

# Structural glitches near the cores of red giants revealed by oscillations in g-mode period spacings

**Margarida Cunha**

*in collaboration with*

**D. Stello, P.P. Avelino and J. Christensen-Dalsgaard**

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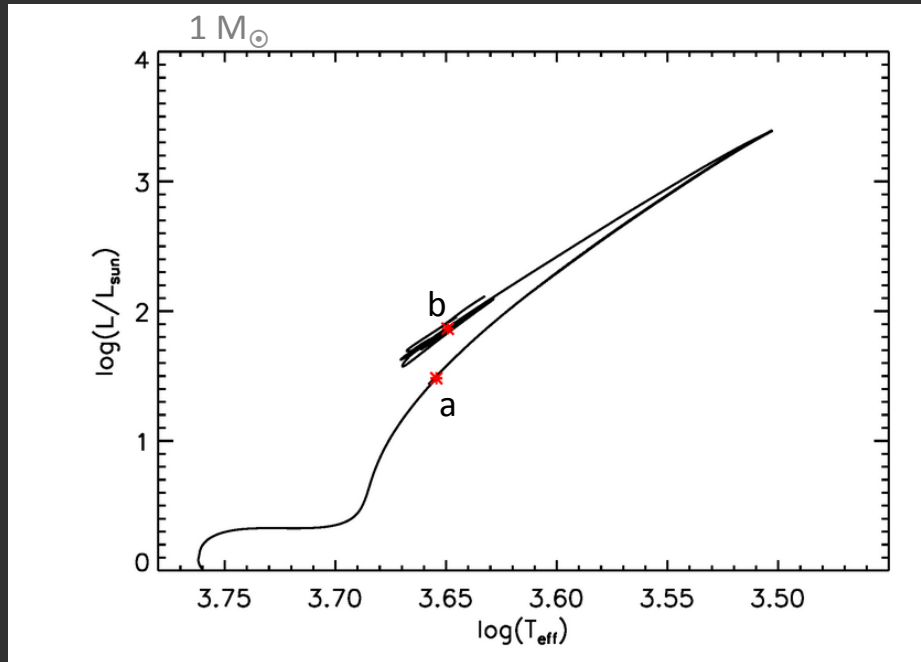
**Structural glitches near the cores  
of red giants revealed by  
oscillations in g-mode  
period spacings**

**Why?**

**Identify particular moments of evolution**

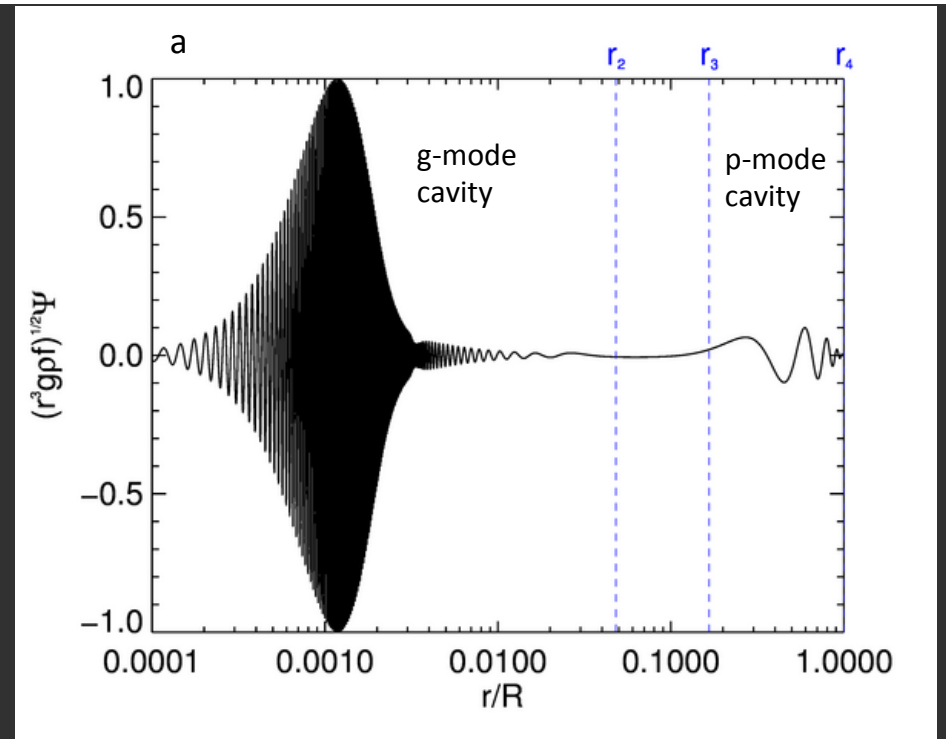
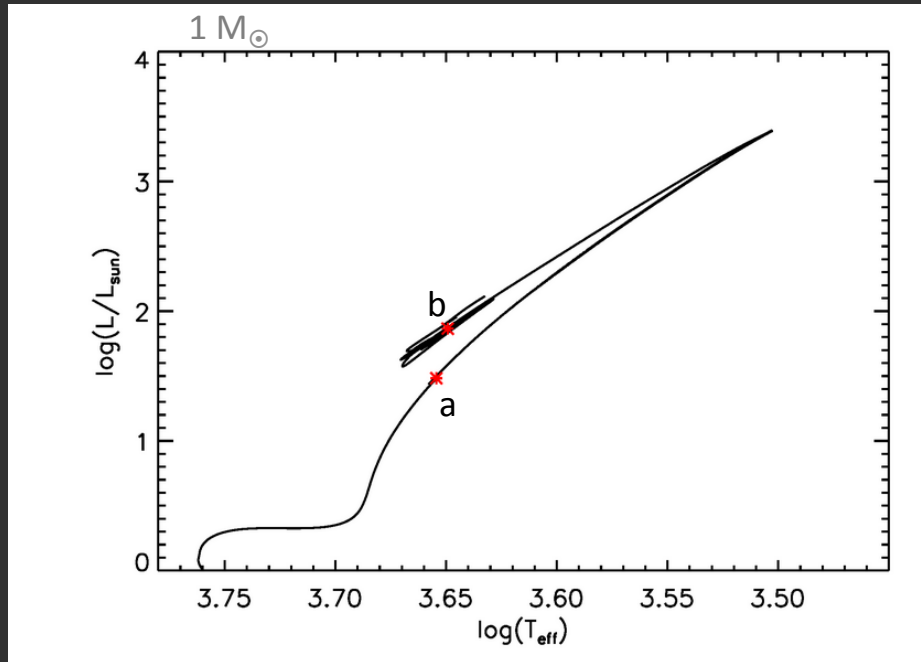
**Infer details of the deep internal structure**

# Models under study



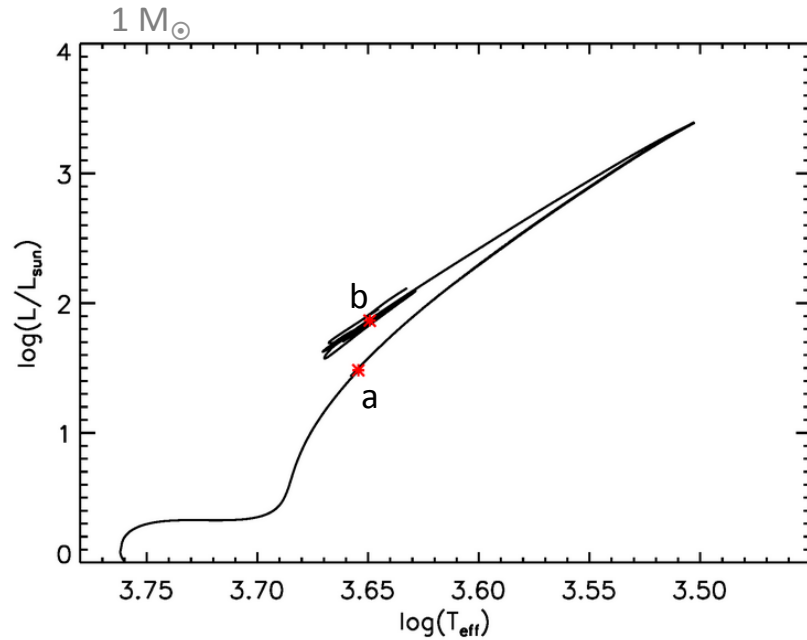
a – ASTEC  
b – MESA

# Models under study

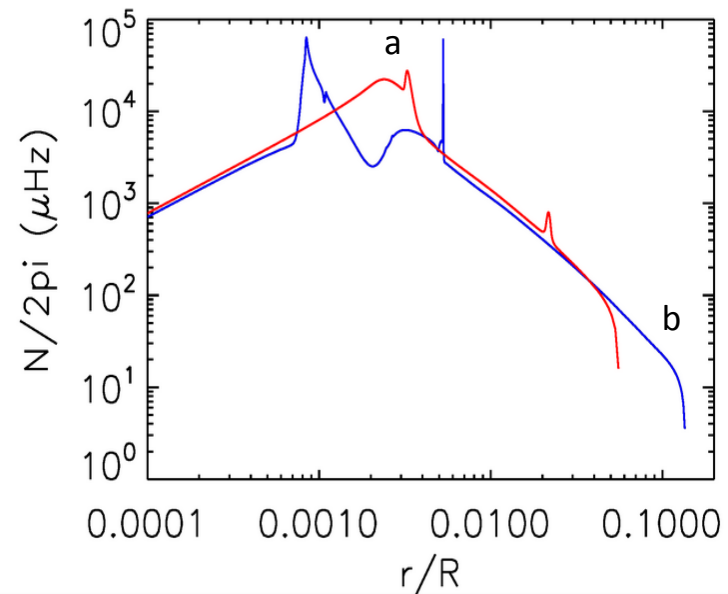
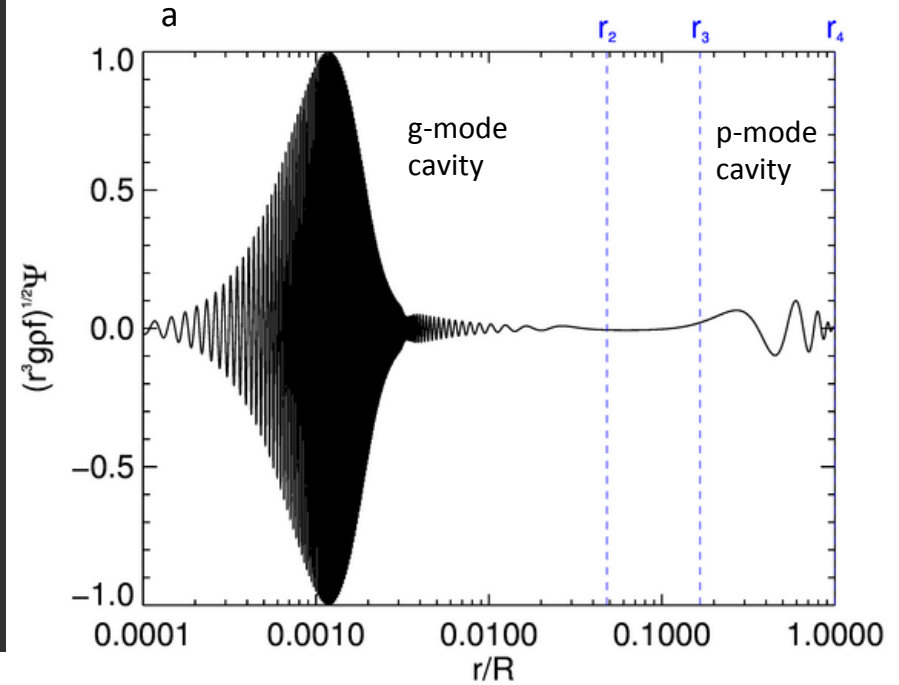


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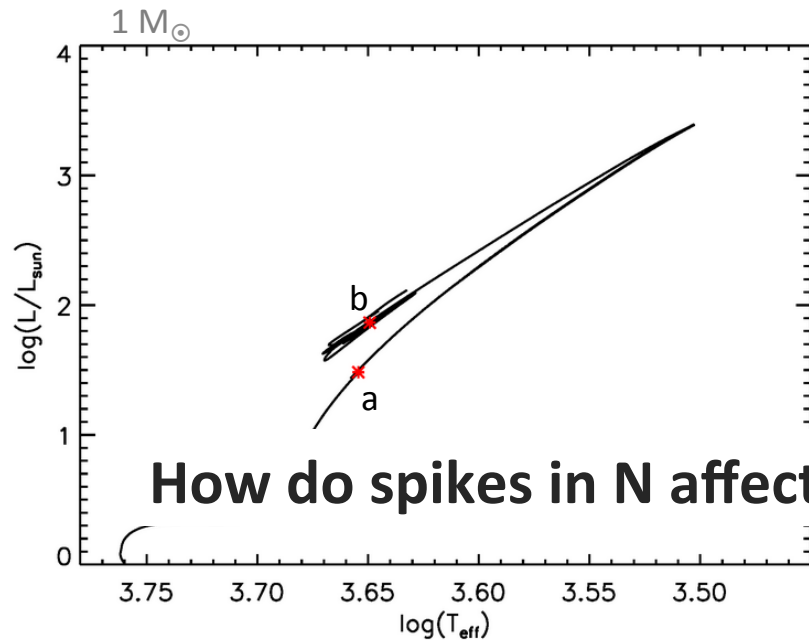


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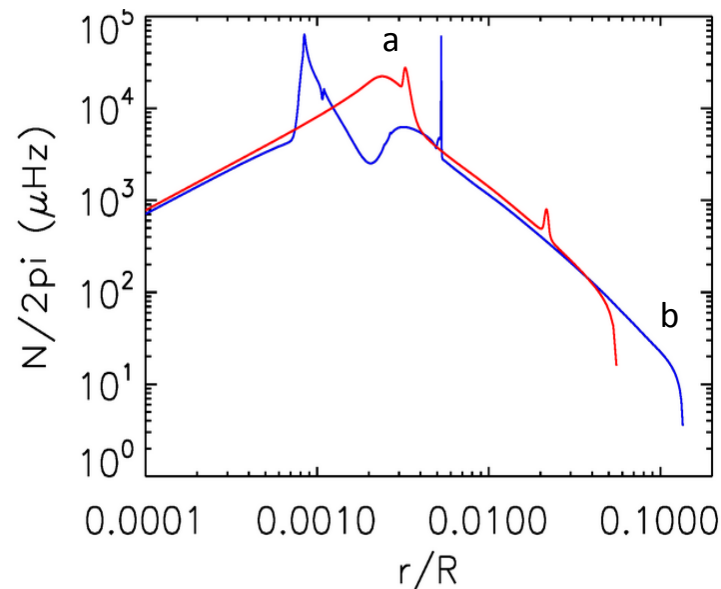
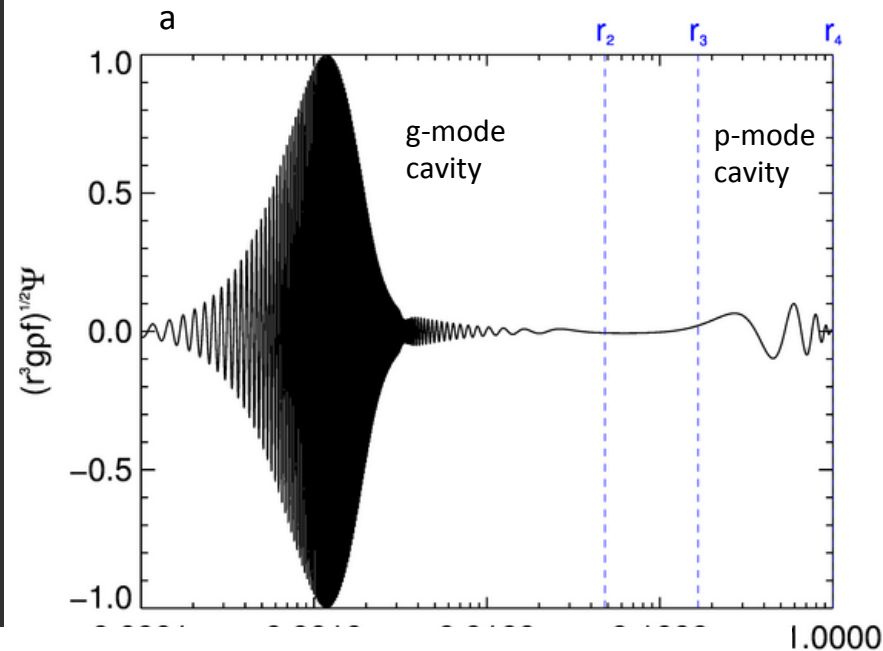


# Models under study

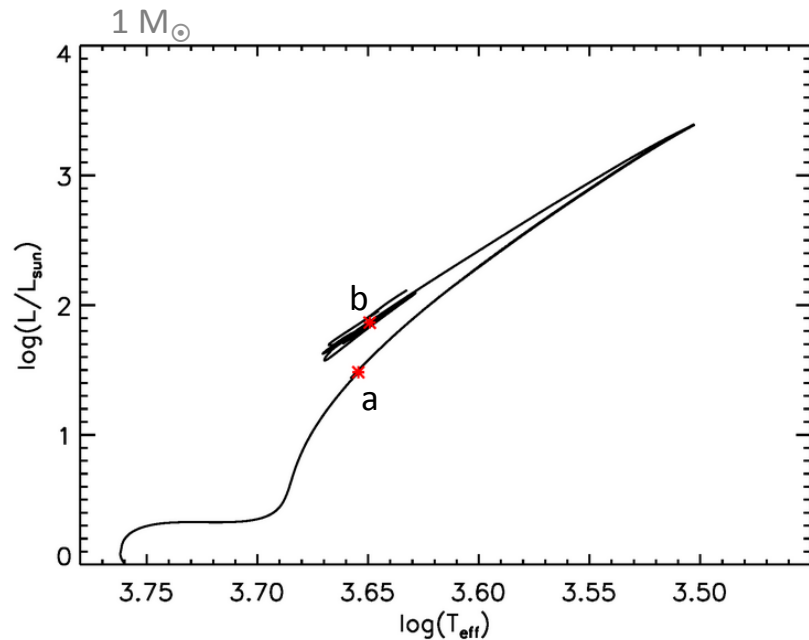


How do spikes in  $N$  affect the periods of the oscillations?

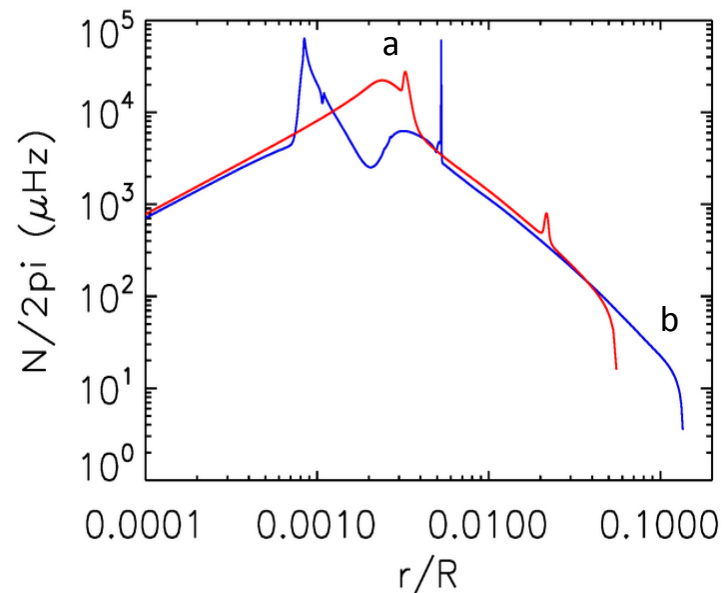
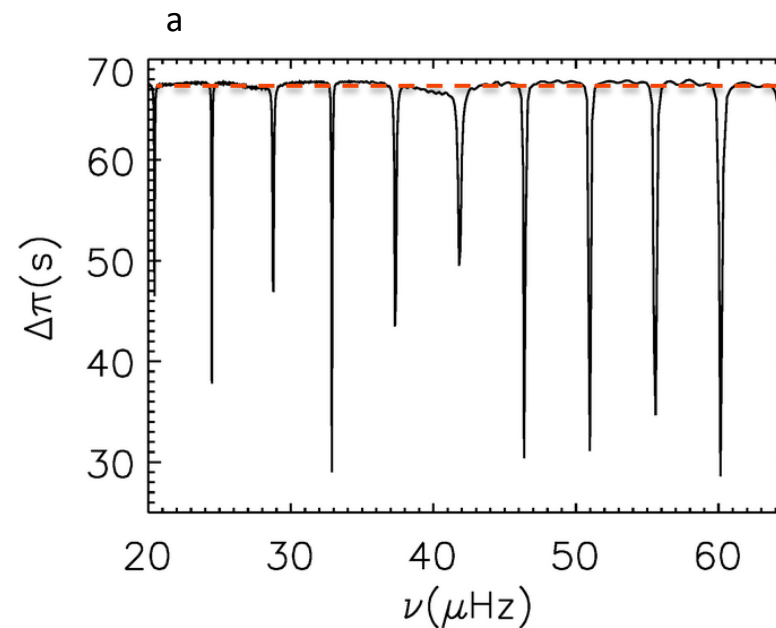
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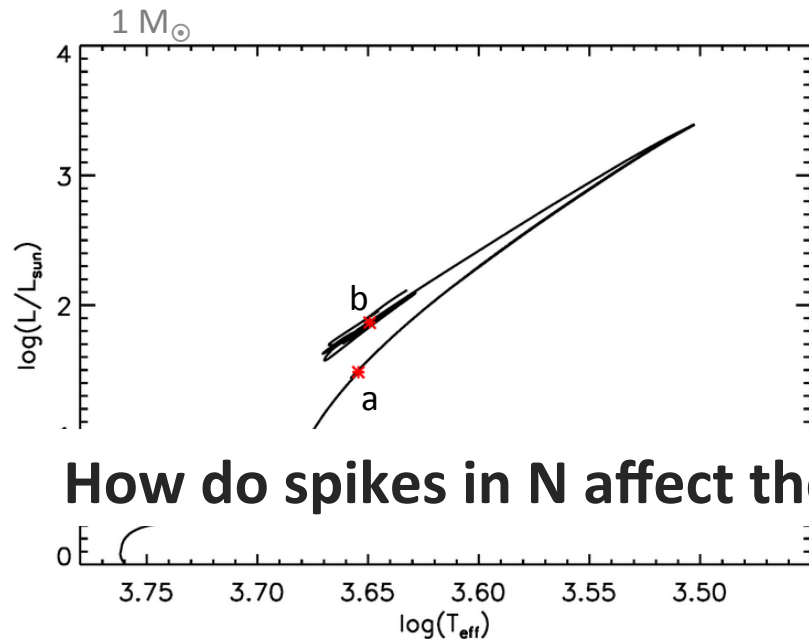
# Models under study



a – ASTEC  
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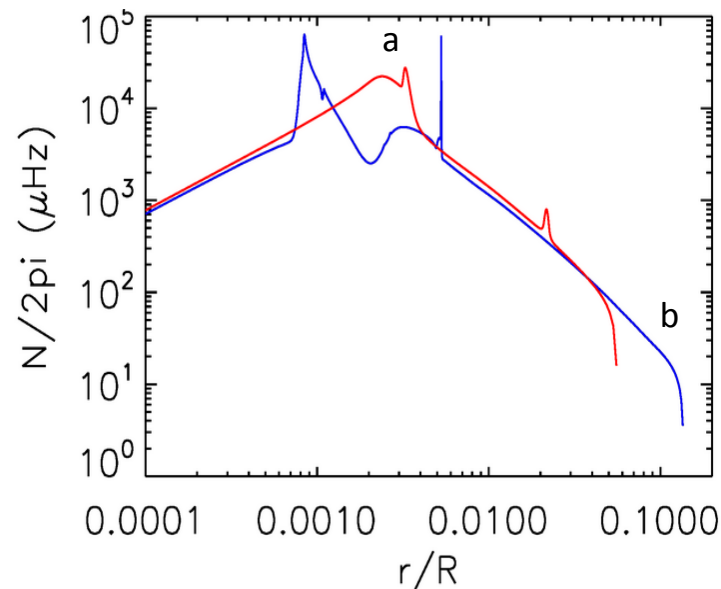
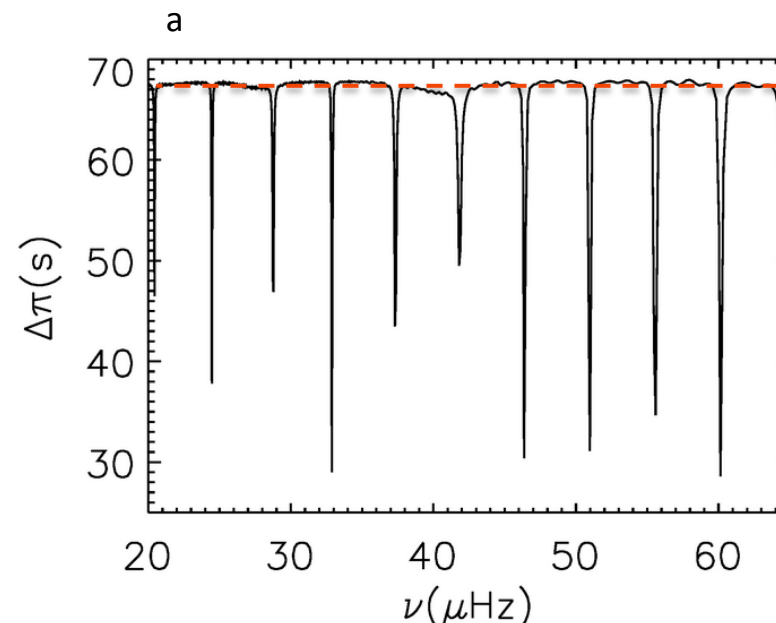


# Models under study



How do spikes in  $N$  affect the **period spacing** of the oscillations?

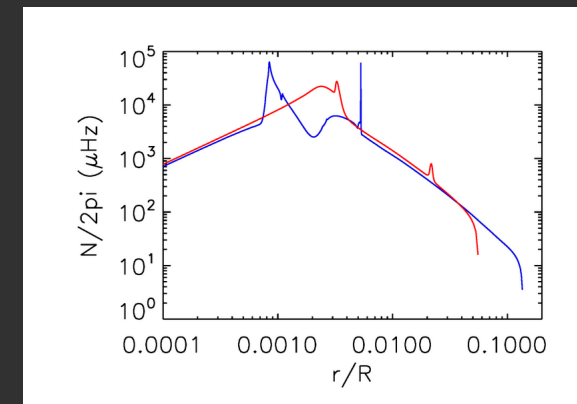
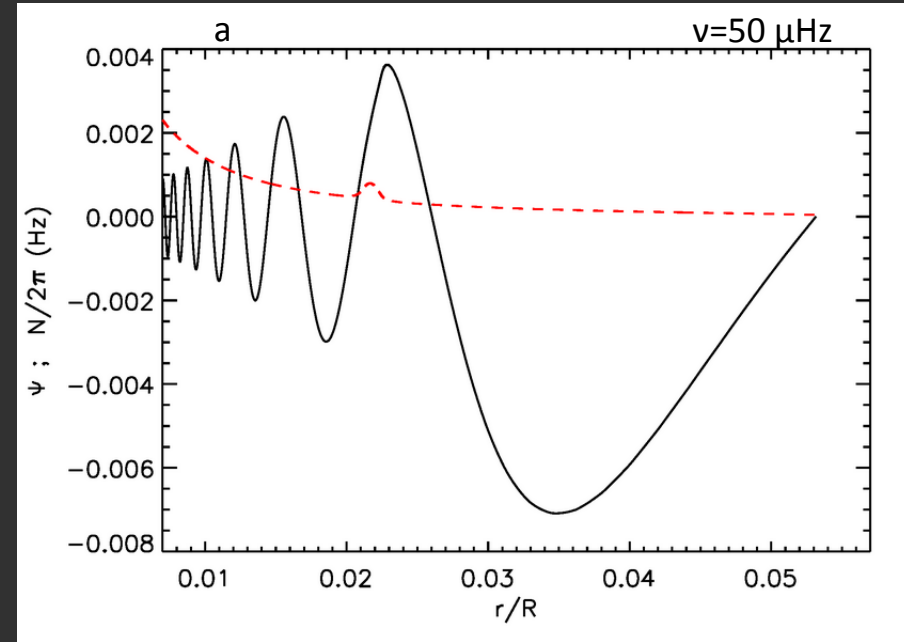
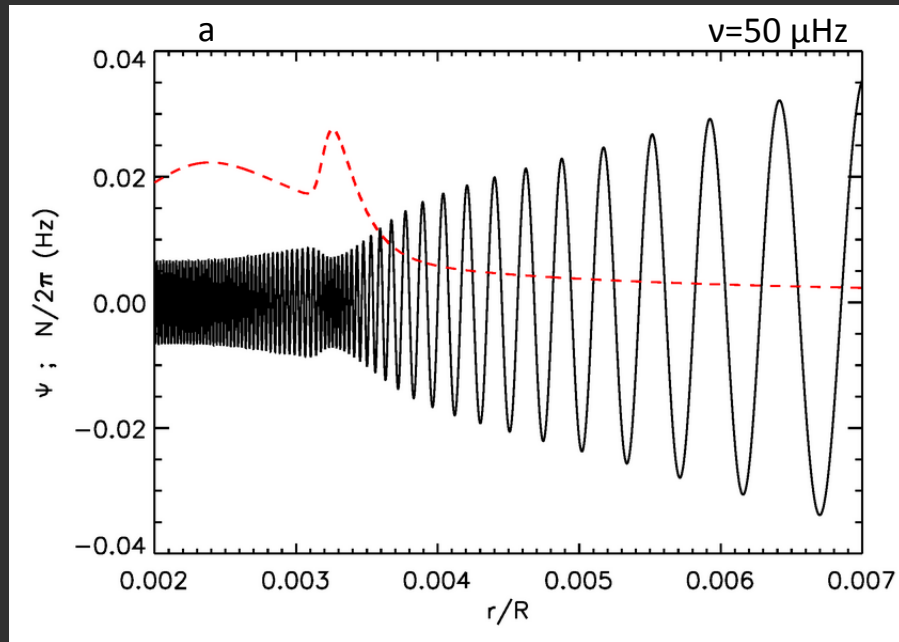
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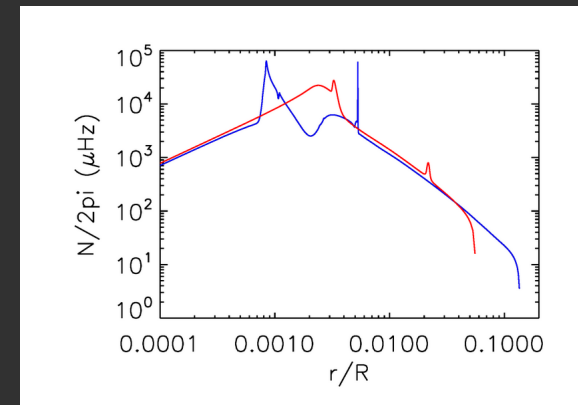
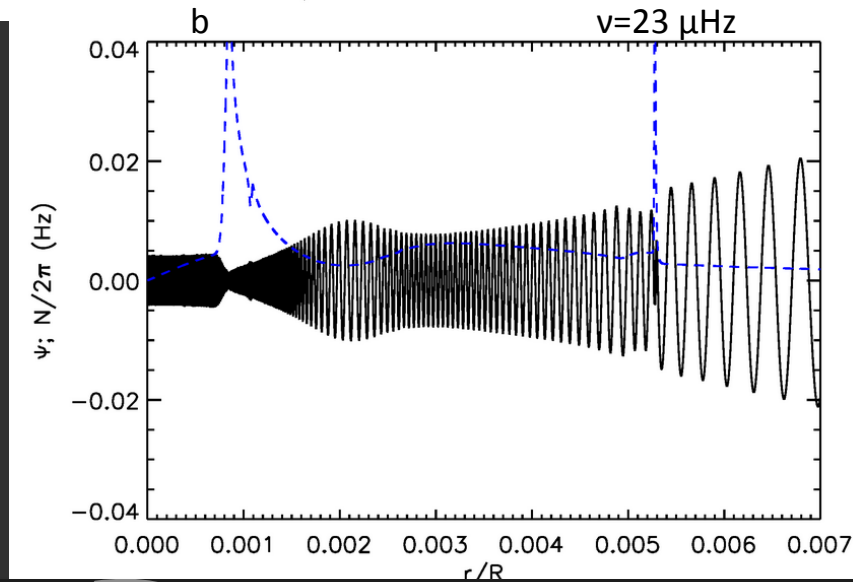
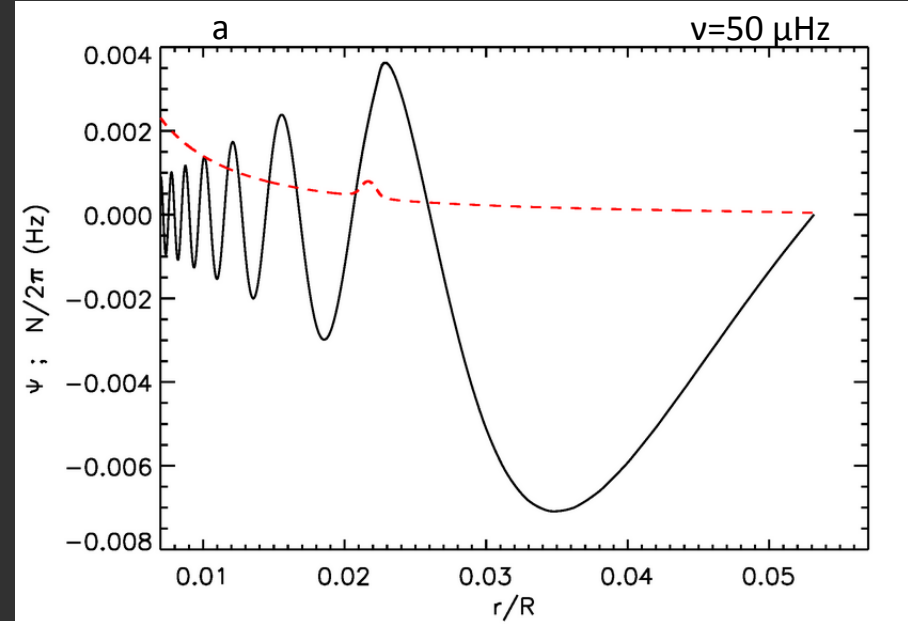
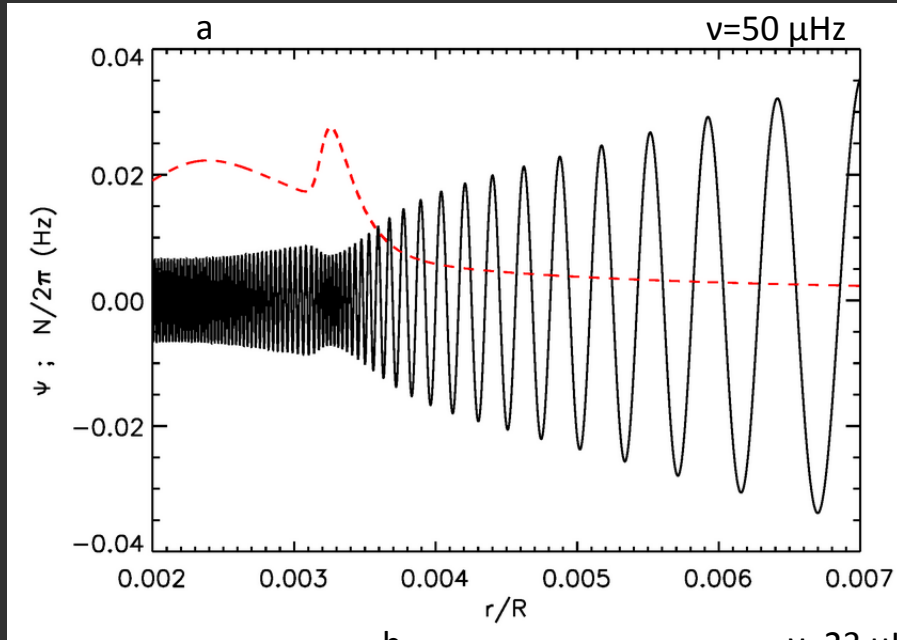
# Glitch or no Glitch ?



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# Pure g-modes (model a)

**Analytical toy-model:**

**Cowling approximation**

**Infinitely thin spike**

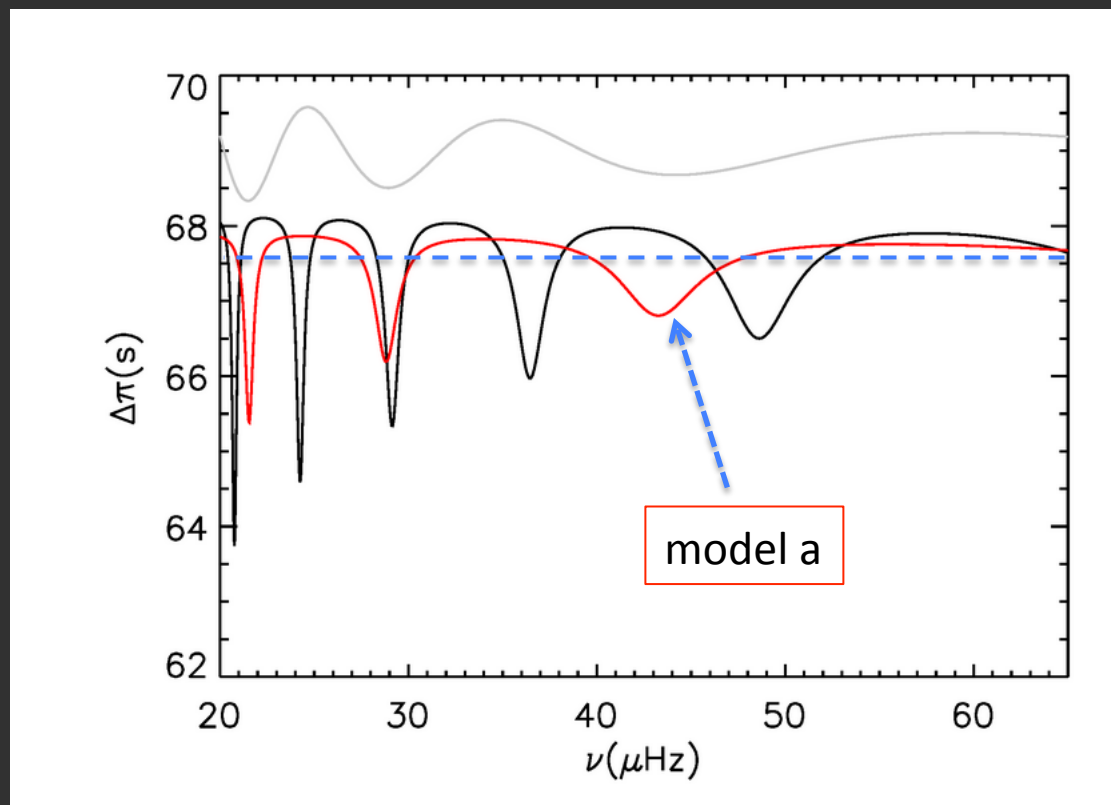
# Pure g-modes (model a)

Analytical toy-model:  
Cowling approximation  
Infinitely thin spike

$$\Delta\Pi \approx \frac{\Delta\Pi_{\text{as}}}{1 + \frac{\tilde{A}}{\omega_g B^2} \left[ \frac{\omega_g^*}{\omega} \cos\left(2\frac{\omega_g^*}{\omega}\right) + \left(1 - \frac{\tilde{A}\omega_g^*}{\omega^2}\right) \sin^2\left(\frac{\omega_g^*}{\omega} + \frac{\pi}{4}\right) \right]},$$

where  $\omega_g^* \equiv L \int_{r_*}^{r_2} \frac{N_0}{r} dr$  and  $B^2$  is given by,

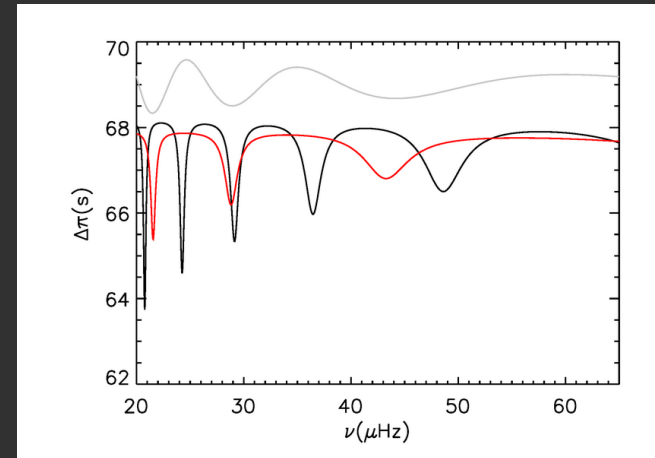
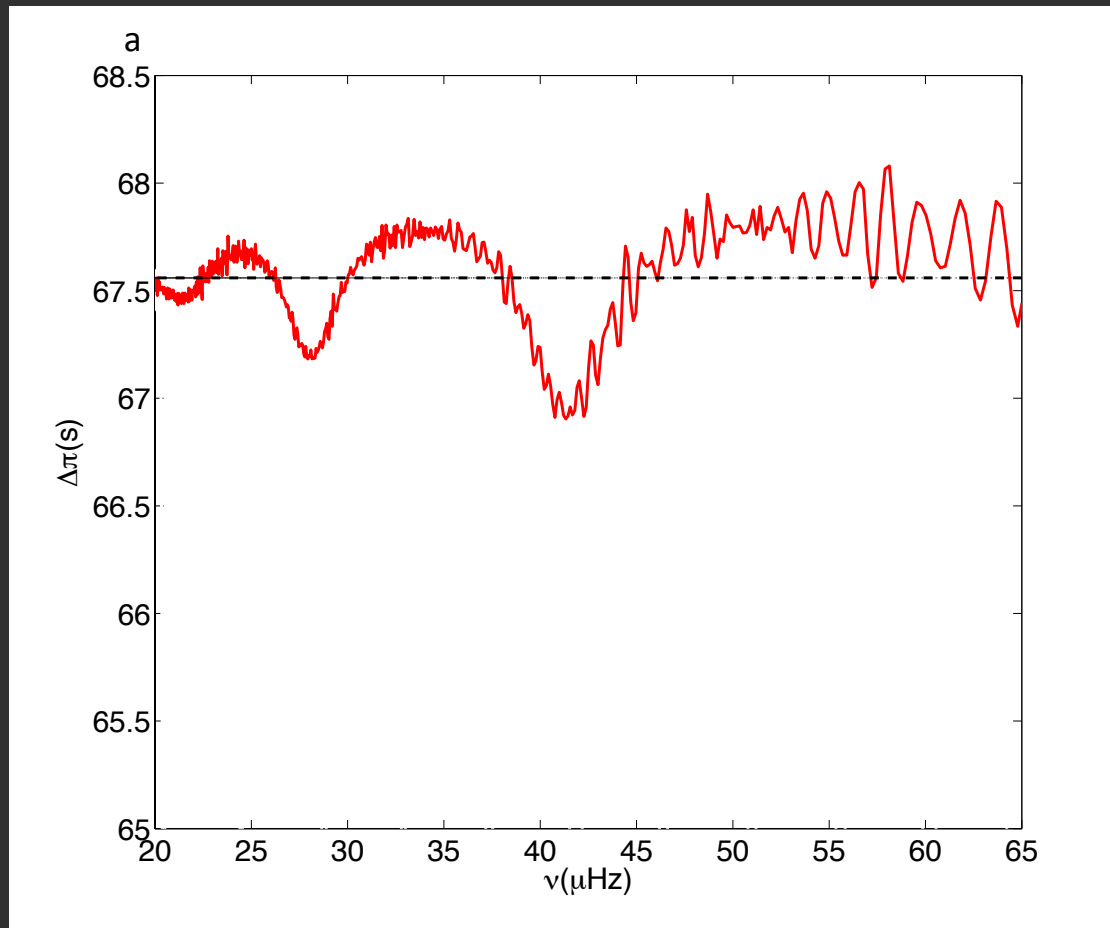
$$B^2 = \left[ 1 - \frac{\tilde{A}}{2\omega} \cos\left(2\frac{\omega_g^*}{\omega}\right) \right]^2 + \left[ \frac{\tilde{A}}{\omega} \sin^2\left(\frac{\omega_g^*}{\omega} + \frac{\pi}{4}\right) \right]^2.$$



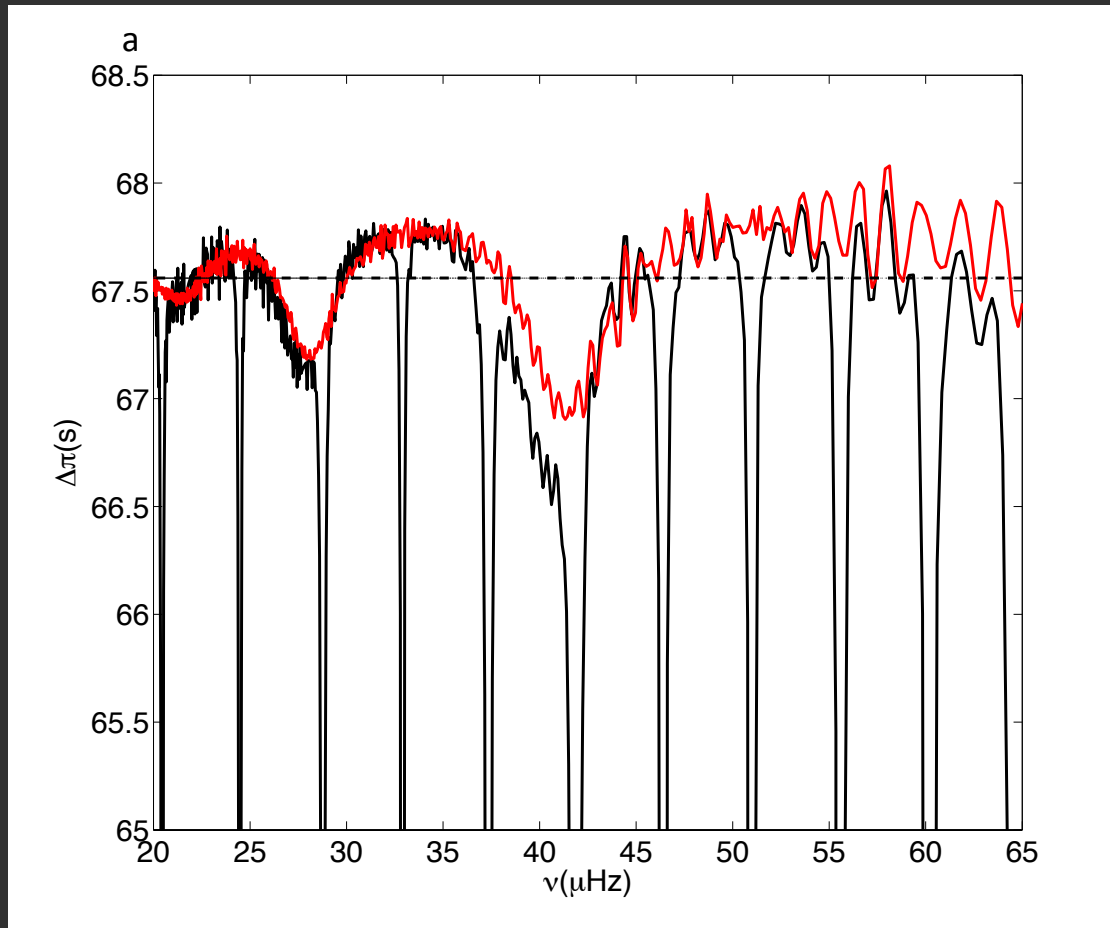


# Pure g-modes (model a)

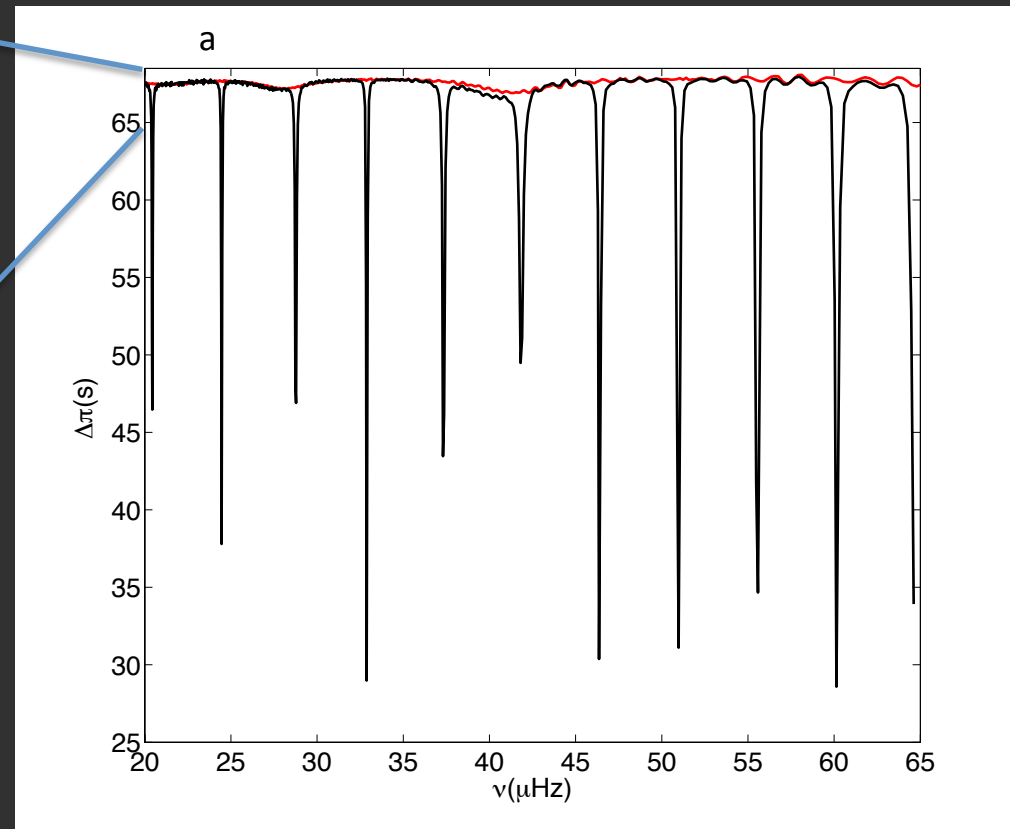
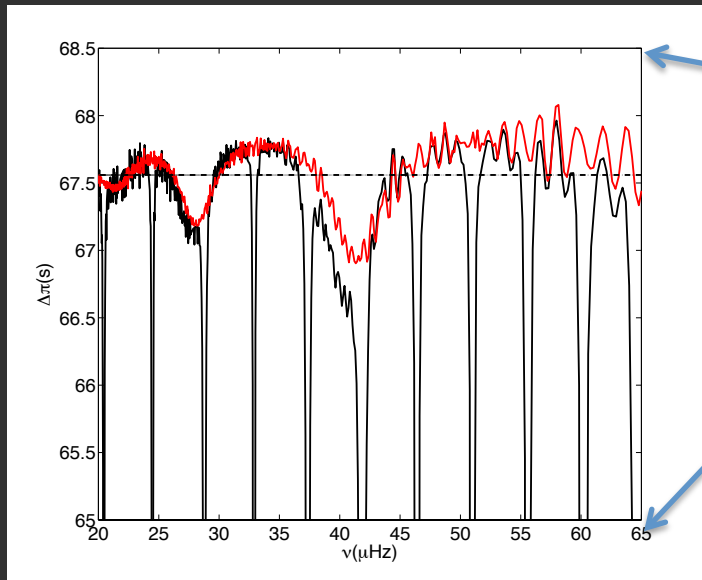
## Numerical solution



# Full numerical solution (model a)



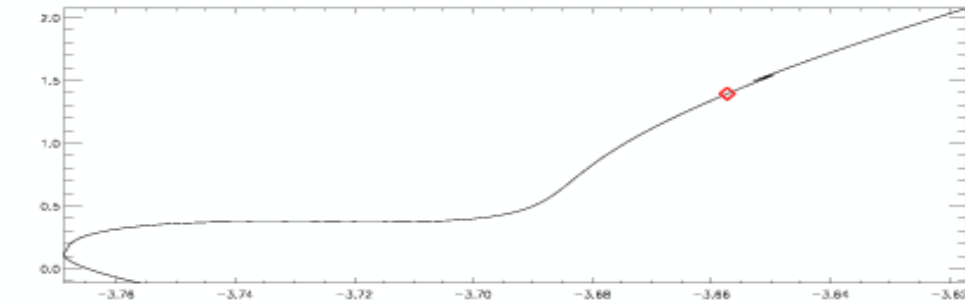
# Full numerical solution (model a)



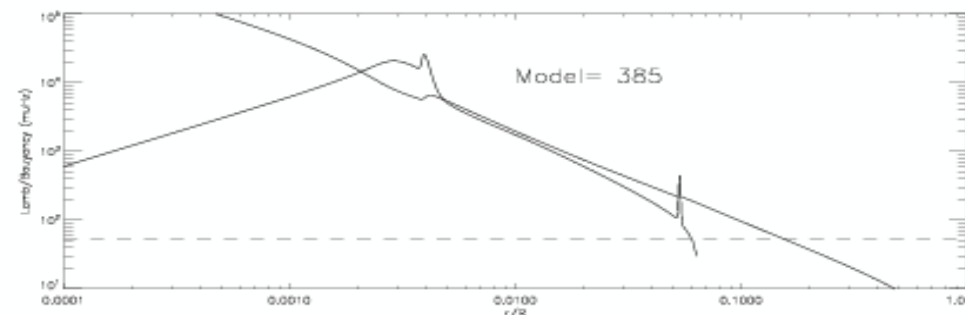
The signature of the glitch in the period spacing is a change in the depth of the dips in the period spacing.

# Stello KASC6

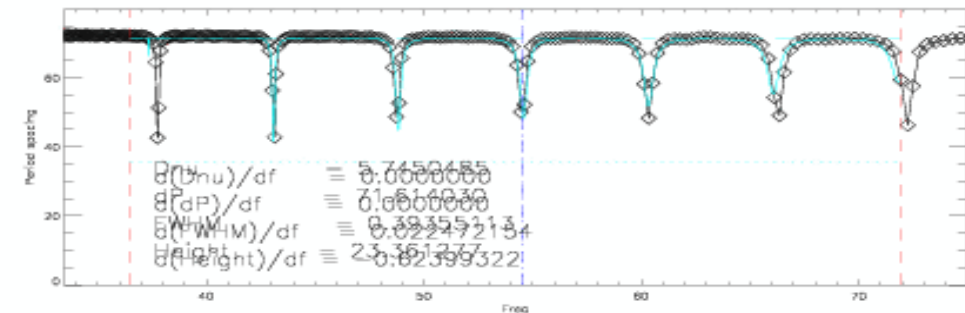
H-R Diagram



Propagation Diagram



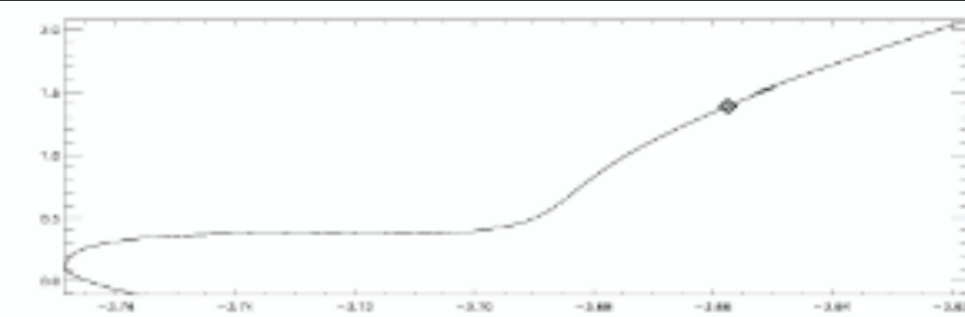
$\Delta P$  vs. Freq.



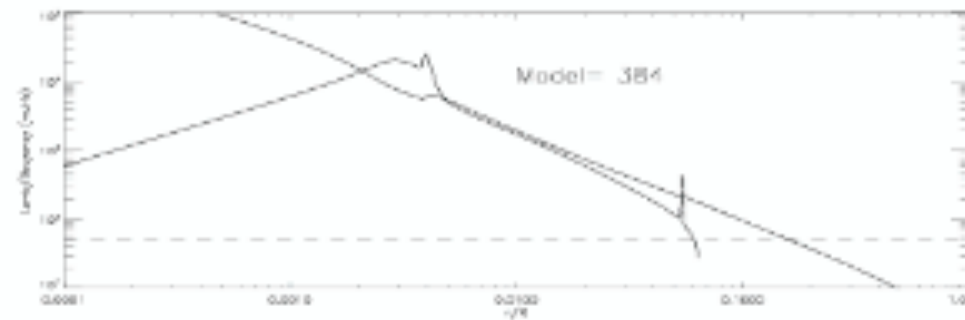
ASTEC models

# Stello KASC6

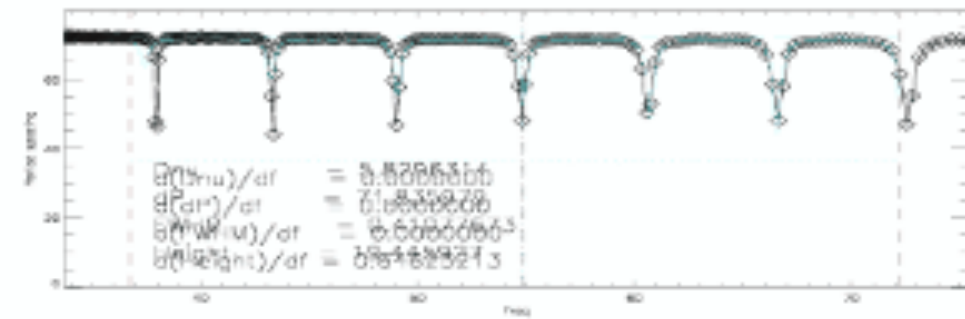
H-R Diagram



Propagation Diagram

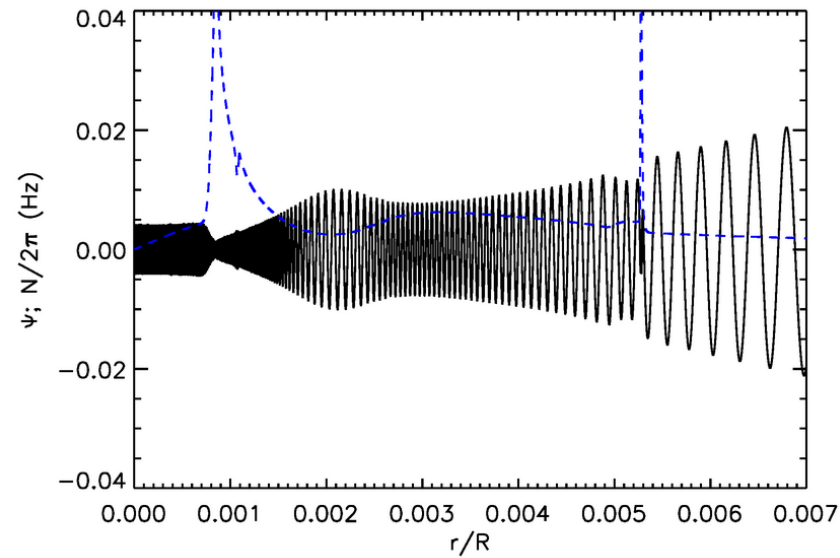
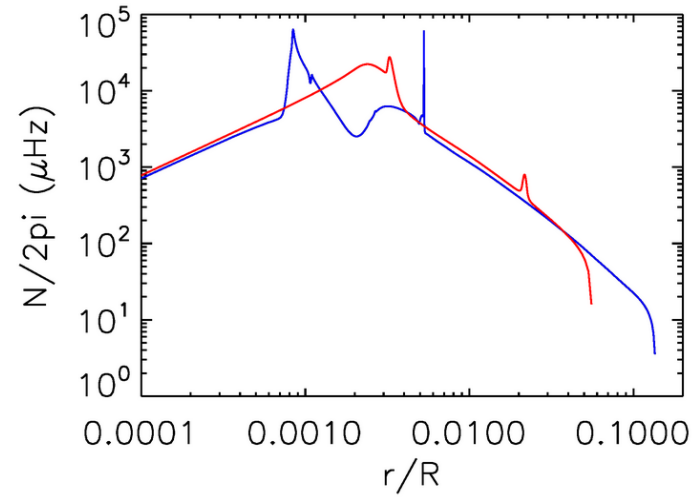
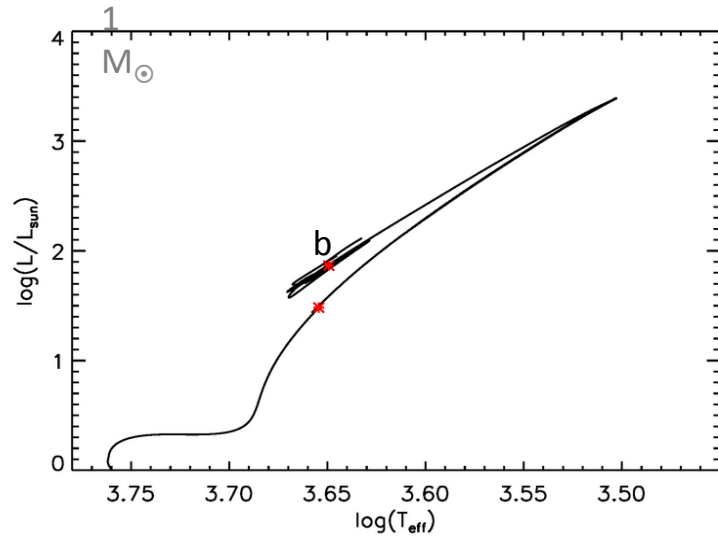


$\Delta P$  vs. Freq.

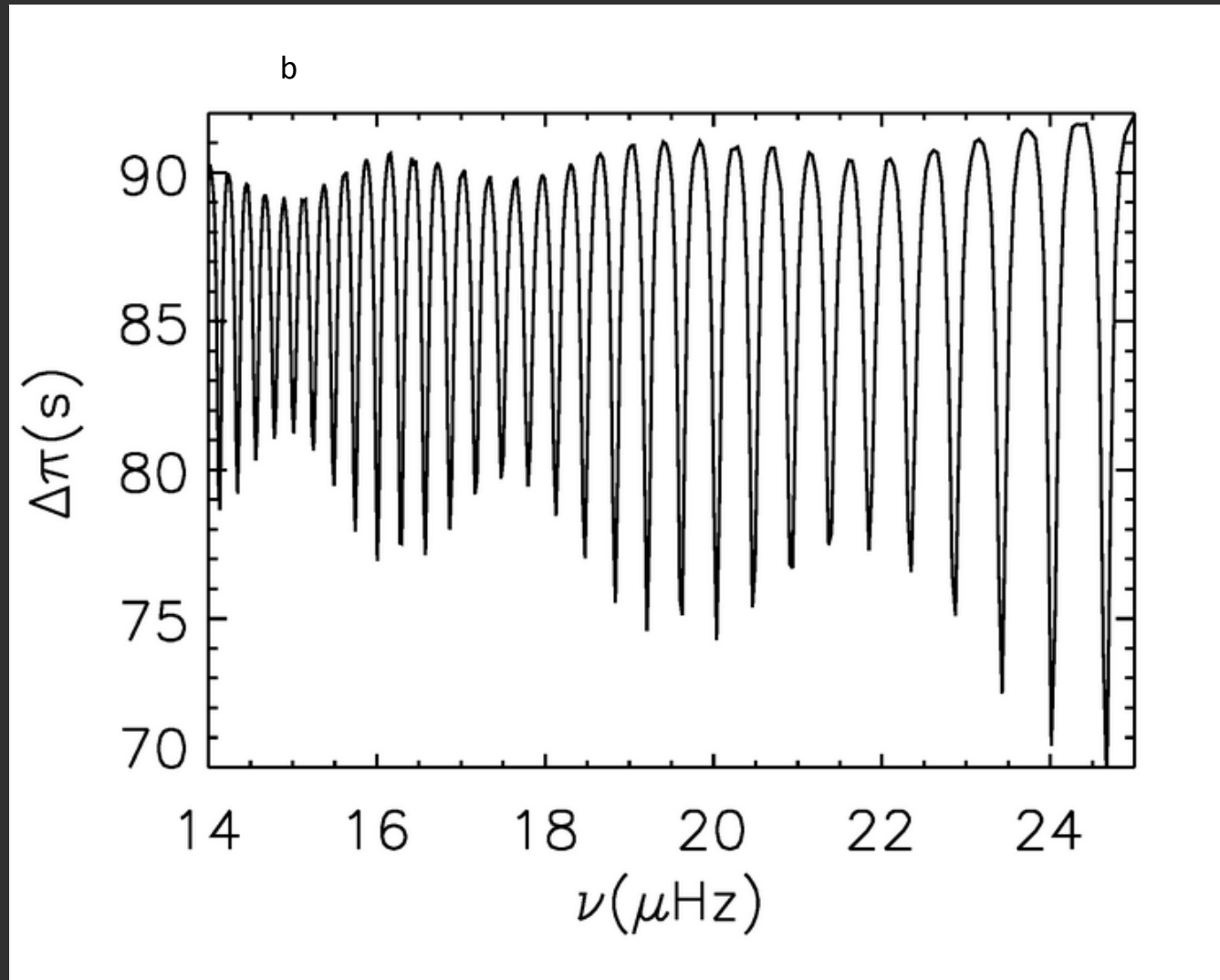


ASTEC models

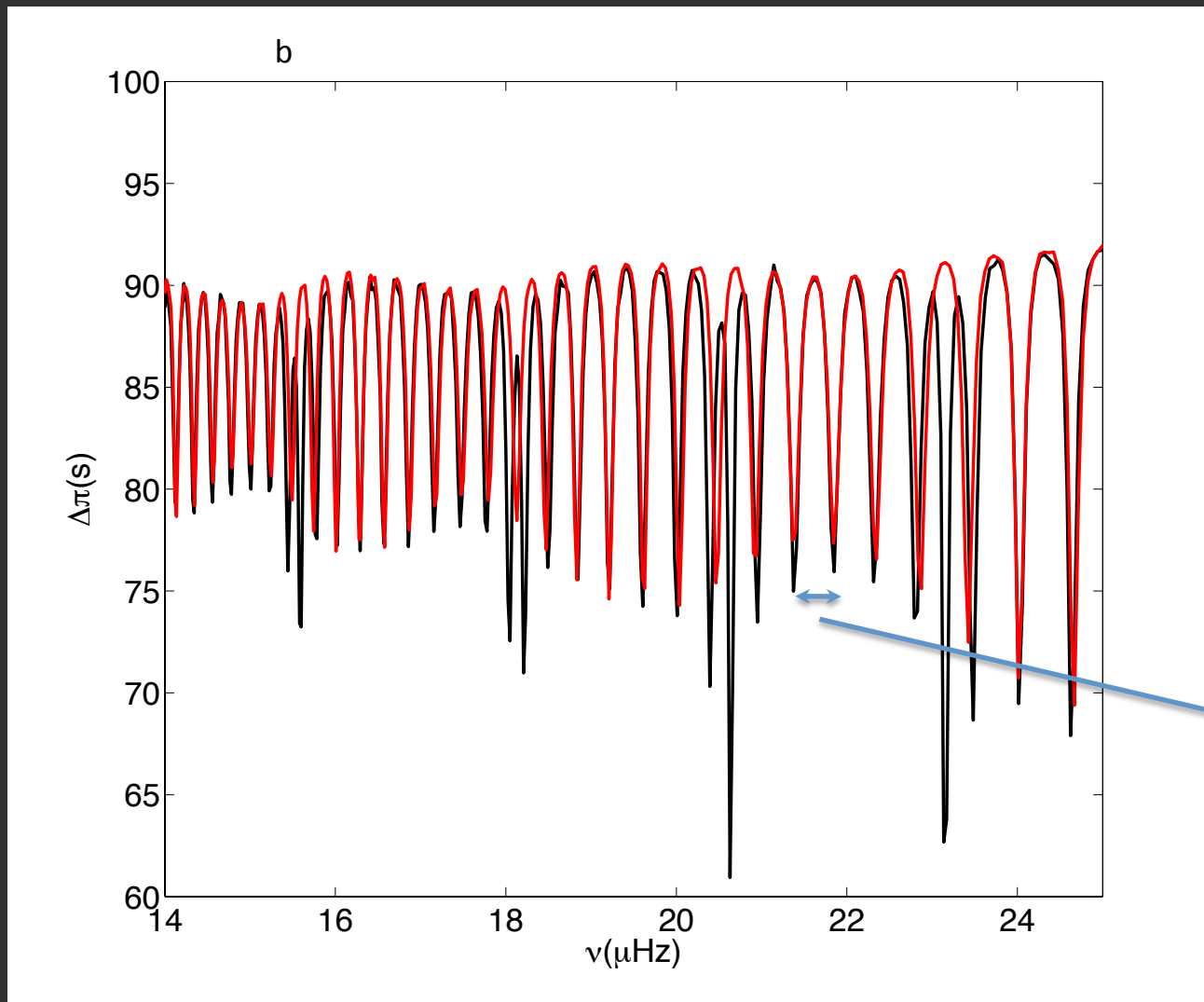
# (model b)



# Pure g-modes or full solution? (model b)



# Including coupling with p-modes (model b)

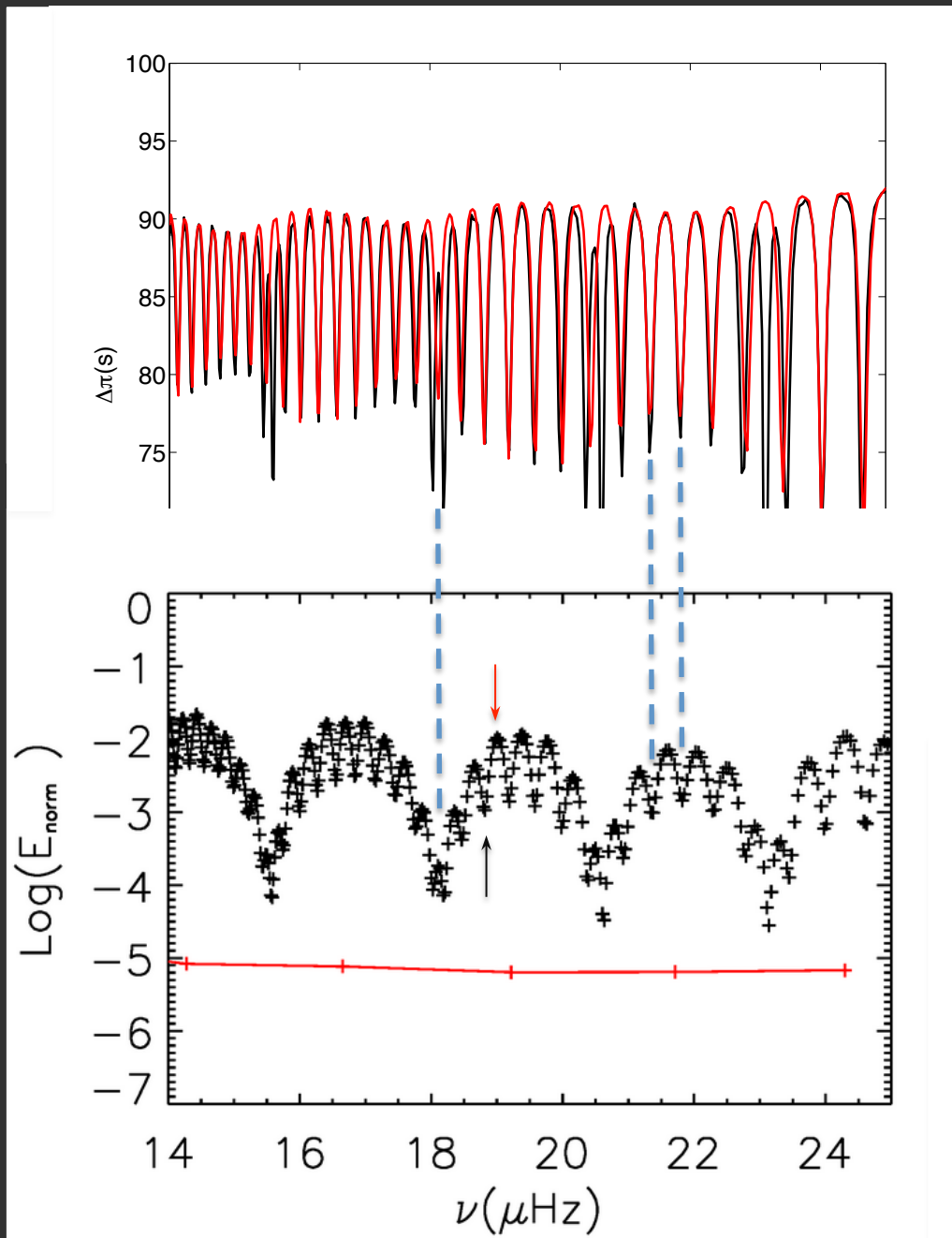


Measure  
position of  
the glitch

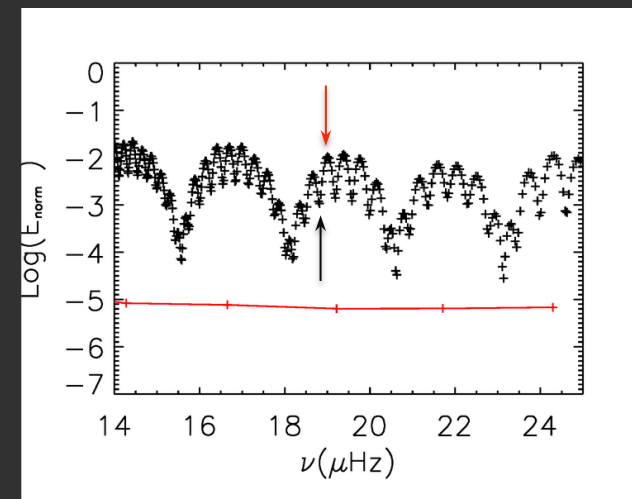
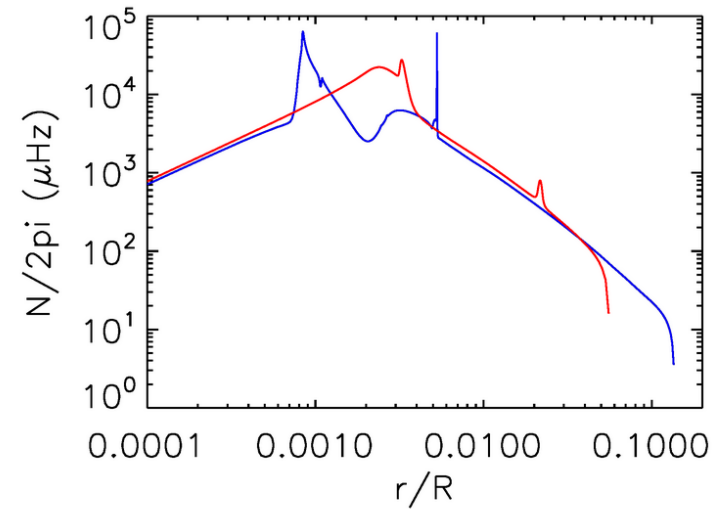
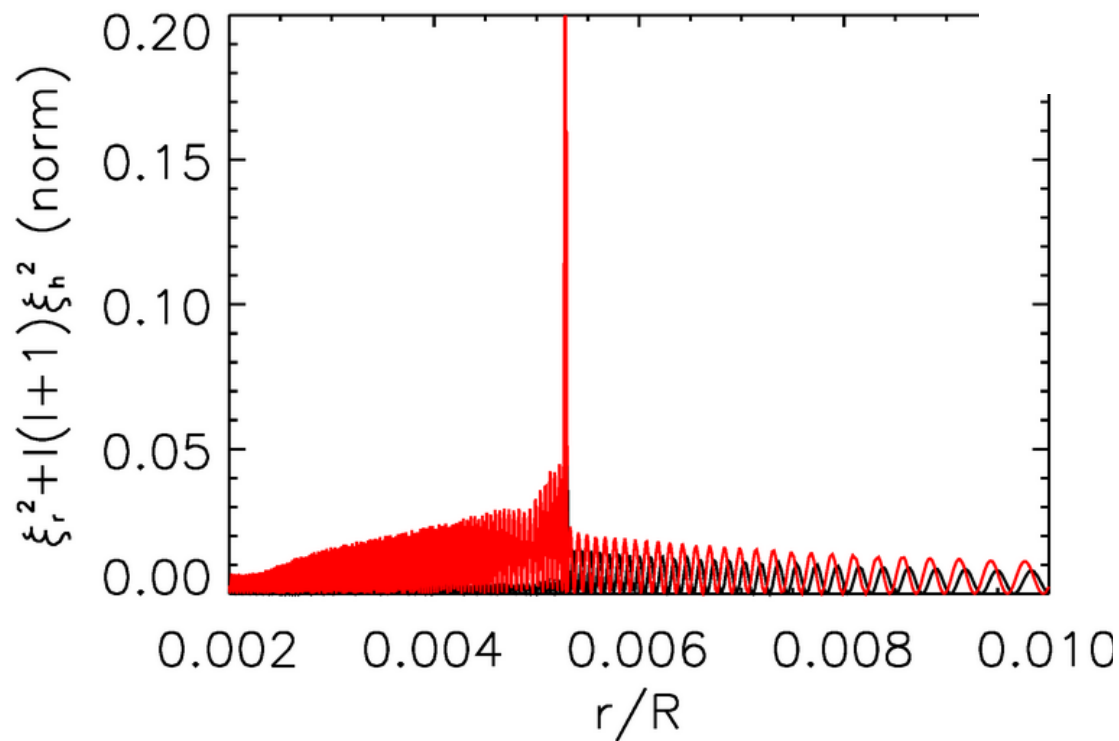
↓  
Position of  
H-shell



# Including coupling with p-modes (model b)



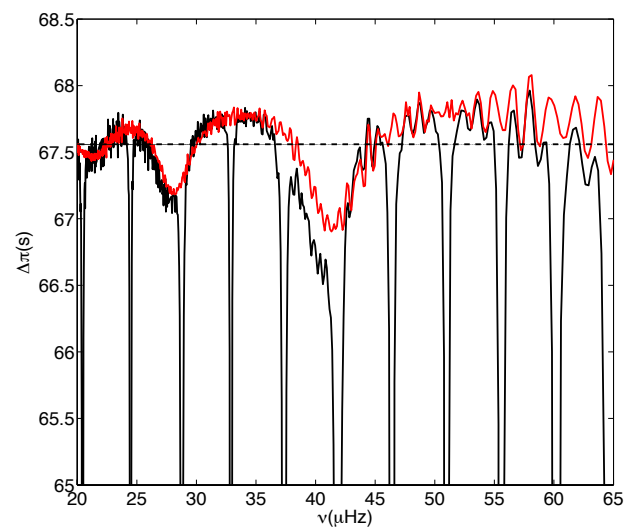
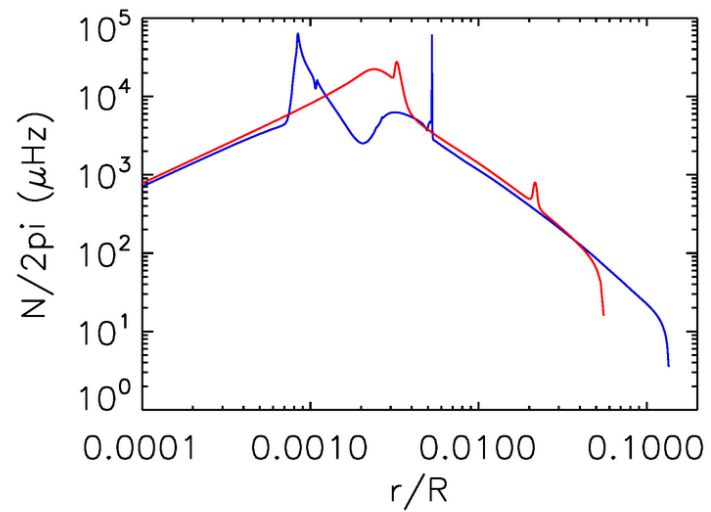
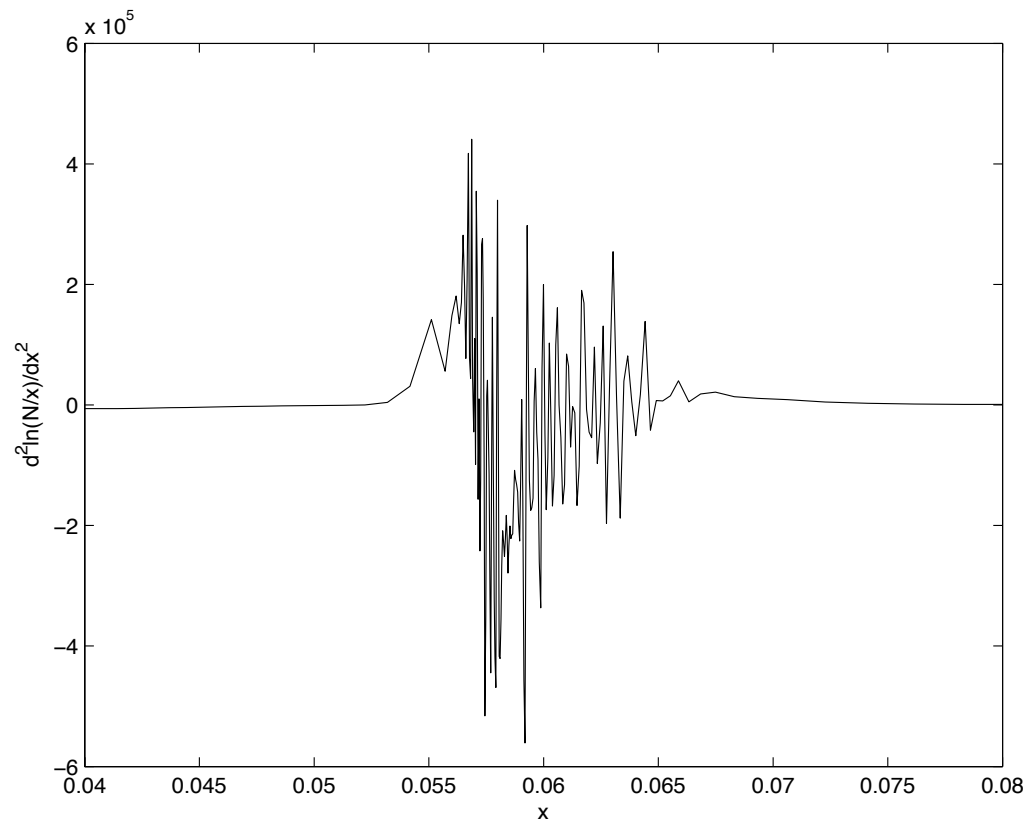
# Including coupling with p-modes (model b)



# Conclusions

- Models predict that **some** spikes in the Buoyancy frequency can affect the period spacing in red giant stars
- We understand the signatures left by these spikes
- If found in present or future space-based data, these signatures may allow us to:
  - Identify very specific evolutionary phases (e.g., Luminosity bump)
  - Measure the “position” of the H-shell burning layer





# Pure g-modes (model a)

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Cowling approximation  
Infinitely thin spike

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where  $\omega_g^* \equiv L \int_{r_*}^{r_2} \frac{N_0}{r} dr$  and  $B^2$  is given by,

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