Precision Asteroseismology
Celebration of the Scientific Opus of Wojtek Dziembowski
Proceedings IAU Symposium No. 301, 2013
A.C. Editor, B.D. Editor & C.E. Editor, eds.
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DOI: 00.0000/X000000000000000X

Energetical aspects of solar-like oscillations in red giants

Mathieu Grosjean[1]†, Marc-Antoine Dupret[1], Kevin Belkacem[2], Josefina Montalban[1], Reza Samadi[2]

[1]Institut d'astrophysique et de geophysique, Universite de Liege,
Allee du 6 Aout 17, B-4000 Liege, Belgium
email: grosjean@astro.ulg.ac.be

[2]LESIA Observatoire de Paris-Meudon
5 place Jules Janssen, F-92195 Meudon, France

Abstract. CoRoT and Kepler observations of red giants reveal a large variety of spectra of non-radial solar-like oscillations. So far, we understood the link between the global properties of the star and the properties of the oscillation spectrum ($\Delta\nu$, ν_{max}, period spacing). We are interested here in the theoretical predictions not only for the frequencies, but also for the other properties of the oscillations : linewidths and heights. The study of energetic aspects of these oscillations is of great importance to predict the mode parameters in the power spectrum. I will discuss under which circumstances mixed modes are detectable for red-giant stellar models from 1 to $2M_\odot$, with emphasis on the effect of the evolutionary status of the star along the red-giant branch on theoretical power spectra.

Keywords. red giants, solar-like oscillations, mixed-modes lifetimes

1. Introduction

In a first part we consider three stellar models of $1.5M_\odot$ on the red giant branch (Fig1). These models have been investigated in the adiabatic case by Montalbán *et al.* (2013) In a second part we selected models of 1, 1.7 and 2.1 $M_\odot$ which have the same number of mixed-modes in a large separation than the model B of $1.5M_\odot$(Fig1). All these models (see details in Table1) are computed with the code ATON (Ventura *et al.* (2008)) using the MLT for the treatment of the convection with $\alpha_{MLT} = 1.9$. The initial chemical composition is $X = 0.7$ and $Z = 0.02$.

Table 1. Characteristics of the models studied

Model	**Mass**[$M_\odot$]	**Radius**[$R_\odot$]	$T_{eff}[R_\odot]$	**log(g)**
A	1.5	5.17	4809	3.19
B	1.5	7.31	4668	2.88
C	1.5	11.9	4455	2.46
E	1.0	6.29	4549	2.84
F	1.7	8.06	4682	2.85
G	2.1	10.6	4665	2.72

To compute the mode lifetimes, we used the non-adiabatic pulsation code MAD (Dupret *et al.* 2002) with a non-local time-dependant treatment of the convection (TDC, Grigahcène *et al.* (2005) (G05), Dupret *et al.* 2006 (D06)). The amplitudes are computed using a stochastic excitation model (Samadi & Goupil (2001) (SG01)) with solar parameters for the description of the turbulence in the upper part of the convective envelope.

† This work is supported throught a PhD grant from the F.R.I.A.

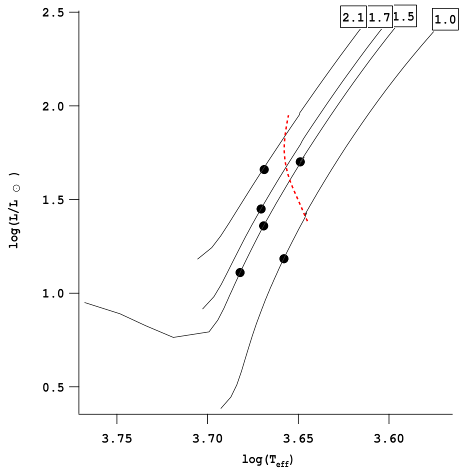

Figure 1. Evolutionary track for stars of 1, 1.5, 1.7, and 2.1 $M_{\odot}$ (from right to left). The models studied here are indicated by black dots. The dashed line represent the detectability limit we have found.

2. Energetical aspects

2.1. *Radiative damping*

The damping rate η of a mode is given by the expression :

$$\eta = -\frac{\int_V dW}{2\sigma I|\xi_r(R)|^2 M} \tag{2.1}$$

Where σ is the angular frequency of the mode, I the dimensionless mode inertia, ξ_r the radial displacement andR and M the total radius and mass of the star. In deep radiative zones we can write this asymptotic expression for the work integral (Dziembowski (1977), Van Hoolst *et al.* (1998), Godart *et al.* (2009)) :

$$-\int_{r_0}^{r_c} \frac{dW}{dr} dr \simeq \frac{K(l(l+1))^{3/2}}{2\sigma^3} \int_{r_0}^{r_c} \frac{\nabla_{ad} - \nabla}{\nabla} \frac{\nabla_{ad} N g L}{p r^5} dr \tag{2.2}$$

With N the Brunt-Vaisala frequency, p the pressure, and K a normalisation constant. The factor Ng/r^5 in this expression indicate that the radiative damping increase with the density contrast (Dupret *et al.* 2009).

2.2. *Convection - oscillation interaction*

For solar-like oscillations in red giants, in the upper part of the convective envelope, the thermal time scale, the oscillation period and the time-scale of most energetic turbulent eddies are of the same order.Hence it is important for the estimation of the damping to take into account the interaction between convection and oscillations. This is made using a non-local, time-dependant treatment of the convection which take into account the variations of the convective flux and of the turbulent pressure due to the oscillations (see G05, D06). The TDC treatment involves a complex parameter β in the closure term of the perturbed energy equation. It is adjusted so that the depression of the damping rates occur at ν_{max} as suggested by Belkacem *et al.* (2012).

2.3. *Stochastic excitation*

The estimation of the power injected into the oscillation by the turbulent Reynolds stress is made through a stochastic excitation model (SG01). To compute the height (H) of a

mode in the power spectrum we have to distinguish between :
- resolved modes, i.e. those with $\tau < T_{obs}/2$: $H = V^2(R) * \tau$
- unresolved modes, i.e. those with $\tau \geqslant T_{obs}/2$: $H = V^2(R) * T_{obs}/2$

where V(R) is the amplitude of the oscillation at the surface, τ the lifetime of the mode and T_{obs} the duration of observations. In this study, we used $T_{obs} = 1$year.

3. Results

From models A to C (Fig 2), we see a progressive attenuation of the modulation of the lifetimes due to an increase of the radiative damping. Because of the high radiative damping, mixed modes are not detectable in the model C. These results indicate a theoretical detectability limit for mixed modes on the red-giant branch. For a $1.5M_{\odot}$ star, with 1 year of observations, this limit occur around $\nu_{max} \simeq 50\mu Hz$ and $\Delta\nu \simeq 4.9\mu Hz$

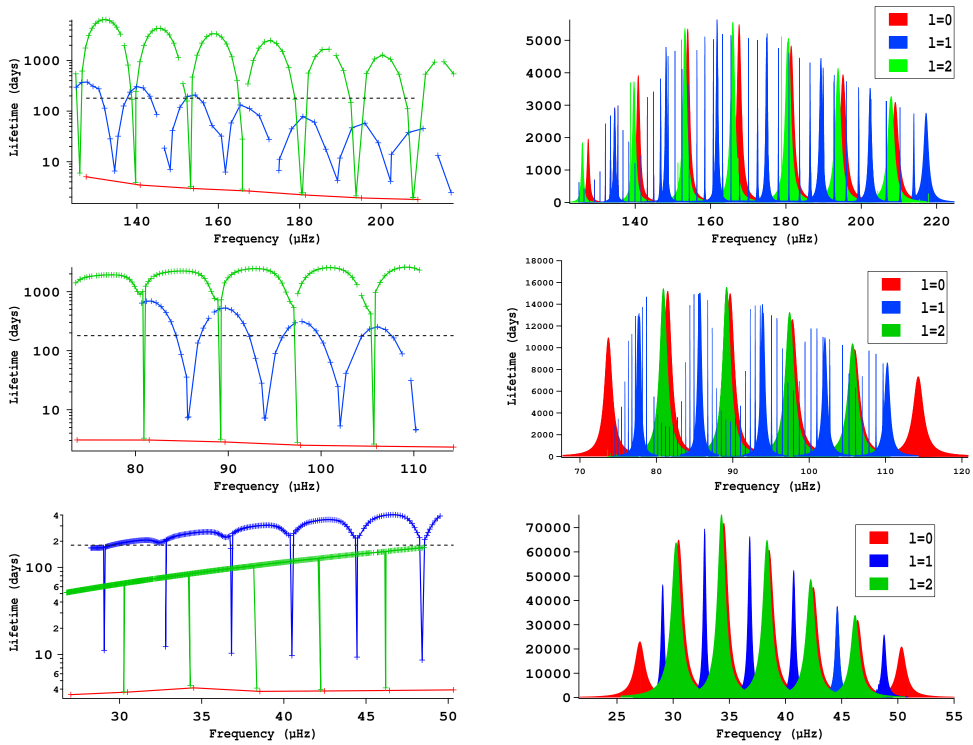

Figure 2. Lifetimes (left) and theoretical power spectra (right) for the model A (top), B (middle) and C (bottom).

The models with the same number of mixed modes in a large separation presents similar lifetimes patterns and similar power spectra (Fig3). Since the number of mixed modes in a large separation is approximately given by :

$$\frac{n_g}{n_p} \simeq \frac{\Delta\nu}{\Delta P \nu_{max}^2} \propto \left[\int \frac{N}{r} dr\right] M^{3/2} R^{5/2} T_{eff} \tag{3.1}$$

we find that this expression is a good theoretical proxi for the detectability of mixed modes.

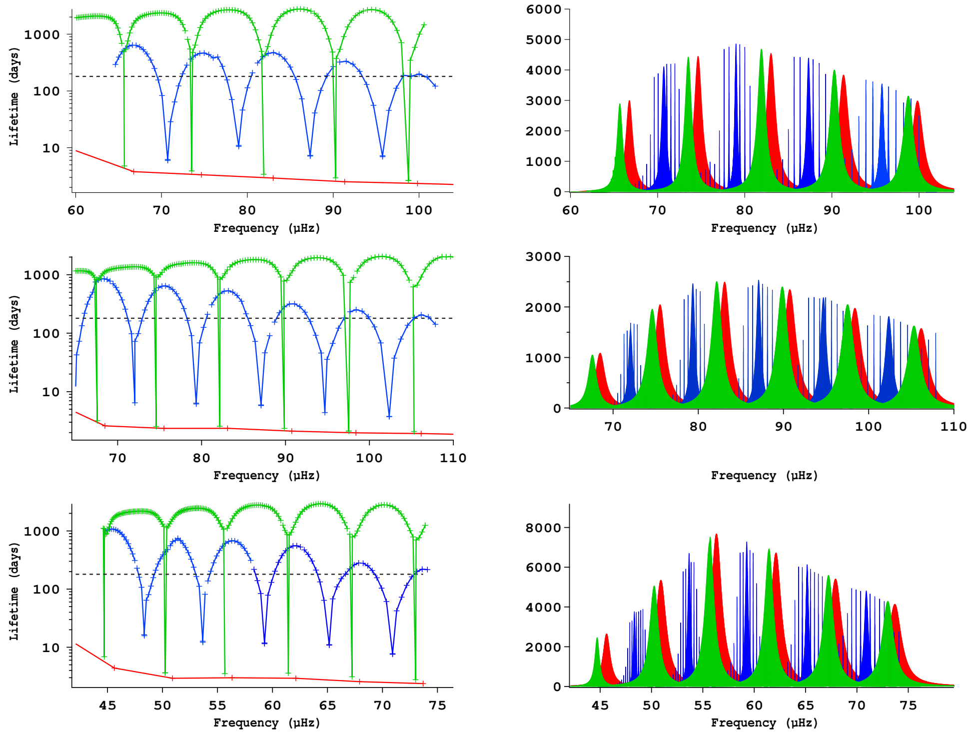

Figure 3. Lifetimes (left) and theoretical power spectra (right) for the model E (top), F (middle) and G (bottom).

4. Conclusions

These results extends to lower masses those found by Dupret *et al.* 2009. On the red giant branch, mixed modes are detectable until the radiative damping become too important. For a $1.5M_\odot$ star with 1 year of observations, mixed modes are detectable for stars with $\nu_{max} \gtrsim 50\mu Hz$ and $\Delta\nu \gtrsim 4.9\mu Hz$. Whatever the masse, models with the same number of mixed modes by large separation will present similar power spectra and the same detectability of mixed modes. This allow us to predict the detectability limit for other masses.

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