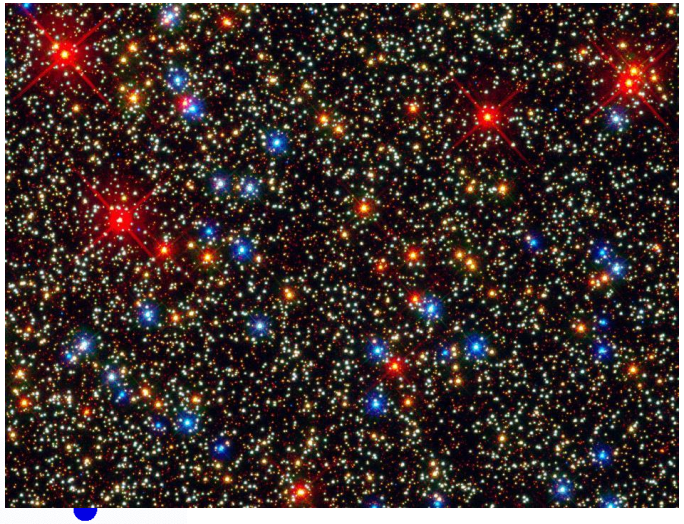
Mass and mass loss: lessons from asteroseismology



Benoît Mosser
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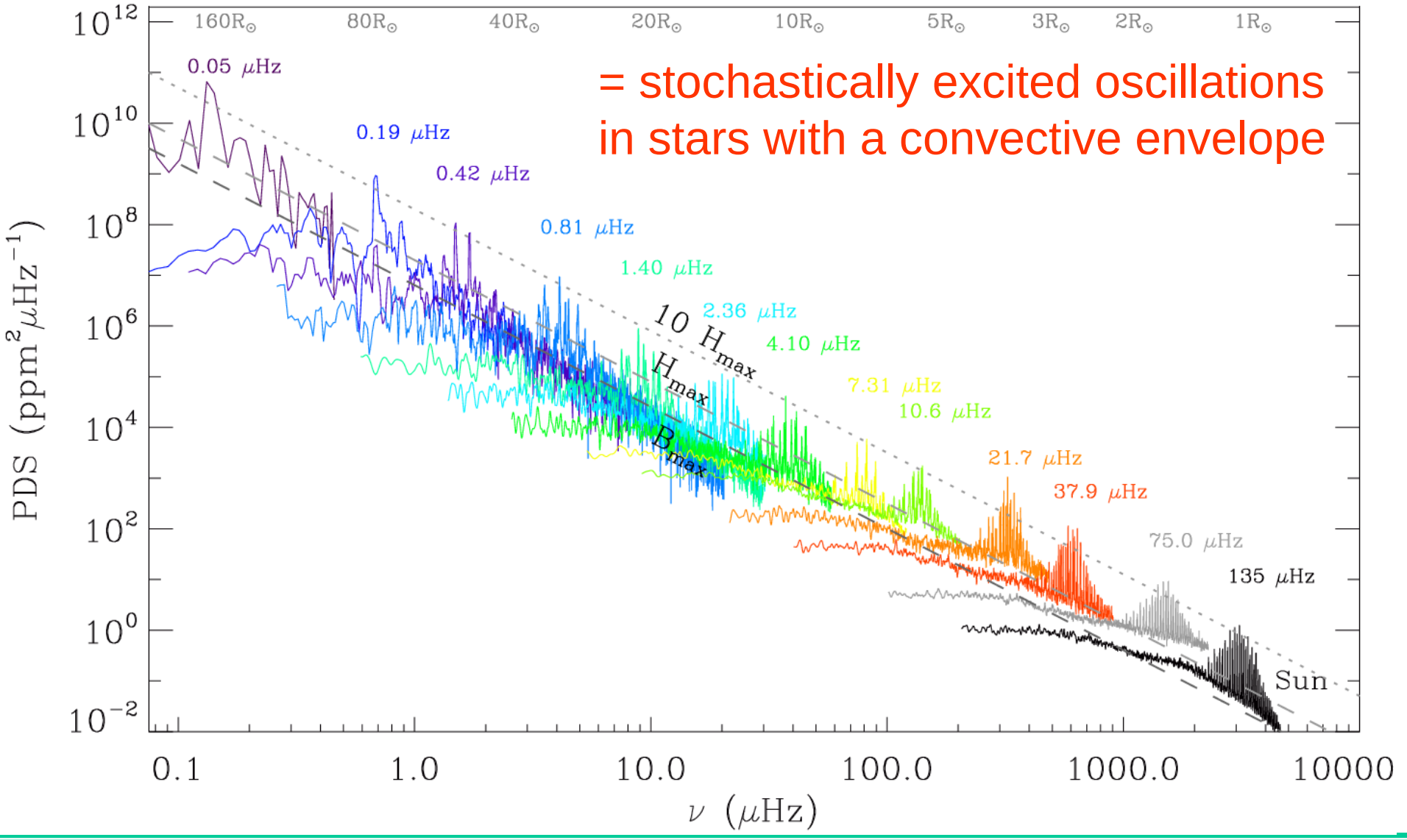
LESIA

l'Observatoire de Paris

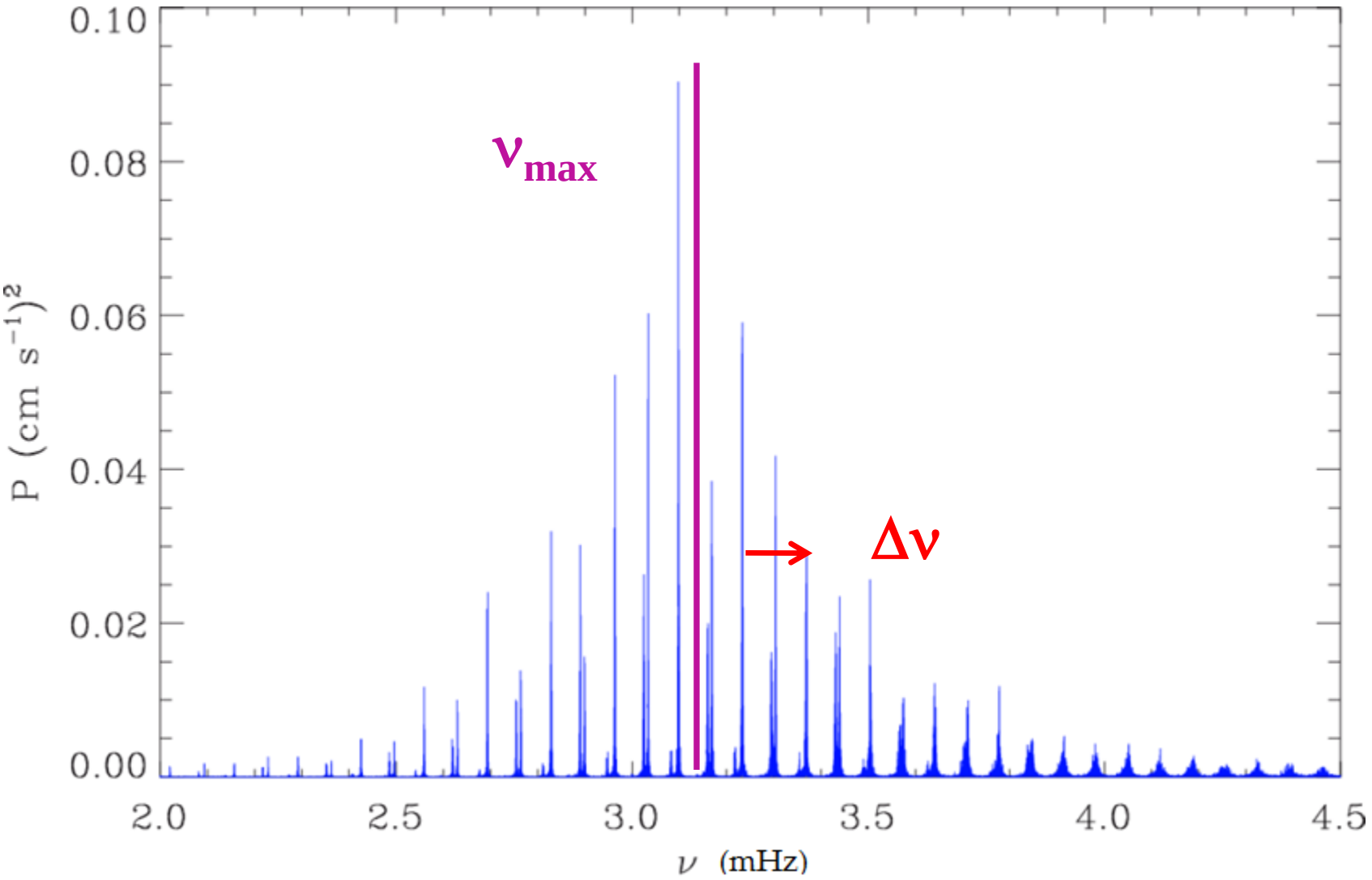
Kepler

Solar-like oscillations…

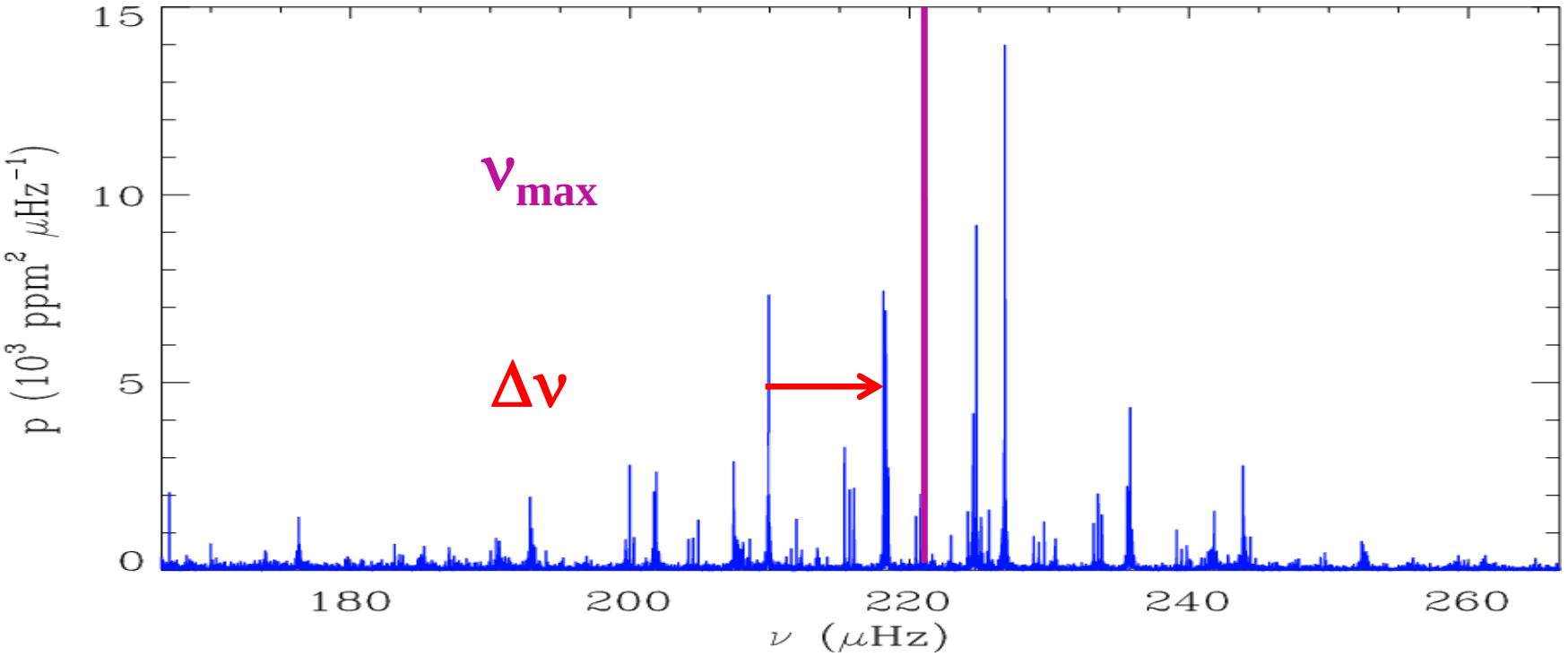


= stochastically excited oscillations in stars with a convective envelope

Solar oscillation spectrum



Global seismic parameters



$\Delta\nu$ scales with the mean density

$\Delta\nu \sim \langle\rho\rangle^{0.5} \sim (M/R^3)^{0.5}$

ν_{max} scales with the cutoff frequency in the photosphere

$\nu_{max} \sim \nu_c \sim g/T_{eff}^{0.5} \sim M/R^2 /T_{eff}^{0.5}$

→ **Seismic estimates of the stellar mass and radius**

Seismic scaling relations

From the global seismic parameters stellar masses and radii,

$$\frac{R}{R_\odot} \simeq \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)\left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2}\left(\frac{T_{\rm eff}}{T_\odot}\right)^{1/2}$$

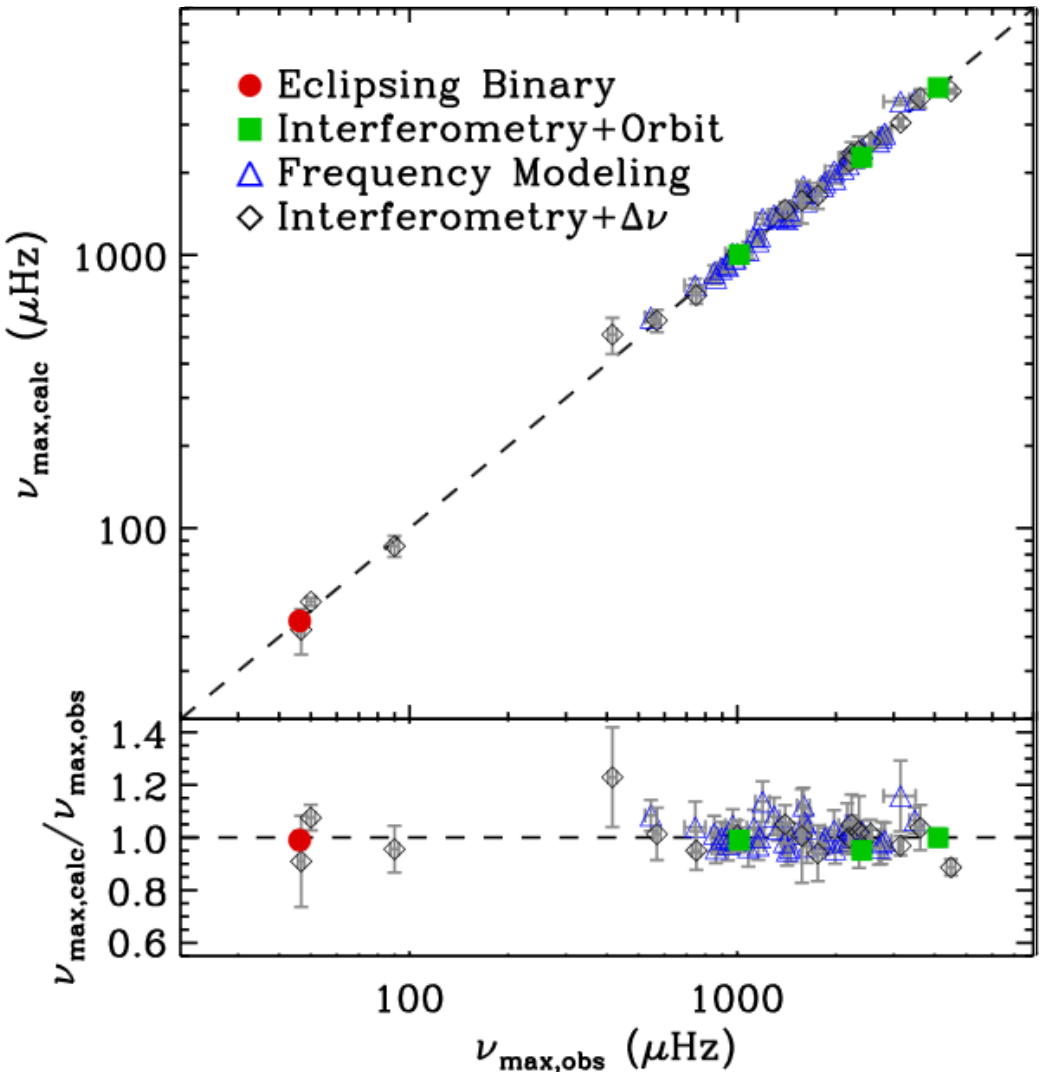
$$\frac{M}{M_\odot} \simeq \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)^{3}\left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-4}\left(\frac{T_{\rm eff}}{T_\odot}\right)^{3/2}$$

with $\nu_{max,\odot} \sim 3100$ µHz; $\Delta\nu_\odot \sim 135$ µHz; $T_\odot \sim 5777$ K
(seismic scaling relations used since the CoRoT red giant paper
Kallinger et al. 2010, A&A 509, A77)

Conservative uncertainties	Statistical	Systematic
dR/R	2-5 %	5 %
dM/M	5-15 %	10 %

Estimates are relevant, precise; **calibration** effort is ongoing

Calibration of the scaling relations



Comparison of ν_{max} and $\Delta\nu$ measured from asteroseismology and calculated using independent measurements of R, M, and T_{eff}

- Eclipsing binaries

Gaulme et al. 2013, , ApJ 767, 82

- Interferometry

Huber et al. 2011, ApJ 760, 32

- Clusters

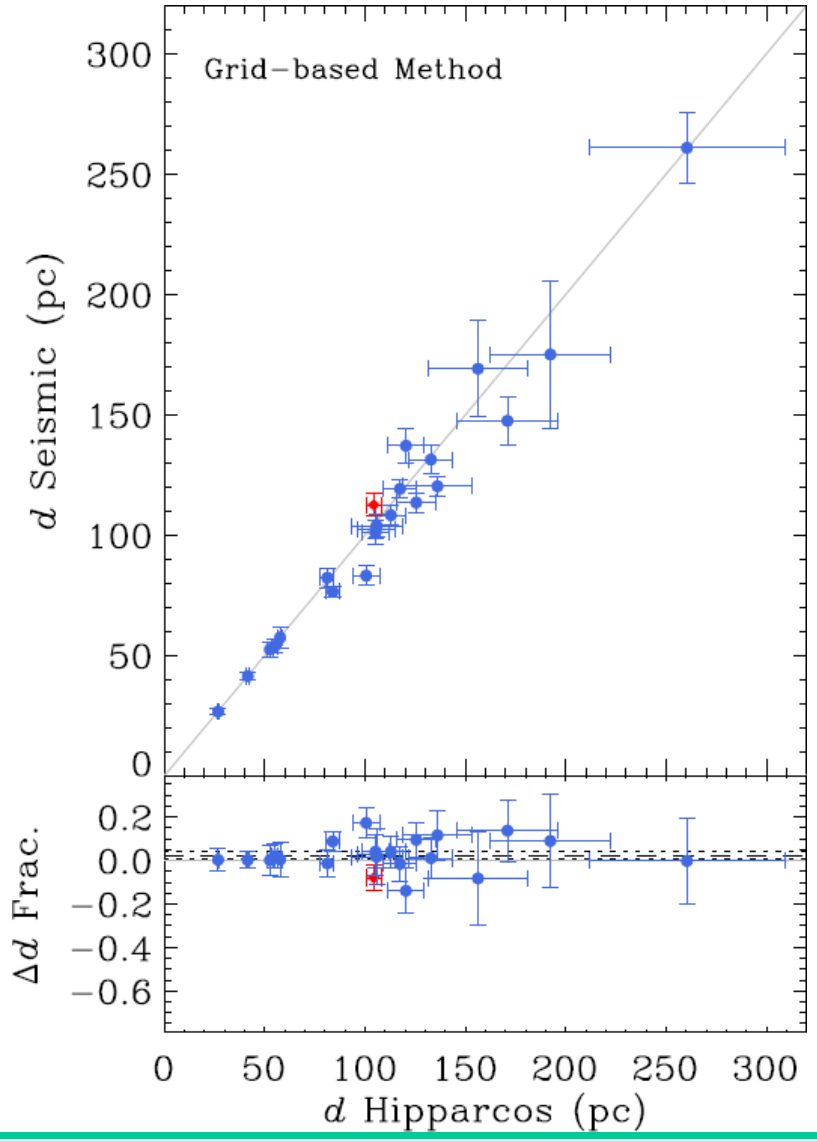
Corsaro et al. 2012, ApJ 757, 190

Miglio et al. 2012, MNRAS 419, 2077

- Astrometry

Silva-Aguirre et al. 2012, ApJ 757, 99

Calibration of the scaling relations



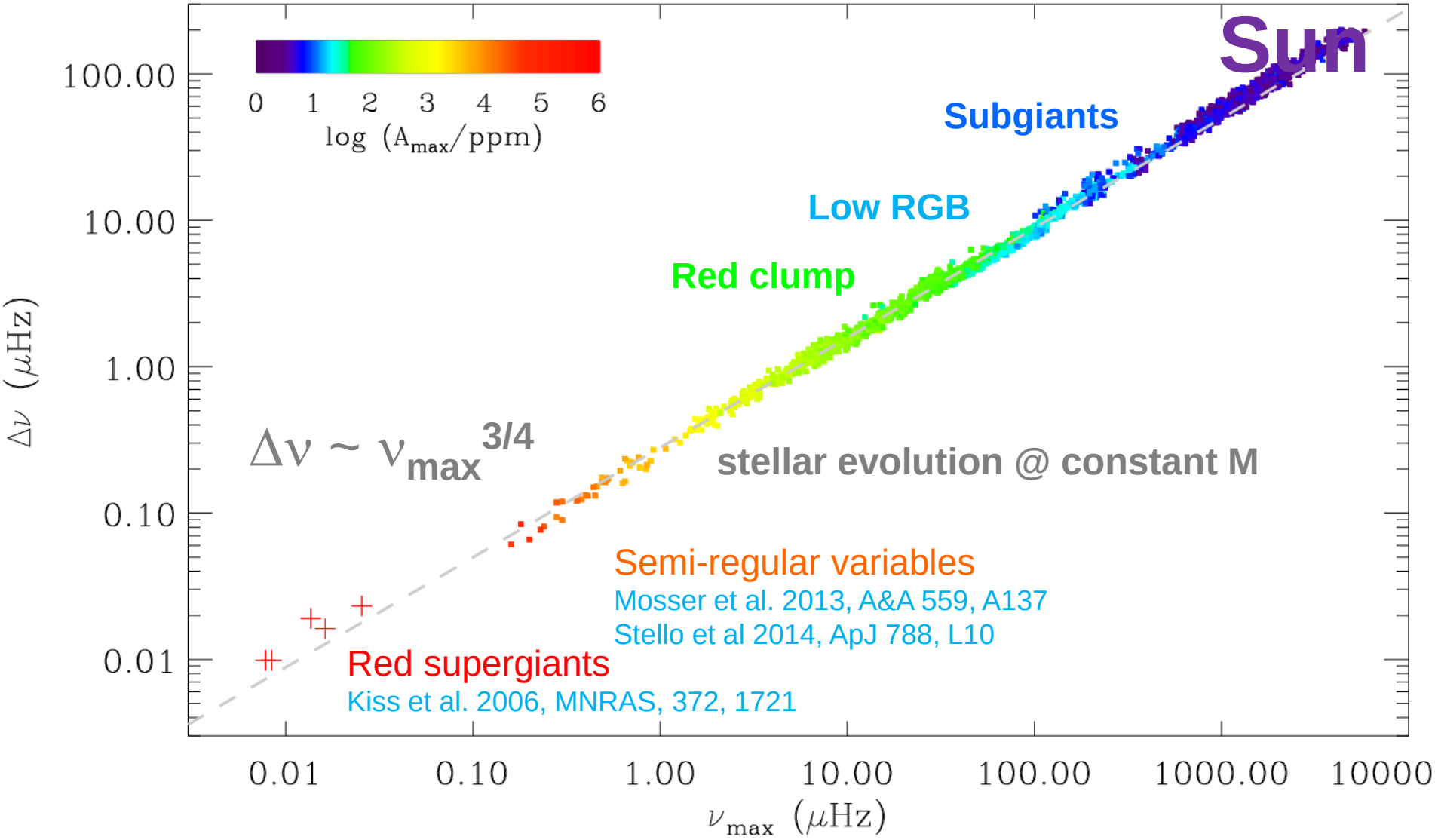
Comparison of inferred seismic distance and Hipparcos distances

R ,T_{eff} and black body
→
Luminosity L

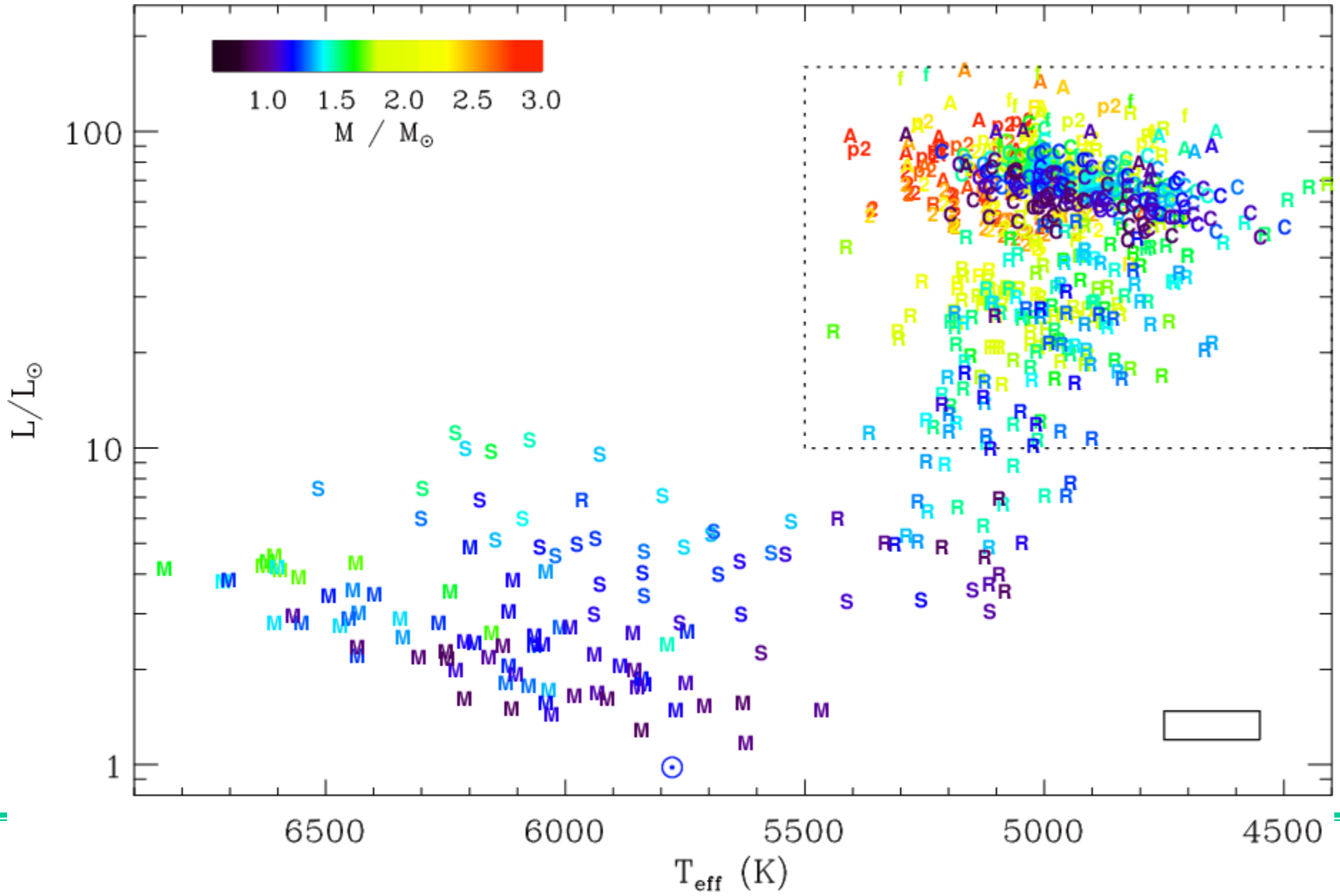
L, m_V and dereddening
→
Distance d

Silva-Aguirre et al. 2012, ApJ 757, 99

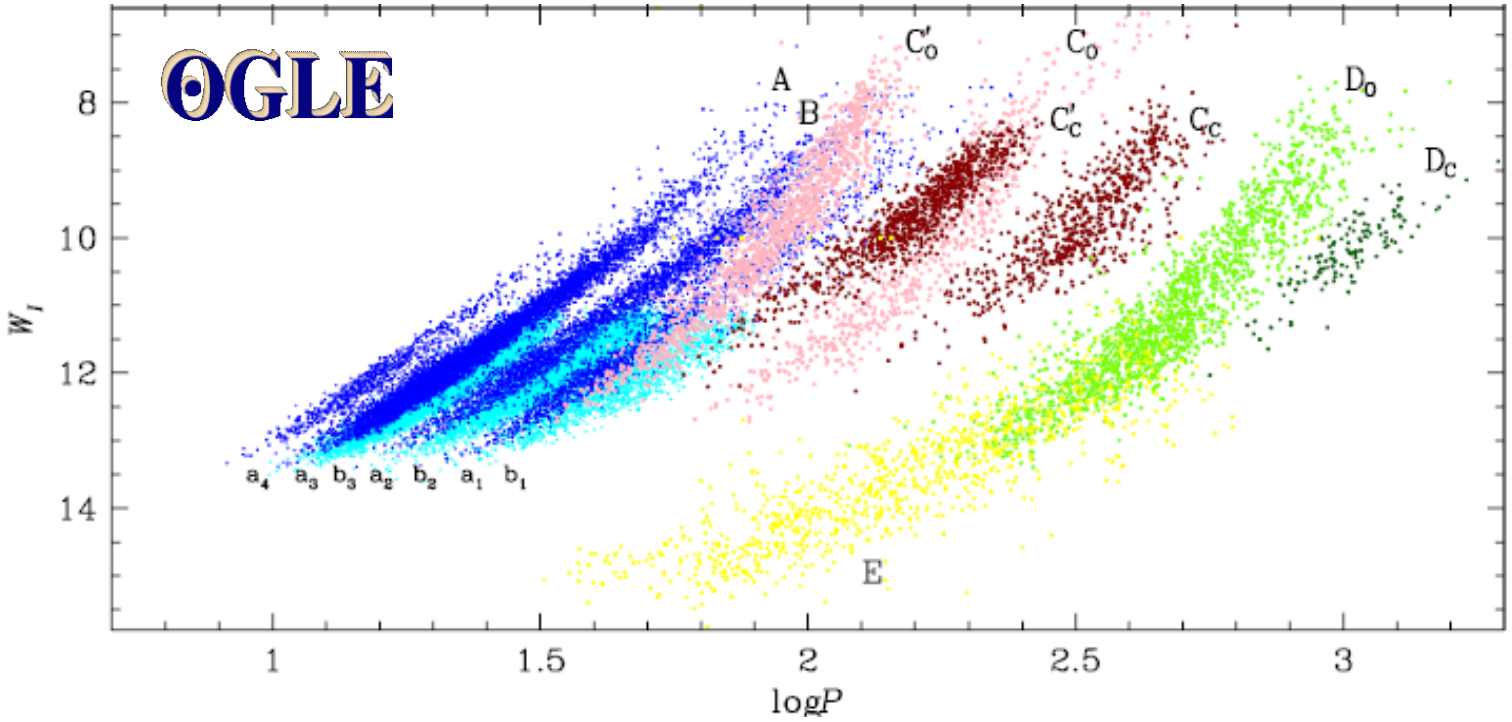
Stellar evolution



Seismic enriched HR diagram



Period-luminosity relations in M giants

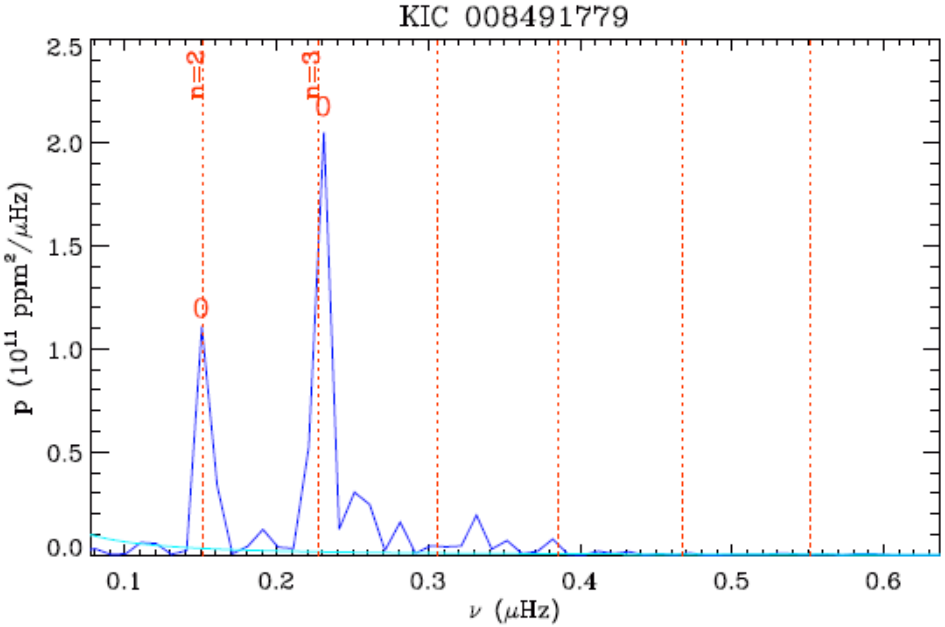


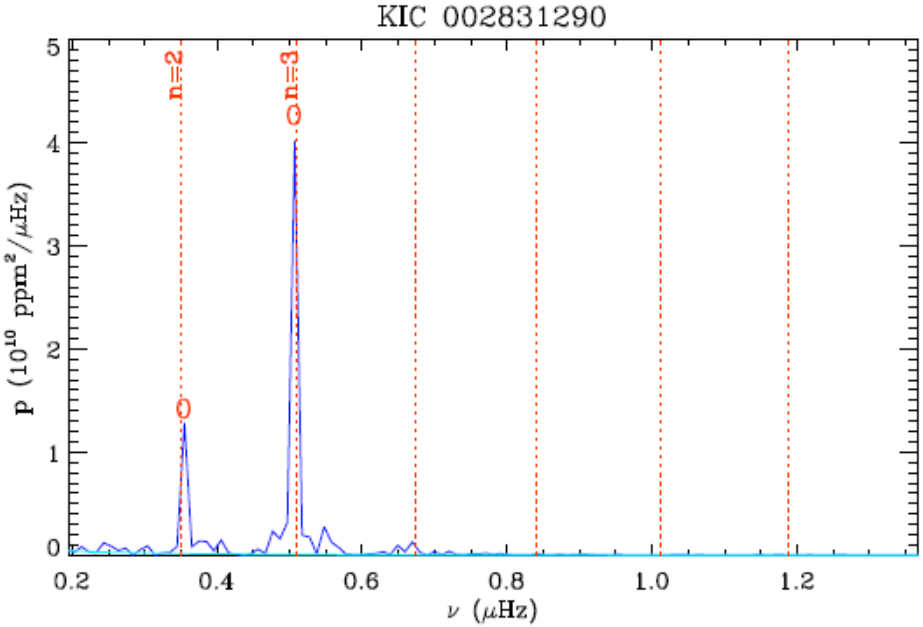
Wood et al. 1999, Soszynski et al. 2007

Infrared microlensing surveys (e.g. MACHO, OGLE, DENIS)
Variability in M giants lightcurves → **Period – Luminosity relations**

Pending questions:

- Radial / non radial oscillations?
- Solar-like oscillations? (= stochastically excited by turbulent convection)


KIC 008491779
n=2
n=3
p (10^11 ppm^2/μHz)
ν (μHz)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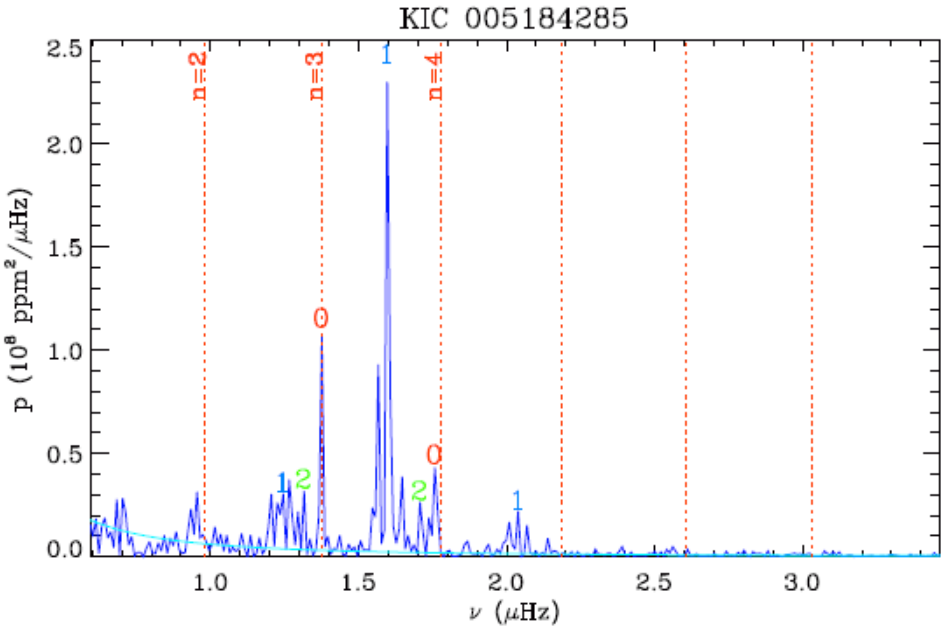
n=3
p (10^10 ppm^2/μHz)
ν (μHz)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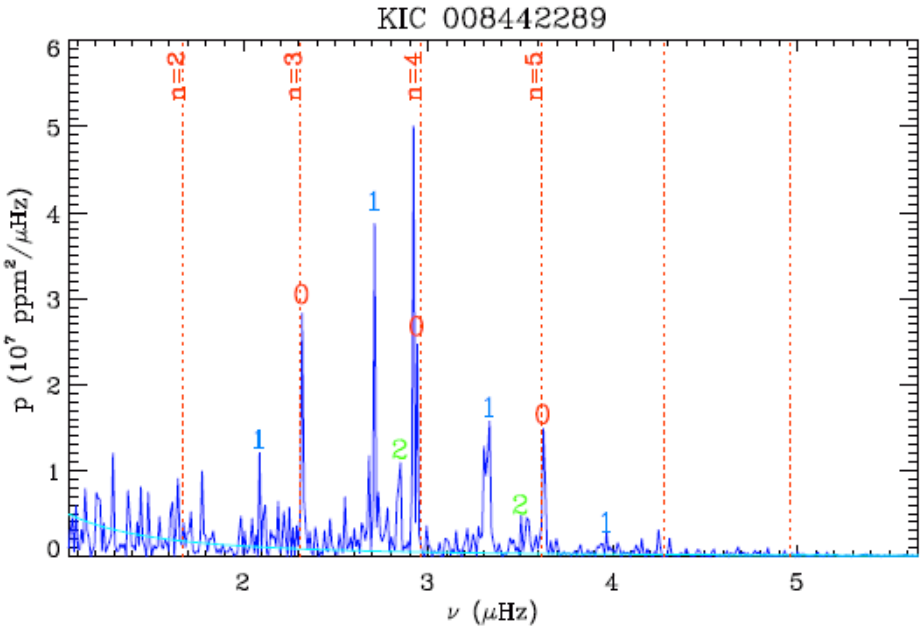
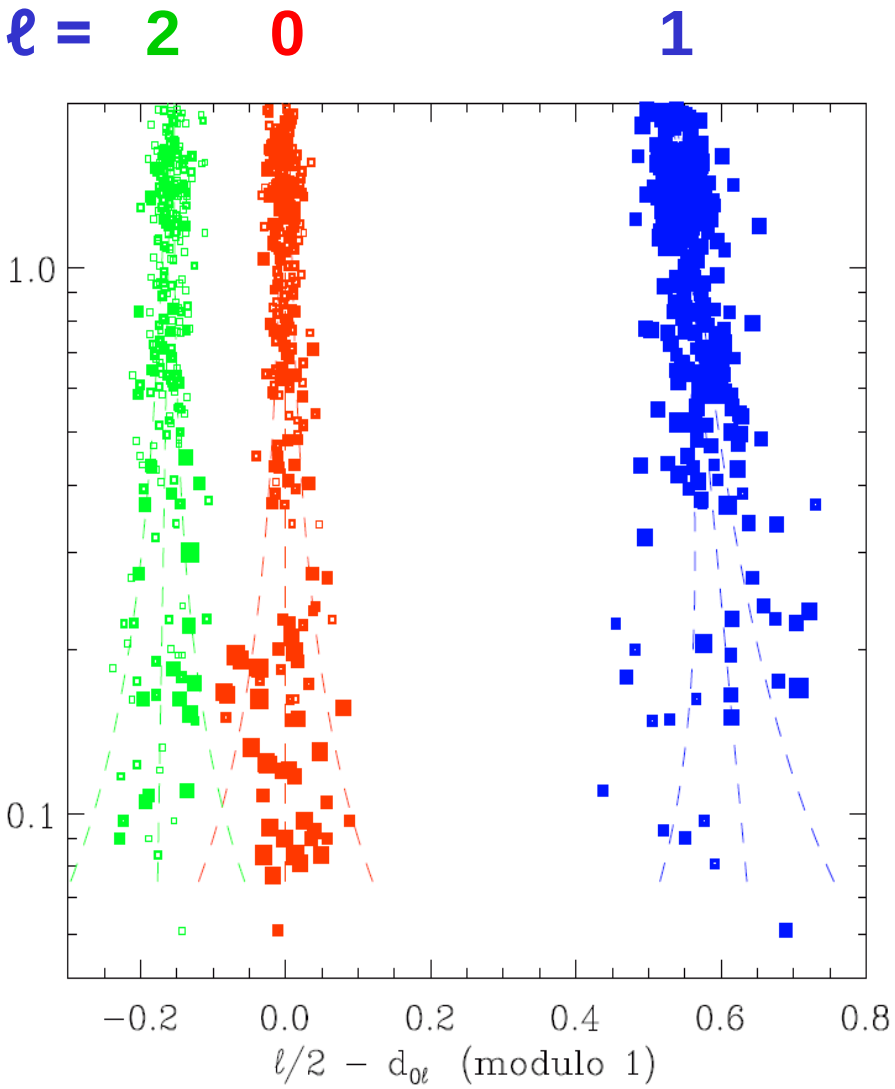
n=4
p (10^8 ppm^2/μHz)
ν (μHz)


KIC 008442289
n=2
n=3
n=4
n=5
p (10^7 ppm^2/μHz)
ν (μHz)

Mode identification, Kepler data at low $\Delta\nu$



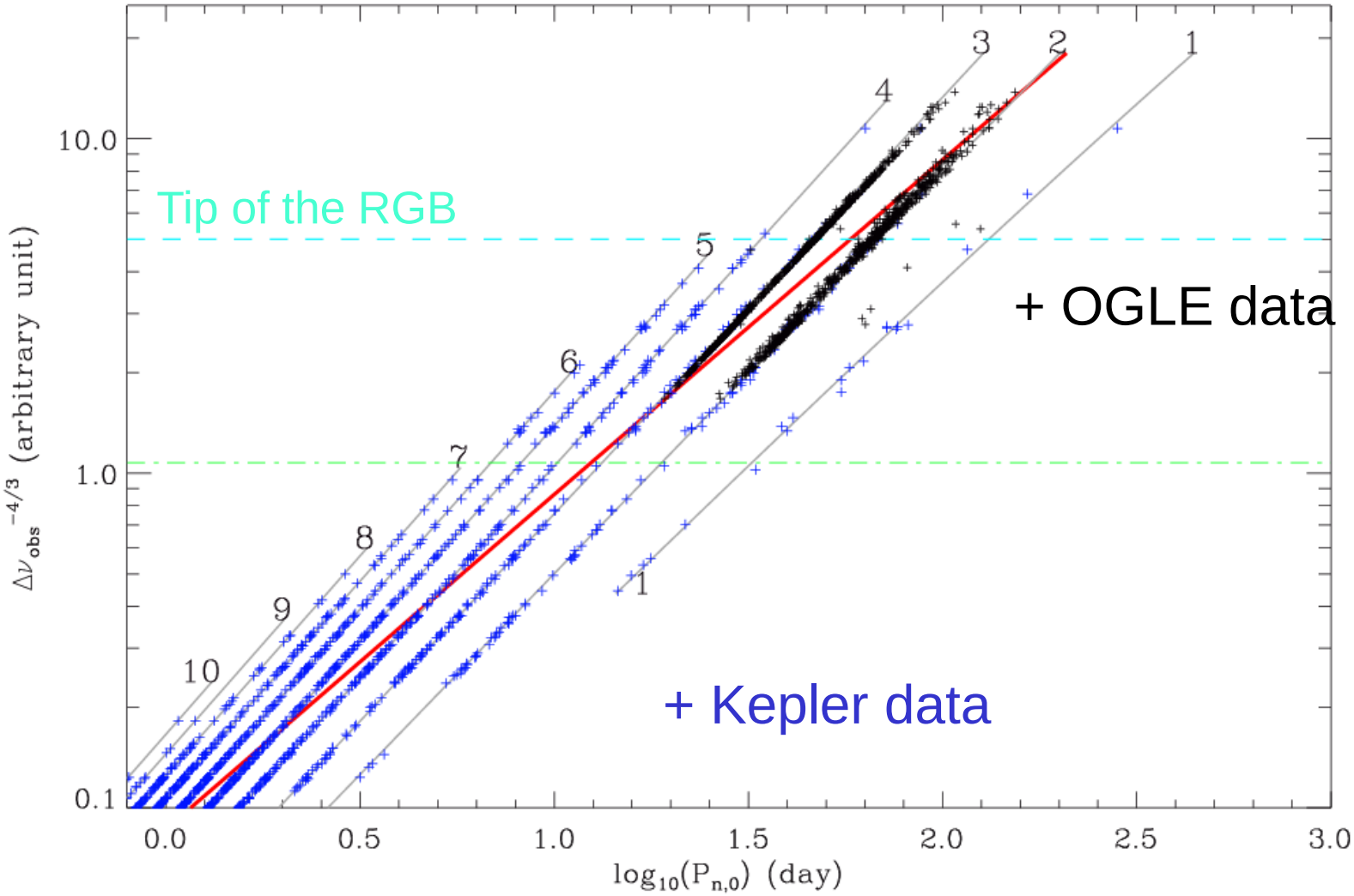
Mosser et al. 2013, A&A 559, A137

Energy equipartition between the different degrees
Quadrupole, radial and dipole modes all present in the spectrum

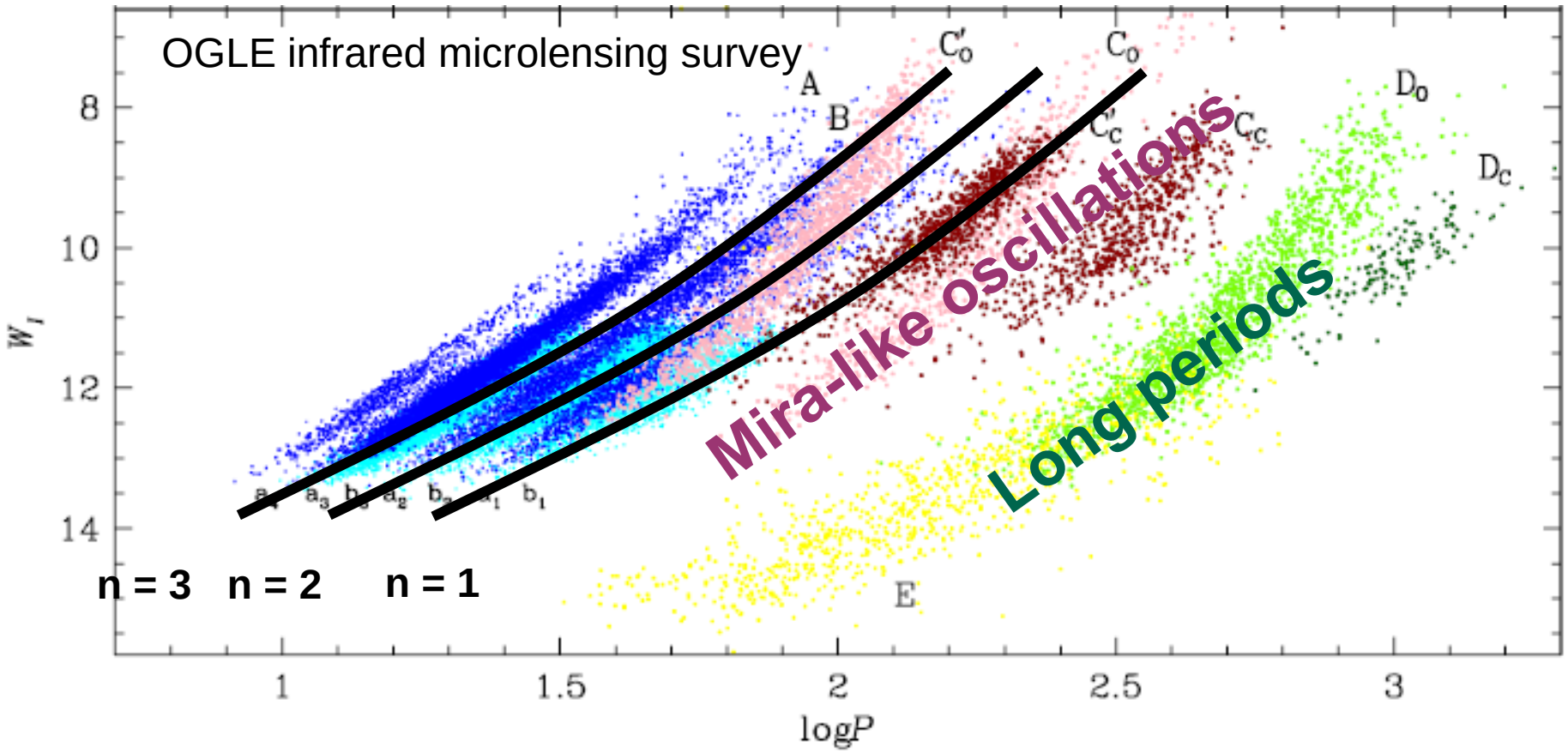
At low frequency
Dipole, quadrupole and radial modes form triplets
Stello et al 2014, ApJ 788, L10

PL sequences / oscillation pattern

Mosser et al. 2013, A&A 559, A137



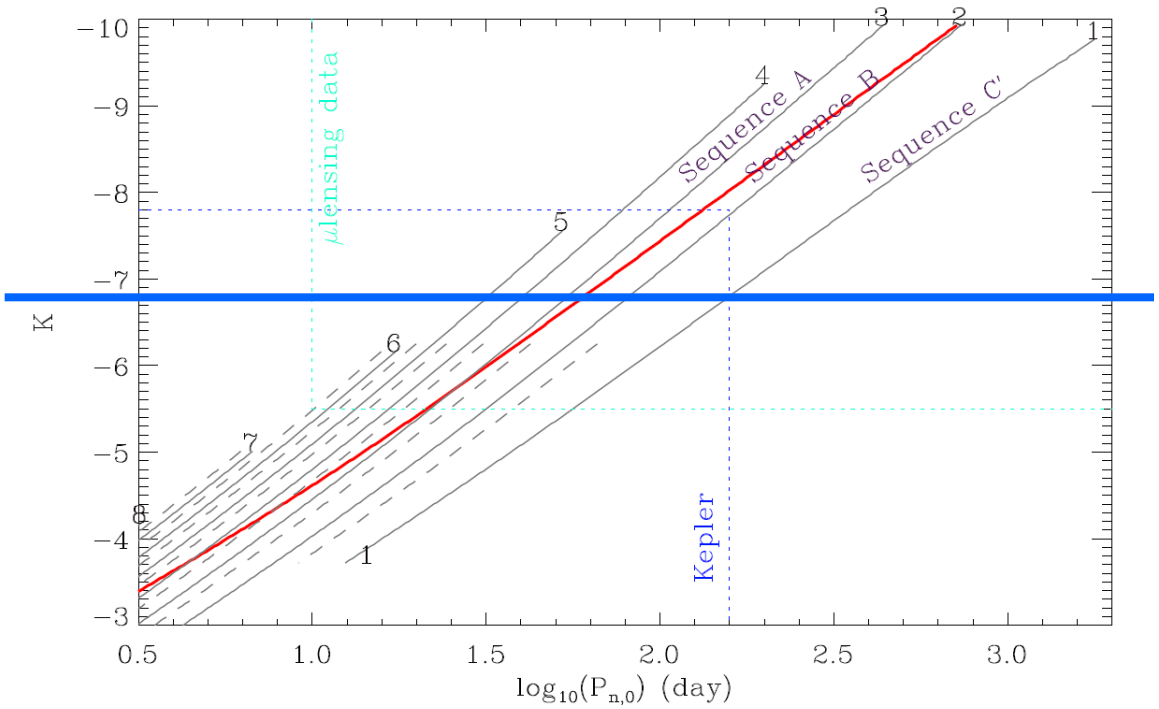
Solar and non-solar like oscillations



Soszynski et al. 2007, Acta Astron., 57, 201

Period luminosity sequences in M giants

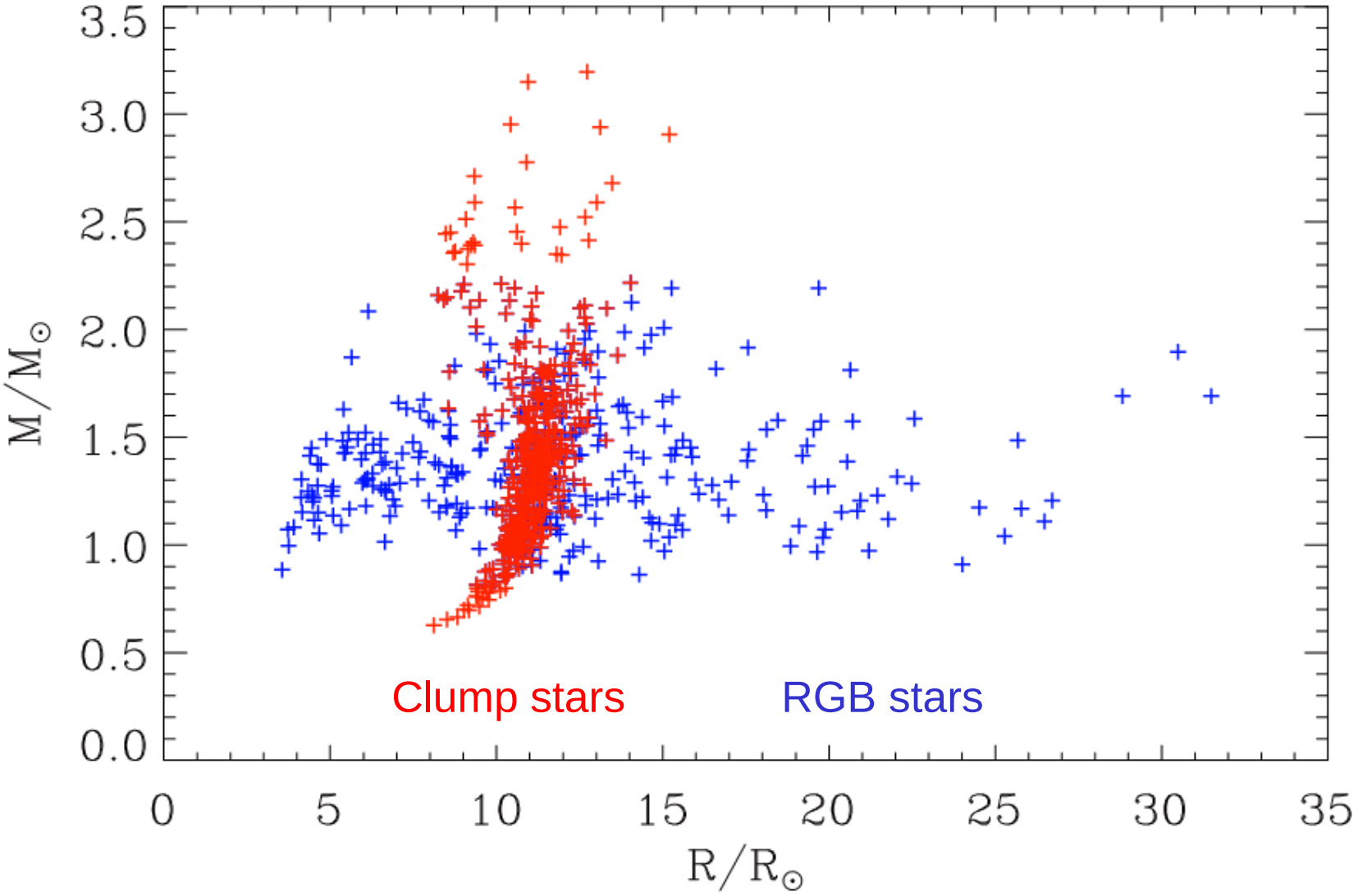
Mosser et al. 2013, A&A 559, A137



Tip of the RGB
K ~ 7.2

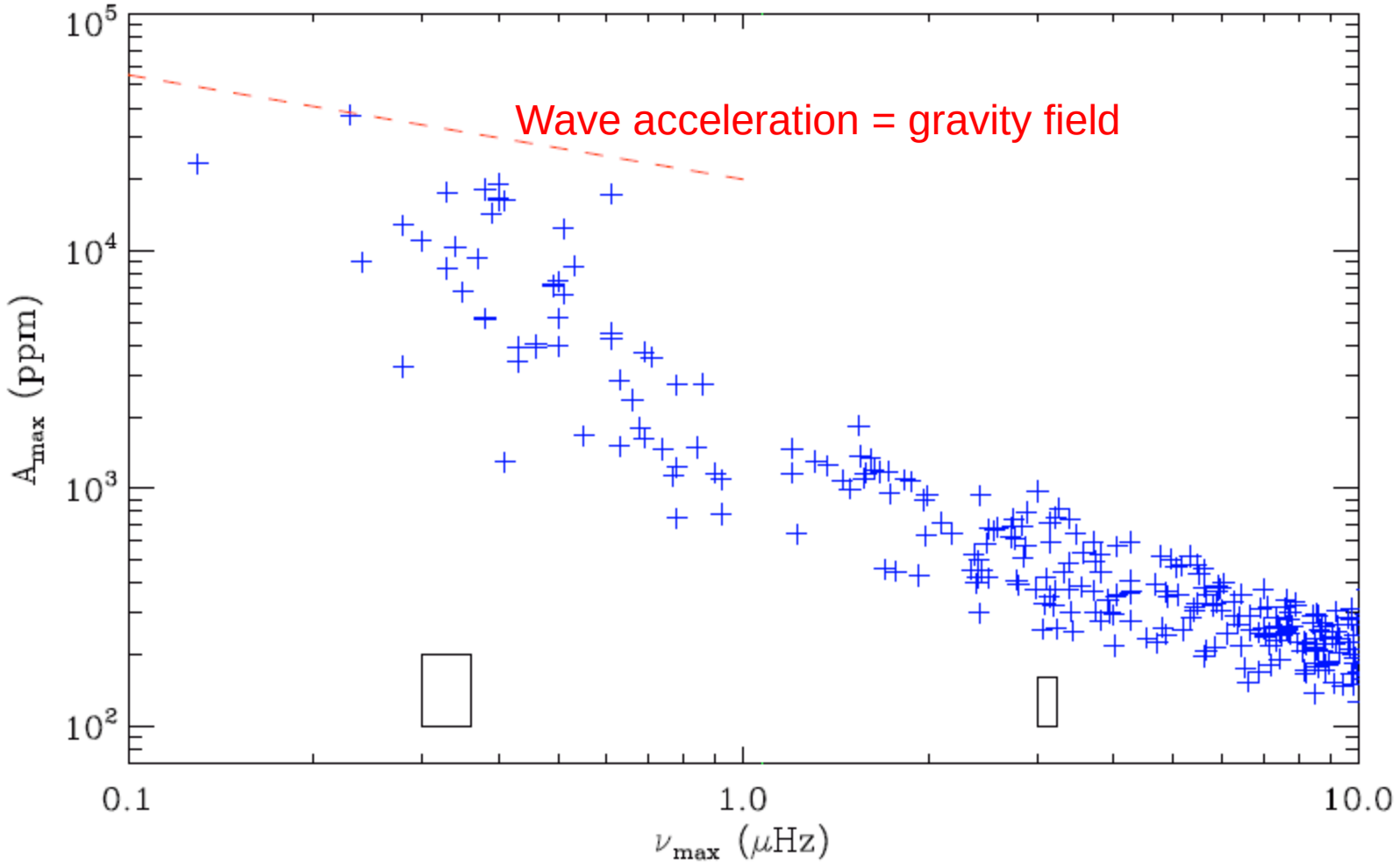
Calibration of the period-luminosity relations based on asteroseismic results

Mass loss



Mosser et al. 2012, A&A 537

Mass loss; solar-like oscillation regime



In the solar-like oscillation regime
(= semi-regular variables, ≠ Mira, ≠ LPV)

→ Seismic determination of R and M

→ Signature of mass loss

Synergies between asteroseismology and upper-RGB and AGB physics still in its infancy