
**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 excitation rates ($P$)
main sequence stars

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

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

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

Lorentzian $\chi_k(\omega) : s = 2.6$
Gaussian $\chi_k(\omega) : s = 3.0$

$\frac{L}{M} \propto \frac{T_{\text{eff}}^4}{g}$
Mode amplitudes in velocity

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

- Damping rates (\( \eta \)) : Houdek et al (1999)
- Excitation rates (\( P \)) : from the scaling laws
  \[ P_{\text{max}} \propto \left( \frac{L}{M} \right)^s \]

\( V \) 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

Réza Samadi - 1st CoRoT International Symposium, Paris, February 2009
Mode amplitudes in intensity
CoRoT main-sequence stars

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):

\[ \frac{\delta L}{L} \propto \frac{V}{\sqrt{T_{\text{eff}}}} \]

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

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

(Michel et al 2008, Science)
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: $H$, $\Gamma$, and peak frequency ($\nu_{\text{max}}$)

Two cases:

- For resolved modes: $\Gamma > \delta \nu$
  \[
  \left\langle \left( \frac{\delta L}{L} \right)^2 \right\rangle = \pi \ \Gamma \ H
  \]
  $\delta L/L$: mode intensity fluctuations
  $\Gamma$: mode line-width ($\mu$Hz)
  $H$: mode height (ppm²/$\mu$Hz)

- For unresolved mode: $\Gamma < \delta \nu$ ($\sim 1$ single bin)
  \[
  \left\langle \left( \frac{\delta L}{L} \right)^2 \right\rangle = 2 \ \delta \nu \ H
  \]
  $\delta \nu$: frequency resolution ($\mu$Hz)
  For LRC01: $\delta \nu \sim 0.08 \mu$Hz

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

Mode intensity as function of $\nu_{\text{max}}$

Hekker et al (2009, sub.) ; see also P-X-100 about 900 RGs
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) ?
➢ \( \nu_{\text{max}} \) scales as the cut-off frequency (Kjeldsen & Bedding 1995, Bedding & Kjeldsen 2003), that is :

\[
\nu_{\text{max}} \propto \nu_c \propto \frac{g}{\sqrt{T_{\text{eff}}}}
\]

\[
\frac{L}{M} \propto \frac{T_{\text{eff}}^4}{g}
\]

\[
\nu_{\text{max}} \propto \frac{g}{\sqrt{T_{\text{eff}}}}
\]

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

➢ For red giants: \( T_{\text{eff}} \sim 4500 \text{ K} - 5500 \text{ K} \)
➢ We then assume \( T_{\text{eff}} \sim 5000 \text{ K} \)

\[\Rightarrow \text{Mode amplitudes scale as } 1/\nu_{\text{max}}\]
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:  \([\text{Fe/H}] = -0.37\)
Teff = 6750 K \(\text{log g} = 4.25\)

Mode excitation rates

\[ Z = 0.0135 \]
\[ Z = 0.0027 \]

Two 3D simulations computed with CO\(^5\)BOLD code by Hans Ludwig:
- \([\text{Fe/H}] = 0\) and \([\text{Fe/H}] = -1\)
- Teff = 6750 K \(\text{log g} = 4.25\)

Mode amplitude in intensity (IR)

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

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 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\textsuperscript{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 $M_t$) than in the Sun and HD 49933
- Allow to test the model of stochastic driving in more extreme conditions

$M_t = u / c_s$

\begin{align*}
\text{RG : } & \text{Teff}=5000 \text{ K ; } \log g = 2.5 \\
\text{HD 49933 : } & \text{Teff}=6750 \text{ K ; } \log g = 4.25 \\
\text{Sun : } & 
\end{align*}
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:

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

Eddy kinetic energy

\[ E_{\text{eddy}} = \Lambda^3 \rho u^2 \]

Eigenfunction

\[ \xi_r / R \]

Turbulent Mach number

\[ M_t = u / c_s \]

Time-correlation function

\[ \tau_\Lambda e^{-(\tau_\Lambda \omega)^2} \]

\[ \tau_\Lambda \approx \Lambda / u \]
Upper part of the CZ:
largest $u \Rightarrow$ shortest $\tau$

Convective velocity ($u$)

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

$\tau_\Lambda < P_{osc} \Leftrightarrow$ efficient excitation

$\tau_\Lambda > P_{osc} \Leftrightarrow$ inefficient excitation

$P_{osc} = 2\pi / \omega_0$
Properties of the convective zone in RG

Density - Temperature

➢ 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: $E_{\text{eddy}} = \Lambda^3 \rho u^2$

➢ Eddy kinetic energy larger than in the Sun or in HD 49933.
➢ The low gravity implies eddies of larger size ($\Gamma$)
➢ larger $u$ and larger $\Gamma$ $\Rightarrow$ higher kinetic energy despite the lower density
Properties of the convective zone in RG

Houdek & Gough (2002)

ζ 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?
Characteristic eddy turn-over time:

\[ \tau \approx \frac{\Lambda}{u} \implies \nu_{\text{max}} \approx \frac{u}{\Lambda} \]

Assuming fully convective envelop:

\[ \sigma T_{\text{eff}}^4 = \rho C_p \delta T \cdot u \]

Eddies accelerated by buoyancy force:

\[ u^2 = g \delta \rho \cdot \Lambda \]

We then derive:

\[ \nu_{\text{max}} \propto g \left( \frac{T_{\text{eff}}}{\rho} \right)^{1/3} \]

\[ \nu_{\text{max}} \propto g^{2/3} \left( RT_{\text{eff}} \right)^{1/3} \]

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.