# Consistent seismic probing of subgiant and red-giant stars using EGGMiMoSA

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## Abstract

*Context:* Owing to the detection of mixed-modes, subgiant and red-giant stars provide a unique opportunity to probe the complete stellar structure of solar-like stars and to constrain stellar structure and evolution models.
*Aims:* Taking advantage of the asymptotic description of mixed-modes, we develop a method that coherently accounts for the complex oscillation spectra of subgiant and red-giant stars. We investigate the probing potential of this technique and define robust seismic indicators, relevant of the stellar structure in order to constrain stellar models.
*Results:* The **EGGMiMoSA** (**E**xtracting **G**uesses about **G**iants via **Mi**xed-**Mo**des **S**pectrum **A**djustment) method is fast (less than a second execution) and allows to study the evolution of the typical mixed-modes spectra parameters along a grid of models ranging from the subgiant to the red-giant phases.

## Motivation

- Mixed-modes are a unique opportunity to probe the whole stellar interior,
- Red-giants are essential to galactic archaeology,
- Numerous oscillation spectra gathered (CoRoT, Kepler and PLATO).

## Method

- Asymptotic description of mixed modes (Shibahashi 1979) adapted by Mosser et al. 2017:

$$\tan\theta_p = q \tan\theta_g, \qquad (1)$$

with:

$$\theta_p = \pi\left(\frac{\nu}{\Delta\nu} - \epsilon_p\right), \qquad (2)$$

$$\theta_g = \pi\left(\frac{1}{\nu\Delta\pi_1} - \epsilon_g + \frac{1}{2}\right) \qquad (3)$$

the pressure and gravity modes phases.
- Function of the frequency $\nu$ and takes only 5 different parameters: the large separation $\Delta\nu$, the period spacing $\Delta\pi_1$, the pressure and gravity offsets $\epsilon_p$ and $\epsilon_g$ and the coupling factor $q$.
- The fitting of the parameters is carried out through a Levenberg-Marquardt minimisation.

### Pros

- Fast convergence
- 5 physical parameters
- Automated

### Cons

- Need for parameters estimation

## Mixed-modes spectra

We present here several fitted spectra for a $1M_\odot$, solar composition track represented in Fig. 1.

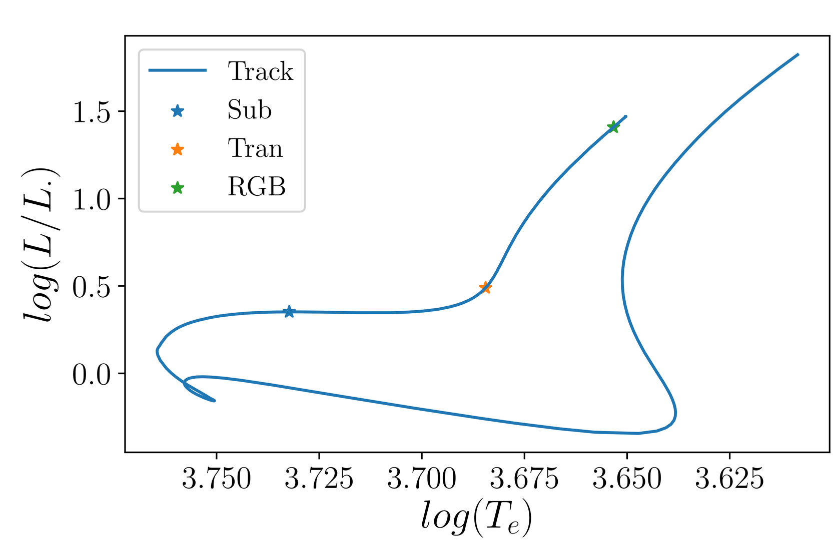


Figure 1:Position of the models presented in Figs. 2 to 4.

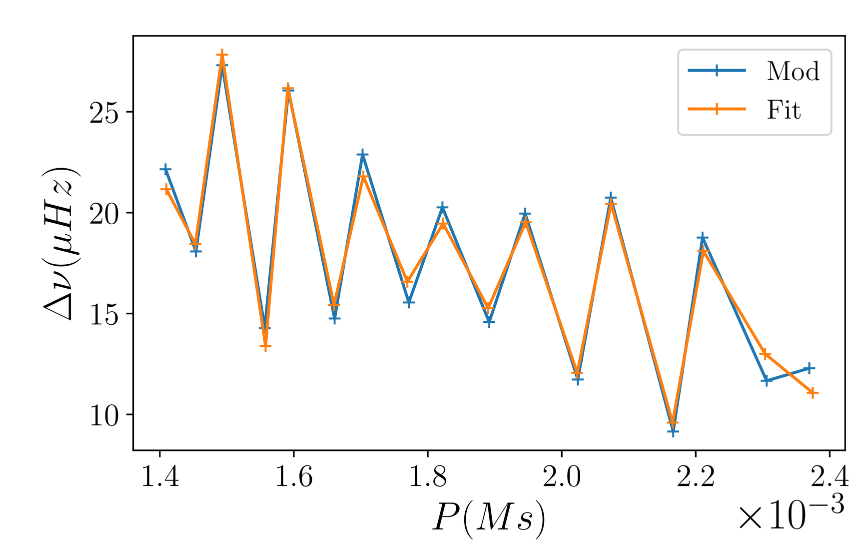


Figure 3:Same as Fig. 2 for a model at the transition between subgiant and red-giant phases.

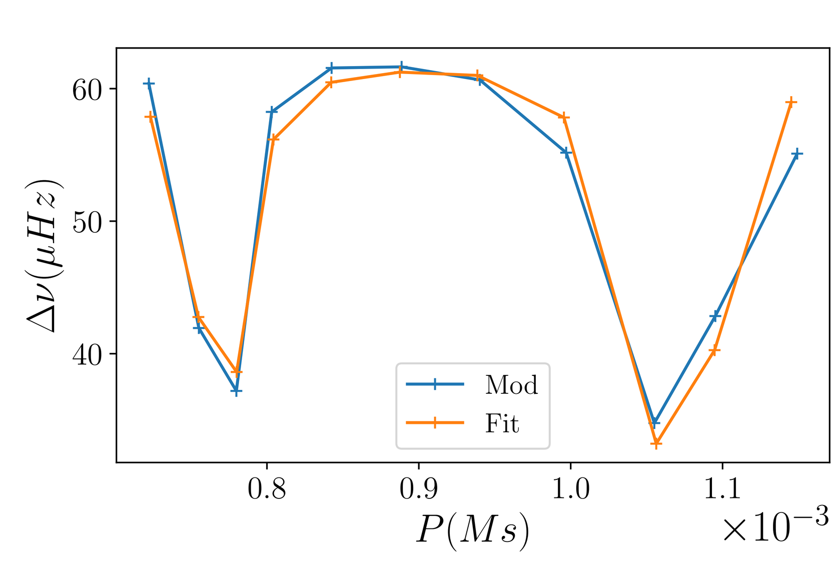


Figure 2:Comparison between model (in blue) and fitted (orange) spectra with EGGMiMoSA for a young subgiant model.

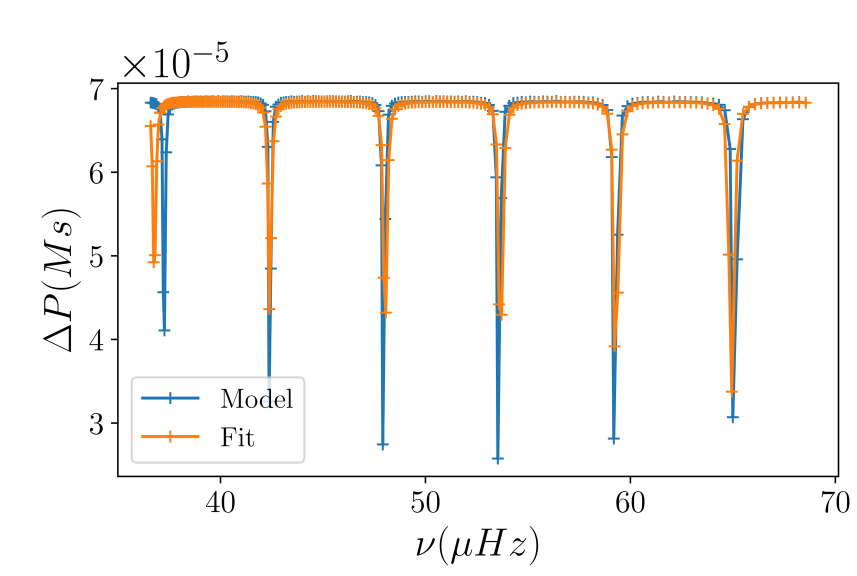


Figure 4:Same as Fig. 2 for an evolved red-giant model.

## Seismic indicators

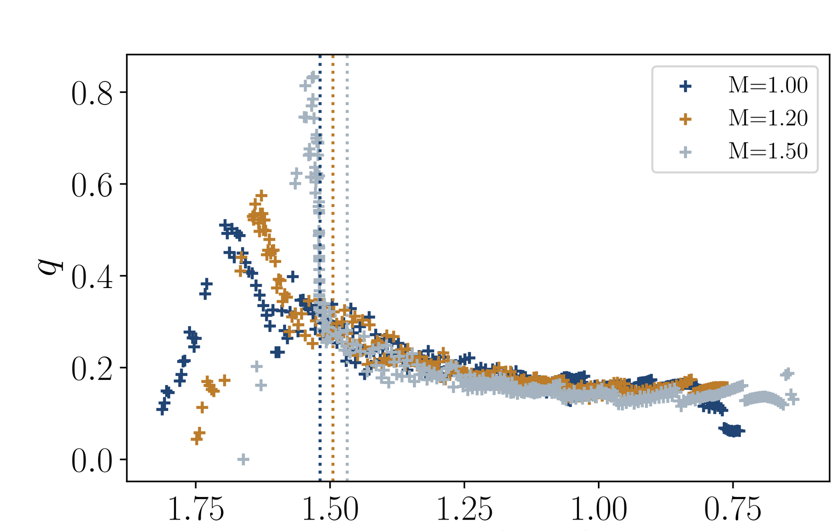


Figure 5:Evolution of the coupling factor with the asymptotic large separation, symbolising stellar evolution. The colours represent the different masses. The vertical dotted lines correspond to the transition between the subgiant and red-giant phases

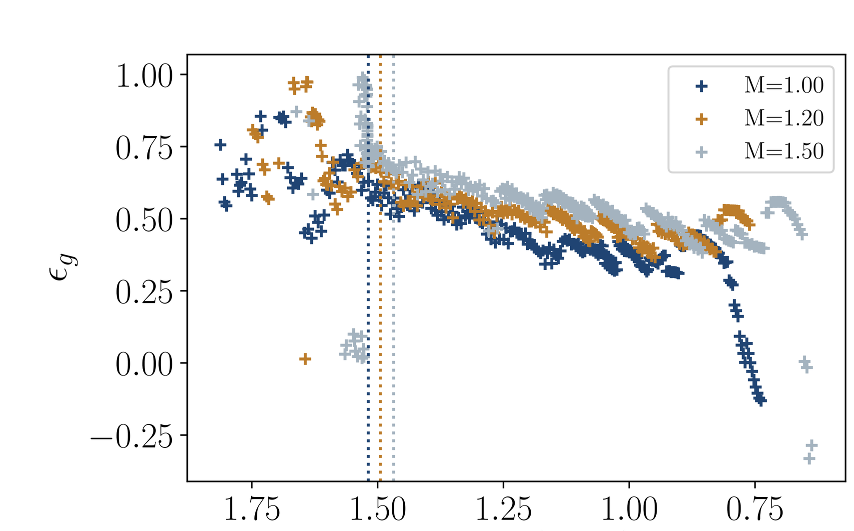


Figure 6:Evolution of the gravity offset as in Fig. 5.

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## Conclusions

- Fast ($< 1s$) adjustment of the complex mixed-modes spectra,
- Efficient thanks to appropriate parameters estimation,
- (To our knowledge,) first evolution of $\epsilon_g$ on a model grid,
- $q$ evolution agrees with Mosser et al. 2017 & Pinçon et al. 2020
- $\epsilon_g$ agrees with Mosser et al. 2018 and Pinçon et al. 2019

## Perspective

- Farnir et al. 2021 in prep.,
- Include $\nu$ dependency in $q$,
- Higher order contribution to $\theta_p$,
- Acoustic and buoyancy glitches treatment,
- Modelling of observed stars.

## References

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