AGE DATING LARGE SAMPLES OF STARS: WAYS TOWARD IMPROVED ACCURACY

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Abstract. The determination of stellar ages is essential in many fields of astrophysics, for instance to understand the formation and evolution of the Galaxy or to characterize exoplanets. We focus on age-dating combining the observed position of stars in the Hertzsprung–Russell diagram and evolutionary tracks. We use a Bayesian method that provides the most probable ages. We discuss the impact of including supplementary observational constraints (seismic parameters and exoplanetary transits) in the determination of the ages.

Keywords: Stars: fundamental parameters, Methods: statistical, Stars: Hertzsprung-Russell and C-M diagrams

1 Introduction

The Gaia ESA mission (Perryman et al. 2001) will be launched in 2013 and will observe 1 billion stars in the Galaxy. Gaia will provide global stellar parameters: effective temperature, absolute magnitude and metallicity. We aim at dating large samples of stars to be observed by Gaia. Among the various methods that can be used to determine the age of stars (see Soderblom 2010), the method based on stellar isochrones placement (Edvardsson et al. 1993) is well-suited for our purpose.
The method of the isochrones placement consists in adjusting the position of a star in the Hertzsprung–Russell diagram (hereafter HDR) by model isochrones. The age of the closest isochrone then corresponds to the most probable age of the star. In this work we have chosen to use the method of da Silva et al. (2006) which is based on Bayesian estimation. We have brought several modifications to the choice of the *a priori* (initial mass function, metallicity distribution function and stellar formation rate) and we have used evolutionary tracks rather than isochrones in order to reduce the number of interpolations and the numerical errors. The method used in the present paper is described in (Guédé et al. 2012, these proceedings).
We have built a Gaia simulated catalogue to evaluate the consistency between the "true" age of the star and the age determined with the Bayesian method. The catalogue is built from Basti evolutionary tracks (Pietrinferni et al. 2004) and Gaia specifications (Perryman et al. 2001). The Gaia simulated catalogue is described in (Guédé et al. 2012, these proceedings). For this work we took an observational error on the metallicity of 0.1 dex and we simulated stars at a distance of 1 kpc.
The CoRoT (Baglin et al. 2006) and Kepler (Christensen-Dalsgaard et al. 2007) missions allow to obtain the asteroseismic parameters of observed stars and/or the parameters of the exoplanetary transits. We have added this information as constraints for the age-dating in order to study the potential improvement of the age determination. In Section 2 we present results on age determination based on three observational constraints ($M_{\rm v}, T_{\rm eff}$, [Fe/H]). In Section 3, we describe the improvement obtained when seismic and/or planetary transit constraints are added in the age determination process.

2 Ages from HRD constraints and metallicity

We determine the ages of stars in the Gaia simulated catalogue considering three observables: the absolute magnitude $M_{\rm v}$, the effective temperature $T_{\rm eff}$ and the metallicity [Fe/H]. The comparison between the determined age and the simulated "true" age is presented in Fig. 1. We use the age relative difference defined by

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$\sigma_\tau/\tau = (\tau_{\rm simulated} - \tau_{\rm determined})/\tau_{\rm simulated}$. We find 75 % of stars with $\sigma_\tau/\tau < 20$ %. These stars have a rather well-determined age and are mainly located in the same regions of the HRD: the turn-off, the sub-giant branch and in the main-sequence (MS) of intermediate mass stars ($1.0M_\odot < m < 2.0M_\odot$). On the other hand, the stars with an ill-determined age are located in three problematic regions of the HRD: close to the zero age main sequence (ZAMS) in particular close to the bottom of the MS (m< $1.0M_\odot$), in the massive stars MS region (m>$2.0M_\odot$) and at the top of the red giant branch (RGB). In these regions there is a well-known degeneracy in the age-dating that can be explained by the evolutionary speed. In the vicinity of the ZAMS, low mass stars evolve very slowly and their age cannot be accurately determined from their HR diagram location. On the other hand, stars in the RGB and massive stars on the MS evolve quickly making the age determination sensitive to the uncertainty on the observed parameters.

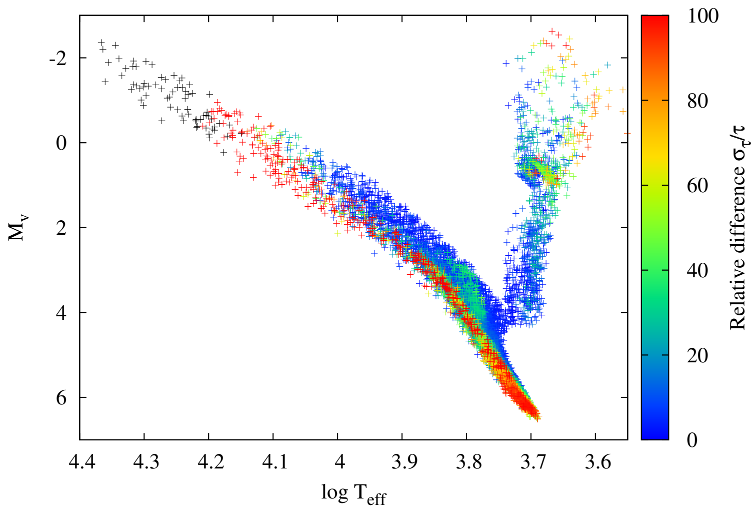

Fig. 1. Comparison of the simulated "true" age and determined age in the $\log T_{\rm eff} - M_{\rm v}$ diagram of the Gaia simulated catalog. The ages are determined with three observables ($M_{\rm v}$, $T_{\rm eff}$, [Fe/H]). Colors represent the relative difference σ_τ/τ. The blue stars have a well-determined age ($\sigma_\tau/\tau \approx 0\%$) while the red stars have an ill-determined age ($\sigma_\tau/\tau \approx 100\%$). The age of black stars cannot be determined.

3 Way toward an age improvement

To reduce the age degeneracy we now add constraints provided by the high precision photometry missions observations CoRoT (Baglin et al. 2006) and Kepler (Christensen-Dalsgaard et al. 2007). These missions detect stellar oscillations which allow to probe the interior of stars in the whole H–R diagram in particular for low mass solar-type stars and red giants. CoRoT and Kepler also detect the transit of exoplanets in front of their host-star which provides information both on the planet and on the star (Southworth 2008 and Torres et al. 2008). We add these constraints in the age-dating to evaluate the improvement on the age determination.

3.1 Adding seismic information

Seismic parameters are extracted from the oscillation power spectrum. We consider here the frequency at maximum power $\nu_{\rm max}$ and the large frequency separation Δ_ν (Brown et al. 1991, Kjeldsen et al. 2008 and Mosser et al. 2010) which corresponds to the regular spacing in the power spectrum between low degree modes ($\ell = 0, 1$) of same order. Kjeldsen & Bedding 1995 andBelkacem et al. 2011 have derived scaling relations that simply relate Δ_ν and $\nu_{\rm max}$ to the global stellar parameters (mass, radius, effective temperature):

$$\frac{\Delta\nu}{\Delta\nu_\odot} = \left(\frac{M}{M_\odot}\right)^{\frac{1}{2}} \left(\frac{R}{R_\odot}\right)^{-\frac{3}{2}} \propto \left(\frac{\rho_{\rm mean}}{\rho_{\rm mean,\odot}}\right)^{\frac{1}{2}}, \tag{3.1}$$

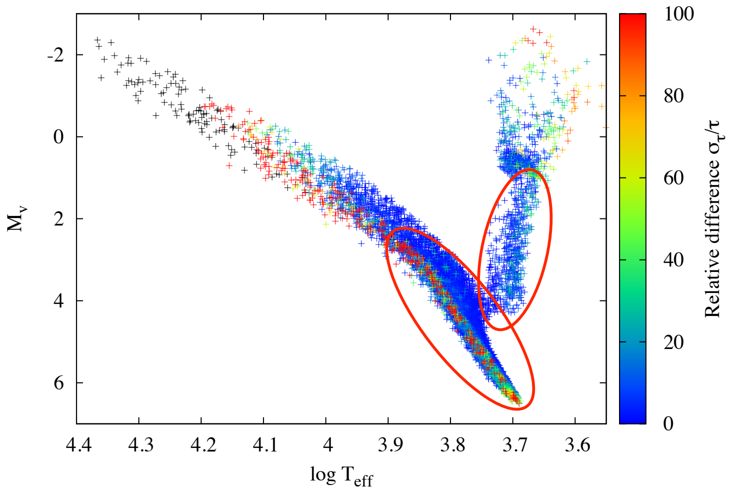

Fig. 2. Comparison of the estimated " true" age and of the determined age in the $\log T_{\rm eff} - M_{\rm v}$ diagram of the Gaia simulated catalogue. The ages are determined from three observables ($M_{\rm v}$, $T_{\rm eff}$, [Fe/H]) and two seismic constraints ($\nu_{\rm max}$, Δ_ν). Colors are the same as in Fig. 1. The red circles represent the region where solar-like oscillations are detected.

$$\frac{\nu_{\rm max}}{\nu_{\rm max,\odot}} = \left(\frac{M}{M_\odot}\right)\left(\frac{R}{R_\odot}\right)^{-2}\left(\frac{T_{\rm eff}}{T_{\rm teff,\odot}}\right)^{-\frac{1}{2}} \propto \frac{g}{g_\odot}\left(\frac{T_{\rm eff}}{T_{\rm eff},\odot}\right)^{-\frac{1}{2}}. \quad (3.2)$$

where $\Delta\nu_\odot = 134.9\ \mu Hz$ and $\nu_{\rm max,\odot} = 3050.0\ \mu Hz$ (Kjeldsen et al. 2008), g ($g_\odot$) is the (solar) gravity and $\rho_{\rm mean}$ ($\rho_{\rm mean,\odot}$) is the (solar) mean density.
The asteroseismic parameters can be calculated for stars in the Gaia simulated catalogue using the scaling relations. The observational errors on these constraints are also considered. For MS stars, we take $\sigma_{\Delta\nu} = 0.018$ $\Delta\nu$ and $\sigma_{\nu_{\rm max}} = 0.038\ \nu_{\rm max}$ (Verner et al. 2011). For RGB stars, we adopt $\sigma_{\Delta\nu} = 0.4\ \mu$Hz, $\sigma_{\nu_{\rm max}} = 2.5\ \mu$Hz if $\nu_{\rm max} \leq 80\ \mu$Hz and $\sigma_{\nu_{\rm max}} = 1.0\ \mu$Hz if $\nu_{\rm max} > 80\ \mu$Hz (Hekker et al. 2011).
We determine the ages for all stars in the HRD but solar-like oscillations are observed in the low mass stars and on the RGB (red circles in Fig. 2). The comparison of the ages is presented in Fig. 2. We find 90 % of stars with σ_τ/τ <20 %. This is an improvement in the age-dating due to the fact that the values of Δ_ν and $\nu_{\rm max}$ vary more than $M_{\rm v}$ and $T_{\rm eff}$ in the HRD.

3.2 *Adding information from planetary transits*

The duration d of the exoplanetary transit is determined as a function of the period P of the orbital motion, of the projected distance b of the planet's center to the star's equator and of the mass M and radius R of the star (REF). It leads to the parameter:

$$\frac{M^{\frac{1}{3}}}{R} = \frac{1.8\sqrt{(1-b)^2}P^{\frac{1}{3}}}{d} \propto \rho^3_{\rm mean} \quad (3.3)$$

We add $M^{1/3}/R$ and observational error $\sigma_{M^{1/3}/R}$ in the Gaia simulated catalogue. We take an observational error $\sigma_{M^{1/3}/R} = 0.022\ {\rm M}^{1/3}/{\rm R}$, which is the mean of the observational errors found in the literature. The results of the comparison are presented in Fig. 3. We find 87 % of stars with $\sigma_\tau/\tau < 20$ % which shows that the degeneracy is reduced for RGB stars and stars close to the ZAMS.
Both $\Delta\nu$ and $\sigma_{M^{1/3}/R}$ provide similar constraints to the age-dating because the mean density $\rho_{\rm mean}$ is proportional to ${\rm M}^{1/3}/{\rm R}$ (Equation 3.3) and $\Delta\nu$ (Equation 3.2).

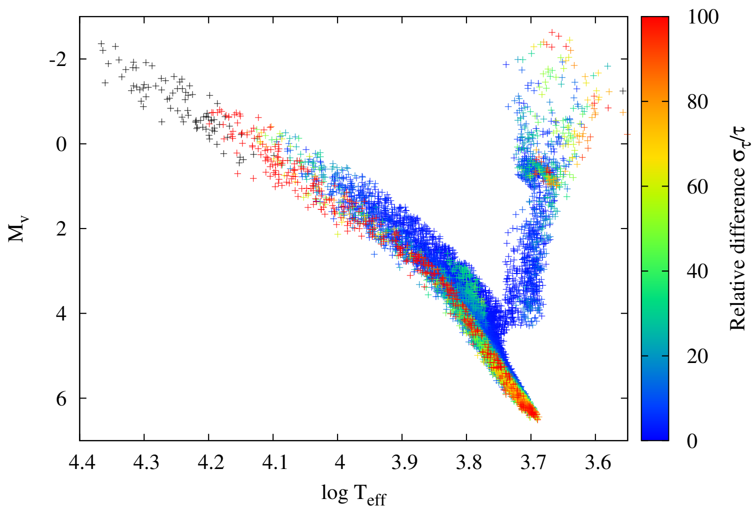

Fig. 3. Comparison of the estimated "true" age and the determined age in the $\log T_{\rm eff} - M_{\rm v}$ diagram of the simulated catalogue. The ages are determined on the basis of three observables ($M_{\rm v}$, $T_{\rm eff}$, [Fe/H]) and exoplanetary transit constraint on the stellar mean density ($M^{1/3}/R$). Colors are the same as in Fig. 1.

4 Conclusions

We used a Bayesian estimation method to date the stars that will be observed by the Gaia ESA mission. This method allows to correctly date 60 % of the stars in a simulated catalogue on the basis of three stellar observables $M_{\rm v}$, $T_{\rm eff}$ and [Fe/H]. The other stars which are mainly located in three problematic regions of the HRD (close to the ZAMS, in the upper MS and in the RGB), have badly determined ages. We added new constraints in the age-dating to improve the ages. We took the seismic parameters and the mean stellar density which can be obtained with the CoRoT and Kepler missions. We showed that it improves the determination of the ages for more of 27 % of stars. Very interestingly there is a great improvement for stars close to the ZAMS which have traditionally poorly determined ages.

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