Energetical aspects of solar-like oscillations in red giants

Mathieu Grosjean
PhD Student - F.R.I.A.

M.A. Dupret, K. Belkacem, J. Montalban, R. Samadi

Thesis supervisor : M.A. Dupret

Université de Liège

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Precision Asteroseismology

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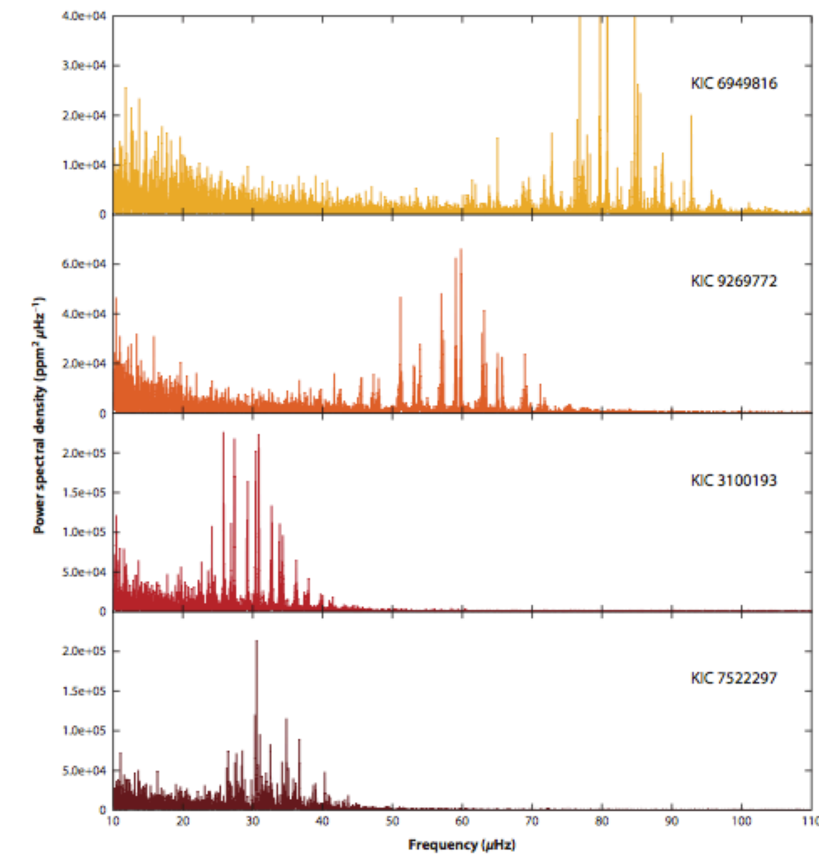
Solar-like oscillations

CoRot and Kepler have produced a large variety of power spectra for red giants

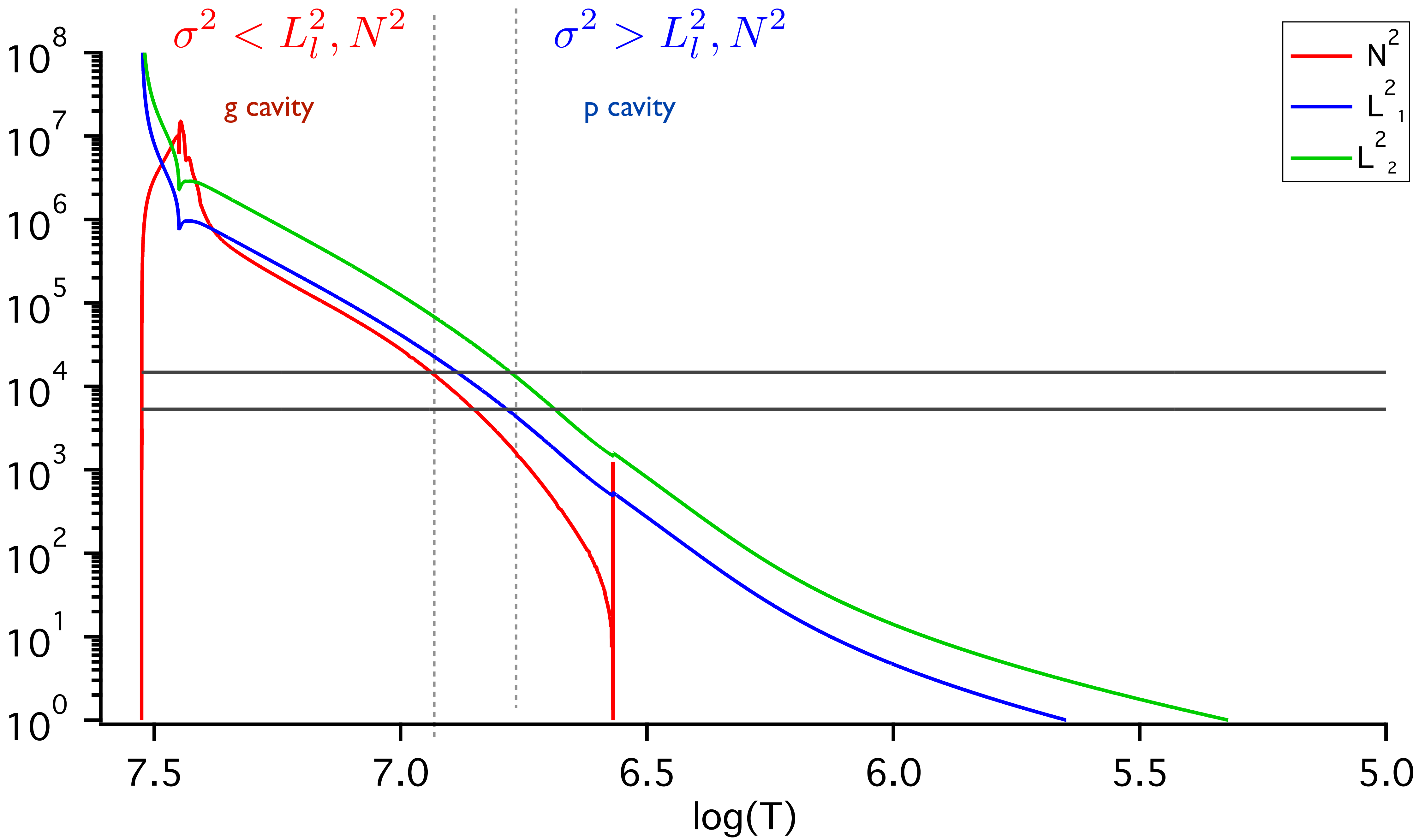


Chaplin, Miglio 2013

What are the theoretical predictions for linewidths and heights of mixed-modes?

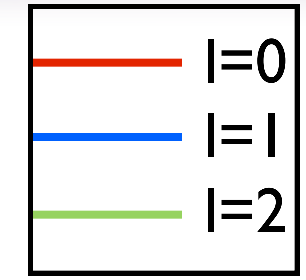
When, during the evolution on the red-giant branch, mixed-modes are detectable?

Red giant acoustic structure

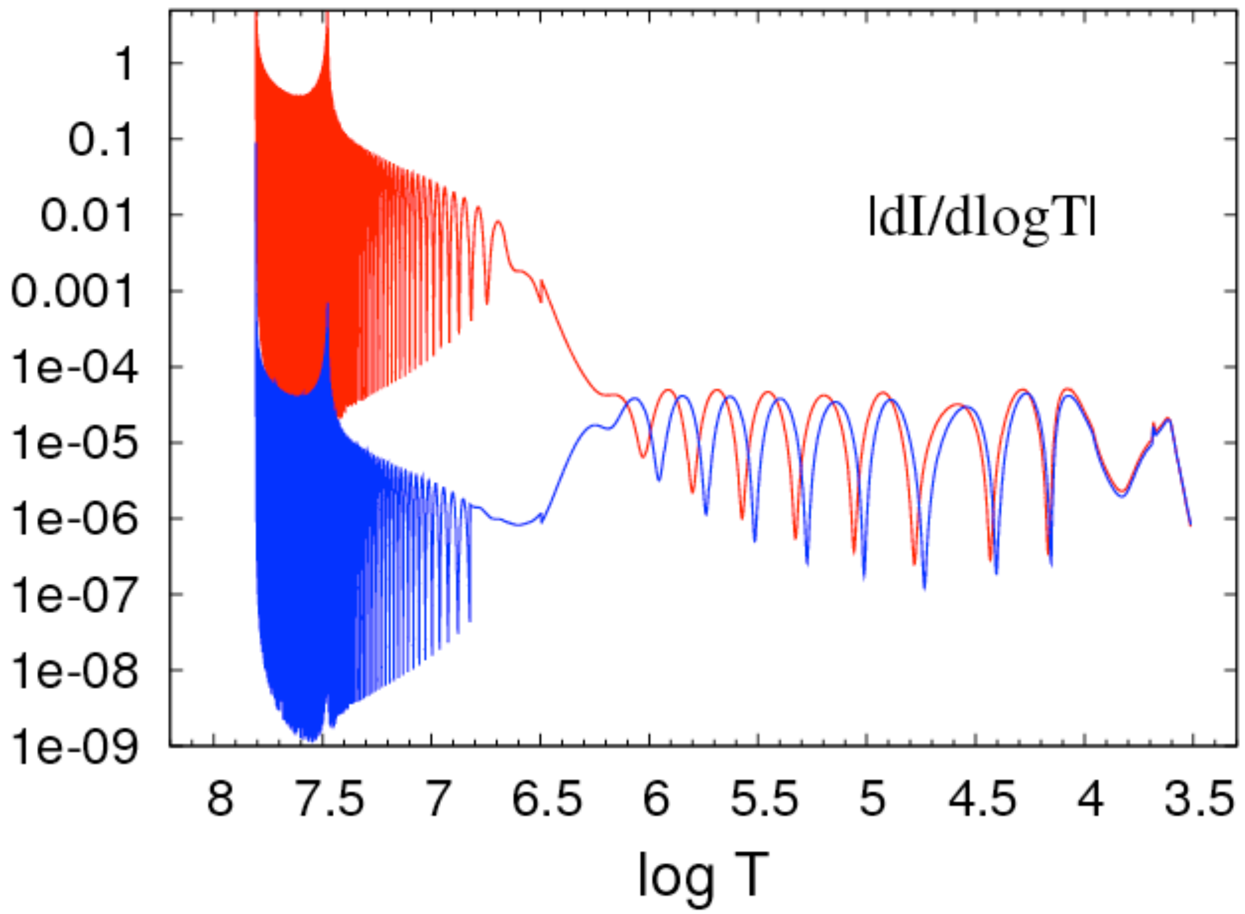


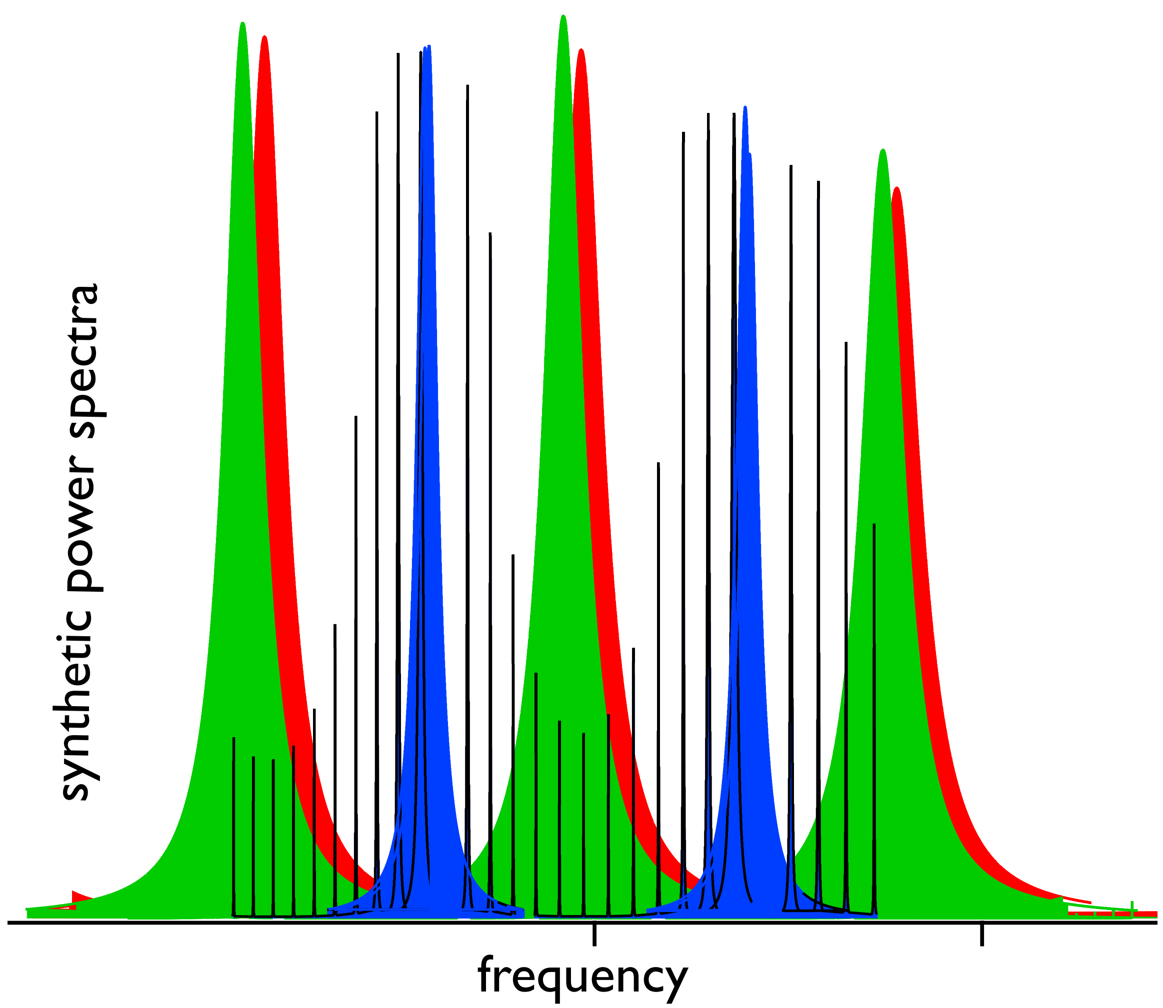
Existence of mixed modes ⇨ Particular aspects of the power spectra

Mixed modes trapping : typical expectation of a RGB



Energy density of modes trapped
in the envelope
in the core





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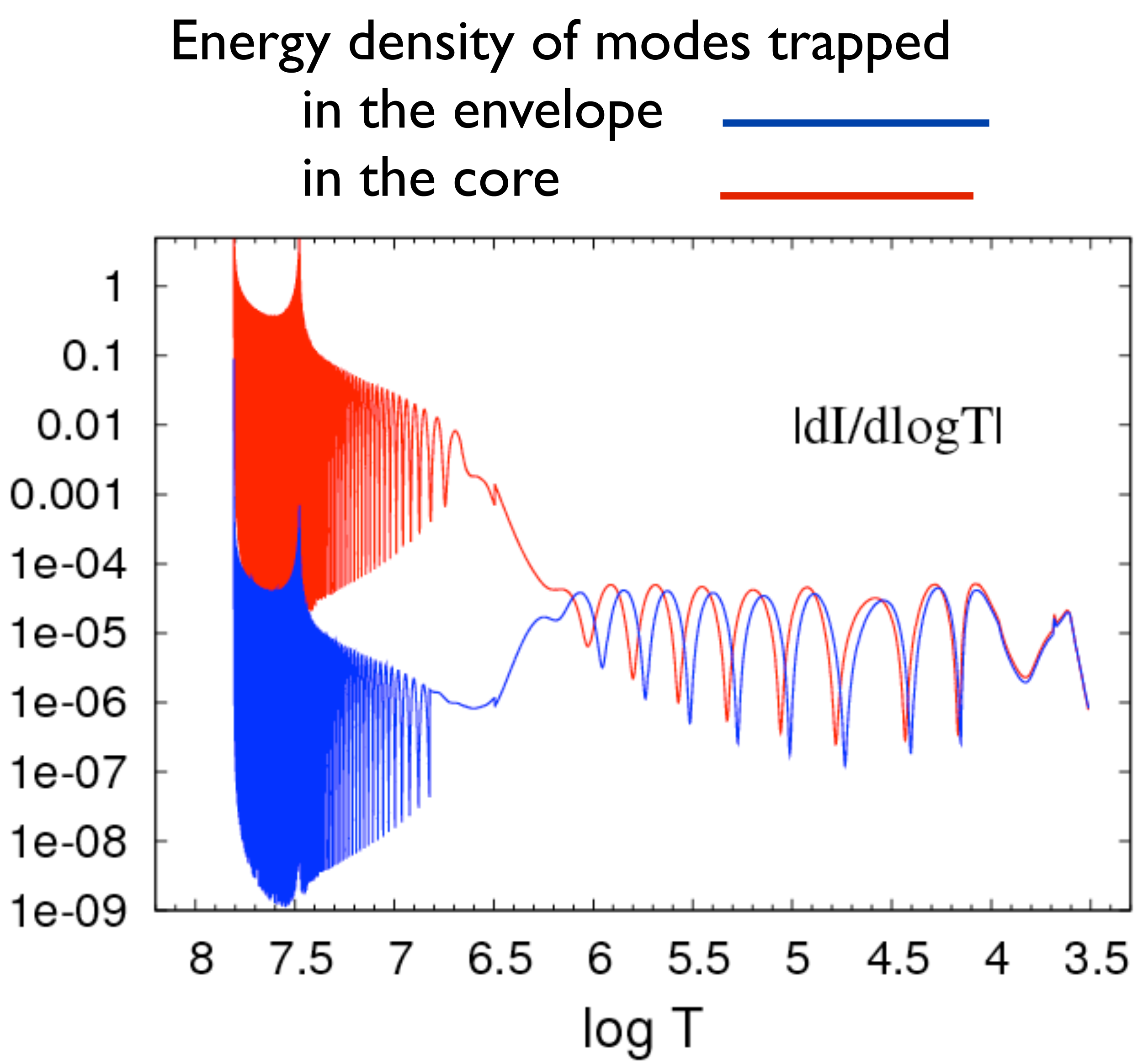

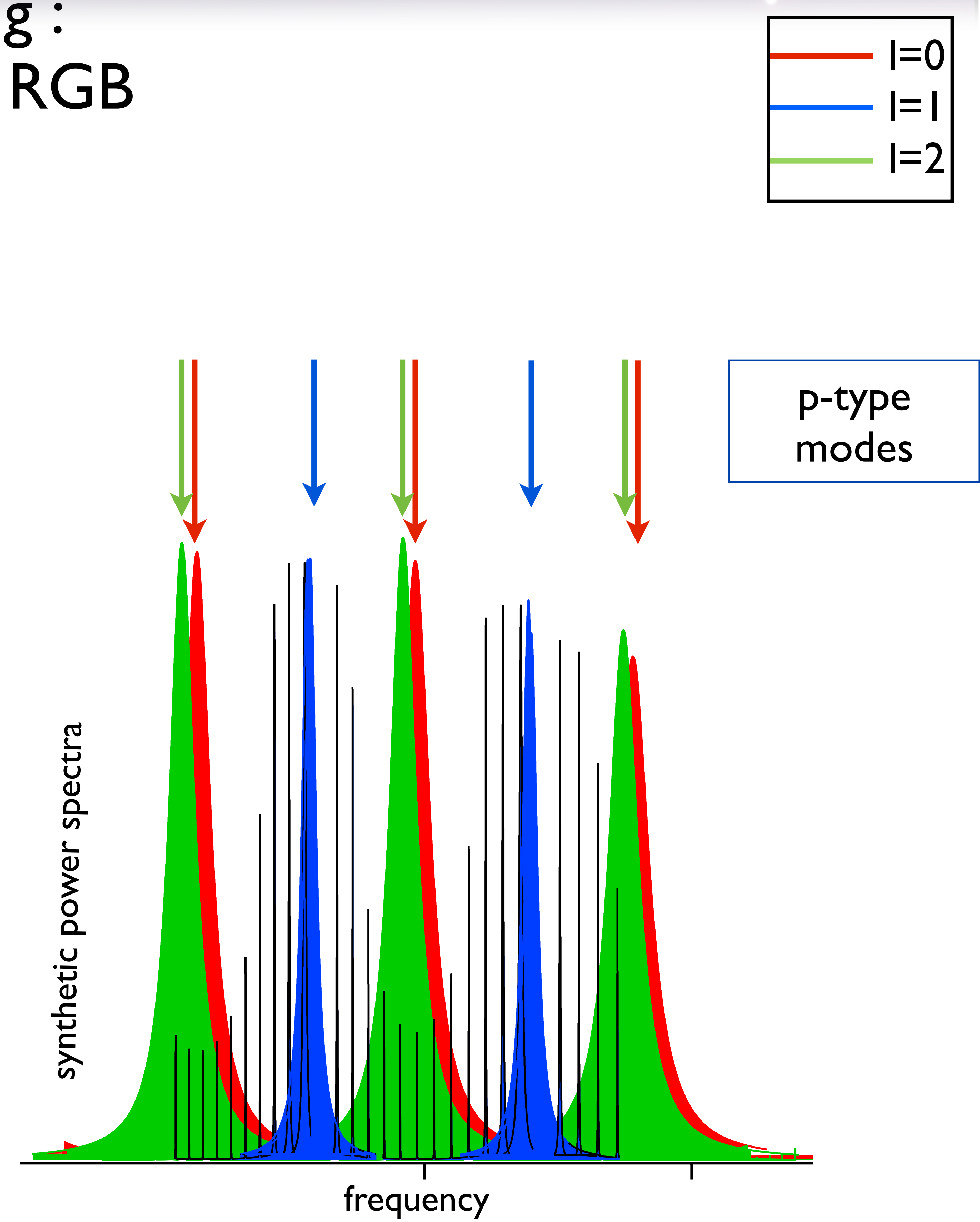

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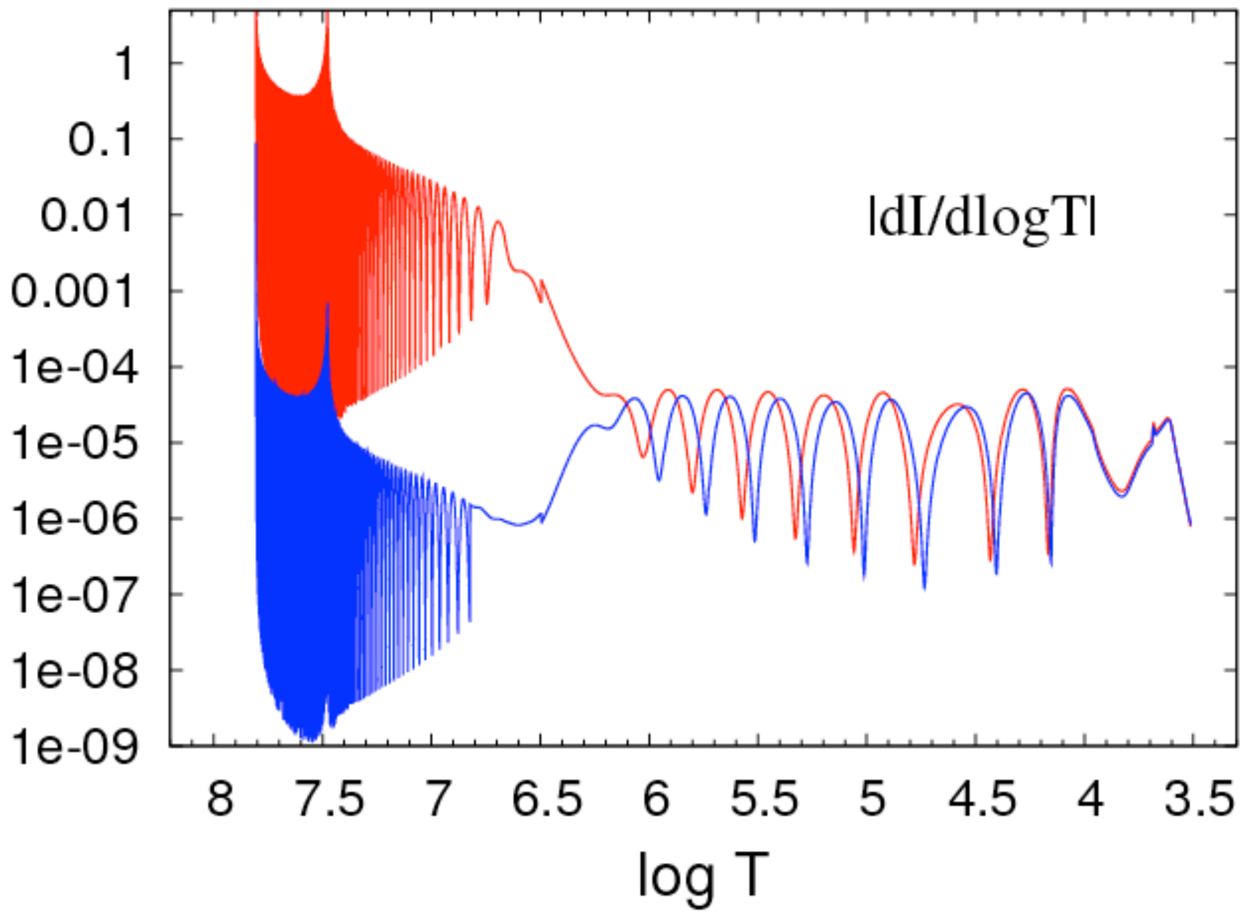
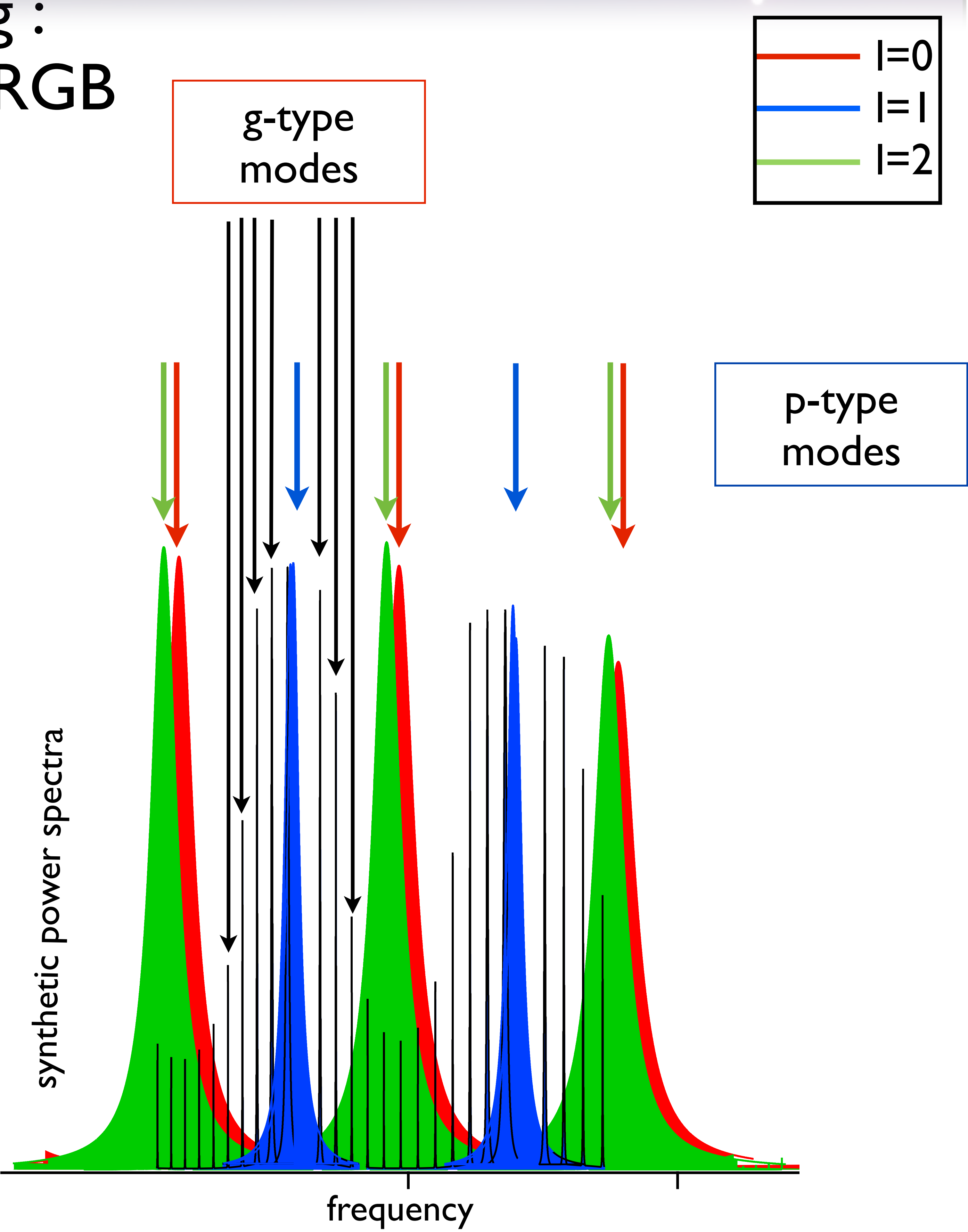




How to obtain the linedwith and heights of the modes ?

Dynamics and energetics of the oscillation

Damping
- radiative
- convective

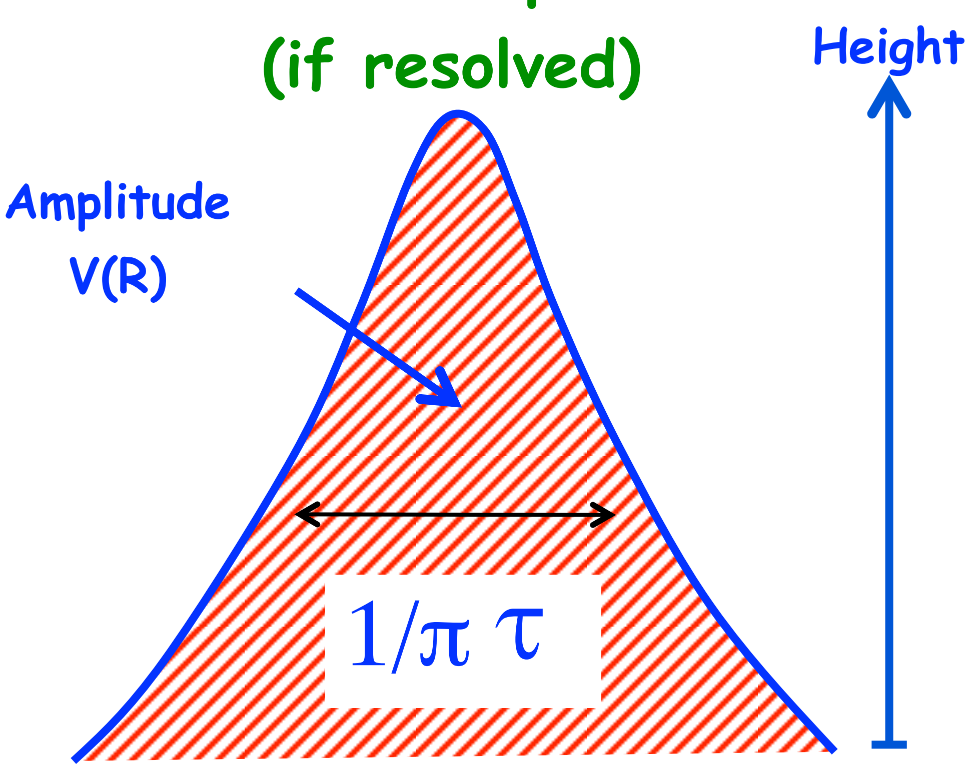
Dupret 2002
Grighacene 2005

Stochastic excitation

e.g. Samadi et al. 2001
Belkacem et al. 2008

$$\frac{d^2}{dt^2}z(t) + 2\eta\frac{d}{dt}z(t) + \omega_0^2 z(t) = f(t)$$

Lorentzian profile (if resolved)



The height of a mode in the power spectra depends on it's lifetime and on the duration of observation

Resolved modes	Unresolved modes
$\tau < T_{obs}/2$	$\tau \geq T_{obs}/2$
$H = V^2(R) * \tau$	$H = V^2(R) * T_{obs}/2$

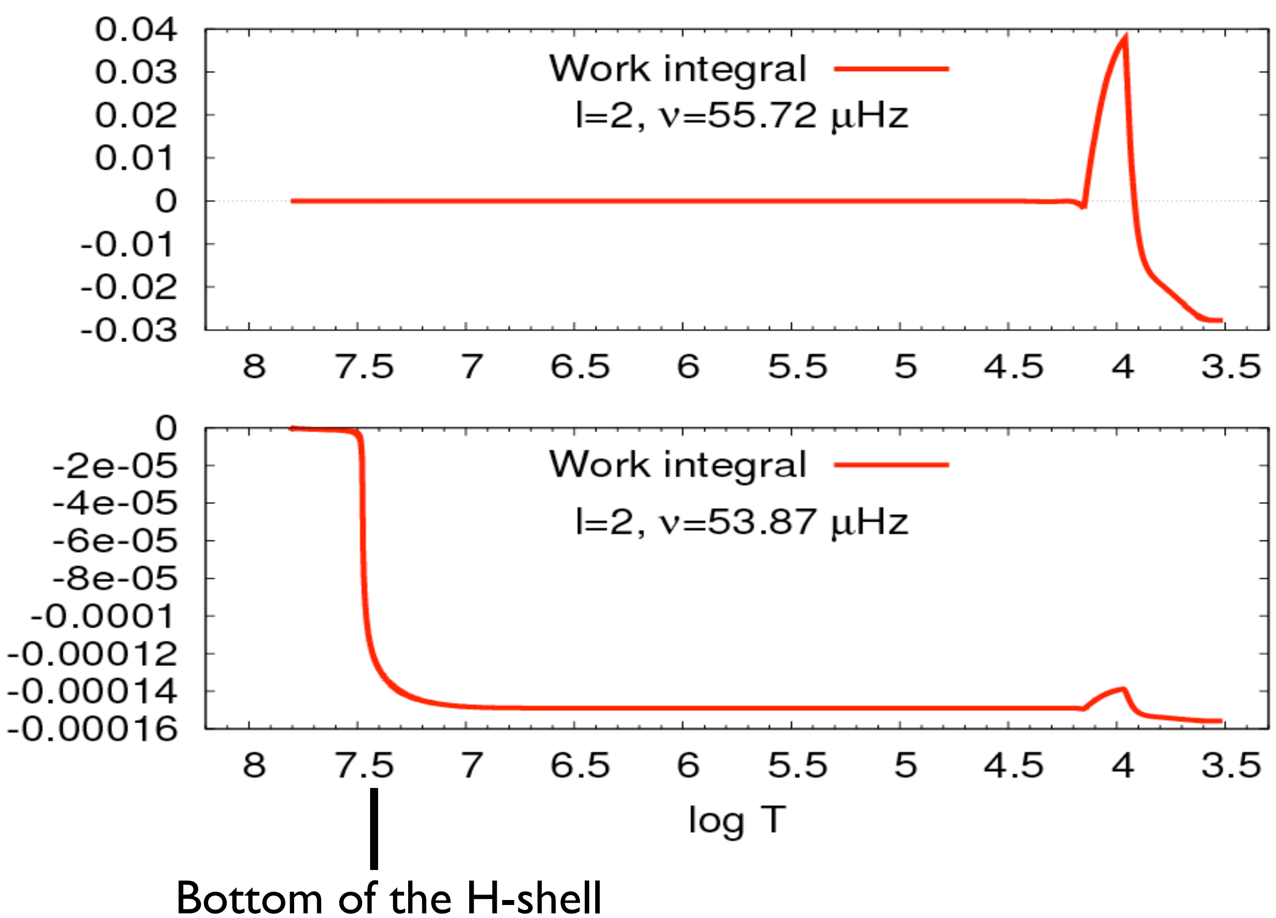
Damping : Work Integral

$$\eta = -\frac{\int_V dW}{2\sigma I |\xi_r(R)|^2 M}$$

In the deep radiative zone :

$$-\int_{r_0}^{r_c} \frac{dW}{dr} dr \simeq \frac{K(l(l+1))^{3/2}}{2\sigma^3} \int_{r_0}^{r_c} \frac{\nabla_{ad} - \nabla}{\nabla} \frac{\nabla_{ad} N g L}{p r^5} dr$$

Dziembowski 1977 ; Van Hoolst et al. 1998 ; Godart et al. 2009



Mode trapped in the envelope :
p-type mode

no damping in the core

Mode trapped in the core :
g-type mode

high radiative damping in the core

Damping : Work Integral

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In the deep radiative zone :

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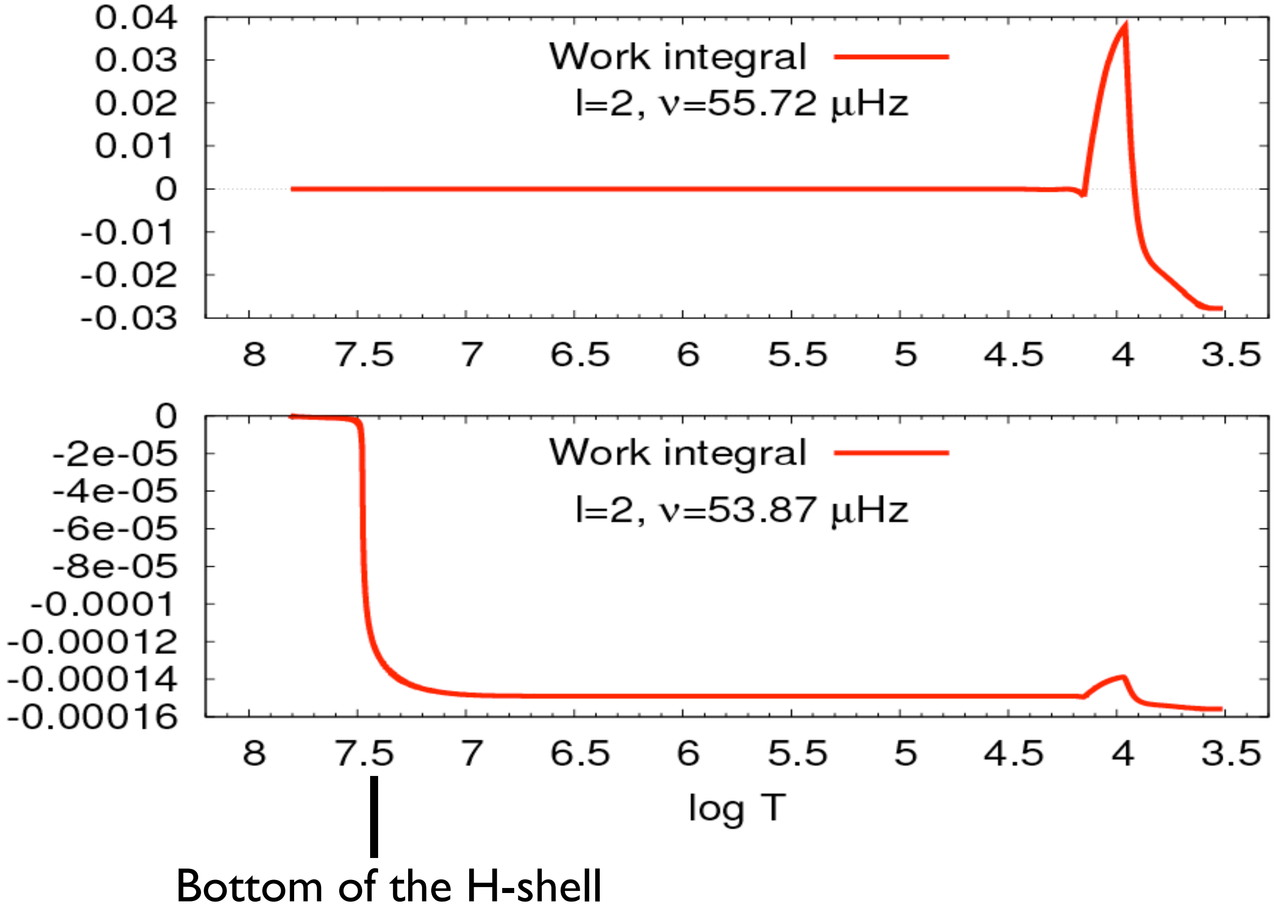

Mode trapped in the envelope :
p-type mode
↓
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Mode trapped in the core :
g-type mode
↓
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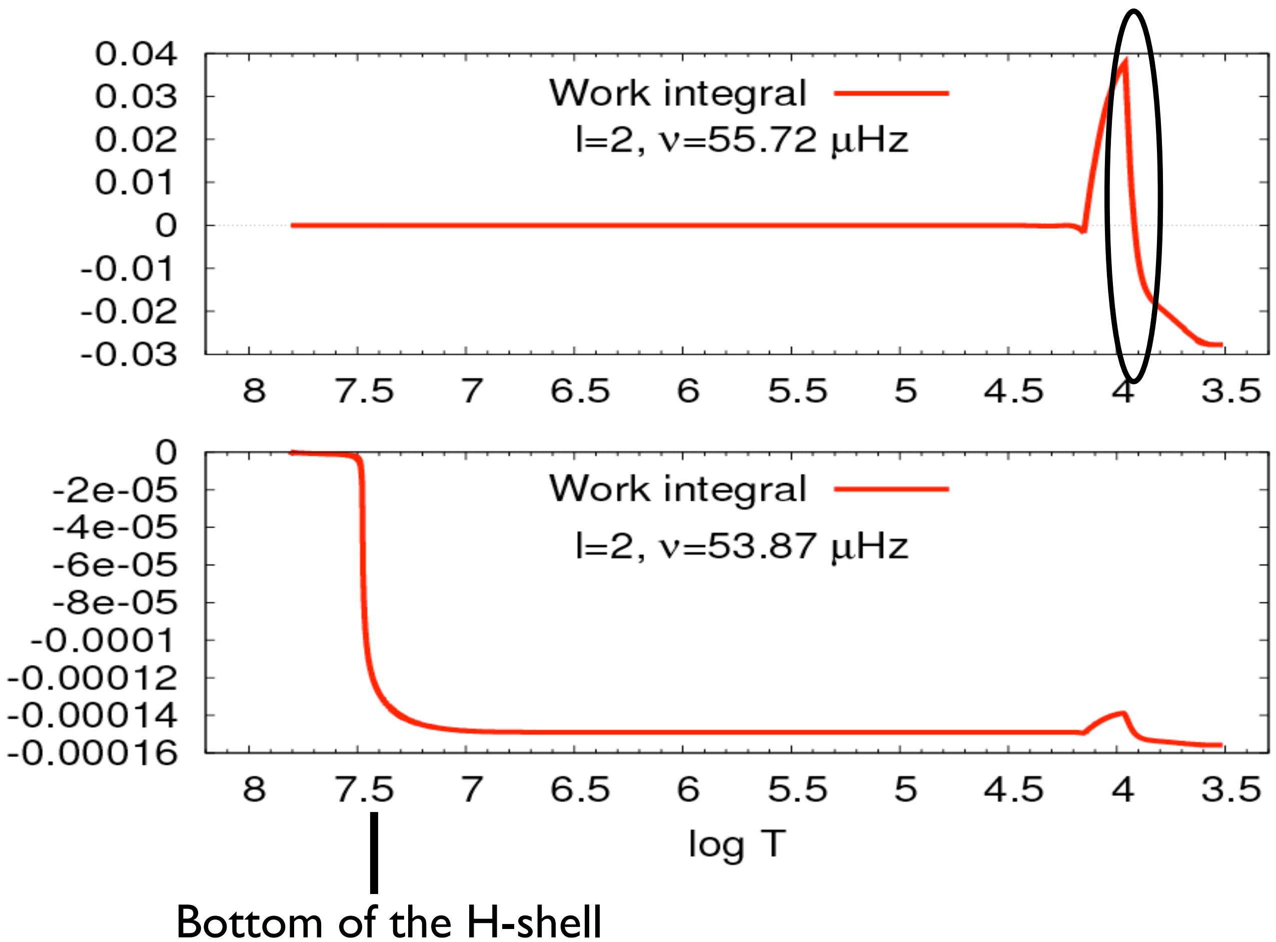

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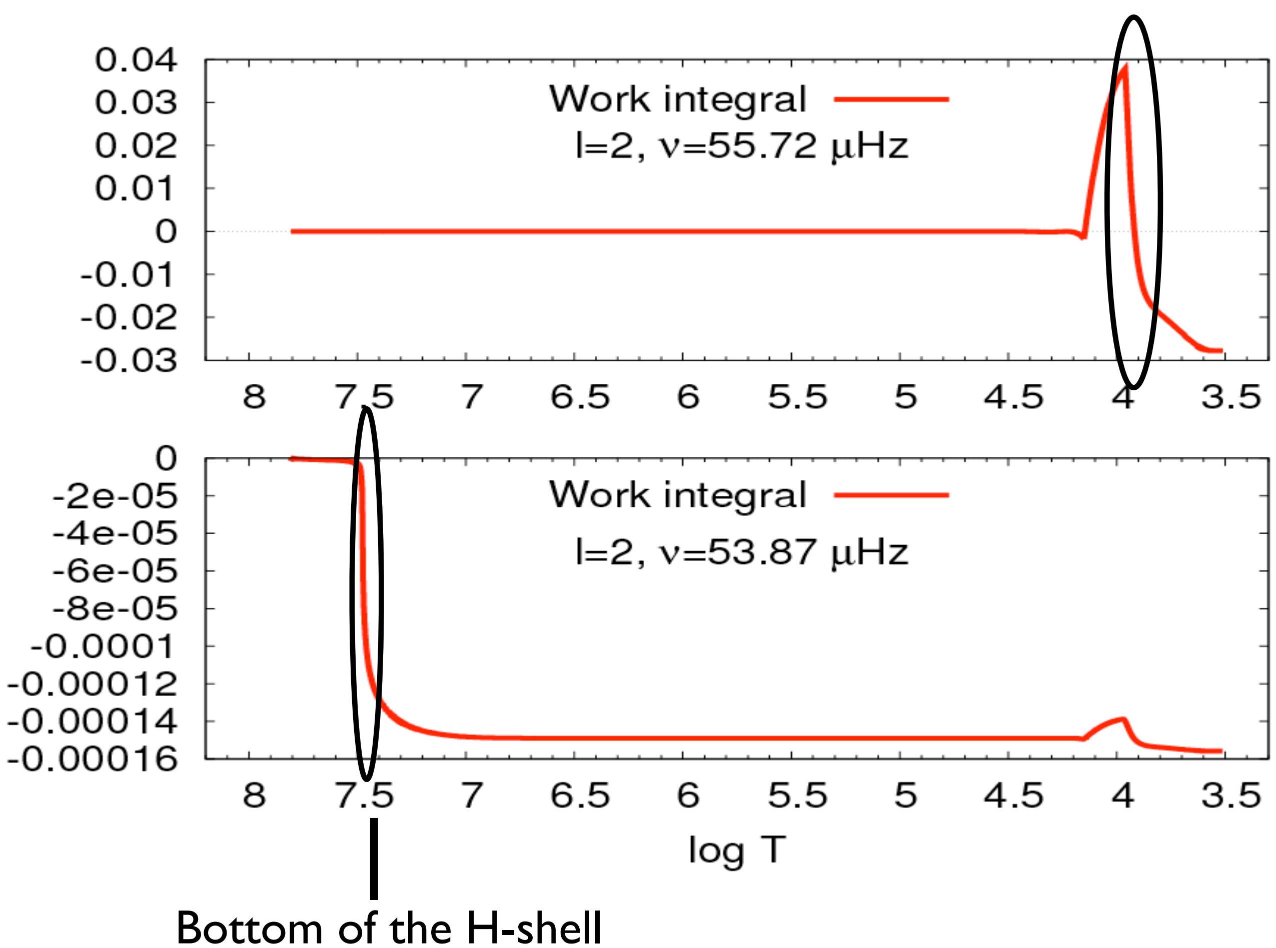


Mode trapped in the envelope :
p-type mode

no damping in the core

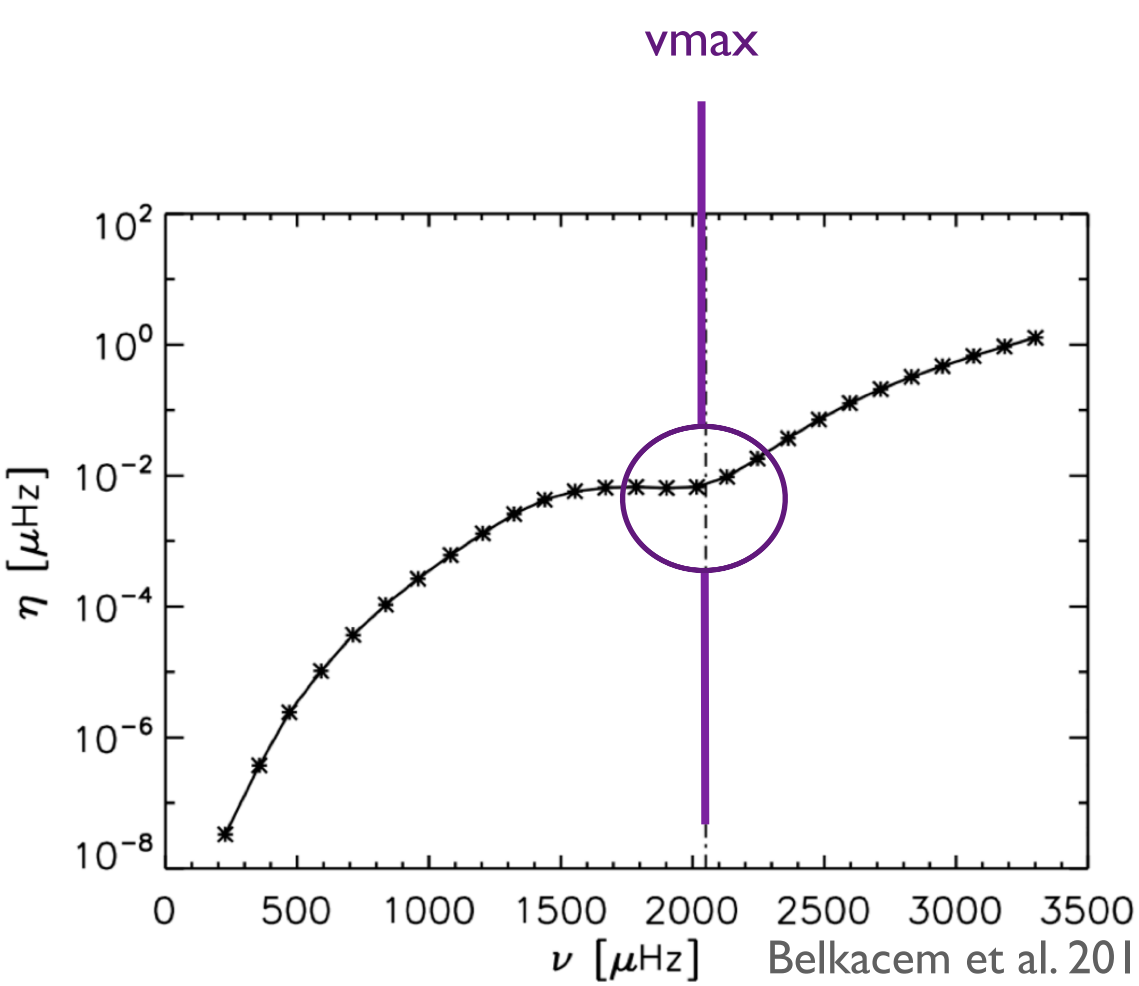
Mode trapped in the core :
g-type mode

high radiative damping in the core

Damping : convective contribution

Interaction between convection and oscillation is difficult to model (Gabriel 1996, Grighacene et al. 2005 ; Gough 1977 ; Xiong 1997)

- a perturbative approach of the mixing-length theory
- involves a free parameter β in the closure term of the perturbed energy equation

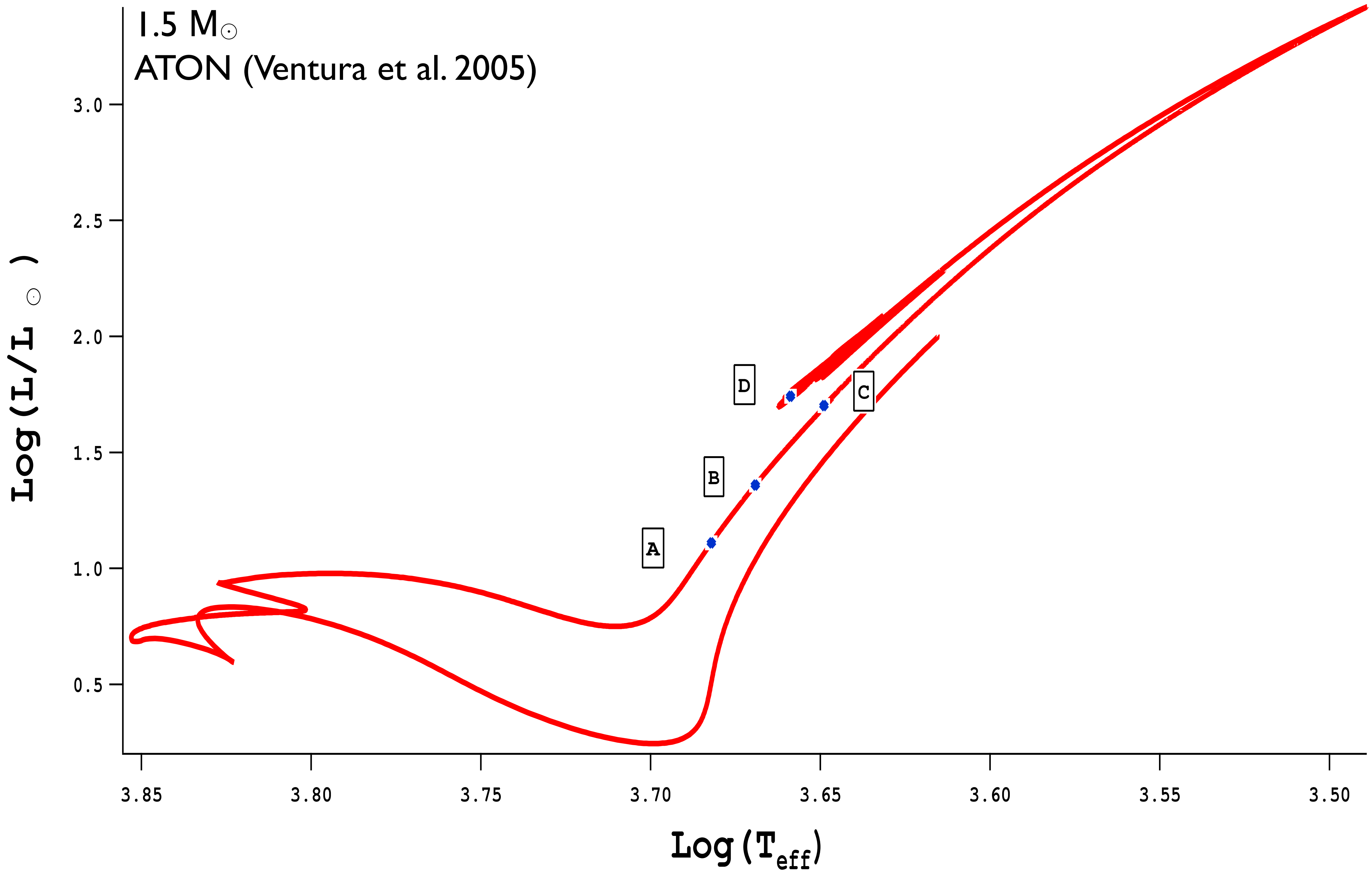


Belkacem et al. 2012

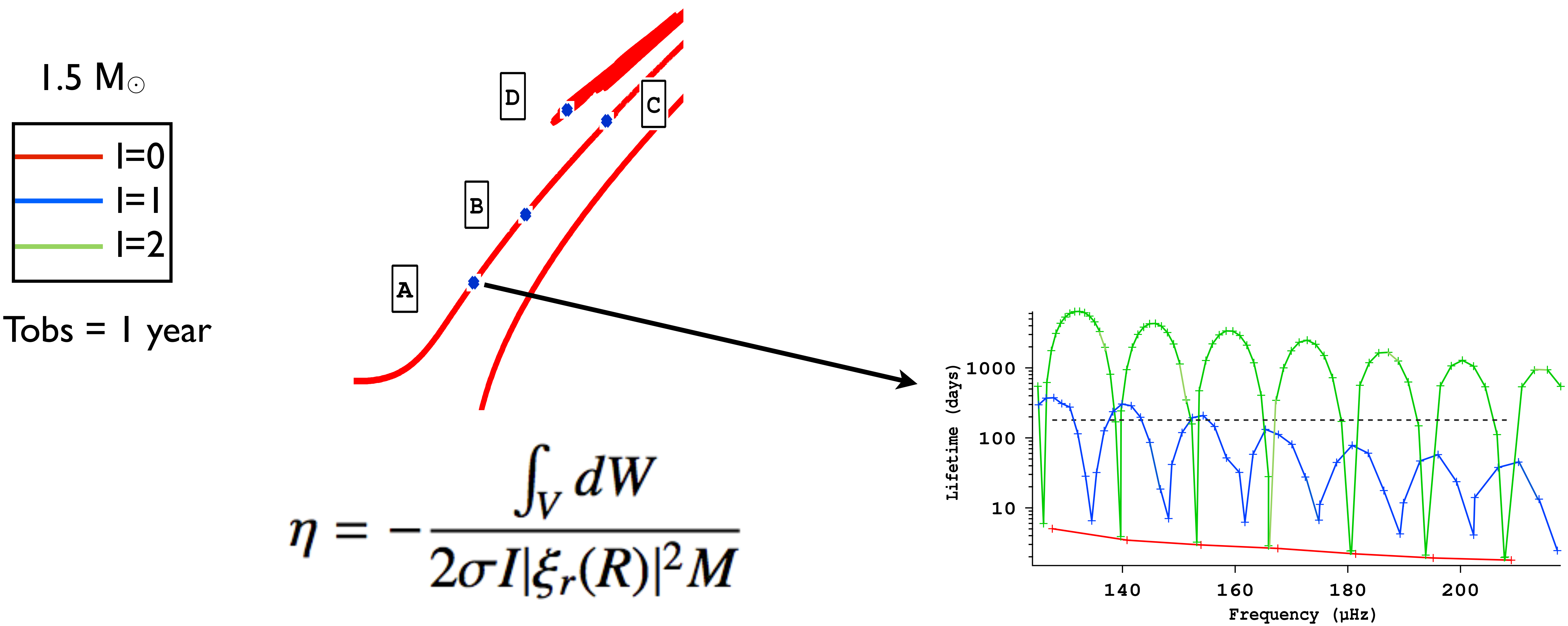
Results are sensible to the β parameter so we have to constrain it.

The β complex parameter is adjusted so that the depression of the damping rates occurs at vmax predicted by scaling relations (Belkacem et al 2012)

Following the evolution of power spectra with the evolution of the star



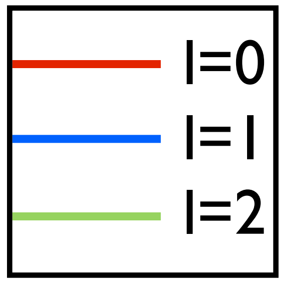
Lifetimes



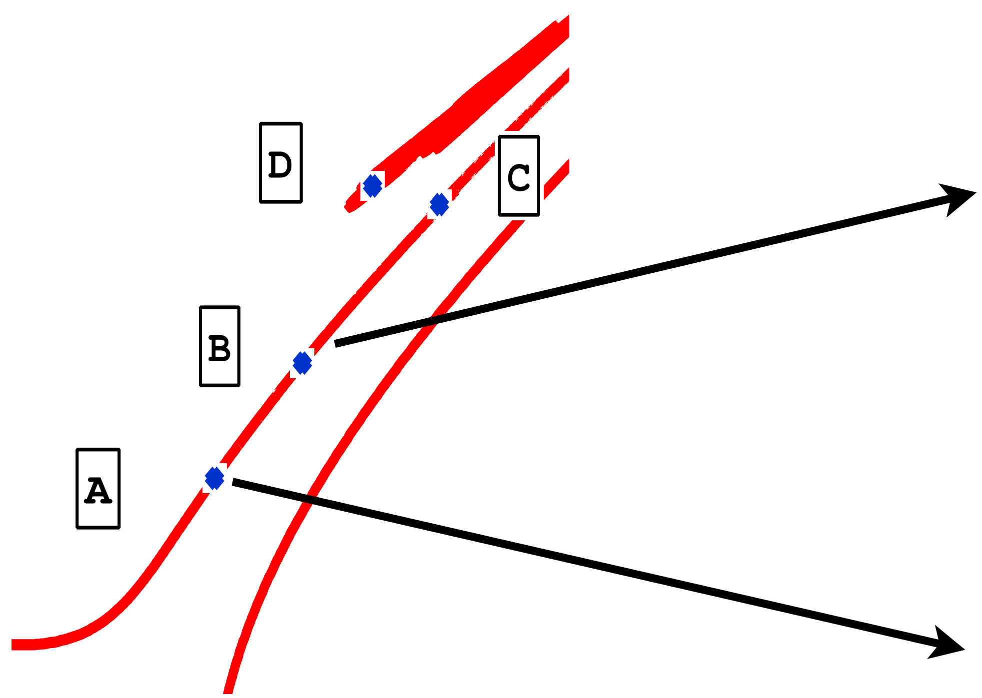
$$\eta = -\frac{\int_V dW}{2\sigma I|\xi_r(R)|^2 M}$$

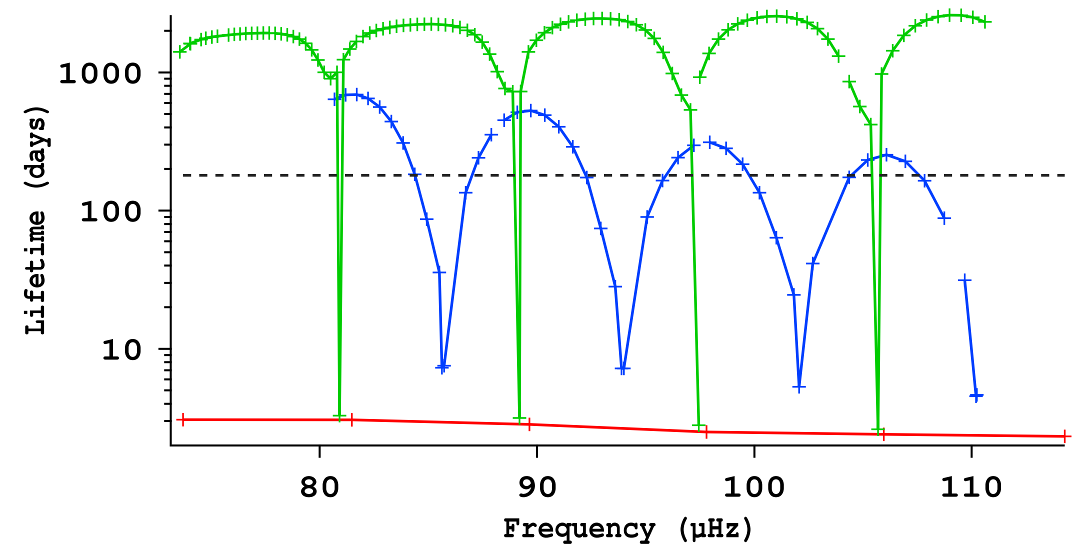
Lifetimes

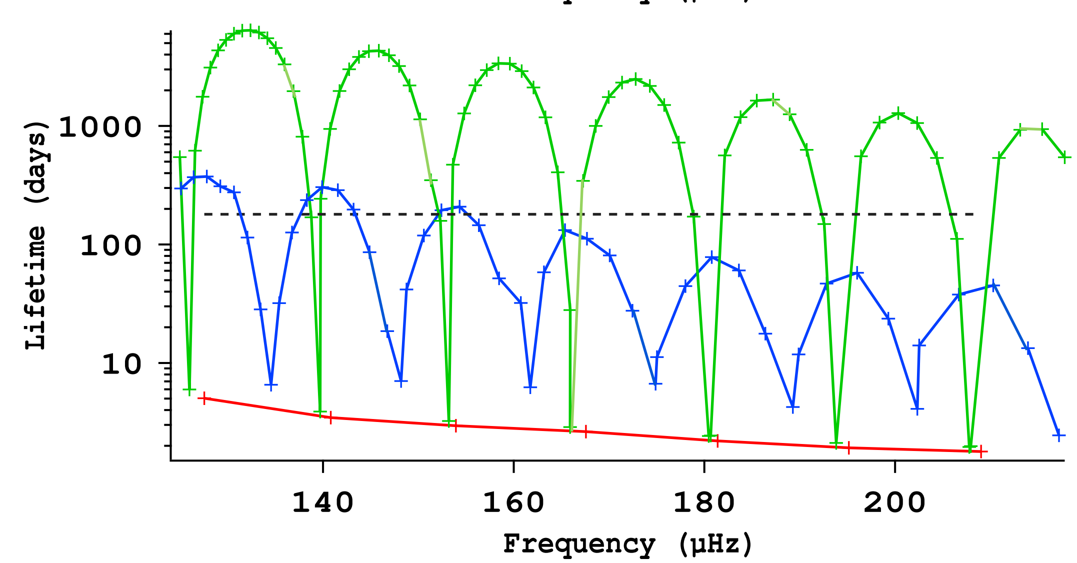
1.5 M$_\odot$



Tobs = 1 year







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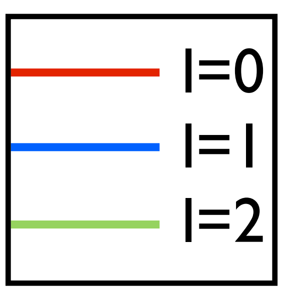

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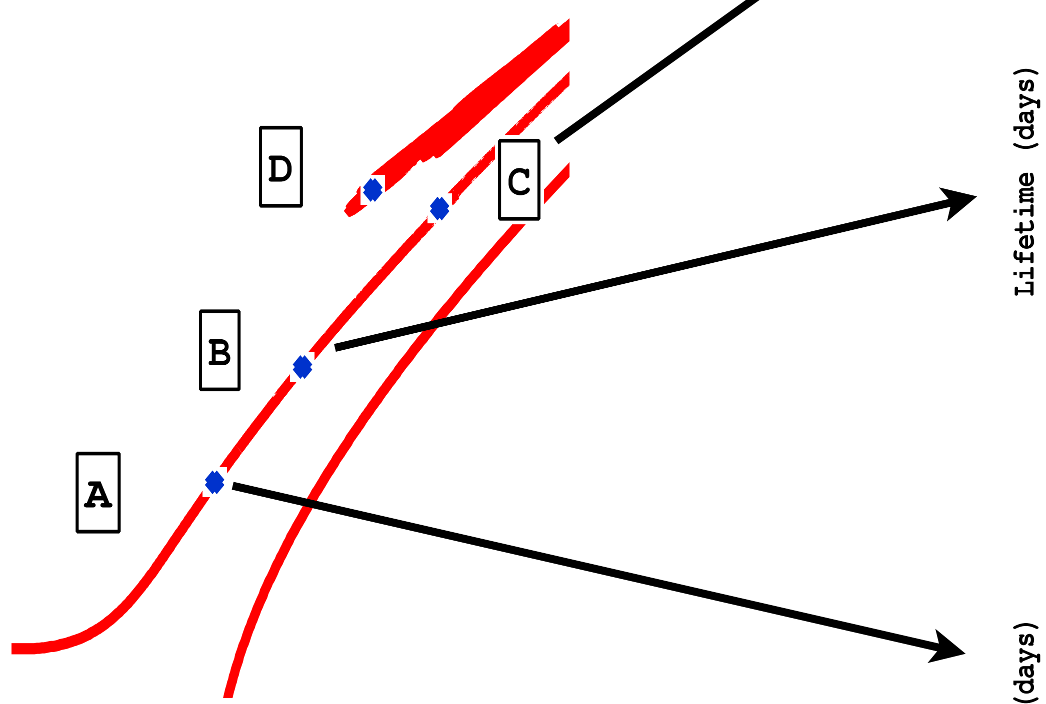

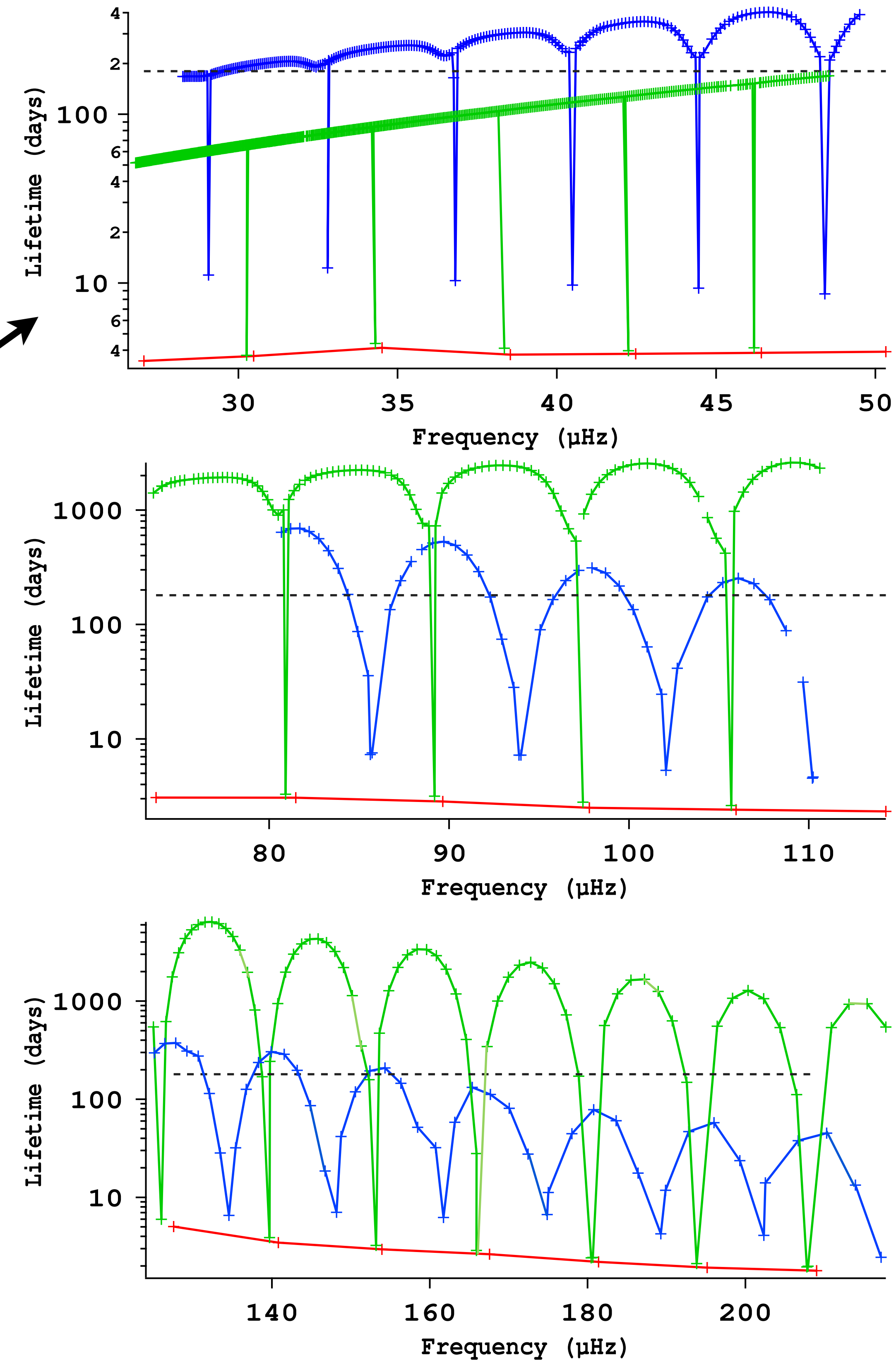

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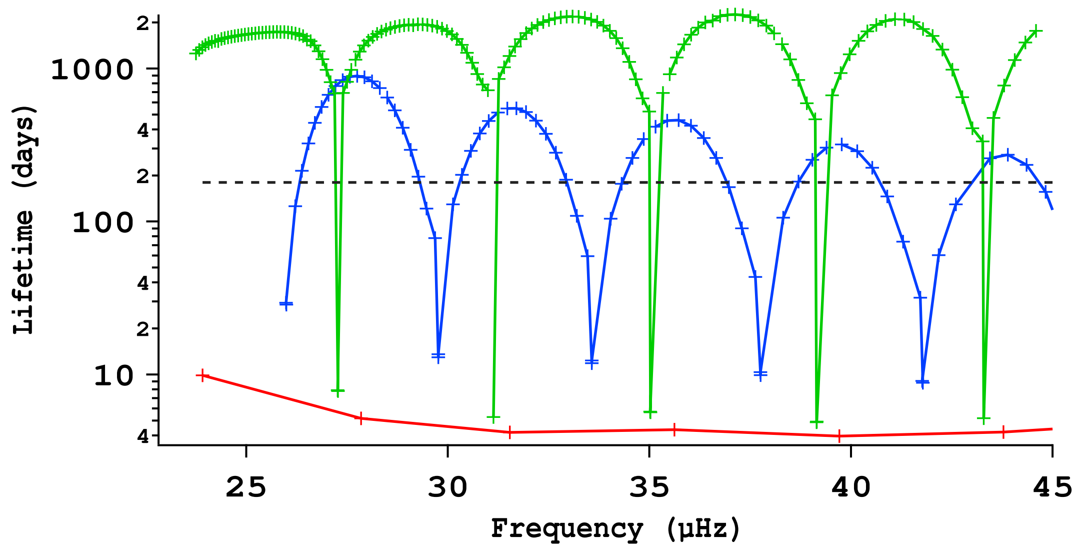
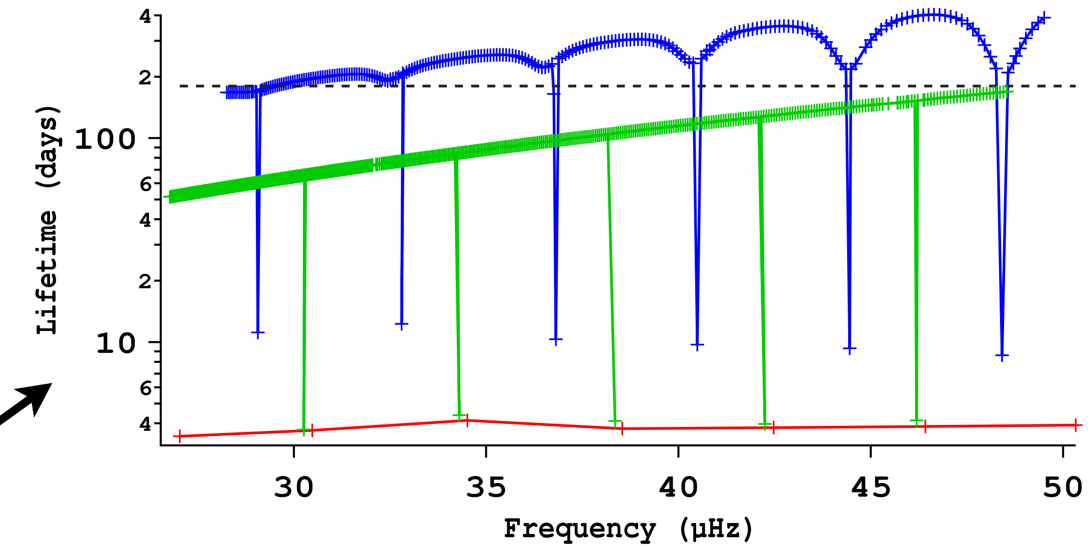
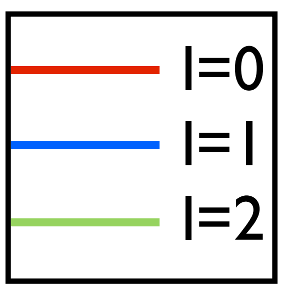
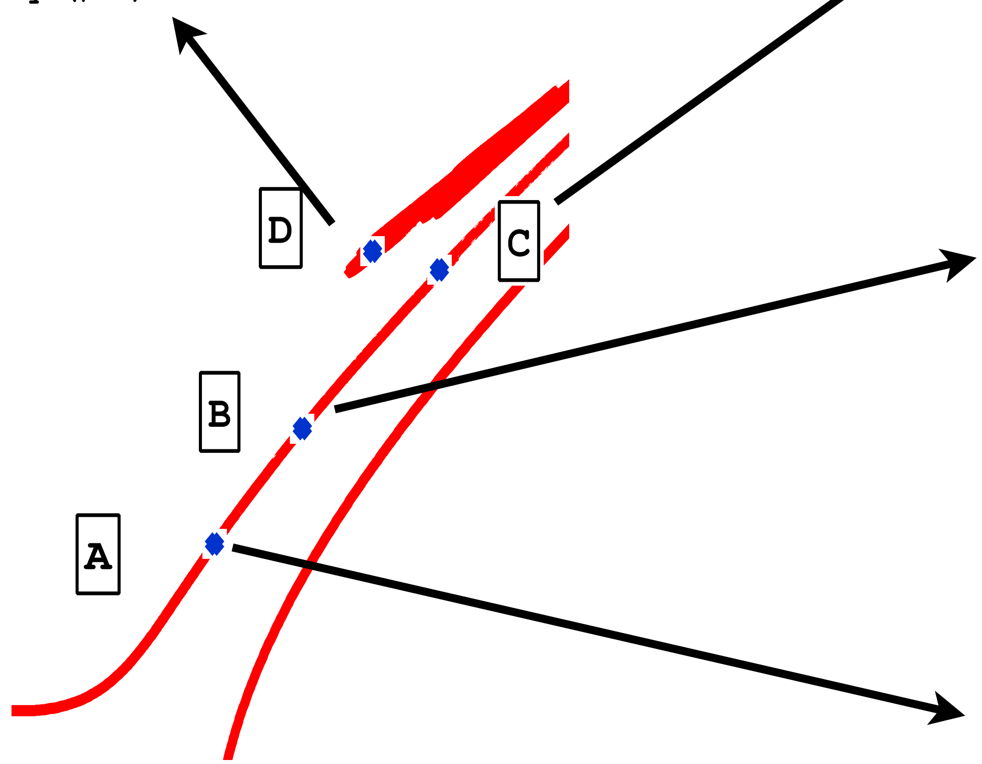
Lifetimes

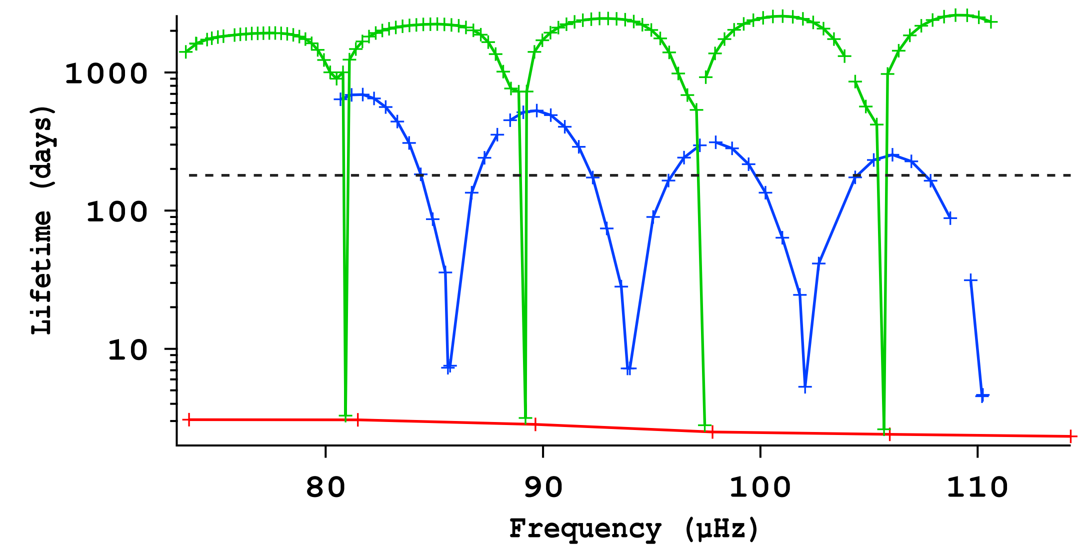




1.5 $M_\odot$







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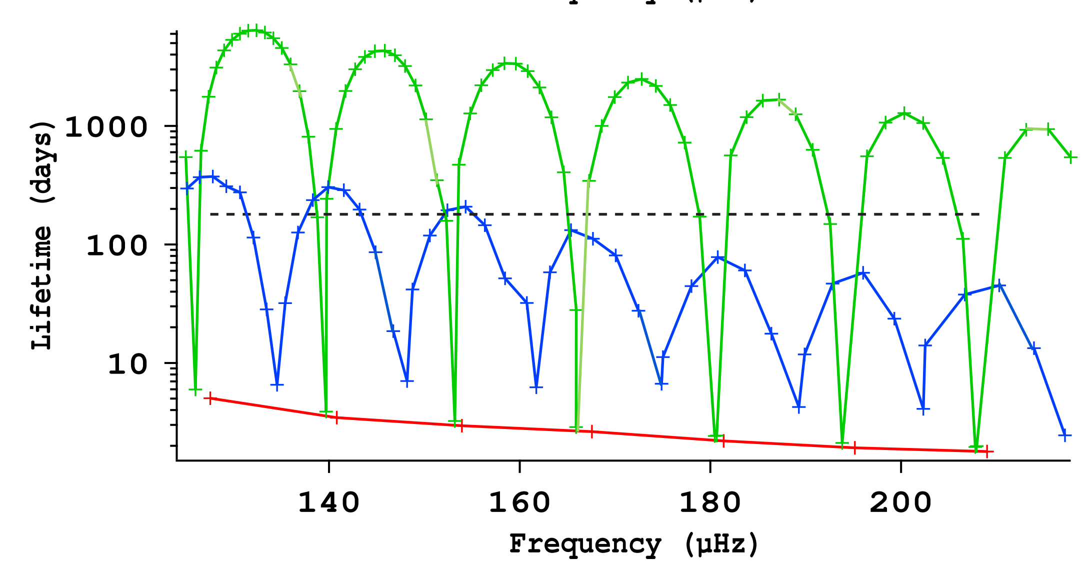
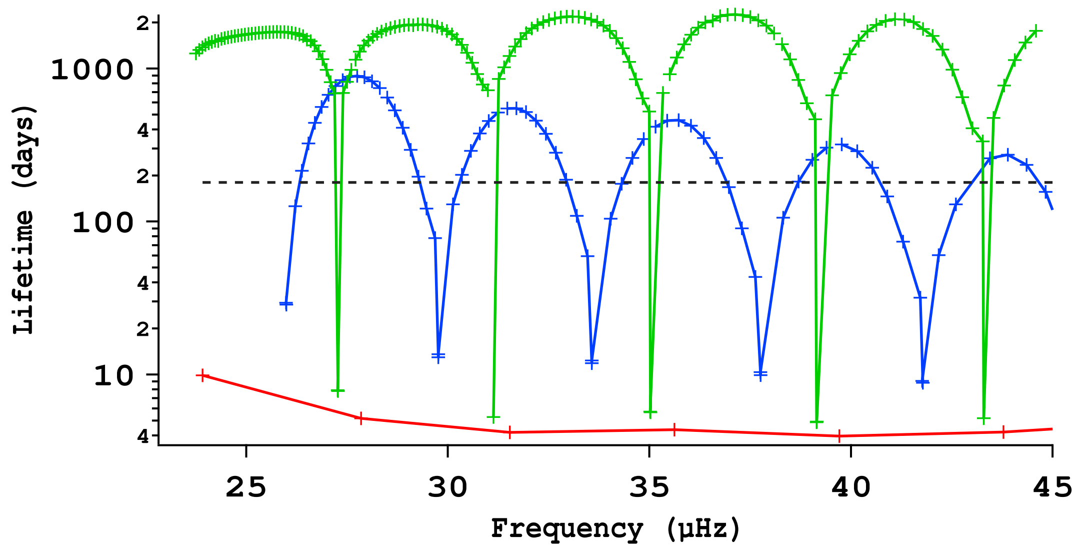
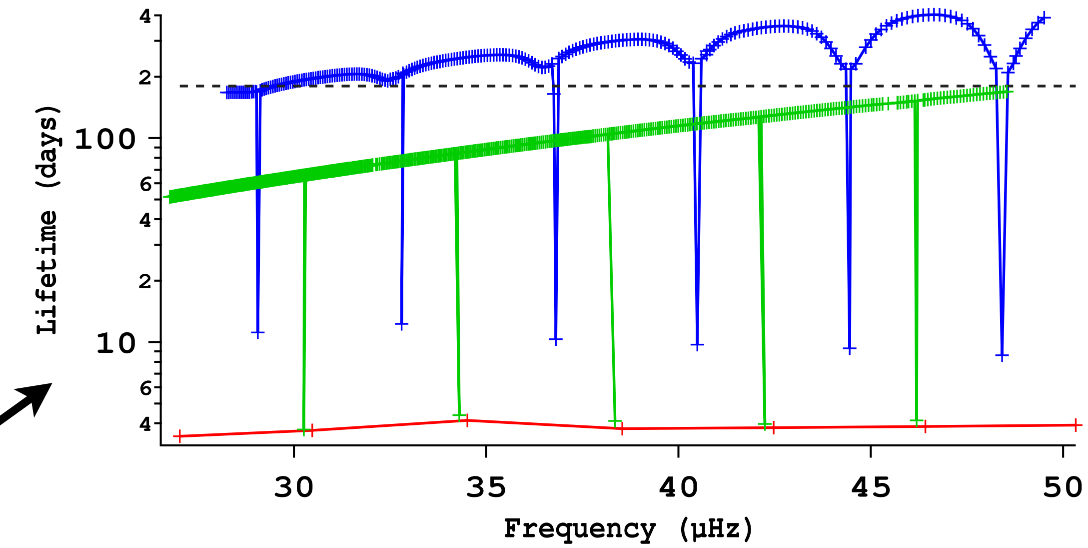


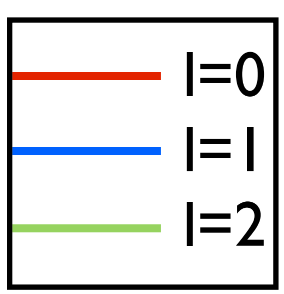
$$\eta = -\frac{\int_V dW}{2\sigma I |\xi_r(R)|^2 M}$$

Lifetimes

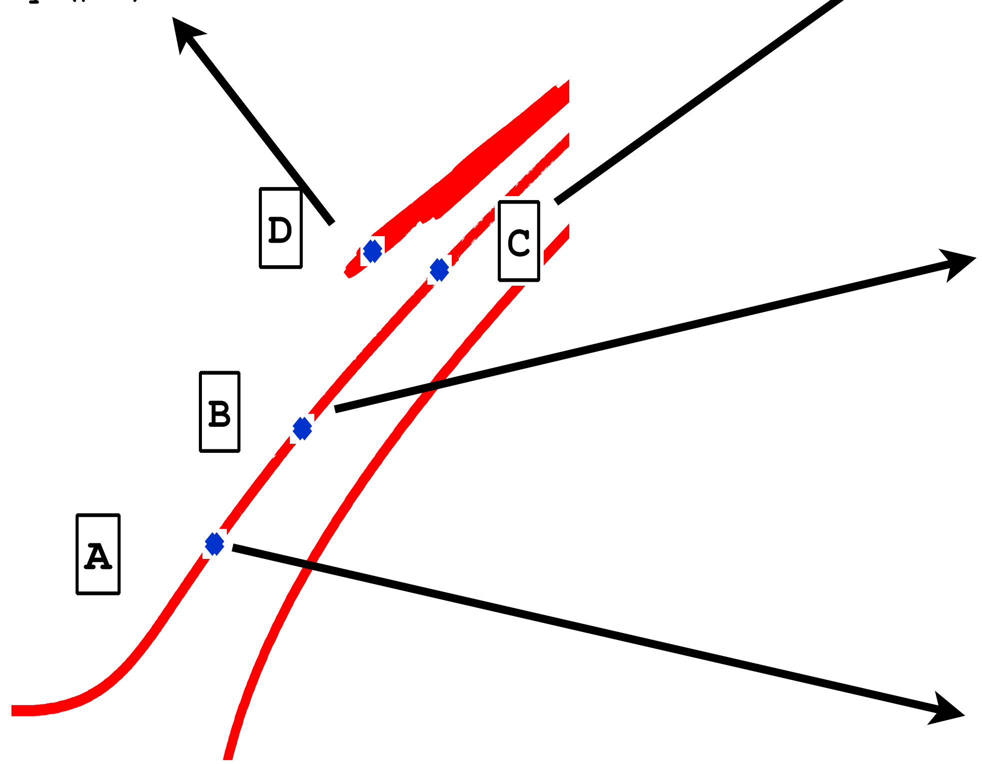


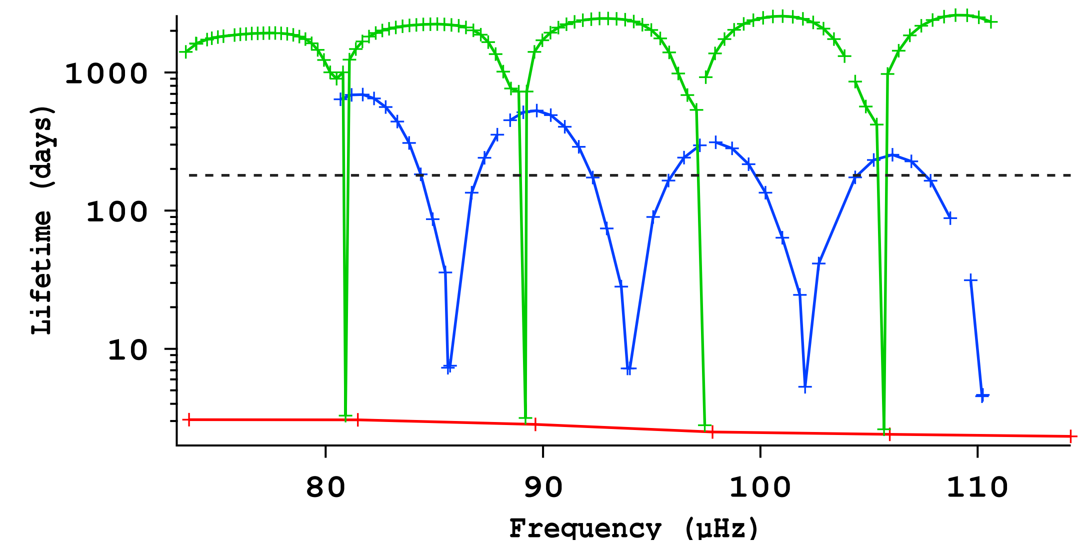


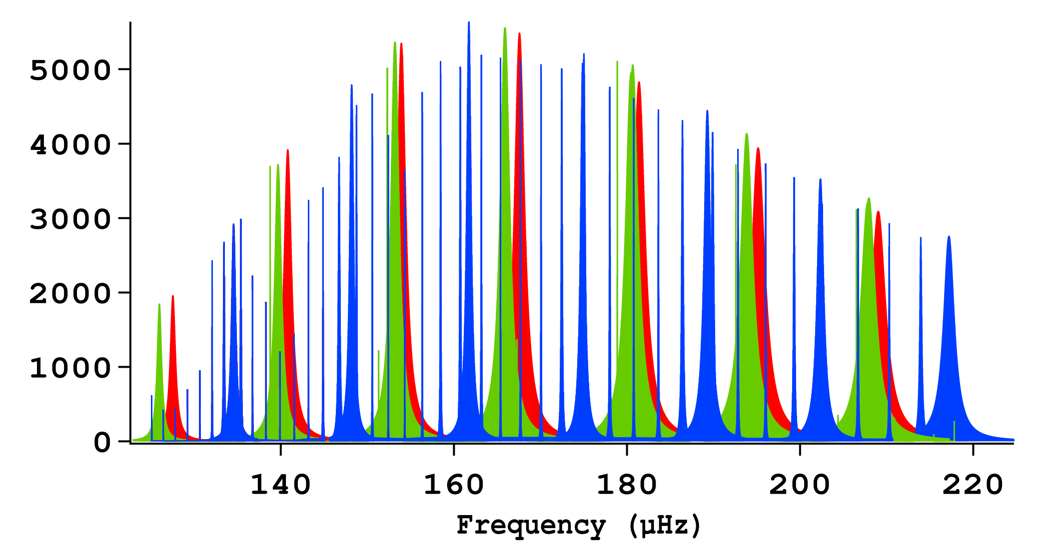
1.5 M☉



Tobs = 1 year







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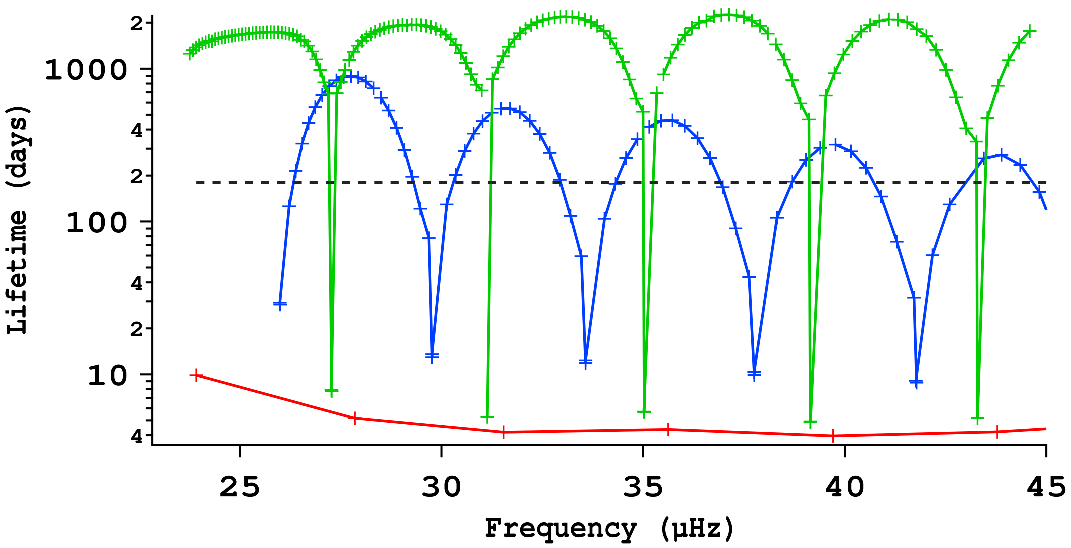
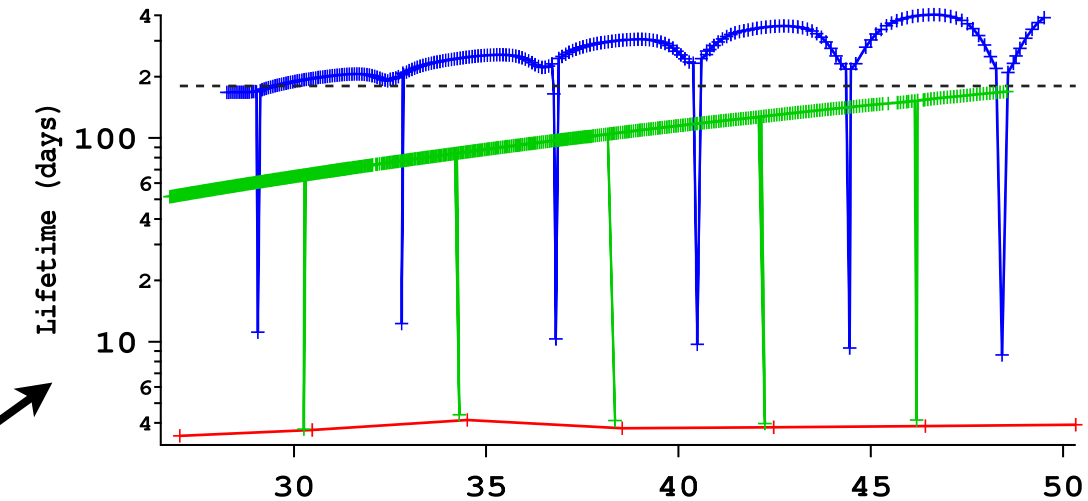
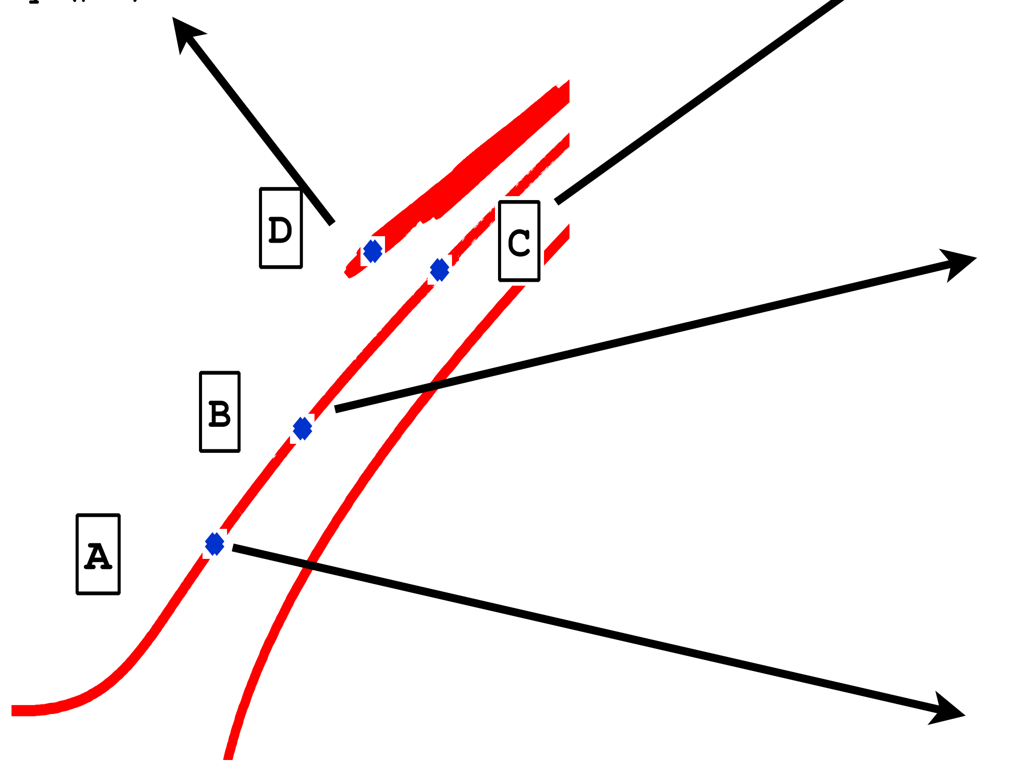
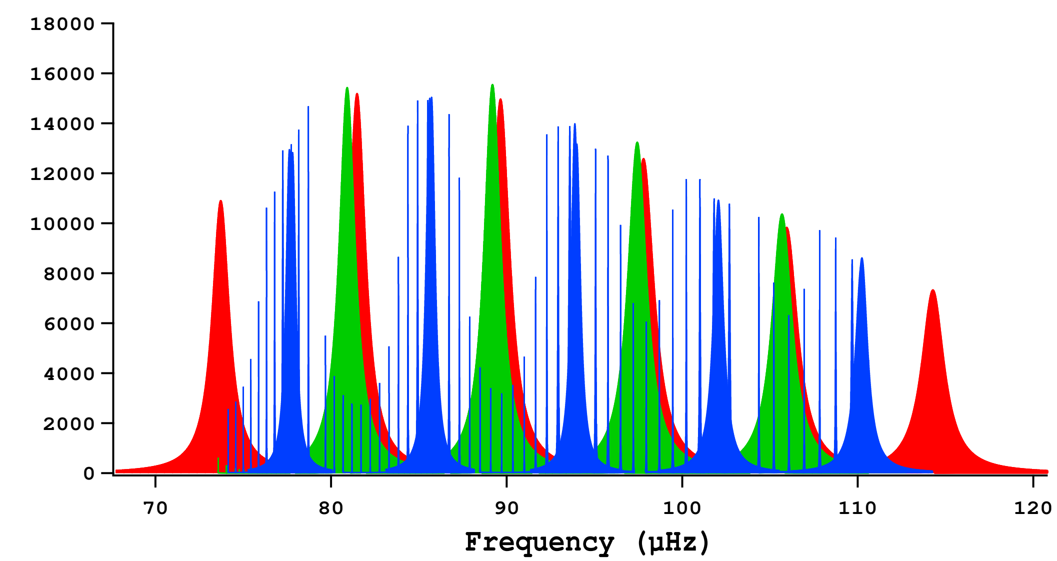
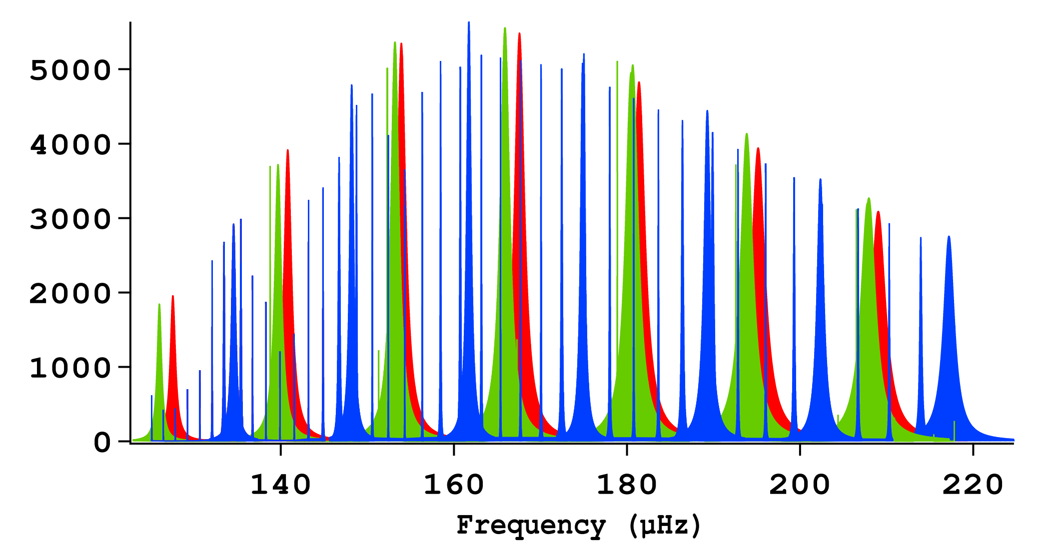
Lifetimes











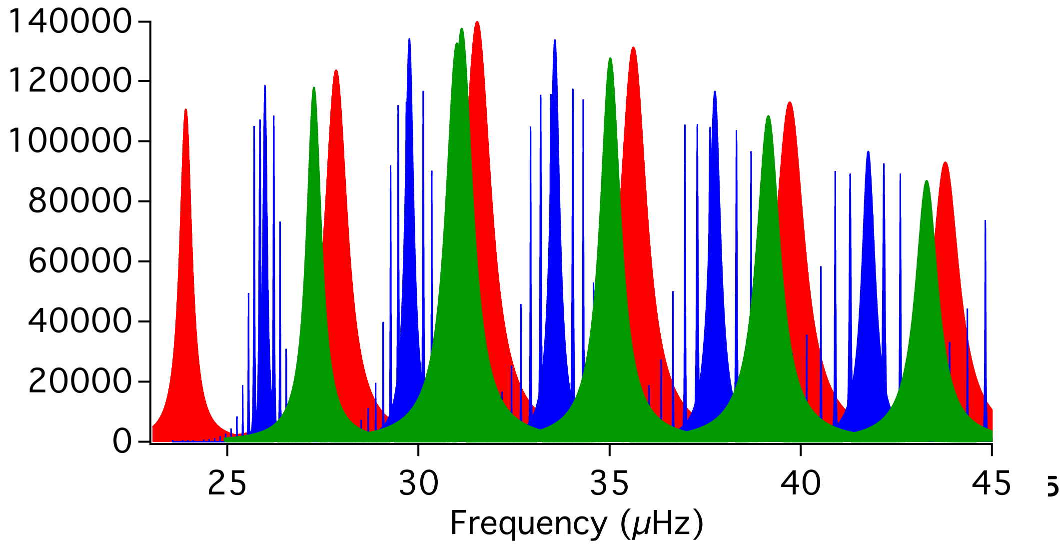
1.5 $M_\odot$

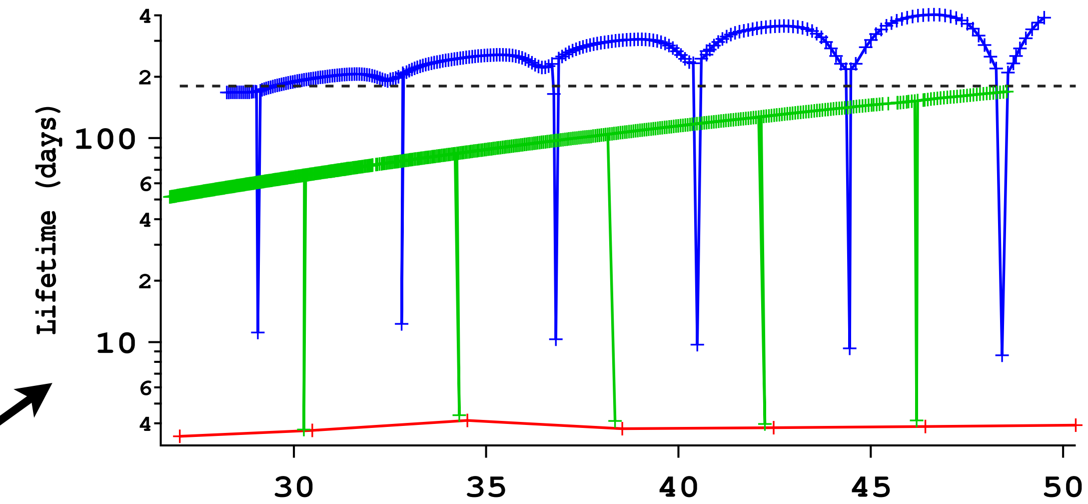
l=0
l=1
l=2

Tobs = 1 year

$$\eta = -\frac{\int_V dW}{2\sigma I |\xi_r(R)|^2 M}$$

Lifetimes





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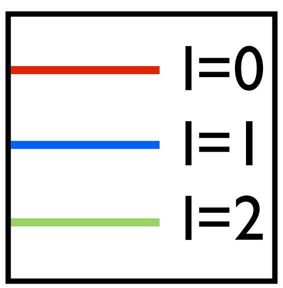
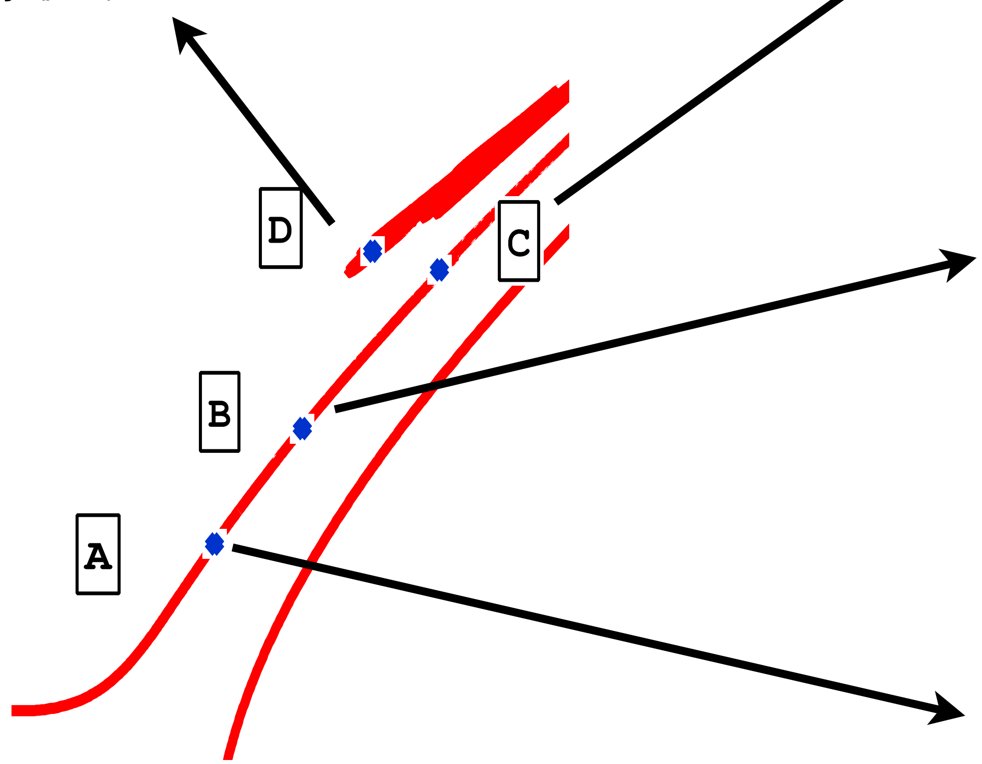
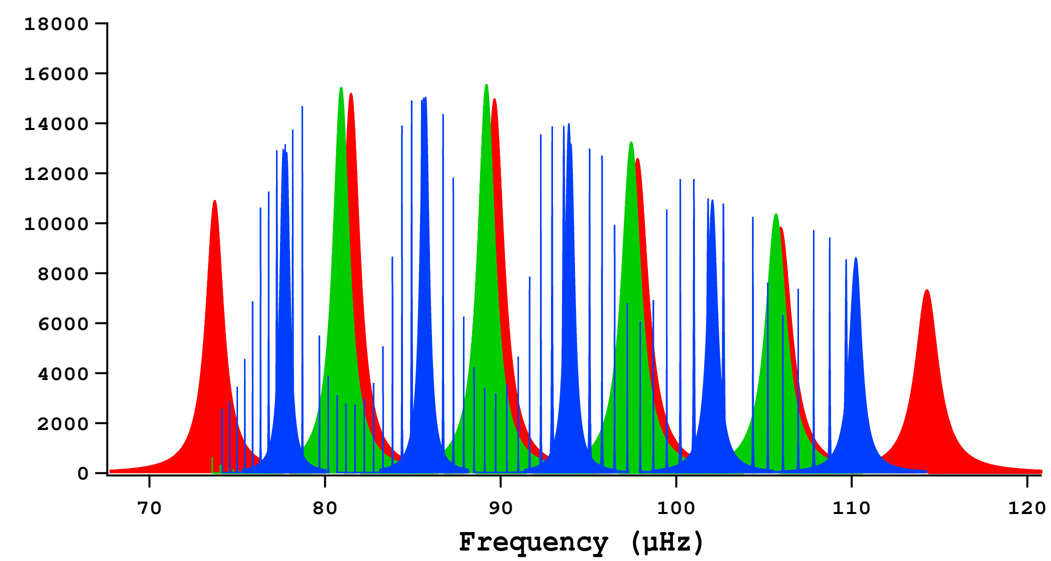
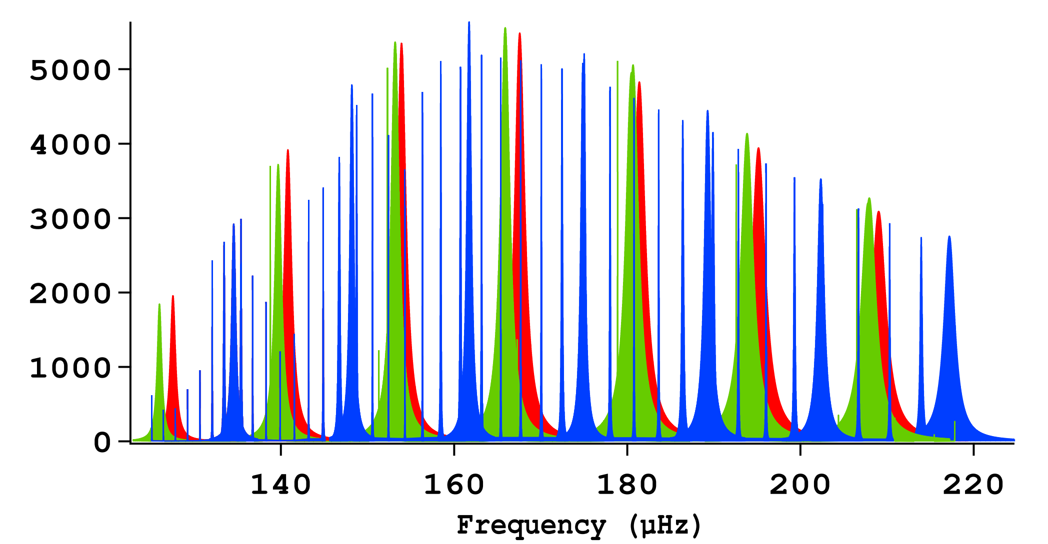


Tobs = 1 year







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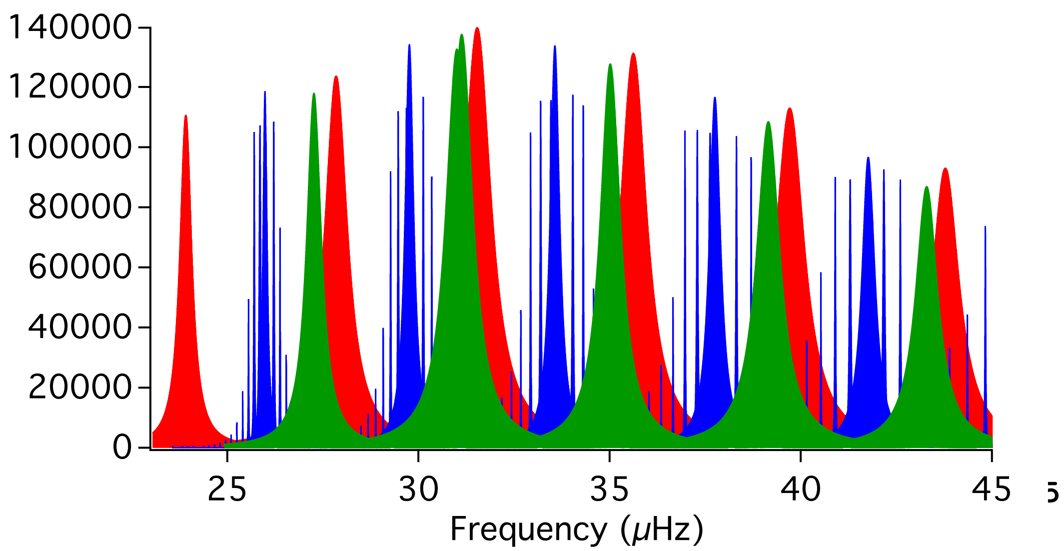
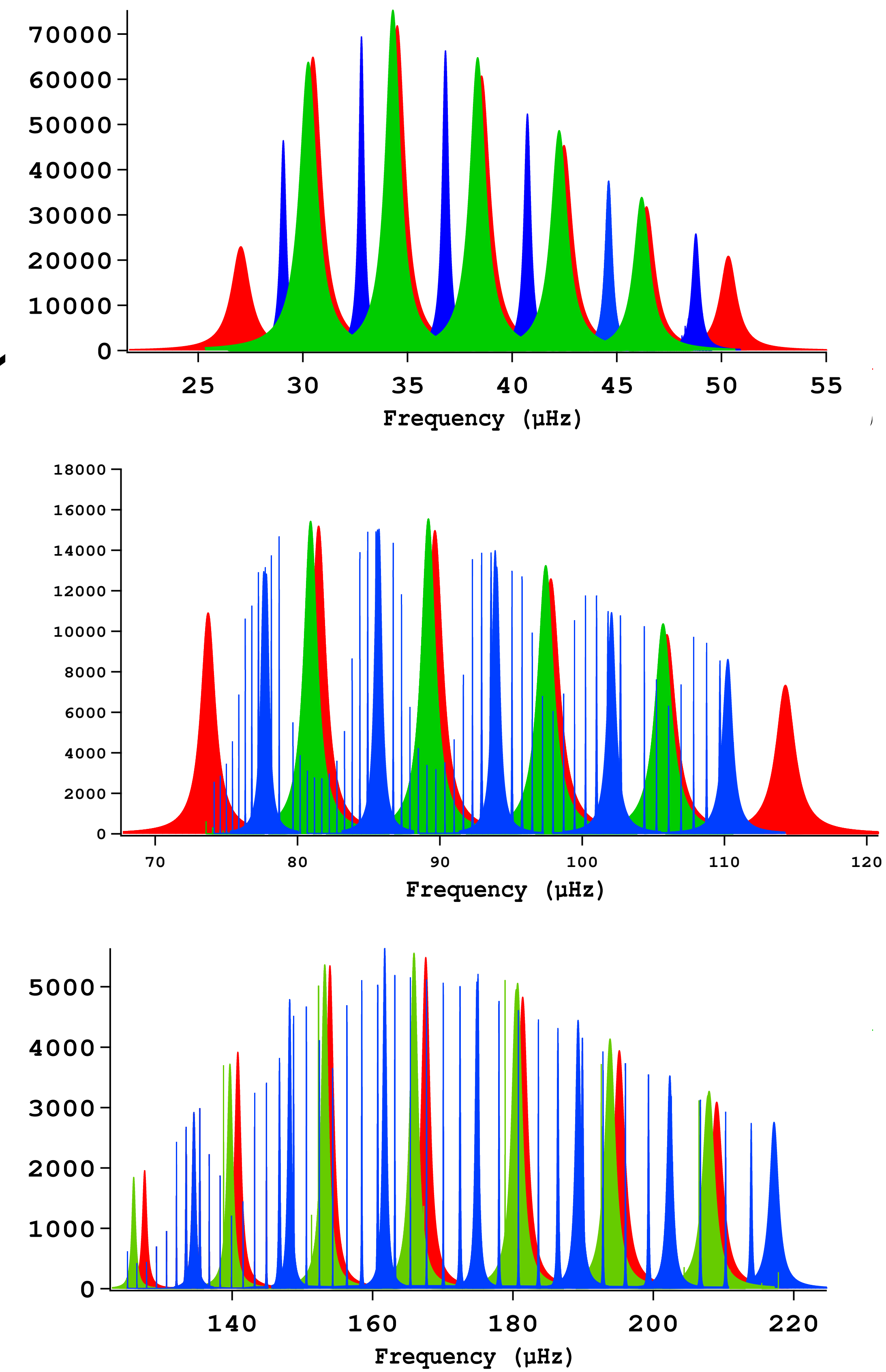
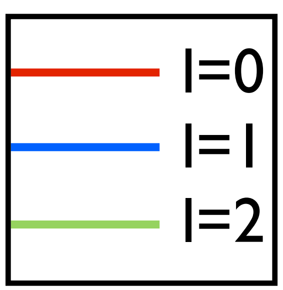
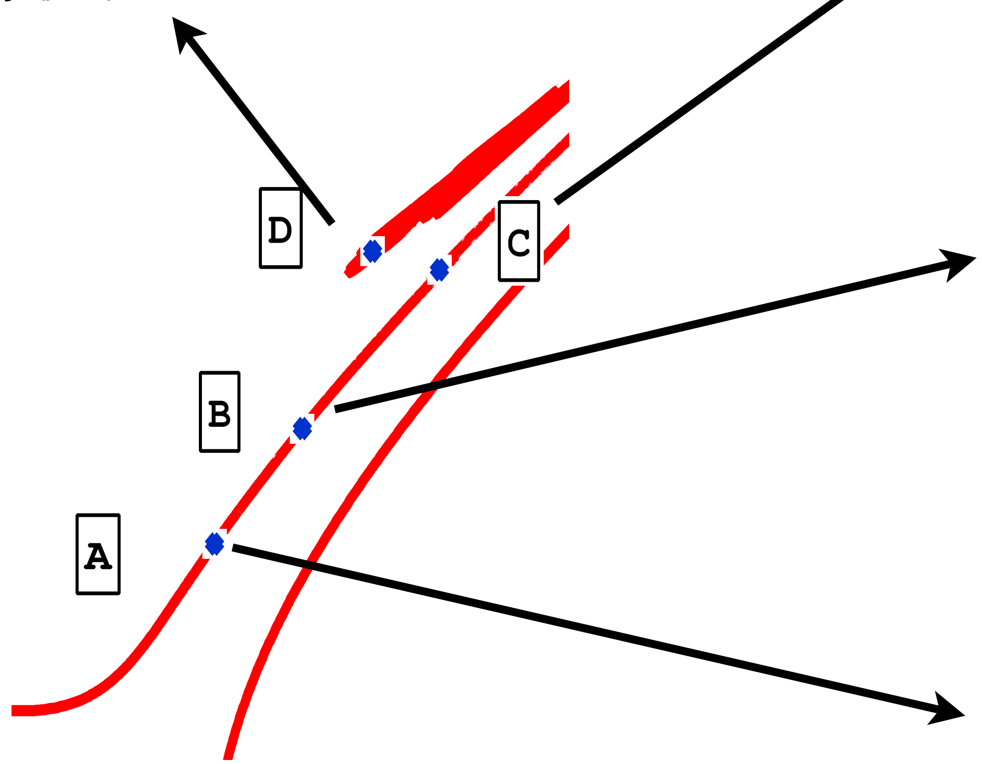
Lifetimes





1.5 $M_\odot$



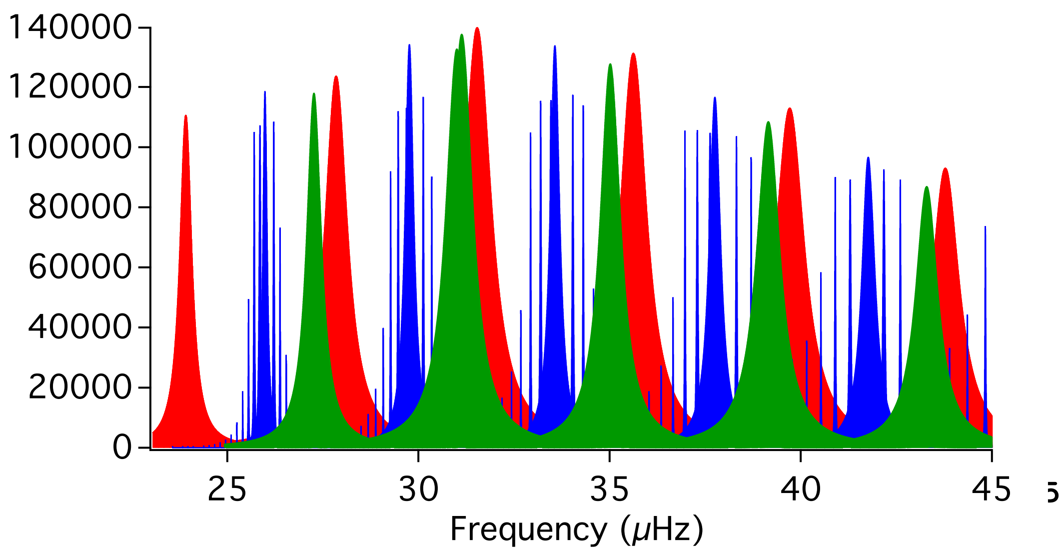


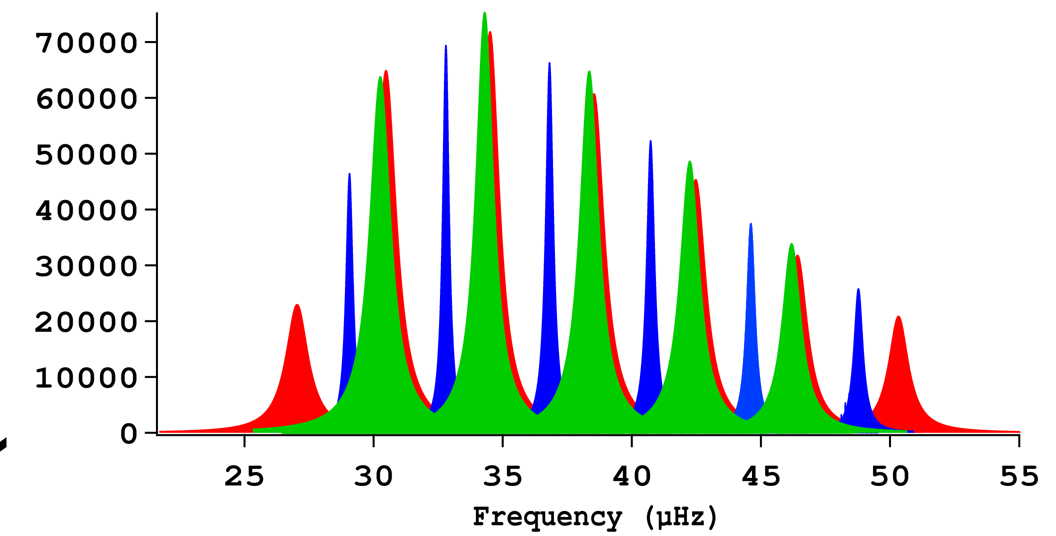
Tobs = 1 year

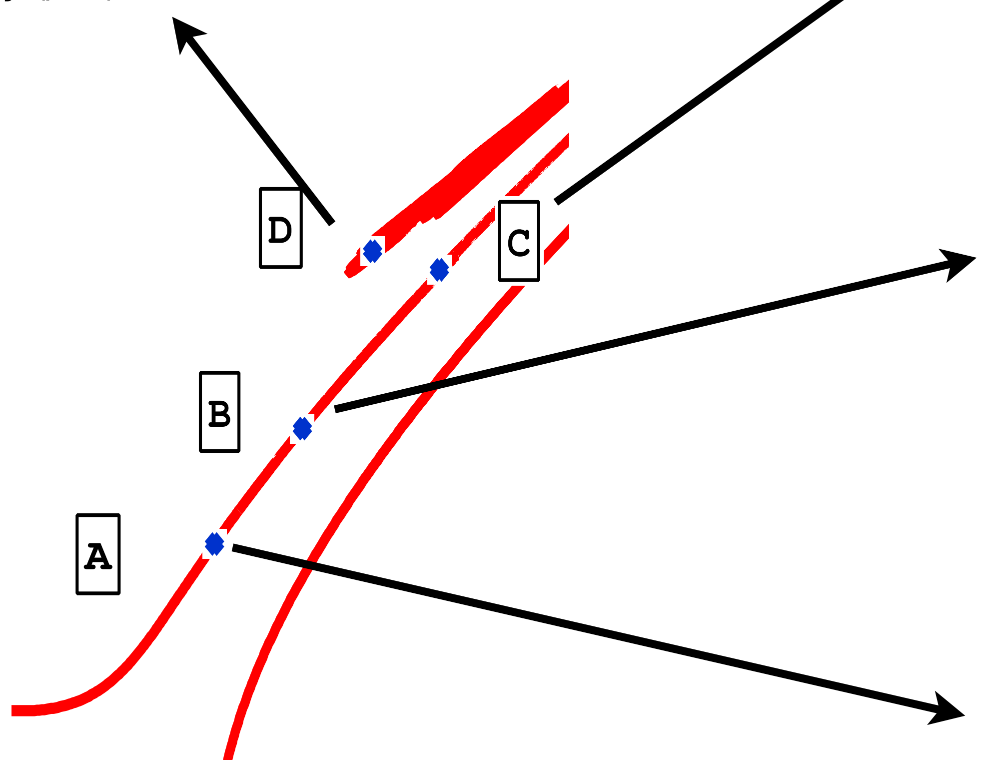
$$\eta = -\frac{\int_V dW}{2\sigma I |\xi_r(R)|^2 M}$$

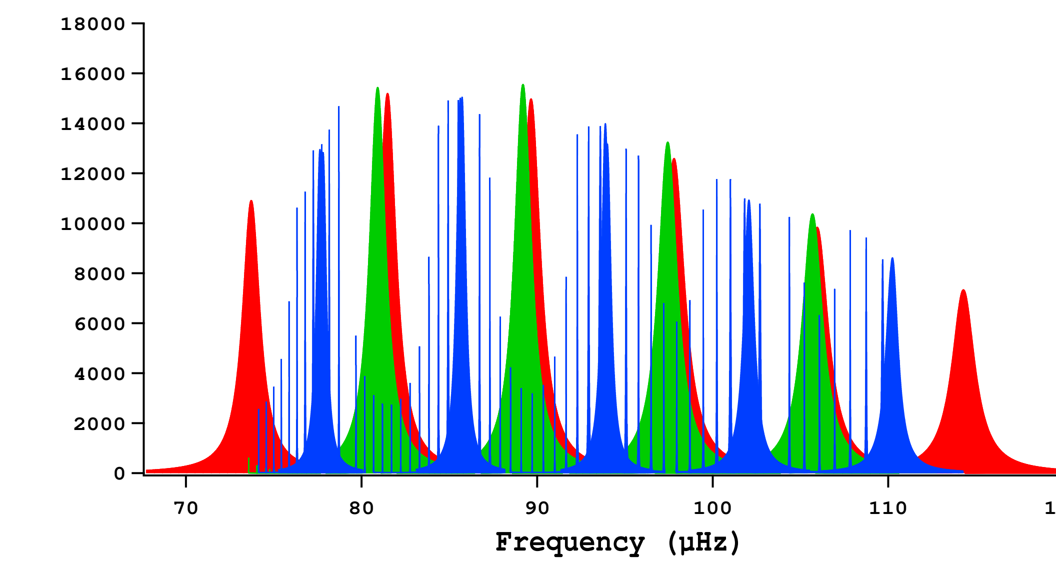
Theoretical power spectrum : Ascending the RGB

Lifetimes

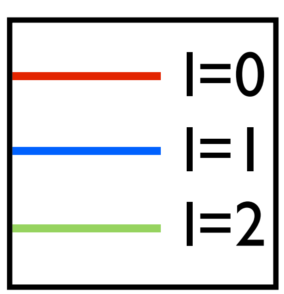




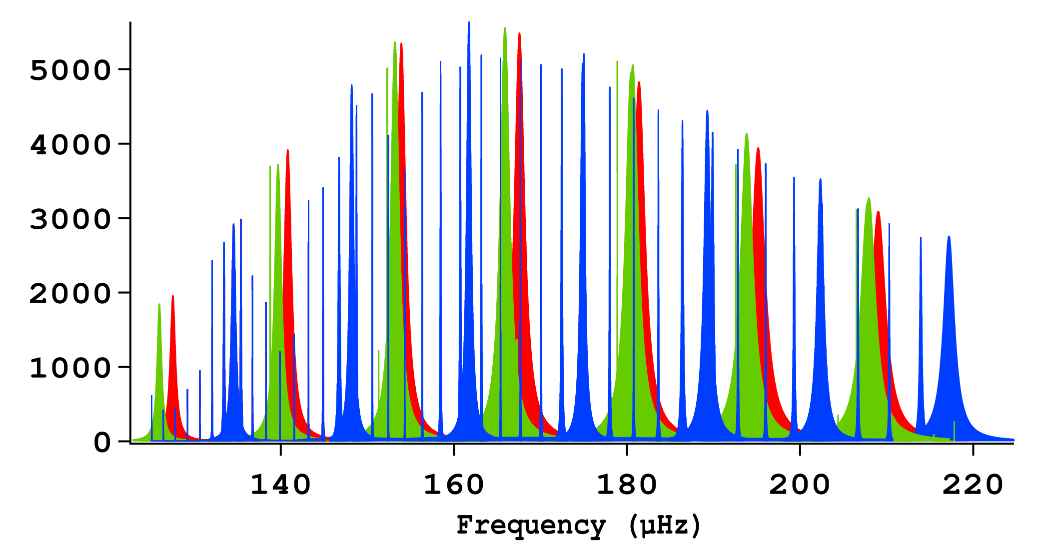




1.5 M$_\odot$

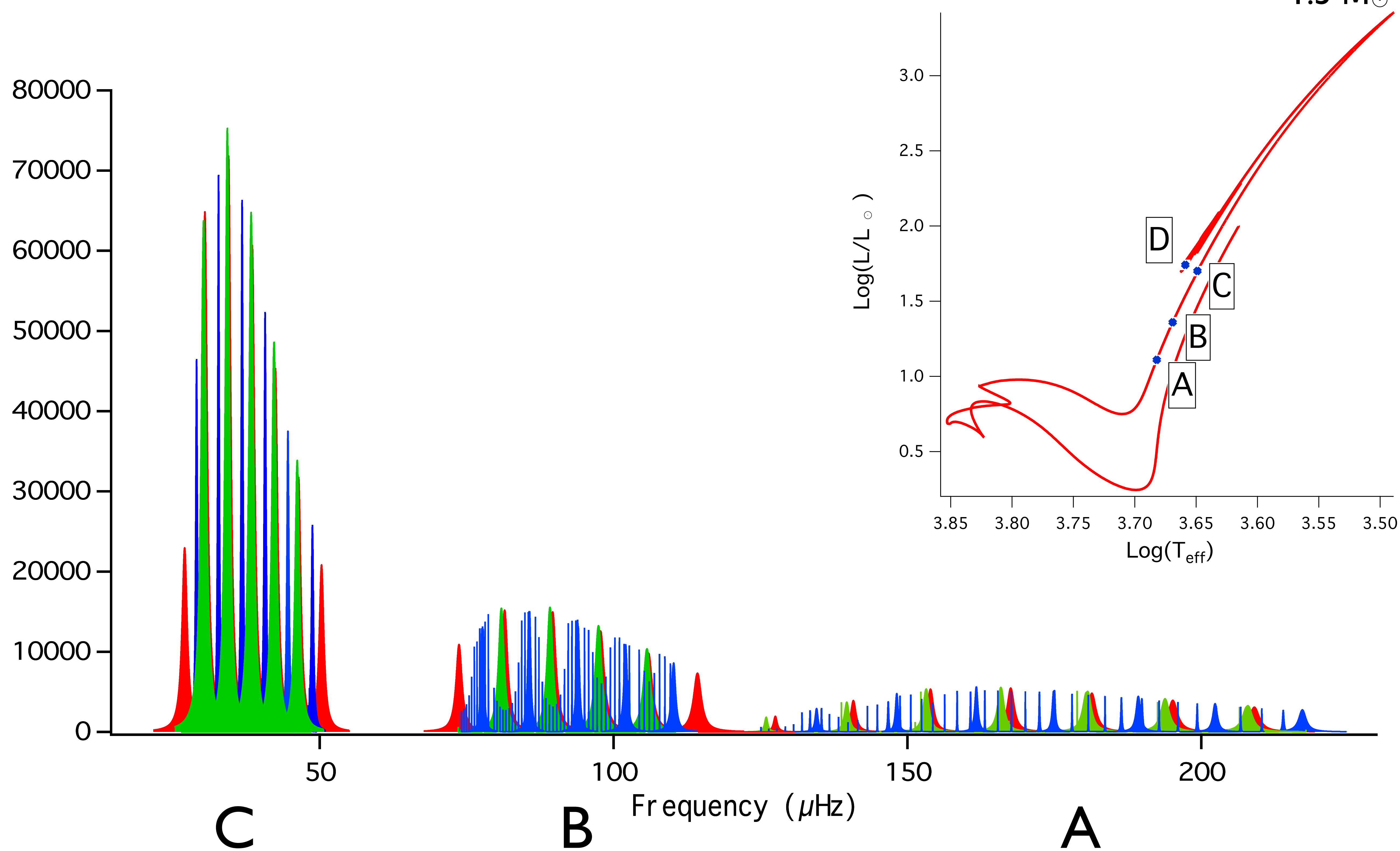


Tobs = 1 year



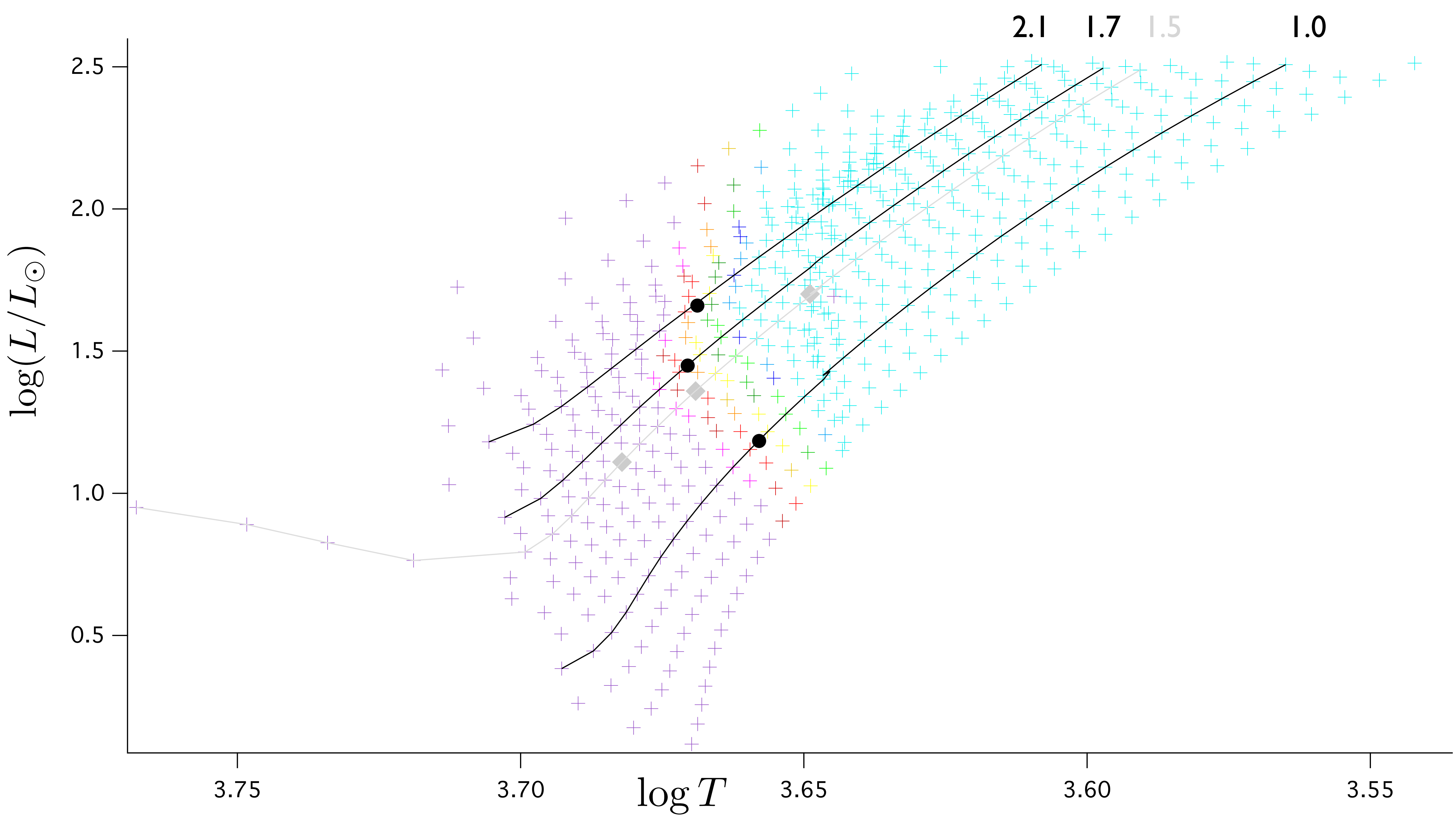
For 1.5 Msun star ascending the RGB (and Tobs =1 year)
Detectable g-dominated mixed-modes for stars
with $\nu_{max} \geq 50$ μHz and $\Delta\nu \geq 4.9$ μHz

power spectrum aspect along the red-giant branch

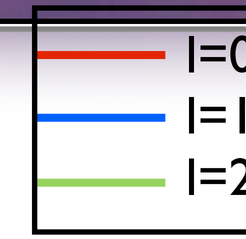


What is the iso-detectability criteria ?

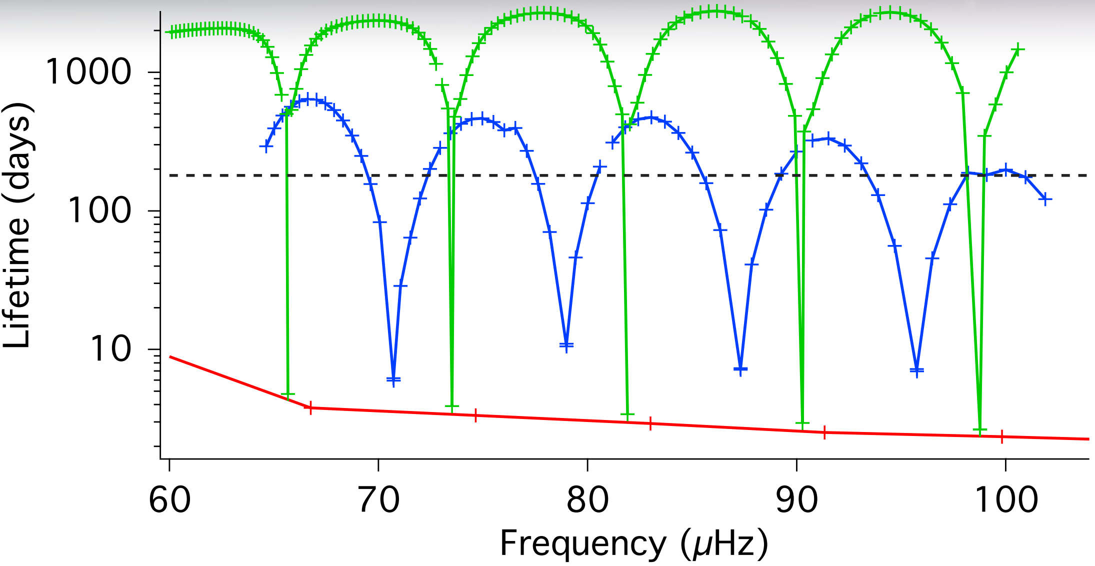
We selected models with the same number of mixed modes in a large separation



Extension to other masses



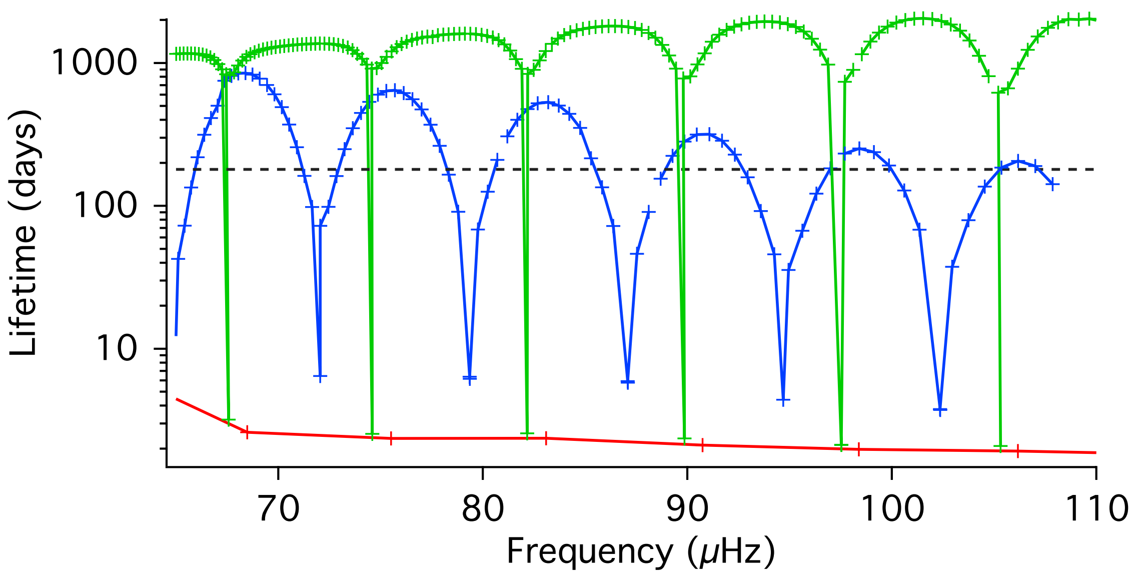
Tobs = 1 year



$1M_\odot$

$\nu_{max} = 84\mu Hz$

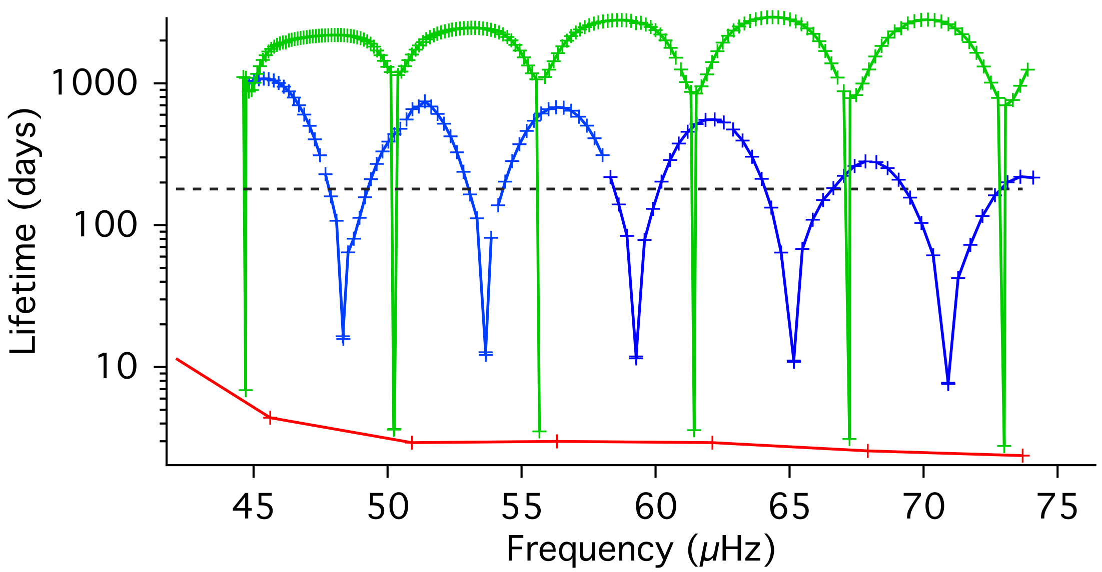
$\Delta\nu = 8.5\mu Hz$



$1.7M_\odot$

$\nu_{max} = 90\mu Hz$

$\Delta\nu = 7.7\mu Hz$

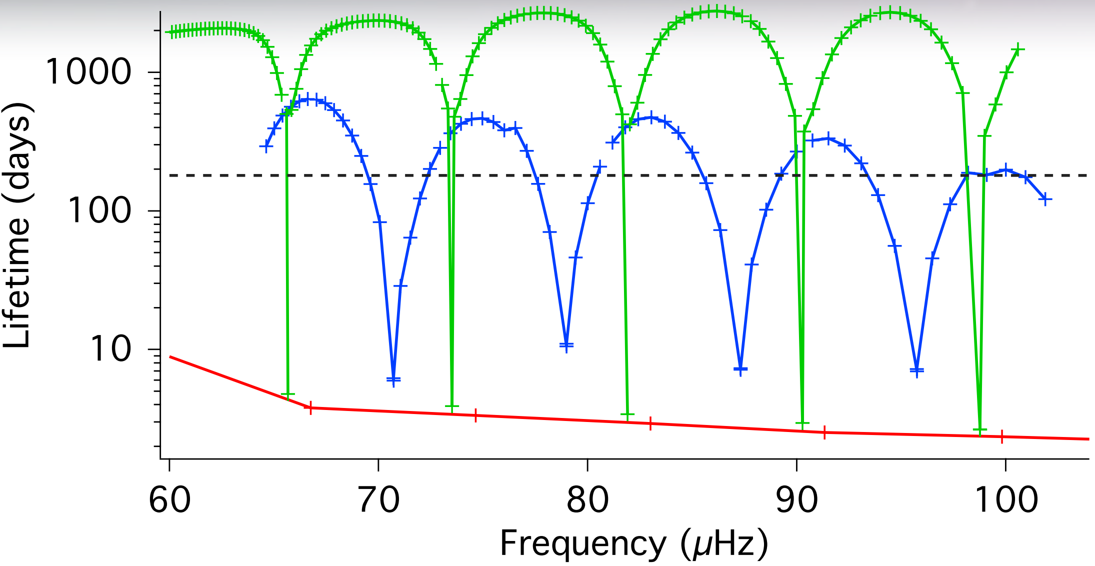


$2.1M_\odot$

$\nu_{max} = 62\mu Hz$

$\Delta\nu = 5.7\mu Hz$

Extension to other masses

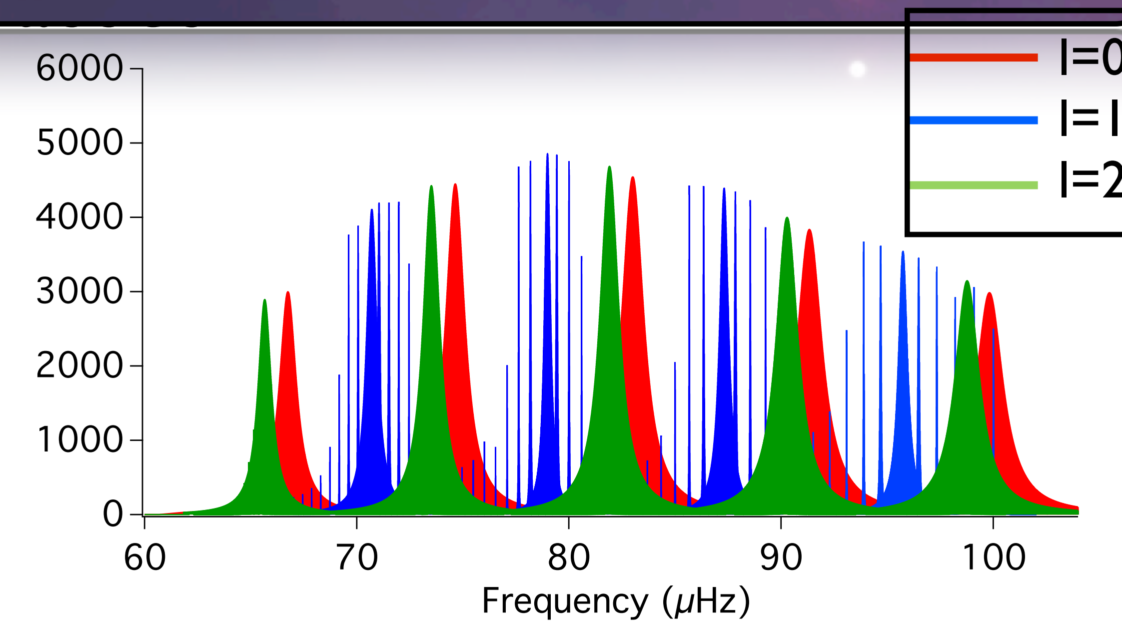


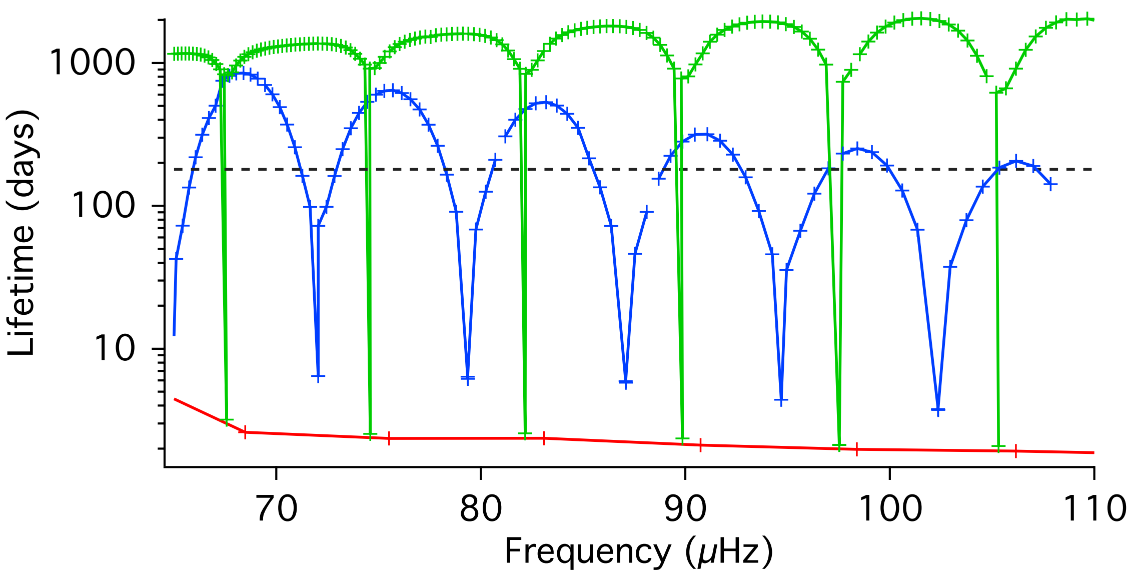
Tobs = 1 year

$1M_\odot$

$\nu_{max} = 84\mu Hz$

$\Delta\nu = 8.5\mu Hz$

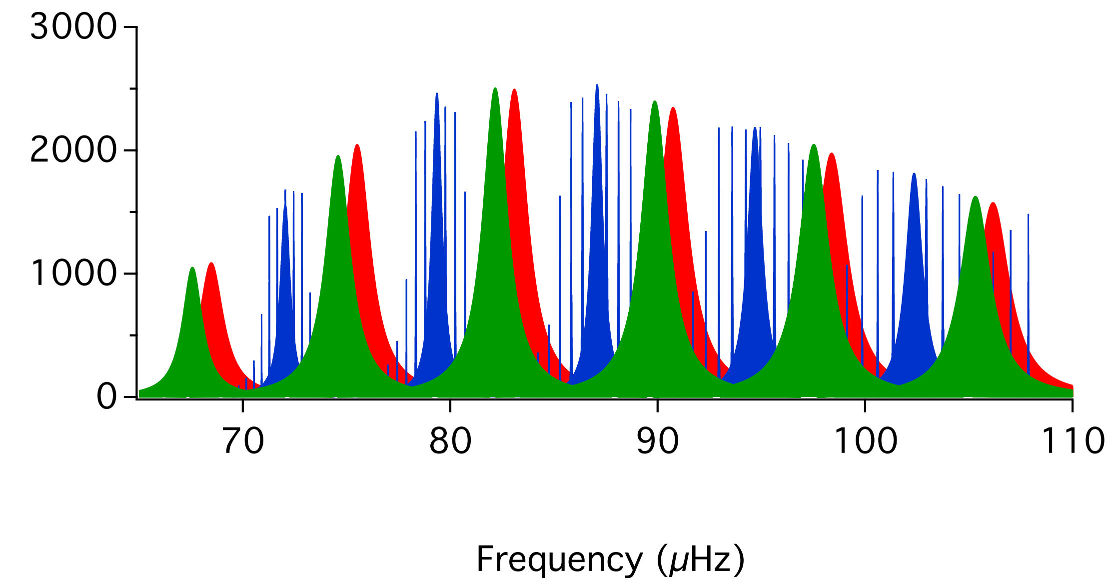


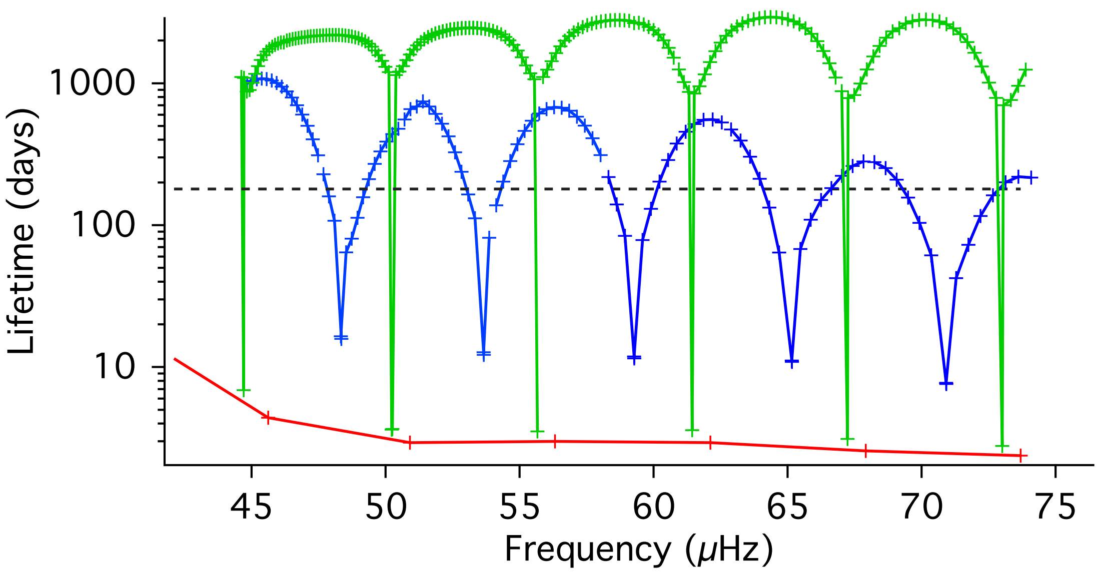


$1.7M_\odot$

$\nu_{max} = 90\mu Hz$

$\Delta\nu = 7.7\mu Hz$

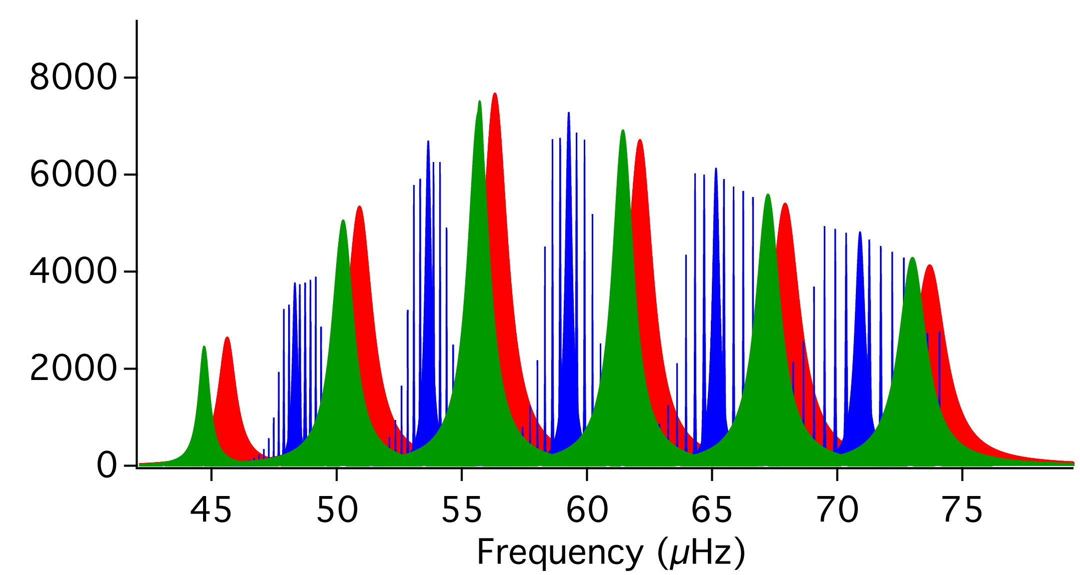




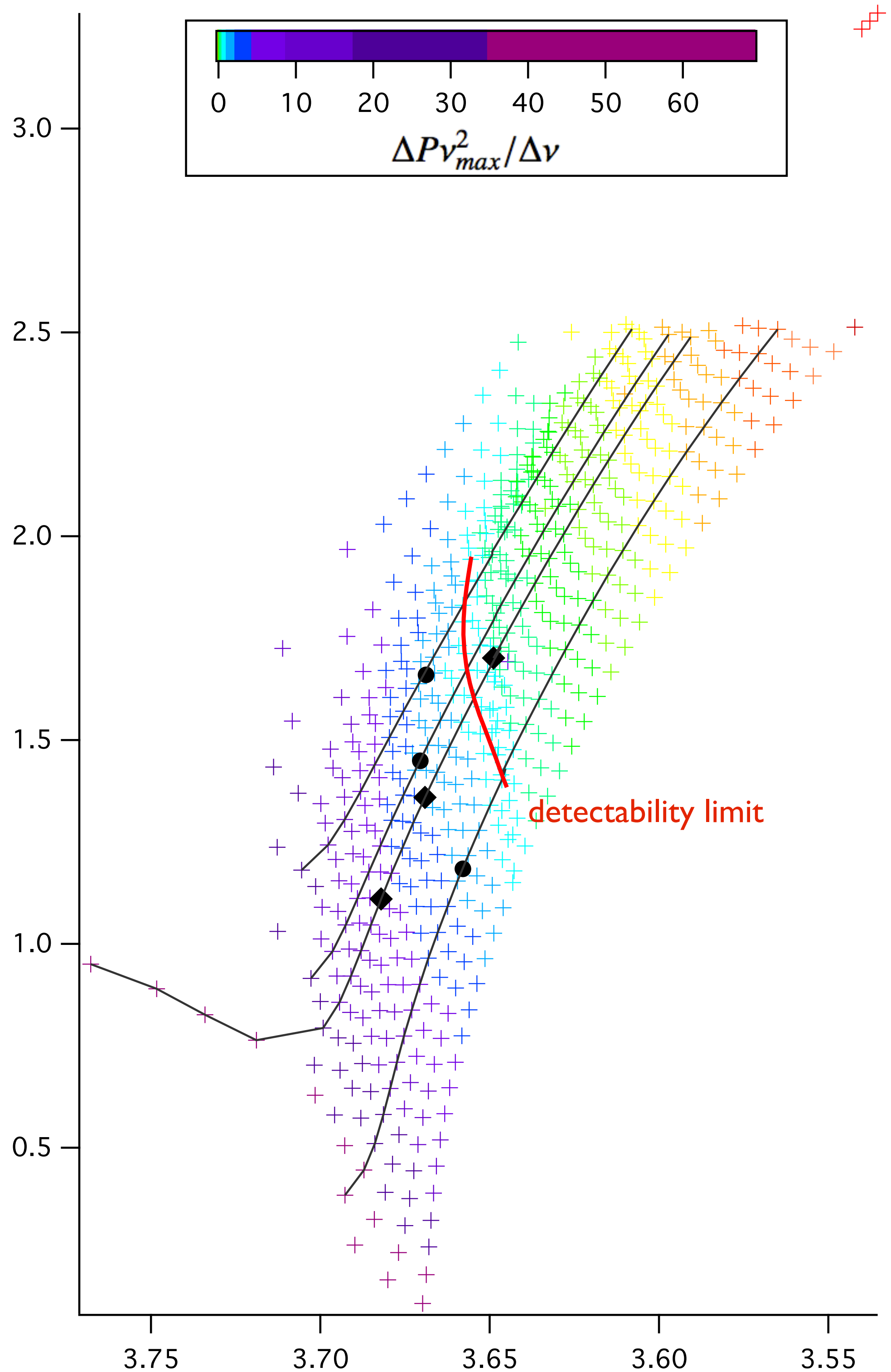
$2.1M_\odot$

$\nu_{max} = 62\mu Hz$

$\Delta\nu = 5.7\mu Hz$



Conclusion



- Theoretical dectability limit on the RGB

for 1.5 $M_\odot$ and Tobs = 1 year, g-dominated mixed modes are detectable for stars with $\nu_{max} \geq 50$ μHz and $\Delta\nu \geq 4.9$ μHz

- Models with the same number of mixed modes in a large separation presents similar power spectra

$$\frac{n_g}{n_p} \simeq \frac{\Delta\nu}{\Delta P \nu_{max}^2} \propto \left[\int \frac{N}{r} dr\right] M^{3/2} R^{5/2} T_{eff}$$

- We extend the detectablity limit to other masses

Perspectives :

- impact of chemical composition, metallicity, overshoot, ...

- quantitative comparaison to observations (measure of individual linewidth and heights Benomar et al. 2013)