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DETERMINATION OF THE AGES OF STARS FROM THEIR POSITION IN THE HR DIAGRAM

C. Guédé[1], Y. Lebreton[1] and G. Dréan[2]

Abstract. The determination of stellar ages is fundamental to understand the formation and evolution of the Galaxy. We determine the age of stars by combining their position in the HR diagram with stellar evolutionary tracks or isochrones. The goal of this study is to prepare the tools that will be used to age-date stars after the Gaia mission.

Keywords: stars: fundamental parameters - methods: statistical - (stars:) Hertzsprung-Russell and C-M diagrams

1 Introduction

To understand the formation and evolution of the Galaxy it is necessary to determine the ages of its stars. There are several methods to determine the age of stars which are based on either the kinematics or expansion of stars, the lithium depletion, the gyrochronology, activity, asteroseismology or isochrones models. These methods are described by Soderblom 2010. Here we are interested in determining the ages of large samples of stars for which the method based on isochrones is applicable. The age of stars is determined by combining their position in the HR diagram and models isochrones (Ng & Bertelli 1998, Lachaume et al. 1999). We use a Bayesian estimation to determine the most probable age from stellar models (Pont & Eyer 2004, Jørgensen & Lindegren 2005 and Casagrande et al. 2011). We adapt this method to use the stellar evolutionary tracks instead of the isochrones. We compare our results to Casagrande et al. (2011) work to validate our tools. This method will be used to determine the ages of stars that will be observed by the Gaia mission.
In Section 2 we describe the Bayesian estimation and the methods that we use. In section 3 we compare the ages obtained with evolutionary tracks and with isochrones. Section 4 describes the age-mass relation and age-metallicity relation and the comparison of these relations with Casagrande et al. (2011) work.

2 Determination of ages

We determine the age of the stars from their position in the HR diagram and either stellar evolutionary tracks or isochrones. In the region of isochrones where the stars evolve very quickly (for example the turn-off) a star that we aim to date, can be adjusted by several isochrones. As an example in Fig 1 (Jørgensen & Lindegren 2005), for the star on the left there are three isochrones that adjust properly the star. Therefore, these stars have three possible ages. In this case, the question is how to choose the correct age? In order to answer this question we use a Bayesian approach: this method allows us to determine the most probable age with the *a priori* density function. The age of a star corresponds to the maximum of the *a posteriori* density function $f(T, [Fe/H], m)$, defined as

$$f(T, [Fe/H], m) \propto f_0(T, [Fe/H], m)L(T, [Fe/H], m) \tag{2.1}$$

where $f_0(T, [Fe/H], m)$ is the *a priori* density function, which depends on the Initial Mass Function, Stellar Formation Rate and initial metallicity distribution. We choose to adopt a flat stellar formation rate and a

[1] GEPI UMR 8111, Observatoire de Paris-Meudon , France
[2] LTSI, INSERM U642 Université de Rennes 1, France

flat initial metallicity distribution. For the initial mass function we use the same than Jørgensen & Lindegren (2005), which is defined as $\xi(m) = m^{-2.7}$ (it is based on the IMF of Kroupa et al. 1993). $L(T, [Fe/H], m)$ is the likelihood defined as

$$L(T, [Fe/H], m) = \left(\prod_{i=1}^{n} \frac{1}{(2\pi)^{\frac{1}{2}} \sigma_i} \right) \exp\left(\frac{-\chi^2}{2} \right) \tag{2.2}$$

where the χ^2 parameter is calculated for the temperature T_{eff} (or color) of the stars, the magnitude M_v (or luminosity) and the metallicity $[Fe/H]$. The σ_i are the corresponding observational errors. For the numerical implementation, we sum the *a posteriori* density function for the evolutionary track that have a metallicity measuring range between $[Fe/H]_{obs} \pm 3.5\sigma_{[Fe/H],obs}$ and for all masses. The age of the star corresponds to the maximum of the *a posteriori* density function.
The method of Jørgensen & Lindegren (2005) determines the age by using isochrones and we have adapted the program to determine the age directly from the evolutionary tracks. We compare both results in Section 3. This method is also well designed to calculate the mass of stars.

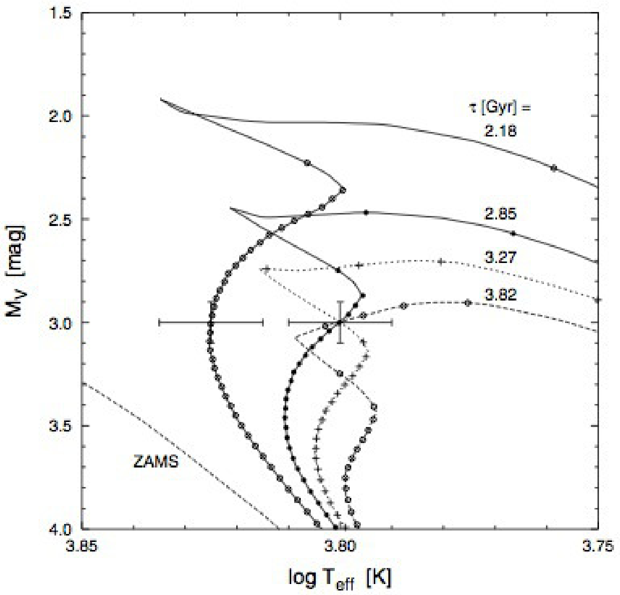

Fig. 1. Isochrones degeneracy in the HR diagram. After Jørgensen & Lindegren (2005)

3 Tracks vs. Isochrones

Traditionally, ages are derived from isochrones built by interpolation of stellar evolutionary tracks and provided by stellar modelers. To determine the ages we use the evolutionary tracks of Basti (Pietrinferni et al. 2004). We calculate the ages of 16 682 stars in the Geneva Copenhagen Survey of the solar neighborhood (Casagrande et al. 2011 but see also Holmberg et al. 2009). These stars are represented in a diagram $\log T_{eff} - M_v$ on the left Figure 2. We compare and classify the ages obtained with the isochrones and evolutionary tracks on the right Figure 2 and in the Table 1. We note that 72.2 % of the stars have similar ages : this shows that we have a good agreement between both methods. We note that the stars have different ages when they are located in the same region in the diagram $\log T_{eff} - M_v$, near the ZAMS. In the vicinity of the ZAMS, low mass stars evolve very slowly in the HR diagram so their age is poorly defined.

4 Age-mass relation and age-metallicity relation

We present the age-mass relation (on the left Figure 3) and the age-metallicity relation (on the right Figure 3) with ages and masses calculated by us with the evolutionary tracks method, for 6670 stars in the GCS catalogue. We obtain a relation that is similar to Casagrande et al. (2011). For the age-metallicity relation we

Table 1. Results of the comparison for the ages obtained with the isochrones and evolutionary tracks.

Similar ages	72.2 %
Relative difference exceeding 30%	7.5 %
Ages lower than 0.3 Gyr	15.2 %
Stars with ages lower than 0.3 Gyr with both evolutionary tracks and isochrones	*47* %
Ages greater than 13.5 Gyr	5.1 %
Stars with ages greater than 13.5 Gyr with both evolutionary tracks and isochrones	*68* %

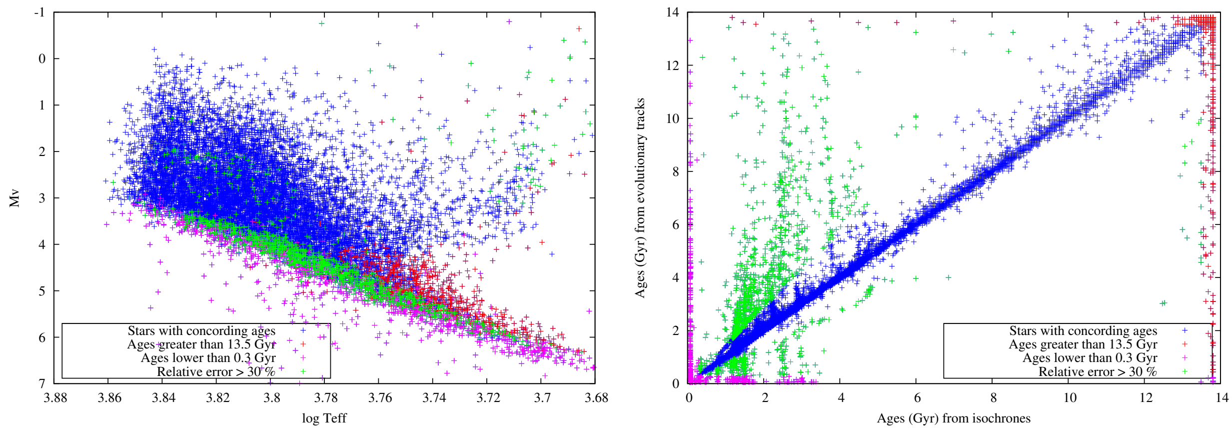

Fig. 2. Left Figure : HR diagram with (i) in red, stars with age > 13.5 Gyr, (ii) in pink stars with age < 0.3 Gyr, (iii) in green stars with ages differing by more than 30 % and (iv) in blue the stars having similar ages. Right Figure : comparison between ages from isochrones and ages from evolutionary tracks.

see a concentration of stars at solar metallicity and small ages: when the age increases there is a metallicity dispersion due to the radial mixing of the stars. The relation allows to demonstrate that a subsample of stars belongs to the thin disk (Haywood 2008).

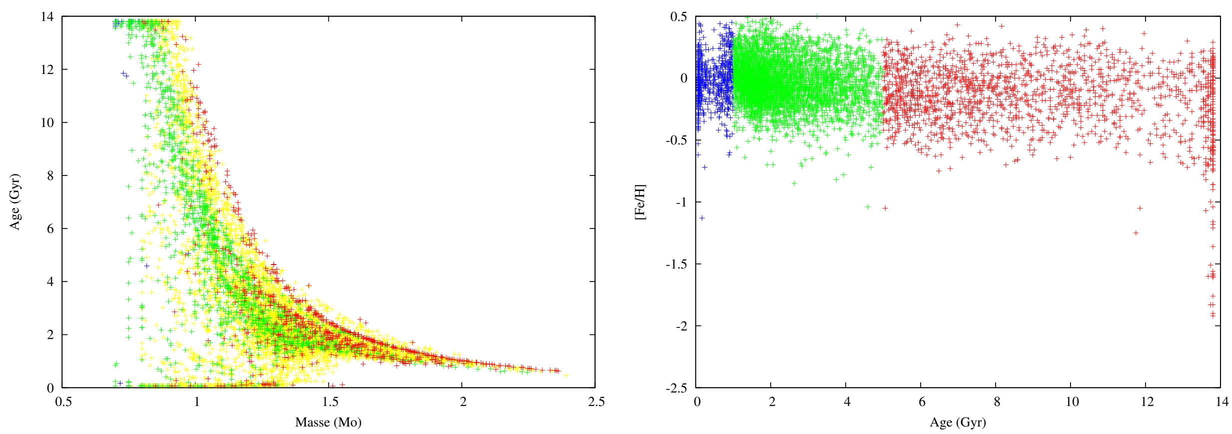

Fig. 3. Left Figure: Mass-Age relation for ages and masses from the evolutionary tracks. Colors indicate increasing metallicity [Fe/H] from metal-poor stars (in blue) to metal-rich stars (in red). Right Figure : Age-[Fe/H] relation for ages from evolutionary tracks. In blue stars with age <1 Gyr, in green stars with 1 Gyr $\leq$ age < 5 Gyr, and in red stars with age $\geq$ 5 Gyr.

5 Conclusions

We adapted the method of Jørgensen & Lindegren (2005) to determine the age of stars from evolutionary tracks. The comparison of the isochrones ages with the evolutionary tracks ages shows that the results of both methods are similar except for the stars close to the ZAMS. In these regions, the stars have a low mass and they evolve very slowly, so their age is arduous to determine. The comparisons of our results with those of Casagrande et al. (2011) shows that we obtain the same trend for the age-mass and age-metallicity relations. These comparisons allow us to validate our program for age determination.

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