A revised age of the Methuselah star from stellar evolution models with tailored abundances

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Abstract

Context: HD140283 is a metal-poor subgiant and key benchmark for Population II stars. Its proximity and precise observations make it ideal for testing stellar age determinations. It is also one of the oldest known stars and there is some debate about its age as various previous works found an age in conflict with the age of the Universe.
Aims: We aim to redetermine its age using updated astrometric, spectroscopic, and seismic data, and assess the impact of chemical composition and stellar evolution model assumptions.
Results: Using a revised astrometric parallax from Gaia ($\pi = 16.26 \pm 0.026$ mas) and dedicated abundances and opacity tables, we inferred an age of **13.08 ± 0.85 Gyr** (Guillaume et al. 2024), and, including the asteroseismic data, we provide a preliminary updated value of **12.23 ± 0.51 Gyr**. These results highlight the importance of considering non-solar mixtures and seismic constraints to study such old stellar populations.

Motivations

HD140283 is among the oldest objects in the Galaxy and has been intensively studied.

- Key object to study chemical evolution of our Galaxy, for Galactic Archaeology and for indirect studies of primordial Pop III stars.
- Ideal benchmark for old, metal-poor subgiant stars: bright, close, no reddening, well-determined surface chemical composition.

Observational constraints

The observational constraints come from interferometric data combined with photometry, spectroscopy and Gaia astrometry, taken from Karovicova et al. (2020).

Table 1: Observational constraints

Name	Value
L ($L_\odot$)	4.731 ± 0.178
[M/H] (dex)	-1.82 ± 0.07
log g (dex)	3.653 ± 0.024
T_{eff} (K)	5792 ± 55
R ($R_\odot$)	2.167 ± 0.041

We consider individual elemental abundances from spectroscopic studies (Nissen et al. 2007, Siqueira-Mello et al. 2015, Amarsi et al. 2019, 2022), including 3D non-LTE values for C, O and Fe. **Opacity tables were computed based on these dedicated abundances.**

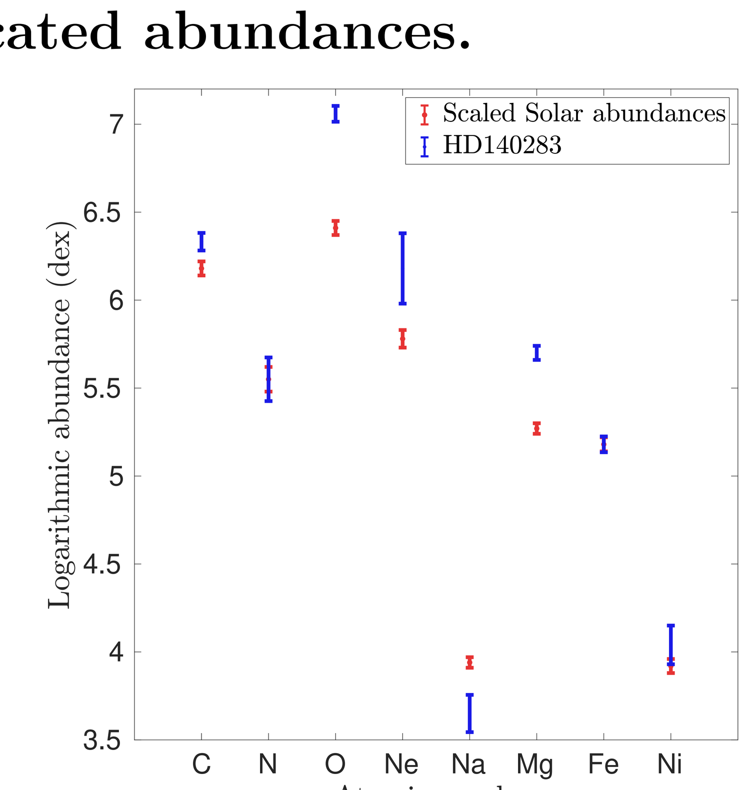

Figure 1: Tailored VS. solar-scaled abundances.

Modelling and Results

We computed 6 grids of 333 evolutionary tracks: half with solar-scaled abundances (AAG21) and the other half with tailored abundances of HD140283. For each composition, three values of the mixing length parameter α_{MLT} were considered (a solar-calibrated and two reduced values by 6.5% and 9%).
For each grid: $M \in [0.66, 1.02]\ M_\odot$ with a step of 0.01, $Z \in [5 \times 10^{-5}, 0.0018]$ with a step of 2×10^{-4} and $Y_{\mathrm{initial}} = 0.251$.

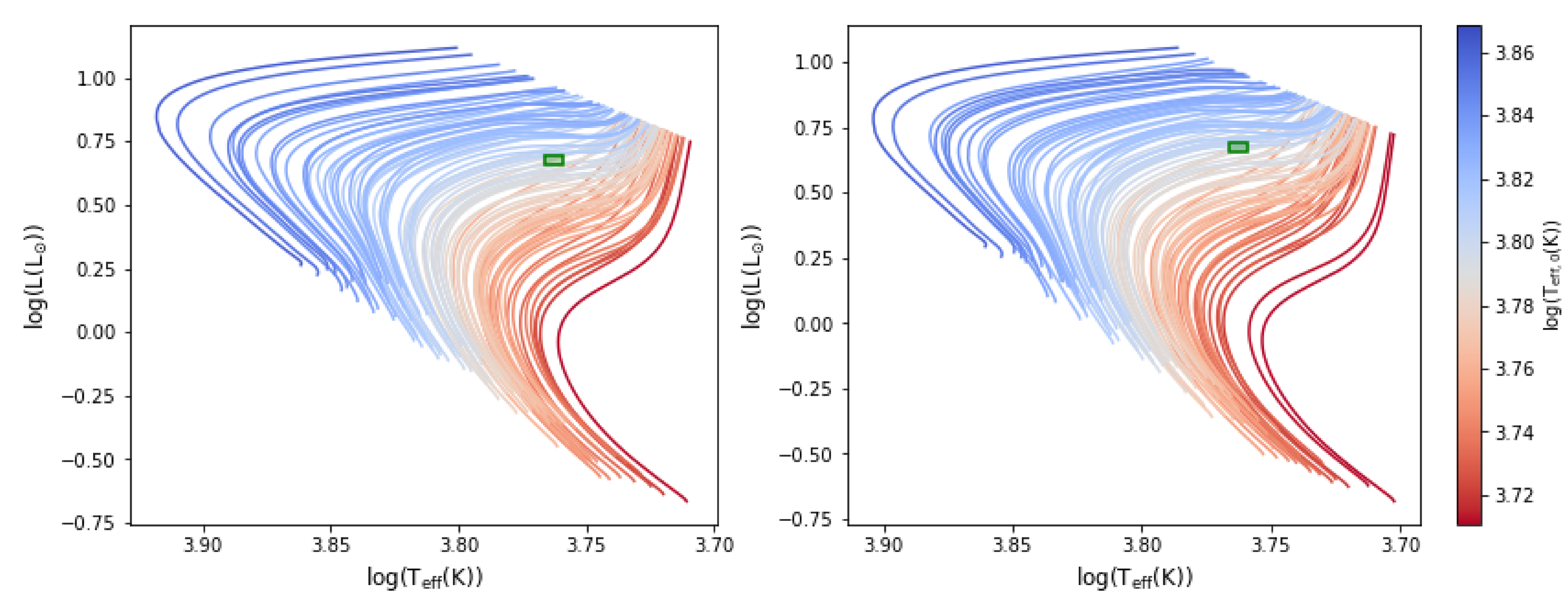

Figure 2: Left: HR diagram for the solar-scaled mixture. Right: Same for the tailored mixture. The green box corresponds to the observed position of HD140283.

We coupled the grids with the SPInS (Stellar Parameters INferred Systematically) MCMC modelling software (Lebreton & Reese 2020) to infer the optimal stellar parameters.

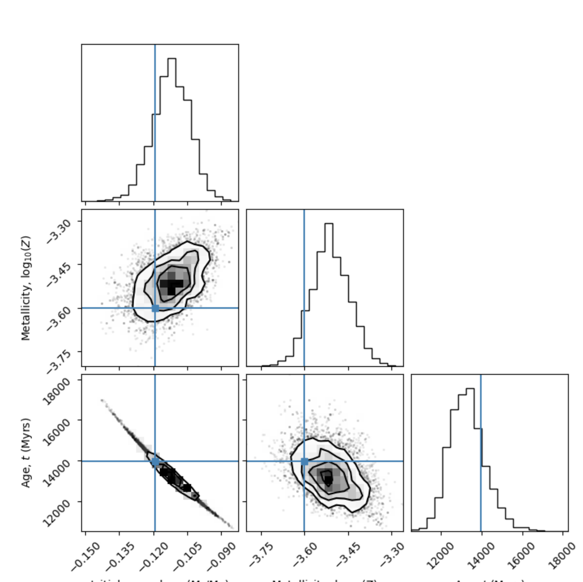

Figure 3: PDF obtained from SPInS for the dedicated abundances. The blue line is the best grid coordinate

We study the impact of non-standard physics on the inferred age, including **turbulent diffusion, dynamical electronic screening, radiative opacities and non-solar** α_{MLT}.

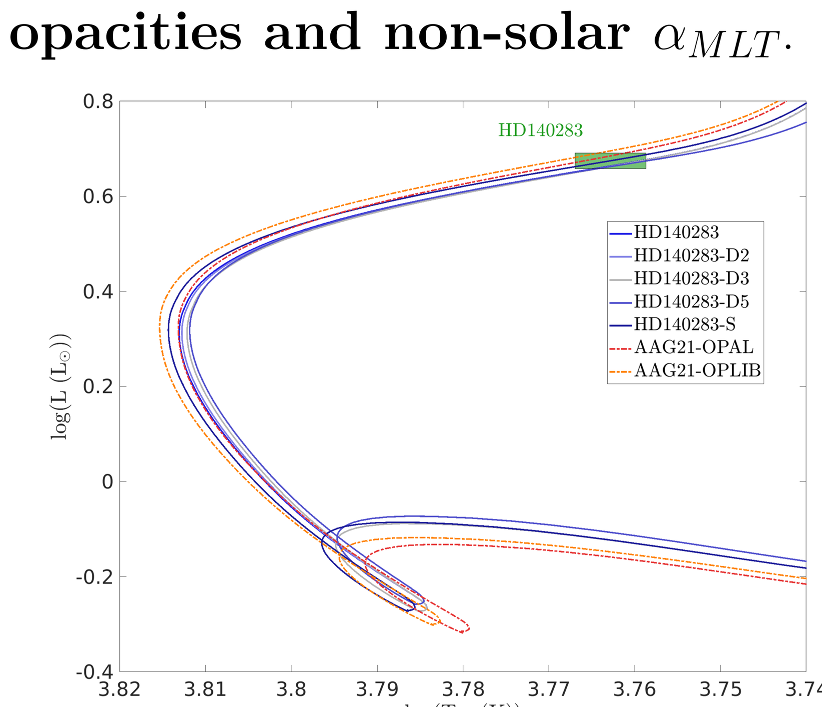

Figure 4: HR diagram of the models with variations of physical ingredients.

Seismic Modelling

Including a recent detection of solar-like oscillations (Lundkvist et al. In prep), we use the individual radial modes to constrain the parameters of HD140283 using AIMS (Asteroseismic Inference on a Massive Scale (Rendle et al. 2019)).

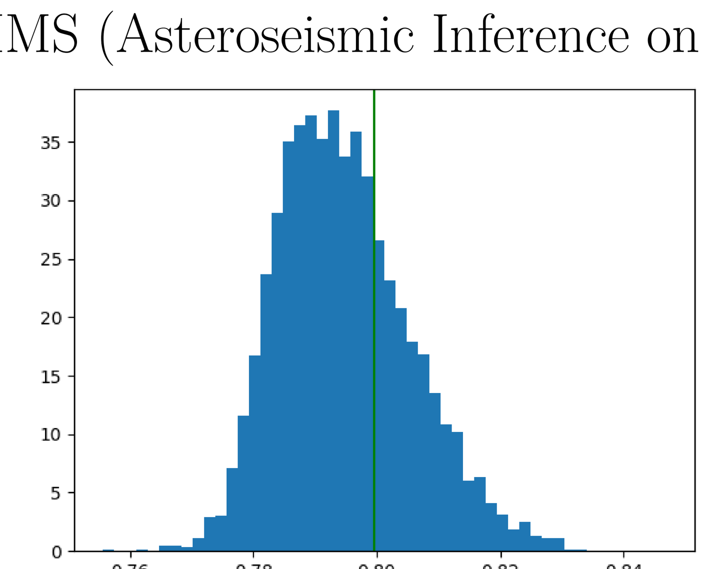

Figure 5: PDF for the mass.

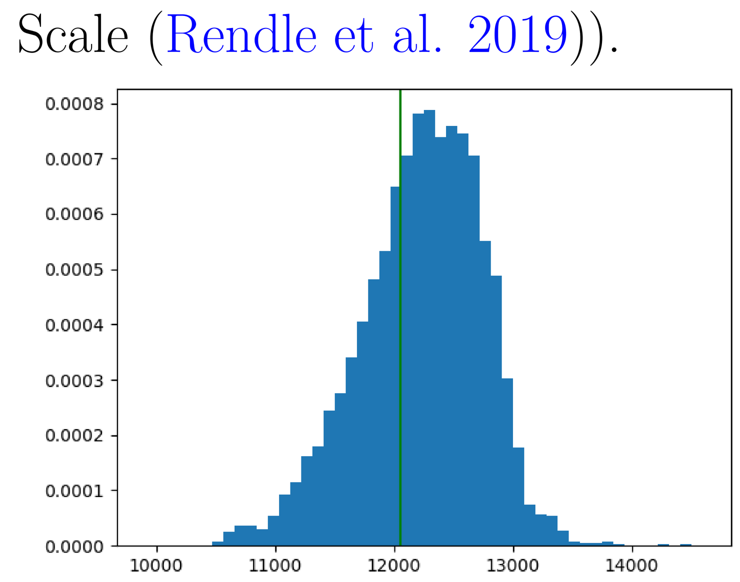

Figure 6: PDF for the age.

Conclusions

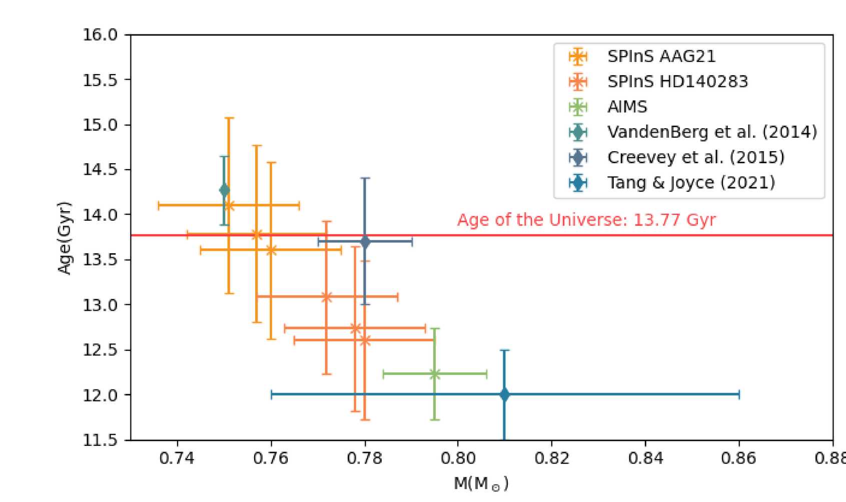

Figure 7: Results for age determination from SPInS, for three different α_{MLT} and two compositions (AAG21 & tailored), and AIMS compared with the literature.

Perspective

- First seismic modelling without the tailored abundances (Lundkvist et al. in prep.)
- Detailed seismic modelling with the tailored abundances.
- Investigating the origin of such a high amount of Oxygen and Nitrogen.

References

Amarsi, A. M. et al. 2022, A&A
Amarsi, A. M. et al. 2019, A&A
Guillaume, C. et al. 2024, A&A
Karovicova, I. et al. 2020, A&A
Lebreton, Y. & Reese, D. R. 2020, A&A
Lundkvist, M. S. et al. In prep.
Nissen, P. E. et al. 2007, A&A
Rendle B. M. et al. 2019, MNRAS
Siqueira-Mello, C. et al. 2015, A&A

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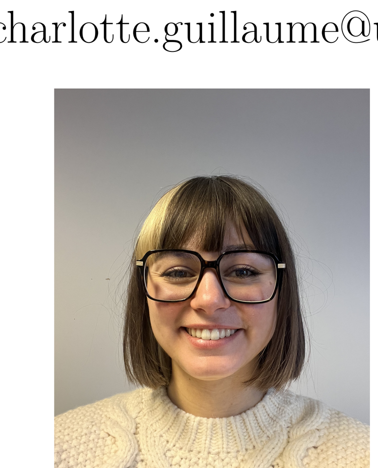

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