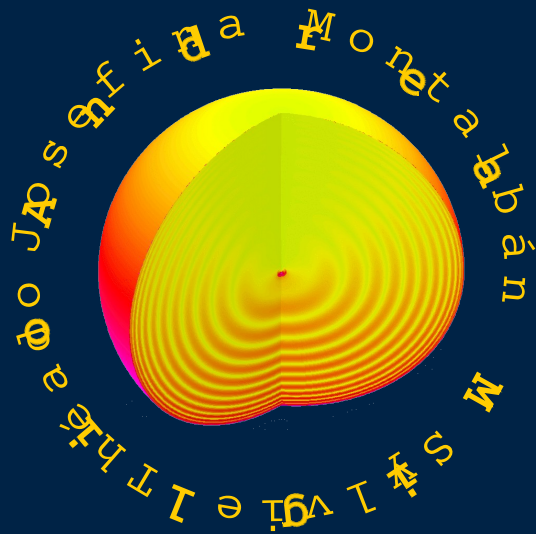


# The HR diagram stability enigmas and the asteroseismology of CoRoT targets



## Part III: Turbulent mixing and overshooting

# Turbulent mixing and overshooting

Mixing in stellar cores: uncertainties in the models:

Observations

-binaries

-stellar clusters



larger mixed region in core than std models

■ Extension extra mixed region



Dependence on the mass?  
on chemical composition?

Definition no overshooting / overshooting mass domain

$$\alpha_{ov}(M) \rightarrow 0 \quad M \rightarrow 1 M_{\odot}$$

■ Physical mechanism responsible for extension

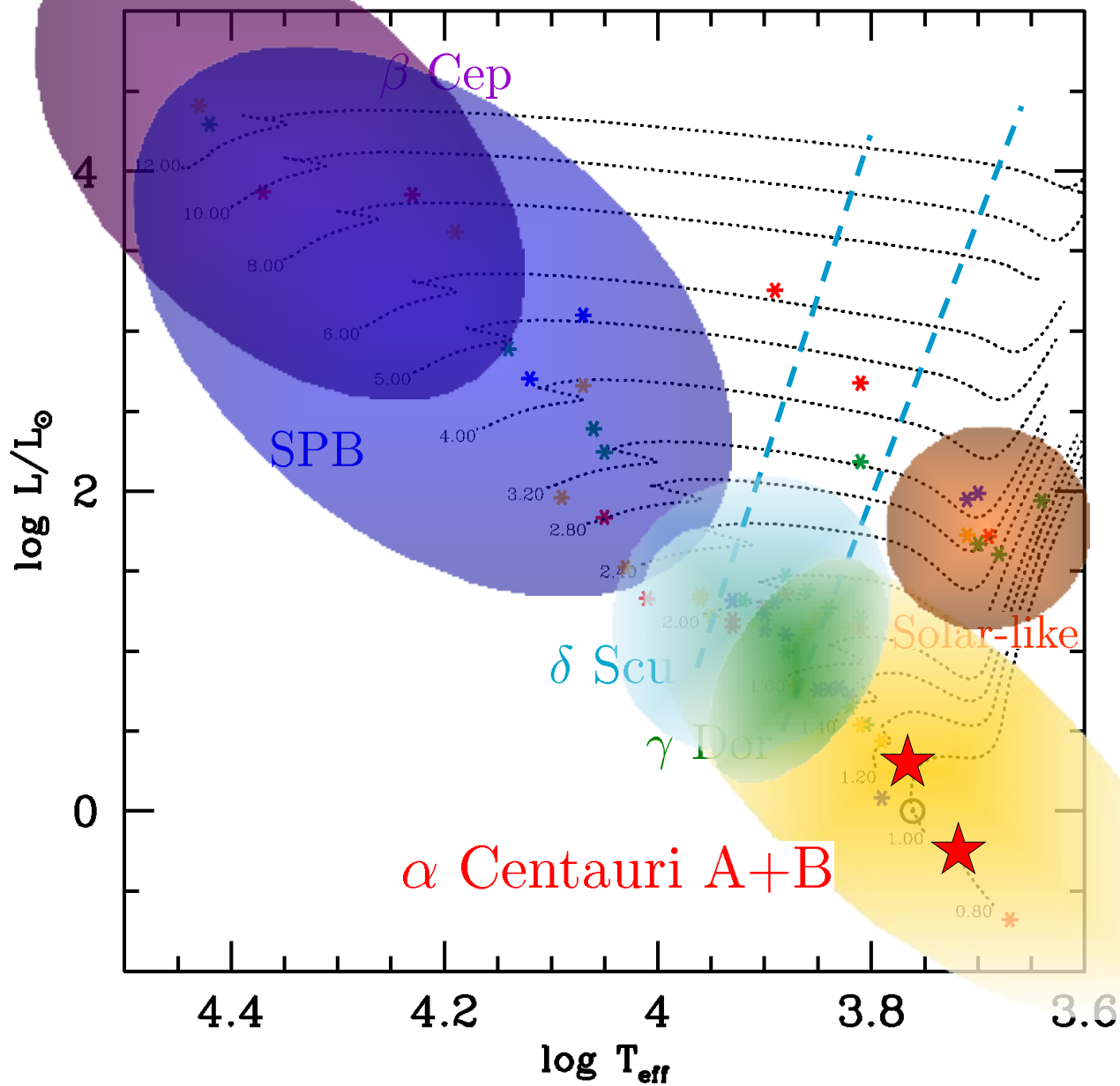


e.g. Overshooting

Rotationally induced turbulent mixing near core



Parametric treatment based on Genève models by P. Eggenberger



$\alpha$  Cen A

- Visual binary
- $M=1.105 M_{\odot}$
- Main-sequence
- solar-like oscillations detected

Bouchy & Carrier  
A&A 2002

Bedding et al.  
2004 ApJ

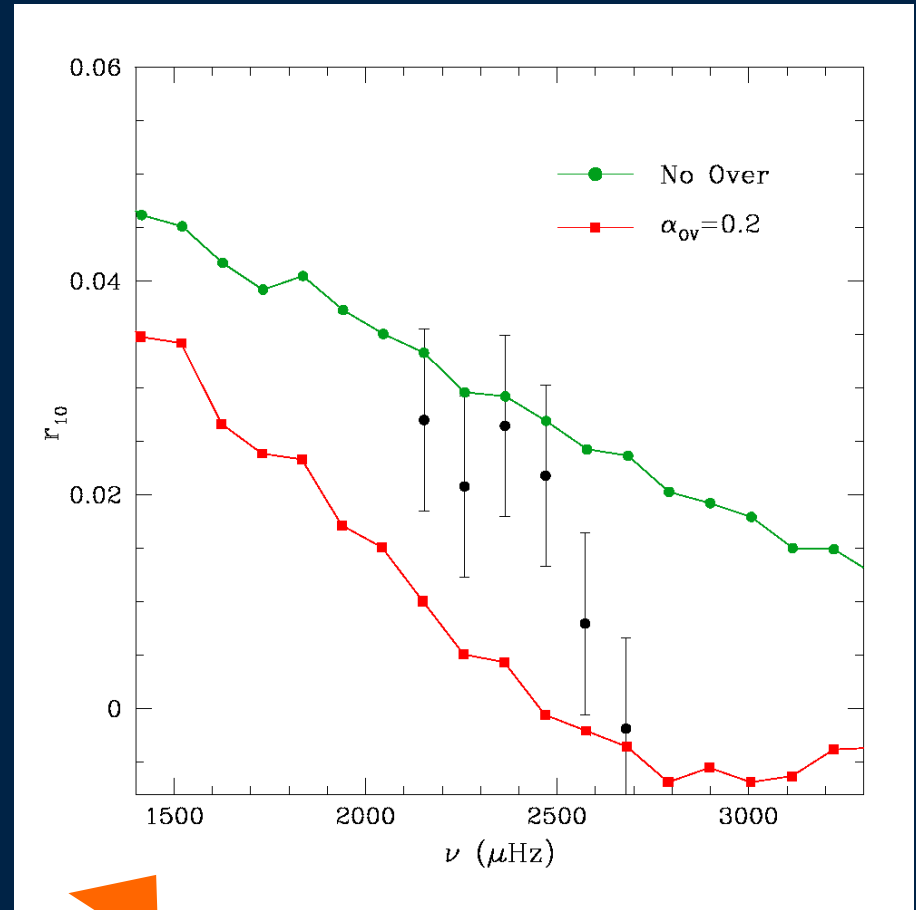
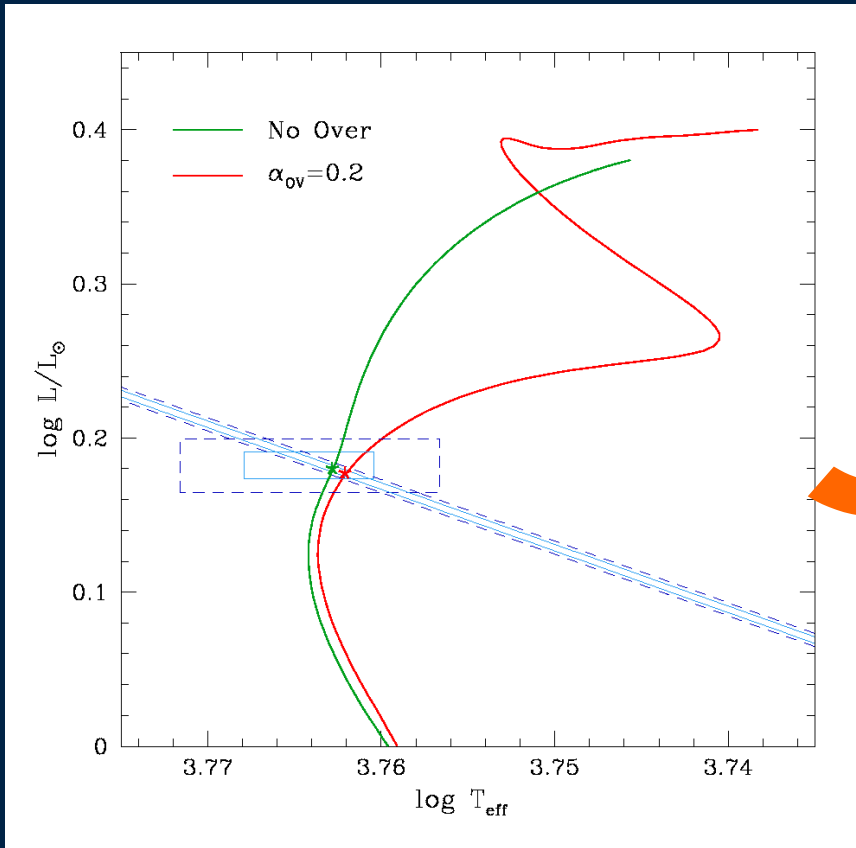


Convective core

# $\alpha$ Centauri A

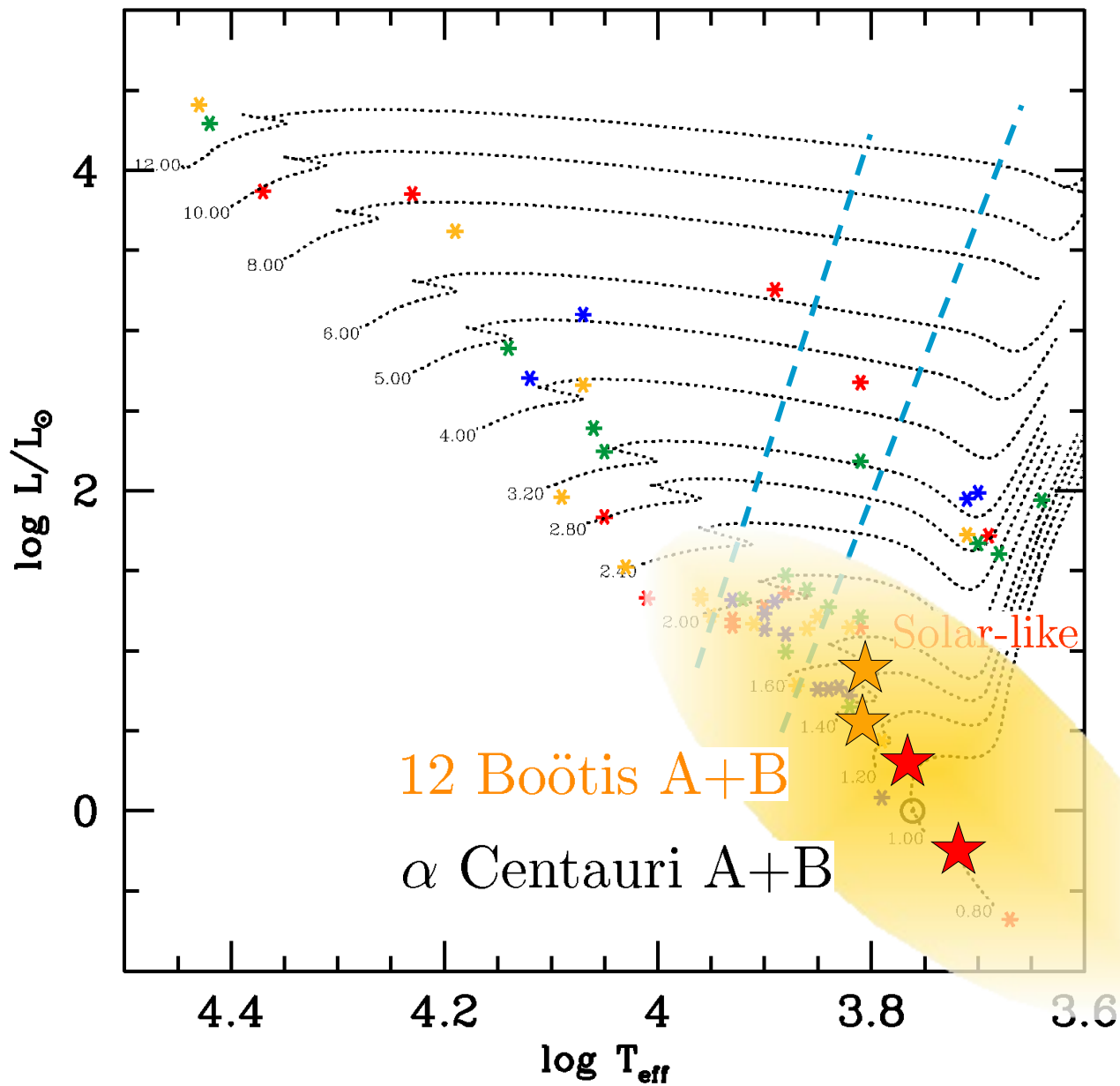
Onset of conv. core in MS depends on overshooting

$\alpha_{ov}=0.2 \rightarrow$  C.Core in MS



Miglio & Montalbán A&A 2005

- Seismic indicator sensitive to small c.cores
- Better data needed!



12 Boo A

■ M=1.416 M

■ Main-sequence  
or sub-giant



$\alpha_{\text{ov}}$



Modes of  
mixed p-  
and g-  
character

# 12 Boötis A: “mixed modes”

In the case of “moderately evolved” stars:

H exhausted  
in the core



The buoyancy frequency

$$N^2 \simeq \frac{g^2 \rho}{p} (\nabla_{ad} - \nabla + \nabla_{\mu})$$

increases in the core

$\nu$  of gravity  
modes  
increases

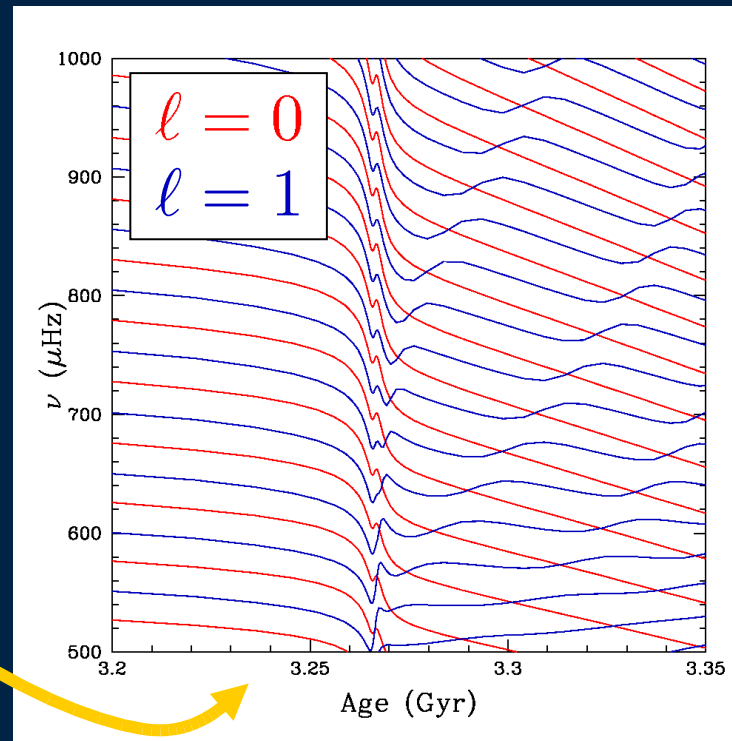
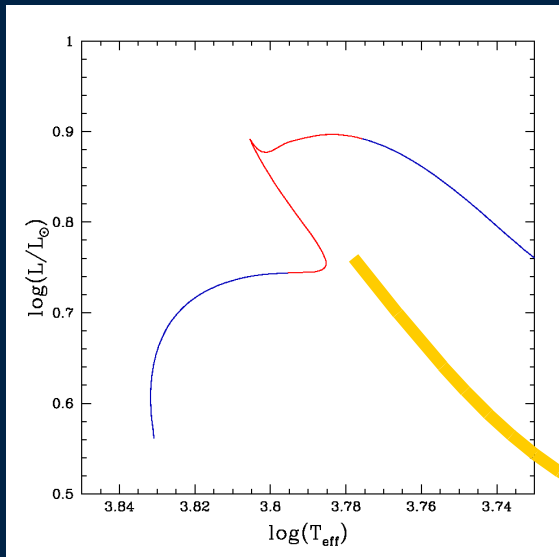


g-modes  
interact with  
non radial p-  
modes



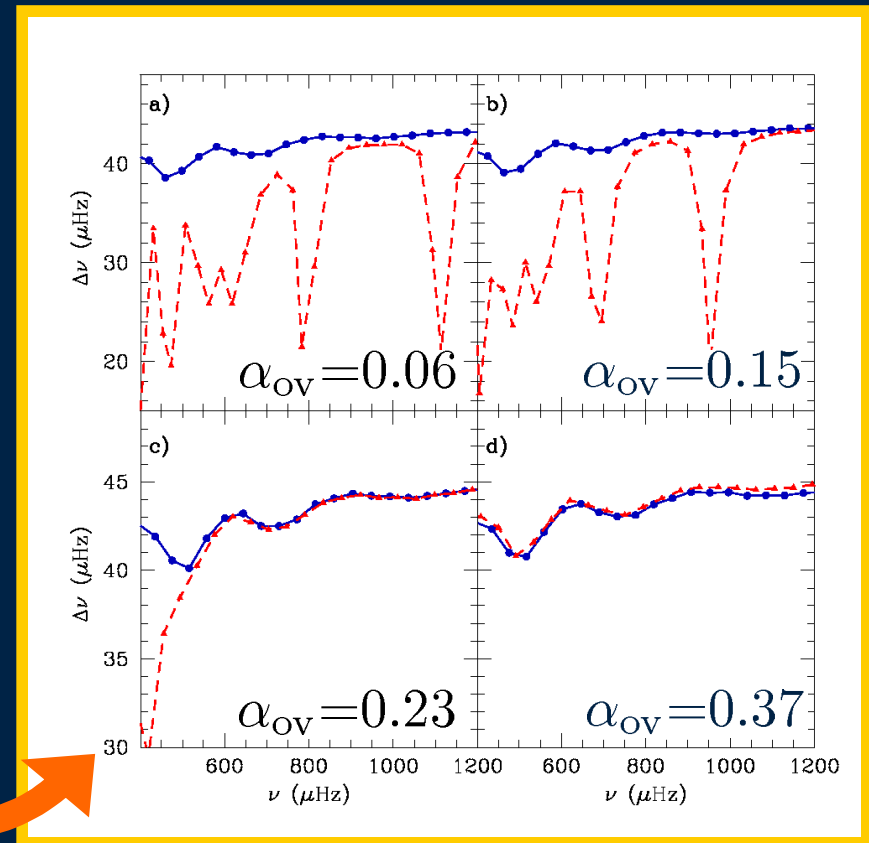
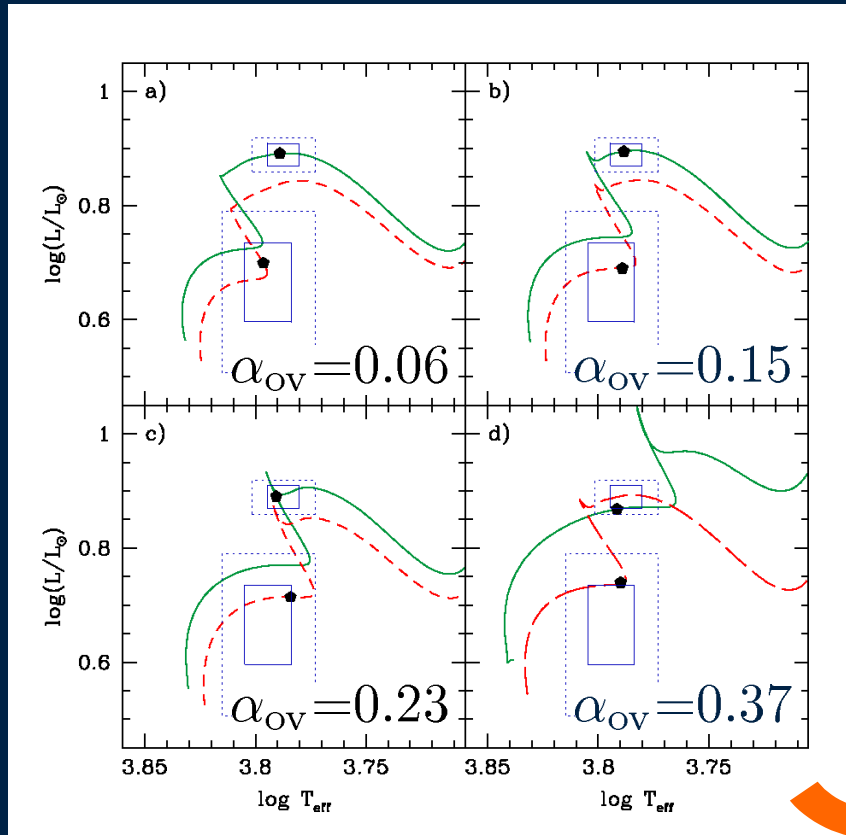
modes of  
mixed p- and  
g- character

Example: 1.4 M



# 12 Boötis A

Evolutionary state depends on extra-mixed region



Miglio, Montalbán, Maceroni MNRAS 2007

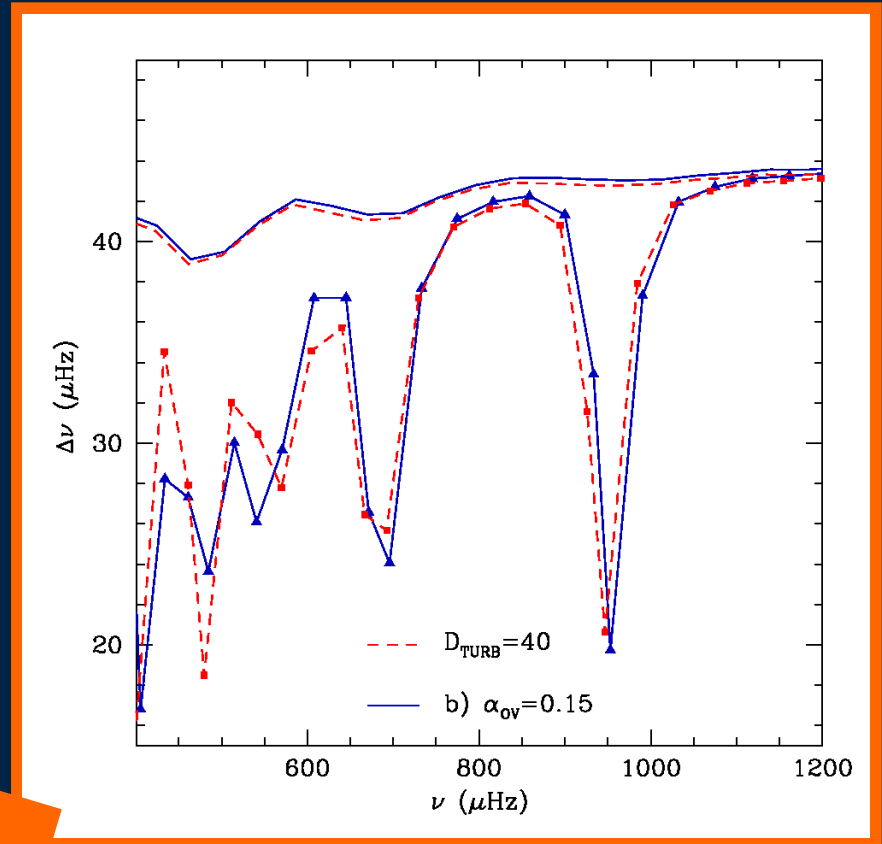
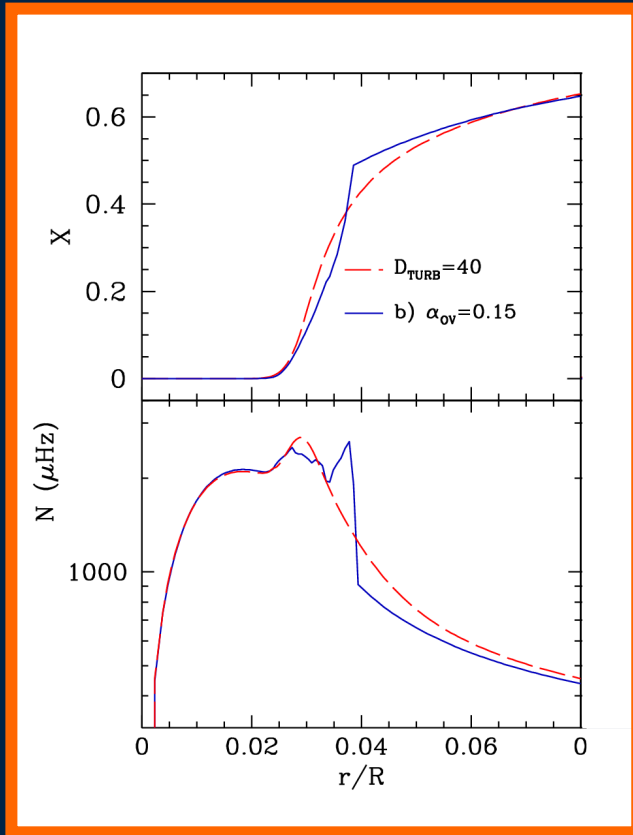
$\nu$  mixed-modes



- “Amount” of extra mixing ✓
- Overshooting vs turbulent ?

# 12 Boötis A

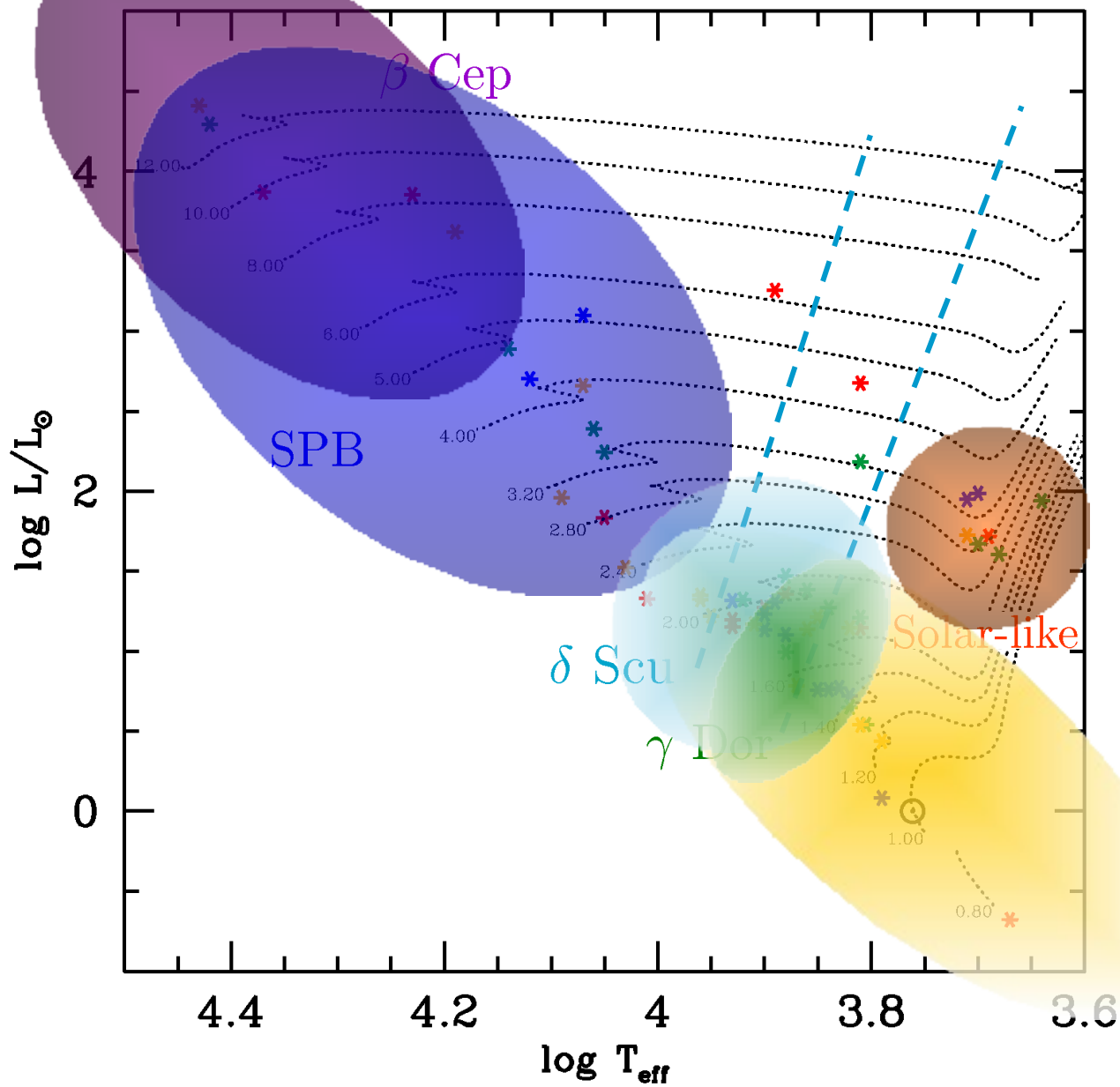
“Mimicking” rotational mixing using  $D_{\text{TURB}}$



Miglio, Montalbán & Maceroni MNRAS 2007

$\nu$  mixed modes / gravity modes

Detailed properties of  $\mu$  gradient near the core



gravity  
modes in  
MS stars

high order

$\gamma$  Doradus

SPB

low order /  
mixed modes

$\delta$  Scuti

$\beta$  Cephei

# Periods of high order g-modes

first order  
asymptotic theory

$$\Delta P(k) \equiv P(k) - P(k-1)$$



$$\text{constant} \propto \left( \int_{r_1}^{r_2} \frac{N_{\text{BV}}(r')}{r'} dr' \right)^{-1}$$

Due to evol. of c.c  
models presents  
sharp features in  $N_{\text{BV}}$



Expected deviations  $\delta P(k)$   
from constant  $\Delta P(k)$

$$\delta P(k) \simeq A(k) \cos \left( 2\pi k \frac{B(\bar{r})}{B_{\top}} + \phi \right) \quad \text{Miglio, (2006) ASPC, 349}$$

$$B(r) = \int_{r_1}^{r_2} \frac{N_{\text{BV}}(r')}{r'} dr'$$

$$T \simeq \frac{B_{\top}}{B(\bar{r})}$$

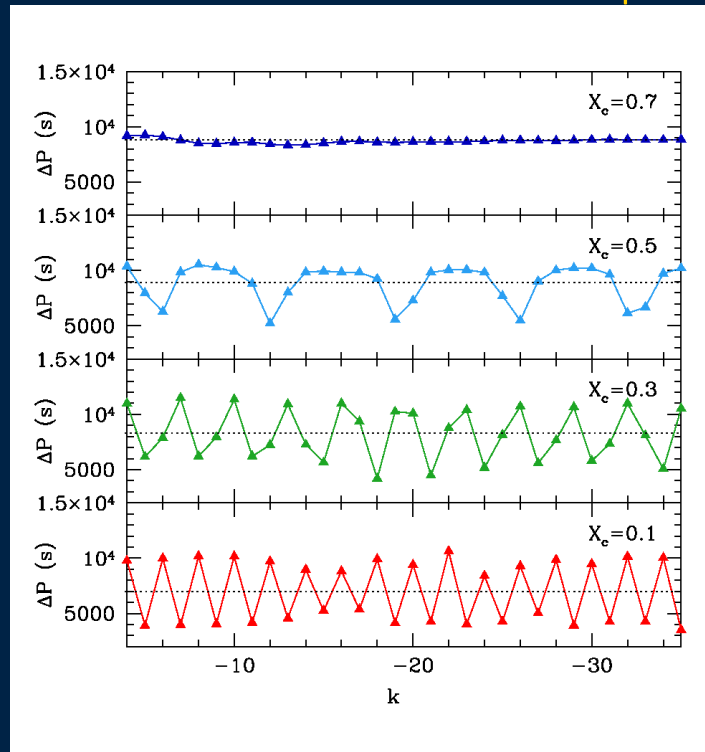
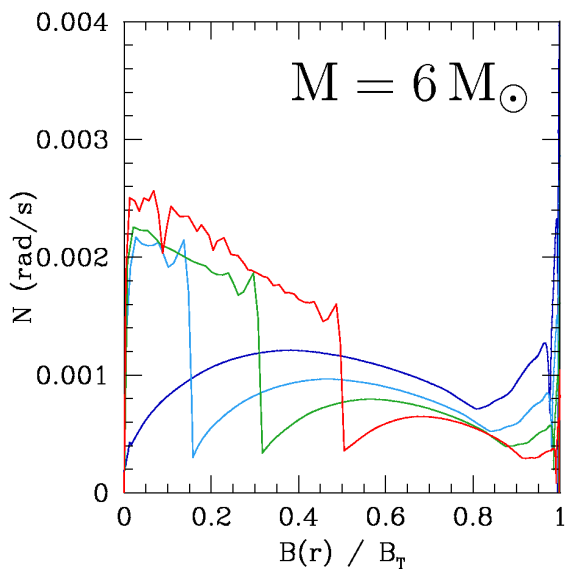
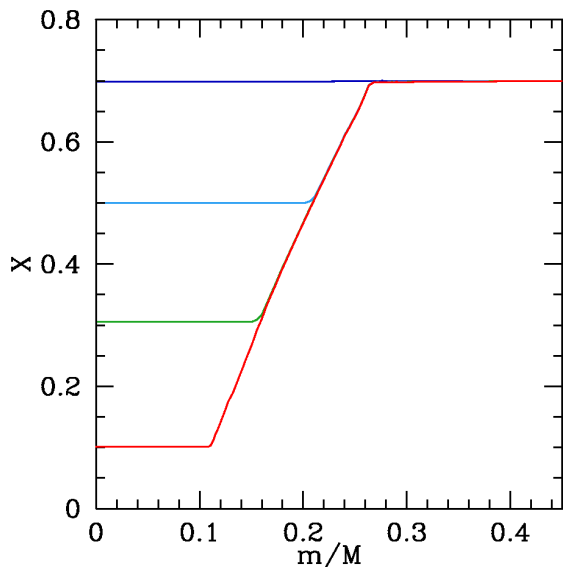
location  
 $\delta N_{\text{BV}}$

$$A(k)$$

“sharpness”  
 $\delta N_{\text{BV}}$

# High-order g-modes in SPB

$$\delta P(k) \simeq A(k) \cos\left(2\pi k \frac{B(\bar{r})}{B_T} + \phi\right)$$

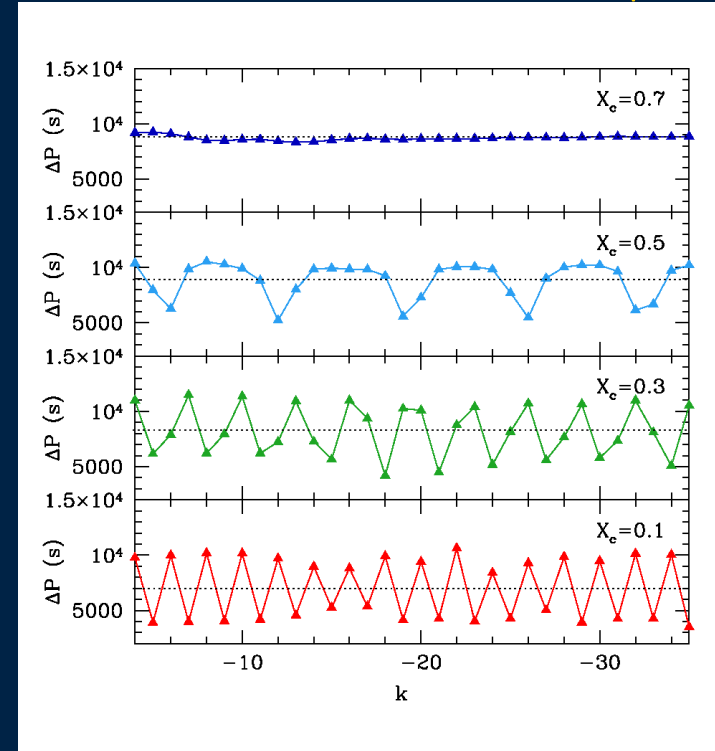
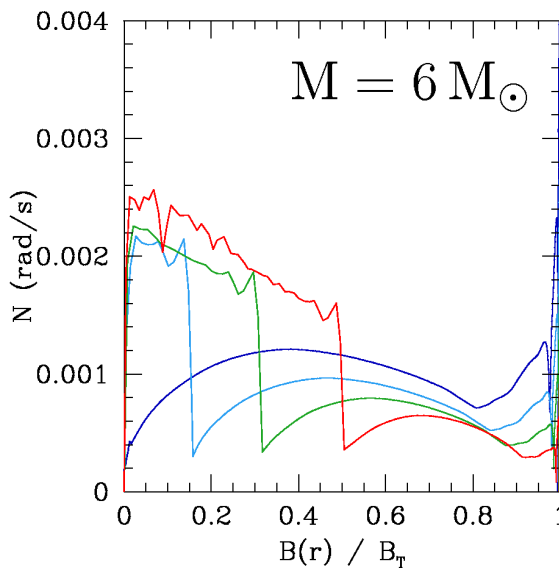
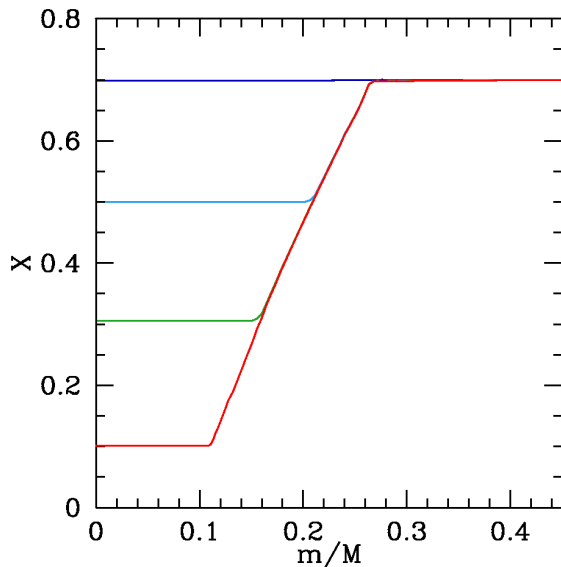


Miglio, Montalbán, Noels & Eggenberger, 2007  
submitted

Effect turbulent  
mixing ?

# High-order g-modes in SPB

$$\delta P(k) \simeq A(k) \cos\left(2\pi k \frac{B(\bar{r})}{B_T} + \phi\right)$$



Miglio, Montalbán, Noels & Eggenberger, 2007  
submitted

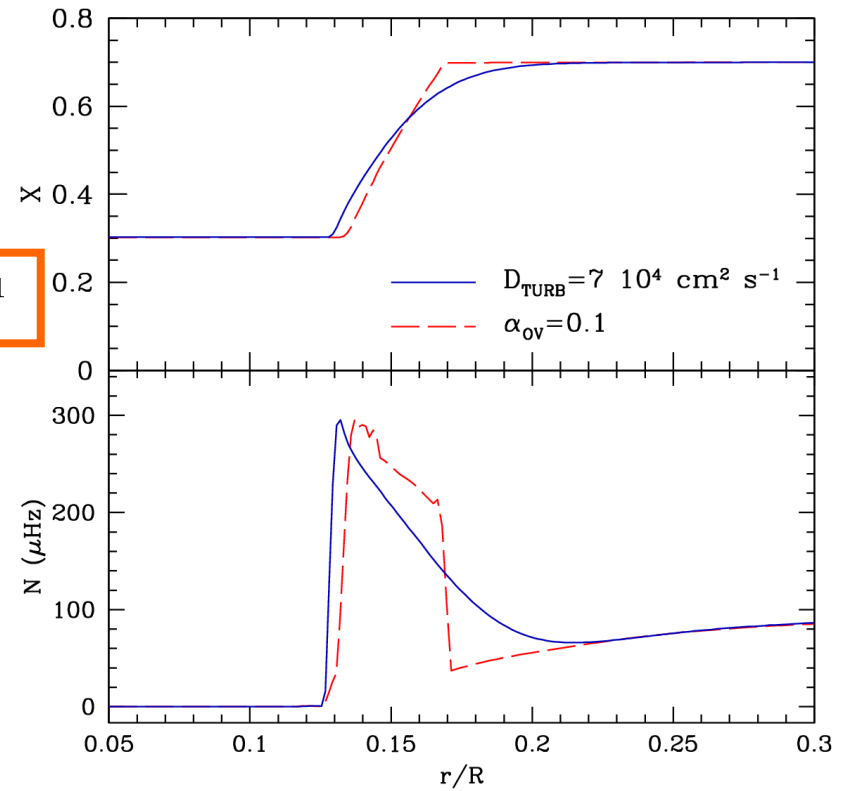
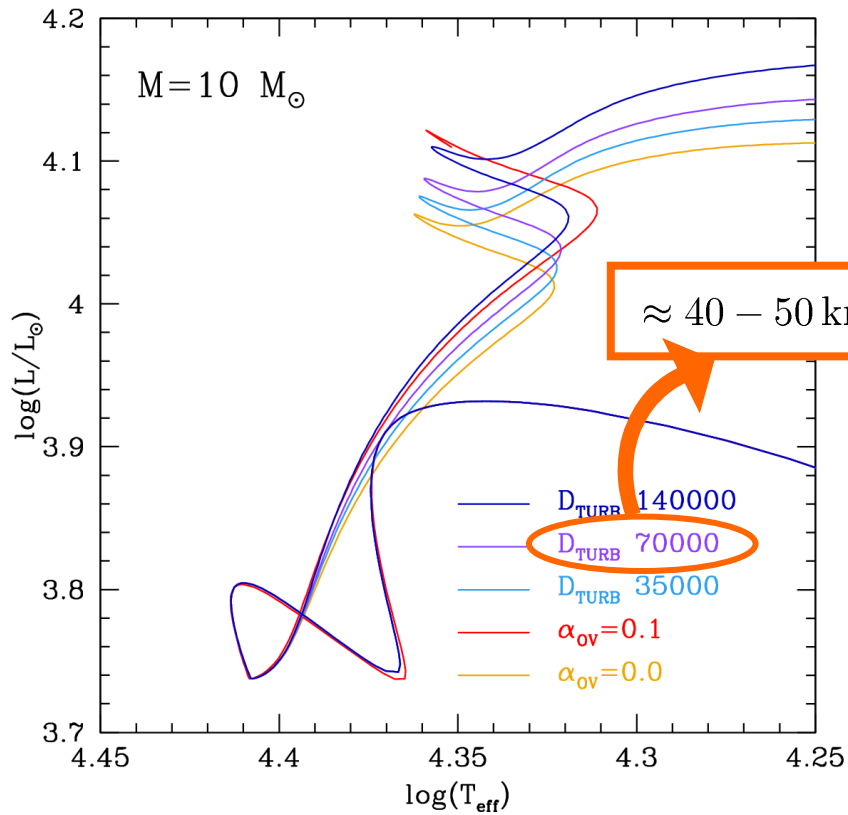


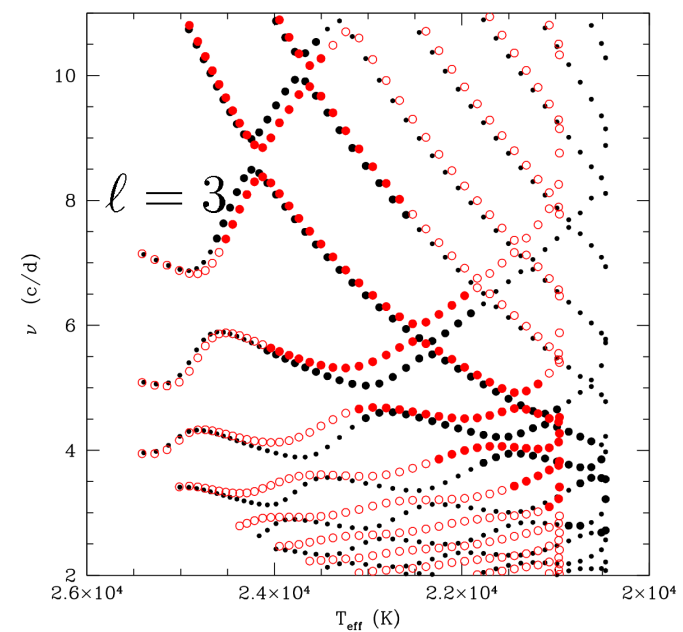
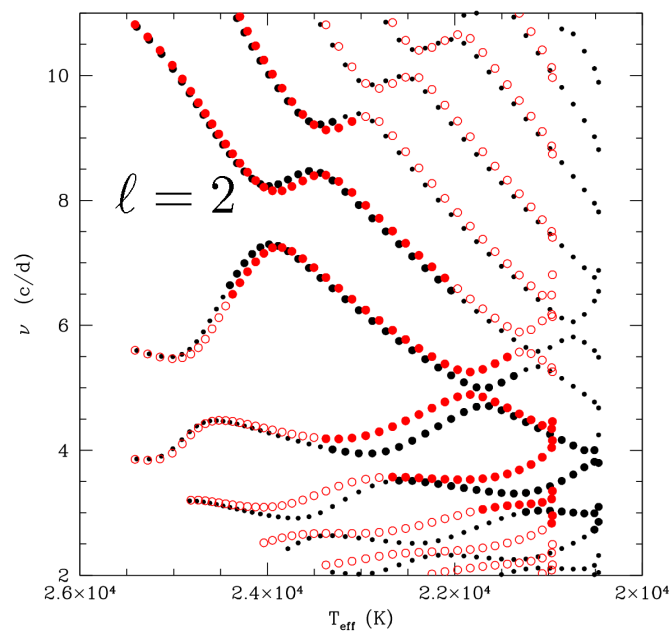
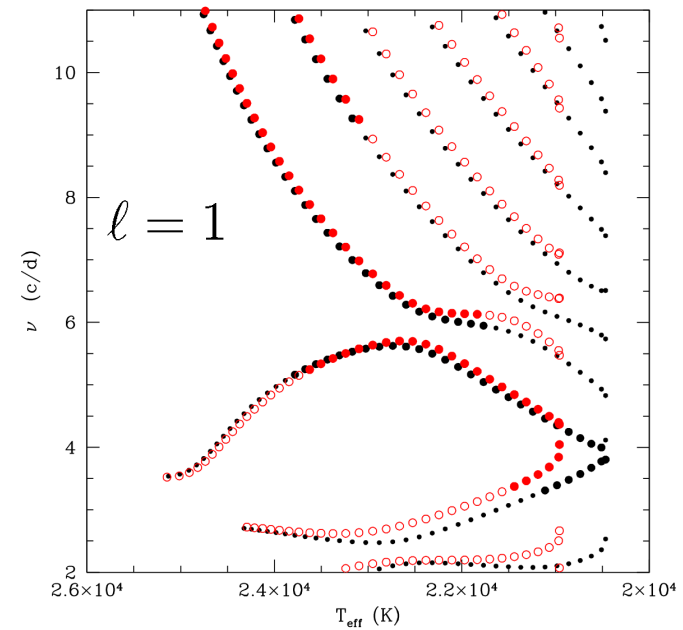
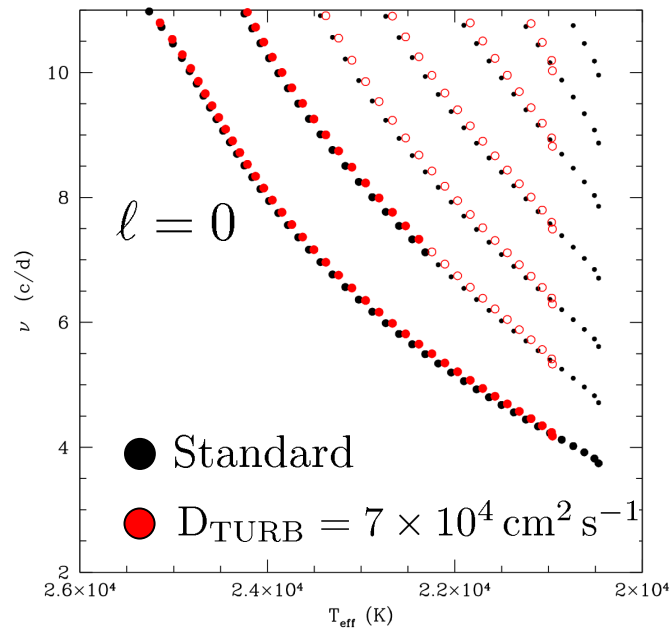
large effects of  
rotation on P

low-order modes  $\beta$  Cep

# Rotational mixing in $\beta$ Cep

Parametric approach  $D_{\text{TURB}}$





# Rotational mixing in $\beta$ Cep

Comparison with  
effect  $\alpha_{ov} = 0.1$

e.g.

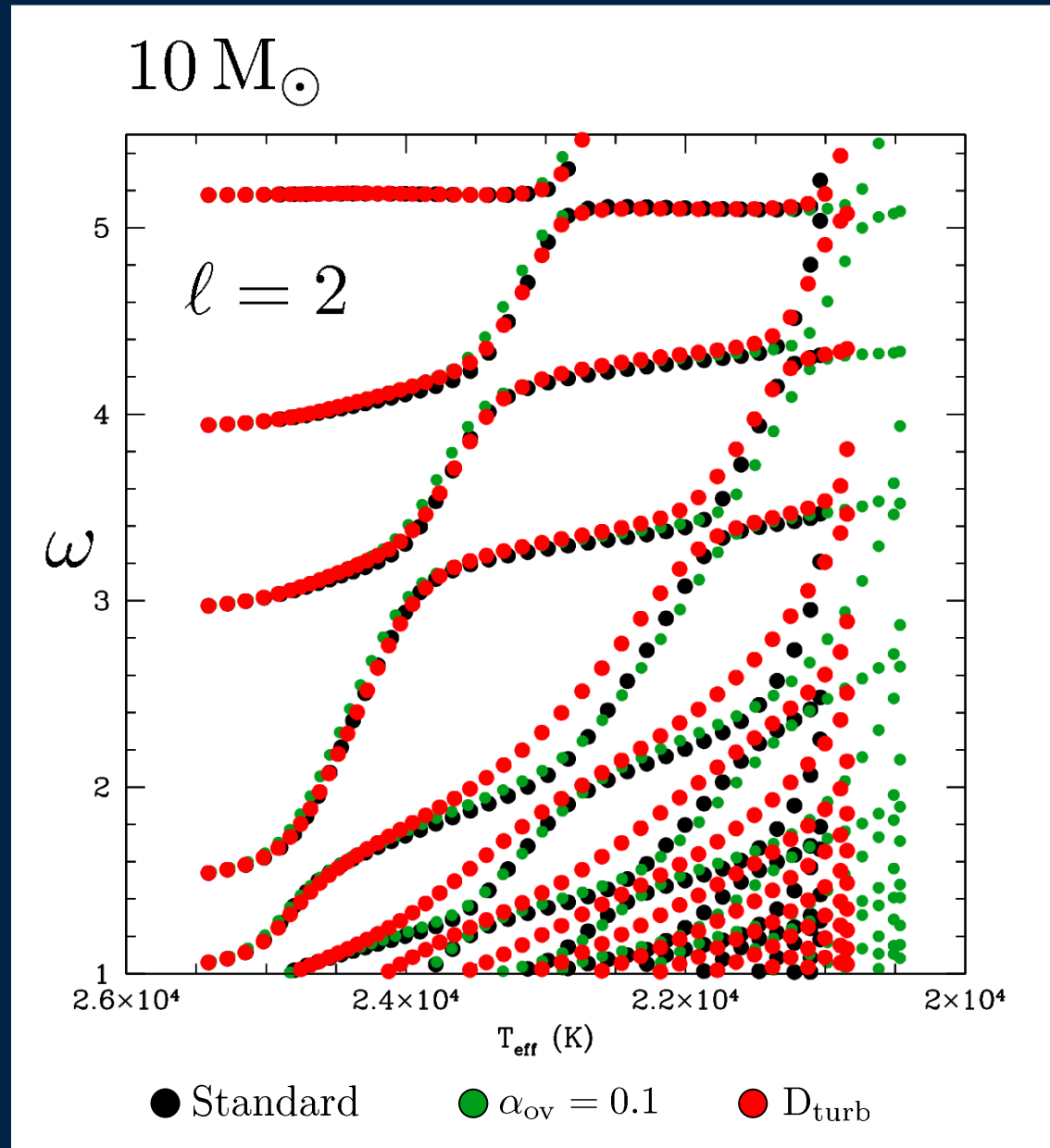
Dziembowski &  
Pamyatnykh 1991 A&A

Goupil et al. 1993 A&A

Audard et al. 1995 A&A



Different  
effect



# Rotational mixing in $\beta$ Cep

$10 M_{\odot}$  models  
computed with Genève code  
thanks to P. Eggenberger

