Gaia benchmark ages

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June 14, 2019

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The need for age standards

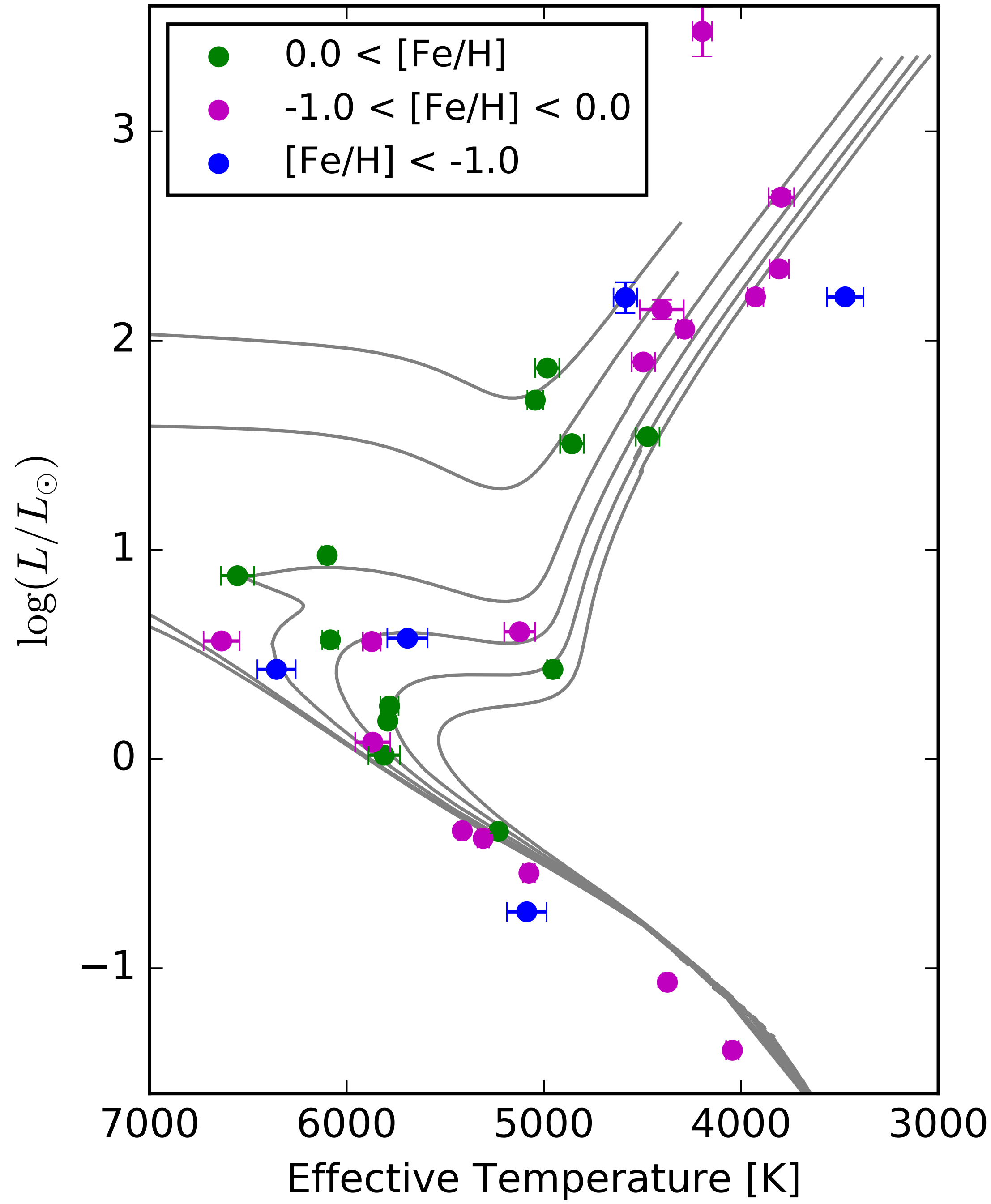
- Stellar ages drive our understanding of the Galaxy's formation history
- Different methods can be used for estimating stellar ages
  - Isochrone fitting
  - Machine learning algorithms (e.g. The Cannon, Ness et al. 2015)
  - Different stellar models
- With a set of calibration standards, estimates from different methods can be validated/calibrated

Gaia benchmark stars

- 33 nearby F, G, and K stars
  (+ the Sun)

- T_{eff} determined from angular diameters and bolometric fluxes, log(g) from radius and mass
  [Heiter et al. (2015), Jofré et al. (2014)]

- Have been used for validation of surface parameters in the Gaia-ESO and GALAH surveys



Can we define benchmark ages?

- We cannot determine “fundamental” ages since all ages (for stars other than the Sun) depend on stellar models

- We can ask:
  How well can we constrain the ages of the benchmark stars given current stellar models?

- Using:
  Isochrone fitting to benchmark stellar parameters,
  and other estimates available in the literature

Bayesian isochrone fitting

- Models described by mass (m), age (τ), metallicity (ζ), and distance modulus (μ)

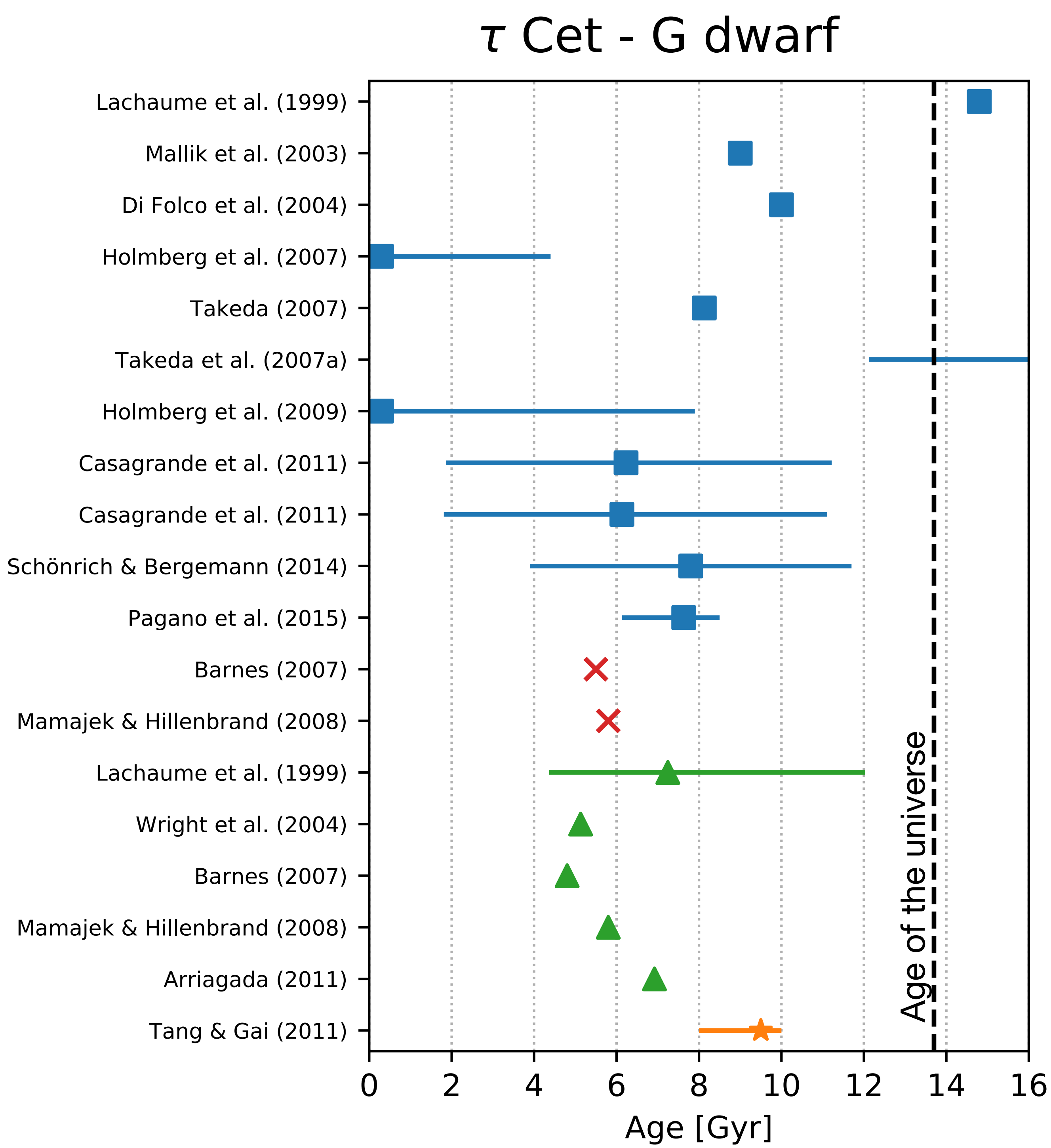
$$G(\tau|\mathbf{x}) \propto \int_\mu \int_m \int_\zeta f(\mu, m, \zeta) L(m, \tau, \zeta, \mu|\mathbf{x}) d\mu dm d\zeta$$

- Only non-uniform prior on the mass (IMF)

- Two fits using benchmark parameters:
  $\mathbf{x_1}$ — [Fe/H], T_{eff}, logg
  $\mathbf{x_2}$ — [Fe/H], T_{eff}, V, parallax

This is described in detail in Howes et al. 2019, Sahlholdt et al. (2019)

Ages in the literature



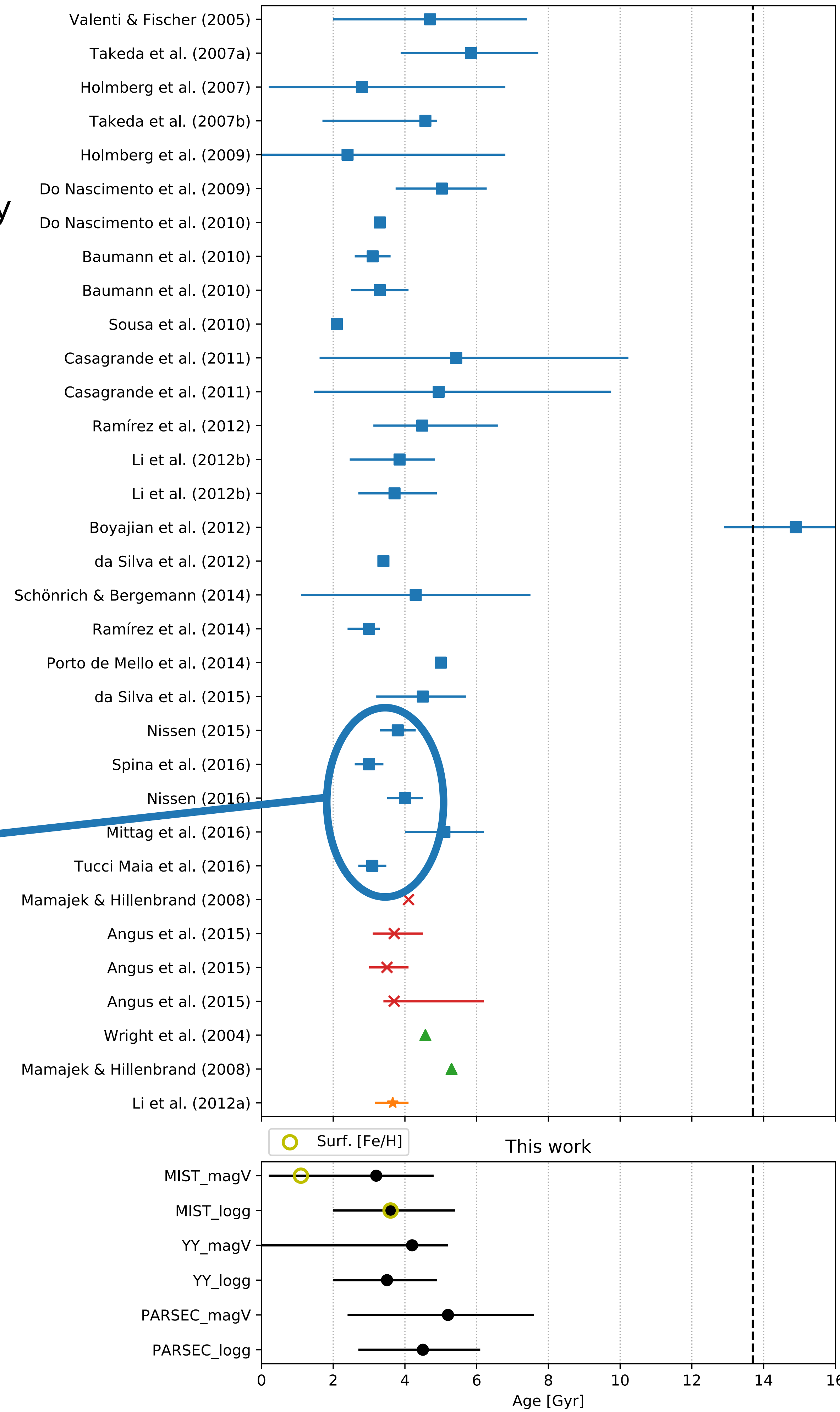
- **Model fitting**
  Evolutionary models fitted to stellar parameters
- **Gyrochronology**
  Age inferred from rotation period
- **Chromochronology**
  Age inferred from chromospheric activity
- **Asteroseismology**
  Model fitting with stellar oscillation frequencies

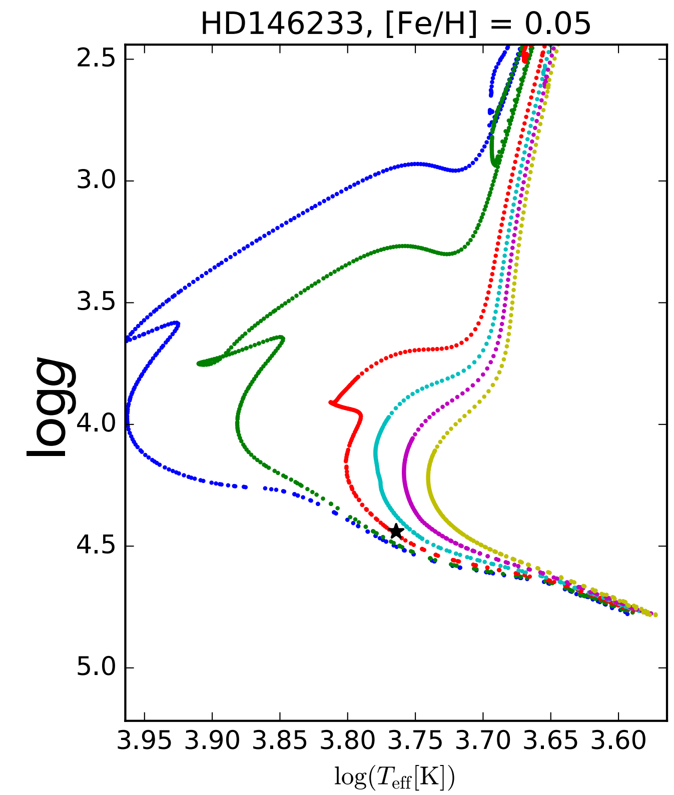
18 Scorpii

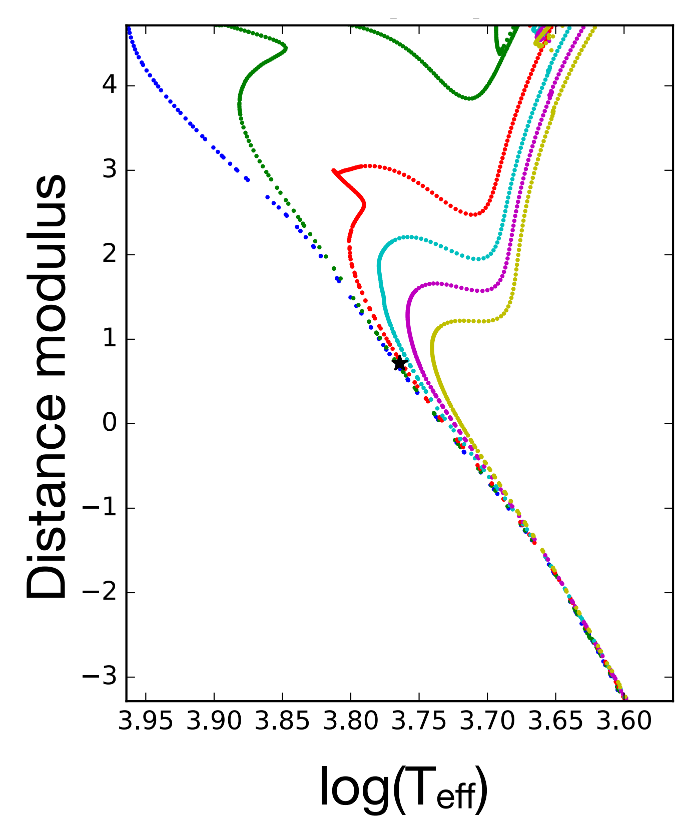
Model fitting
Gyrochronology
Chromochronology
Asteroseismology

Benchmark age: 4.0±1.0 Gyr

Differential spectroscopic analysis





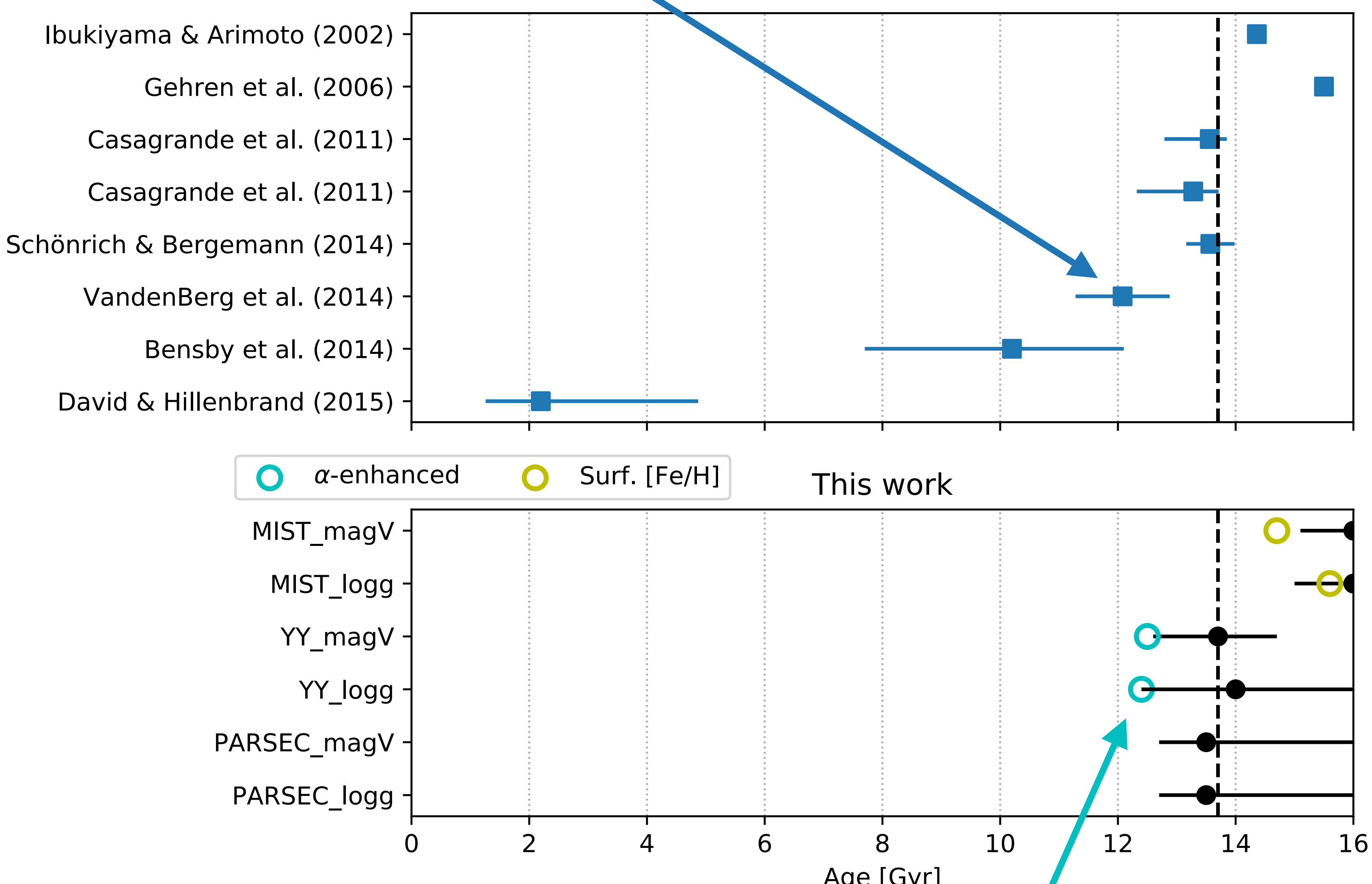


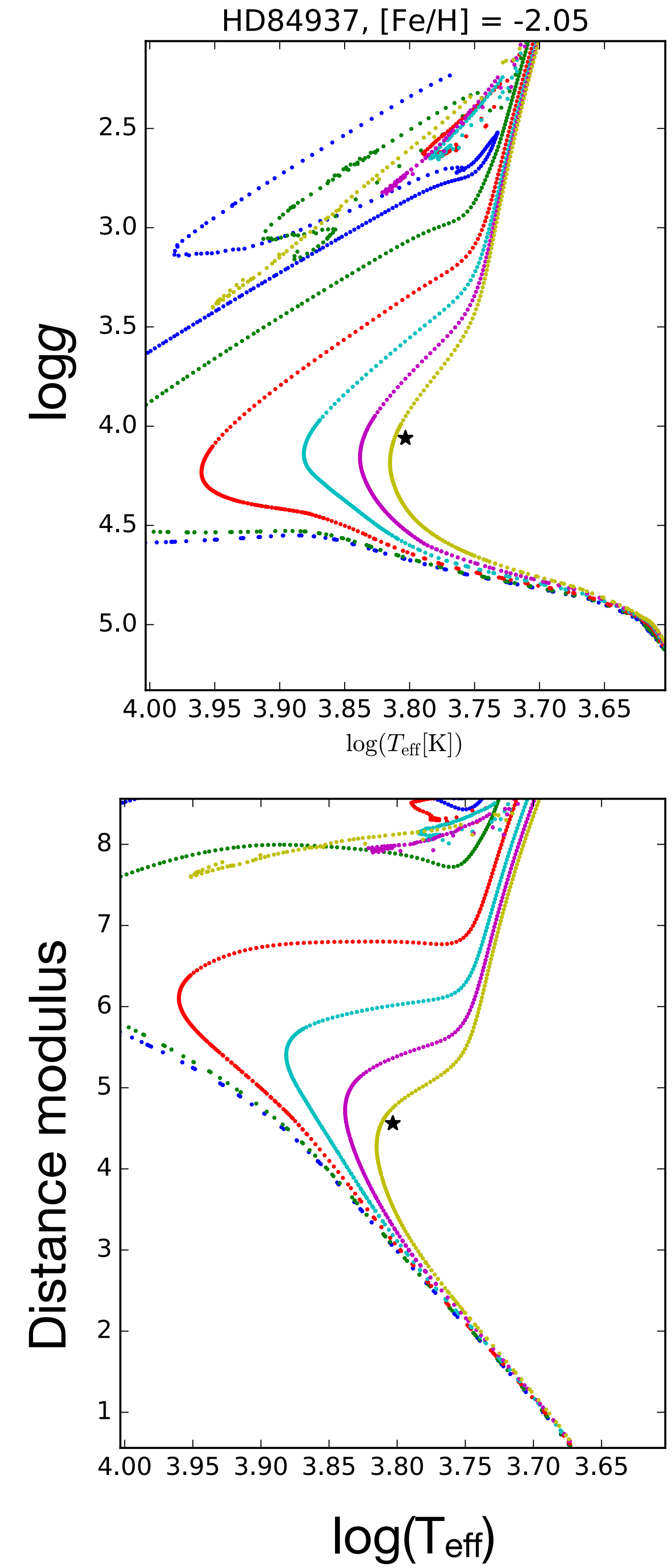
Sahlholdt et al. (2019)

Benchmark age:
11—13.5 Gyr

Models with [O/Fe] = 0.44

HD 84937

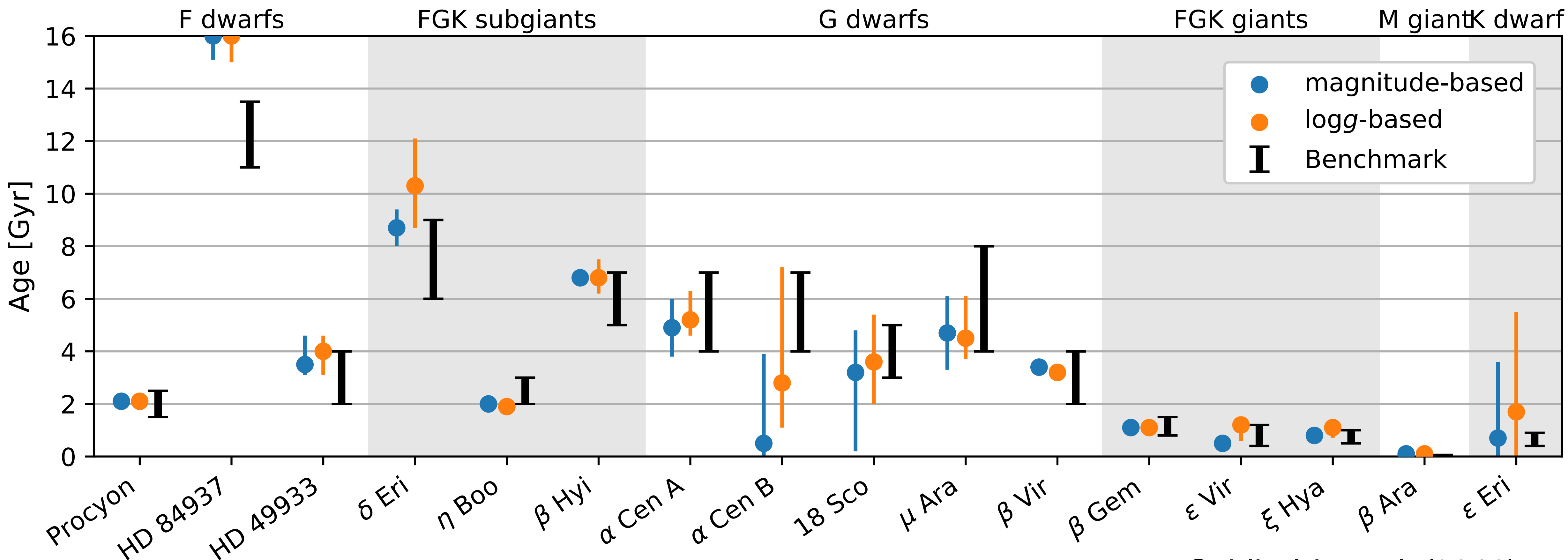




Sahlholdt et al. (2019)

Models with [α/Fe] = 0.4

Benchmark ages



Sahlholdt et al. (2019)

- These can be used as one validation test of ages, but are not enough on their own

- Small sample lacking older giants
  → Asteroseismology will be important for age standards!

From single age estimates to populations

- Imagine now we have age estimates (probability distribution functions) of single stars from a well-calibrated method (or multiple methods)

- PDFs are often broad leading to uncertain age estimates

- Using all PDFs together one can estimate an age PDF for the entire population

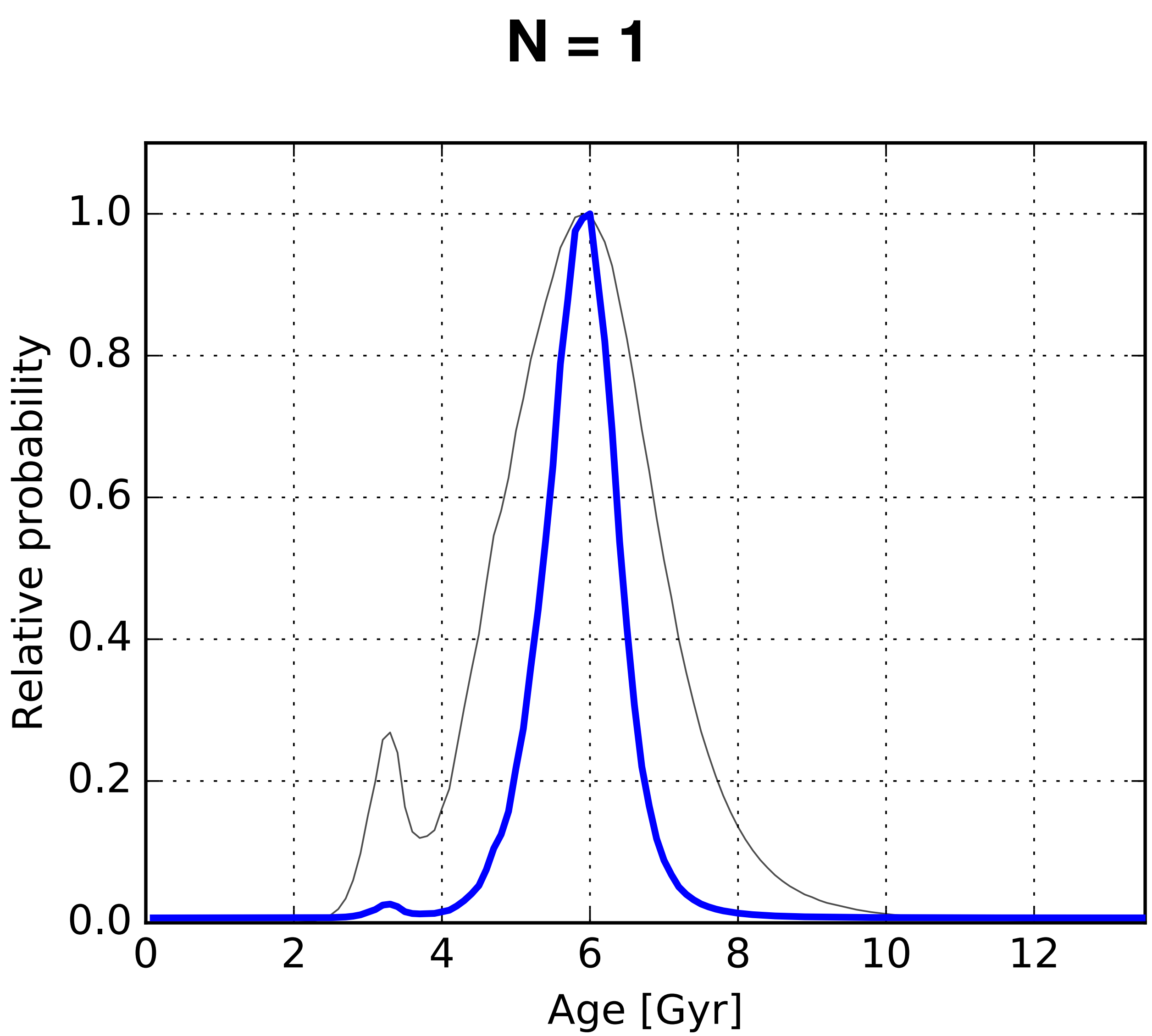
- Discussed by e.g. Hernandez et al. (1999) and Jørgensen & Lindegren (2005)

Non-parametric age distribution

Given age PDFs $G_i(\tau)$,
maximise the likelihood:

$$L = \prod_i \int G_i(\tau)\phi(\tau)\mathrm{d}\tau$$

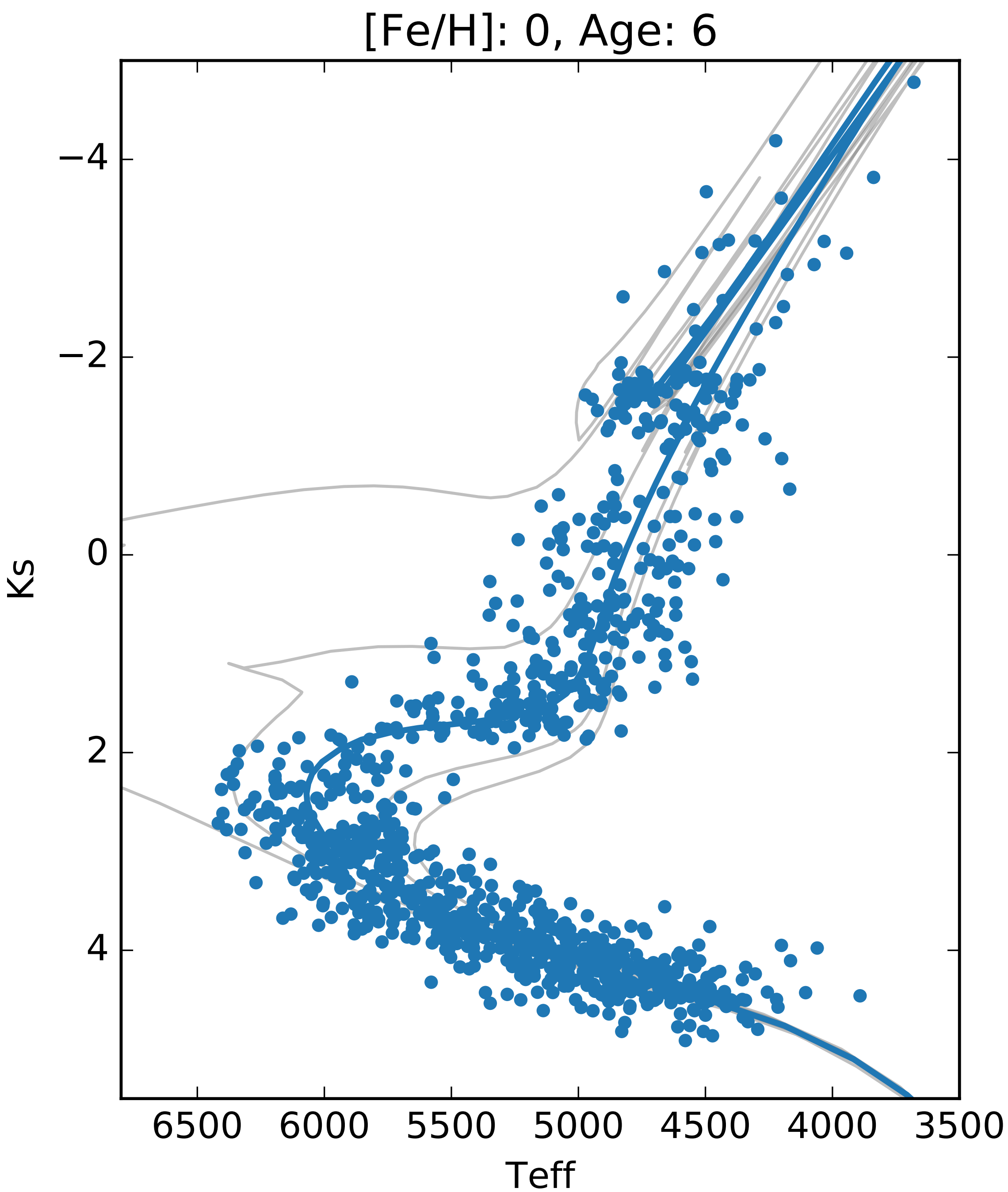
for the age distribution $\phi(\tau)$.



Example: Age recovery of a simple population

Uncertainties:

[Fe/H]: **0.2 dex** — T_{eff}: **200 K** — K_s: **0.02 mag** — parallax: **'Gaia-like' < 2 kpc**



All stars

Sahlholdt et al. (in prep.)

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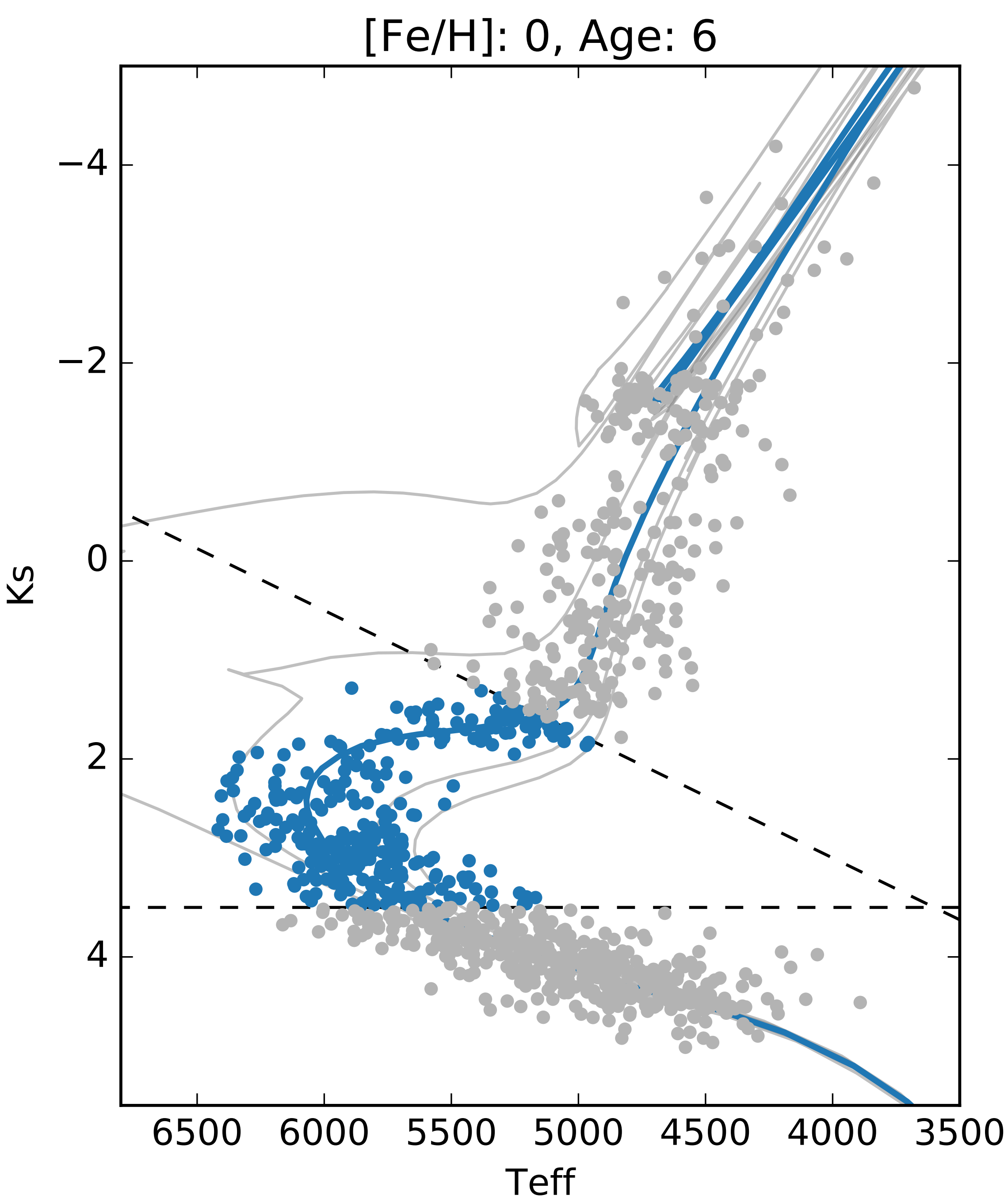

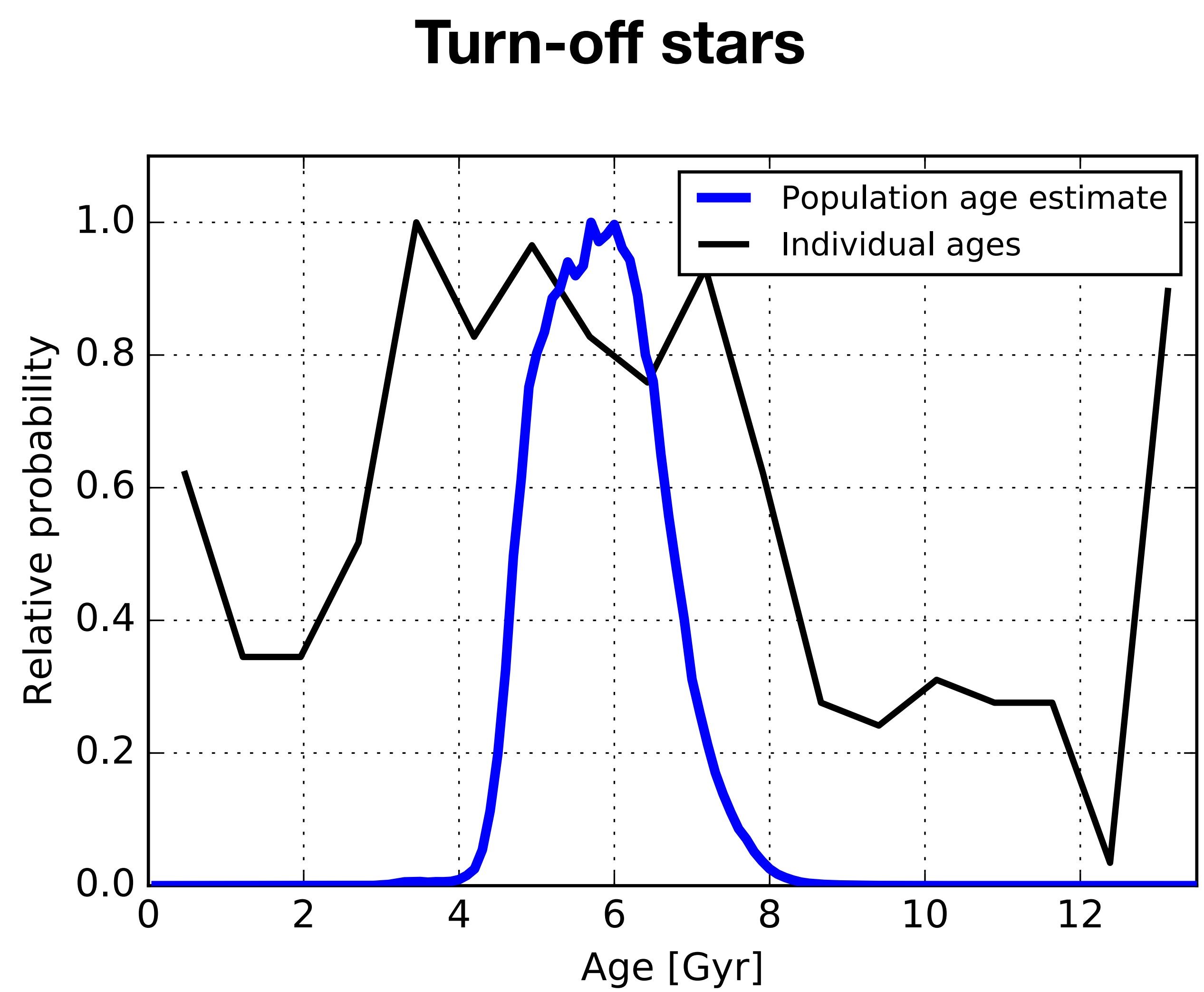

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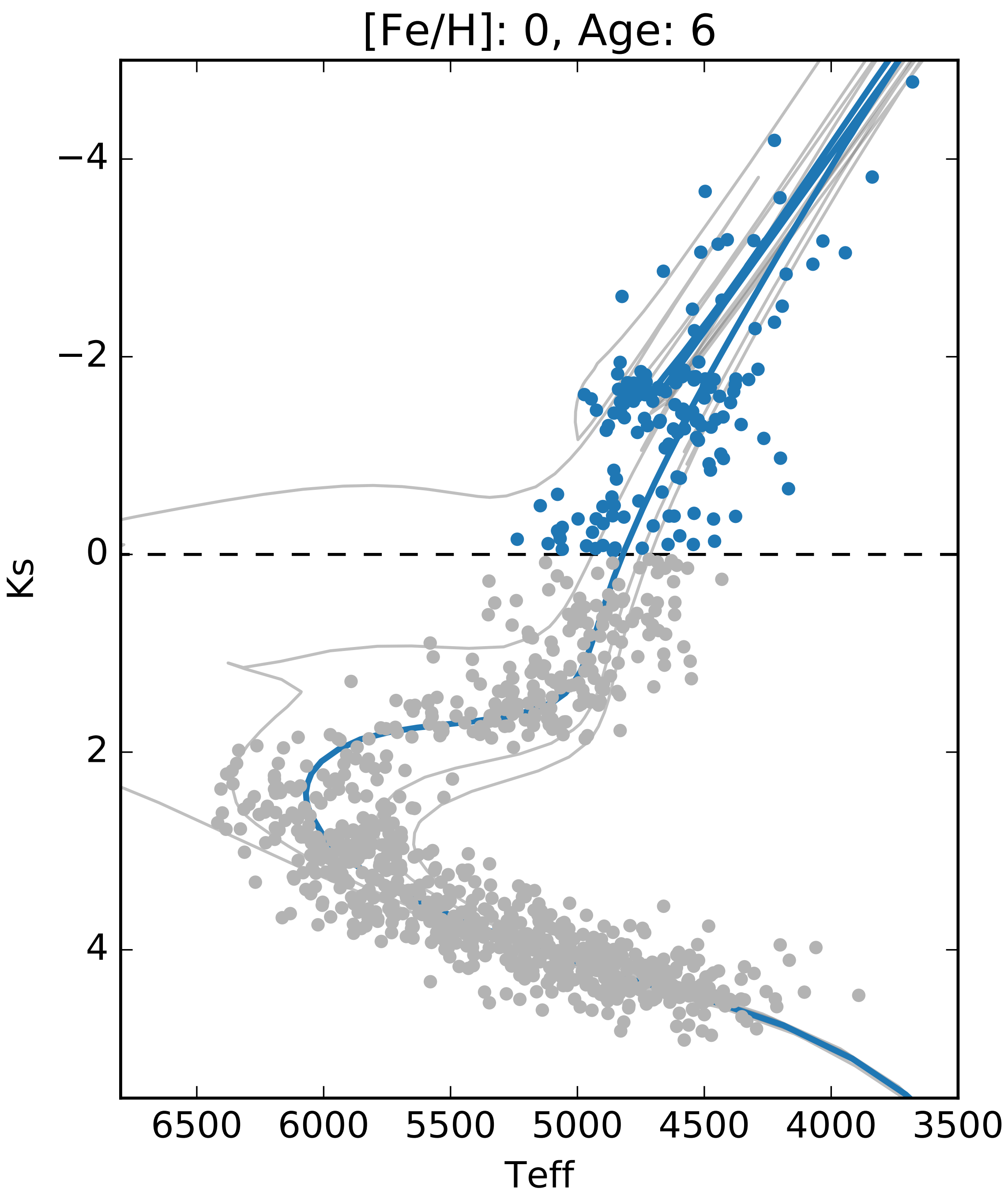

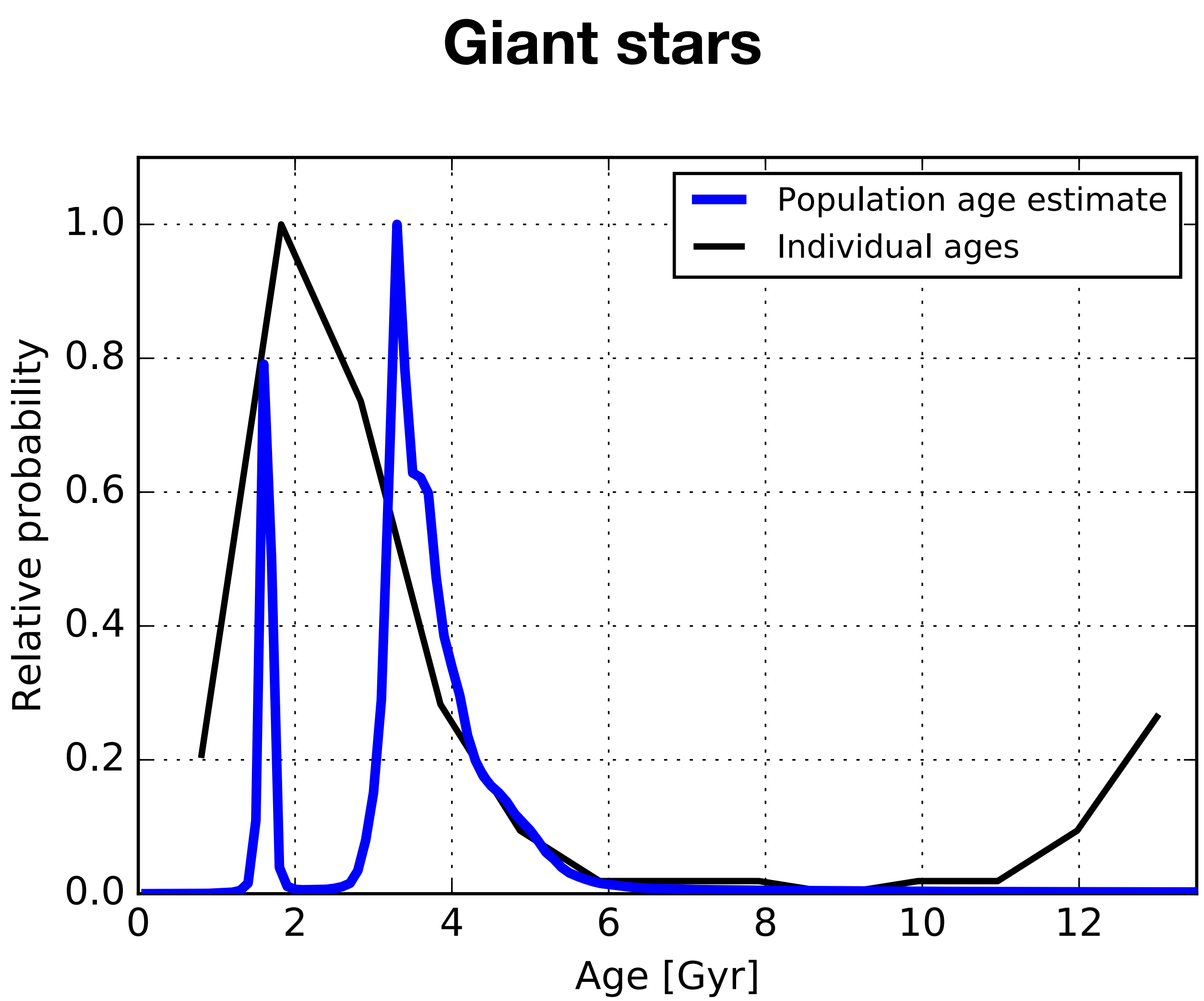

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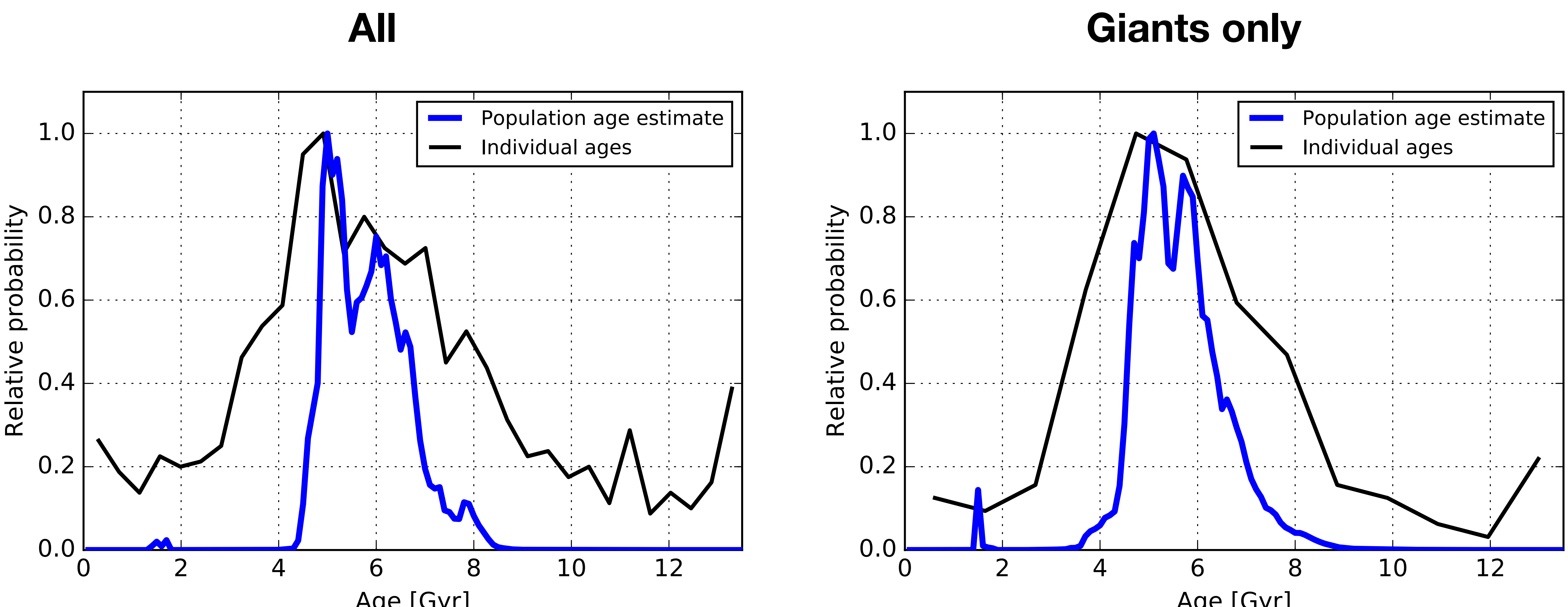
Adding asteroseismology

Scaling relations:

$$\frac{\Delta\nu}{\Delta\nu_\odot} \simeq \left(\frac{M}{M_\odot}\right)^{1/2} \left(\frac{R}{R_\odot}\right)^{-3/2} \qquad \frac{\nu_{\max}}{\nu_{\max,\odot}} \simeq \left(\frac{M}{M_\odot}\right) \left(\frac{R}{R_\odot}\right)^{-2} \left(\frac{T_{\mathrm{eff}}}{T_{\mathrm{eff},\odot}}\right)^{1/2}$$

Uncertainties: $\Delta\nu$: **2%** — $\nu_{\max}$: **4%**



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Summary

- We cannot estimate fundamental stellar ages, but we can benchmark against the best estimates from current stellar models.

- Reliable benchmark ages are determined for 16 of the Gaia benchmark stars

- This sample is suitable for validation tests, but it lacks giants (highlighting the importance of seismology)

- With well-calibrated individual ages, the age of a single population can be more precisely recovered by combining all age PDFs