NEW VIEW OF GALACTIC DISCS: PRECISE AGES WITH INDIVIDUAL OSCILLATION MODES

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European Research Council
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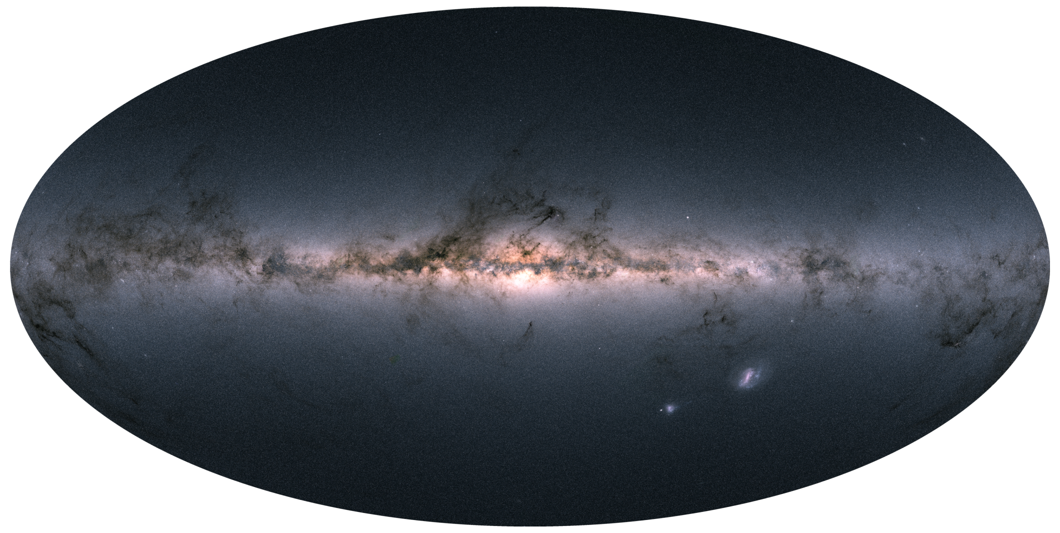
ASTERO CHRONOMETRY

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

To reconstruct the assembly and chemo-dynamical history of the Galaxy

precise, accurate stellar properties (e.g. radius, mass, age to ~10%)

Gaia
astrometry



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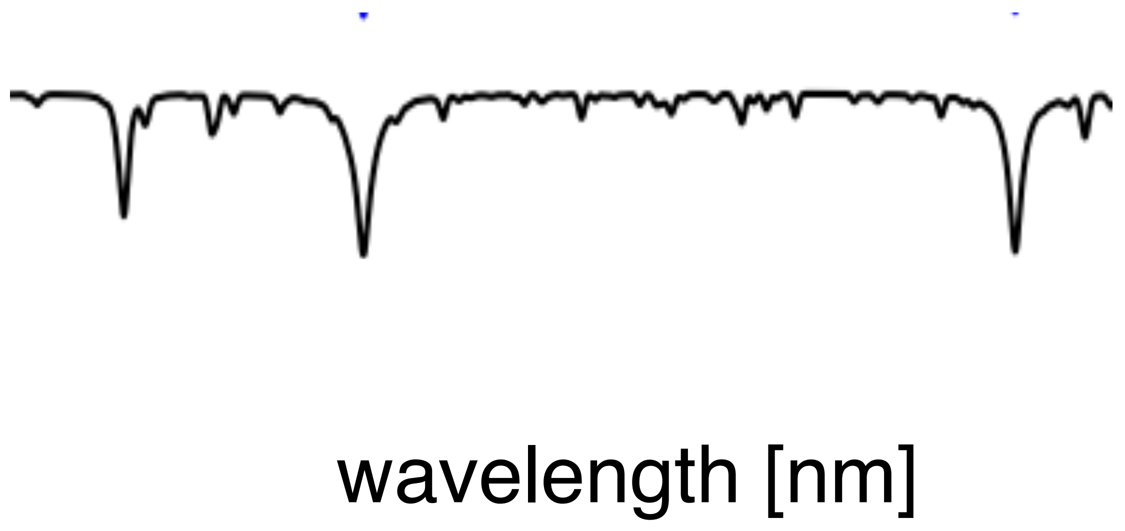
APOGEE-DR17

spectroscopy



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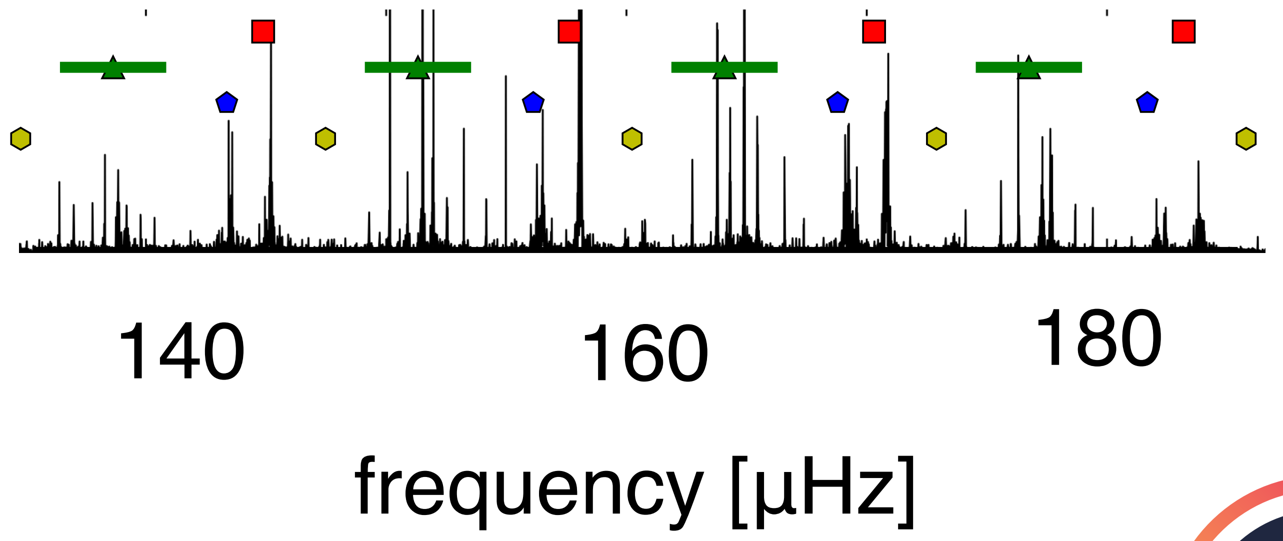
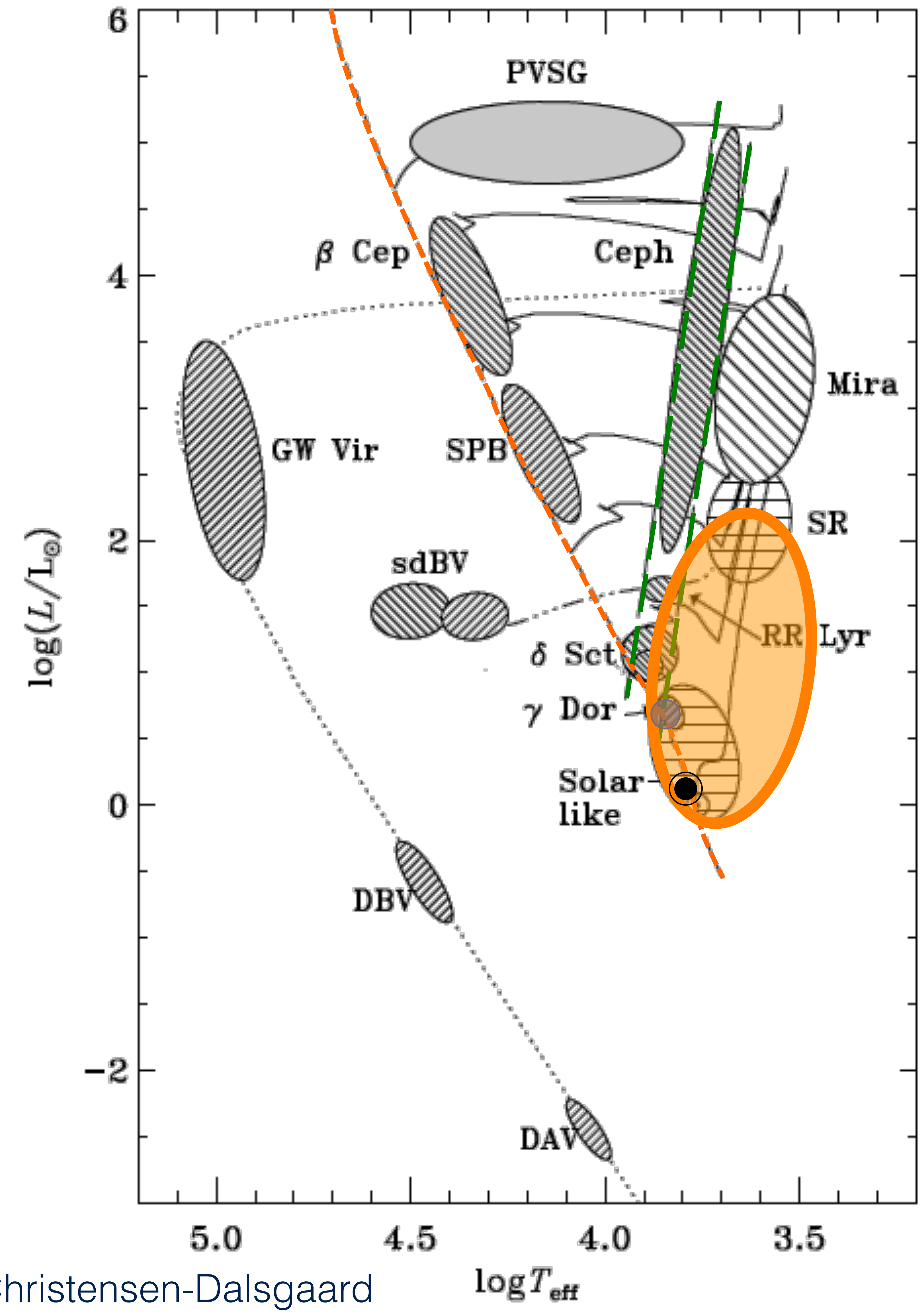
Kepler

asteroseimology

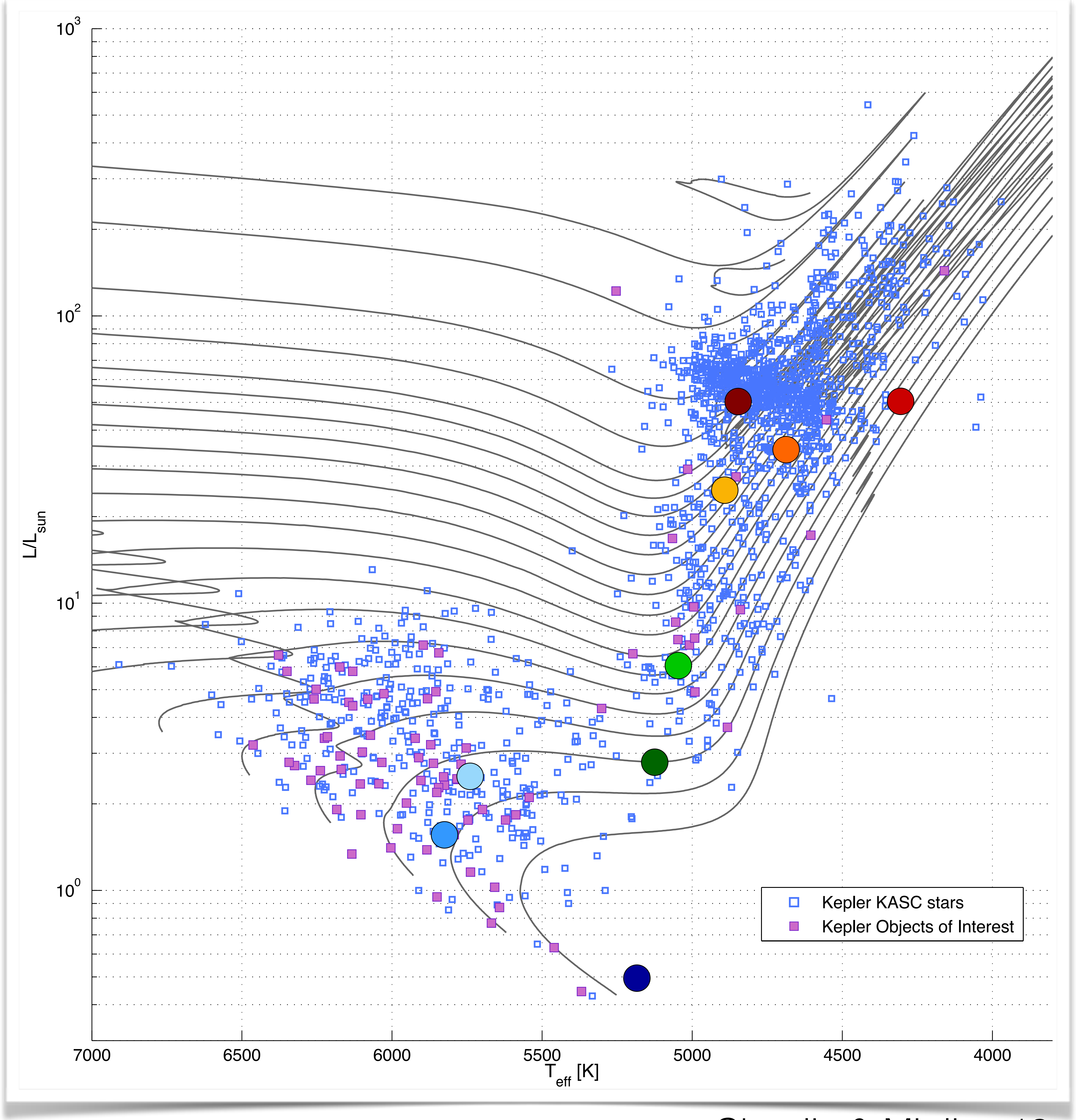


SOLAR-LIKE OSCILLATIONS



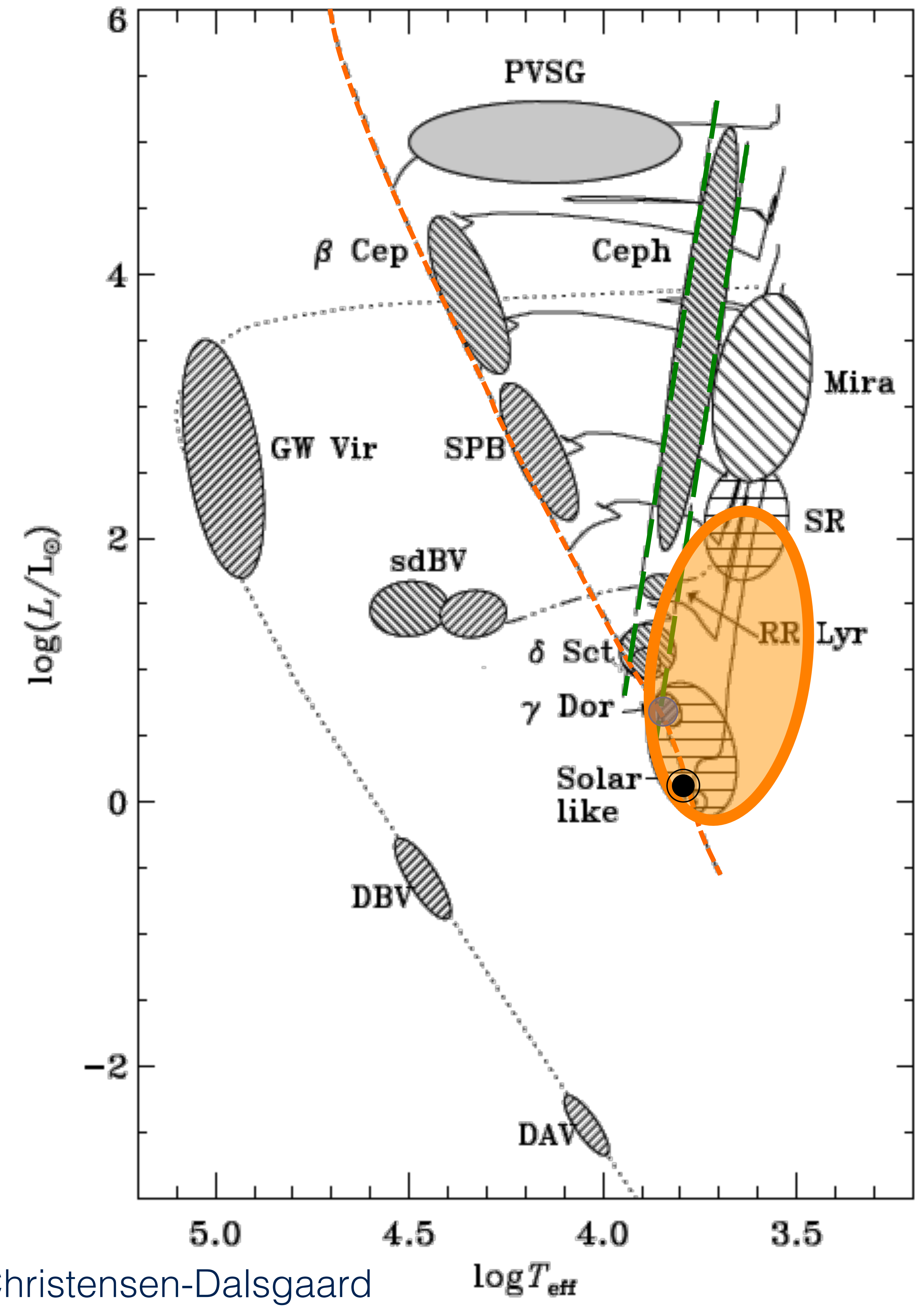
J. Christensen-Dalsgaard

Solar-like oscillators



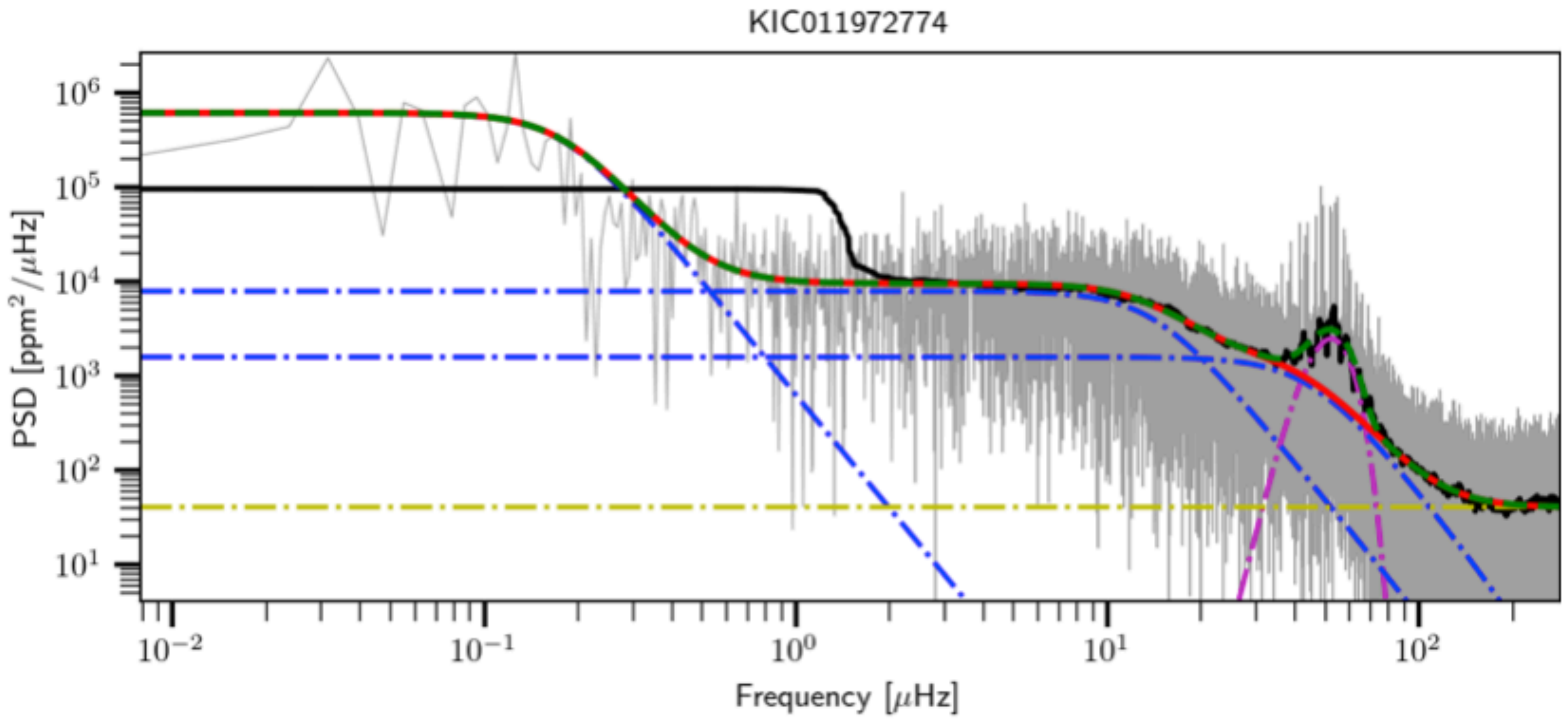
Chaplin & Miglio , 13

SOLAR-LIKE OSCILLATIONS

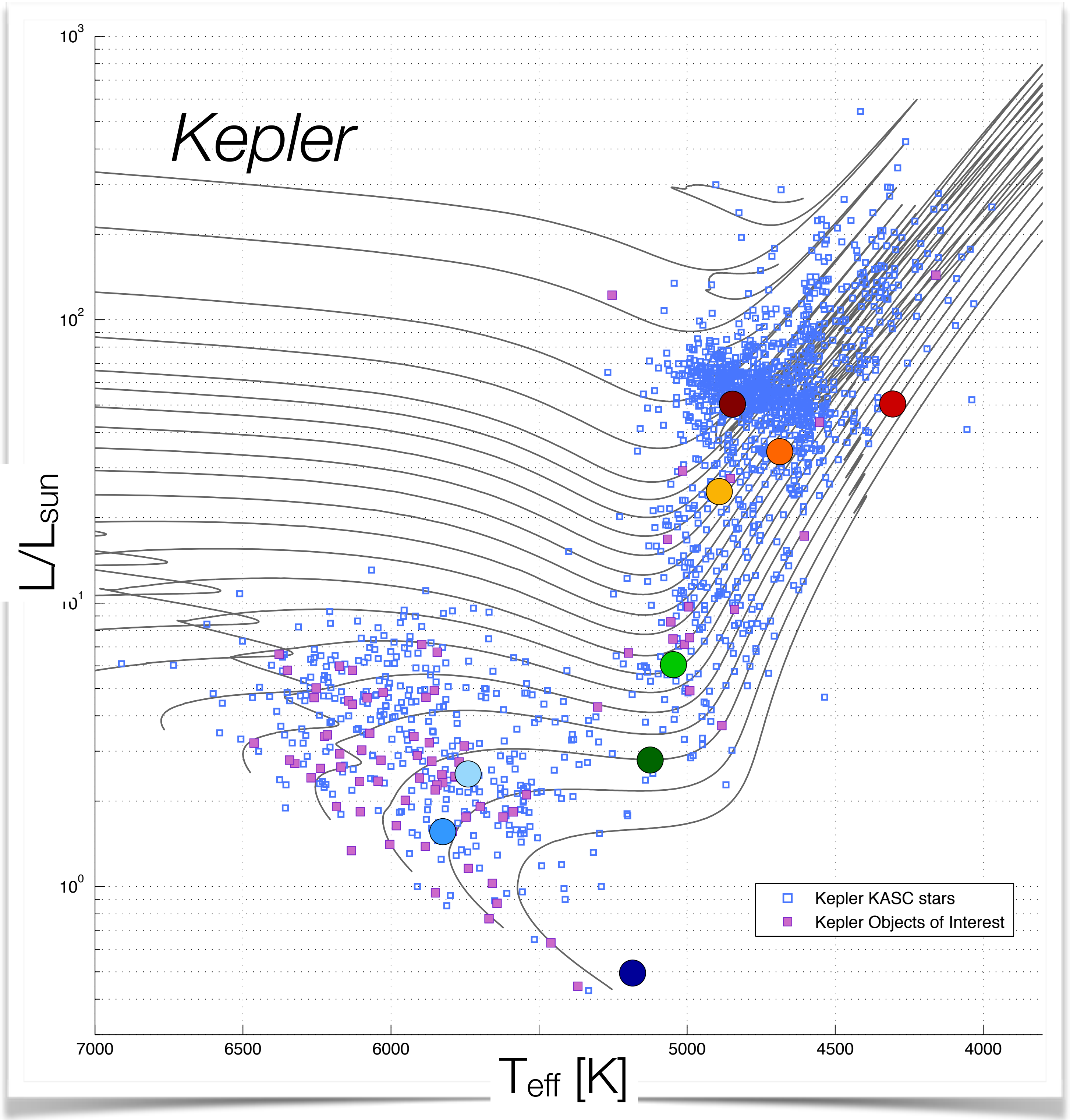


J. Christensen-Dalsgaard

- Oscillations intrinsically dumped but forced by Convection.
- Convection => Red border of Classical Instability stript.
- Multiperiodic oscillators, radial and non-radial, mixed g/p character



SOLAR-LIKE OSCILLATIONS

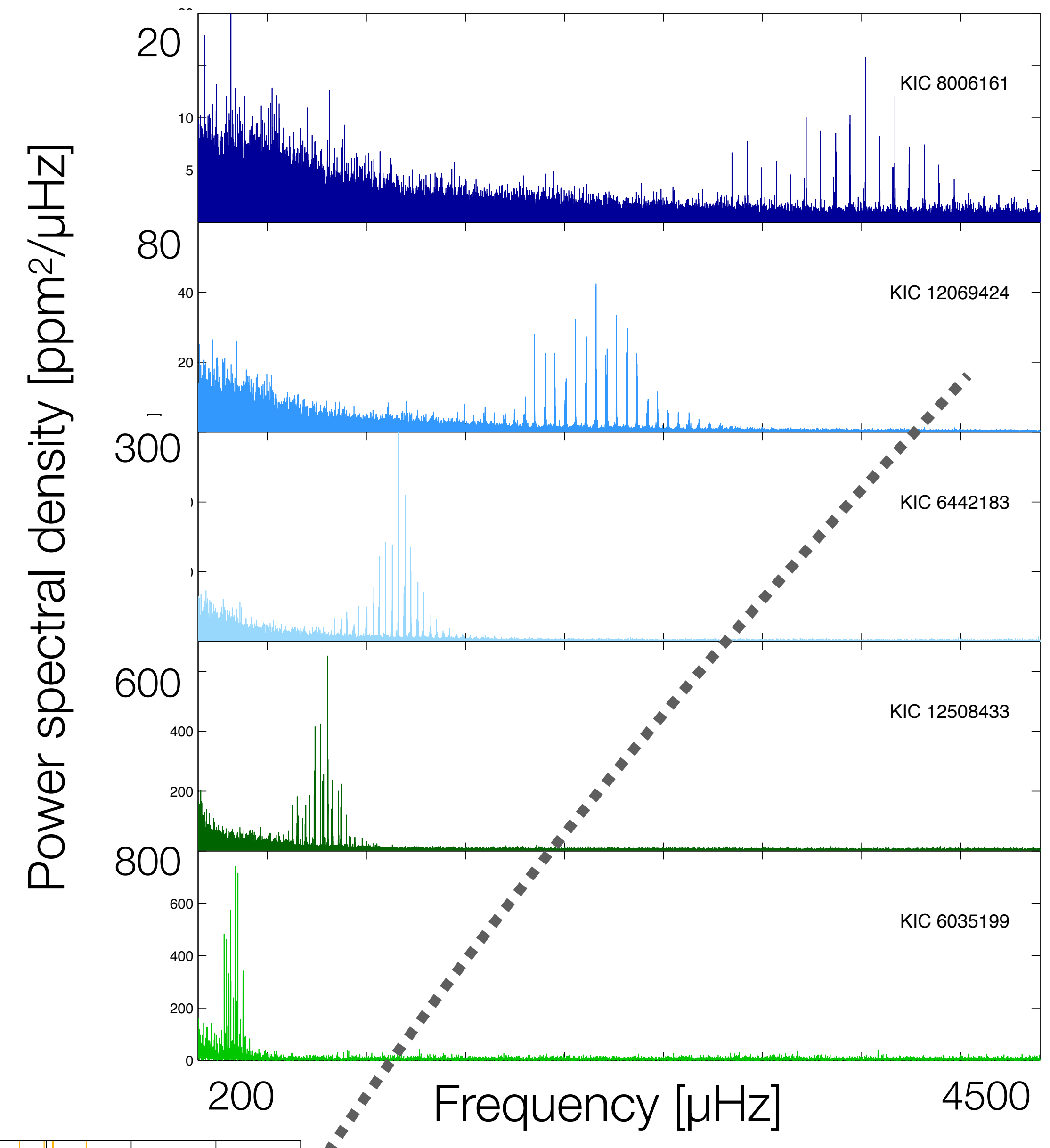


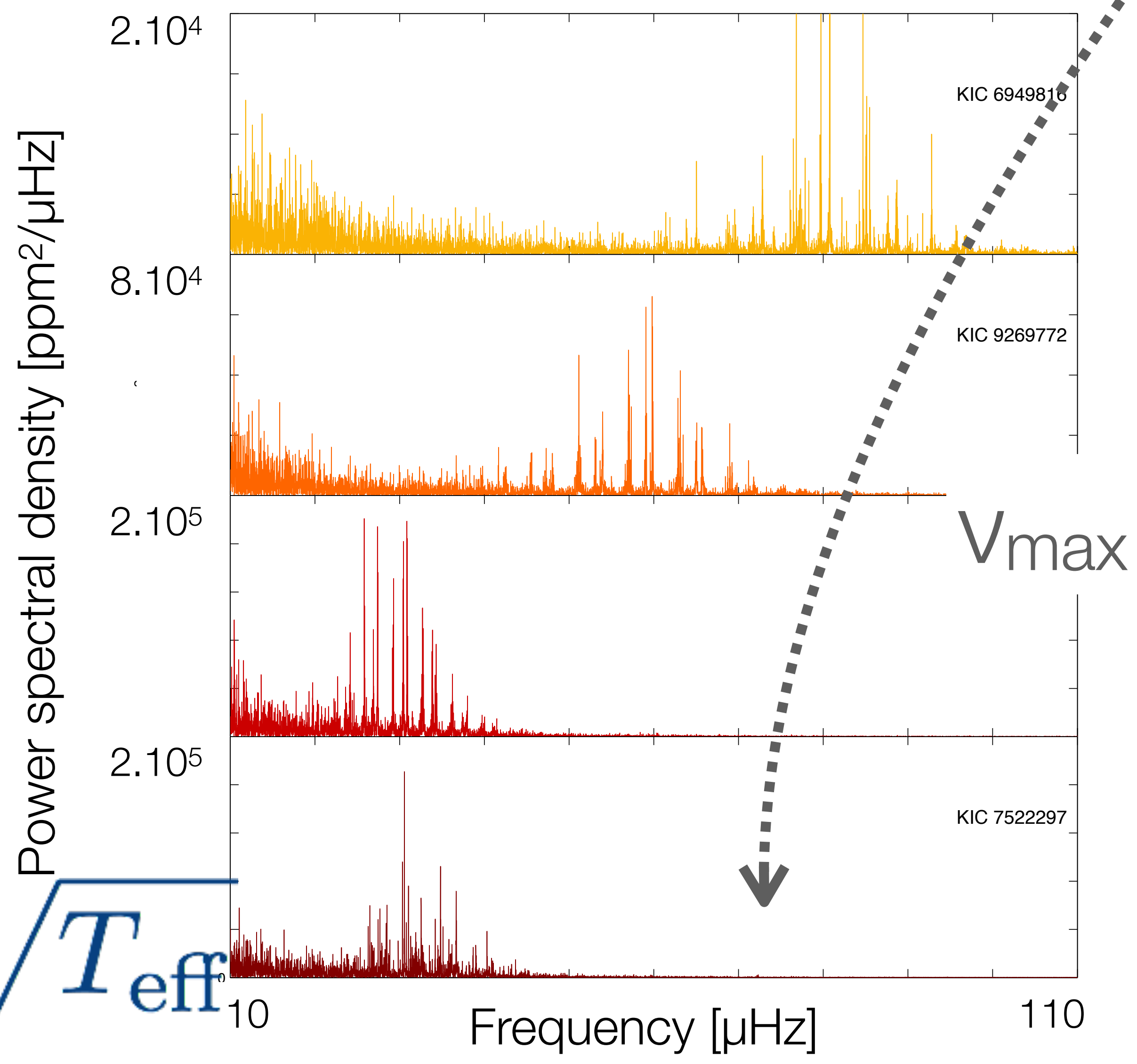
Chaplin & Miglio 2013

Solar-like oscillators

- Periods: minutes to hours
- Intrinsically damped, but forced by turbulent convection
- Amplitudes: ppm-tens of ppm
- Acoustic modes: radial and non-radial (~ asymptotic regime)
- In subgiants/giants: p-g mixed modes (probing inner regions)

MS/Subgiants



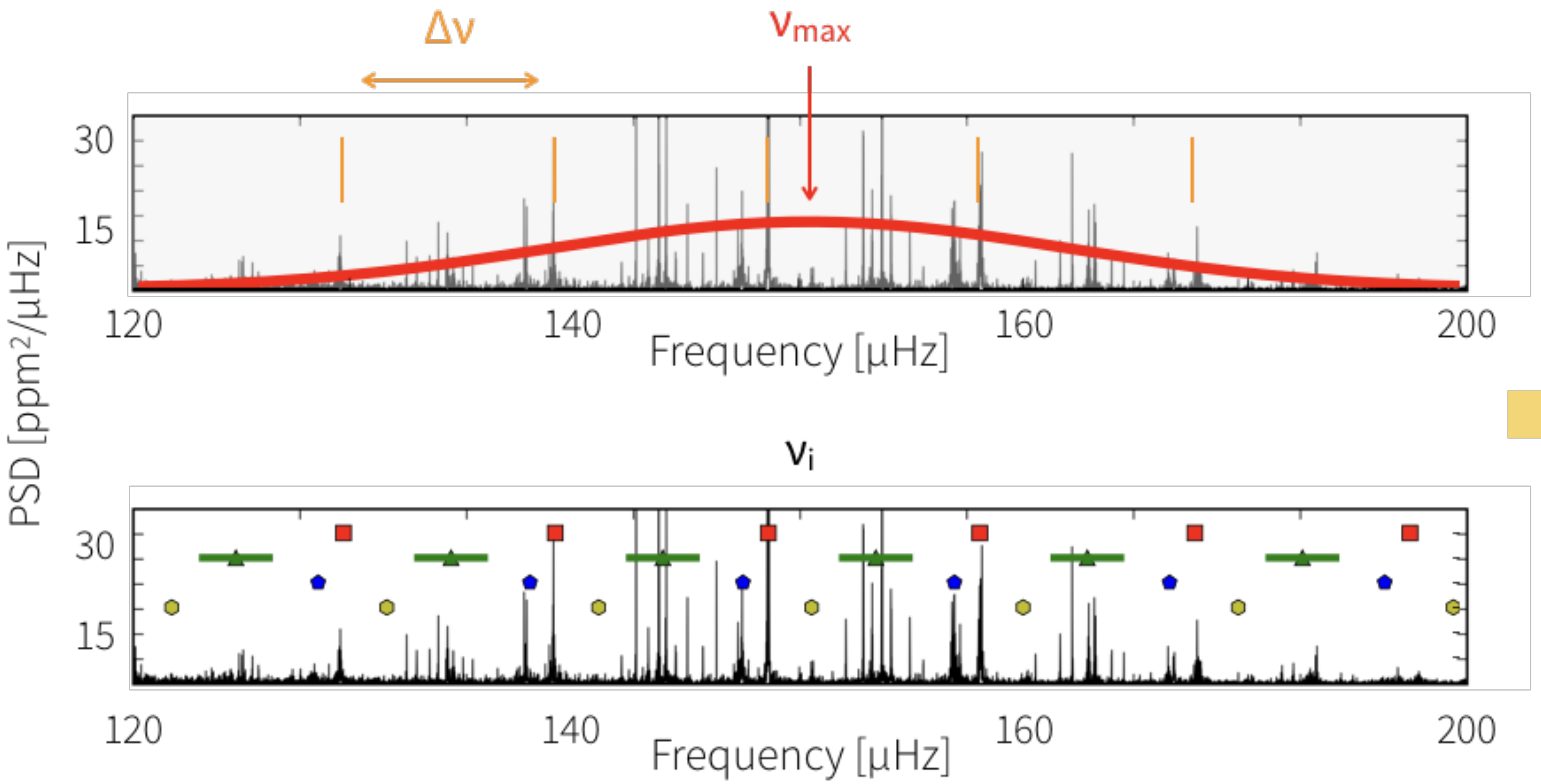


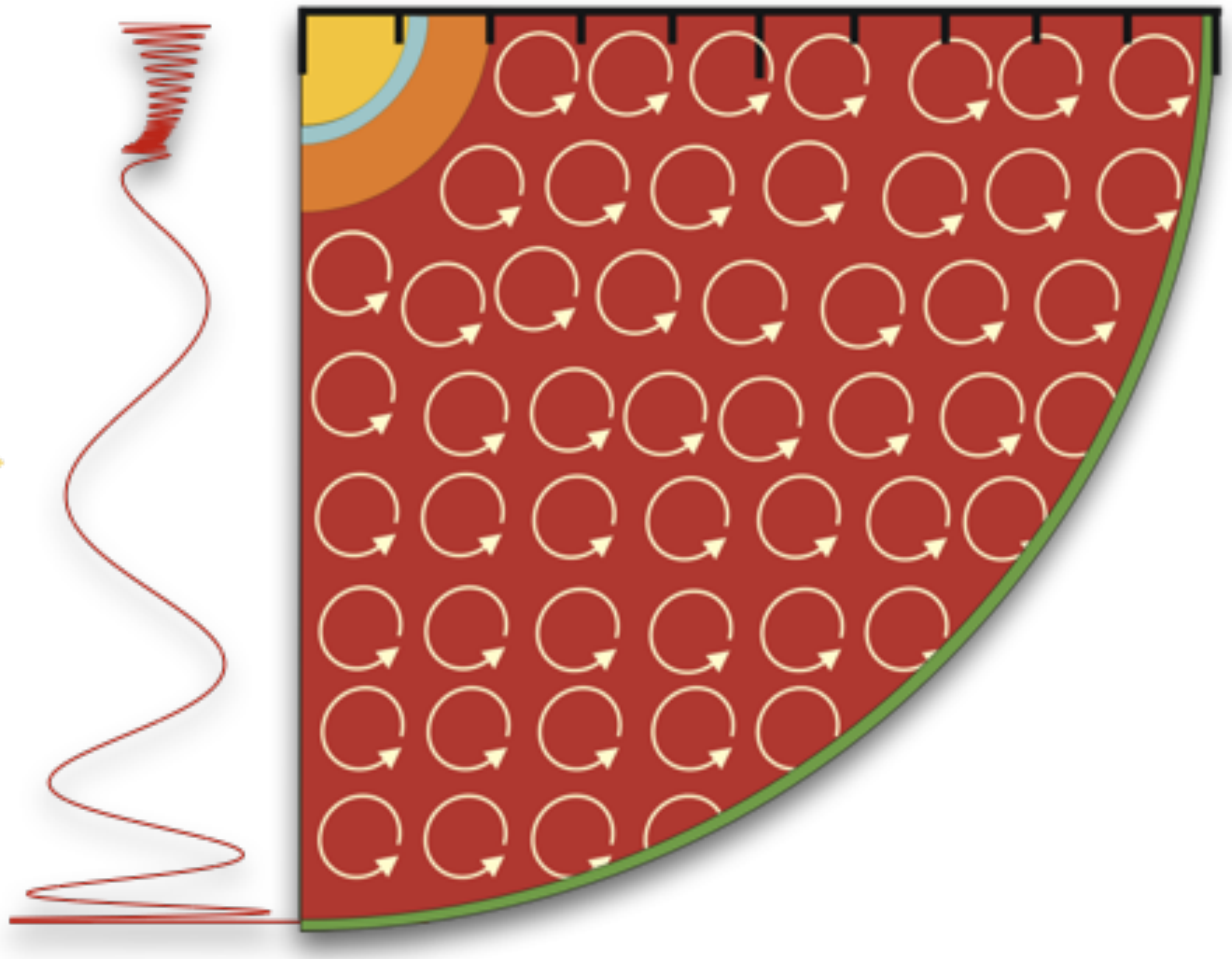
Red giants

ν_{max} ~ surf. gravity

$$\nu_{\rm max} \propto \nu_{\rm cutoff} \propto g/\sqrt{T_{\rm eff}}$$

SOLAR-LIKE OSCILLATION SPECTRA





Frequencies of modes or regular patters in freq. or period: $\langle \Delta\nu \rangle^2 \propto \bar{\rho}$ ΔP ,$\delta\nu_{02}$ ...

Info. density profile or at least mean density

+

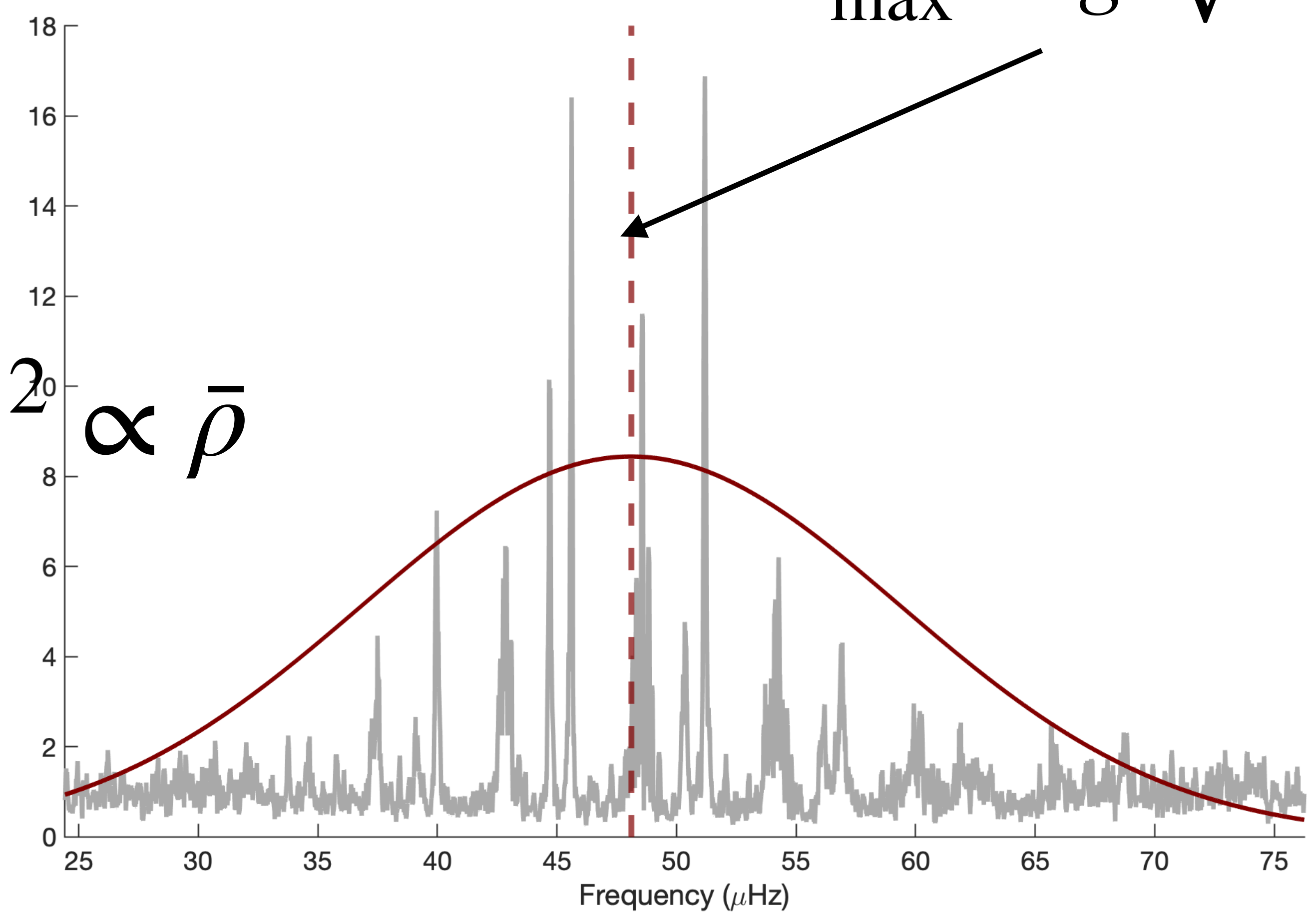
Radius (or equiv.)

MASS

Solar-like oscillations in Red Giants: scaling relations

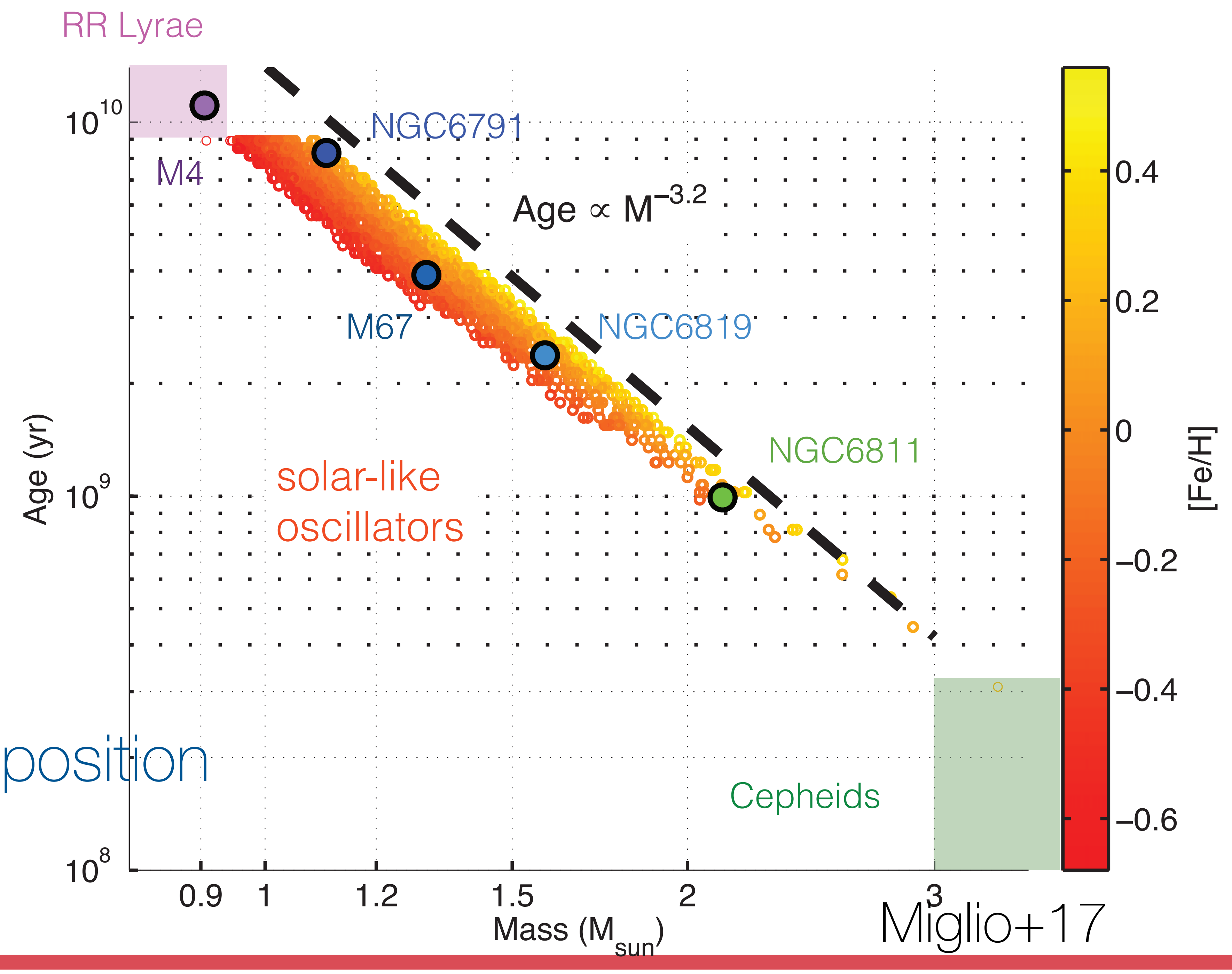
$\nu_{\max} \propto g/\sqrt{T_{\rm eff}}$

$\langle \Delta\nu \rangle^2 \propto \bar{\rho}$



Regular patters: ΔP as proxy of Evol. State (if available)

- $\log g = \log g_\odot + \log\left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right) + \frac{1}{2}\log\left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)$
- $\frac{R}{R_\odot} \simeq \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)\left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2}\left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{1/2}.$ → **Distance**
- $\frac{M}{M_\odot} \simeq \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)^{3}\left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-4}\left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{3/2},$



Miglio+17

in red giants AGE is determined
- firstly by Initial stellar mass
- secondly by the chemical composition

And many more, e.g.: Pinsonneault+14,18(APOKASC-1/2) Rodrigues+17; Valentini+19; Anders+15, Miglio+09,13, Stello+10, Mosser+10,11…

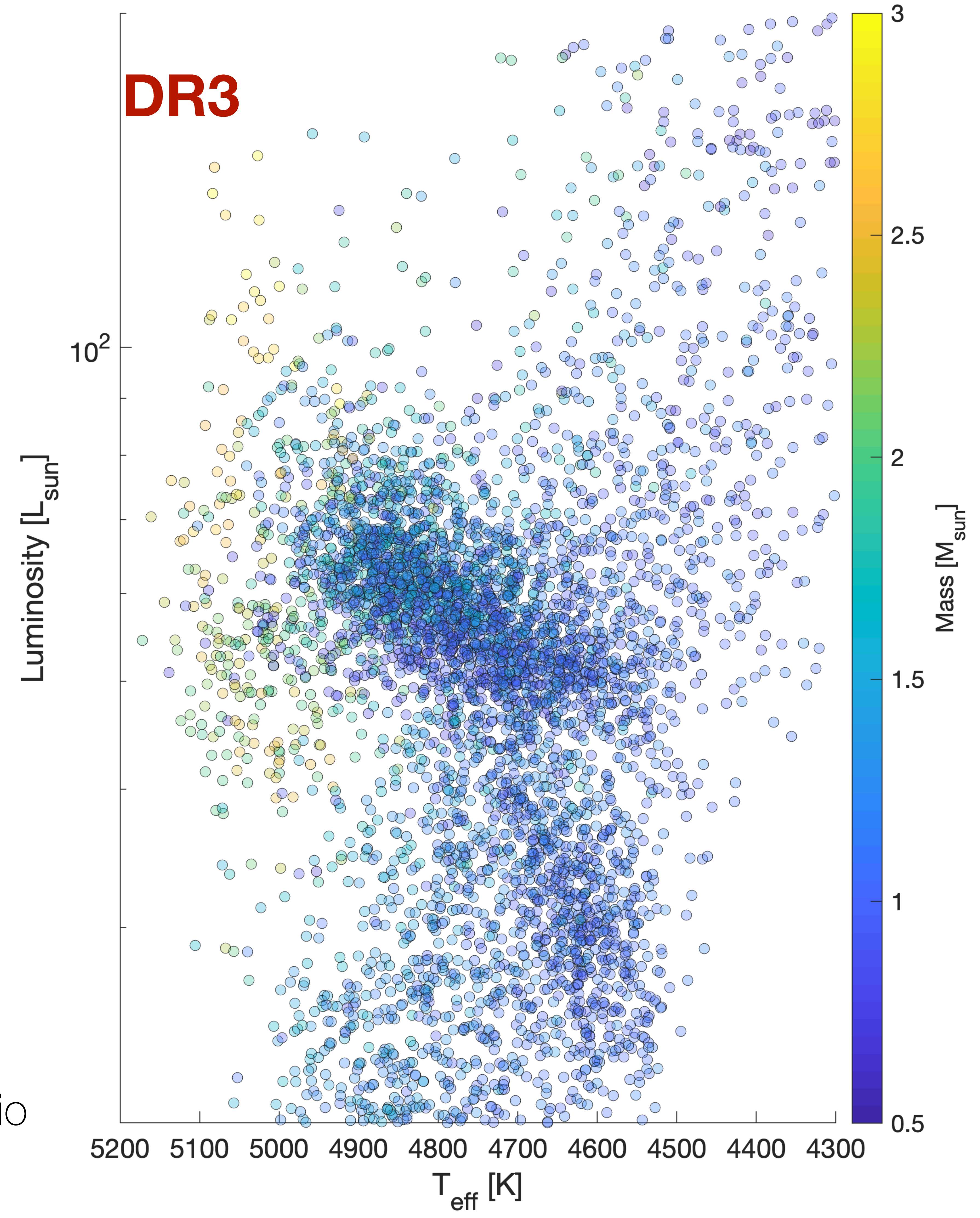
Even if M and R are known with high precision and accuracy

AGE IS ALWAYS MODEL DEPENDENT

And one needs to know the relation between current MASS and initial MASS

HRD of red giants in Kepler field

Sismo
+
Gaia **DR3**
+
APOGEE



credits: A.Miglio

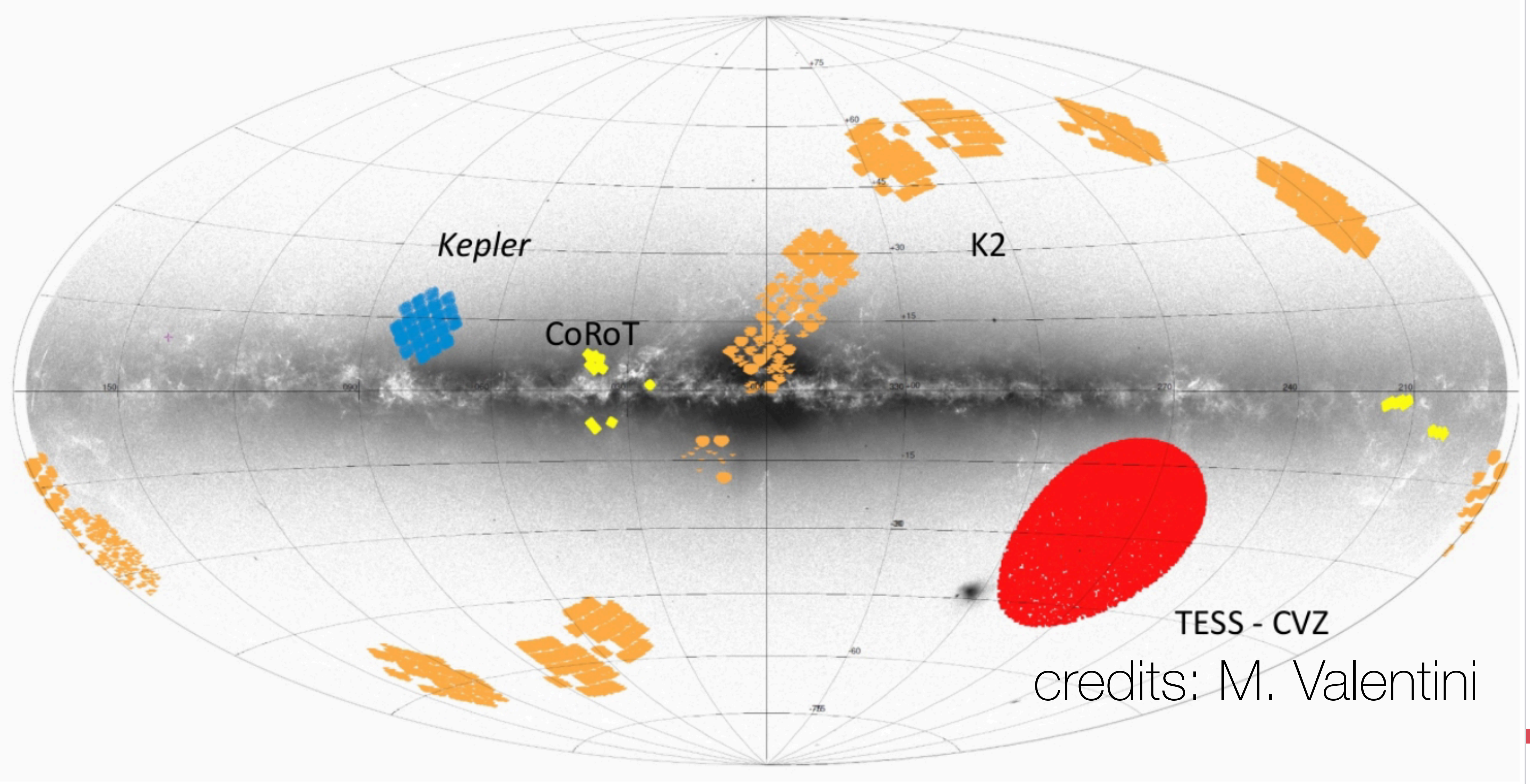
5400 *Kepler* Red Giants

$\Delta\nu$ + ν_{max} and ΔP

3300 RGB

APOGEE - DR14

T_{eff}, σ_{Teff} =75K
[Fe/H], $\sigma_{[Fe/H]}$=0.03
[α/Fe], $\sigma_{[\alpha/Fe]}$=0.012



credits: M. Valentini

Age dissection of the MW discs (Miglio+21)

M, R , AGE and distances from code PARAM (da Silva+06, Rodrigues+17) based on a grid of models with:

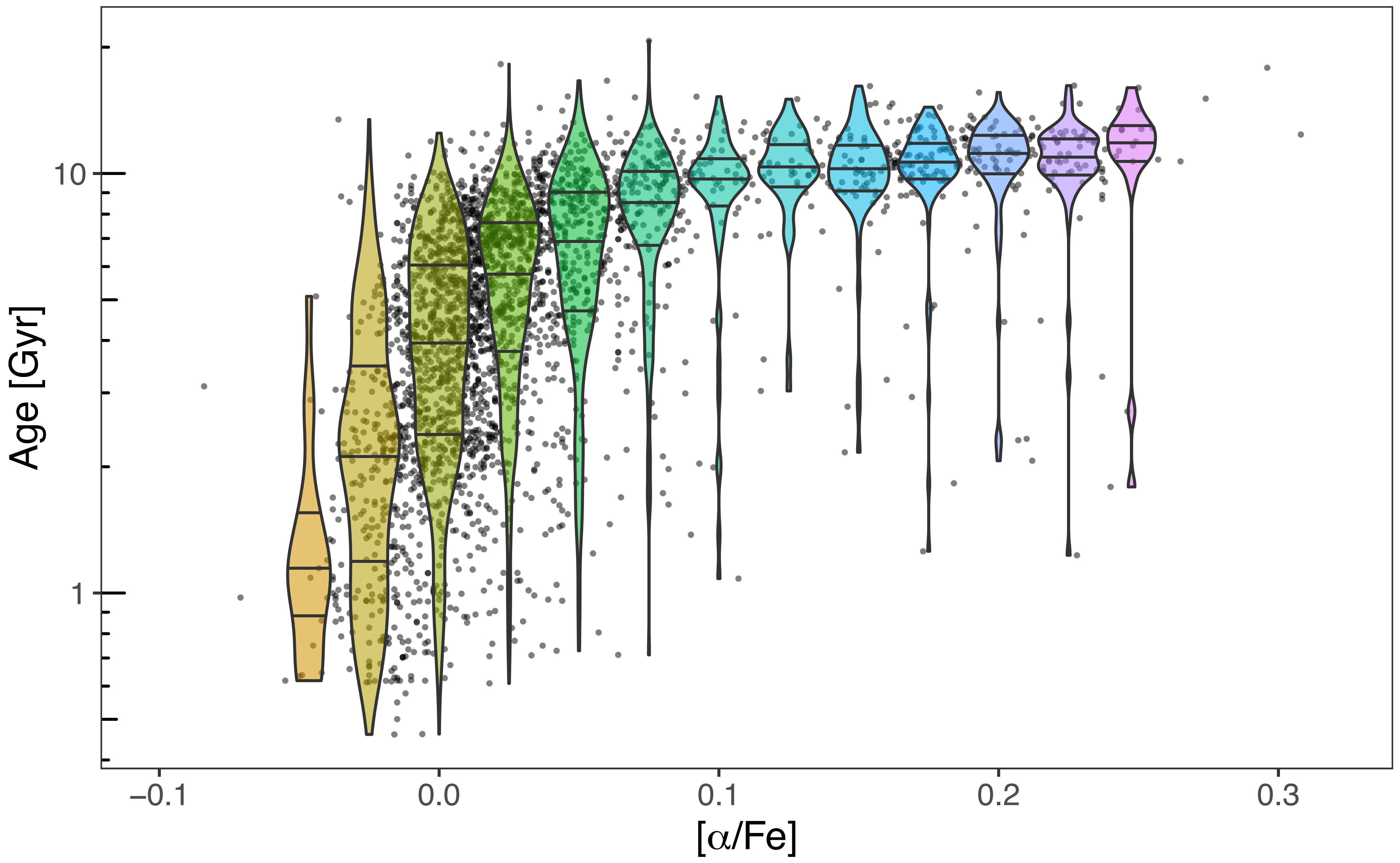
<Δv> computed from theoretical radial modes NOT from scaling

$$\nu_{\max} = \frac{M/M_{\odot}}{(R/R_{\odot})^2\sqrt{T_{\rm eff}/T_{\rm eff\odot}}}\,\nu_{\max\odot}$$

ΔP -> select only RGBs (R < $11R_{sun}$)

3300 RGB: Median (random) uncertainties 6% and **23%** for M and AGE

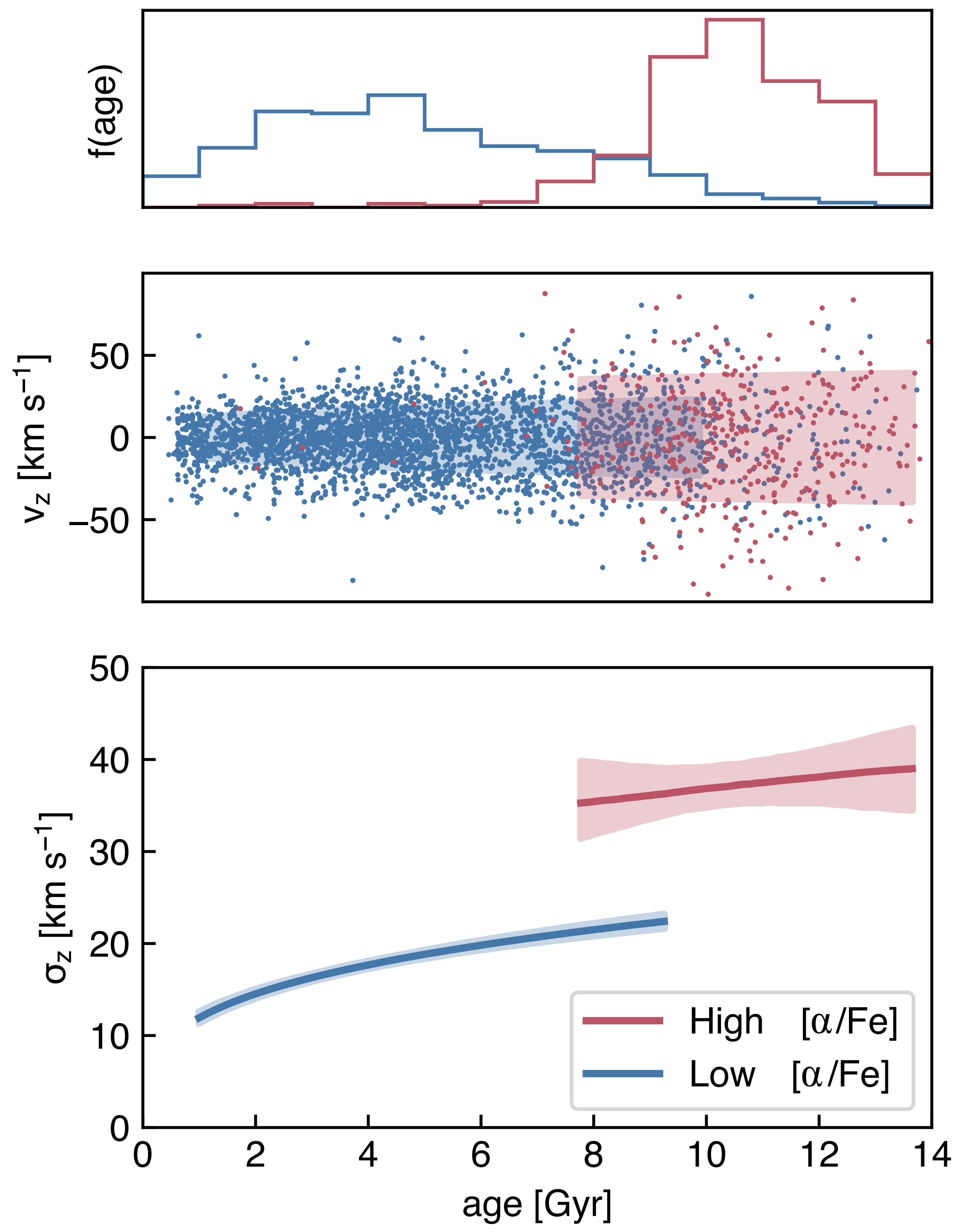
AGE-[α/Fe] in the solar neib.



The [α/Fe]-rich population is composed primarily of very old objects, older than most of the [α/Fe]-poor ones, and a very tight age-[α/Fe] relation for α-rich pop.
Mean AGE (α-rich) ~ 11Gyr with 95% of the population born within $1.52^{+0.54/-0.46}$ Gyr

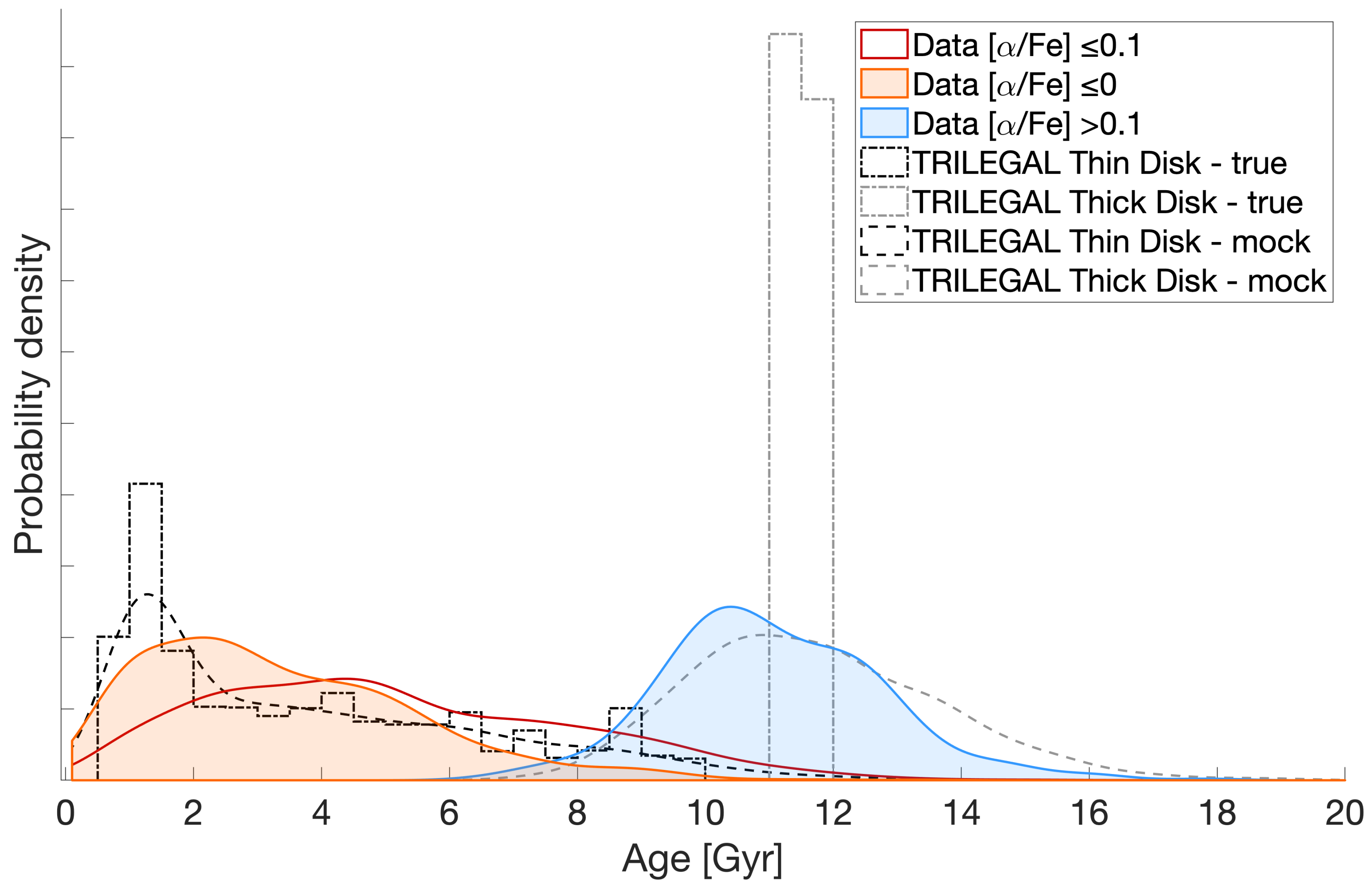
Age dissection of the MW discs (Miglio+21)

AGE-velocity dispersion (AVR)



The precision (~20%) in age allow to clearly see the abrupt change at 10Gyr and the difference in kinematics between the low- and high-[α/Fe] populations. => important observational constraint toward understanding the origin of this difference.

- Star formation rate halt after the formation of the thick disc (z~2)
- Evidence of radial migration: old metal rich likely born in the inner regions (2-4 kpc) are now in the solar vicinity.

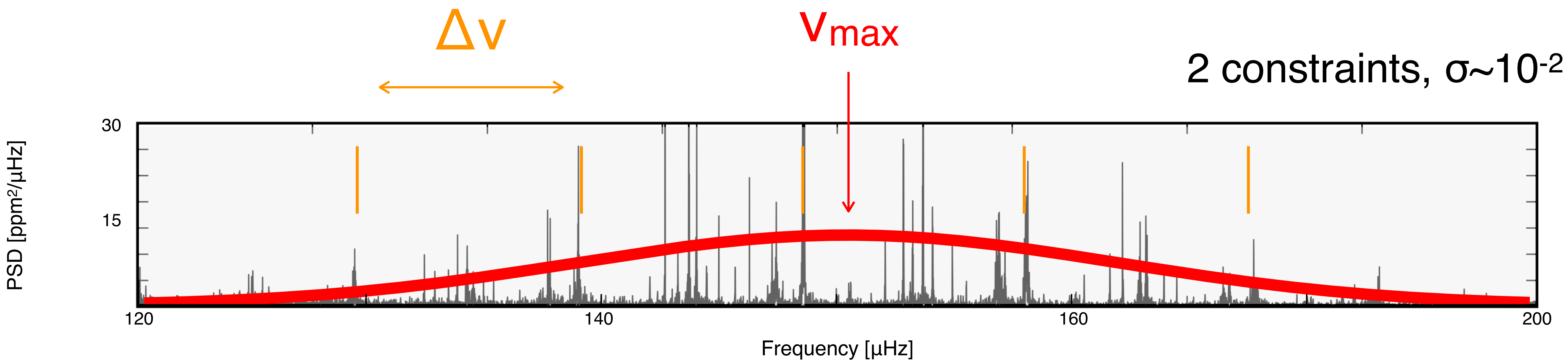


See also Aguirre+18 but with a much smaller number of Kepler stars

oscillation spectrum: global parameters or individual frequencies

- average seismic parameters

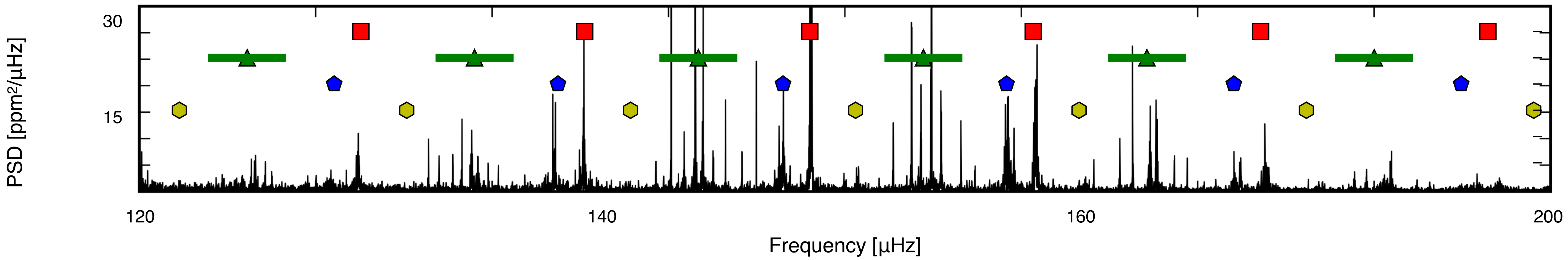
2 constraints, $\sigma \sim 10^{-2}$



- individual mode frequencies

ν_i

tens of constraints, $\sigma_i \sim 10^{-4}$

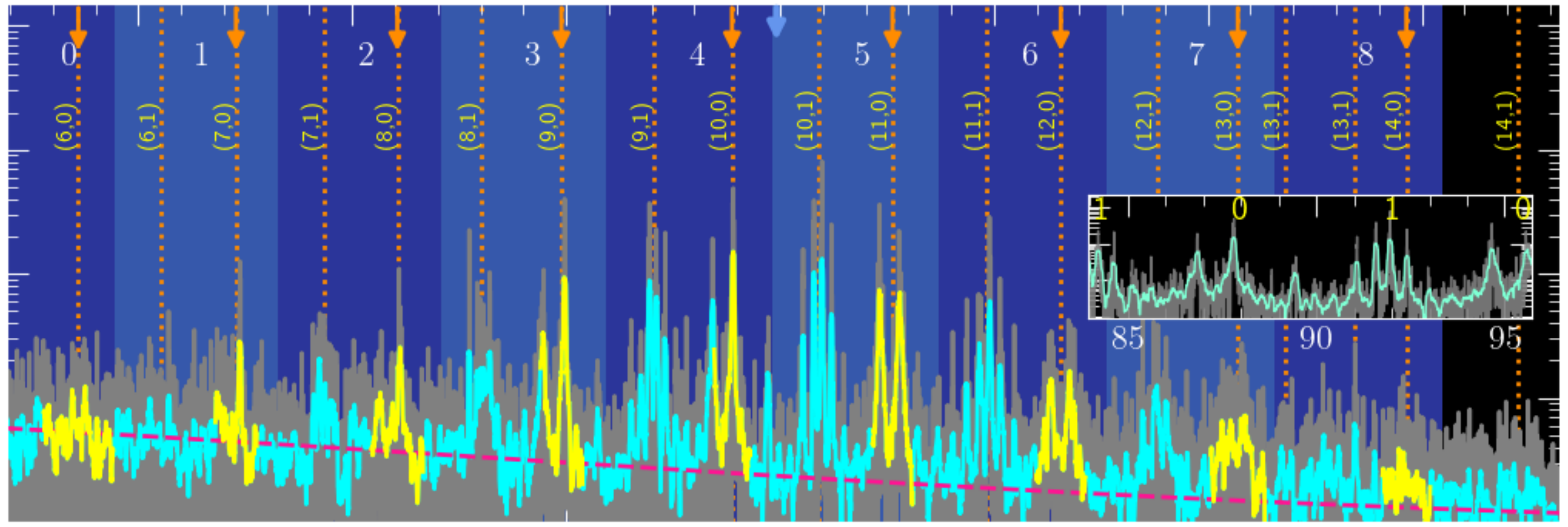


R, M, age, detailed properties of the internal structure

Methodology

Obs. constraints

- Extract and identify individual frequencies of radial $\{\nu_{0n}\}$ and quadrupole (ν_2) modes for the seismic sample + global seismic parameters: $\Delta\nu$, ΔP, ν_{max}



+crossmatch with different pipelines: FAMED (Corsaro) x PBJam (Nissen) x ABBA (Kallinger)

- APOGEE-DR17 => Teff [Fe/H] [α/Fe]

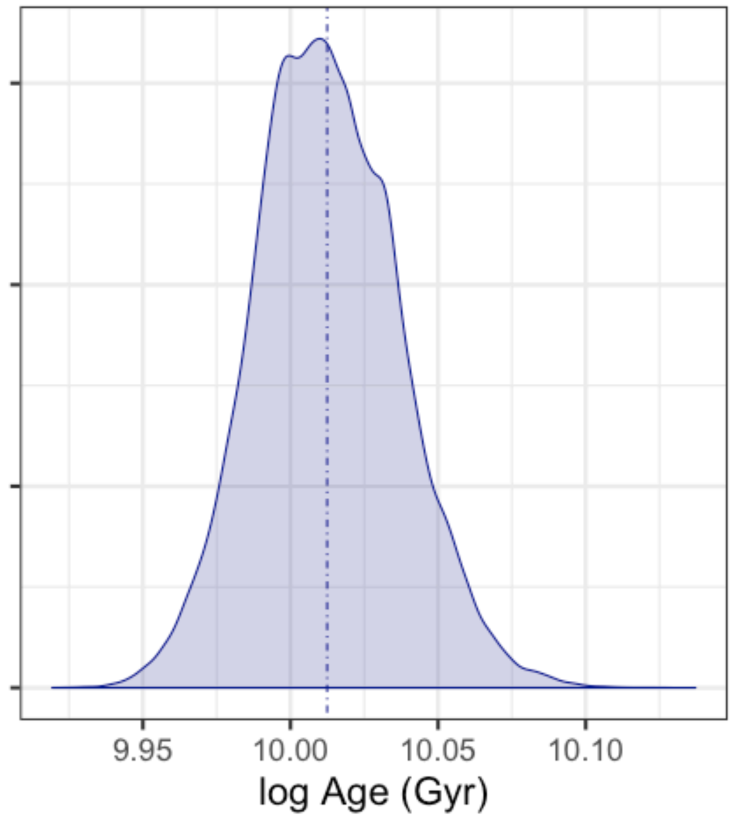
AIMS : Asteroseismic Inference on Massive Scale (Reese2016, Rendel+19):

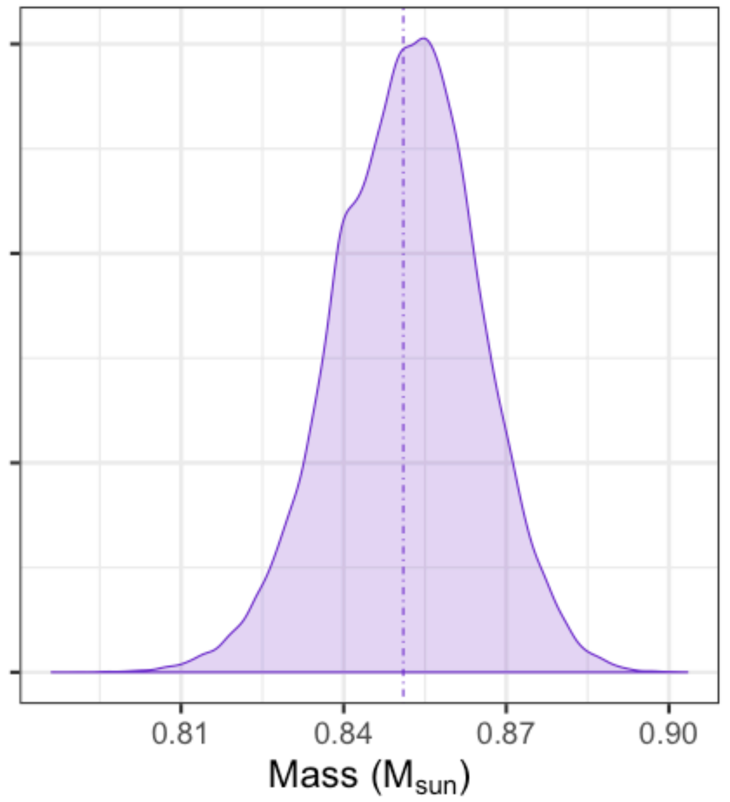
Bayesian inference + MCMC sampler.

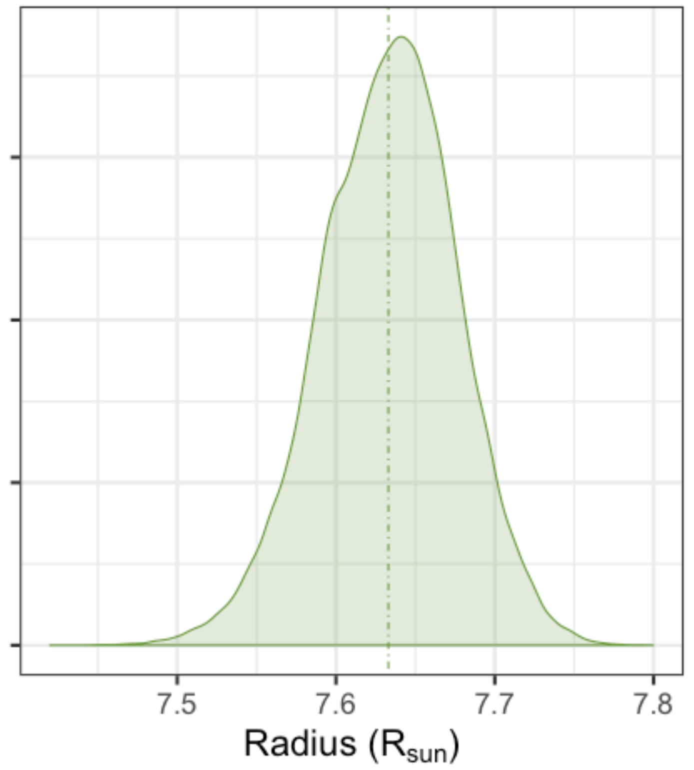
+ Grids of stellar evolution models (CLES) & theoretical frequencies (LOSC)

interpol. parameters: M, Z_0, Age

& surf. effect corrections

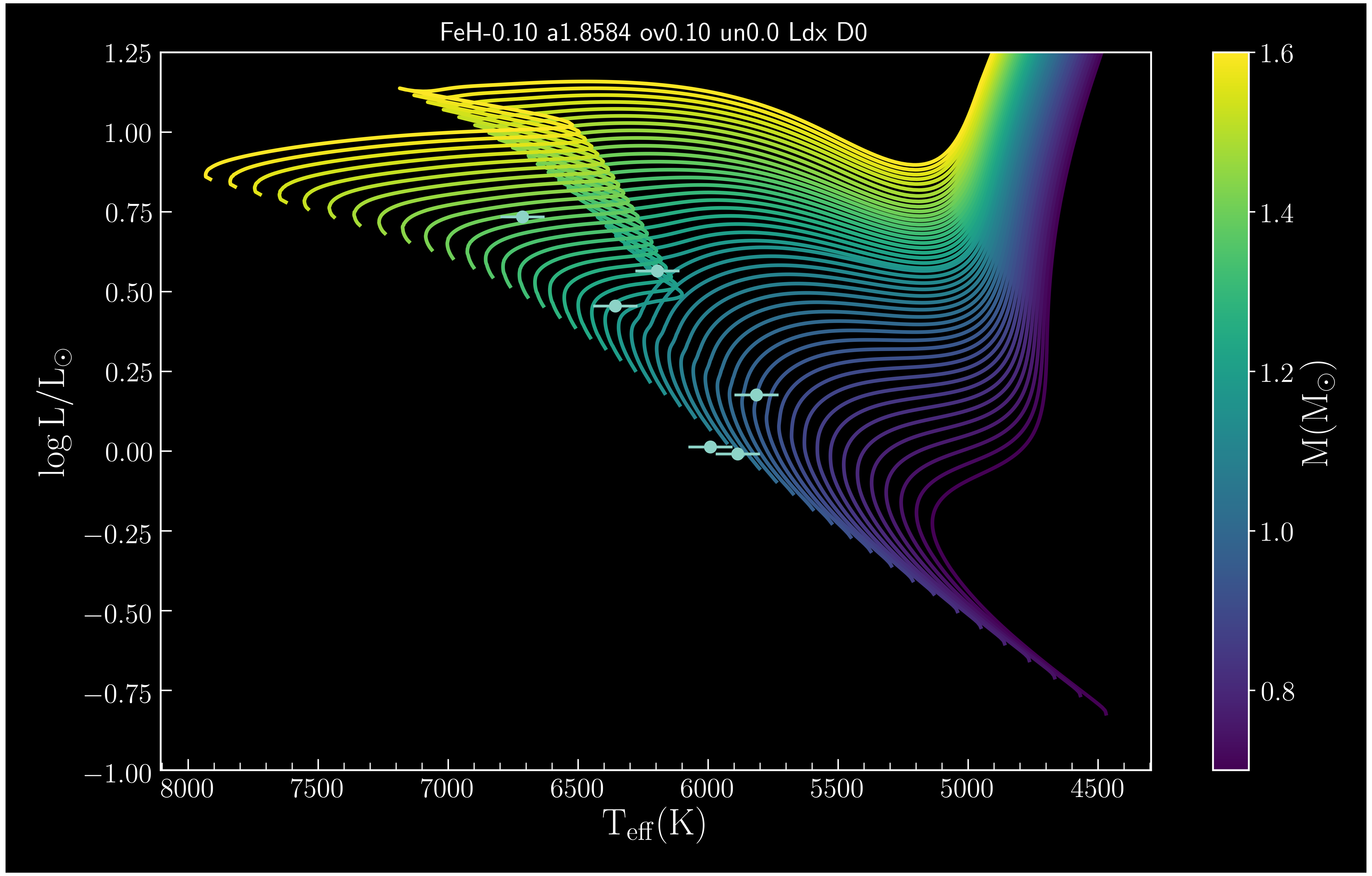






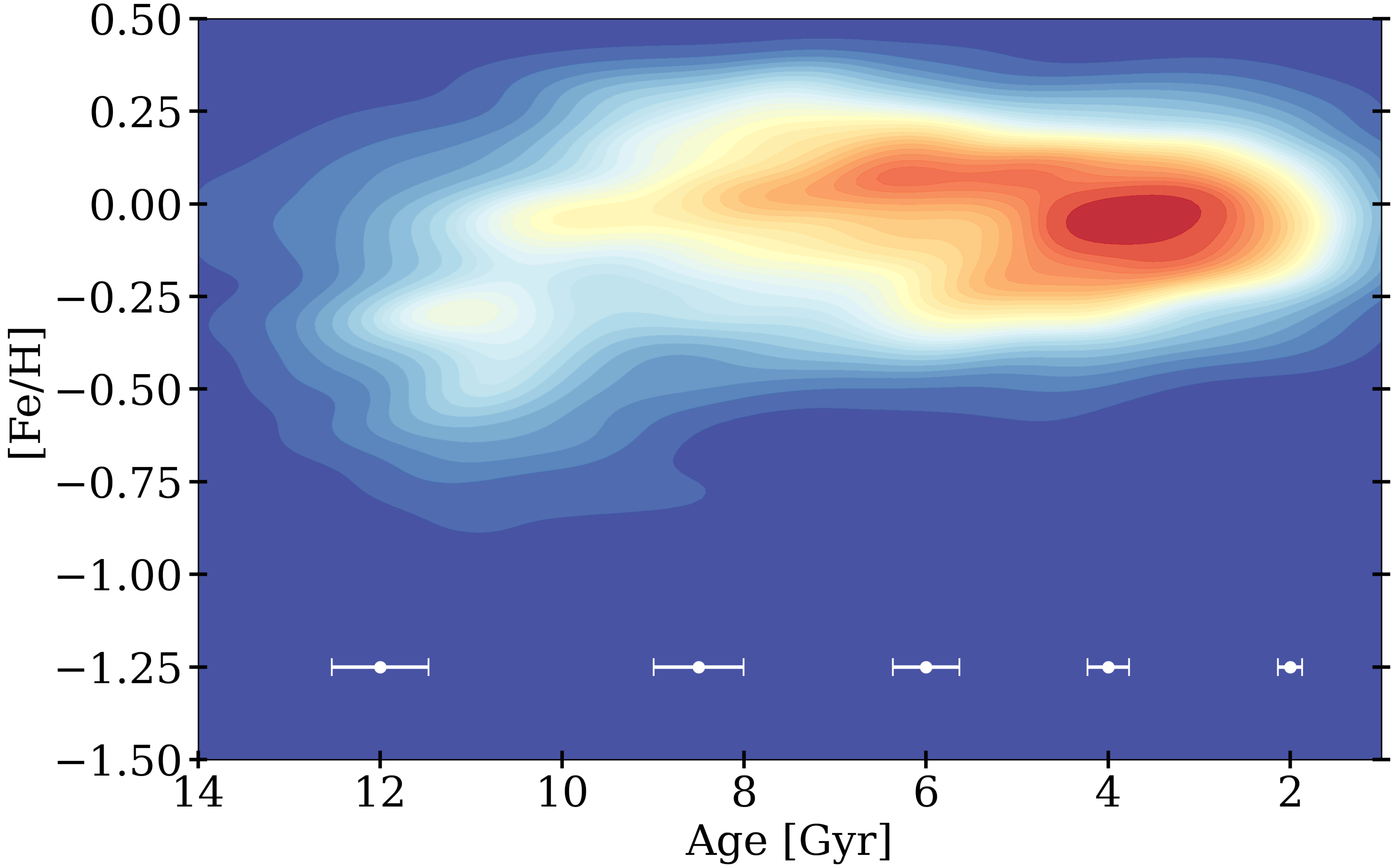
Grid of stellar models

- Stellar models with code CLES (Scuflaire +08) from PMS to RGB (25 Rsun)
- M: 0.6 - 2.5 Msun (step 0.02)
- [Fe/H]: -4.5 to 0.6
- [α/Fe]: -0.1; 0.0; 0.1; 0.2; 0.3; 0.4; 0.5 and 0.6
- Asplund+09 solar mixture
- ΔY/ΔZ= 1.0; 1.5. and 2.0
- OPACITY Tables for each metal mixture (OPAL + Wichita University tables for low temperature)
- Microscopic diffusion
- Small core-overshooting (0.1)

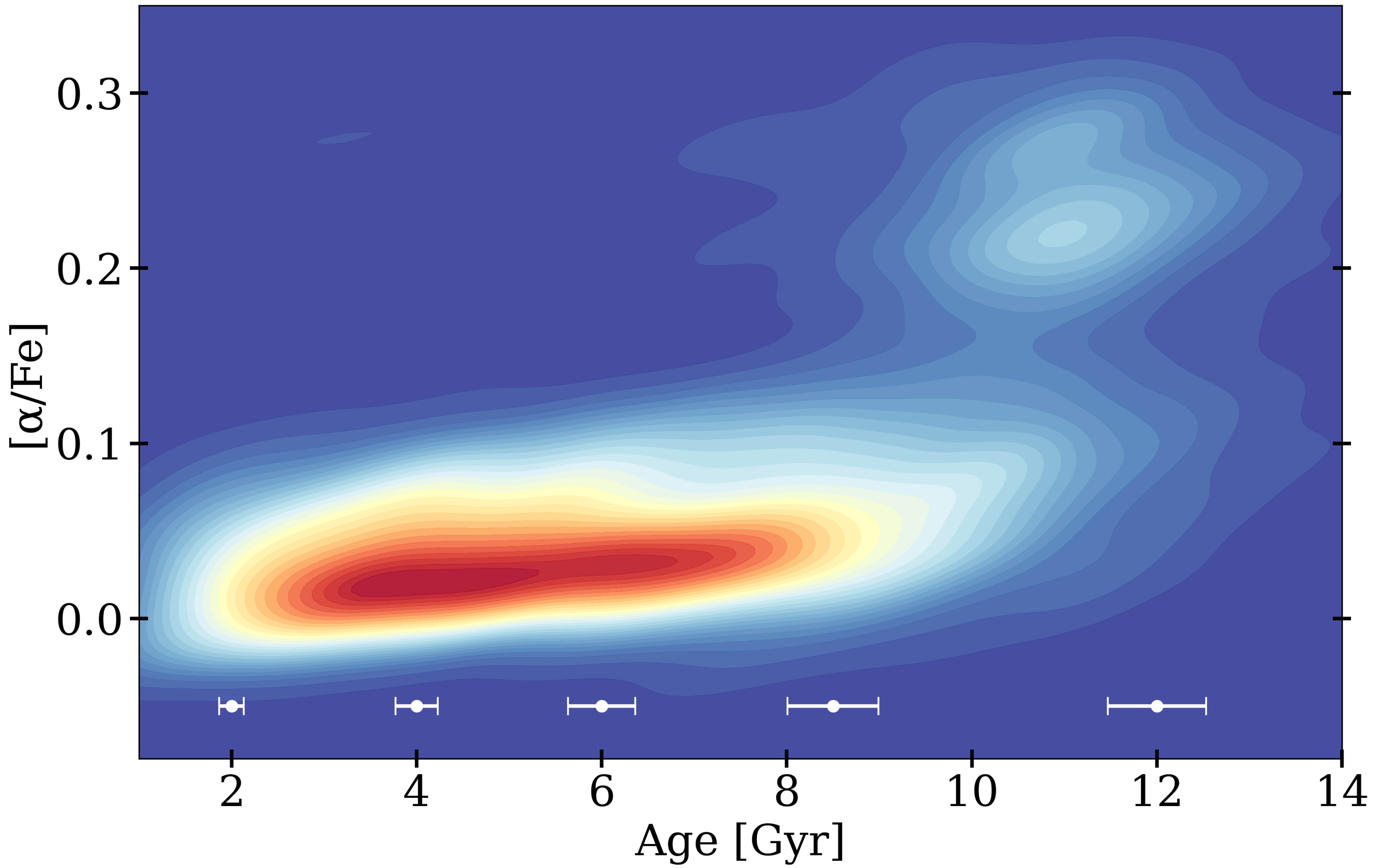


- Adiabatic radial mode frequencies for each model from ZAMS until end of the track

Stellar AGES



- SAMPLE of Kepler RGBs survived after all the steps: **2325**



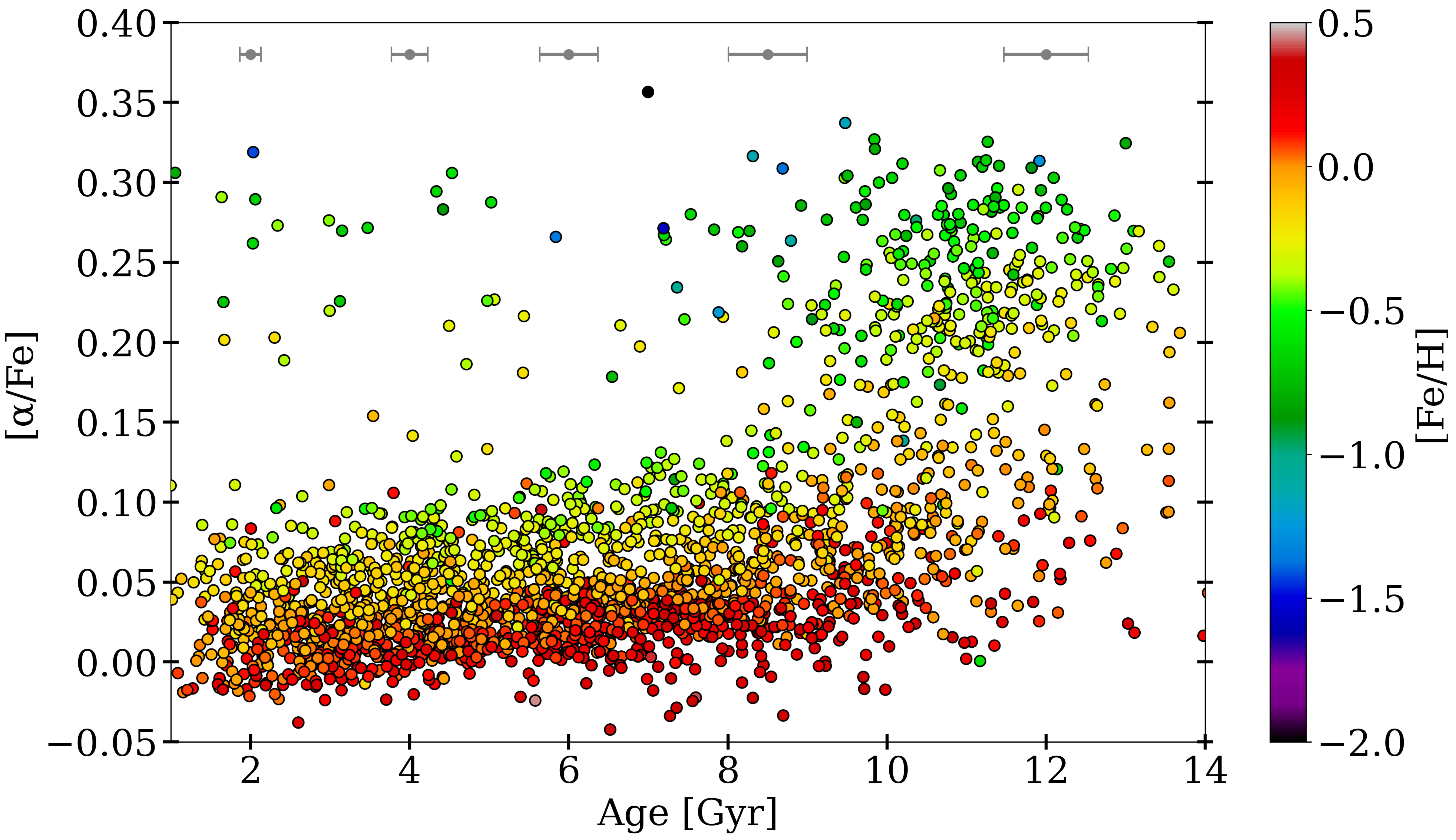
See also Rendel+19, Chaplin+20, Montalban+21, Poster by J. Sinkbæk Thomsen

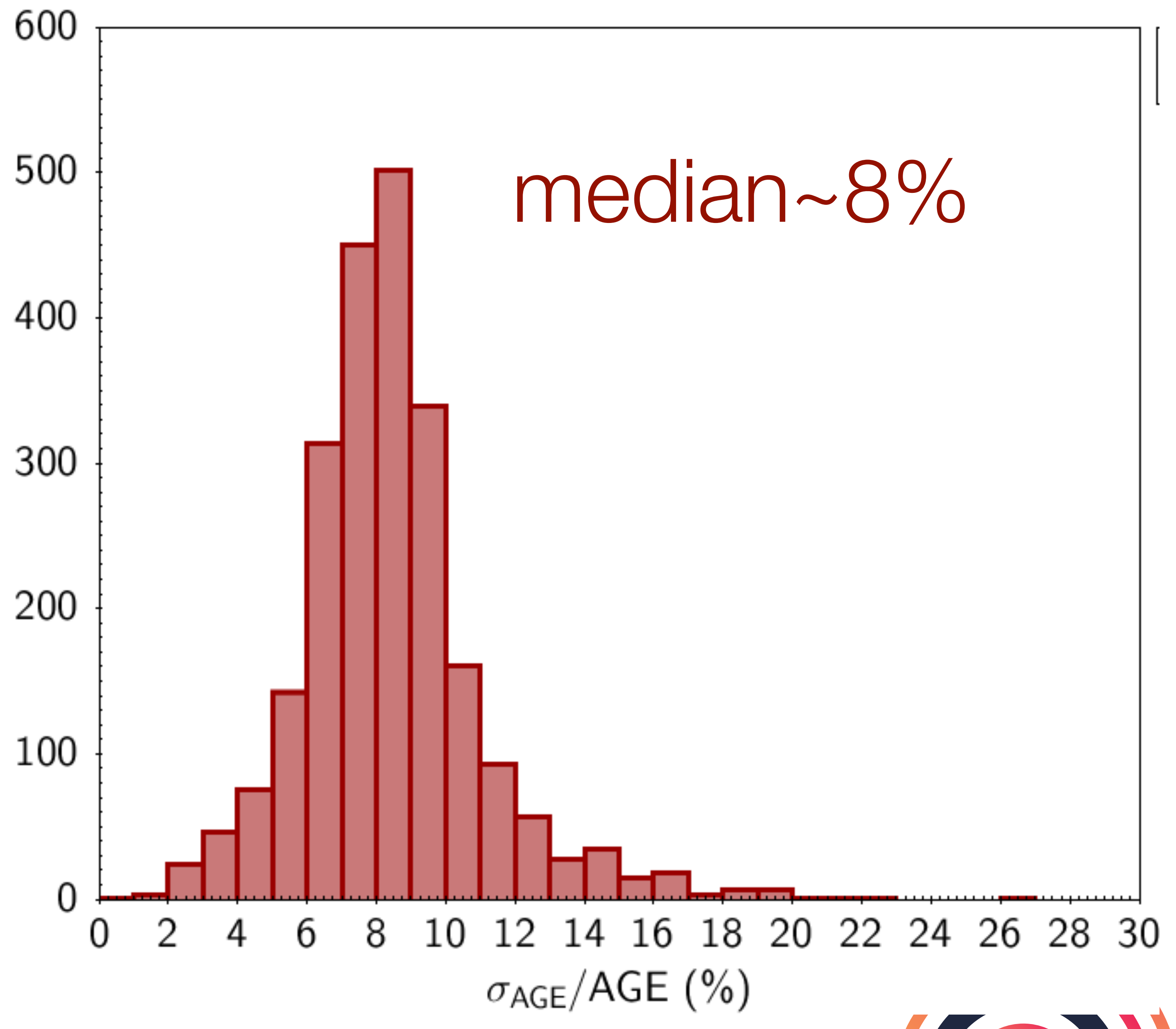
Stellar AGES

AGE inferred from best fit of :

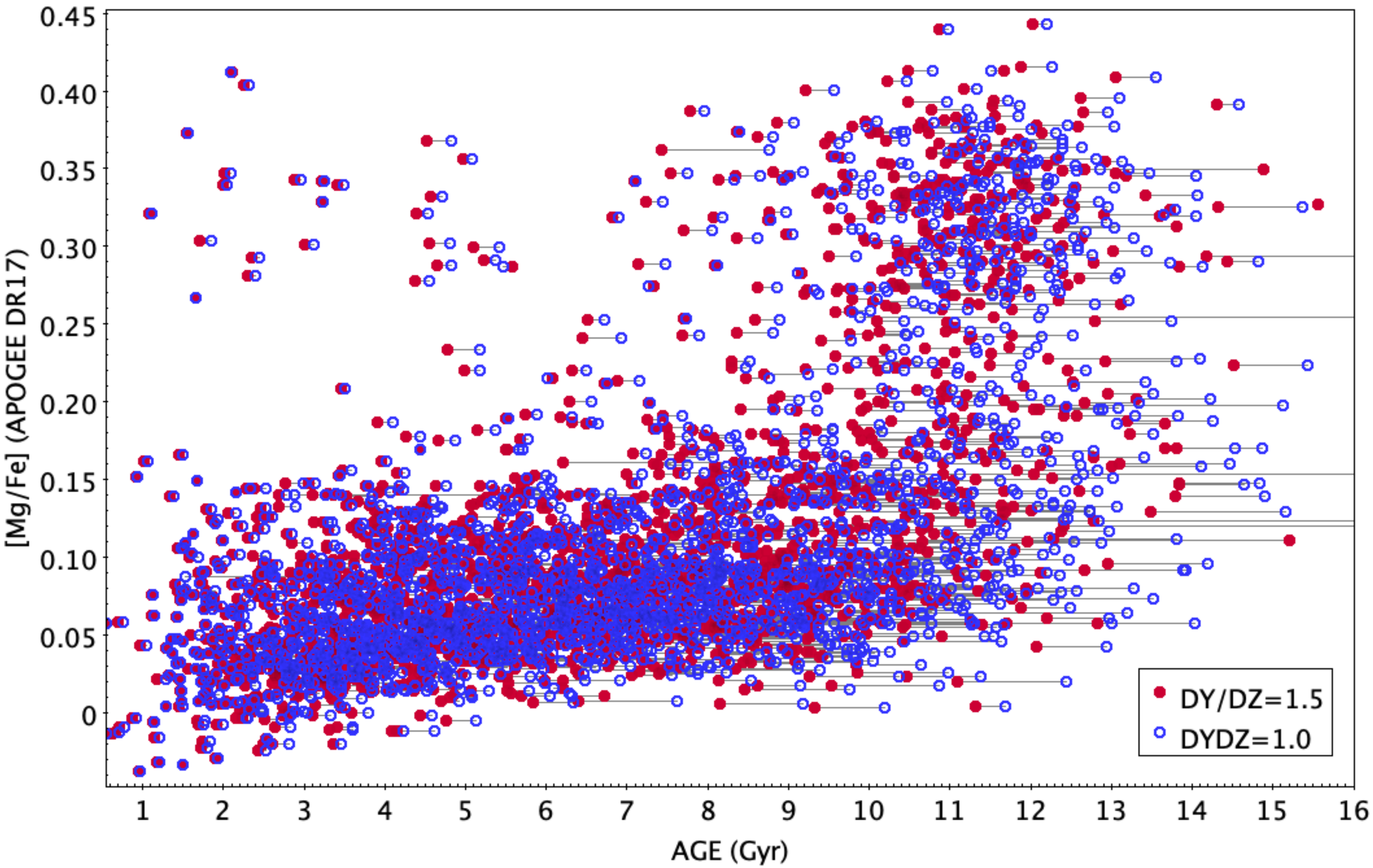
individual frequencies

ν_{max}, Z/H_surface , Teff

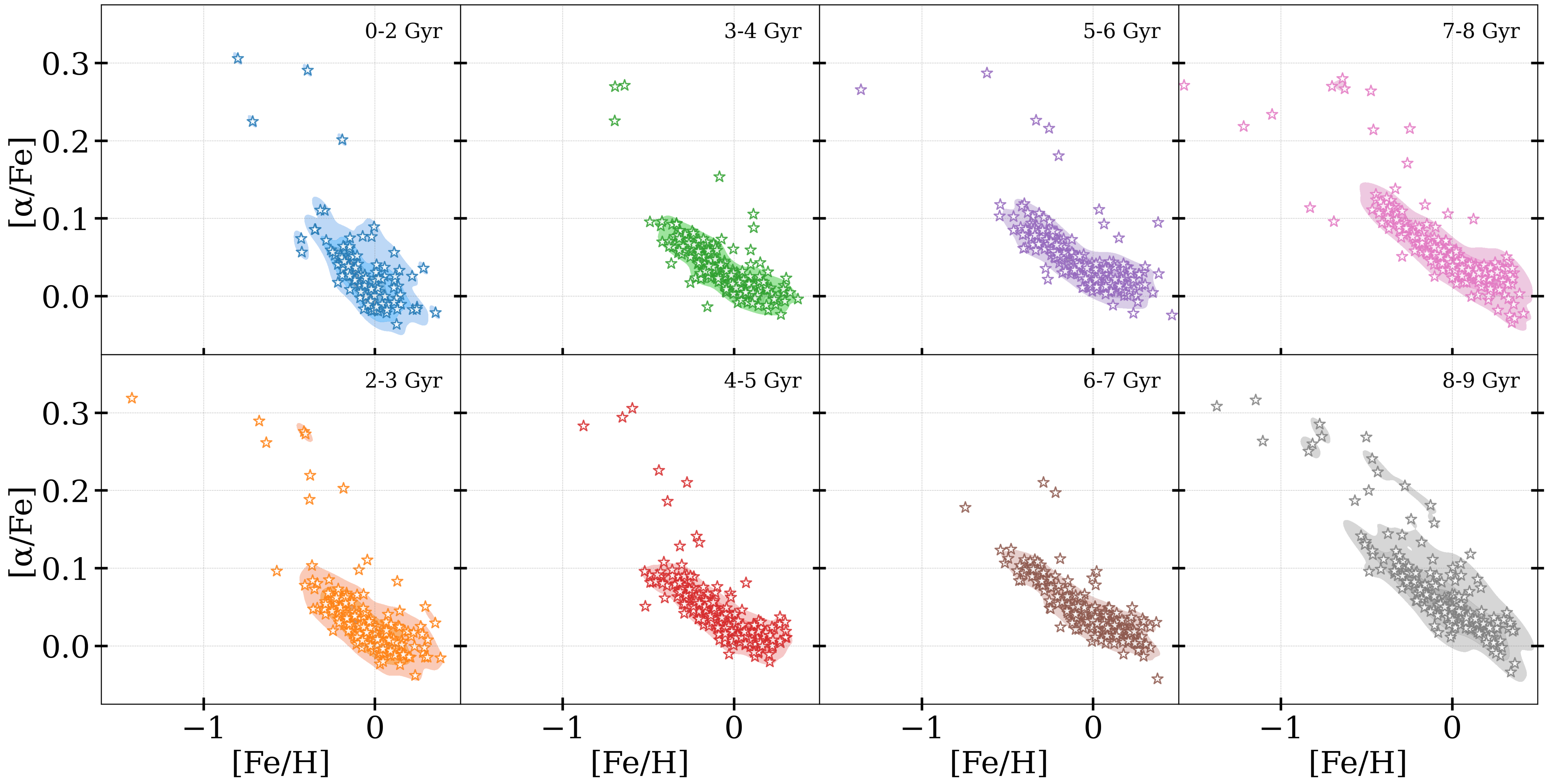




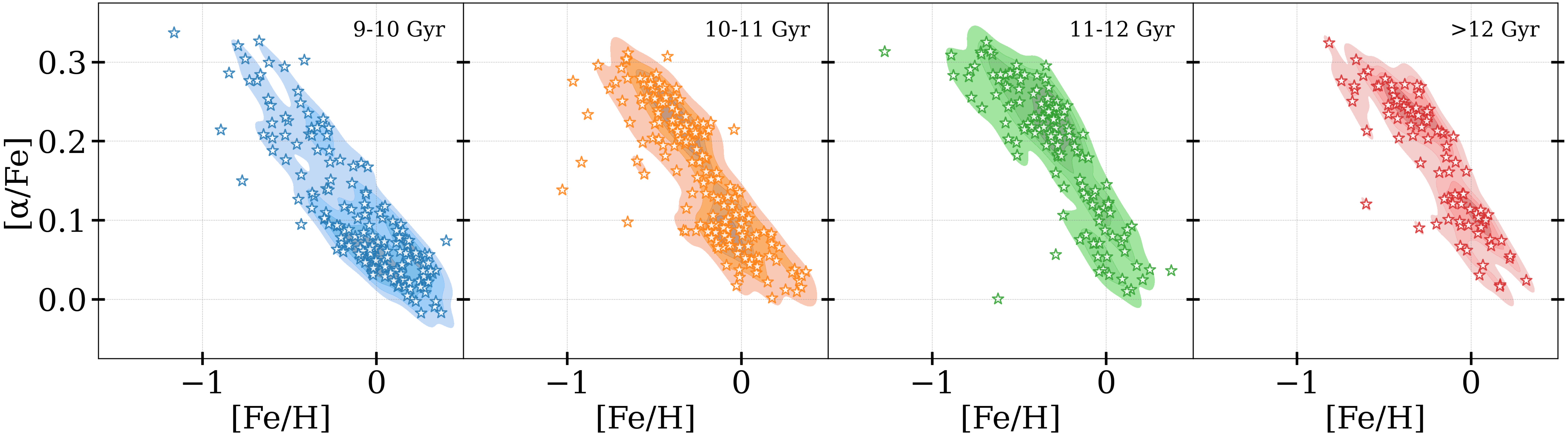
Effect of enrichment-law ΔY/ΔZ on age determination



Young population (< 9 Gyr) vs [Fe/H]



Old population (>= 9 Gyr) vs [Fe/H]

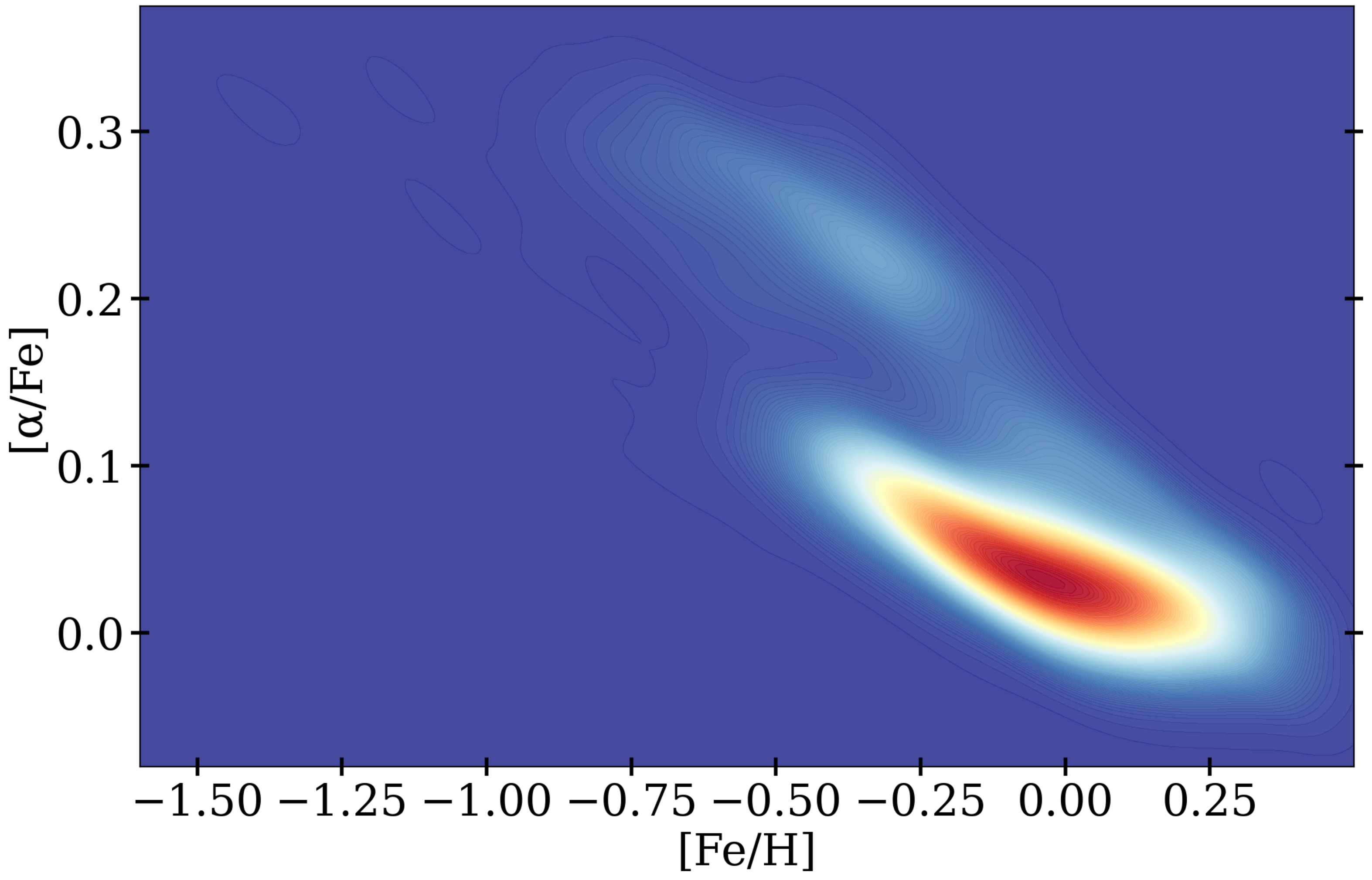


The [α/Fe]-rich population is composed primarily of very old objects

With a narrow age-domain

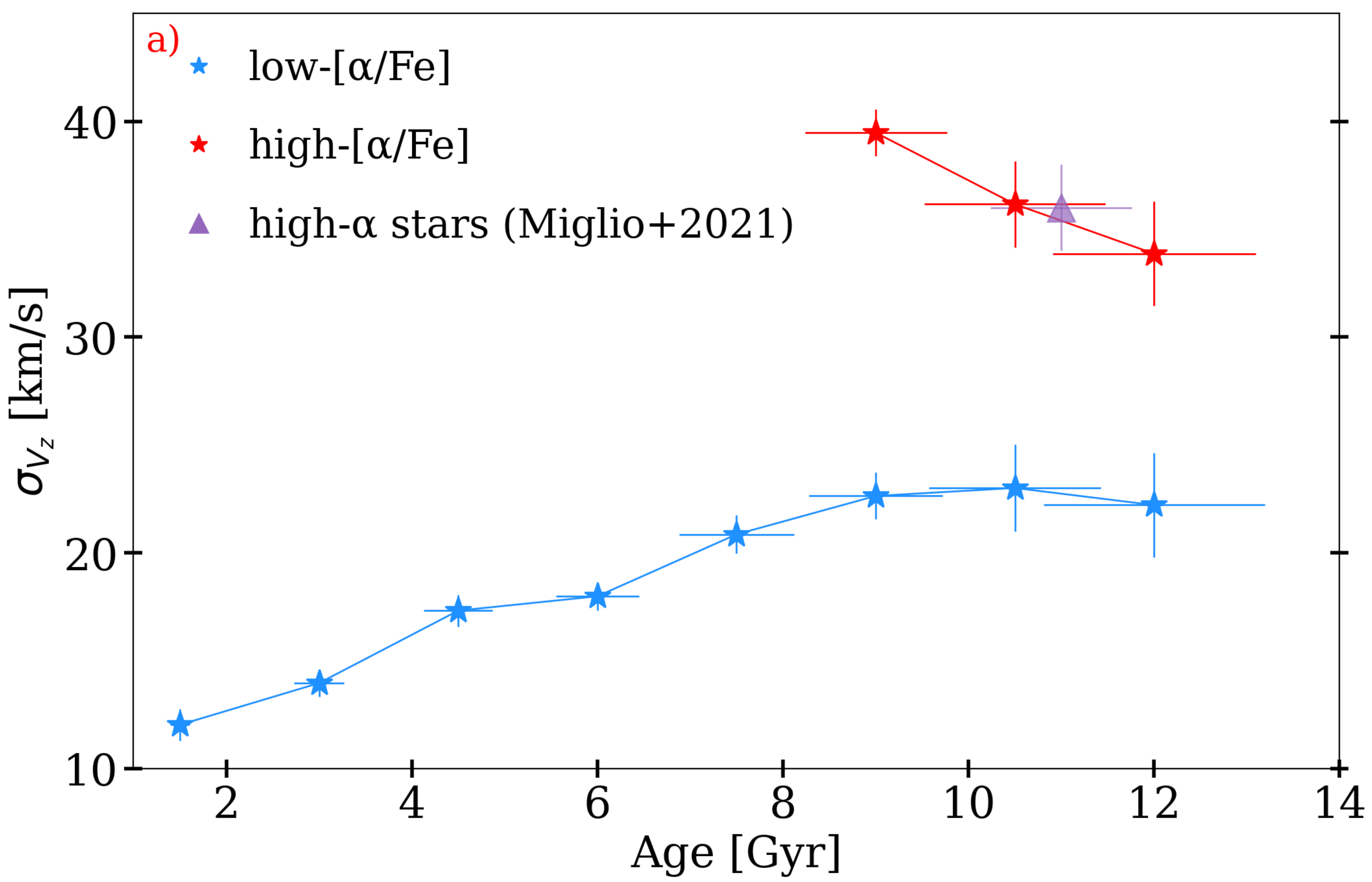
-

Also appears an old [α/Fe]-poor population with old ages (still another evidence. of this pop. now with RGB (distances ~ 3kpc)

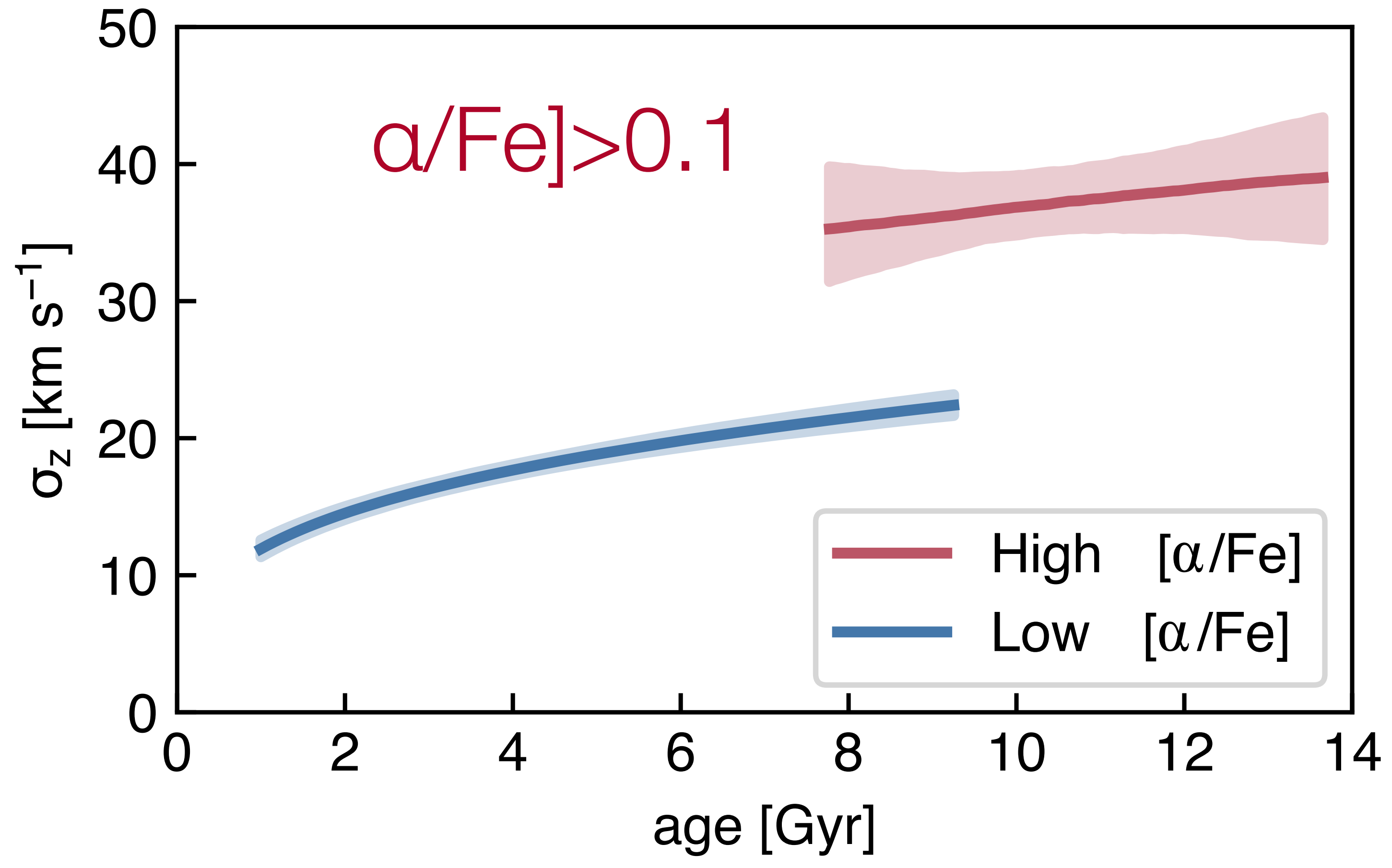


AGE-velocity dispersion

[α/Fe]> 0.15

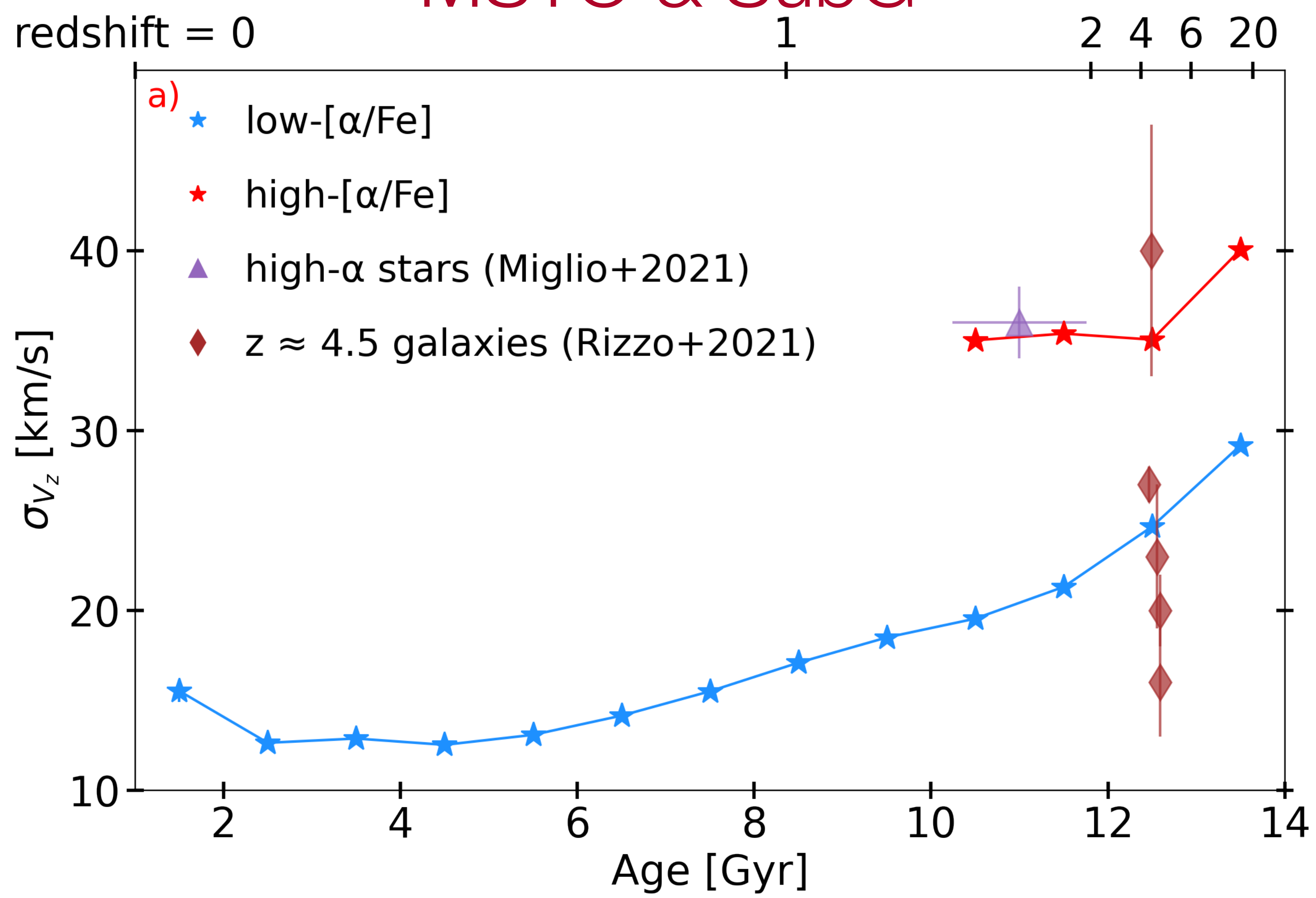


RGB



Miglio+21

MSTO & SubG

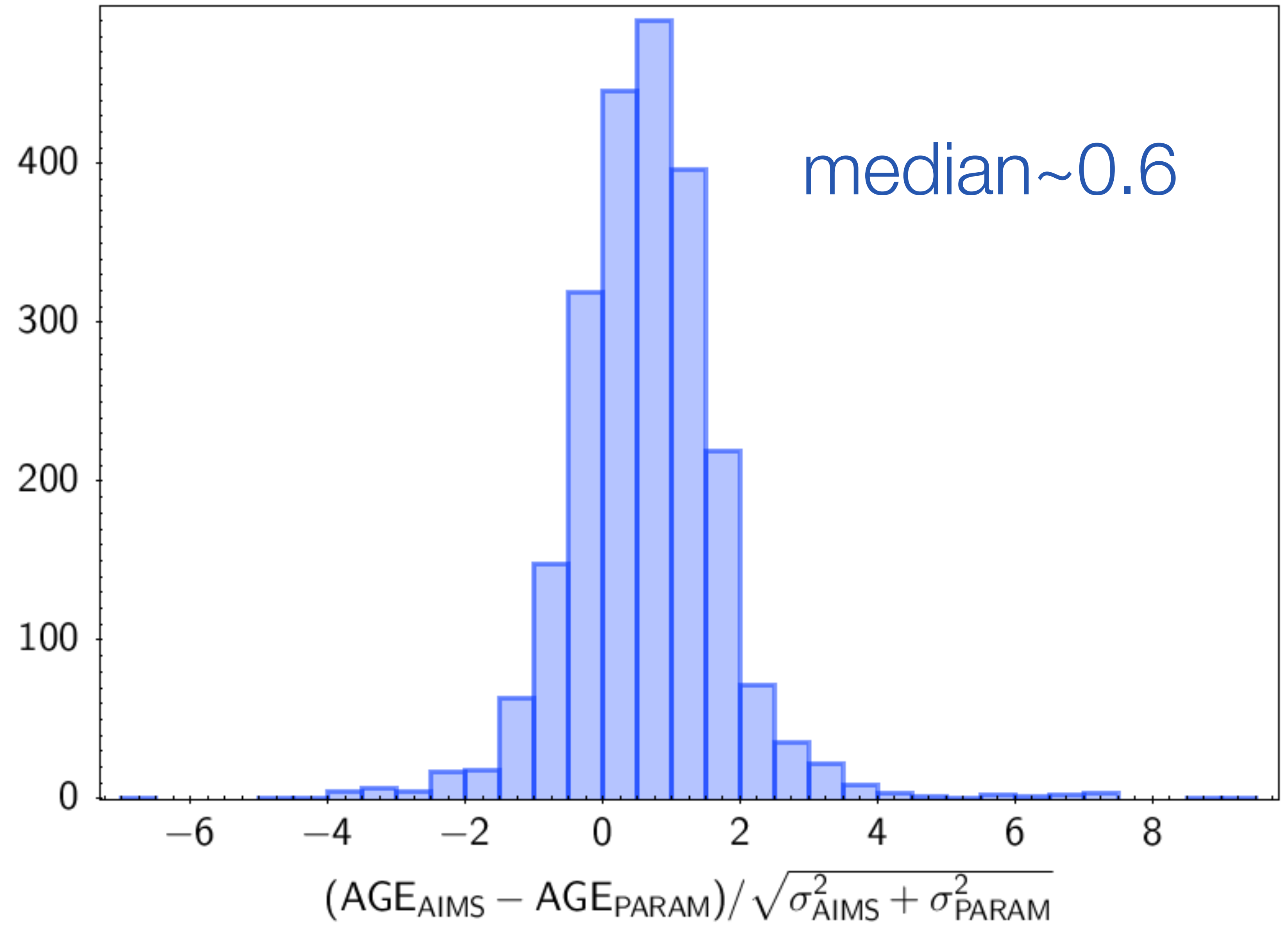


Nepal+24

Summary/perspectives

Thanks to the combination of very high quality data Kepler, APOGEE-DR17 and Gaia-DR3

- We have characterised a sample of 2300 RGB in Kepler field using the individual radial modes as seismic constraints, and got AGE relative precisions ~ 10% and confirm the results presented in Miglio+21



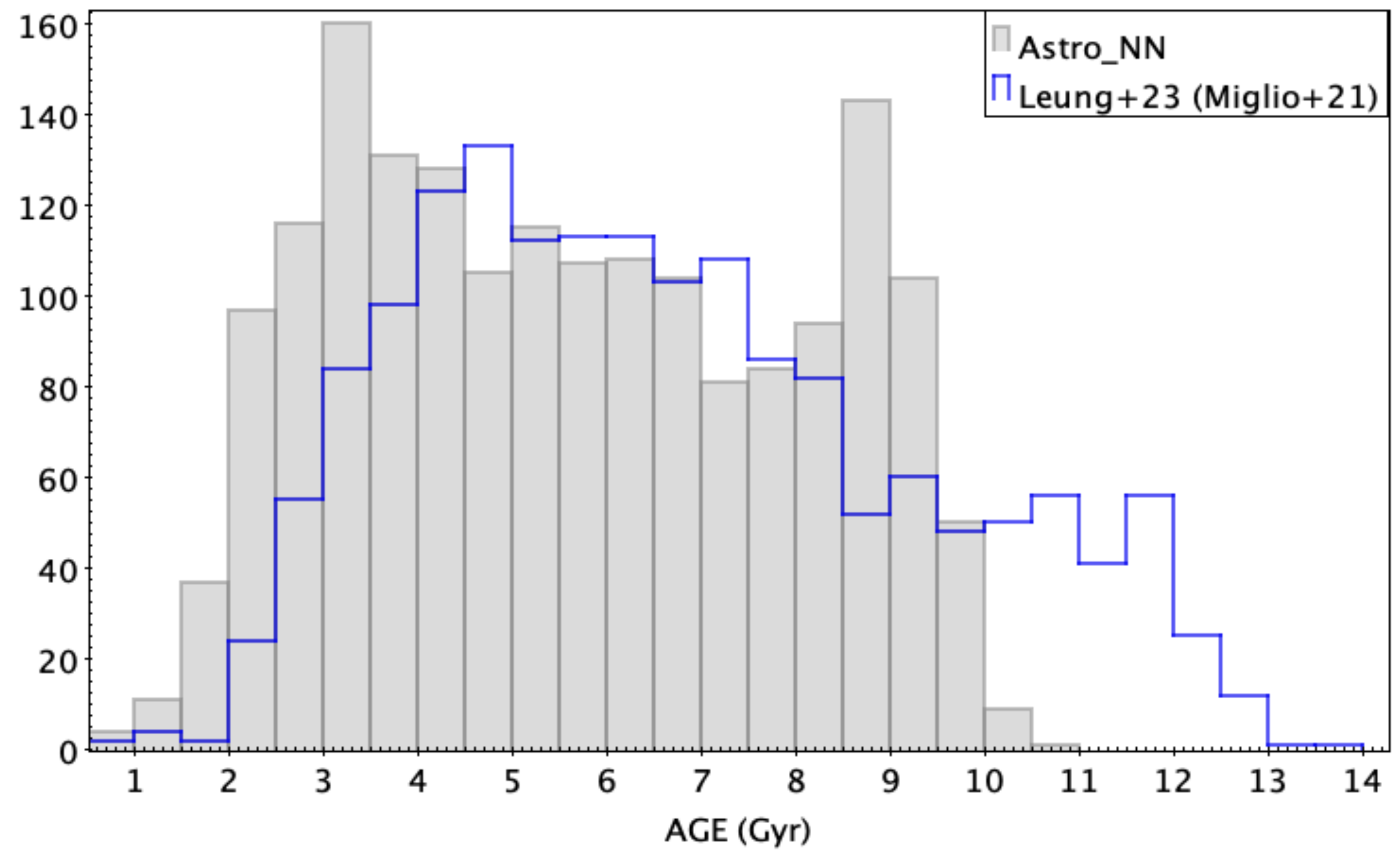
- We also find an old metal-rich population (thin-disk orbits?)
- The properties of our RGB pop present similar features than MSTO and SubG
- A consistent and careful application scaling relations and a based grid-of- models procedure (e.g. PARAM) provide precise masses and ages (Mass with 6%, AGE with 23% uncertainty) in good agreement with individual radial modes
- Ensemble Asteroseismology allows us also to constraint unknown aspects of stellar physics, in particular Mass LOSS => improve models => better AGES (poster by Karsten Brogaard)

Summary/perspectives

- The sample will be very soon increased by, at least, 50%

- We expect this new data will be included as training sets in ML procedures.

e.g. Leung+23: New Astro-NN ages based on Miglio+21 (~25% uncertainty on age) for training:

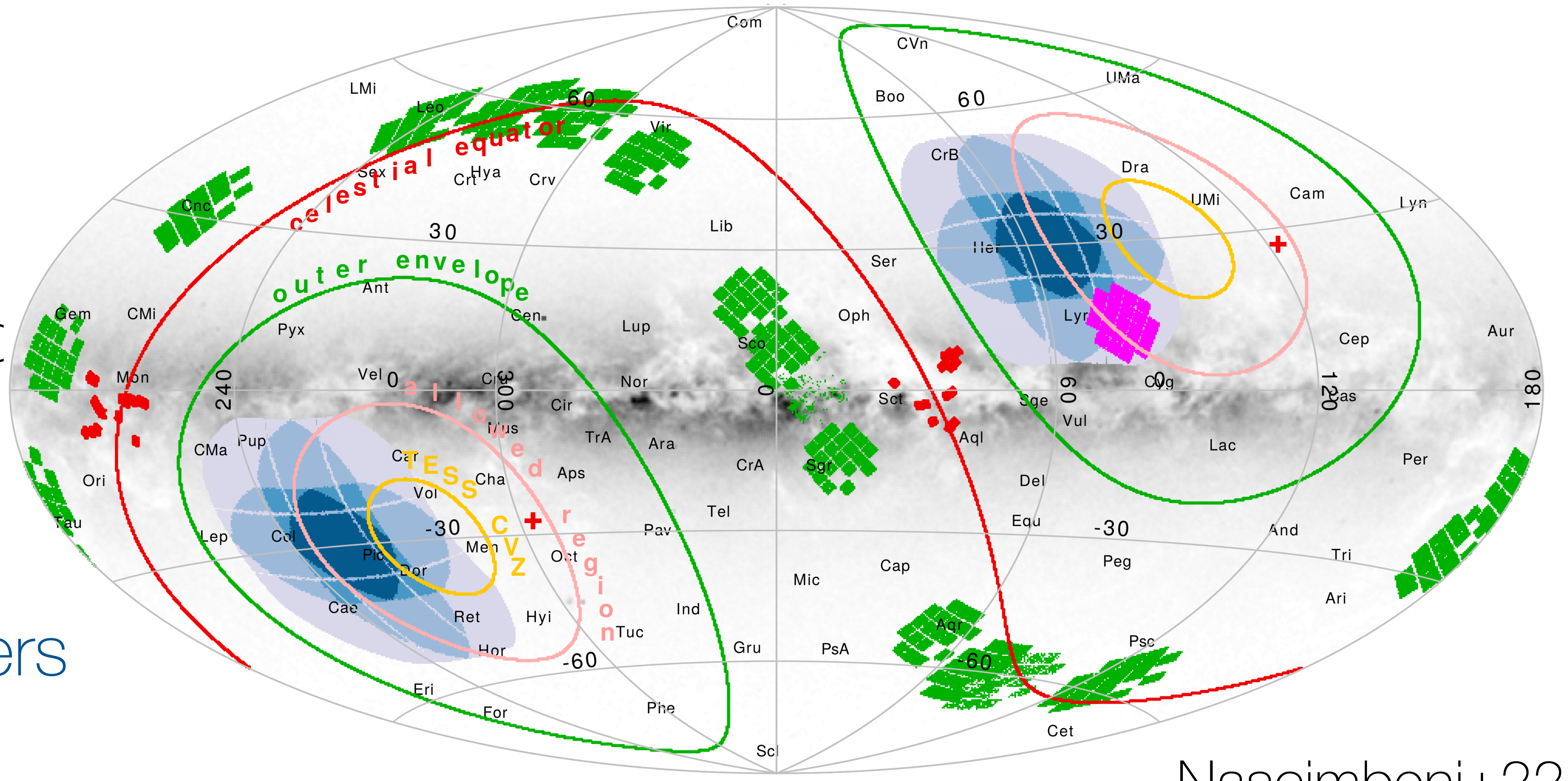


See also Patil+23; Anders+23; Das+20; Sanders&Das18…

Next…

PLATO calibration catalogue will contain 24k red giants that will be also observec by 4MOST (in 4MIDABLE-LR, PIs: Cristina Chiappini, Ivan Minchev)

Some of them belonging to stellar clusters (see poster by Lorenzo Briganti)



Nascimbeni+22

PLATO-Additional Science Galactic Archeology (=> Saskia's talk)

haydn ?

THANK YOU FOR YOUR ATTENTION !

Thanks also to the other participants in this project:

Andrea Miglio, Enrico Corsaro, Cristina Chiappini, Emma Willett, Samir Nepal, Arlette Noels, Richard Scuflaire, Guy R. Davies, Martin Bo Nielsen, Ben M. Rendle, Jason W. Ferguson,…

FAMED PIPELINE https://github.com/EnricoCorsaro/FAMED

PBJam https://github.com/grd349/PBjam

ABBA https://github.com/tkallinger/KeplerRGpeakbagging

AIMS https://gitlab.com/sasp/aims

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