Amplitudes of acoustic modes in red giant stars : *preliminary* results

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Outlines

- Mode excitation rates and amplitudes in velocity
- Mode amplitudes in intensity

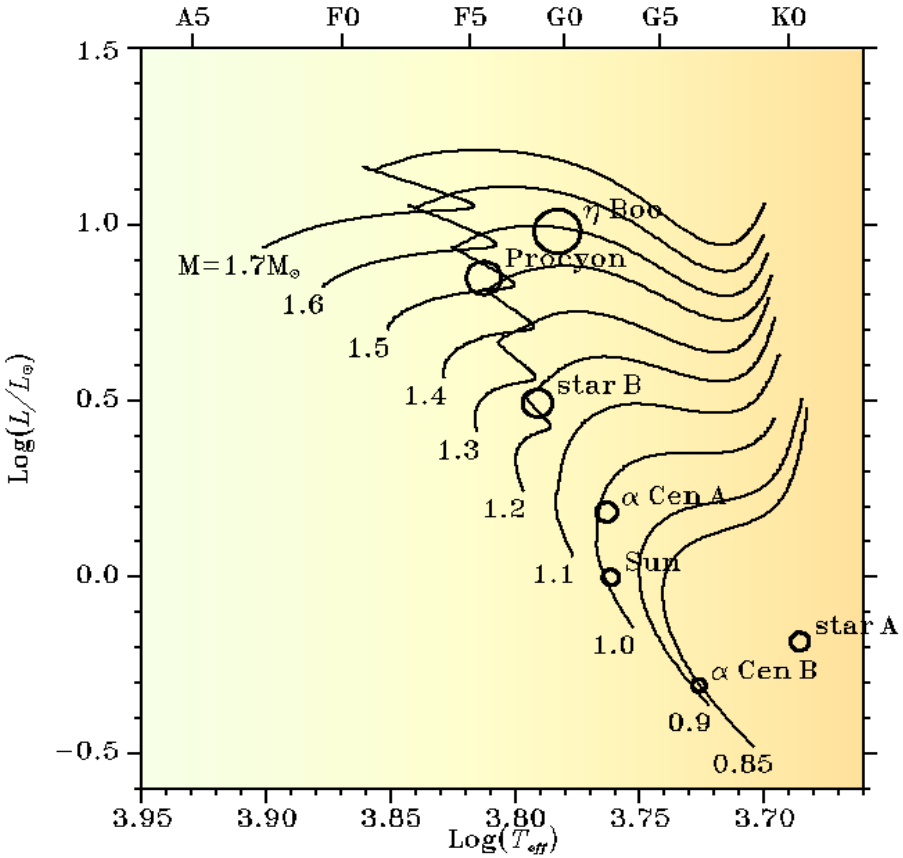
  Case of Main Sequence stars (MS)

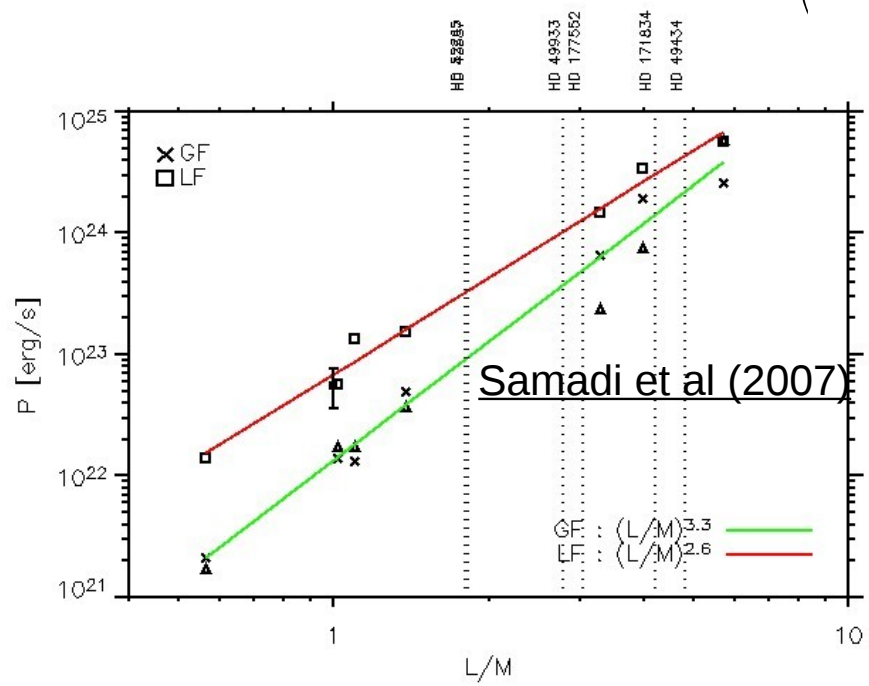
  Case of Red Giant stars (RG)
- Effect of the metal abundance
- Conclusion & perspectives

Mode exictation rates (P)

main sequence stars

$$P_{max} \propto \left(\frac{L}{M}\right)^s$$





$\chi_k(\omega)$: eddy time-correlation function

Lorentzian $\chi_k(\omega)$: s = 2.6

Gaussian $\chi_k(\omega)$: s = 3.0

$$\frac{L}{M} \propto \frac{T_{eff}^4}{g}$$

- Seven 3D simulations of outer layers of MS stars
- Computed with Stein & Norlund's code
- Excitation rates (P) : Samadi & Goupil (2001)'s formalism

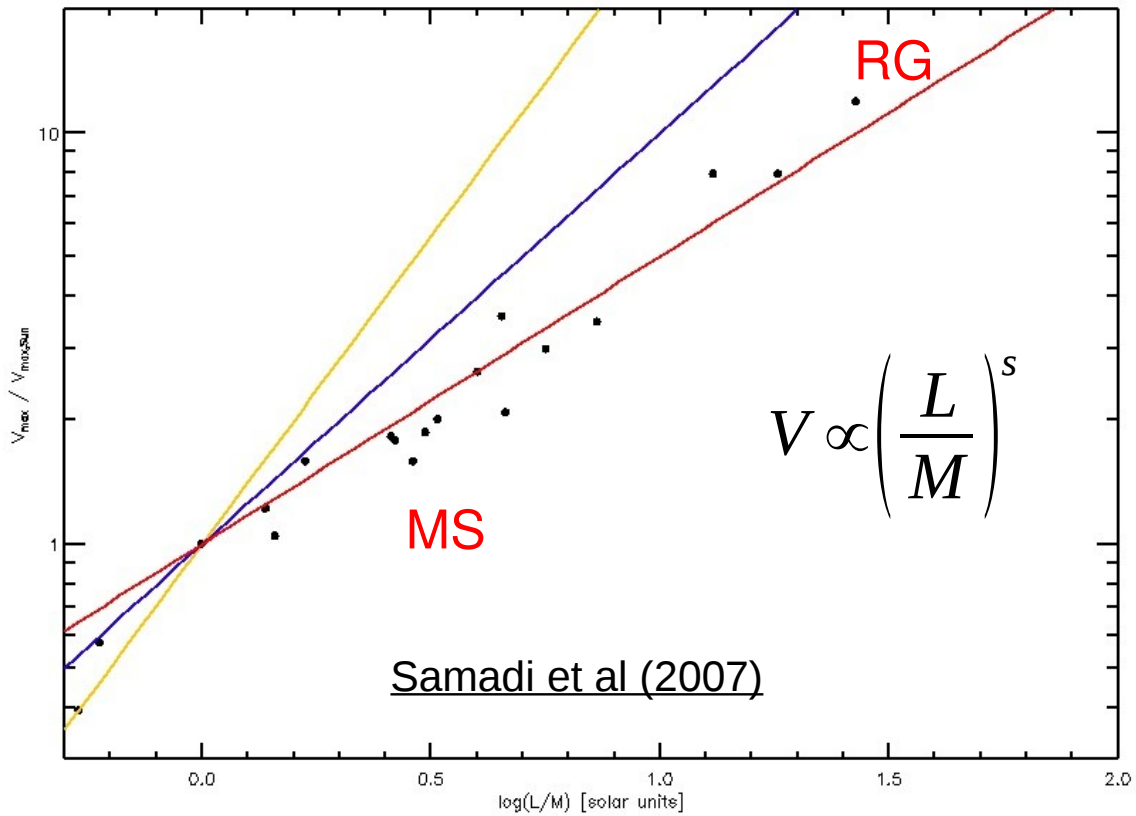
Mode amplitudes in velocity

$$V \propto \left(\frac{P}{I \quad \eta} \right)^{1/2}$$

- Damping rates (η) : Houdek et al (1999)
- Excitation rates (P) : from the scaling laws

$$P_{max} \propto \left(\frac{L}{M} \right)^{s}$$

V scales as : $V \propto \left(\frac{L}{M} \right)^{s}$



- Good matching using Lorentzian $\chi_k(\omega)$
- Use of a Gaussian over-estimates the mode velocity

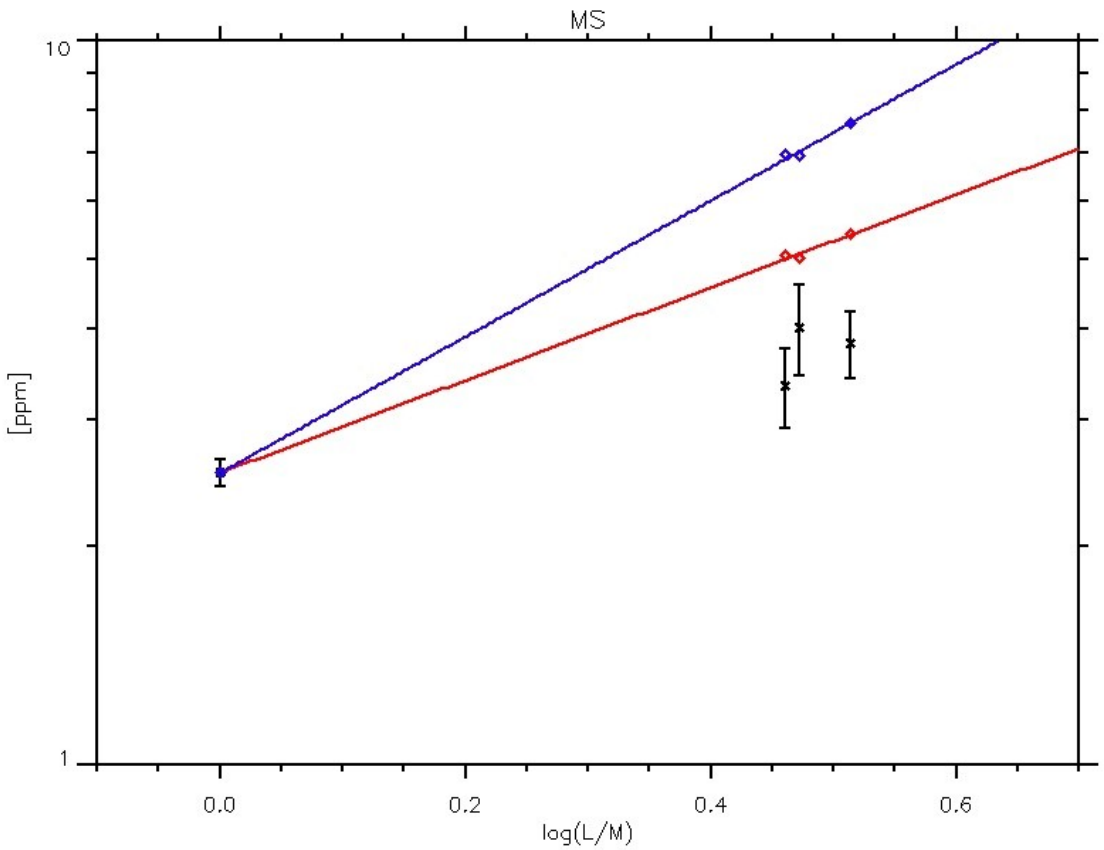
Houdek & Gough (2002) : s=1.5

Samadi et al (2007) :

- s= 0.7 : Lorentzian
- s= 1.0 : Gaussian

Mode amplitudes in intensity

CoRoT main-sequence stars



(Michel et al 2008, Science)

'Lorentzian' scaling law (s=0.7)

'Gaussian' scaling law (s=1.0)

- We assume the scaling laws in velocity found by Samadi et al (2007):

$$V \propto \left(\frac{L}{M}\right)^{s}$$

- We assume a calibrated and adiabatic relation between intensity and velocity (Kjeldsen & Bedding 1995):

$$\frac{\delta L}{L} \propto \frac{V}{\sqrt{T_{eff}}}$$

- CoRoT intensity are converted into *bolometric* intensity following Michel et al (2009)

- The 'Lorentzian adiabatic' scaling law over-estimated the observations by ~ 25%

CoRoT Read Giants : the data set

RMS mode amplitudes

- Fit of individual modes (Lorentzian profile) performed by Frédéric Baudin and Caroline Barban on ~ 180 stars (Lrc01)
- Provides: H, Γ, and peak frequency (ν_{max})

Two cases:

- For resolved modes : $\Gamma > \delta\nu$

$$\left\langle \left(\frac{\delta L}{L} \right)^2 \right\rangle = \pi \quad \Gamma \quad H$$

$\delta L/L$: mode intensity fluctuations

Γ: mode line-width (μHz)

H : mode height (ppm²/μHz)

- For *un*resolved mode: $\Gamma < \delta\nu$ (~ 1 single bin)

$$\left\langle \left(\frac{\delta L}{L} \right)^2 \right\rangle = 2 \quad \delta\nu \quad H$$

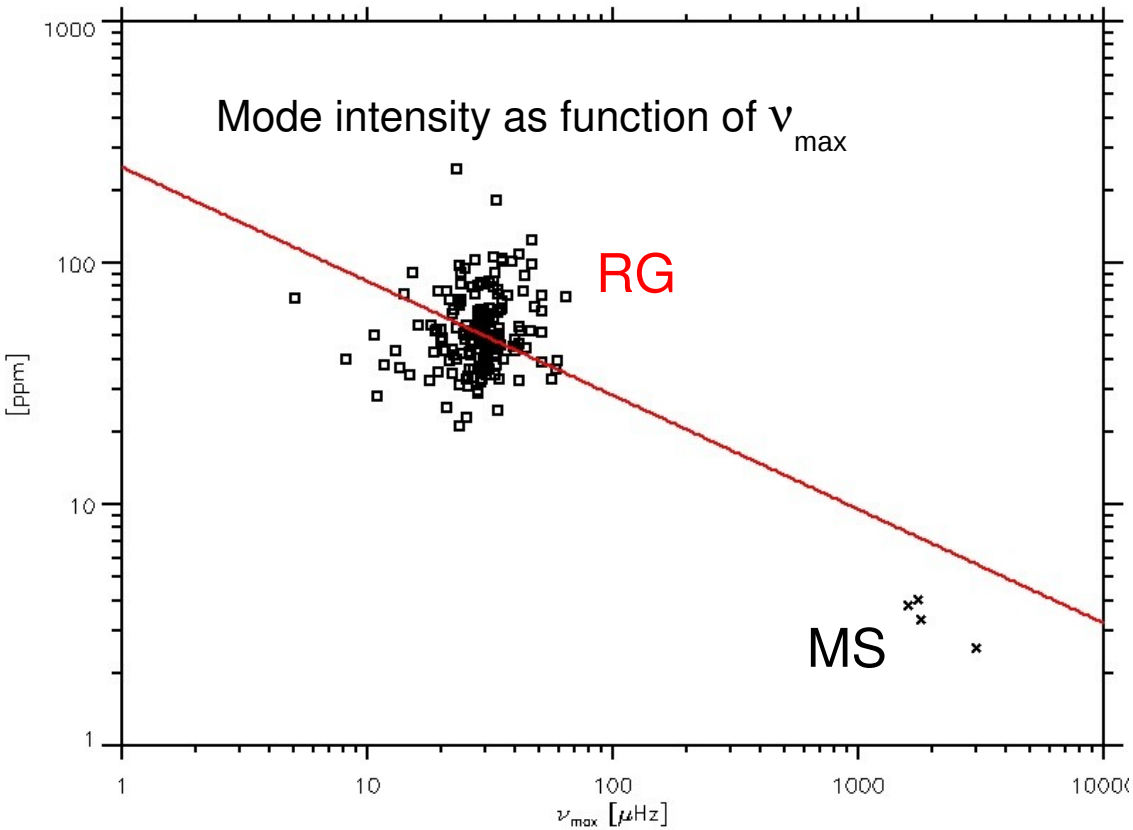
$\delta\nu$: frequency resolution (μHz)

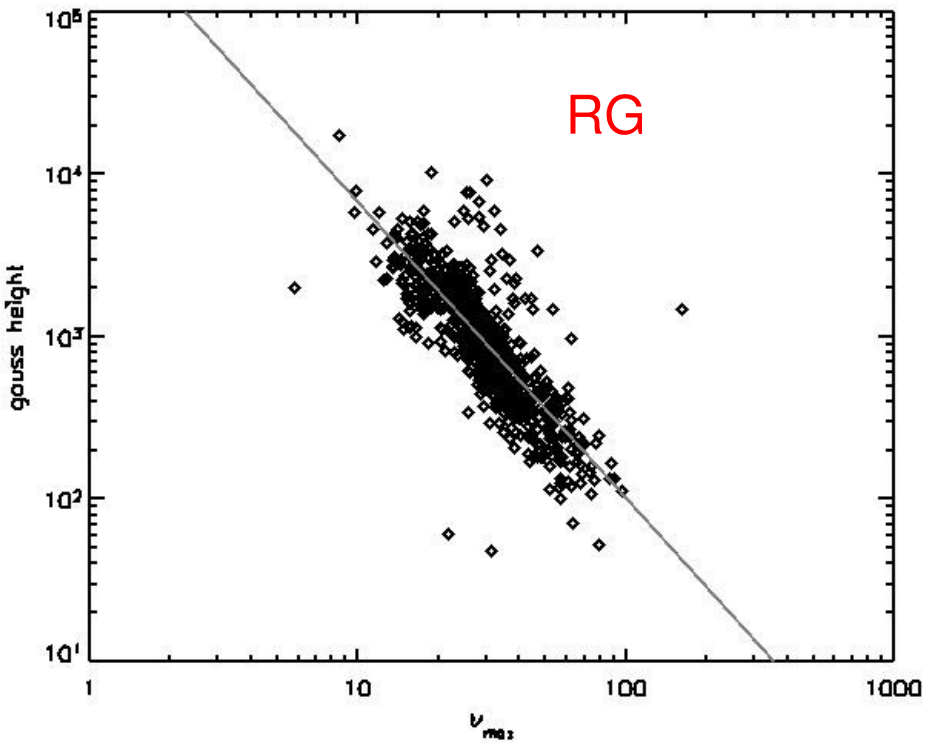
For LRc01 : $\delta\nu$ ~ 0.08 μHz

Alternative analysis/fit by S. Hekker (see P-X-100)

Mode amplitudes in intensity
CoRoT Red Giants (Lrc01)

- Amplitude of non-radials modes / radial modes : see Marc-Antoine Dupret's talk
- Bolometric corrections performed assuming we deal only with radial modes





Hekker et al (2009,sub.) ; see also P-X-100

about 900 RGs

➔ Clear variation of the amplitudes with ν_{max}

Mode amplitudes in intensity
CoRoT Red Giants

- As in velocity, we must expect a variation with L/M
- But, problem : how to derive (L/M) ?
- ν_{max} scales as the cut-off frequency (Kjeldsen & Bedding 1995, Bedding & Kjeldsen 2003), that is :

$$\nu_{max} \propto \nu_c \propto \frac{g}{\sqrt{T_{eff}}}$$

$$\frac{L}{M} \propto \frac{T_{eff}^4}{g}$$

$$\nu_{max} \propto \frac{g}{\sqrt{(T_{eff})}}$$

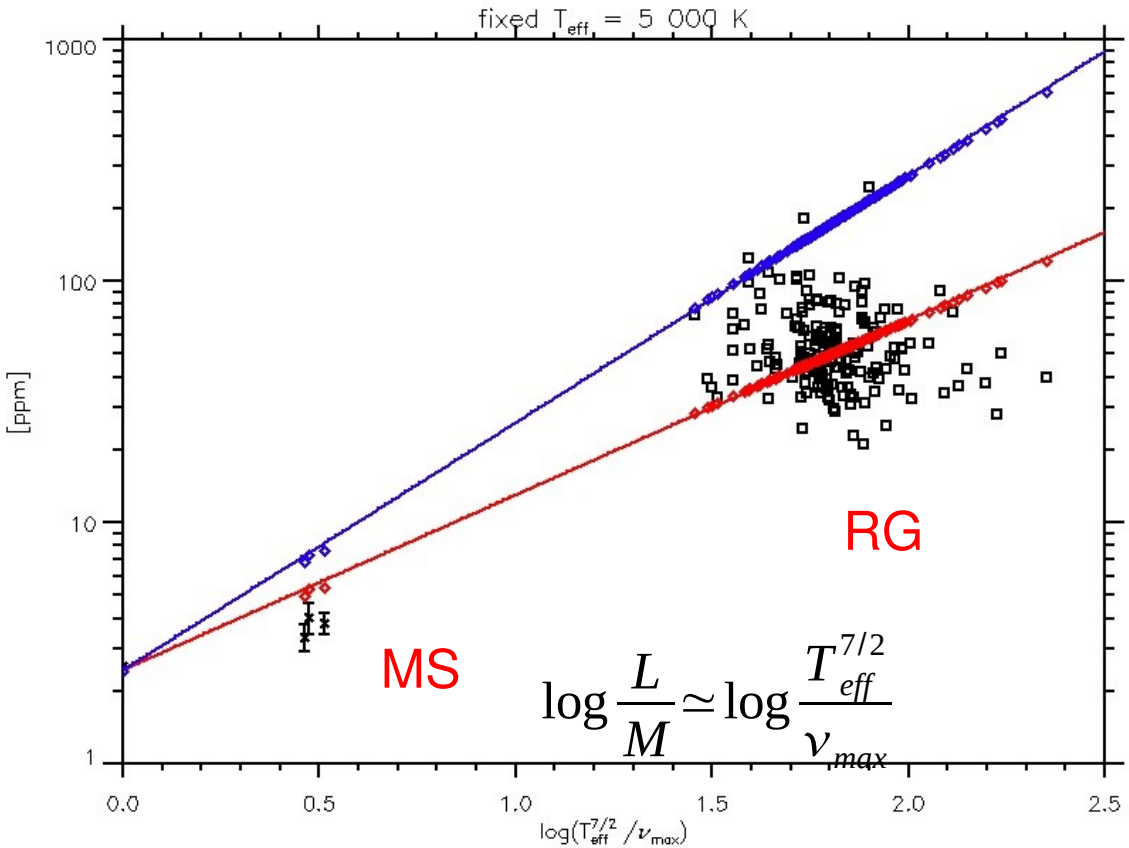
$$\Rightarrow \quad \frac{L}{M} \propto \frac{T_{eff}^{7/2}}{\nu_{max}}$$

- For red giants: Teff ~4500 K - 5500 K
- We then assume Teff ~ 5000 K

$\Rightarrow$ Mode amplitudes scale as $1/\nu_{max}$

Mode amplitudes in intensity

CoRoT Red Giants and MS



- Squares: the RGs analysed by Frédéric & Caroline
- Crosses: the main sequence stars observed by CoRoT (Michel et al 2008, Science)

Theoretical calculations based on 'adiabatic' scaling laws:

'Lorentzian' scaling law

'Gaussian' scaling law

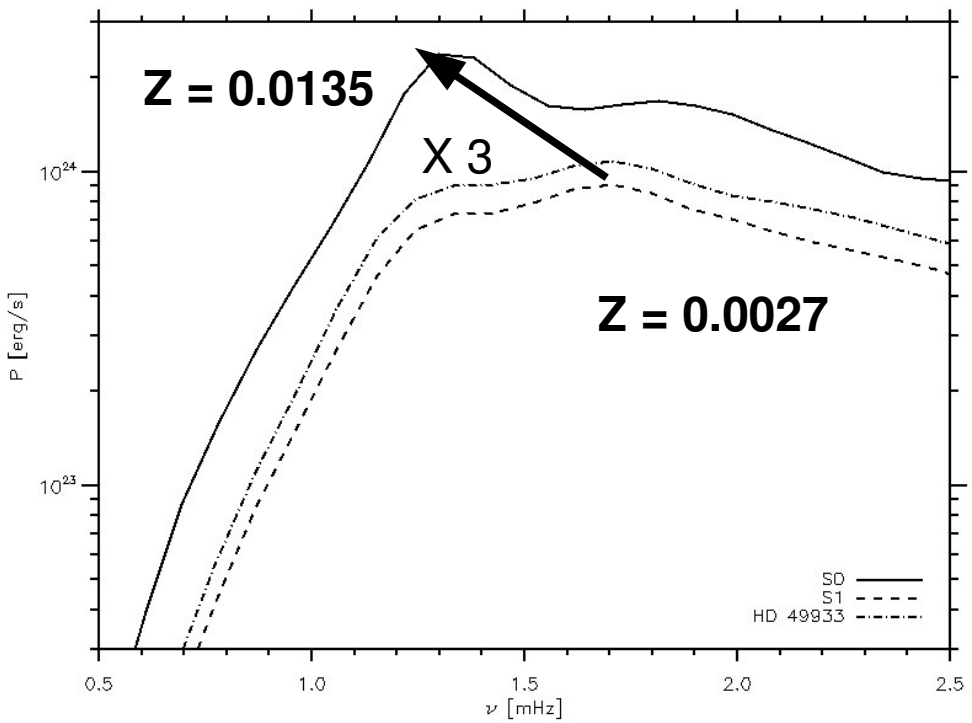
- For RG: We observe a *dispersion* with respect to the 'adiabatic' scaling law
- How to explain the dispersion: dispersion on Teff ? Metallicity effect ? Non-adiabtic effect ? Bias in the seismic analysis ? .... ?
- From a *validated/empirical* scaling law could we derive the ratio L/M ? (see also T. Kallinger's talk)

Effect of the (surface) metal abundance

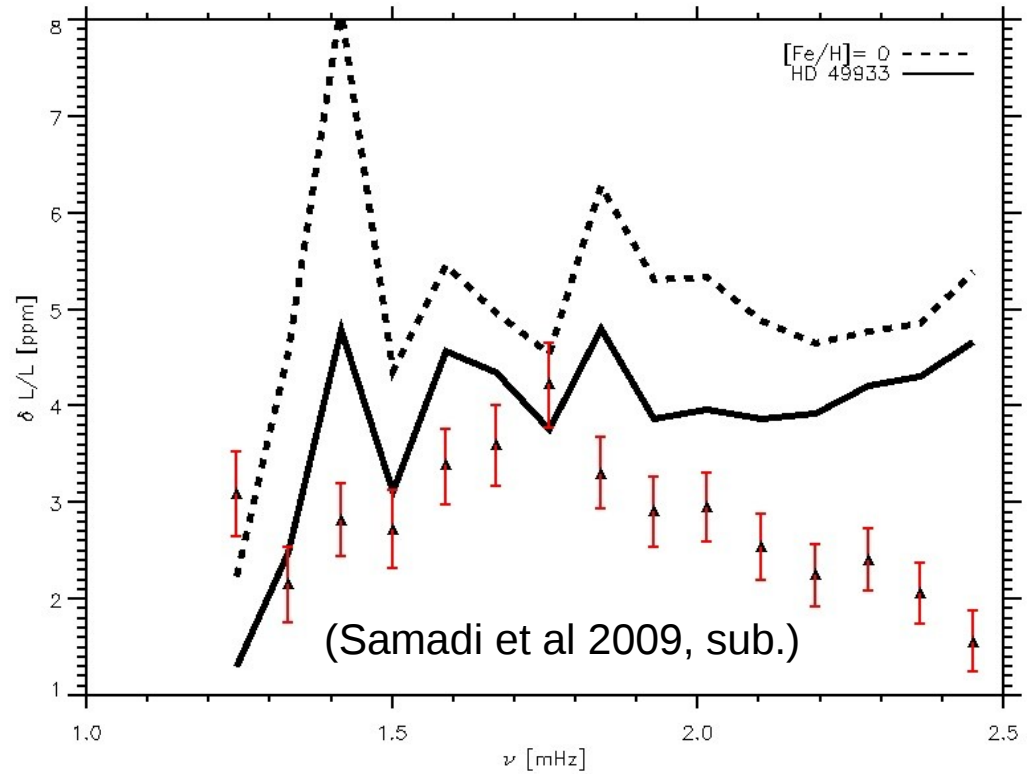
the case of HD 49933 (IR)

HD 49933 : [Fe/H] = -0.37
Teff=6750 K log g = 4.25

Mode excitation rates



Mode amplitude in intensity (IR)



CoRoT data (IR) : Appourchaux et al (2008) ; Benomar et al (2009, sub.)

Two 3D simulations computed with CO^{5}BOLD code by Hans Ludwig:

- [Fe/H] = 0 and [Fe/H] = -1
- Teff=6750 K log g = 4.25

Surface metal abundance:

⇒ Important effect on the mode amplitudes

Conclusion and perspectives

Why RGs are interesting ?

- Convection is more vigorous in RG because of the lower density (consequence of the lower gravity)
- Higher turbulent Mach number, stronger mode driving , larger amplitudes
- We can test the model of excitation in more extreme conditions, in a large set of faint RGs

- On *'first order'*, the 'Lorentzian' and *calibrated* 'adiabatic' scaling law reproduces in *average* the observed amplitudes
- But important *dispersion* which is *very likely* due to a our lack of knowledge of Teff and to the metal abundance which must differ from a star to an other.

Problem: we extrapolate the different scaling laws in the domain of the RG stars !

⇒ Need to be validated !

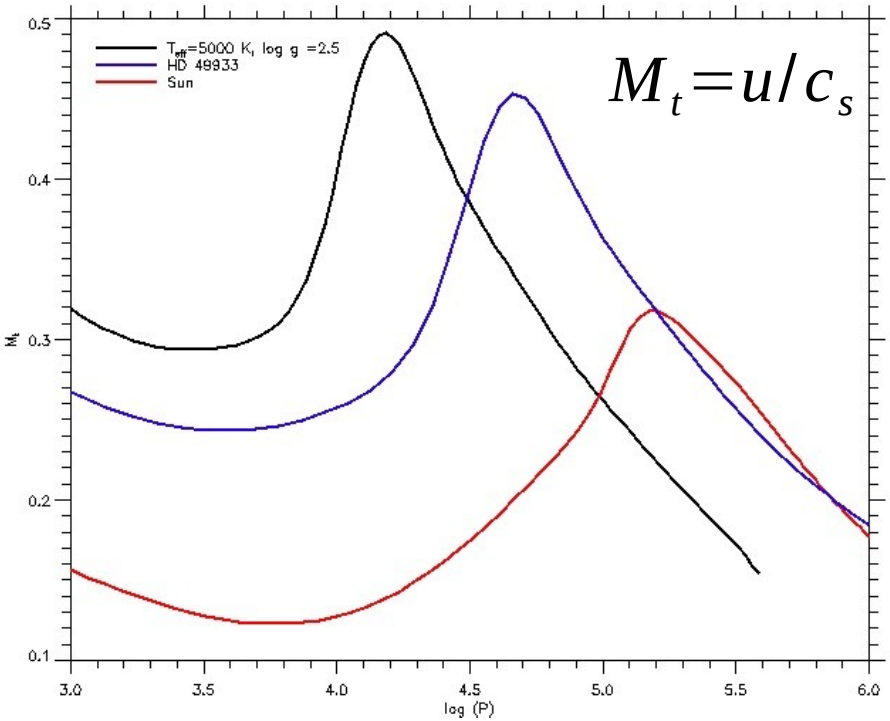
Perspectives:

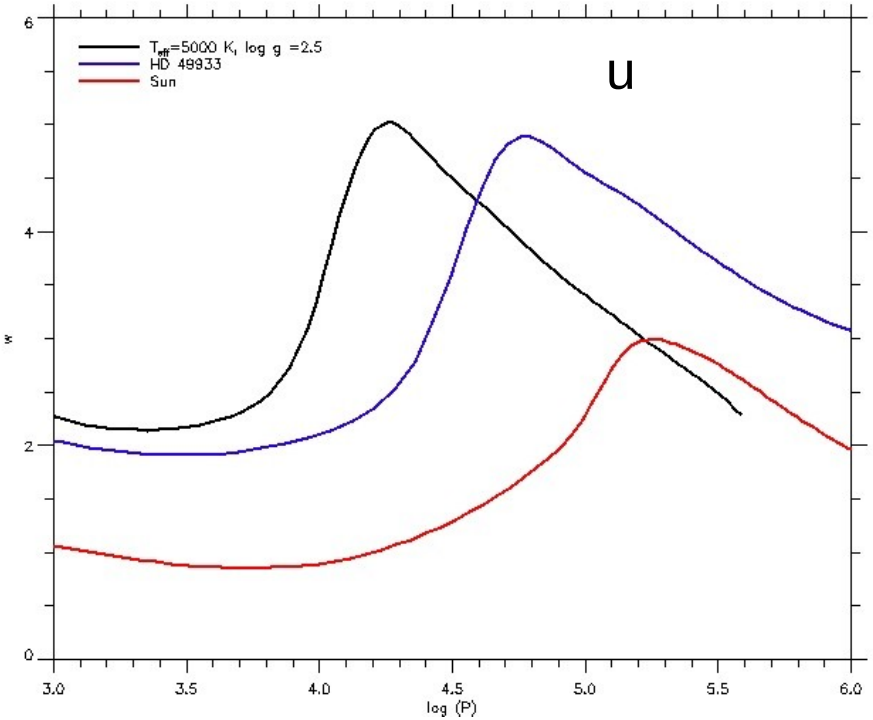
- Compute the expected mode excitation rates associated with a set of RG 3D simulations.
- Compute the expected mode damping rates (i.e. mode line widths) using the MAD code
- More reliable calculations of the mode amplitudes for RG ⇒ comparison with the observations

Properties of the convective zone in RG

3D simulations computed with CO^{5}BOLD code by Hans Ludwig
Here all 3D simulations have solar abundance

- More vigorous convection (larger **u**) than in the Sun
- As vigorous as in HD 49933
- More turbulent (larger $\mathbf{M_t}$) than in the Sun and HD 49933
- Allow to test the model of stochastic driving in more extreme conditions





RG : Teff=5000 K ; log g = 2.5

HD 49933 : Teff=6750 K ; log g = 4.25

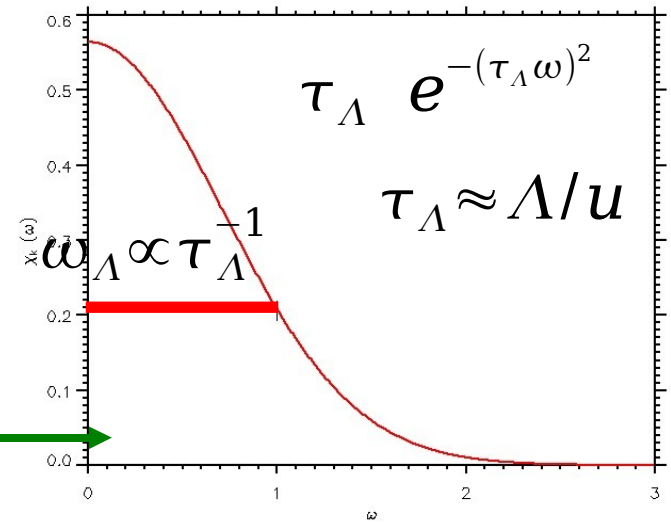
Sun

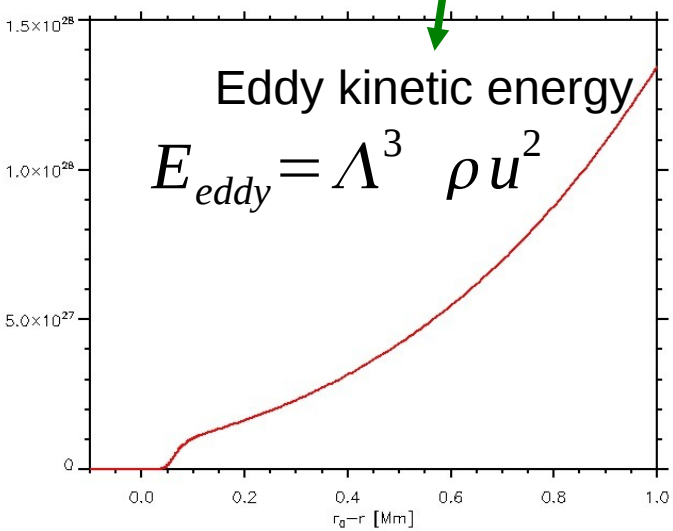
Part II Properties of the convective zone in RG

- What are the relevant quantities for modelling the mode driving ?
- Simplified expression for the mode excitation rates:

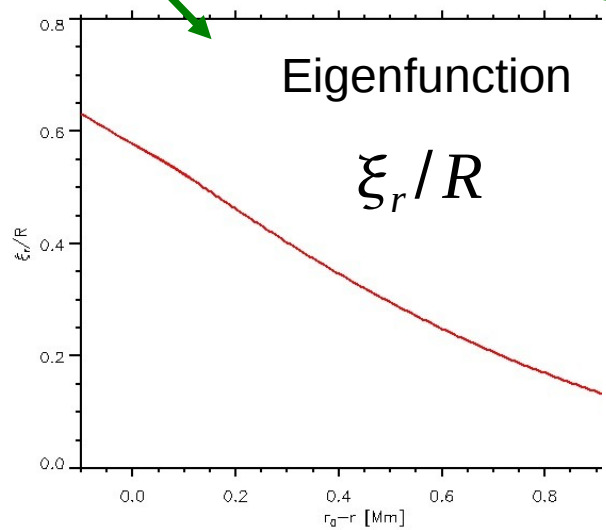
$$P \propto \frac{1}{I} \int dm \left(E_{eddy}\, \omega_0 \right) \left(\xi_r^2 \;\; M_t^2 \;\; \tau_\Lambda \omega_0 e^{-(\tau_\Lambda \omega_0)^2} \right)$$

Time-correlation function

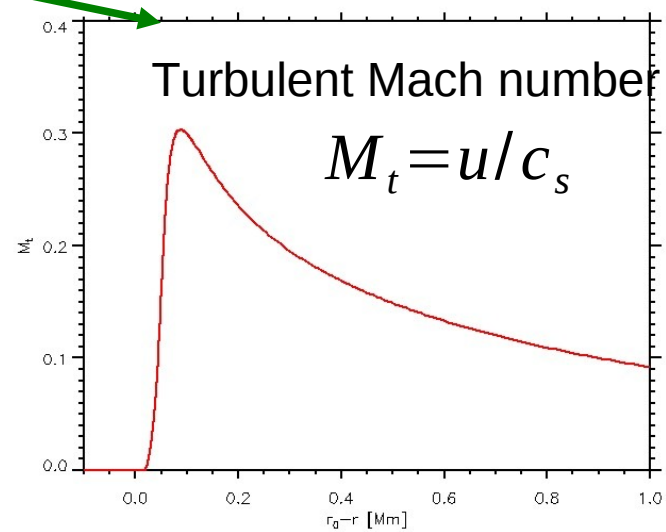




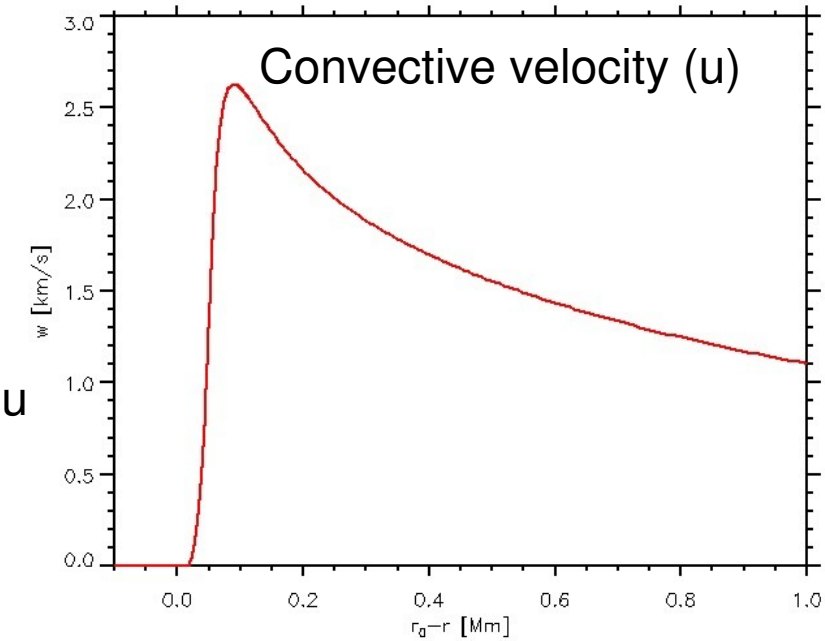
surface interior



surface interior



surface interior



u

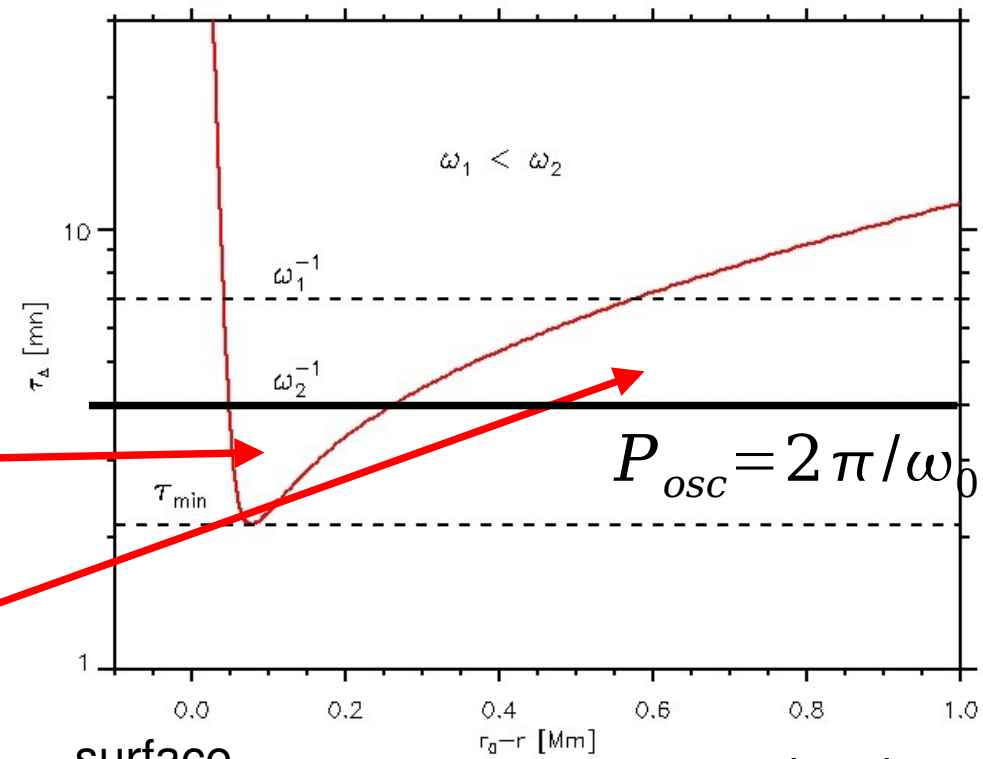
surface

interior

Upper part of the CZ :

largest u ➪ shortest τ

Eddy turn-over time: $\tau_\Lambda \approx \Lambda / u$



$\tau_\Lambda < P_{osc}$ ➪ **efficient** excitation

$\tau_\Lambda > P_{osc}$ ➪ **inefficient** excitation

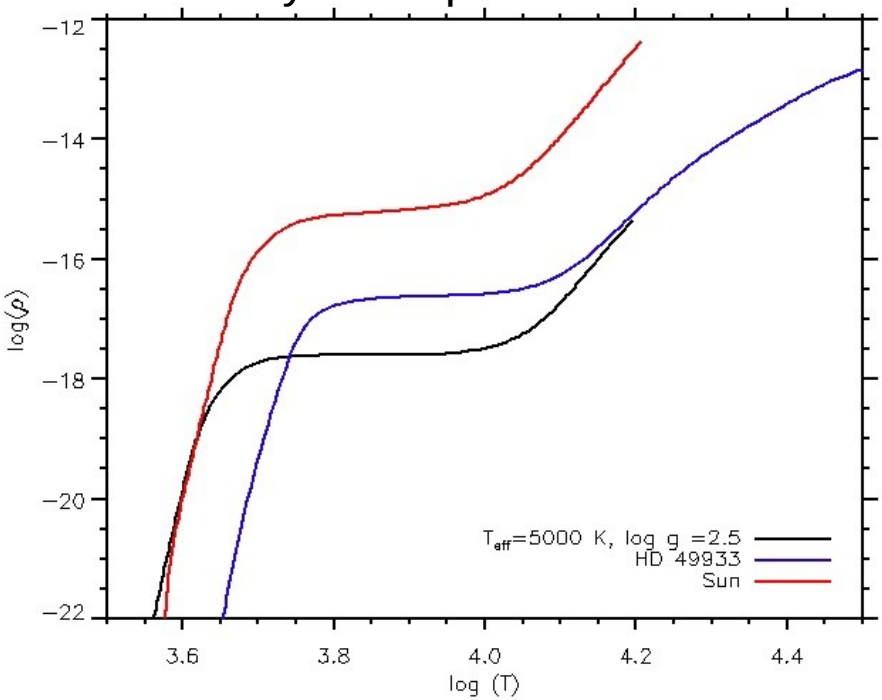
$P_{osc} = 2\pi / \omega_0$

surface

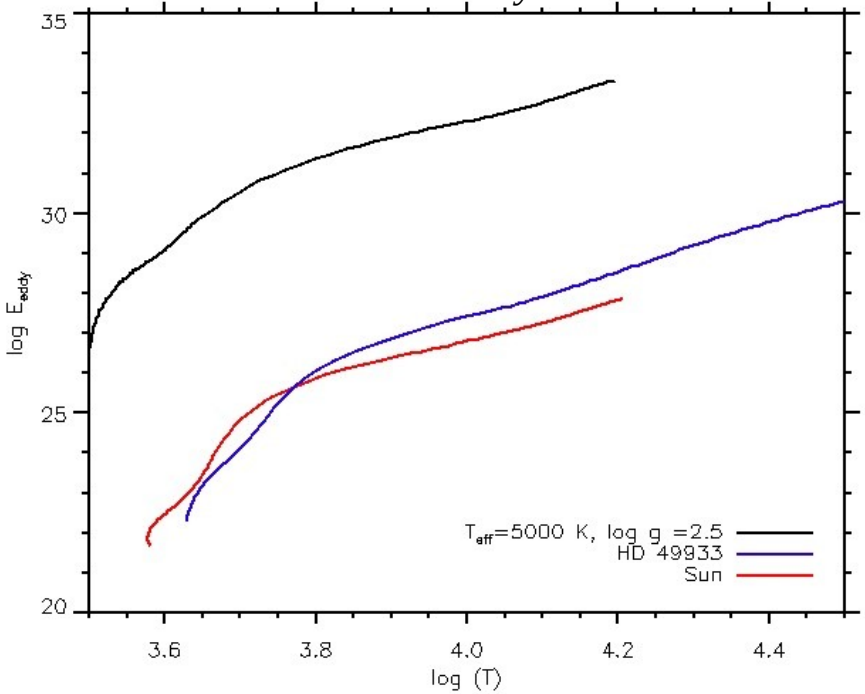
interior

Properties of the convective zone in RG

Density - Temperature



Eddy kinetic energy: $E_{eddy} = \Lambda^3 \ \rho u^2$



$$\Lambda \propto H_p = \frac{P}{\rho g} \propto \frac{T}{g}$$

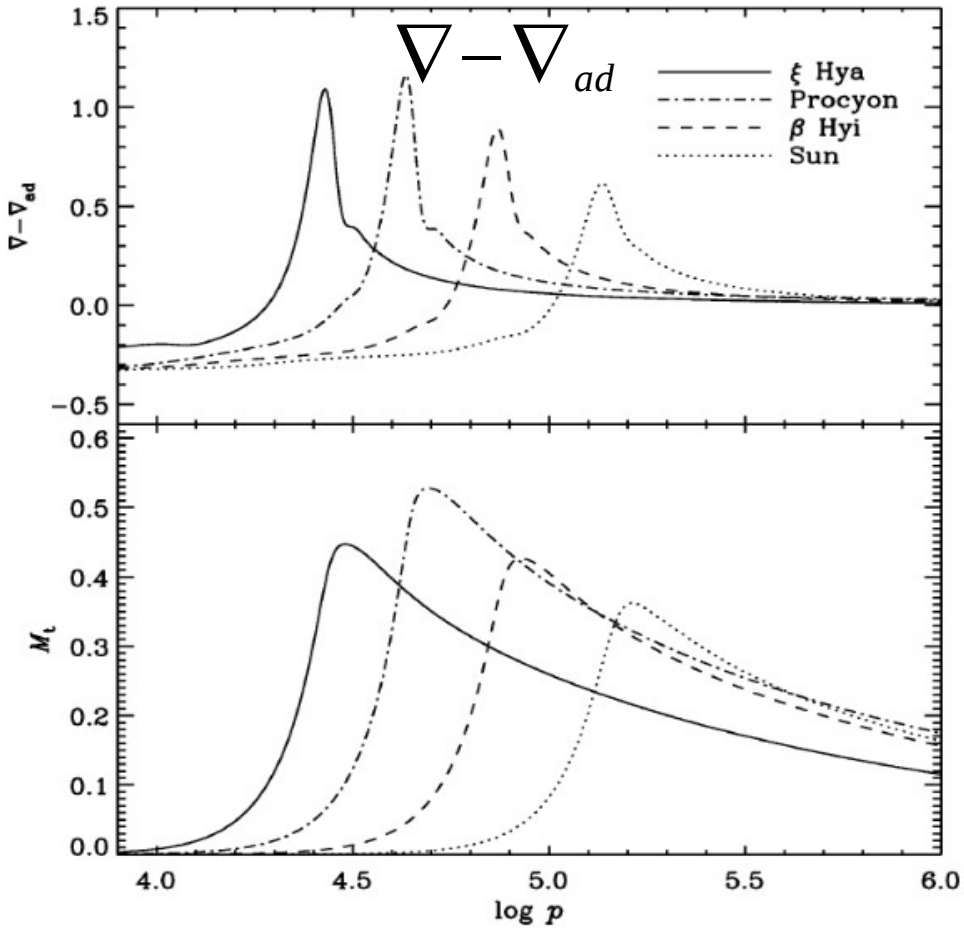
- Less dense super-adiabatic layers than in the Sun and in HD 49933
- This is a consequence of the low gravity
- This explains the more vigorous convective movements (larger **u**)

- Eddy kinetic energy larger than in the Sun or in HD 49933.
- The low gravity implies eddies of larger size (Γ)
- larger **u** and larger Γ ➪ higher kinetic energy despite the lower density

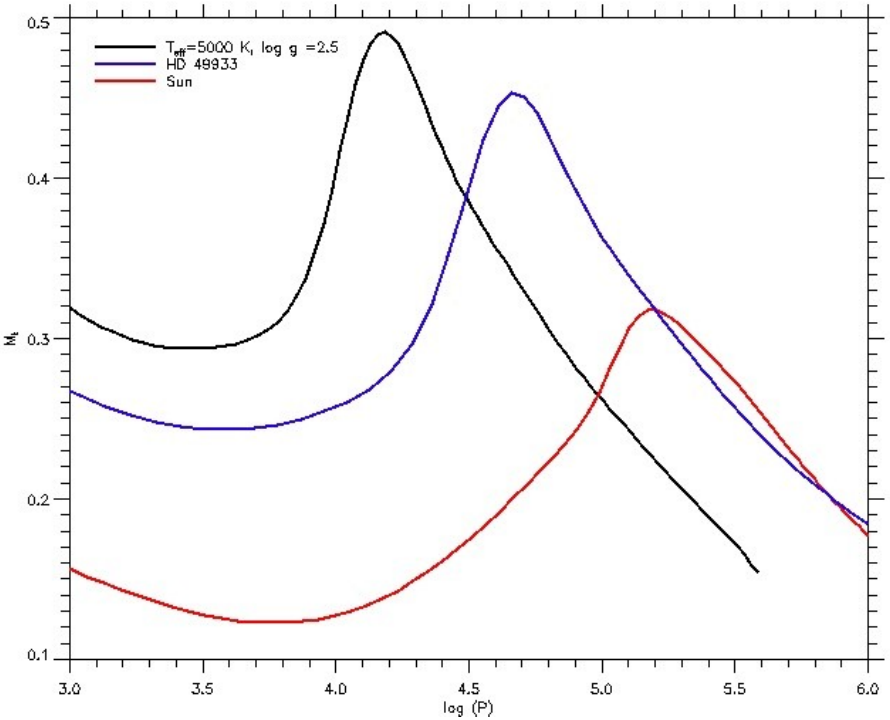
Properties of the convective zone in RG

Houdek & Gough (2002)

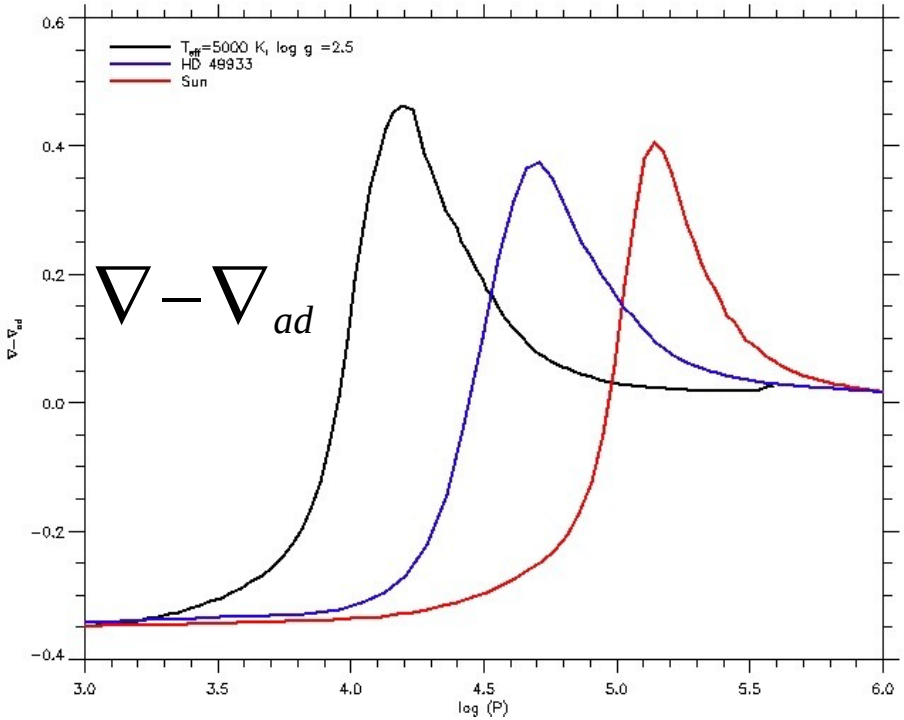
ξ Hya: Log Teff=3.69 log g = 2.9



3D simulations computed with CoBOLD code by Hans Ludwig



- More turbulent super-adiabatic layers than in Houdek & Gough's model
- Perhaps because of slightly higher gravity (log g= 2.9)



- Super-adiabatic gradient similar than in the Sun and in HD 49933 ; why ?

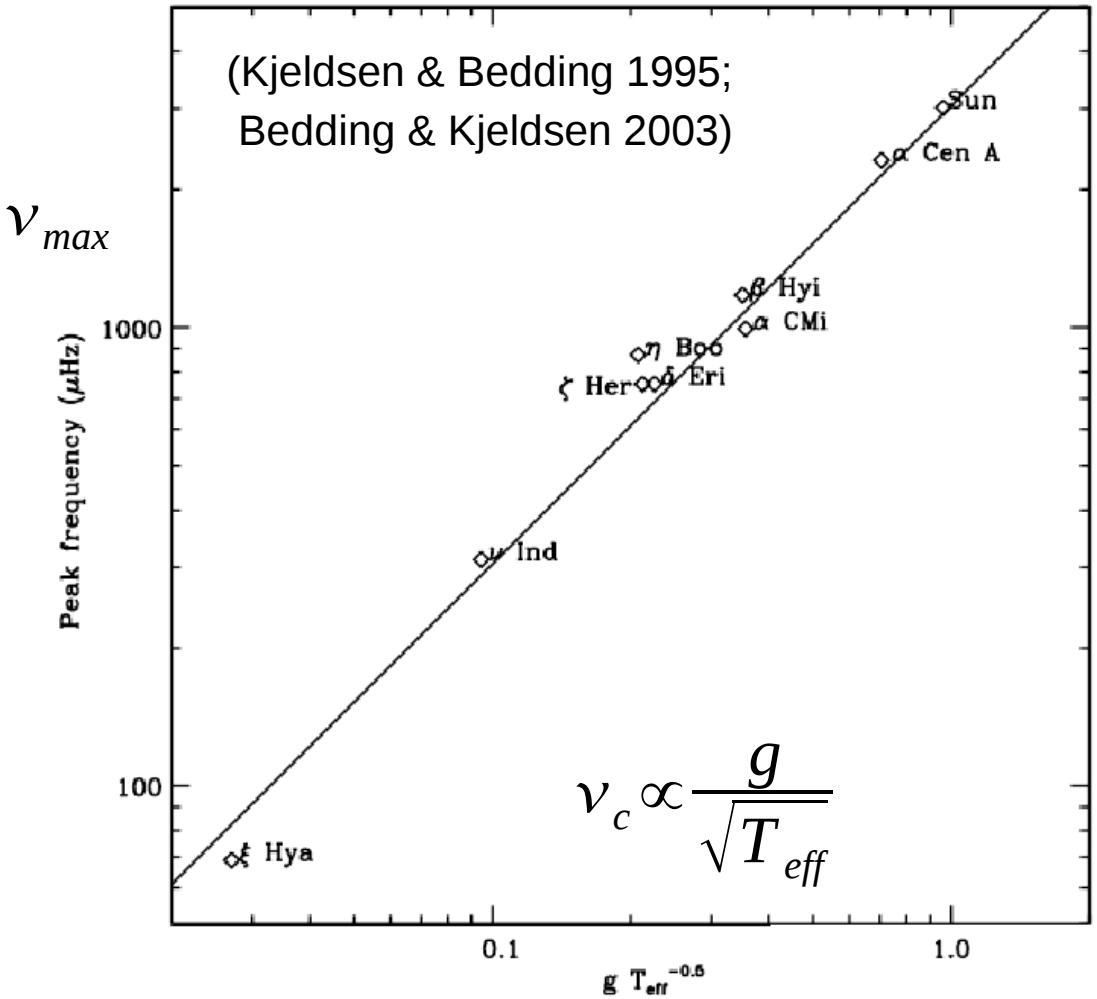


Figure 9 Observed versus expected peak frequencies, where expected values are based on scaling the acoustic cutoff frequency. The diagonal line has a slope of one and passes through the solar value.

Characteristic eddy turn-overtime:

$$\tau \approx \frac{\Lambda}{u} \quad \Rightarrow \quad \nu_{max} \approx \frac{u}{\Lambda}$$

Assuming fully convective envelop:

$$\sigma T_{eff}^4 = \rho C_p \delta T \quad u$$

Eddies accelerated by buoyancy force:

$$u^2 = g \delta \rho \quad \Lambda$$

We then derive :

$$\nu_{max} \propto g \quad \left(\frac{T_{eff}}{\rho} \right)^{1/3}$$

$$\nu_{max} \propto g^{2/3} \quad \left(R T_{eff} \right)^{1/3}$$