Ages for the Gaia Benchmark stars

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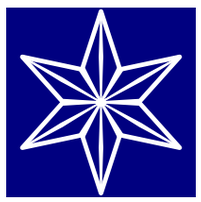


Sahlholdt et al. (2019) MNRAS 482 895

What are the Gaia Benchmark stars?

- Sample designed to anchor Gaia astrophysical parameters (Apsis, Bailer-Jones et al. 2013)

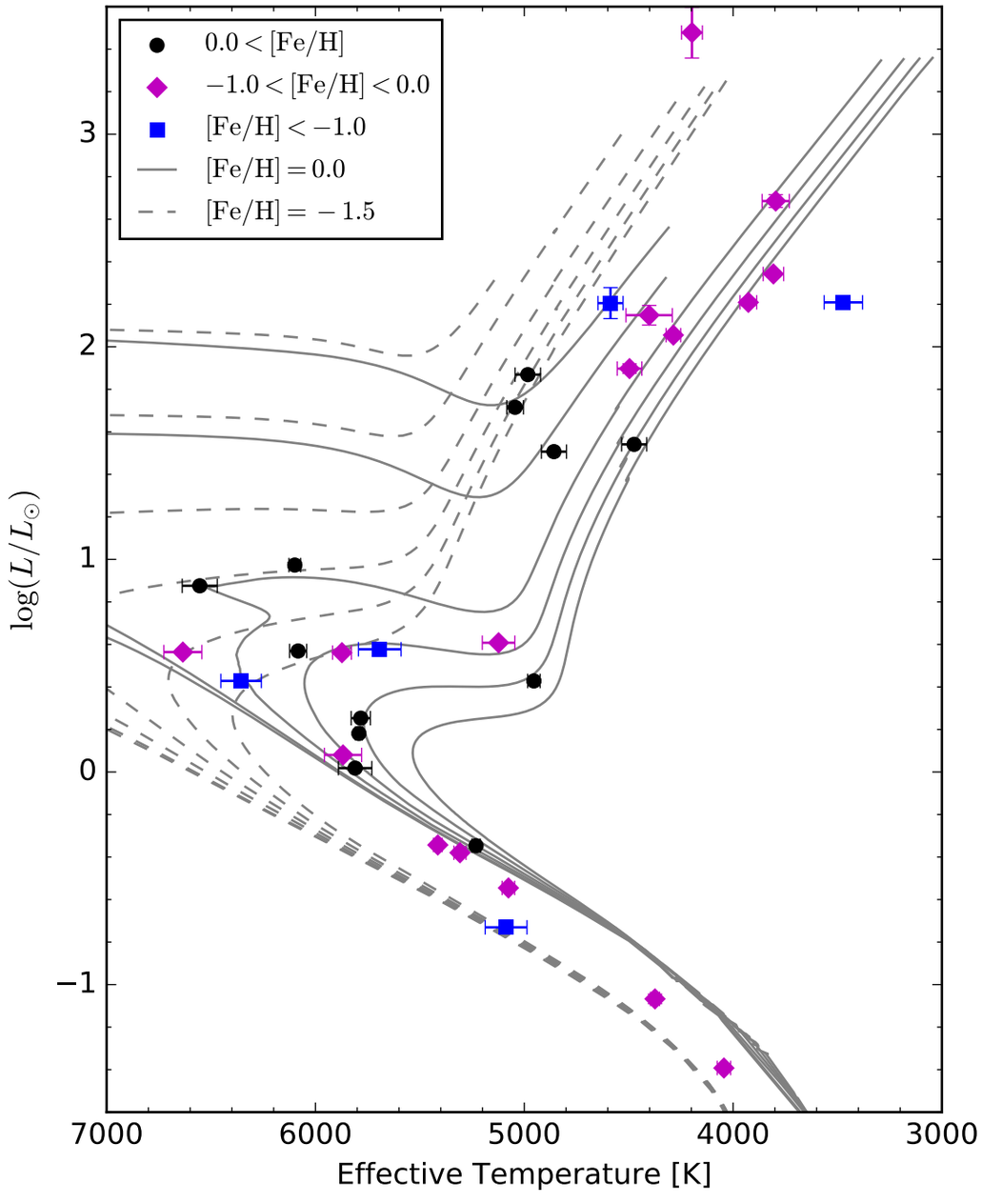
- Uses interferometric measurements of the angular diameter and the bolometric flux

$$T_{\rm eff} = \left(\frac{F_{\rm bol}}{\sigma}\right)^{0.25} (0.5\,\theta_{\rm LD})^{-0.5}$$

- Reference values for [Fe/H] and various elements are defined

Heiter et al. (2015) A&A 582 A49
Jofré et al. (2015) A&A 582 A81

30 stars sparsely covering the HR diagram



Heiter et al. (2015) A&A 582 A49
Jofré et al. (2015) A&A 582 A81

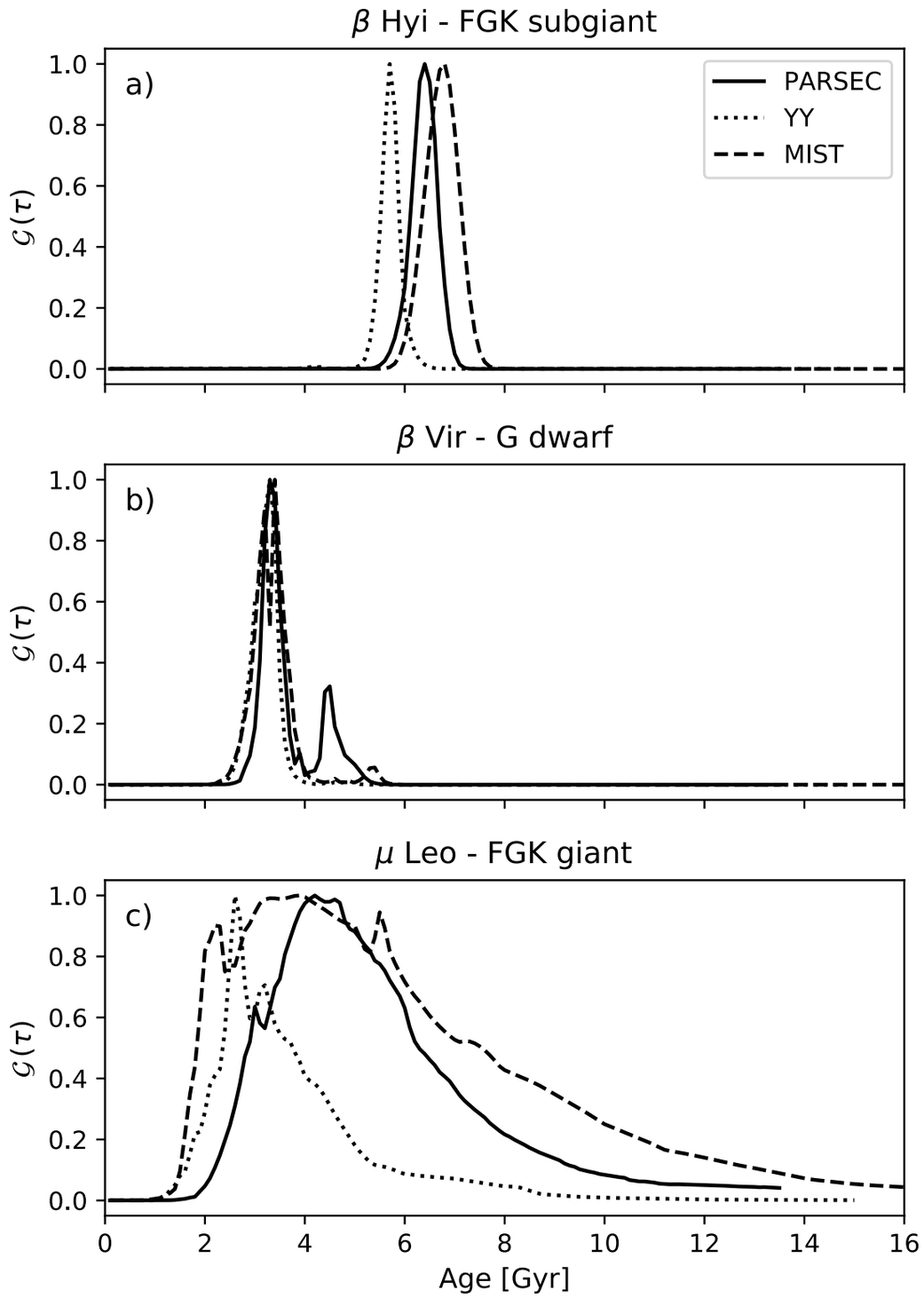
Motivation for our project

- We thought it would be a good idea to see if it is possible to not only provide reference values of Teff, logg, [Fe/H], and [X/Fe] but also age for these stars
- Such ages could then be used for benchmarking and for checking your pipelines

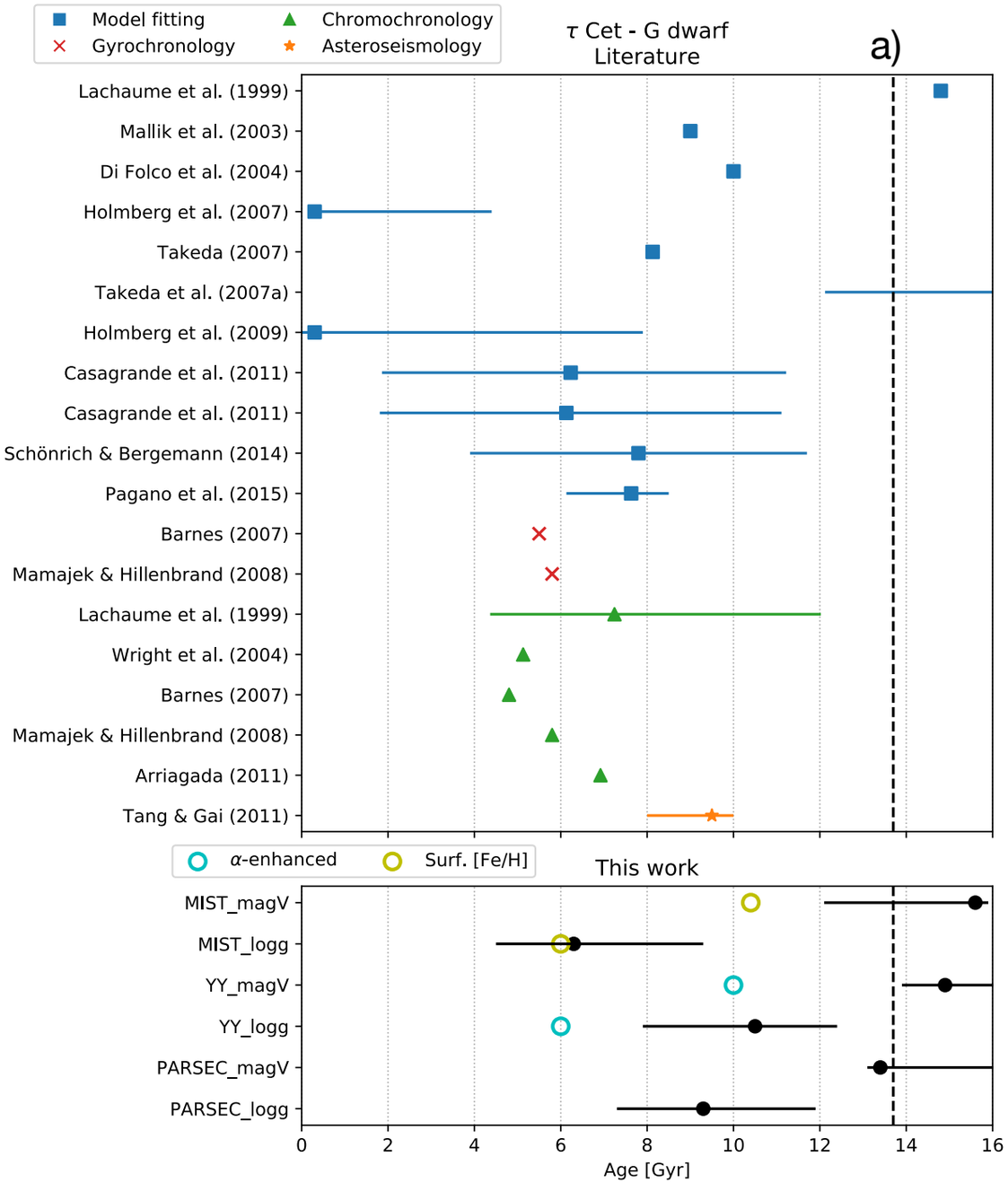
We did 4 things

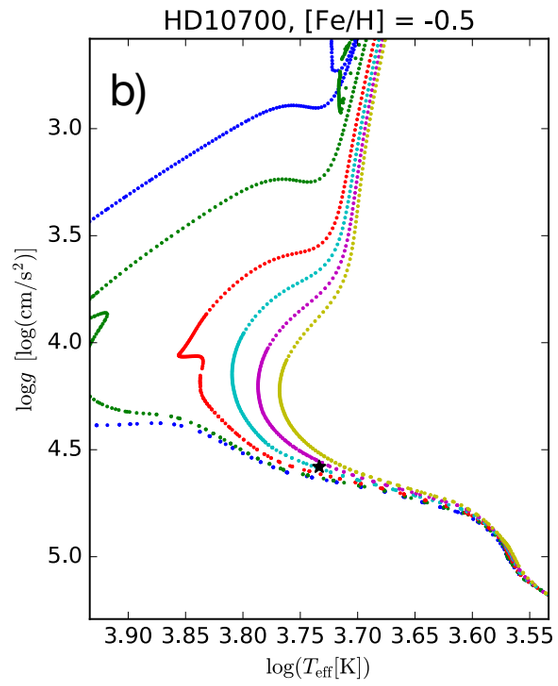
1. Bayesian estimate of ages using three isochrone models
2. Extracted all refereed articles post 1997 for each star with the word “age” in the abstract
   - then we checked if the articles included potentially interesting information on the age
   - those articles were further scrutinised to check that it was an independent age estimate
   - age estimates were collected, errors retrieved when available
3. An informed discussion (see article) was done per star to define a benchmark age(-range)
4. Checked what results would be like in “survey” mode

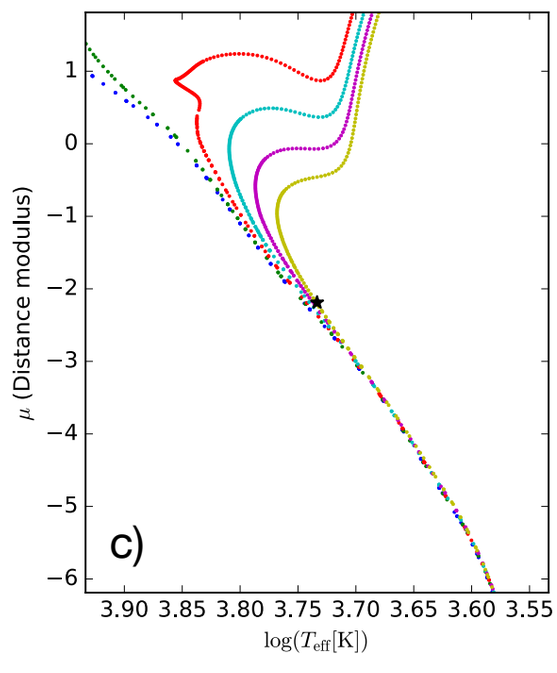
Our analysis



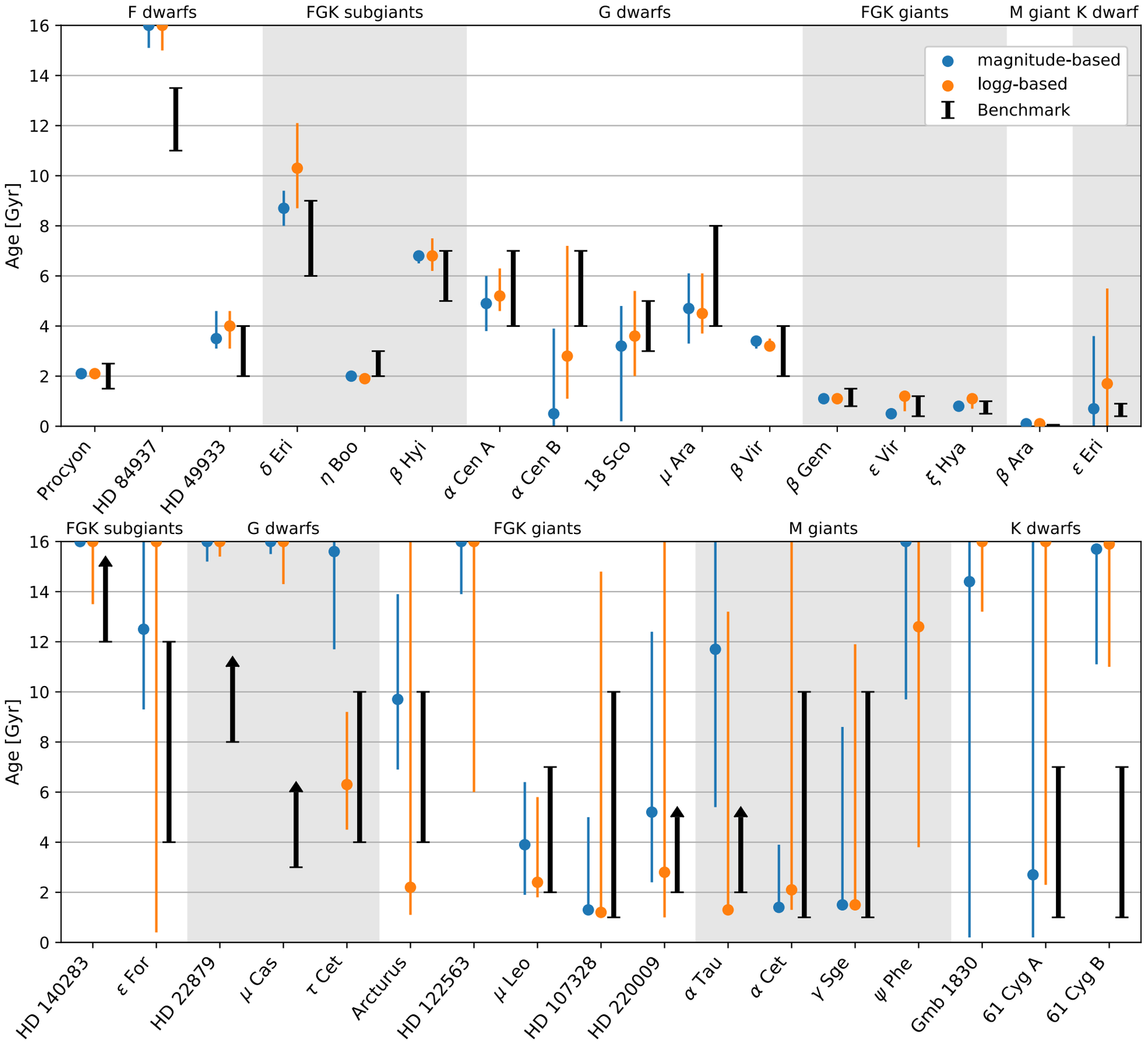
G dwarf example





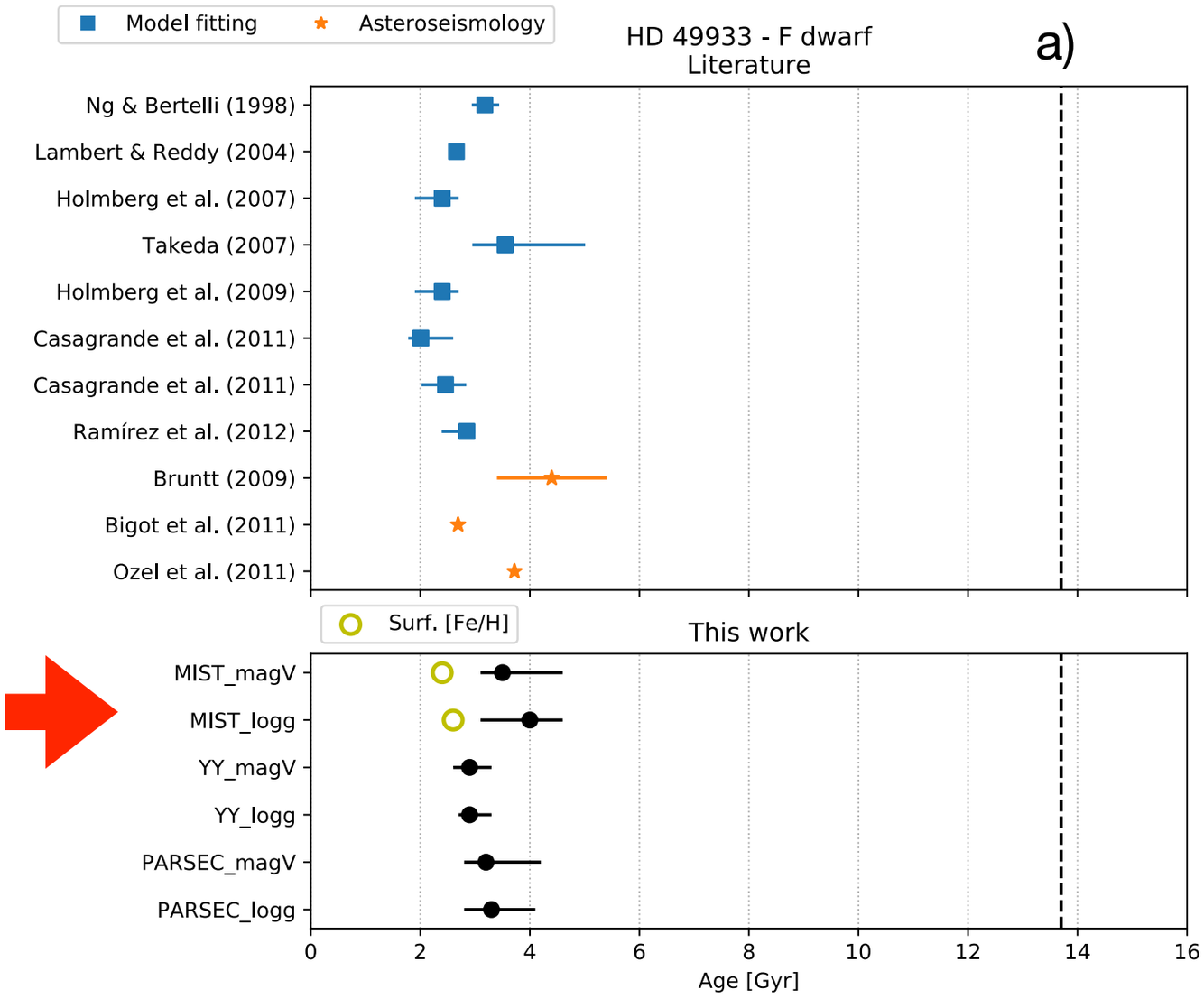


4 – 10 Gyr

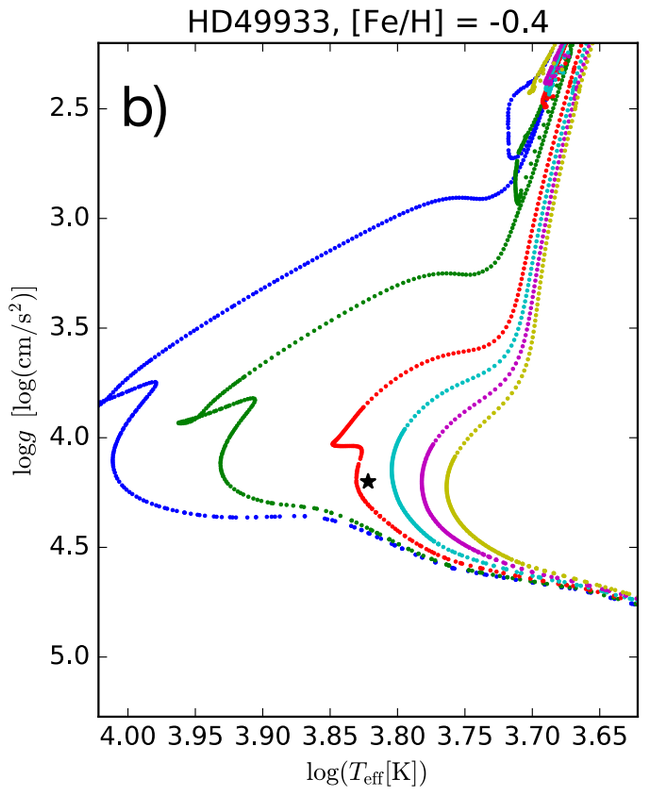

F dwarfs
FGK subgiants
G dwarfs
FGK giants
M giant
K dwarf
magnitude-based
logg-based
Benchmark
Age [Gyr]
0
2
4
6
8
10
12
14
16
Procyon
HD 84937
HD 49933
δ Eri
η Boo
β Hyi
α Cen A
α Cen B
18 Sco
μ Ara
β Vir
β Gem
ε Vir
ξ Hya
β Ara
ε Eri
FGK subgiants
G dwarfs
FGK giants
M giants
K dwarfs
HD 140283
ε For
HD 22879
μ Cas
τ Cet
Arcturus
HD 122563
μ Leo
HD 107328
HD 220009
α Tau
α Cet
γ Sge
ψ Phe
Gmb 1830
61 Cyg A
61 Cyg B

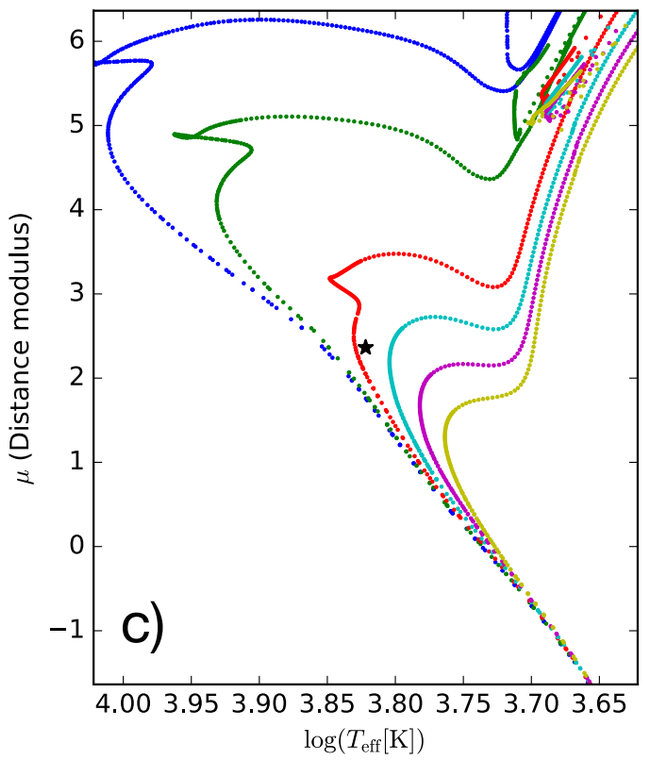
HD49933

Surface abundance

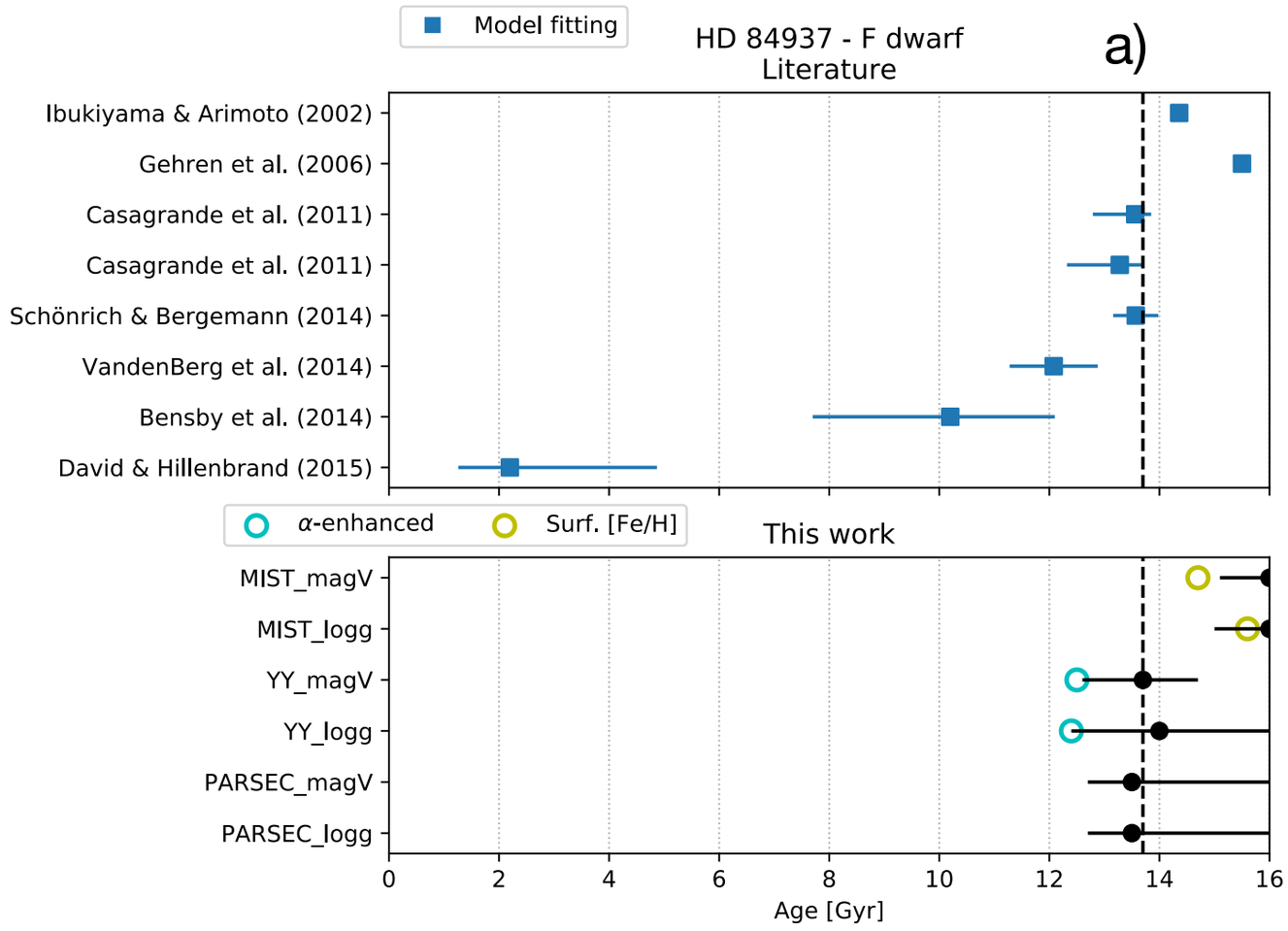


2 – 4 Gyr

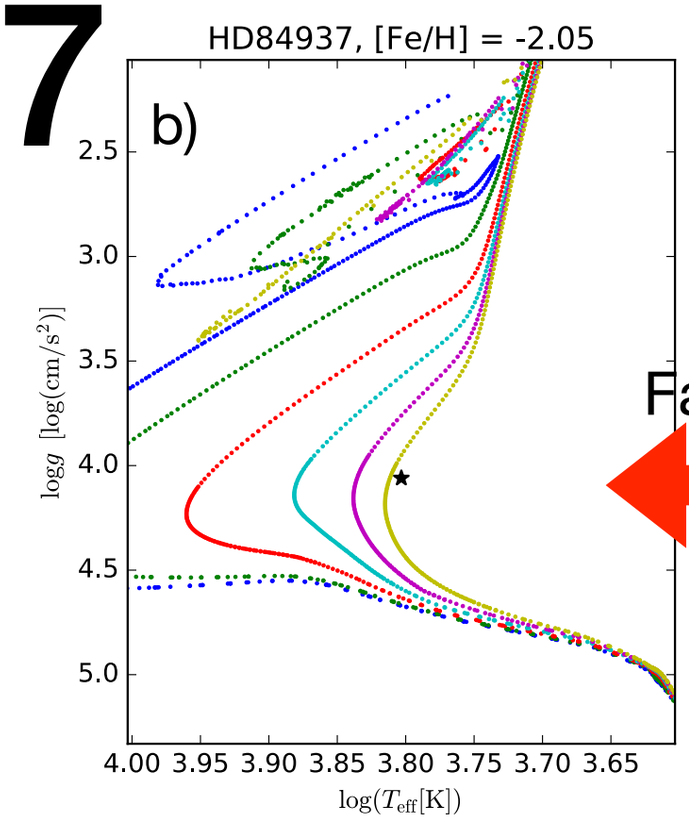




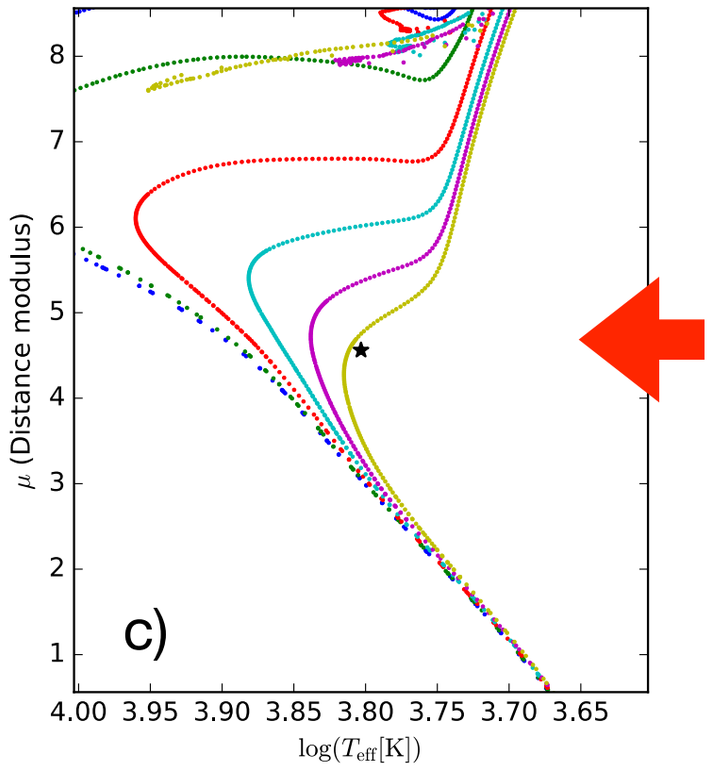
HD84937



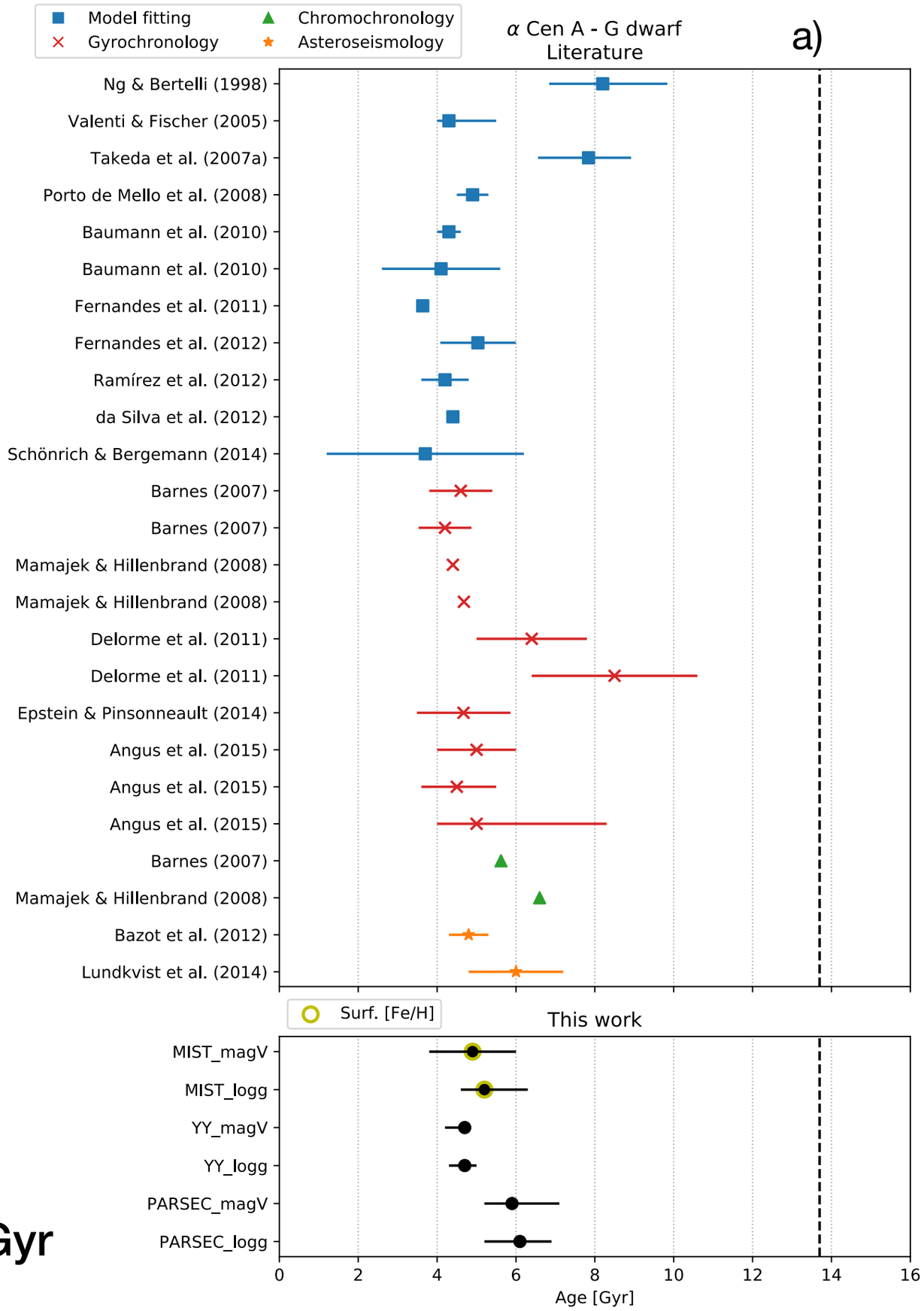
11 – 13.5 Gyr

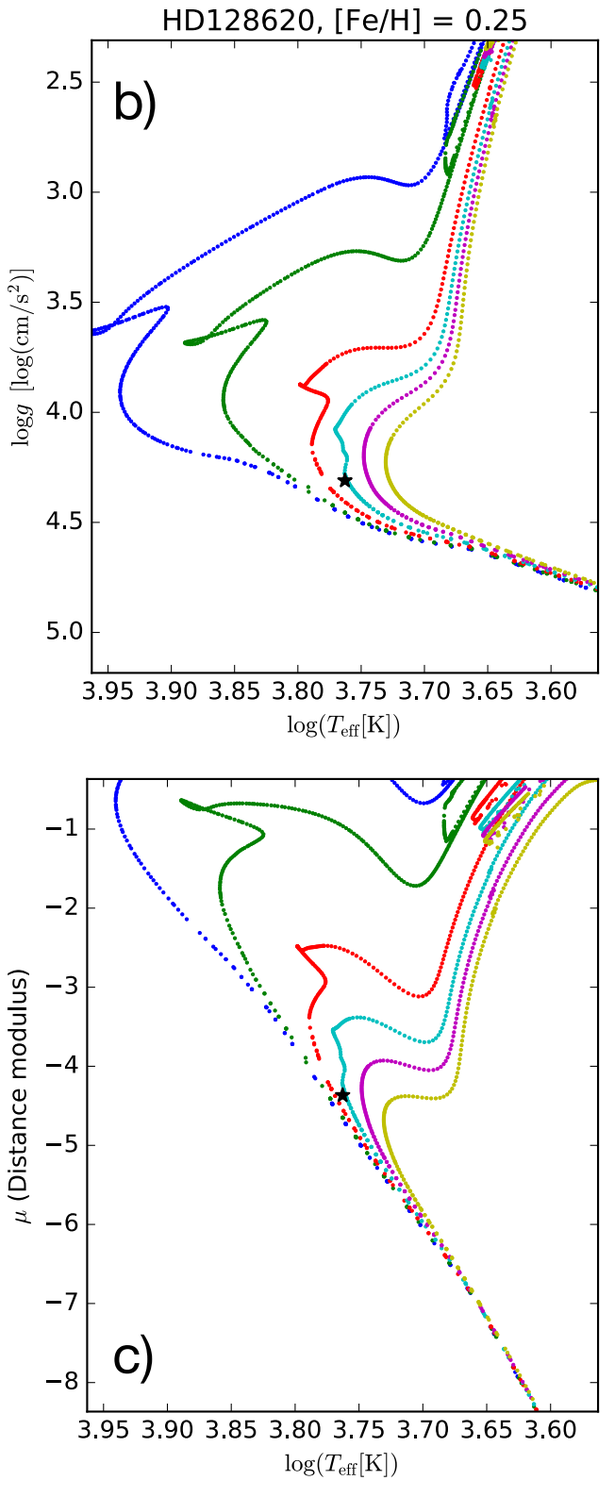


Fall outside grid



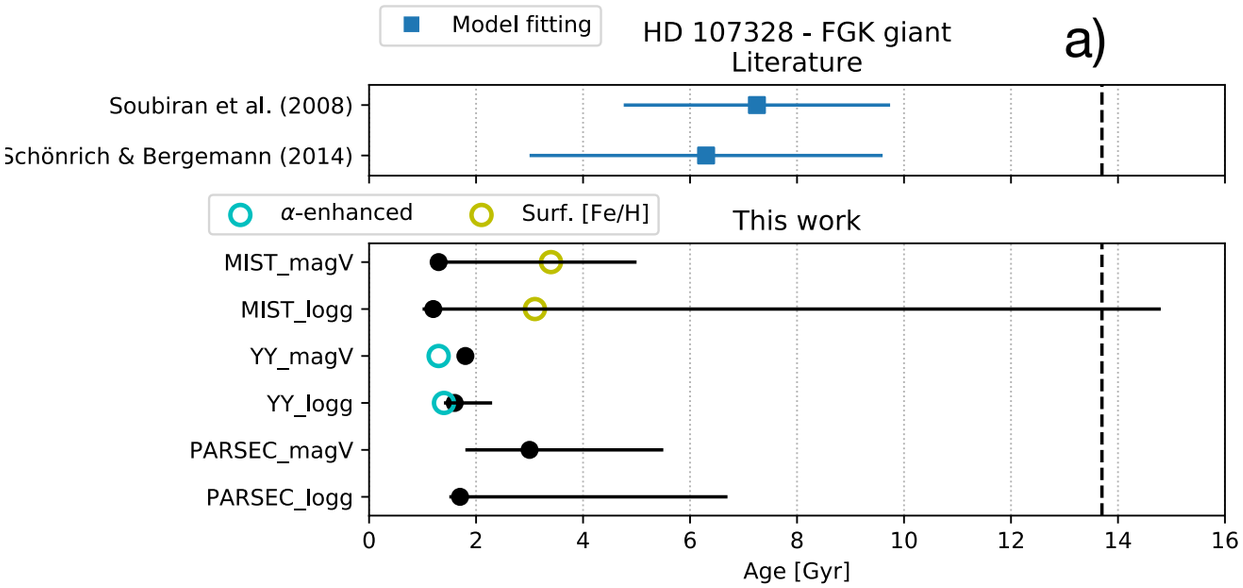
α Cen A


Model fitting
Gyrochronology
Chromochronology
Asteroseismology
α Cen A - G dwarf
Literature
a)
Ng & Bertelli (1998)
Valenti & Fischer (2005)
Takeda et al. (2007a)
Porto de Mello et al. (2008)
Baumann et al. (2010)
Baumann et al. (2010)
Fernandes et al. (2011)
Fernandes et al. (2012)
Ramírez et al. (2012)
da Silva et al. (2012)
Schönrich & Bergemann (2014)
Barnes (2007)
Barnes (2007)
Mamajek & Hillenbrand (2008)
Mamajek & Hillenbrand (2008)
Delorme et al. (2011)
Delorme et al. (2011)
Epstein & Pinsonneault (2014)
Angus et al. (2015)
Angus et al. (2015)
Angus et al. (2015)
Barnes (2007)
Mamajek & Hillenbrand (2008)
Bazot et al. (2012)
Lundkvist et al. (2014)
Surf. [Fe/H]
This work
MIST_magV
MIST_logg
YY_magV
YY_logg
PARSEC_magV
PARSEC_logg
0
2
4
6
8
10
12
14
16
Age [Gyr]

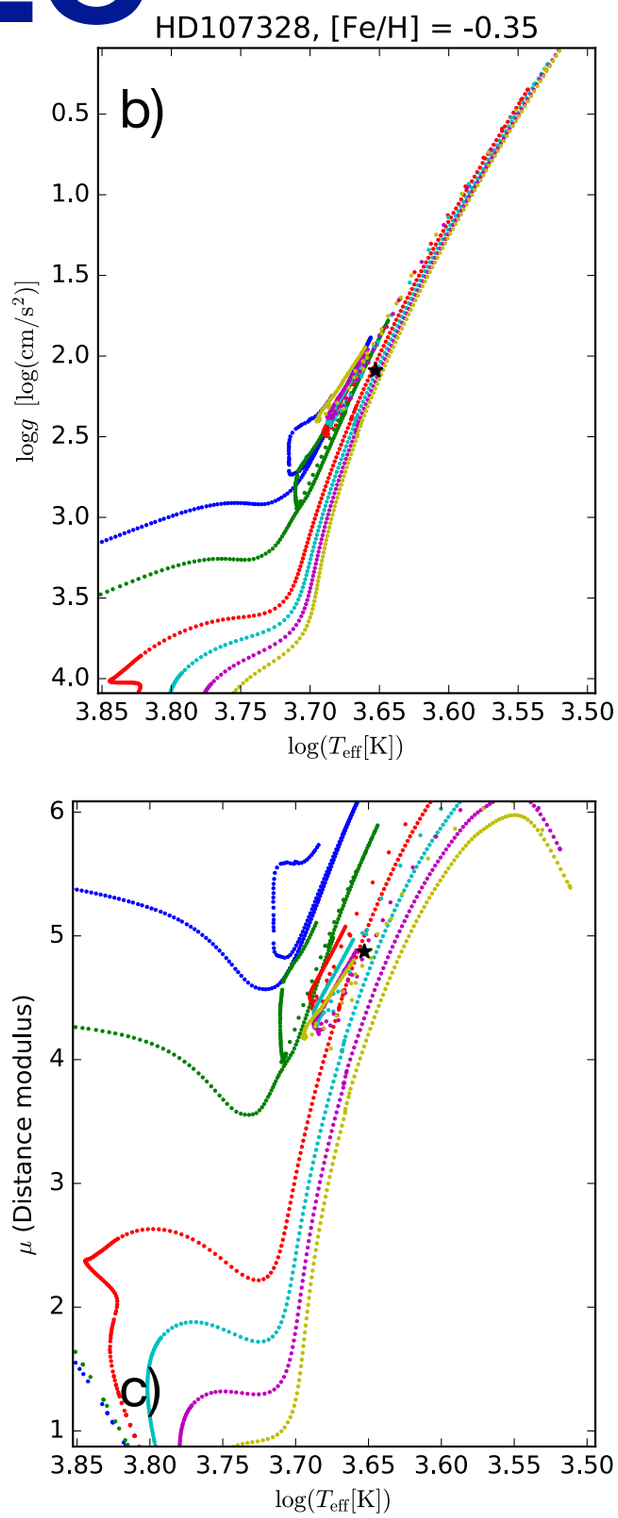

HD128620, [Fe/H] = 0.25
b)
2.5
3.0
3.5
4.0
4.5
5.0
$\log g$ [$\log(\mathrm{cm/s^2})$]
3.95 3.90 3.85 3.80 3.75 3.70 3.65 3.60
$\log(T_{\mathrm{eff}}[\mathrm{K}])$
−1
−2
−3
−4
−5
−6
−7
−8
μ (Distance modulus)
c)
3.95 3.90 3.85 3.80 3.75 3.70 3.65 3.60
$\log(T_{\mathrm{eff}}[\mathrm{K}])$

4 – 7 Gyr

HD107328



1 – 10 Gyr



γ Sge

Literature For this star we have found two literature values based on model fitting which agree on an age of around 5 Gyr, but with uncertainties which in the worst case span the range 2–10 Gyr.

This work This far up the RGB there is almost no age information in $\log g$ since the isochrones converge. Using the magnitude instead, the isochrones are better separated, and this star falls among the younger isochrones. The magnitude-based ages are in the range 1–4 Gyr, but with upper ends of the confidence intervals reaching 8 Gyr. Additionally, the $\mathcal{G}$ functions have extended tails which reach all the way up to the upper edge of the grid due to the large uncertainty on the metallicity for this star (0.39 dex). The extended $\mathcal{G}$ function makes the mean of the distribution quite different from the mode; in this case the mean of the distribution is 6.5 Gyr which is closer to the literature values which both used the mean instead of the mode.

Conclusion The literature value indicates an age in the interval 2–10 Gyr, and our best estimates prefer the low end of the interval, namely 1–4 Gyr, but with large uncertainties. The difference can be entirely explained by our estimates being based on the mode of the $\mathcal{G}$ function instead of the mean. This choice has a large impact in this case because the $\mathcal{G}$ function has an extended tail towards high ages due to the large uncertainty on the metallicity. Based mainly on our own results, we give the age as 1–10 Gyr.

β Vir

Literature All of the literature values based on model fitting agree well on an age in the range 2–4 Gyr, with most of them falling near the middle of the interval. Out of the seven estimates based on rotation/activity-age relations, one of the X-ray ages and the single rotation-based age fall within 2–4 Gyr. The other X-ray age is underestimated, and the chromochronology ages are all higher than the ones based on model fitting. They are also scattered which seems to be due to the use of different calibrations and activity measurements. For example, Vican (2012) uses the calibration of Mamajek & Hillenbrand (2008) with the activity measurement by Wright et al. (2004) and find an age in between the ones given by Mamajek & Hillenbrand and Wright et al..

This work Our age estimates all agree very well across different isochrones and input parameters. They are all very close to 3 Gyr in agreement with the isochrone ages in the literature.

Conclusion The age of this star is well determined by isochrone fitting, and based on both our own values and the literature, we give the age as 2–4 Gyr.

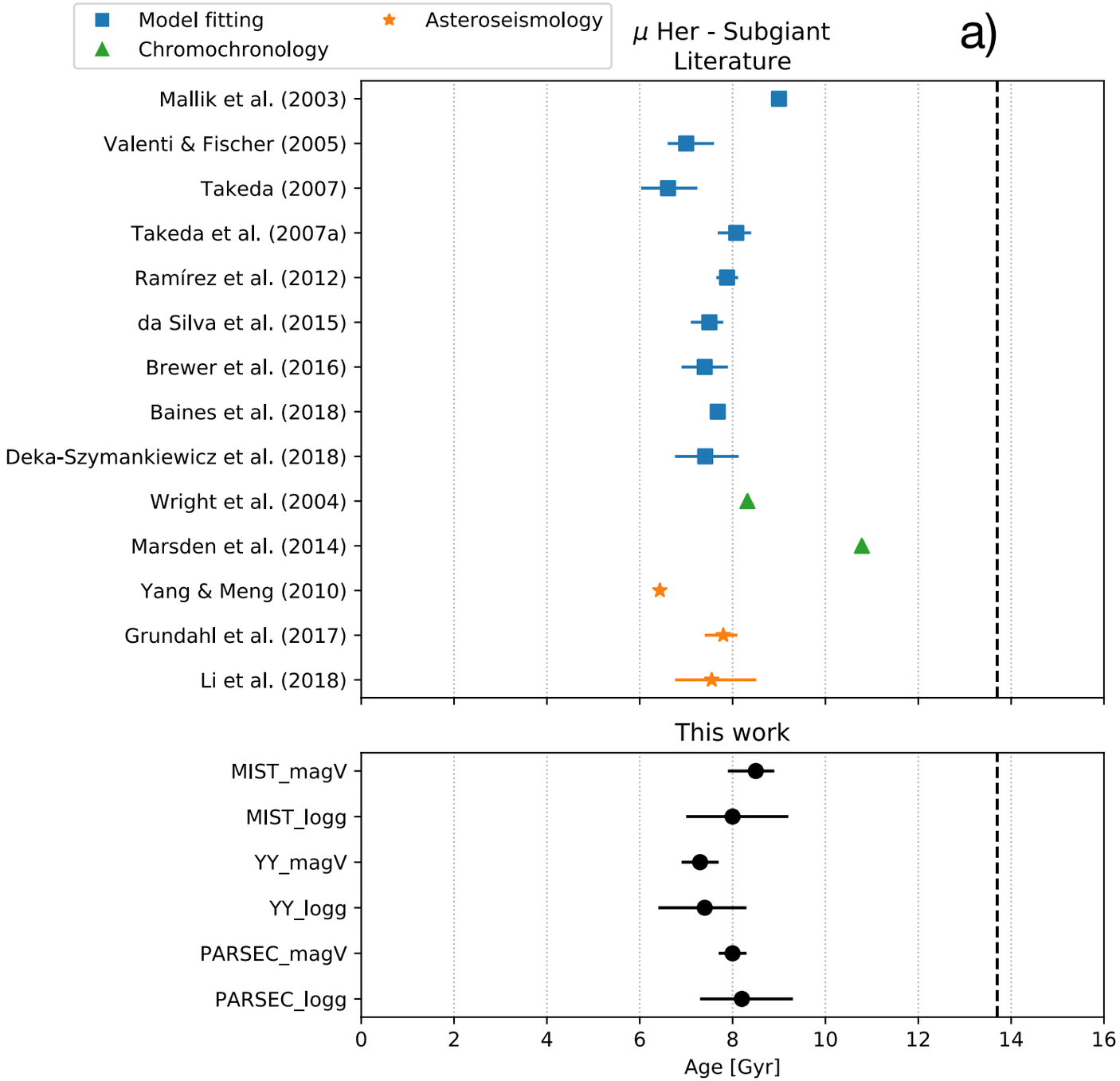
Benchmark ages for Gaia benchmark stars

- Gaia benchmark stars have well determined stellar parameters

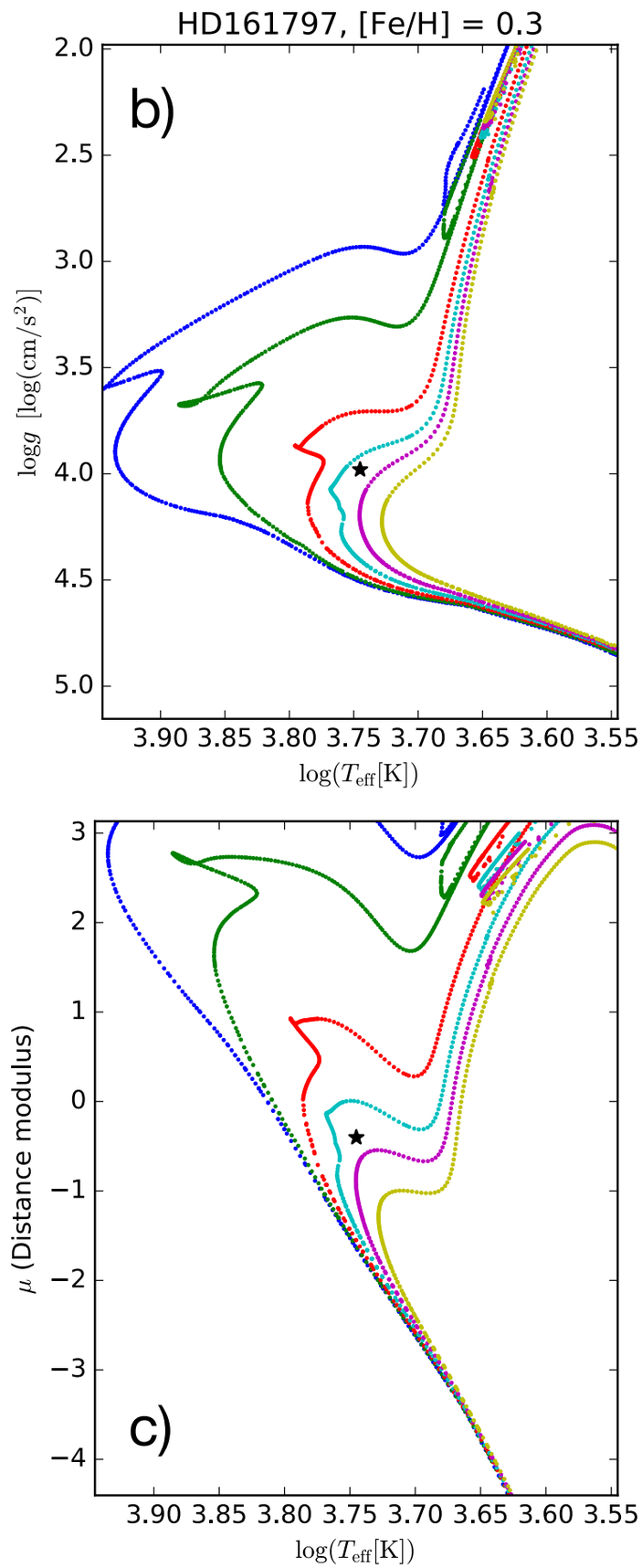
- Our work provides an initial set of benchmark ages to test and validate pipelines and analysis methods against

- We plan to keep updating the list of potential stars and their reference values

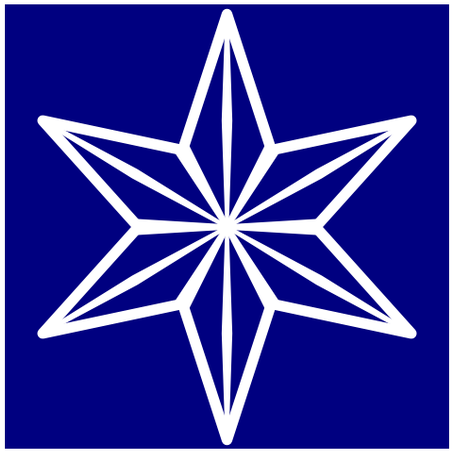
Sahlholdt et al. (2019) MNRAS 482 895



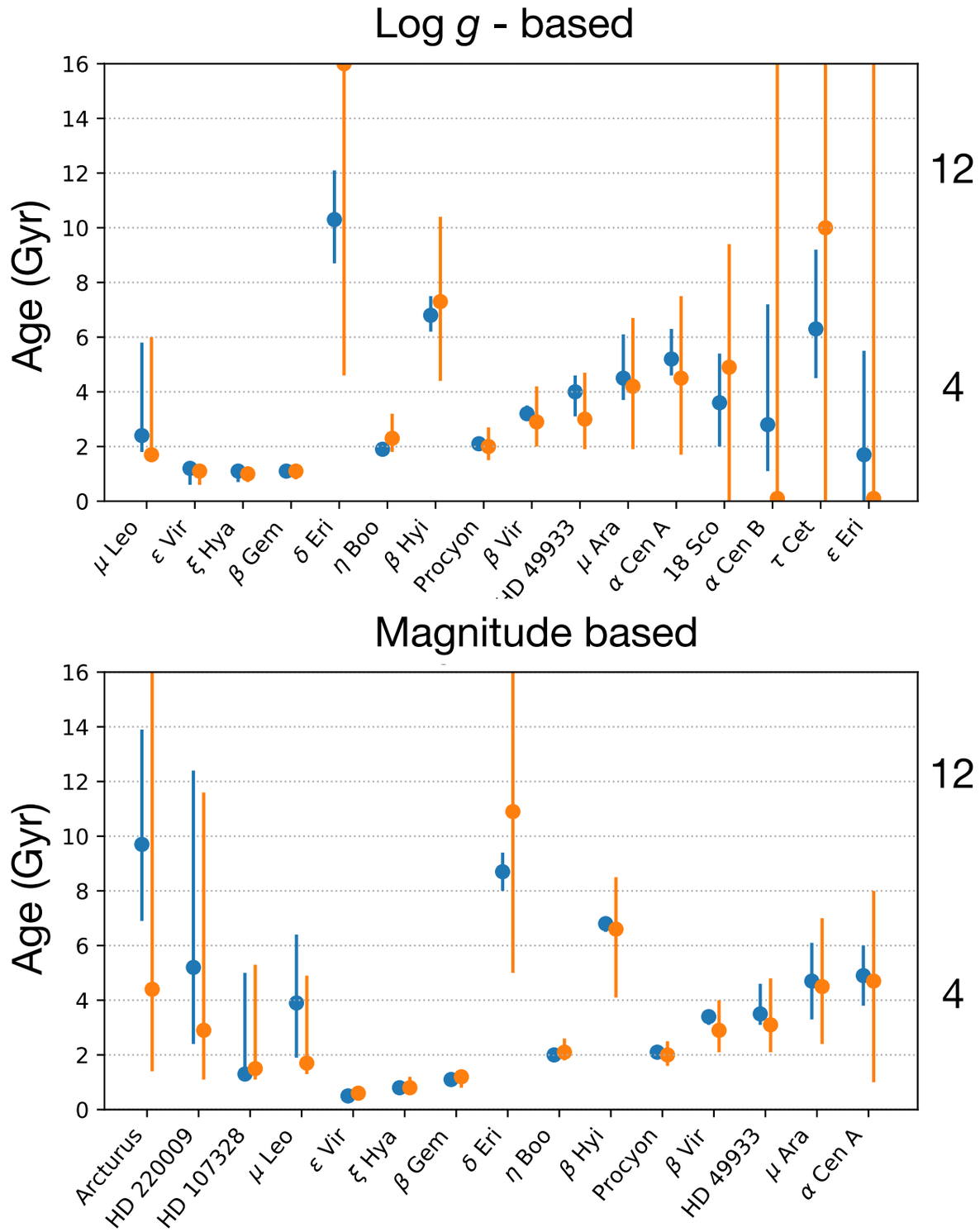
7.5 – 8 Gyr



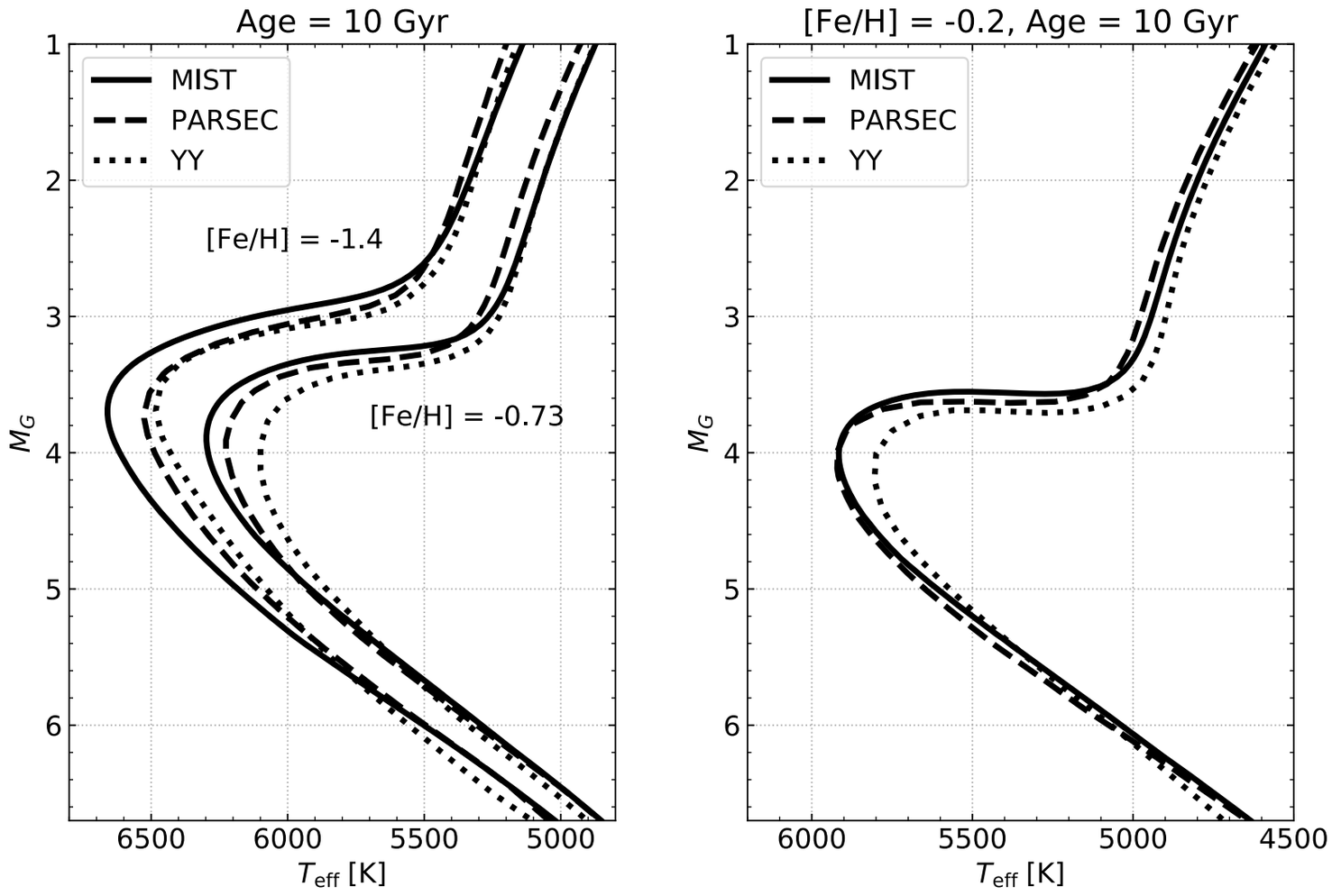
Sahlholdt & Feltzing (2019) RNAAS

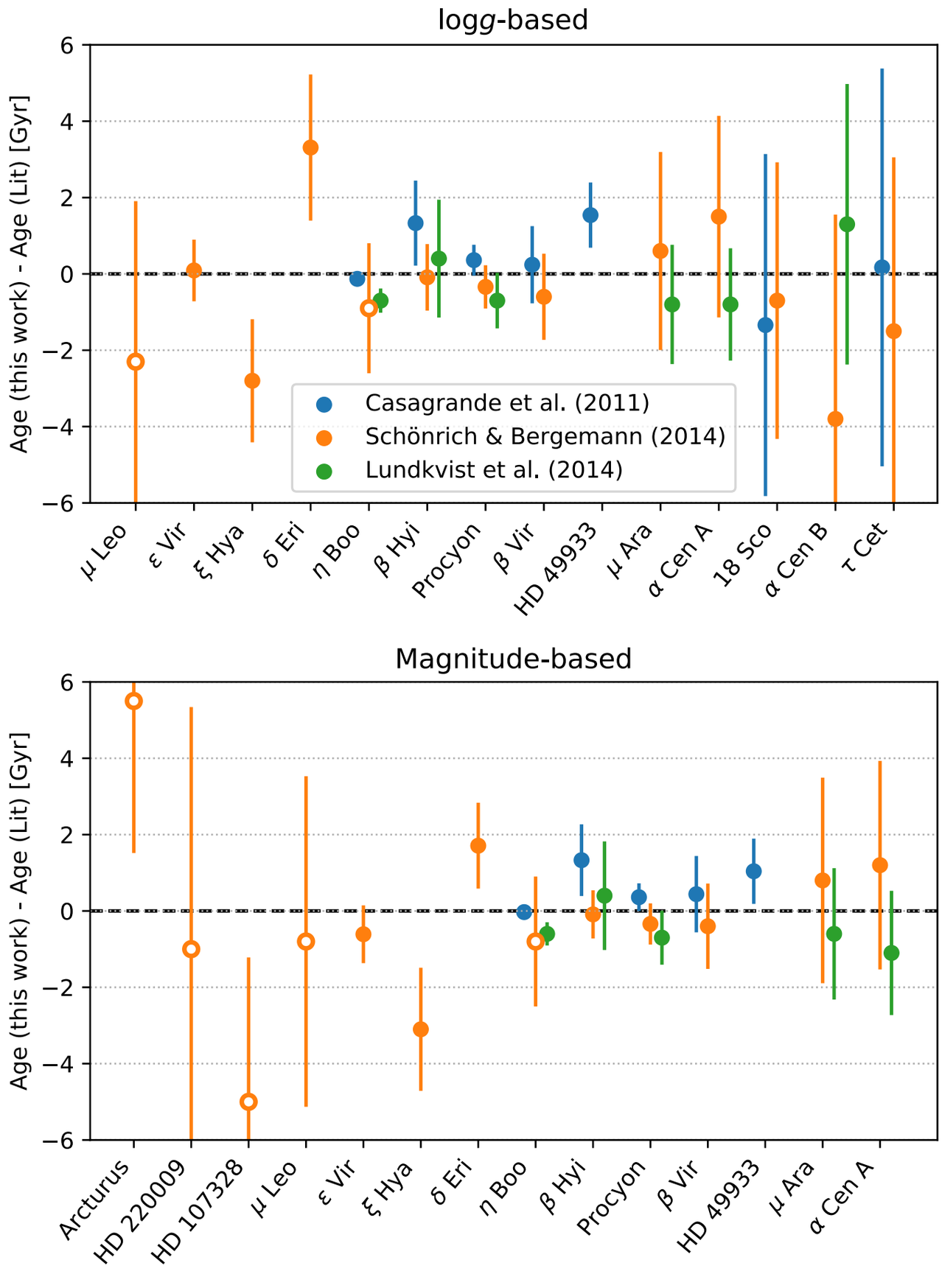


Survey mode for well



Best case
Inflated to survey level precision


Age = 10 Gyr
MIST
PARSEC
YY
[Fe/H] = -1.4
[Fe/H] = -0.73
M_G
$T_{\rm eff}$ [K]
[Fe/H] = -0.2, Age = 10 Gyr
MIST
PARSEC
YY
M_G
$T_{\rm eff}$ [K]


logg-based
Age (this work) - Age (Lit) [Gyr]
6
4
2
0
−2
−4
−6
Casagrande et al. (2011)
Schönrich & Bergemann (2014)
Lundkvist et al. (2014)
μ Leo
ε Vir
ξ Hya
δ Eri
η Boo
β Hyi
Procyon
β Vir
HD 49933
μ Ara
α Cen A
18 Sco
α Cen B
τ Cet
Magnitude-based
Age (this work) - Age (Lit) [Gyr]
6
4
2
0
−2
−4
−6
Arcturus
HD 220009
HD 107328
μ Leo
ε Vir
ξ Hya
δ Eri
η Boo
β Hyi
Procyon
β Vir
HD 49933
μ Ara
α Cen A