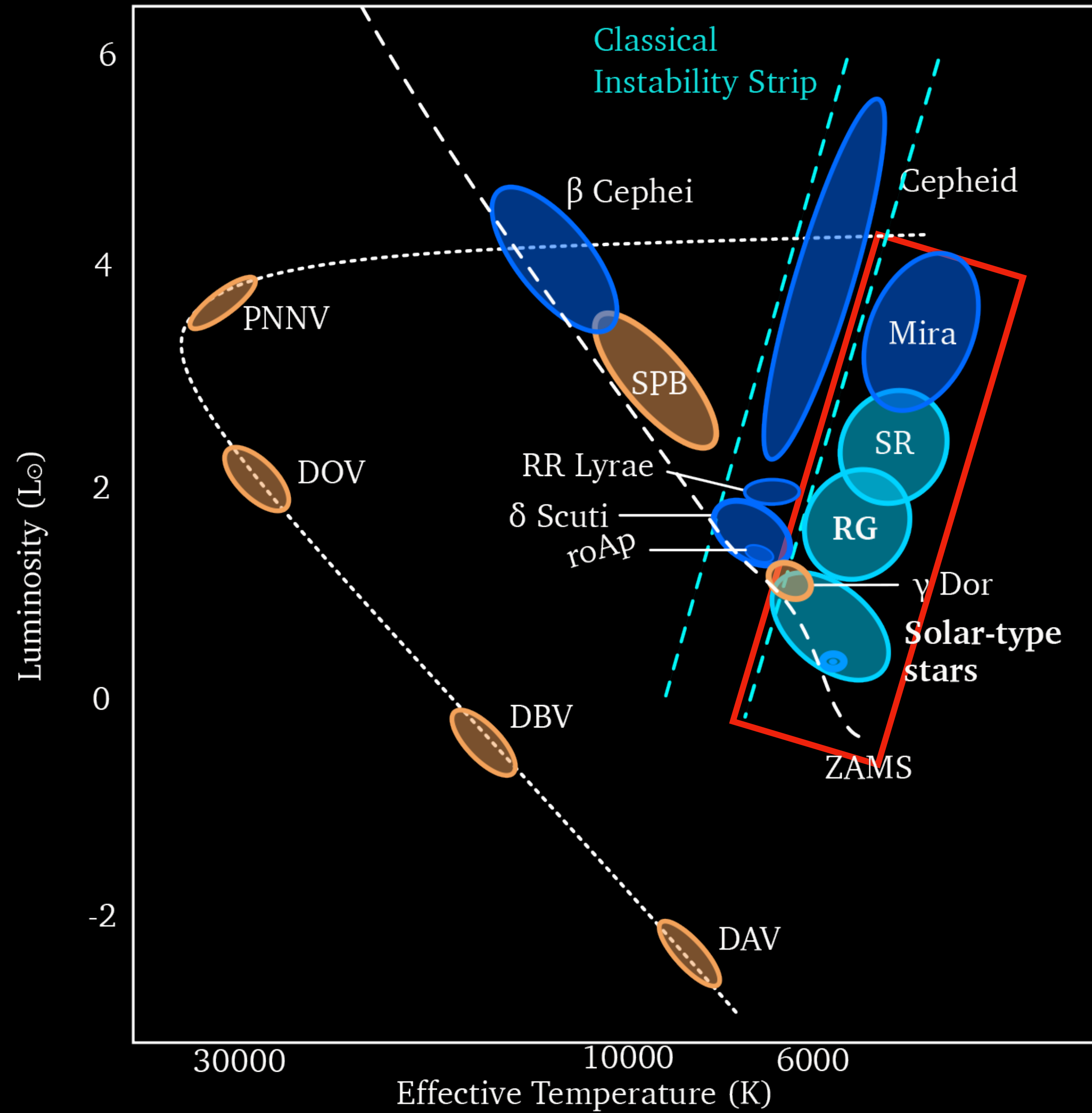


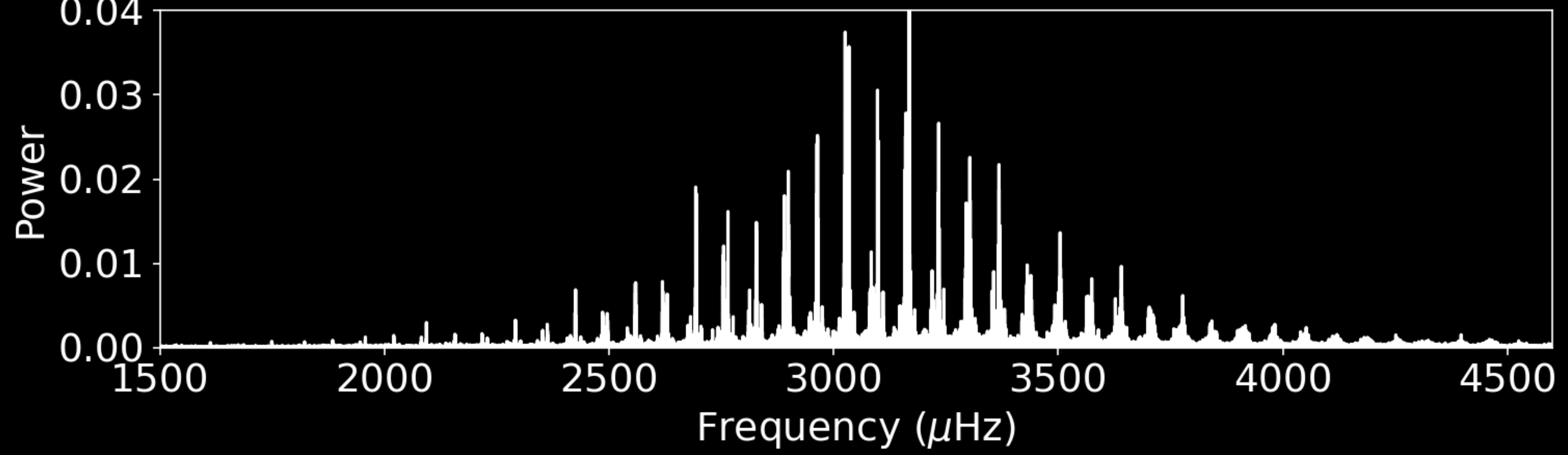
Decoupling mixed modes Stretched Frequency Recovers Pure P-modes

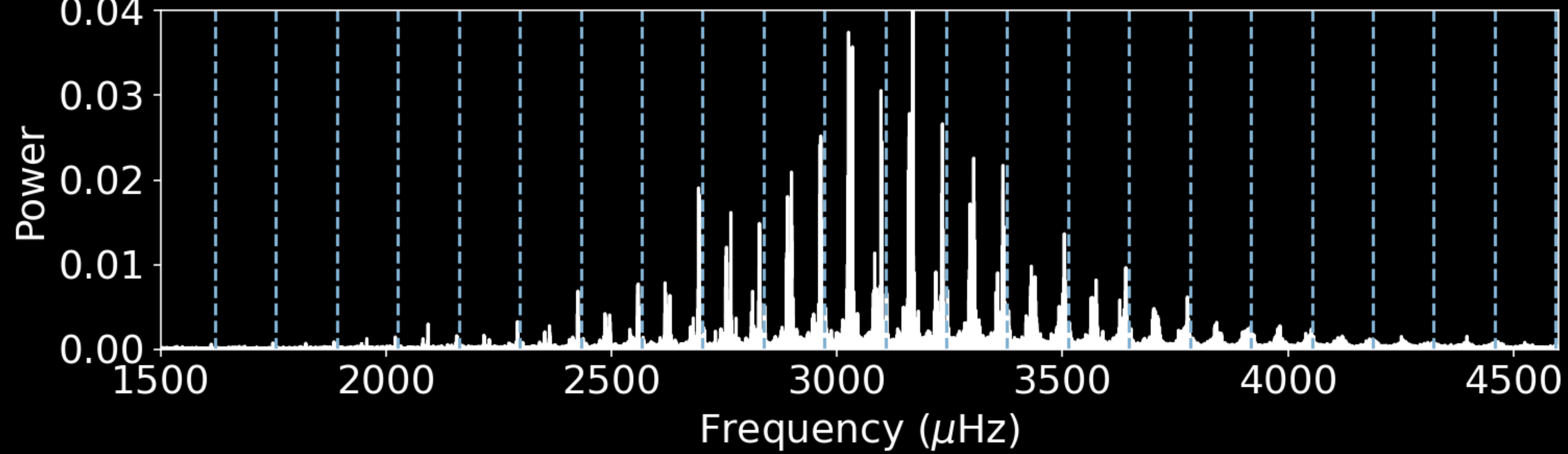
Yaguang Li, Joel Ong, Daniel Huber, Jennifer van Saders

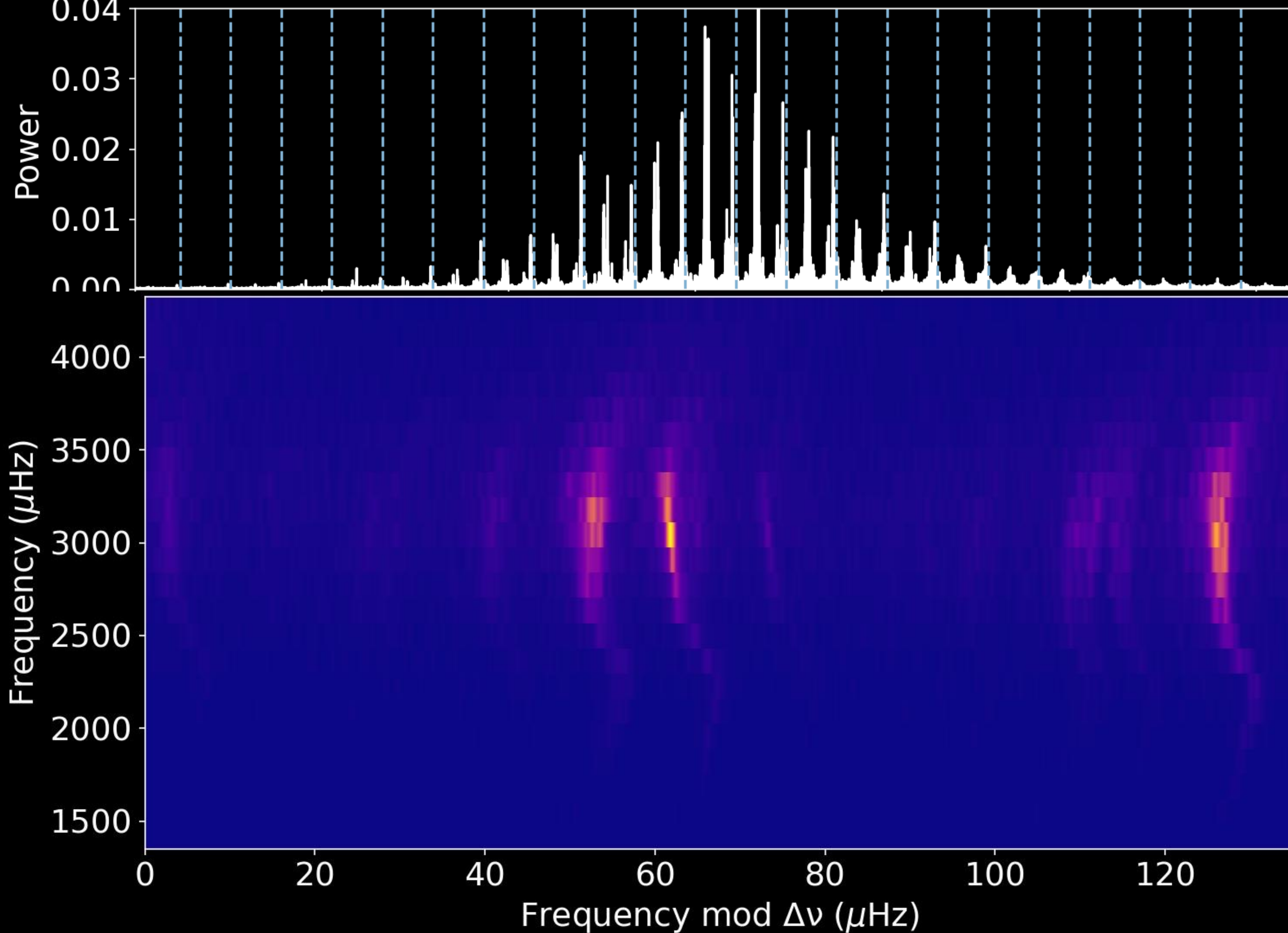
University of Hawaii

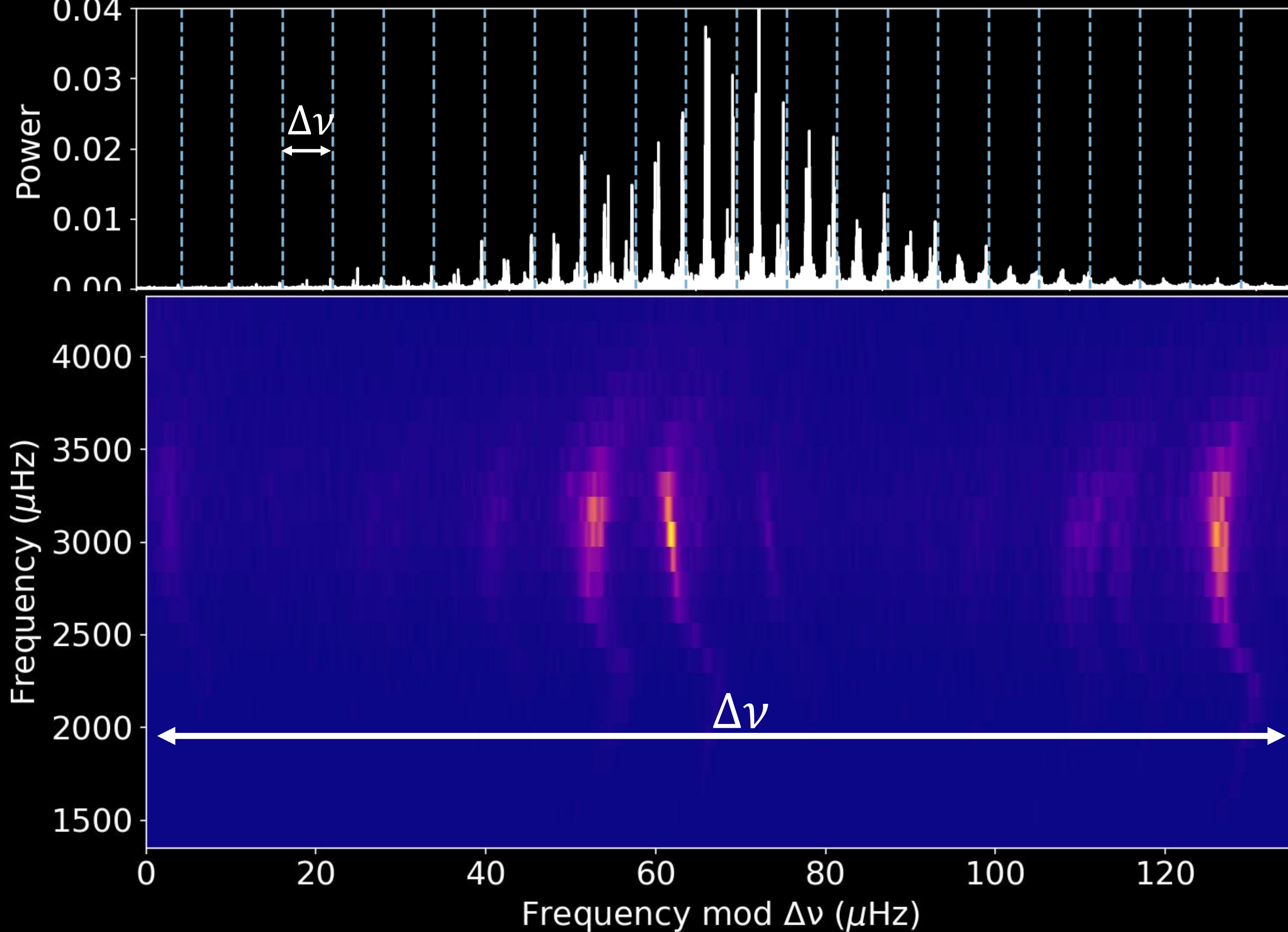
Asteroseismic H-R Diagram

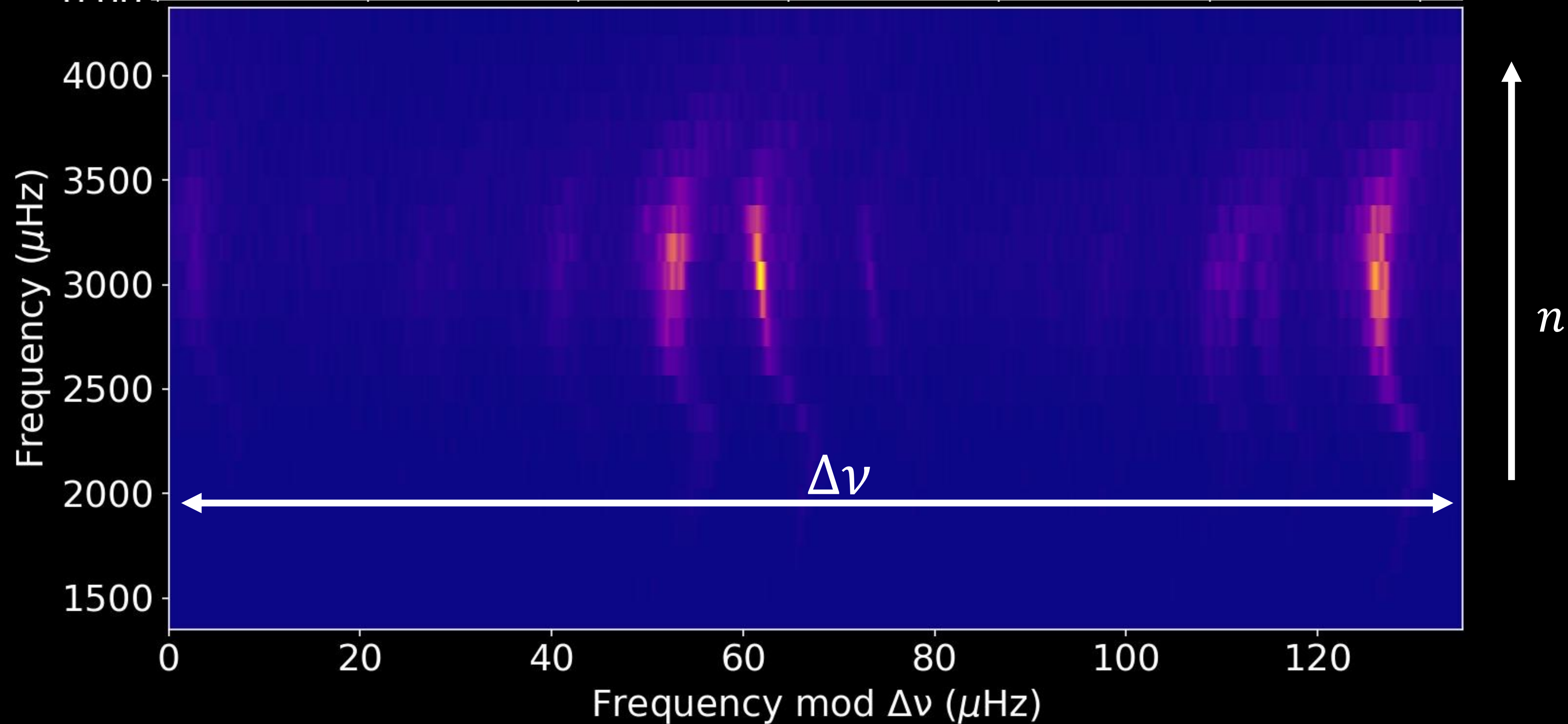
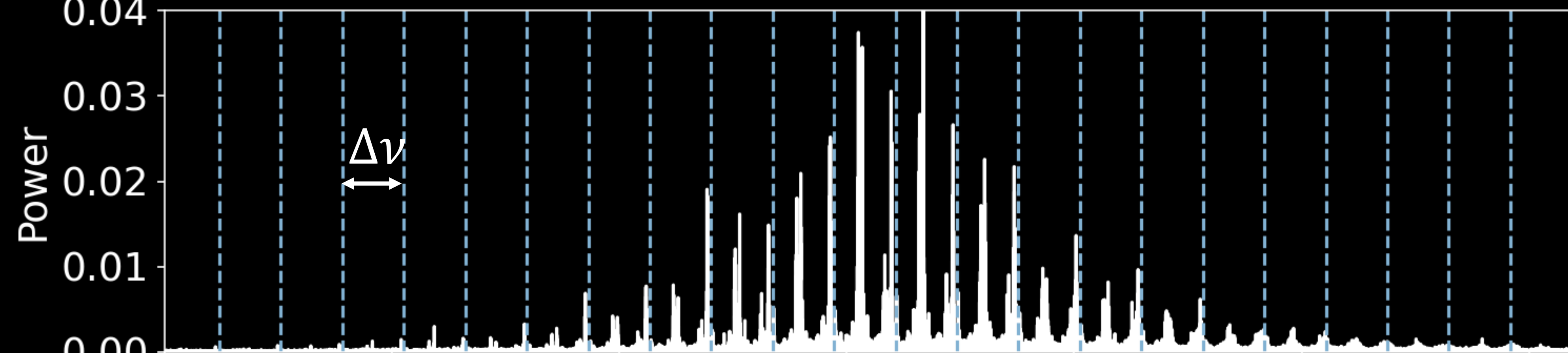


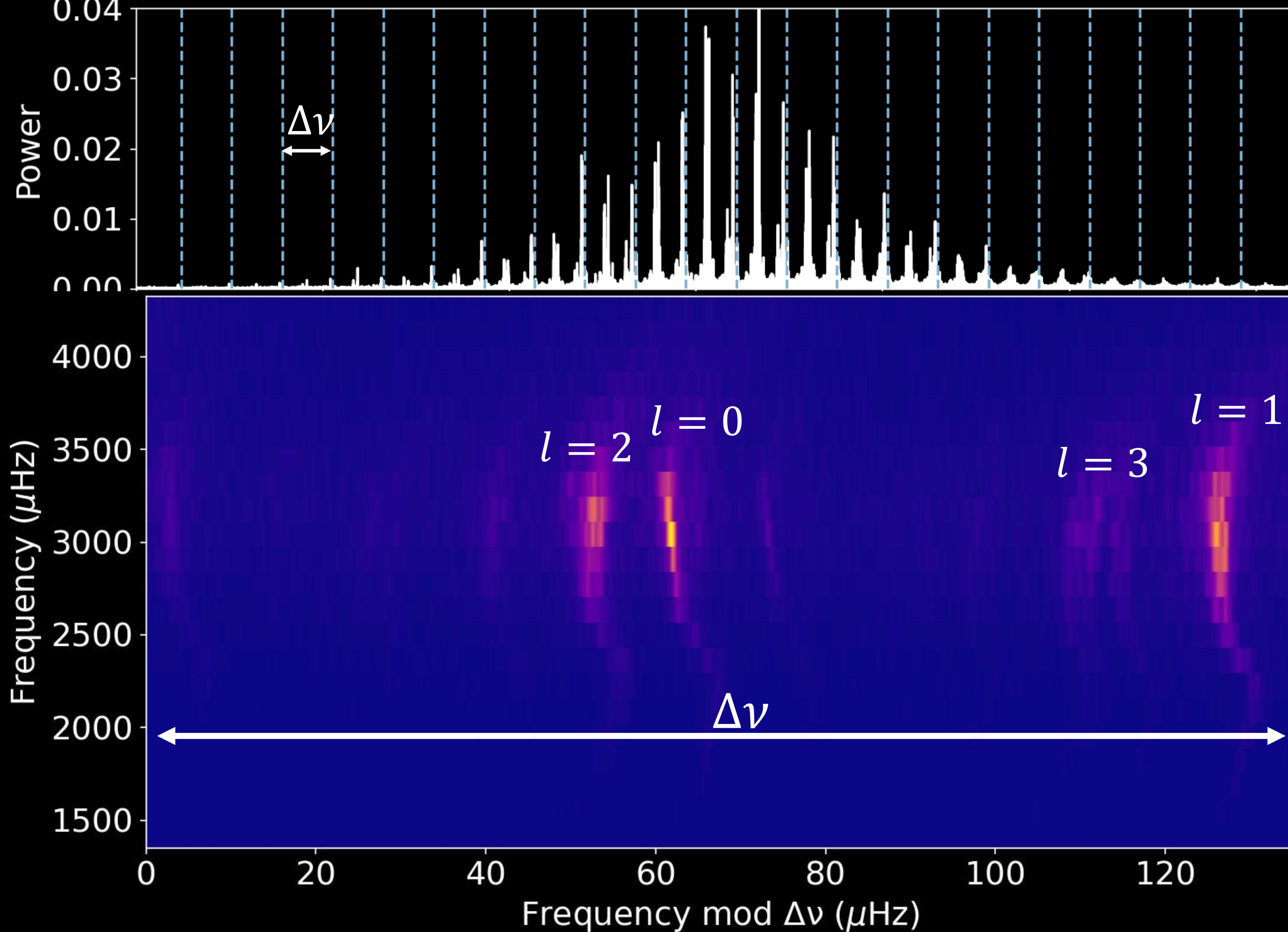




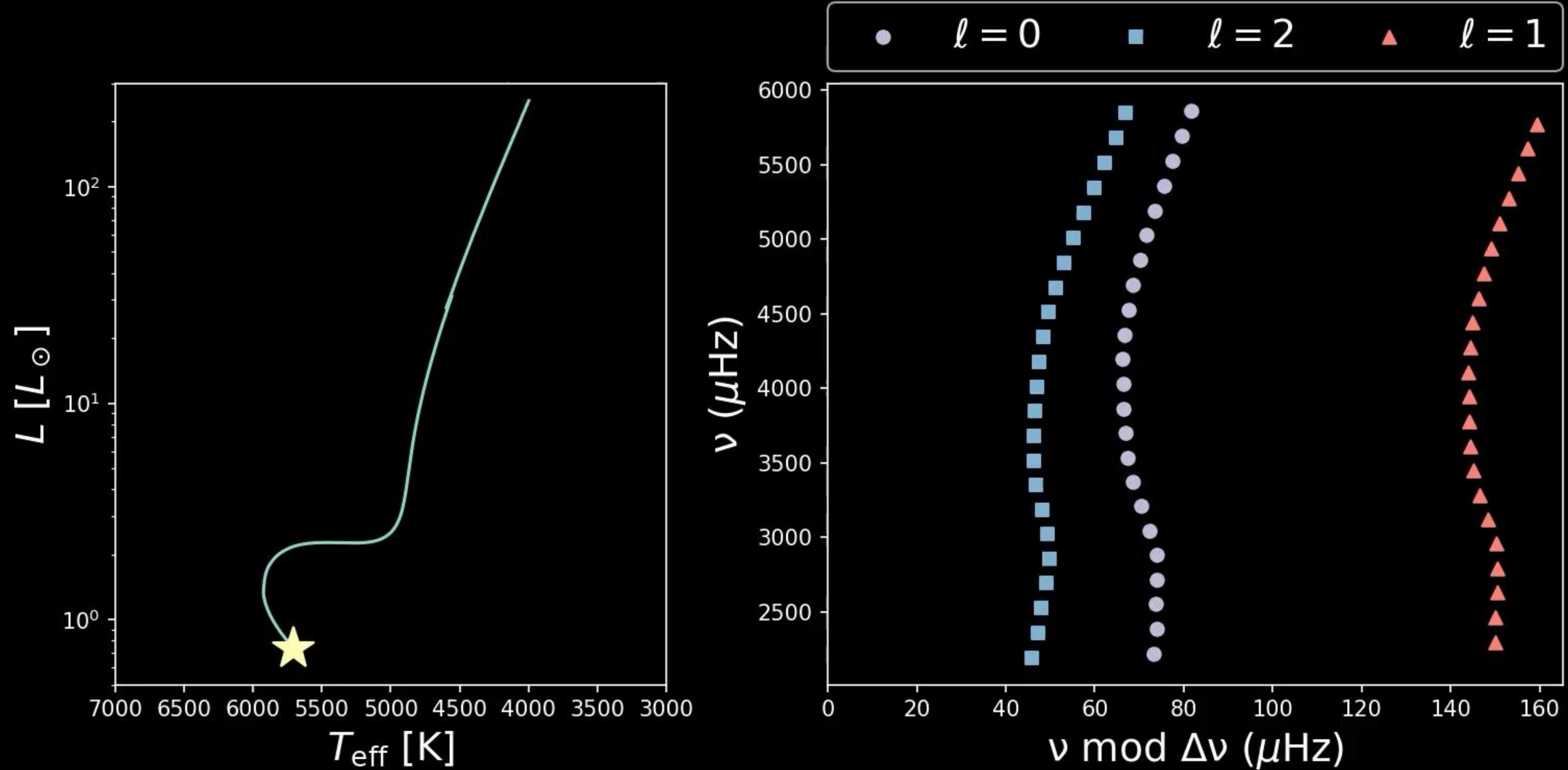




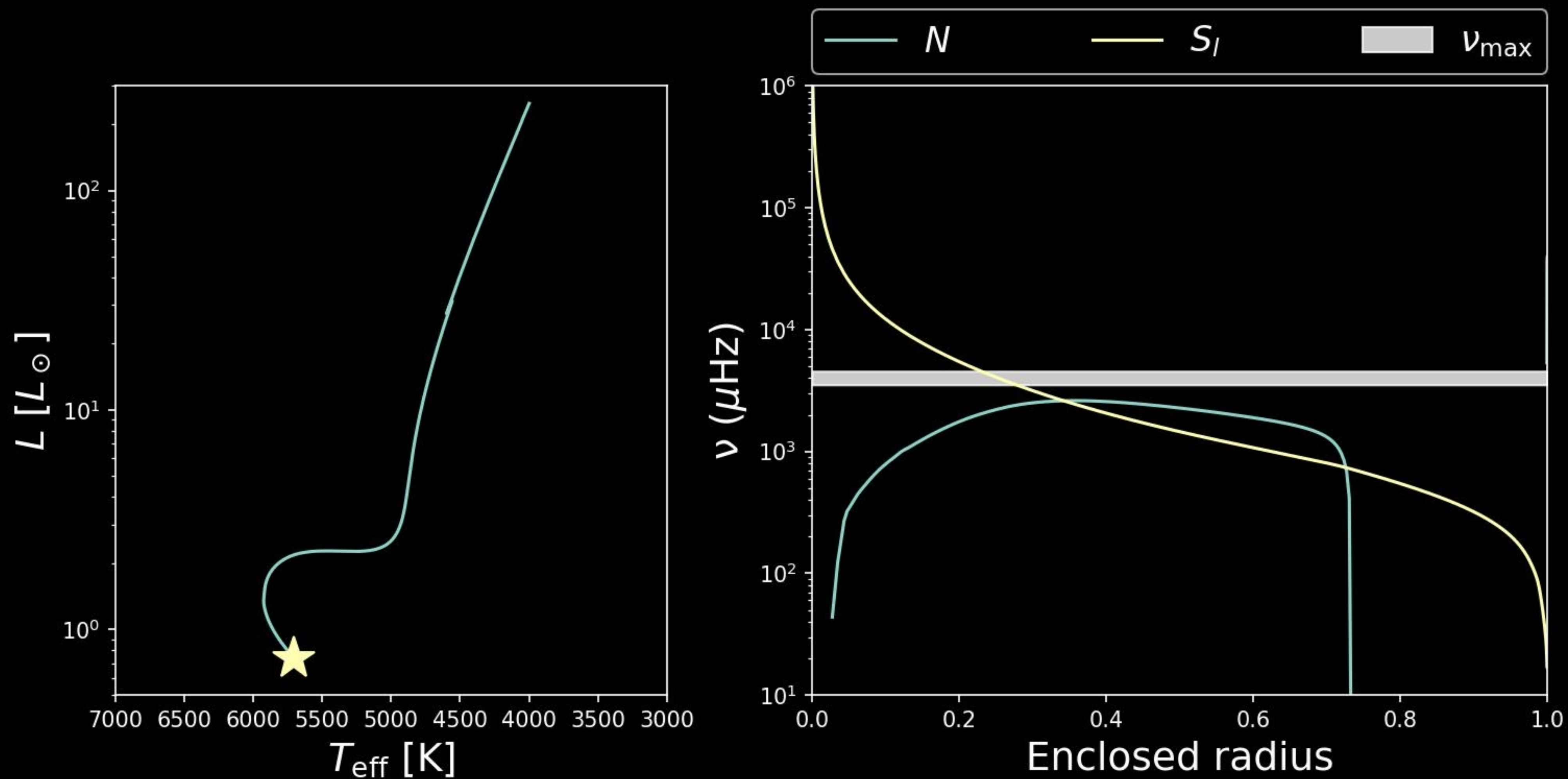




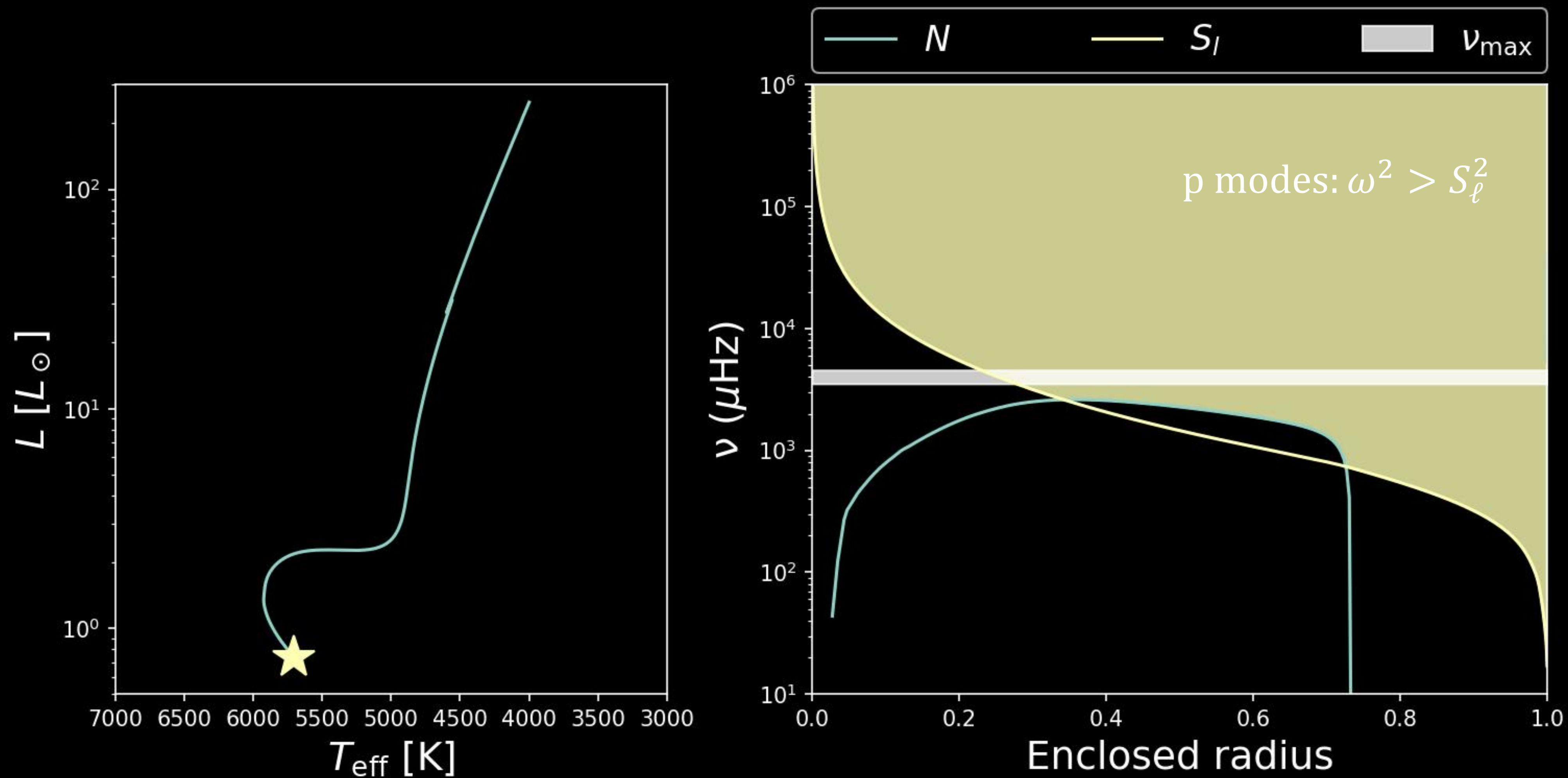
Stellar frequency evolution



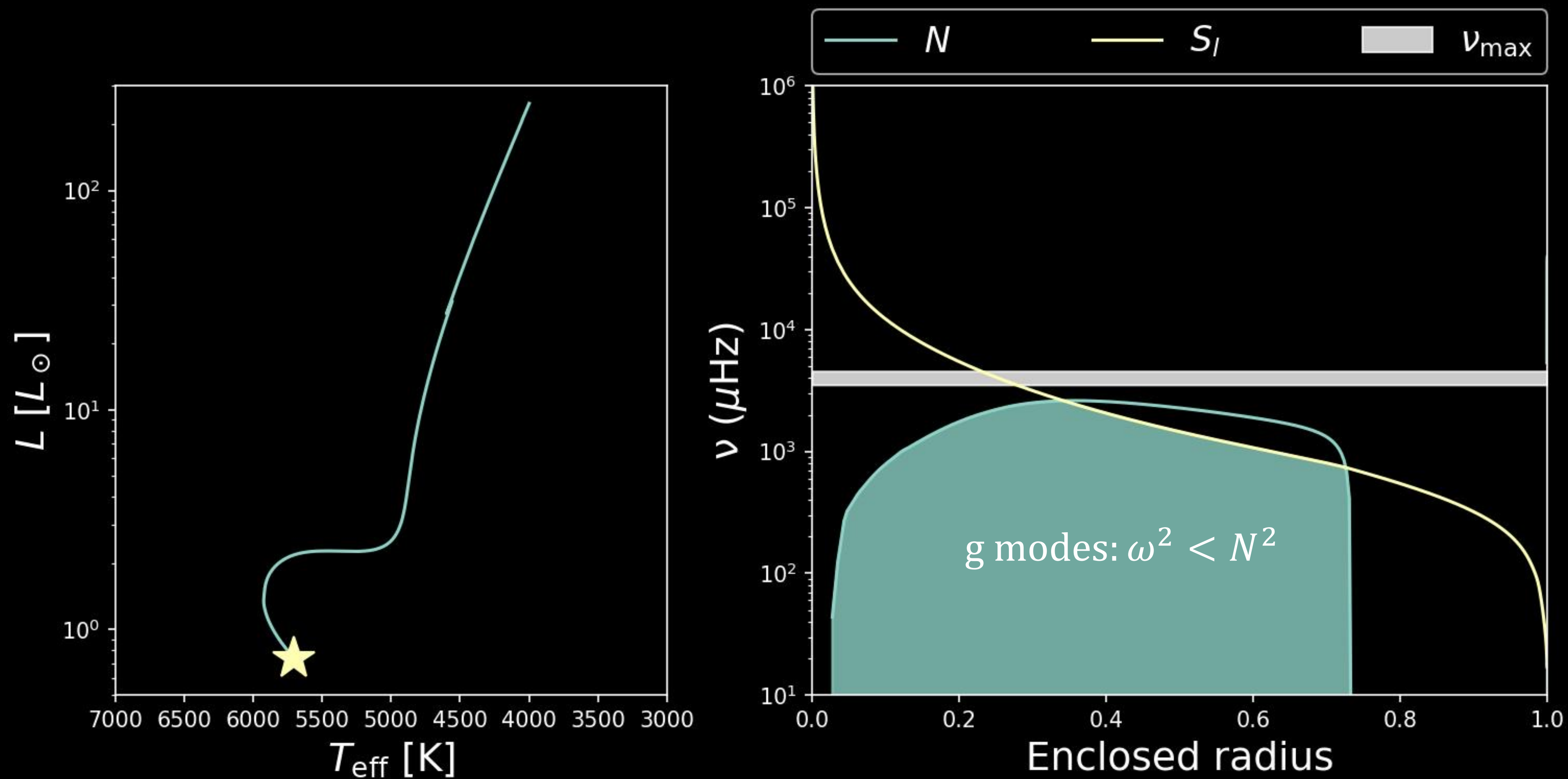
Propagation diagram



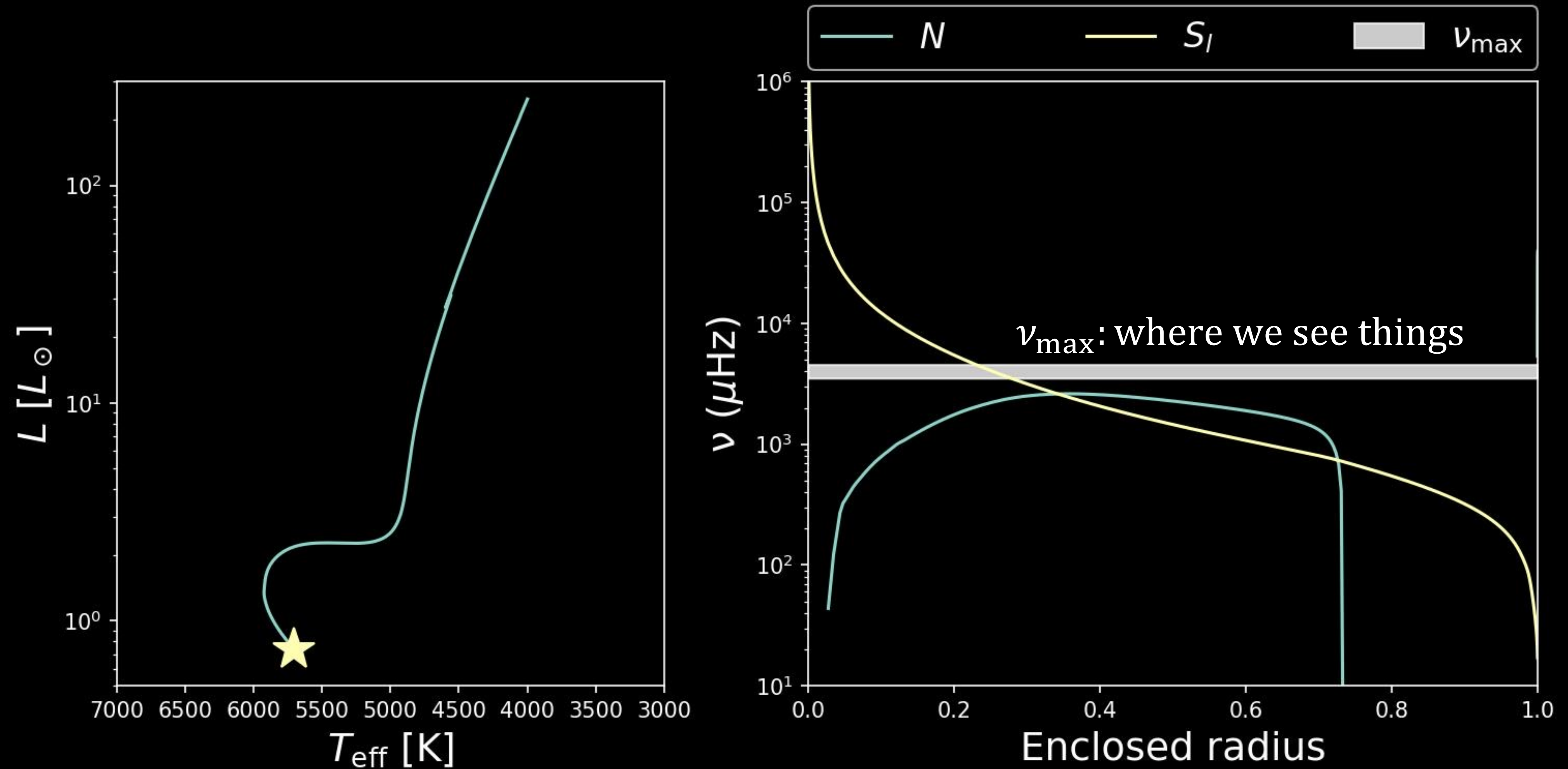
Propagation diagram



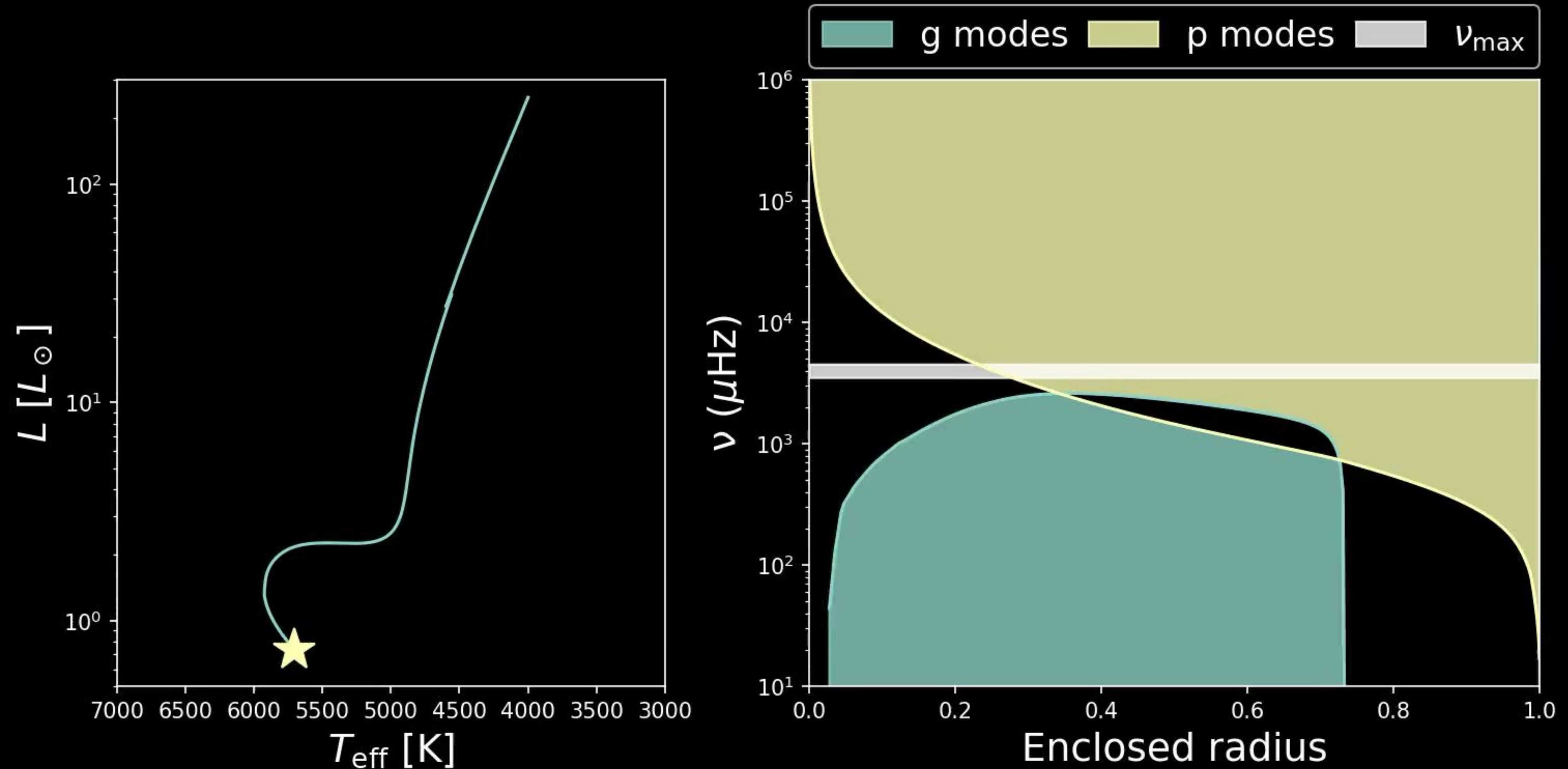
Propagation diagram



Propagation diagram



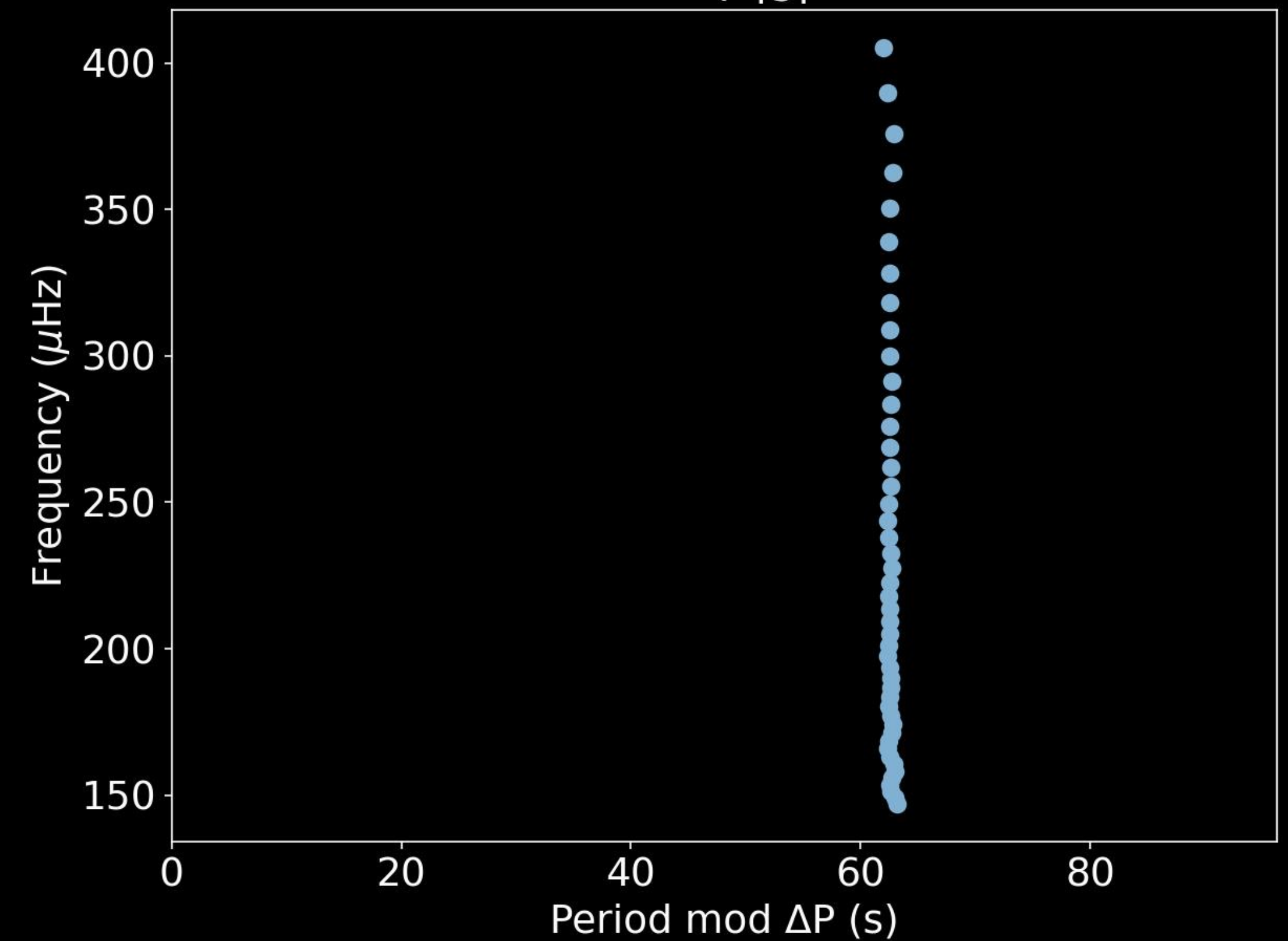
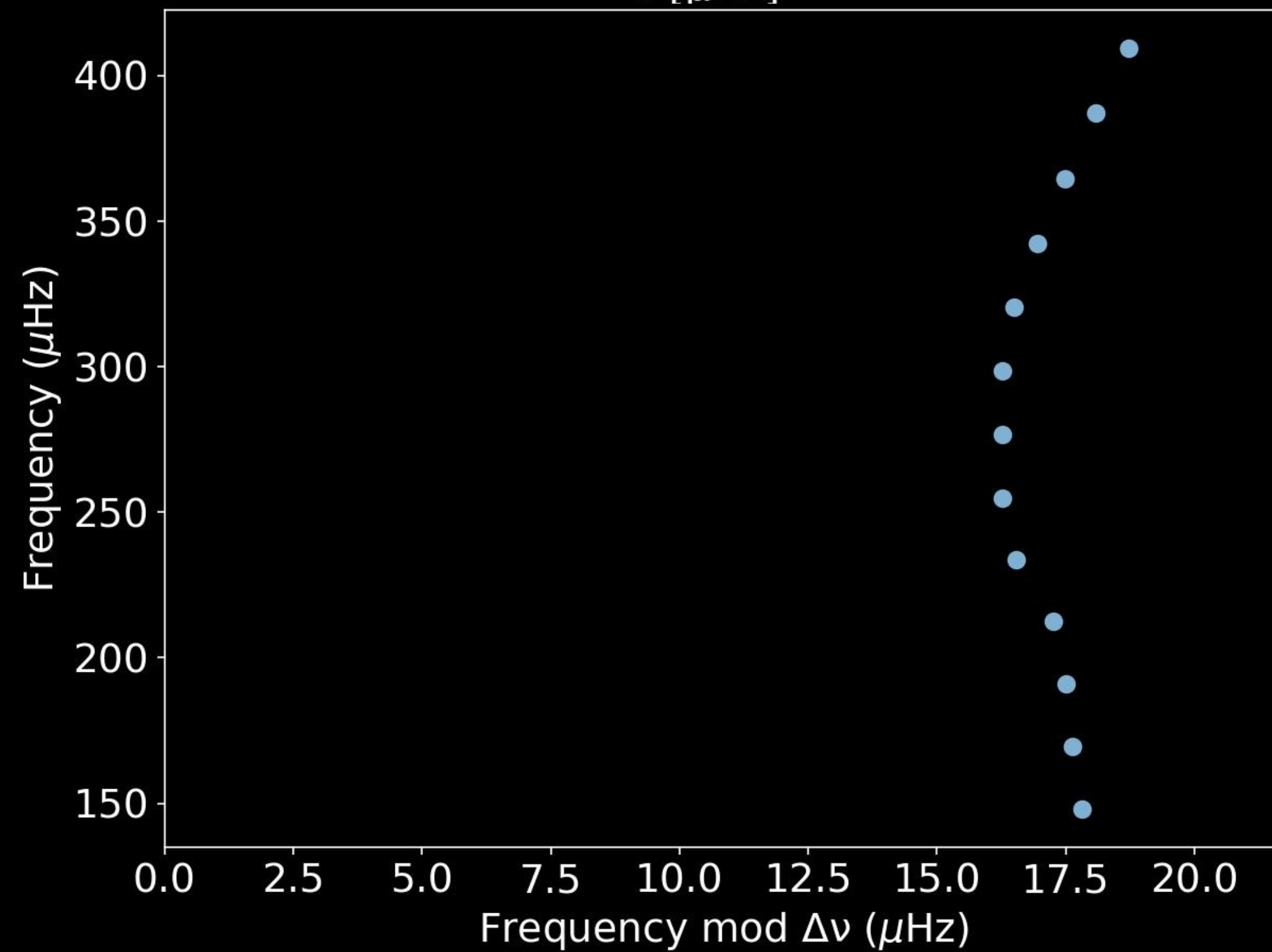
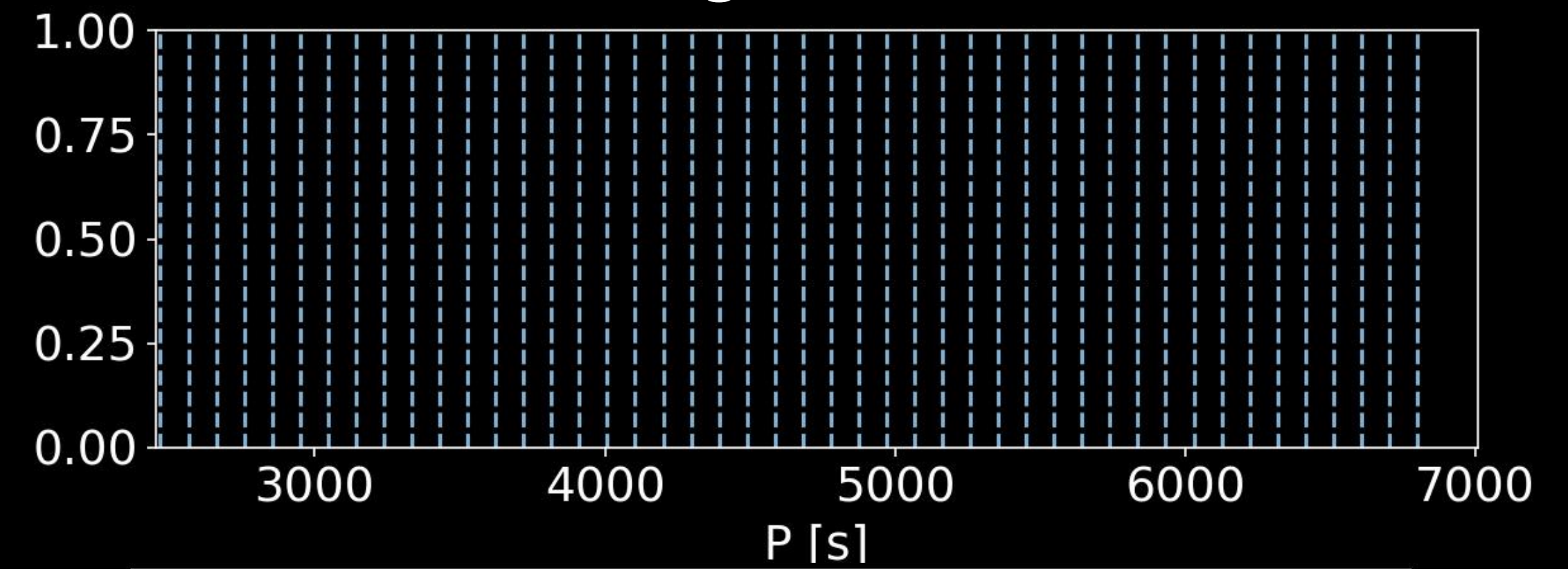
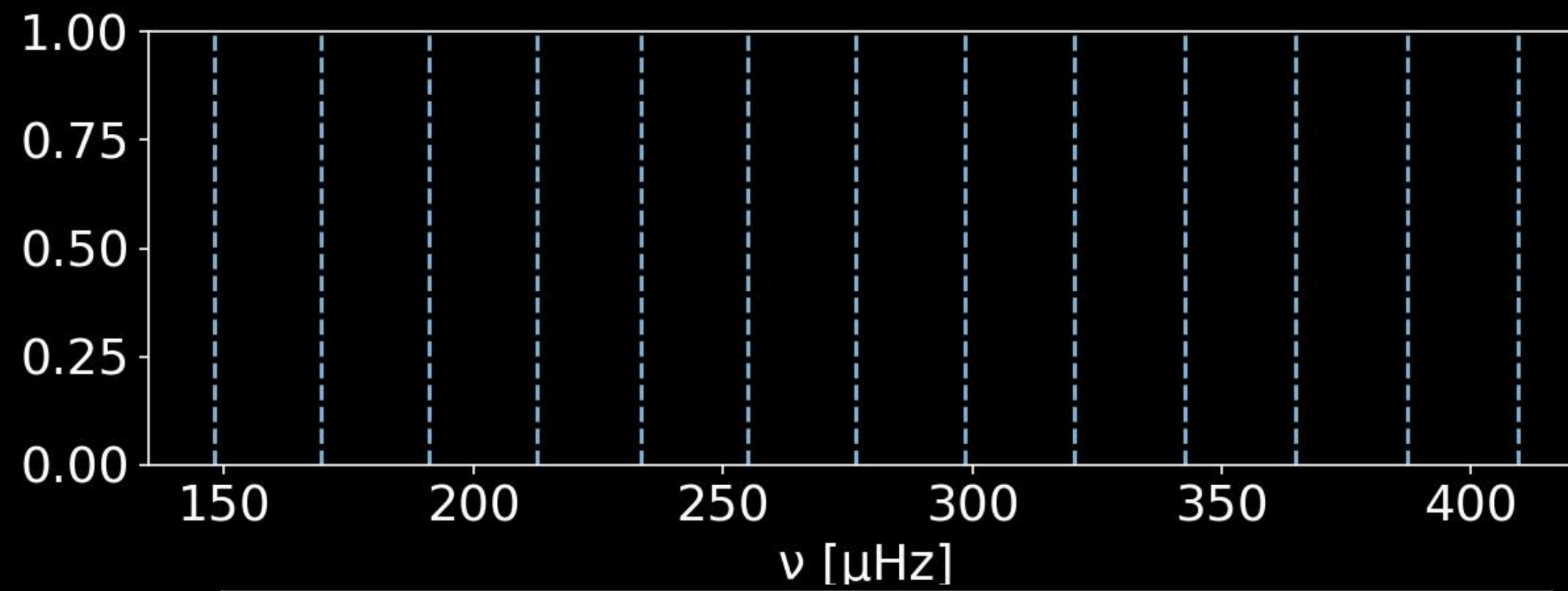
Propagation diagram evolution



$$\nu_{p,n,l} = \Delta\nu(n + \epsilon_{p,l})$$

p/g modes

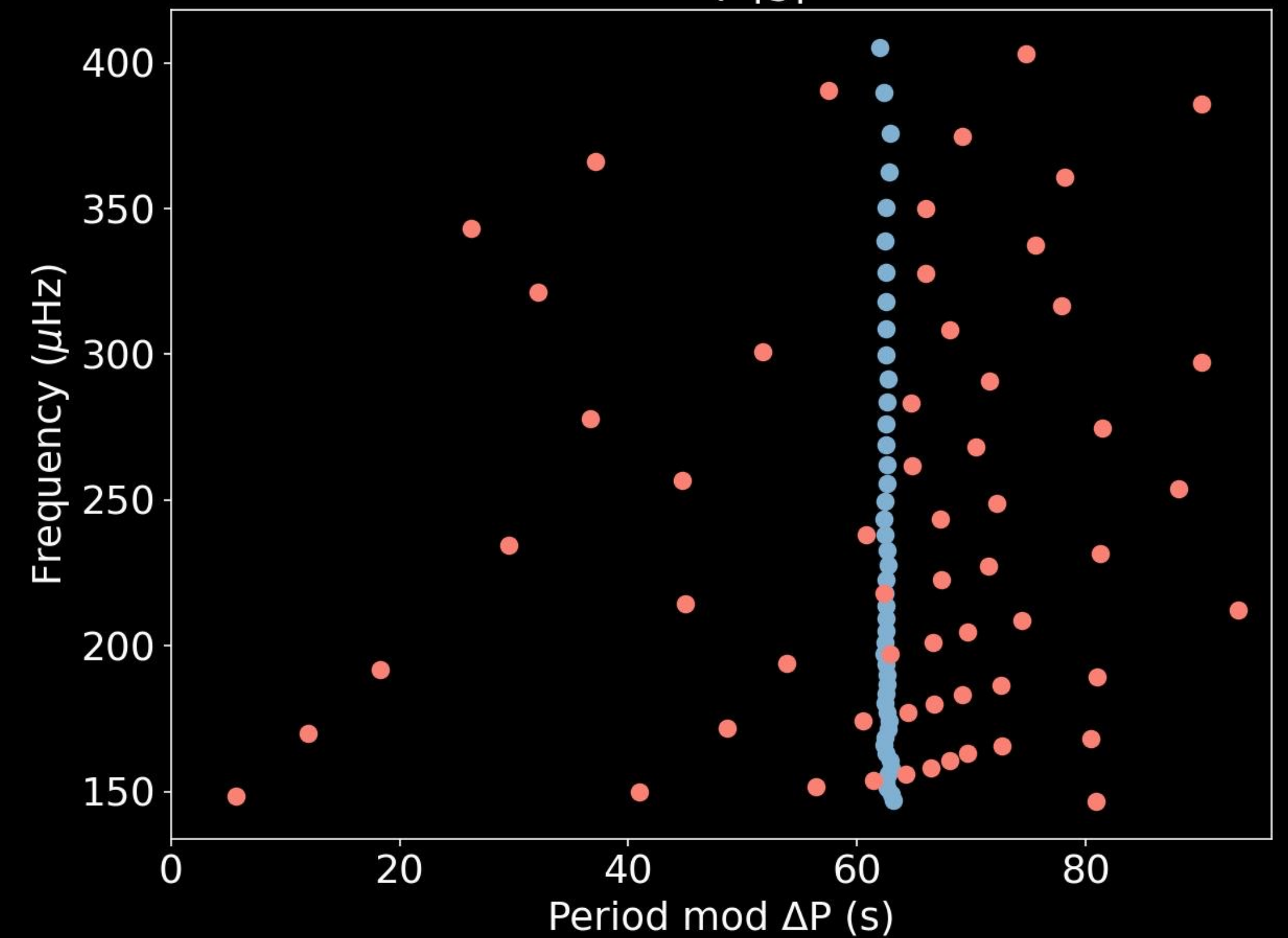
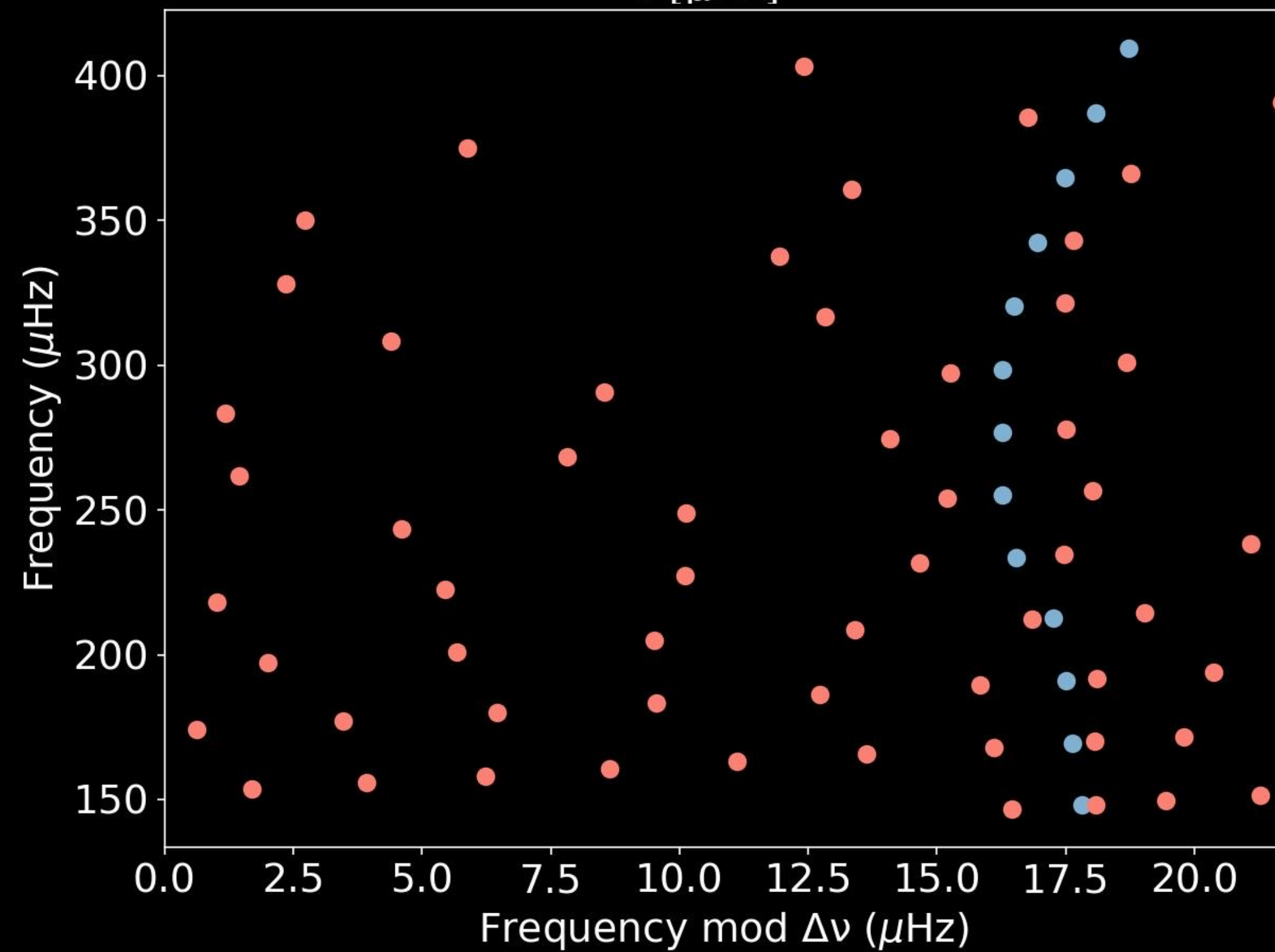
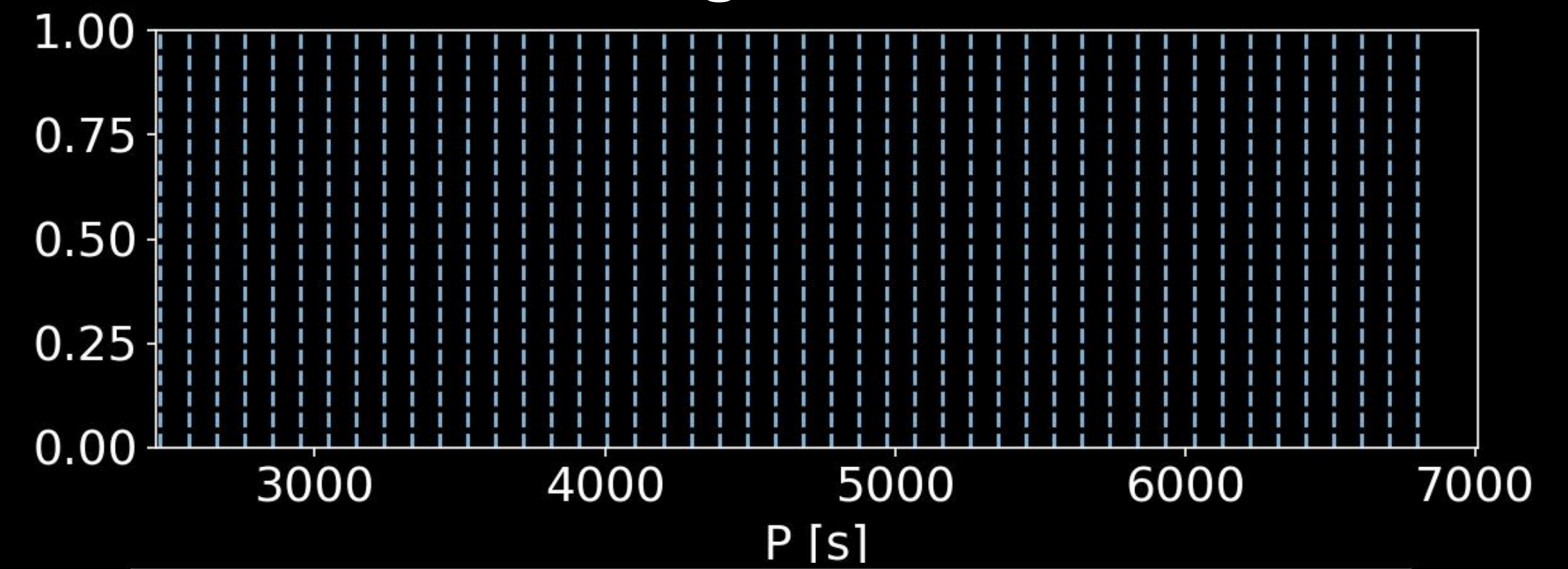
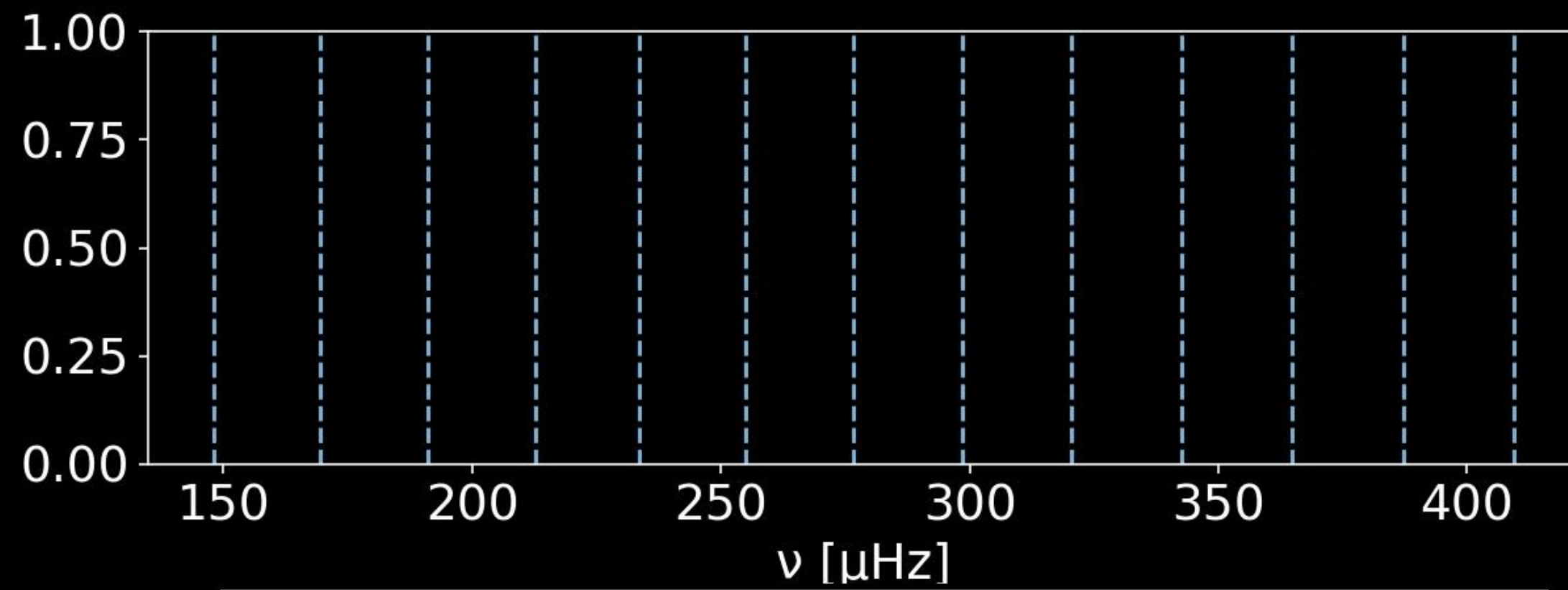
$$\frac{1}{\nu_{g,n,l}} = \Delta\Pi(n + \epsilon_{g,l})$$



$$\nu_{p,n,l} = \Delta\nu(n + \epsilon_{p,l})$$

p/g modes

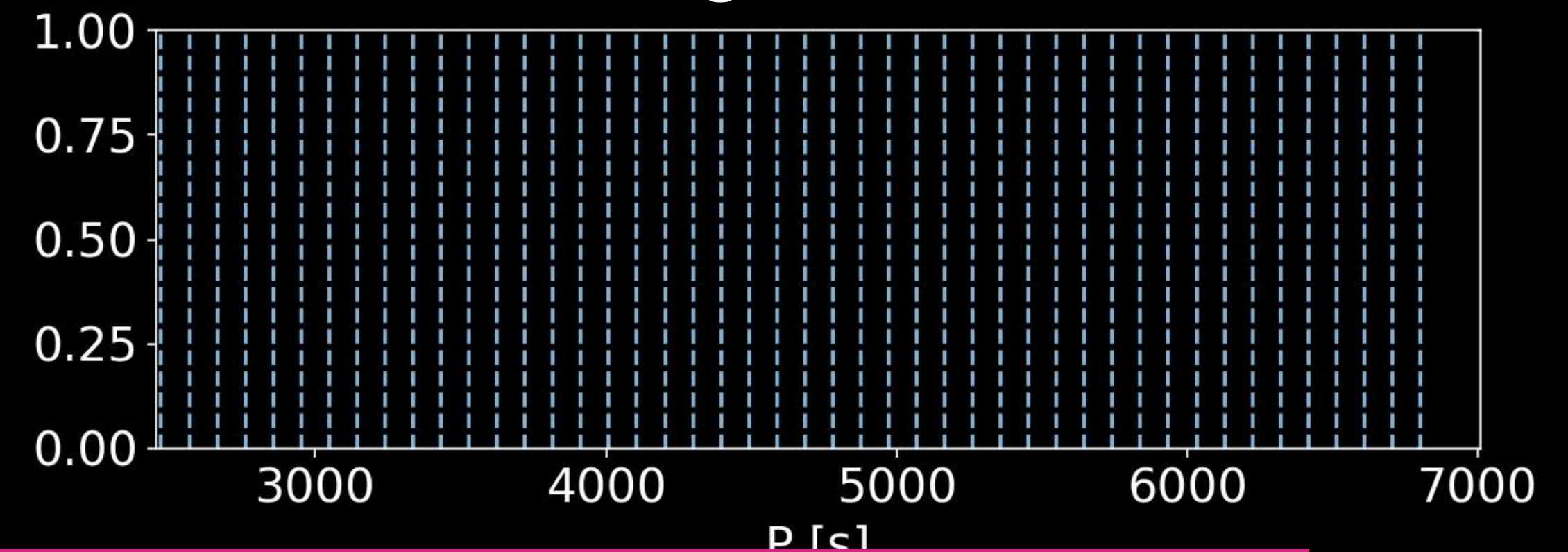
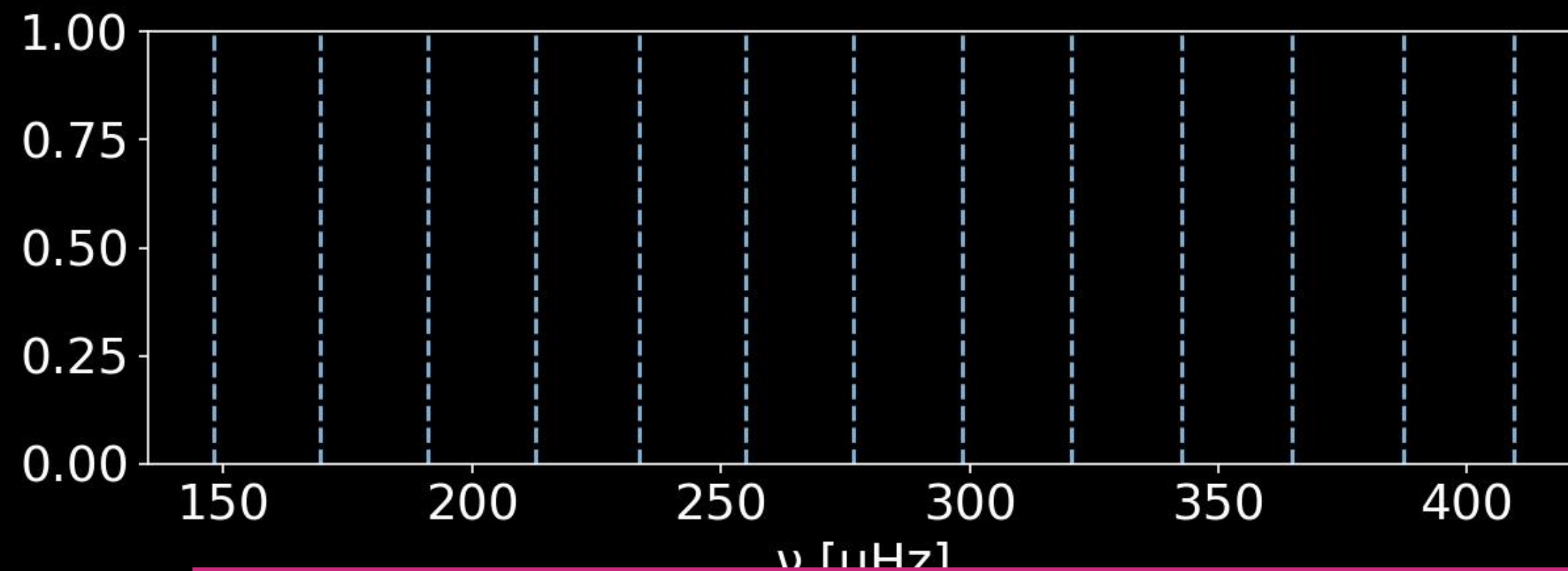
$$\frac{1}{\nu_{g,n,l}} = \Delta\Pi(n + \epsilon_{g,l})$$



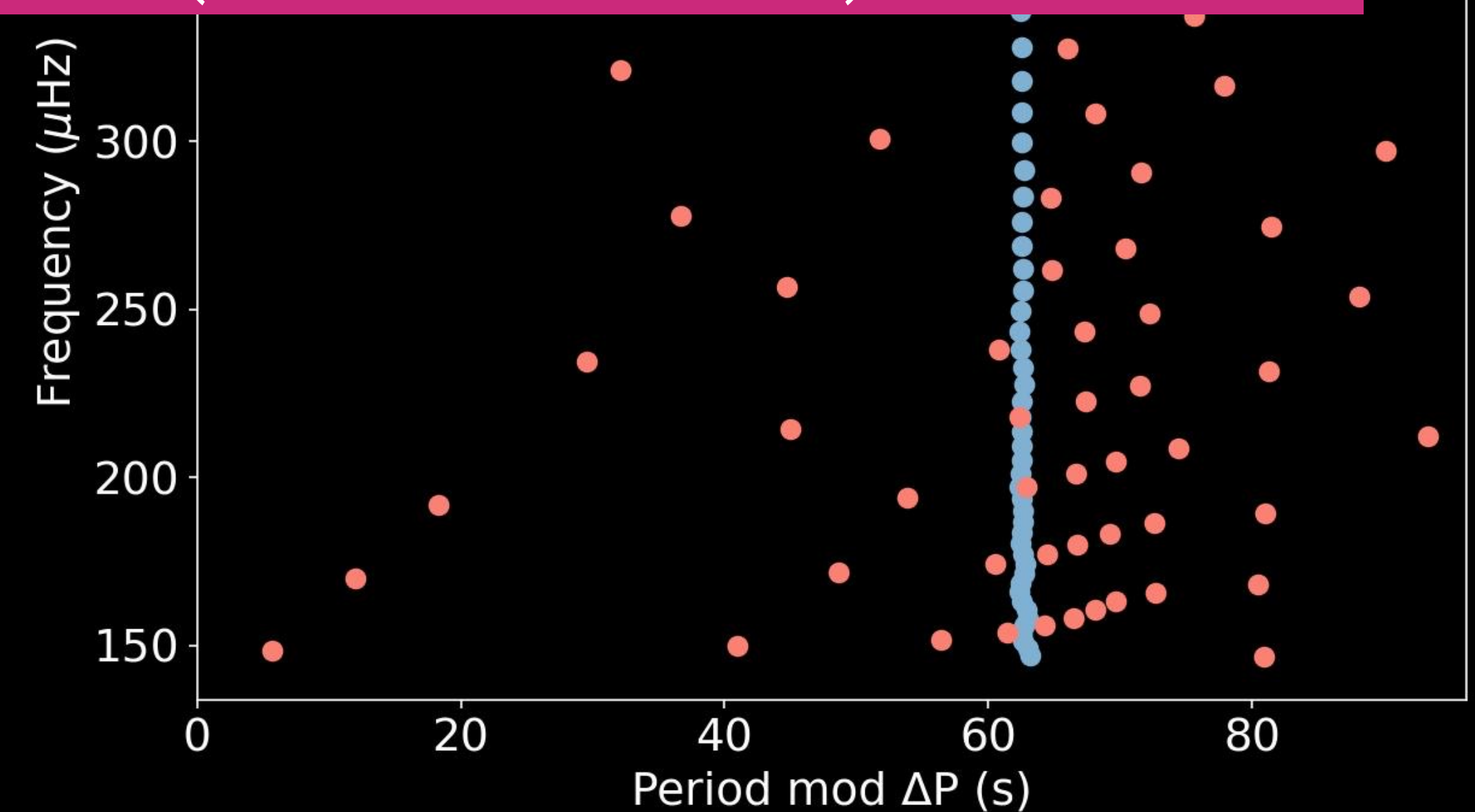
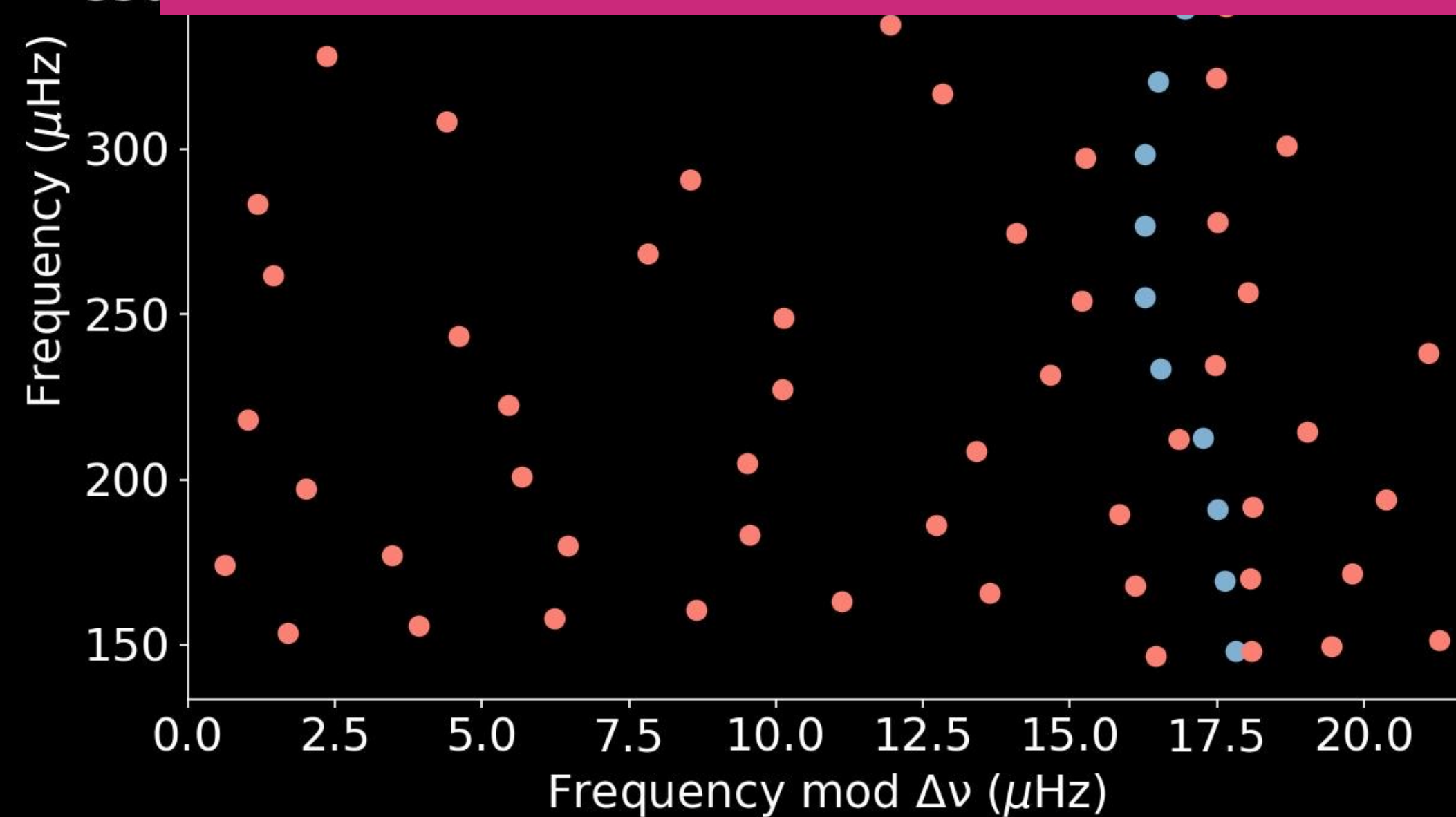
$$\nu_{p,n,l} = \Delta\nu(n + \epsilon_{p,l})$$

p/g modes

$$\frac{1}{\nu_{g,n,l}} = \Delta\Pi(n + \epsilon_{g,l})$$



$$F(\nu_m, \nu_p, \nu_g) \approx \tan\left(\pi \frac{\nu_m - \nu_p}{\Delta\nu}\right) \tan\left(\pi \frac{1/\nu_g - 1/\nu_m}{\Delta\Pi}\right) - q = 0$$



mixed modes

$$F(\nu_m, \nu_p, \nu_g) \approx \tan\left(\pi \frac{\nu_m - \nu_p}{\Delta\nu}\right) \tan\left(\pi \frac{1/\nu_g - 1/\nu_m}{\Delta\Pi}\right) - q = 0$$

$$\Theta(\nu_m, \nu_p)$$

mixed modes

$$F(\nu_m, \nu_p, \nu_g) \approx \tan\left(\pi \frac{\nu_m - \nu_p}{\Delta\nu}\right) \tan\left(\pi \frac{1/\nu_g - 1/\nu_m}{\Delta\Pi}\right) - q = 0$$

$$\Theta(\nu_m, \nu_g)$$

mixed modes

$$F(\nu_m, \nu_p, \nu_g) \approx \tan\left(\pi \frac{\nu_m - \nu_p}{\Delta\nu}\right) \tan\left(\pi \frac{1/\nu_g - 1/\nu_m}{\Delta\Pi}\right) - \boxed{q} = 0$$

Coupling strength

When $q = 0$, $\nu_m = \nu_p$ or ν_g

mixed modes

$$F(\nu_m, \nu_p, \nu_g) \approx \tan\left(\pi \frac{\nu_m - \nu_p}{\Delta\nu}\right) \tan\left(\pi \frac{1/\nu_g - 1/\nu_m}{\Delta\Pi}\right) - q = 0$$

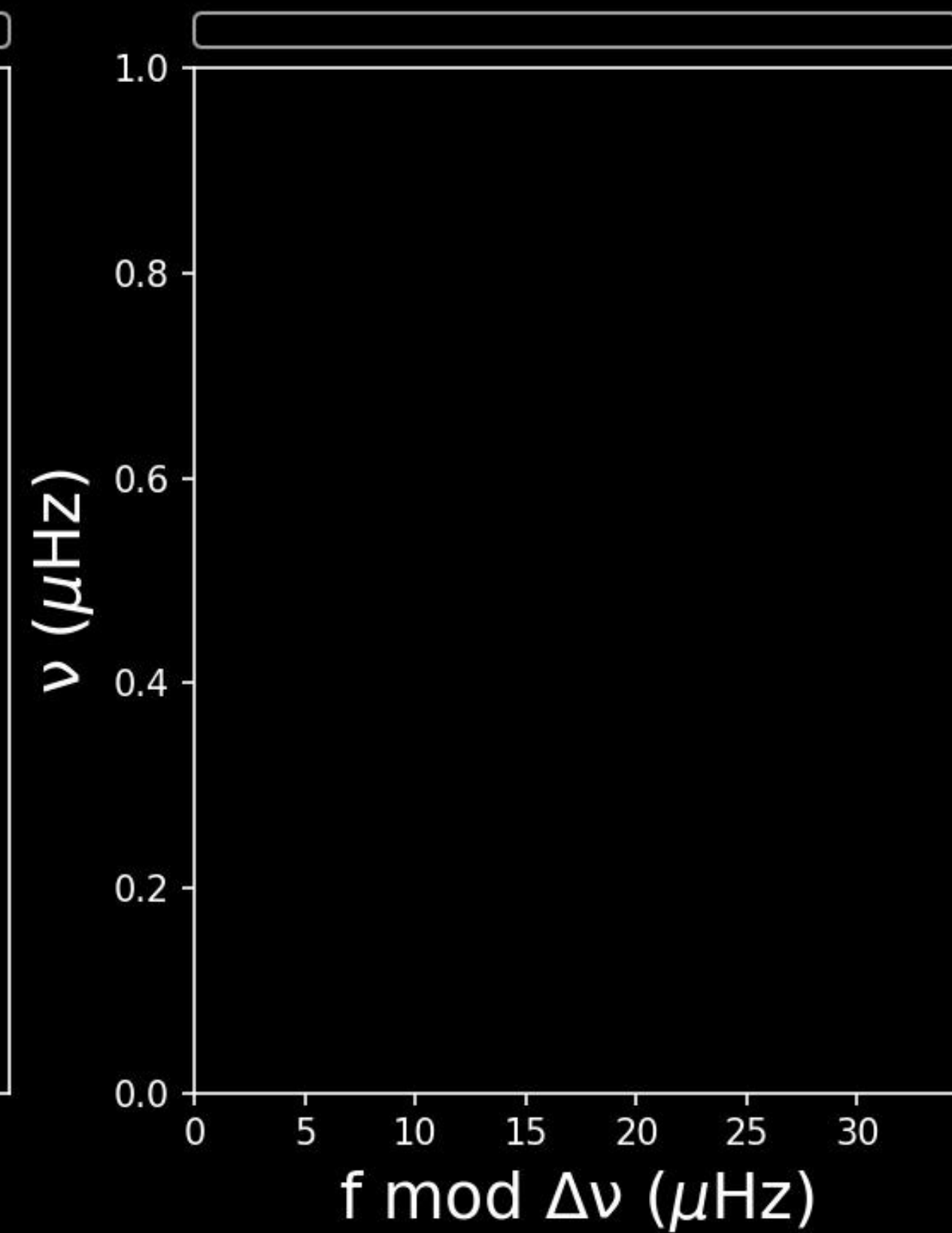
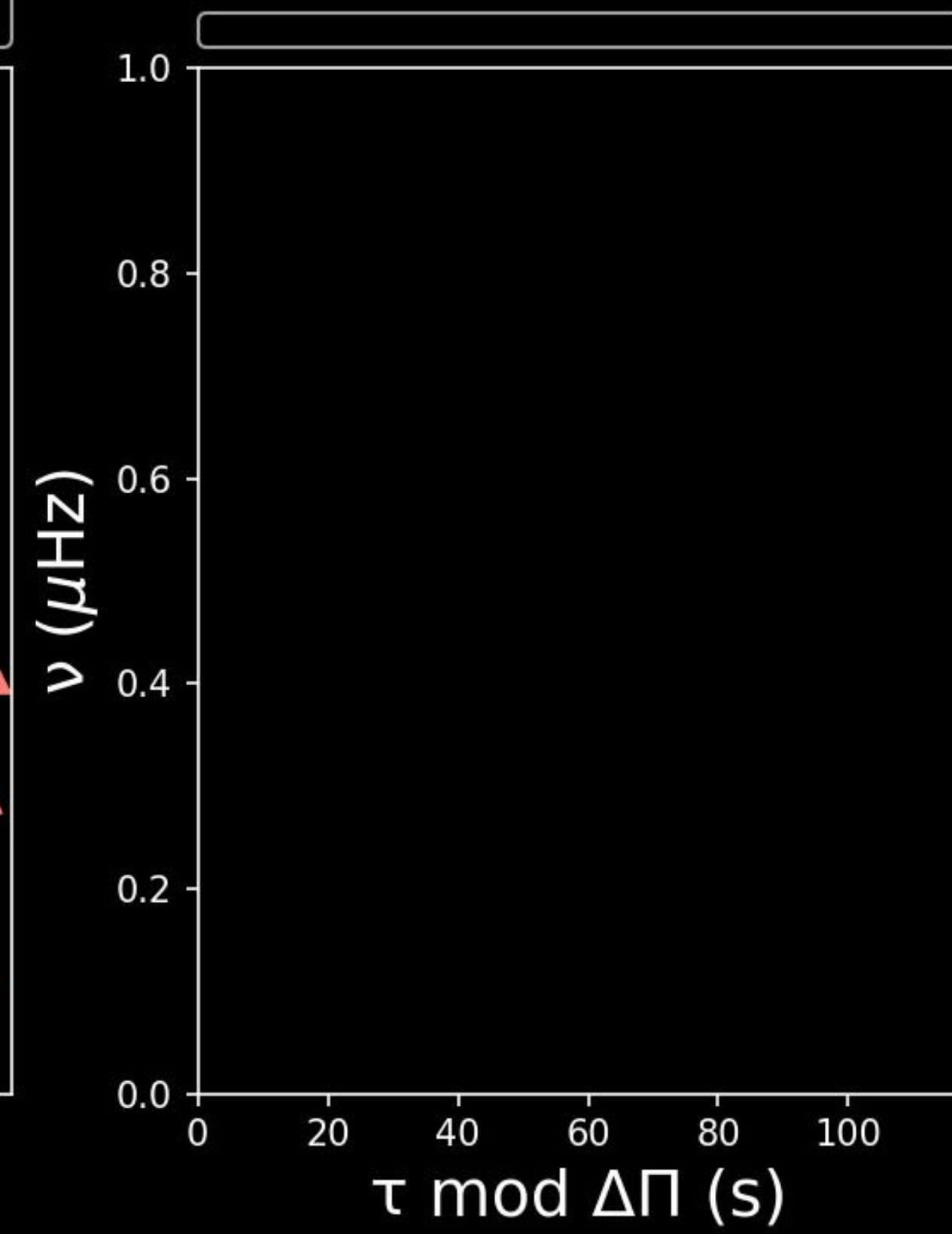
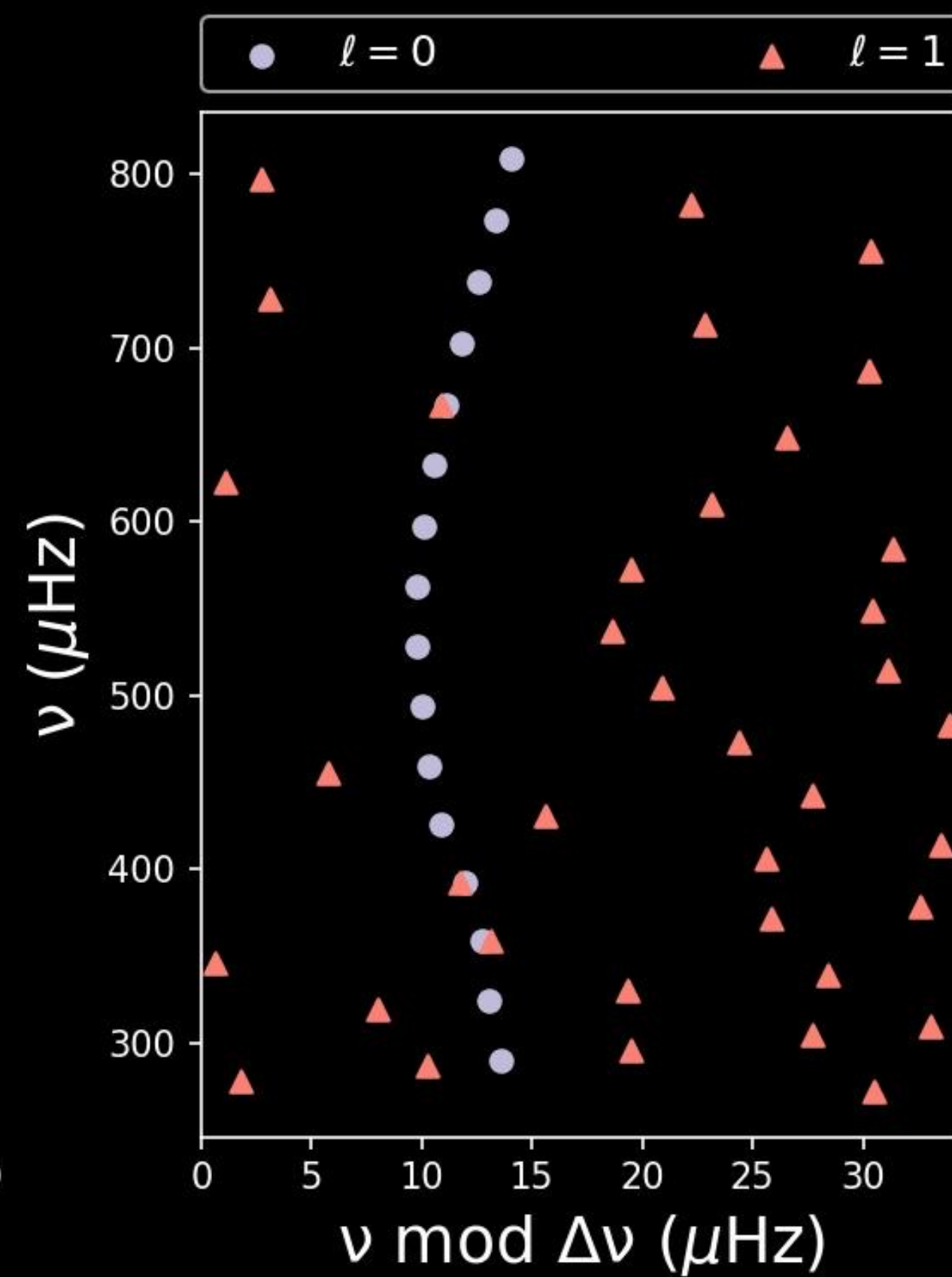
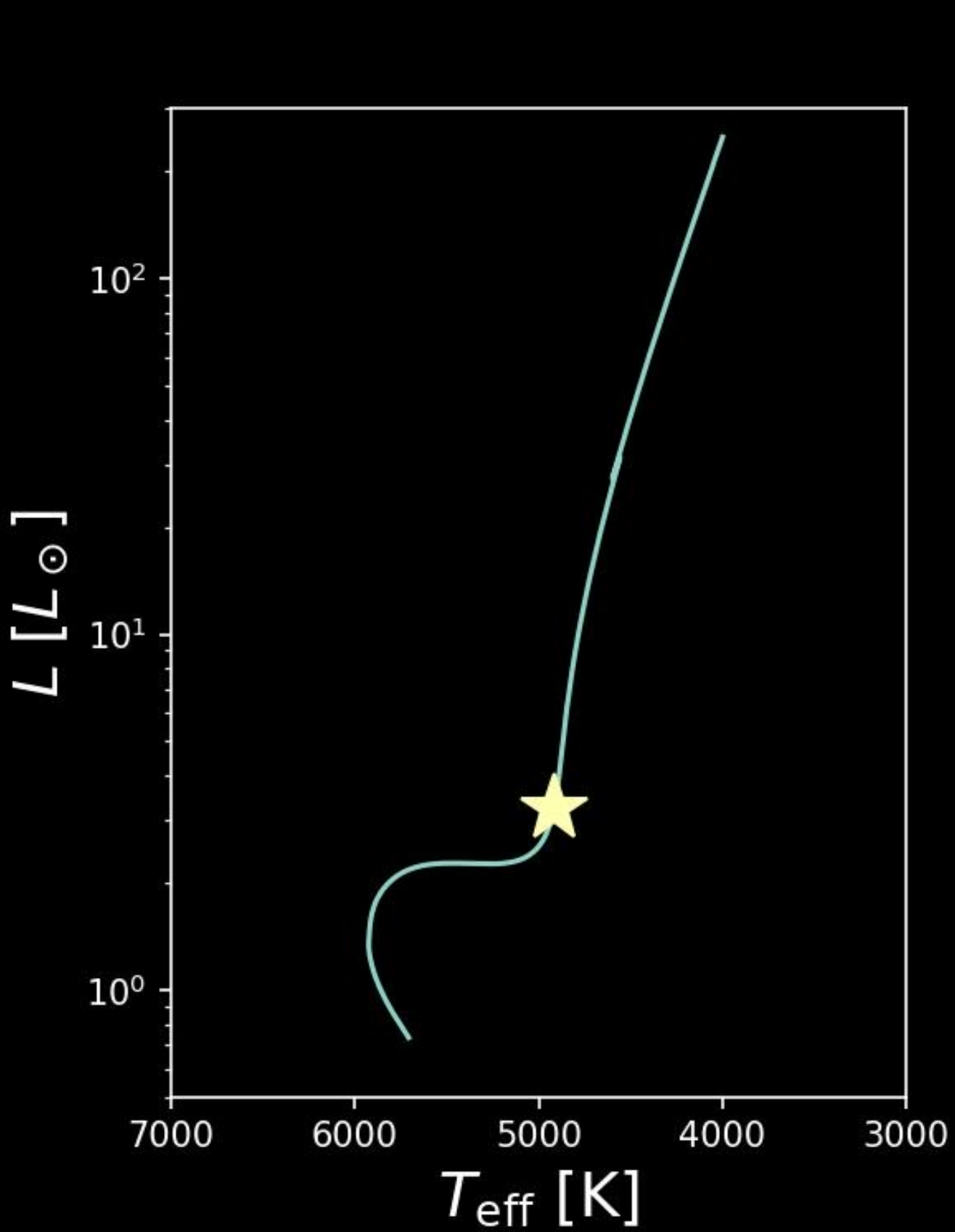
Stretched period $\tau(\nu_m, \nu_p) \equiv \frac{1}{\nu_g} = \frac{1}{\nu_m} + \frac{\Delta\Pi_l}{\pi} \arctan\left[\frac{q(\nu_m)}{\tan\pi \frac{\nu_m - \nu_p}{\Delta\nu}}\right]$

Stretched frequency $f(\nu_m, \nu_g) \equiv \nu_p = \nu_m - \frac{\Delta\nu}{\pi} \arctan\left[\frac{q(\nu_m)}{\tan\pi \frac{1/\nu_g - 1/\nu_m}{\Delta\Pi}}\right]$ **This work ✓**

Evolution of stretched mixed modes

$$\tau(\nu_m, \nu_p) \equiv \nu_g^{-1}$$

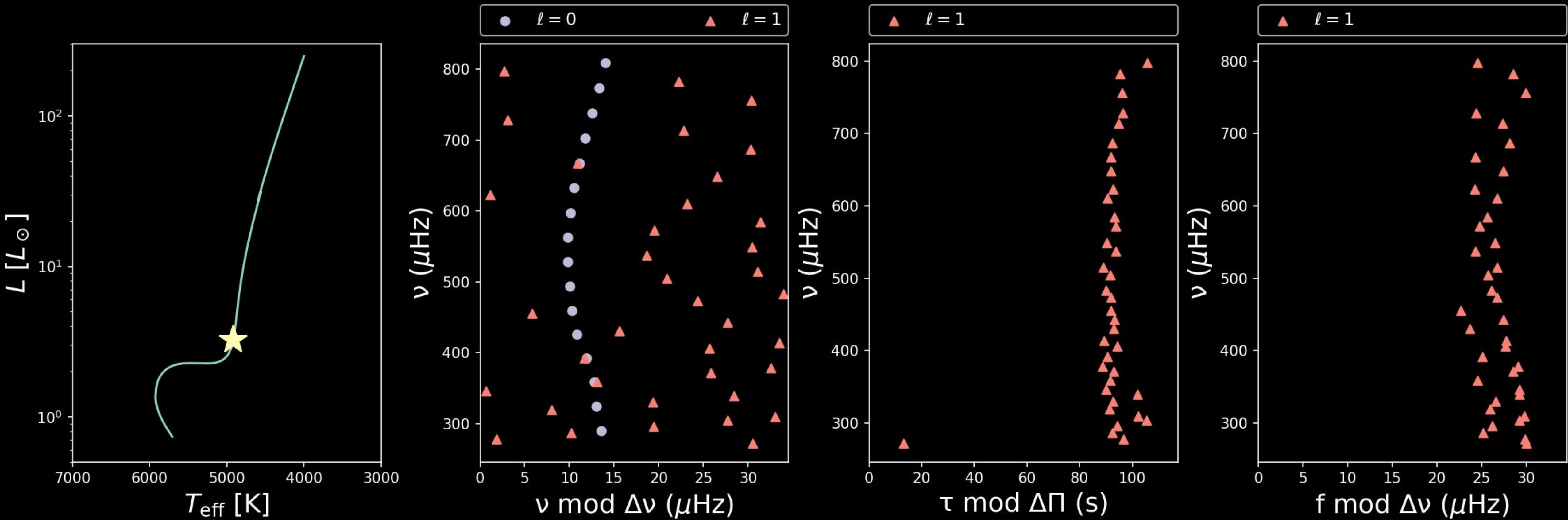
$$f(\nu_m, \nu_g) \equiv \nu_p$$



Evolution of stretched mixed modes

$$\tau(\nu_m, \nu_p) \equiv \nu_g^{-1}$$

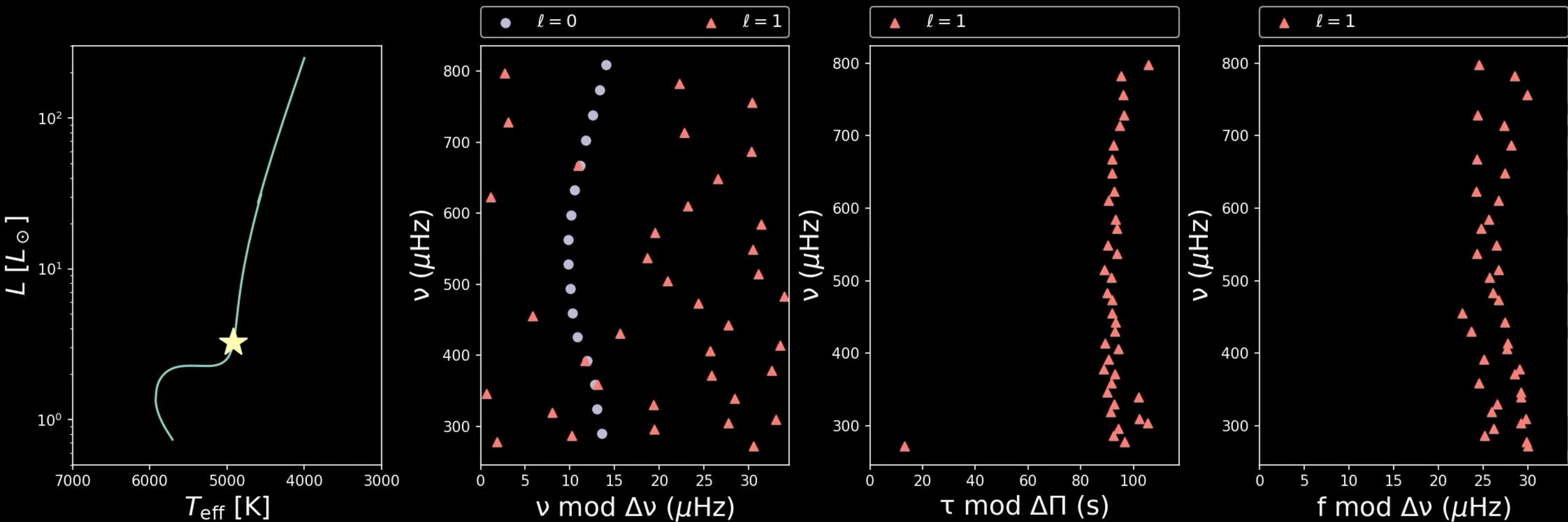
$$f(\nu_m, \nu_g) \equiv \nu_p$$



Evolution of stretched mixed modes

$$\tau(\nu_m, \nu_p) \equiv \nu_g^{-1}$$

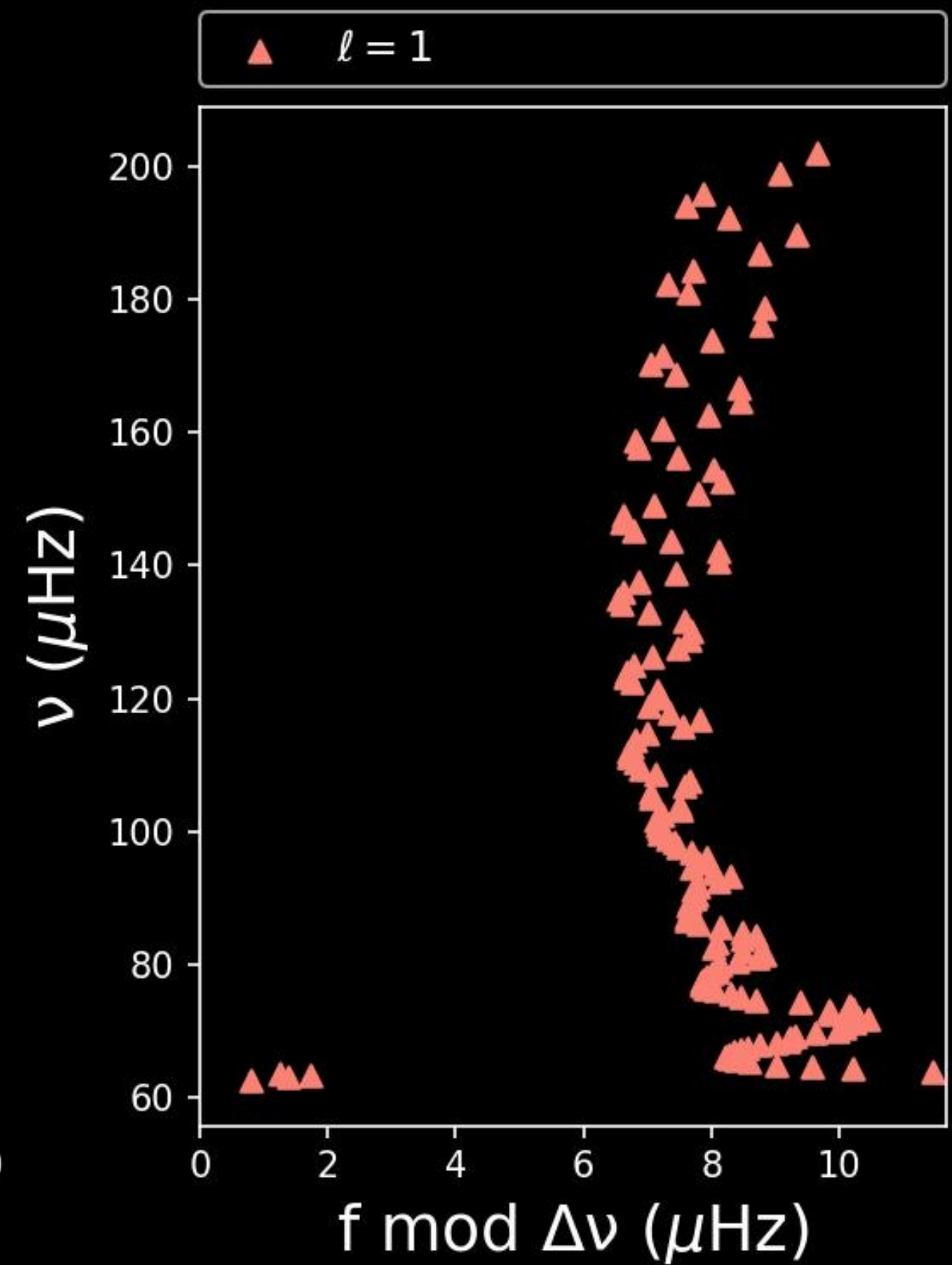
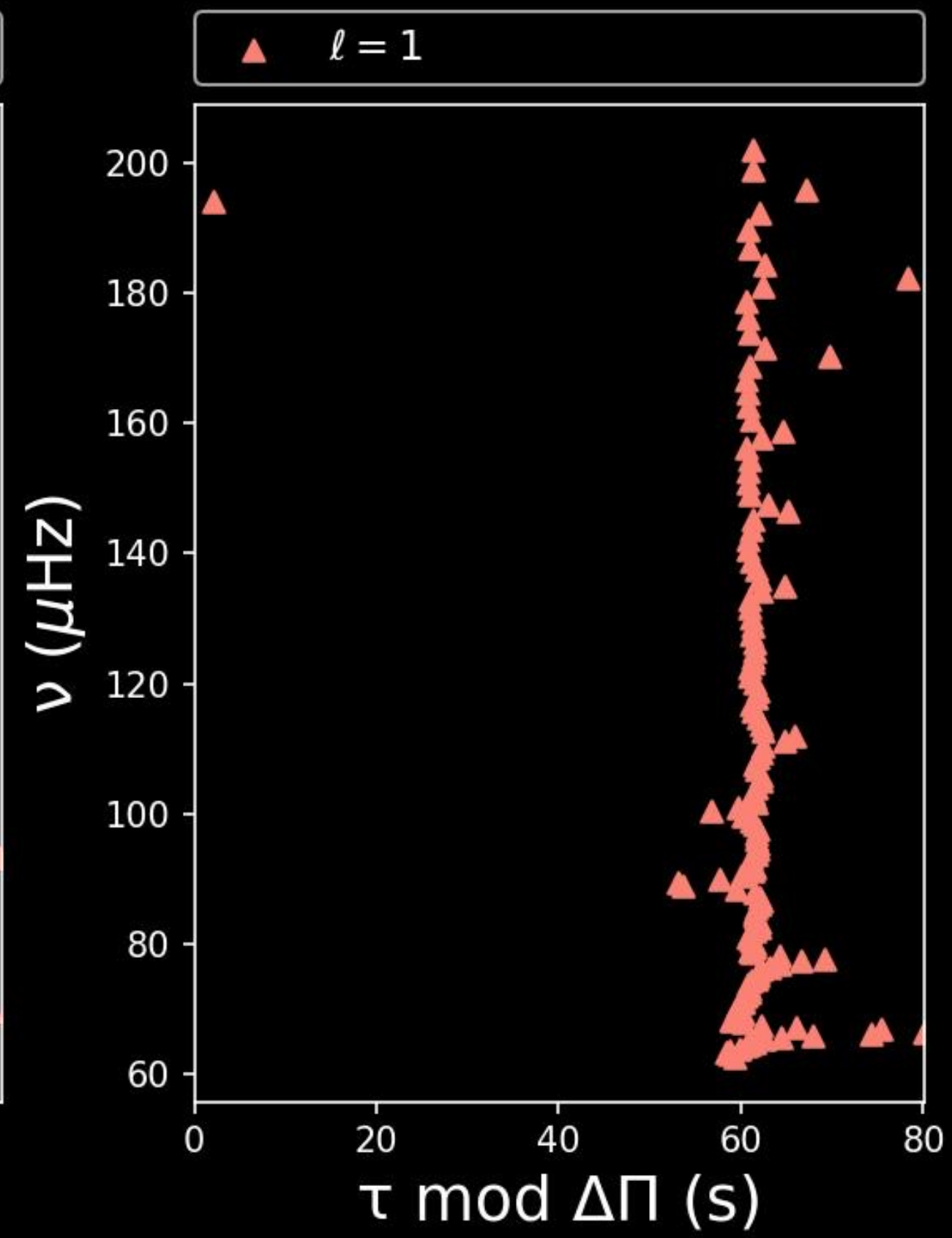
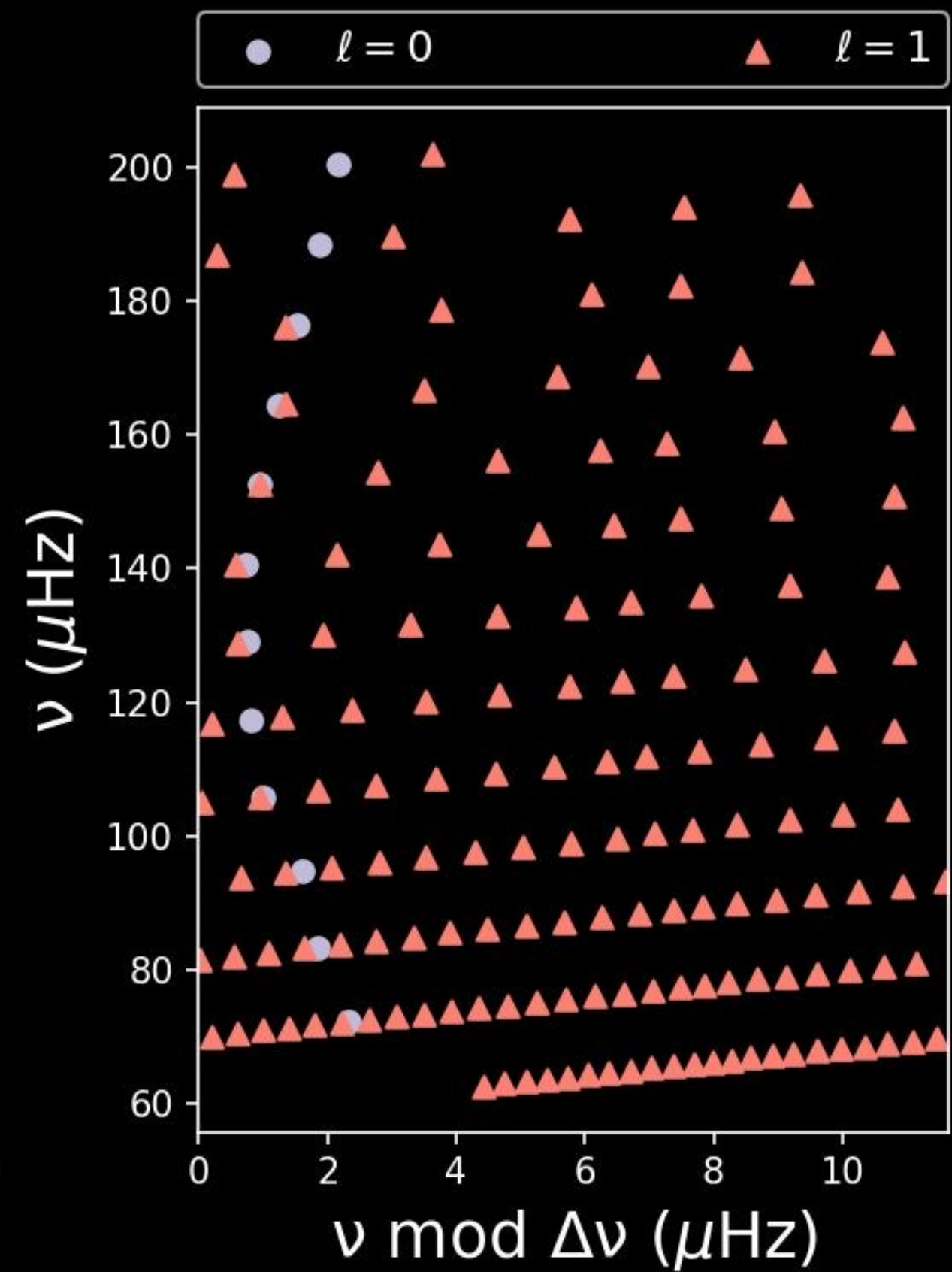
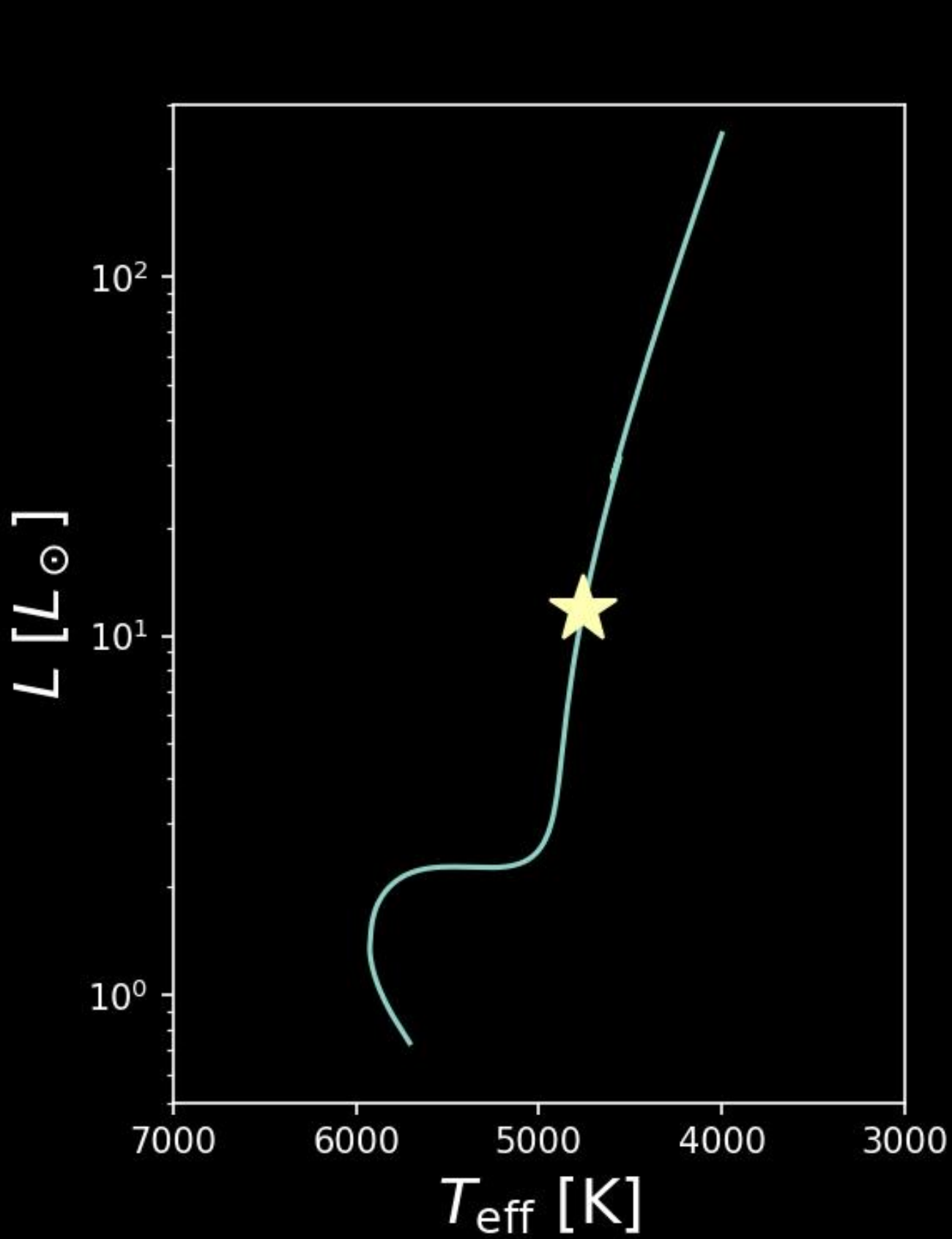
$$f(\nu_m, \nu_g) \equiv \nu_p$$



Evolution of stretched mixed modes

$$\tau(\nu_m, \nu_p) \equiv \nu_g^{-1}$$

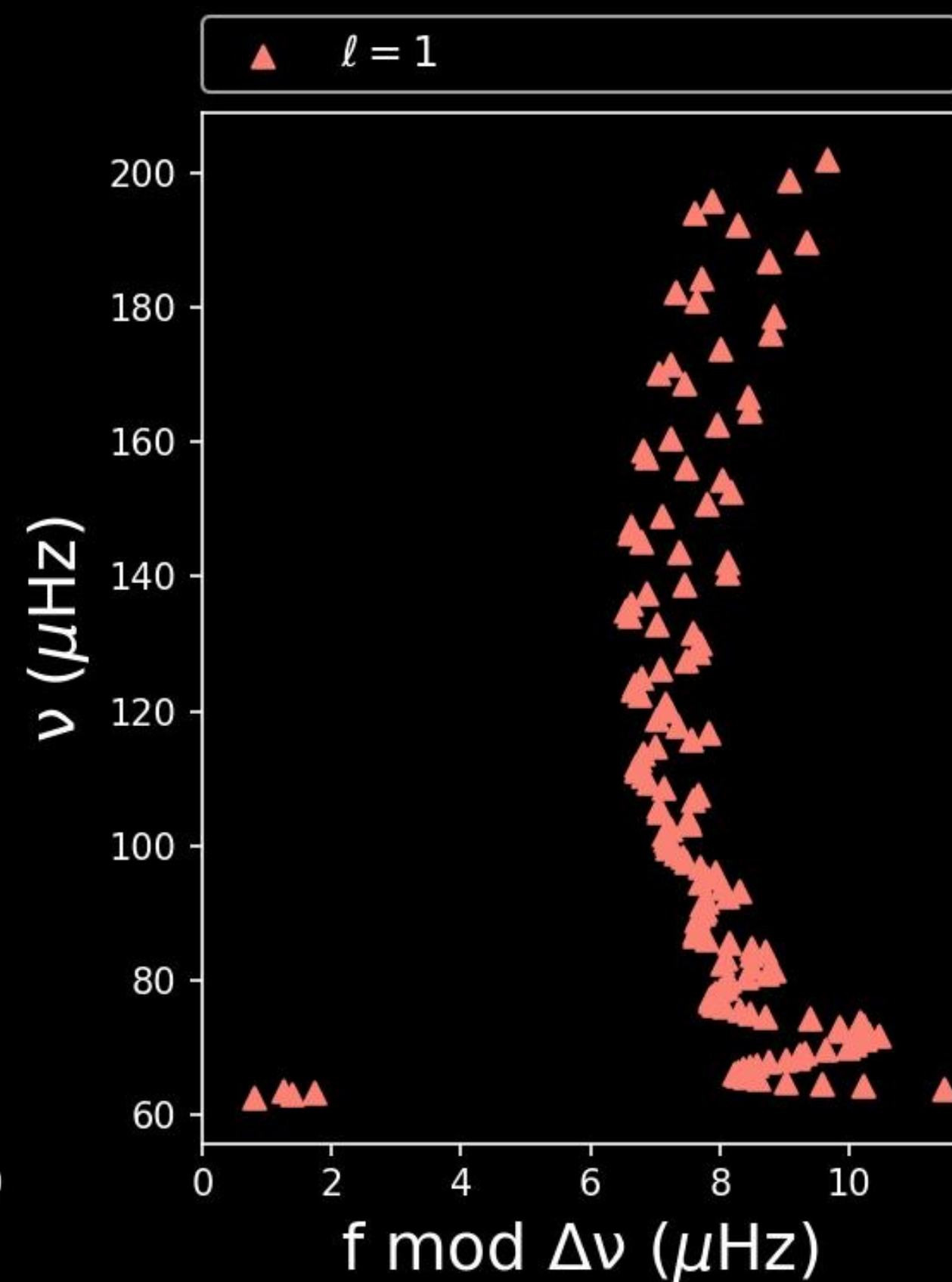
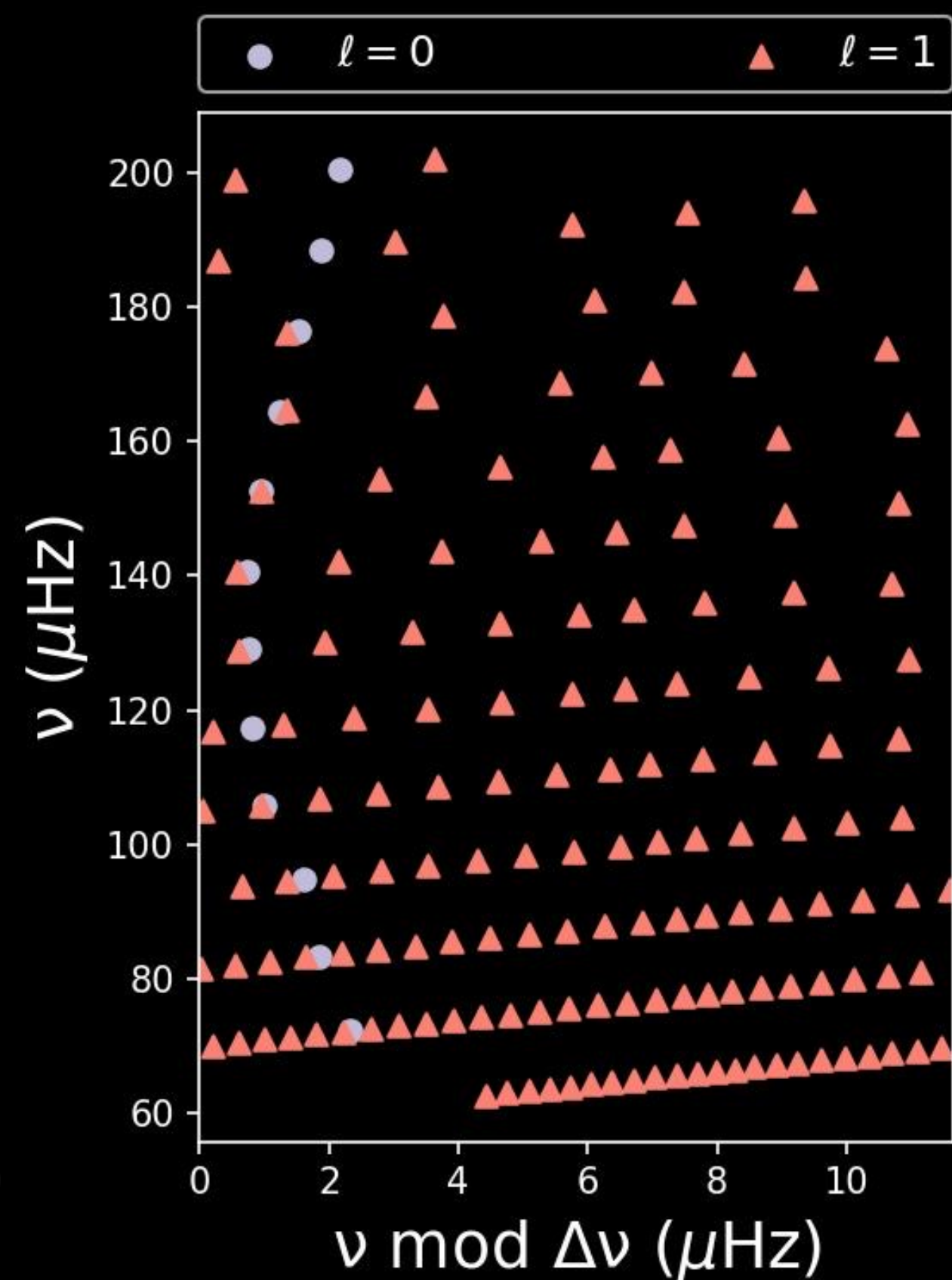
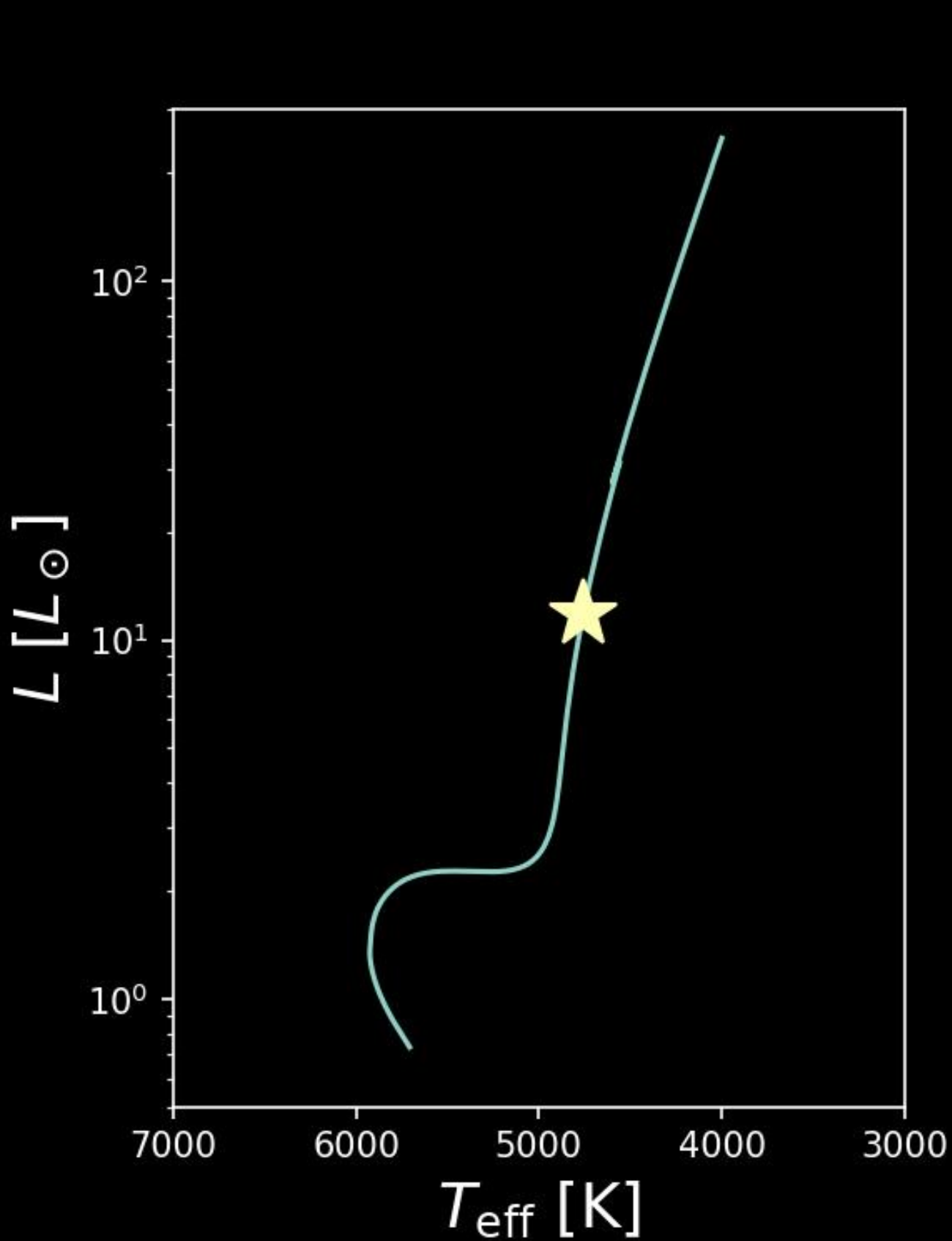
$$f(\nu_m, \nu_g) \equiv \nu_p$$



Evolution of stretched mixed modes

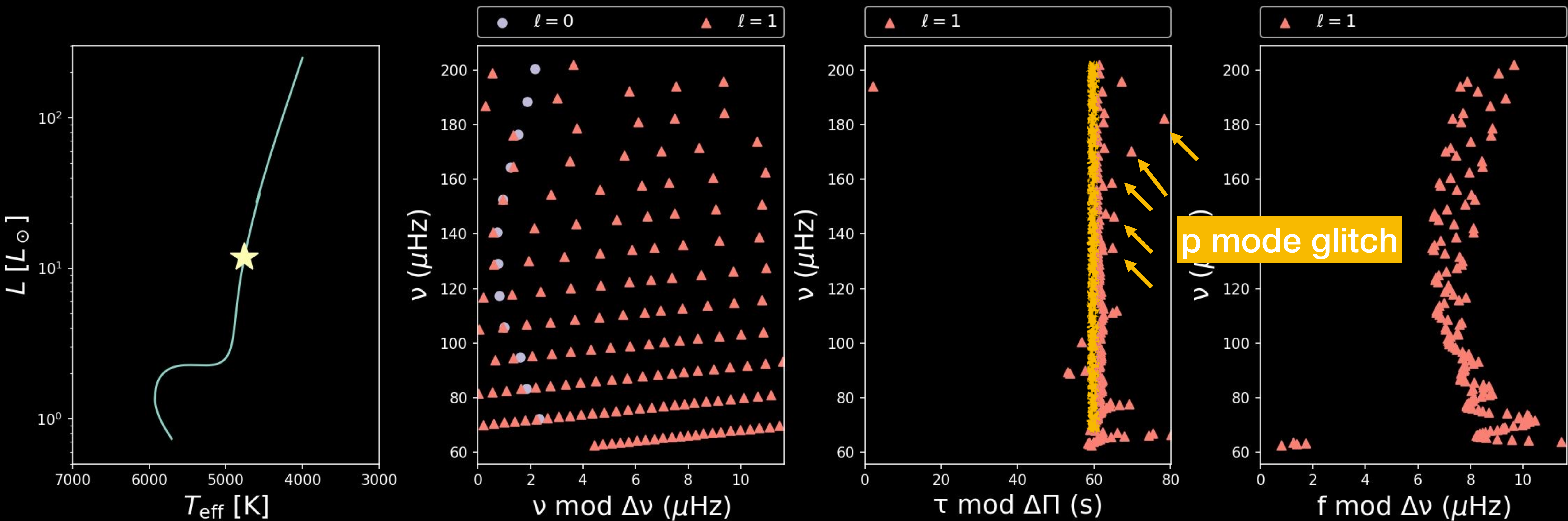
$$\tau(\nu_m, \nu_p) \equiv \nu_g^{-1}$$

$$f(\nu_m, \nu_g) \equiv \nu_p$$



Evolution of stretched mixed modes

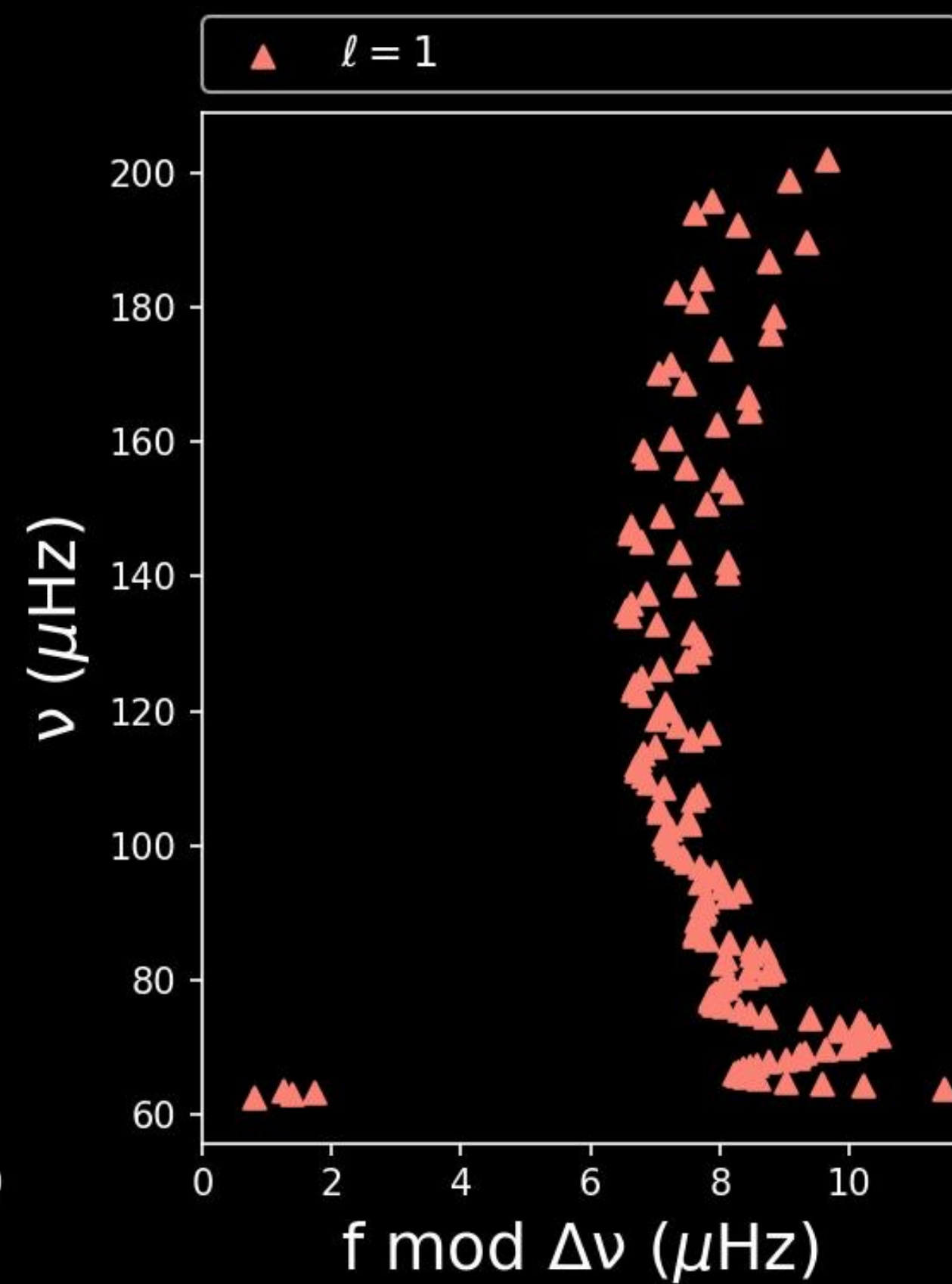
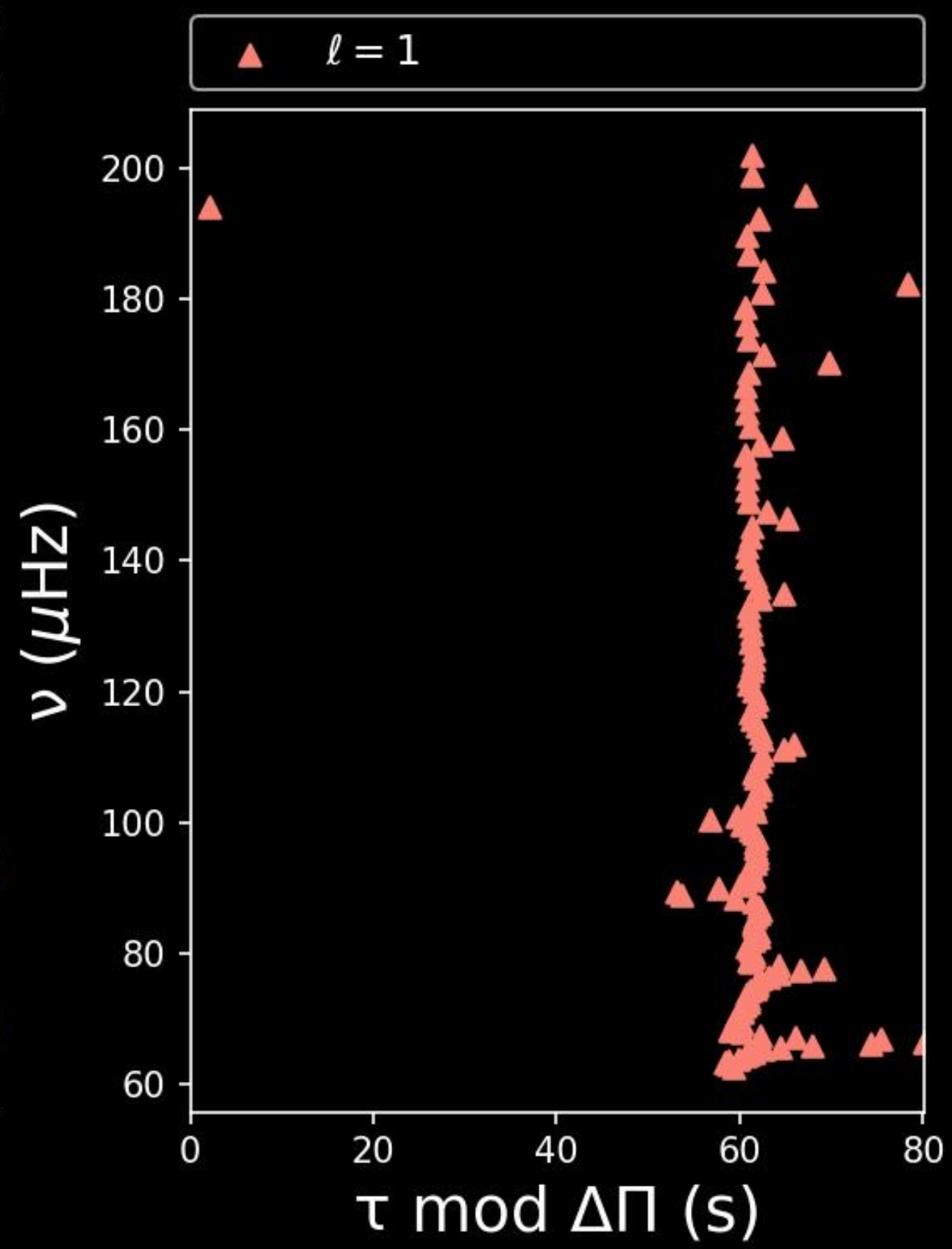
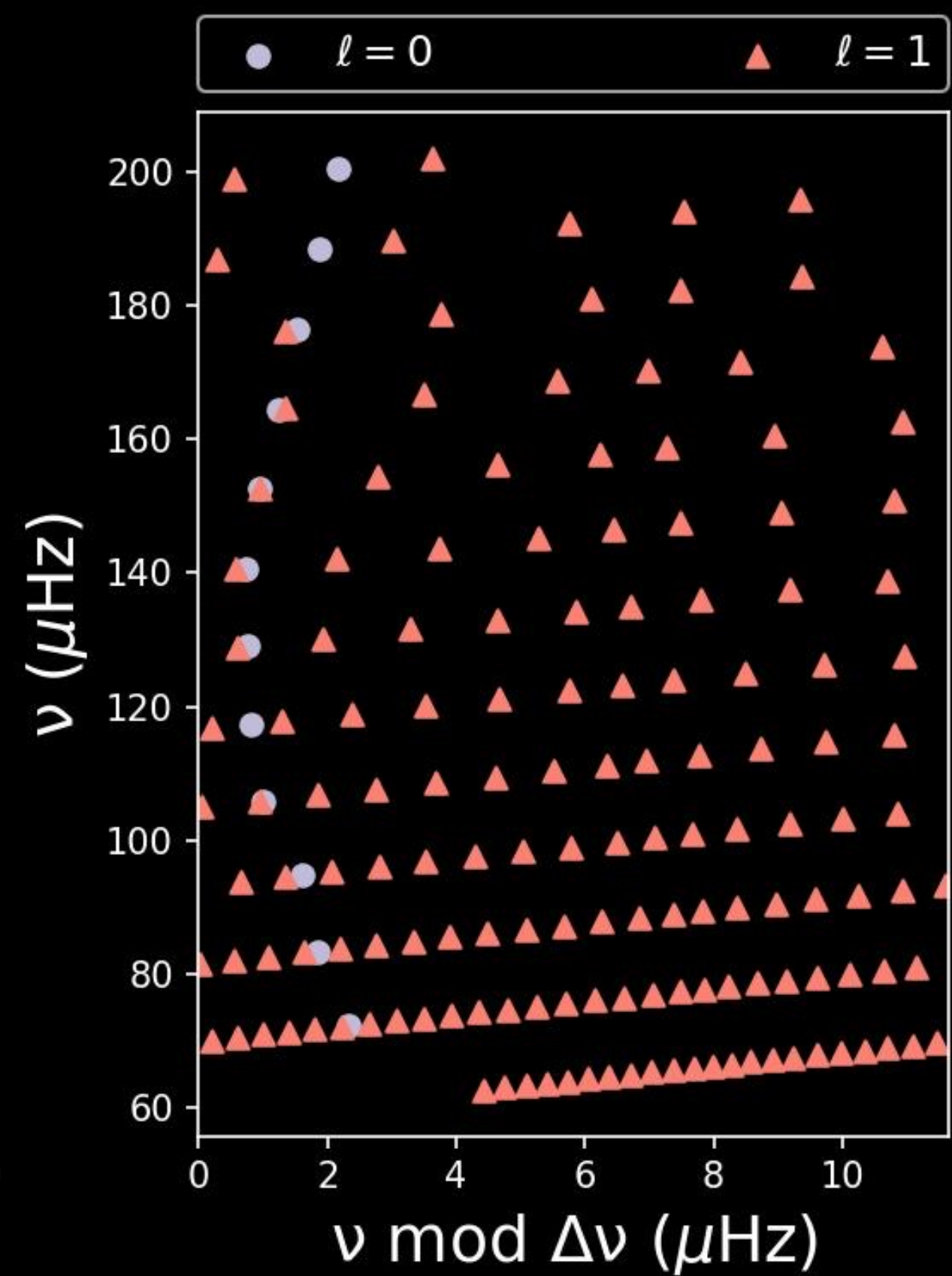
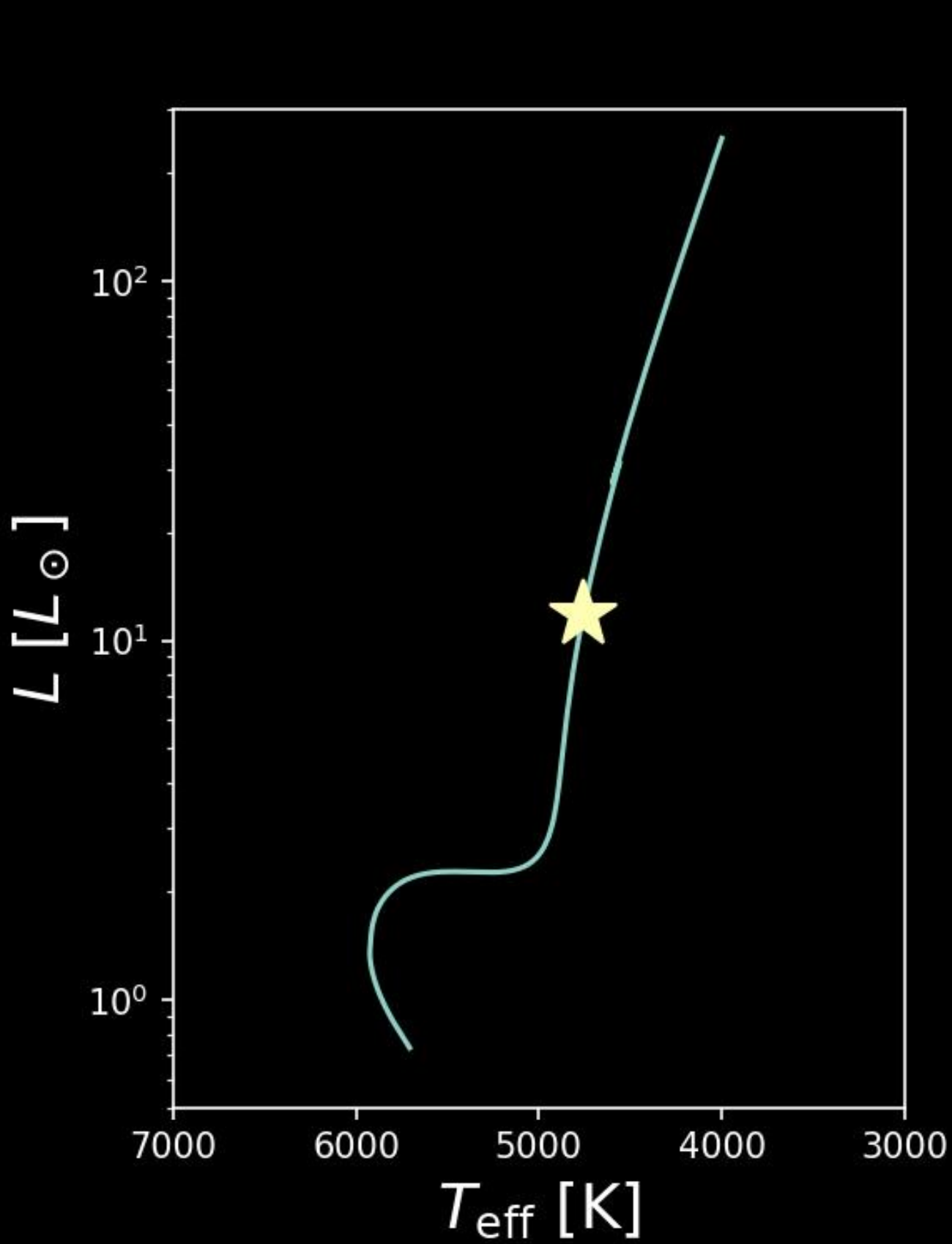
$$\tau(\nu_m, \nu_p) \equiv \nu_g^{-1} \quad f(\nu_m, \nu_g) \equiv \nu_p$$



Evolution of stretched mixed modes

$$\tau(\nu_m, \nu_p) \equiv \nu_g^{-1}$$

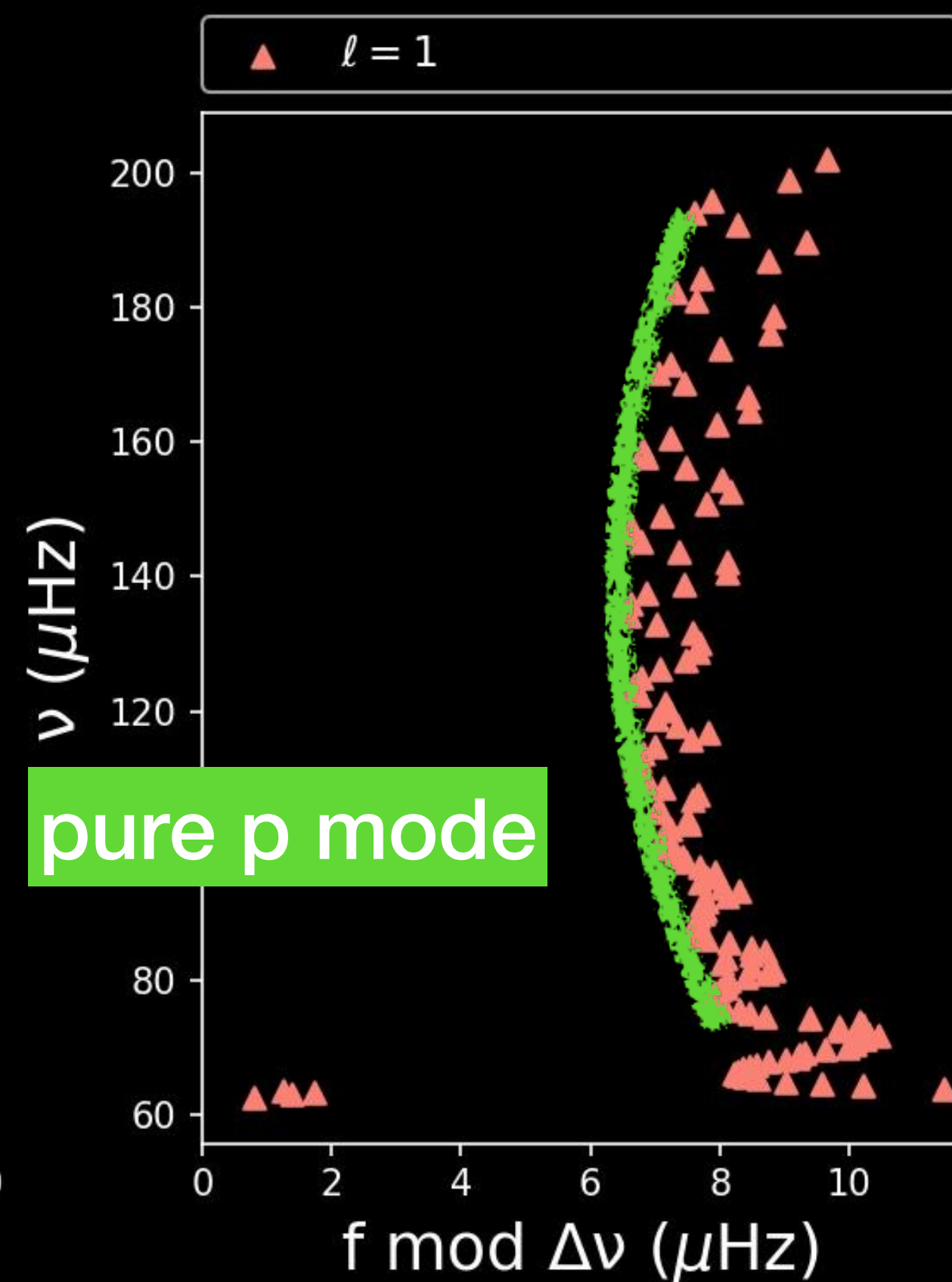
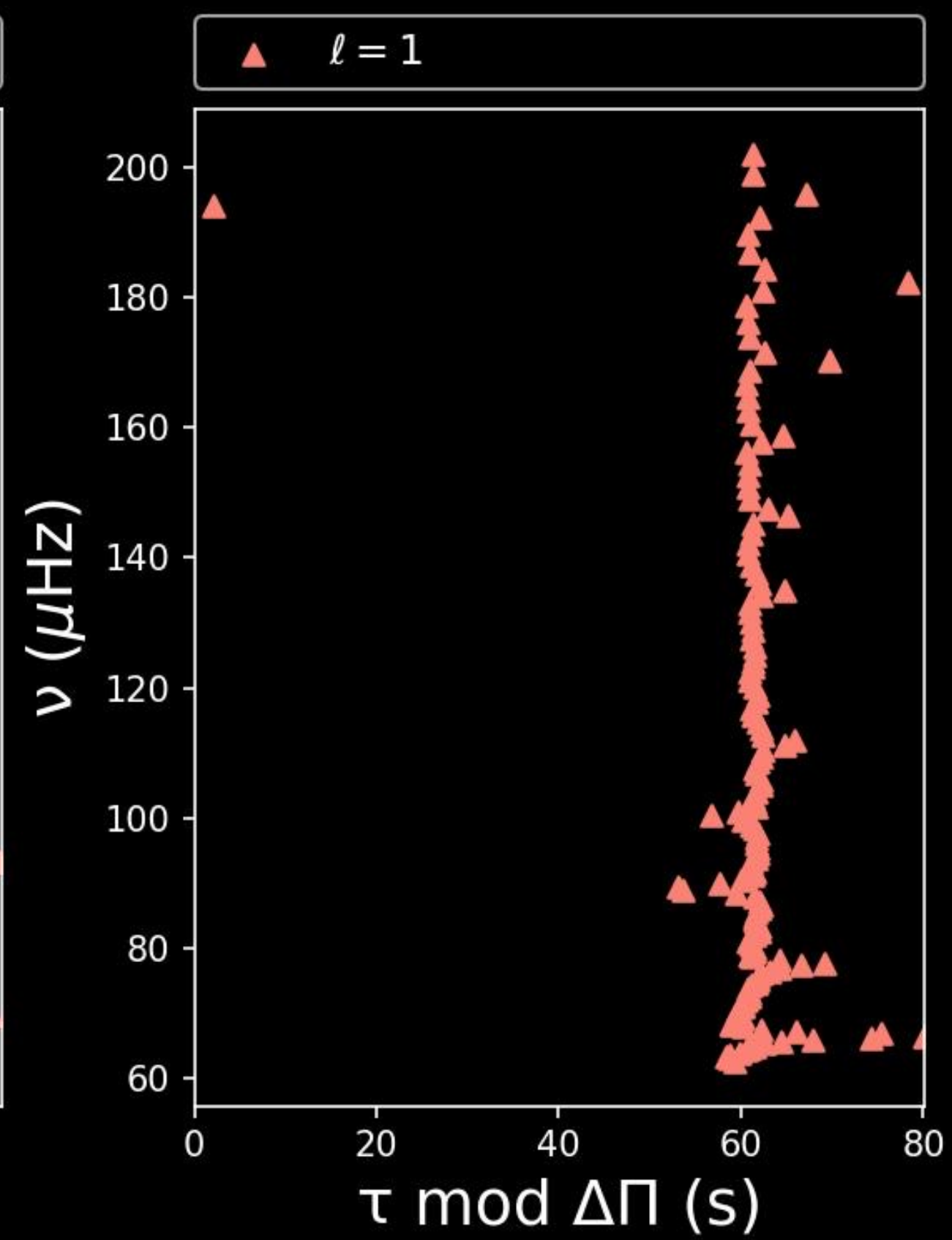
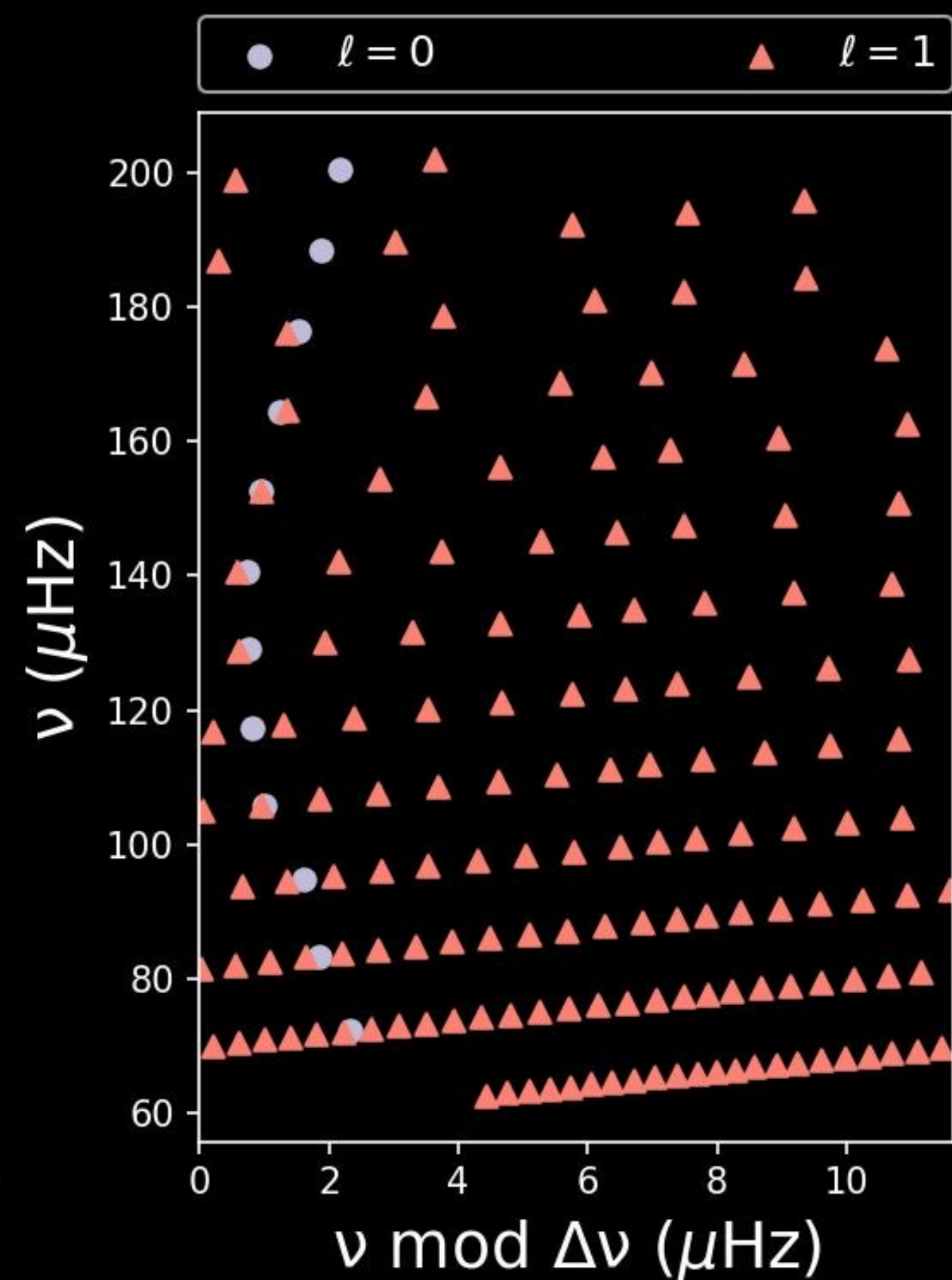
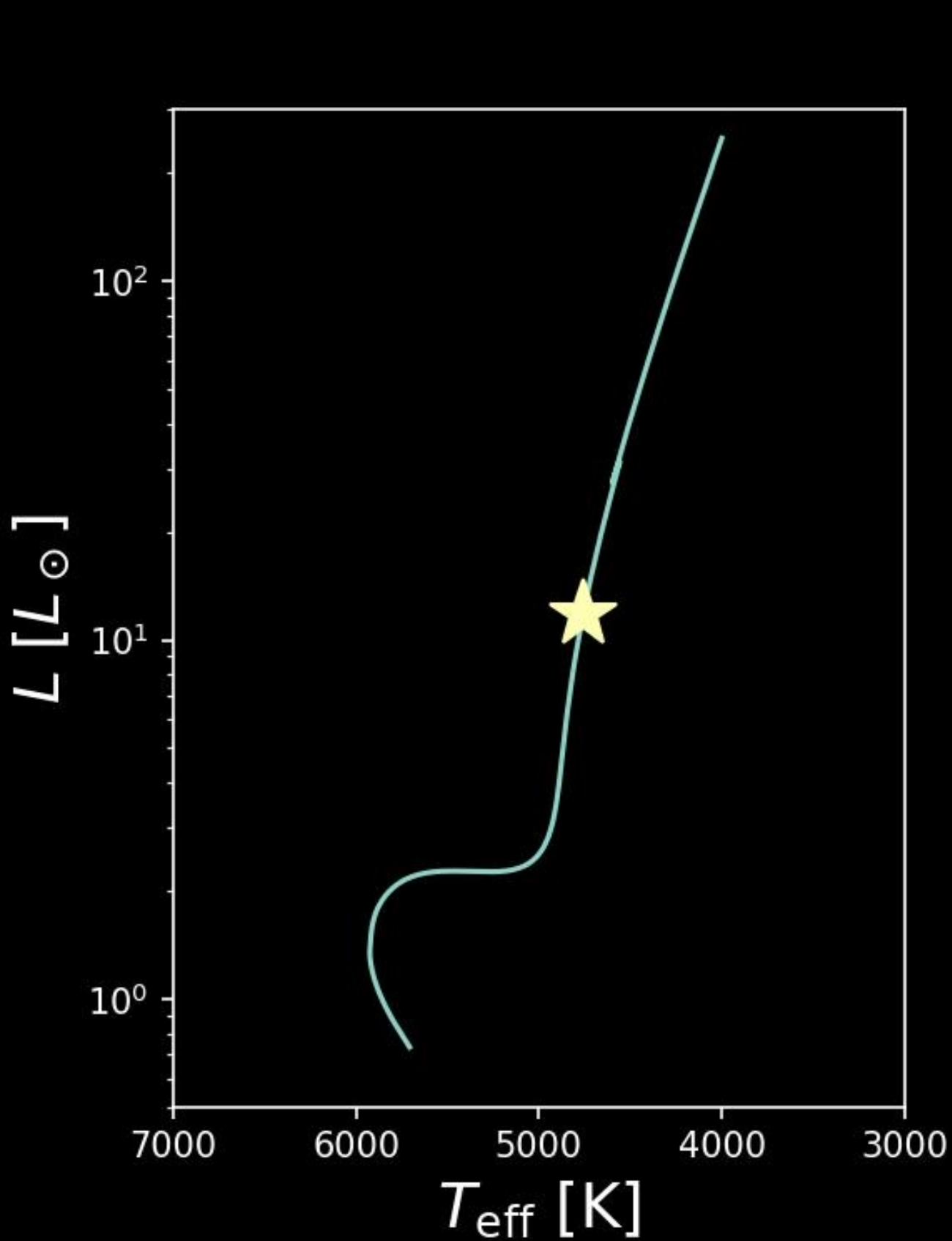
$$f(\nu_m, \nu_g) \equiv \nu_p$$



Evolution of stretched mixed modes

$$\tau(\nu_m, \nu_p) \equiv \nu_g^{-1}$$

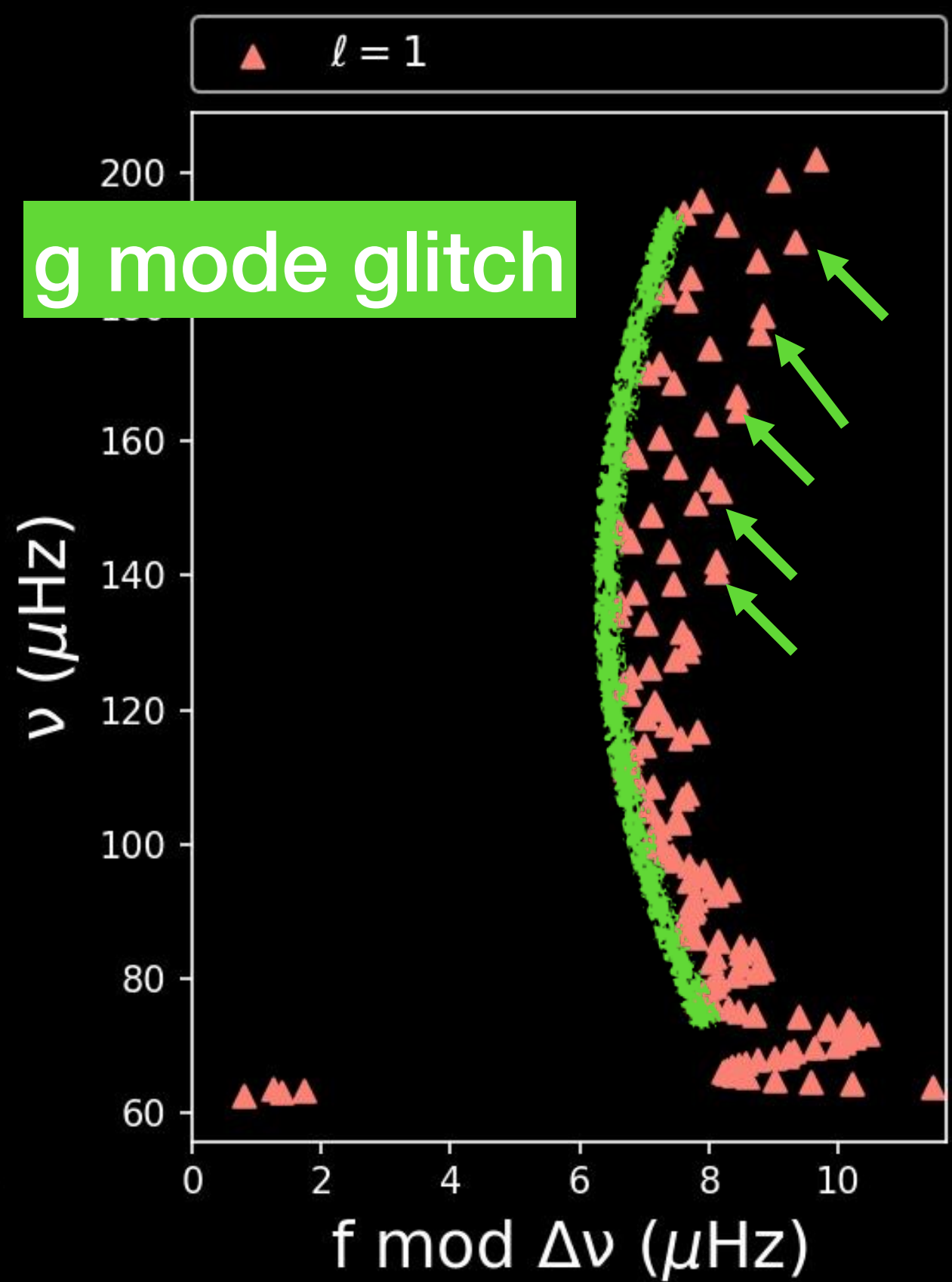
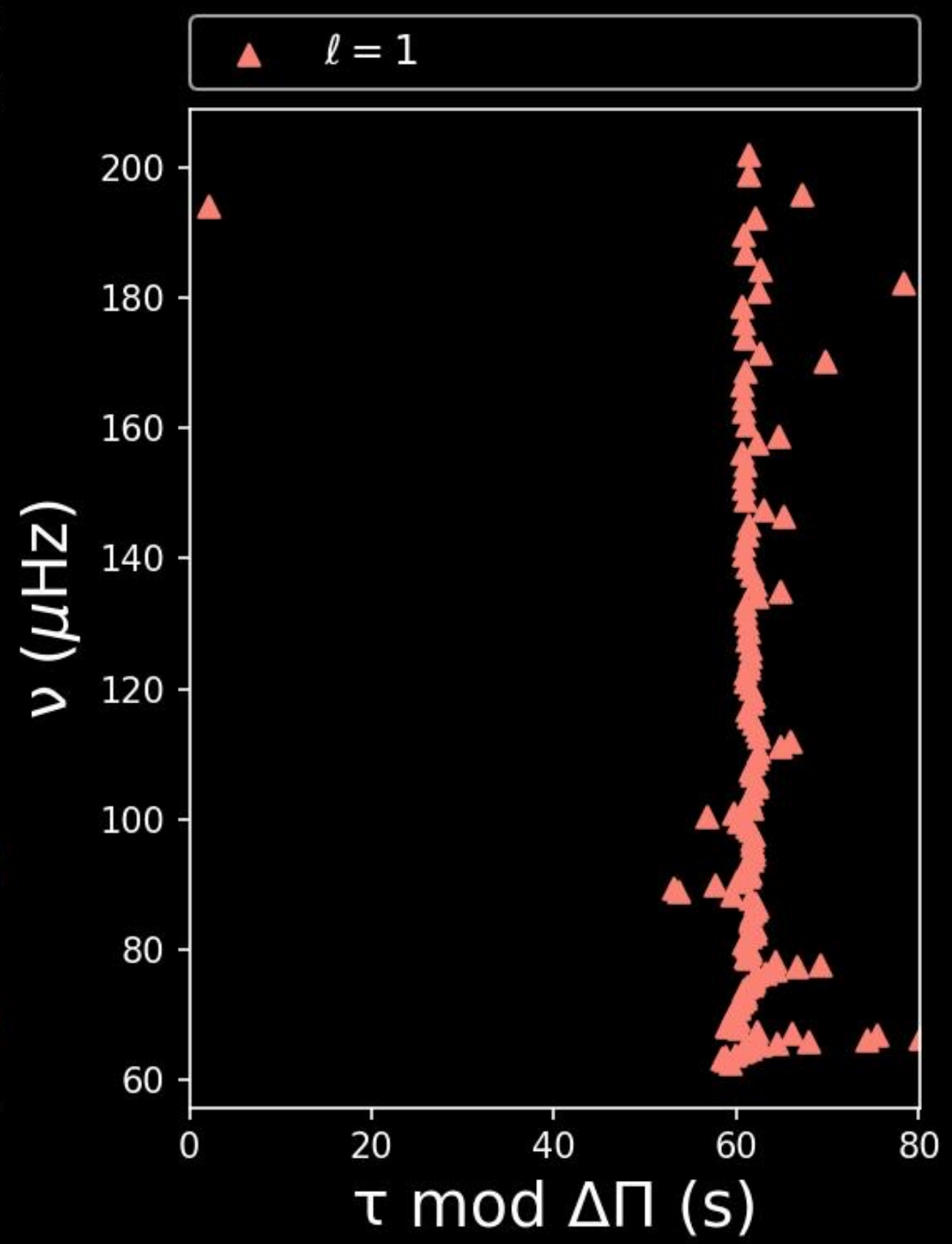
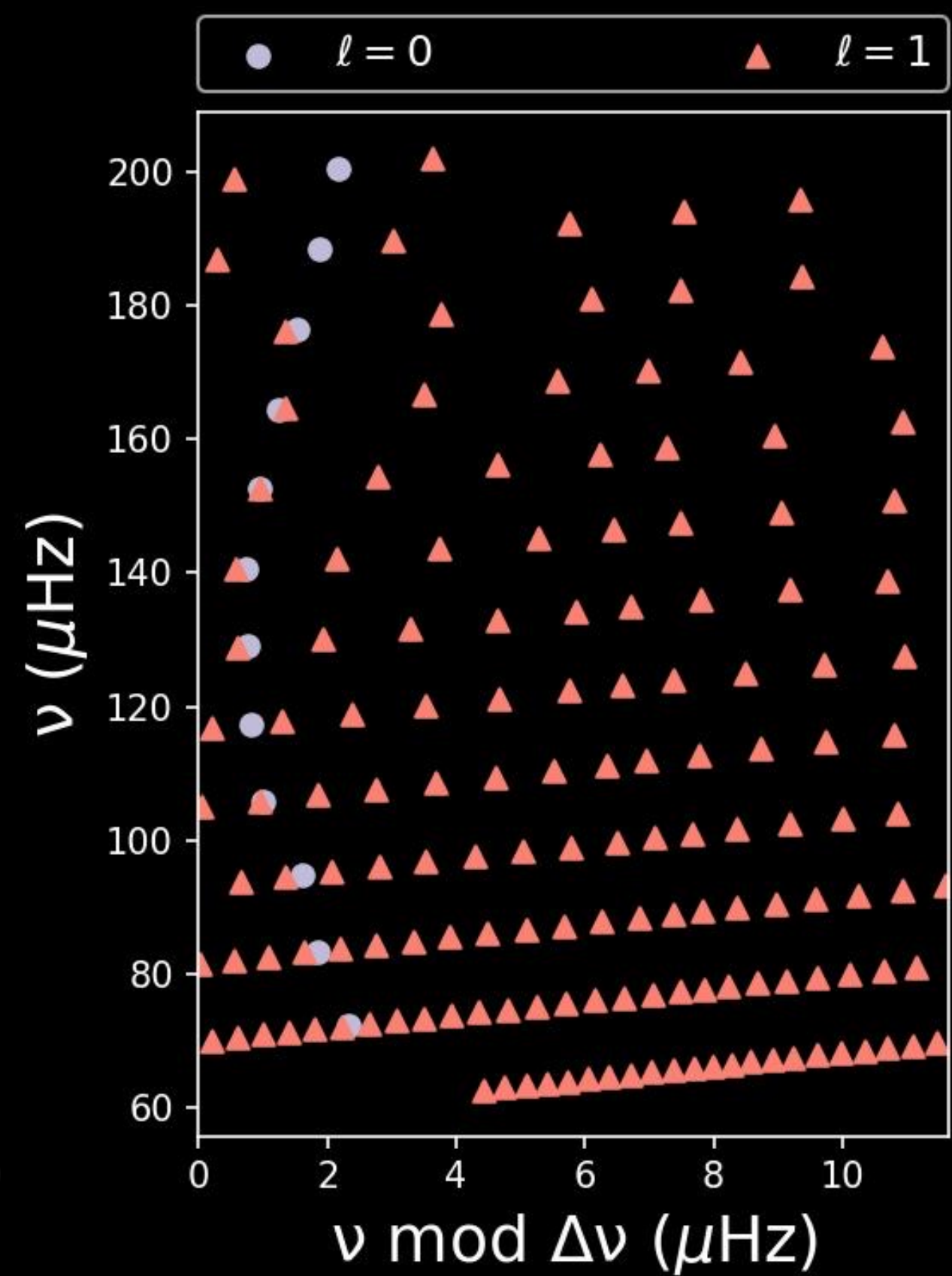
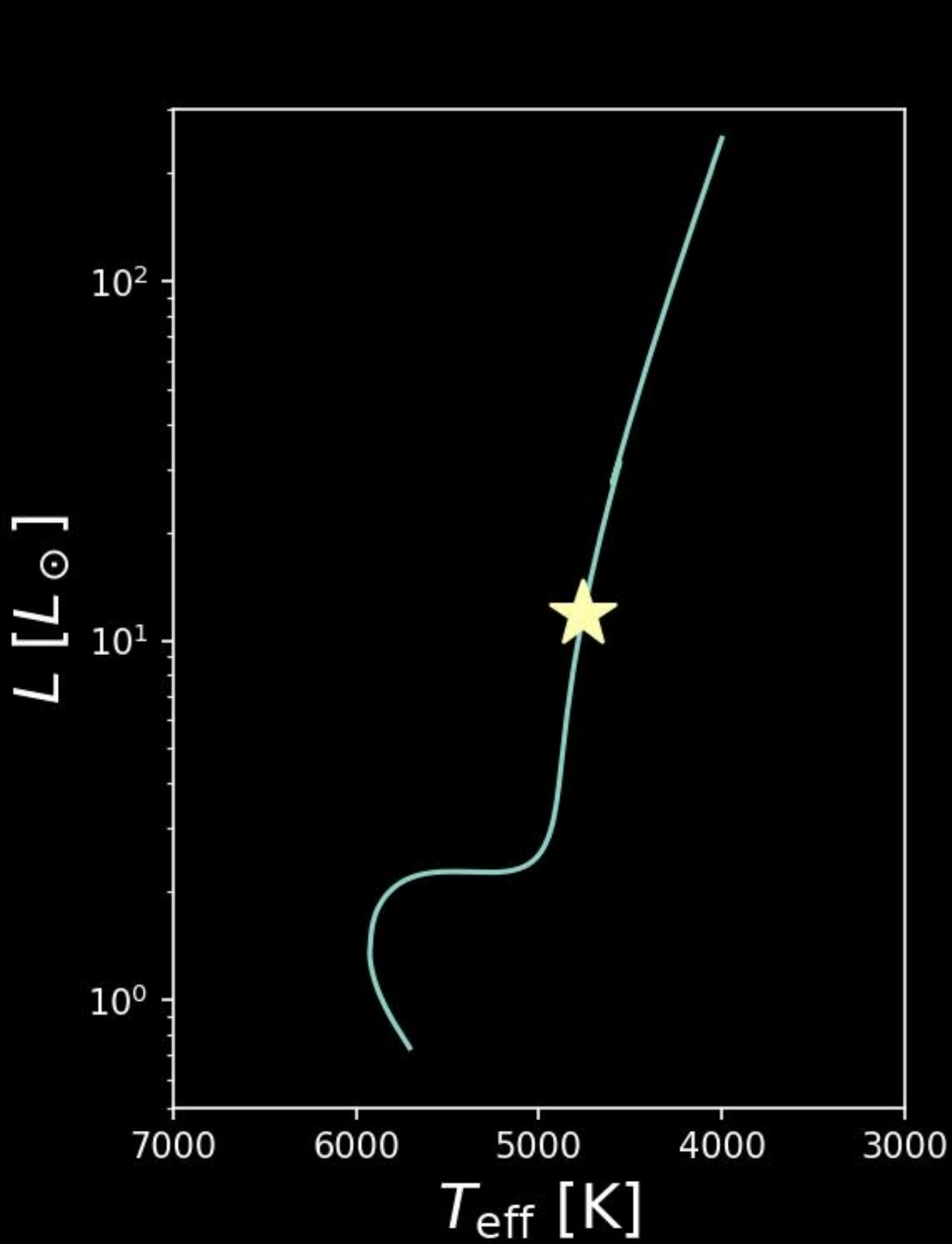
$$f(\nu_m, \nu_g) \equiv \nu_p$$



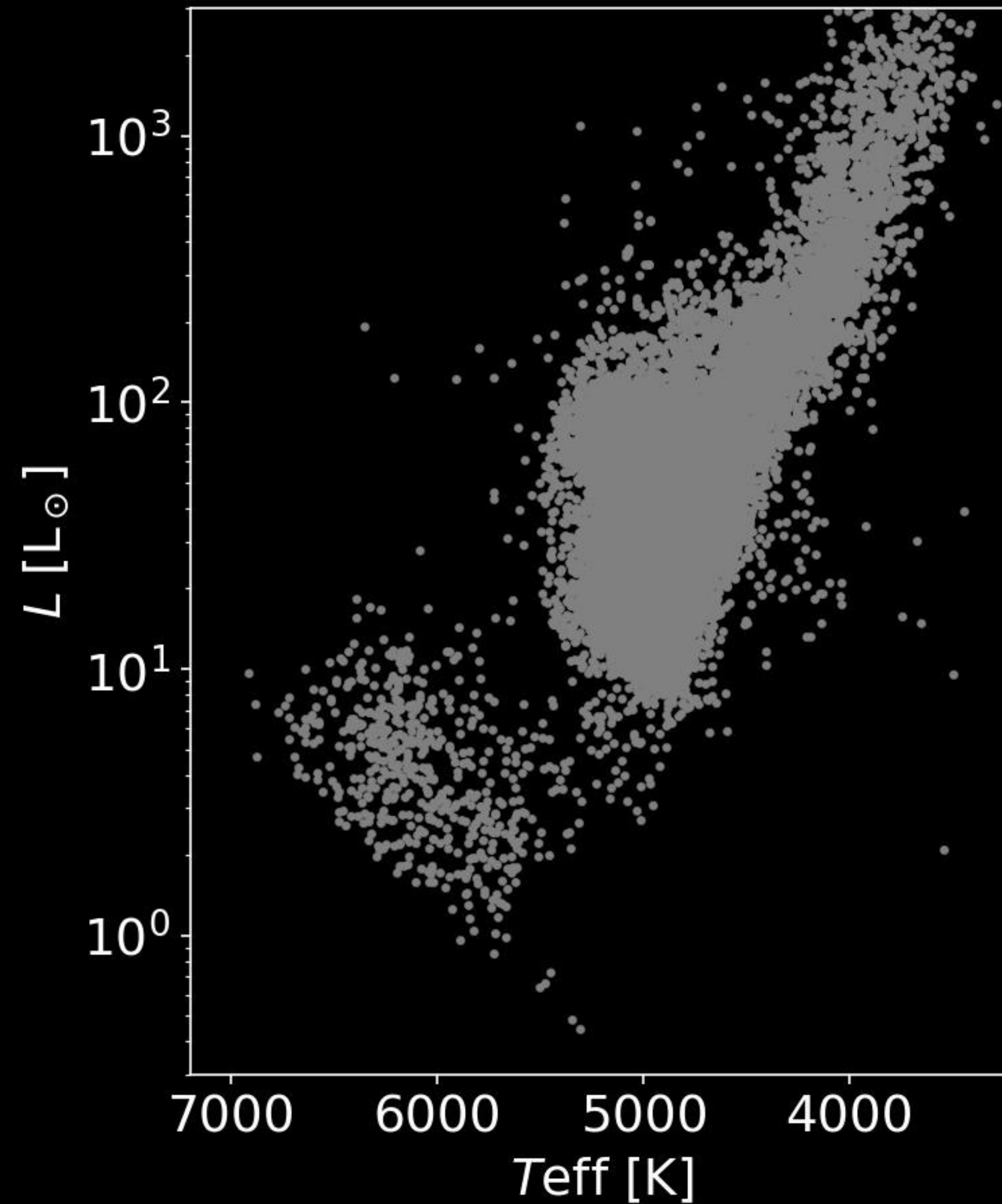
Evolution of stretched mixed modes

$$\tau(\nu_m, \nu_p) \equiv \nu_g^{-1}$$

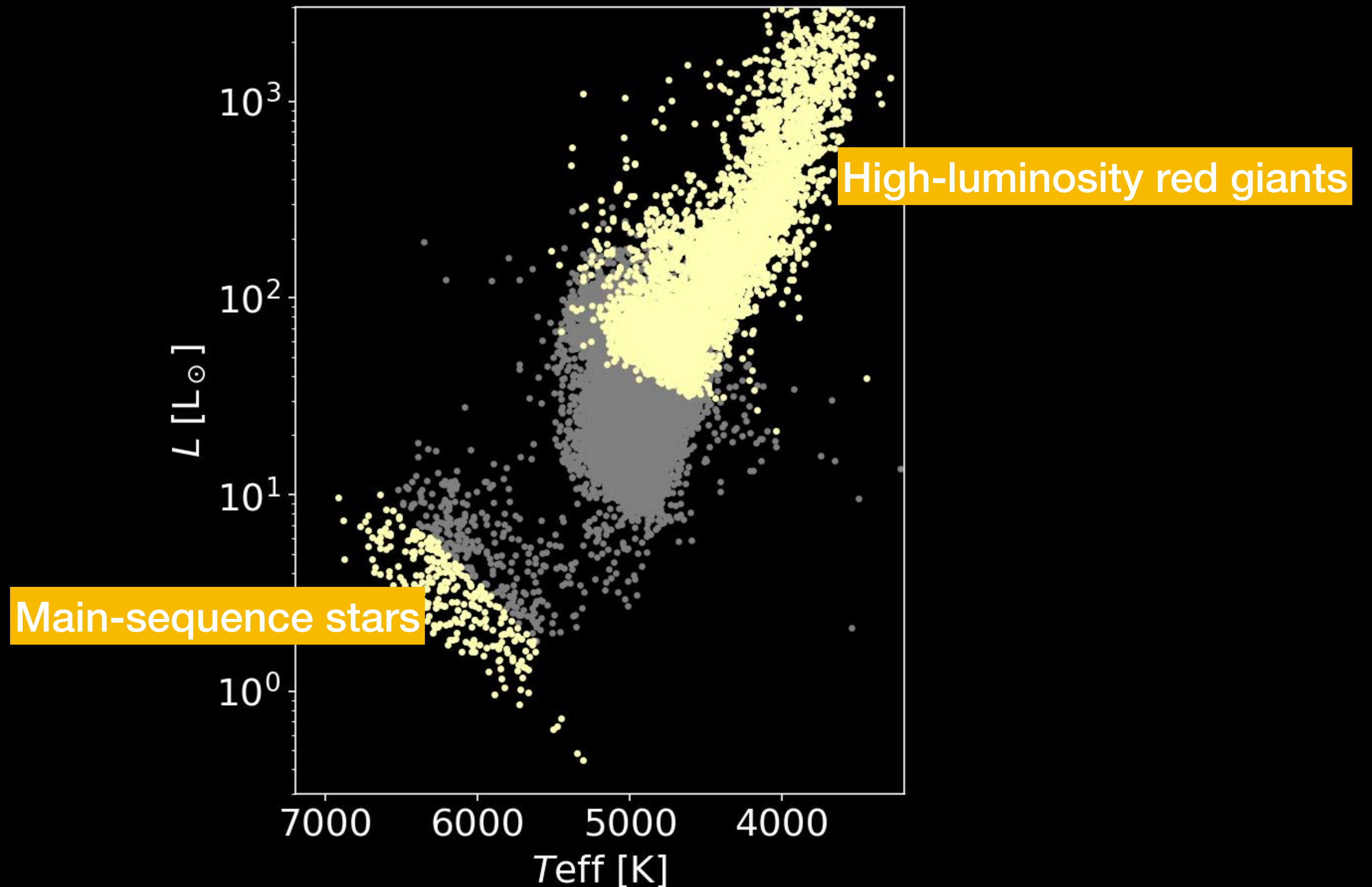
$$f(\nu_m, \nu_g) \equiv \nu_p$$



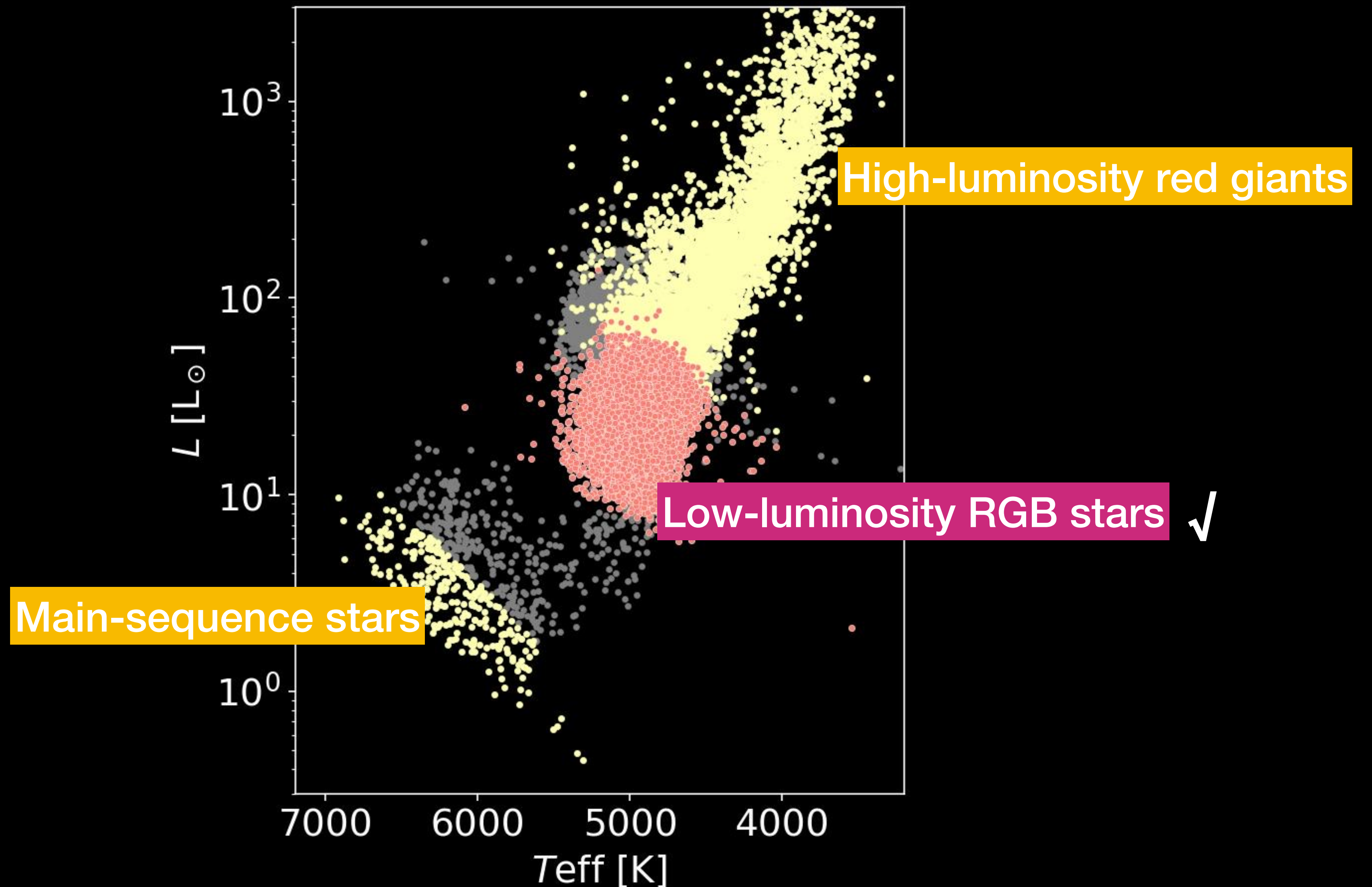
Where is this method relevant?



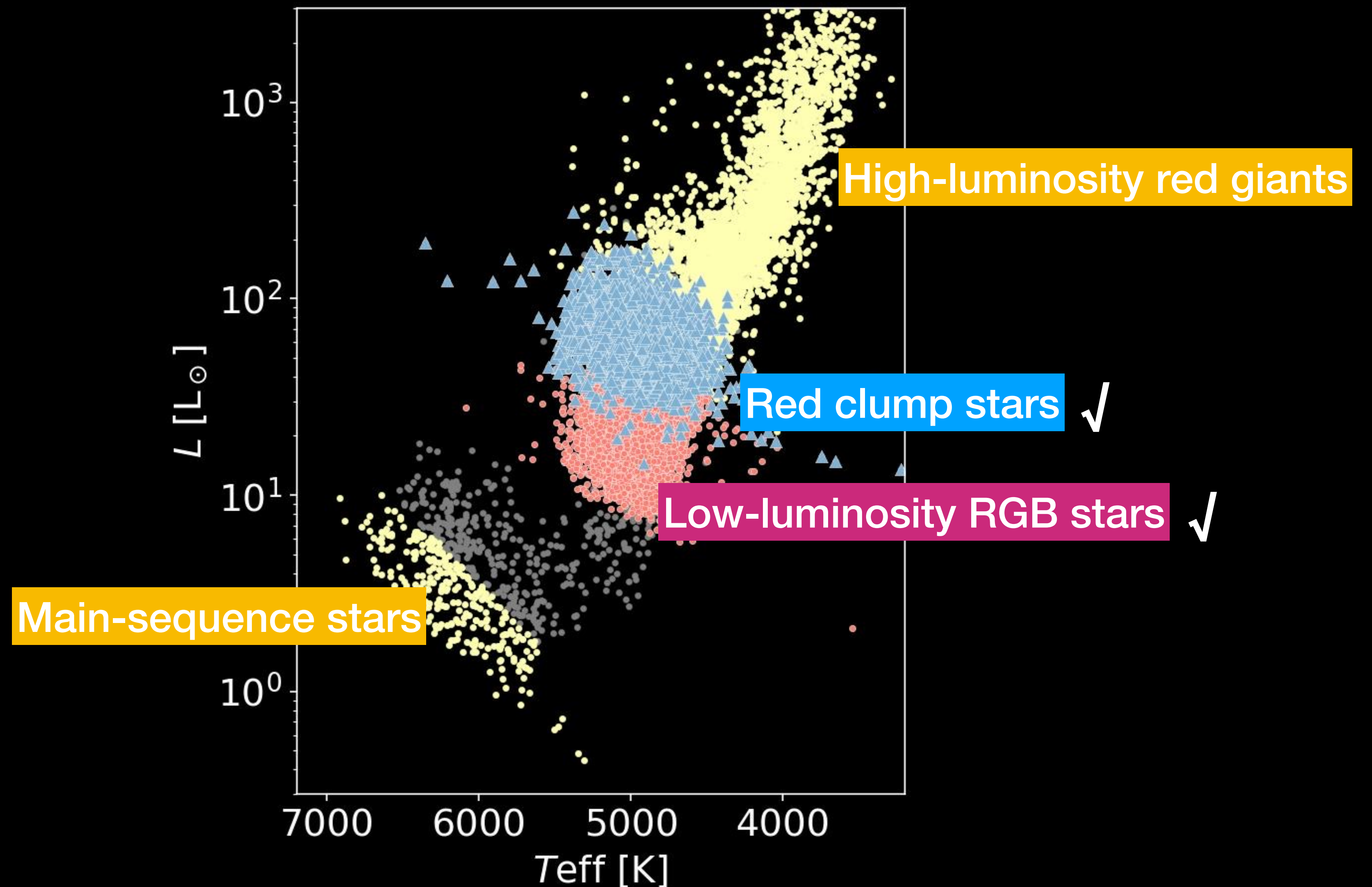
Where is this method relevant?



Where is this method relevant?



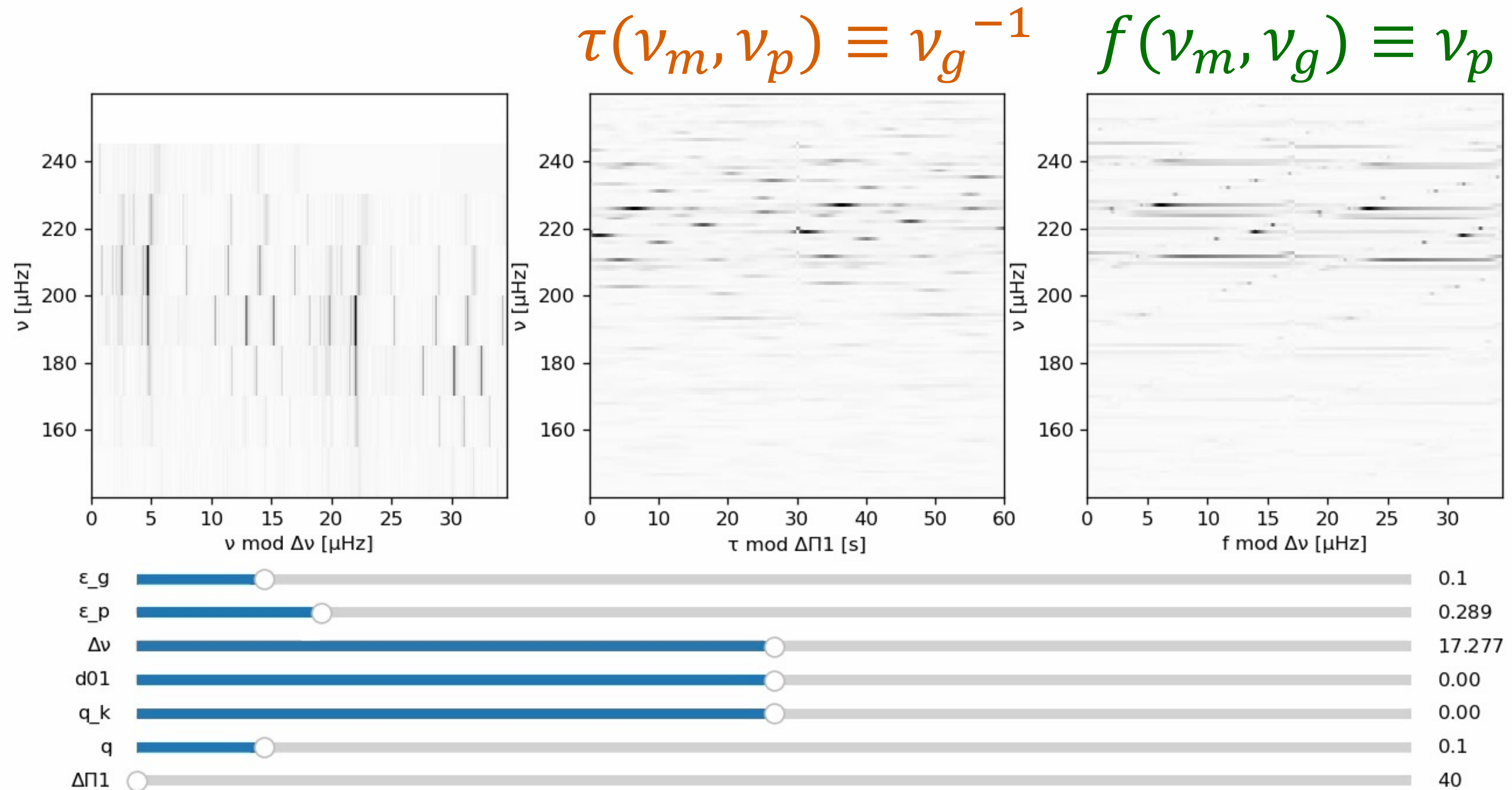
Where is this method relevant?



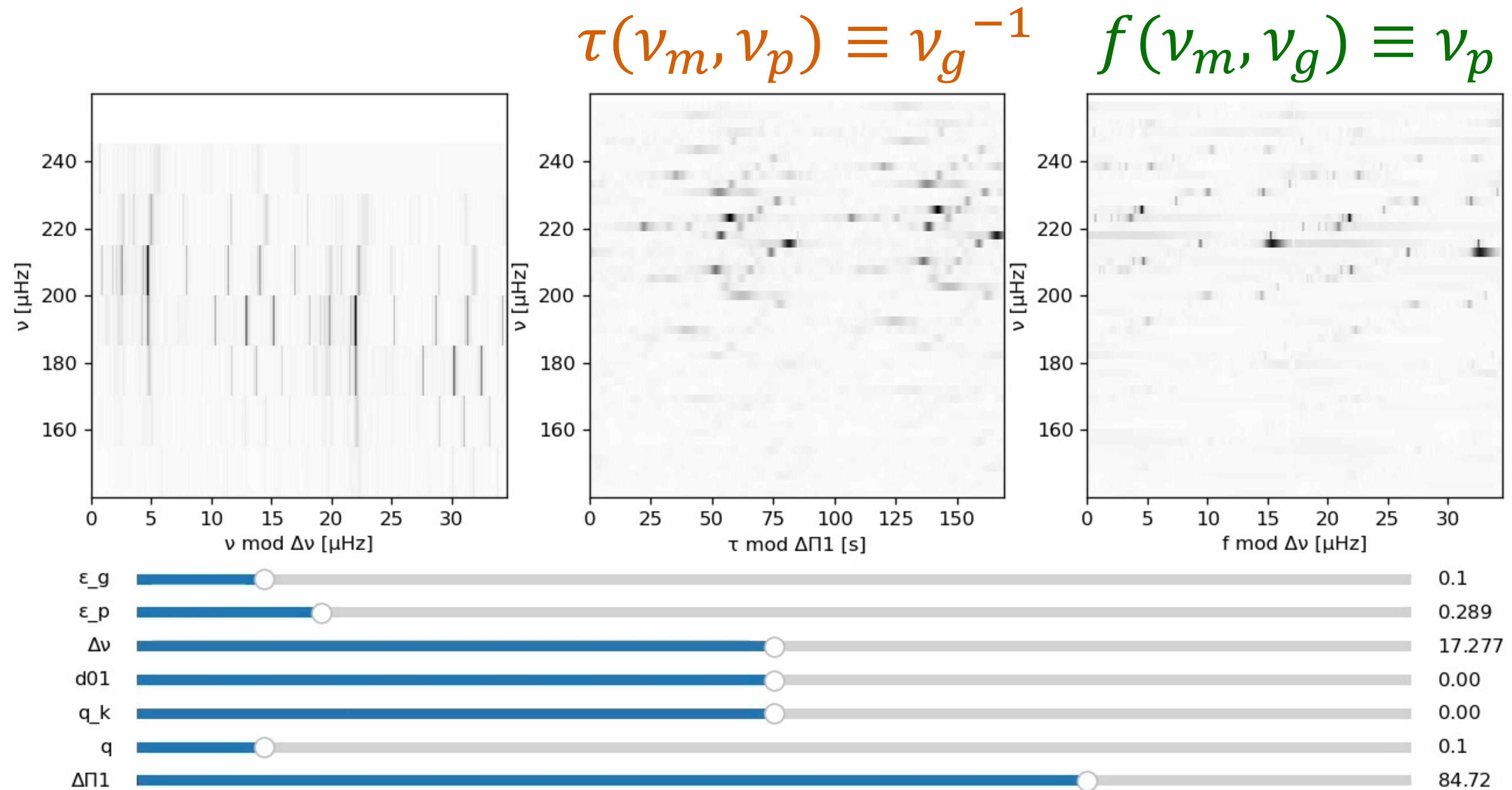
Applications

- ★ **Mode identification**
- ★ **Acoustic glitch**
- ★ **Asteroseismic model fitting**

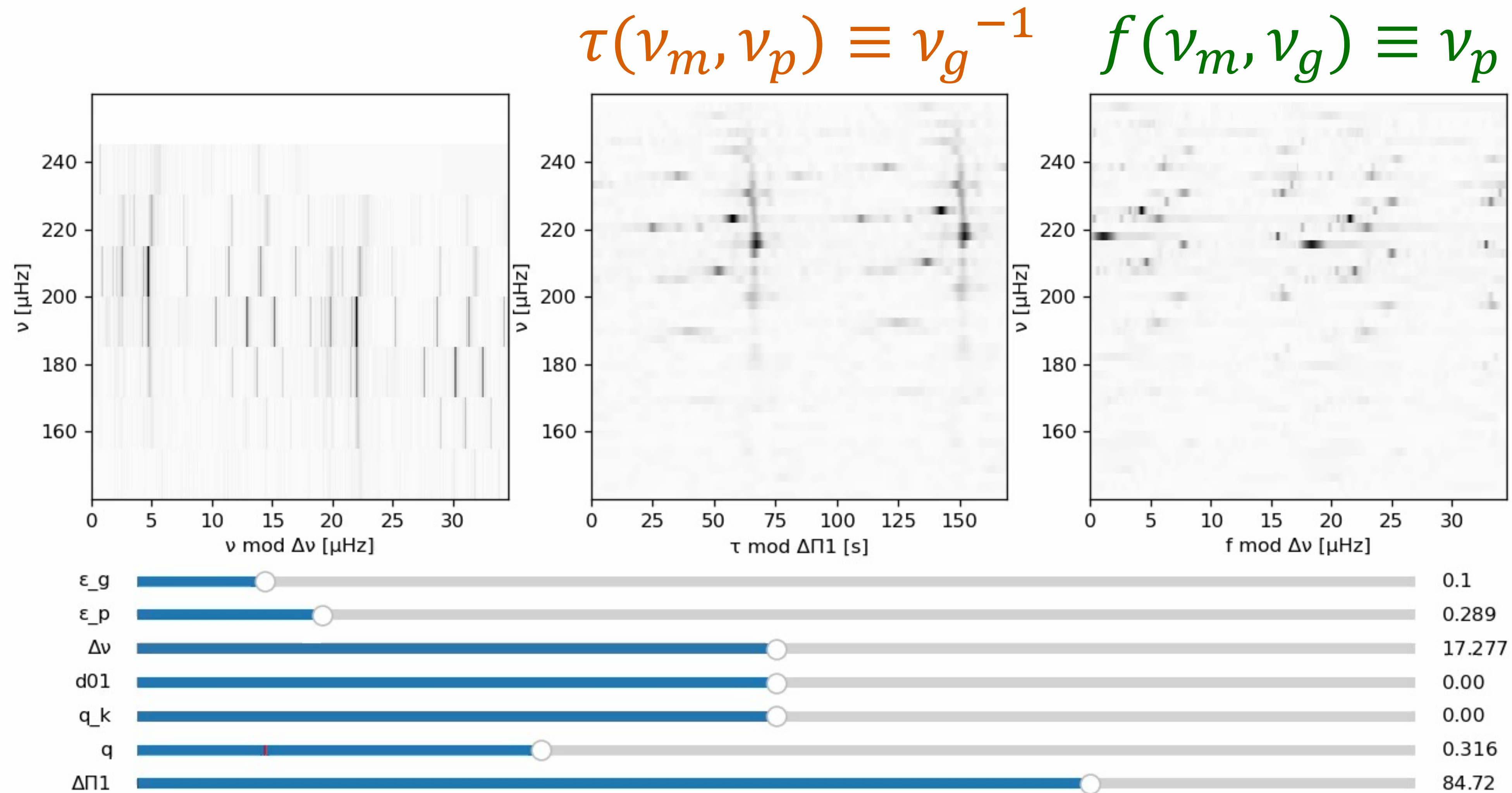
1. Mode Identification



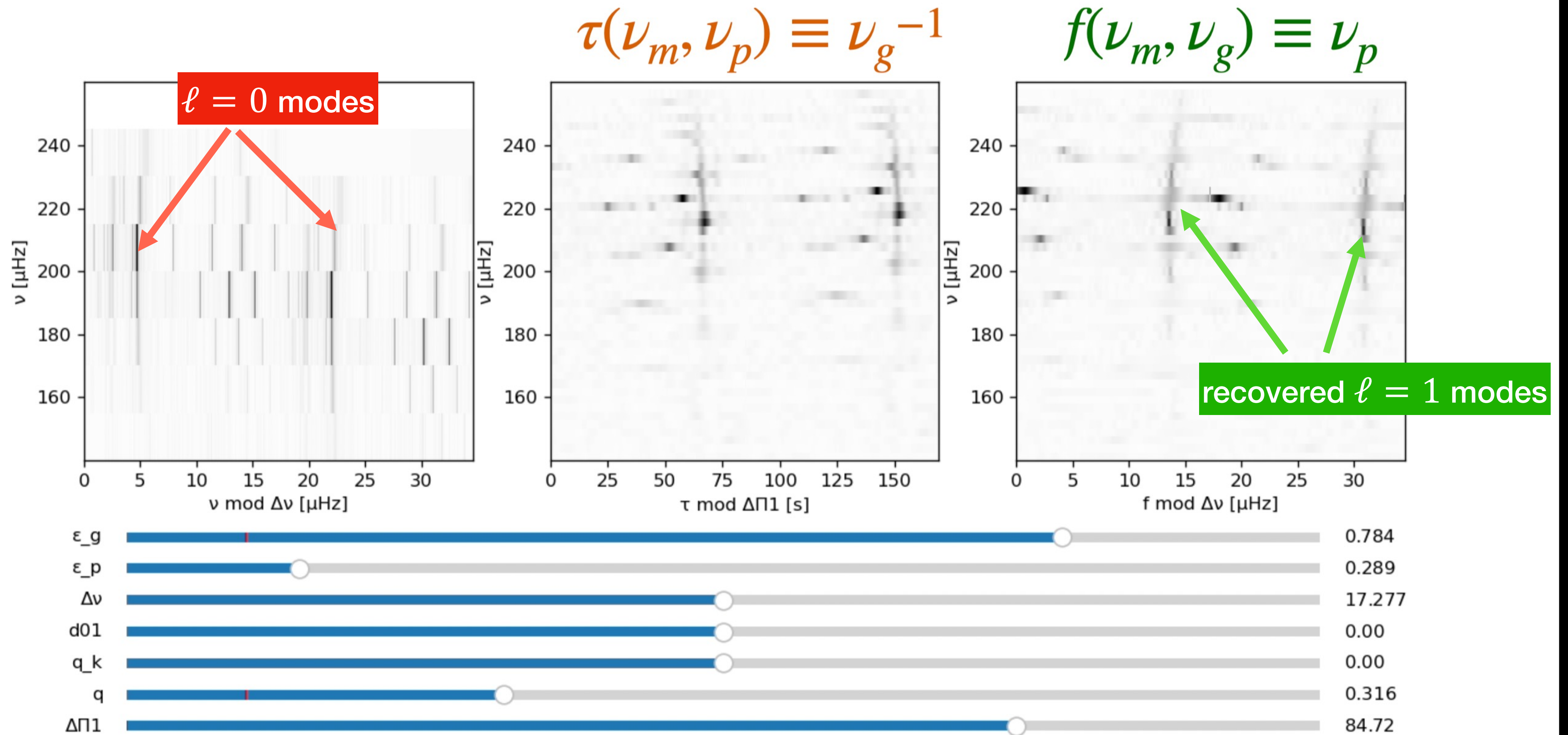
1. Mode Identification



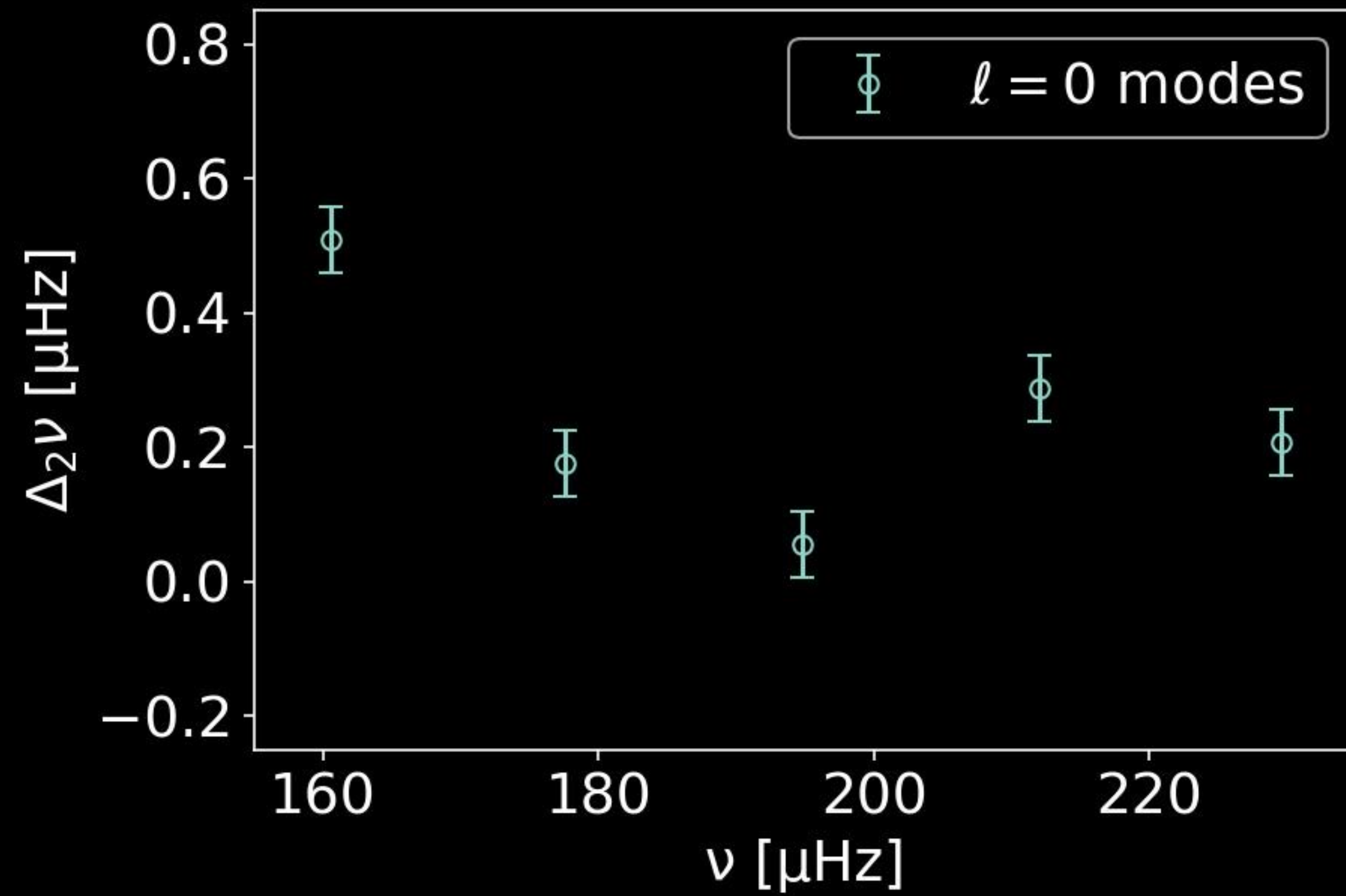
1. Mode Identification



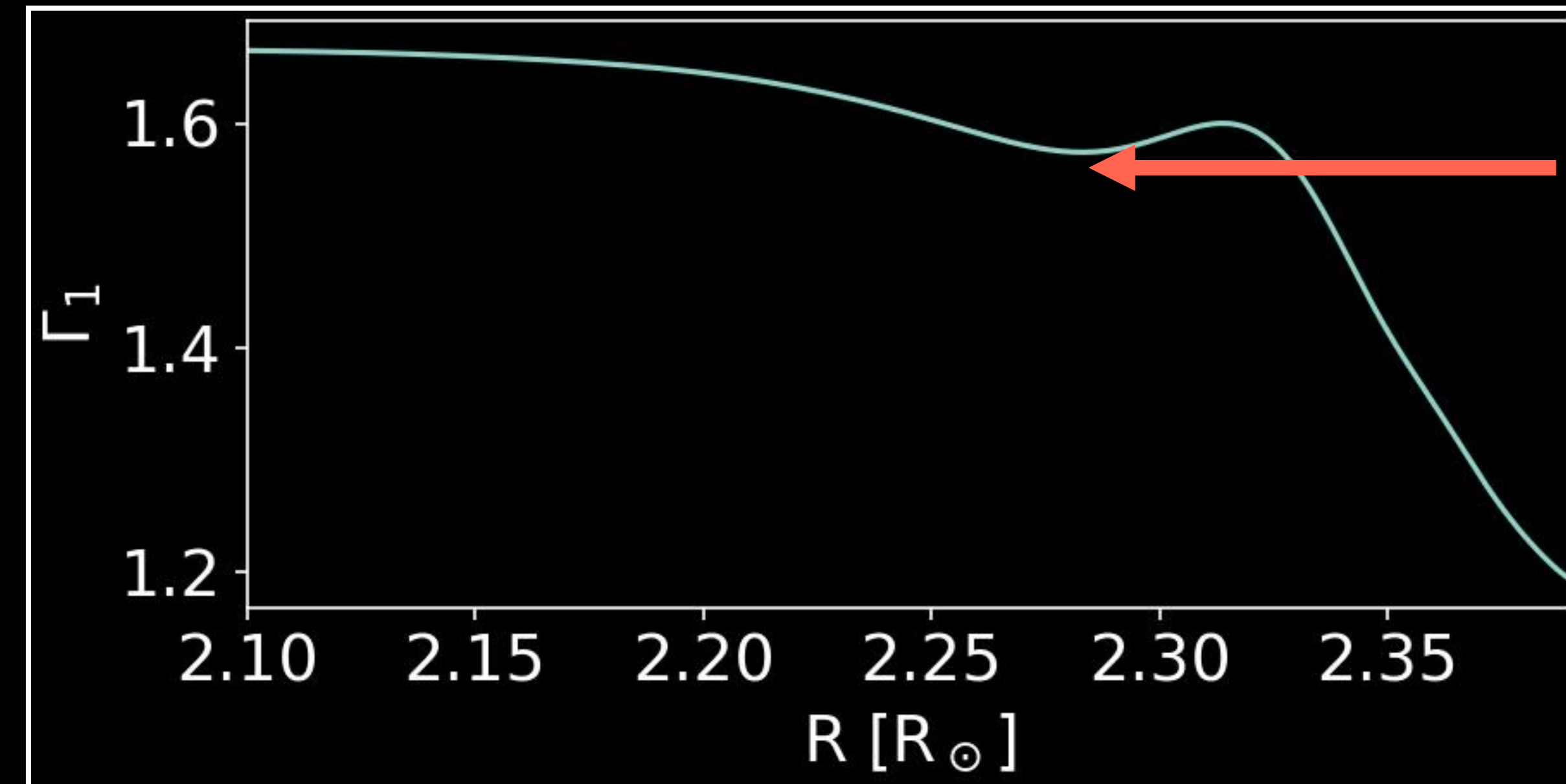
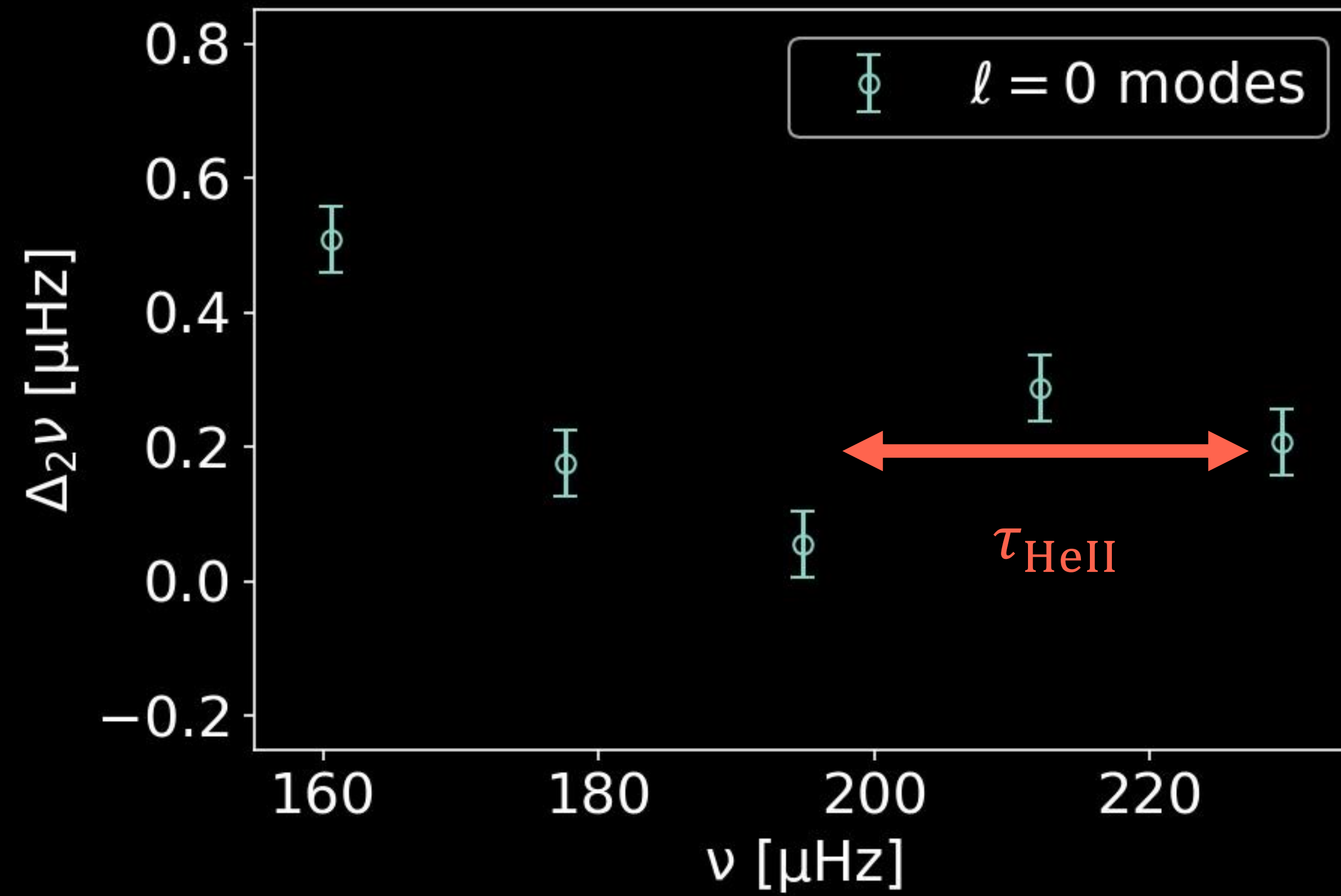
1. Mode Identification



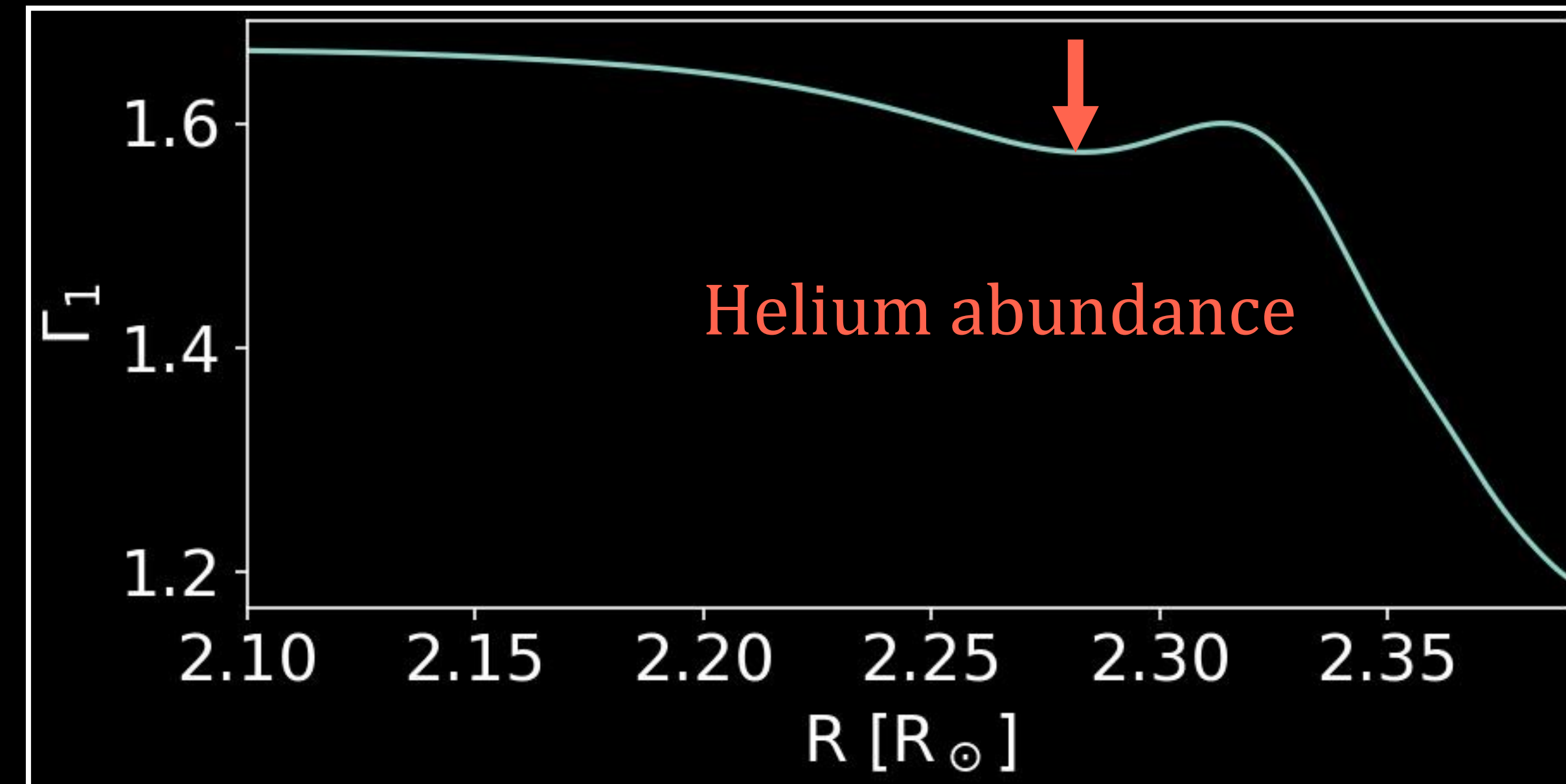
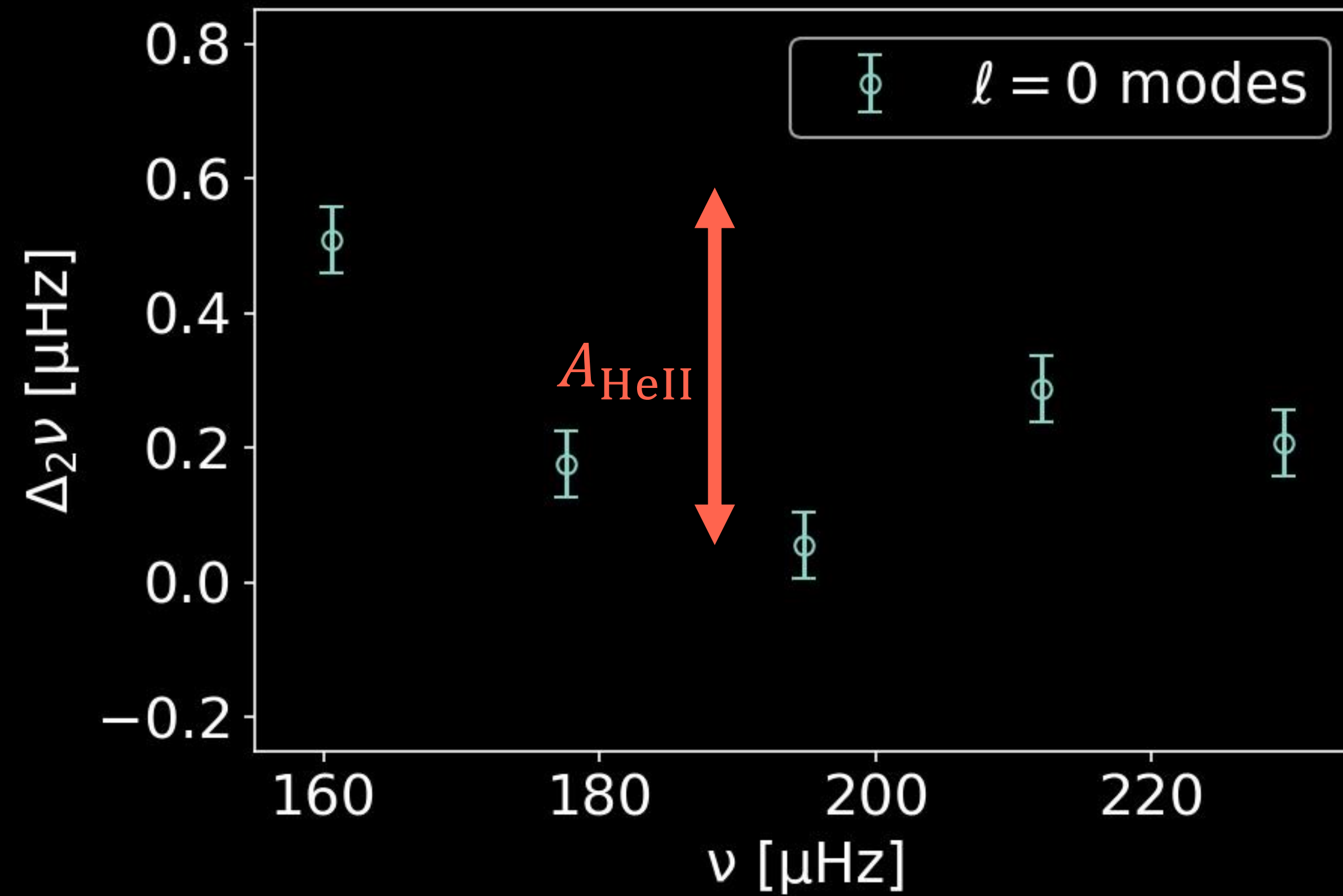
2. p-mode (acoustic) glitch



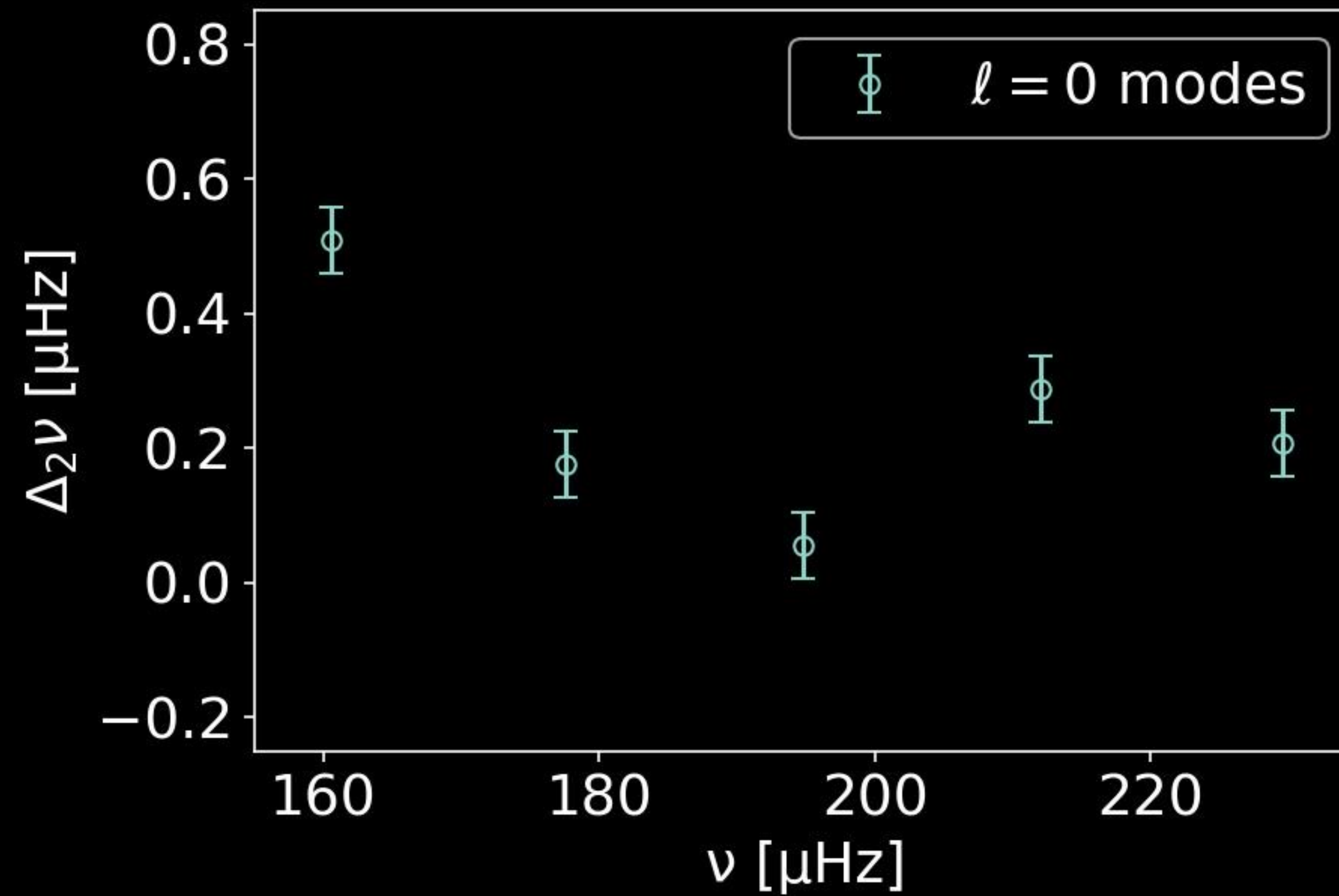
2. p-mode (acoustic) glitch



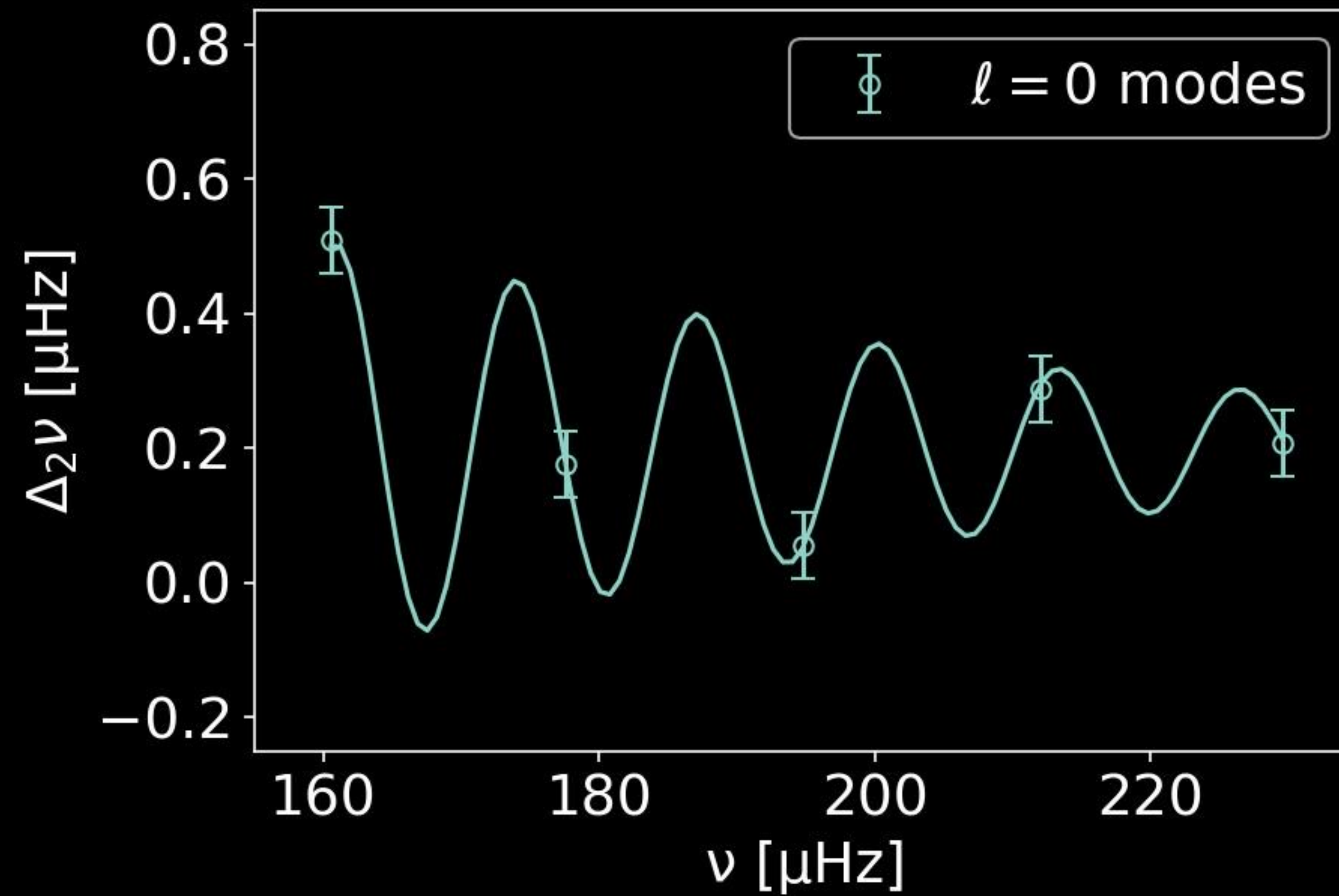
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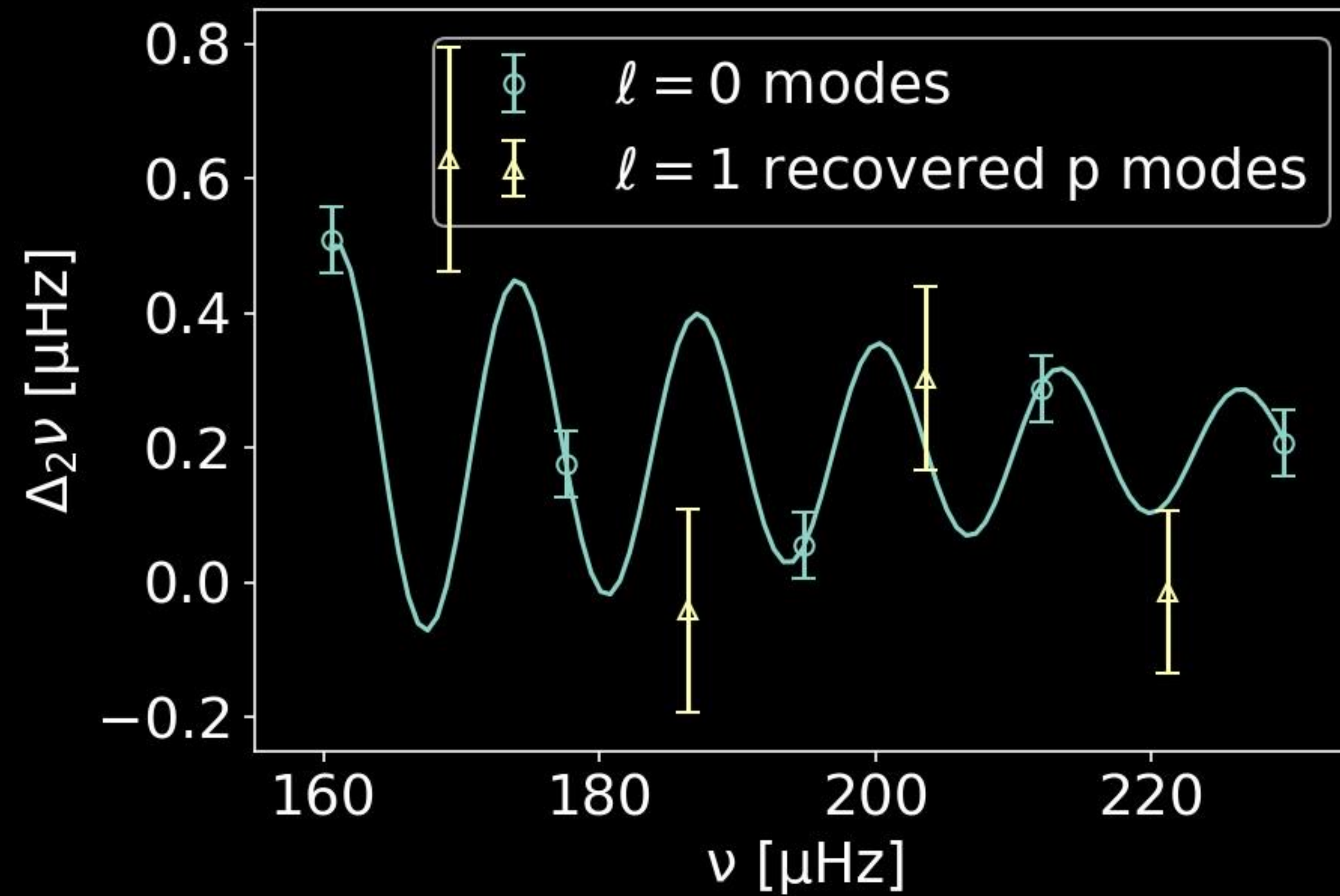
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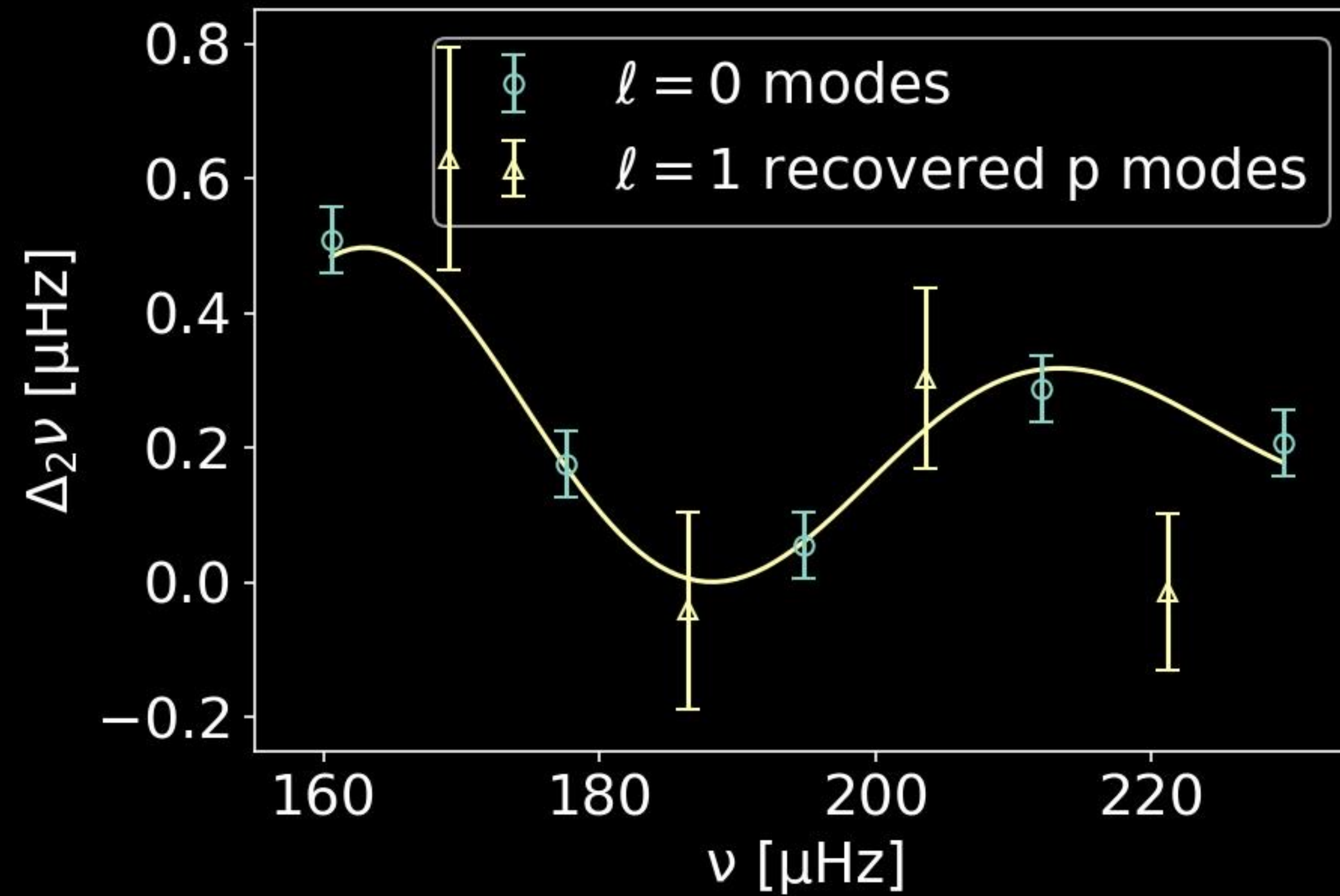
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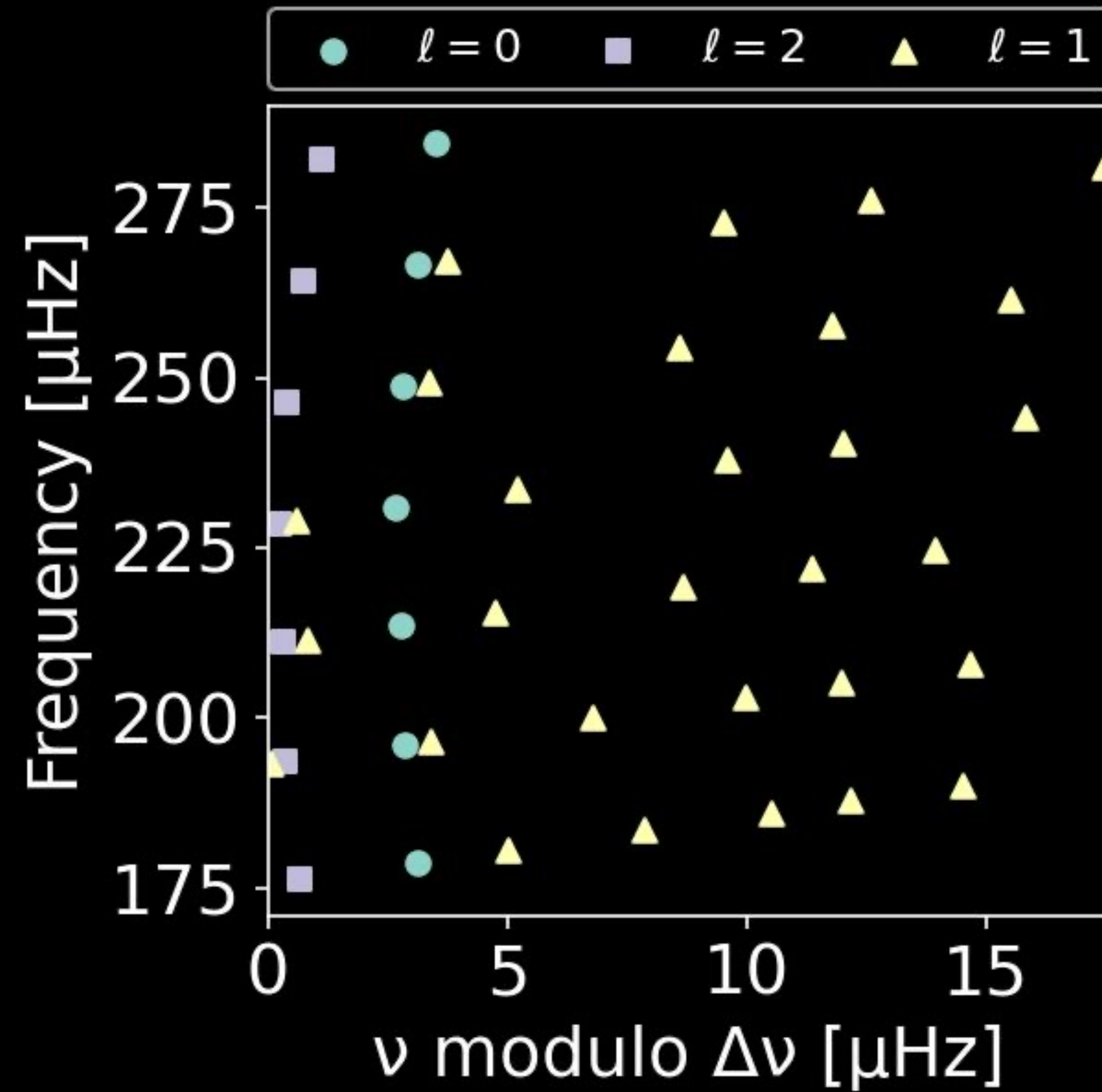
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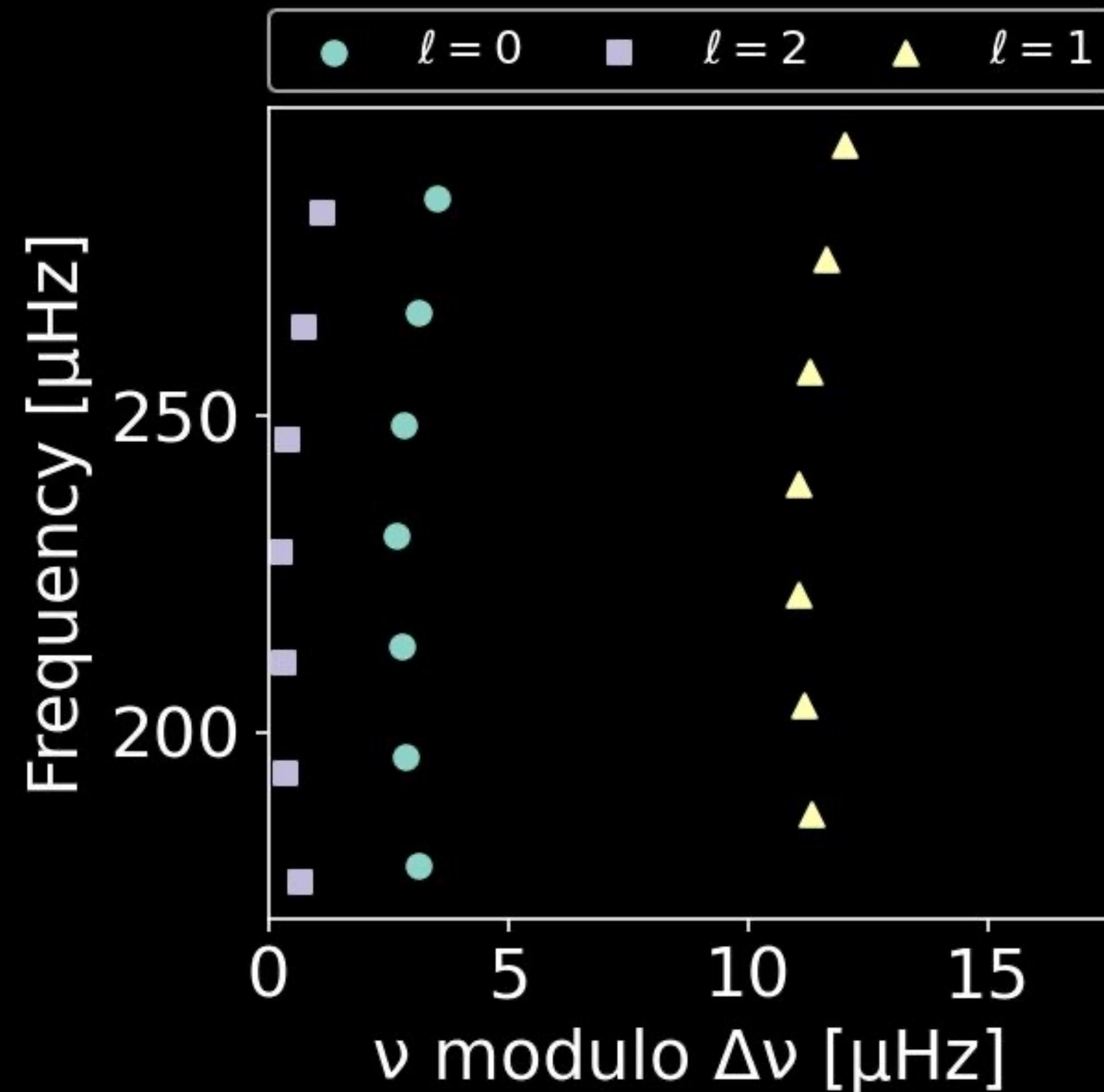
2. p-mode (acoustic) glitch



3. asteroseismic model fitting

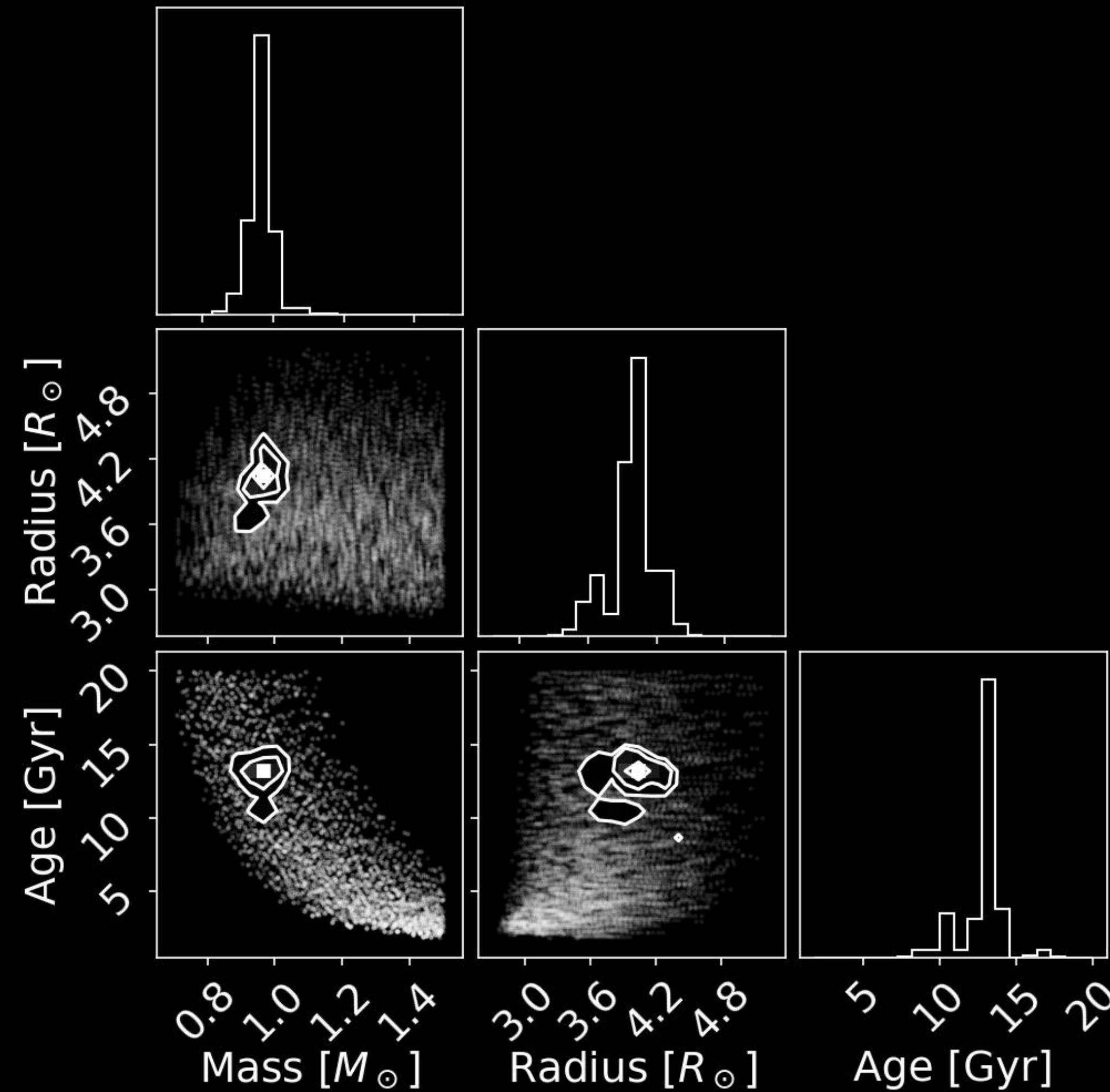


3. asteroseismic model fitting



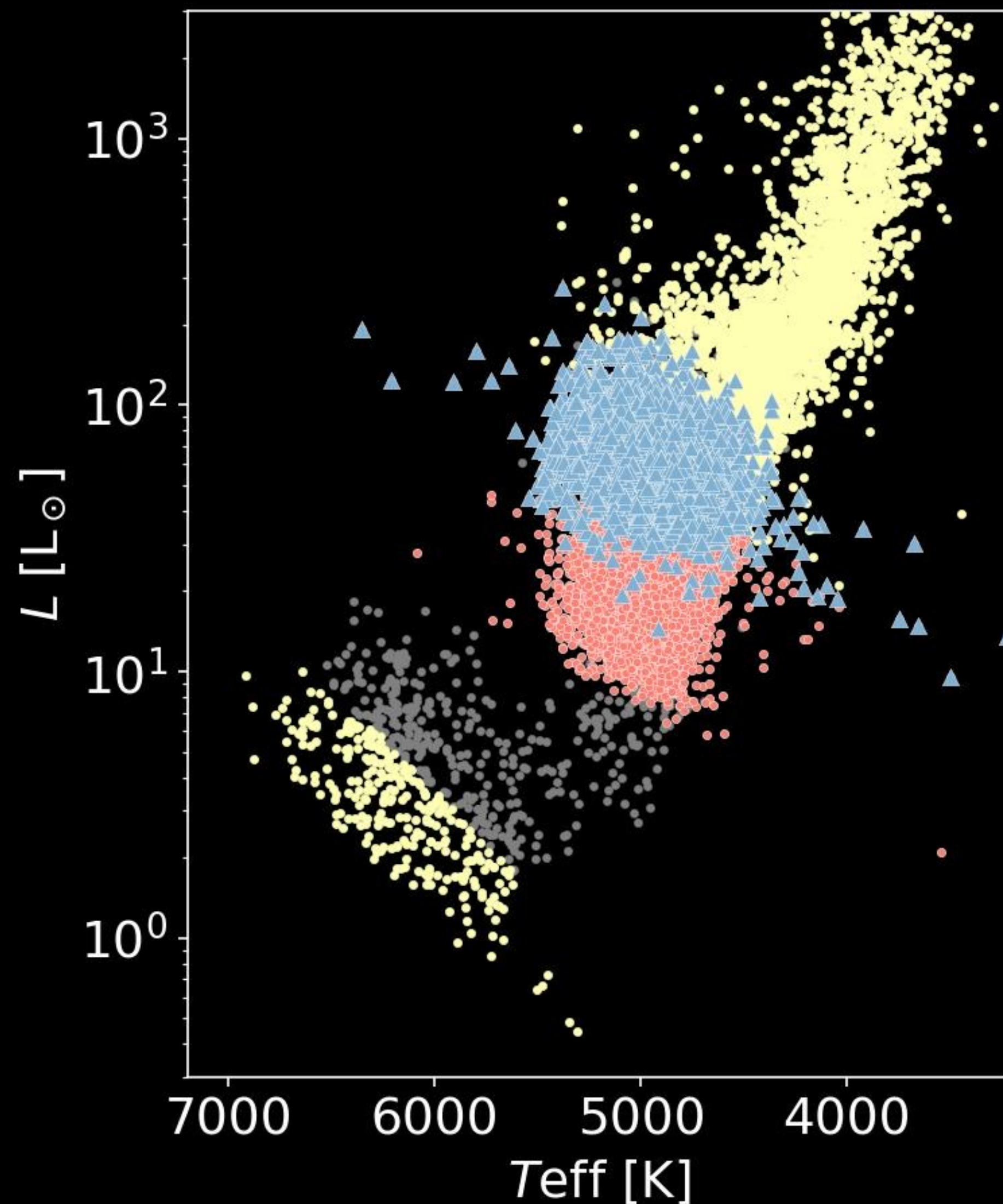
r_{01}, r_{02}

3. asteroseismic model fitting



r_{01}, r_{02}

Summary



- Stretched frequency recovers pure p mode frequency in red giants.
- Applications include:
 - Mode identification
 - Robust estimation of acoustic glitch
 - p-mode modelling for red giants
- Ensemble p-mode asteroseismology!