

STELLAR ASTROPHYSICS CENTRE

# Ages for dwarfs and giants from asteroseismology

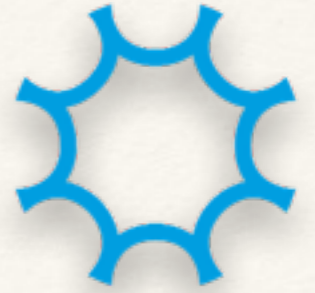
Víctor Silva Aguirre  
Aldo Serenelli

Bad Honnef, June 1st 2015

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# Introduction

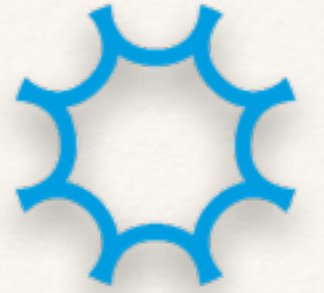
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# Introduction

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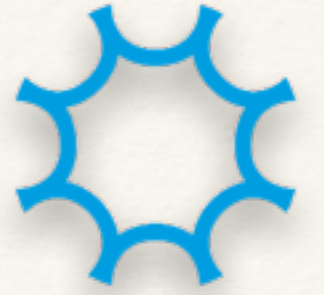


- ❖ Revolution: seismic data for thousands of field stars
- ❖ Seismic stellar parameters for galactic archaeology
- ❖ How is it done?
- ❖ Which observables are used?
- ❖ What are they sensitive to?
- ❖ How good are the seismic stellar properties?

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# Disclaimer

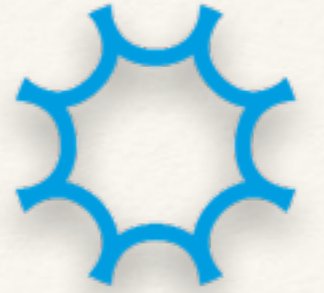
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# Disclaimer

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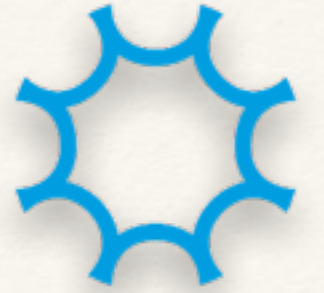
Under the hood:

- ❖ **BA**yesian **ST**ellar **A**lgorithm: **BASTA** Silva Aguirre et al. 2015, MNRAS
- ❖ **Be**llaterra **St**ellar **P**roperties **P**ipeline: **BeSPP** Serenelli et al. 2013, MNRAS

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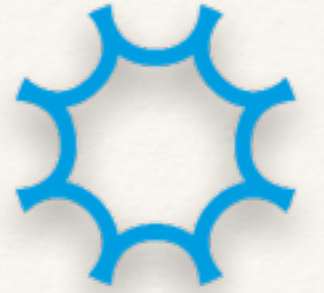
## Reference stellar properties for:

- ❖ 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. 2014, ApJ  
Pinsonneault et al. 2014, ApJS
- ❖ Gyrochronology: van Saders et al. 2015, in prep

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## Under the hood:

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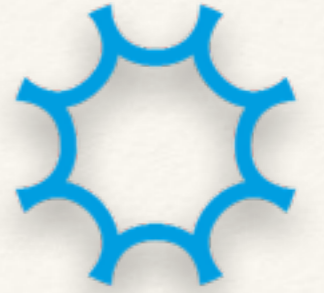
## The basics:

- ❖ Work with GARSTEC and BaSTI grids of models
- ❖ Flexible input: averages, individual freqs., combinations...
- ❖ Rev. Bayes in the core: priors, weighting, etc...

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# Asteroseismic data

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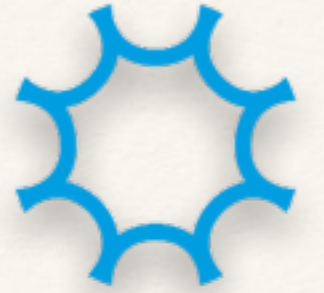
How does the seismic trick works:



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# Asteroseismic data

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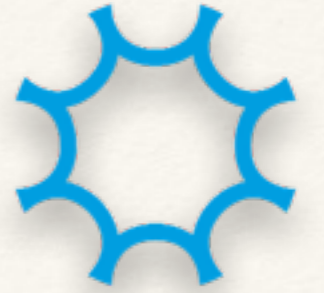
## How does the seismic trick works:

- ❖ The bare minimum: scaling relations (dwarfs and giants)

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# Asteroseismic data

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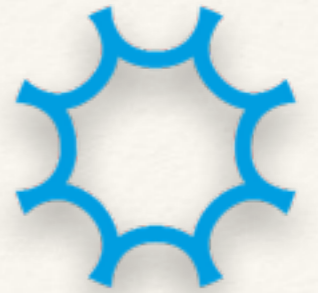
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- ❖ Improvements: individual frequencies (dwarfs for now)

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# Asteroseismic data

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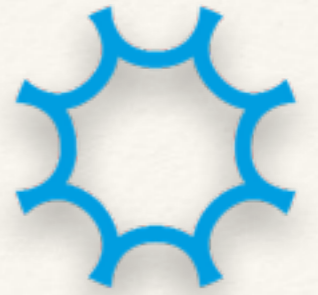
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# Asteroseismic data

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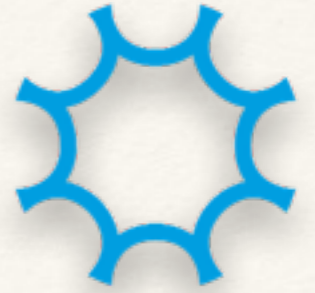


## How does the seismic trick works:

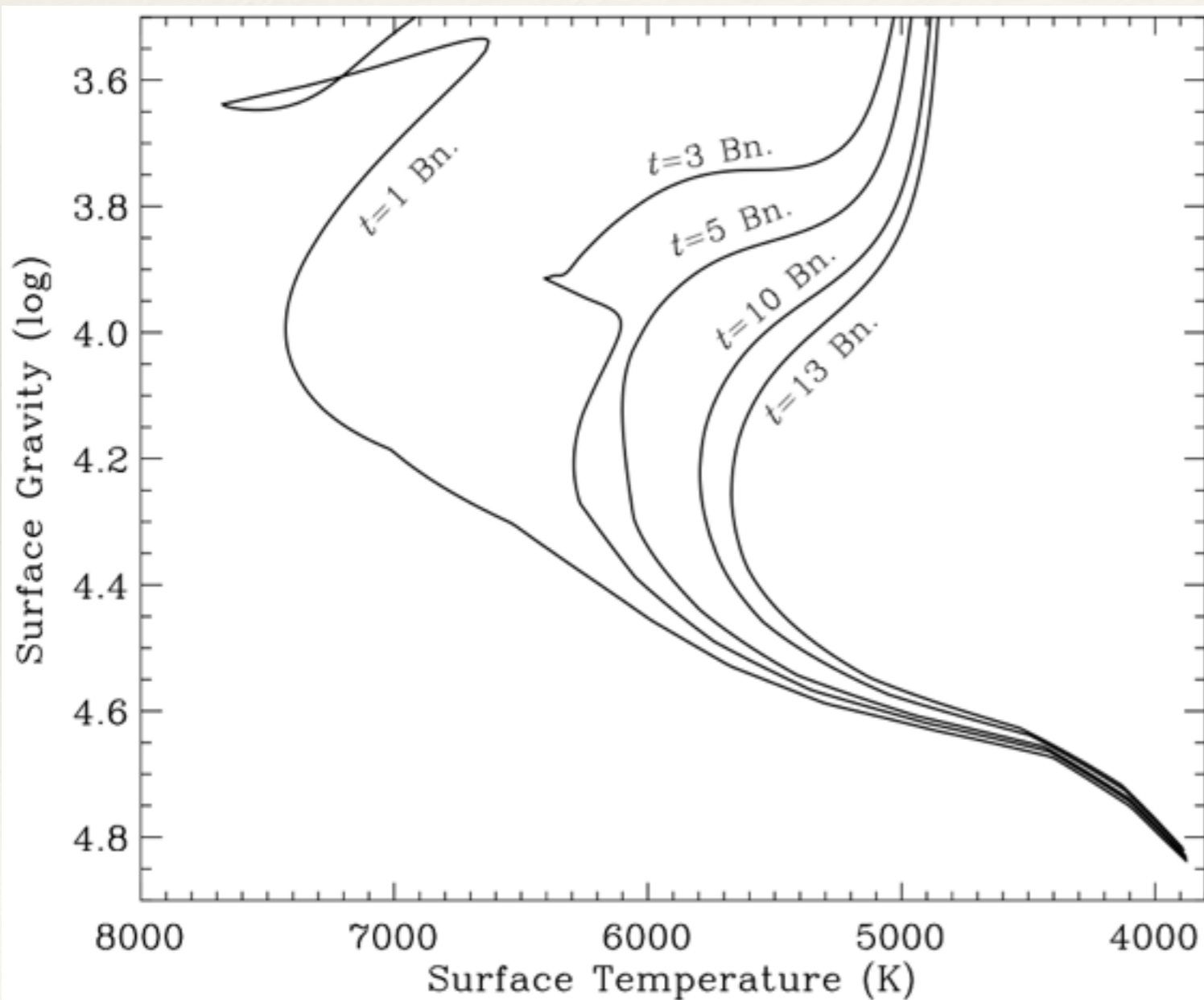
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**Always need  $T_{\text{eff}}$  and  $[\text{Fe}/\text{H}]$**

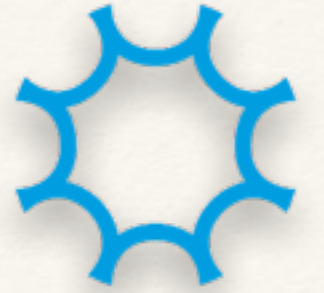
# The problem at hand



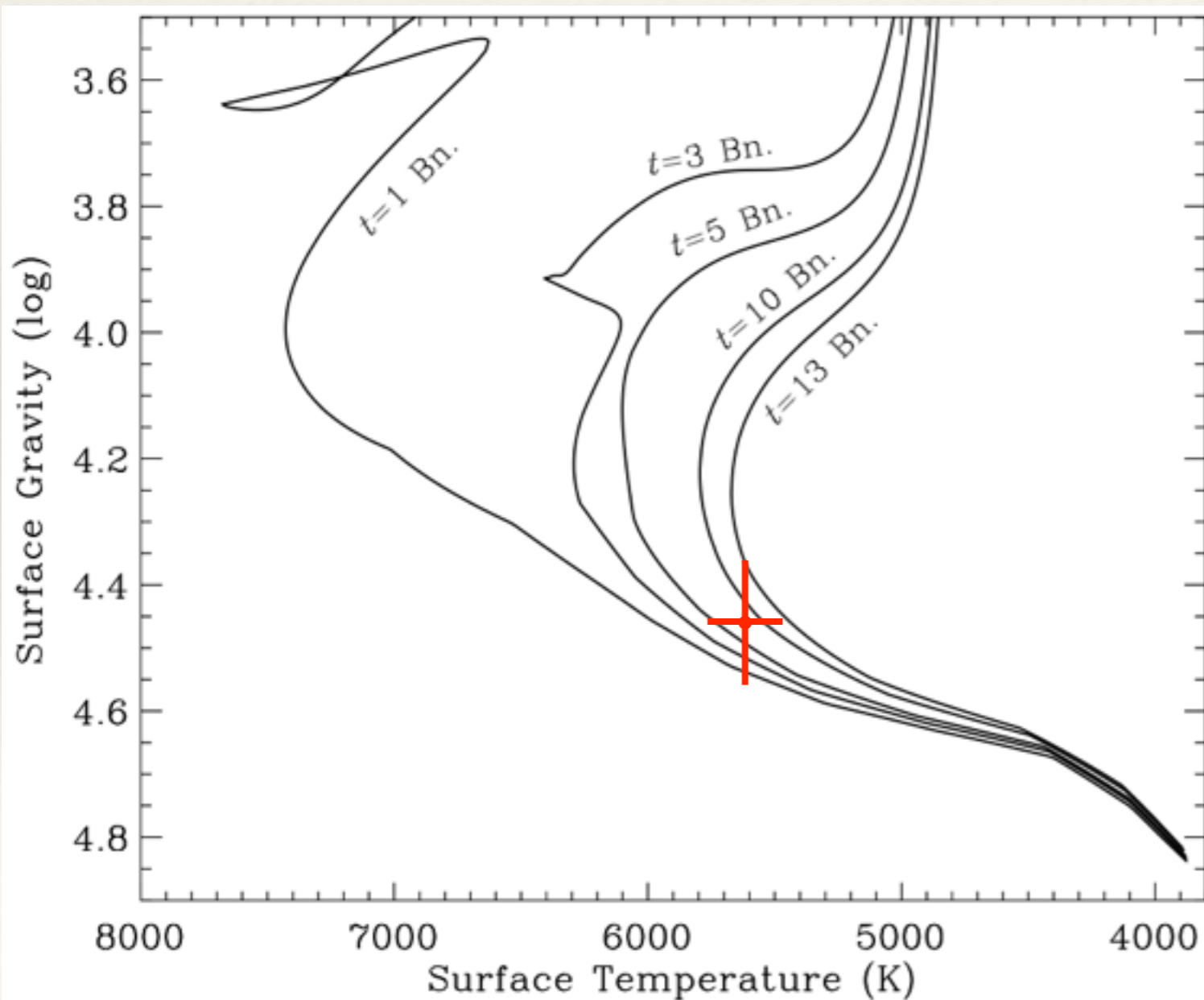
## Dwarfs:



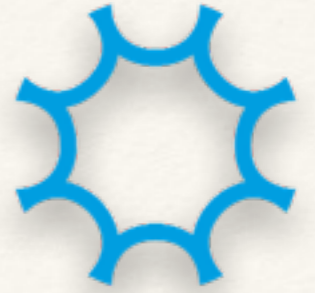
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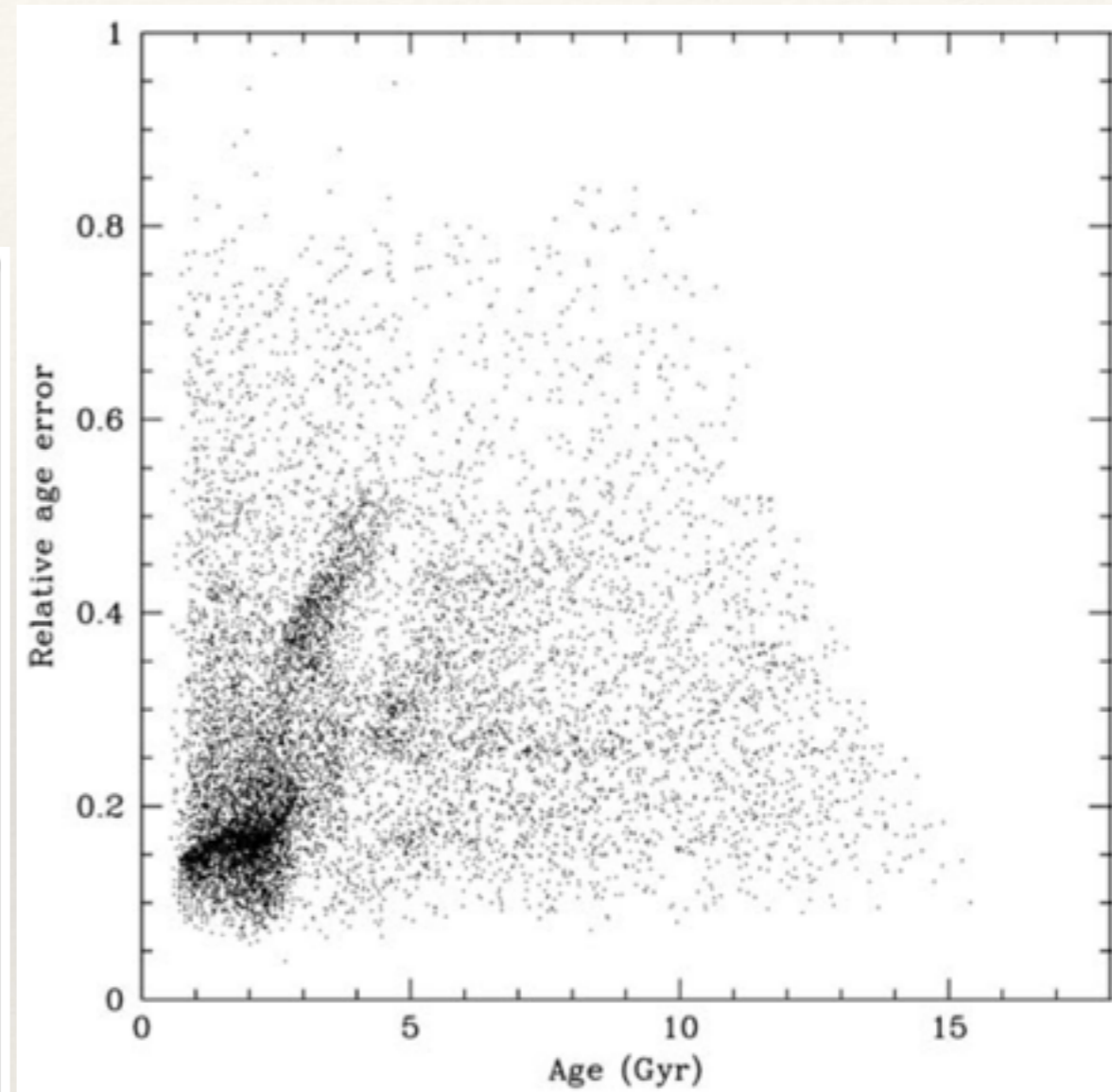
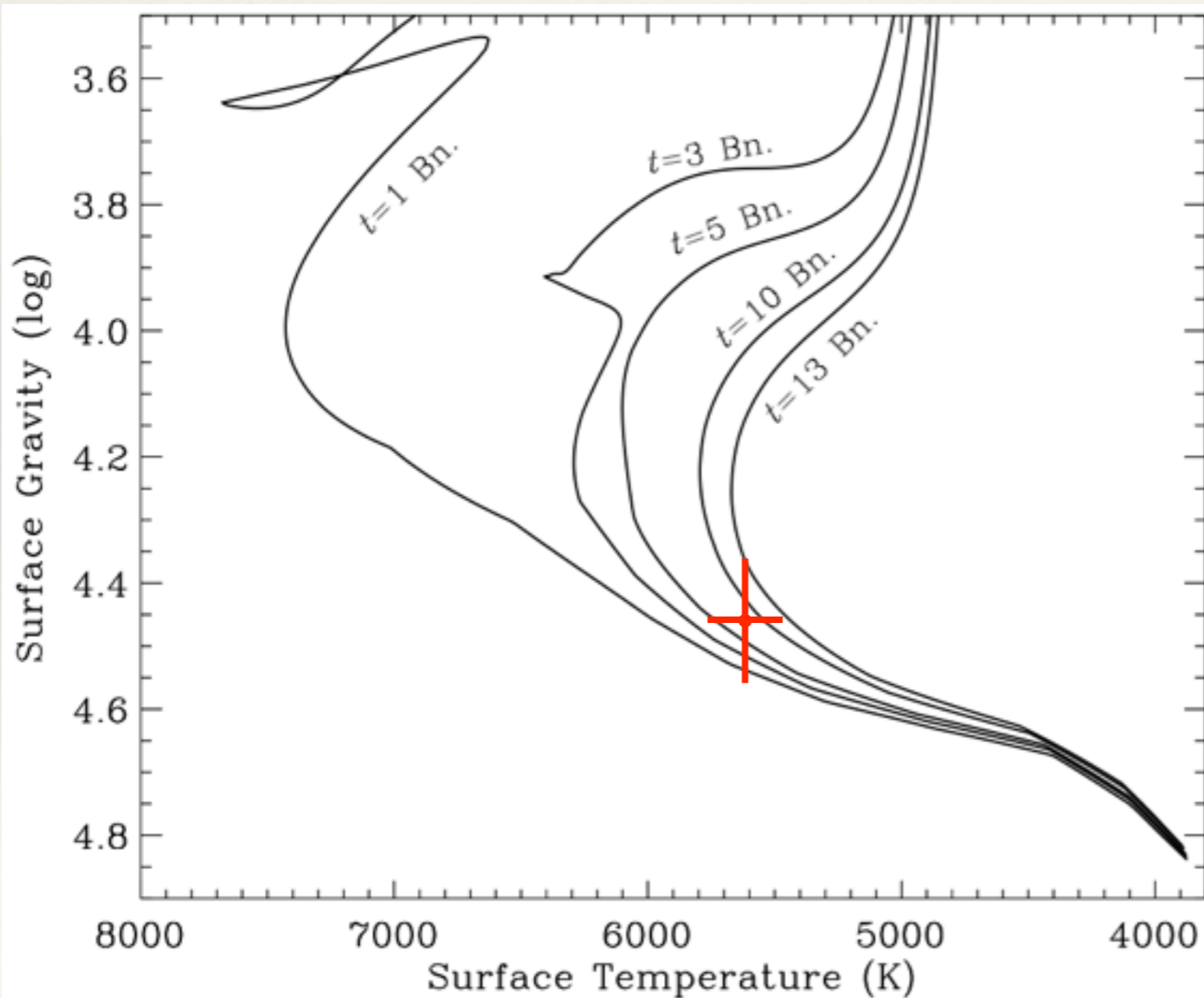
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# The problem at hand



Dwarfs:

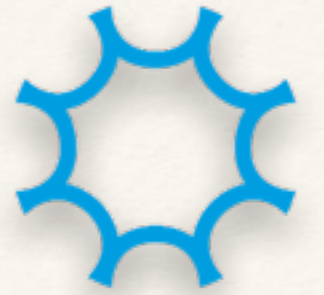


e.g., Nordström et al. 2004, A&A

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# Asteroseismic data

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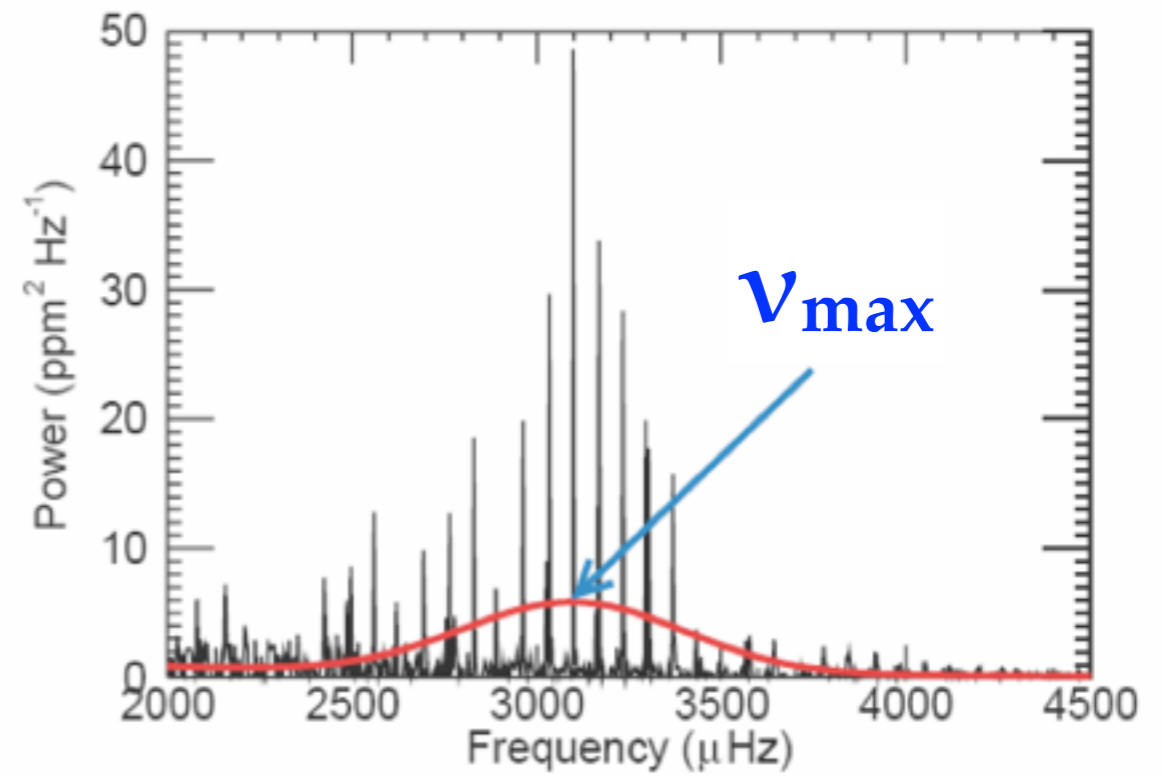
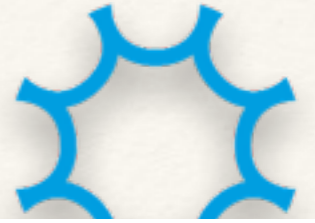
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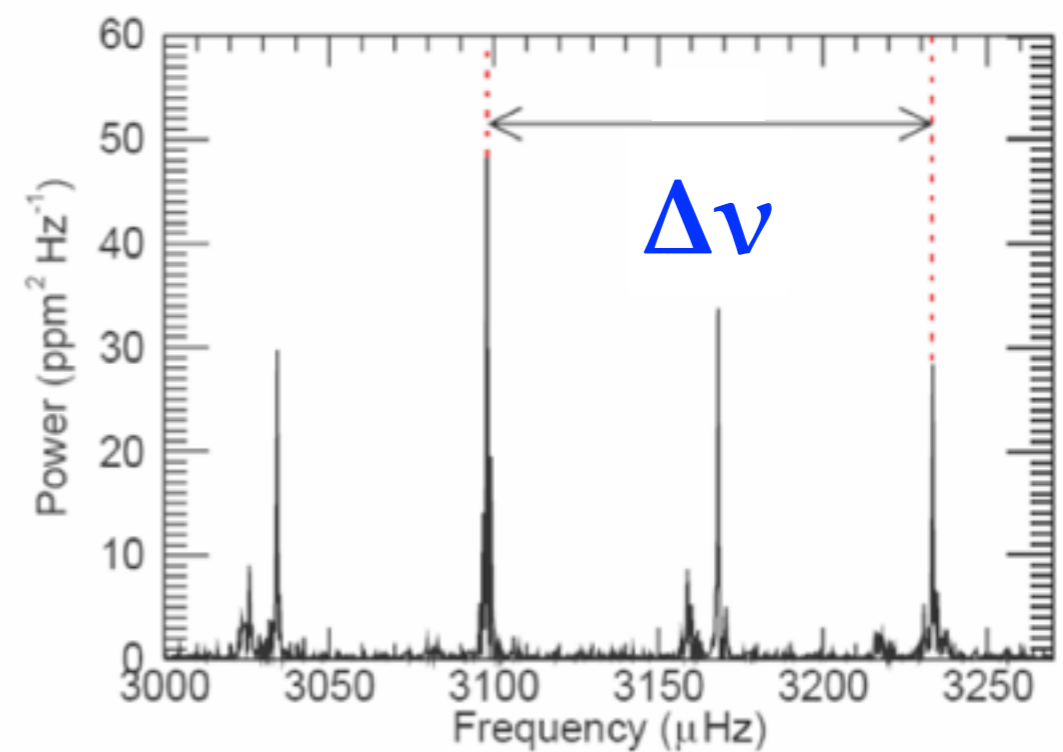
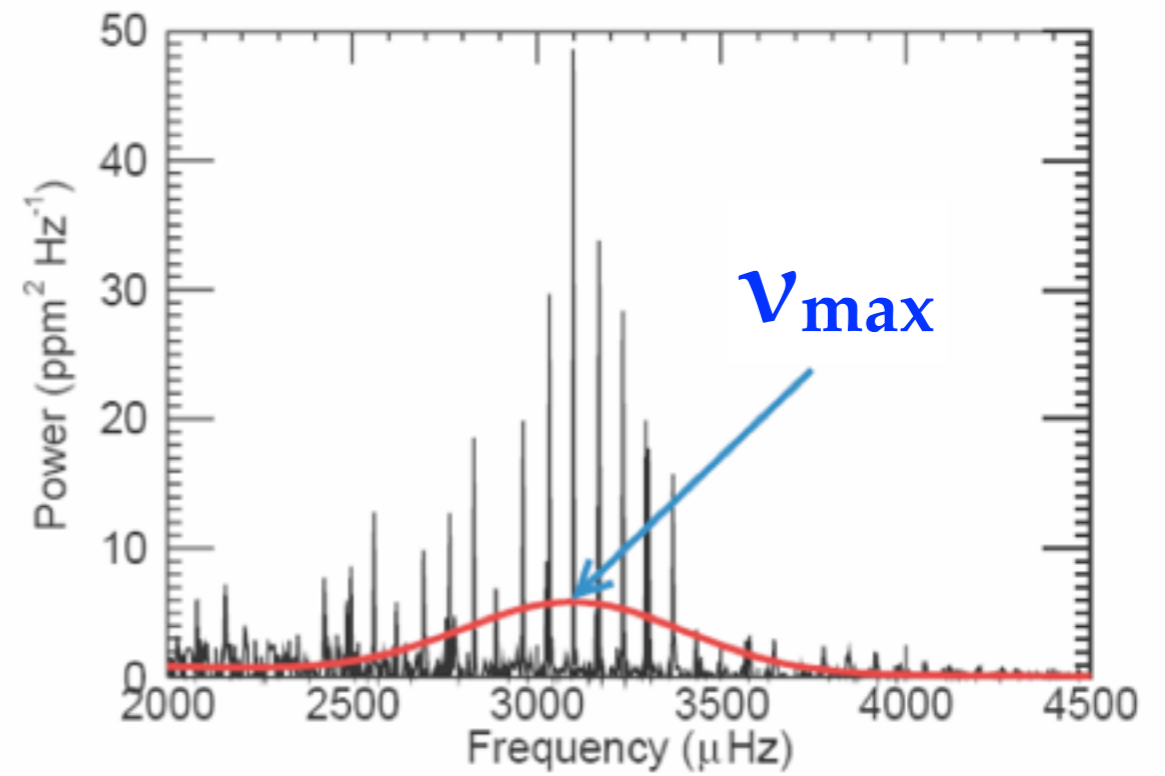
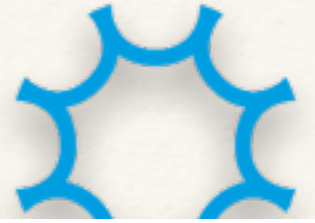
Always need  $T_{\text{eff}}$  and  $[\text{Fe}/\text{H}]$



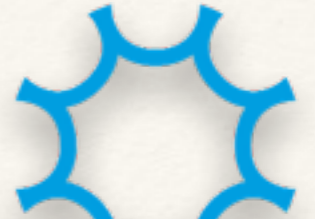
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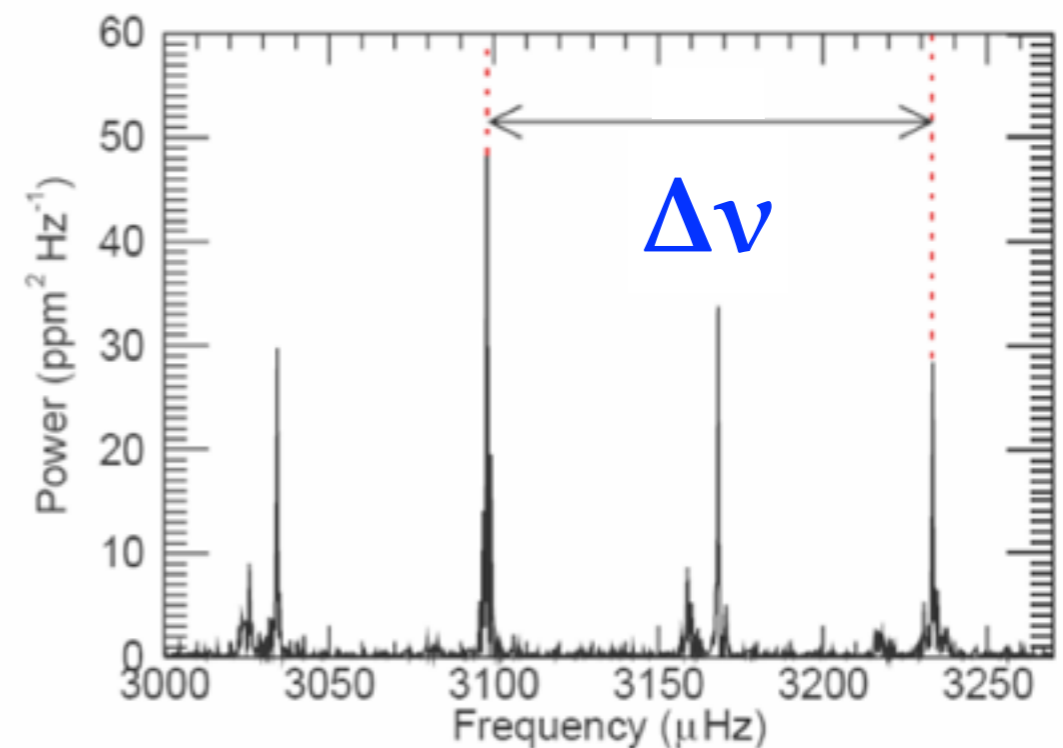
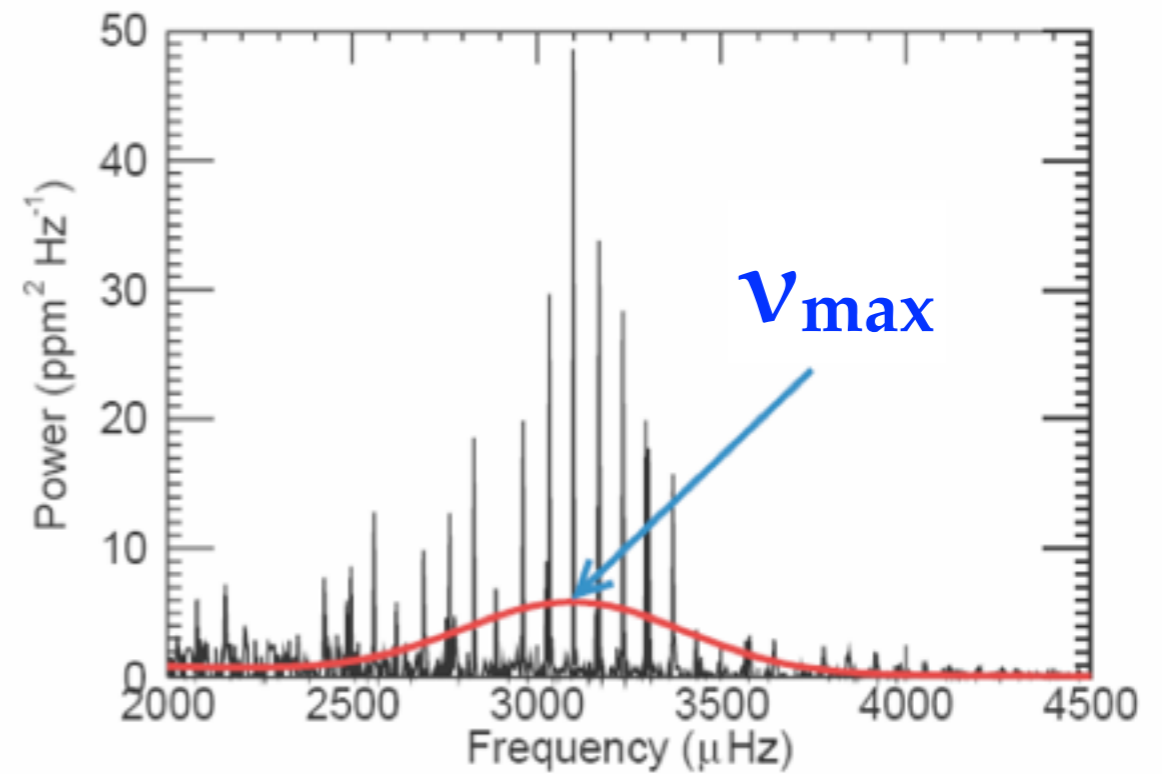
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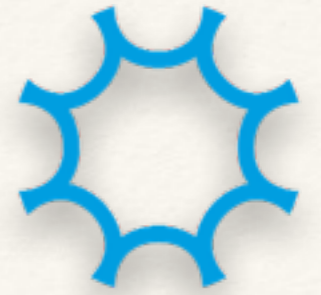
$\Delta\nu$ ,  $\nu_{\max}$   $\rightarrow$  sensitive to  
the mass and radius  
of the star (p-modes)



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# The scaling relations

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In the following we trust:

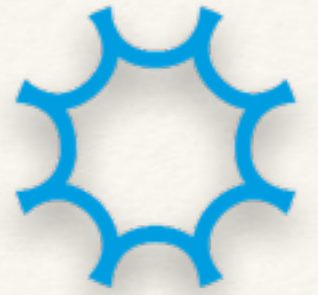
e.g. Basu et al. 2010, ApJ

Gai et al. 2011, ApJ

Silva Aguirre et al. 2013, ApJ

Chaplin et al. 2014, ApJS

# The scaling relations



In the following we trust:

$$\left( \frac{\rho}{\rho_{\odot}} \right) \simeq \left( \frac{\langle \Delta v_{nl} \rangle}{\langle \Delta v_{nl} \rangle_{\odot}} \right)^2$$

Ulrich 1986, ApJ

$$\left( \frac{g}{g_{\odot}} \right) \simeq \left( \frac{v_{\max}}{v_{\max, \odot}} \right) \left( \frac{T_{\text{eff}}}{T_{\text{eff}, \odot}} \right)^{0.5}$$

Kjeldsen & Bedding 1995, PASP

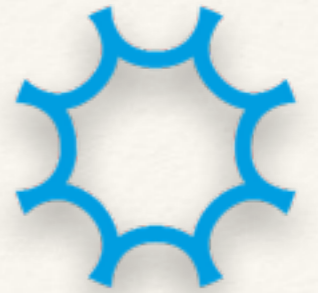
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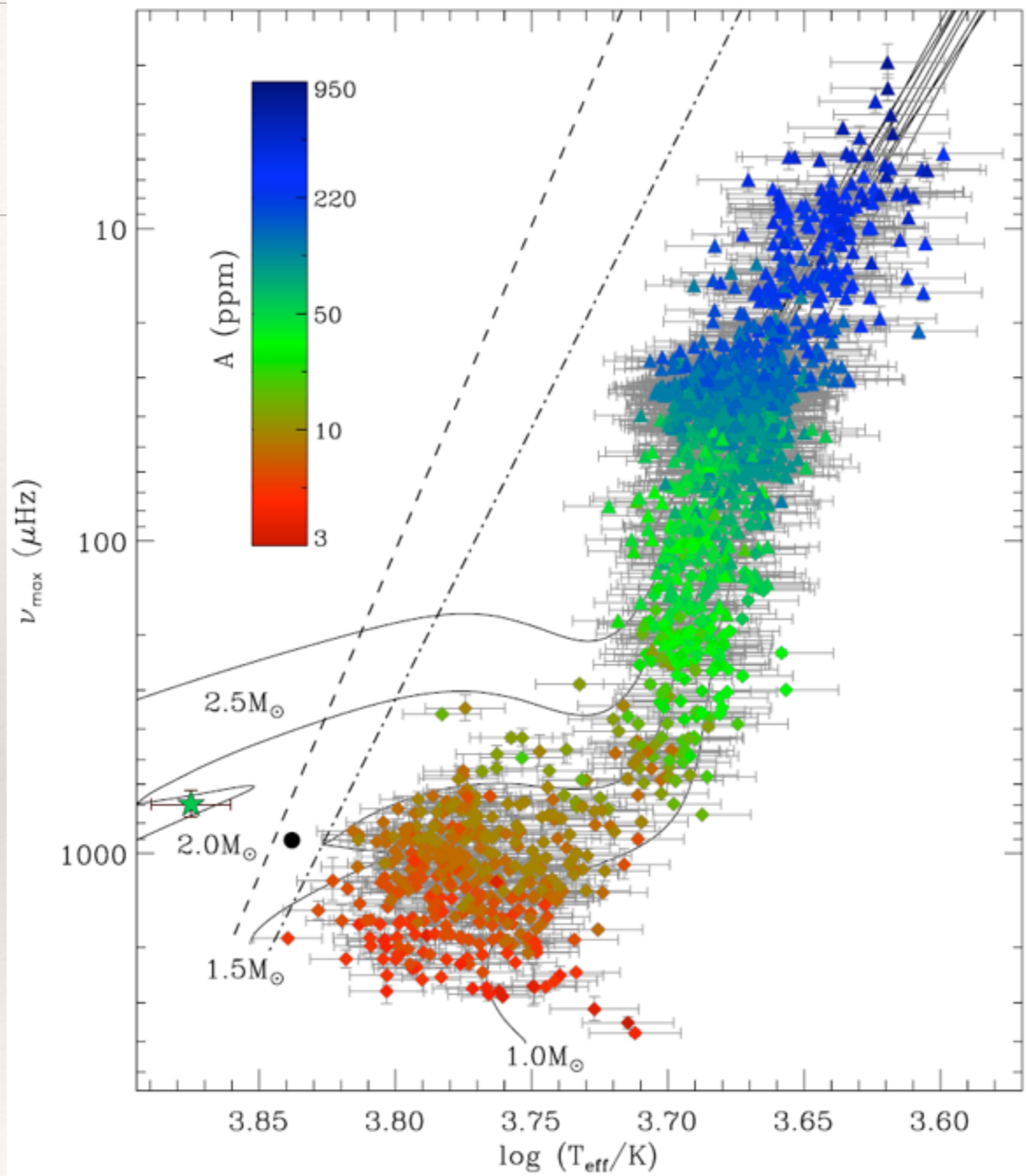
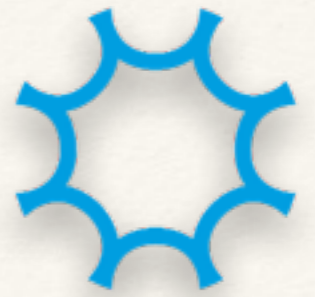
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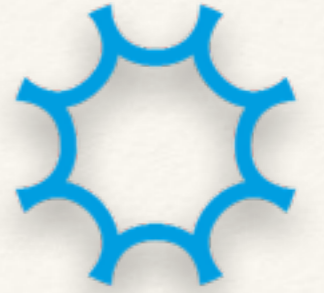
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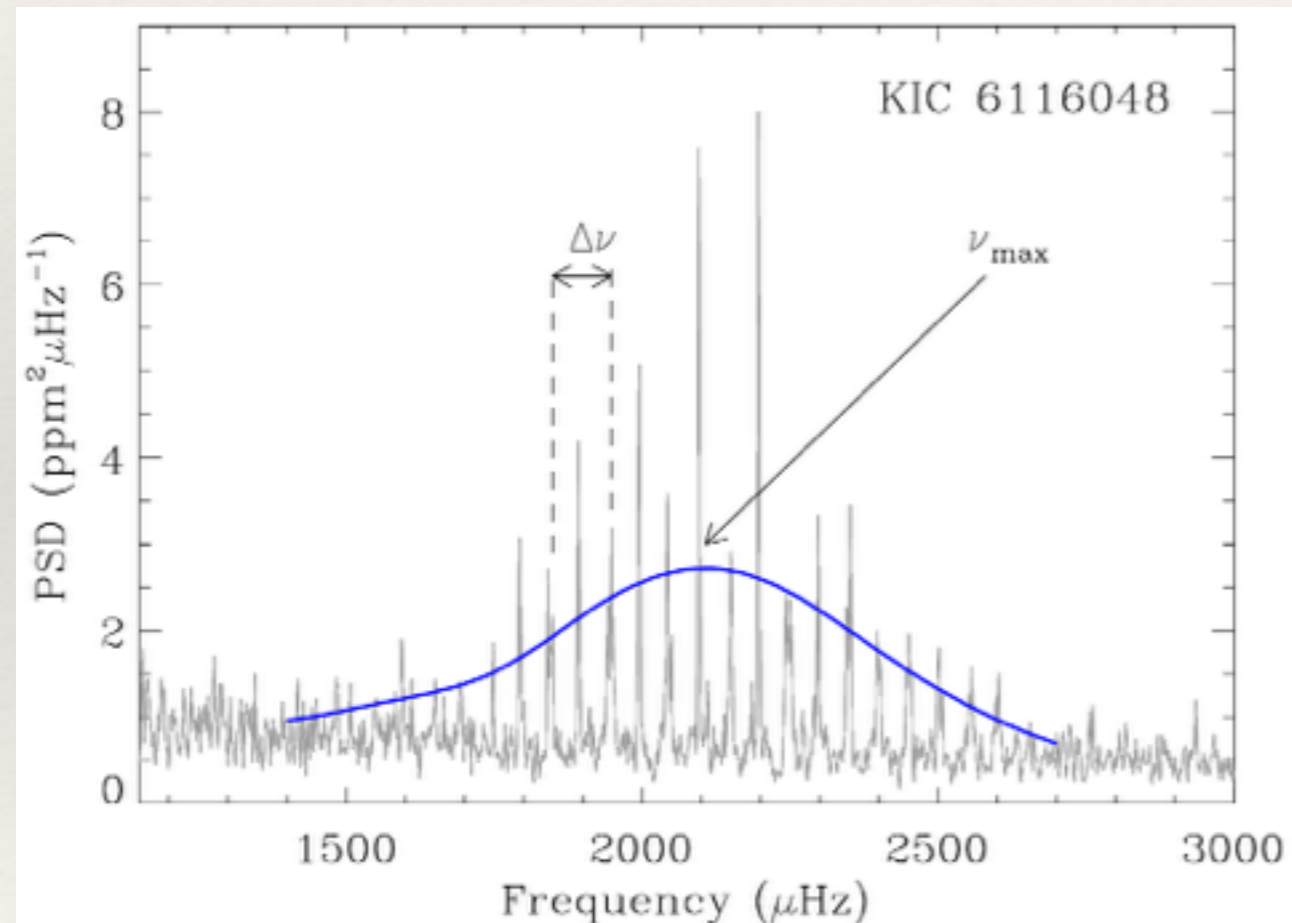
## Why?



# Dwarf stars



The bare minimum:



Chaplin et al. 2014, ApJS



Temperature  
Composition  
 $\Delta\nu$   
 $\nu_{\text{max}}$



Bayesian  
Magic  
(BASTA, BeSPP)

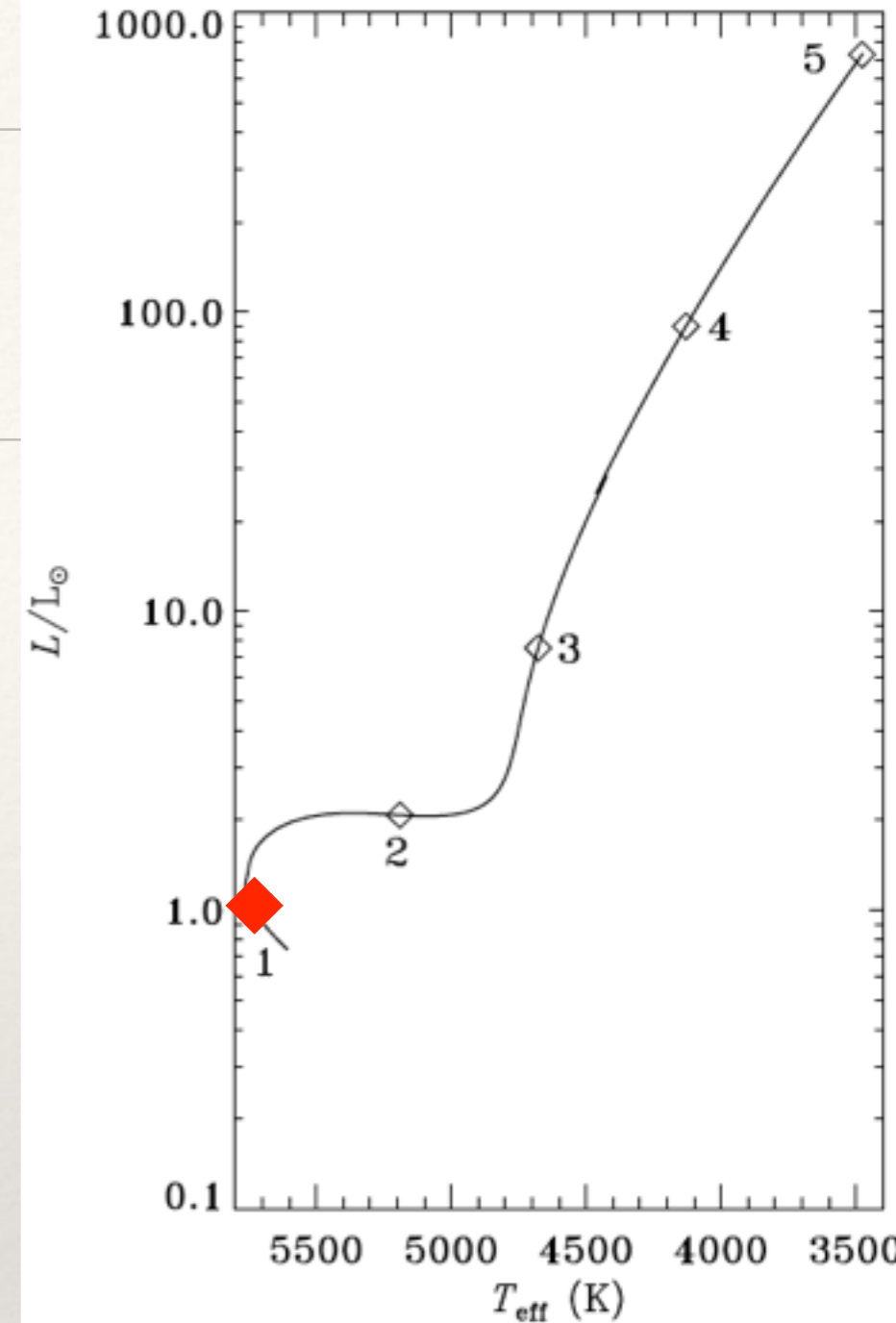
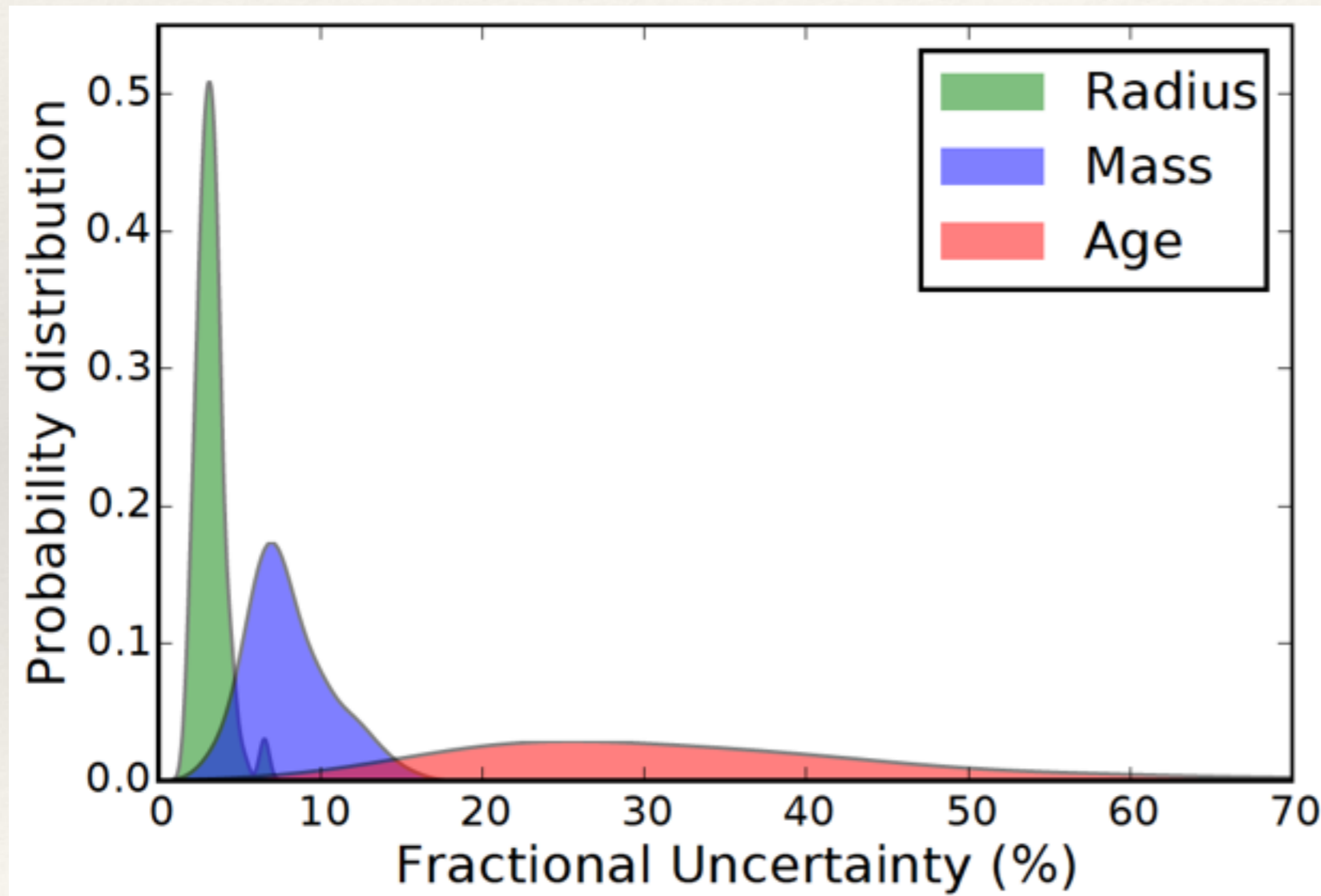


Stellar Properties  
(R, M, Age, etc)



# Dwarf stars

The bare minimum:



Radii  $\sim 2.2\%$

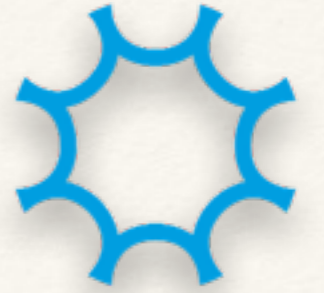
Mass  $\sim 5.5\%$

Age  $\sim 25\%$

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# Asteroseismic data

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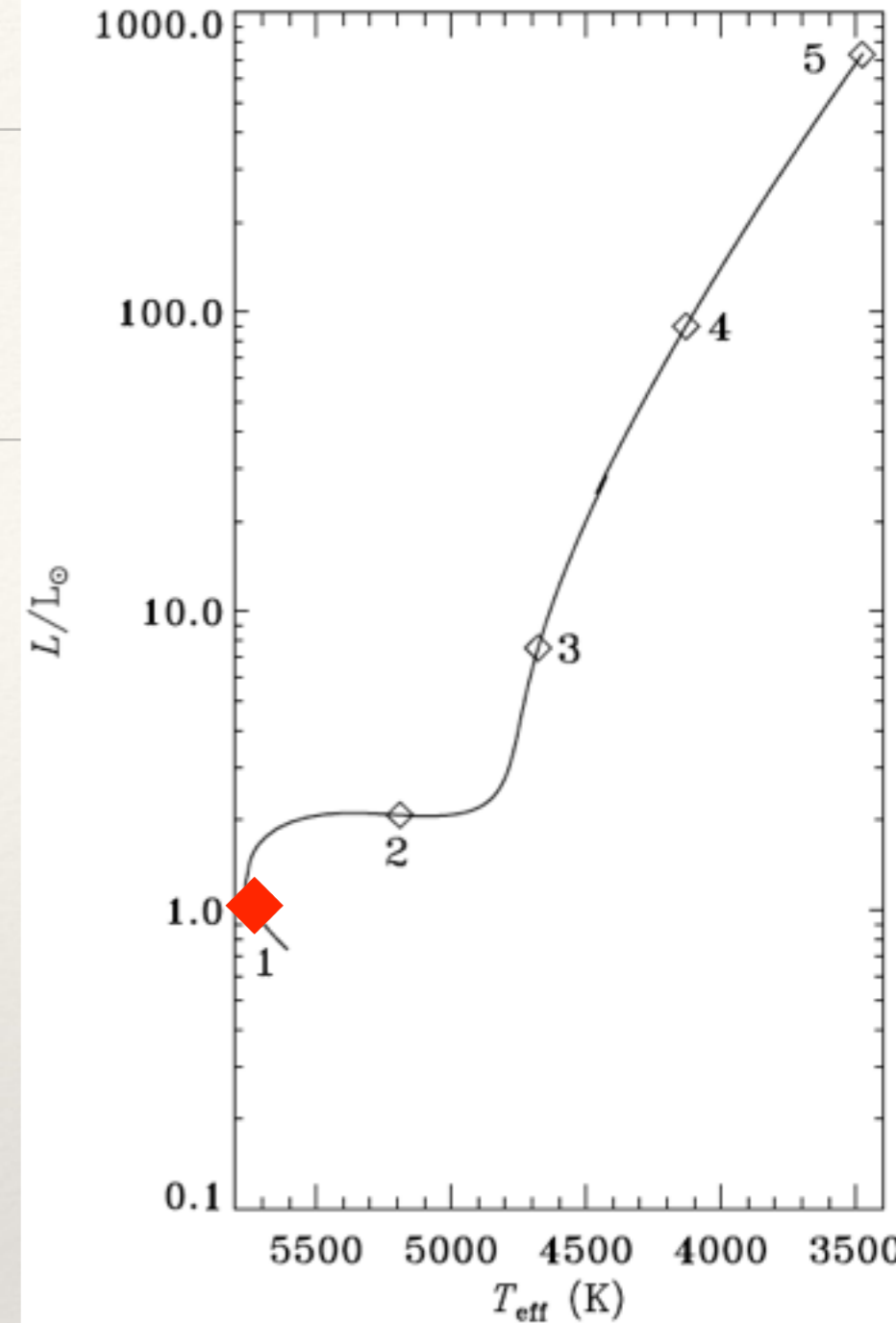
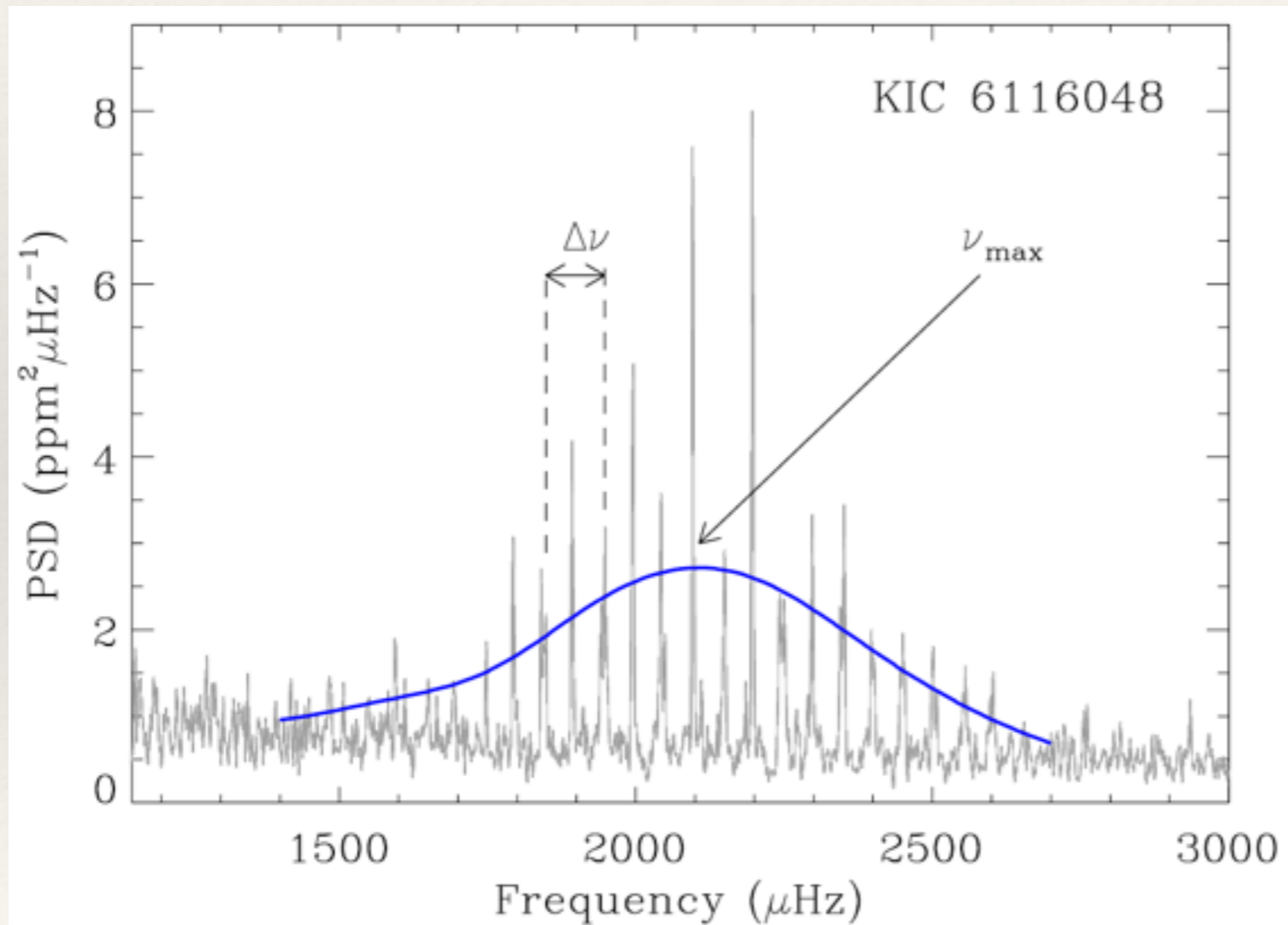
## How does the seismic trick works:

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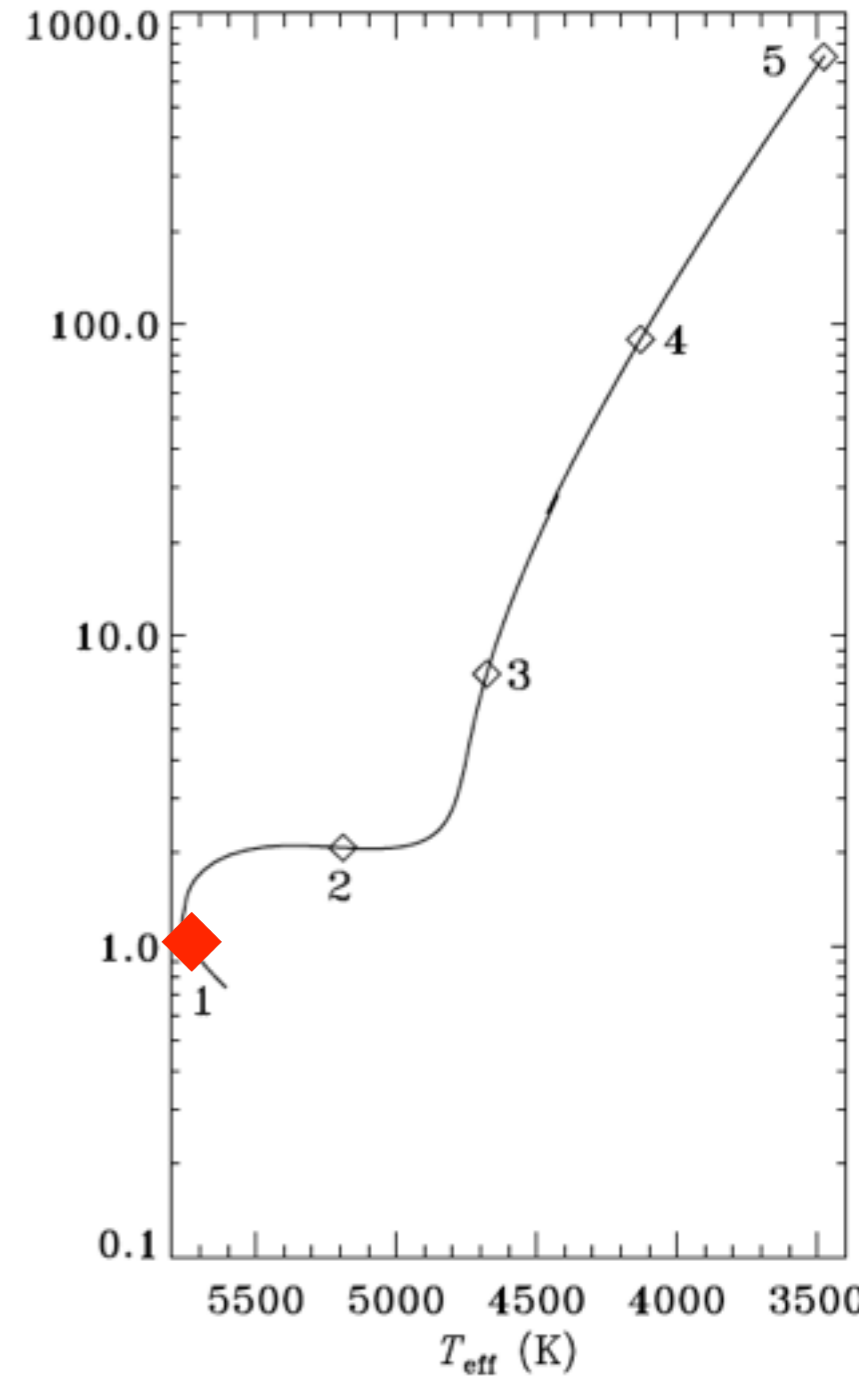
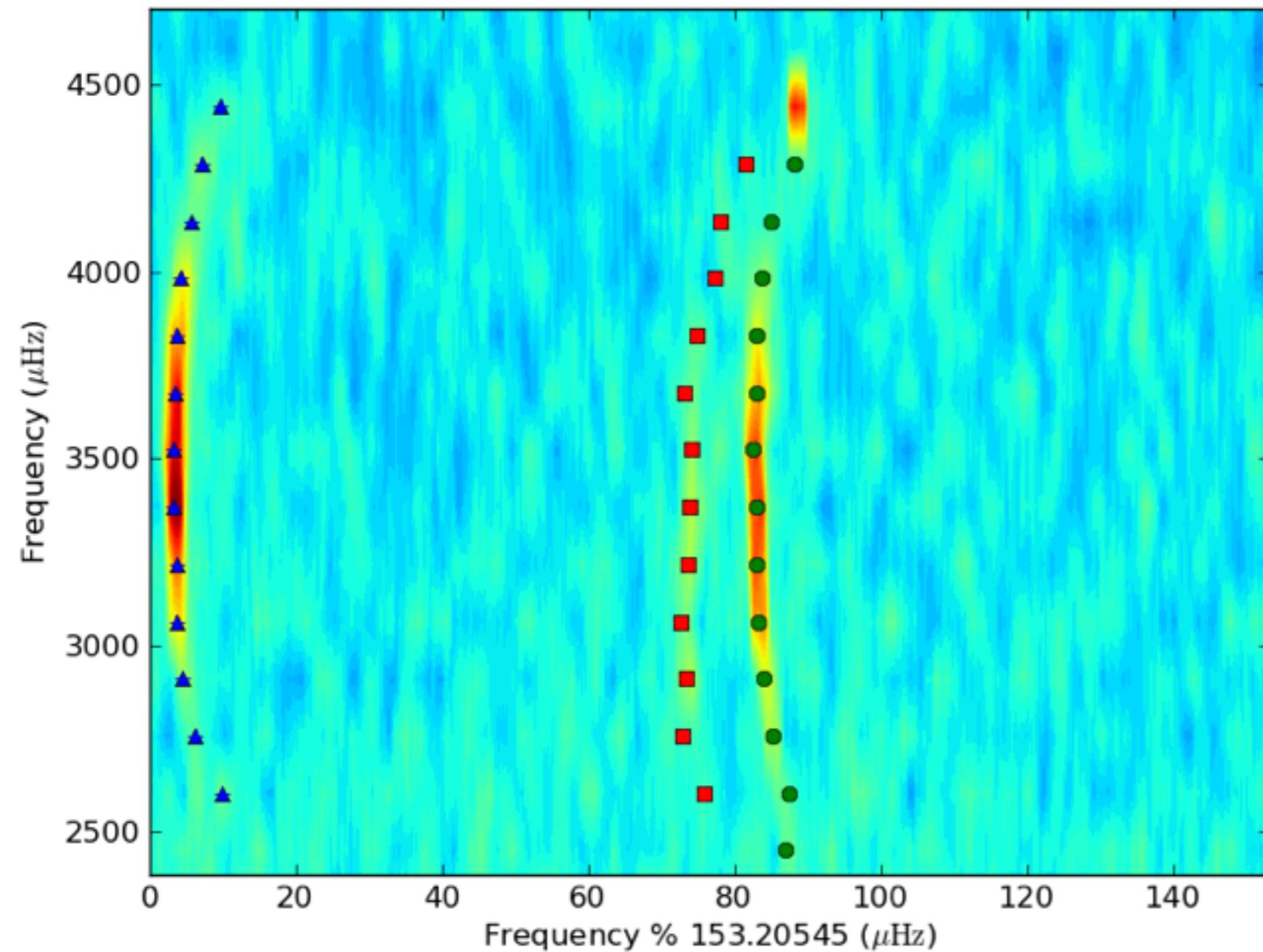
**Always need  $T_{\text{eff}}$  and  $[\text{Fe}/\text{H}]$**

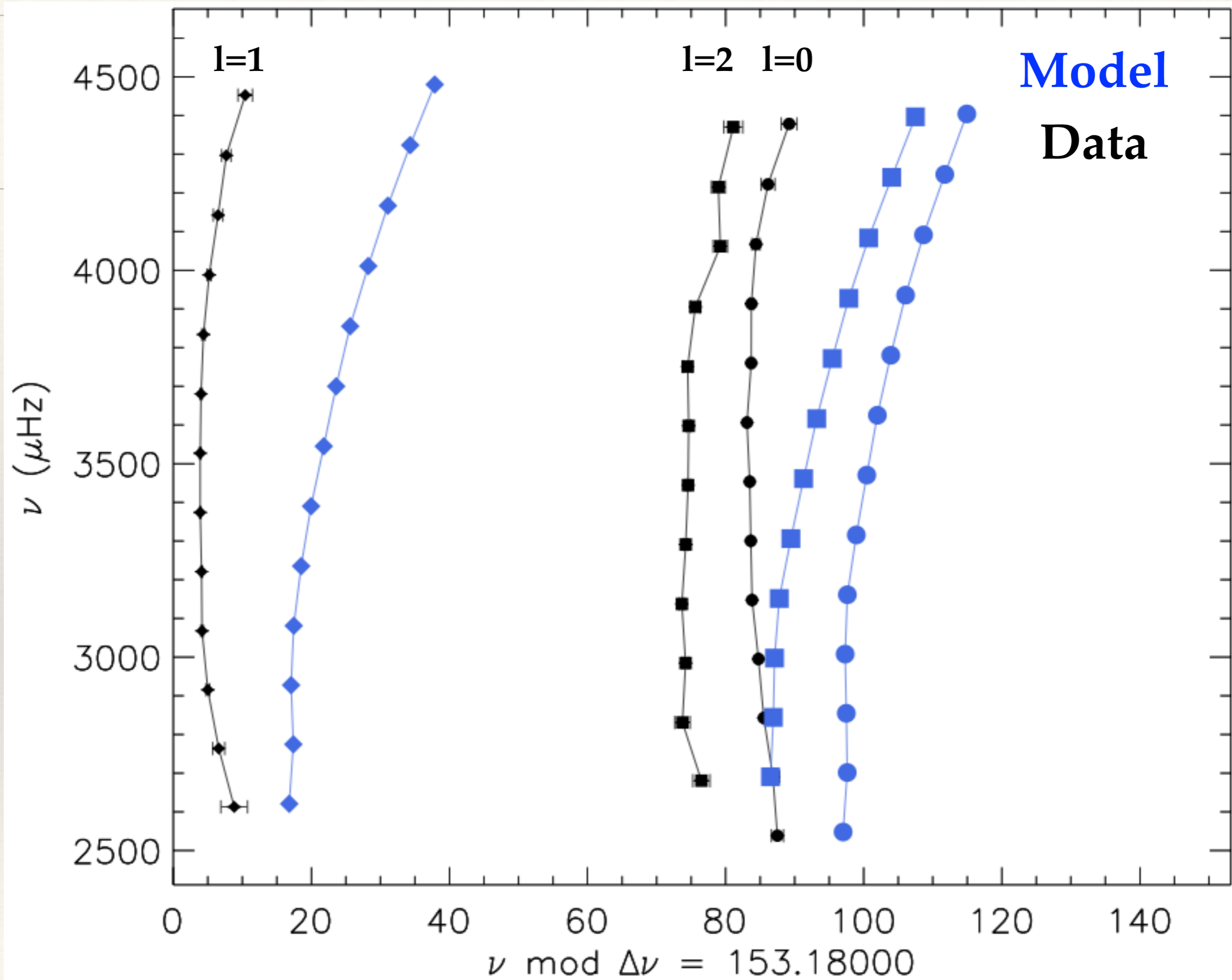
# Dwarf stars

Individual frequencies:



# Dwarf stars

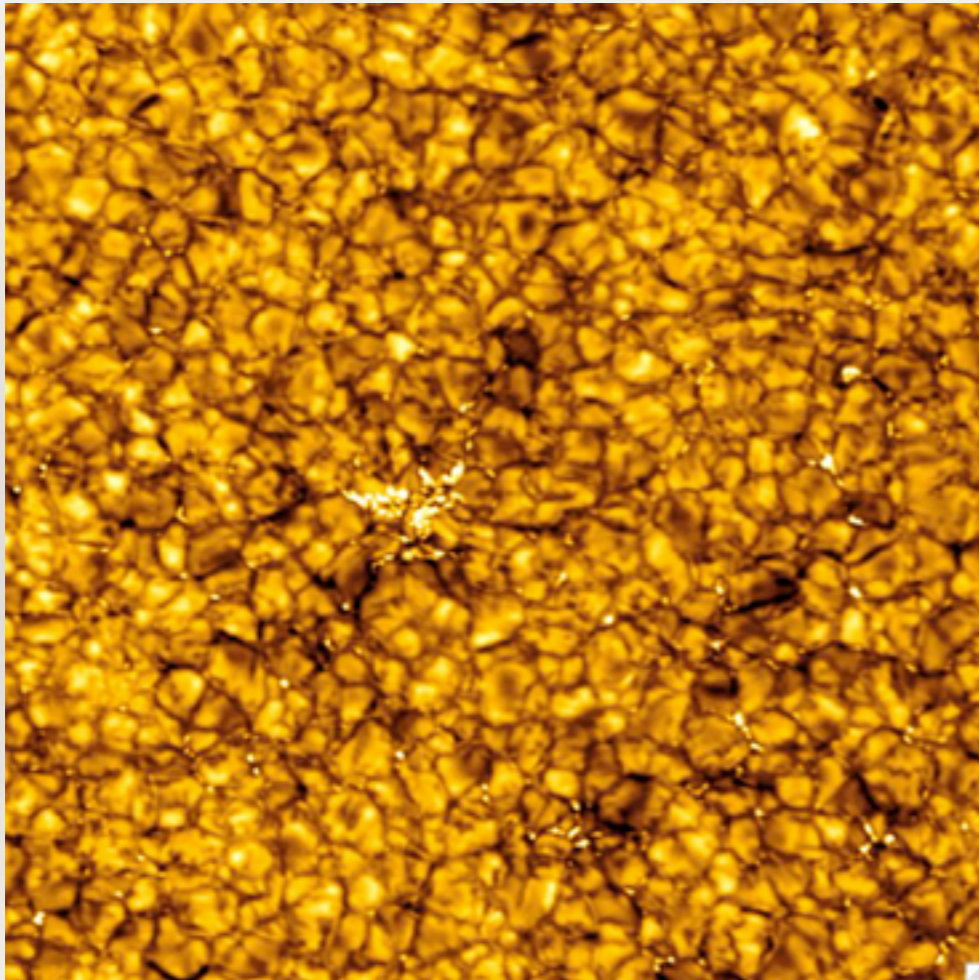
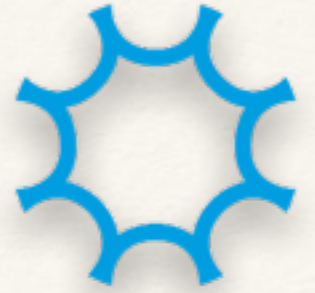




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# Dwarf stars

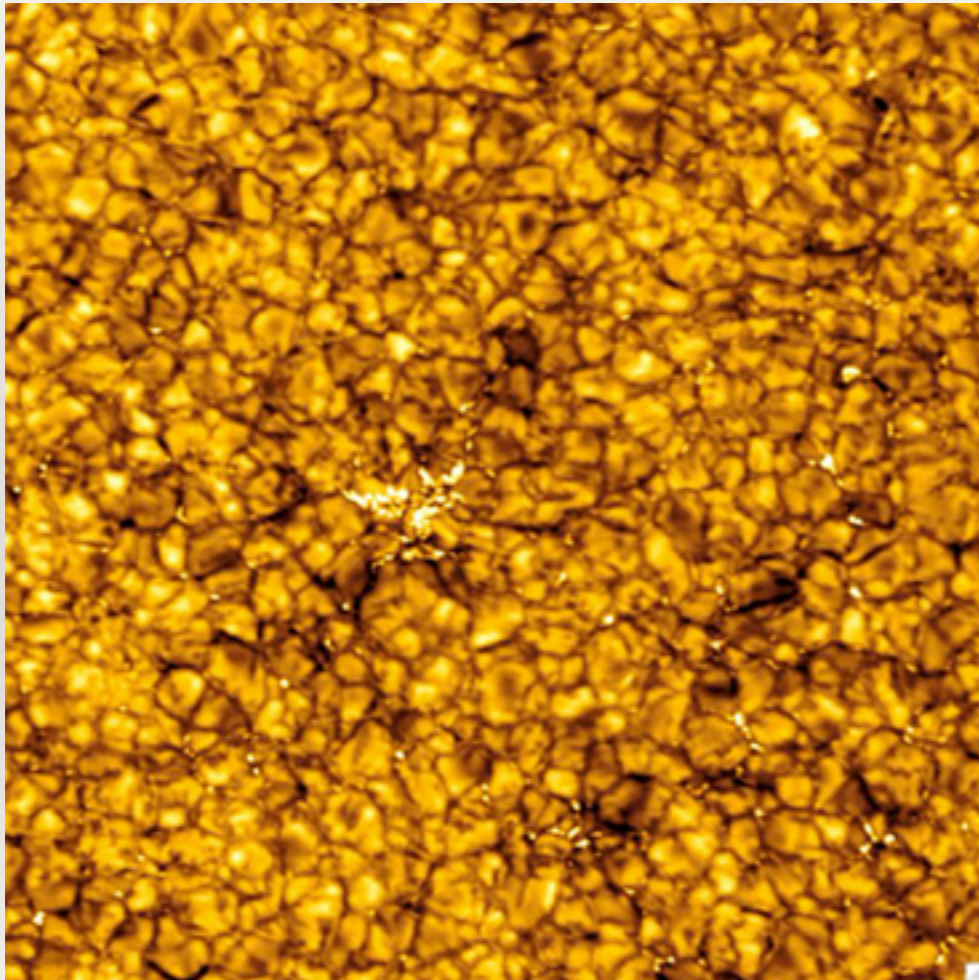
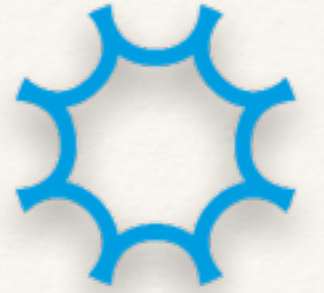
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# Dwarf stars

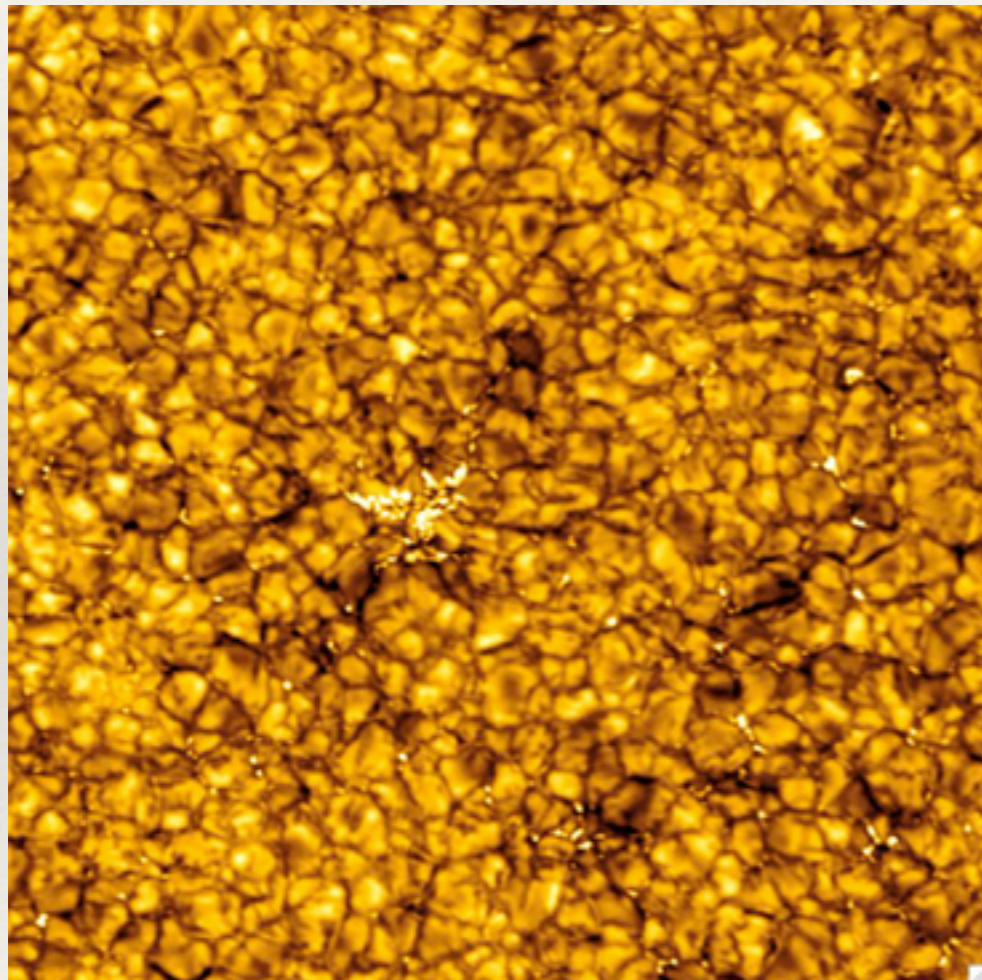
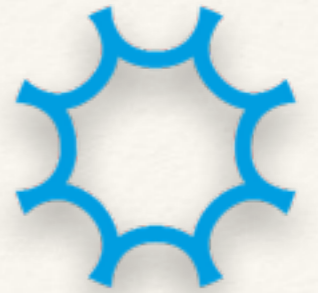
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# Dwarf stars

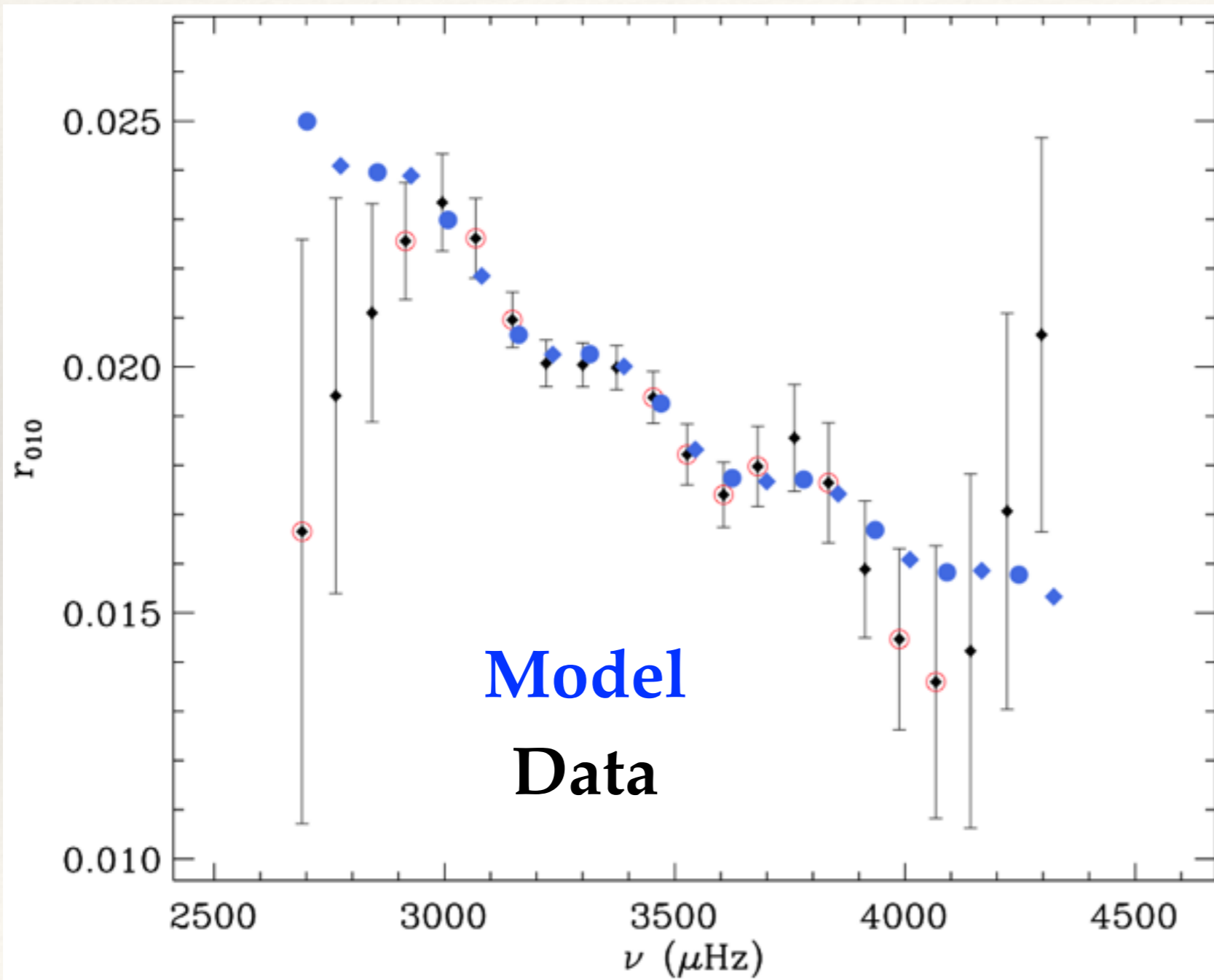
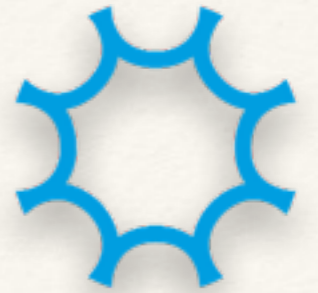
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- ❖ Cannot properly follow convection in 1D stellar models
- ❖ Theoretical frequencies suffer from “surface effect”
- ❖ Use combinations that cancel contribution from outer layers
- ❖ Sensitive to the core (we understand it better)



# Dwarf stars

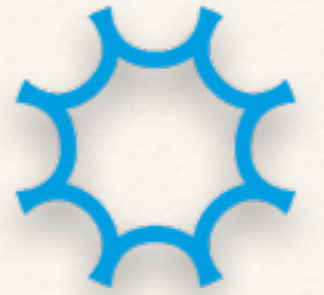


Temperature  
Composition  
frequencies  
(combinations)

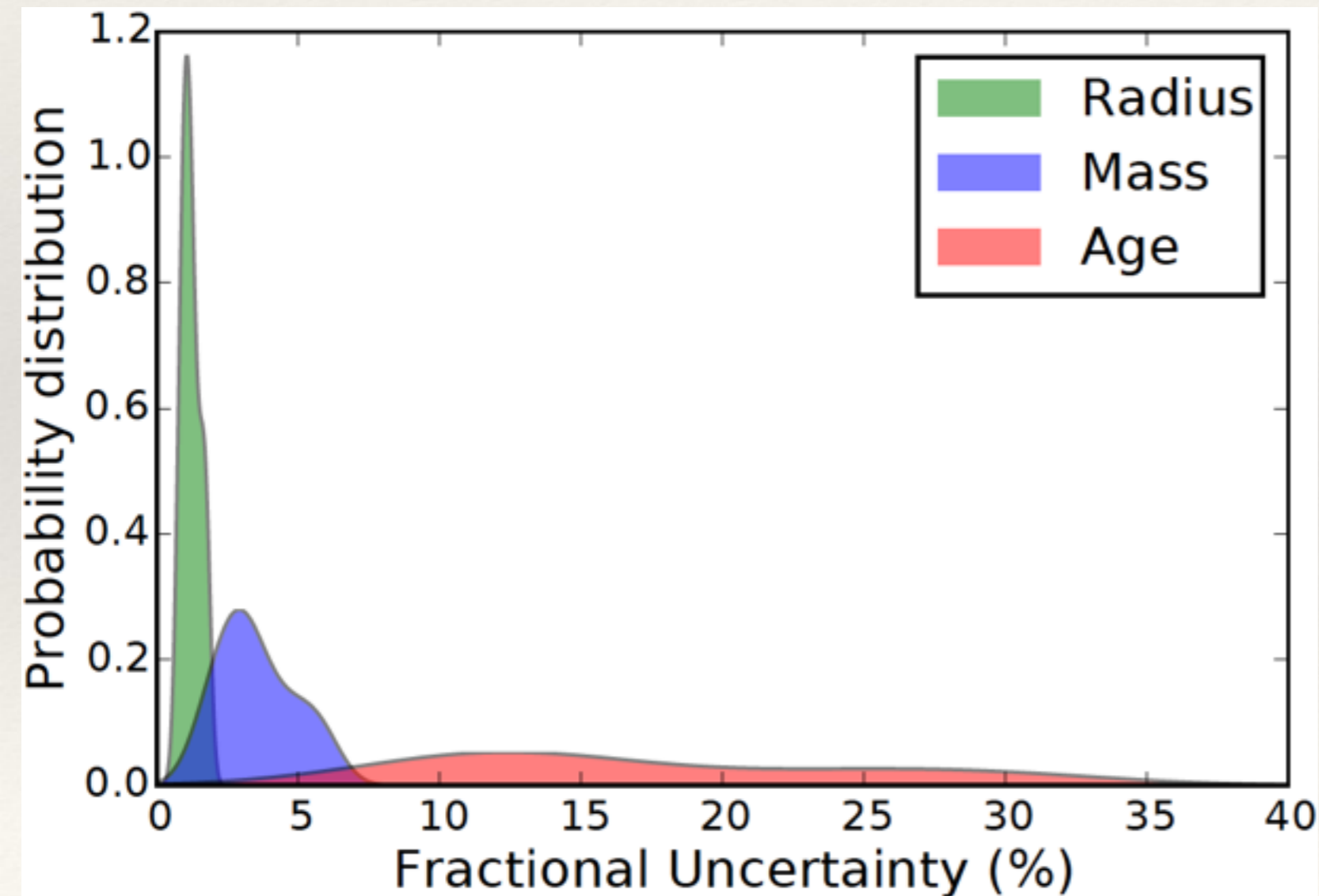
Bayesian  
Magic  
(BASTA, BeSPP)

Stellar Properties  
(R, M, Age, etc)

# Dwarf stars



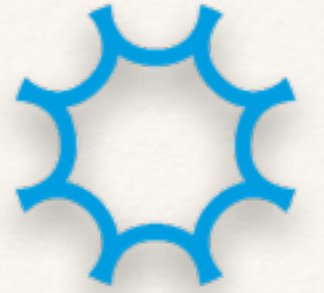
Precision from frequency combinations:



**Radii ~ 1.1%**  
**Masses ~ 3.3%**  
**Ages ~ 14%**

Silva Aguirre et al. 2015, MNRAS  
see also: Lebreton & Goupil  
2014, A&A

# Dwarf stars



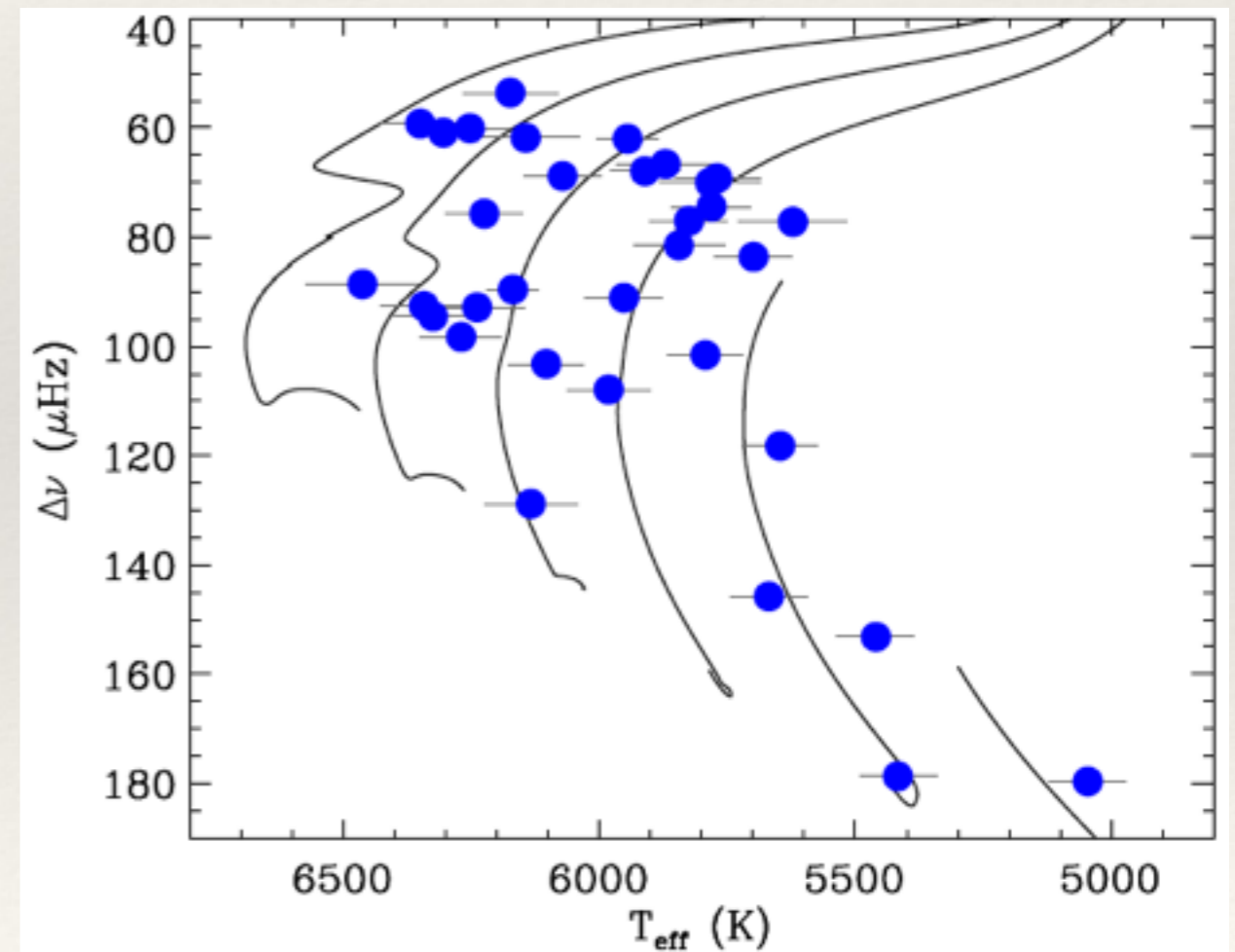
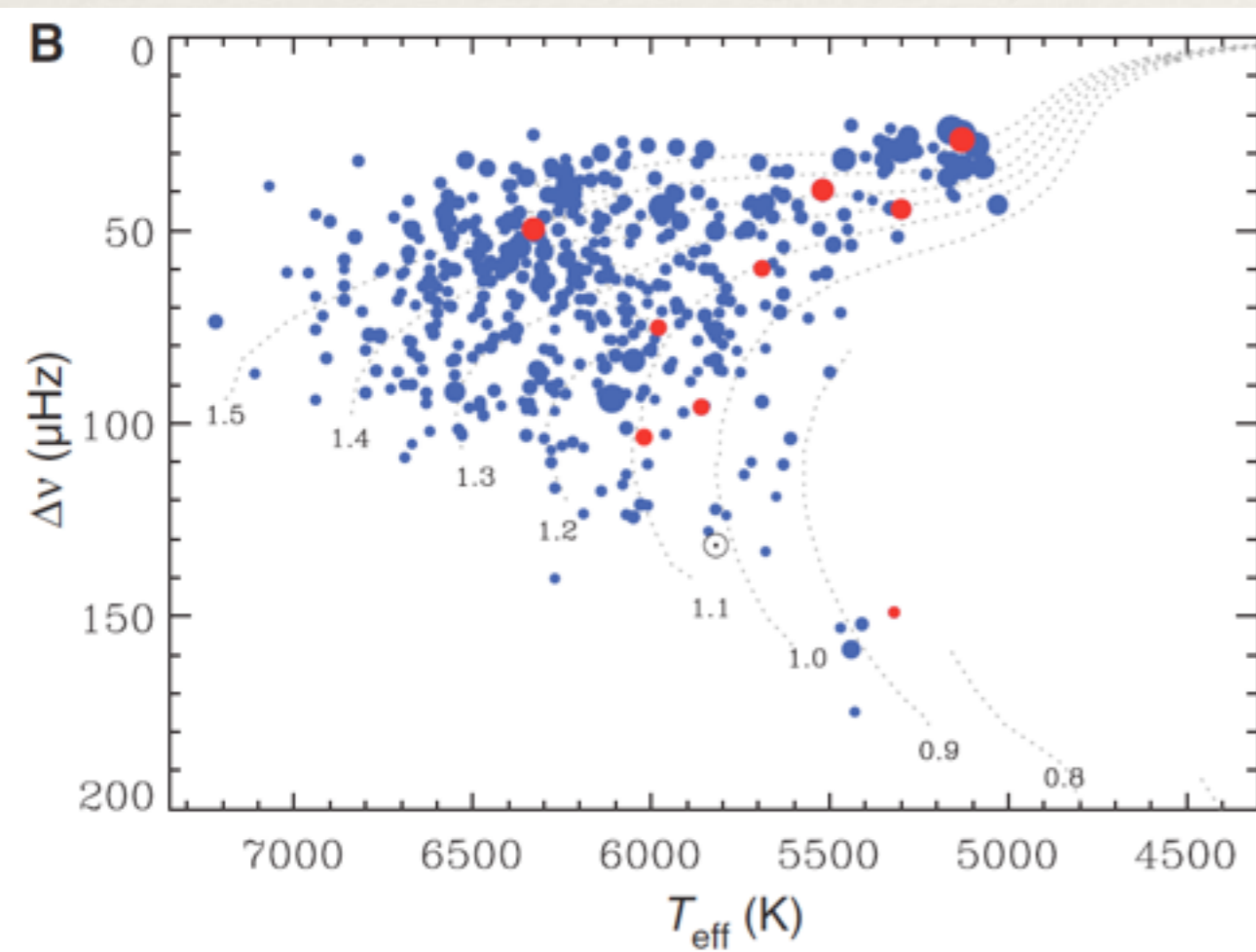
Scaling  $\nu$  /  $s$  individual frequencies:

Ages  $\sim 25\%$

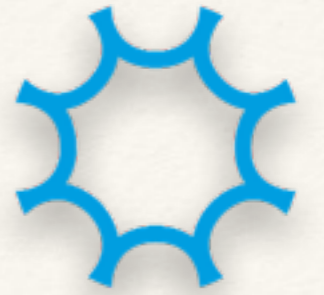
$\sim 580$  stars

Ages  $\sim 14\%$

33 stars



# Dwarf stars



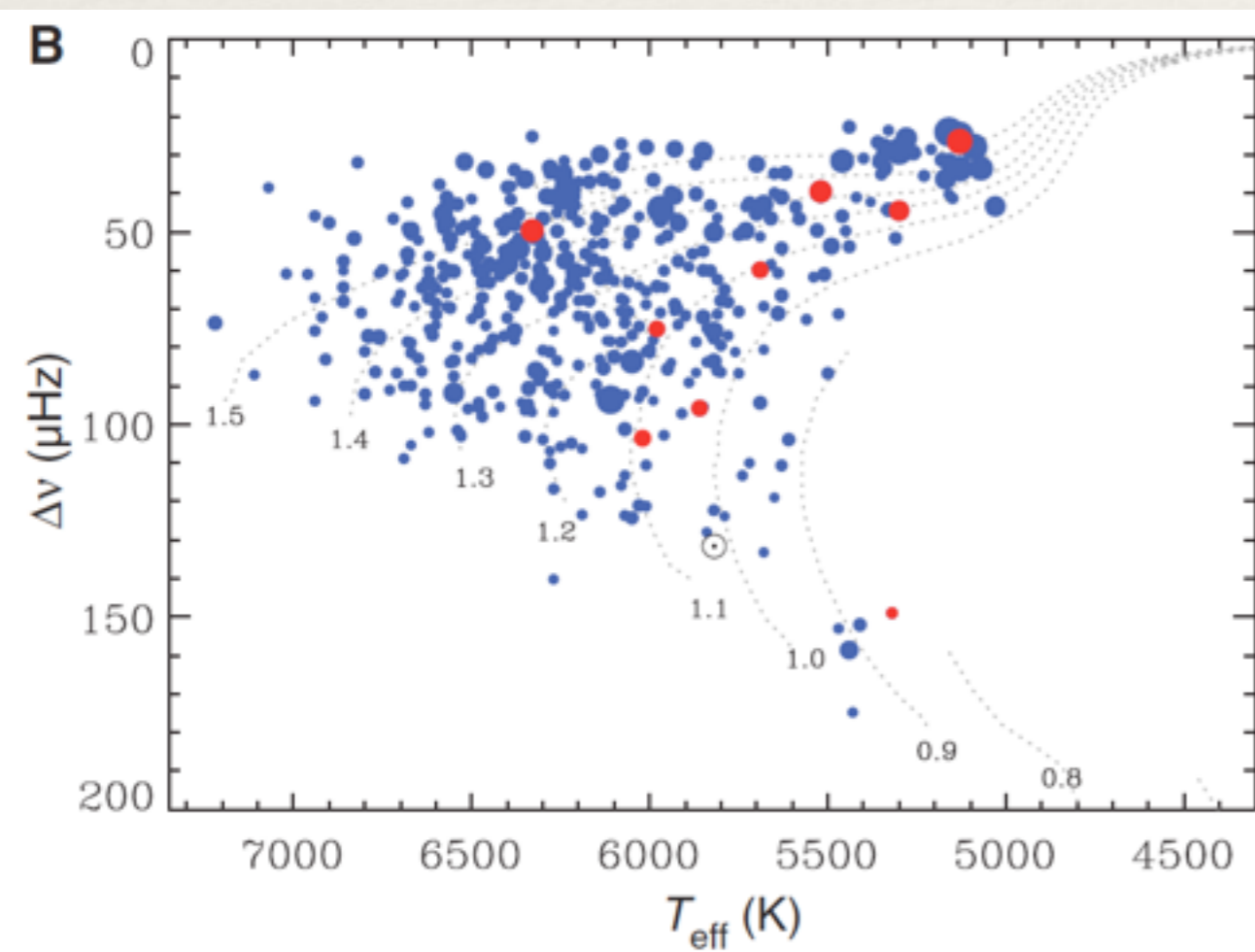
Scaling  $\nu$  /  $s$  individual frequencies:

Ages  $\sim 25\%$

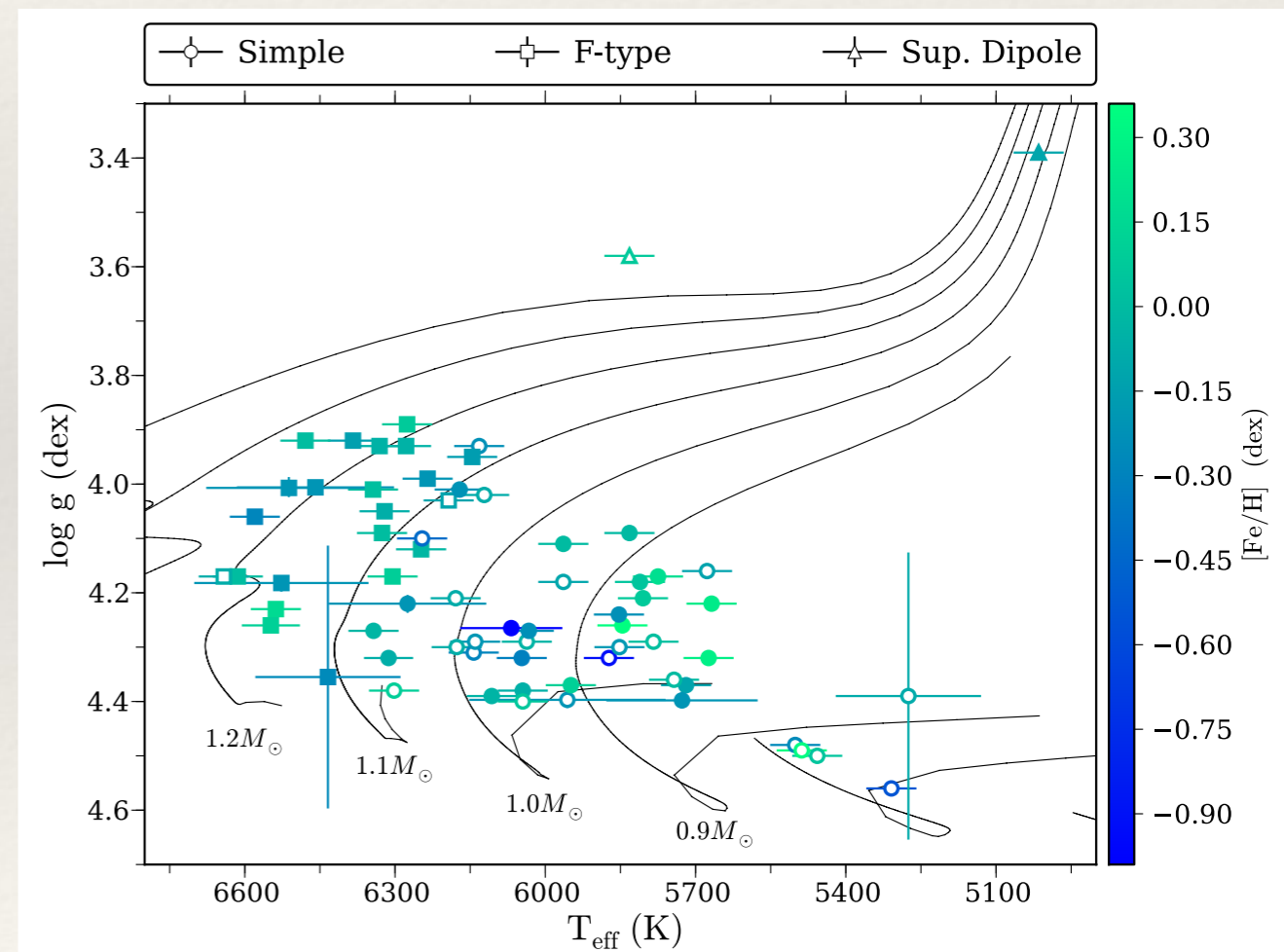
$\sim 580$  stars

Ages  $\sim 14\%$

64 stars

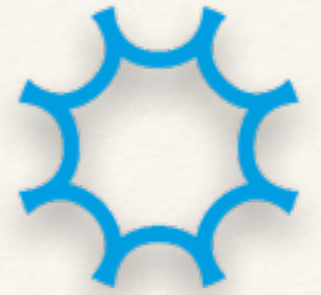


Chaplin et al. 2011, Science

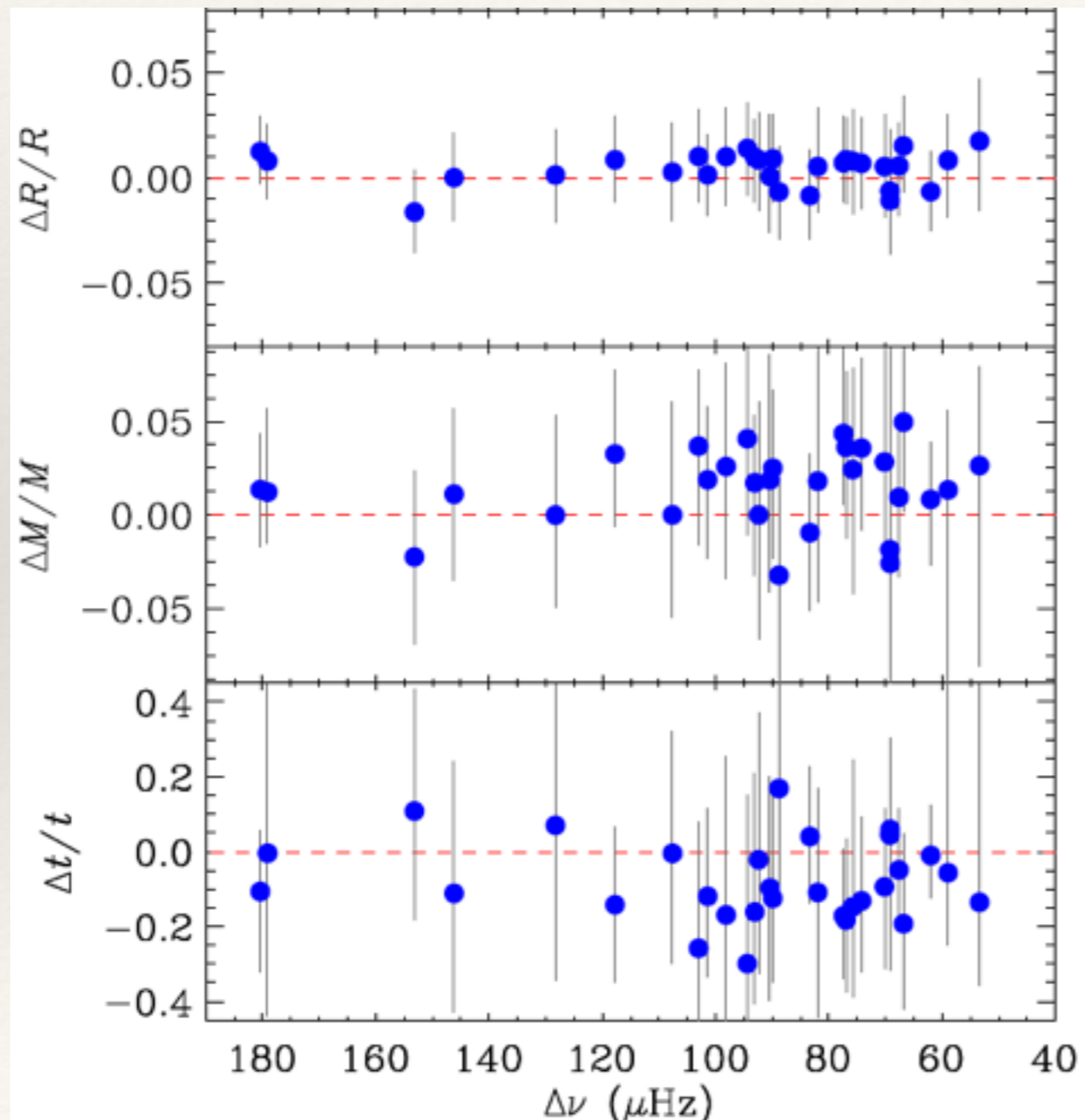


Silva Aguirre et al. 2015, in prep

# Dwarf stars



Scaling  $v/s$  individual frequencies:

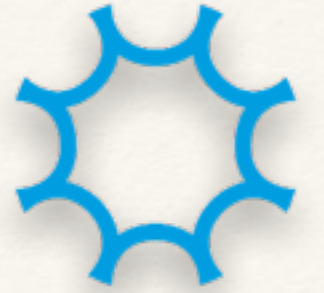


**Systematics  
below the  
statistical  
uncertainties**  
(Note:  $\Delta\nu$  from  
individual frequencies)

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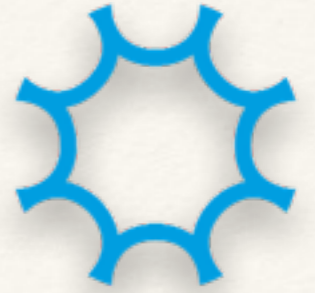
# The problem at hand

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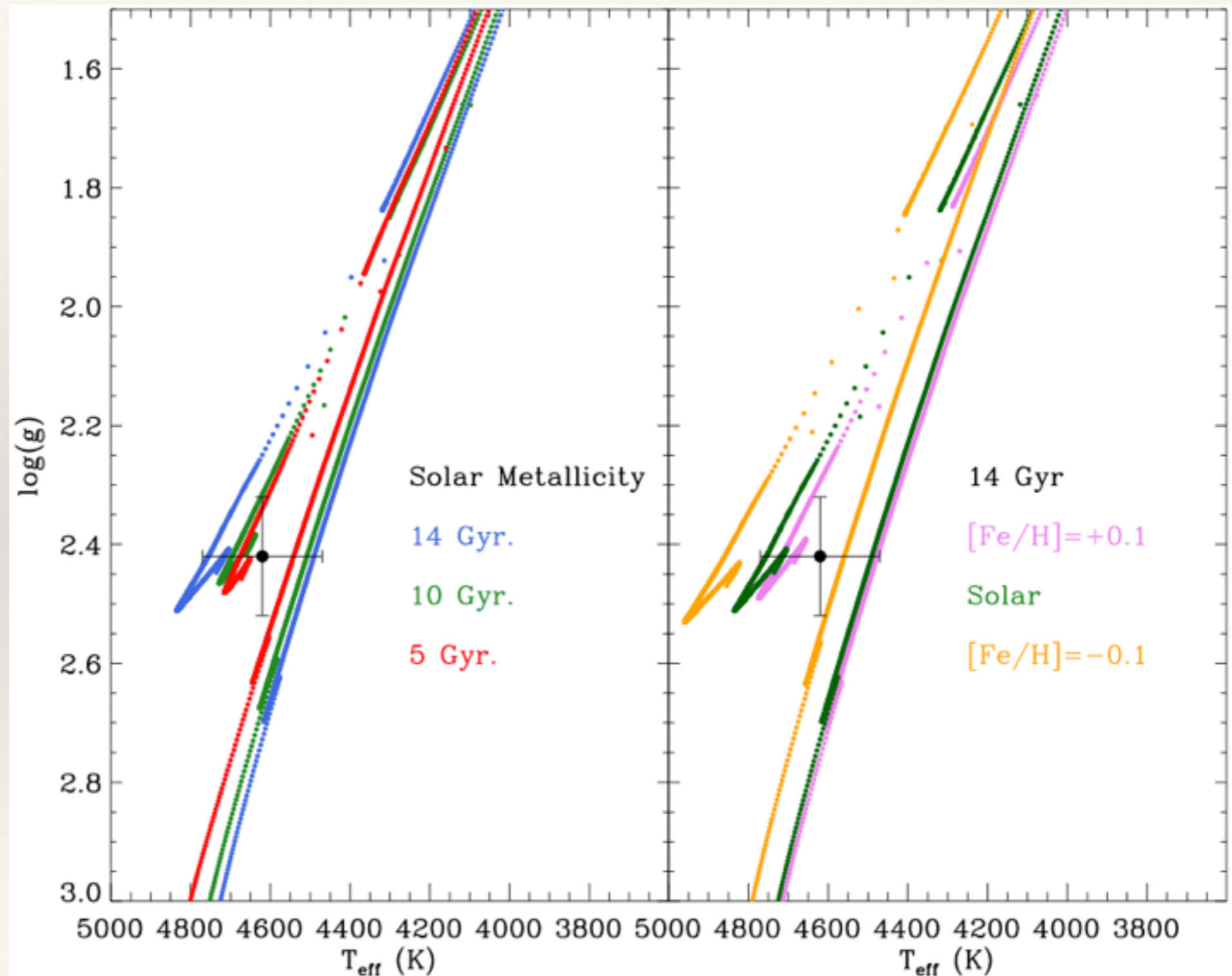


Giants:

# The problem at hand

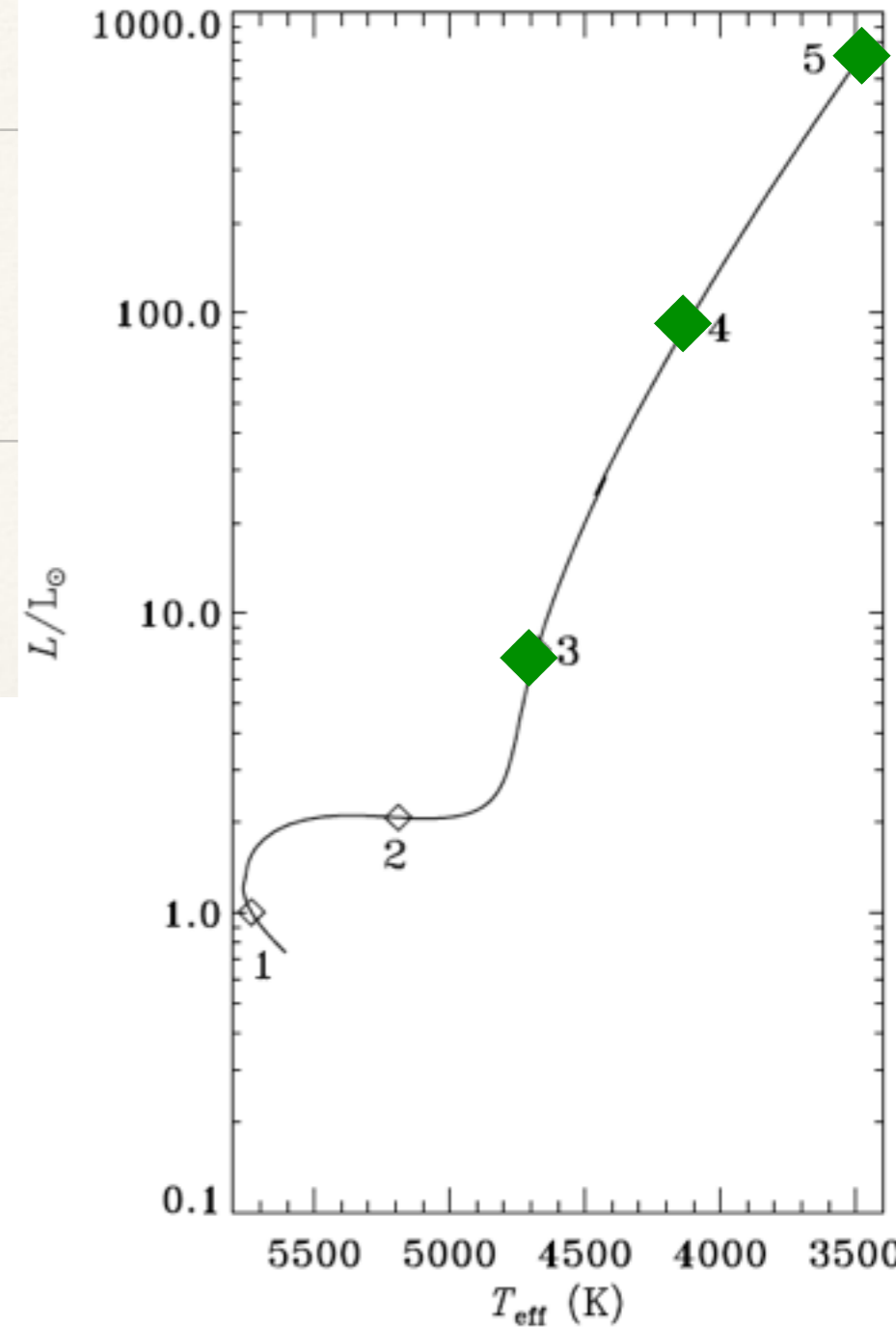
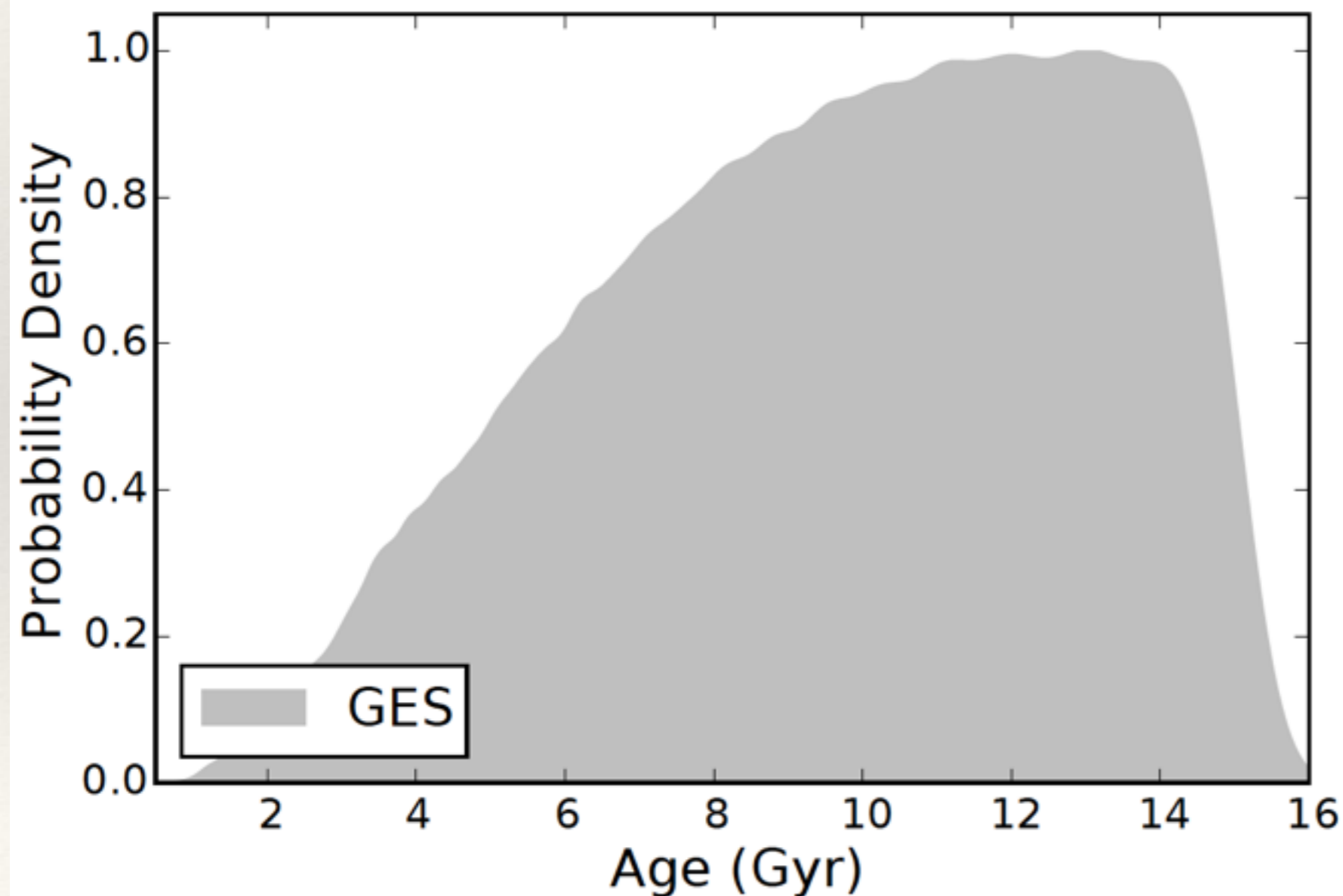


Giants:



# Red giants

## Example: spectroscopy

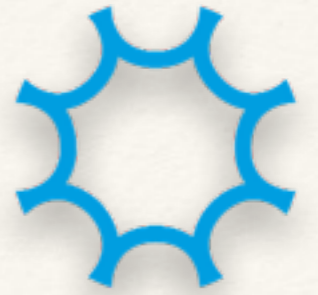




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# Asteroseismic data

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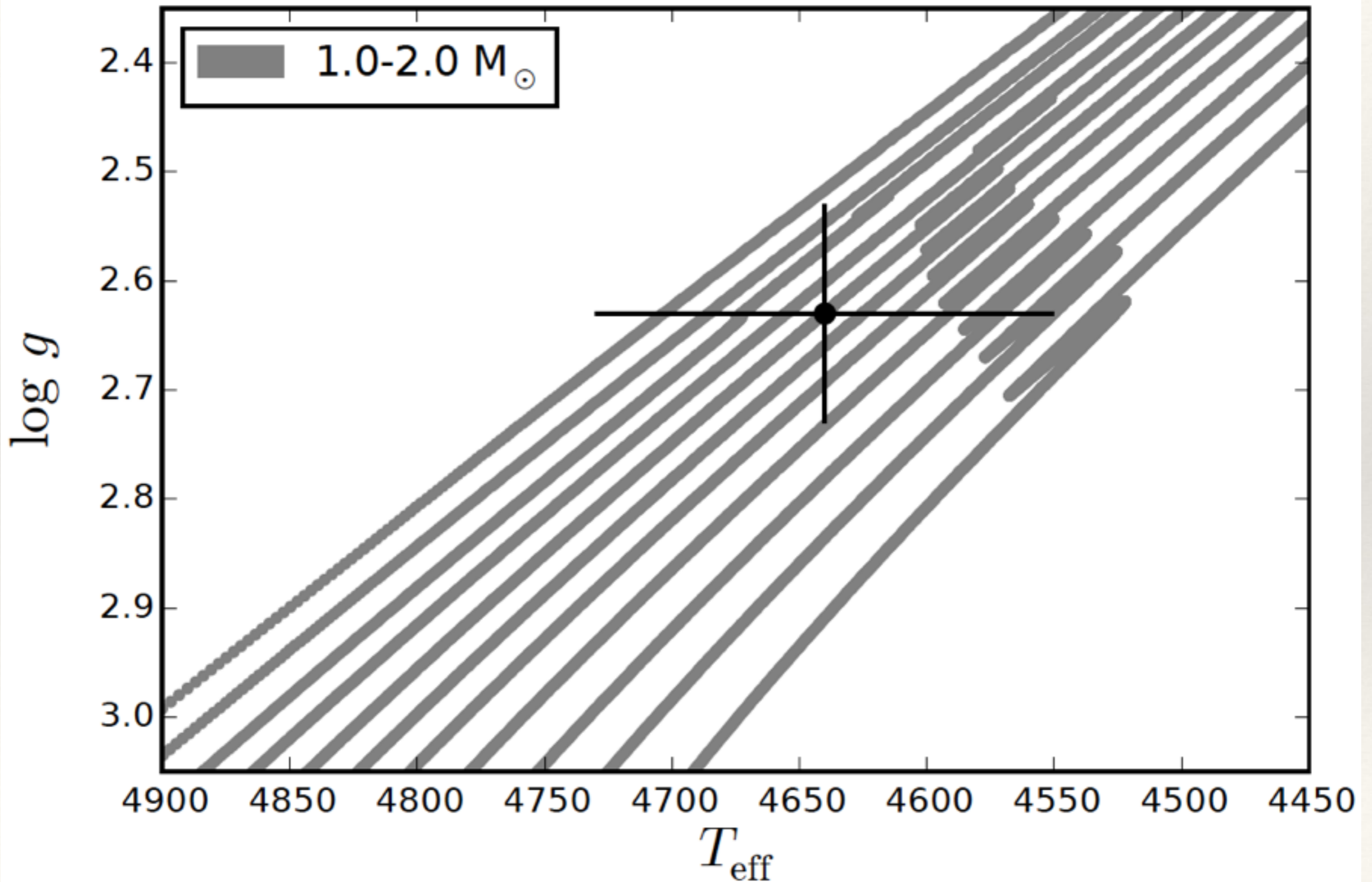
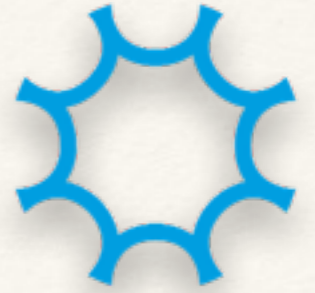


## How does the seismic trick works:

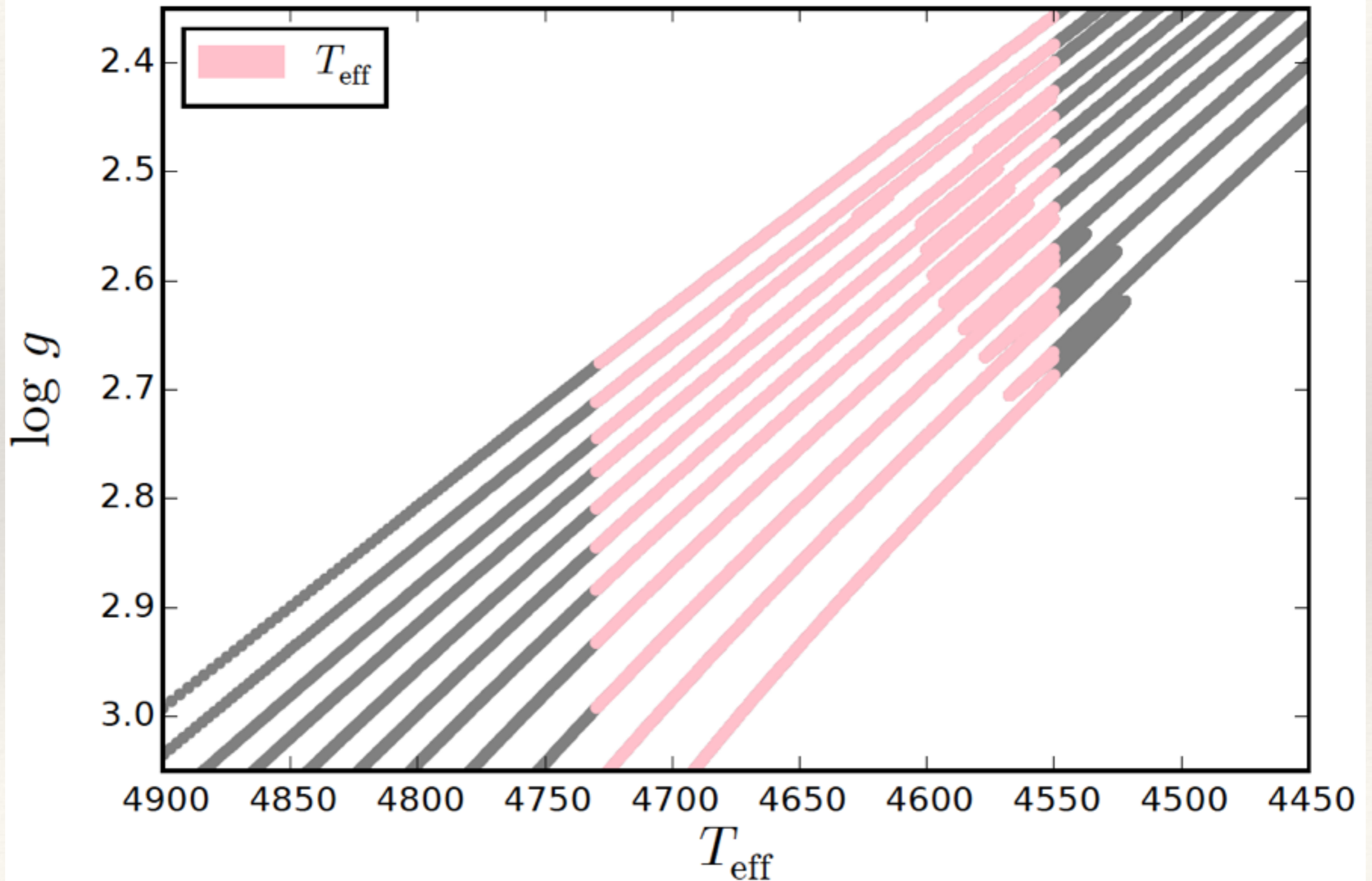
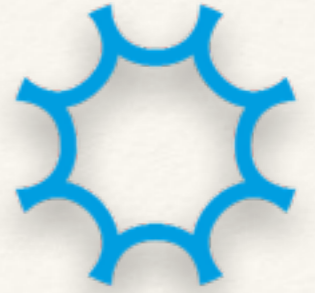
- ❖ The bare minimum: scaling relations (dwarfs and giants)
- ❖ Improvements: individual frequencies (dwarfs for now)
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**Always need  $T_{\text{eff}}$  and  $[\text{Fe}/\text{H}]$**

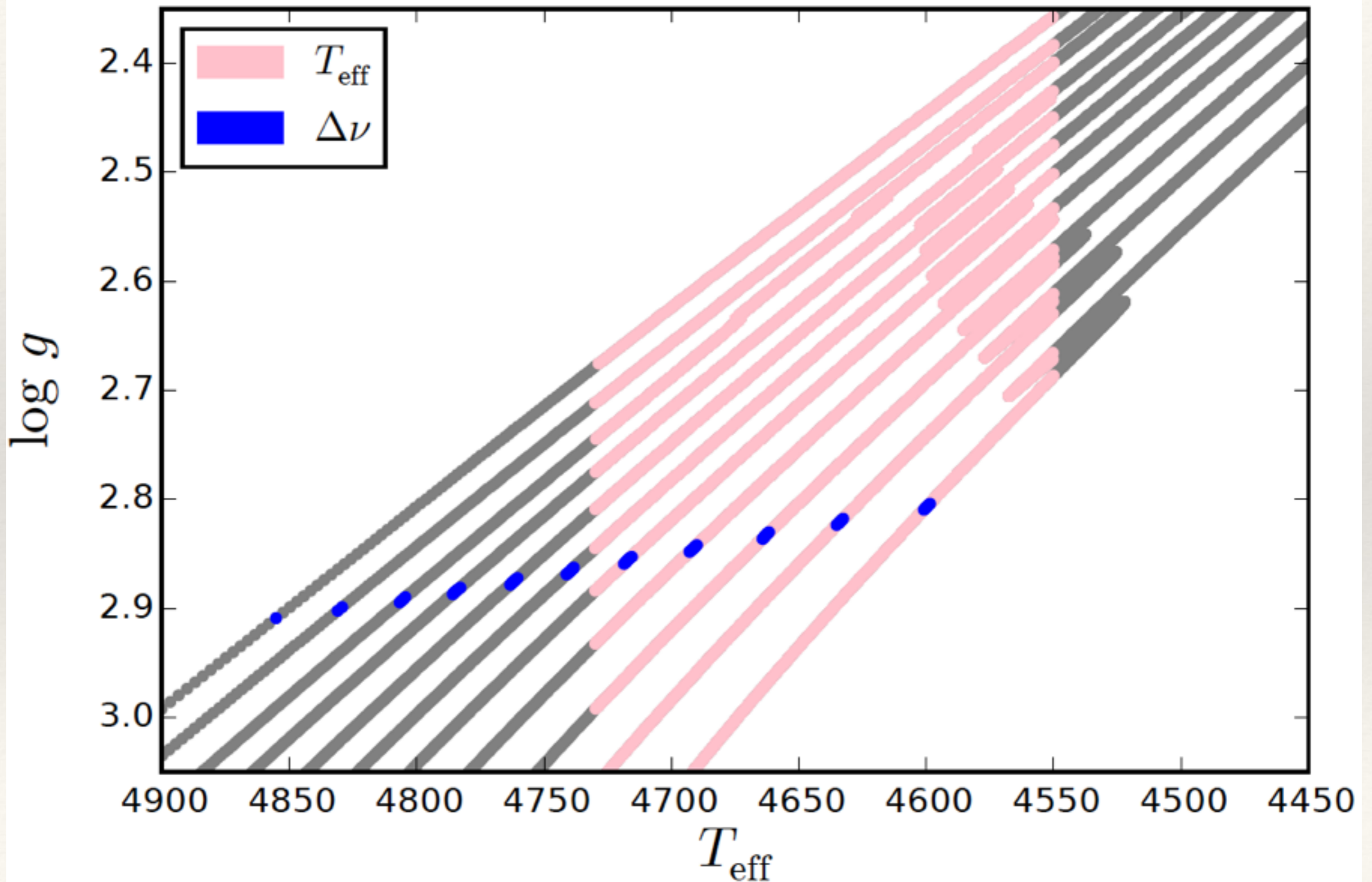
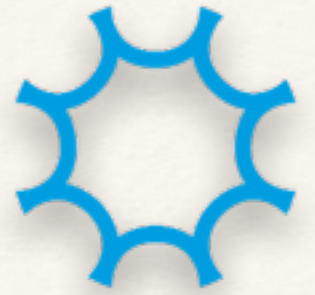
# The bare minimum



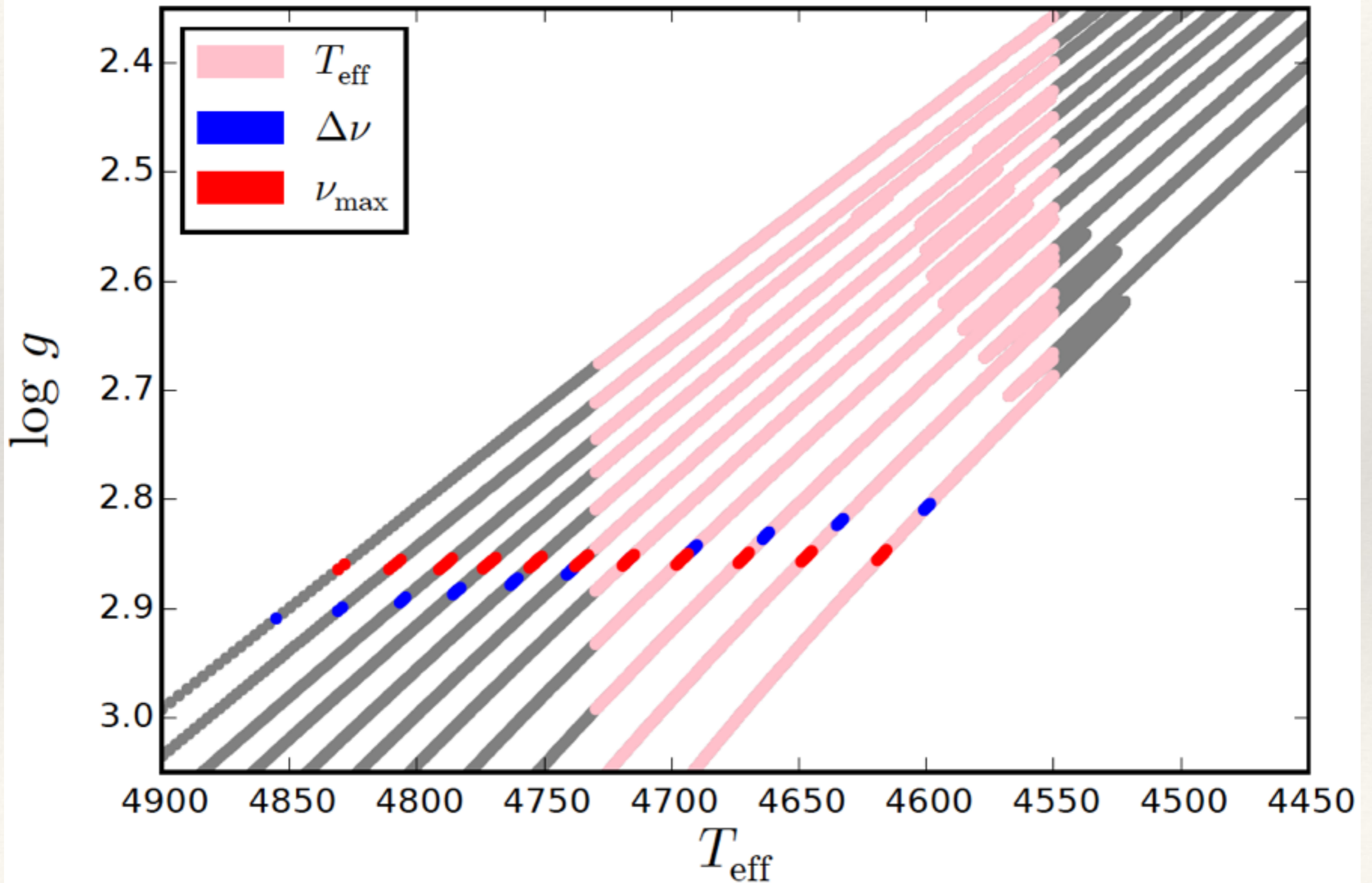
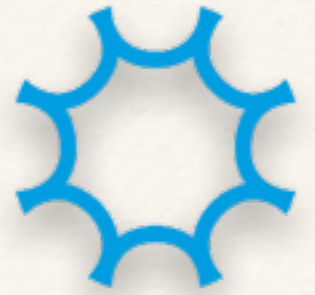
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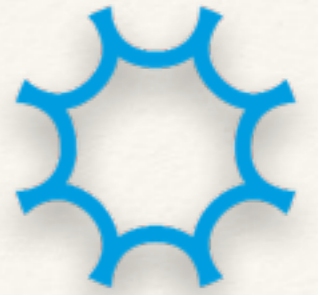
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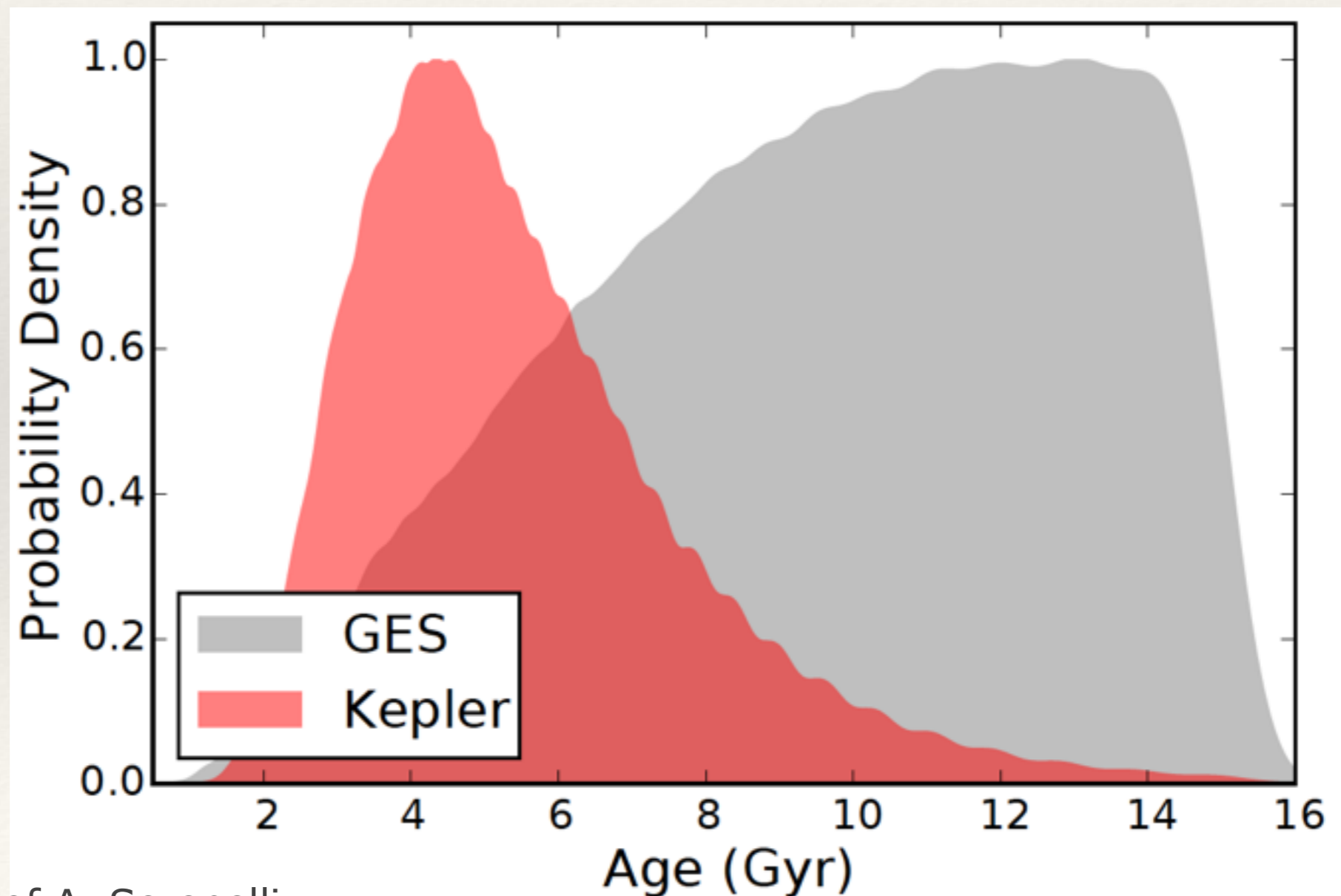
# The bare minimum



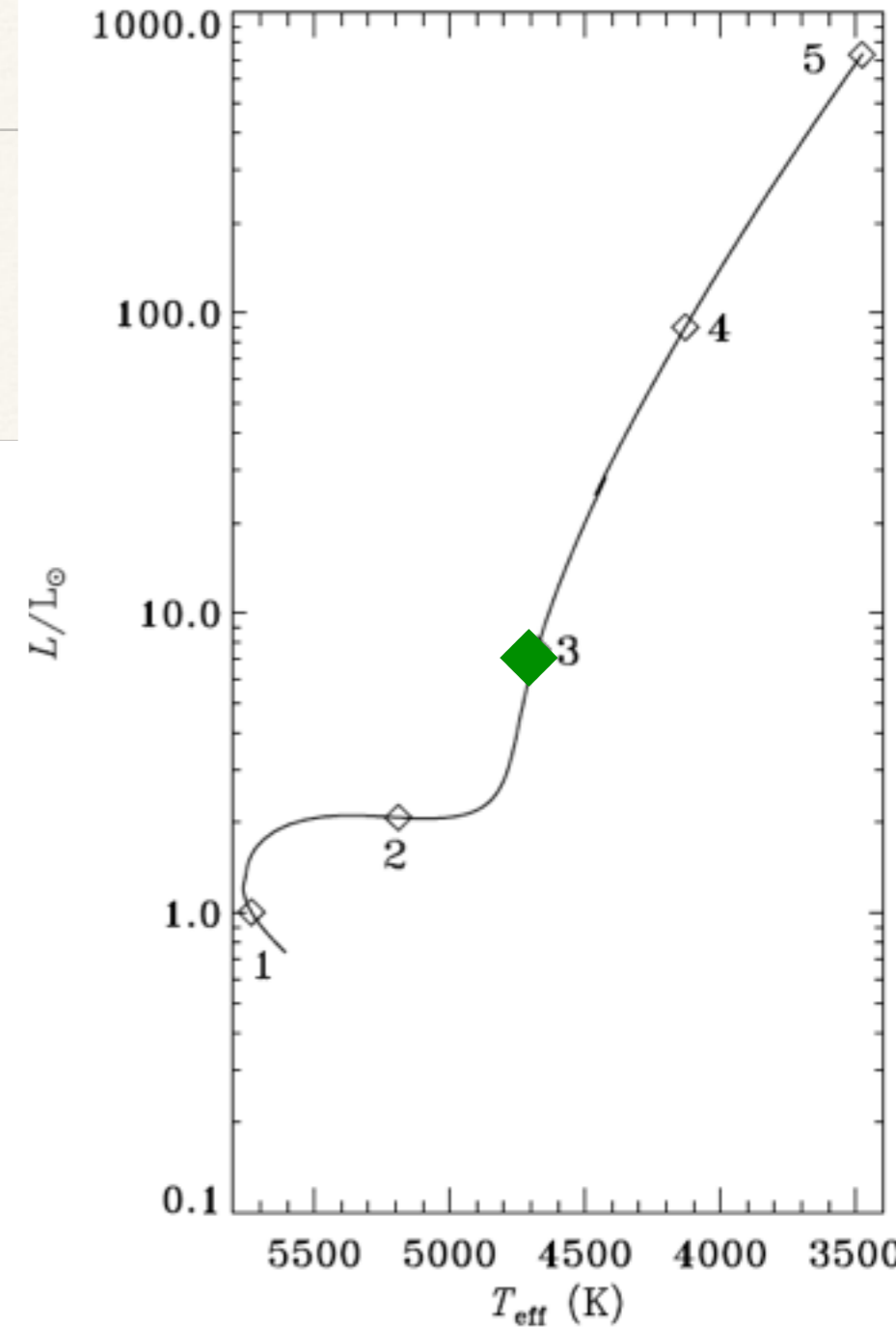
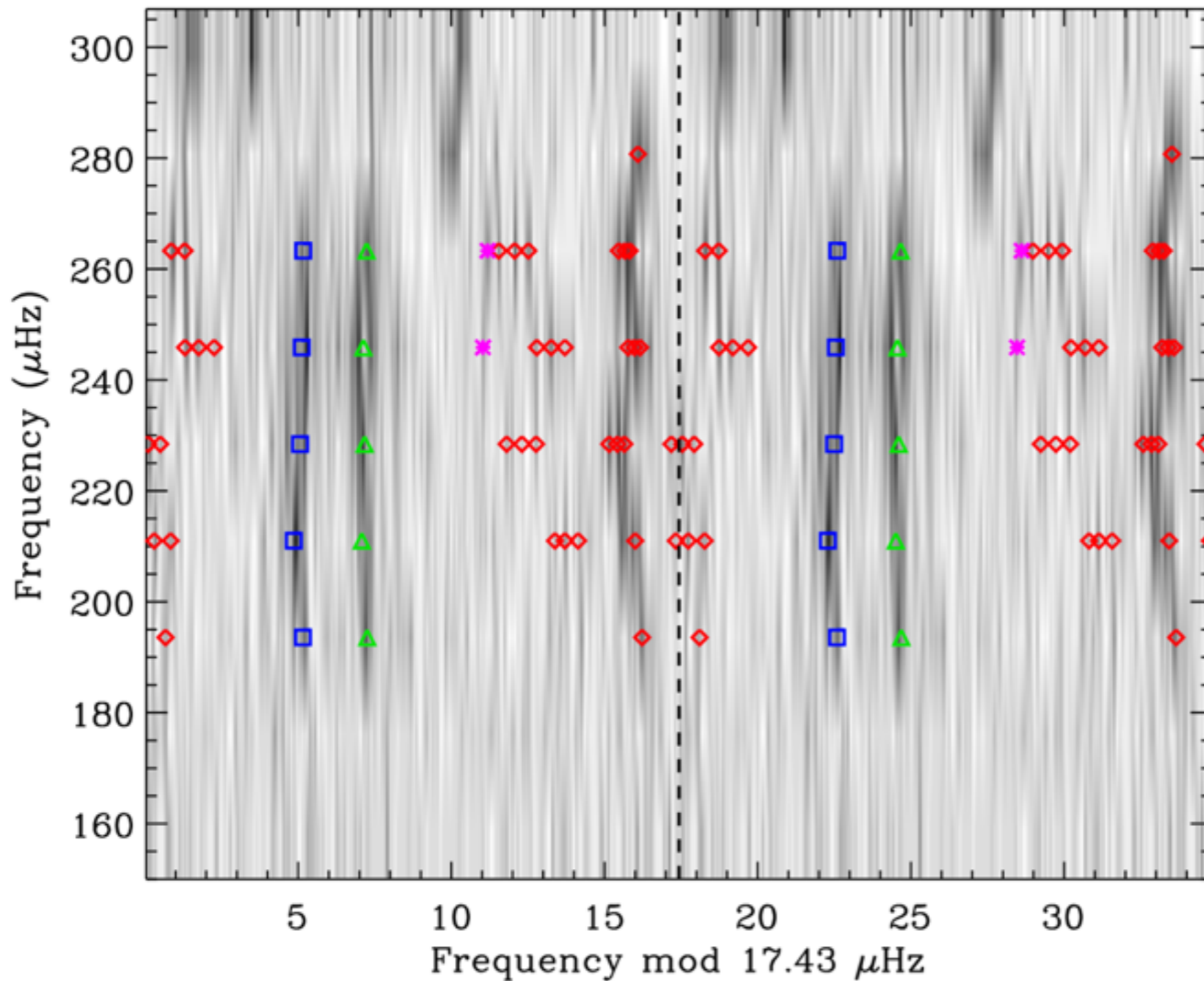
# Red giants



## Example: spectroscopy

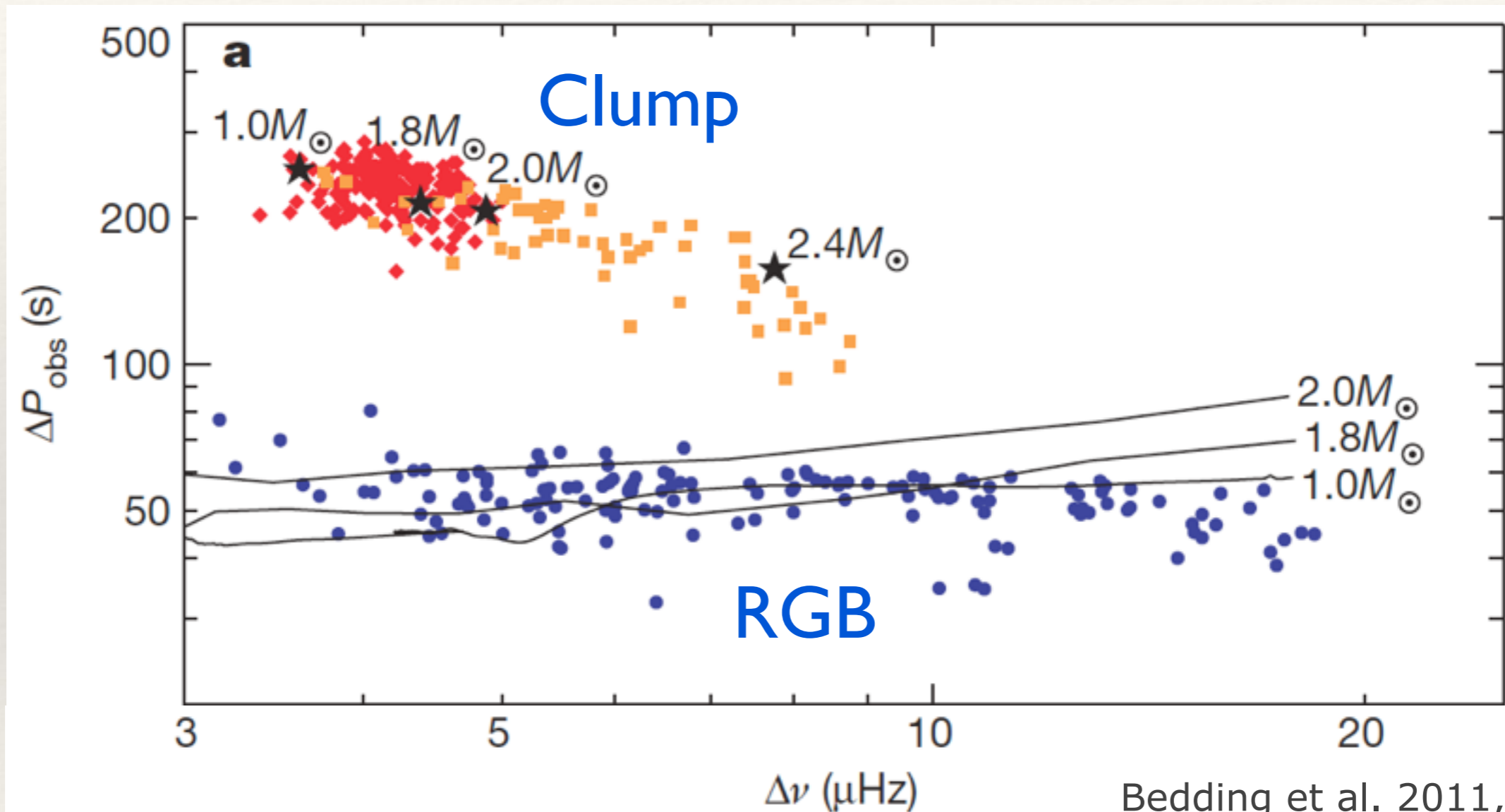
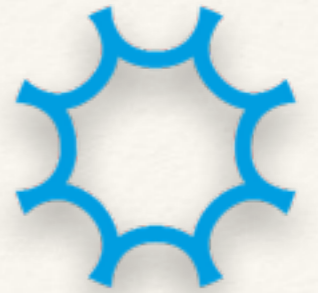


# Red giants



Note  
separation in  
 $|=|$  modes

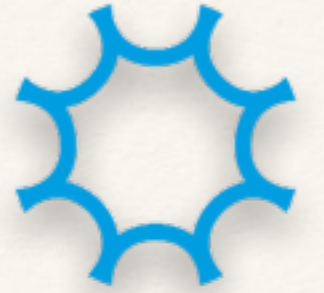
# Red giants



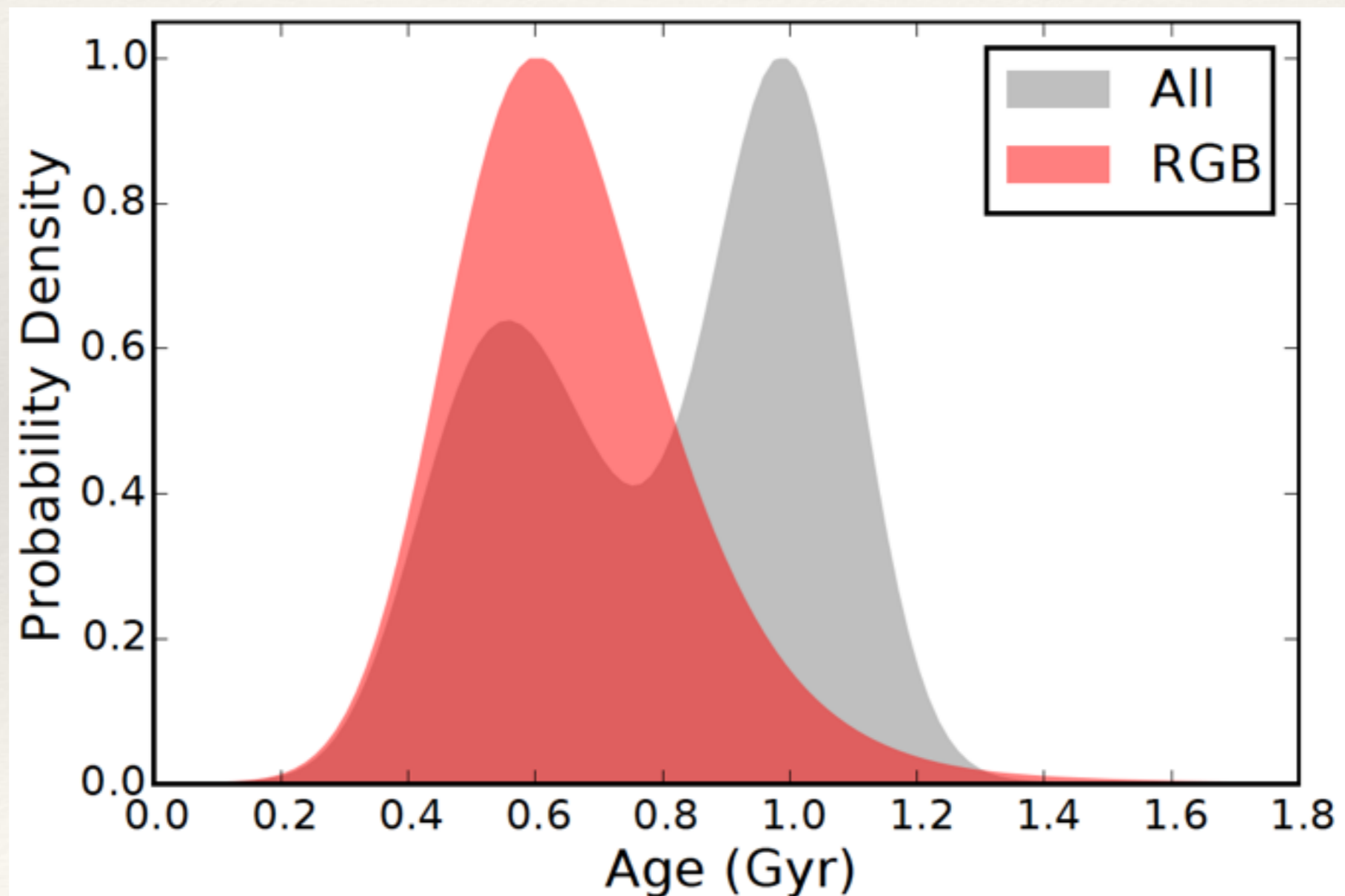
Two distinct sequences according to evolutionary stage



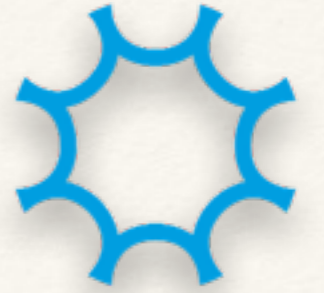
# Red giants



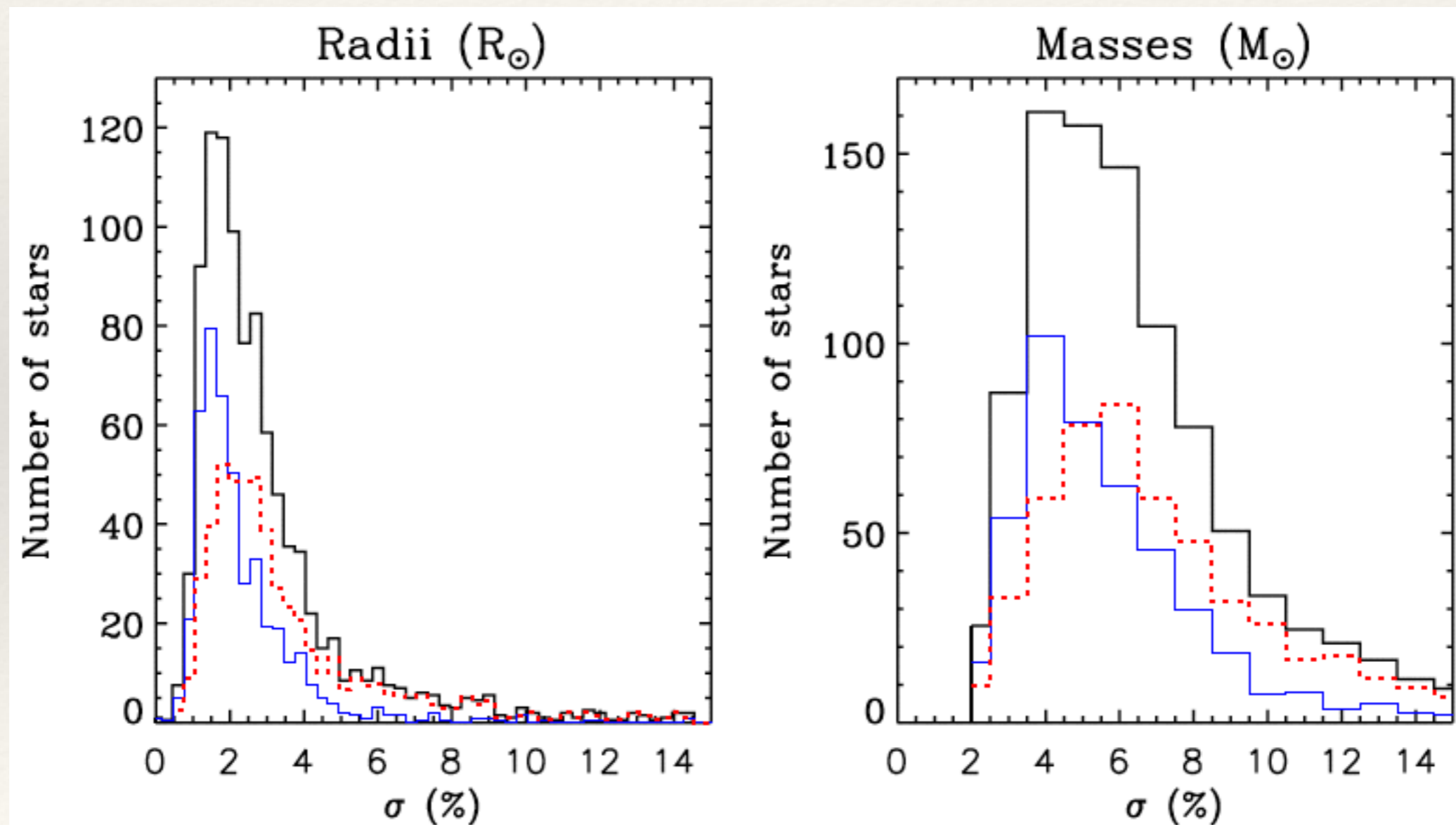
i.e. SAGA (also APOKASC this year):



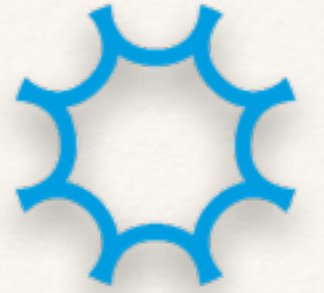
# Red giants



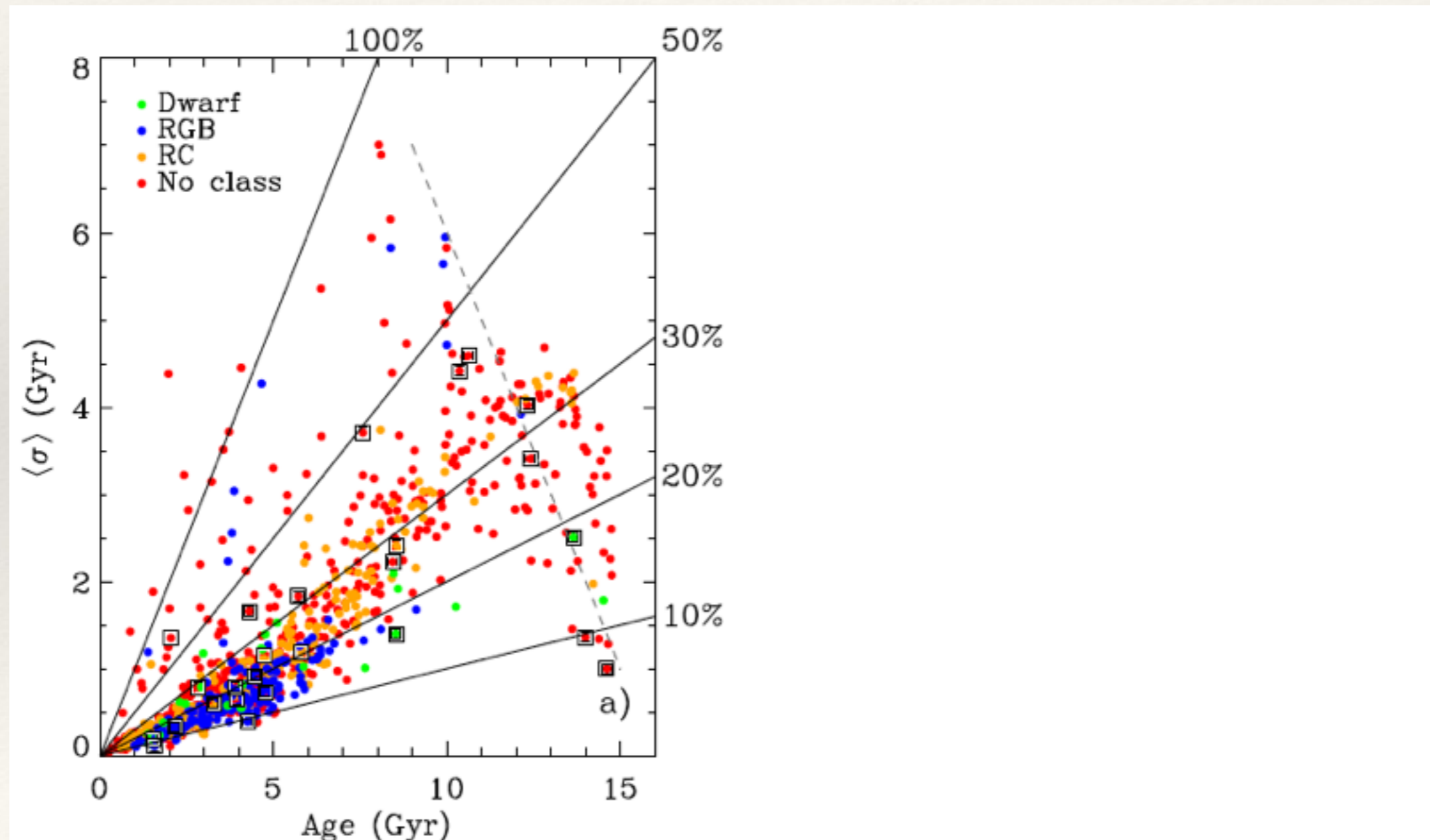
What we can obtain for giants (i.e. SAGA):



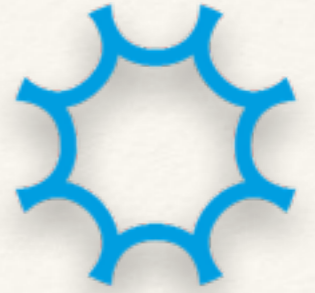
# Red giants



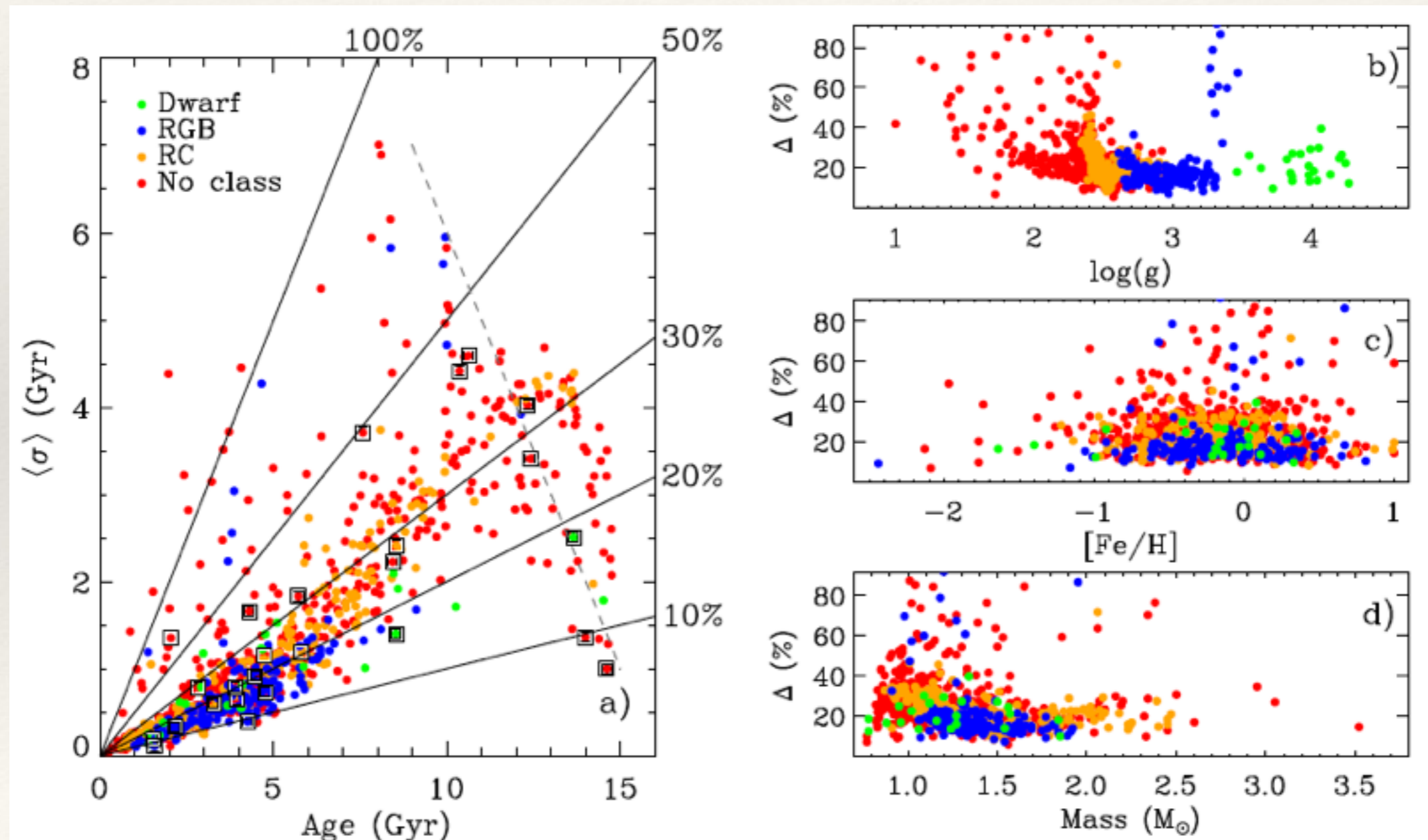
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# Red giants



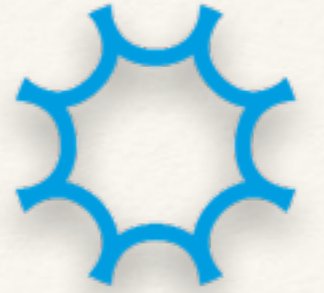
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# Red giants

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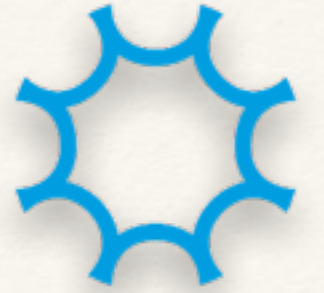
What we can obtain for giants (i.e. SAGA):

- ❖ Stellar radius  $\sim 2\%$
- ❖ Stellar mass  $\sim 6\%$
- ❖ Stellar age  $\sim 20\%$

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# Red giants

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

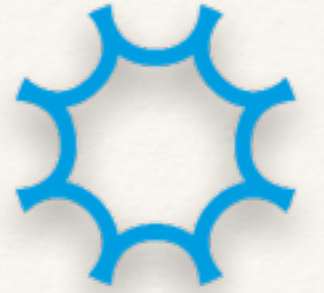
- ❖ Stellar radius  $\sim 2\%$
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- ❖ Stellar age  $\sim 20\%$

Can we improve?

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# Asteroseismic data

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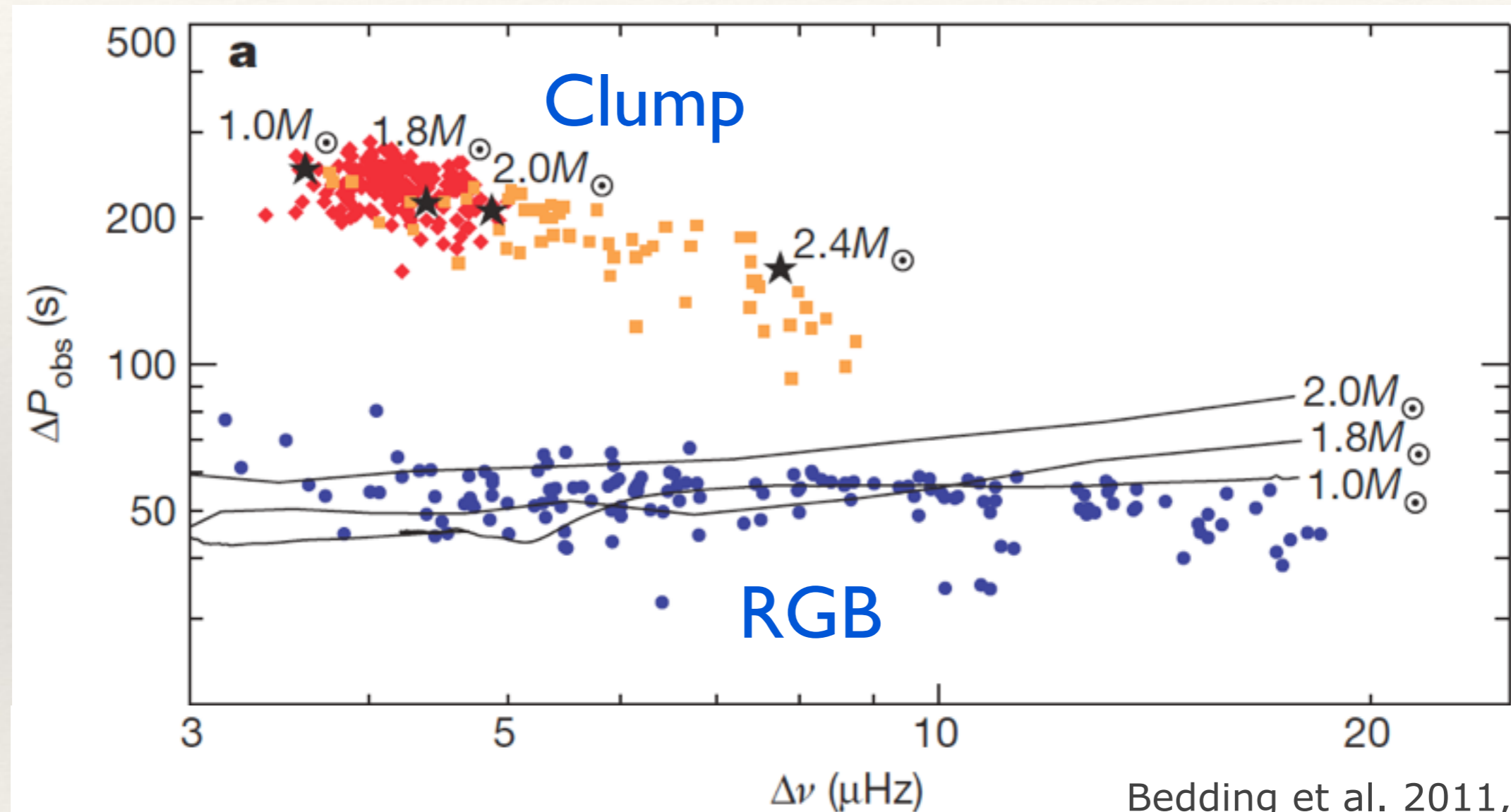
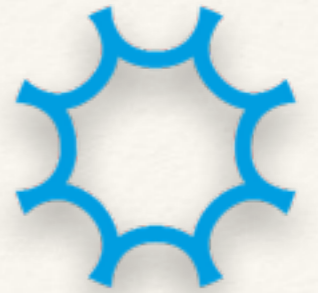


## How does the seismic trick works:

- ❖ The bare minimum: scaling relations (dwarfs and giants)
- ❖ Improvements: individual frequencies (dwarfs for now)
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Always need  $T_{\text{eff}}$  and  $[\text{Fe}/\text{H}]$

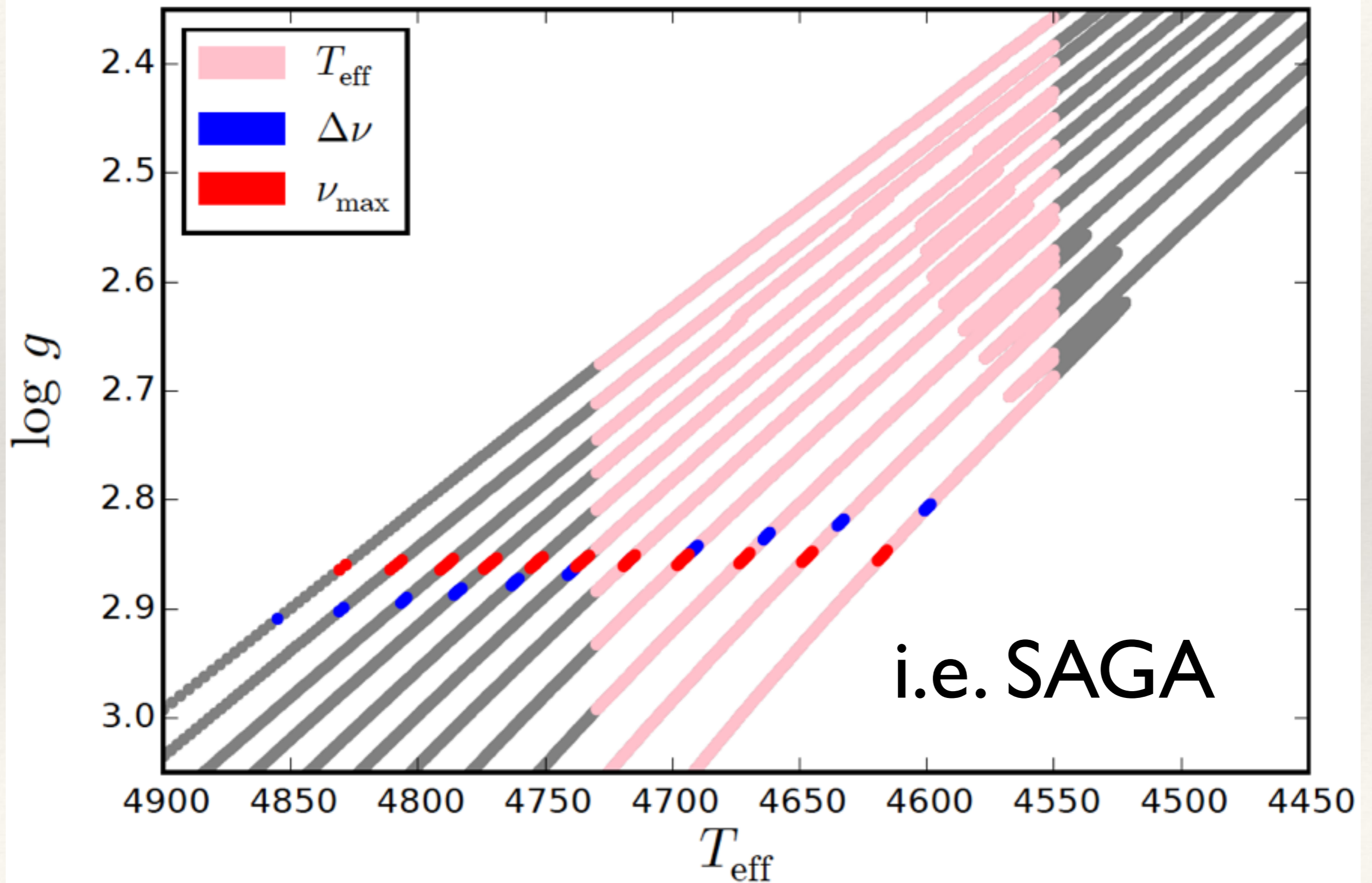
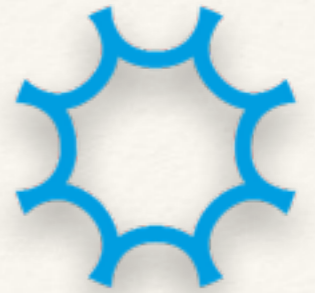
# Red giants



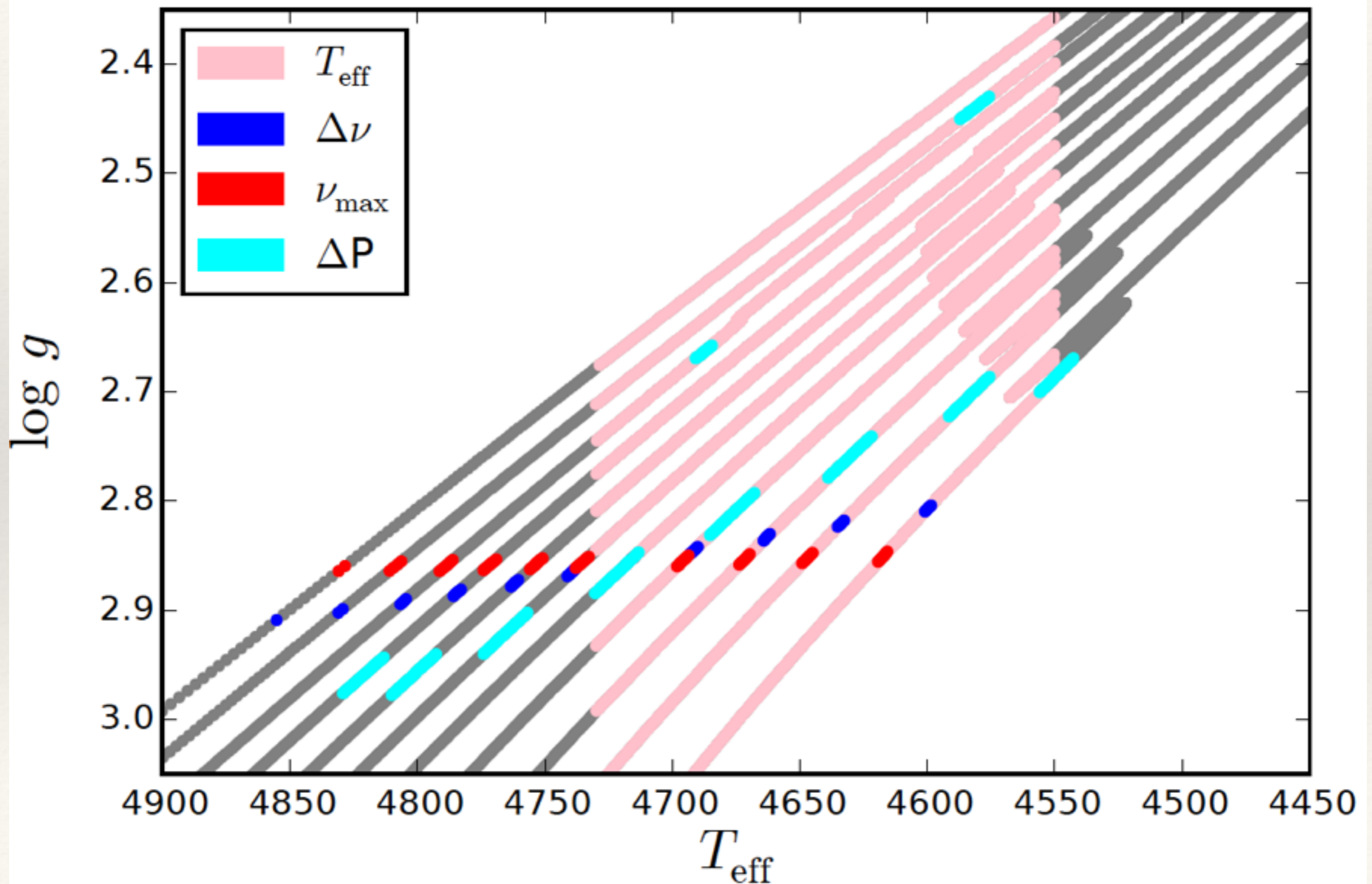
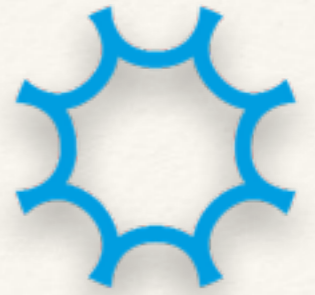
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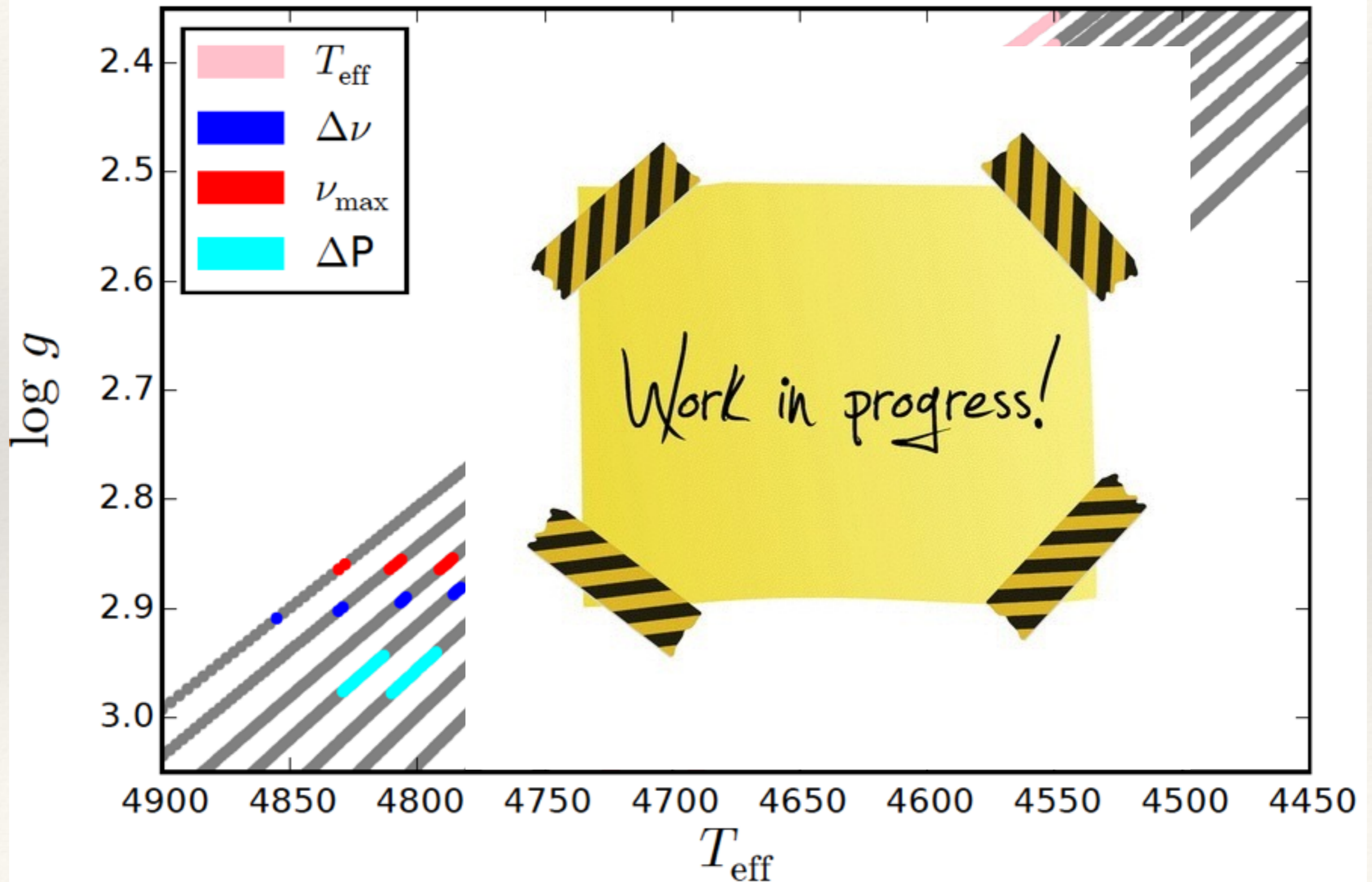
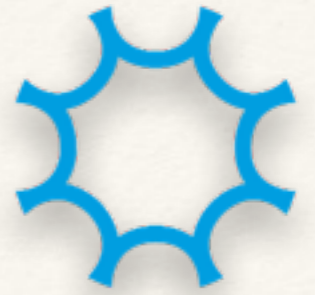
# The added dimension



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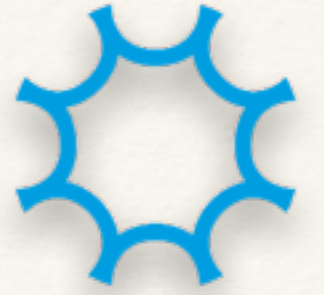
# The added dimension



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# Conclusions

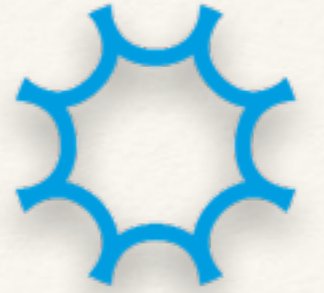
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# Conclusions

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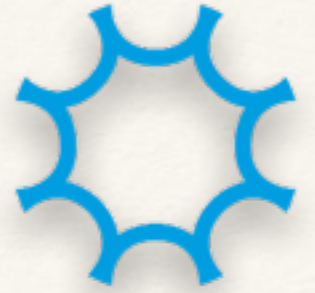


- ❖ Ages to ~15% (dwarfs) and ~20% (giants)

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# Conclusions

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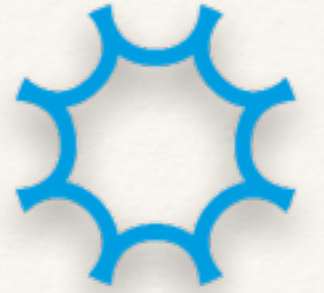


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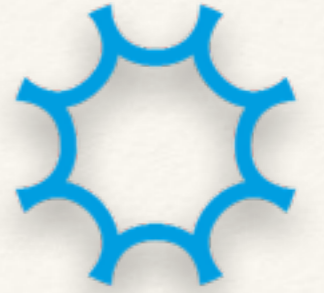


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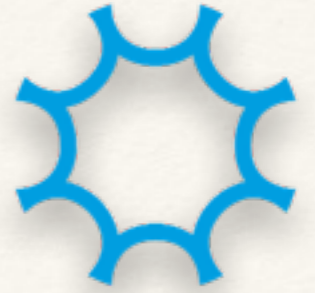
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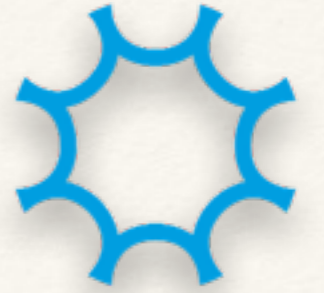


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# Conclusions

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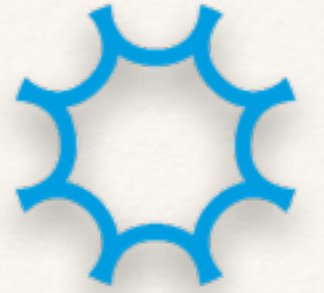


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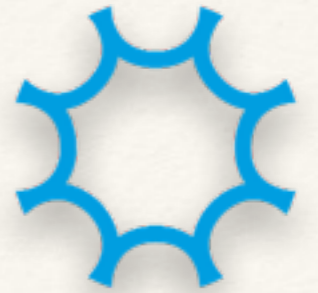
# Conclusions

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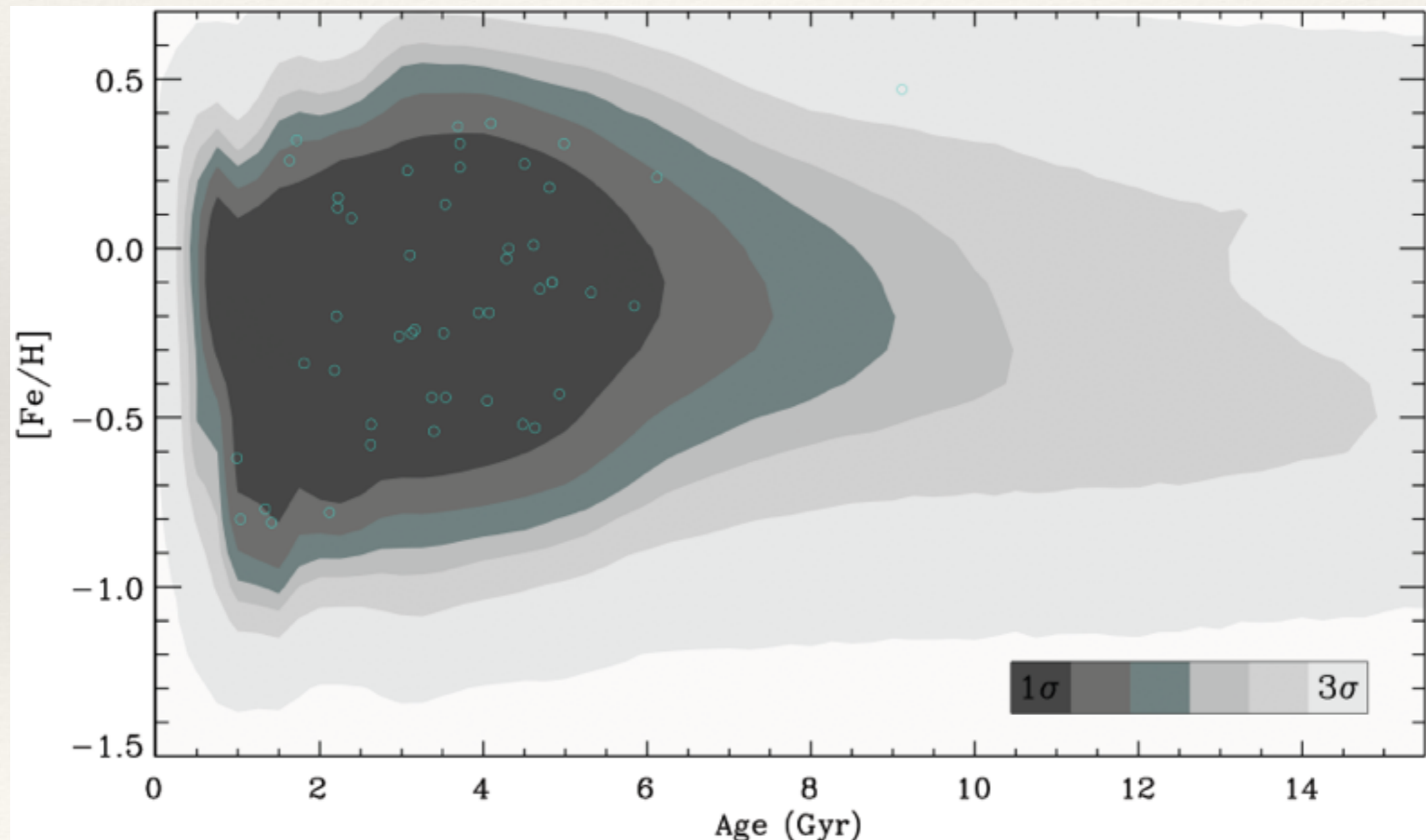


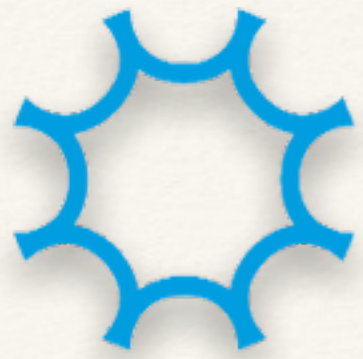
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- ❖ We need to get a handle on mass-loss
- ❖ Future looks bright: K2, TESS, PLATO
- ❖ Asteroseismology can deliver!

# Conclusions



Seismic age-metallicity relation (SAGA):





STELLAR ASTROPHYSICS CENTRE

# Ages for dwarfs and giants from asteroseismology

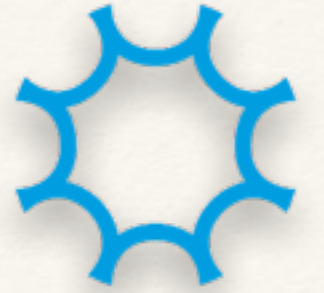
Víctor Silva Aguirre  
Aldo Serenelli

Bad Honnef, June 1st 2015

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# Appendix

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## Systematic uncertainties (dwarfs)

### Statistical

- ❖ Radius  $\sim 1.1\%$
- ❖ Mass  $\sim 3.3\%$
- ❖ Age  $\sim 14\%$

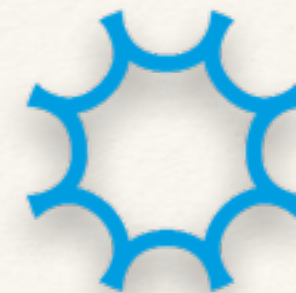
### Physics

- ❖ Radius  $\sim 0.7\%$
- ❖ Mass  $\sim 2.3\%$
- ❖ Age  $\sim 9.6\%$

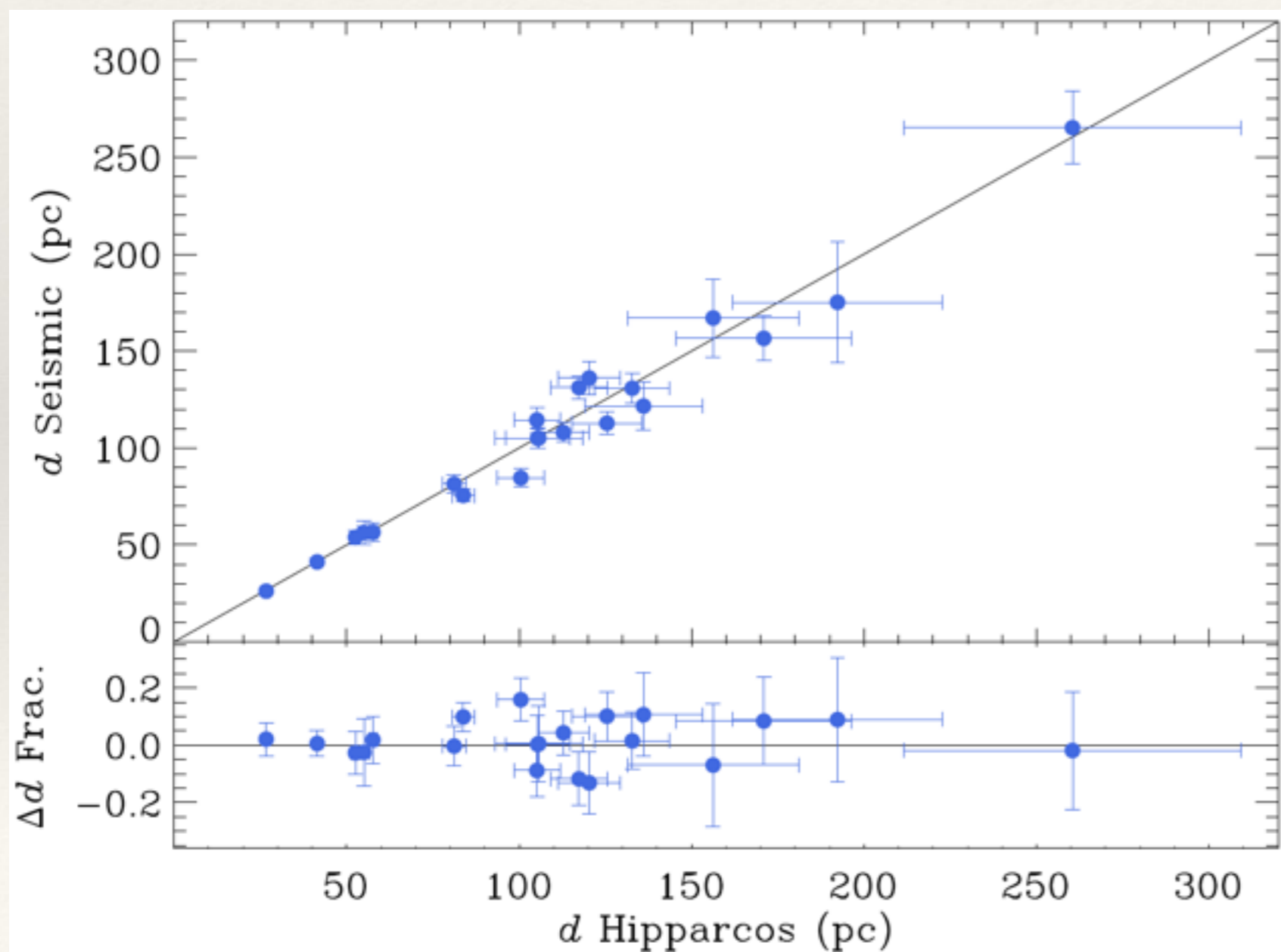
### Fitting Algo.

- ❖ Radius  $\sim 1.6\%$
- ❖ Mass  $\sim 3.6\%$
- ❖ Age  $\sim 16.8\%$

# Appendix

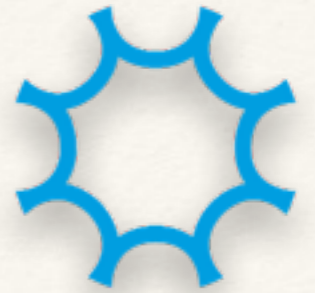


## 22 dwarfs with accurate parallaxes

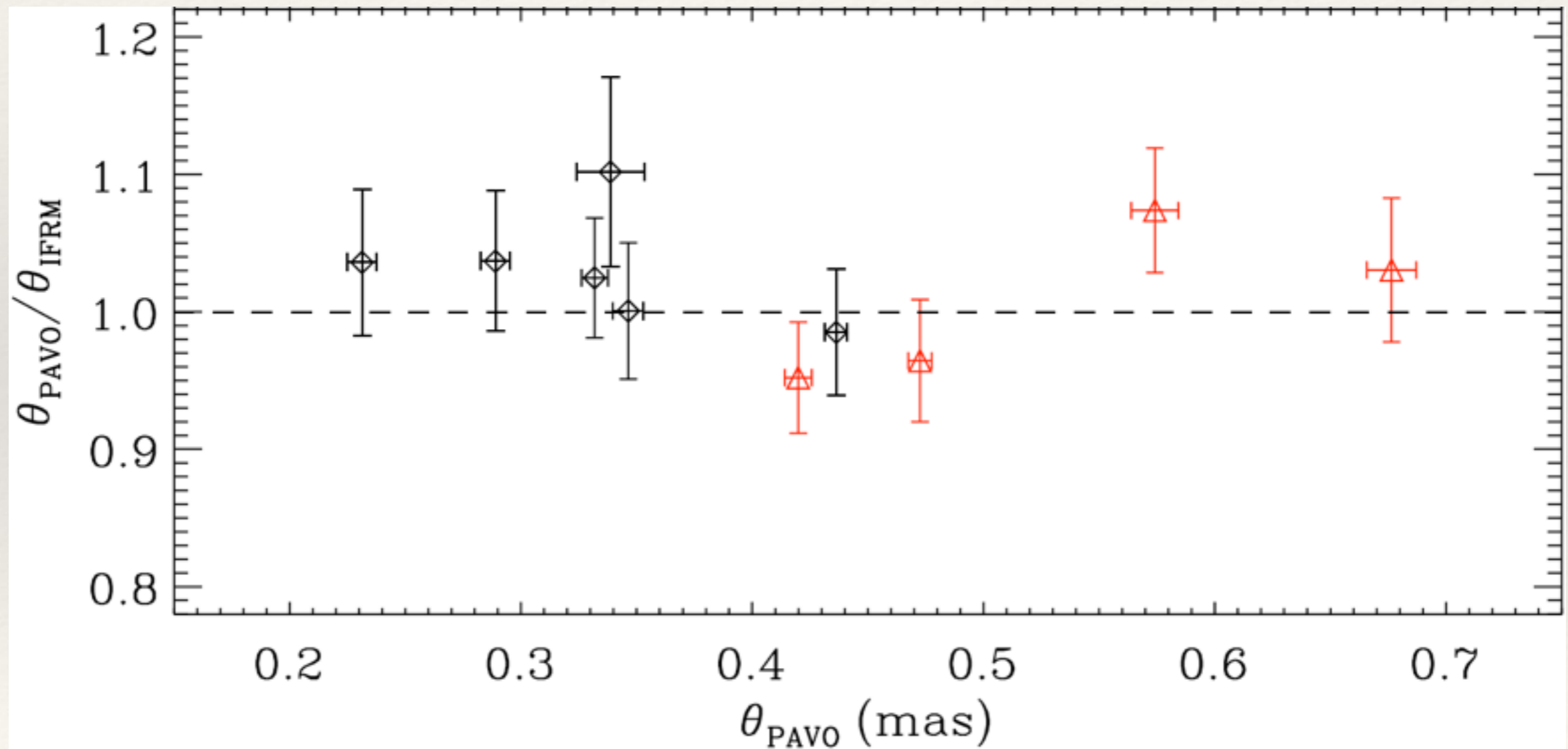


$2.3 \pm 1.8\%$

# Appendix

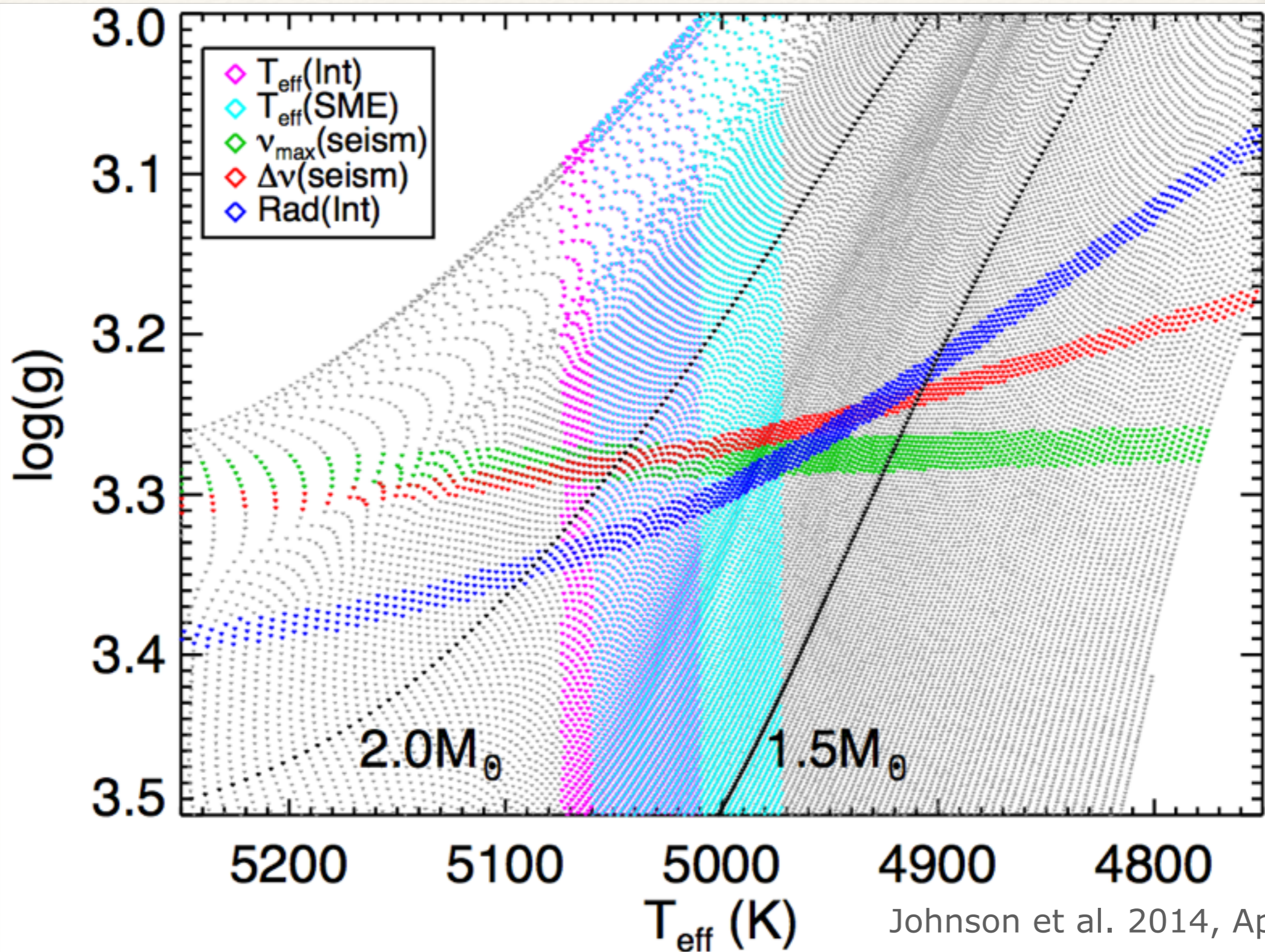
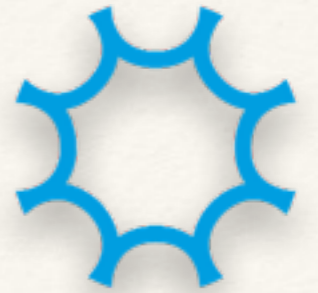


## 10 stars with interferometric measurements

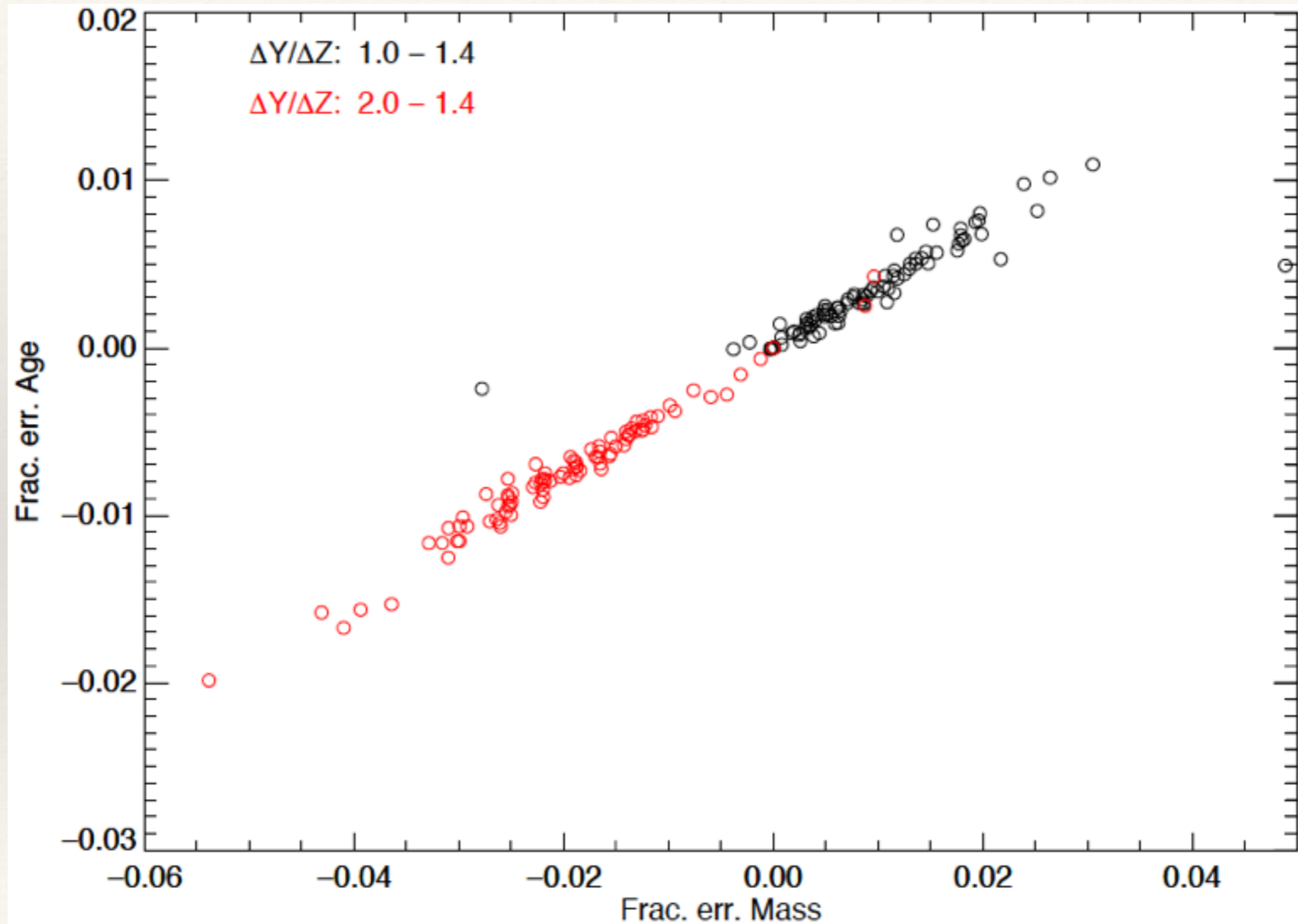
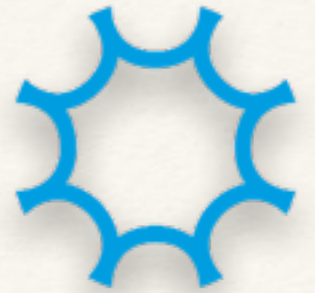


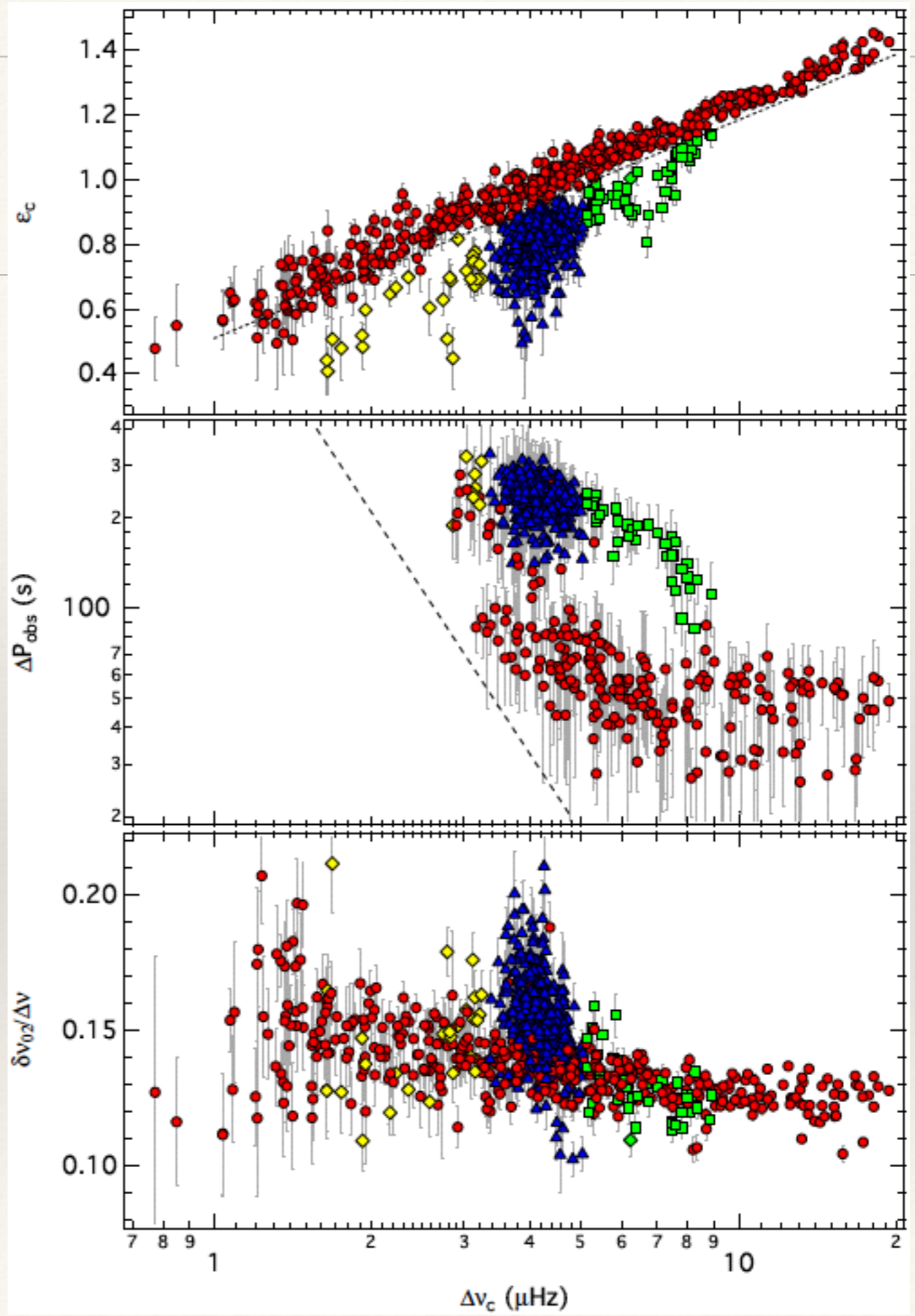
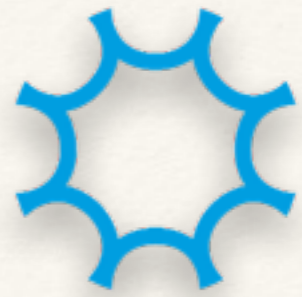


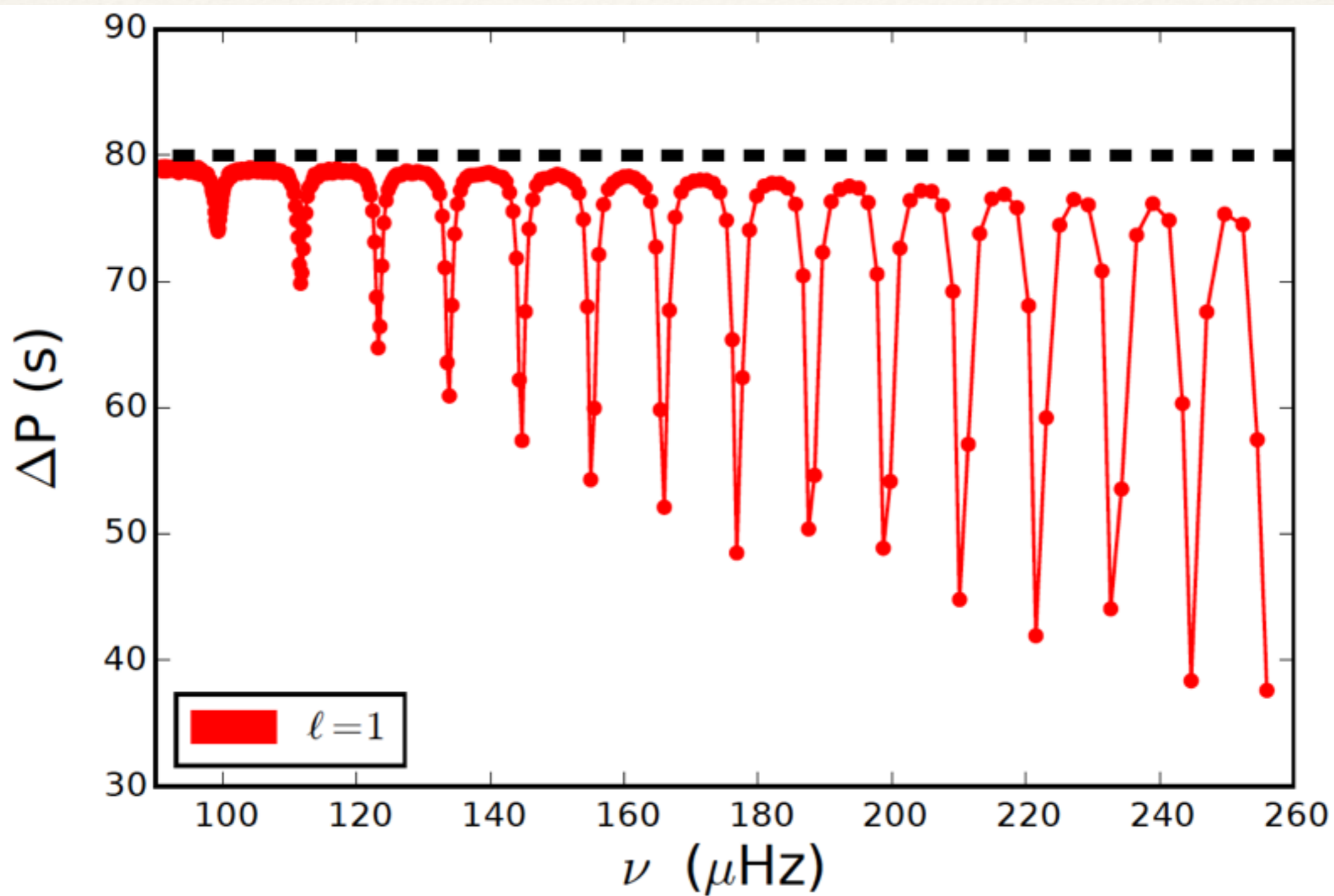
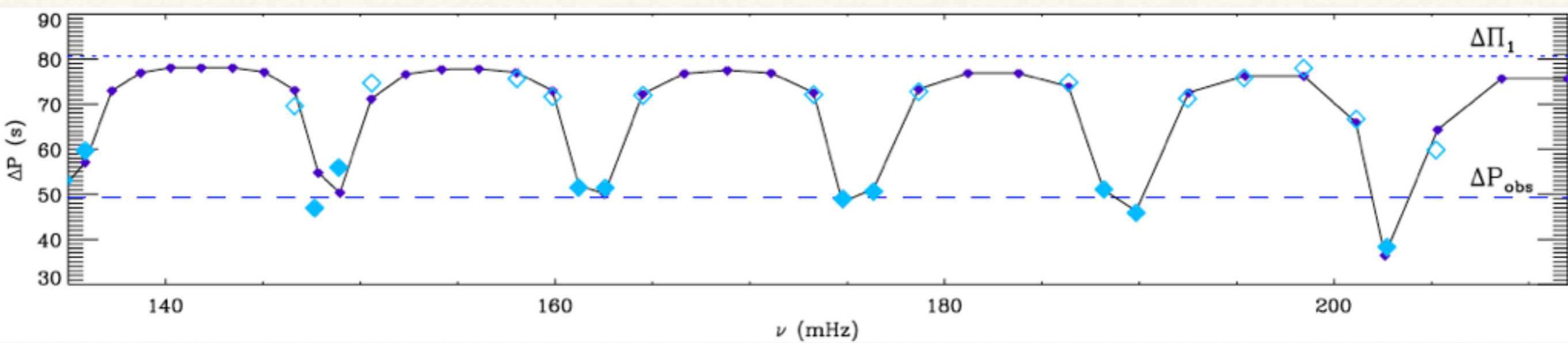
# Appendix



# Appendix







# Appendix

KIC 11395018

