Theoretical amplitudes and lifetimes of non-radial oscillations in Red Giants

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Universidade do Porto

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Paris
2-5 February 2009

Plan of the presentation

- Mode physics in red giant stars

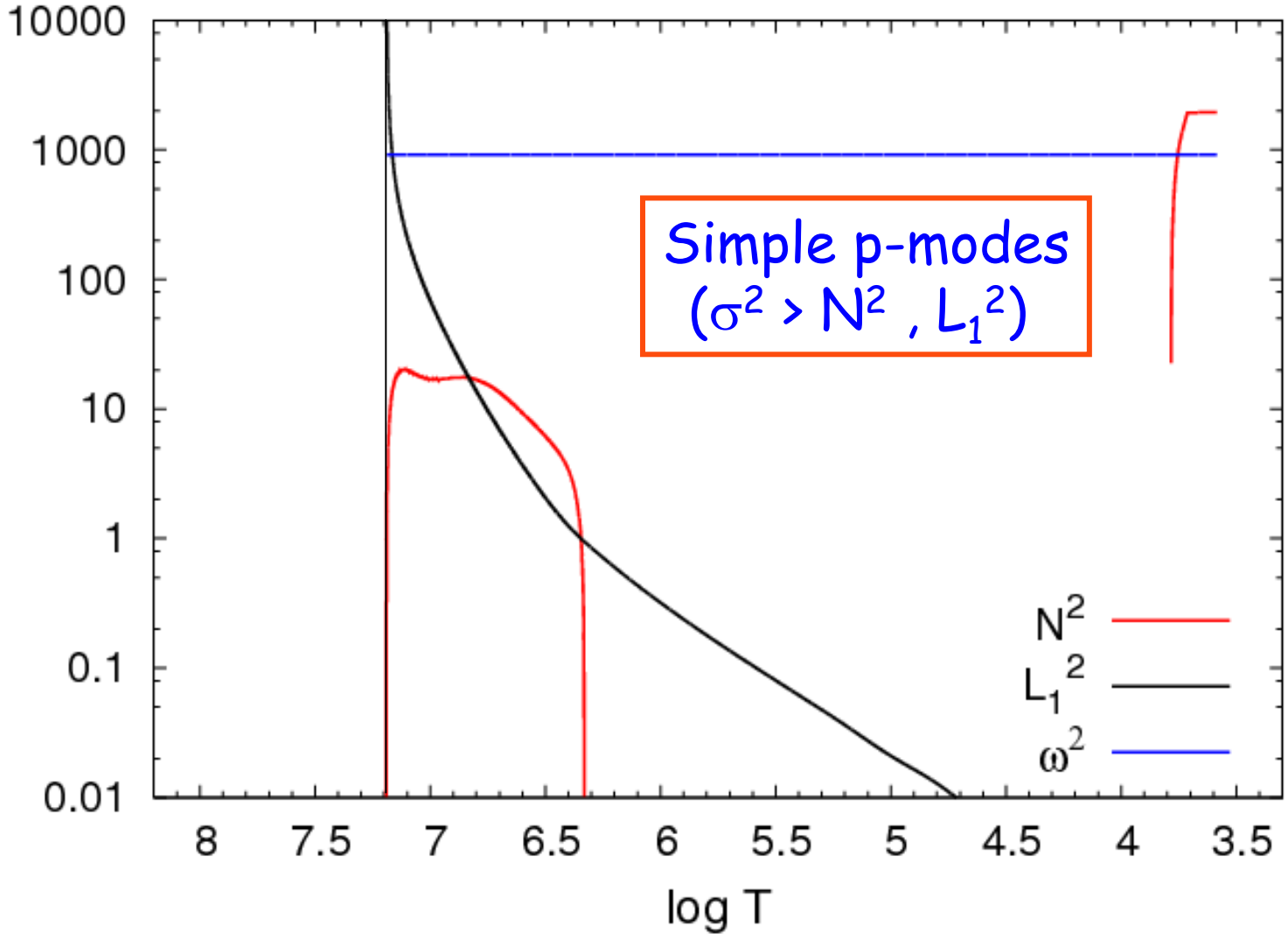
- Predictions for specific models

Subgiants Intermediate High luminosity

- Conclusions

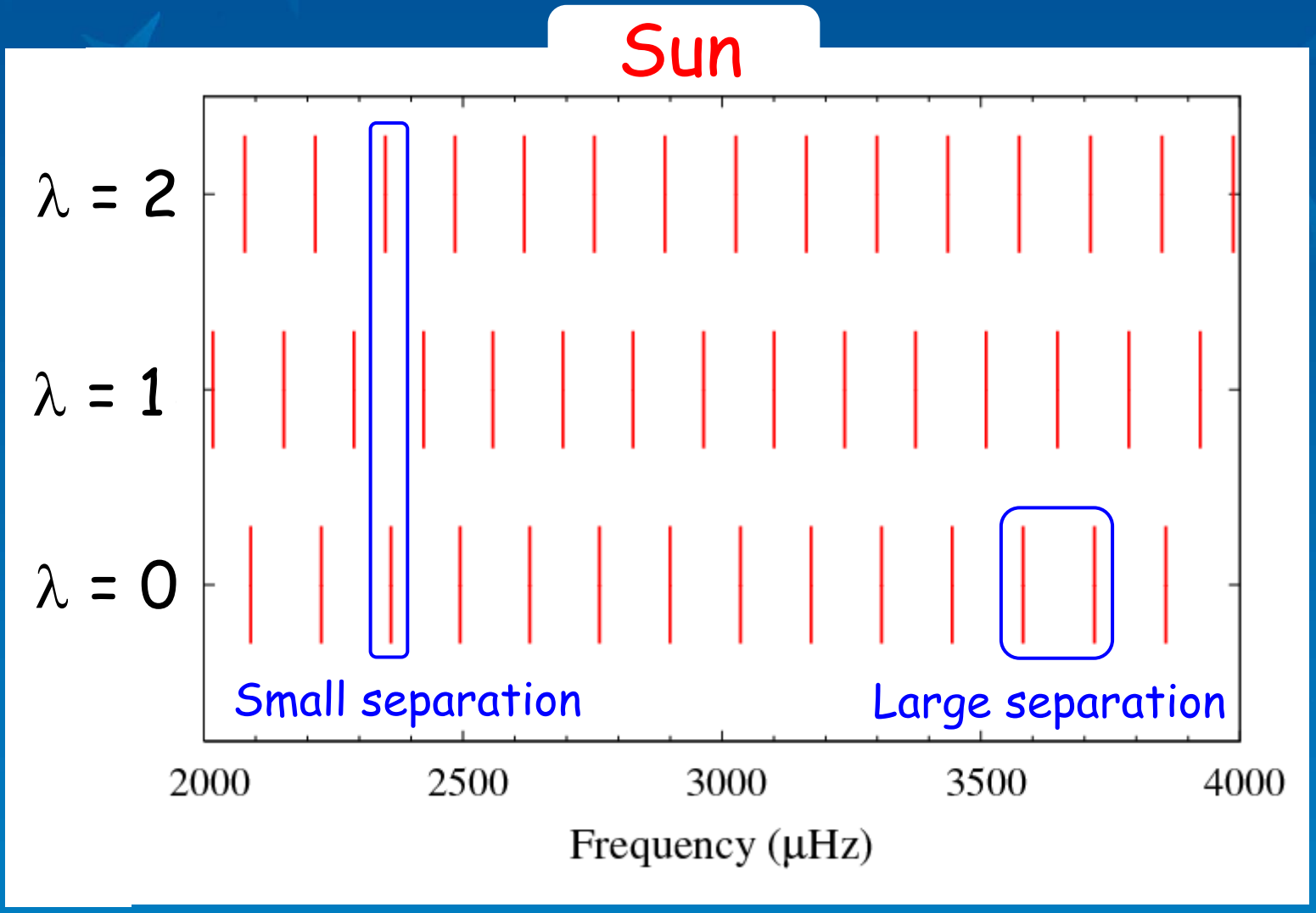
How red giants differ from the Sun ?

Sun



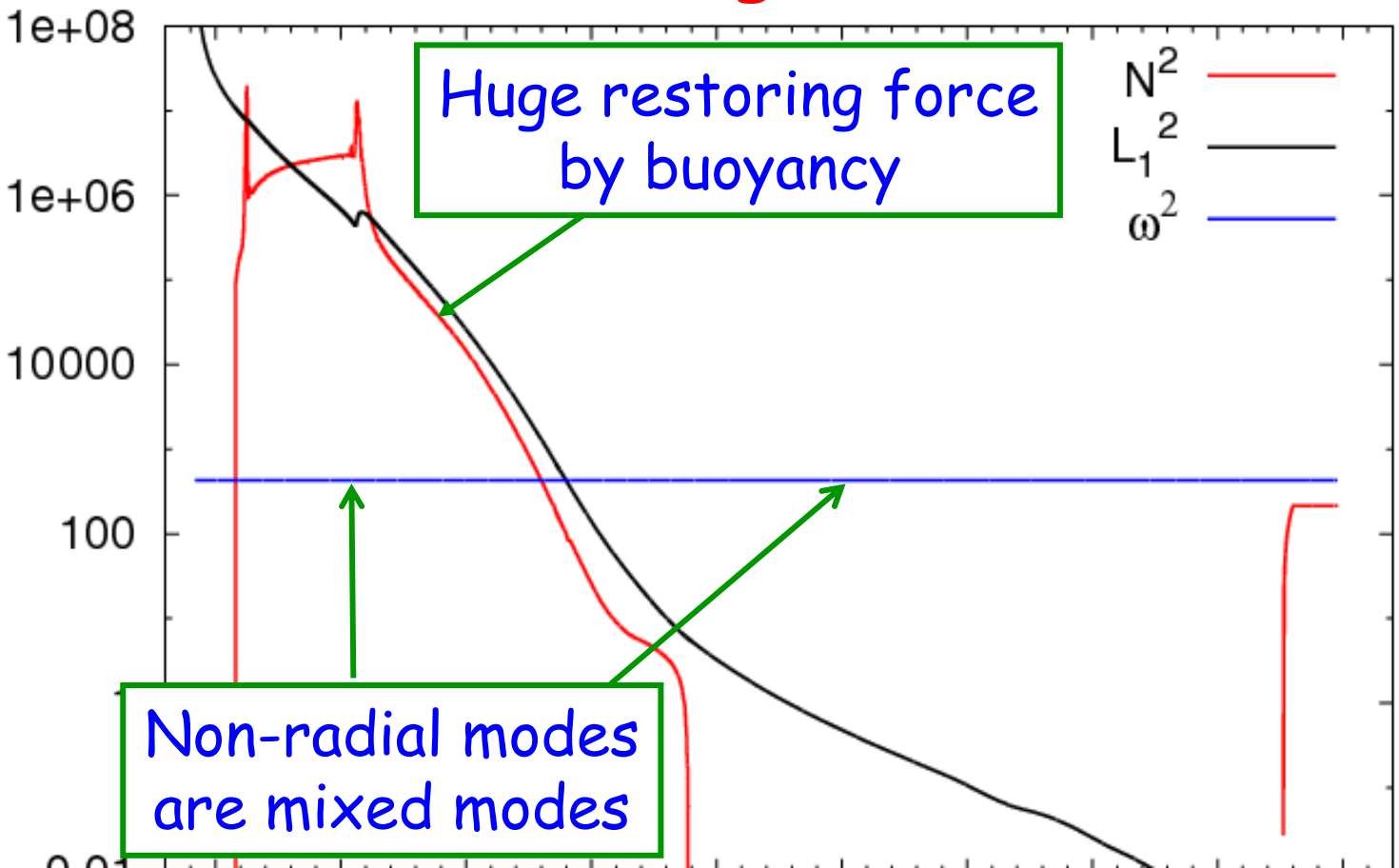
How red giants differ from the Sun ?

Regular frequency pattern ~ Asymptotic



Mode physics in Red Giants

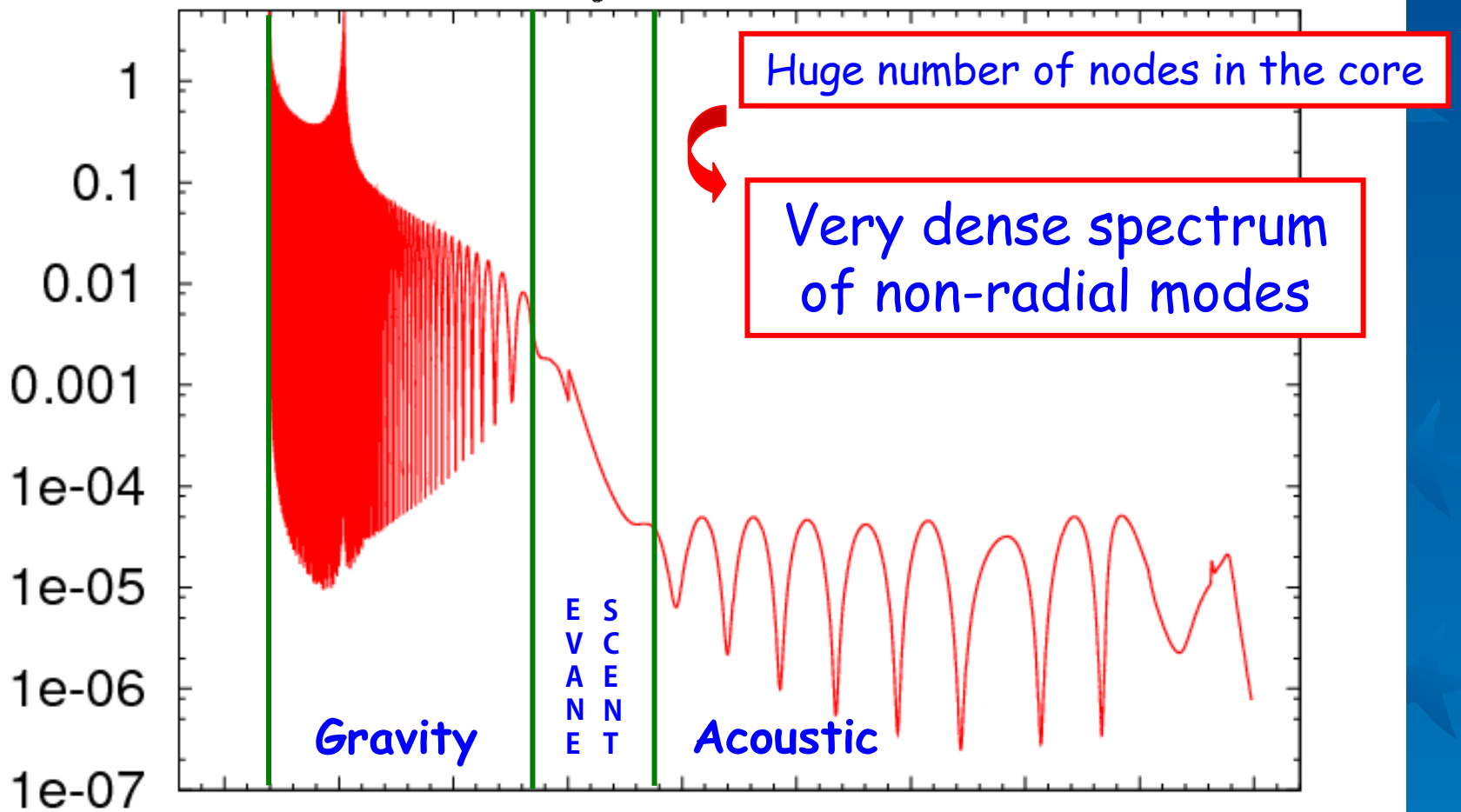
Helium burning Red Giant



Mode physics in Red Giants

NETIC ENERGY

$$\text{Inertia} = \int_0^M |\vec{\delta r}|^2 \, dm = \int (dI/d\log T)\, d\log T$$



Huge number of nodes in the core

Very dense spectrum of non-radial modes

Mode physics in Red Giants

Mode trapping

See also Dziembowski et al. (2001)
Christensen-Dalsgaard (2004)

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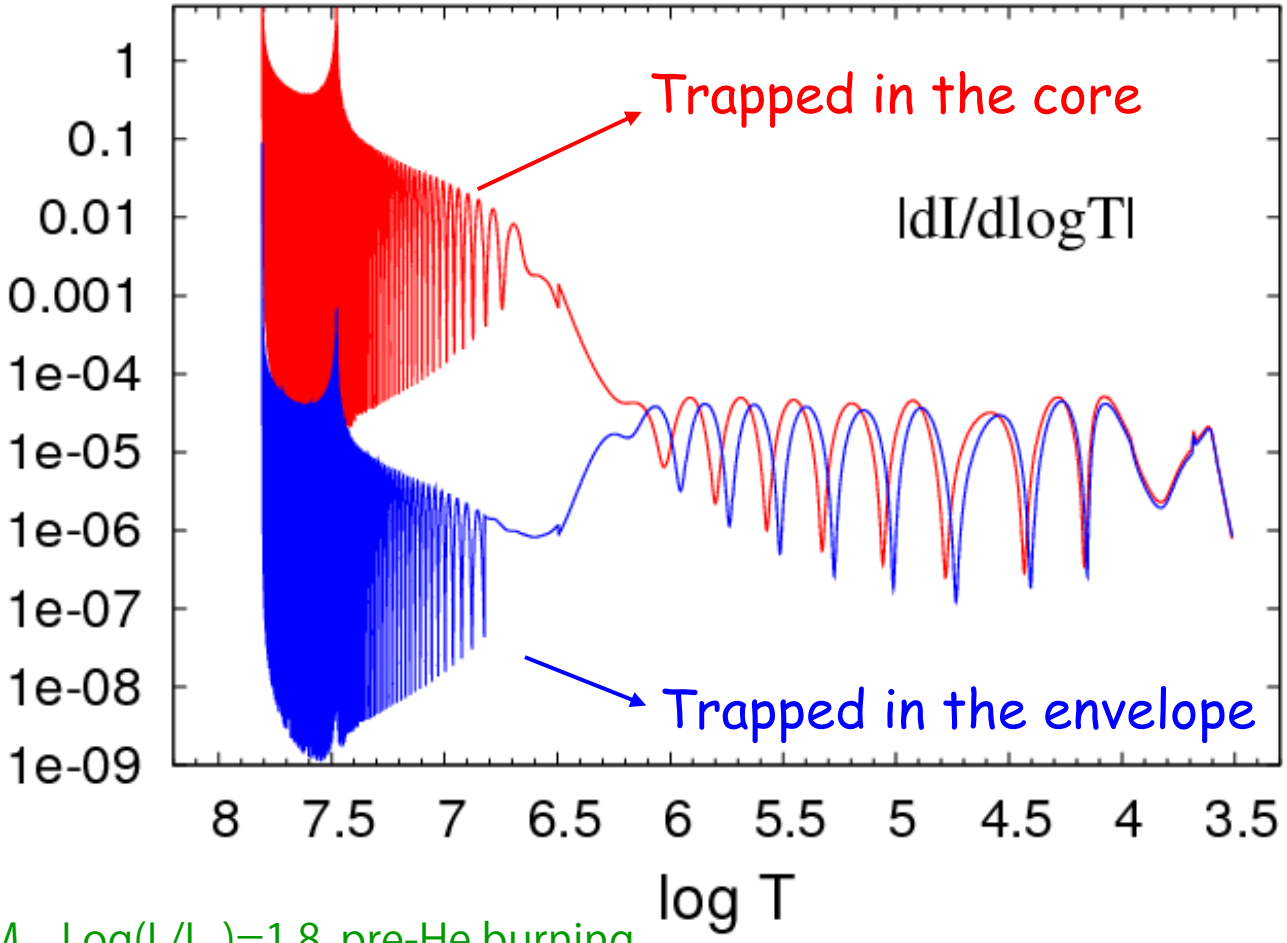


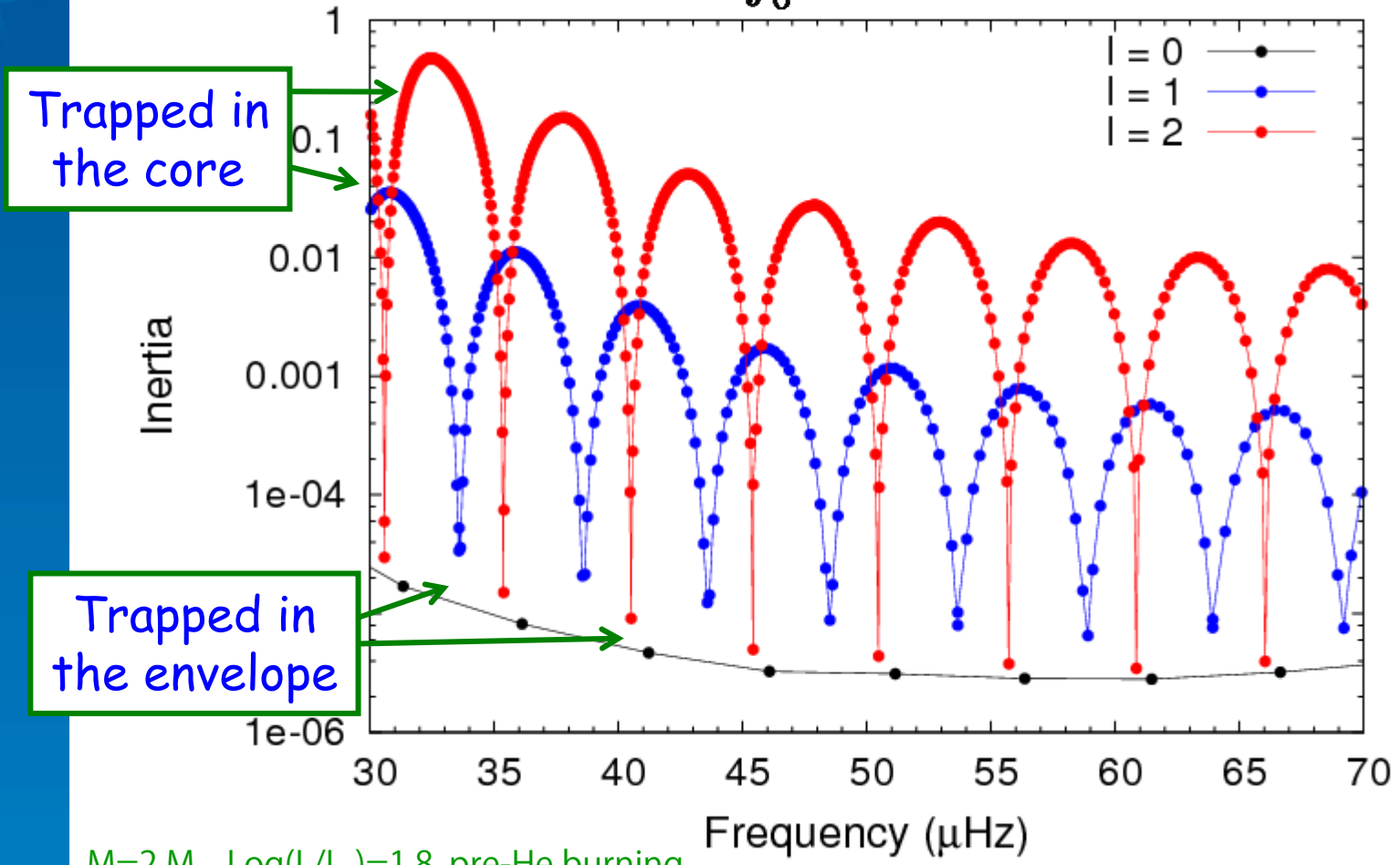
M=2 M–, Log(L/L–)=1.8, pre-He burning

Mode physics in Red Giants

Mode trapping

See also Dziembowski et al. (2001)
Christensen-Dalsgaard (2004)

$$\text{Inertia} = \int_0^M | \vec{\delta r} |^2 \, dm$$



M=2 M⊙, Log(L/L⊙)=1.8, pre-He burning

Mode physics in Red Giants

Stochastic excitation (top of the convective envelope)

Samadi et al. (2003, …), Belkacem et al. (2006, …)

Amplitude (velocity)

$$V^2(R) = \frac{P}{2\,\eta\, I}$$

- P: Stochastic power
- I: Inertia
- η: Damping rate

$$P = p\, I^{-1}$$

- p: Reynolds stress
- I^{-1}: Entropy

Stochastic excitation model

Mode physics in Red Giants

chastic excitation (top of the convective envelope)

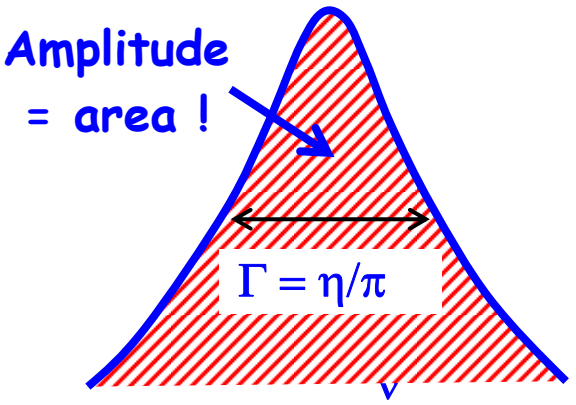
the modes
e resolved :
– time $<<$ T_{obs}

Height in the power spectrum

$$H = \frac{p}{2\,\eta^2\,I^2}$$

If η / I^{-1} : $H \propto p$

Mode profile



Similar heights for radial and resolved non-radial modes

f the modes
not resolved :
$<<$ life – time

$$H = \frac{T_{obs}\,p}{4\,\eta\,I^2}$$

If η / I^{-1} :

$H \propto T_{obs}/\tau$

Mode physics in Red Giants

nvective damping in the envelope

erent interaction convection-oscillations

→ Gabriel (1996), Grigahcène et al. (2005) theory

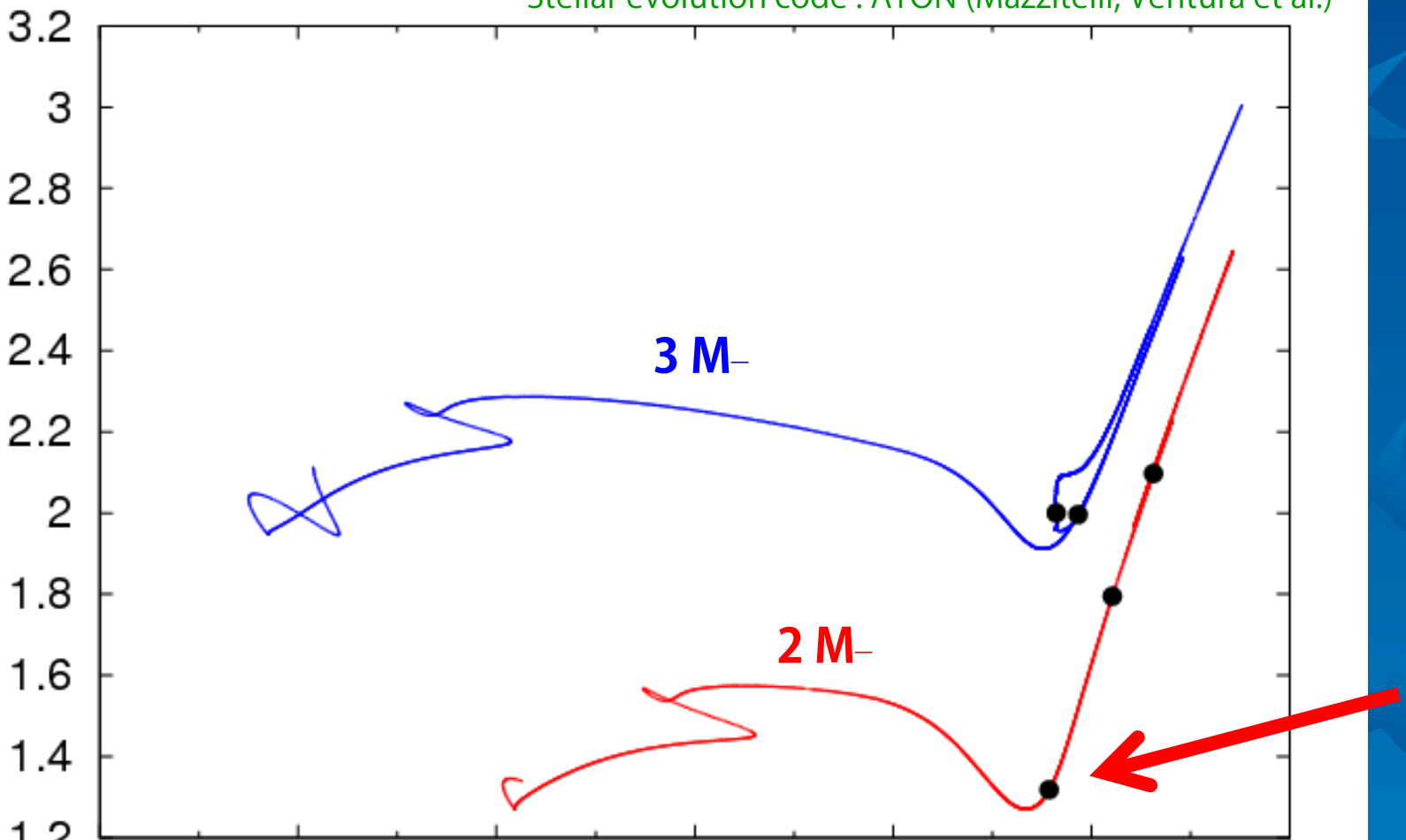
diative damping in the core

a cavity with short
elength oscillations :

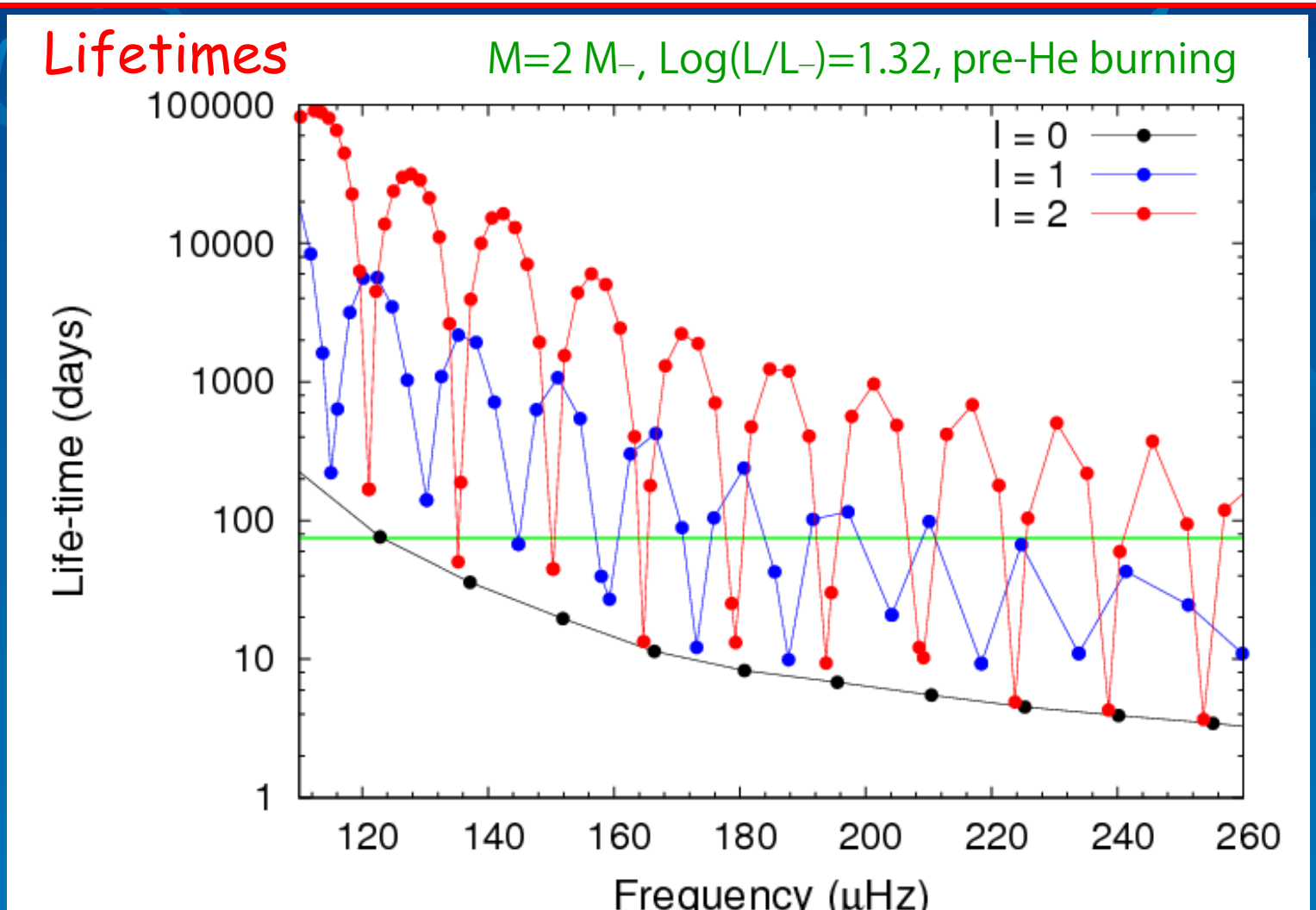
Large variations of the
temperature gradient

Models considered

Stellar evolution code : ATON (Mazzitelli, Ventura et al.)



A : Model at the bottom of red giant branch



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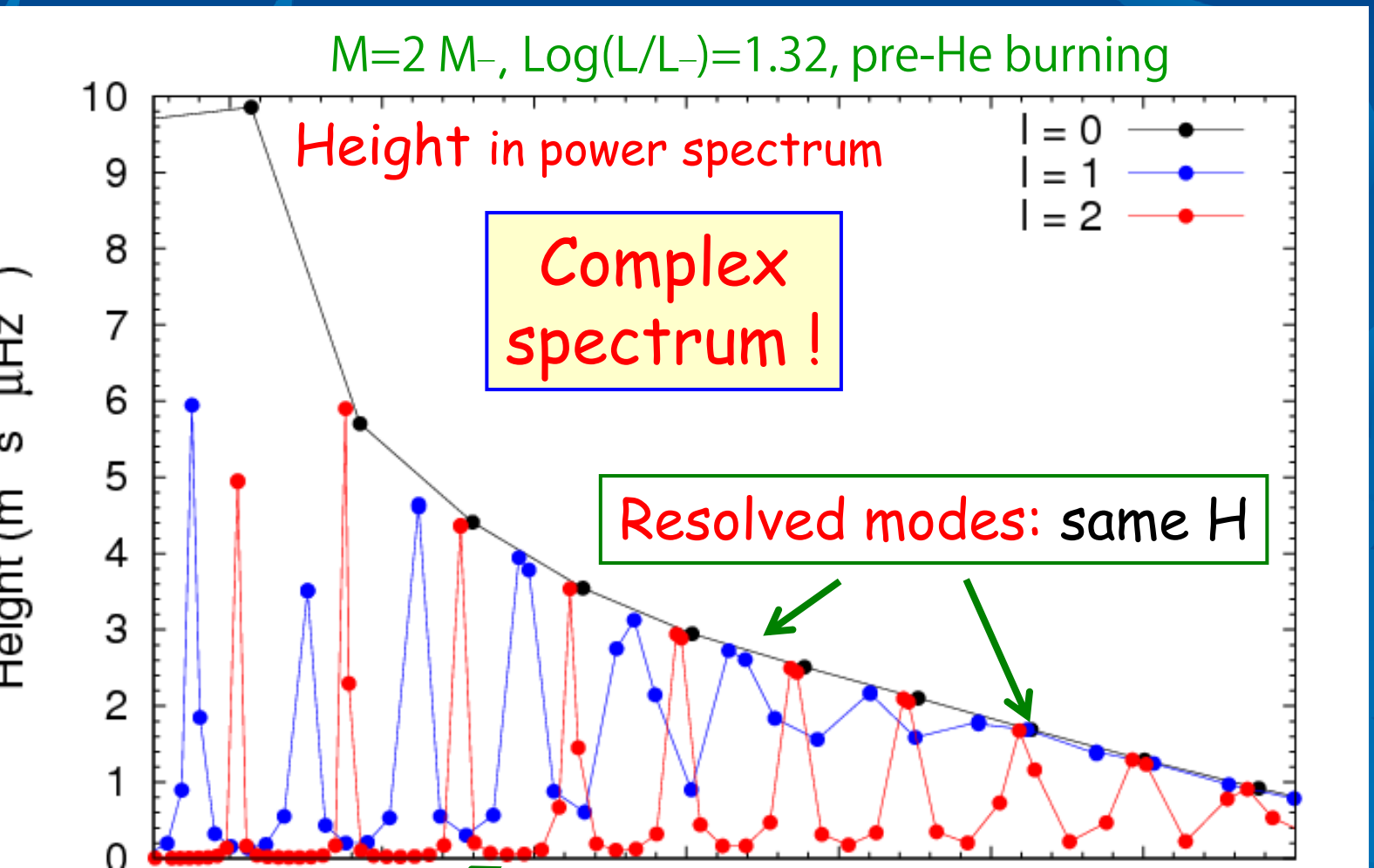
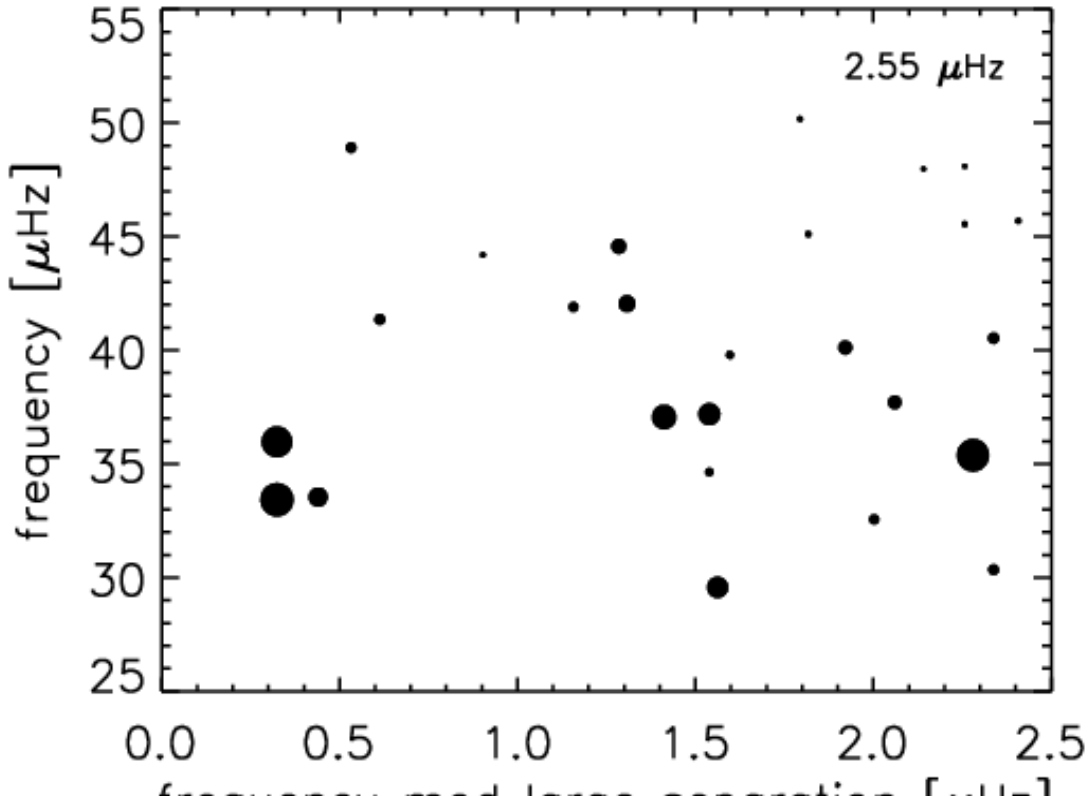


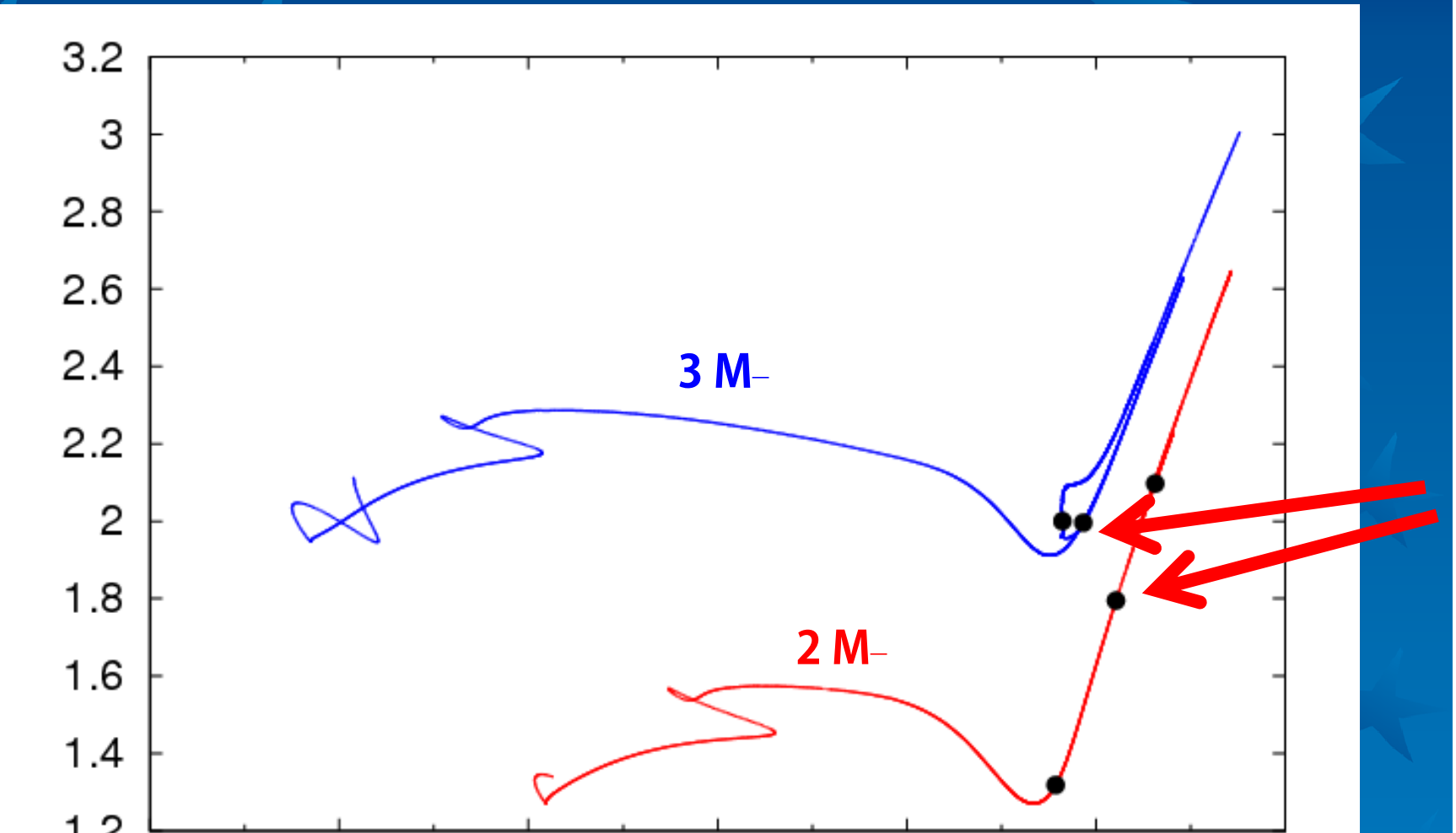
A : Model at the bottom of red giant branch

e CoRoT red giants have a complex frequency spectrum !

Echelle diagram



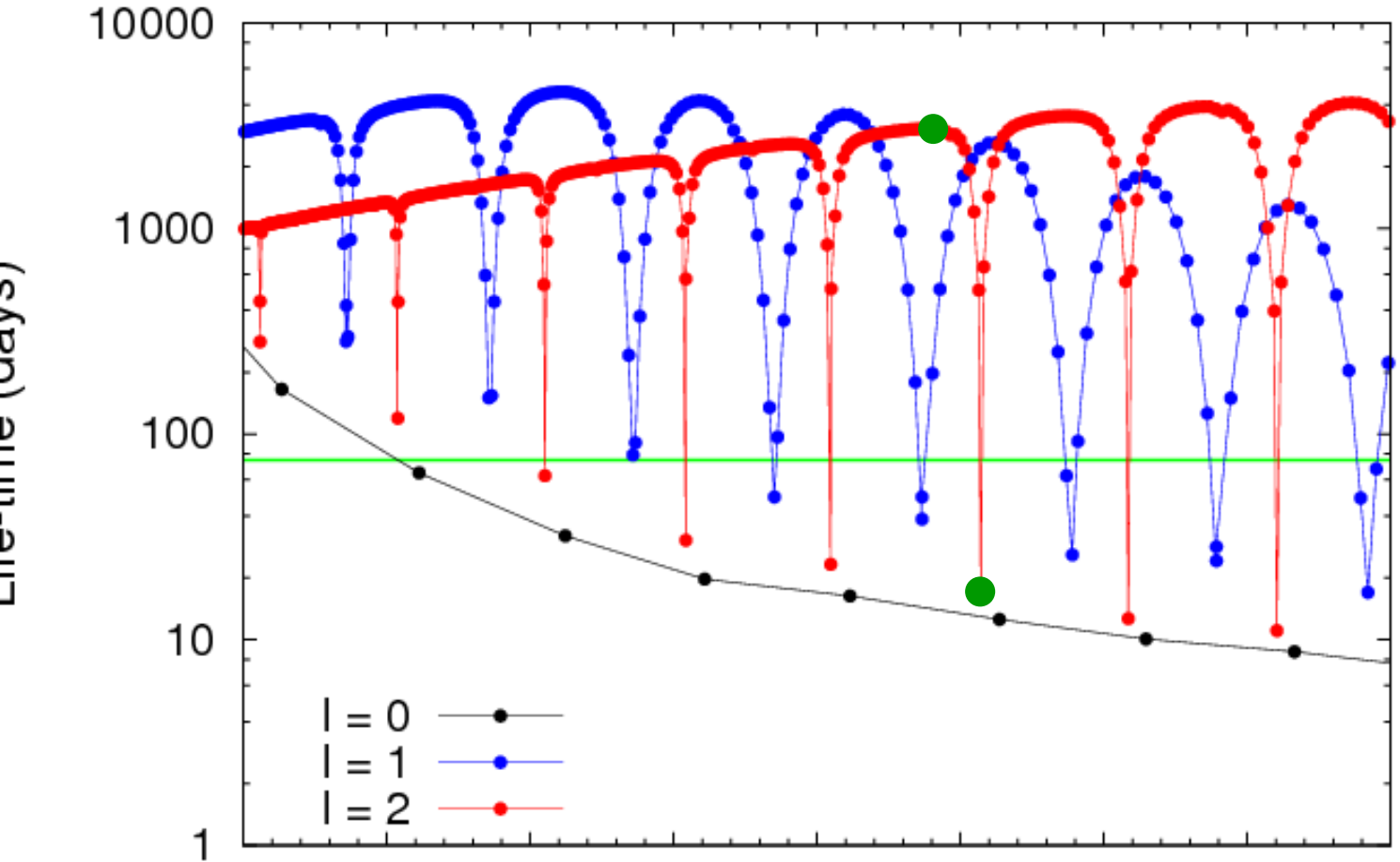
: Intermediate model in the red giant branch



: Intermediate model in the red giant branch

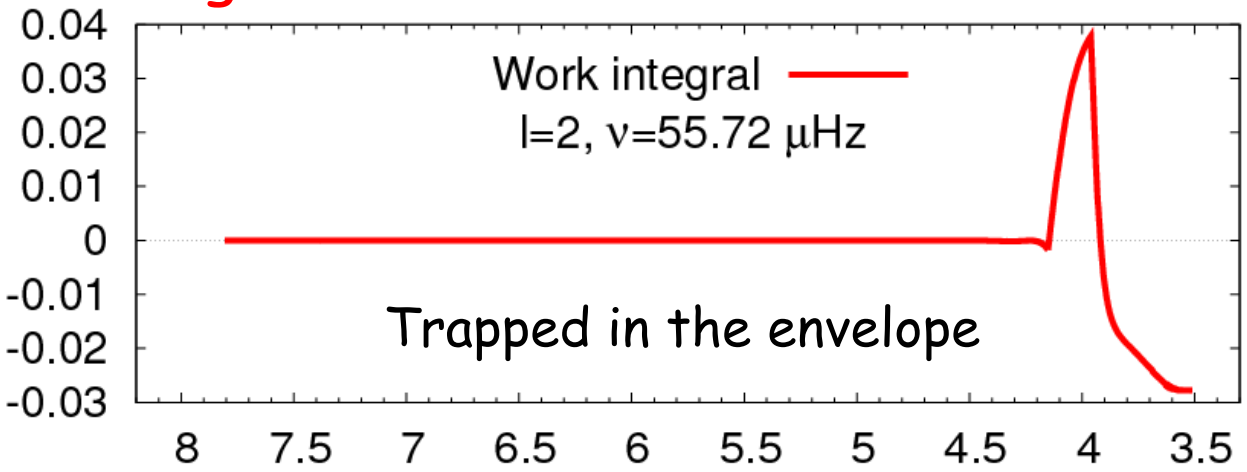
Lifetimes

M=2 M–, Log(L/L–)=1.8, pre-He burning

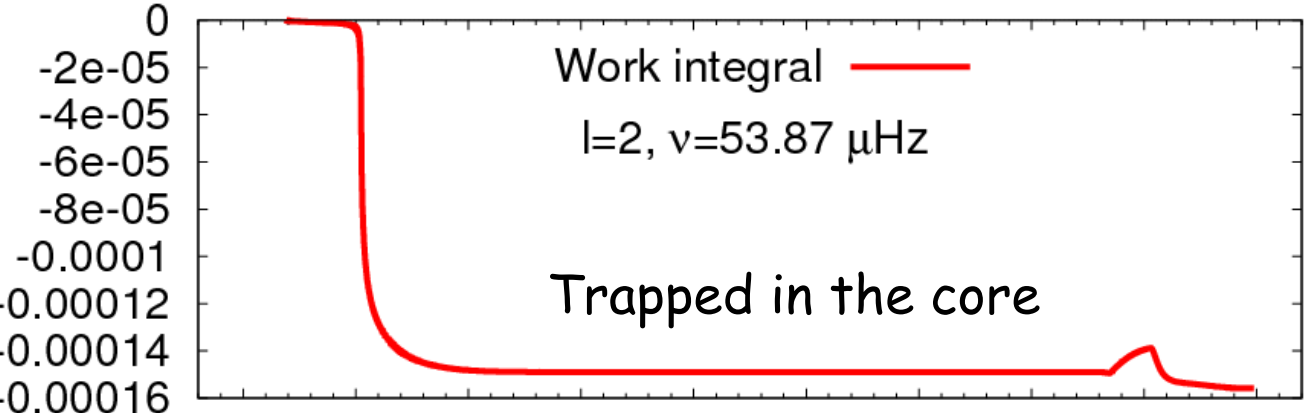


: Intermediate model in the red giant branch

Work integrals M=2 M–, Log(L/L–)=1.8, pre-He burning



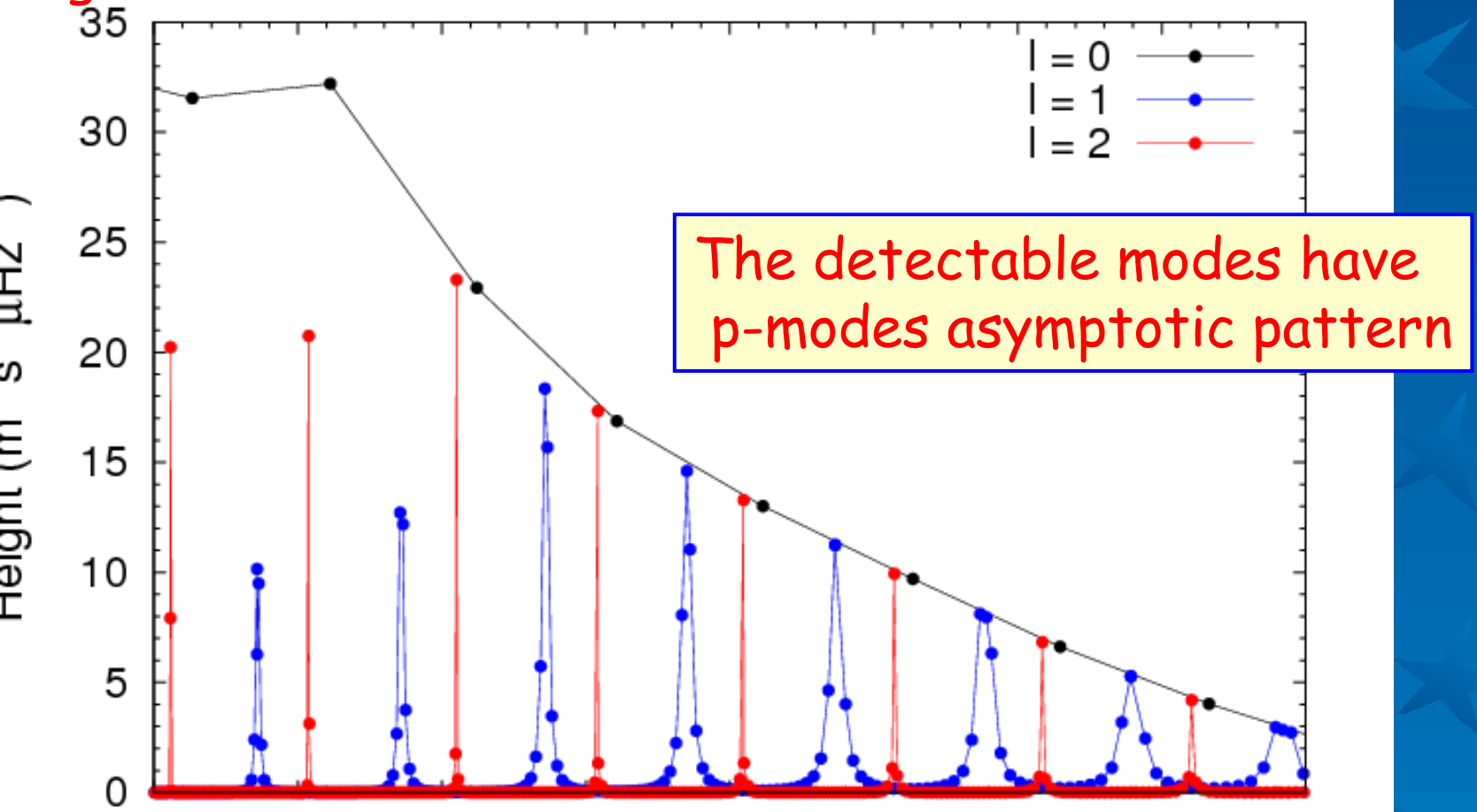
Convective damping near the surface



Radiative damping in the core

: Intermediate model in the red giant branch

Height in PS M=2 M–, Log(L/L–)=1.8, pre-He burning

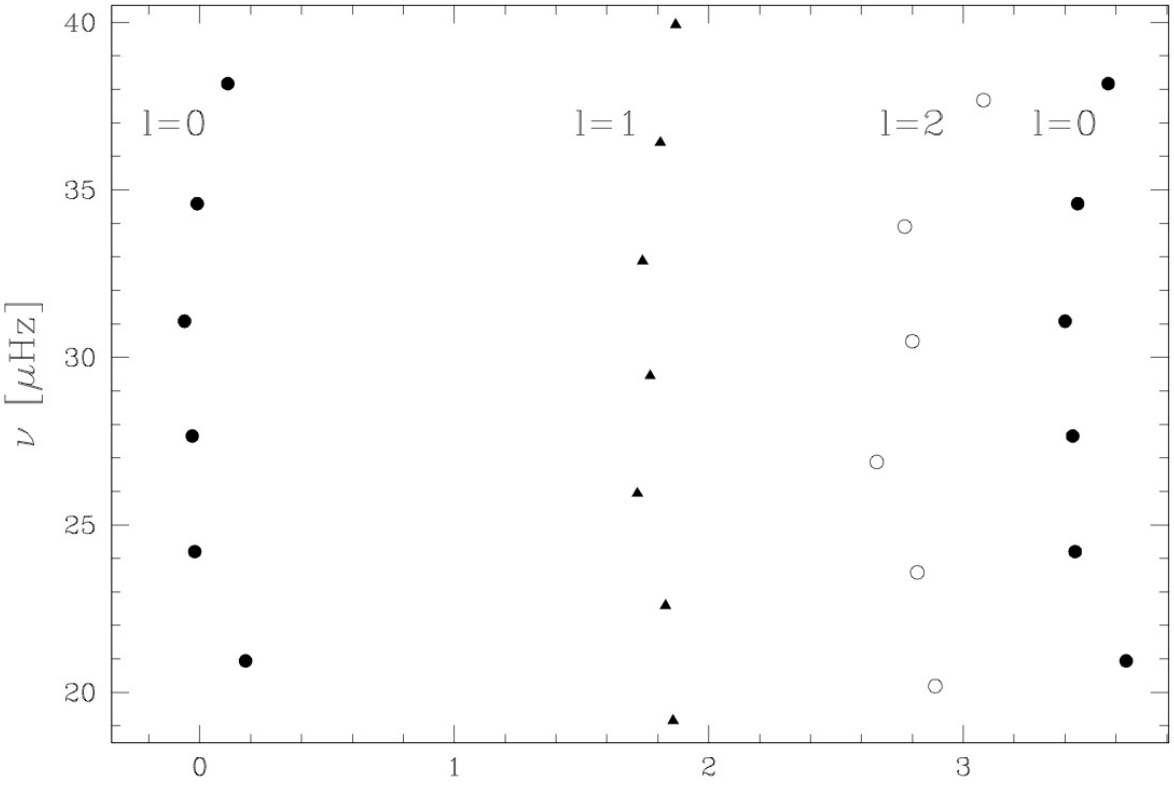


The detectable modes have p-modes asymptotic pattern

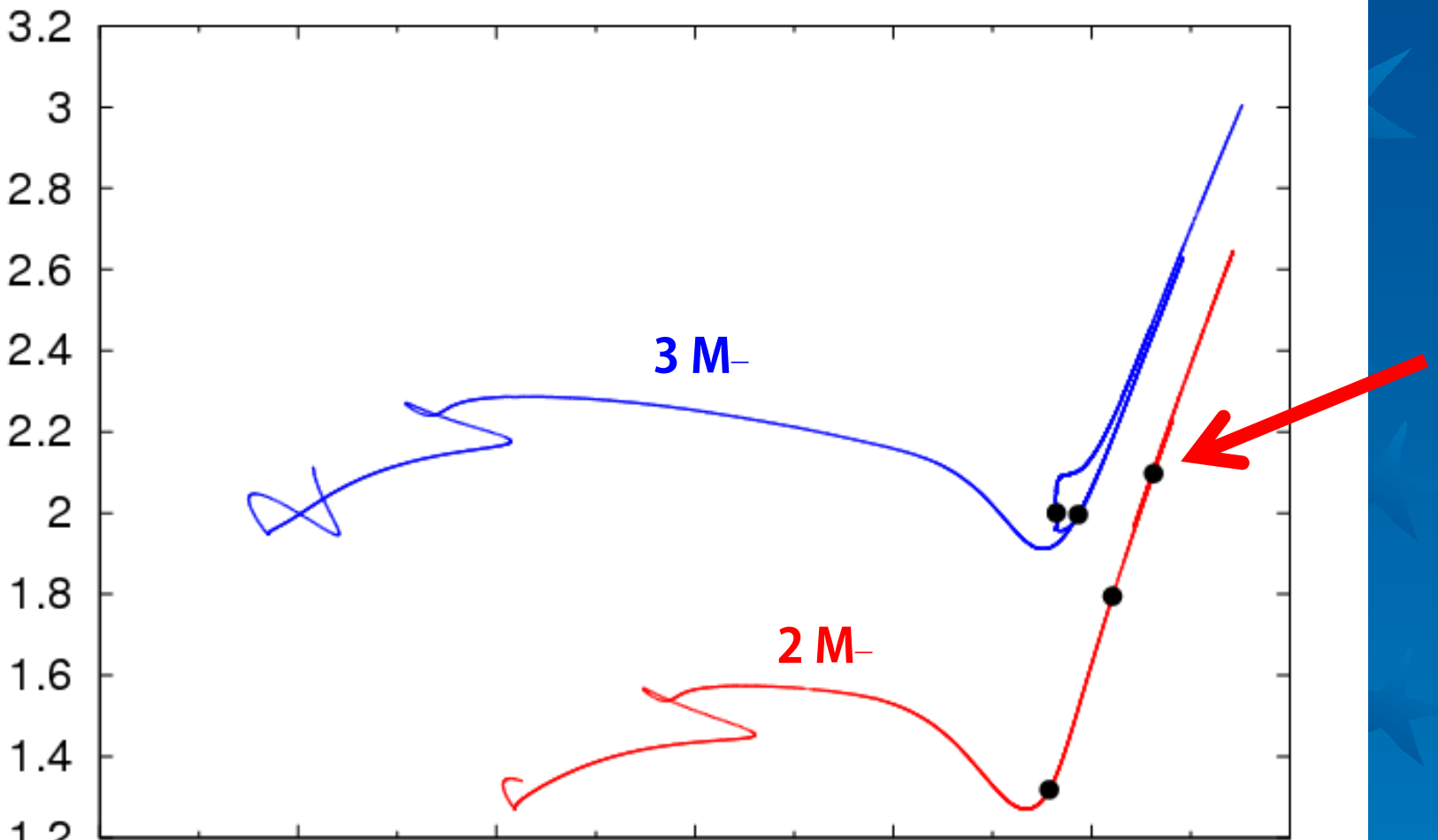
: Intermediate model in the red giant branch

some CoRoT red giants, echelle diagrams can be built !

Echelle diagram HD 181907



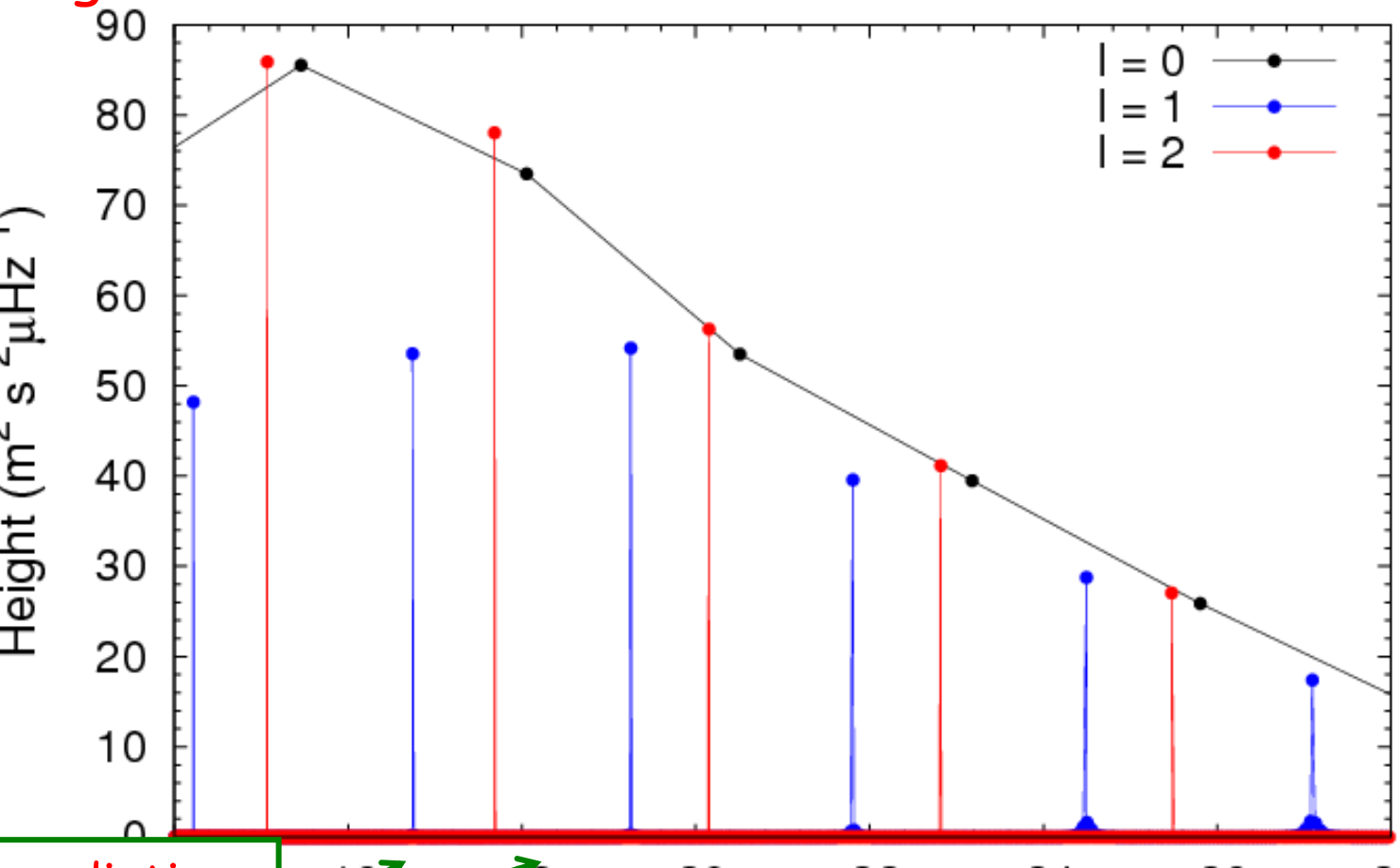
High luminosity model in the red giant branch



High luminosity model in the red giant branch

Height in PS

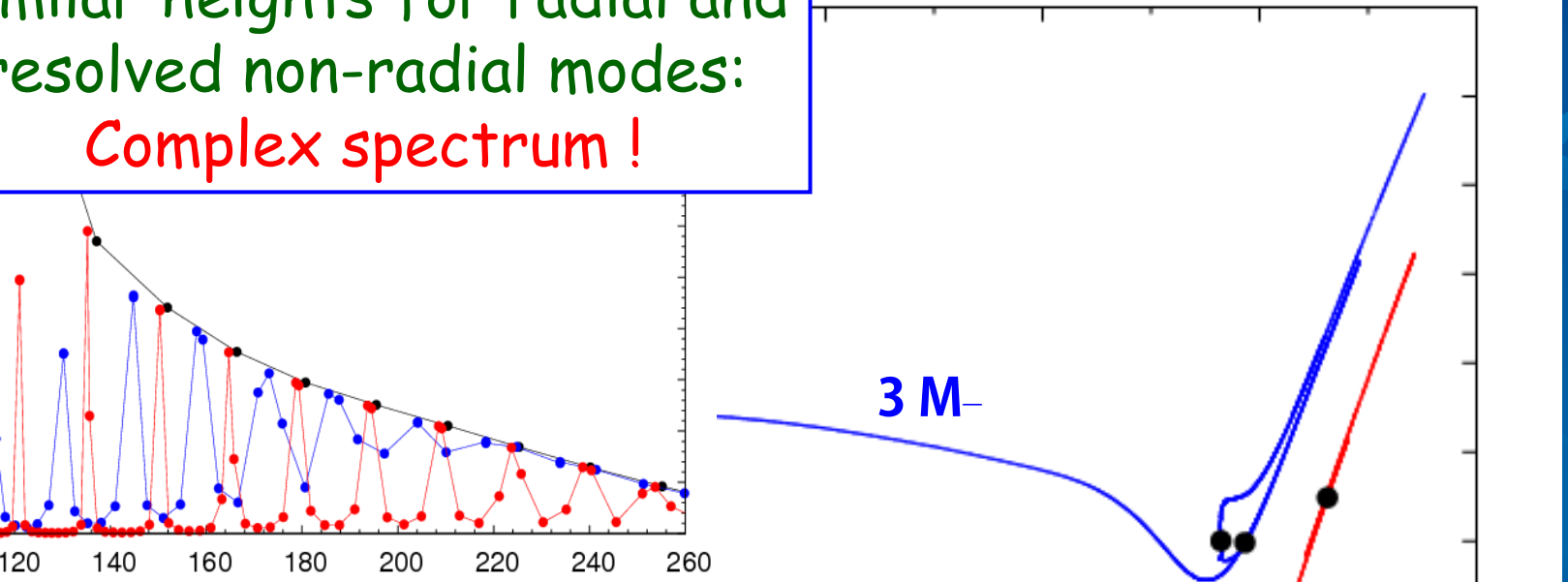
M=2 M⊙, Log(L/L⊙)=2.1, pre-He burning



clusions:

A. Model at the bottom of red giant branch

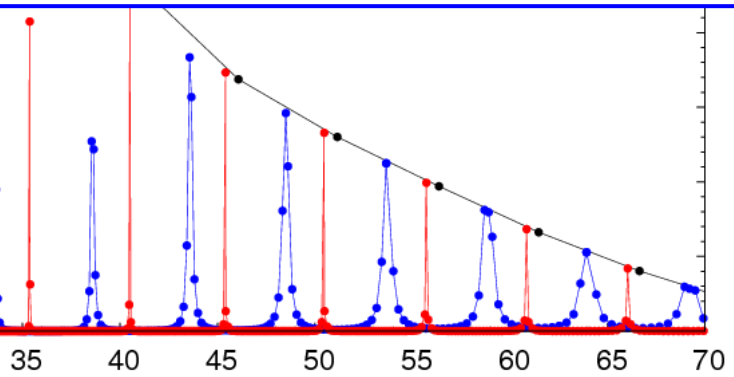
milar heights for radial and
resolved non-radial modes:
Complex spectrum !

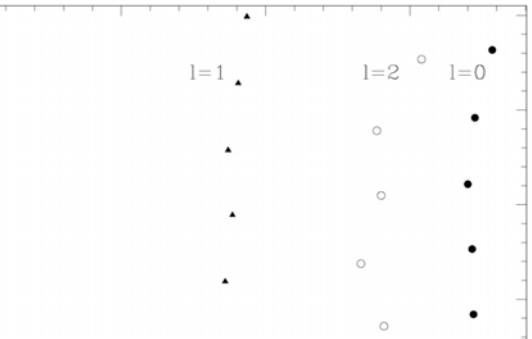


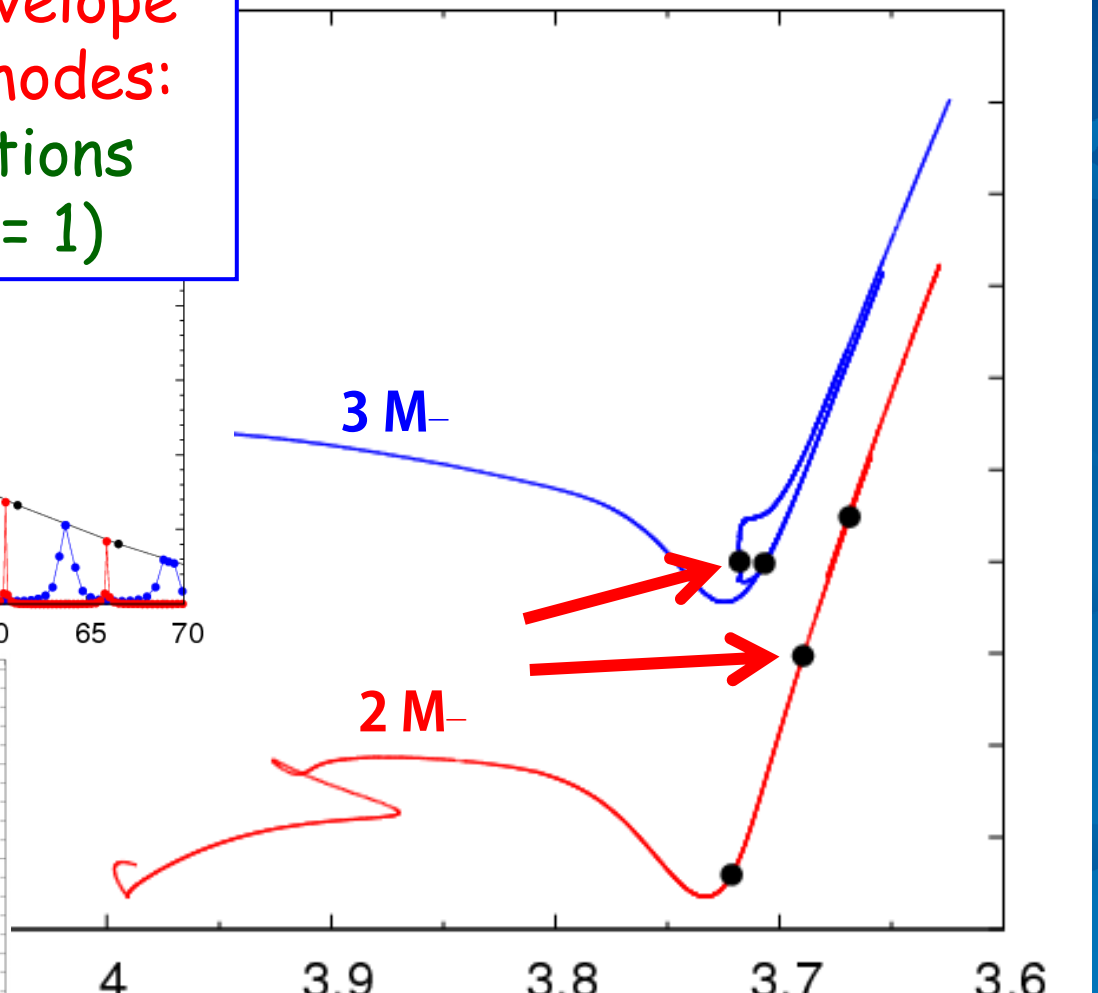
clusions:

B. Intermediate model in the giant branch

dial modes and envelope
apped non-radial modes:
arge, small separations
(but groups for $\lambda = 1$)



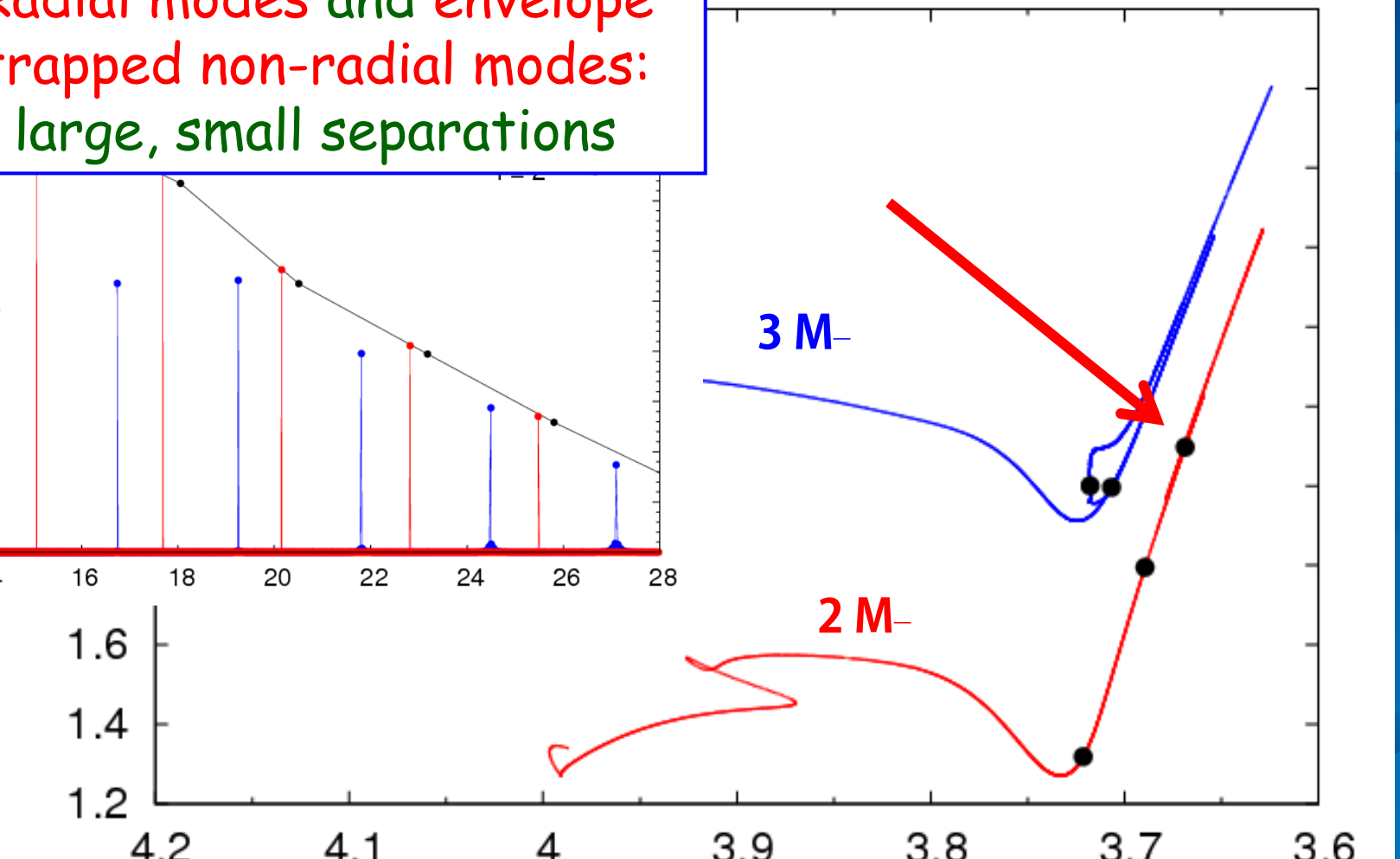




clusions:

C. Intermediate model in the giant branch

Radial modes and envelope
trapped non-radial modes:
large, small separations



Conclusions of the conclusions

an we explain the detection of
on-radial modes in red giants ?

Can we explain the regular
tterns in some power spectra ?

Yes !
Thanks to mode trapping and
radiative damping effects

Interpretation

Damping rate

$$=$$

$$\frac{\ell(\ell+1)}{2\sigma^2}\int_0^{r_0}\left(\frac{\nabla_{\rm ad}}{\nabla}-1\right)\frac{\nabla_{\rm ad}\,N\,g\,L}{P\,r^5}\,{\rm d}r \quad + \quad \ldots$$

$$4\pi\int_0^{r_0} N/r\,{\rm d}r \quad + \quad \ldots$$

$$\propto \quad \sqrt{GM_c/R_c^3}$$

$$\propto \quad \sqrt{\frac{GM_c}{R_c^3}\,\frac{RL}{GM^2}\,\frac{R^2}{R_c^2}\,\frac{M}{M_c}}$$

1 / Kelvin-Helmholtz time

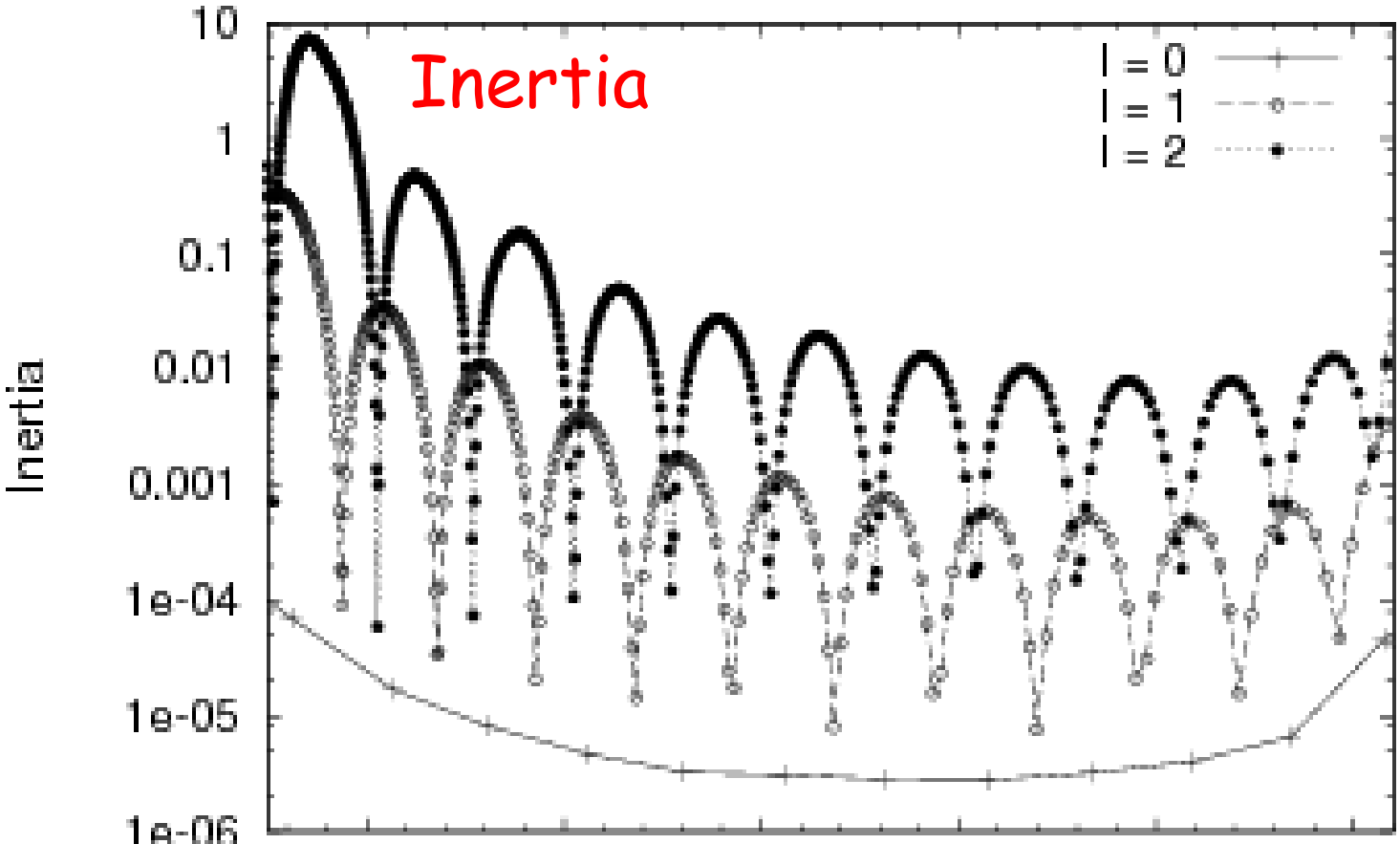
Radiative damping

as star evolves

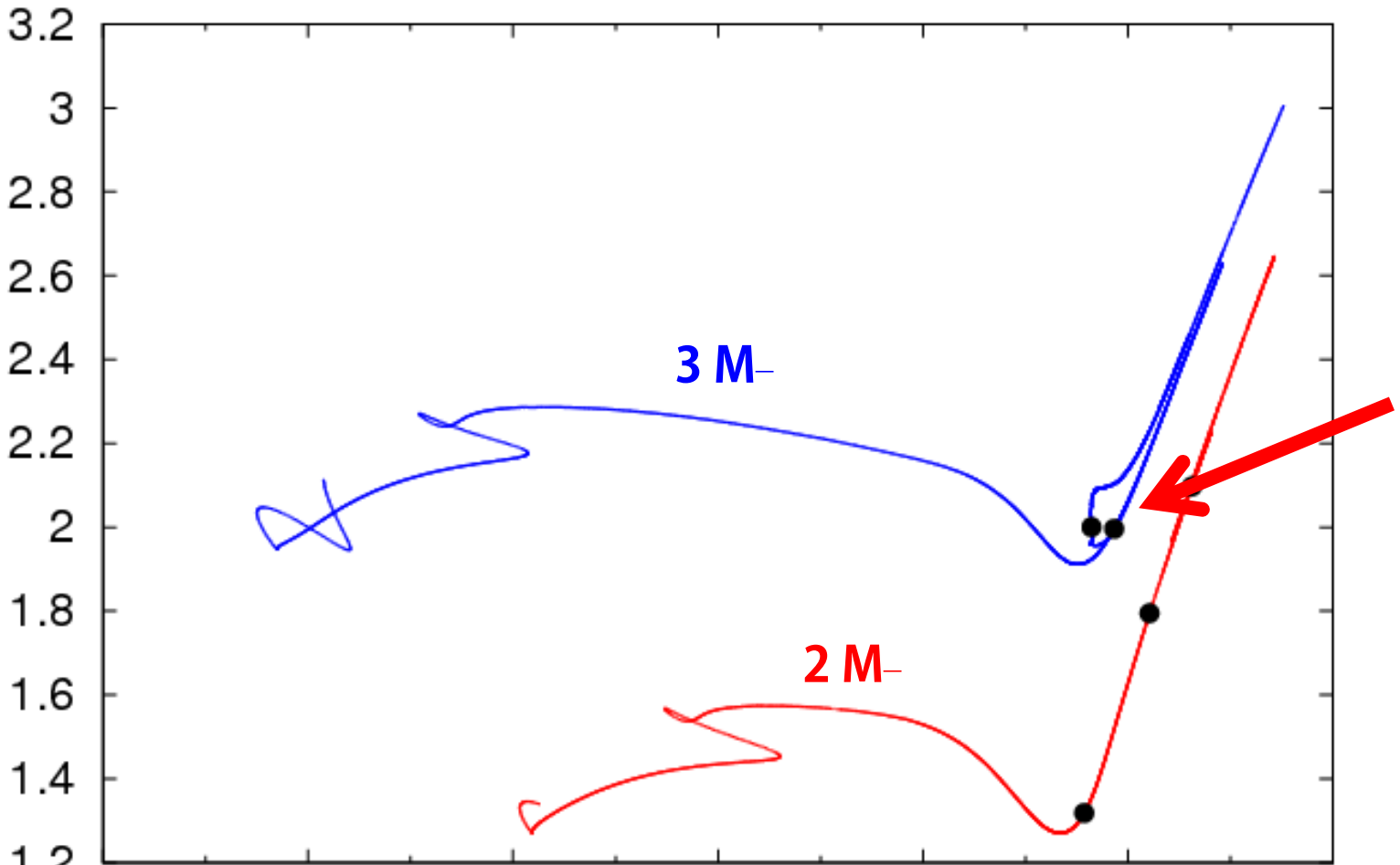
Most radiative damping occurs at

Intermediate model in the red giant branch

M=2 M$_\odot$, Log(L/L$_\odot$)=1.8, pre-He burning

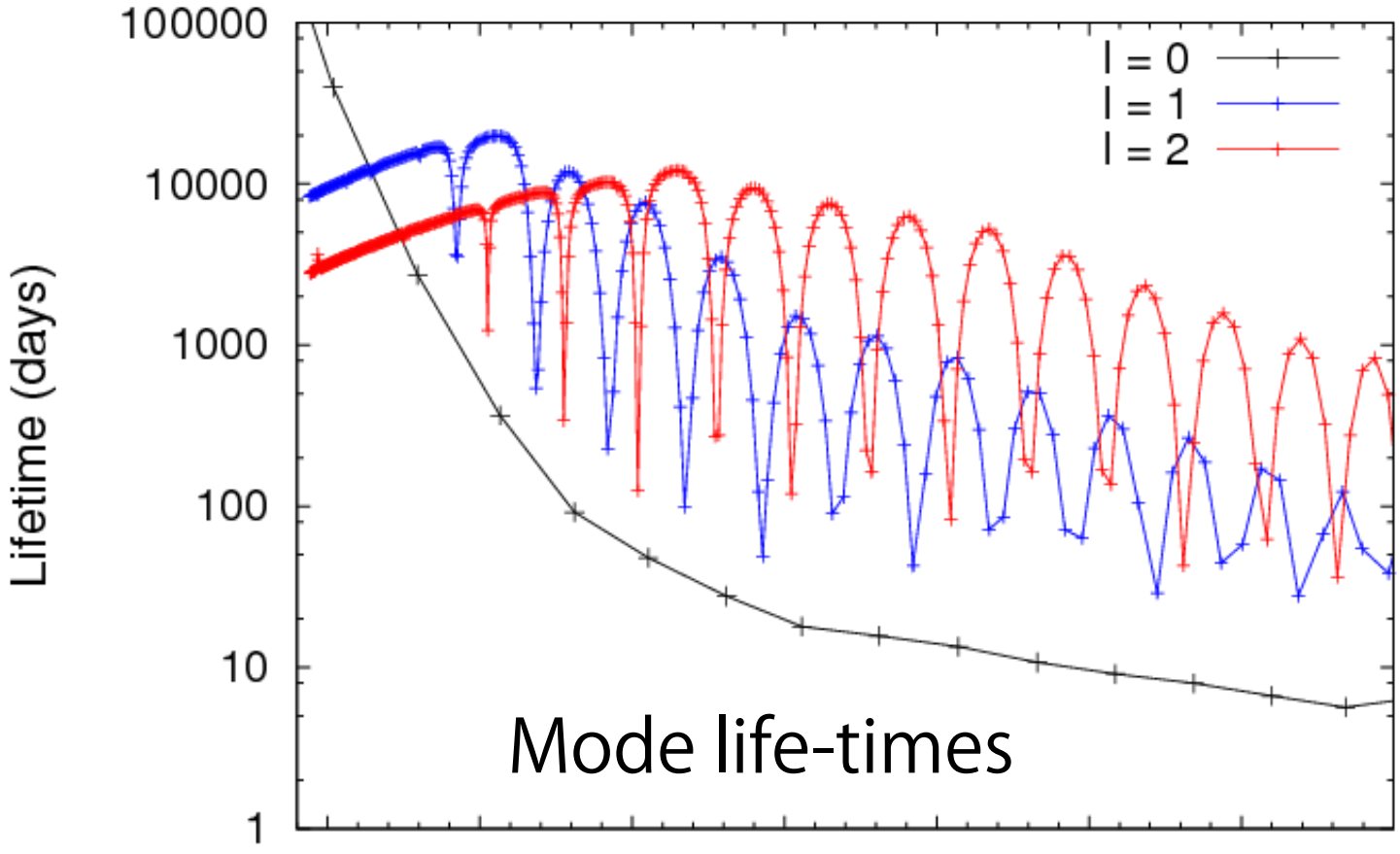


Pre-Helium versus Helium burning



Pre-Helium

M=3 M$_\odot$, Log(L/L$_\odot$)=2, pre-He burning



Helium burning

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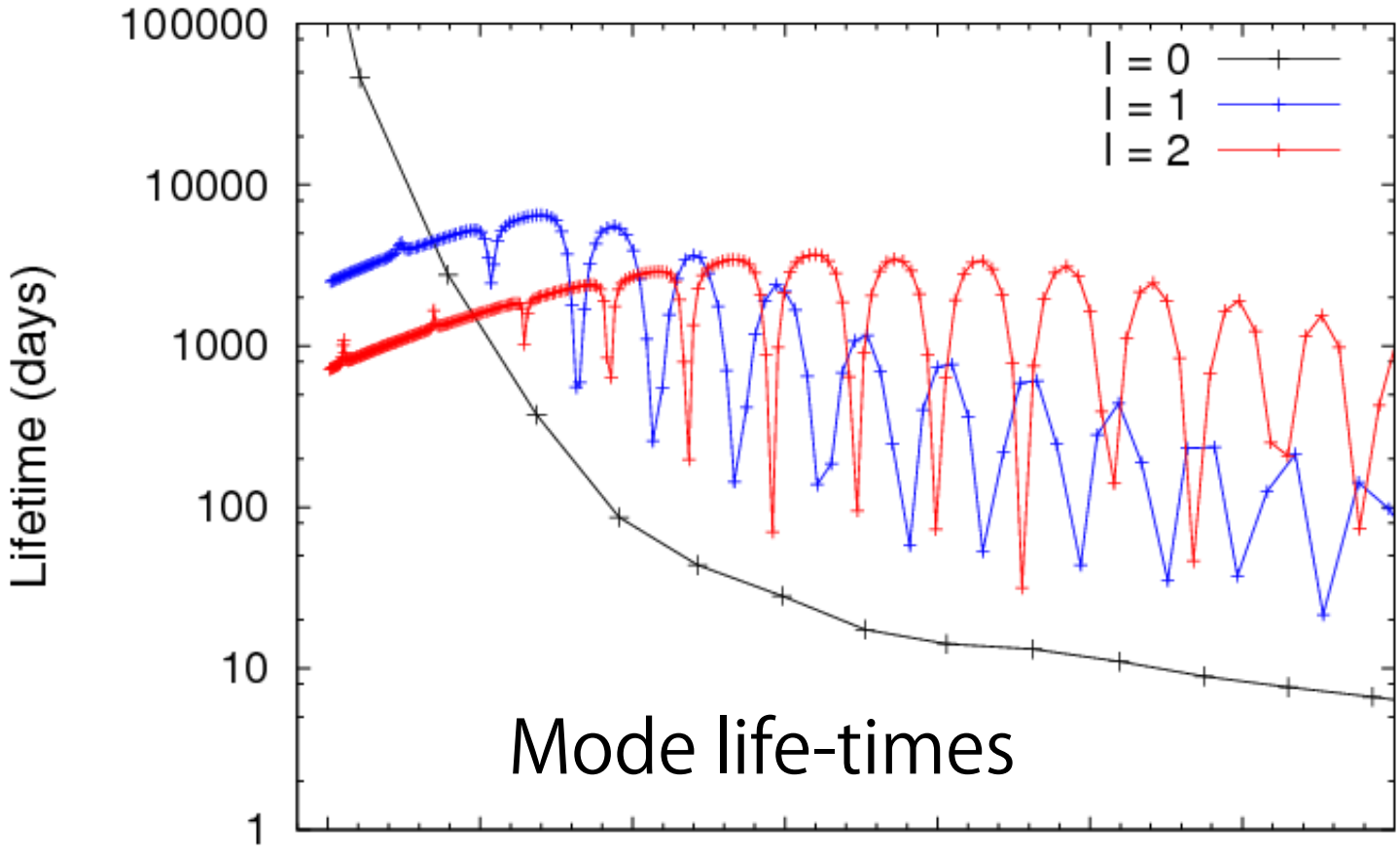

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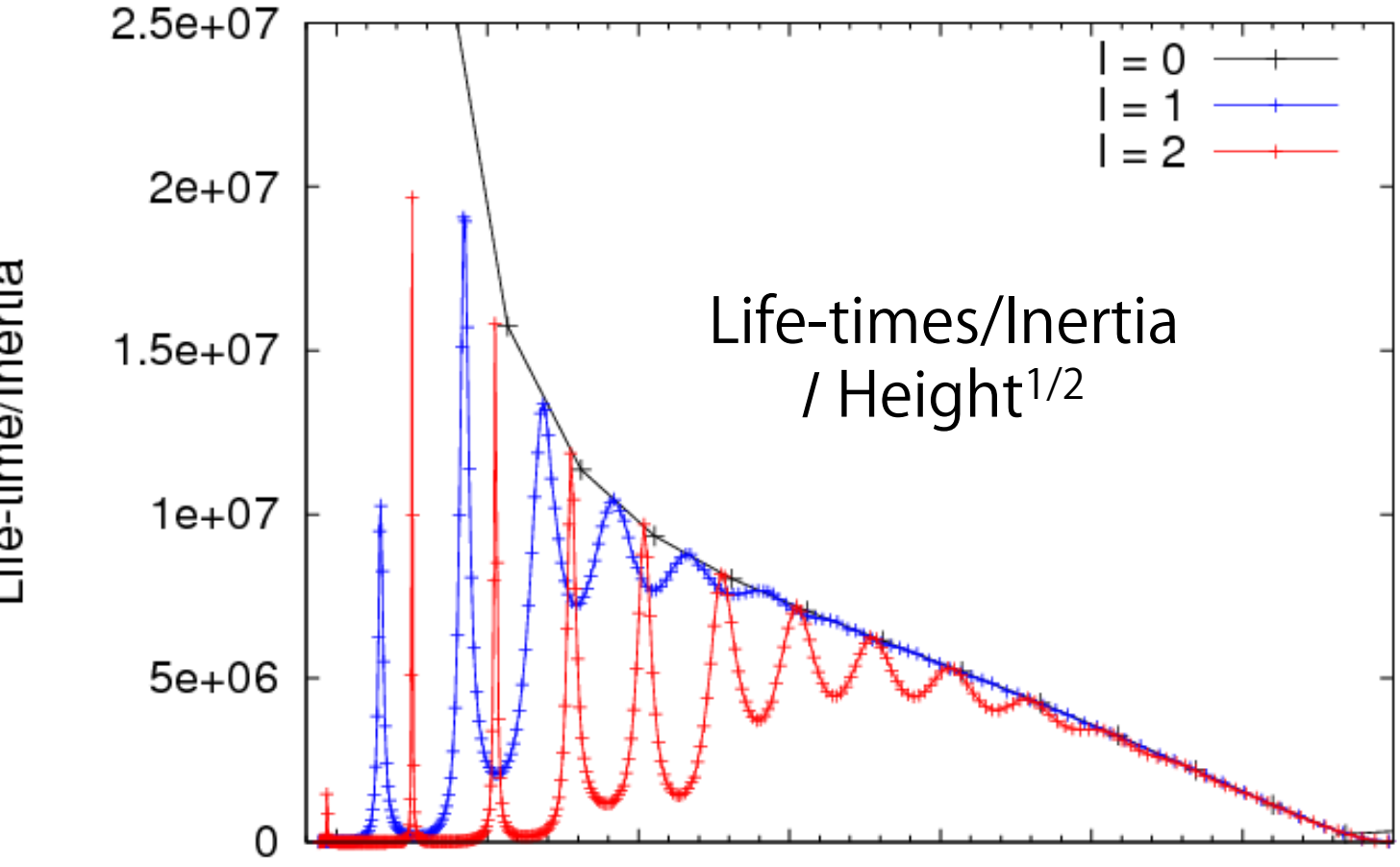
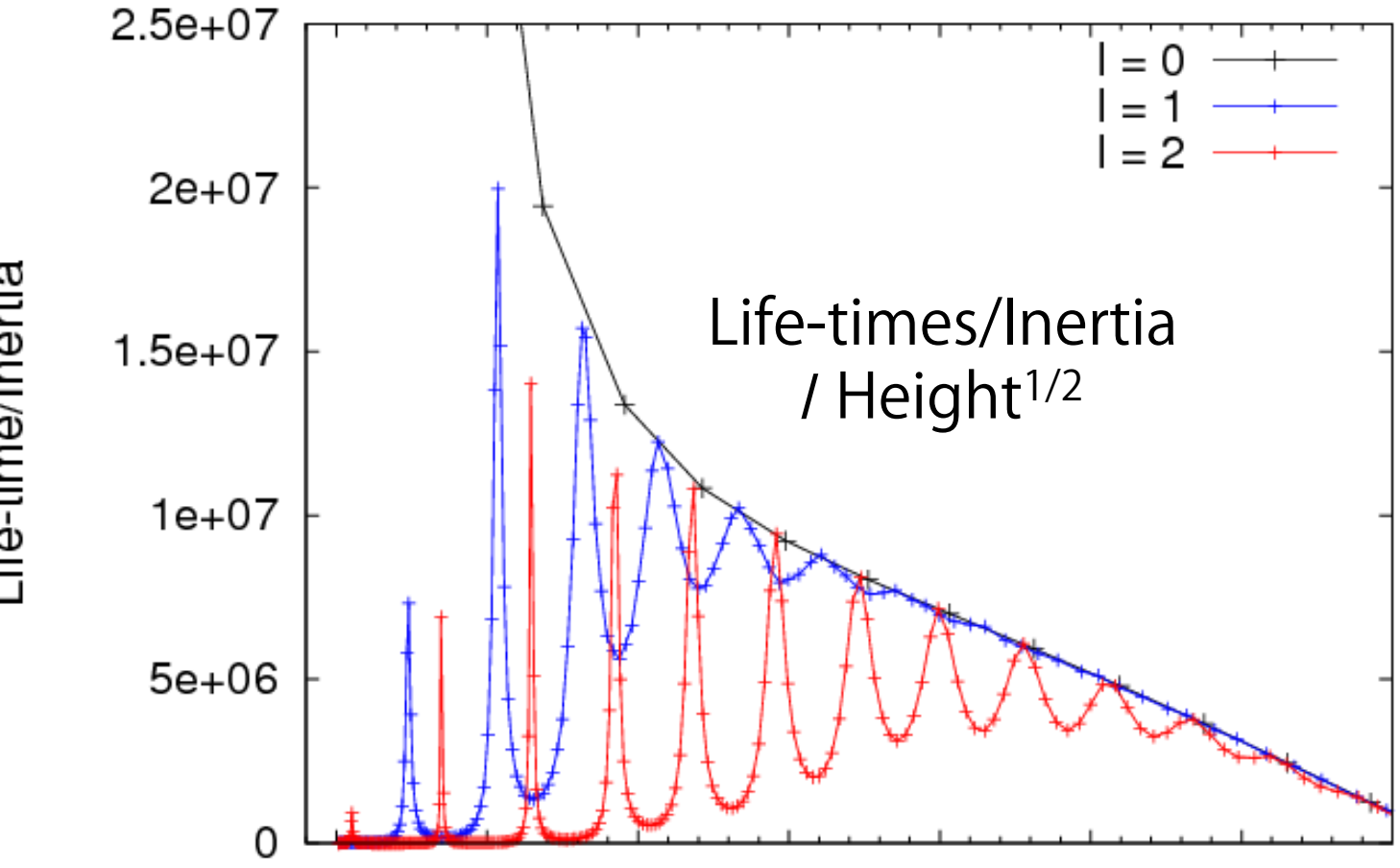


Helium burning

M=3 M$_\odot$, Log(L/L$_\odot$)=2, He burning



Numerical improvements

Damping rate $$\eta = \frac{\int_0^M \mathrm{Im}\left(\frac{\delta\rho^*}{\rho}\frac{\delta P}{\rho}\right)\mathrm{dm}}{2\sigma \int_0^M |\,\xi_r + \ell(\ell+1)\xi_h\,|^2\; dm}$$

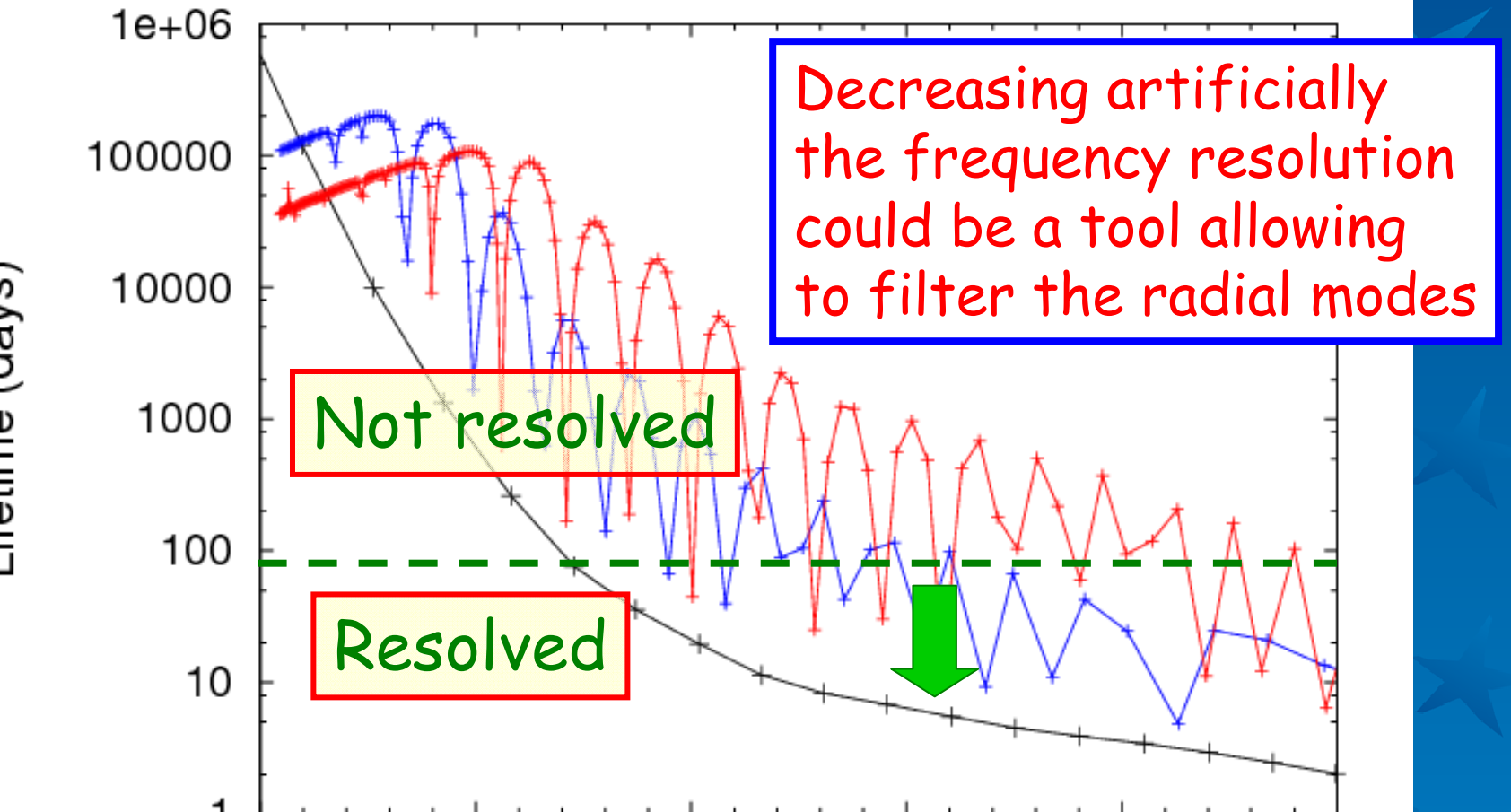
nptotic treatment

Numerator
n the core $$\frac{K^2\,[\ell(\ell+1)]^{3/2}}{2\sigma^2}\int_0^{r_0}\left(\frac{\nabla_{\mathrm{ad}}}{\nabla}-1\right)\frac{\nabla_{\mathrm{ad}}\,N\,g\,L}{P\,r^5}\,\mathrm{d}r$$

Denominator
in the core $$K^2\,4\pi\sqrt{\ell(\ell+1)}\int_0^{r_0} N/r\,\mathrm{d}r$$

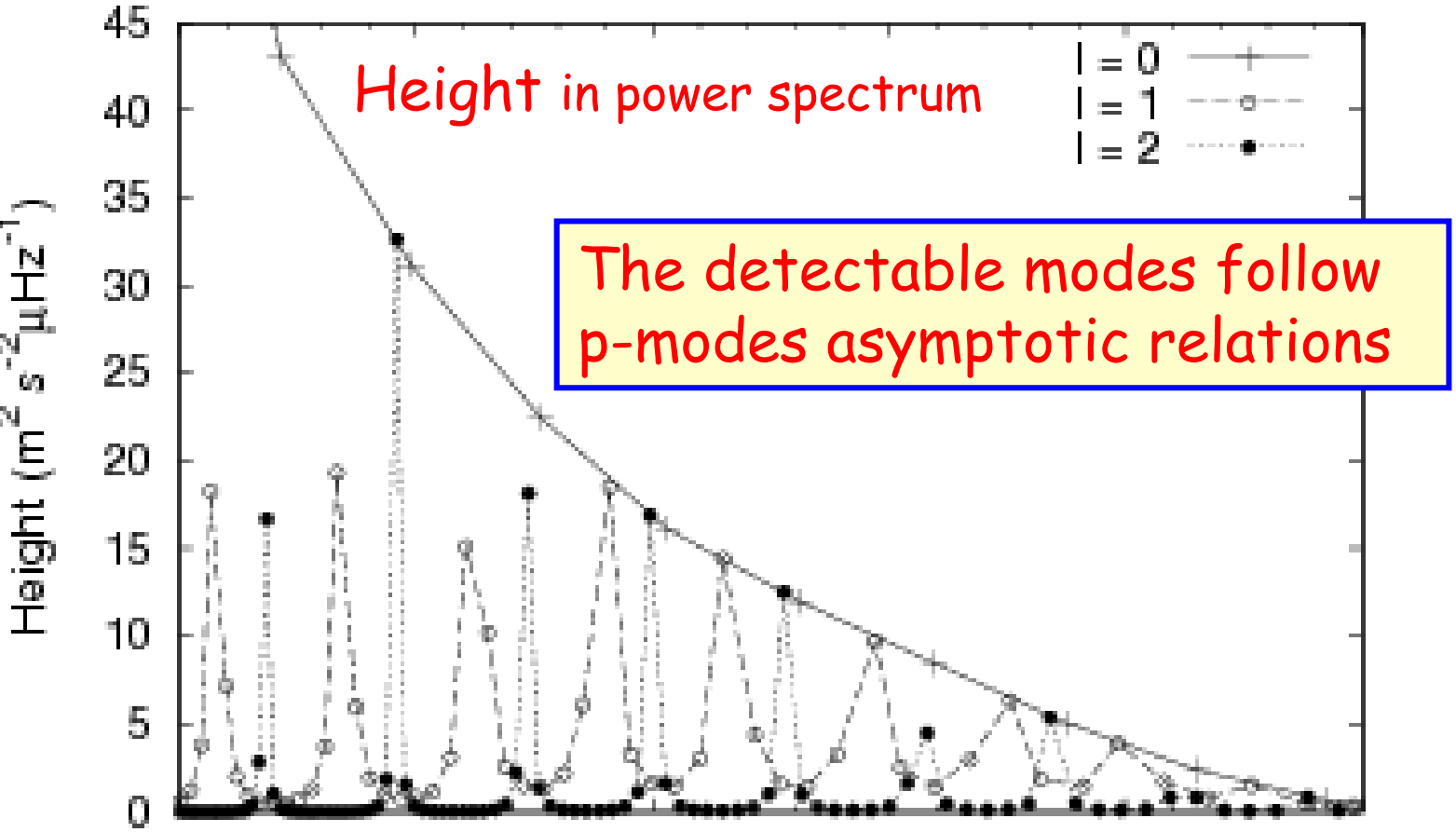
Model at the bottom of red giant branch

M=2 M$_\odot$, Log(L/L$_\odot$)=1.32, pre-He burning



Intermediate model in the red giant branch

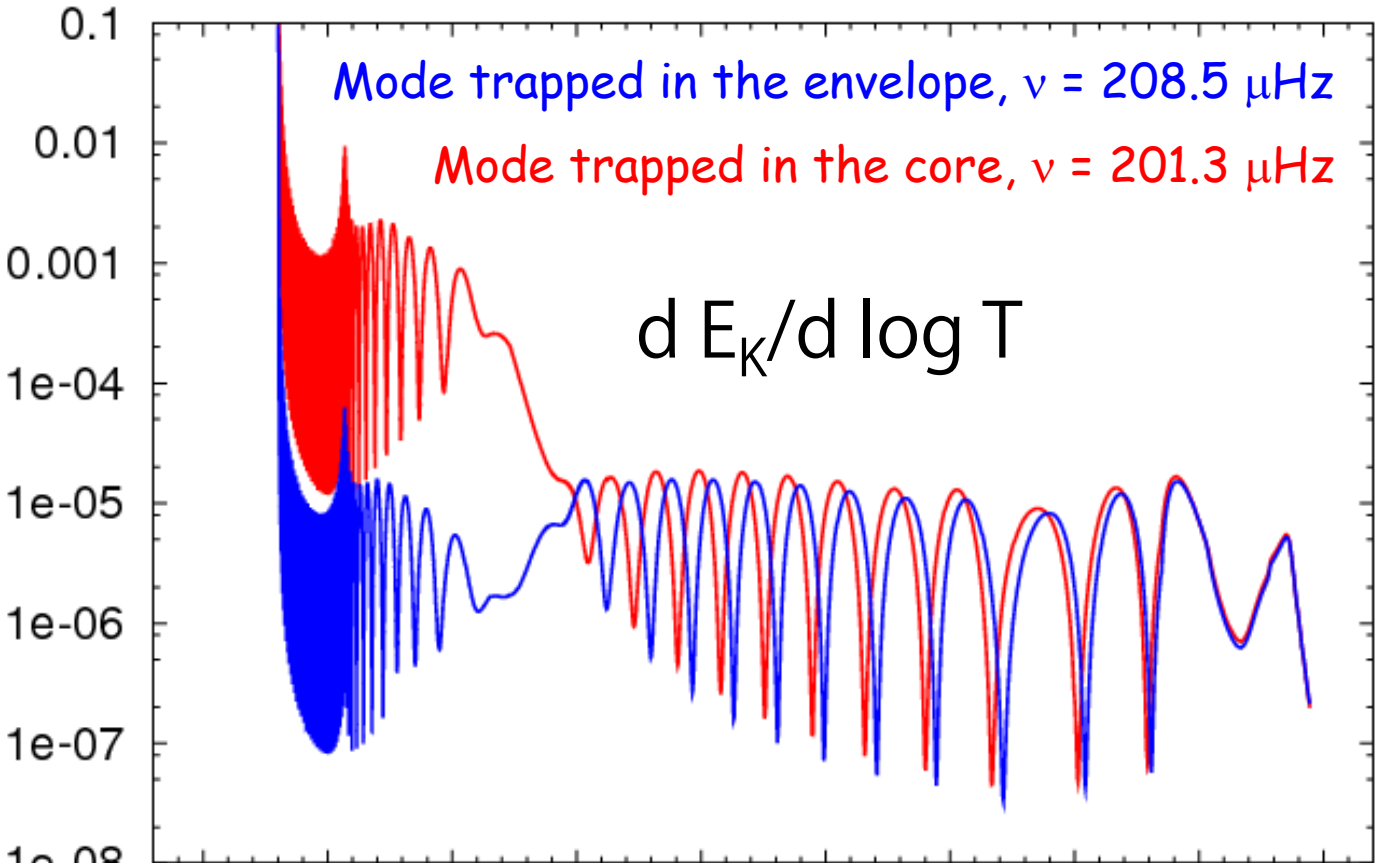
M=3 M$_\odot$, Log(L/L$_\odot$)=2, Helium burning



The detectable modes follow p-modes asymptotic relations

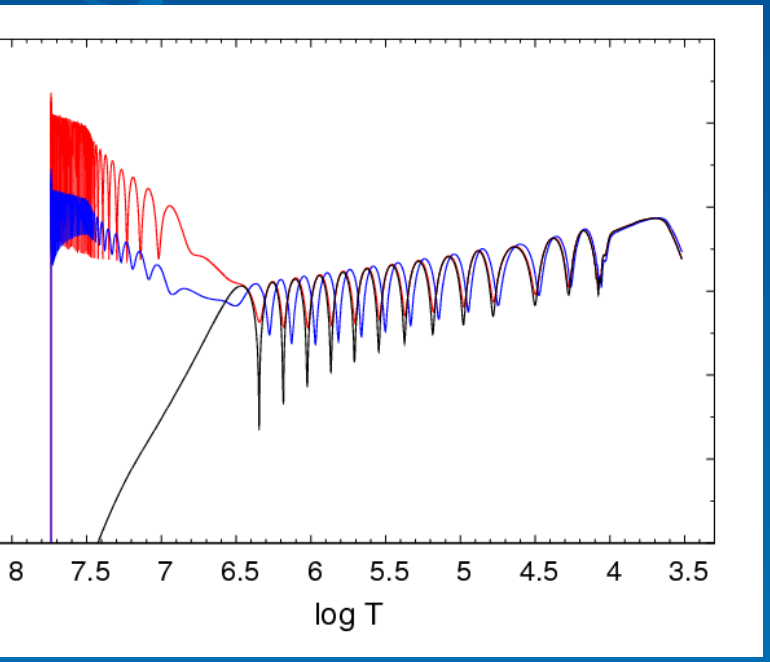
Model at the bottom of red giant branch

M=2 M$_\odot$, Log(L/L$_\odot$)=1.32, pre-He burning



Mode physics in Red Giants

nfunctions with many nodes in the g-mode cavity



$$P_{n,\ell} \approx \frac{2\pi^2(n_g + 1/2)}{\sqrt{\ell(\ell+1)}} \frac{1}{\int_{r_a}^{r_b} \frac{N}{r} \mathrm{d}r}$$

Huge !

Solar-type modes : n_g ~ 100 - 1000 !!!
in the g-cavity

Trapping and radiative damping

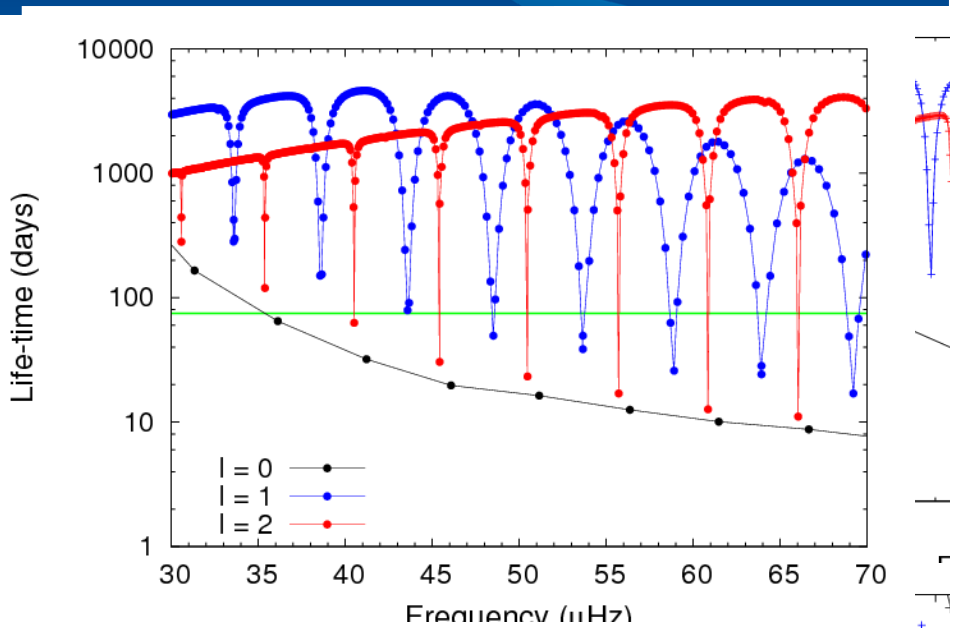
nertia : depends on λ
and mode trapping

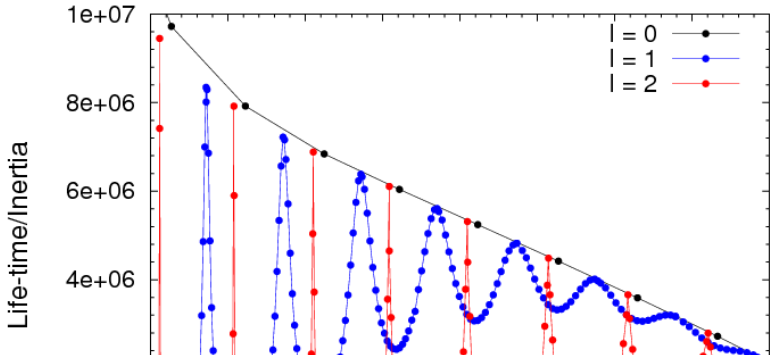
Life-time =

$$\frac{\int_0^M \mid \xi_r + \ell(\ell+1)\xi_h \mid^2 \, dm}{\int_0^M \mathrm{Im}(\frac{\delta\rho*}{\rho}\frac{\delta \mathrm{P}}{\rho})\,\mathrm{dm}}$$

velope : Convective damping
independent of λ

re : Radiative damping





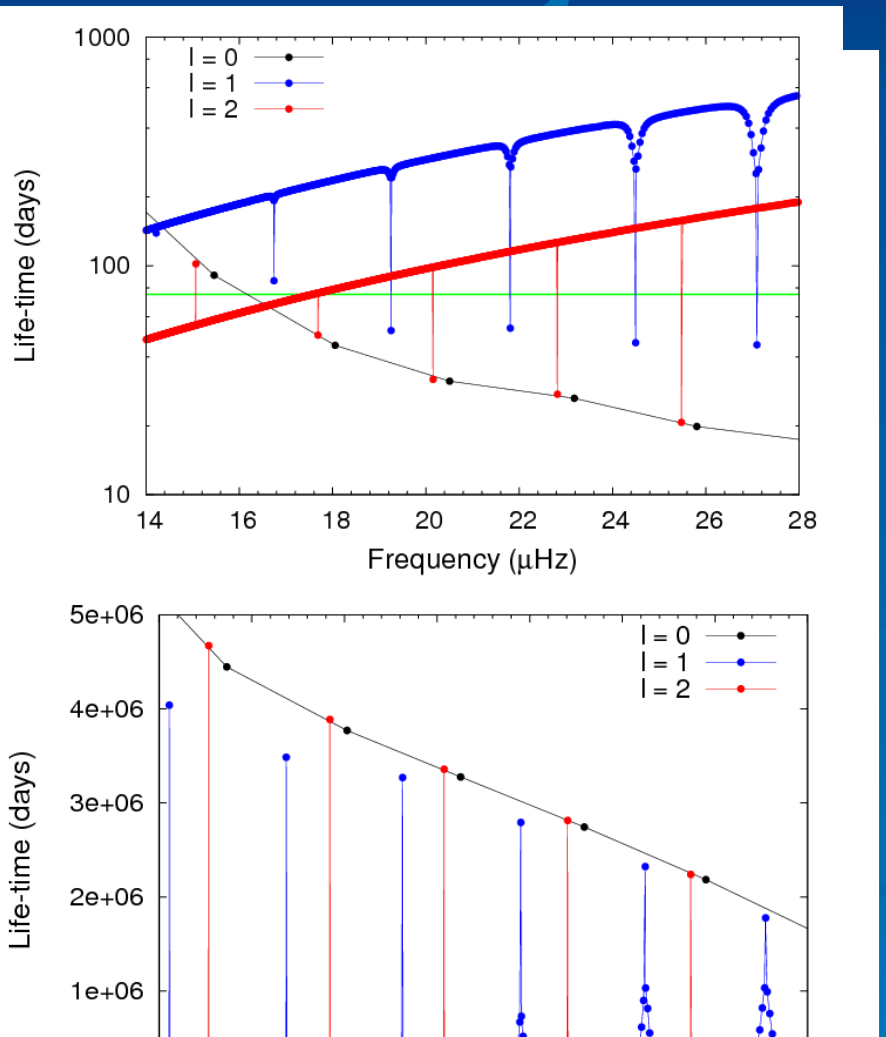
Radiative damping

Life-time ~

$$\frac{4\pi \int_0^{r_0} N/r \, \mathrm{d}r}{1) \int_0^{r_0} \left(\frac{\nabla_{\mathrm{ad}}}{\nabla} - 1 \right) \frac{\nabla_{\mathrm{ad}} N g L}{P r^5} \, \mathrm{d}r}$$

radiative damping:

Life-time depends on λ

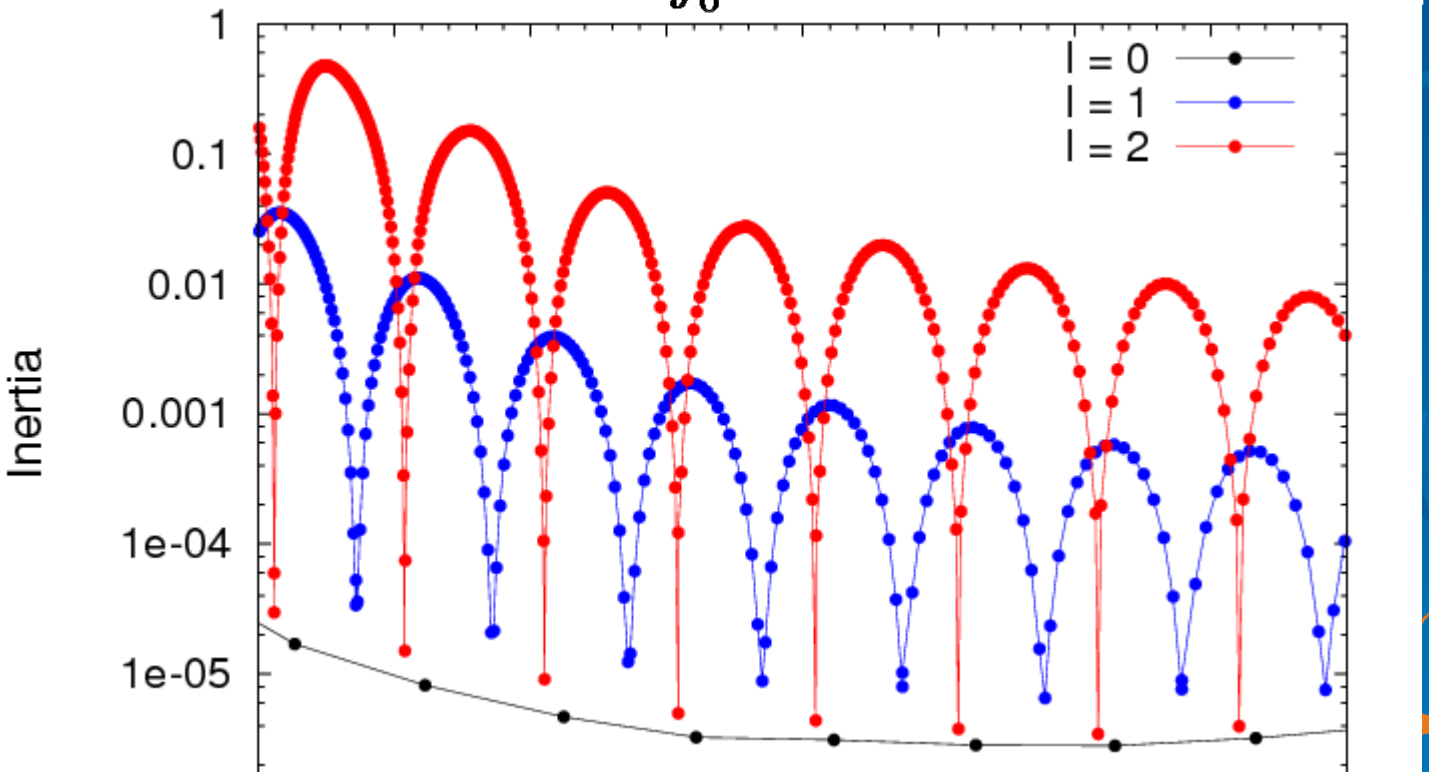


Mode physics in Red Giants

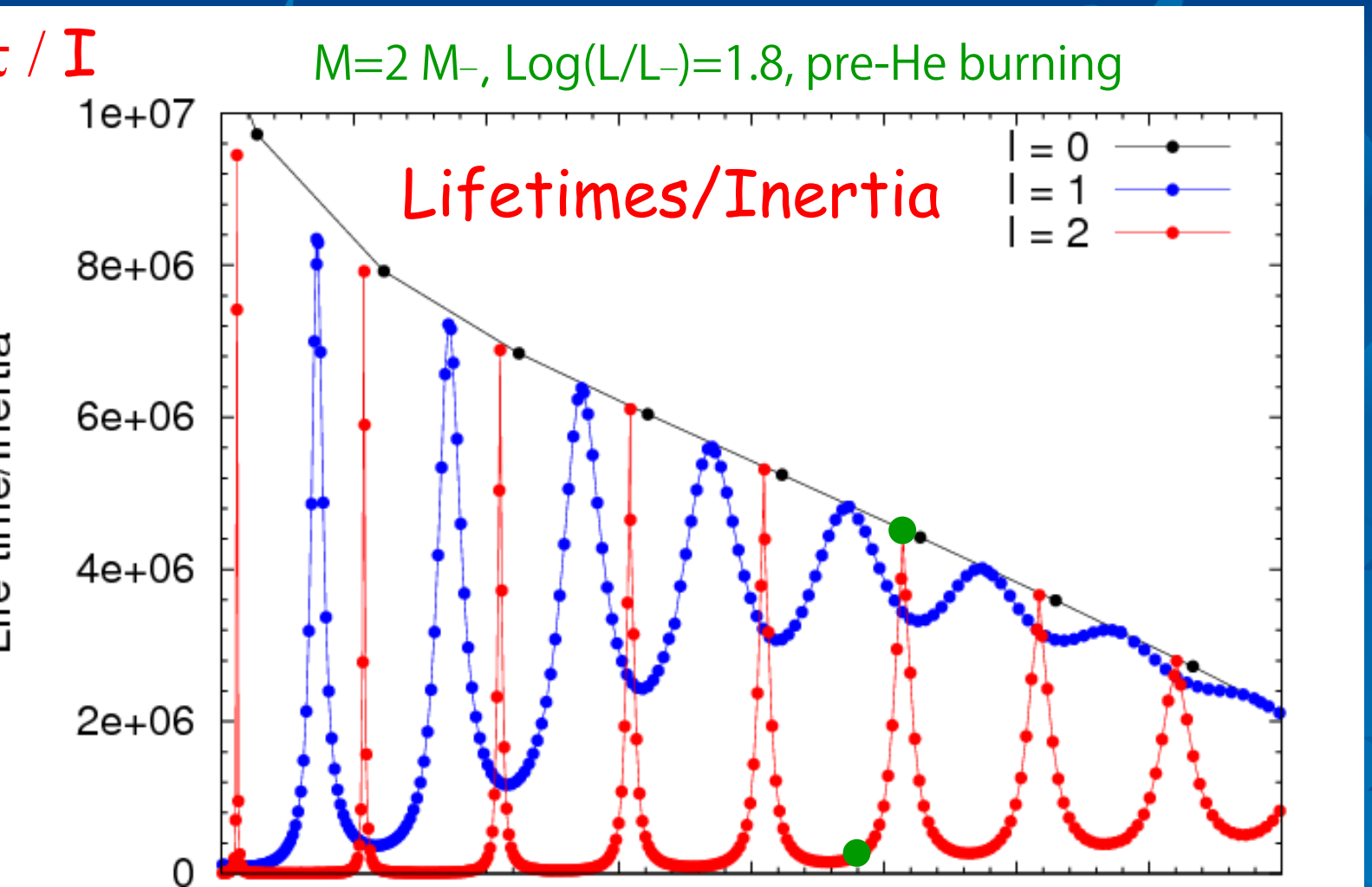
Mode trapping

See also Dziembowski et al. (2001)
Christensen-Dalsgaard (2004)

$$\text{Inertia} = \int_0^M |\,\vec{\delta r}\,|^2 \, dm$$



Intermediate model in the red giant branch

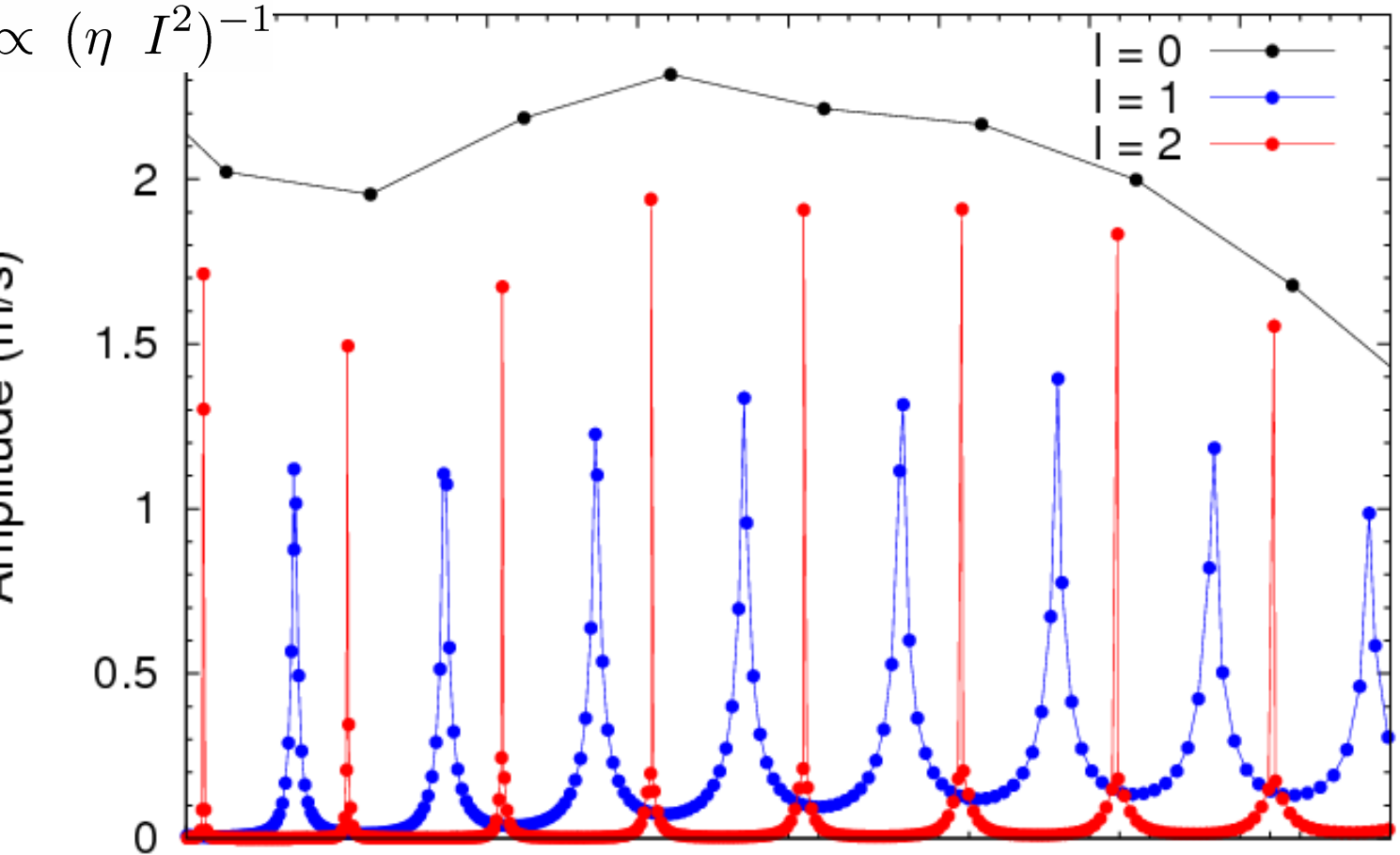


Intermediate model in the red giant branch

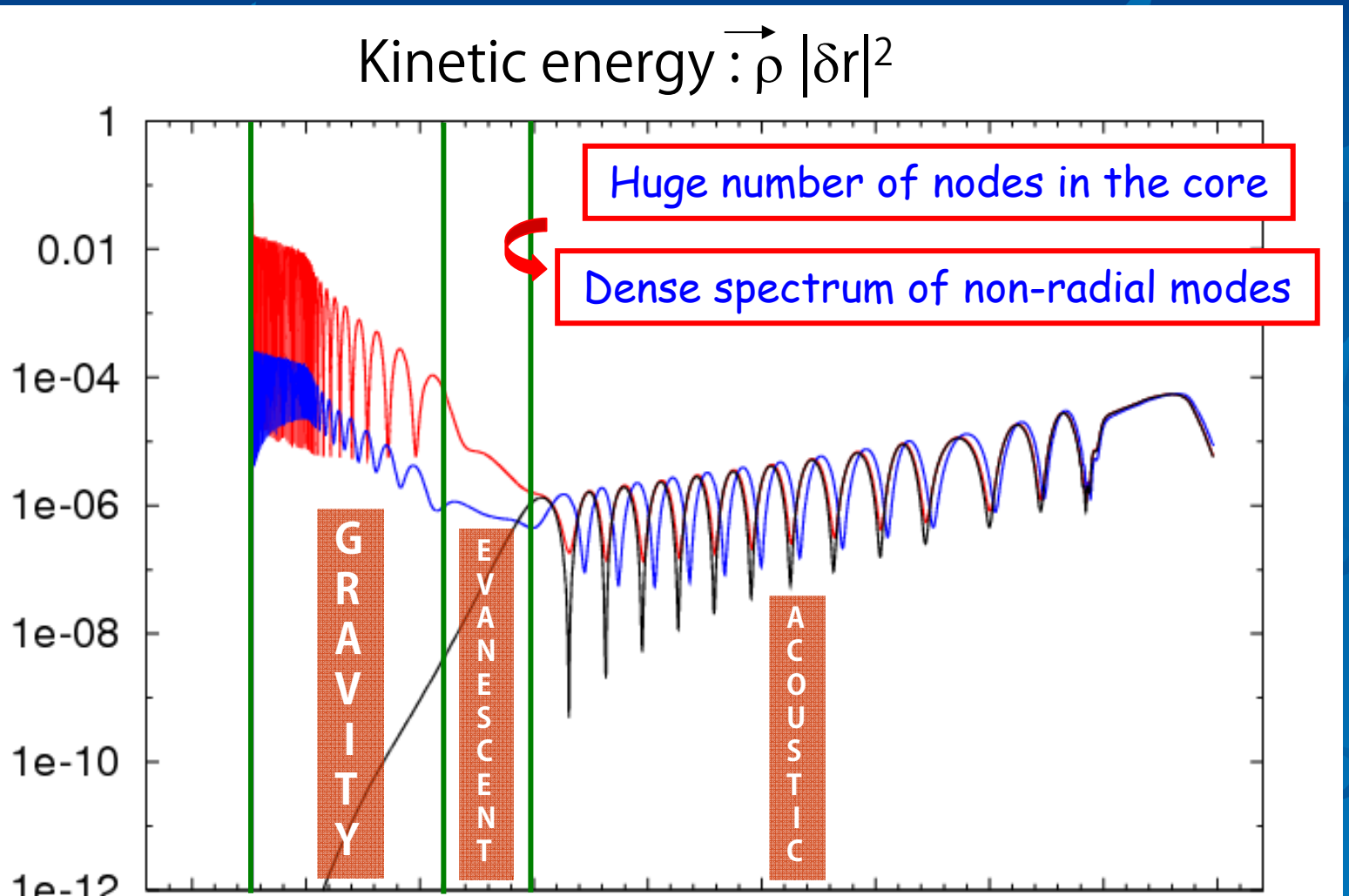
Amplitude

M=2 M–, Log(L/L–)=1.8, pre-He burning

$\propto (\eta\ I^2)^{-1}$

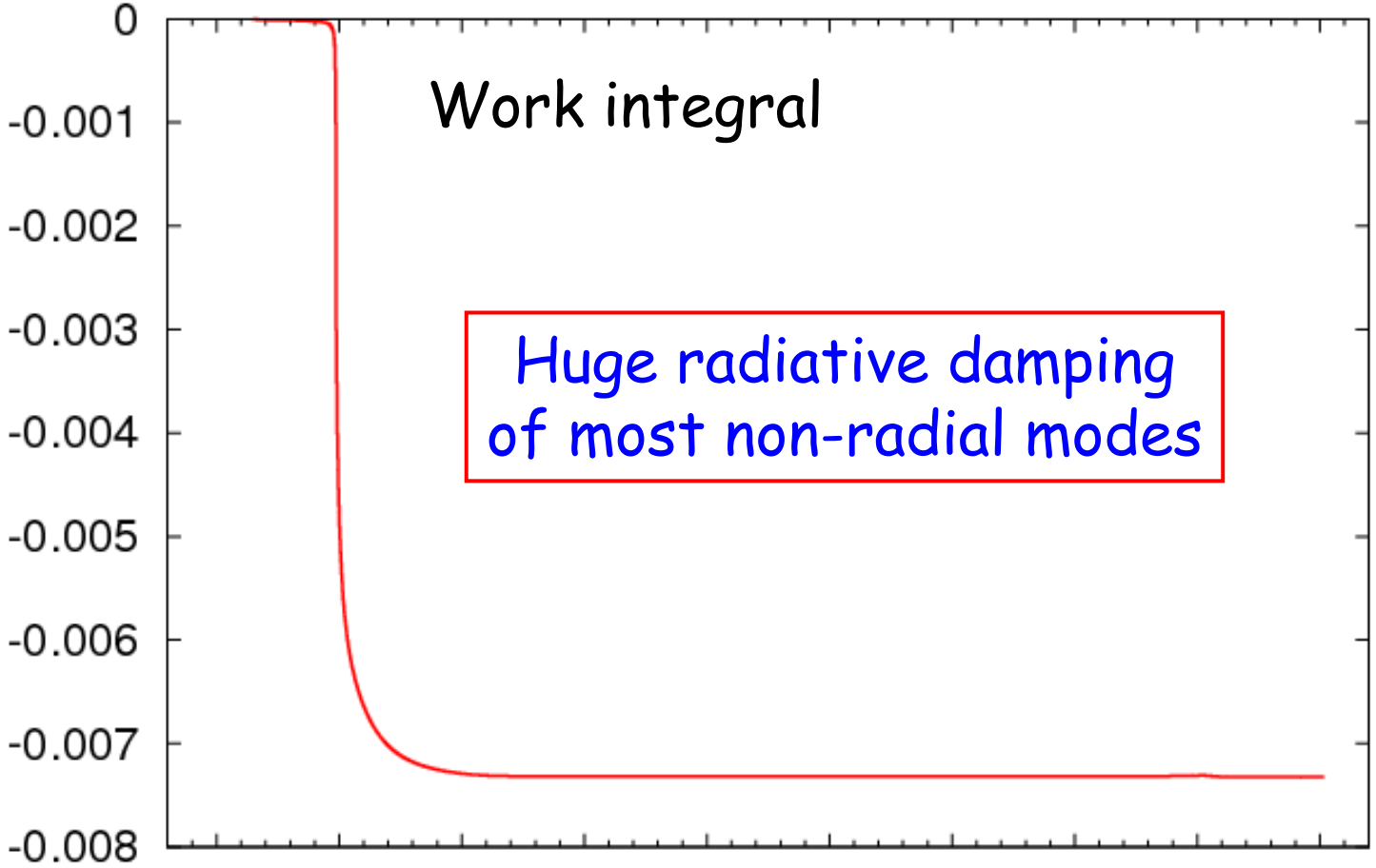


Mode physics in Red Giants



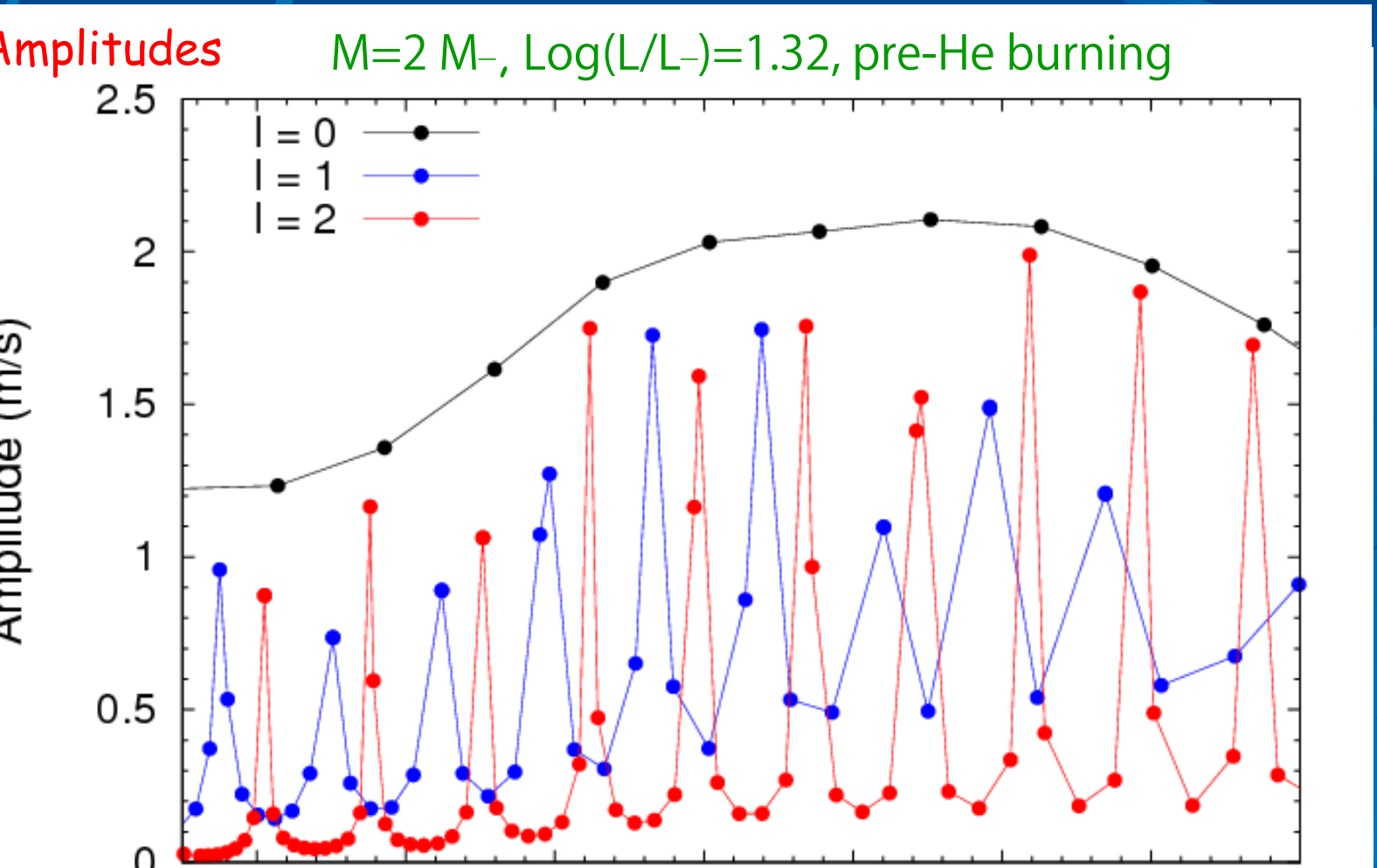
High luminosity model in the red giant branch

M=2 M⊙, Log(L/L⊙)=2.1, pre-He burning



Huge radiative damping
of most non-radial modes

Model at the bottom of red giant branch



low red giants differ from the Sun ?

Sun

Pure acoustic modes,
(radial component of displacement dominates everywhere)

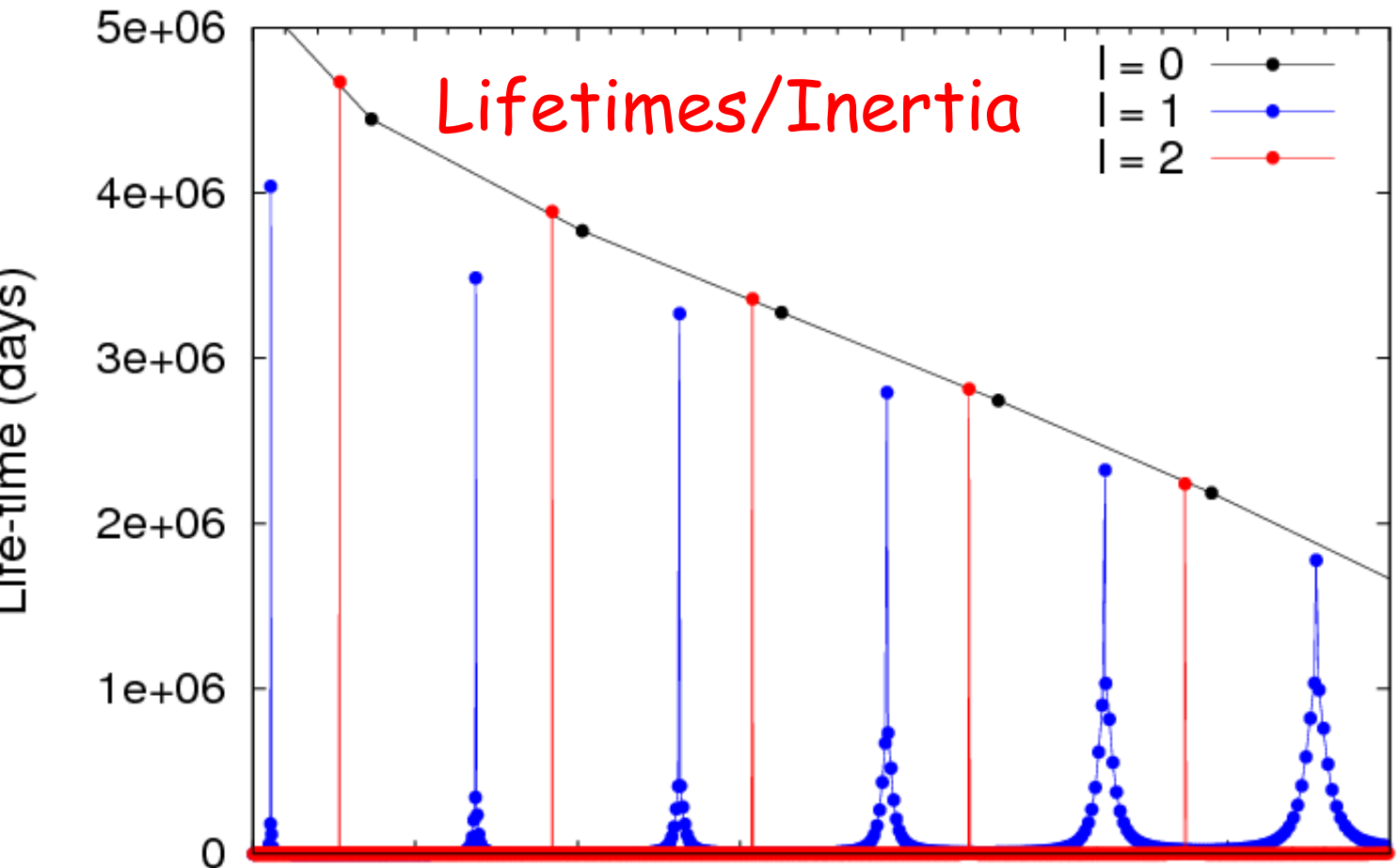
Mode lifetimes do not depend on λ

(for small λ)

High luminosity model in the red giant branch

t / I

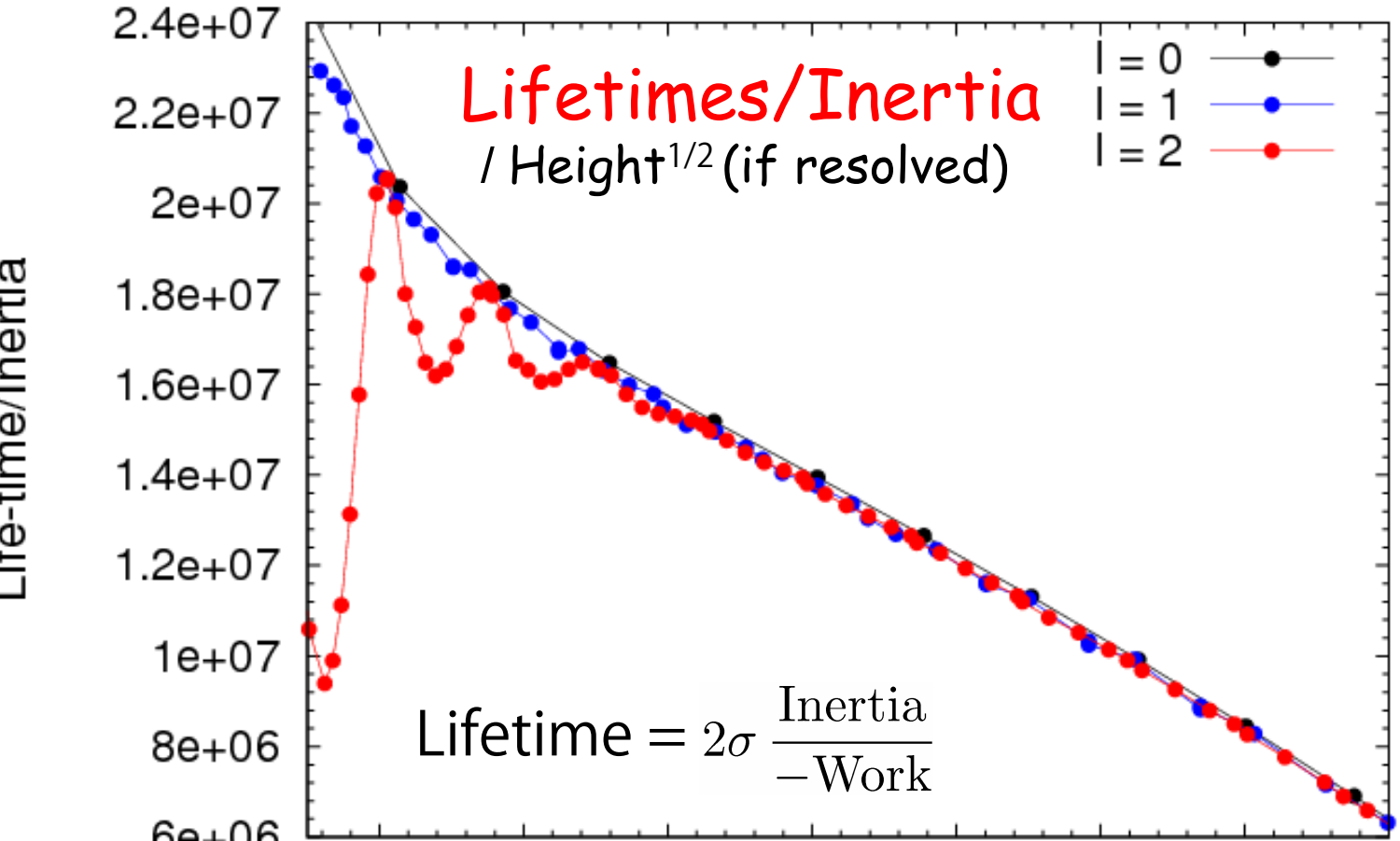
M=2 M–, Log(L/L–)=2.1, pre-He burning



A : Model at the bottom of red giant branch

τ / I

M=2 M–, Log(L/L–)=1.32, pre-He burning



A : Model at the bottom of red giant branch

τ / I

M=2 M–, Log(L/L–)=1

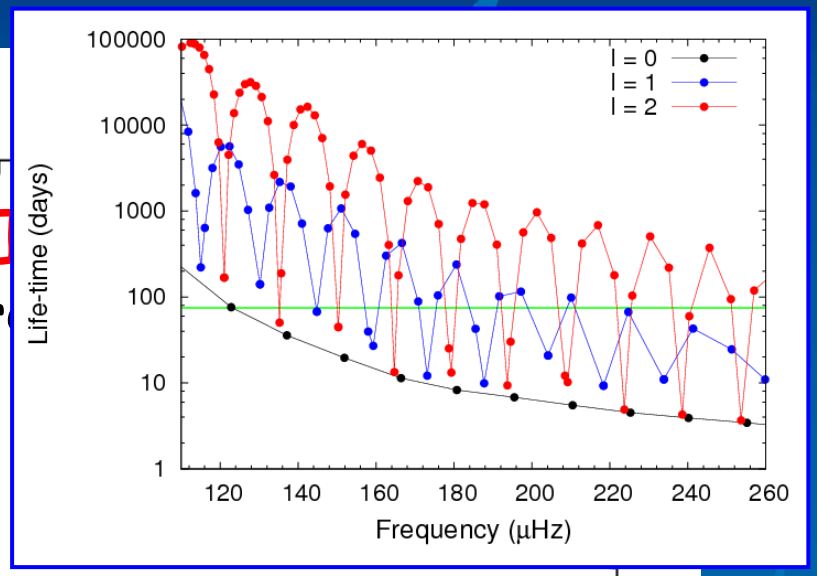
Lifetimes/I

/ Height$^{1/2}$ (if r

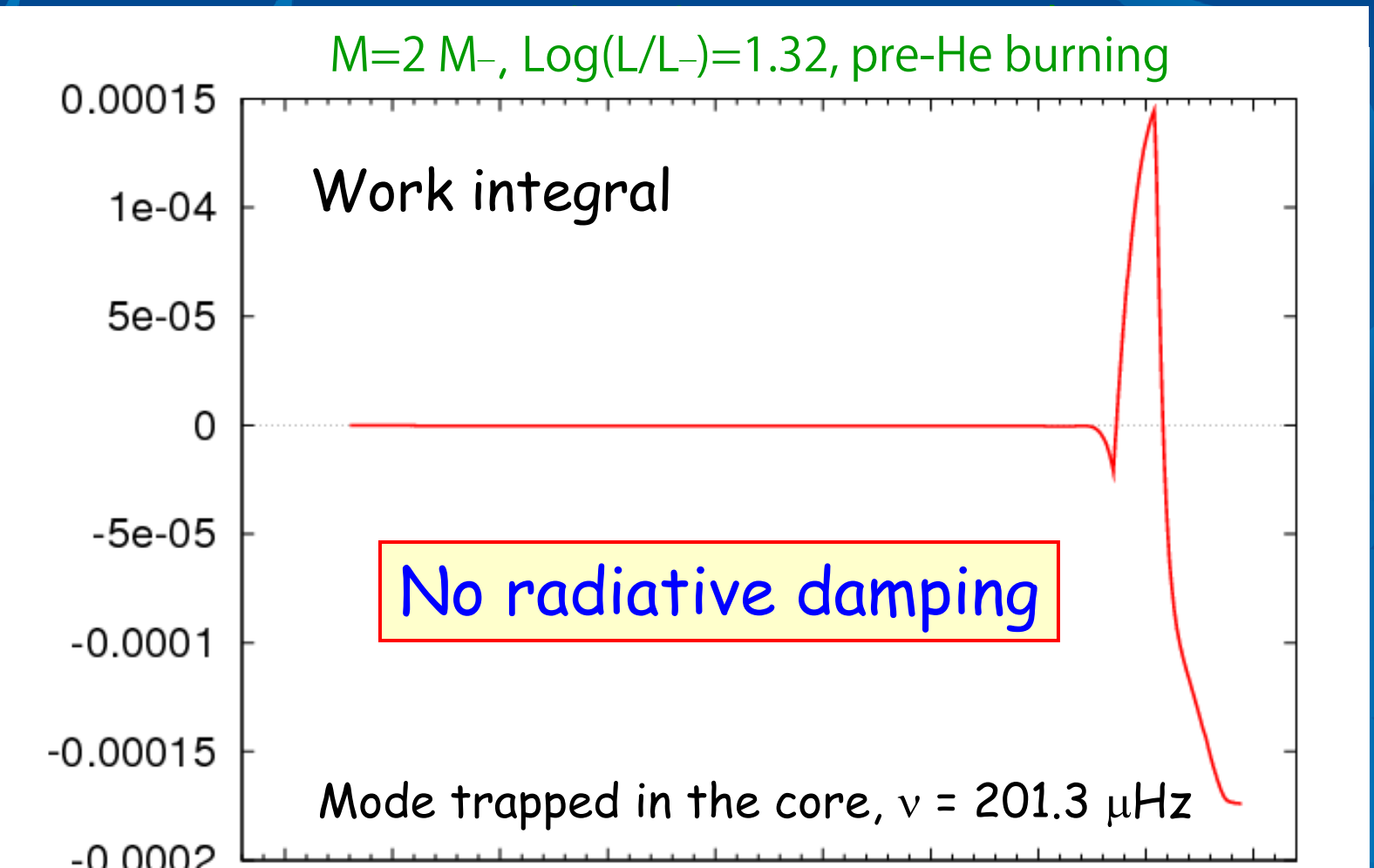
Life-time/Inertia

2.4e+07
2.2e+07
2e+07
1.8e+07
1.6e+07
1.4e+07
1.2e+07
1e+07
8e+06
6e+06

$$\text{Lifetime} = 2\sigma \frac{\text{Inertia}}{\text{Work}}$$



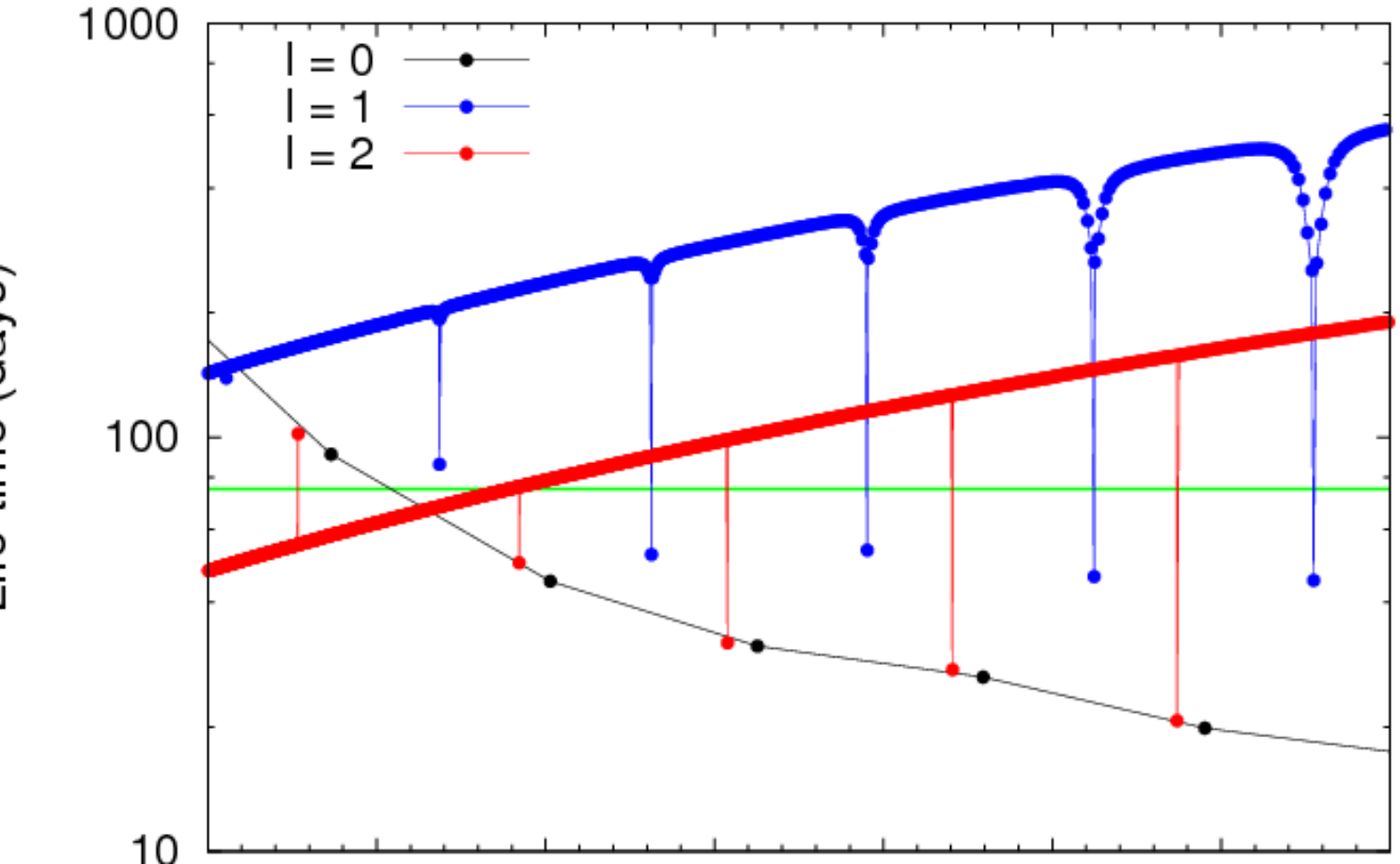
A : Model at the bottom of red giant branch



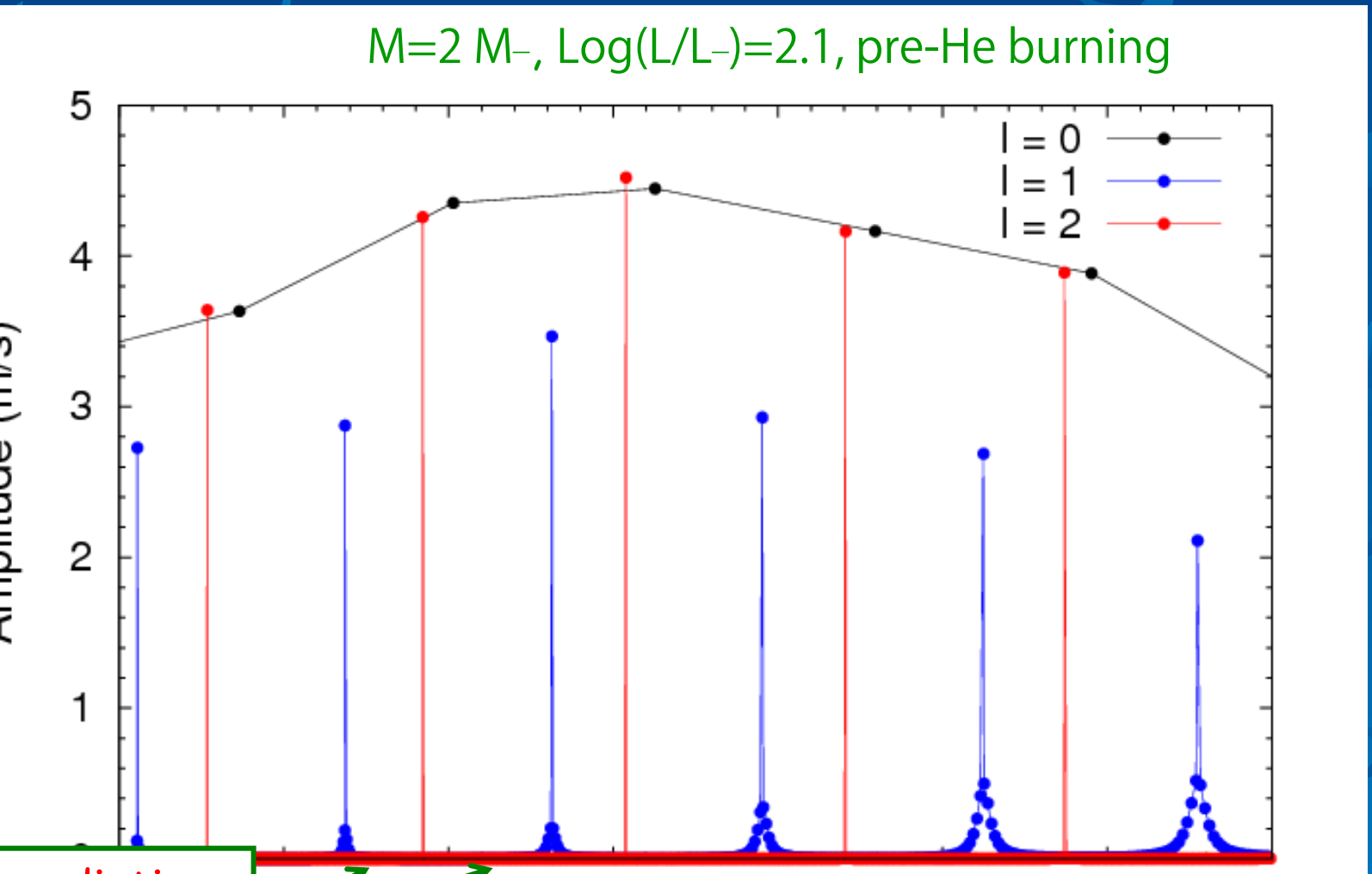
High luminosity model in the red giant branch

fetimes

M=2 M–, Log(L/L–)=2.1, pre-He burning



High luminosity model in the red giant branch



Mode physics in Red Giants

Very dense spectrum of non-radial modes !!

Pre-Helium burning Red Giant