Precision Asteroseismology
Proceedings IAU Symposium No. 301, 2013
J. A. Guzik, W. J. Chaplin, G. Handler & A. Pigulski, eds.

doi:10.1017/S1743921313014555

Energy of solar-like oscillations in red giants

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

[1]Institut d'astrophysique et de géophysique, Université de Liège,
Allée du 6 Août 17, B-4000 Liège, 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 nonradial solar-like oscillations. So far, we understood pretty well the link between the global properties of the star (radius, mass, evolutionary state) and the properties of the oscillation spectrum ($\Delta\nu$, $\nu_{\max}$, period spacing). We are interested here in the theoretical predictions of two other components of a power spectrum, the mode linewidths and heights. The study of the energy of the oscillations is of great importance to predict the peak parameters in the power spectrum. We will discuss circumstances under which mixed modes are detectable for red-giant stellar models from 1 to 2 $M_\odot$, 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-mode lifetimes

1. Introduction

We consider three stellar models of 1.5 $M_\odot$ on the red-giant branch (Fig. 1). These models have been investigated in the adiabatic case by Montalbán & Noels (2013). We have also selected models of 1.0, 1.7 and 2.1 $M_\odot$ which have the same number of mixed modes in a large separation as in model B of 1.5 $M_\odot$ (Fig. 1). All of these models (see details in Table 1) were computed with the code ATON (Ventura *et al.* 2008) using the mixing-length theory (MLT) for the treatment of the convection with $\alpha_{\rm MLT} = 1.9$. The initial chemical composition is $X = 0.7$ and $Z = 0.02$.

Table 1. Characteristics of the models studied

Model	Mass [$M_\odot$]	Radius [$R_\odot$]	$T_{\rm eff}$ [K]	$\log g$
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 nonadiabatic pulsation code MAD (Dupret *et al.* 2002) with a nonlocal time-dependent treatment of convection (TDC, Grigahcène *et al.* 2005 (G05), Dupret *et al.* 2006 (D06)). The amplitudes were 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 through a PhD grant from the F.R.I.A.

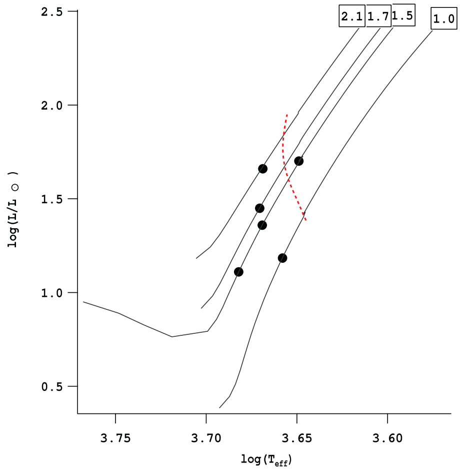

Figure 1. Evolutionary tracks for stars of 1.0, 1.5, 1.7, and 2.1 $M_\odot$ (from right to left). The models studied here are indicated by black dots. The dashed line represents the detectability limit we have found.

2. Energetic aspects

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 and R and M the total radius and mass of the star. In deep radiative zones we can write the following asymptotic expression for the work integral (Dziembowski 1977, Van Hoolst *et al.* 1998, Godart *et al.* 2009):

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

The factor Ng/r^5 in this expression indicates that the radiative damping increases with the density contrast.

For solar-like oscillations in red giants, in the upper part of the convective envelope, the thermal time scale, the oscillation period and the timescale 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 nonlocal, time-dependent treatment of the convection which takes 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 occurs at the frequency of maximum oscillation power, $\nu_{\rm max}$, as suggested by Belkacem *et al.* (2012).

The estimation of the power injected into the oscillations by the turbulent Reynolds stresses 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 $\tau < T_{\rm obs}/2$: $H = V(R)^2 \times \tau$,

— unresolved modes, i.e. those with $\tau \geqslant T_{\rm obs}/2$: $H = V(R)^2 \times T_{\rm obs}/2$,

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

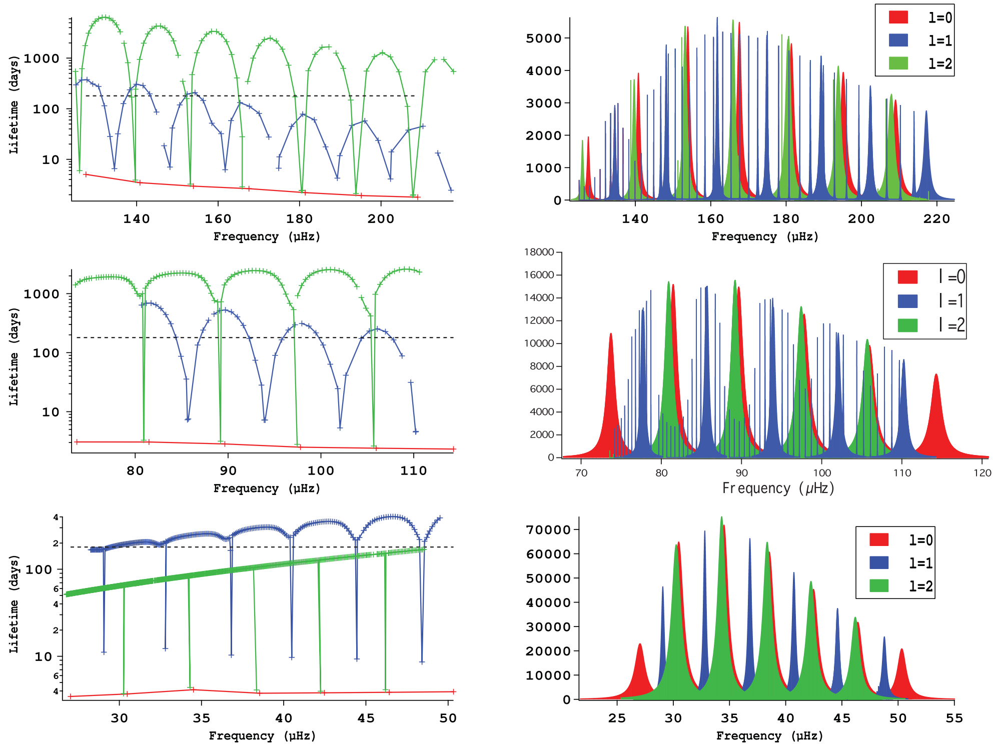

Figure 2. Lifetimes (left) and theoretical power spectra (right) for the model A (top), B (middle) and C (bottom).

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 model C. These results indicate a theoretical detectability limit for mixed modes on the red-giant branch. For a 1.5 $M_\odot$ star, with one year of observations, this limit occurs around $\nu_{\rm max} \simeq 50$ μHz and $\Delta\nu \simeq 4.9$ μHz.

The models with the same number of mixed modes in one large separation present similar lifetime patterns and similar power spectra (Fig. 3). Since the number of mixed modes in a large separation is approximately given by

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

we find that this expression provides a good theoretical proxy for the detectability of mixed modes.

4. Conclusions

These results extend to lower masses those found by Dupret *et al.* (2009). On the red-giant branch, mixed modes are detectable until the radiative damping becomes too important. For a 1.5 $M_\odot$ star with 1 year of observations, mixed modes are detectable for stars with $\nu_{\rm max} \gtrsim 50$ μHz and $\Delta\nu \gtrsim 4.9$ μHz. Whatever the mass, models with the same number of mixed modes in a large separation will present similar power spectra

https://doi.org/10.1017/S1743921313014555 Published online by Cambridge University Press

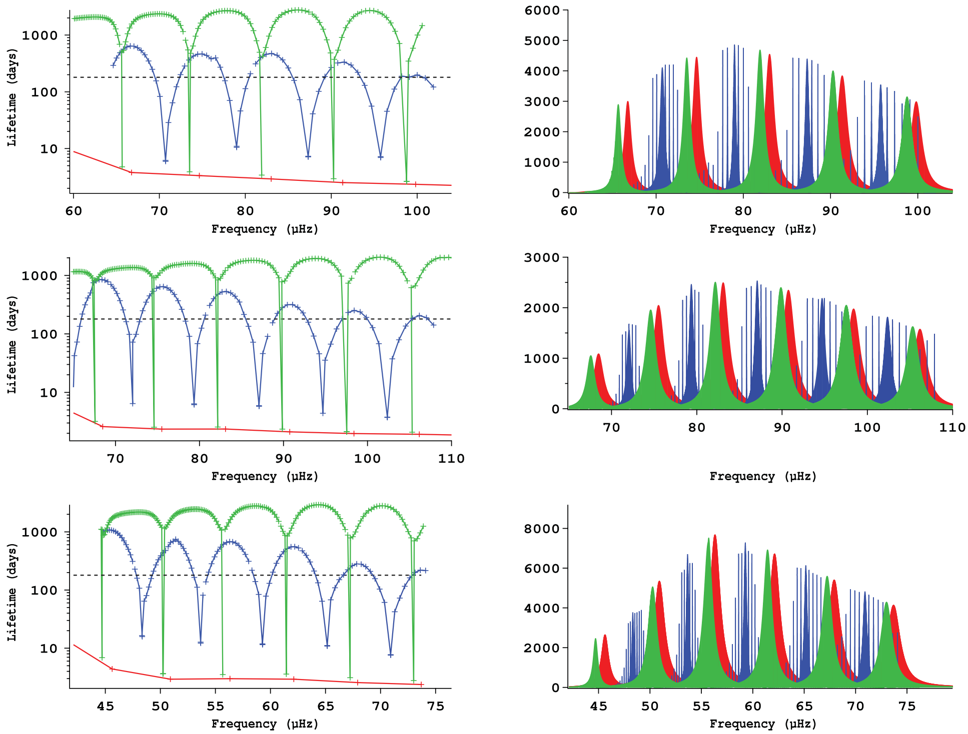

Figure 3. Lifetimes (left) and theoretical power spectra (right) for the model E (top), F (middle) and G (bottom).

and the same detectability of mixed modes. This criterium can thus be used to predict the detectability limit of mixed modes in red giants of different masses.

References

Belkacem, K., Dupret, M.-A., Baudin, F., Appourchaux, T., Marques, J. P., & Samadi, R. 2012, *A&A*, 540, L7

Dupret, M.-A., De Ridder, J., Neuforge, C., Aerts, C., & Scuflaire, R. 2002, *A&A*, 385, 563

Dupret, M.-A., Goupil, M.-J., Samadi R., & Grigahcène, A., Gabriel M. 2006, in: K. Fletcher (ed.), Proceedings of SOHO 18/GONG 2006/HELAS I, *Beyond the Spherical Sun*, ESA SP-624, p. 78.1

Dupret, M.-A., Belkacem, K., Samadi, R., *et al.* 2009, *A&A*, 506, 57

Dziembowski, W. A. 1977, *AcA*, 27, 95

Godart, M., Noels, A., Dupret, M.-A., & Lebreton, Y. 2009, *MNRAS*, 396, 1833

Grigahcène, A., Dupret, M.-A., Gabriel, M., Garrido, R., & Scuflaire, R. 2005, *A&A*, 434, 1055

Montalbán, J. & Noels, A. 2013, in: J. Montalbán, A. Noels, & V. Van Grootel (eds.), 40th Liège International Astrophysical Colloquium. *Ageing Low Mass Stars: From Red Giants to White Dwarfs*, EPJ Web of Conferences, 43, 03002

Samadi, R. & Goupil, M.-J. 2001, *A&A*, 370, 136

Van Hoolst, T., Dziembowski, W. A., & Kawaler, S. D. 1998, *MNRAS*, 297, 536

Ventura, P., D'Antona F. & Mazzitelli, I. 2008, *Ap&SS*, 316, 93