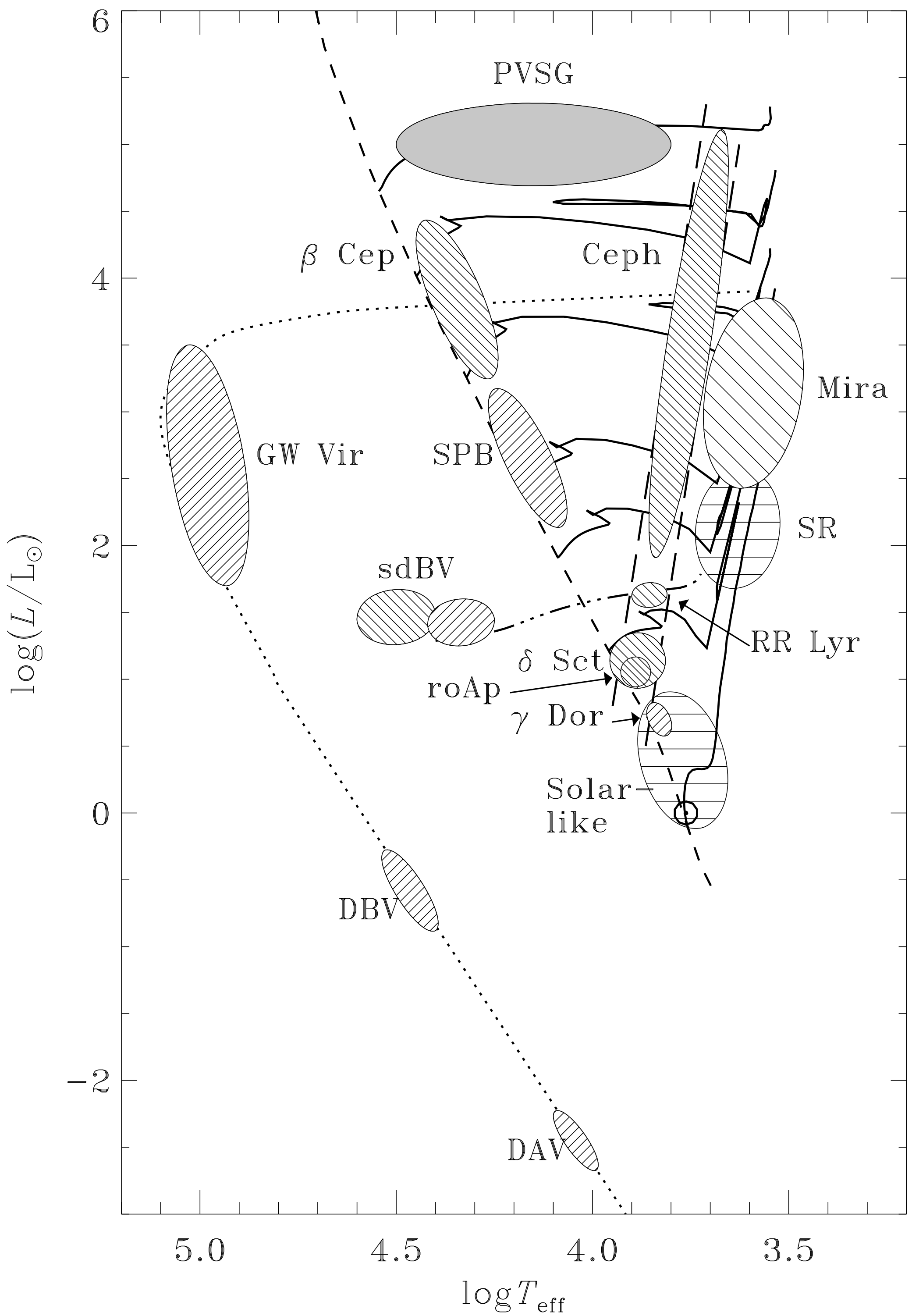
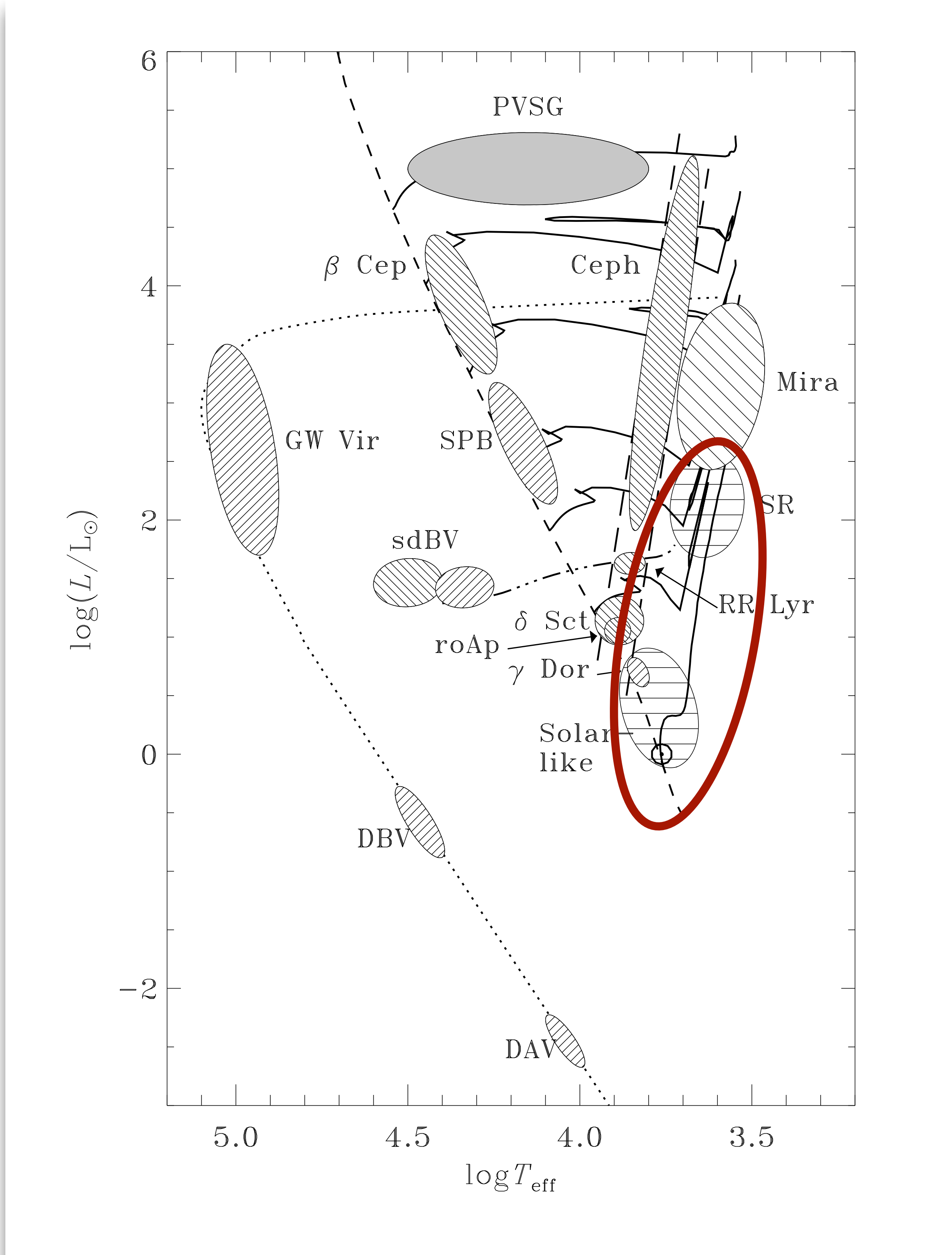
ENSEMBLE ASTEROSEISMOLOGY SCALING LAWS

Josefina Montalbán

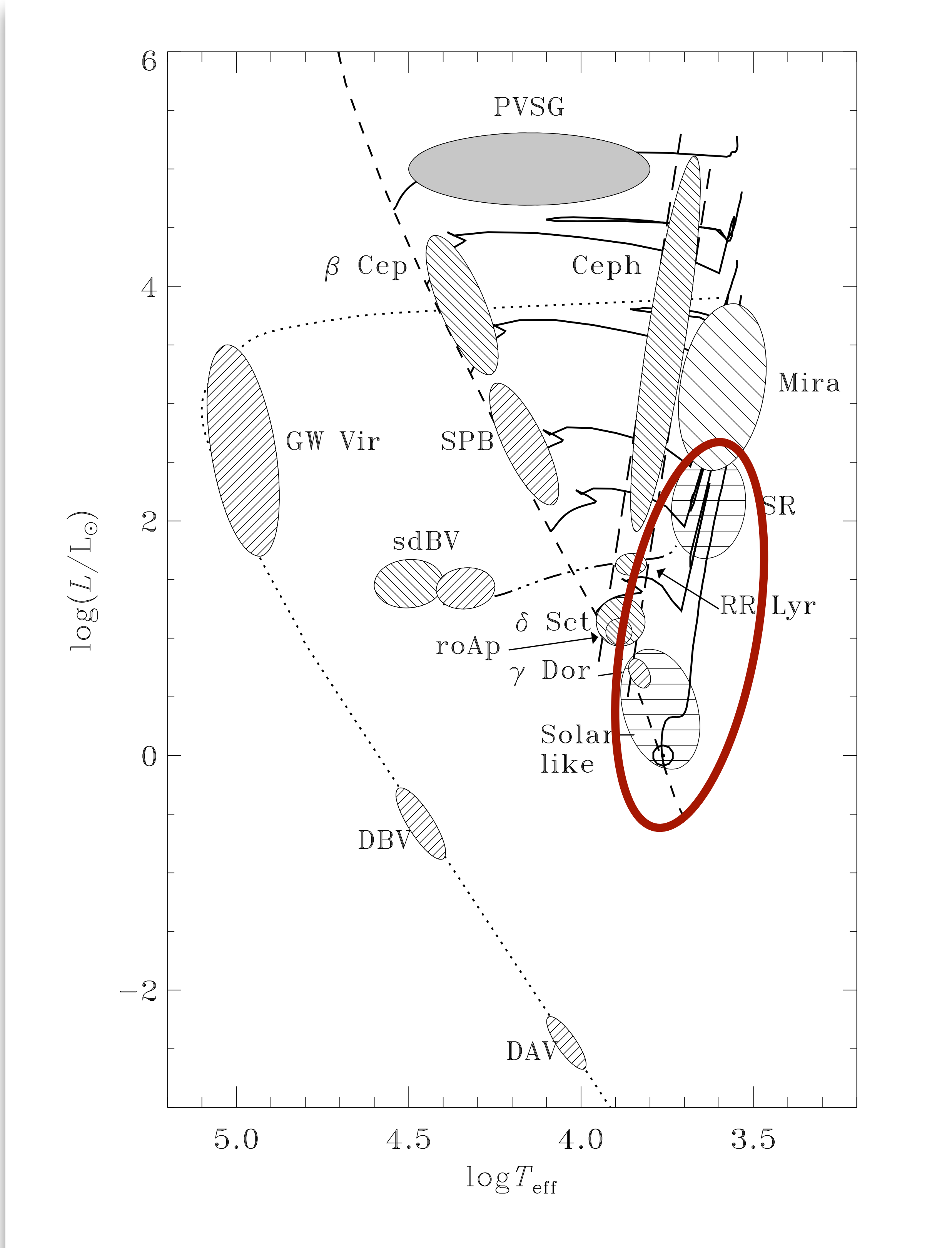


credit Christensen-Dalsgaard



credit Christensen-Dalsgaard

Solar-like oscillations



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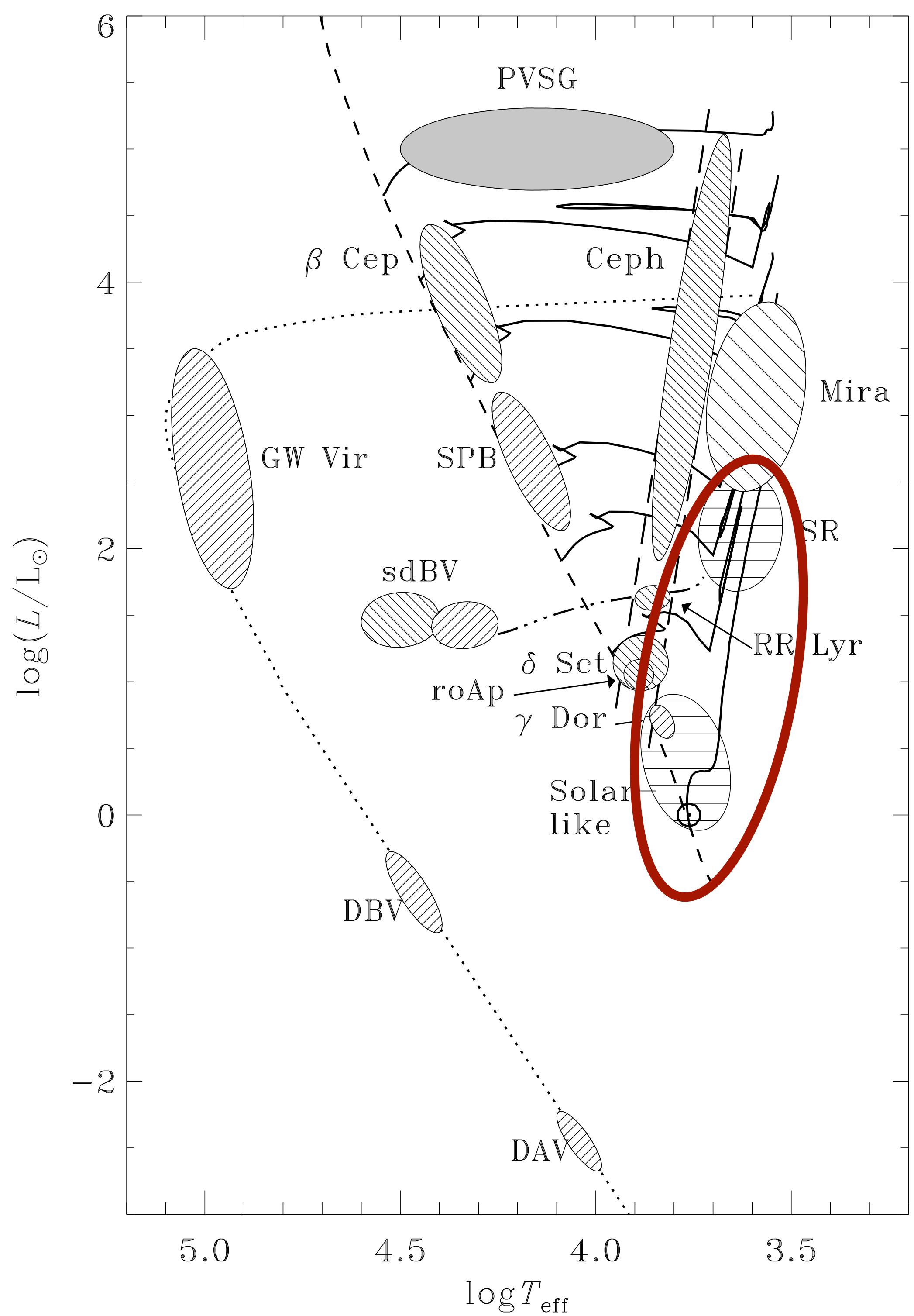
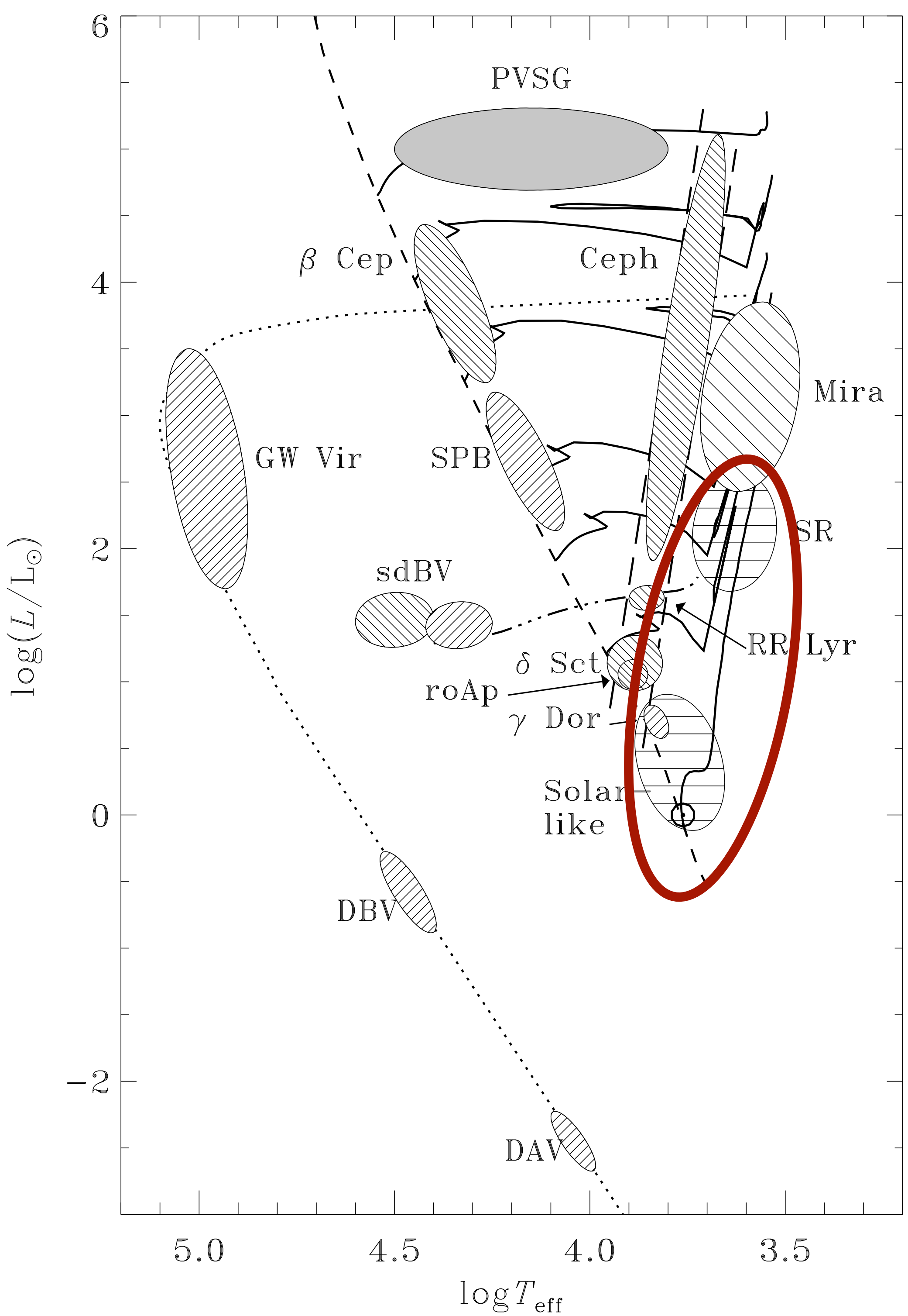


credit Christensen-Dalsgaard

- periods: minutes to hours

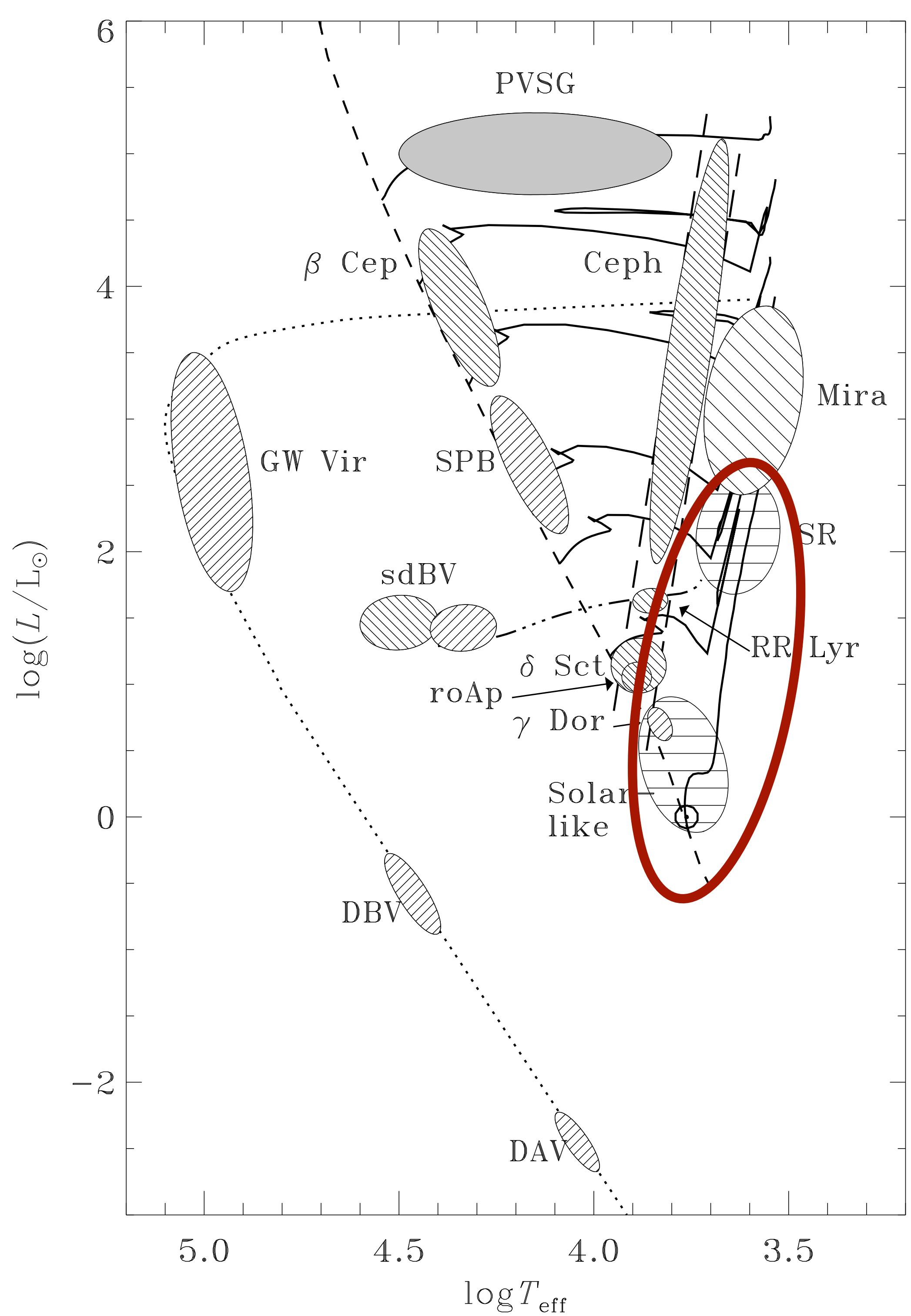


credit Christensen-Dalsgaard

Solar-like oscillations

- periods: minutes to hours
- intrinsically damped, externally forced by turbulent convection

Solar-like oscillations



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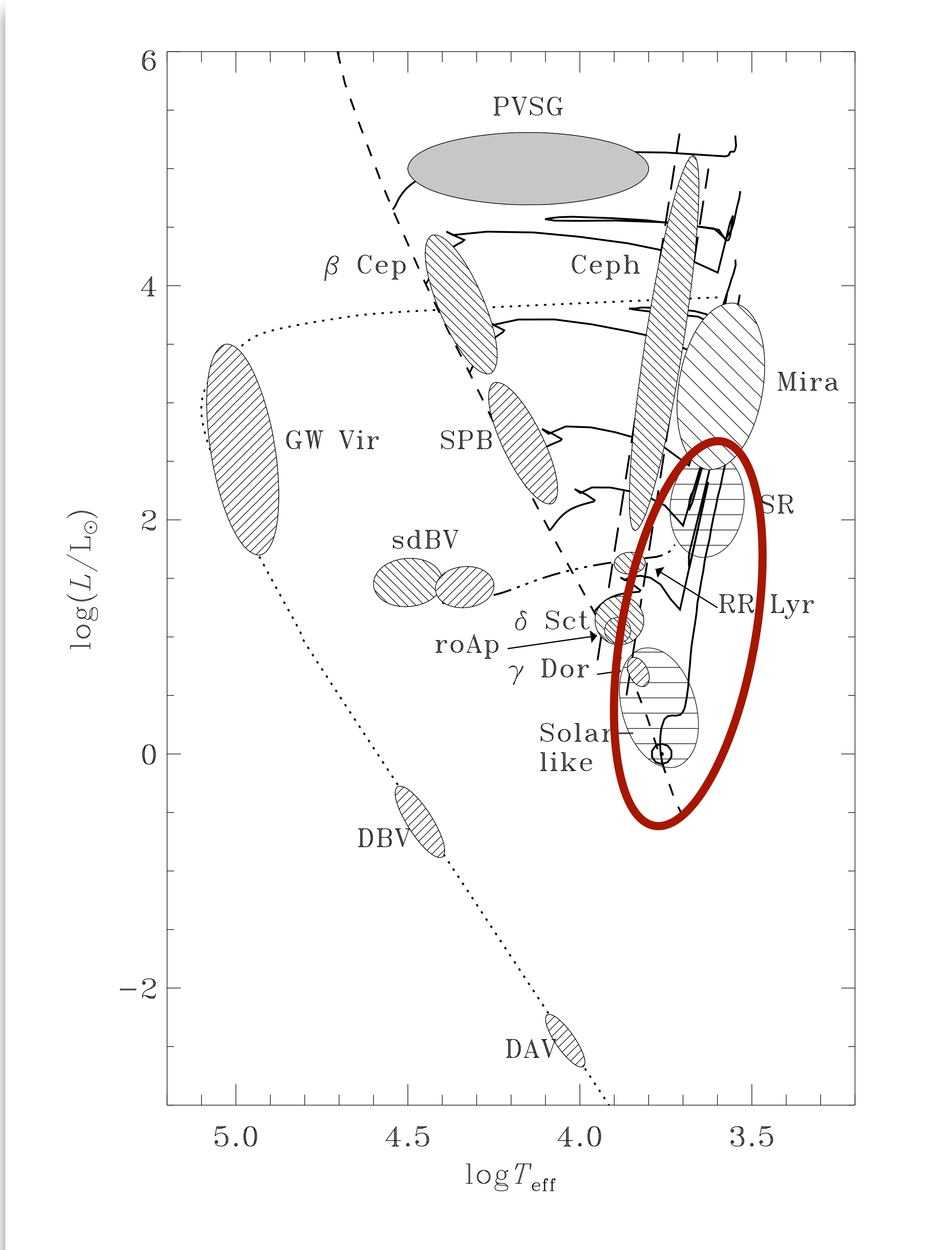
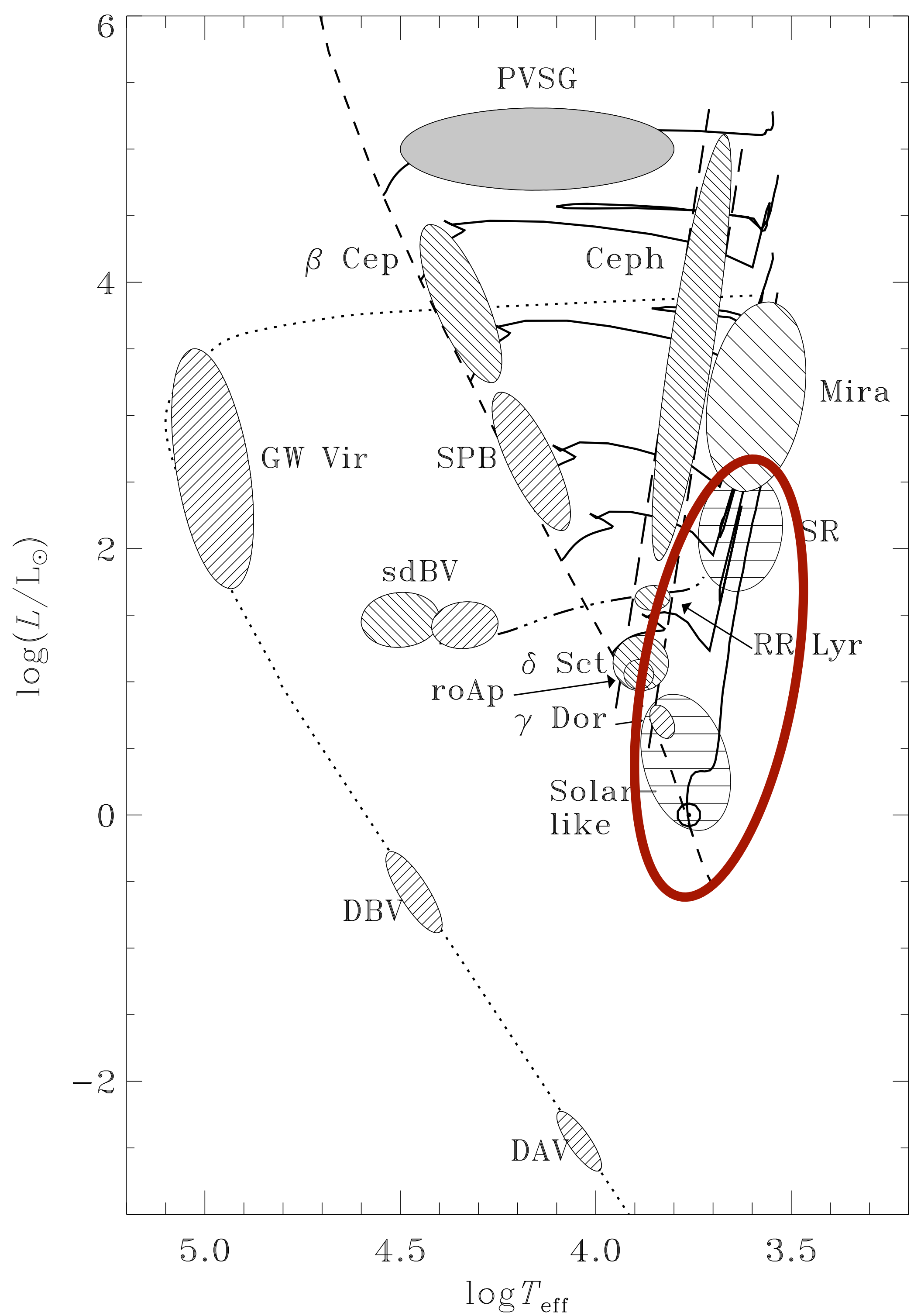
- periods: minutes to hours
- intrinsically damped, externally forced by turbulent convection
- amplitudes: ppm-tens of ppm

Solar-like oscillations



credit Christensen-Dalsgaard

- periods: minutes to hours
- intrinsically damped, externally forced by turbulent convection
- amplitudes: ppm-tens of ppm
- acoustic modes:
  radial and non-radial

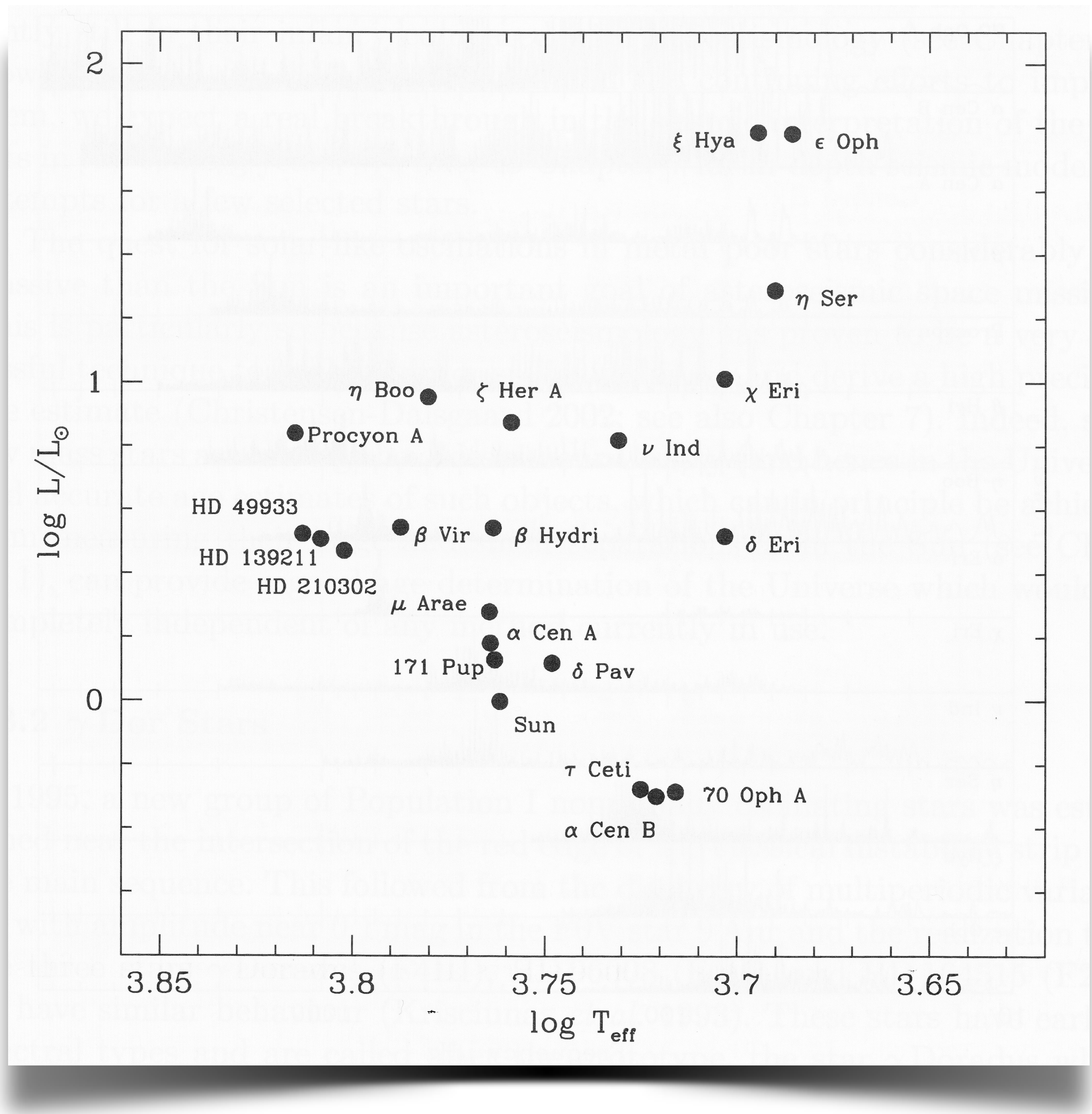


credit Christensen-Dalsgaard

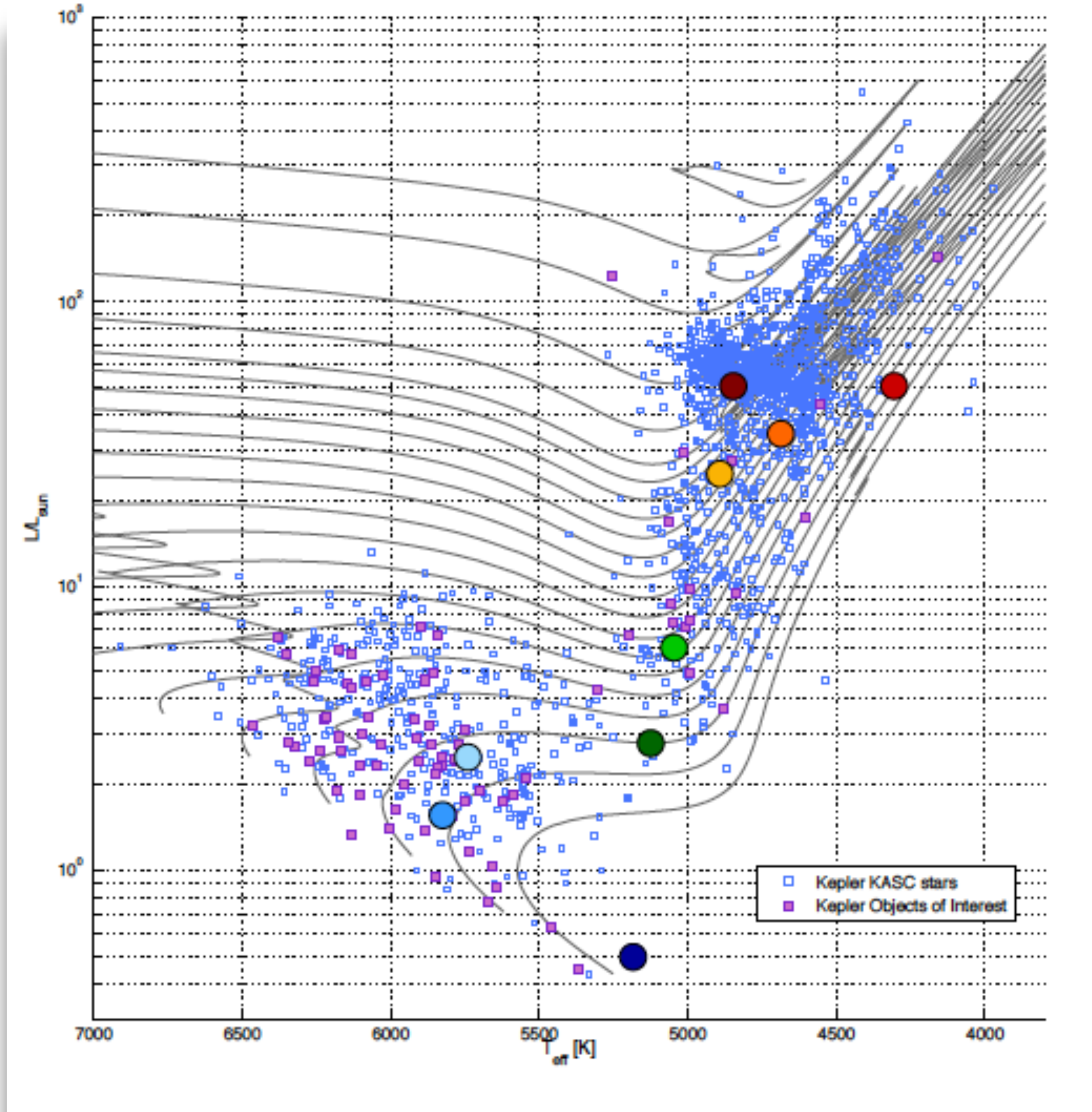
Solar-like oscillations

- periods: minutes to hours
- intrinsically damped, externally forced by turbulent convection
- amplitudes: ppm-tens of ppm
- acoustic modes: radial and non-radial
- in subgiants/giants: g-p mixed modes

HRD OF SOLAR-LIKE PULSATORS BEFORE COROT & KEPLER

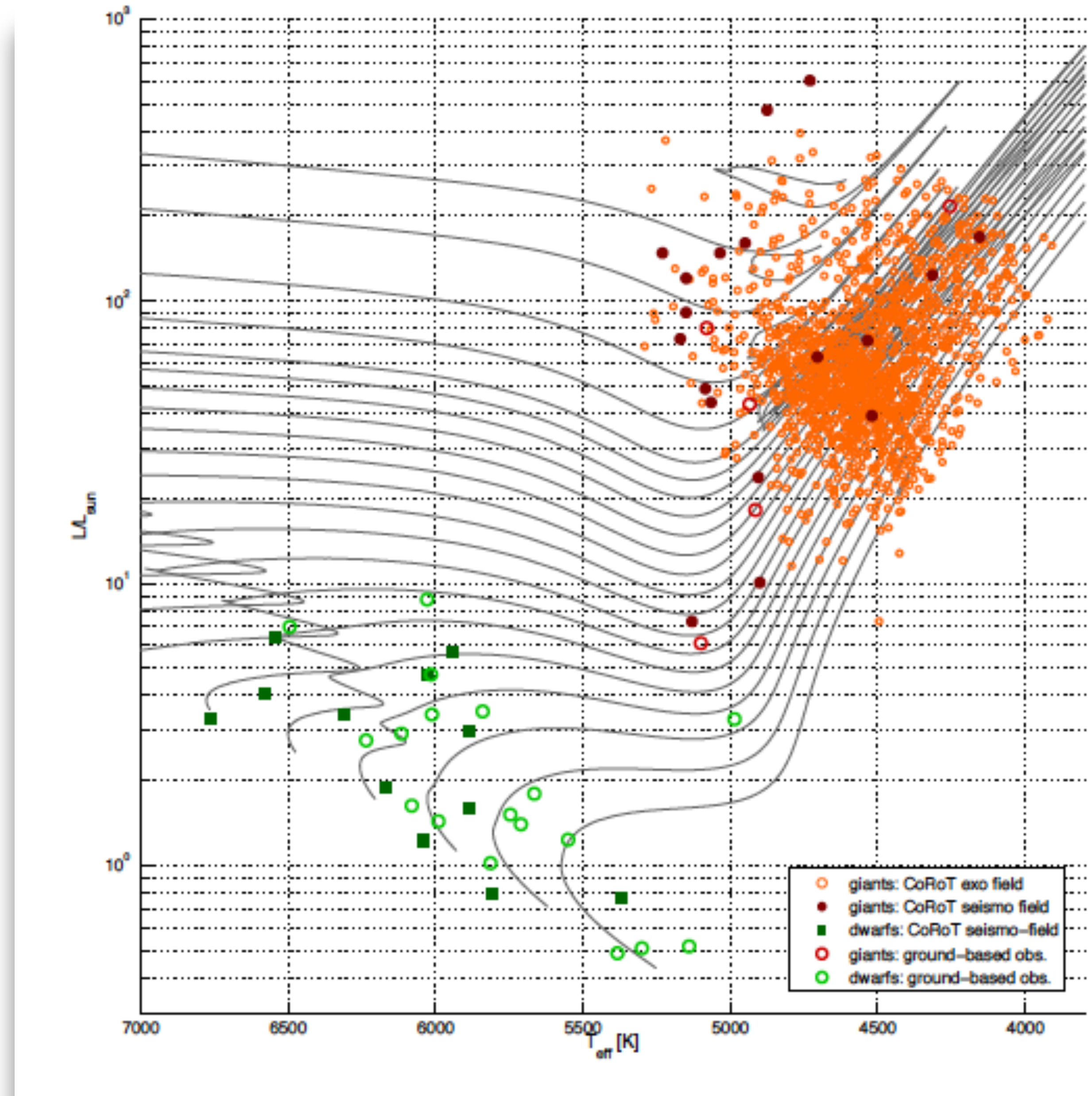


Straka et al. 2006, Carrier et al. 2005, Guenther 2004, Kjeldsen et al. 2003, Di Mauro et al 2002 , Christensen-Dalsgaard et al. 1995, Kjeldsen et al 1995, Provost et al. 2006, Claudi et al. 2005, Eggenberger et al. 2004, Martic et al. 2004, Eggenberger&Carrier 2006, Bedding et al. 2006, Carrier&Eggenberger 2006, Bouchy et al. 2005, Bazot et al. 2005, Bedding et al. 2001 Carrier & Bouchy 2001,2, …



Kepler: ~500 dwarfs & subgiants
14000 giants
giants in 4 clusters

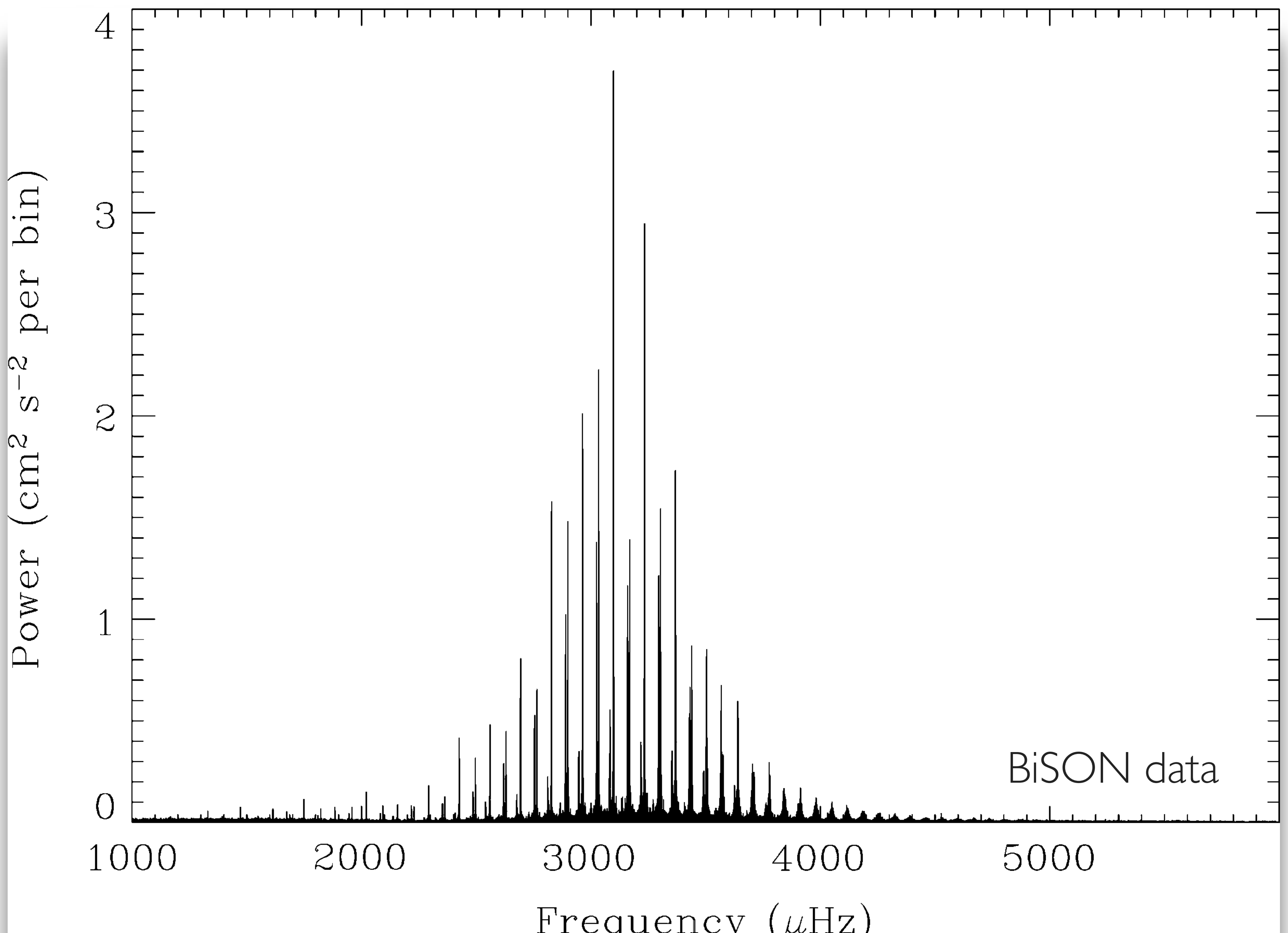
CoRoT: a few bright solar-like pulsators in the seismofield
~20000 giants in the exo-field
4 giants in NGC6633



Chaplin & Miglio 2013

SOLAR-LIKE PULSATIONS

radial modes



comb-like spectrum

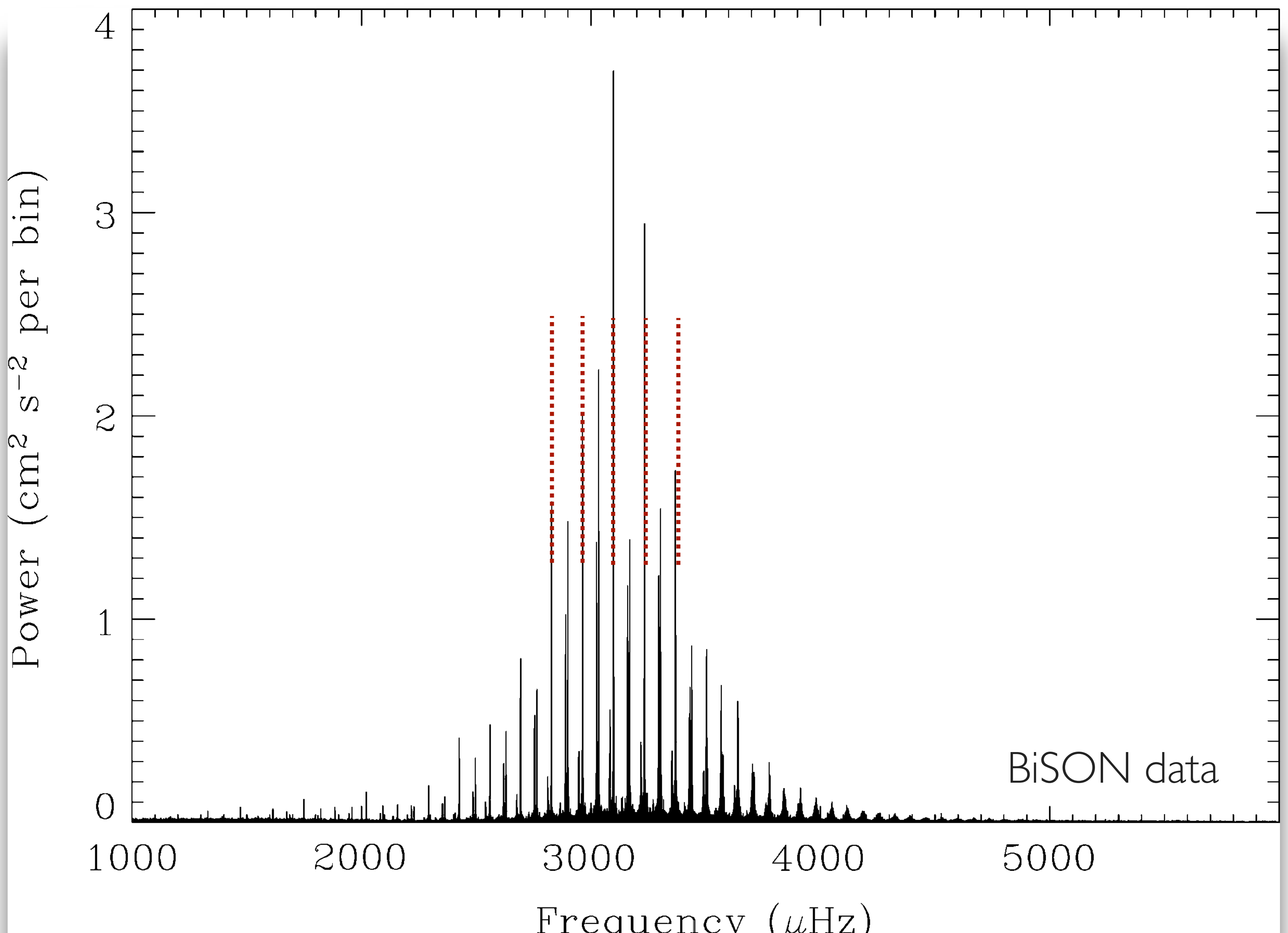
$$\Delta\nu = \left(2\int \frac{dr}{r}\right)^{-1}$$
$$\propto (M/R^3)^{1/2}$$

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

Ulrich 1986
Brown et al. 1991
Kjeldsen & Bedding 1995
Belkacem et al. 2011

SOLAR-LIKE PULSATIONS

radial modes



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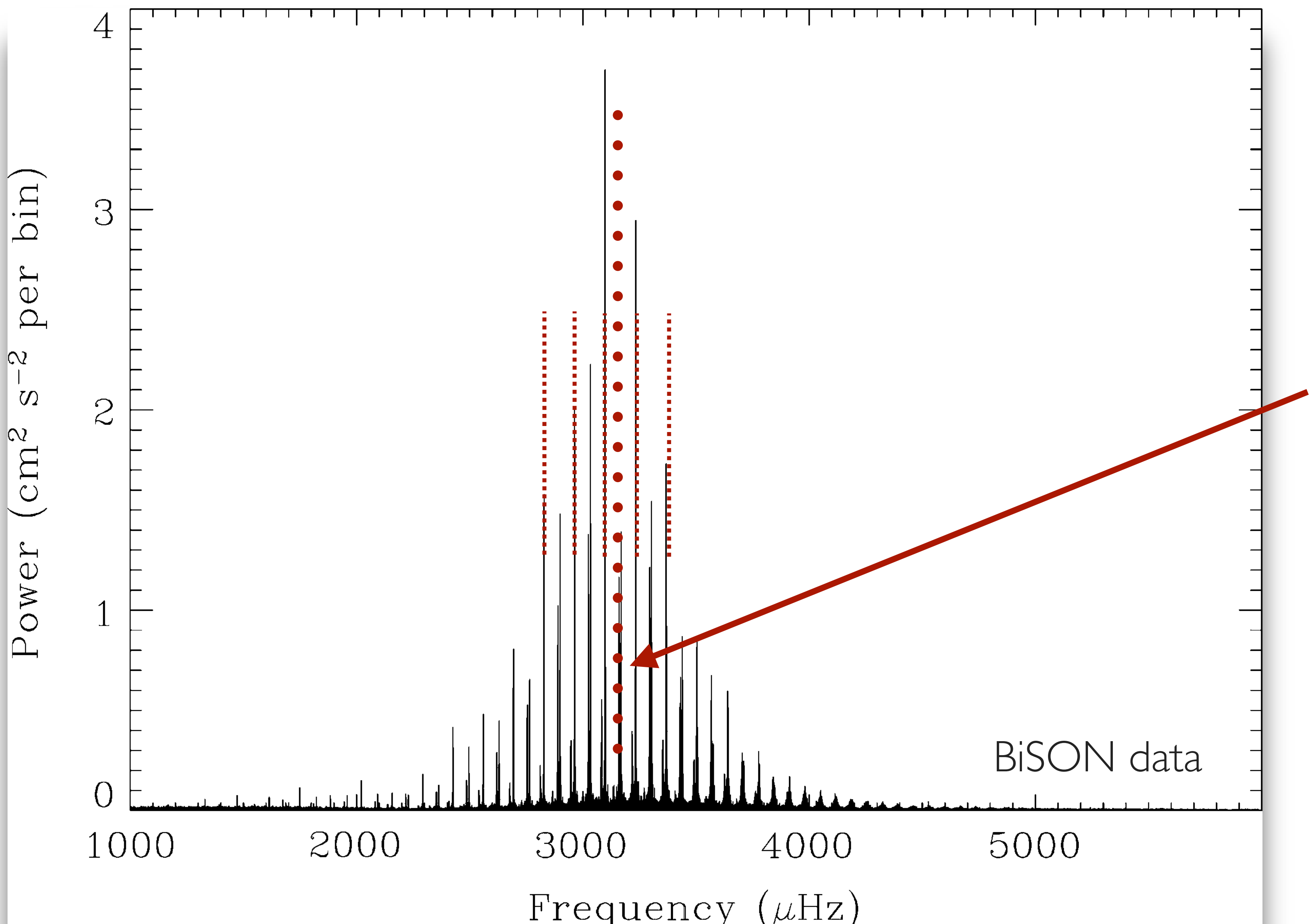

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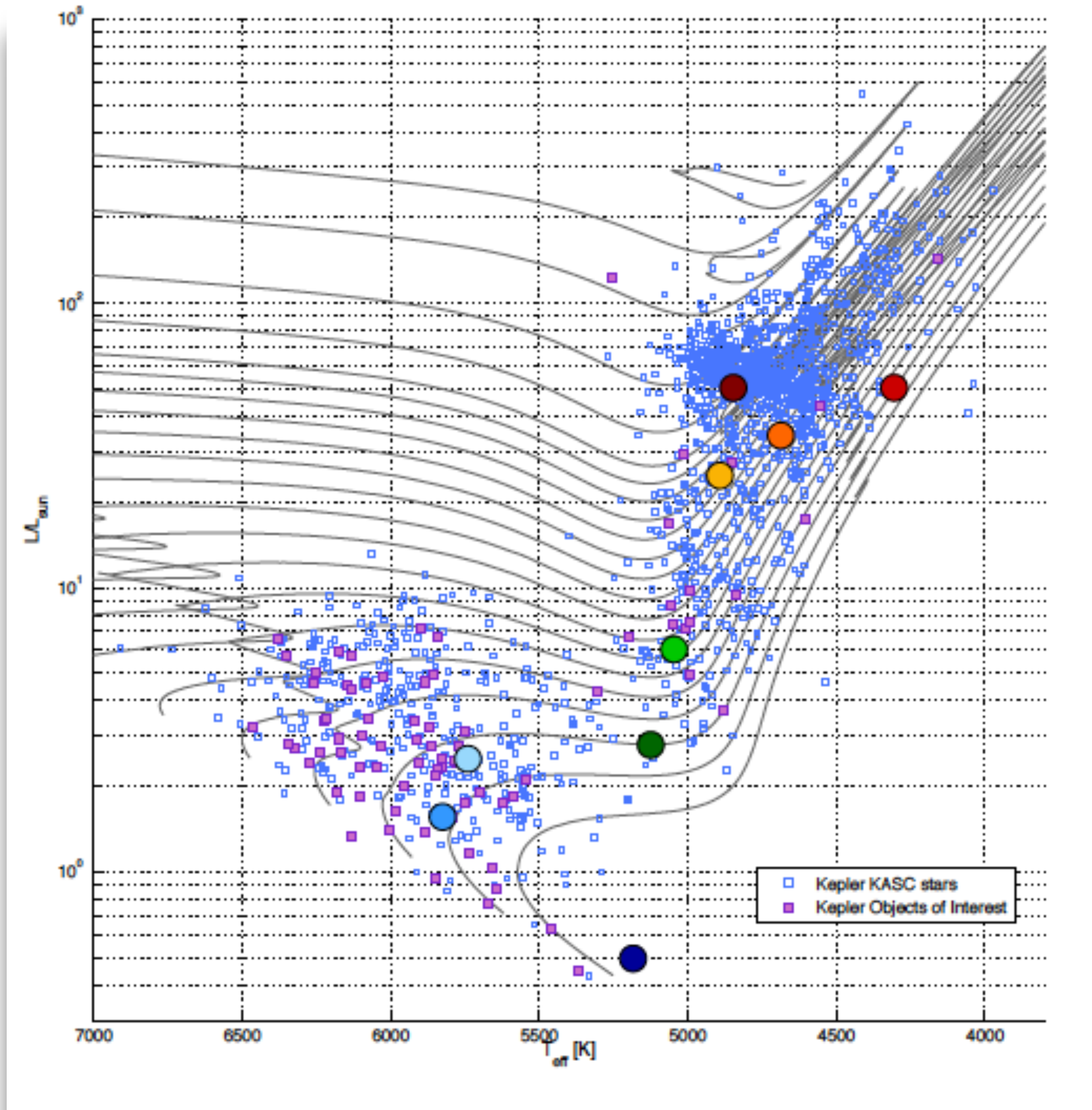
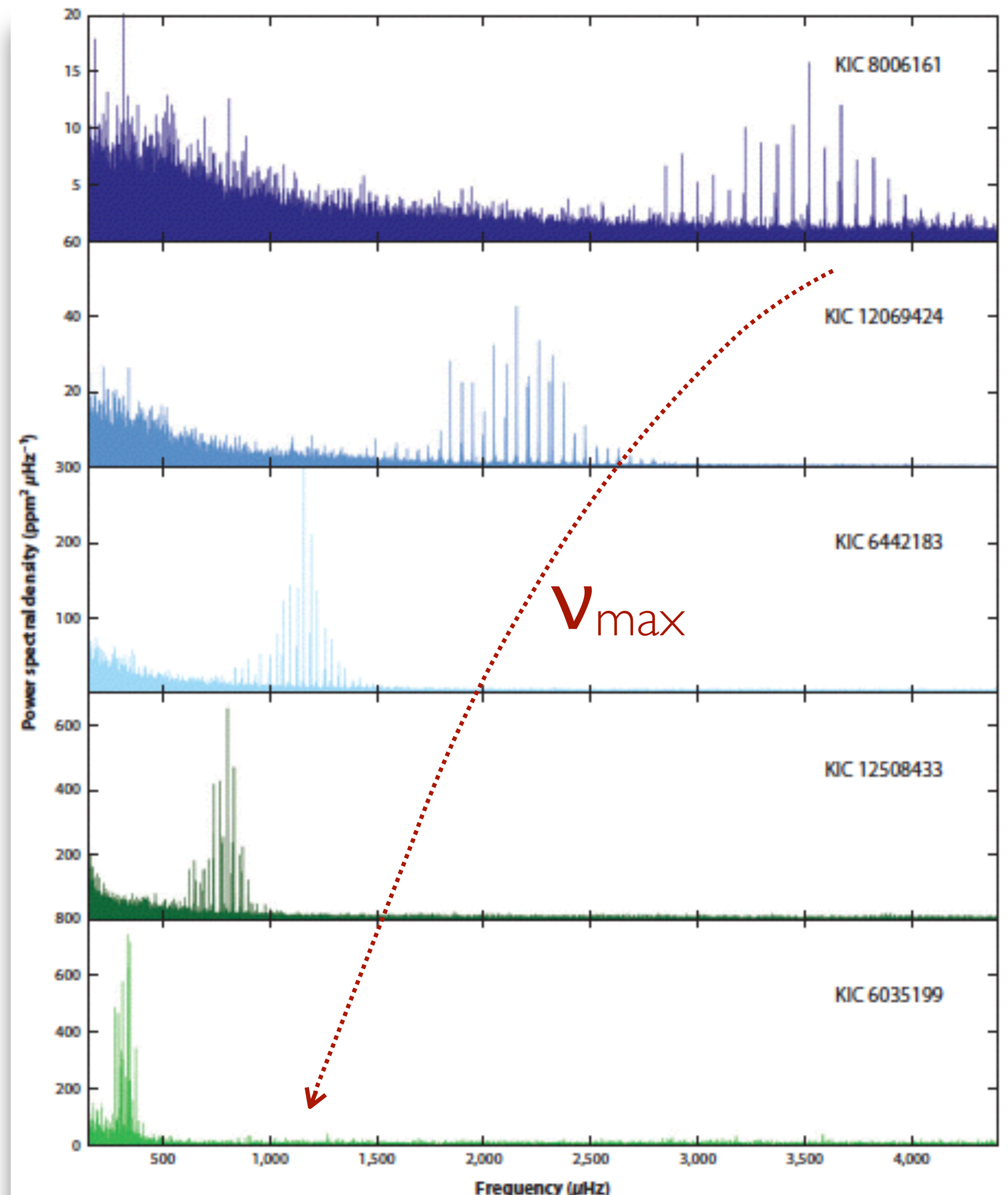
EVOLUTION OF DWARF AND SUB-GIANT SPECTRUM

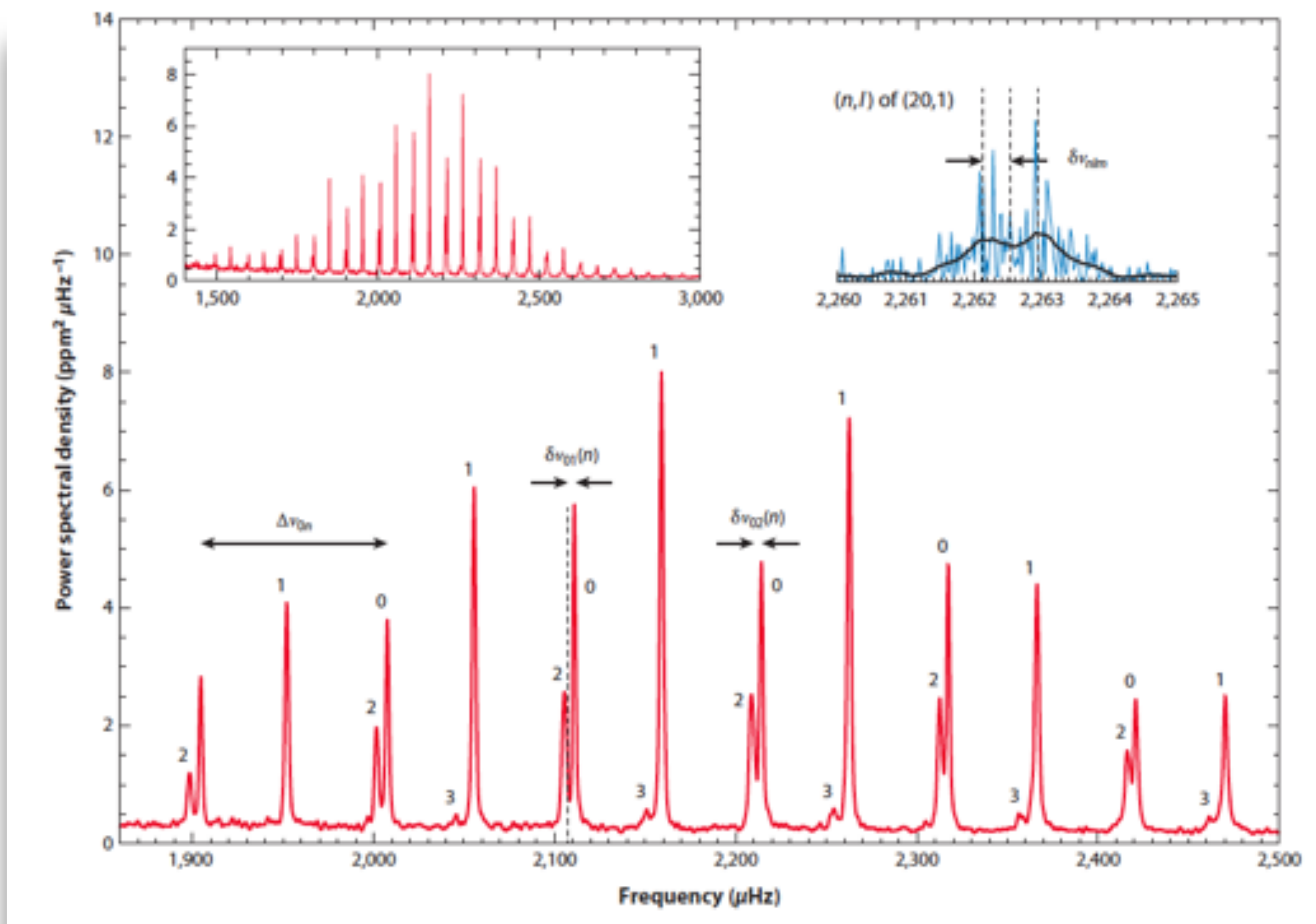




Chaplin & Miglio 2013

SOLAR-LIKE PULSATIONS

non-radial modes



Chaplin & Miglio 2013

acoustic modes:

$$\nu_{n\ell} \approx \Delta\nu_0 \left(n + \frac{\ell}{2} + \epsilon_0\right) + \delta\nu_{n\ell}$$

$$\delta\nu_{n\ell} \propto -\int_0^R \frac{dc}{dr}\frac{dr}{r}$$

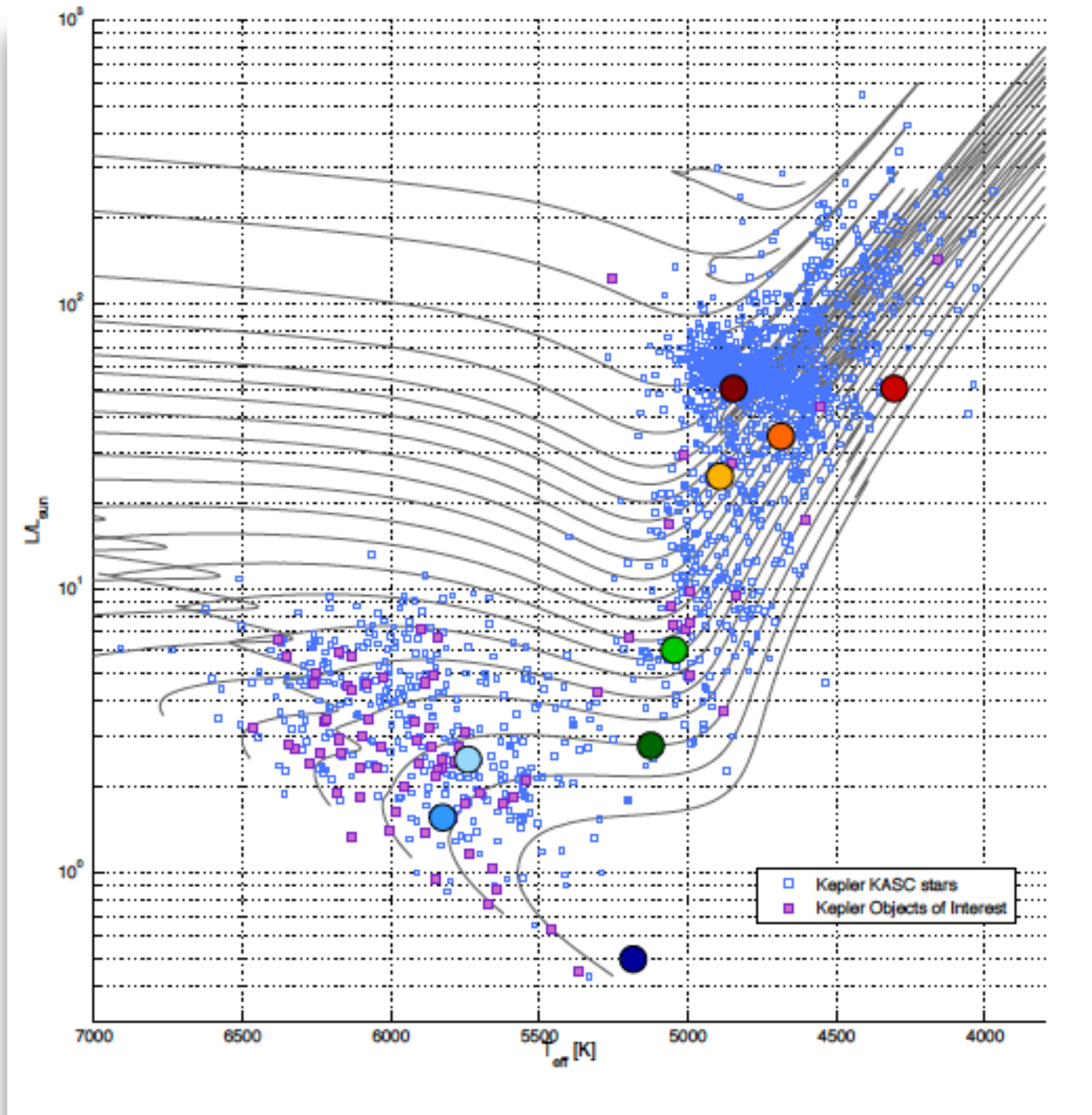
$$\frac{\rho_c}{\langle\rho\rangle}$$

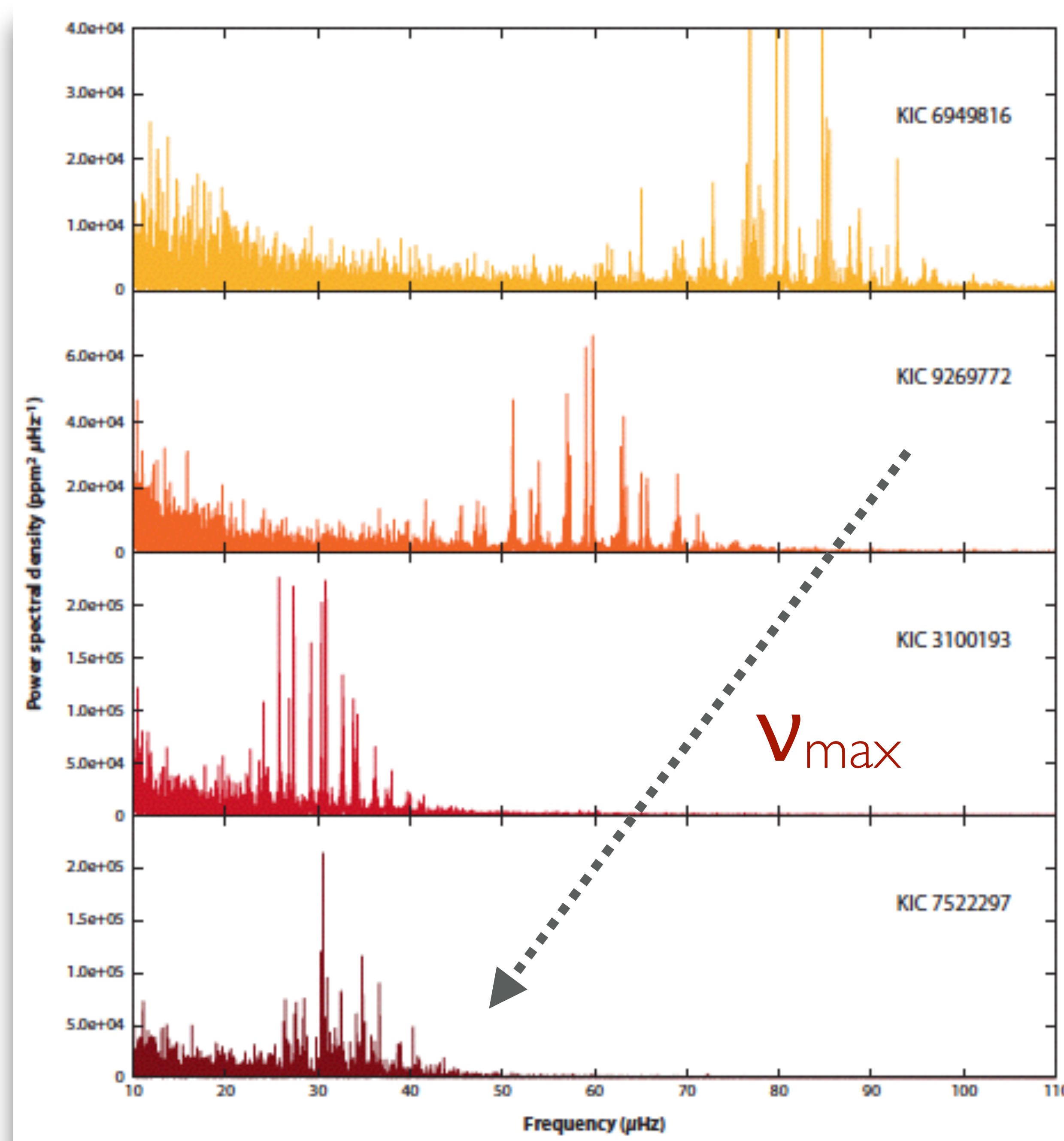
AGE

gravity/mixed modes: $\Delta P_\ell = \frac{2\pi^2}{\sqrt{\ell(\ell+1)}} \left(\int_{r1}^{r2} N \frac{dr}{r}\right)^{-1}$

Tassoul 1980; Gough 1986

EVOLUTION OF GIANT SPECTRUM

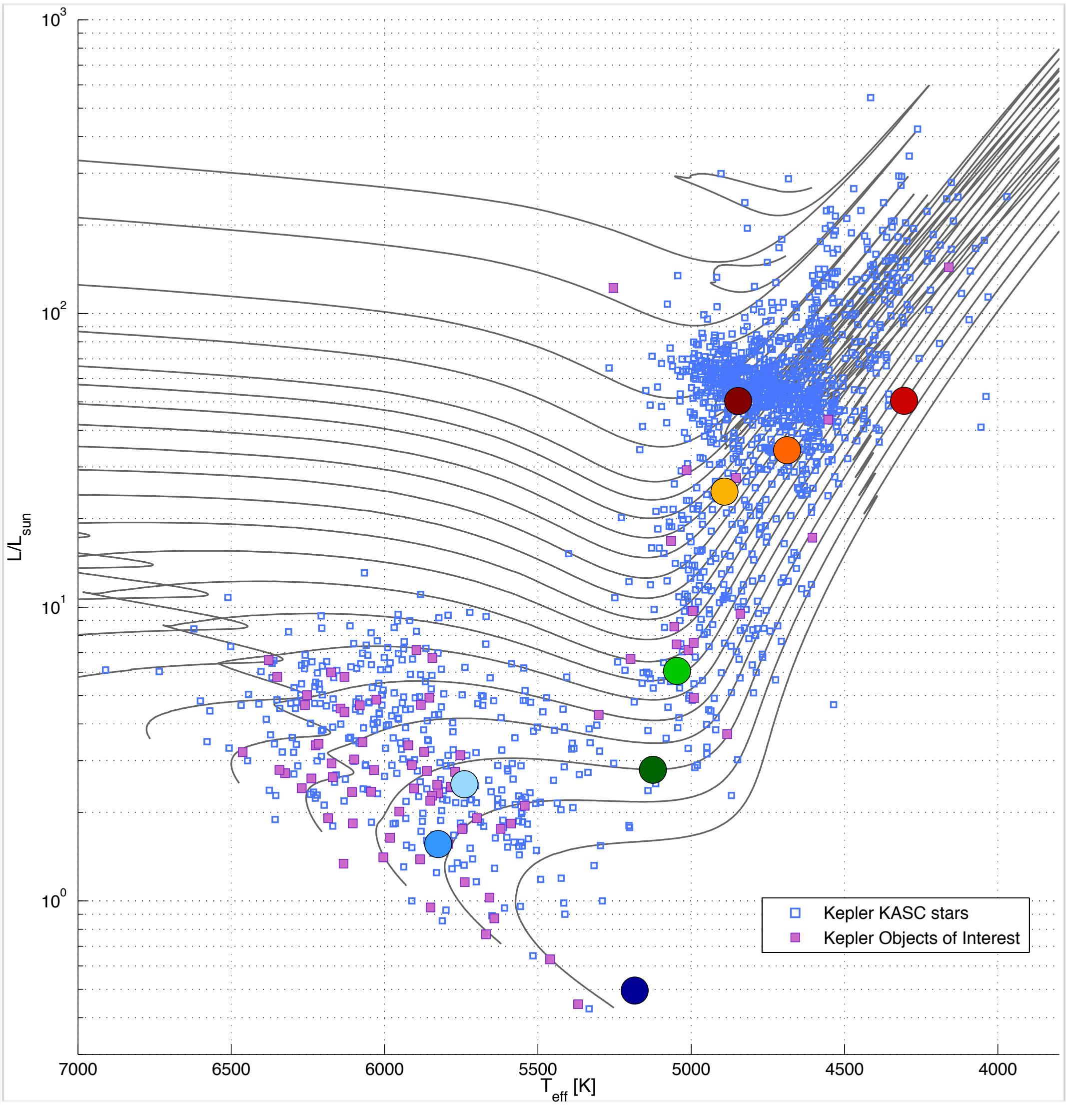




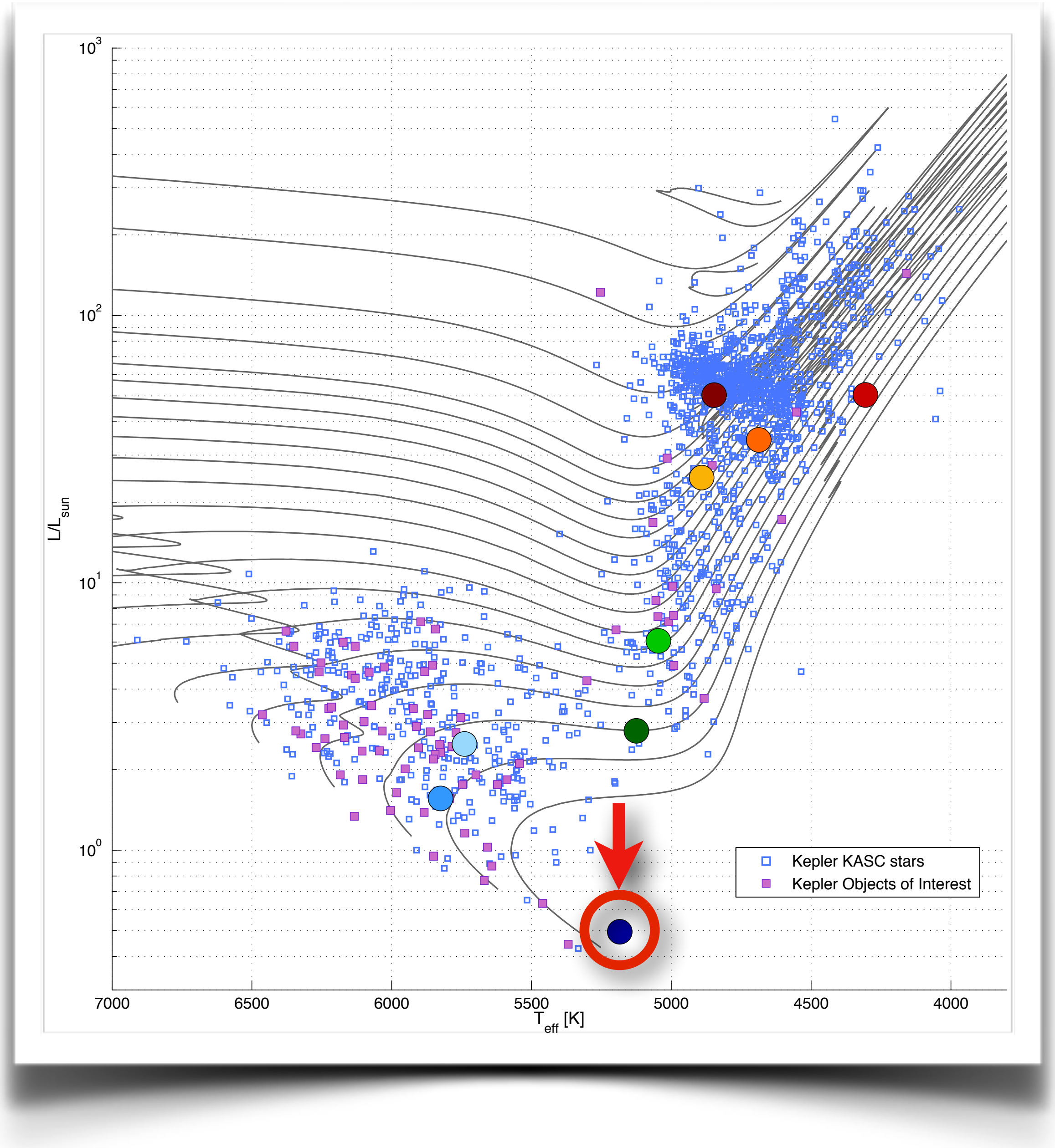
ν_{max} decreases

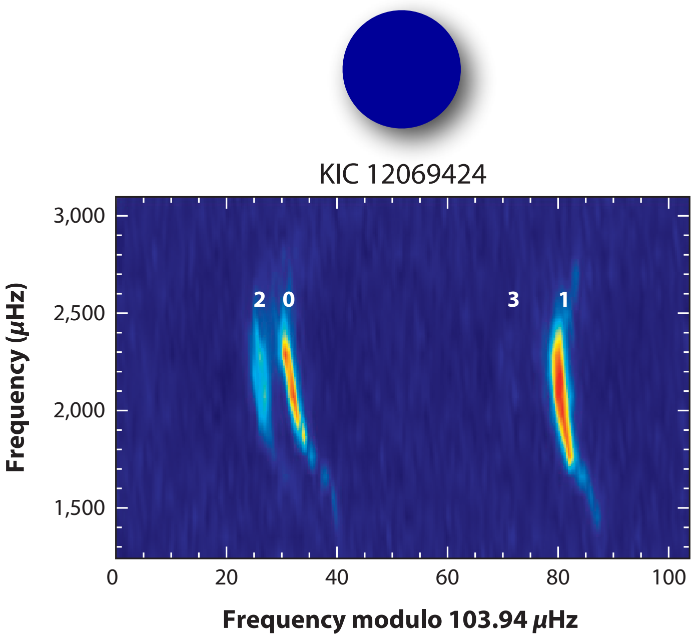
and complexity increases

Chaplin & Miglio 2013

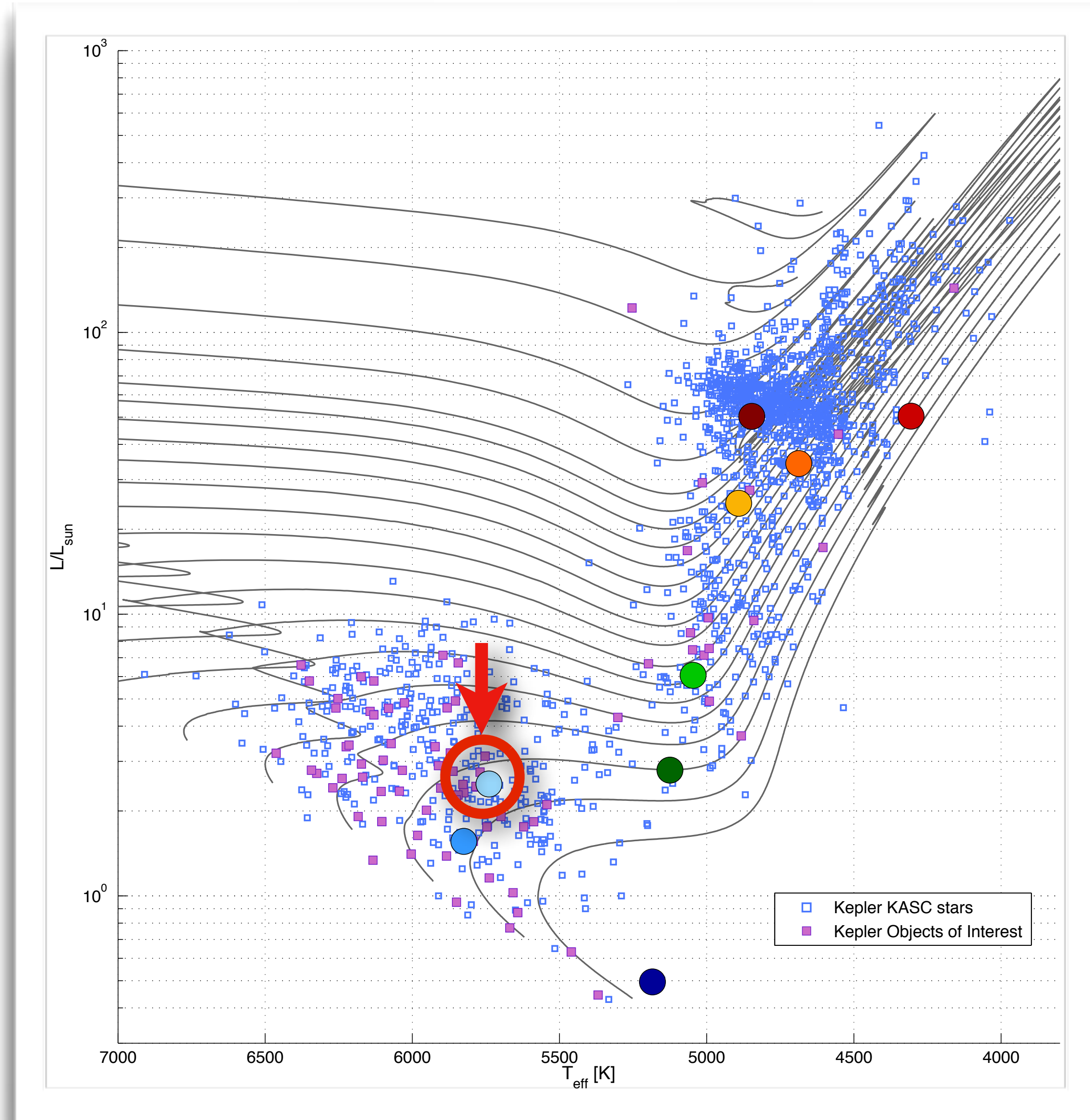


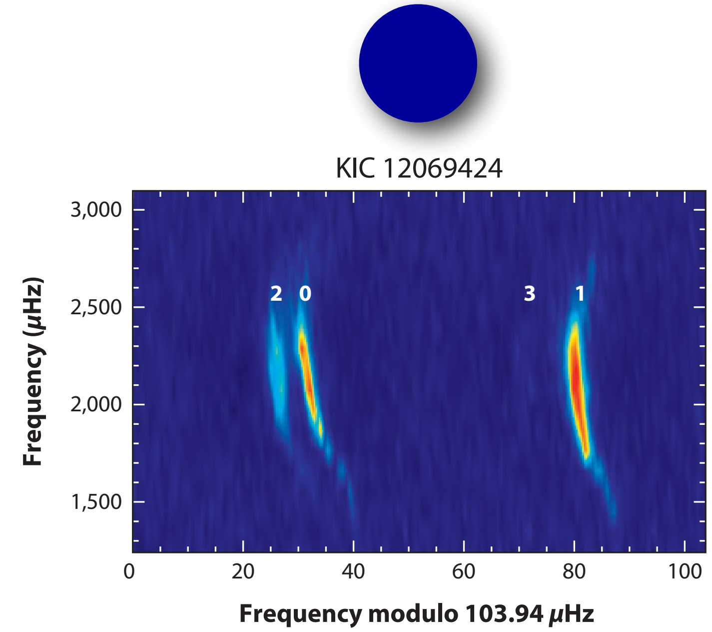
Chaplin & Miglio 2013

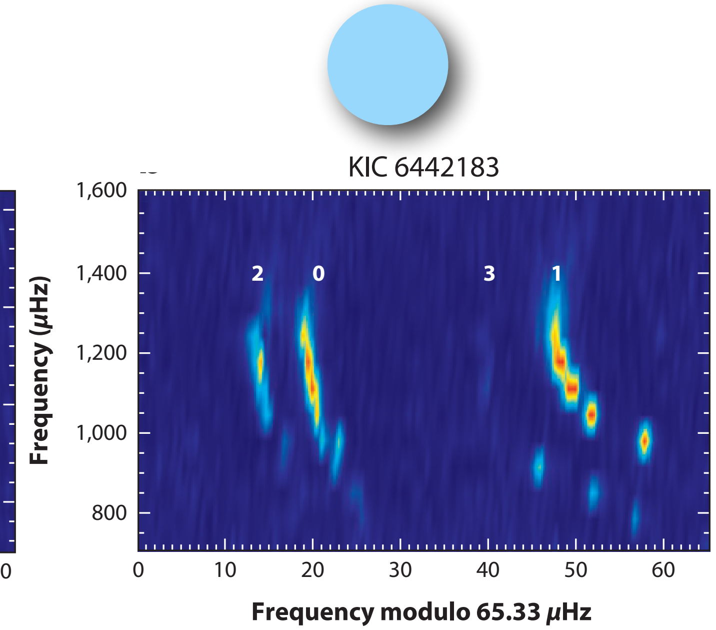




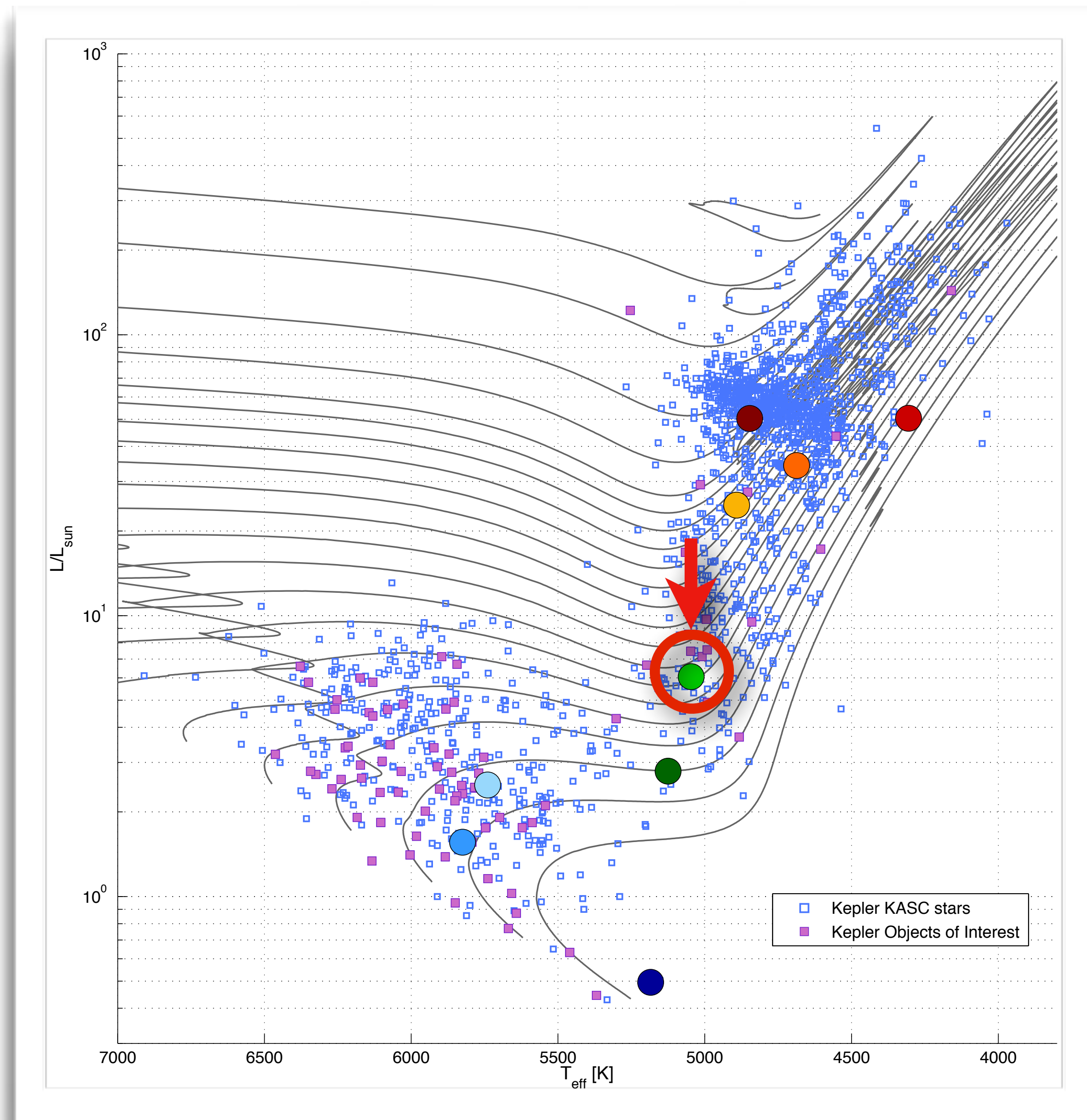
Chaplin & Miglio 2013

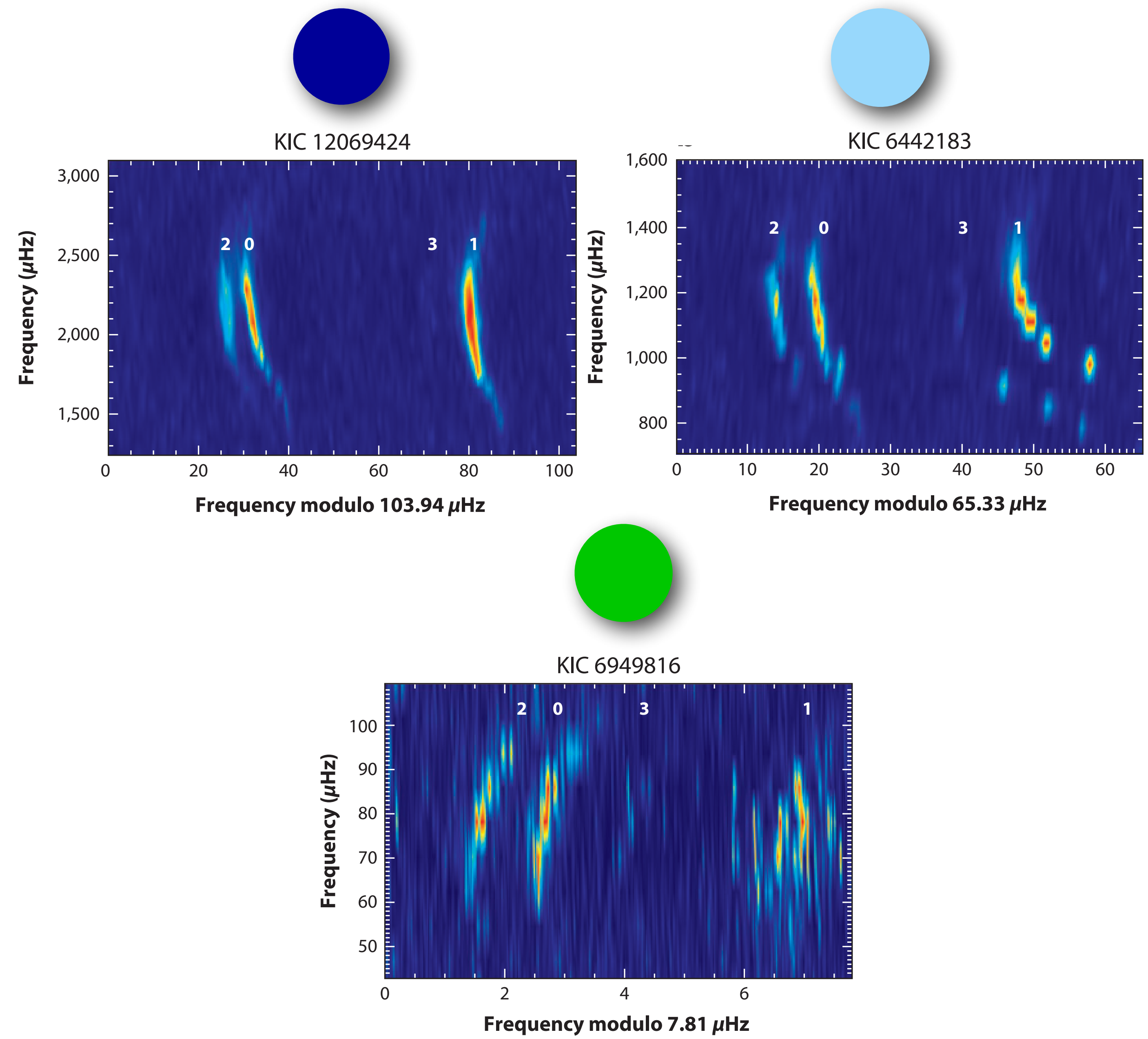






Chaplin & Miglio 2013





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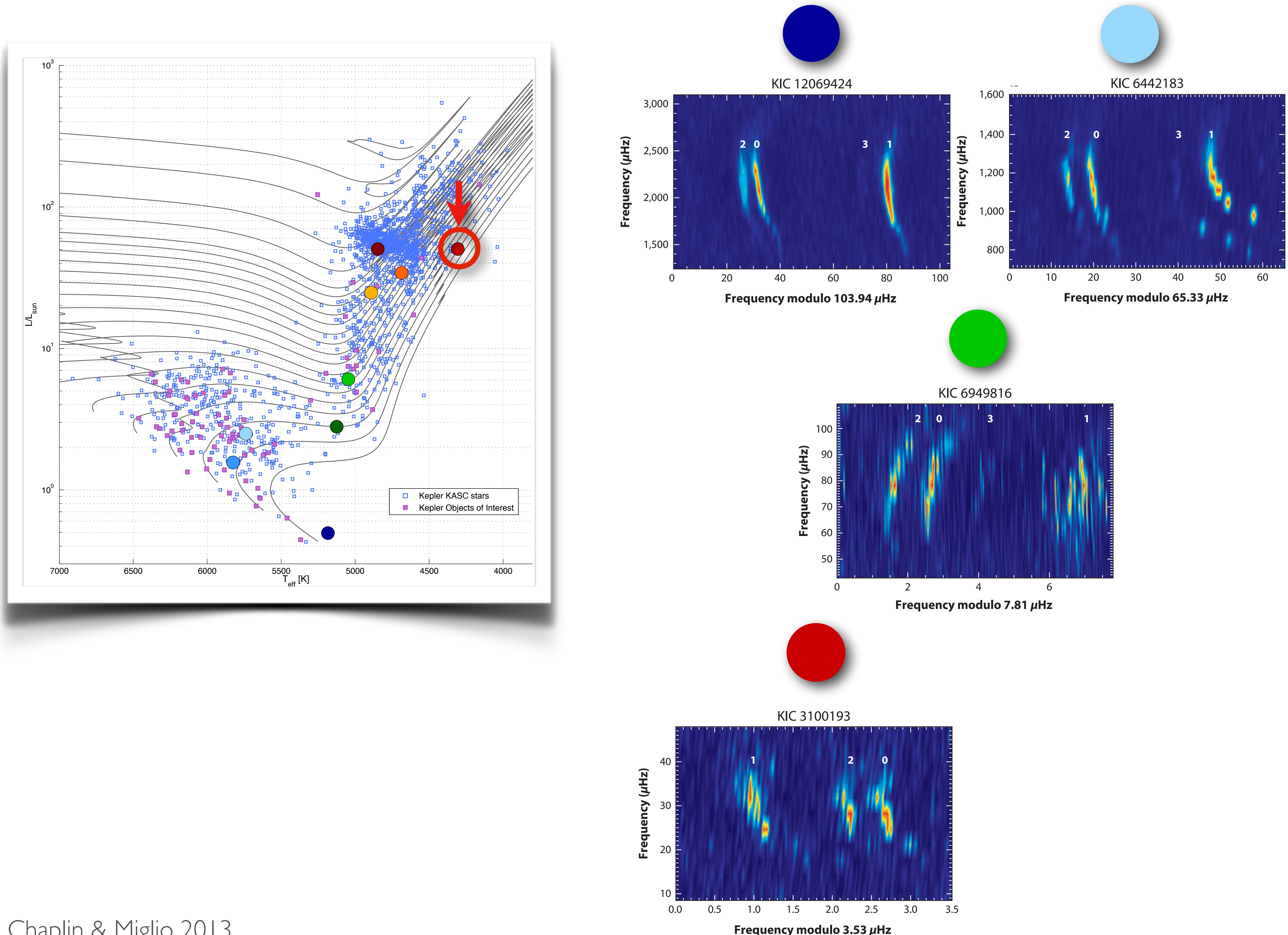

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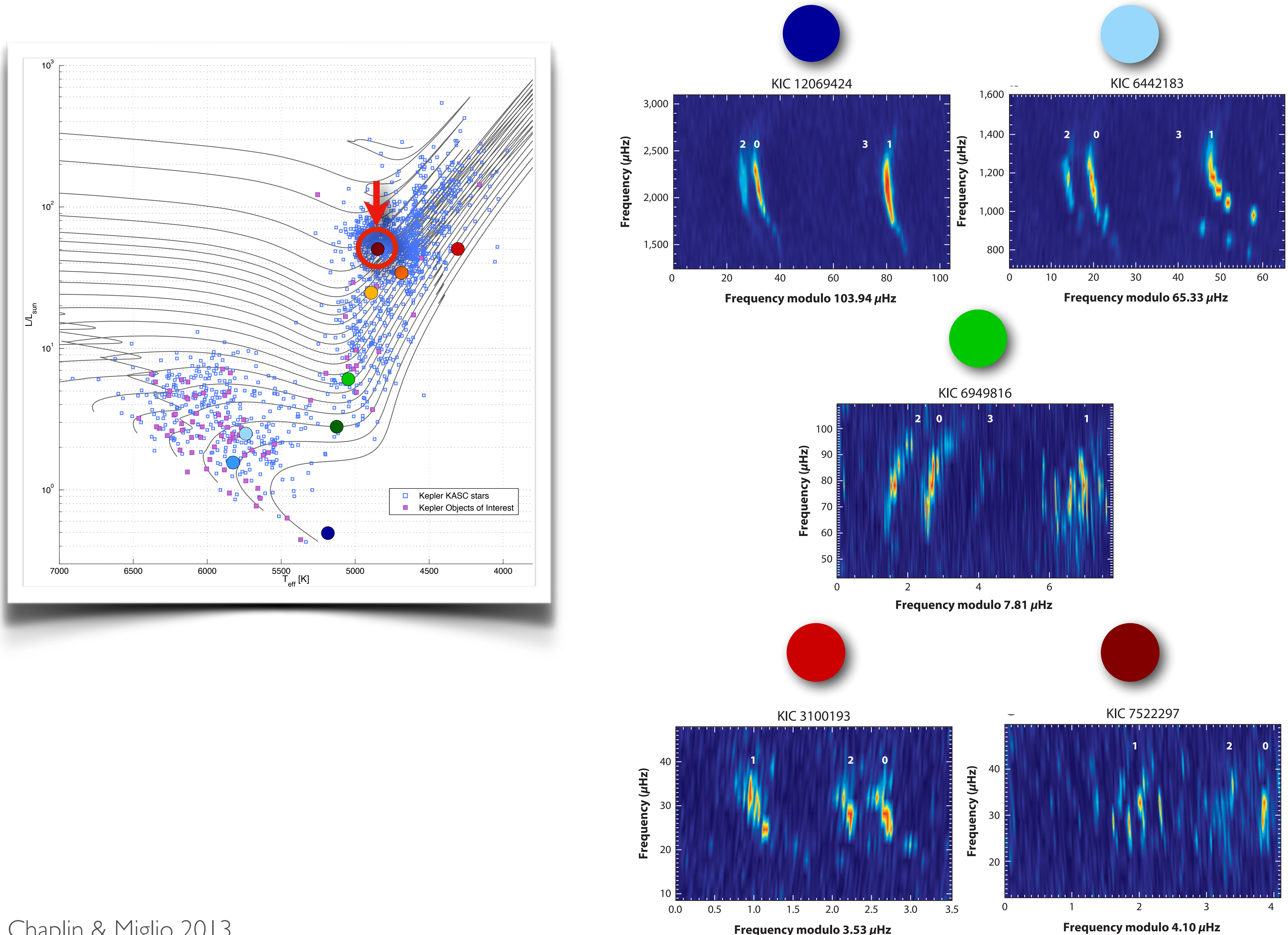

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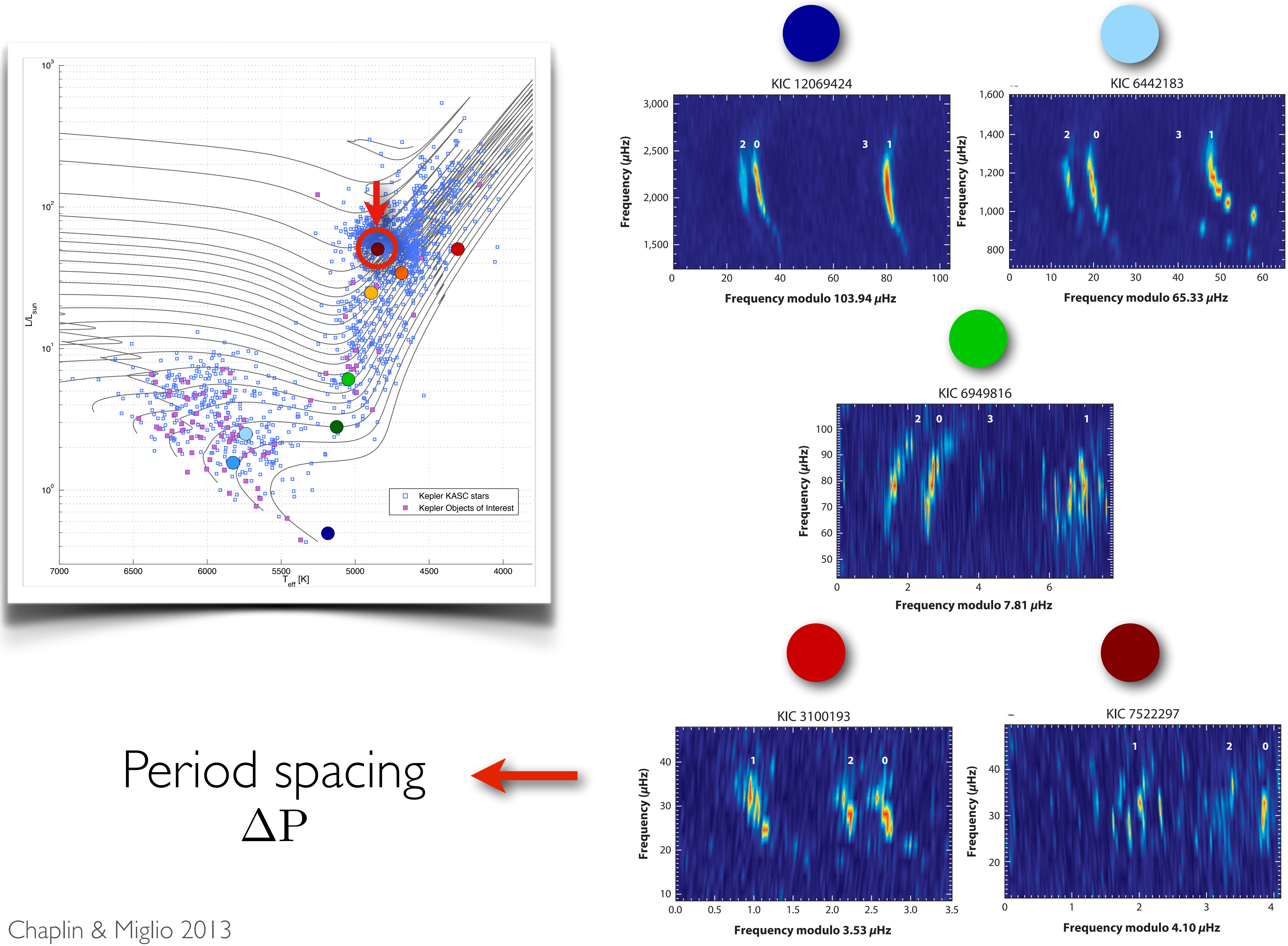


Period spacing
ΔP

Chaplin & Miglio 2013

ENSEMBLE SEISMOLOGY

average seismic parameters:

$$\Delta\nu \simeq \sqrt{\frac{M/\mathrm{M}_\odot}{(R/\mathrm{R}_\odot)^3}}\,\Delta\nu_\odot$$

$$\nu_{\max} \simeq \frac{M/\mathrm{M}_\odot}{(R/\mathrm{R}_\odot)^2\sqrt{T_{\mathrm{eff}}/T_{\mathrm{eff},\odot}}}\,\nu_{\max,\odot}$$

+ T_{eff}

radius and mass estimates:

$$\left(\frac{R}{\mathrm{R}_\odot}\right) = \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)\left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2}\left(\frac{T_{\mathrm{eff}}}{\mathrm{T}_{\mathrm{eff},\odot}}\right)^{0.5}$$

$$\left(\frac{M}{\mathrm{M}_\odot}\right) = \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)^{3}\left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-4}\left(\frac{T_{\mathrm{eff}}}{\mathrm{T}_{\mathrm{eff},\odot}}\right)^{1.5}$$

Stello et al. 2009, Miglio et al. 2009, 13, Mosser et al. 2010,11, Kallinger et al. 2010, Hekker et al. 2010, Chaplin et al. 2011 …

ENSEMBLE ASTEROSEISMOLOGY

- Global parameters (M, R): forward or based in grid of models

  Mosser et al. 2010, Kallinger et al 2010, Hekker et el. 10,11, Gai et al. 2011, Basu et al 2011, Chaplin et al 2014 …

- Determination of log g → spectroscopy σ_{logg}=0.04 dex

  Gai et al. 2011, Miglio & Morel 2012, Creevey et al 2013, Morel et al. 2014

- Study of stellar populations: simple (stellar cluster) and multiple (Milky Way)

  Miglio et al 2009, 13, Hekker et al. 2009, Mosser et al 2010, 11, Chaplin et al 2011, Corsaro et al. 2012, Basu et al. 2011, Stello 2010, 2011

- Stellar cluster membership

  Stello et al. 2010, 2011

- Mass loss in the RGB, from clusters

  Miglio et al. 2012

- Distance indicators

  Miglio et al. 2013

- M → age (but model dependent)

AGE FROM STELLAR MASS

- Mass → age

GIANTS:

$\text{Age(RGB)} \sim \tau_H$

$\tau_H \sim M/L$

$L \sim M^{\eta} \quad \eta \sim 3.5$

↓

$\text{Age(RGB)} \sim M^{-2.5}$

Miglio 2012

AGE FROM STELLAR MASS

- Mass ➡ age

GIANTS:

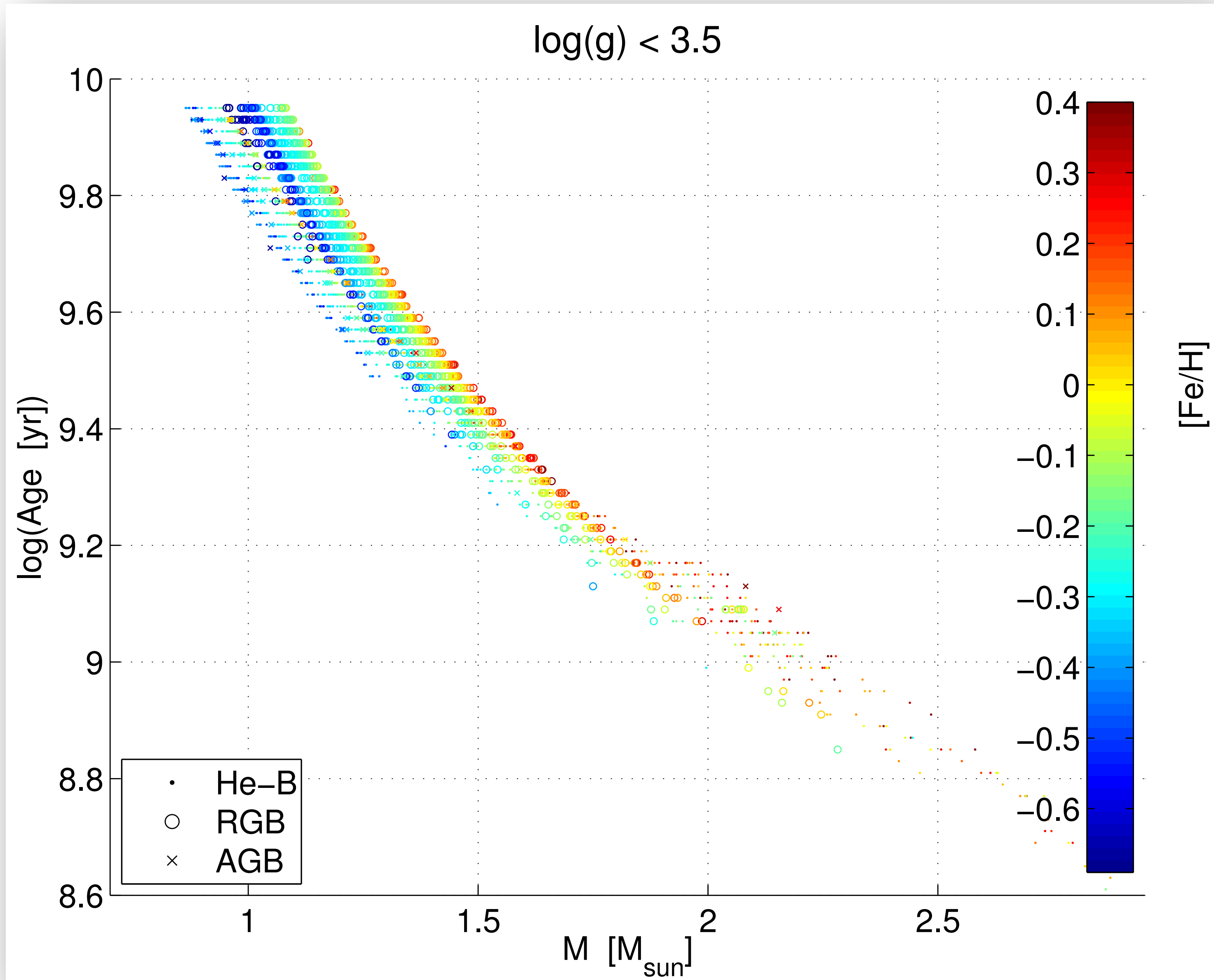
Age(RGB)~ τ_H

τ_H~M/L

L~M^{η} η~3.5

⬇

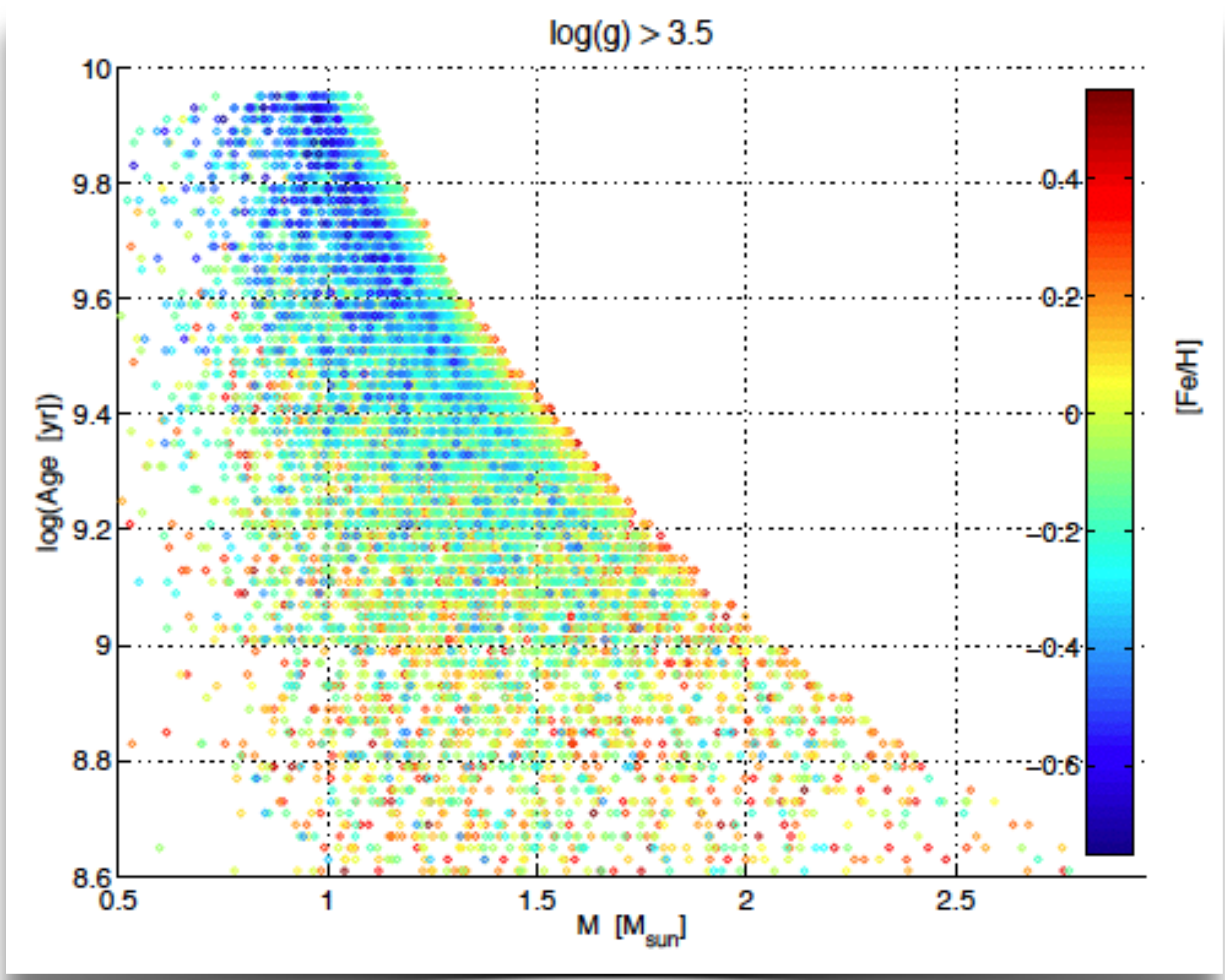
Age(RGB)~ $M^{-2.5}$



M+[Fe/H]: "chronometer" for evolved stars

Miglio 2012

AGE FROM STELLAR MASS



Main sequence evolutionary phase

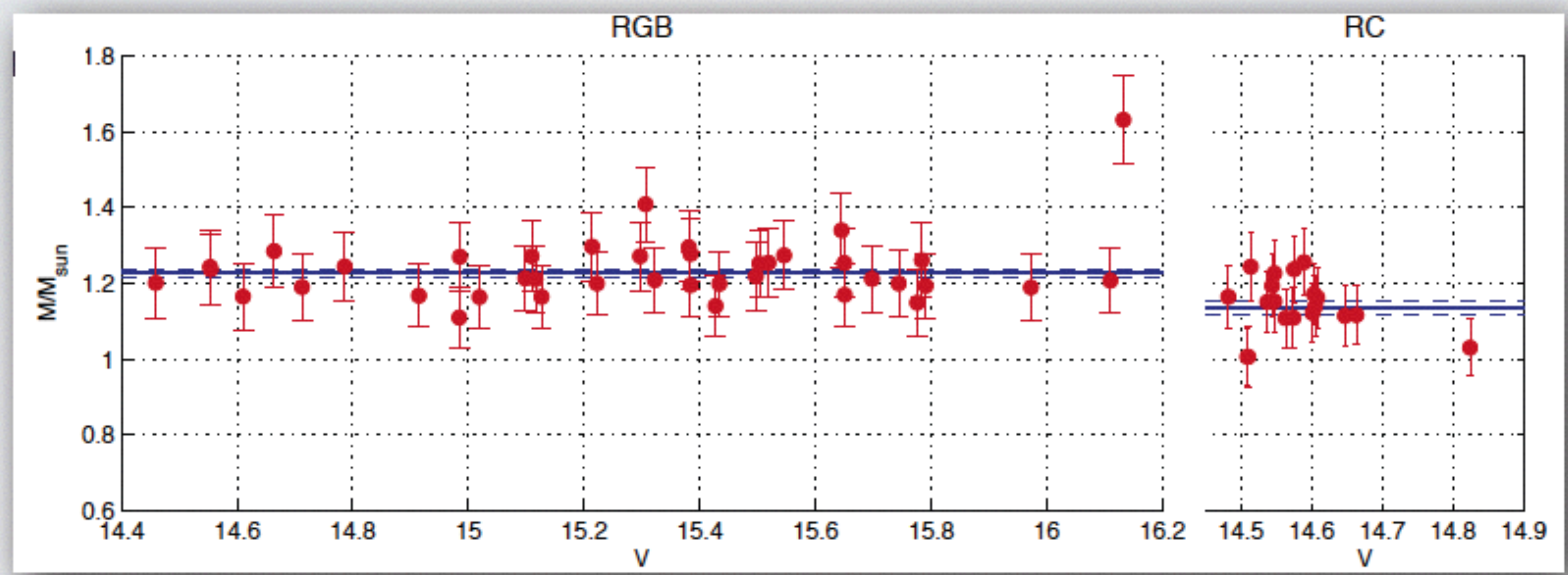
Miglio 2012

Constraining RGB mass loss

RGB mass loss rate: $\frac{\mathrm{d}M}{\mathrm{d}t} = 1.27\,10^{-5}\,\eta\,M^{-1}L^{1.5}\,T_{\rm eff}^{-2}$ Reimers' "law"

Reimers 1975

Mass(RGB) vs Mass(RC)



Miglio et al. 2012

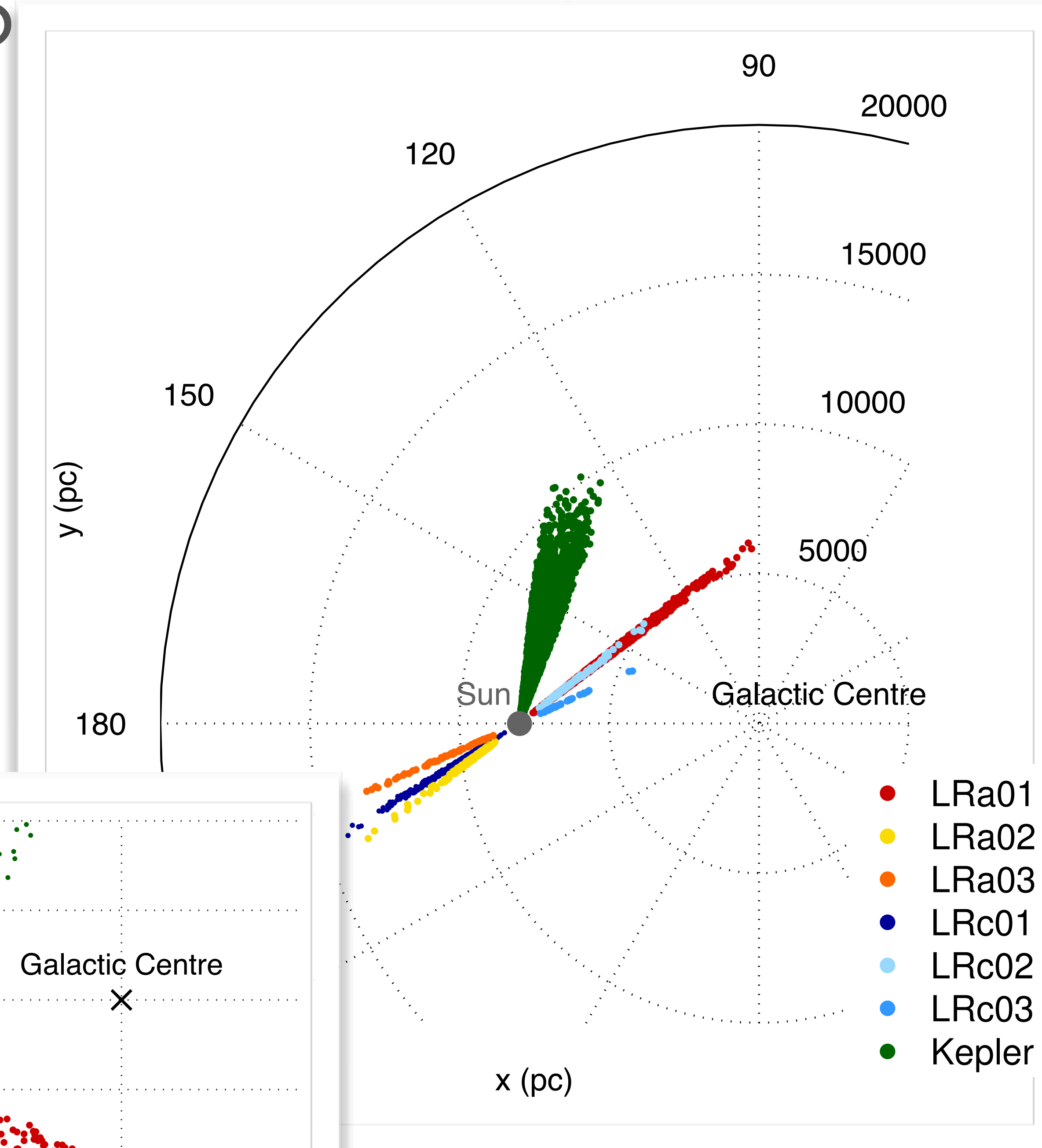
quantitative estimate of integrated RGB mass loss

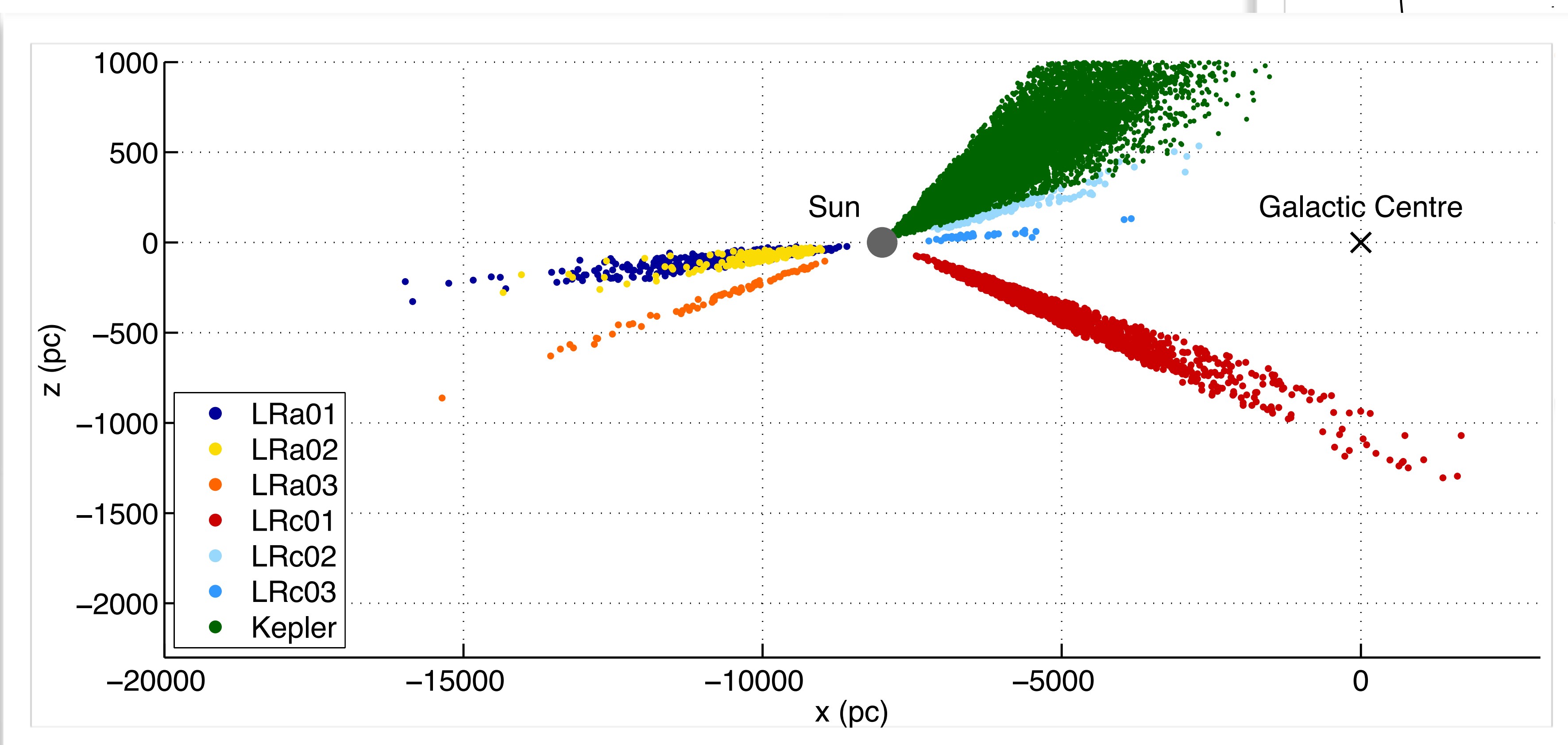
STELLAR POPULATIONS

CoRoT LRs: ~ 3000 stars (analysed)
Mosser et al. 2010

Kepler data: ~ 14000 stars
Hekker et al. 2011, Stello et al. 2013

CoRoT LRc01+ LRa01 : ~ 2000
stars with average global parameters





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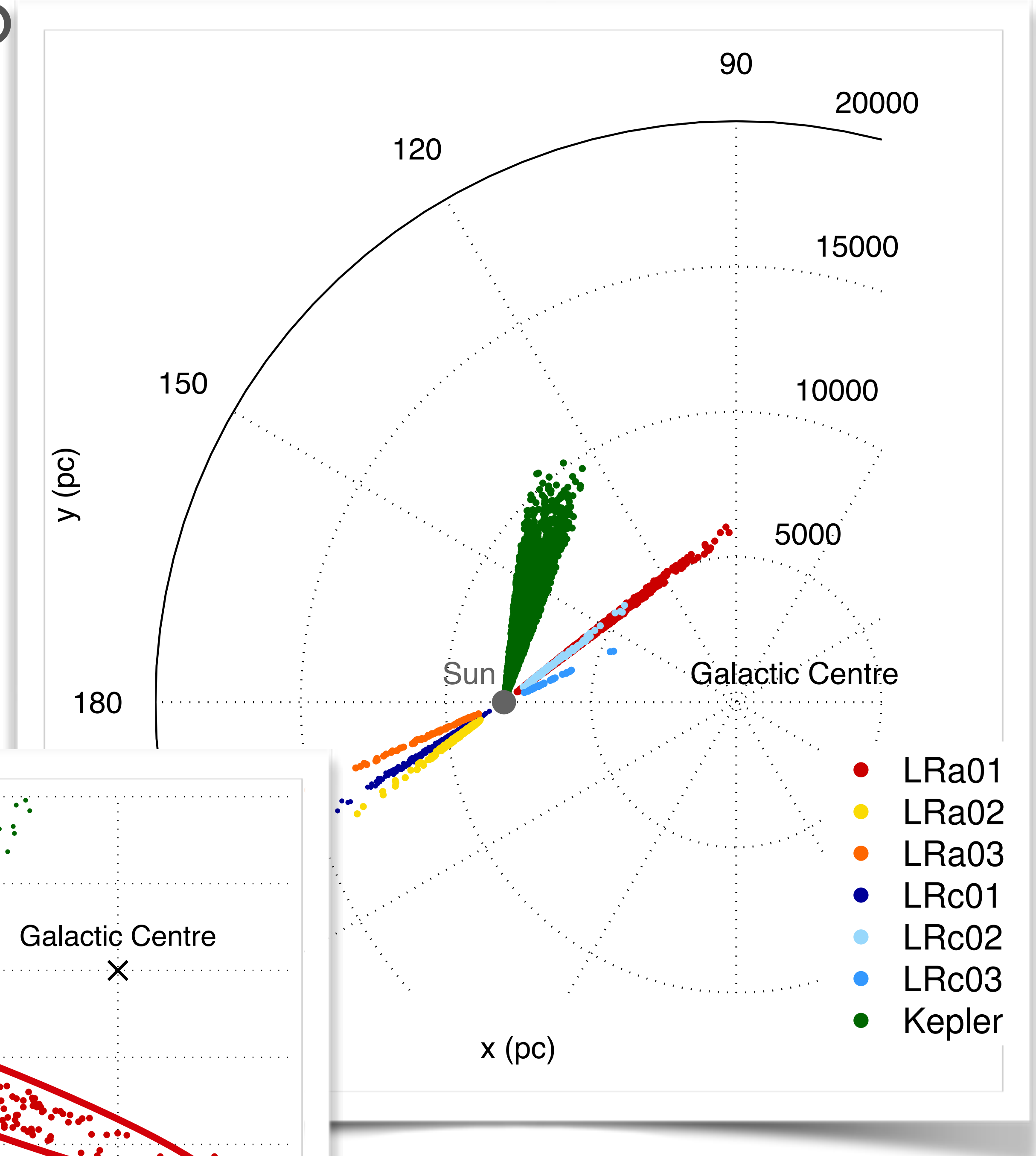
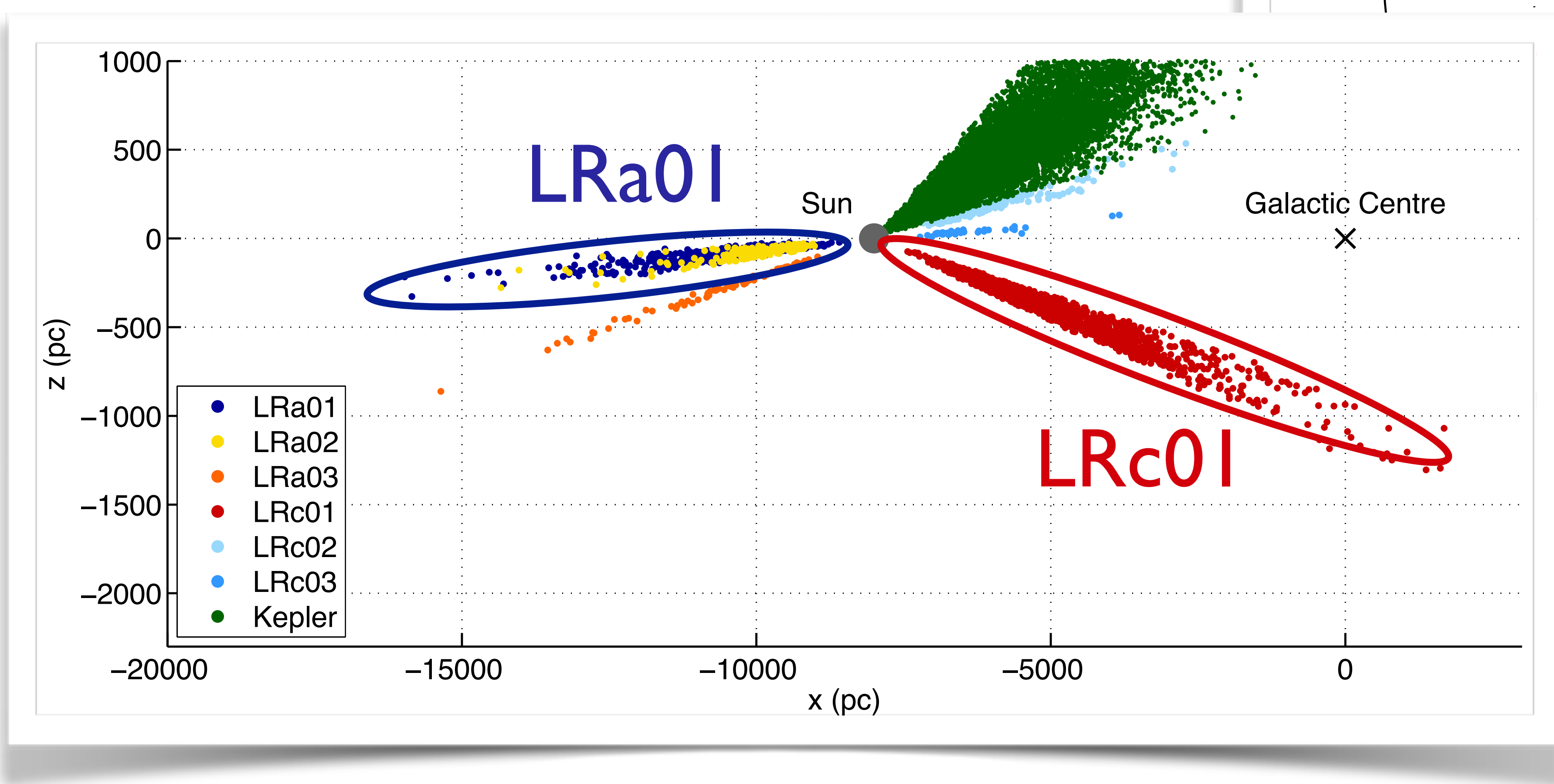
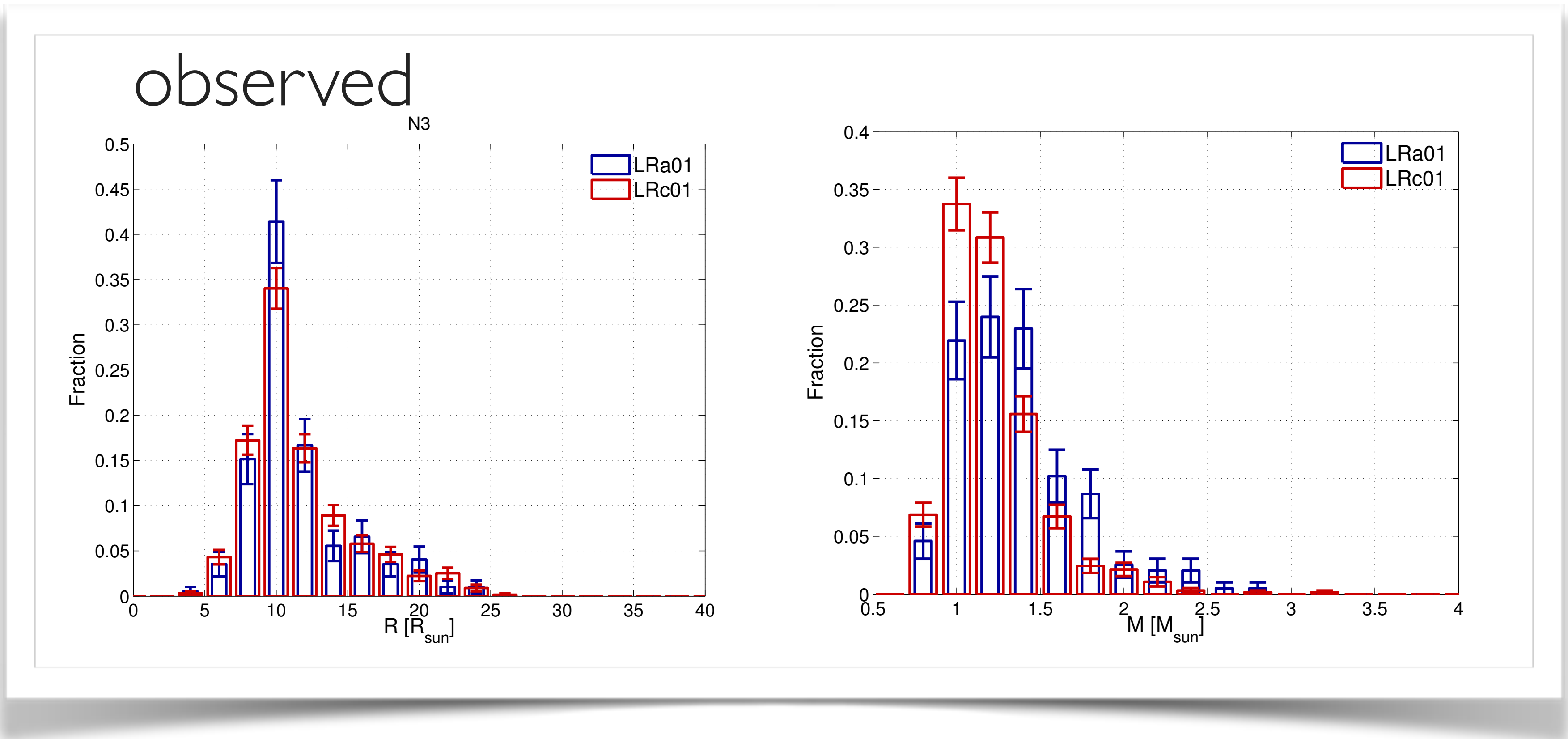




Differential population studies



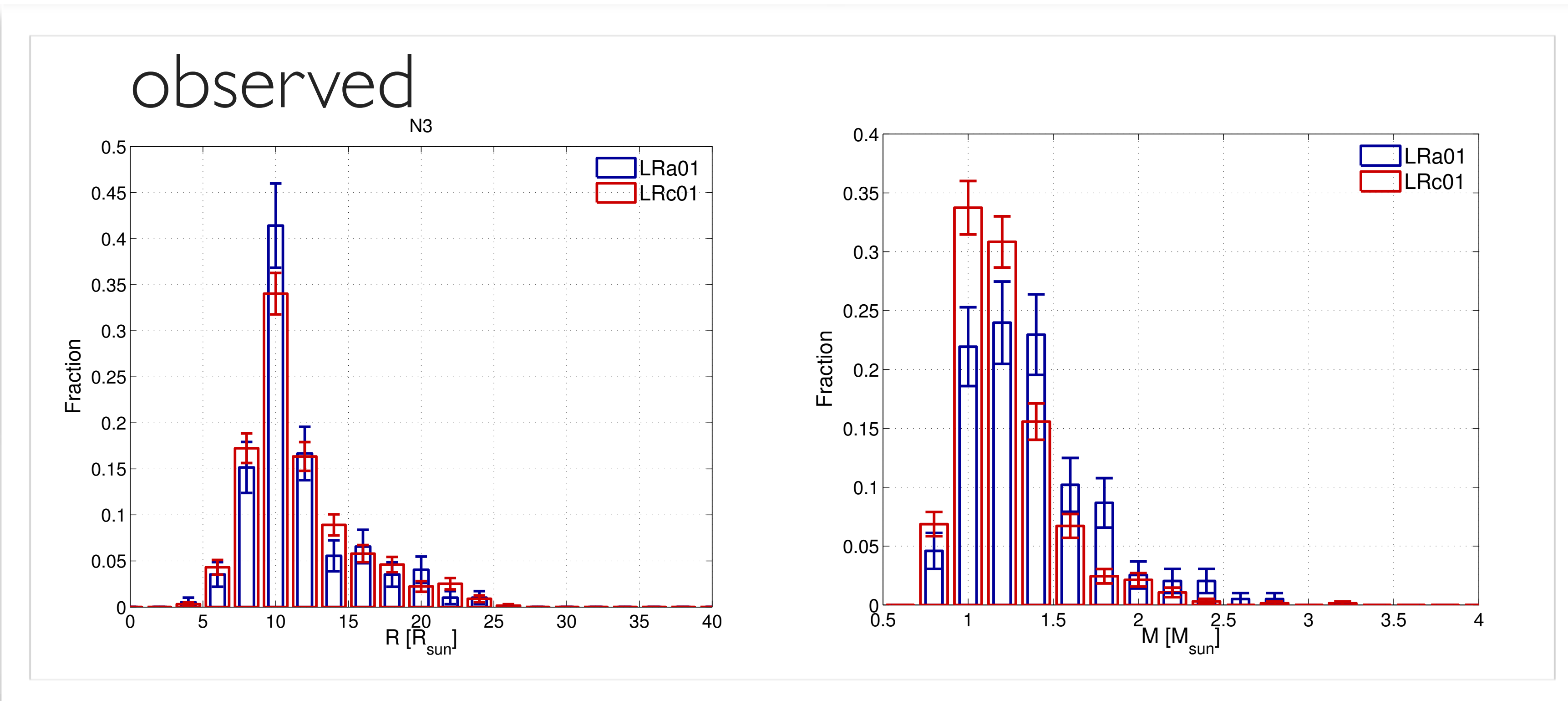
Differential distribution of M in LRc01 et LRa01

LRc01 sample older than LRa01

$\bar{z}_{LRa01} < \bar{z}_{LRc01}$

Miglio et al. 2013

Differential population studies



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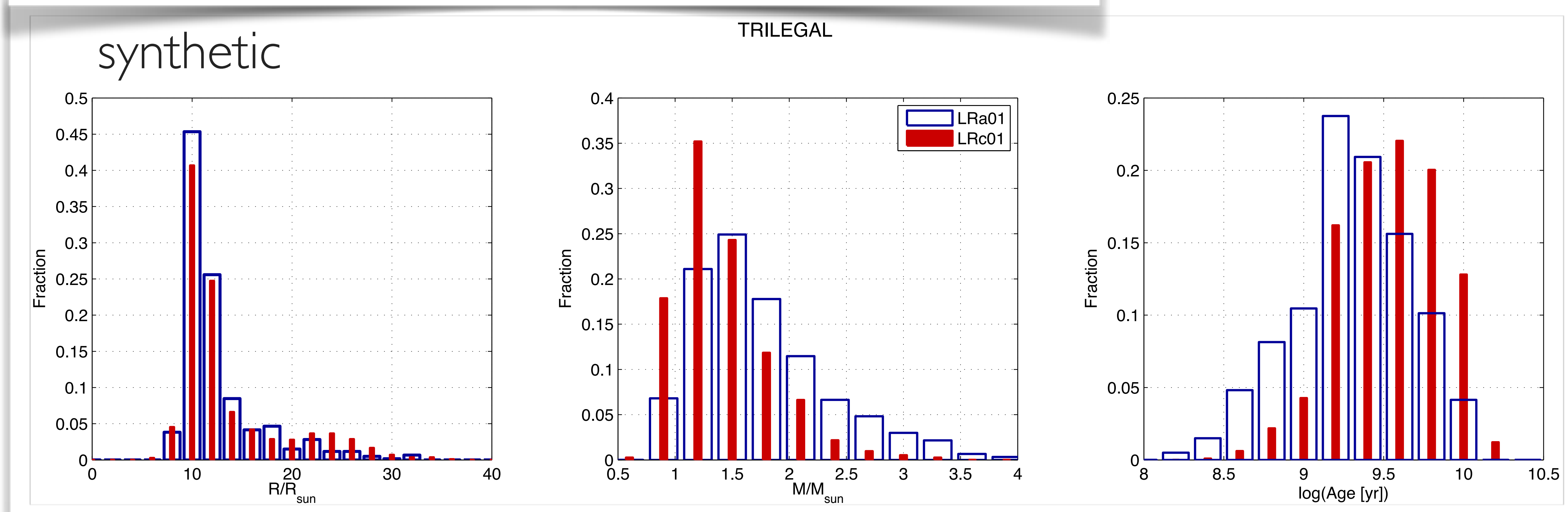


Miglio et al. 2013

Challenges

Test seismic scaling relations:

$$\left(\frac{R}{\mathrm{R}_\odot}\right) = \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)\left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2}\left(\frac{T_{\mathrm{eff}}}{\mathrm{T}_{\mathrm{eff},\odot}}\right)^{0.5}$$

$$\left(\frac{M}{\mathrm{M}_\odot}\right) = \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)^{3}\left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-4}\left(\frac{T_{\mathrm{eff}}}{\mathrm{T}_{\mathrm{eff},\odot}}\right)^{1.5}$$

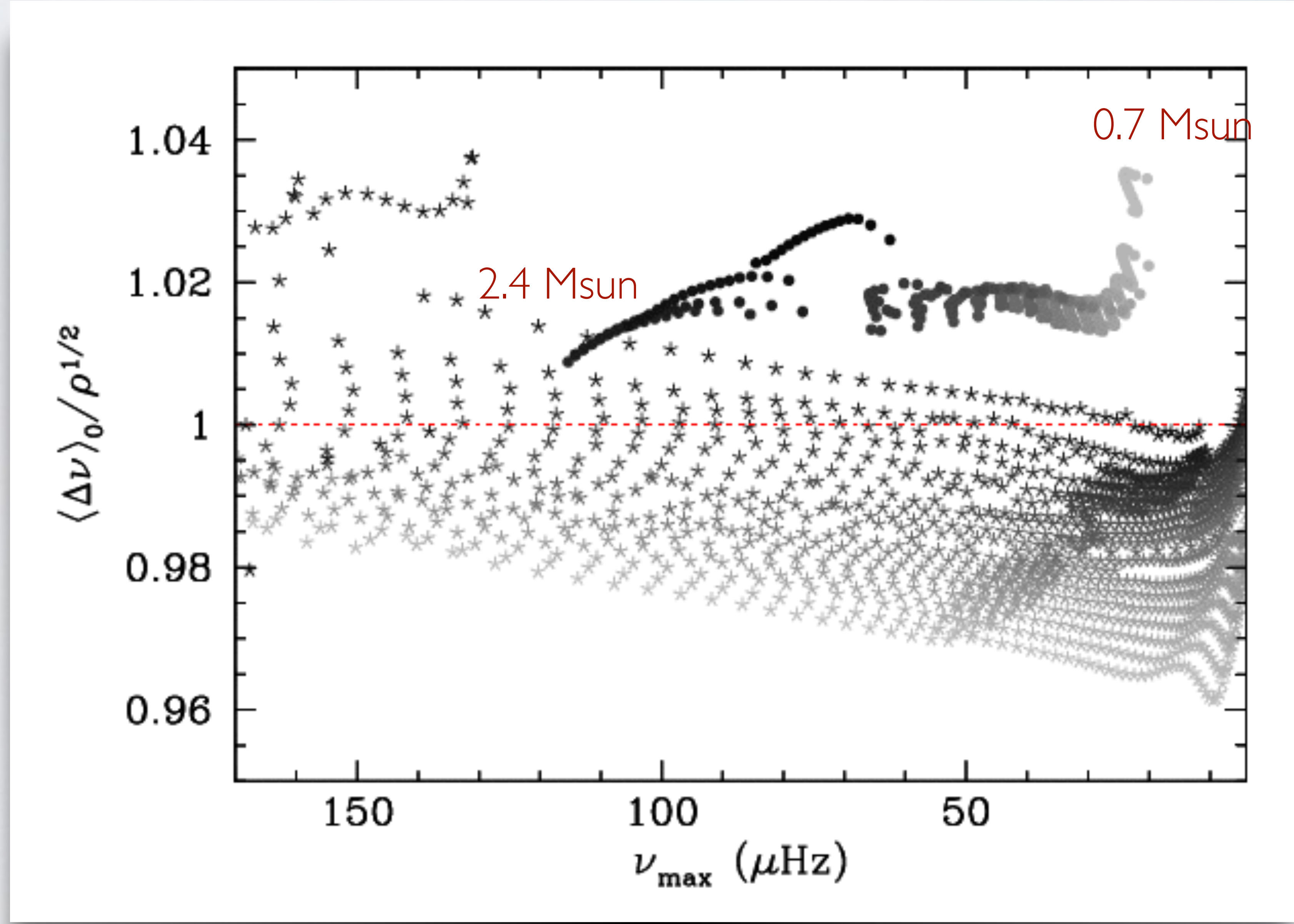
vs

models ($\Delta\nu$) and/or independent measurements
of R and M

TESTING SCALING RELATIONS

from models

Depends on:
evolutionary state
stellar mass



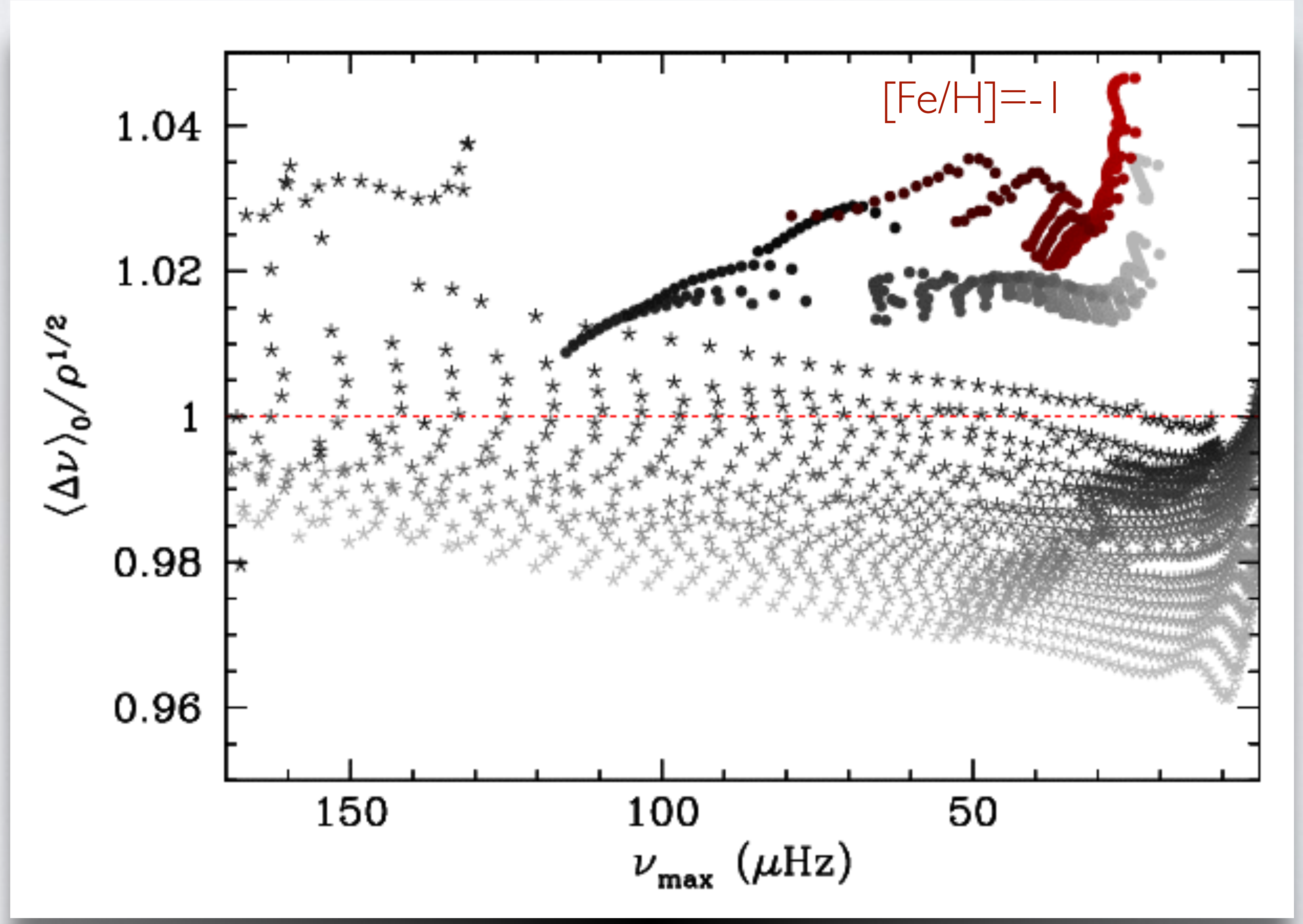
see also White et al. 2011

TESTING SCALING RELATIONS

from models

Depends on:
evolutionary state
stellar mass

and on
chemical composition

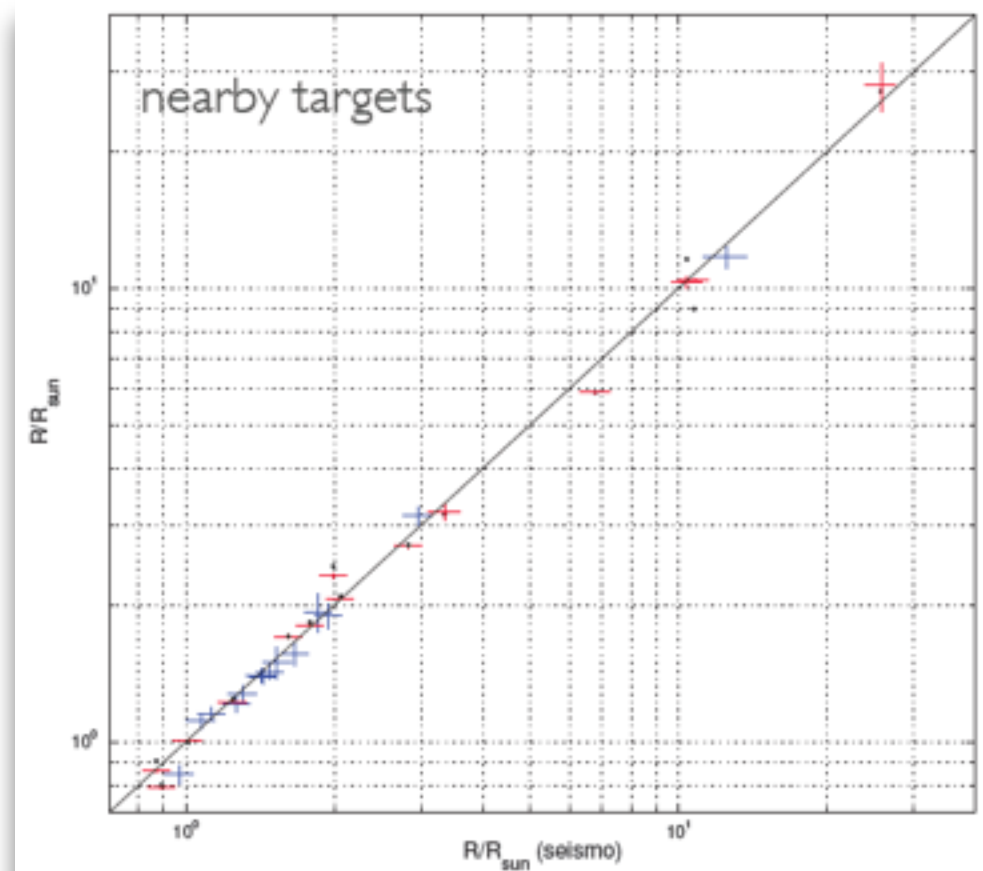


TESTING SCALING RELATIONS

empirical tests of scaling relations

e.g.

- a few nearby/CoRoT dwarfs and giants
  Bruntt et al. 2011, Miglio 2011, Bedding 2011
- interferometry
  Huber et al. 2012
- *Kepler* dwarfs+ Hipp parallaxes
  Silva Aguirre et al. 2012
- NGC6791: R and M
  Miglio et al. 2012, Brogaard et al. 2012, Sandquist et al. 2013
- Eclipsing binaries



~ 4% for Radius

~10% for Mass

Challenges

Age estimate: inherently model dependent

⬇

need to test stellar models!

can seismology help?

- evolutionary state
- near-core mixing
- RGB mass loss
- ...

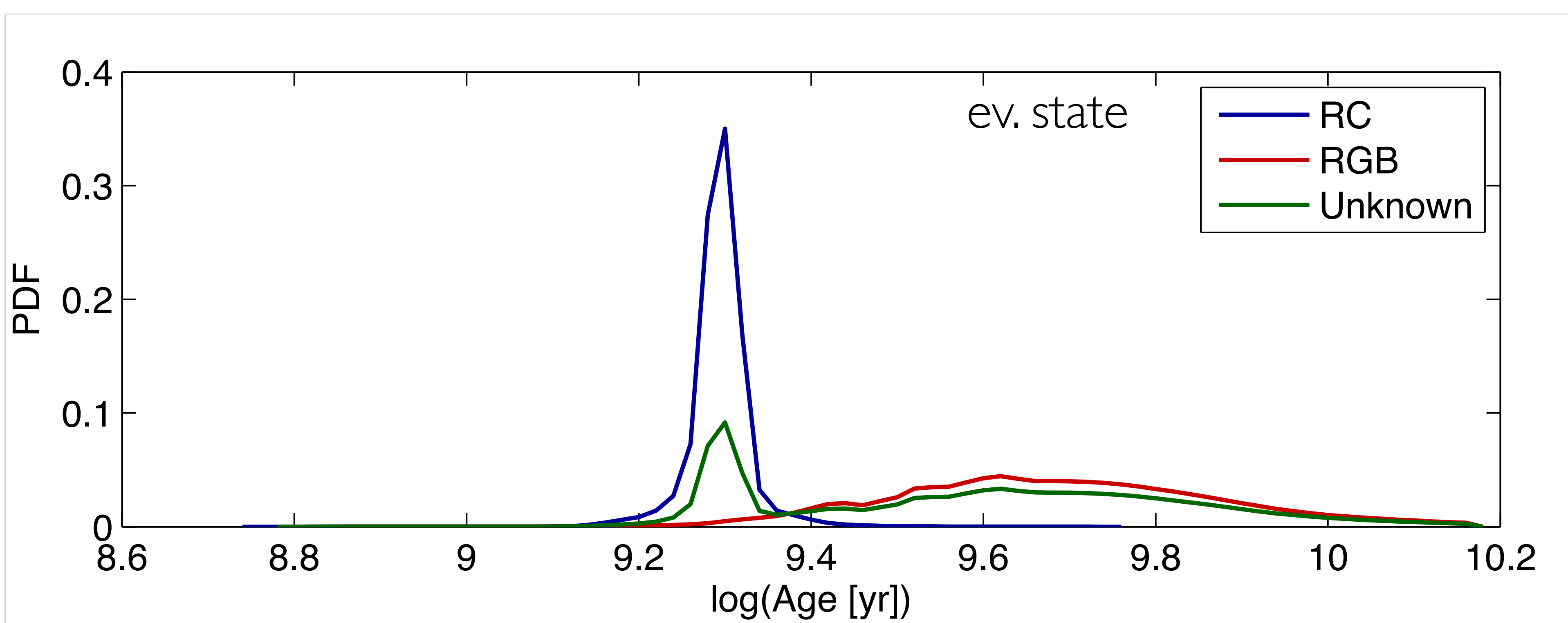
Period spacing ➡ RGB vs RC

why is it relevant to determine ev. state of a ~10 R_{sun} giant ?

constraints: **Δν**, **ν**$_{max}$, [Fe/H], T_{eff}, ev. state

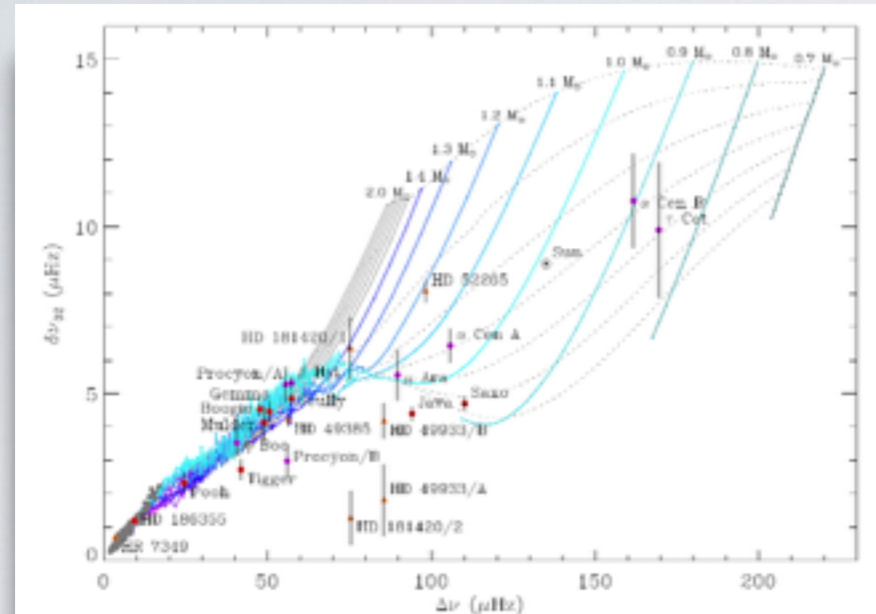
⬇

age estimates using PARAM (as in Da Silva et al. 2006, Nordstrom et al. 2004)



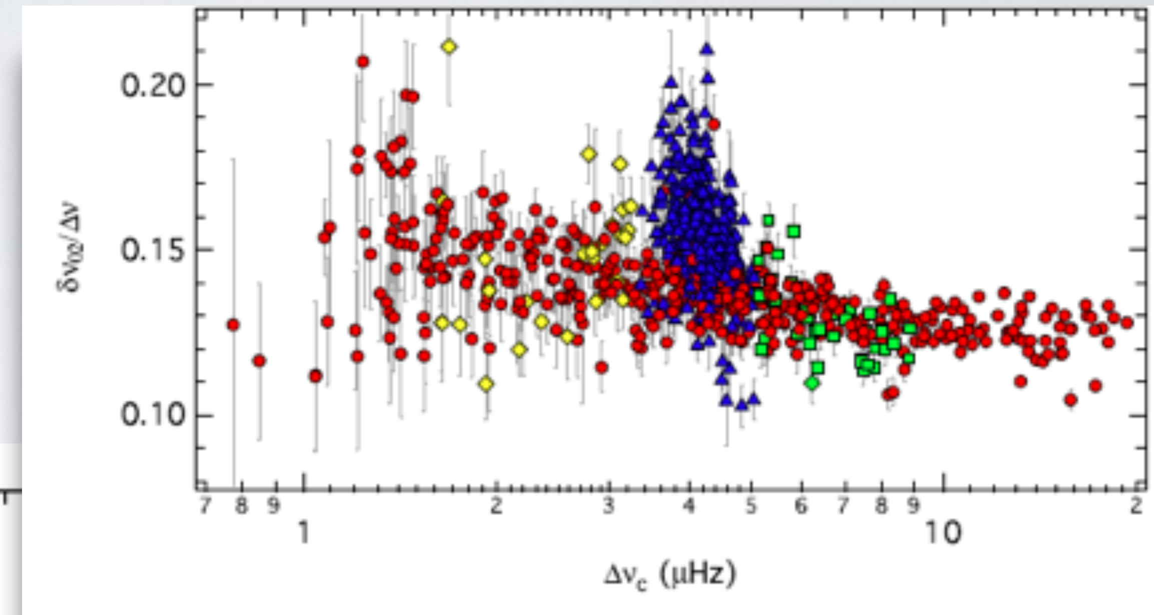
ENSEMBLE ASTEROSEISMOLOGY

non-radial modes

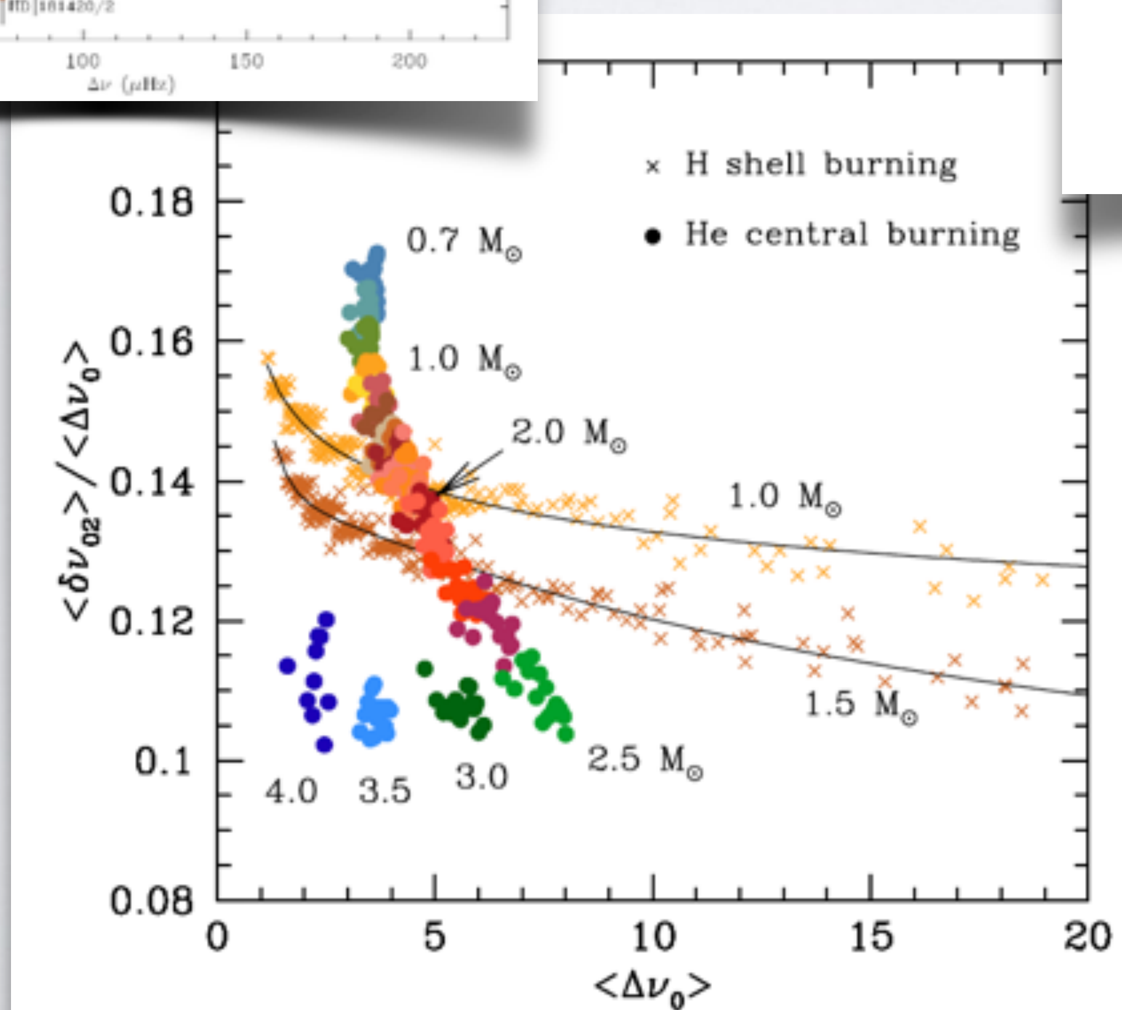


White et al. 2011

600 d with Kepler



Kallinger et al. 2012



Montalban et al. 2012

$$\delta\nu_{n\ell} \propto -\int_0^R \frac{dc}{dr}\frac{dr}{r}$$

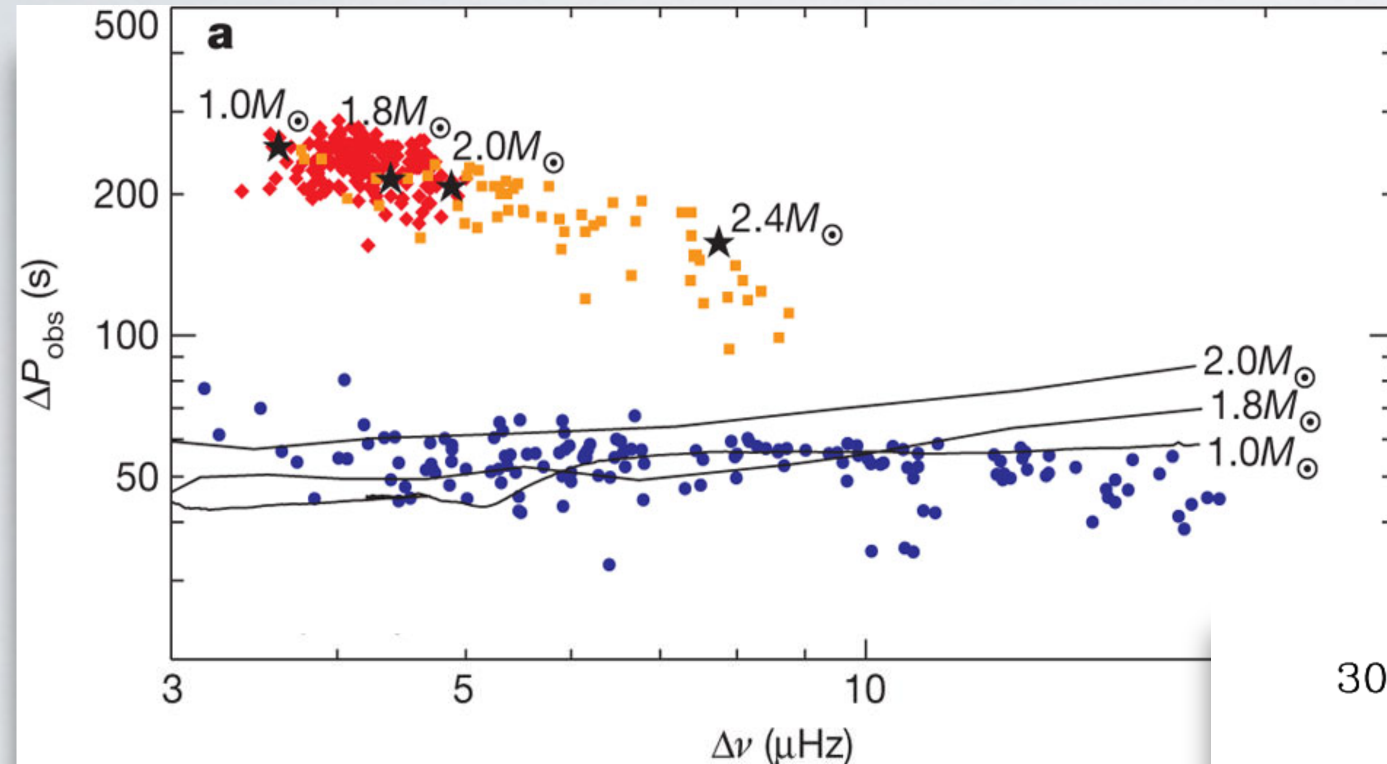
Evolutionary state

See also poter by **Rasmus Handberg**

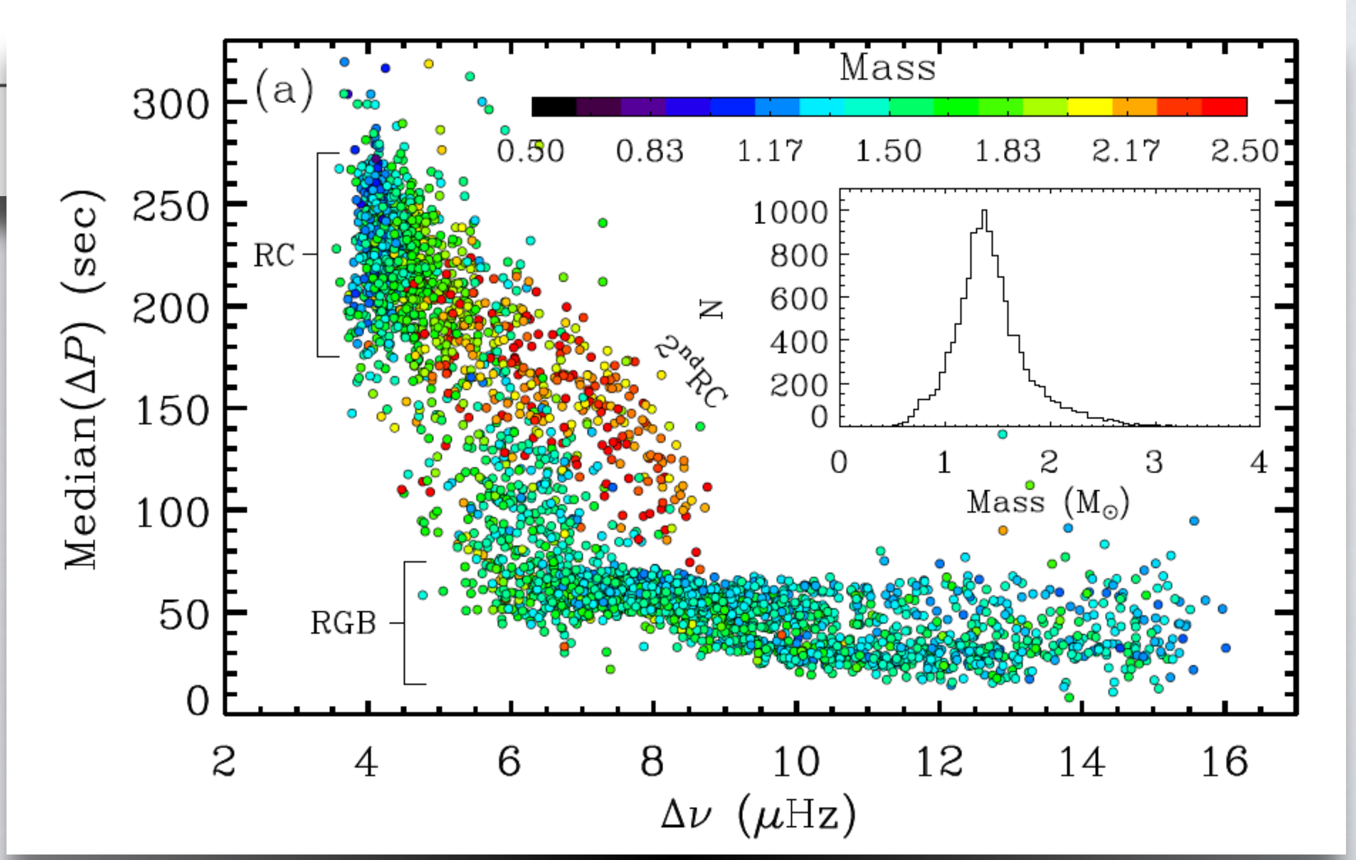
ENSEMBLE ASTEROSEISMOLOGY

non-radial mixed modes

Evolutionary state from period spacing of dipole modes



Bedding et al. 2011



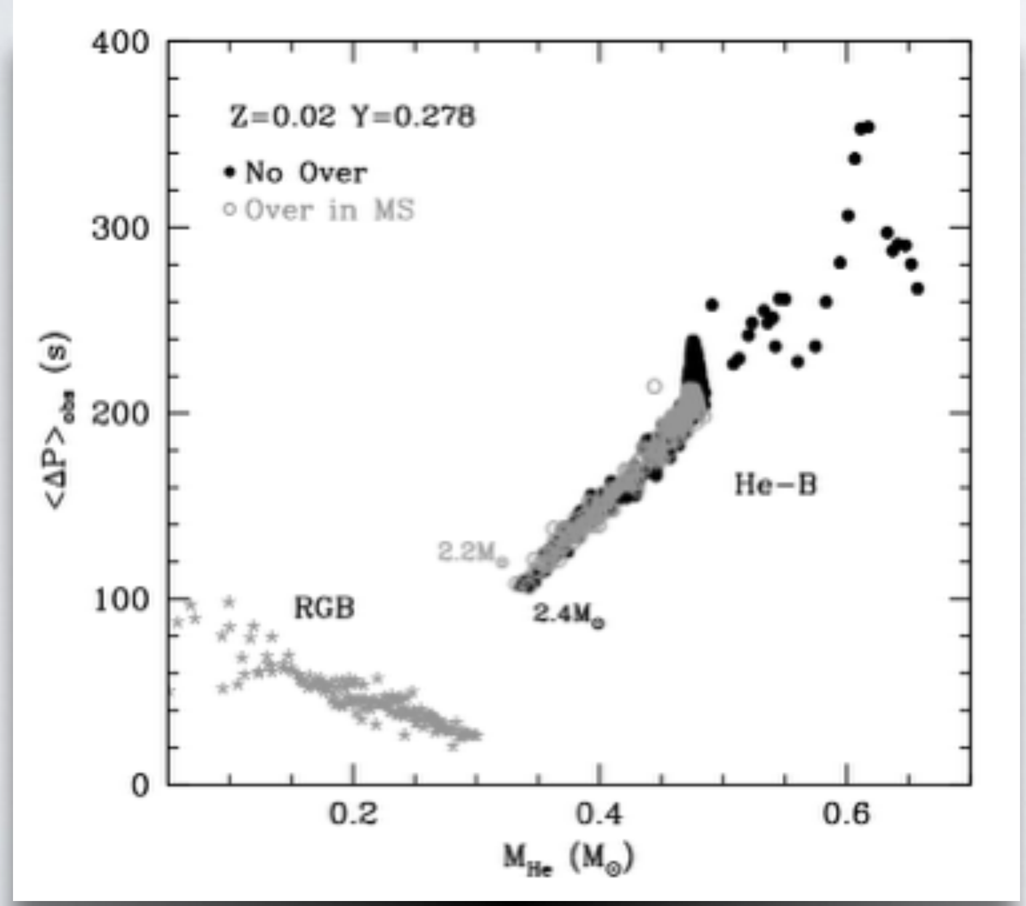
Stello et al. 2013

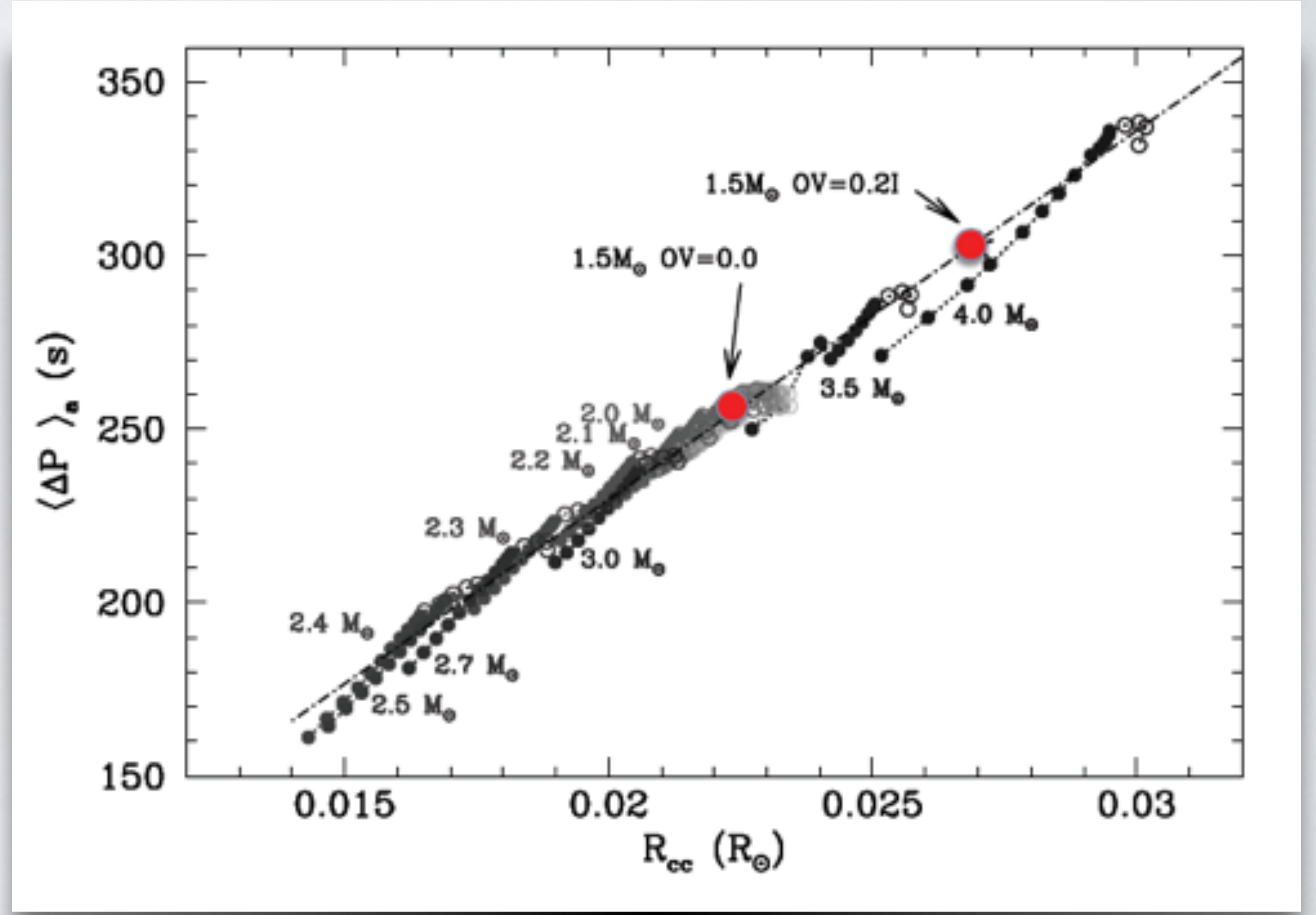
ENSEMBLE ASTEROSEISMOLOGY

non-radial mixed modes

Δν+**ν**max
period spacing
metallicity

mixing during MS





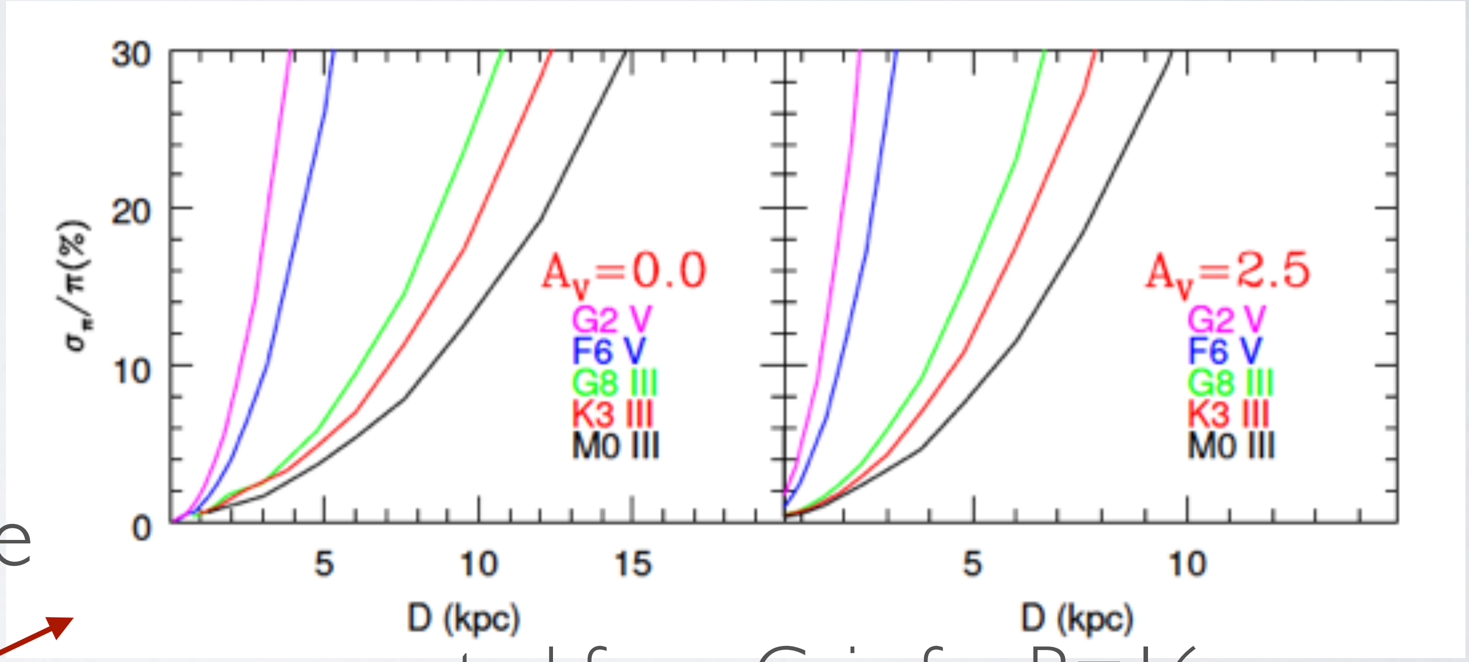
asymptotic period spacing

mixing during He burning

CONCLUSIONS

Scaling relations have an enormous potential, in particular to study stellar populations, but we need:

- We need to constraint/calibrate the scaling relations, for example EB, parallaxes



expected from Gaia for R=16
Cacciari, 2014

- To exploit the potential of scaling relations in the study of stellar populations we need chemical composition

APOGEE (talk M. Pinsonneault)
Gaia-ESO Survey (talk M.Valentini)
GALAH-Hermes @ AAT


17 juin 2014
une dernière télécommande
Le travail continue au sol pour de nombreuses années
... et encore tant de choses à découvrir...

Thank you !