What can we learn from asteroseismology of β Cephei stars through forward approach modelling?

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1. Setting the stage

β Cephei are main-sequence B stars presenting:
- M = 8 – 18 M⊙ ,
- low-order g and p modes with P ~2 – 8 hours,
- a convective core surrounded by a radiative envelope.

Limit and shape of $\nabla\mu$ between these 2 regions reflect extra-mixing processes, e.g. overshooting or mixing induced by rotation.

With asteroseismology, global parameters of β Cephei stars can be determined following the forward approach (see Sect. 2). As one of the main successes, extra-mixing was retrieved under the form of an (instantaneous) overshooting parameter (αov) for several β Cephei, as listed in Tab. 1. However, αov shows no clear trend, asking what is really measured?

Tab. 1: seismic inference of αov in a sample of β Cephei stars

Name	References	αov	Rotation (km/s)
HD 129929	Dupret et al. 04, A&A 415	0.10 ±0.05	$v \sin i \lesssim 13$ km/s
ν Eri	Pamyatnykh et al. 04, MNRAS 350	0 – 0.12	$v \sin i \lesssim 20$ km/s
β CMa	Mazumdar et al. 06, A&A 459	0.20 ±0.05	$v_{eq} \simeq 31 \pm 5$ km/s
δ Ceti	Aerts et al. 06, ApJ 642	0.20 ±0.05	$v \sin i = 1 \pm 1$ km/s
V 1449 Aq	Aerts et al. 11, A&A 534	0-0.05	$v \sin i \lesssim 30$ km/s
12 Lac	Desmet et al. 09, MNRAS 396	<0.40	$v \sin i \simeq 30$ km/s
θ Oph	Briquet et al. 07, MNRAS 381	0.44 ±0.07	$v \sin i \simeq 36 \pm 2$ km/s
V 2052 Oph	Briquet et al. 12, MNRAS 427	0 – 0.15	$v_{eq} \simeq 71 - 75$ km/s

➡ We present in this poster hare and hound exercises based on models simulating observed β Cephei stars: we first investigate how the derived parameters behave depending on the seismic data accessible to the observer. Particular attention is then given to the dependency of inferred parameters on micro- and macro-physics adopted in the modelling process.

Tab. 2 : stellar parameters of the theoretical grid

Parameter	Range	Step
M (in M⊙)	7.6 – 18.6	0.1
X	0.68 – 0.74	0.02
Z	0.010 – 0.018	0.002
α_{ov}	0 – 0.50	0.05

2. Forward approach modelling

$$\chi^2 = \frac{1}{N_{obs}} \sum_{i}^{N_{obs}} \frac{(\nu_{obs\ i} - \nu_{th\ i})^2}{\sigma_i^2}$$

is used as seismic merit function, where $\nu_{obs\ i}$ and $\nu_{th\ i}$ are the observed and theoretical frequencies of oscillation modes, and σ_i the uncertainty on $\nu_{obs\ i}$. This function is computed on a grid of Liège models with the solar AGS05 (Asplund et al. 05, ASPC 336) mixture and OP (Badnell et al. 05, MNRAS 360) opacities. Models adopt an instantaneous mixing prescription in the overshoot region. More details on the grid can be found in Tab.2 and Briquet et al. 09 (A&A 506).

The model minimising χ^2 provides the fitting stellar parameters of the solution.

3. Hare and hound exercises

We vary the number of frequencies assumed as detected between case a) and b), keeping the same physics in the target observed star and theoretical grid. Exercise c) considers a target with a different mixture (GN93, Grevesse & Noels 93), while extra-mixing of diffusive nature is considered in case d).

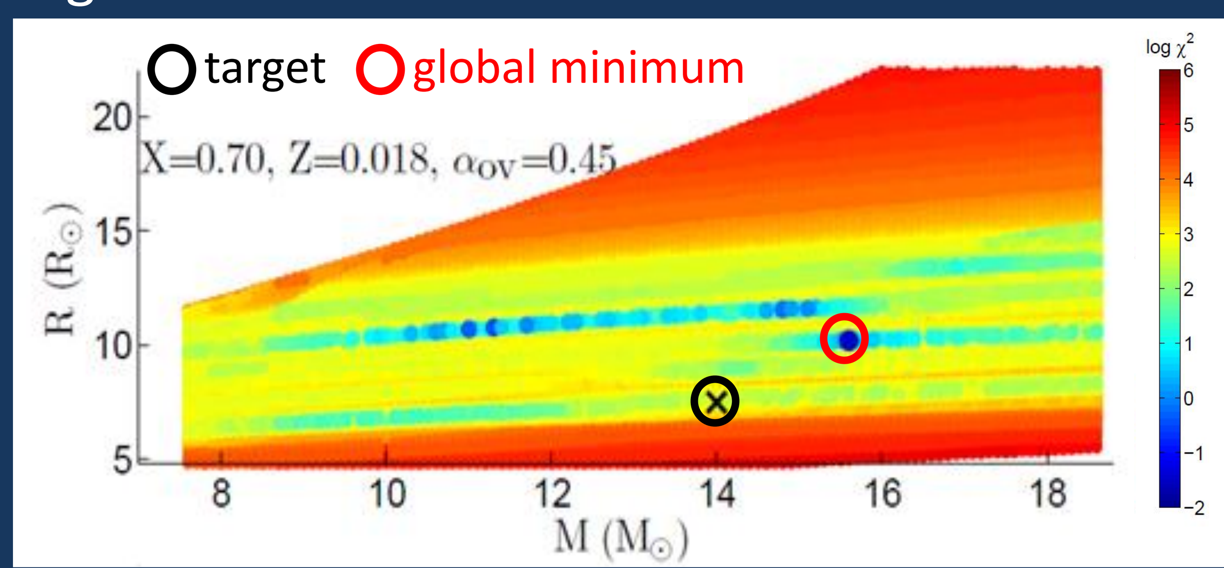
a) Same physics, 3 νobs with angular degree identified, from ℓ=0 to 2

Parameter	Target star	Fitting model
M (M⊙)	14	15.6
R (R⊙)	7.48	10.18
X | Z	0.70 | 0.014	0.70 | 0.018
αov	0.20	0.45
Xc	0.288	0.237

- Global miminum in the χ^2 map (Fig. i) clearly fails to reproduce parameters of the target star

➡ insufficient number of constraints

Fig. i



b) Same physics, 5 νobs with angular degree identified, from ℓ=0 to 2

Parameter	Target star	Fitting model
M (M⊙)	14	13.8
R (R⊙)	7.48	7.45
X | Z	0.70 | 0.014	0.68 | 0.014
αov	0.20	0.20
Xc	0.288	0.274

- Solution matches the target star (Fig. ii)
- Extension of the central mixed region and $\nabla\mu$ well retrieved, within 1% (see Fig. iii, profile of H abundance in regards of relative mass)

Fig. ii

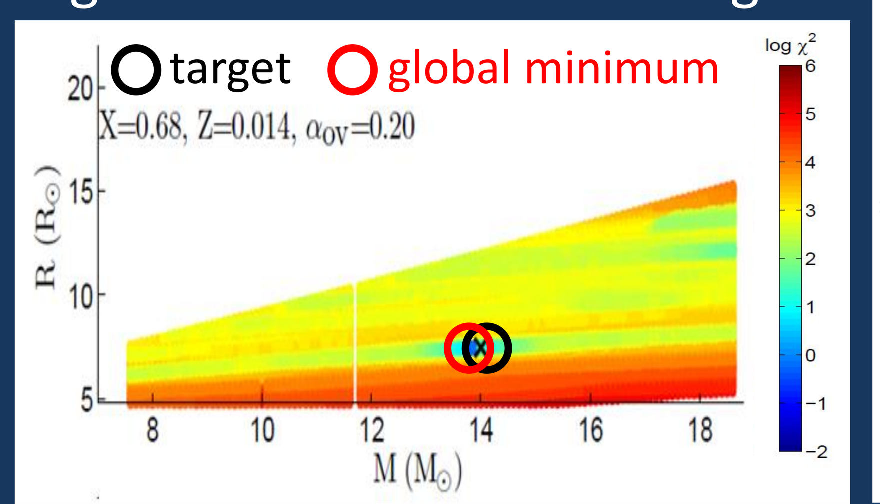
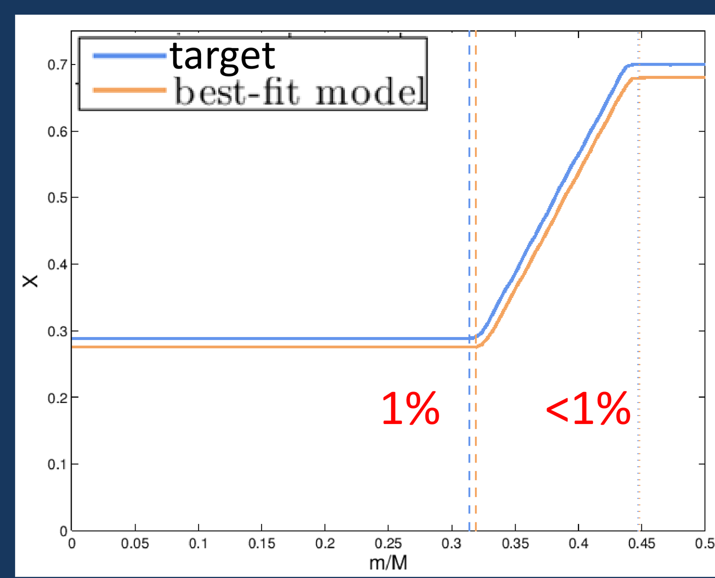


Fig. iii



c) Different micro-physics (GN93 vs AGS05), 6 νobs with known ℓ from 0 to 2

Parameter	Target star	Fitting model
M (M⊙)	11	11.4
R (R⊙)	5.98	6.07
X | Z	0.70 | 0.016	0.70 | 0.012
αov	0.20	0.30
Xc	0.351	0.354

- Good fitting of the global parameters (Fig. iv), except αov
- Inferred αov overestimated
- Location of $\nabla\mu$ is poorly constrained (Fig. v)

Fig. iv

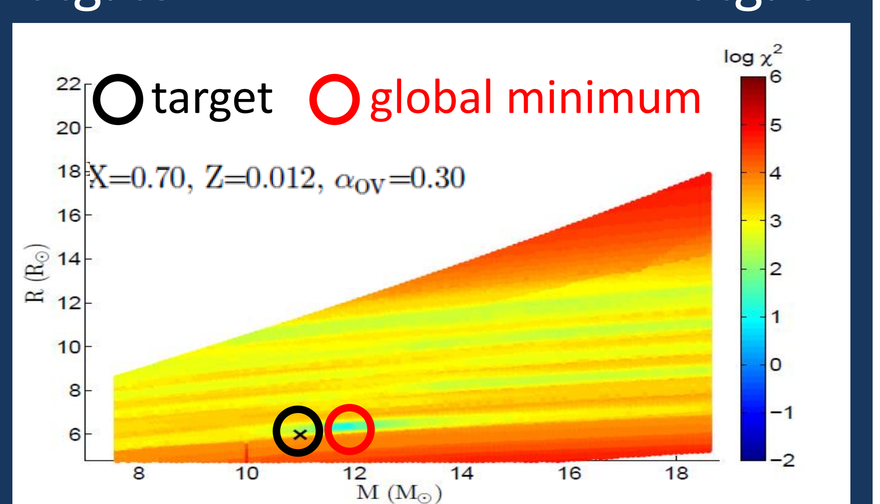
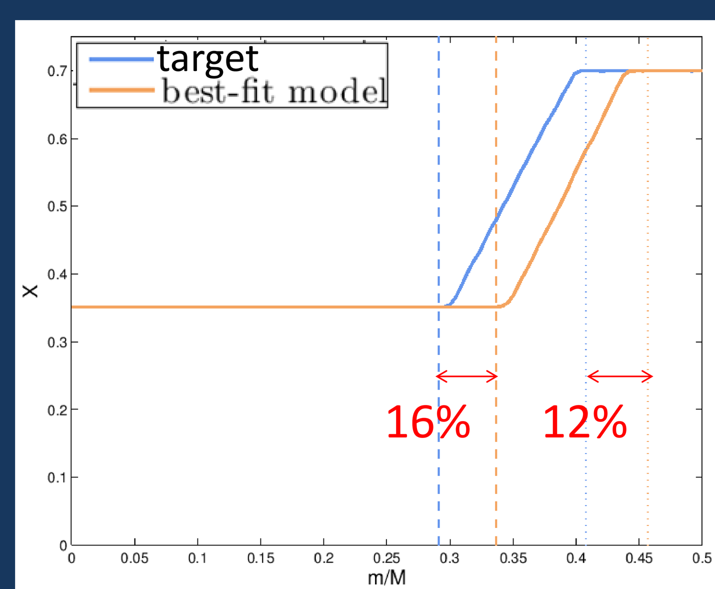


Fig. v



d) Turbulent mixing (reproducing effect of rotational mixing), 8 νobs with known ℓ from 0 to 2

Parameter	Target star	Fitting model
M (M⊙)	10	10.2
R (R⊙)	5.12	5.16
X | Z	0.70 | 0.014	0.72 | 0.016
αov	0.05* (calibrated)	0.05
Xc	0.388	0.419

- Good fitting of the global parameters (Fig. vi)
- Although inferred αov has the same value as in target star, this method does not provide information on the nature of the extra-mixing (Fig. vii)

Fig. vi

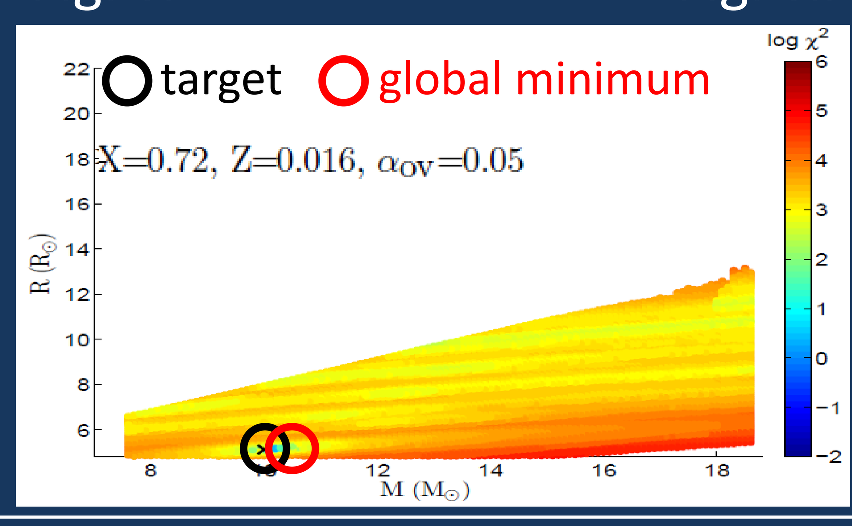
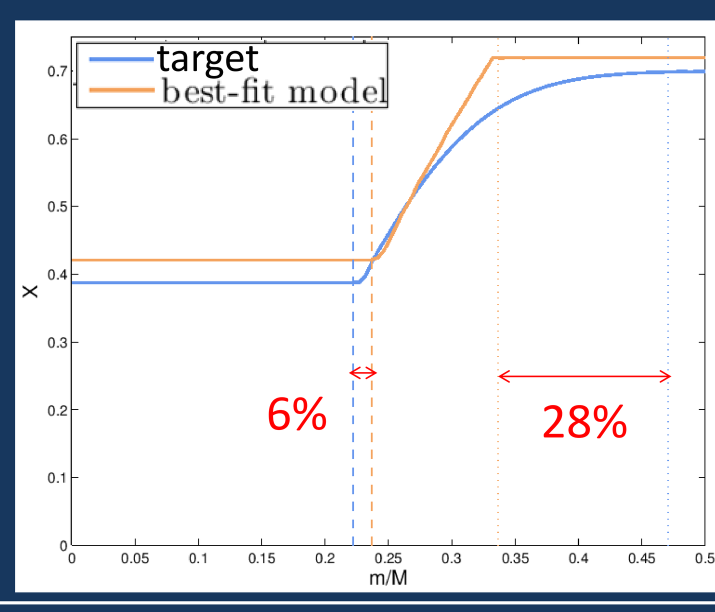


Fig. vii



Conclusion

- If the physics is the same, a set of 5 identified modes is required to determine the stellar parameters with a high level of accuracy
- If the chemical mixture is different, the central mixed region may be poorly estimated, highlighting the need for complementary observations
- How to constrain the nature of extra-mixing shall be further investigated in the future