STELLAR ASTROPHYSICS CENTRE

BAyesian STellar Algorithm (BASTA)

Víctor Silva Aguirre

Meudon, May 23rd 2016

Introduction

Under the hood:

- BAyesian STellar Algorithm: BASTA Silva Aguirre et al. 2015, MNRAS

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Determined stellar properties for:

- Exoplanet host stars: Silva Aguirre et al. 2015, MNRAS, etc…
- Dwarfs and subgiants: Chaplin et al. 2014, ApJS
- Red giants: SAGA, APOKASC   Casagrande et al. 2016, MNRAS
  Pinsonneault et al. 2014, ApJS
- Gyrochronology: van Saders et al. 2016, Nature
- Clusters: Hyades, M67   Lund et al. 2016, sub.; Stello et al. 2016, in prep.

Introduction

Under the hood:

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The basics:

- Works with GARSTEC and BaSTI grids of models
- Python (and Cython) + hdf5 libraries (any)
- Flexible input: asteroseismic, spectroscopic, etc…
- Rev. Bayes in the core: priors, weighting, etc…
- Posterior distributions and correlations

BASTA

The basics:

$$\mathcal{L}(\mathcal{O}|v) = \frac{1}{(2\pi)^{1/2}\sqrt{|\mathbf{C}|}} \exp\left(-\chi^2/2\right)$$

$$\chi^2 = \left(\boldsymbol{o}_{\mathrm{obs}} - \boldsymbol{o}_{\mathrm{model}}\right)^{\mathrm{T}} \mathbf{C}^{-1} \left(\boldsymbol{o}_{\mathrm{obs}} - \boldsymbol{o}_{\mathrm{model}}\right)$$

$$p(x|\mathcal{O}) = \int \delta(x(v) - x)\, p(v|\mathcal{O})\, w_v \mathrm{d}^3 v,$$

Silva Aguirre et al. 2015, MNRAS

BASTA

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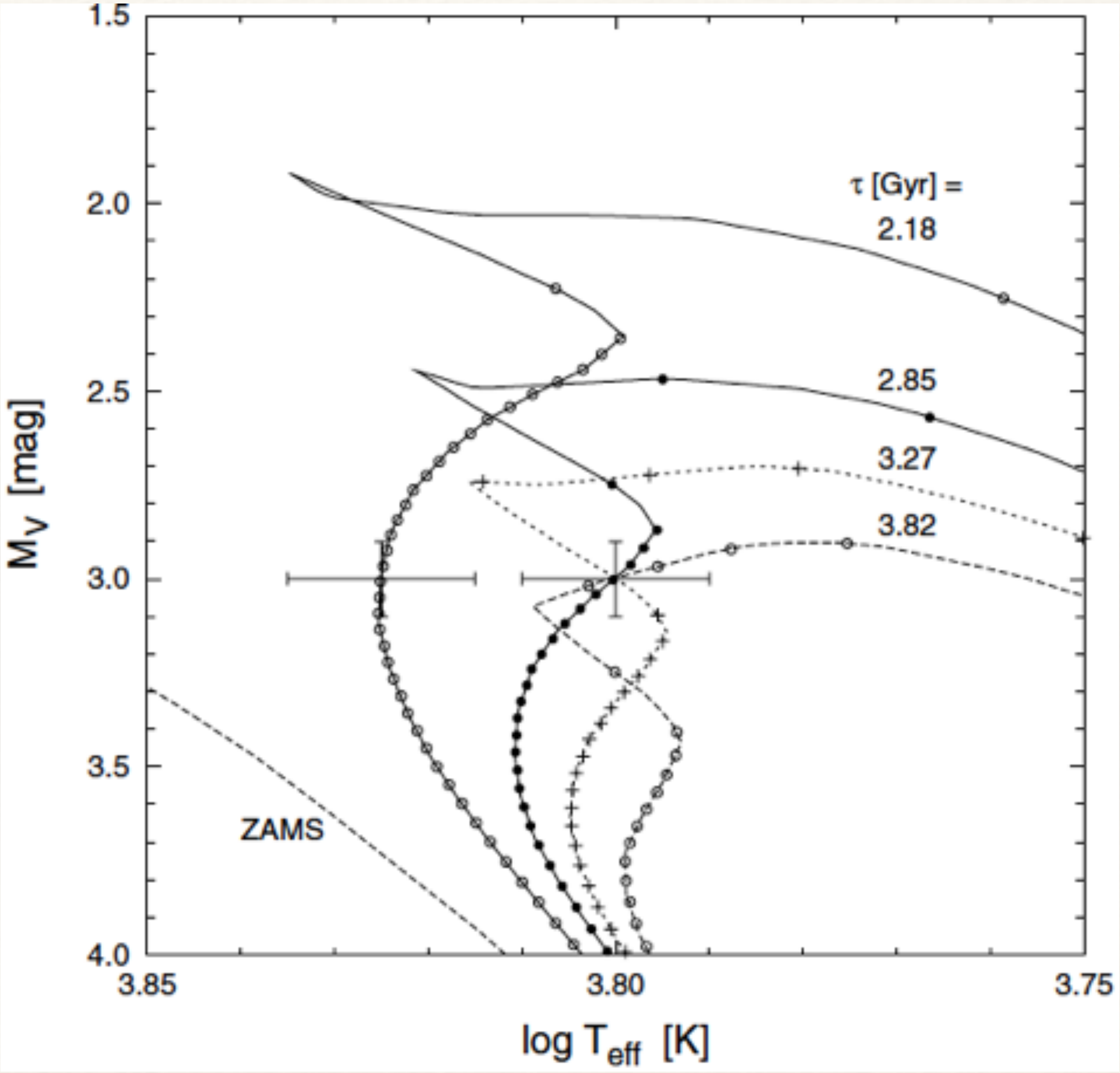

Jørgensen & Lindegren 2005, A&A

Asteroseismic data

Some fitting examples

- The bare minimum: scaling relations (dwarfs and giants)
- Improvements: individual frequencies (dwarfs for now)
- Improvements: period spacing (giants)

Asteroseismic data

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Always use Teff and [Fe/H]

Asteroseismic data

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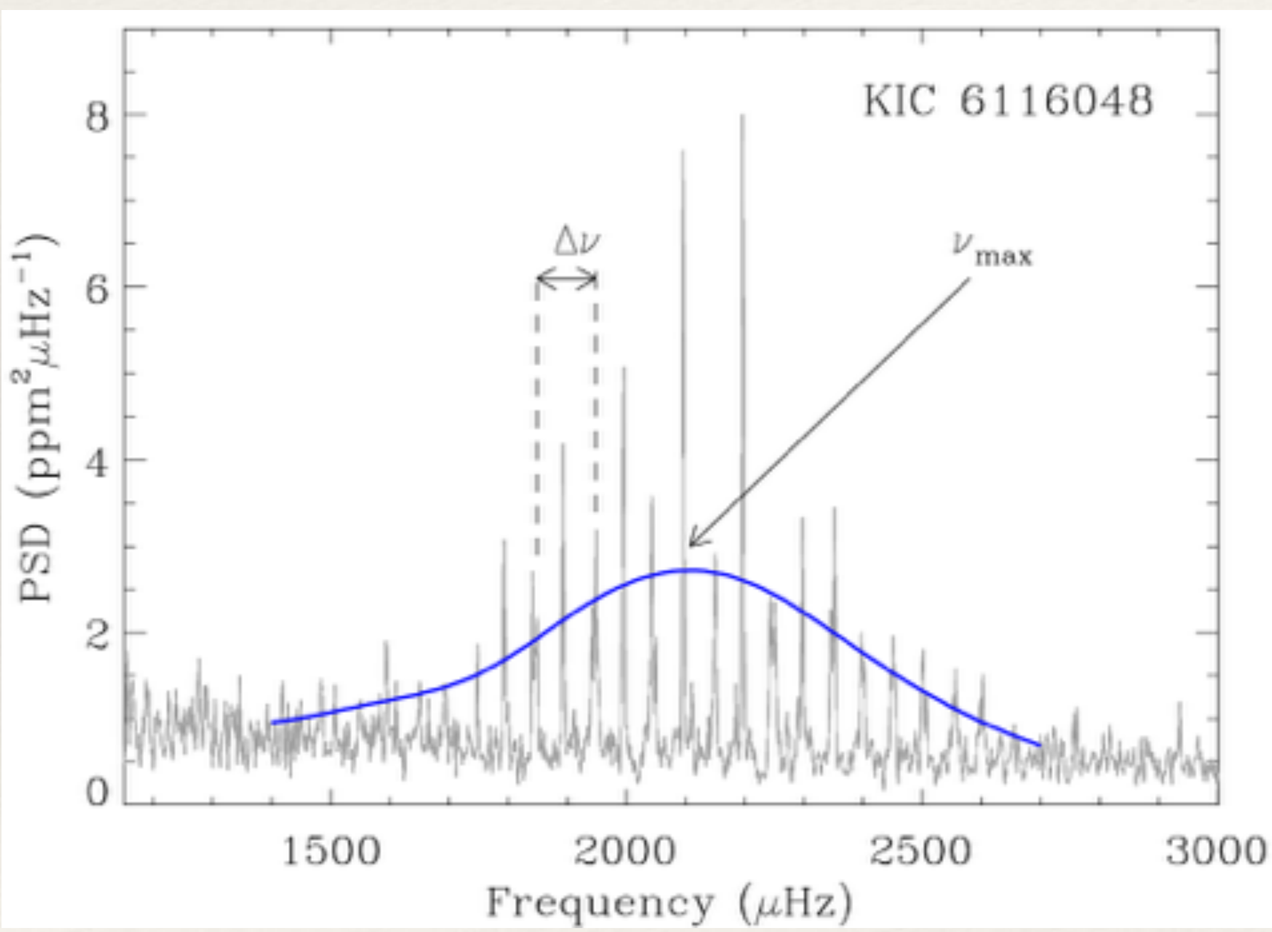
Dwarf stars

The bare minimum:



Chaplin et al. 2014, ApJS

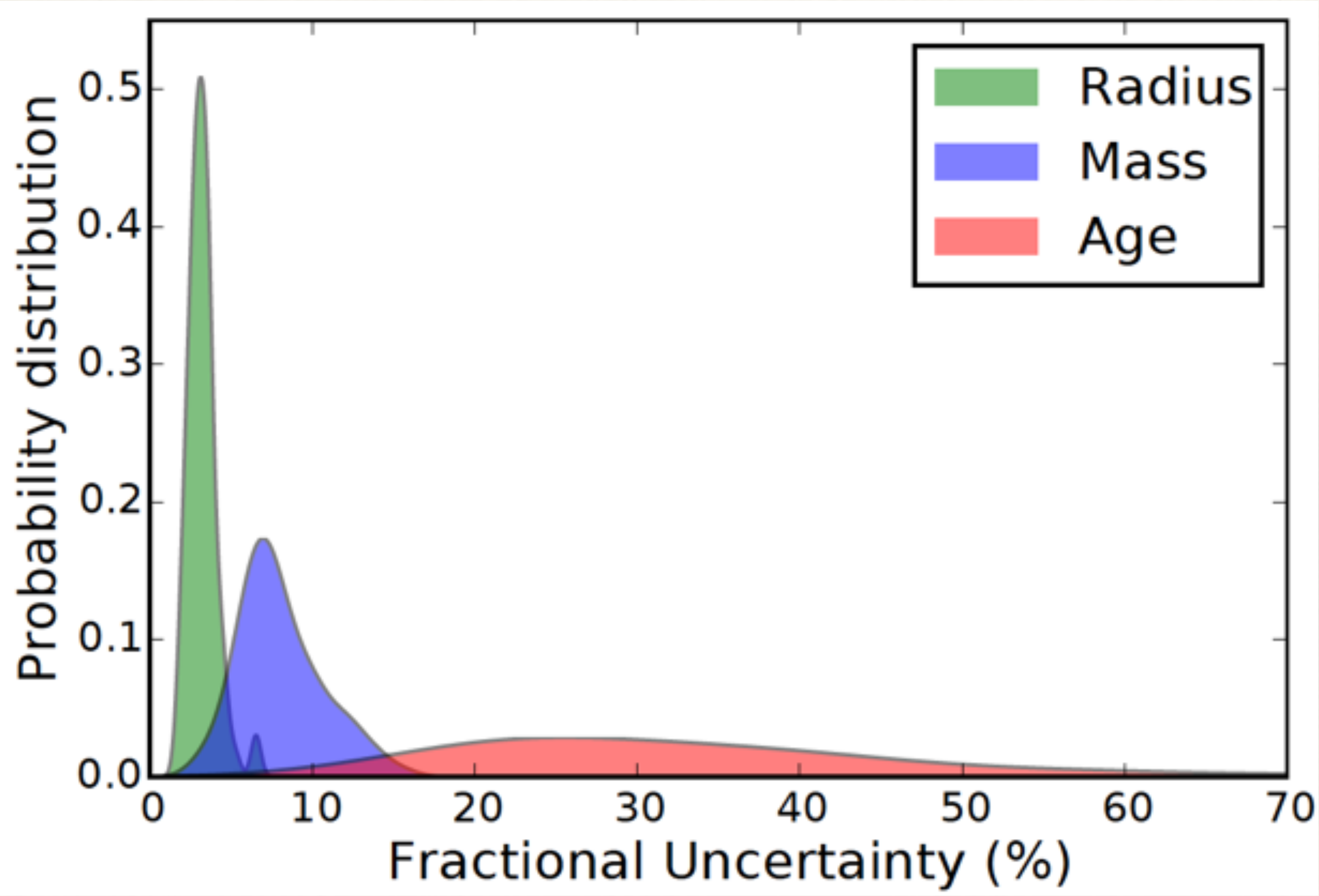
Temperature
Composition
$\Delta\nu$
ν_{max}

BASTA

Stellar Properties
(R, M, Age, etc)

Dwarf stars

The bare minimum:



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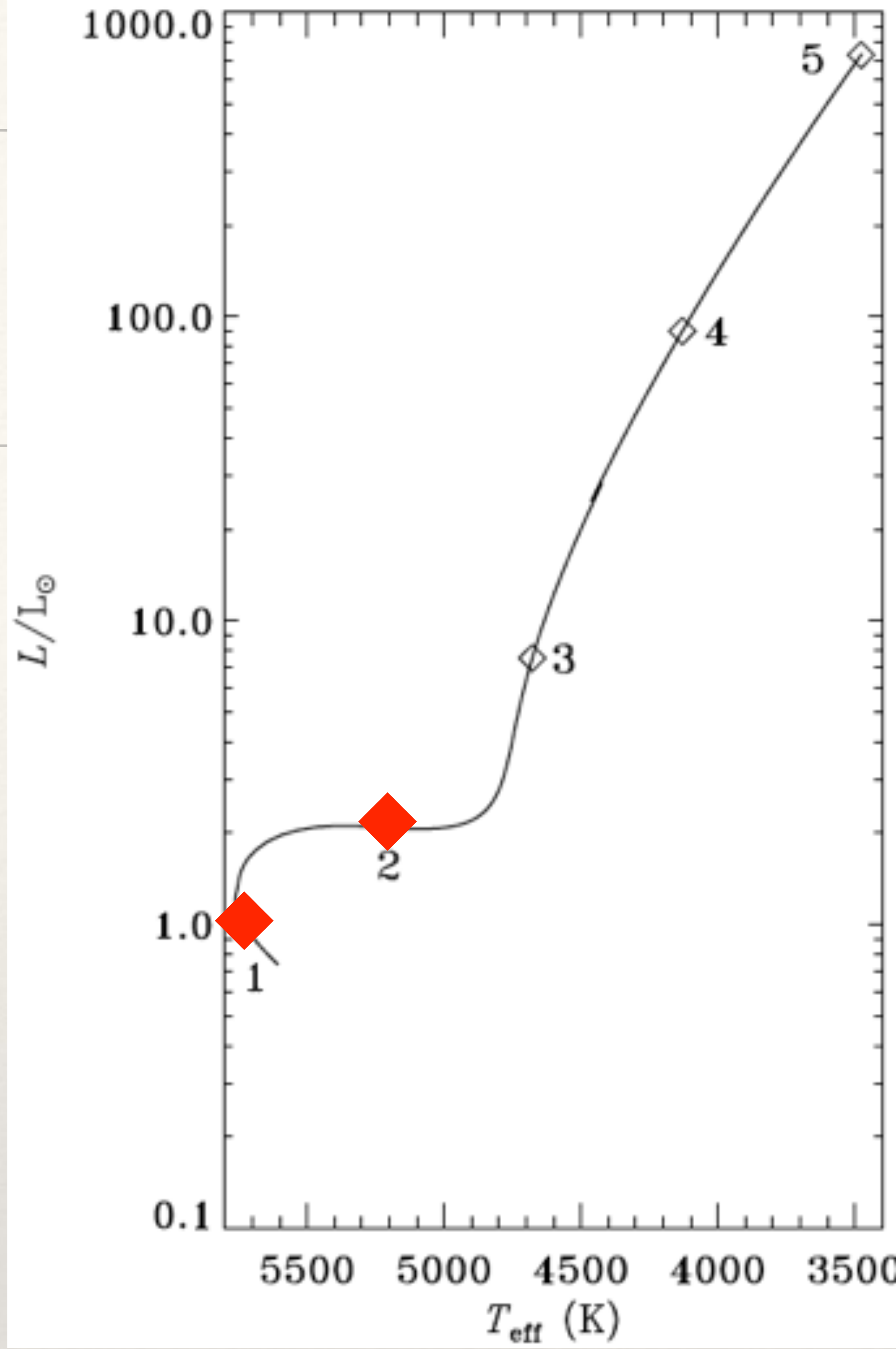

Radii ~2.2%

Mass ~5.5%

Age ~25%

Asteroseismic data

Some fitting examples

- The bare minimum: scaling relations (dwarfs and giants)
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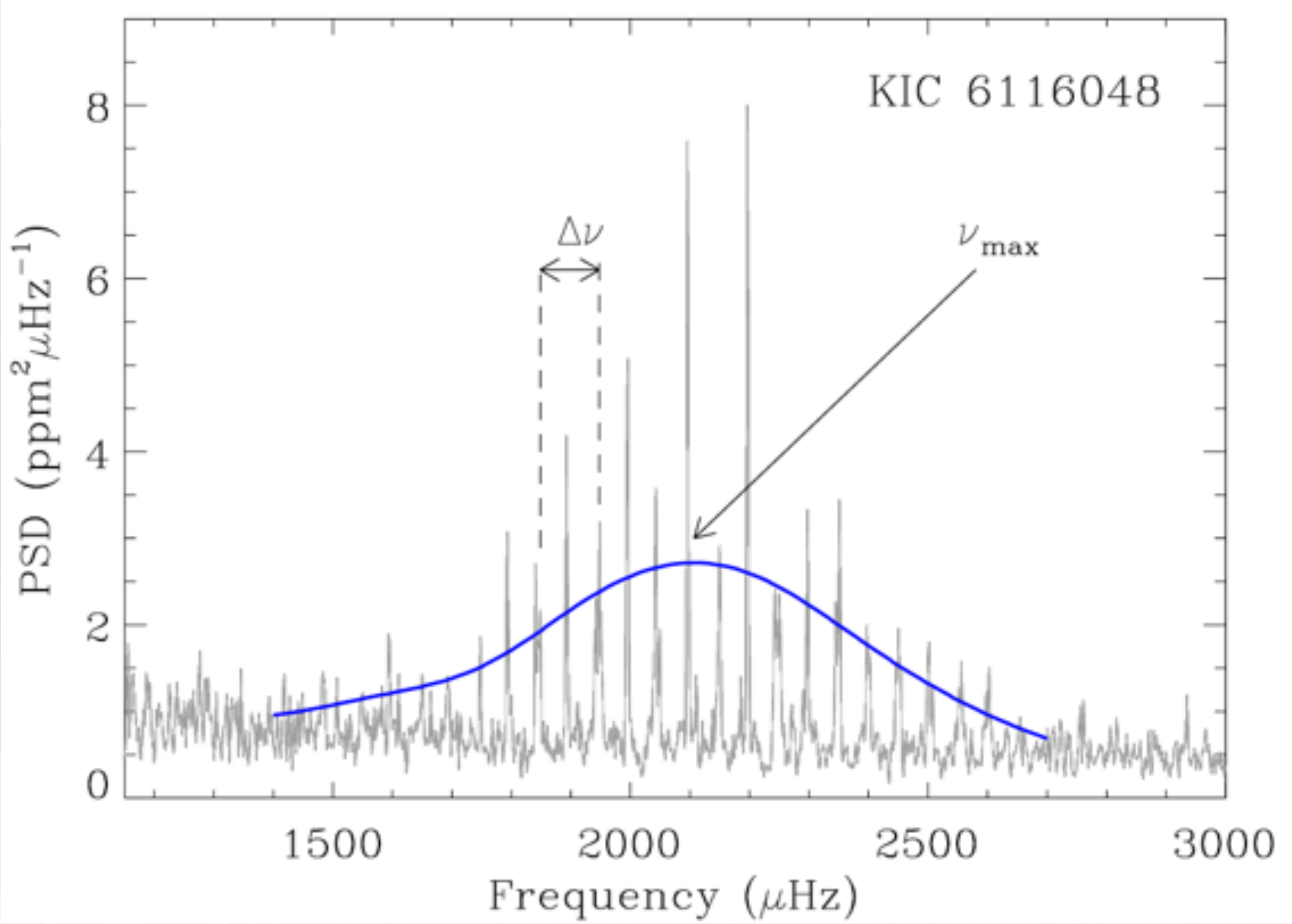
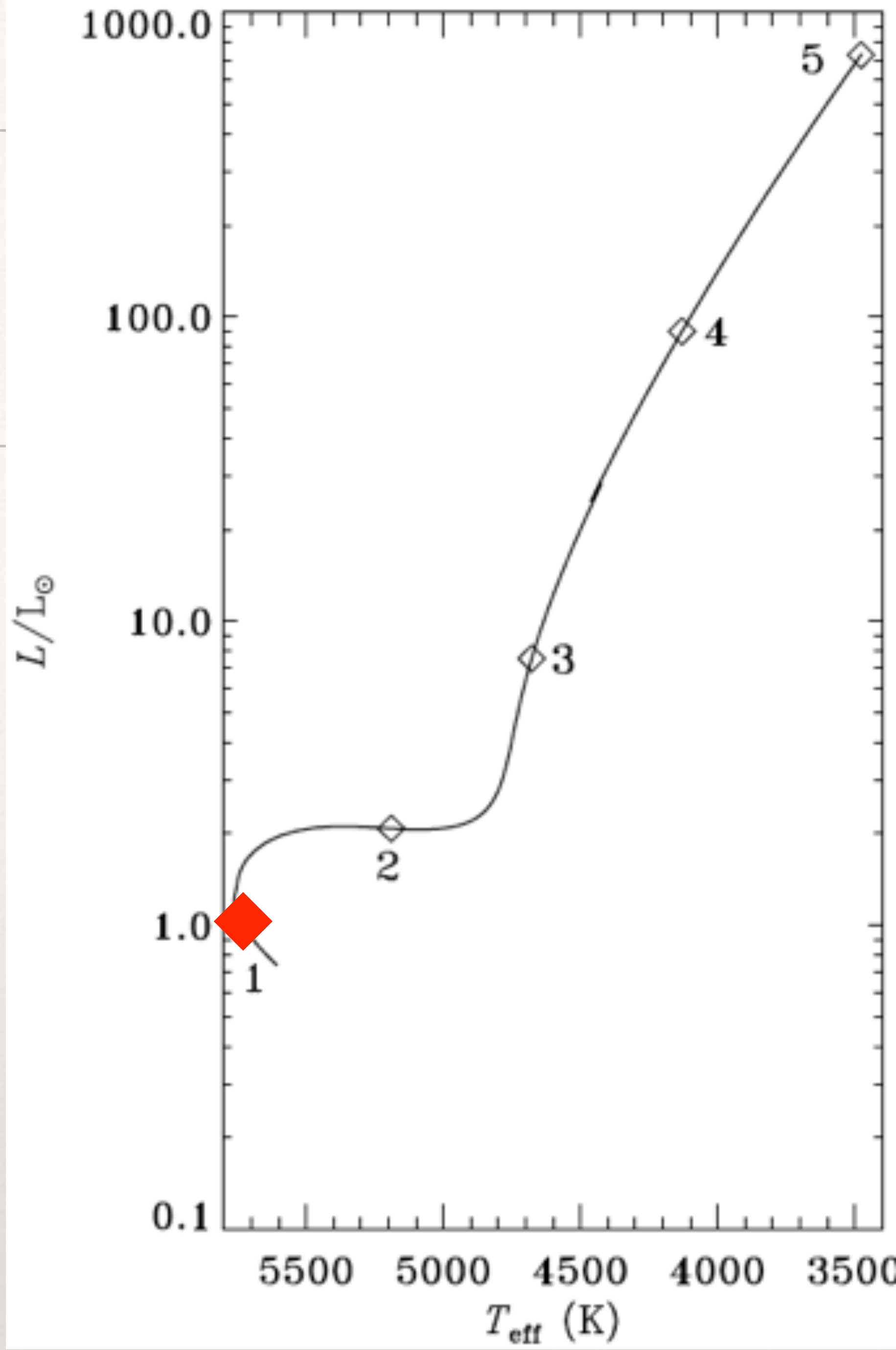
Always use Teff and [Fe/H]

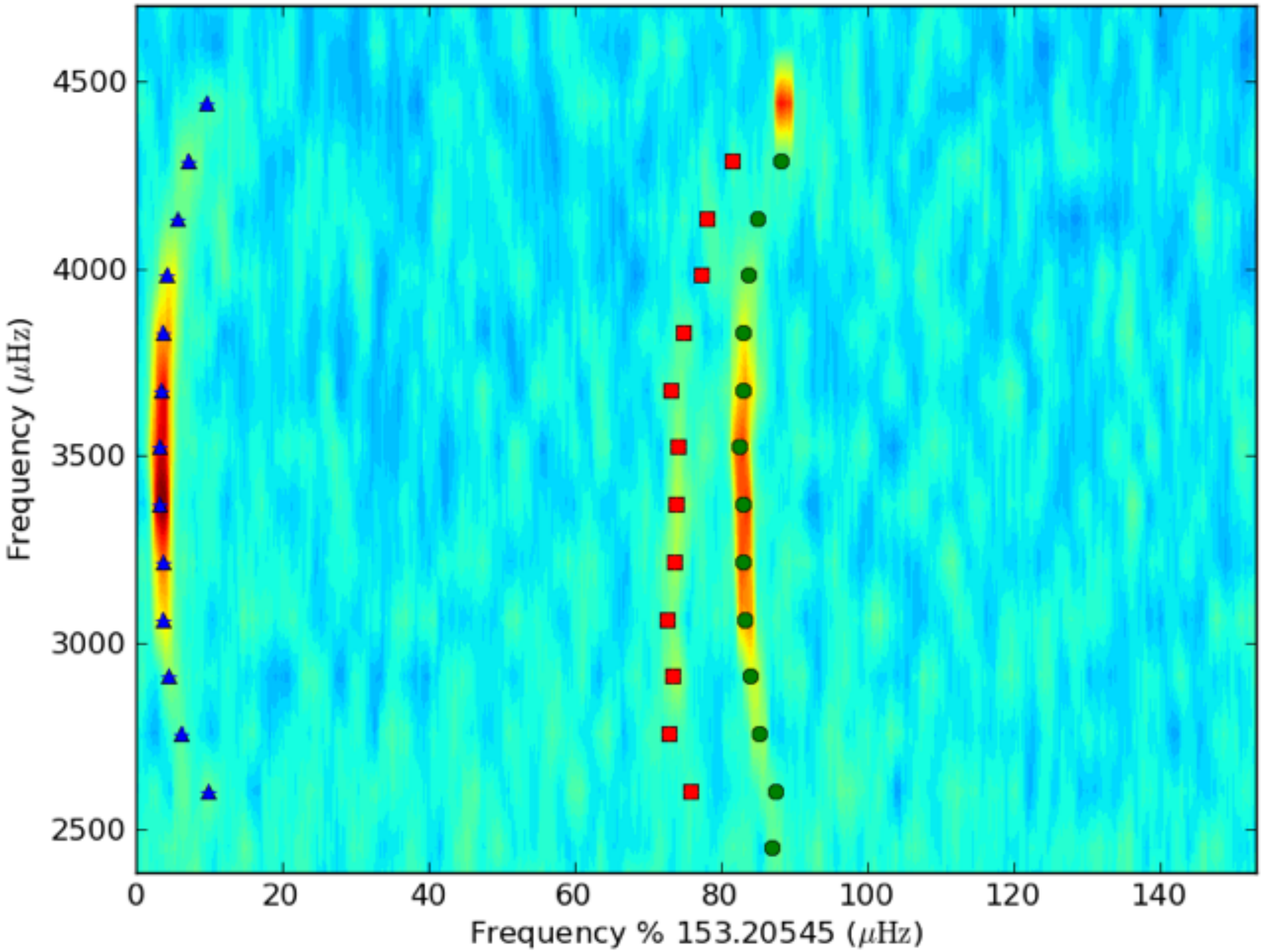
Dwarf stars

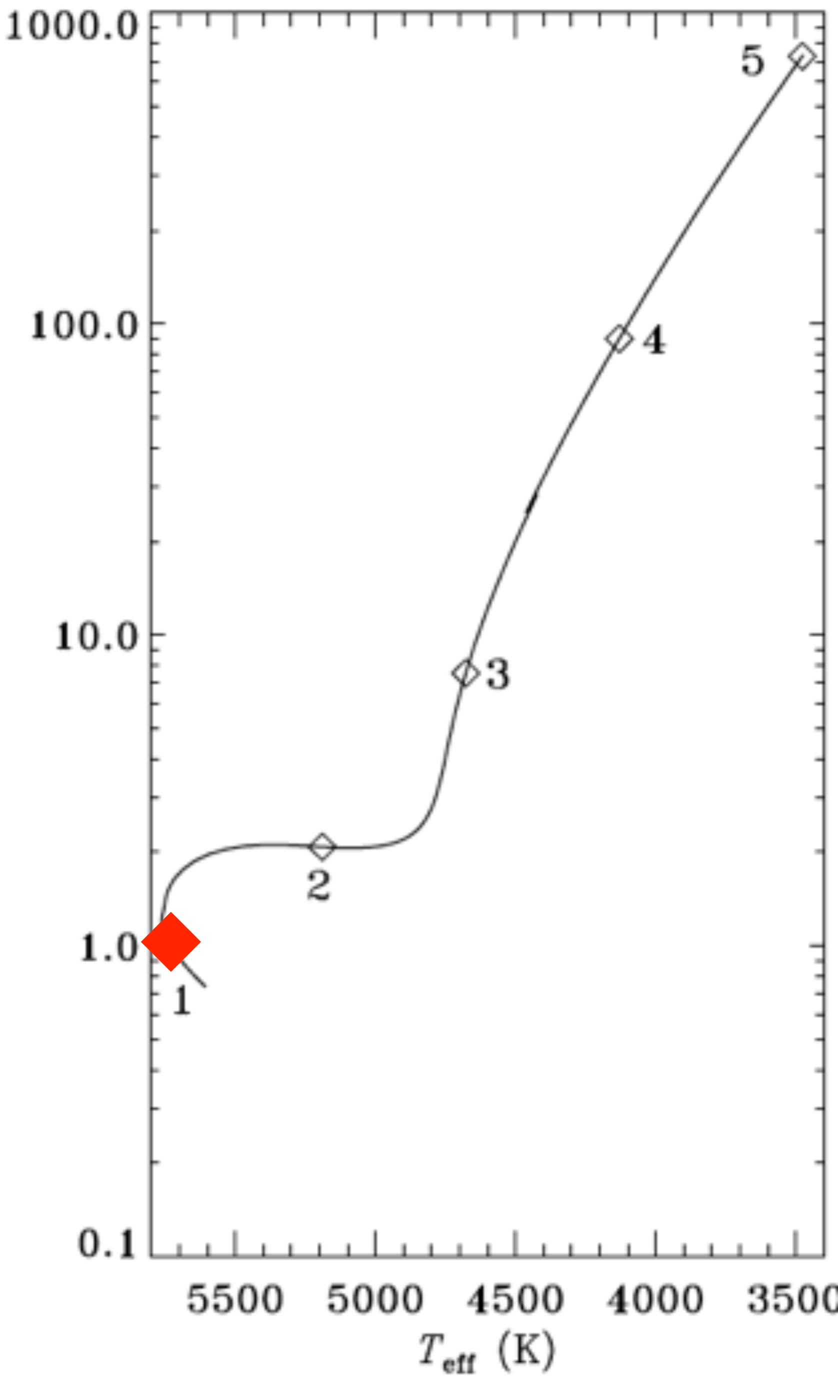
Individual frequencies:



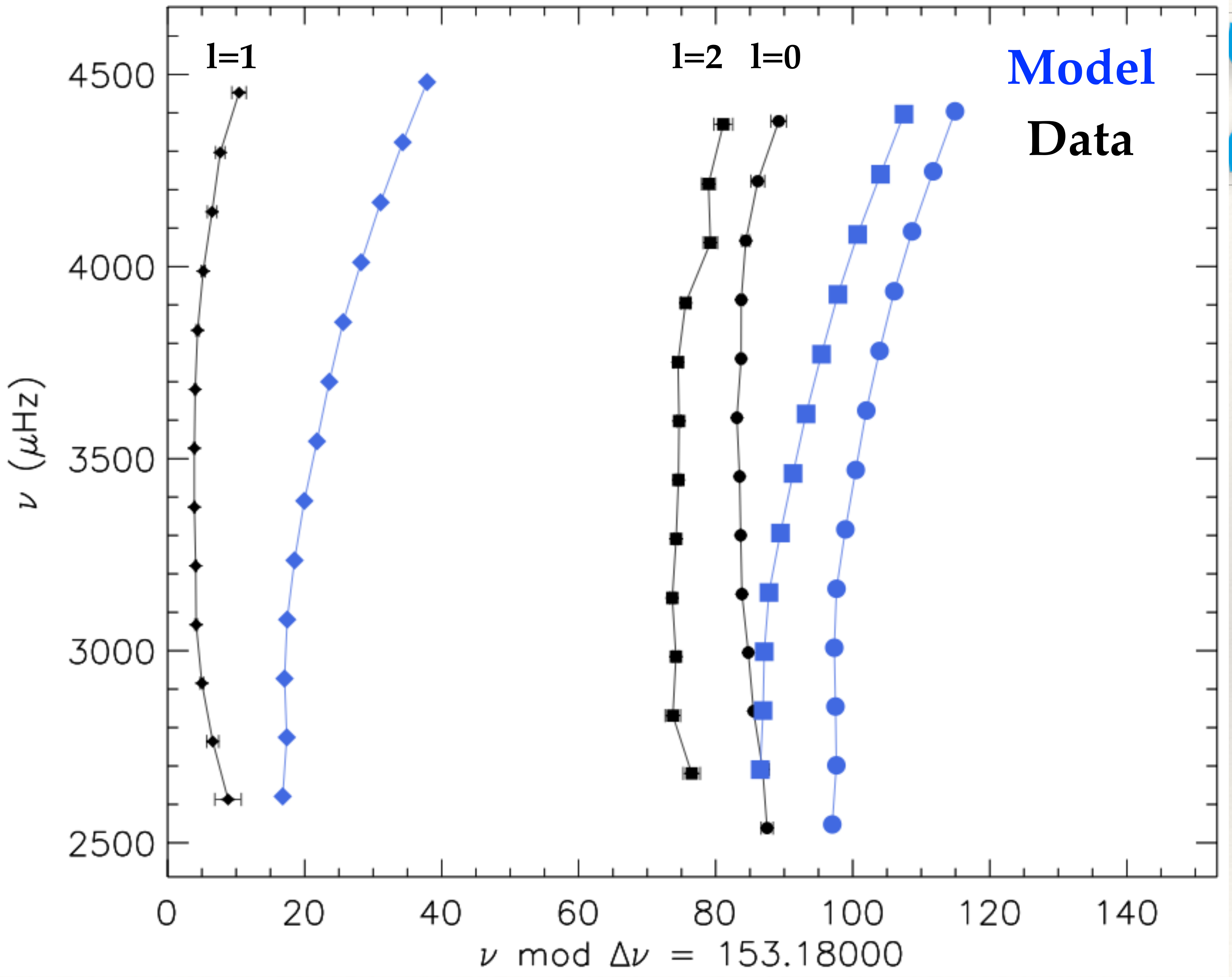


Dwarf stars



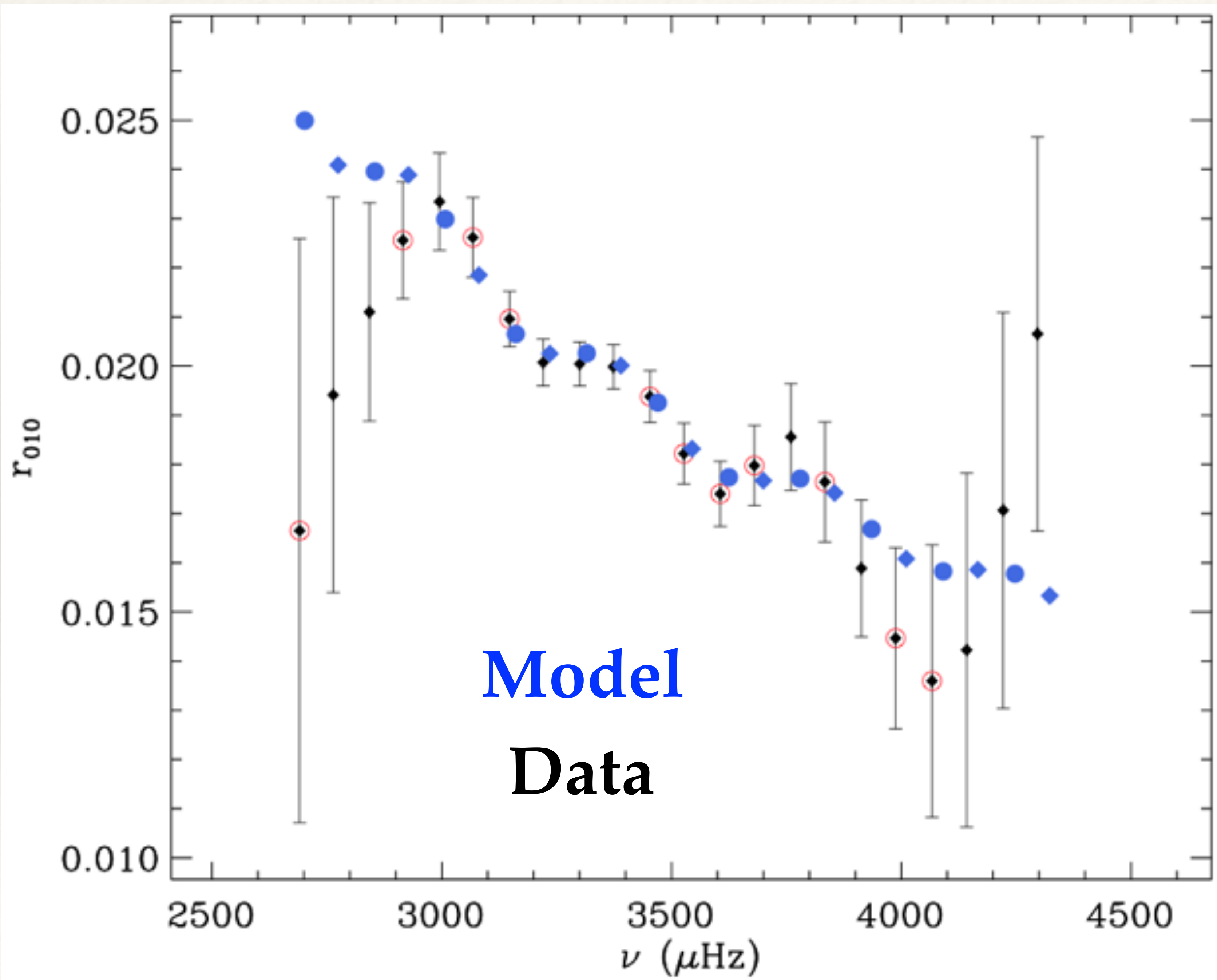


Davies et al. 2016, MNRAS



l=1
l=2
l=0
Model
Data
4500
4000
3500
3000
2500
ν (μHz)
0
20
40
60
80
100
120
140
ν mod Δν = 153.18000

Dwarf stars



Temperature
Composition
frequencies
(combinations)

↓

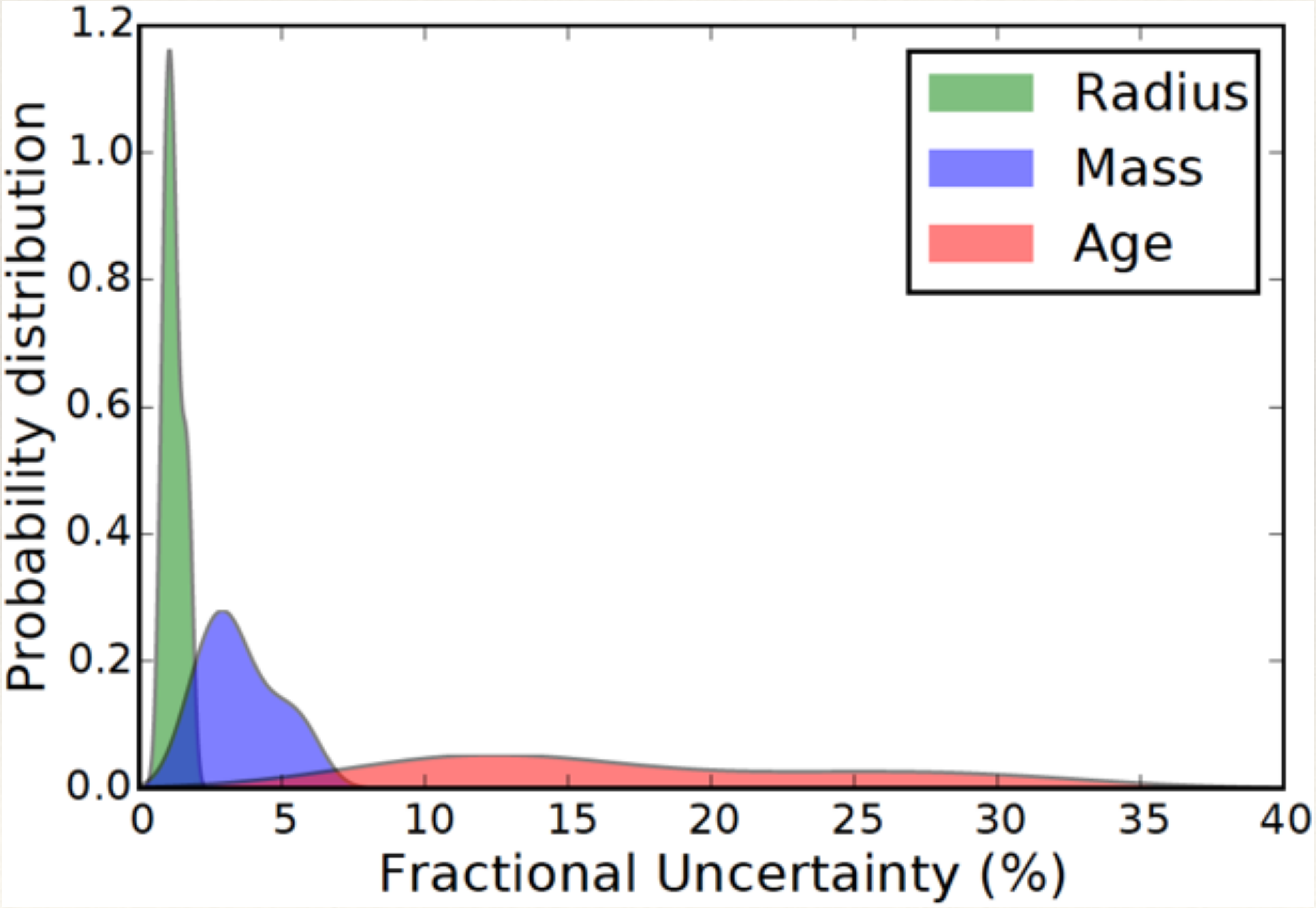
BASTA

↓

Stellar Properties
(R, M, Age, etc)

Dwarf stars

Precision from frequency combinations:



Radii ~1.1%

Masses ~3.3%

Ages ~14%

Silva Aguirre et al. 2015, MNRAS

Lebreton & Goupil 2014, A&A

Dwarf stars

Systematic uncertainties (dwarfs)

Statistical

- Radius ~1.1%
- Mass ~3.3%
- Age ~14%

Physics

- Radius ~0.7%
- Mass ~2.3%
- Age ~9.6%

Fitting Algo.

- Radius ~1.6%
- Mass ~3.6%
- Age ~16.8%

Dwarf stars

Reese et al. 2016, A&A

Mass

Hounds	**Aardvark**	**Blofeld**	**Coco**	**Diva**	**Elvis**	$\varepsilon_{\mathrm{rel.}}$	$b_{\mathrm{rel.}}$
Solution	1.000	1.220	0.780	1.220	1.000	–	–
GOE	0.974 ± 0.018	1.214 ± 0.018	0.777 ± 0.017	1.262 ± 0.025	1.001 ± 0.014	2.69 %	−1.35 %
YMCM	0.983 ± 0.017	1.279 ± 0.016	0.769 ± 0.012	1.163 ± 0.018	0.951 ± 0.008	3.47 %	−0.69 %
ASTFIT	1.008 ± 0.012	1.184 ± 0.012	0.782 ± 0.012	1.161 ± 0.036	1.003 ± 0.013	2.59 %	−0.01 %
YL	0.912 ± 0.006	1.326 ± 0.004	0.783 ± 0.009	1.235 ± 0.003	0.974 ± 0.008	5.94 %	0.38 %
AMP	0.960 ± 0.040	1.210 ± 0.020	0.780 ± 0.010	1.160 ± 0.030	1.000 ± 0.020	5.68 %	−1.81 %
BASTA	$1.009^{+0.011}_{-0.009}$	–	$0.779^{+0.009}_{-0.011}$	–	$0.998^{+0.011}_{-0.009}$	0.61 %	0.09 %
MESAastero	0.993 ± 0.007	–	0.772 ± 0.007	–	1.008 ± 0.009	1.40 %	−0.61 %
V&A, grid	0.960 ± 0.020	1.190 ± 0.020	0.770 ± 0.020	1.240 ± 0.030	0.960 ± 0.040	3.91 %	0.58 %
$\varepsilon_{\mathrm{rel.}}$	3.88 %	4.35 %	0.80 %	3.78 %	2.43 %	3.86 %	–
$b_{\mathrm{rel.}}$	−2.51 %	1.13 %	−0.44 %	−1.34 %	−1.32 %	–	−0.44 %
$\varepsilon_{\mathrm{norm.}}$	5.28	10.96	0.56	2.79	2.49	–	–
$b_{\mathrm{norm.}}$	−2.43	4.12	−0.28	0.12	−1.17	–	–
Hounds	**Felix**	**George**	**Henry**	**Izzy**	**Jam**	$\varepsilon_{\mathrm{norm.}}$	$b_{\mathrm{norm.}}$
Solution	1.330	1.330	1.100	1.100	1.330	–	–
GOE	1.284 ± 0.048	1.325 ± 0.048	1.076 ± 0.051	1.036 ± 0.068	1.308 ± 0.071	0.85	−0.30
YMCM	1.303 ± 0.039	1.333 ± 0.020	1.101 ± 0.029	1.066 ± 0.033	1.406 ± 0.042	2.60	−0.72
ASTFIT	1.352 ± 0.027	1.388 ± 0.035	1.078 ± 0.024	1.094 ± 0.024	1.368 ± 0.031	1.34	−0.11
YL	1.198 ± 0.000	1.319 ± 0.021	1.137 ± 0.008	1.189 ± 0.005	1.384 ± 0.010	12.09	4.61
AMP	1.170 ± 0.020	1.440 ± 0.050	1.030 ± 0.040	1.070 ± 0.030	1.390 ± 0.030	2.87	−1.01
BASTA	$1.338^{+0.021}_{-0.009}$	–	$1.099^{+0.009}_{-0.019}$	$1.089^{+0.019}_{-0.021}$	$1.338^{+0.030}_{-0.040}$	0.46	0.10
MESAastero	–	1.329 ± 0.008	1.077 ± 0.027	1.074 ± 0.033	1.345 ± 0.014	0.88	−0.26
V&A, grid	1.360 ± 0.040	1.370 ± 0.050	1.100 ± 0.040	1.110 ± 0.040	1.460 ± 0.060	1.18	−0.04
$\varepsilon_{\mathrm{rel.}}$	6.17 %	3.74 %	2.85 %	3.95 %	4.71 %	–	–
$b_{\mathrm{rel.}}$	−3.27 %	2.08 %	−1.15 %	−0.82 %	3.37 %	–	–
$\varepsilon_{\mathrm{norm.}}$	3.34	1.11	1.83	6.36	2.33	4.55	–
$b_{\mathrm{norm.}}$	−1.26	0.58	0.08	1.69	1.69	–	0.26

Dwarf stars

Reese et al. 2016, A&A

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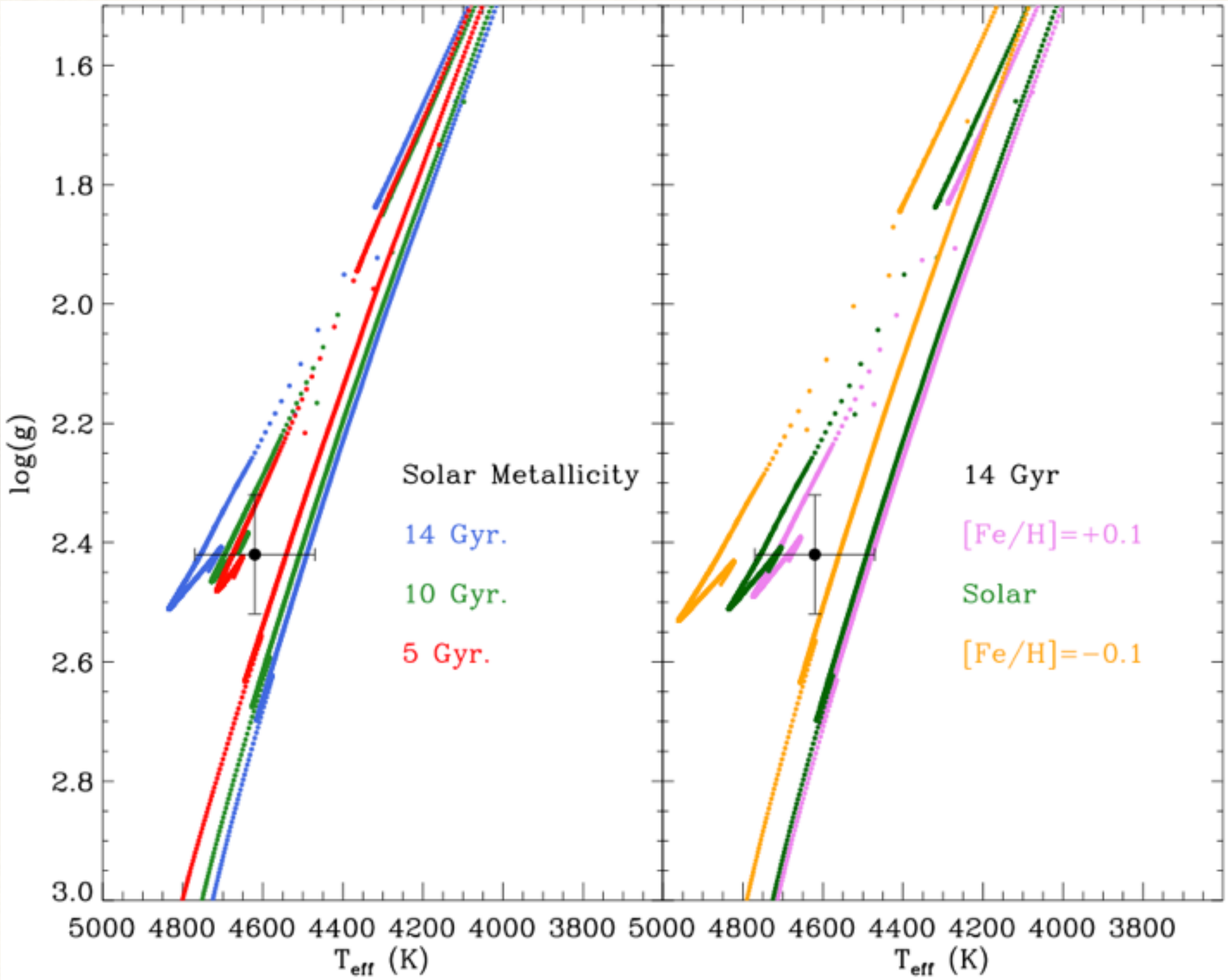
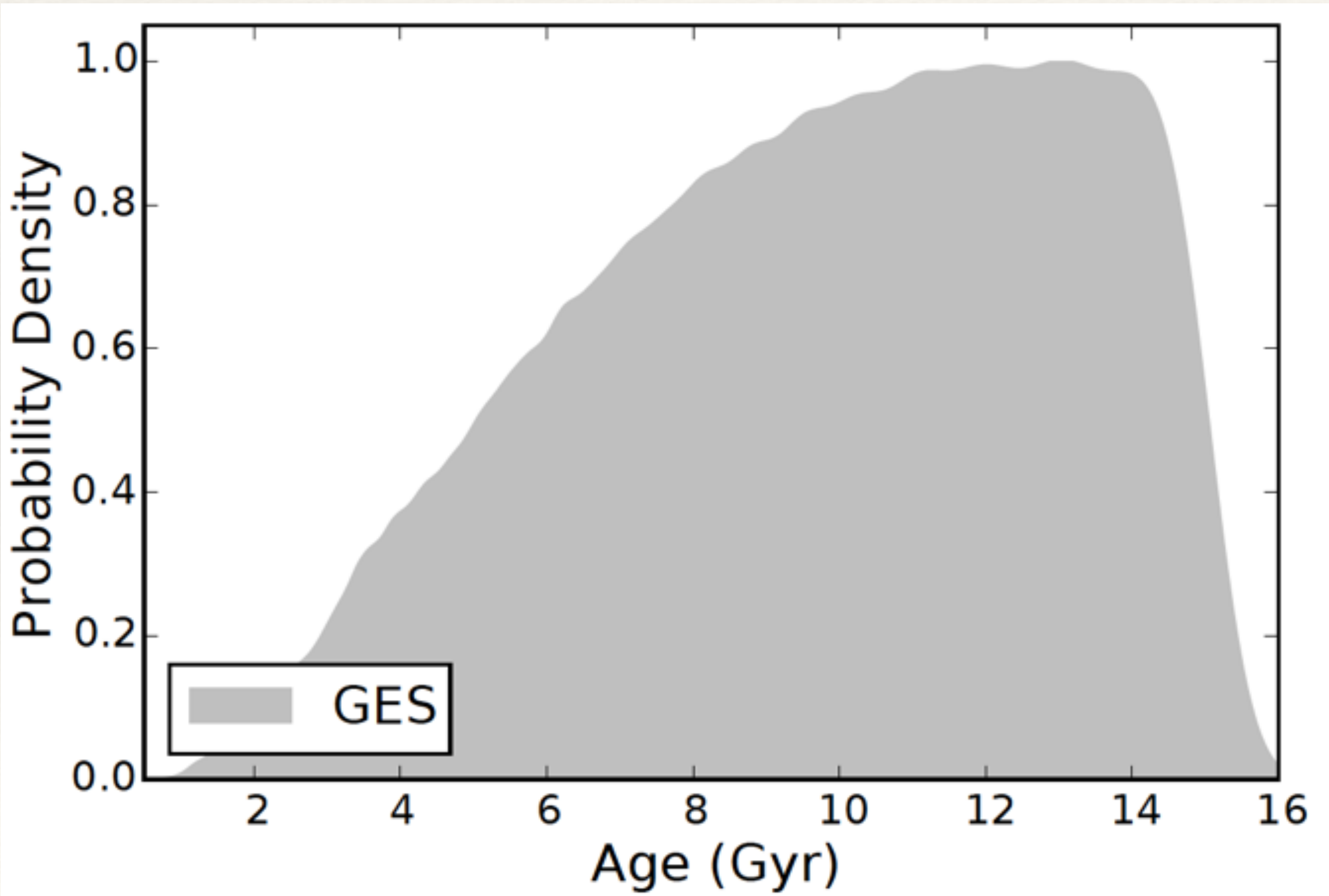
Red giants

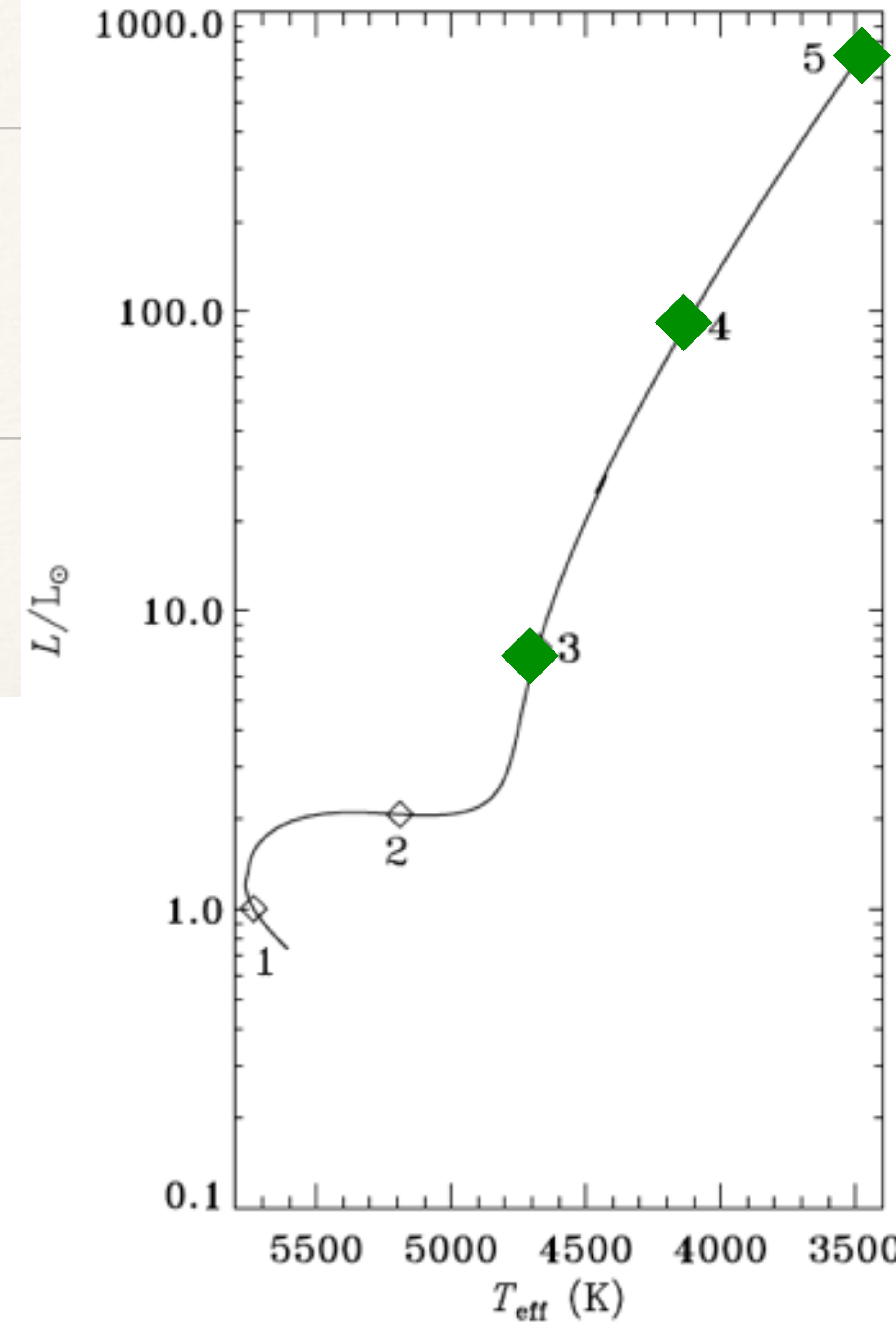


log(g)
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
Solar Metallicity
14 Gyr.
10 Gyr.
5 Gyr.
14 Gyr
[Fe/H]=+0.1
Solar
[Fe/H]=−0.1
5000 4800 4600 4400 4200 4000 3800
5000 4800 4600 4400 4200 4000 3800
T_{eff} (K)
T_{eff} (K)

Red giants

Example: spectroscopy





Data courtesy of A. Serenelli

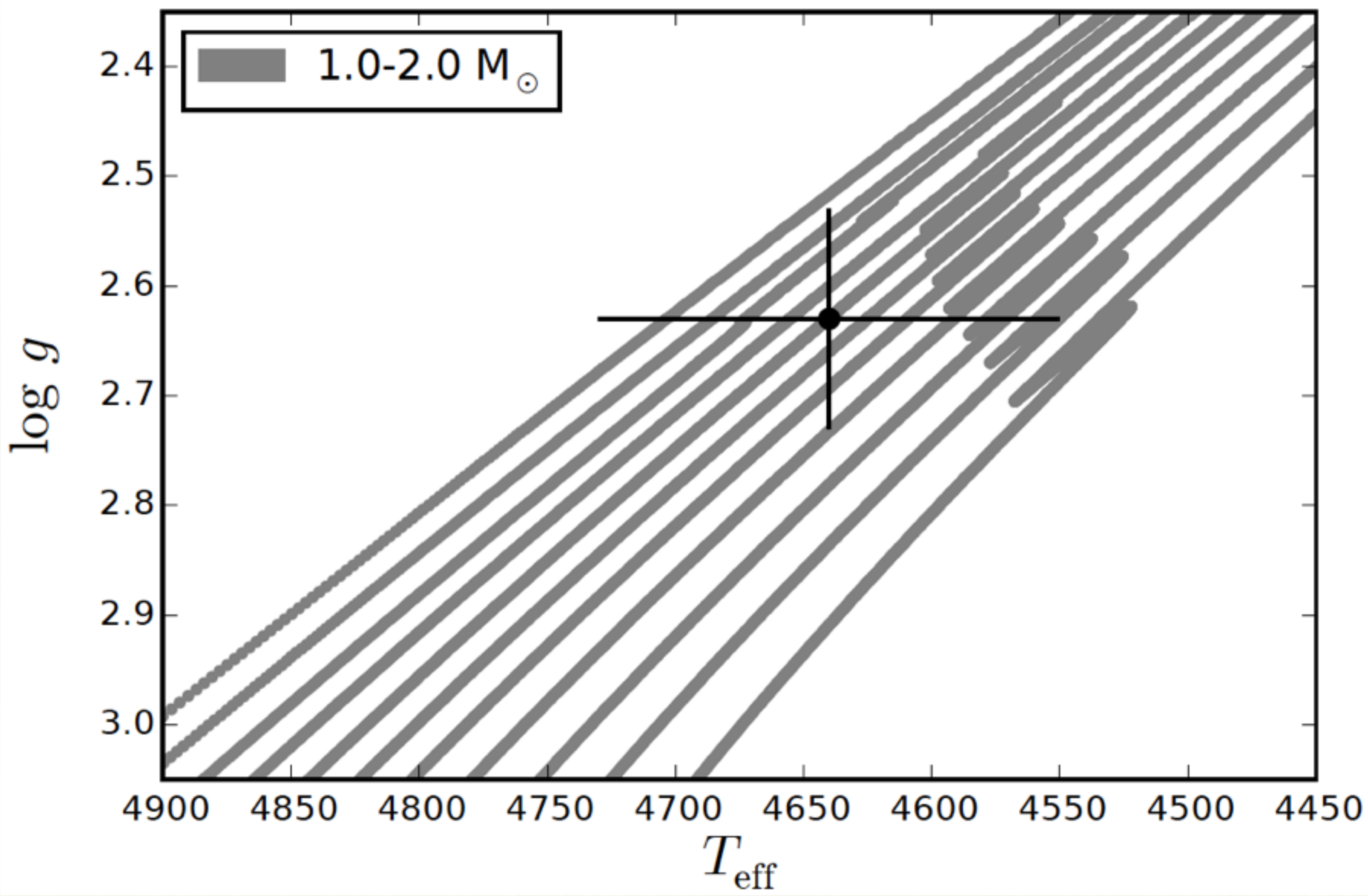
Asteroseismic data

Some fitting examples

- The bare minimum: scaling relations (dwarfs and giants)
- Improvements: individual frequencies (dwarfs for now)
- Improvements: period spacing (giants)

Always use Teff and [Fe/H]

The bare minimum



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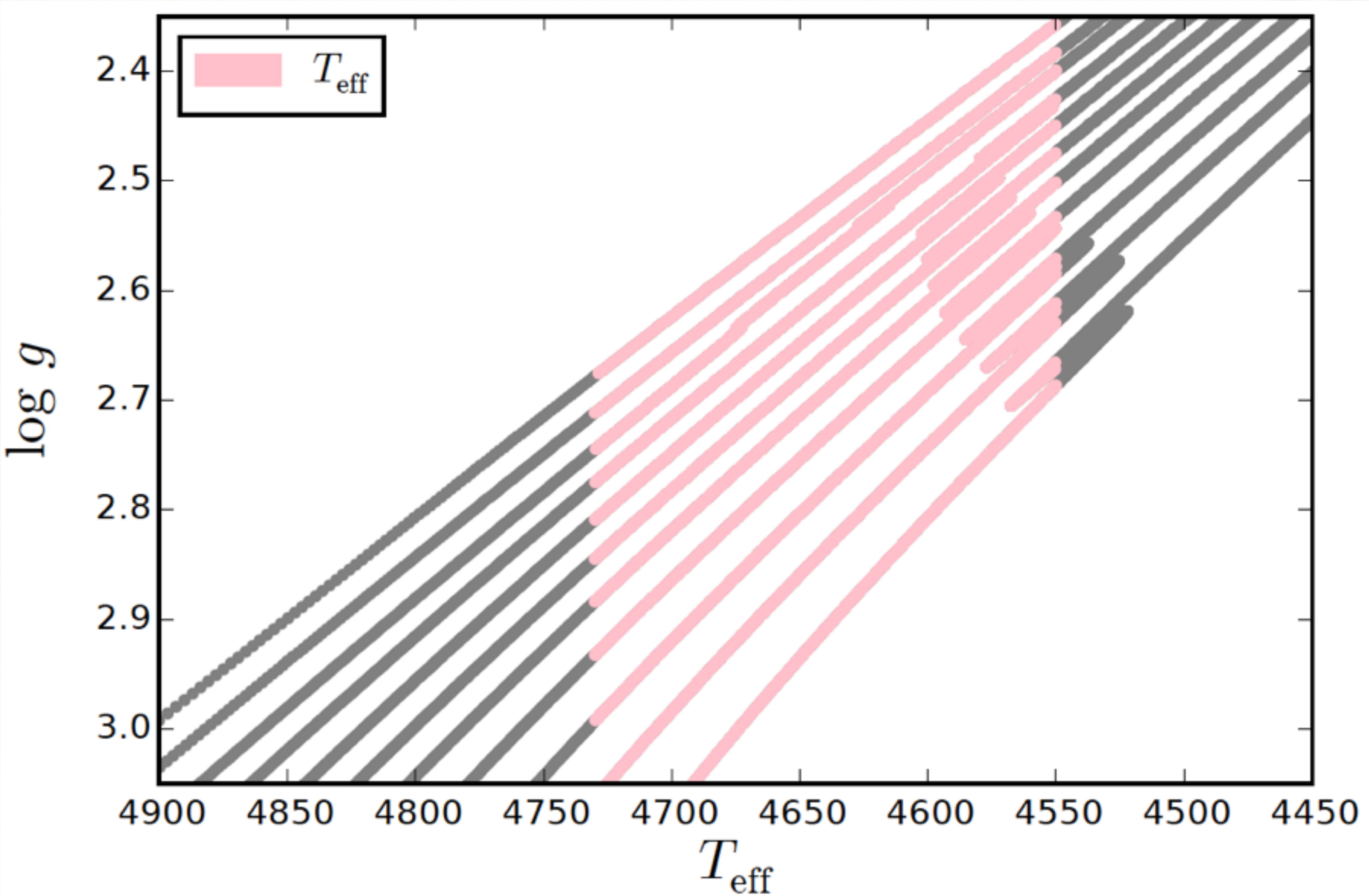

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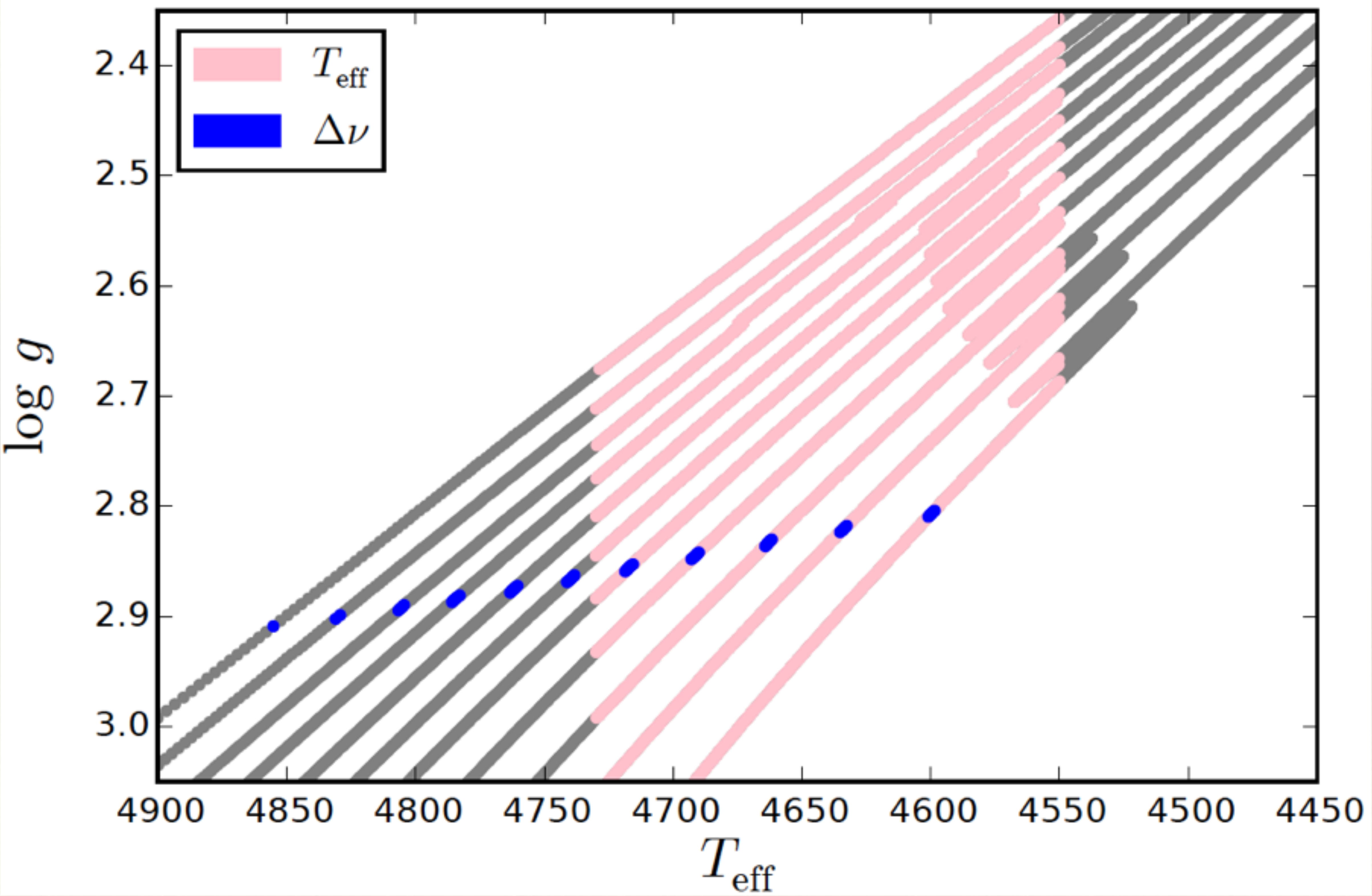

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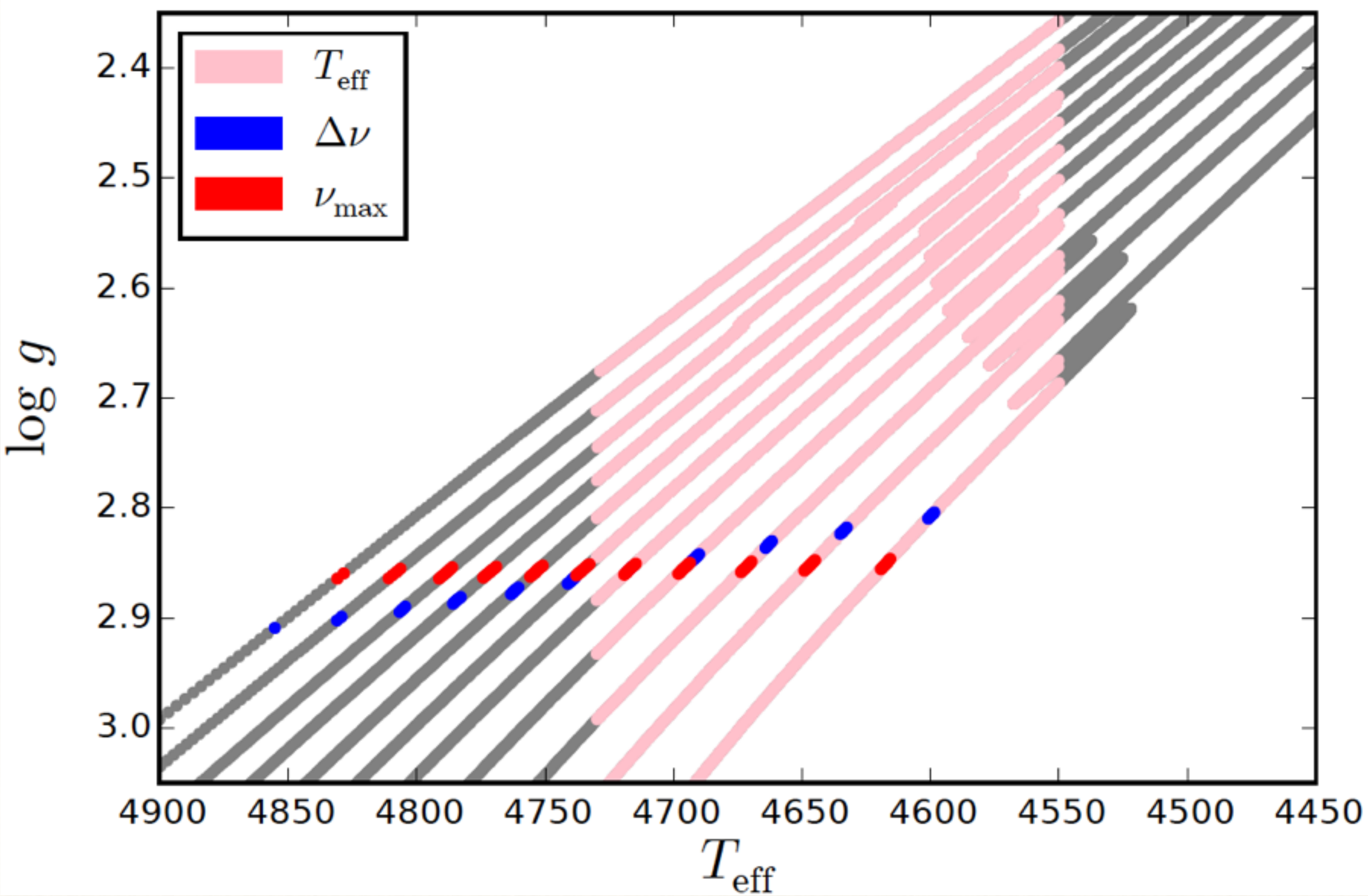
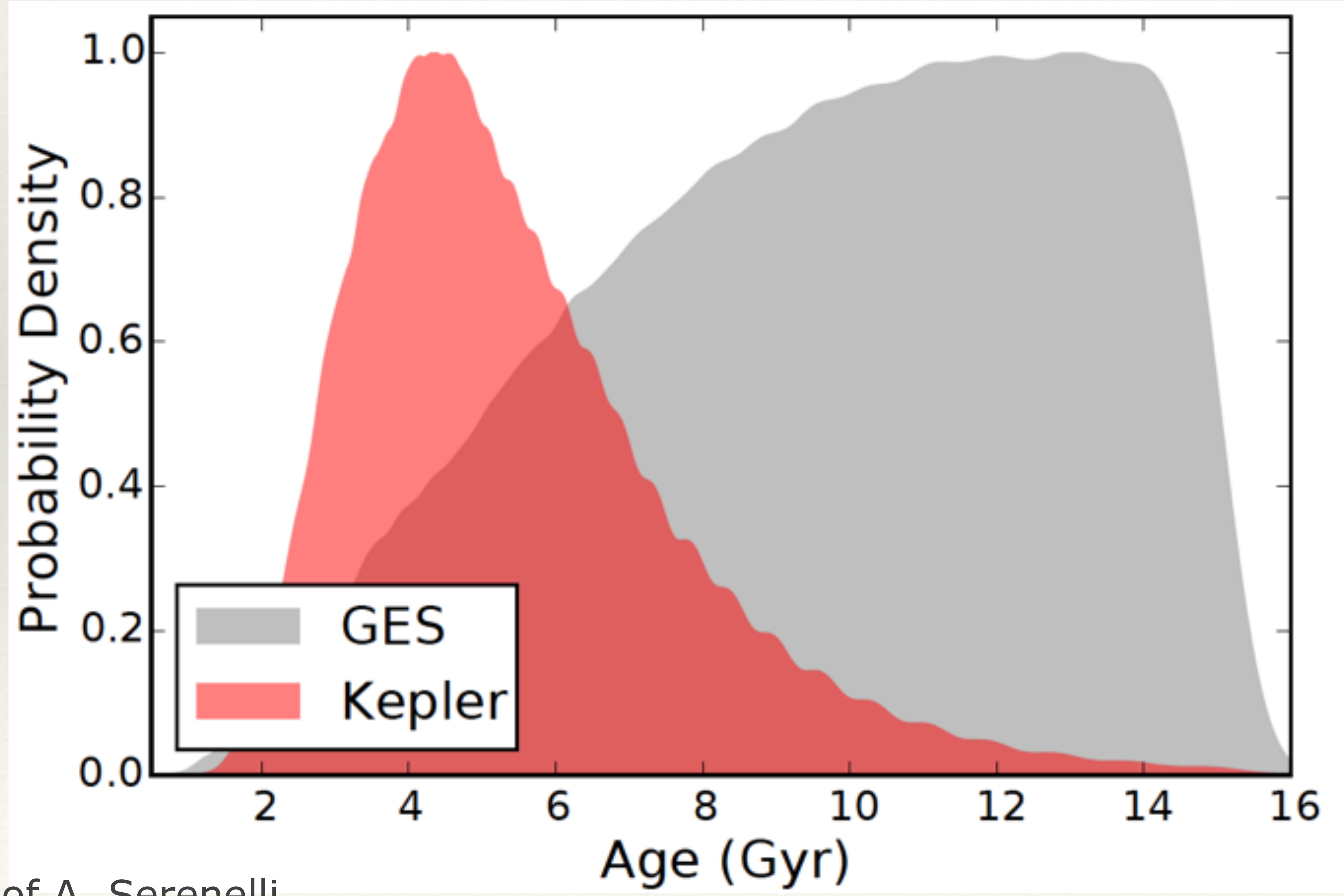


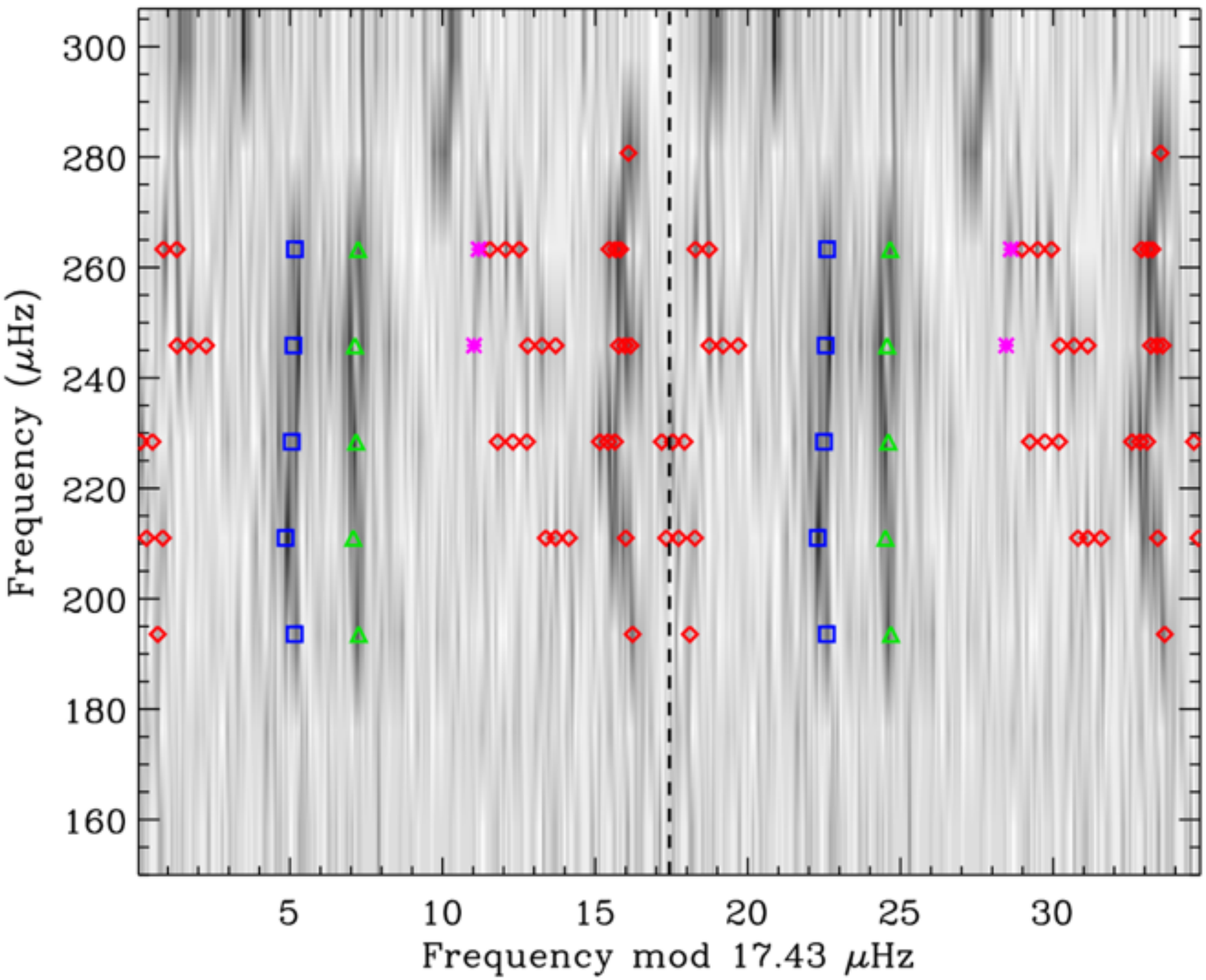
Red giants

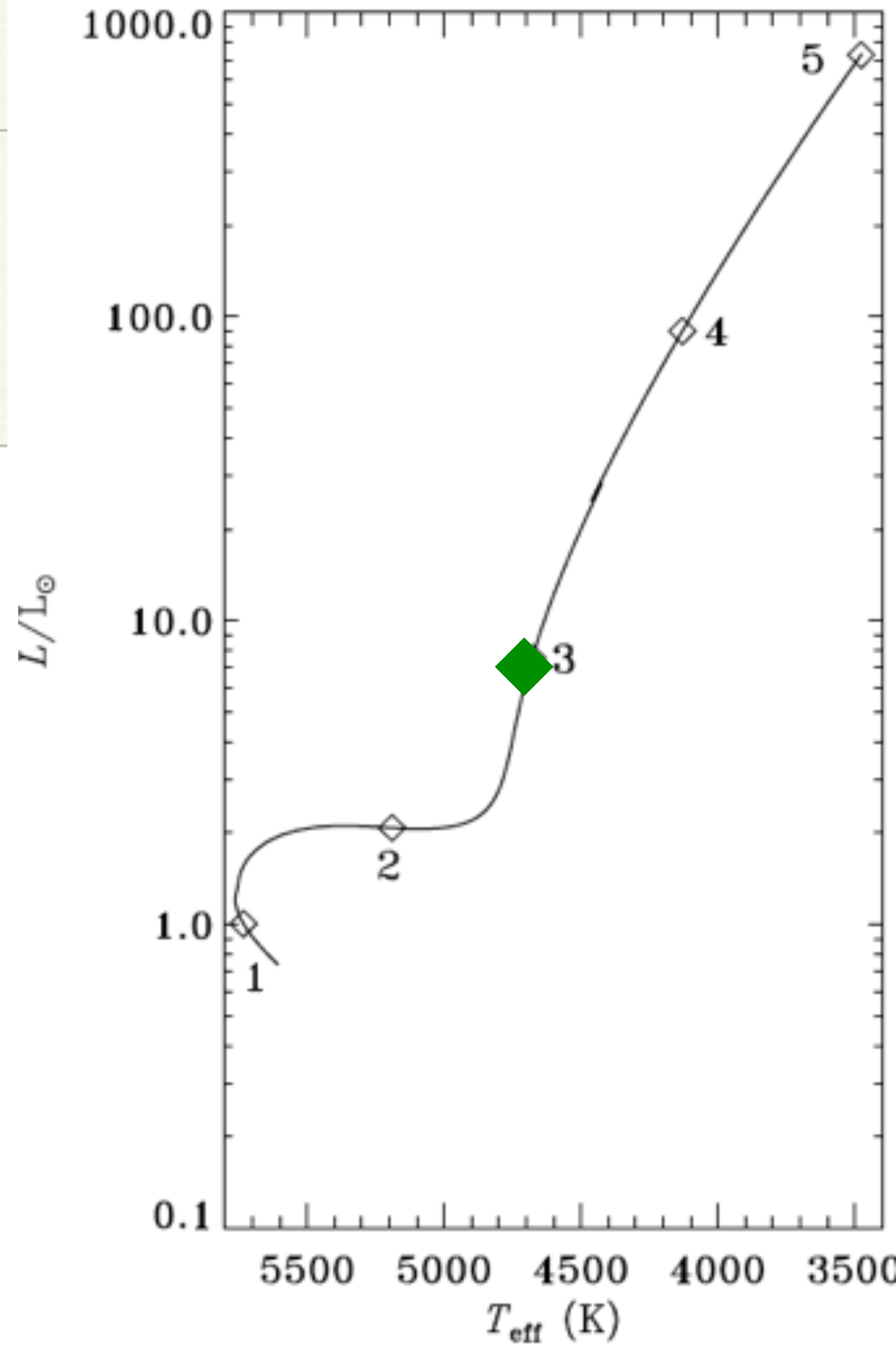
Example: spectroscopy



Data courtesy of A. Serenelli

Red giants



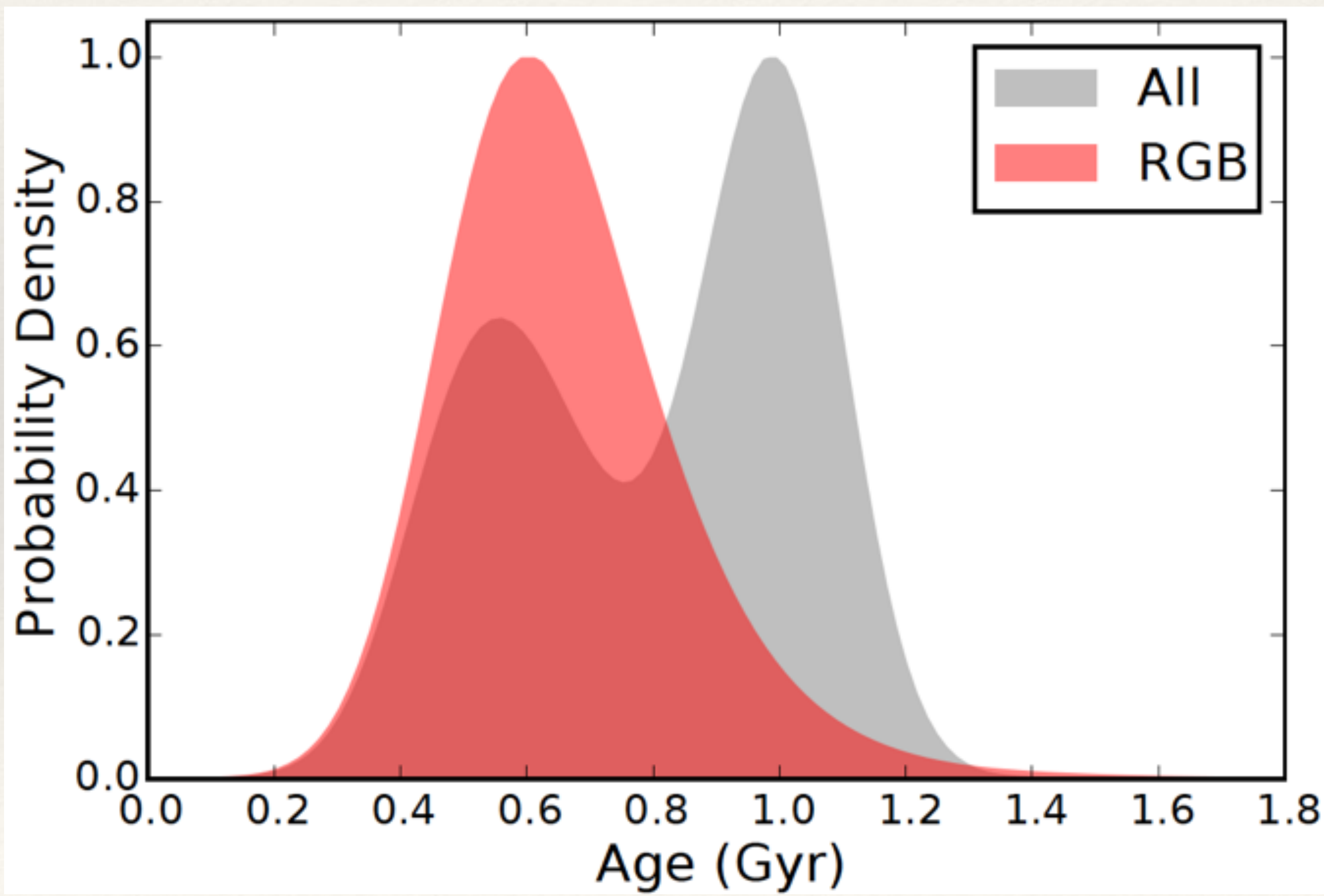


Note separation in l=1 modes

Huber et al. 2013, Science

Red giants

Using evolutionary phase



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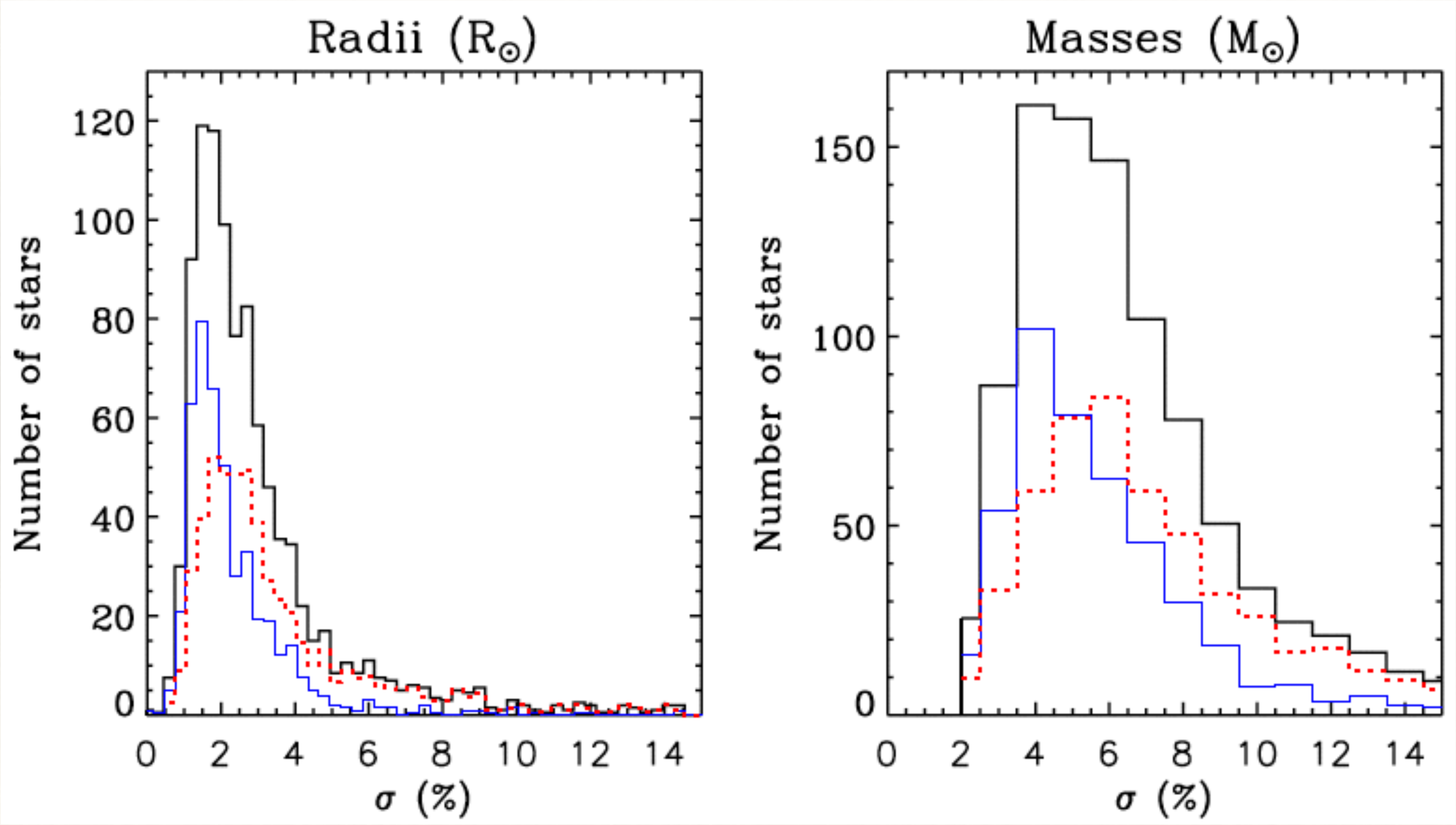
Red giants

What we can obtain for giants (i.e. SAGA):



Casagrande et al. 2014, ApJ

Red giants

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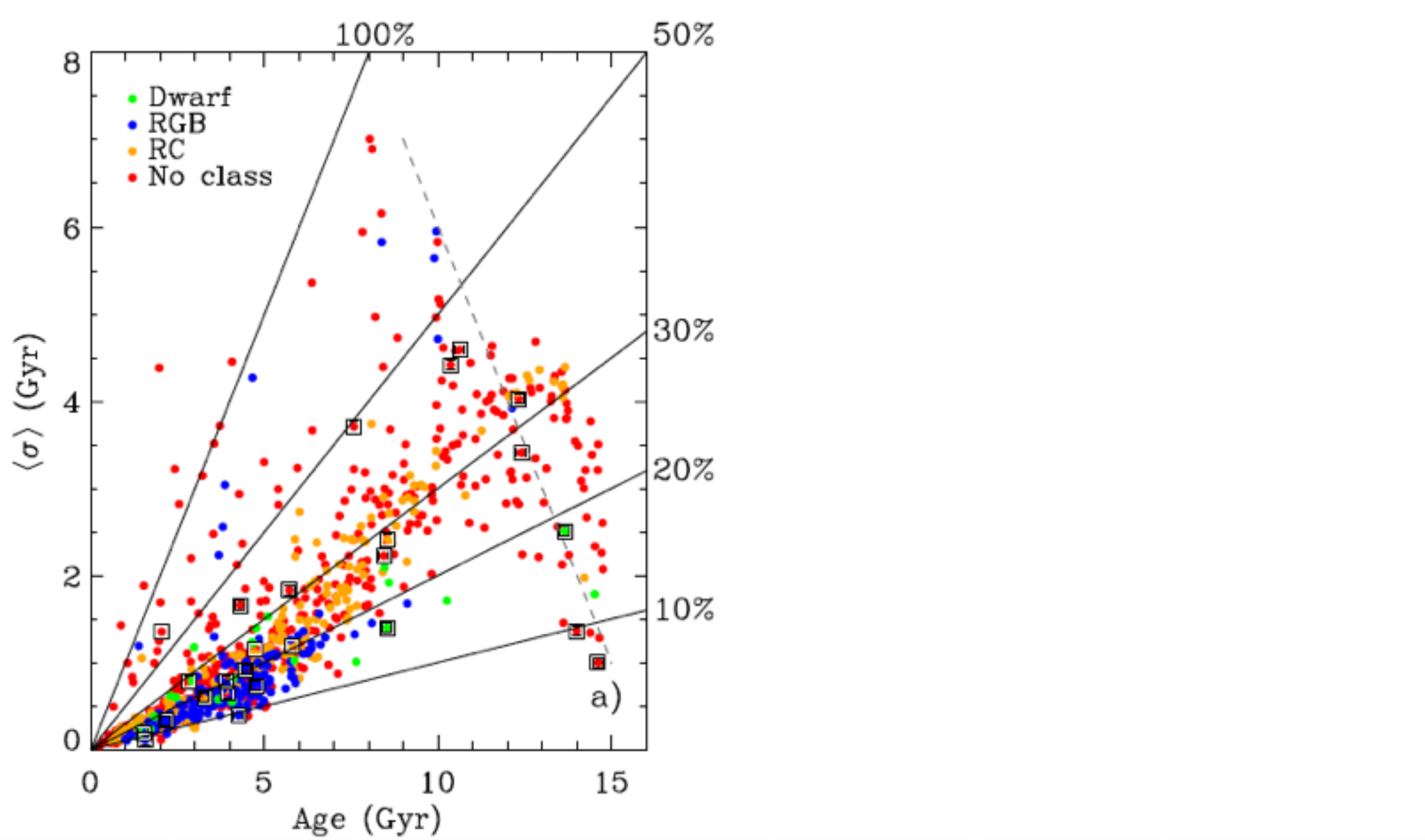

Casagrande, Silva Aguirre, Schlesinger, et al. 2016, MNRAS

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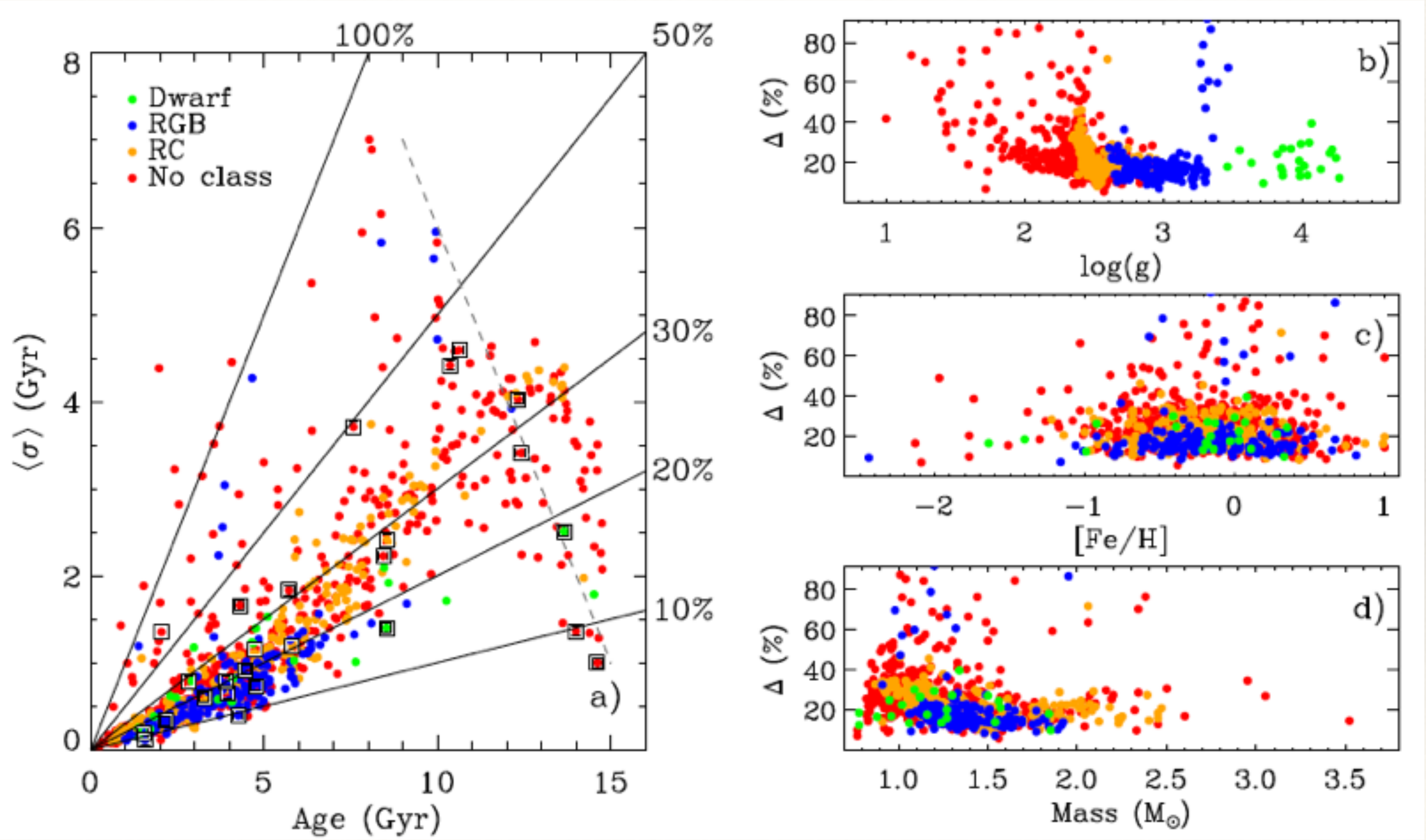

Casagrande, Silva Aguirre, Schlesinger, et al. 2016, MNRAS

Red giants

What we can obtain for giants (i.e. SAGA):

- Stellar radius ~2%
- Stellar mass ~6%
- Stellar age ~20%

Red giants

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- Stellar radius ~2%
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Can we improve?

Asteroseismic data

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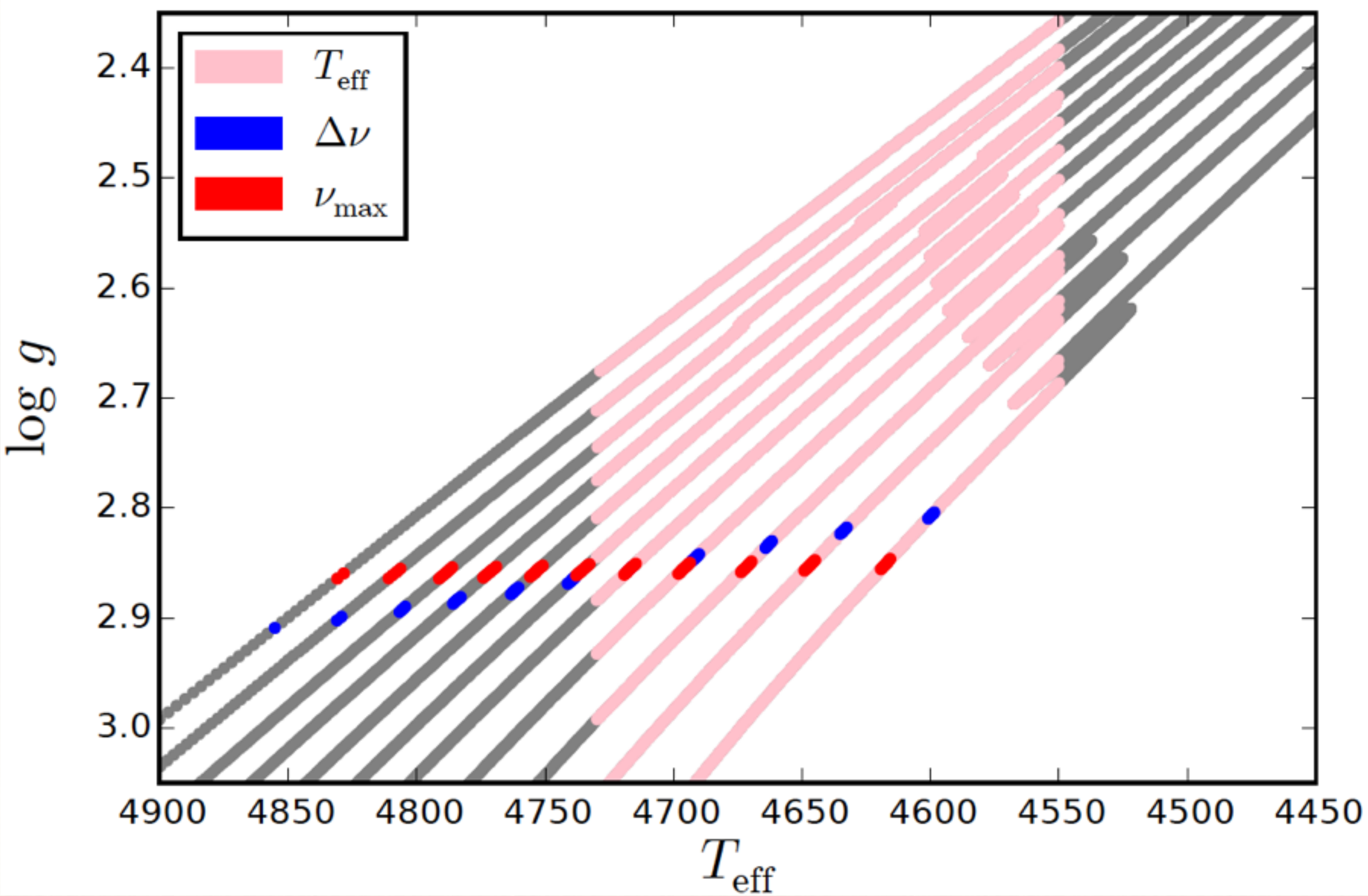
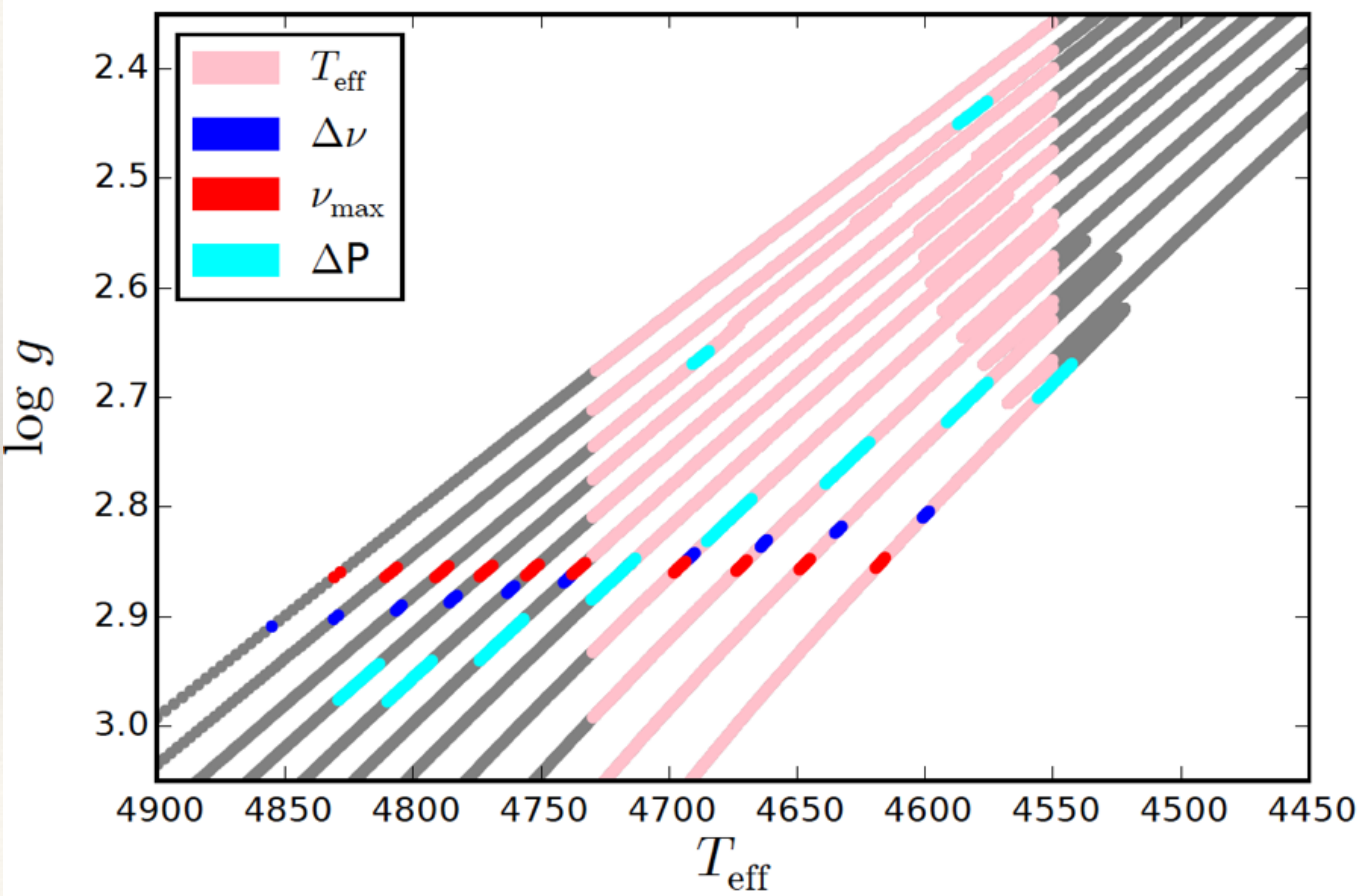
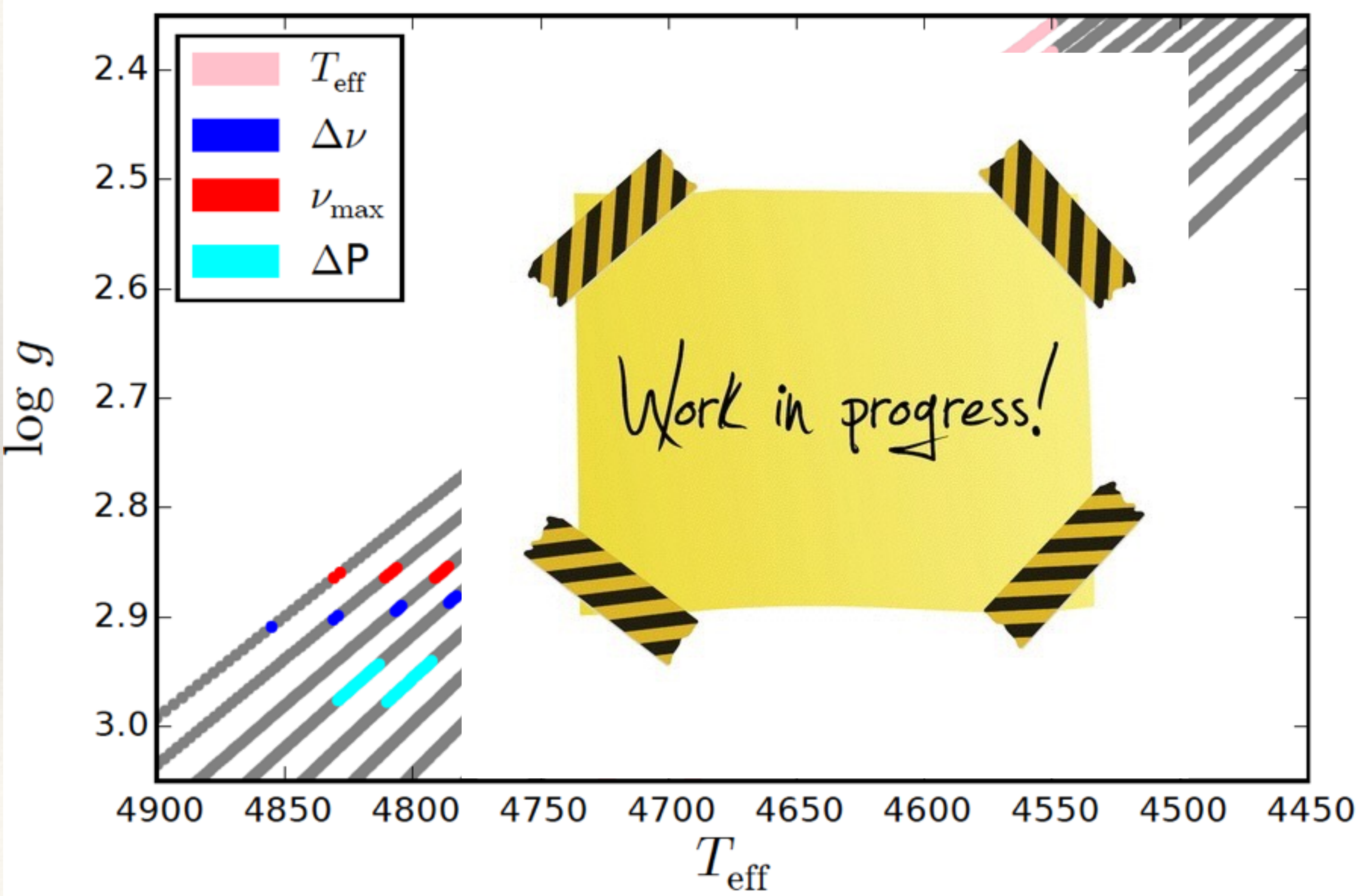
The added dimension



The added dimension



The added dimension



The future of BASTA

The future of BASTA

- Fitting individual frequencies for subgiants

The future of BASTA

- Fitting individual frequencies for subgiants
- Inclusion of period spacing

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- Use of distributions and probability in the input

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- Missing physics in current grids (i.e., rotation, radiative levitation, thermohaline-mixing, etc.)

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- Use of distributions and probability in the input
- Include results from 3D simulations
- Missing physics in current grids (i.e., rotation, radiative levitation, thermohaline-mixing, etc.)
- Different surface-effect terms

The future of BASTA

- Fitting individual frequencies for subgiants
- Inclusion of period spacing
- Use of distributions and probability in the input
- Include results from 3D simulations
- Missing physics in current grids (i.e., rotation, radiative levitation, thermohaline-mixing, etc.)
- Different surface-effect terms
- Web-interface

STELLAR ASTROPHYSICS CENTRE

BAyesian STellar Algorithm (BASTA)

Víctor Silva Aguirre

Meudon, May 23rd 2016