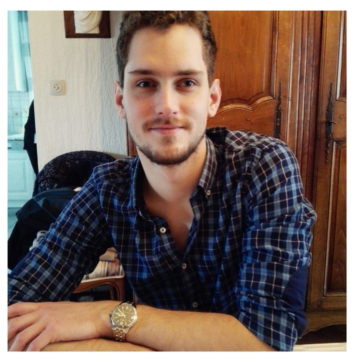

Comprehensive stellar seismic analysis

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Abstract

Aims: We develop a method that provides a comprehensive analysis of the oscillation spectra of solar-like pulsators. We define new seismic indicators that should be as uncorrelated and as precise as possible and should hold detailed information about stellar interiors. This is essential to improve the quality of the results obtained from asteroseismology as it will provide better stellar models which in turn can be used to refine inferences made in exoplanetology and galactic archeology.
Method: The presented method – WhoSGlAd – relies on *Gram-Schmidt*'s orthogonalisation process. A Euclidean vector subspace of functions is defined and the oscillation frequencies are projected over an orthonormal basis in a specific order. This allows the obtention of independent coefficients that we combine to define independent seismic indicators.
Results: The developed method has been shown to be stable and to converge efficiently for solar-like pulsators. Thus, detailed and precise inferences can be obtained on the mass, the age, the chemical composition and the undershooting in the interior of the studied stars. However, attention has to be paid when studying the helium glitch as there seems to be a degeneracy between the influence of the helium abundance and that of the heavy elements on the glitch amplitude. As an example, we analyse the 16CygA (HD 186408) oscillation spectrum to provide an illustration of the capabilities of the method.

Motivations

- **Convection zone glitch** should provide information on convection and overshooting,
- **Helium glitch** should allow inferences on the helium content.

However,

- **Smooth component** of the spectrum information is often discarded in glitches analyses,
- Use of correlated indicators,

⇒ Need of a method that allows statistically relevant inferences and uses all of the available information:

WhoSGlAd

Starting point : Verma et al. (2014)

Method

Relies only on linear algebra ⇒ Fast computations and definition of independent indicators.
Building steps:

- Define the oscillation frequencies Euclidean vector space,
- Separate the oscillation spectrum into two components:
  1. Smooth component,
  2. Glitch / oscillating component.
- Linearise the glitch component,
- Build an orthonormal basis over the vector space by using *Gram-Schmidt*'s algorithm,
- Project the observed frequencies over the basis following the proper order and retrieve independant coefficients,
- Combine the coefficients to build indicators as uncorrelated as possible.

Indicators

Small separation ratios

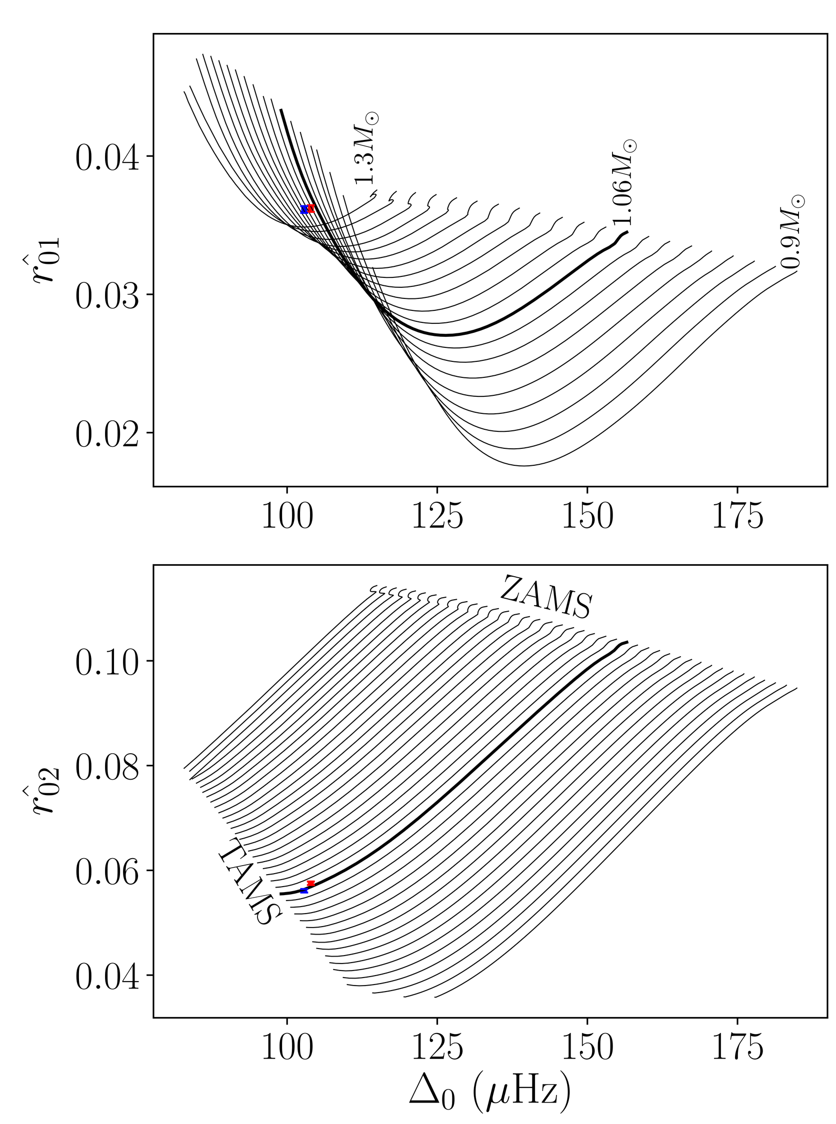

Figure 1: Seismic HR diagram defined with the new indicators $\hat{r_{0l}}$ and computed along a grid of models of masses $0.9\ M_\odot$ to $1.3\ M_\odot$ (right to left). The blue marker shows the observed value for 16 Cyg A while the red one shows the value corrected for the surface effects following Kjeldsen et al. (2008)'s prescription.

Definition, from the **smooth component**, of small separation ratios estimators inspired by those introduced by Roxburgh & Vorontsov (2003) to reduce the influence of surface effects.

Helium glitch amplitude

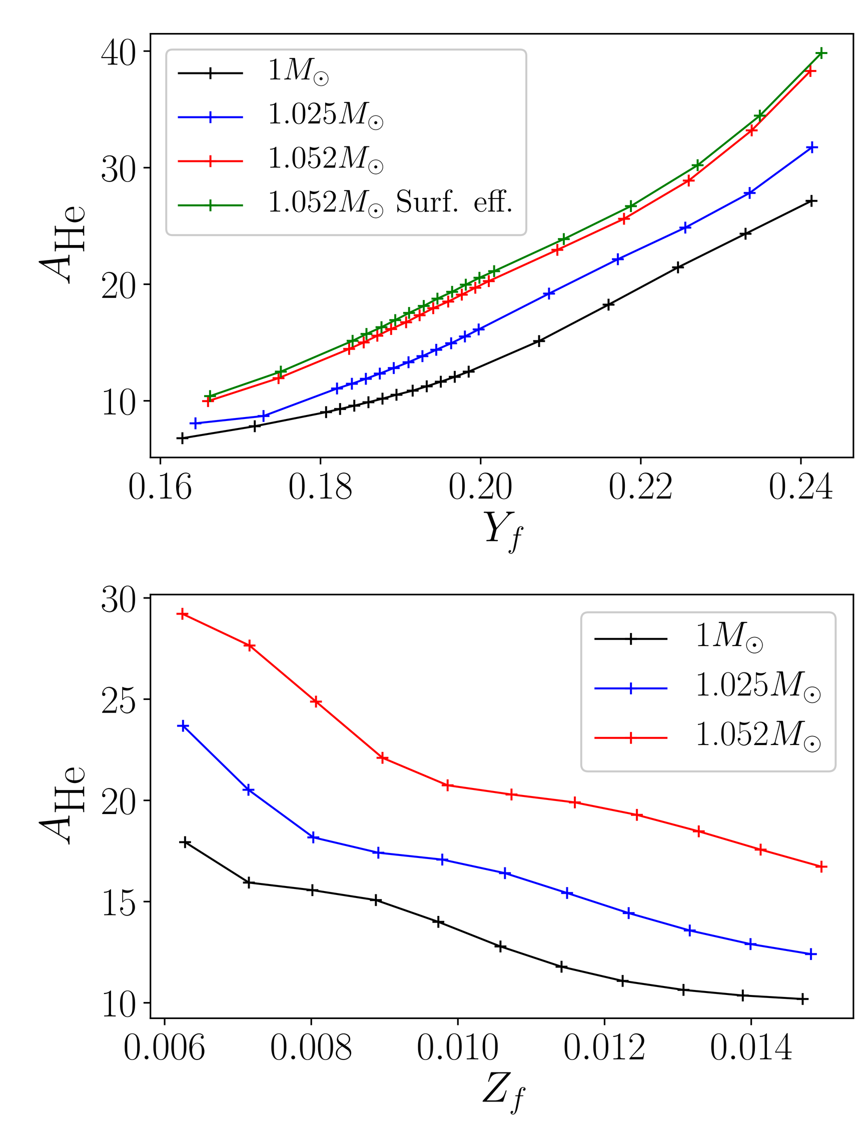

Figure 2: Evolution of the helium glitch amplitude $A_{\rm He}$ with Y_f (top) and Z_f (bottom). Each track corresponds to a given mass labeled in the legend. Each point has been computed with the same large separation to remain at the same evolutionary stage. On the top panel, the green line represents the amplitude for a $1.052M_\odot$ model of which the frequencies have been corrected for surface effects as in Kjeldsen et al. (2008)

Independent of **smooth component** indicators.

Advantages

- The defined indicators are as uncorrelated as possible,
- Negligible computation times - of the order of the fraction of a second,
- 'Holes' in the spectrum are never a problem: information is averaged over the whole spectrum,
- Both **glitches** and **smooth component** are analysed.

Limitations

- Only suited for solar-like pulsators. High mass and surface helium abundances stars do not yet allow to draw proper inferences from the glitch;
- Degeneracy in metallicity and helium abundance for the helium glitch amplitude indicator.

16 Cyg A Adjustment

Illustrative adjustment of 16 Cyg A observed indicators.

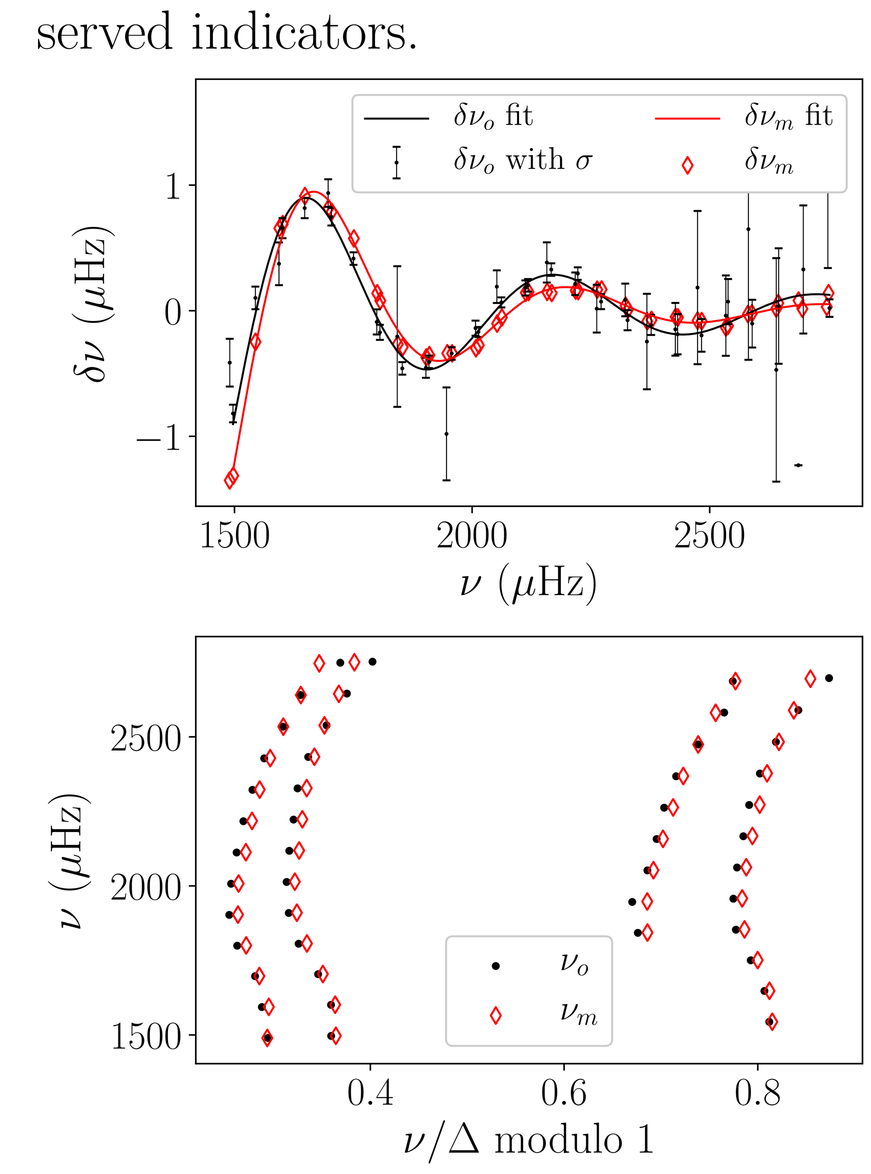

Figure 3: Observed and best model fitted helium glitches (top) and *échelle* diagram (bottom) for 16 Cyg A.

Quantity	Value	σ
$M(M_\odot)$	1.06	0.02
$R(R_\odot)$	1.219	0.006
age (Gyr)	6.9	0.1
Y_f	0.232	0.008
$[Fe/H]$	0.1307	0.0003

Table 1: Adjusted stellar parameters.

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Further Information

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- Farnir M., Dupret M.-A., S.J.A.J. Salmon, Noels, A. & Buldgen, G. 2018, A&A, submitted