Determination of the ages of stars from their position in the HR diagram

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Abstract

The determination of stellar ages is fundamental to understand the formation and evolution of the Galaxy. We determine the age of stars combining their position in the HR diagram and 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.

Determination of ages

We determine the age of stars from their position in the HR diagram and either stellar evolution tracks or isochrones. As an example, in Fig. 1, there is an age degeneracy for the star on the left, with 3 possible ages. In order to determine the most probable age we use a Bayesian approach. The age of the star corresponds to the maximum of the *a posteriori* density function $f(T,[Fe,H],m)$, defined as

$$f(T,[Fe,H],m) \propto f_0(T,[Fe,H],m)L(T,[Fe,H],m)$$

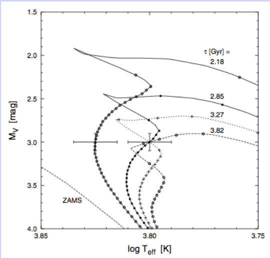


Fig 1 : Isochrones degeneracy in the HR diagram. Jorgensen et Lindegren (2005)

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. L is the the likelihood defined as

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

the χ^2 parameter is calculated for the temperature T (or color) of stars, the magnitude m (or luminosity) and the metallicity [Fe/H]. The σ_i are the corresponding observational errors. This method is also well designed to calculate the mass and radius of stars.

Tracks vs. Isochrones

Traditionally ages are derived from isochrones built by interpolation of stellar evolutionary tracks and provided by stellar modelers. Here we derive the ages directly from the tracks and compare with the ages we obtain from isochrones. We use the Basti tracks (Pietrinferni et al. 2004) to determine the ages. We calculate the ages of 16 589 stars in the Geneva Copenhagen Survey of the solar neighbourhood (Casagrande et al, 2011, but see also Holmberg et al, 2008).

We compare the ages derived from tracks to the isochrones ages in Fig 2A.

- 72.2 % of the stars have similar ages.
- 7.5 % of the stars have relative differences between the isochrones-ages and evolutionary tracks-ages exceeding 30 %. They lie near the ZAMS.
- 15.2 % of the stars have an age lower than 0.3 Gyr (brown crosses in Fig 2), this is because their f-function is not 'well-defined'. In the HR diagram they are located near the ZAMS. For 47% of these stars an age lower that 0.3 Gyr is found both with the tracks and with the isochrones.
- 5.1% of the stars have ages greater than 13.5 Gyr (red crosses in Fig 2), for 68% of these stars an age greater than 13.5 Gyr is found both with the tracks and with the isochrones. These stars are all located in the same region of the HR diagram, above the ZAMS.

In the vicinity of the ZAMS, low mass stars evolve very slowly in the HR diagram so that their age is poorly defined.

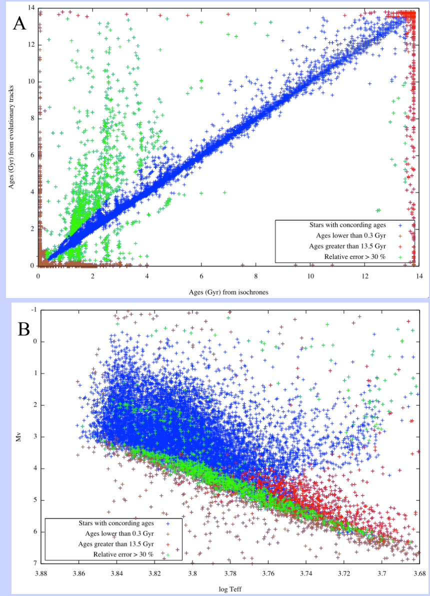
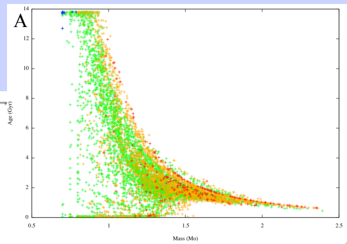


Fig 2A: comparison between ages from isochrones and ages from evolutionary tracks. Fig 2B : HR diagram with (i) in red, stars with age > 13.5 Gyr, (ii) in brown stars with age < 0.3 Gyr, (iii) in green stars with ages differing by more than 30 % and (iv) in blue the stars having concording ages.

Mass vs. Age

We compare the age-mass relation for a subsample of 6670 stars in the GCS catalogue. We obtain a similar relation than Casagrande et al (2011).



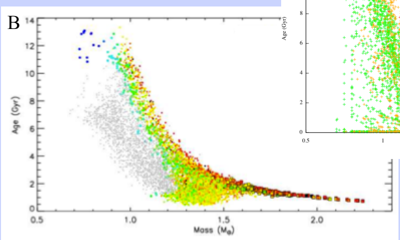
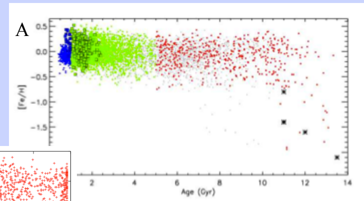


Fig 3 : Mass-Age relation for a subsample of 6670 GCS stars. Panel A: Ages and masses calculated by us with the evolutionary tracks. Panel B : ages from Casagrande et al (2011). Colors indicate increasing metallicity [Fe/H] from metal-poor stars (in blue) to metal-rich stars (in red).

[Fe/H] vs. Age



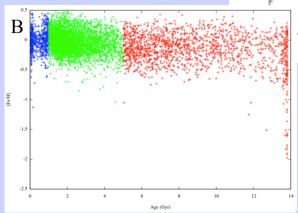


Fig 4: Age-[Fe/H] relation for a subsample of 6670 stars in the GCS. Panel A Casagrande et al (2011). Panel B: ages from evolutionary tracks. In blue stars with age < 1 Gyr, in green stars with 1 Gyr ≤ age < 5 Gyr, and in red stars with age ≥ 5 Gyr.

We show the [Fe/H]-age relation for 6670 stars in the GCS catalogue. Our ages from evolutionary tracks are compared with those of Casagrande et al (2011). We note that the relation is similar in the two figures. We 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).

References

Casagrande et al. 2011, A&A, 530, 138, Holmberg et al. 2009, A&A, 501, 941, Jorgensen and Lindegren 2004,A&A, 436, 127, Pietrinferni et al, 2004, ApJ, 612, 168, Haywood 2008, MNRAS, 388 1175.

Conclusion

The comparison of our results with those of Casagrande et al (2011) allows to validate our program for age determination. We find the same trend for the age-mass and age-metallicity relations. The comparison of the isochrones ages with the tracks ages shows that the ages are similar except for the stars close to the ZAMS.