



Space-Inn School on Astero/Helioseismology
and Stellar/Solar Physics

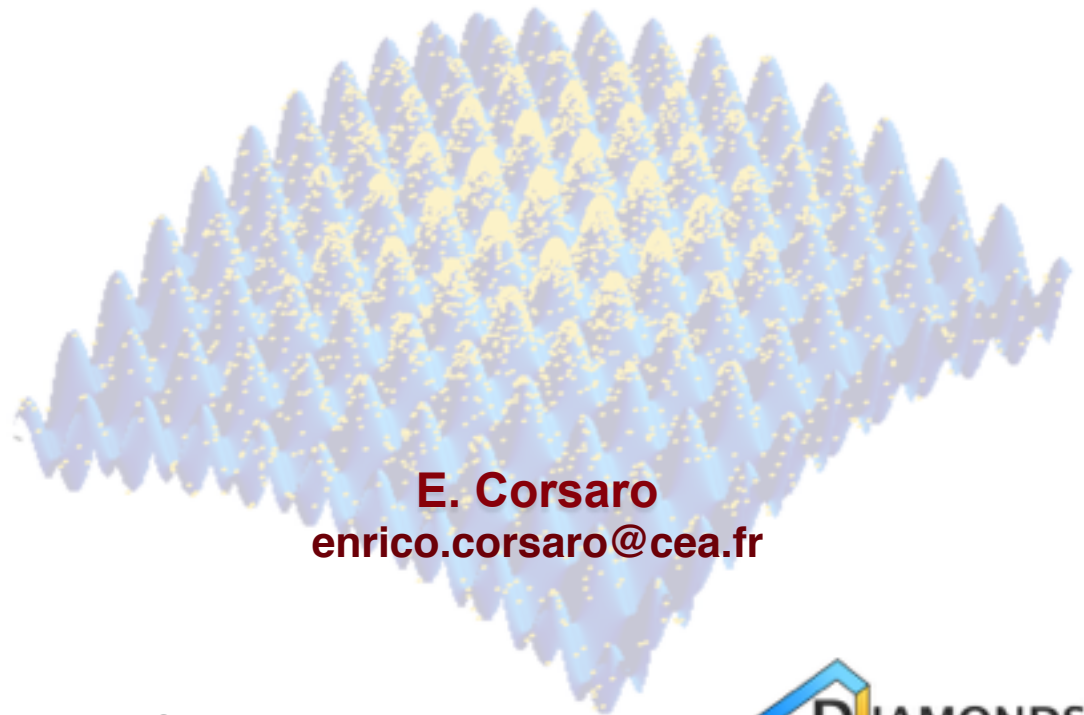
DE LA RECHERCHE À L'INDUSTRIE



Institute of Research into the
Fundamental Laws of the Universe
Astrophysics Division

www.cea.fr

Bayesian vs. frequentist statistics and asteroseismic data analysis



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DSM/IRFU/SAp
27 OCTOBER 2015



1. - BAYESIAN STATISTICS

2. - NESTED SAMPLING MONTE CARLO

3. - THE DIAMONDS CODE

4. - FITTING A PSD: BACKGROUND COMPONENTS

5. - FITTING A PSD: THE OSCILLATION MODES

The background model equation for a *Kepler* star

$$H_{\text{osc}} \exp \left[-\frac{(\nu - \nu_{\text{max}})^2}{2\sigma_{\text{env}}^2} \right]$$

$$G(\nu)$$

Gaussian envelope oscillations

$$\sum_{i=1}^3 \frac{\xi a_i^2 / b_i}{1 + (\nu / b_i)^4}$$

$$B(\nu)$$

super-Lorentzian profiles

W Photon noise (flat)

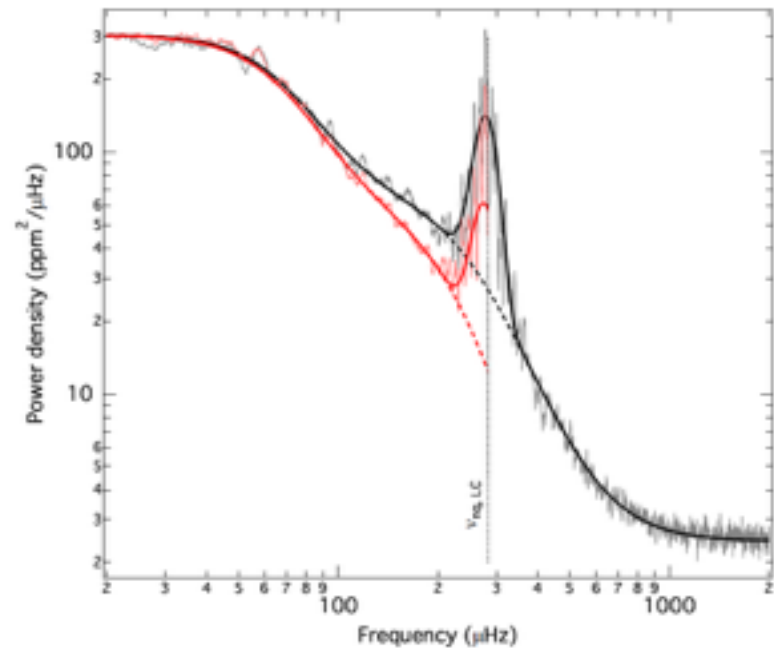
4. - FITTING A PSD: BACKGROUND COMPONENTS

The background model equation

$$P_{\text{bkg}}(\nu) = [G(\nu) + B(\nu)]R(\nu) + W$$

$$R(\nu) = \sin^2 \left(\frac{\pi \nu}{2\nu_{\text{Nyq}}} \right)$$

Apodization - Decrease of the signal for discrete time observations

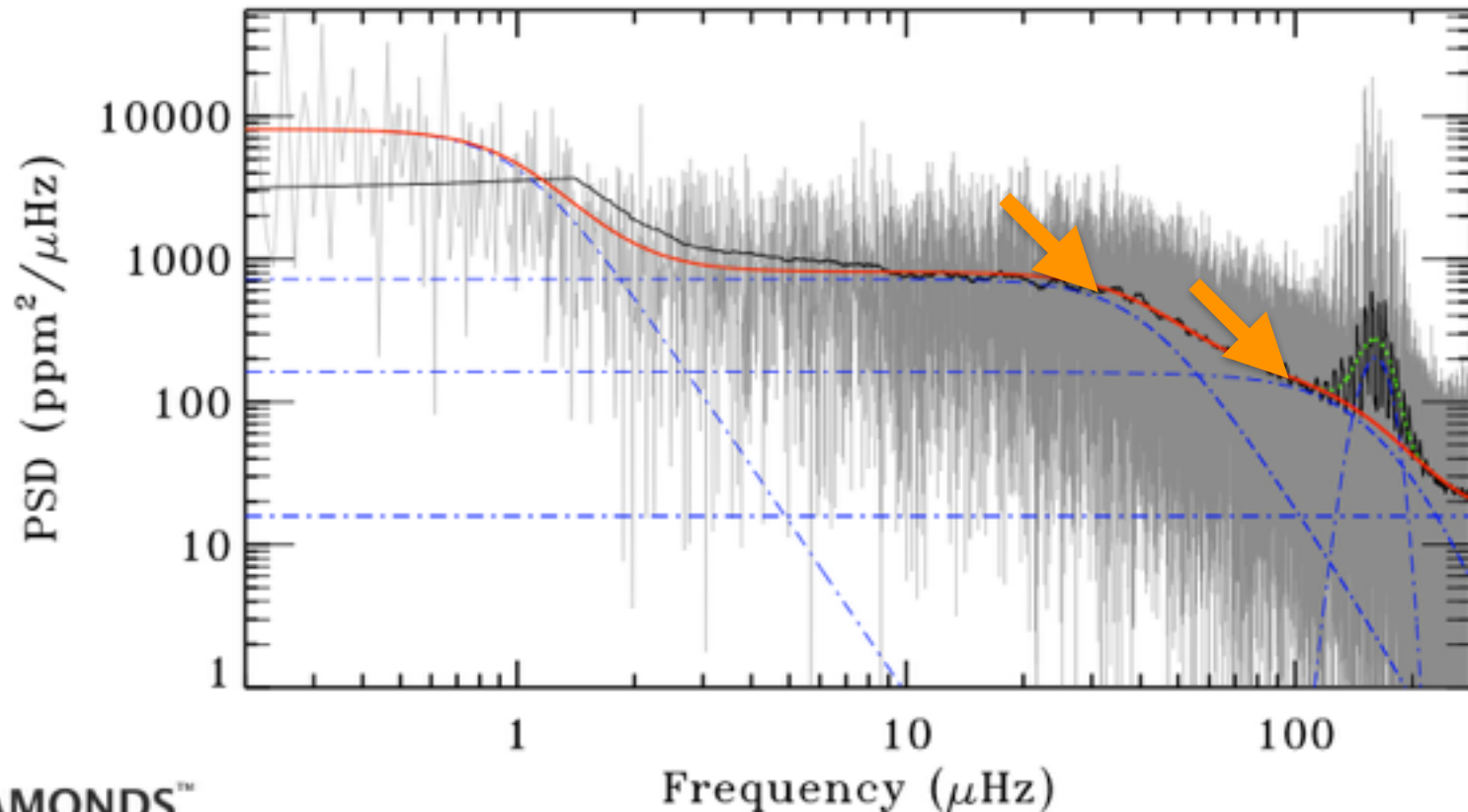


Kallinger et al. 2014

4. - FITTING A PSD: BACKGROUND COMPONENTS

The background model fit for a *Kepler* star

Corsaro, De Ridder, García 2015 A&A, 579, 83



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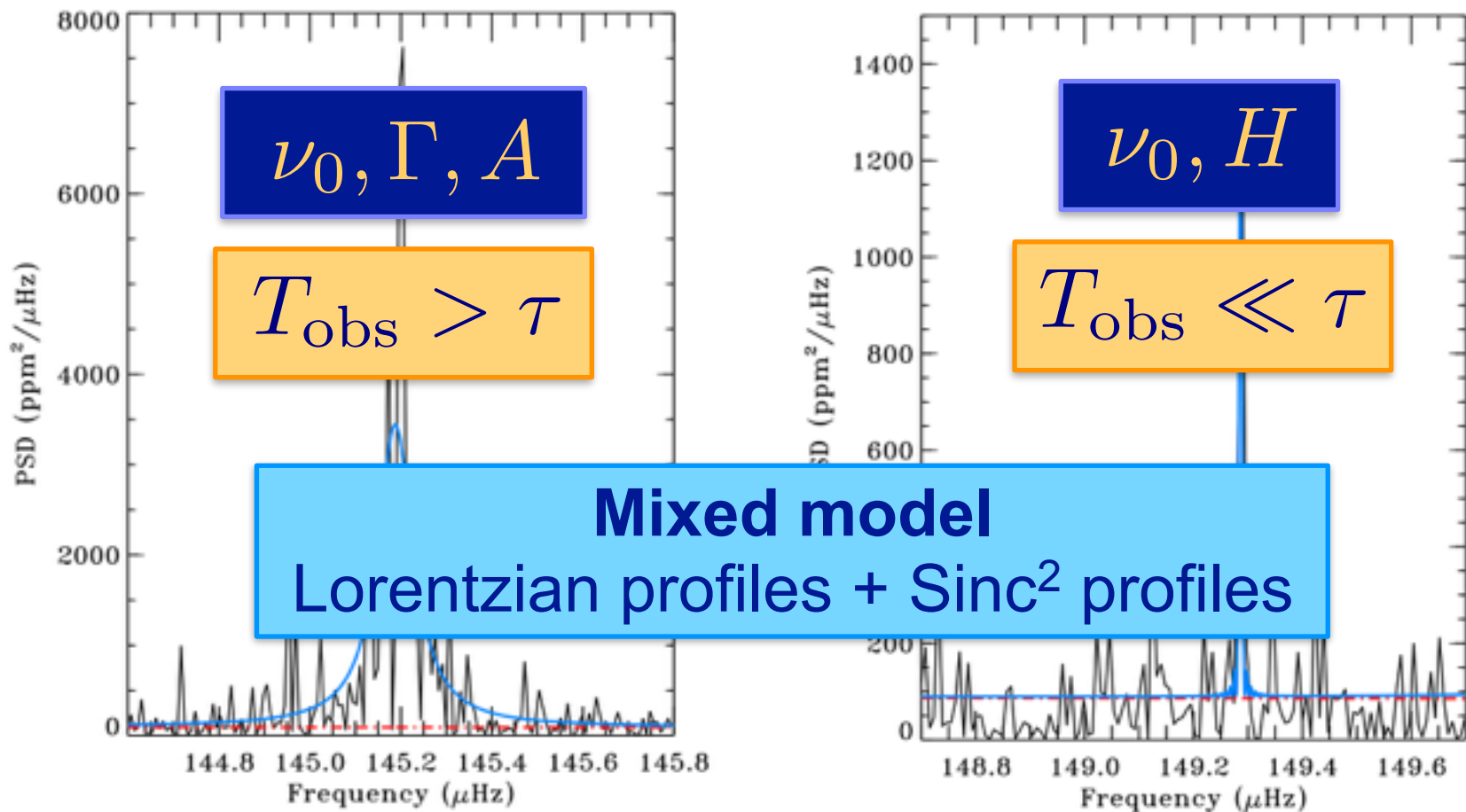
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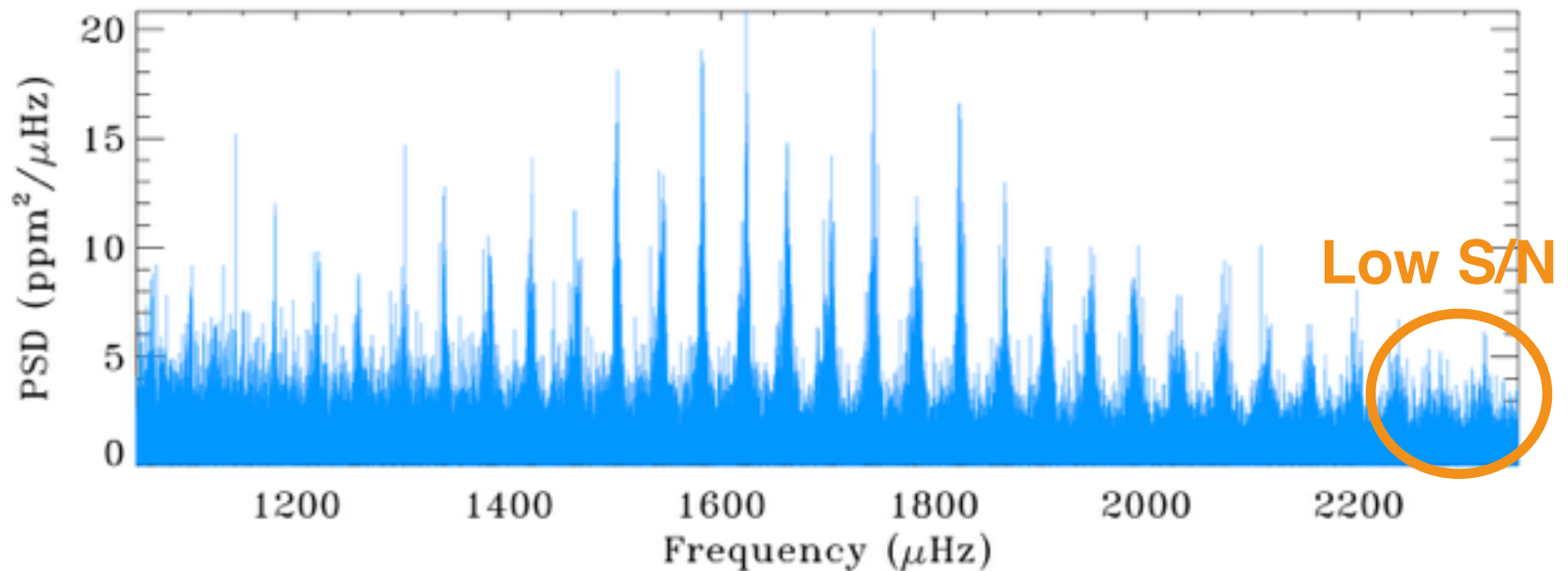
**5. - FITTING A PSD: THE OSCILLATION
MODES**

4. - FITTING A PSD: THE OSCILLATION MODES

The Lorentzian and sinc² profiles



Problems in the fitting of the oscillations



- **Problem 1:** big dataset + fitting numerous oscillation modes (peaks) per star (can be more than 100)
- **Problem 2:** testing if a peak is real or not (noise)

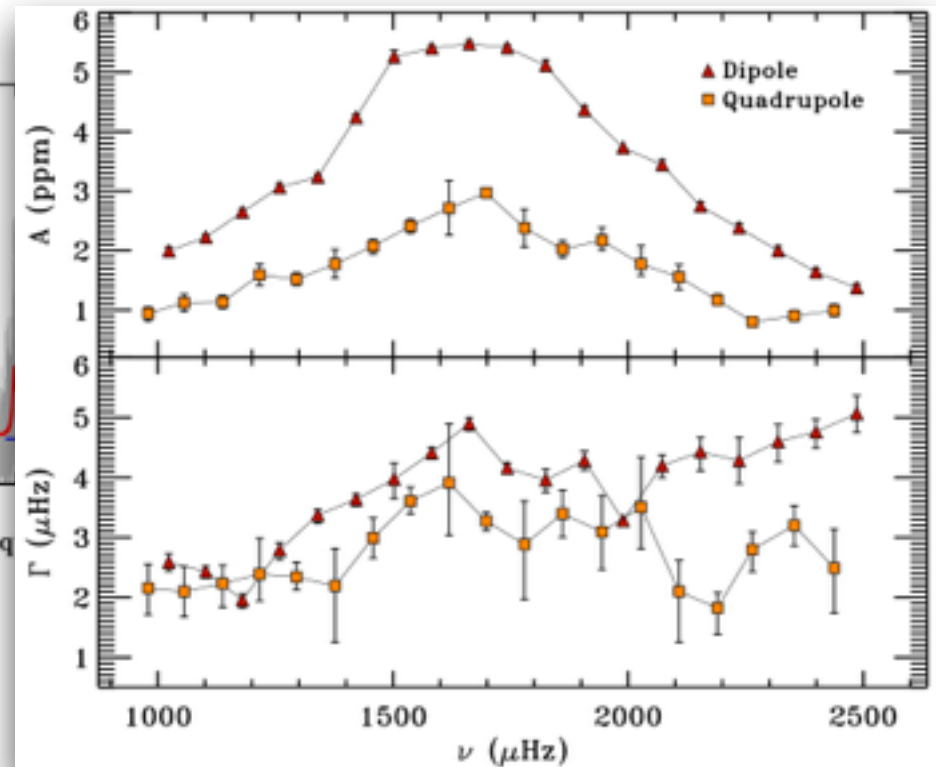
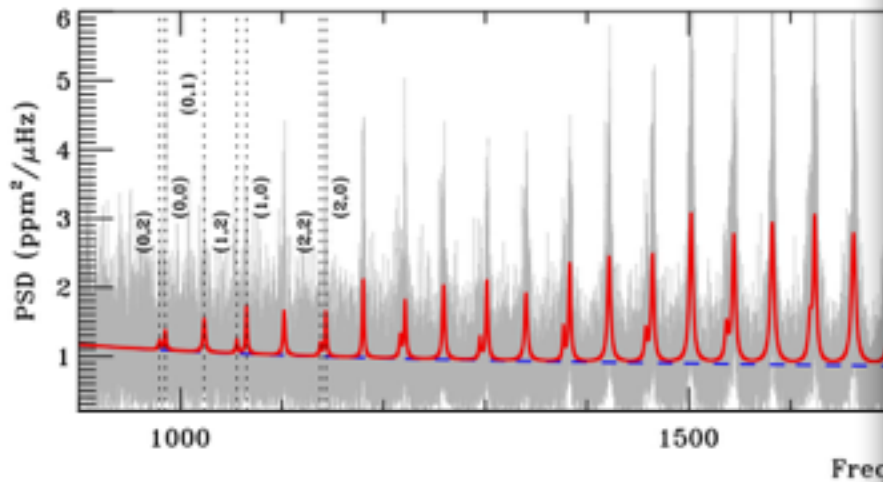
Problem 1

Solving a high-dimensional
fitting problem

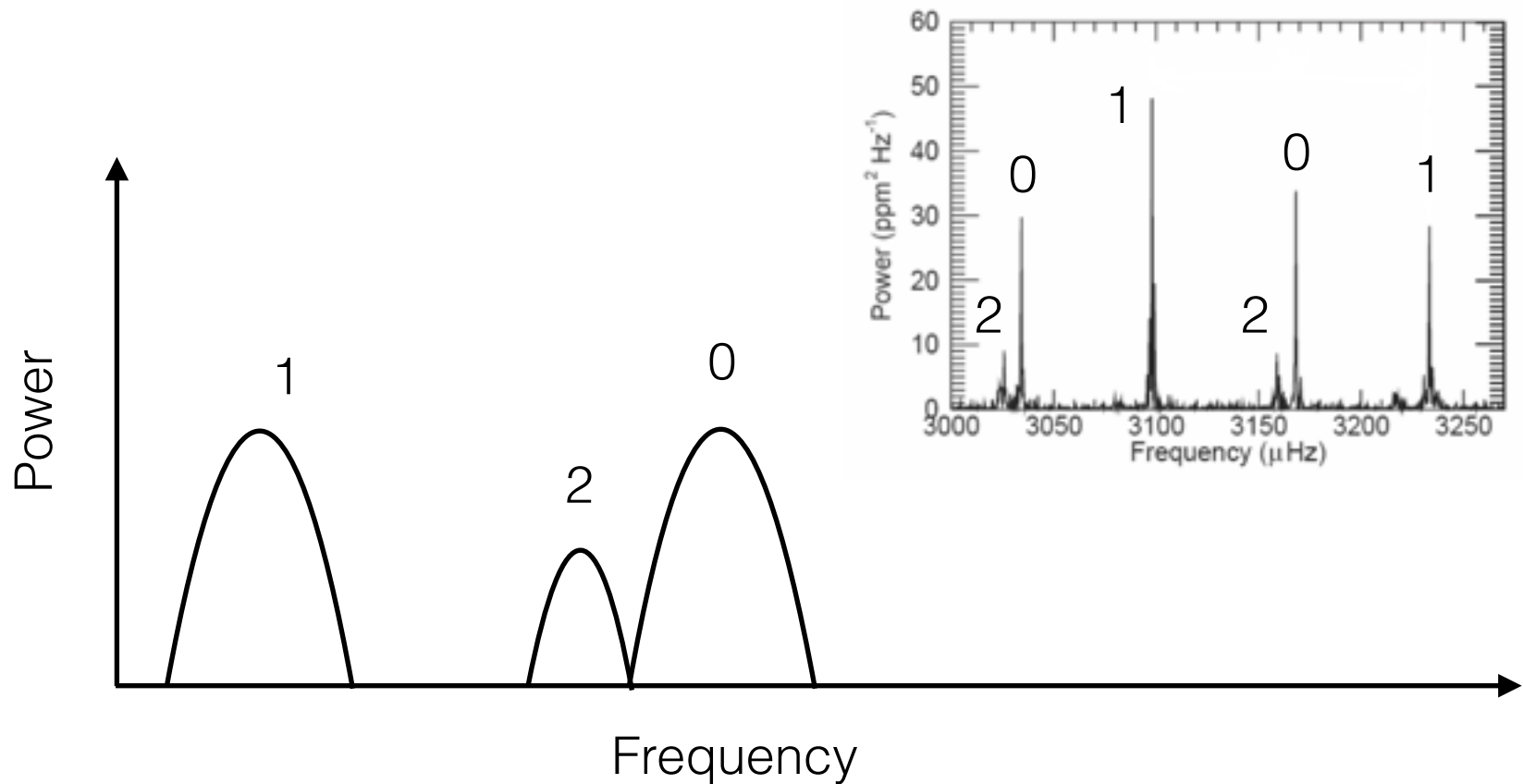
High-dimensional Model

About **180 free parameters!**
Computational time increases a lot

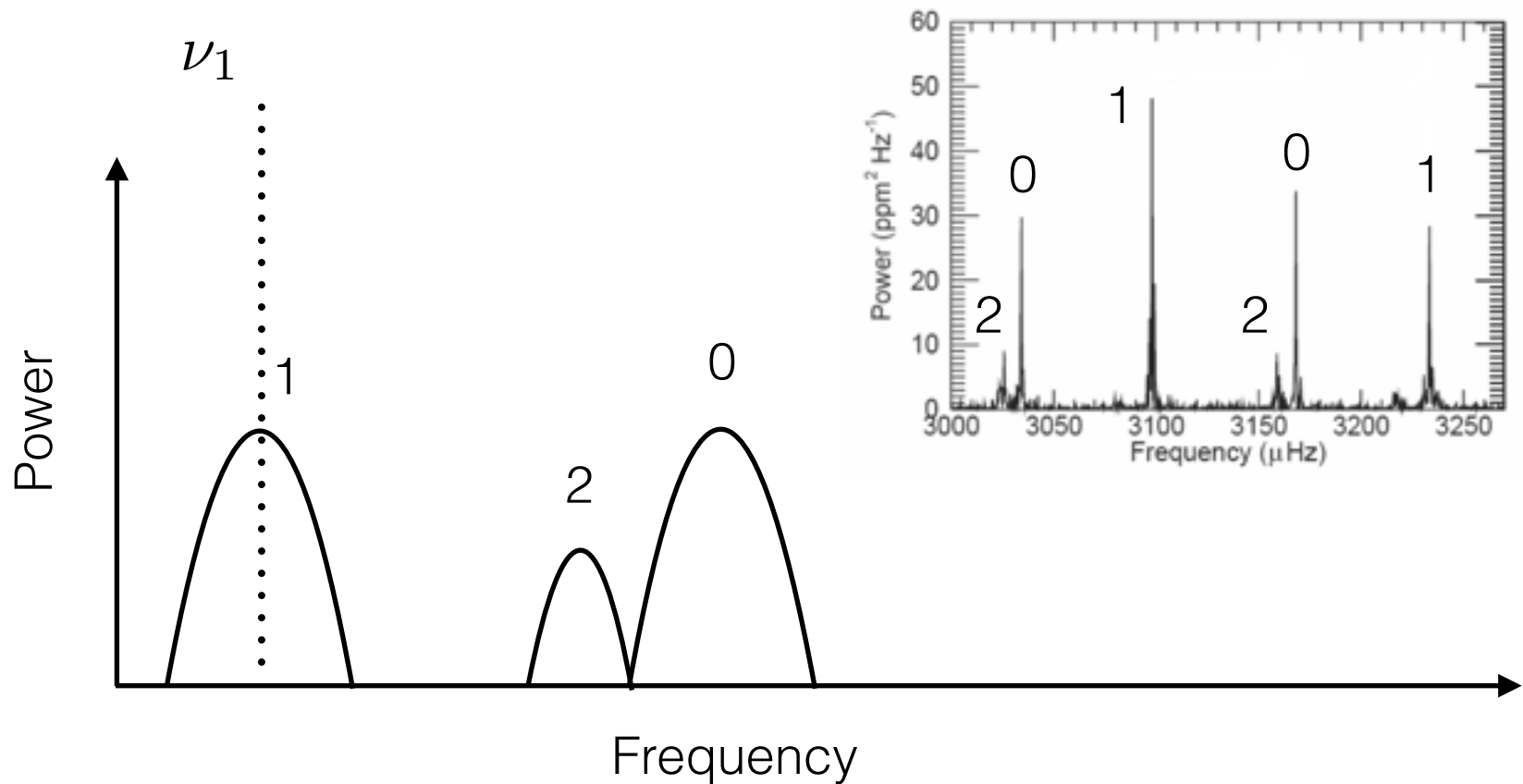
KIC 9139163



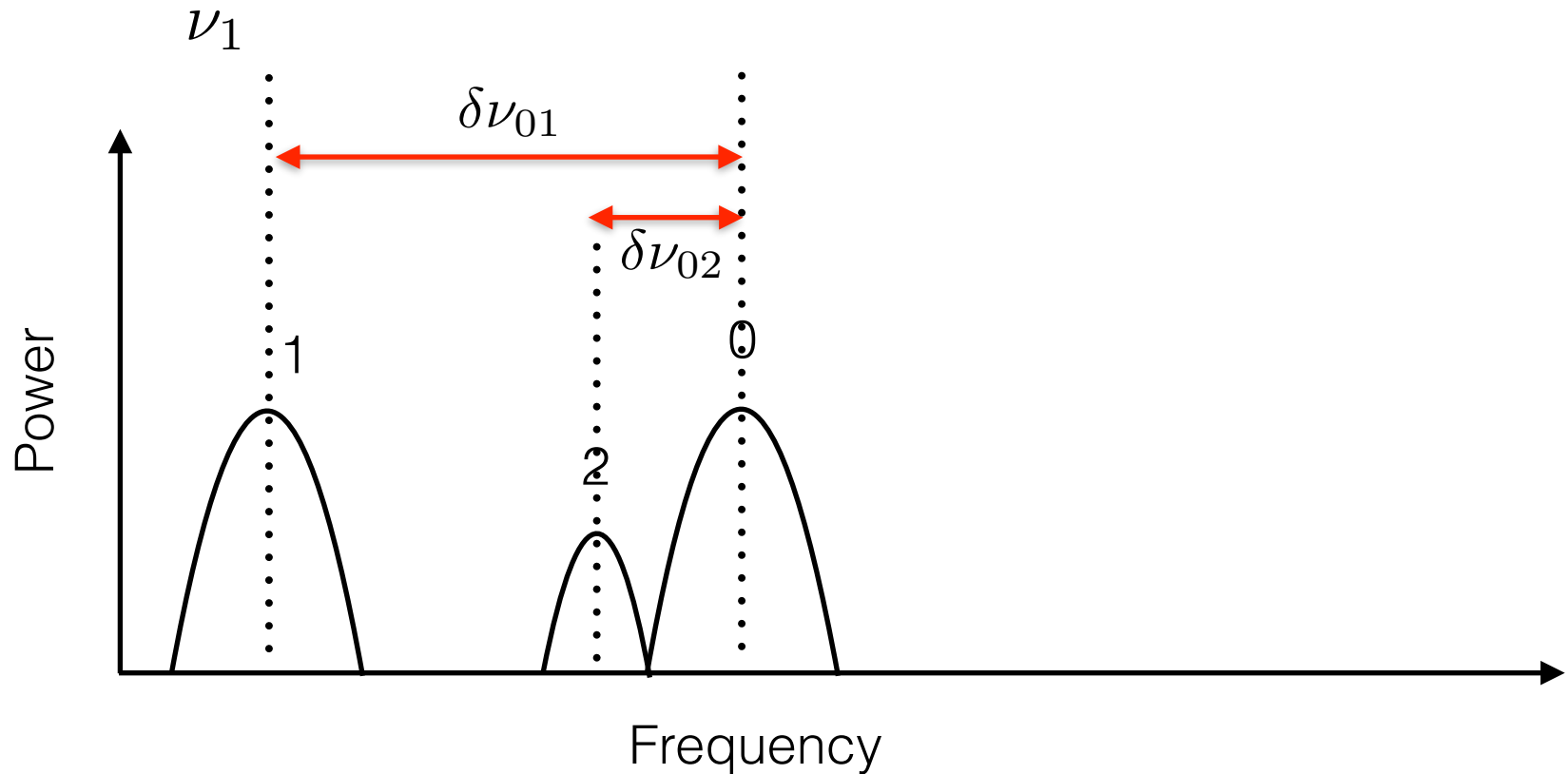
Multi-modal Model



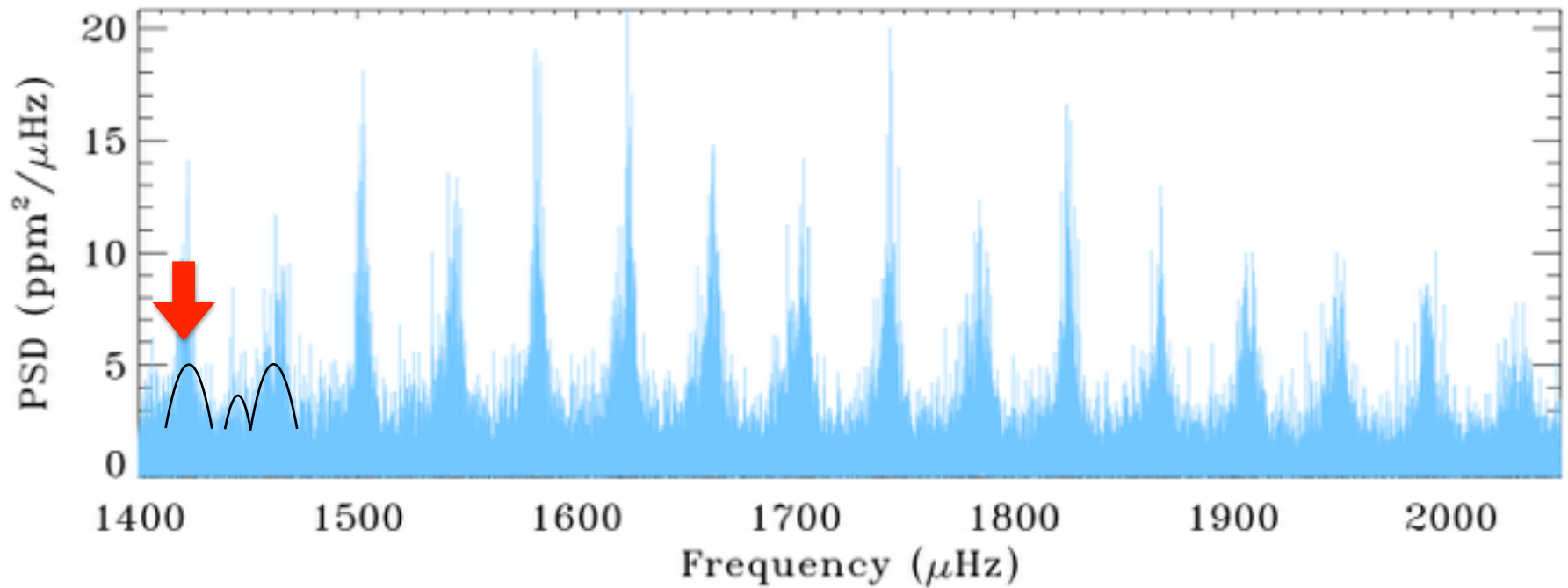
Multi-modal Model



Multi-modal Model



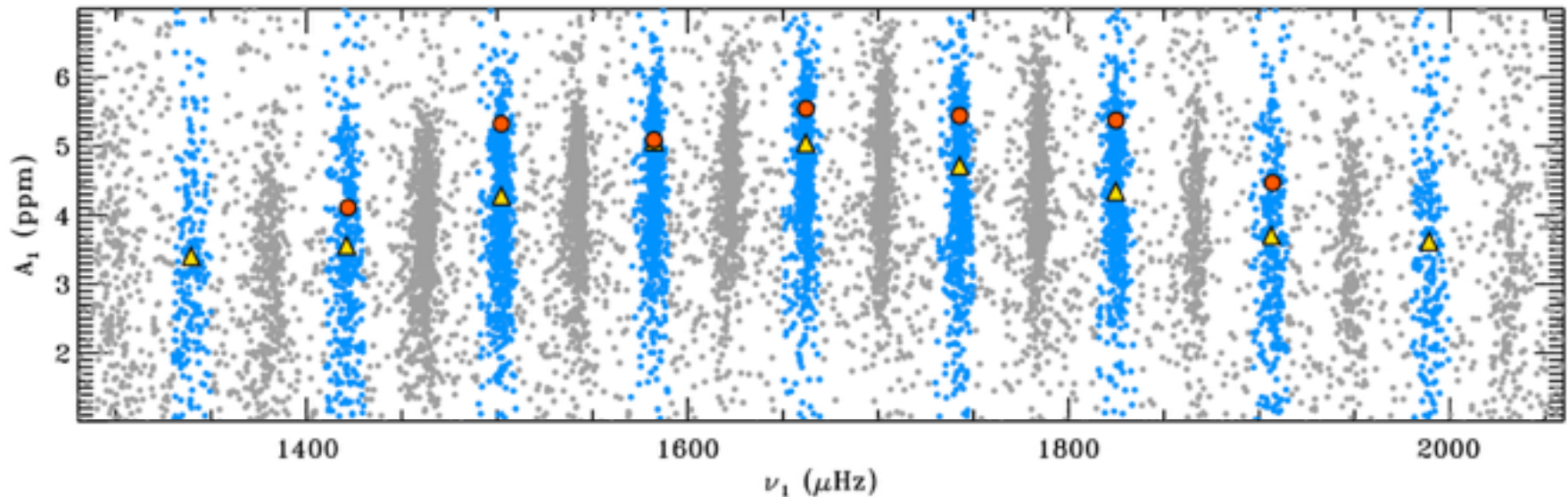
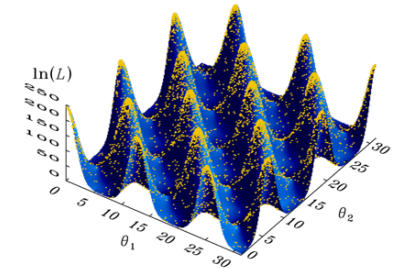
Multi-modal Model



Results

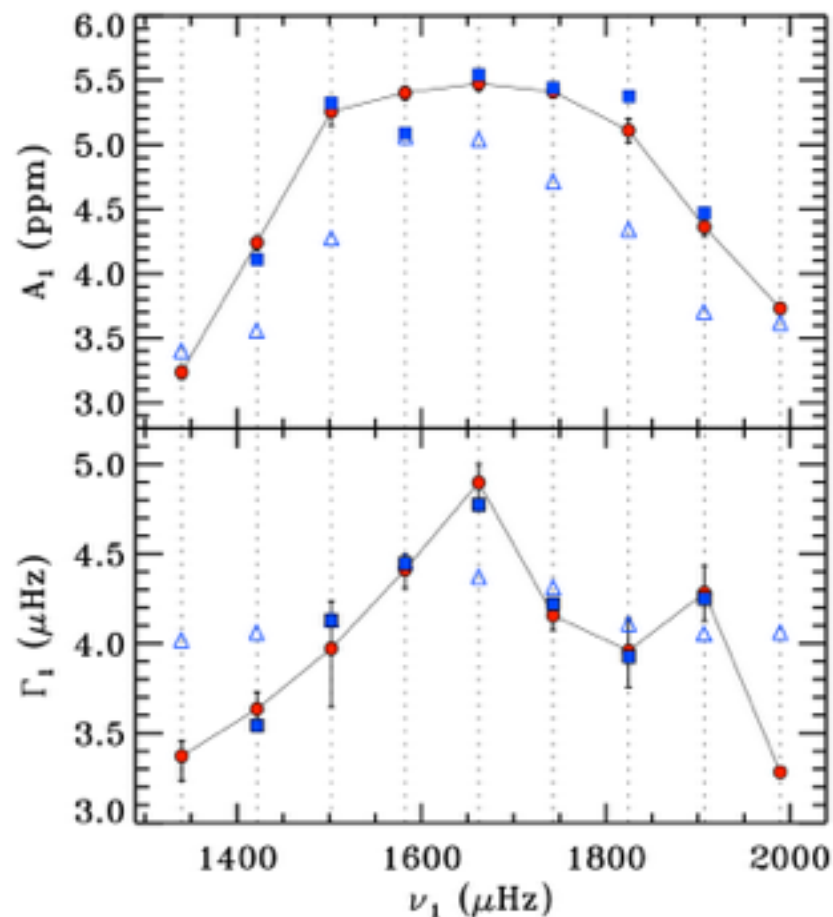
Multi-modal inference problem on 9 consecutive radial orders (27 peaks)

Only 9 free parameters!



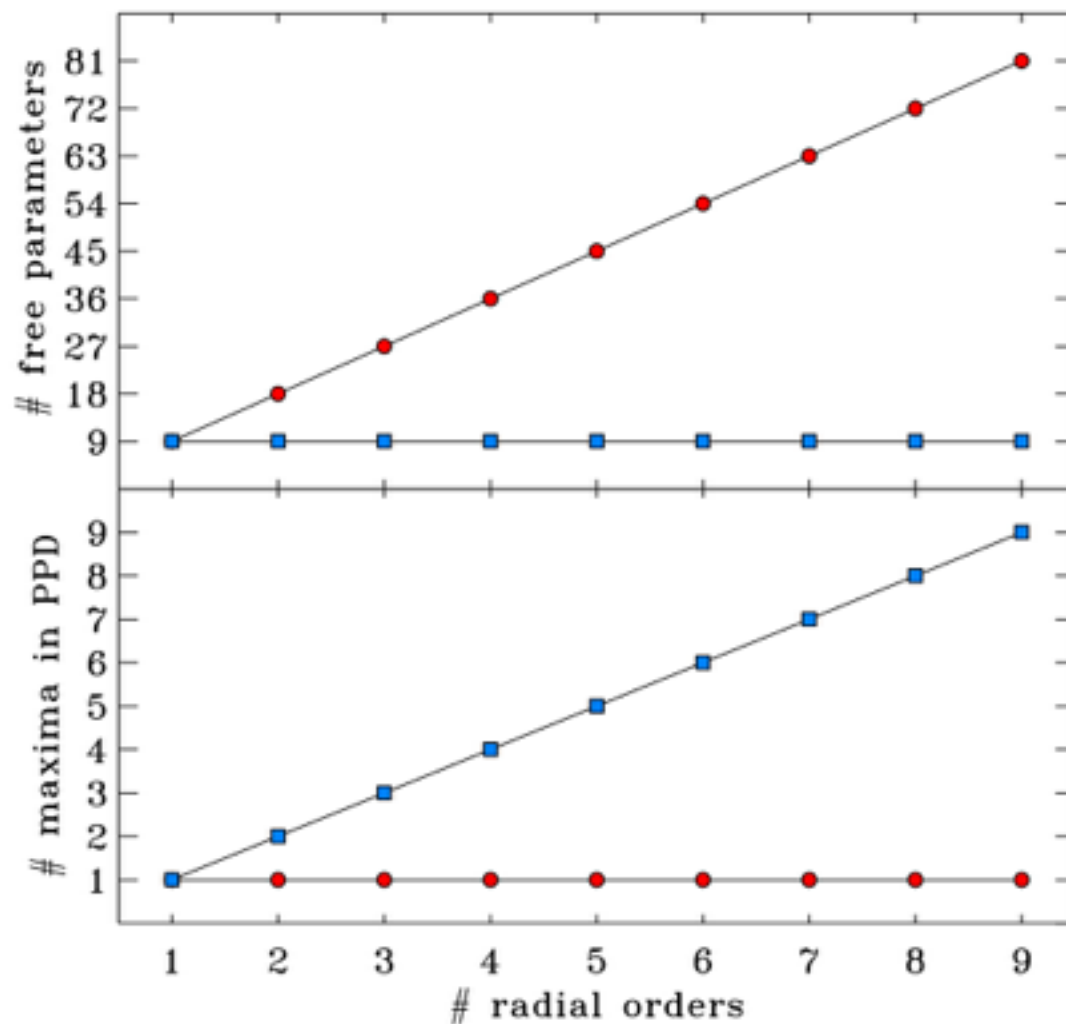
Comparison

Red: uni-modal fit
Blue: multi-modal fit



Comparison

Red: uni-modal fit
Blue: multi-modal fit



Problem 2

Test the significance of
an oscillation peak

Bayesian Model Comparison

Bayesian Evidence

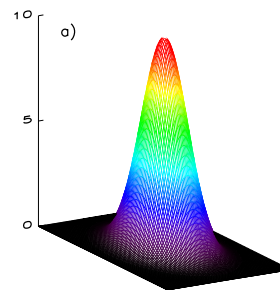


WEIGHT: simple models are preferred (Occam's razor)

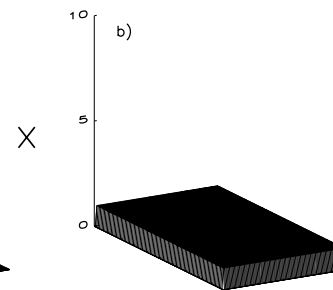
Bayes' Theorem

$$p(\theta) = \frac{\mathcal{L}(\theta) \pi(\theta)}{\mathcal{E}}$$

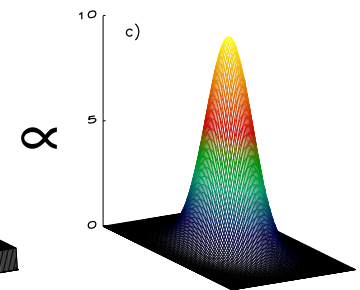
Likelihood



Prior



Posterior



\times

\propto

Peak Significance Criterion

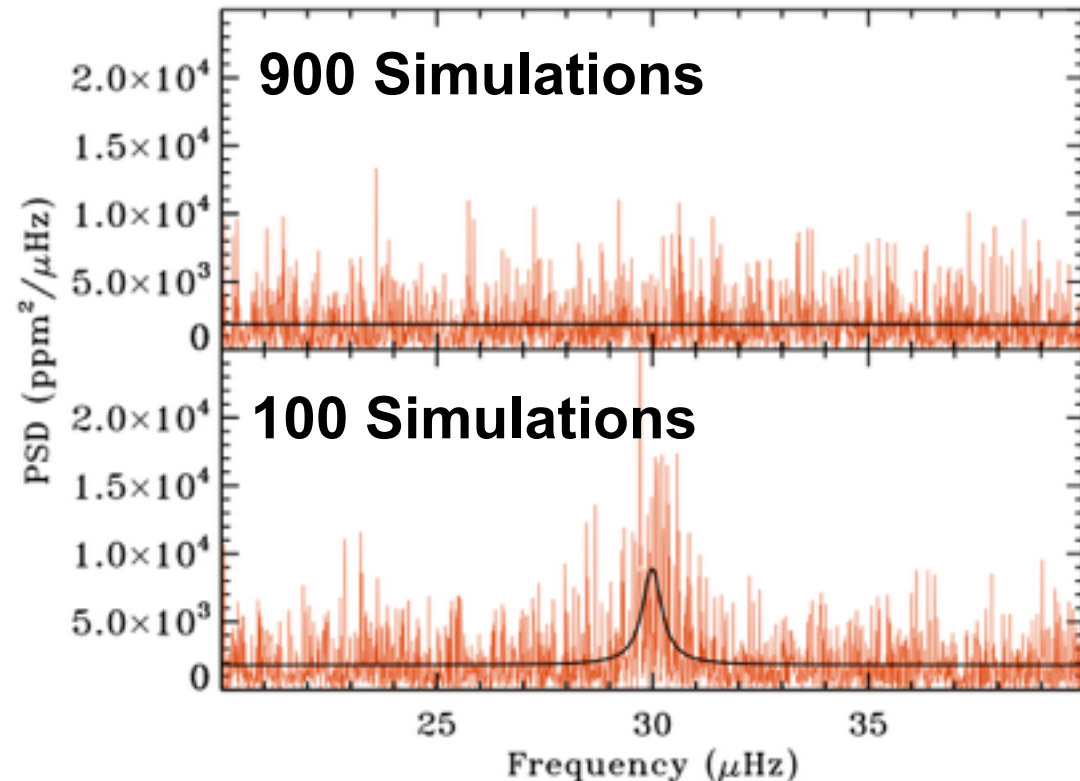
- Simulations test
- **1000** artificial chunks of PSD
- Blind search for those with a peak

Bayes' factor

$$B_{yes,no} = \frac{\mathcal{E}_{yes}}{\mathcal{E}_{no}}$$

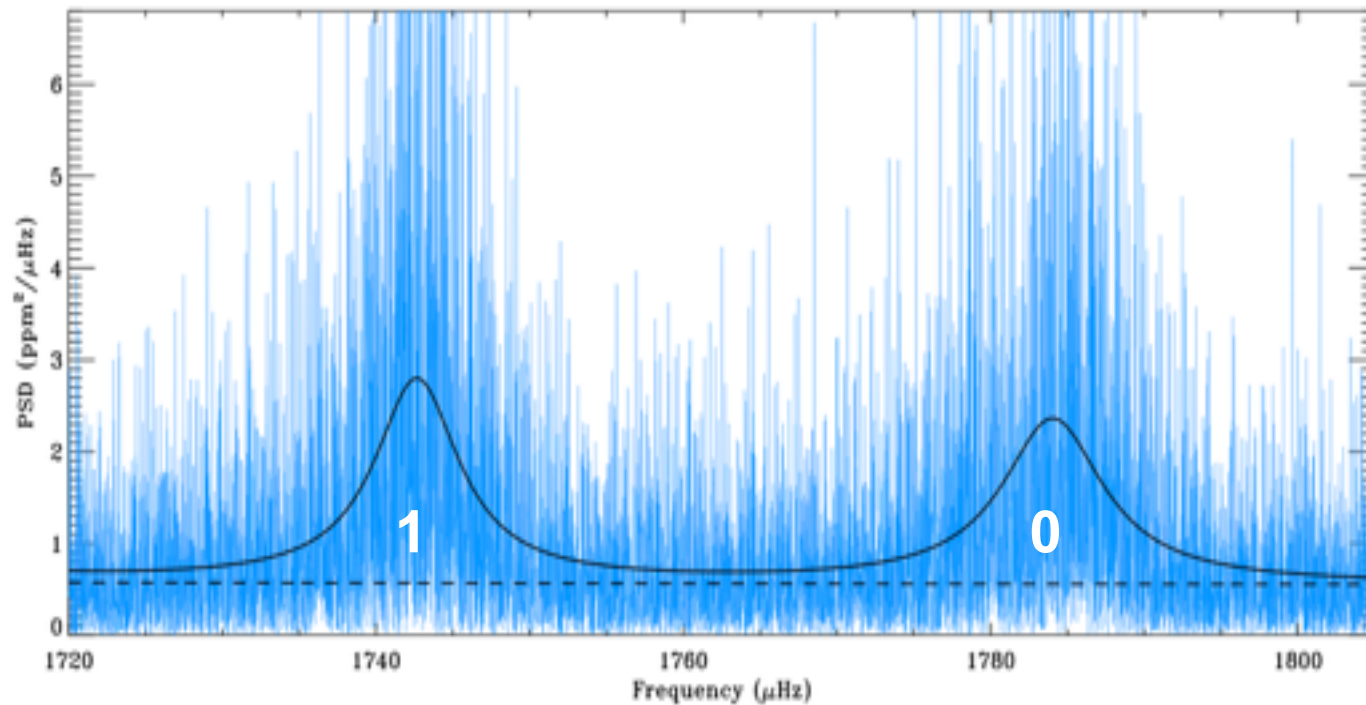
$$B_{yes,no} \sim 150$$

Strong Evidence (Jeffreys' scale)



All peaks found!

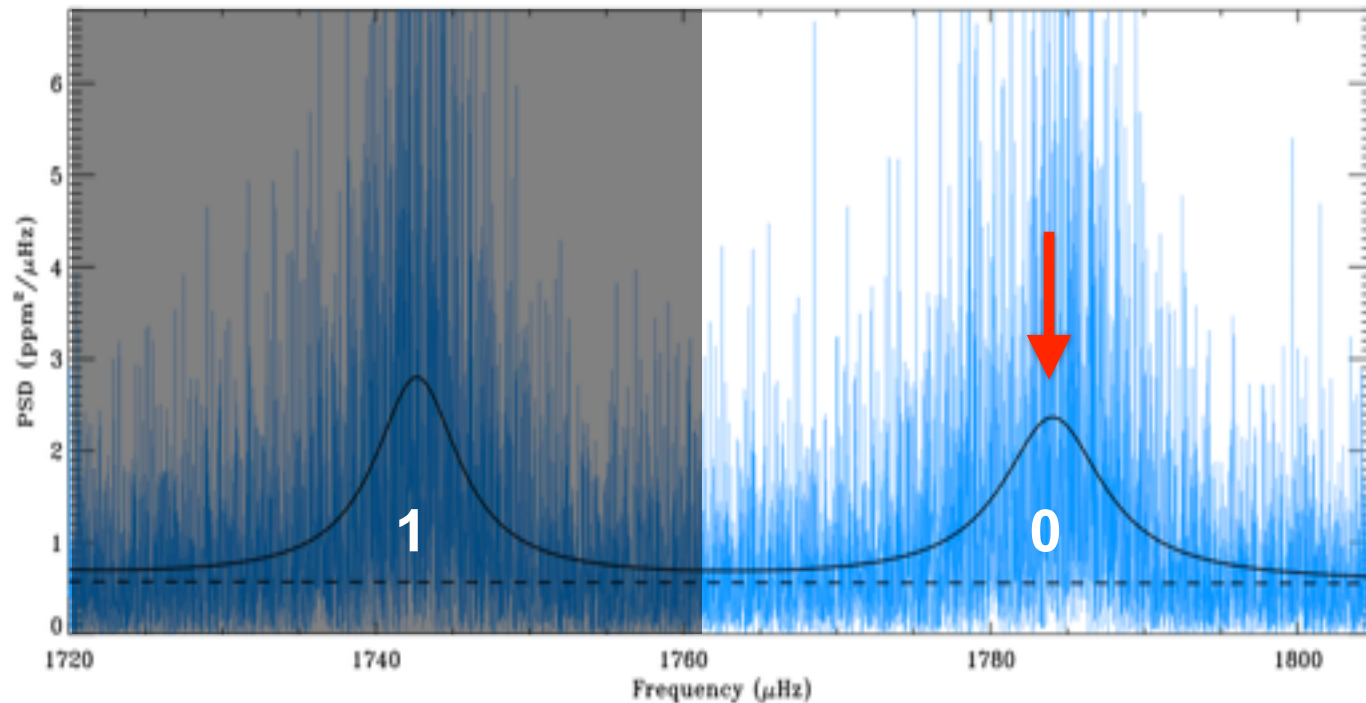
Peak significance



Peak significance

$\mathcal{M}_{\ell=0}$ Only $\ell = 0$

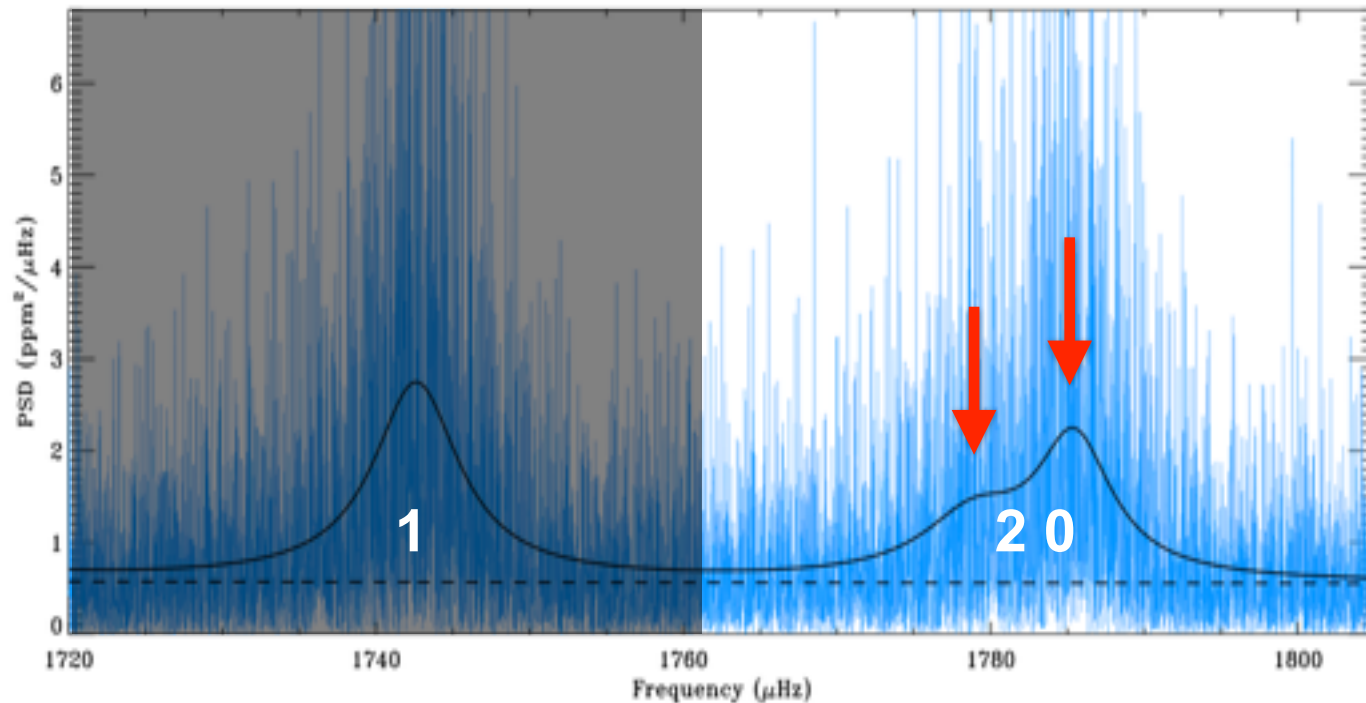
$\mathcal{E}_{\ell=0}$ Bayesian Evidence



Peak significance

$\mathcal{M}_{\ell=2}$ Both $\ell = 2$ and $\ell = 0$

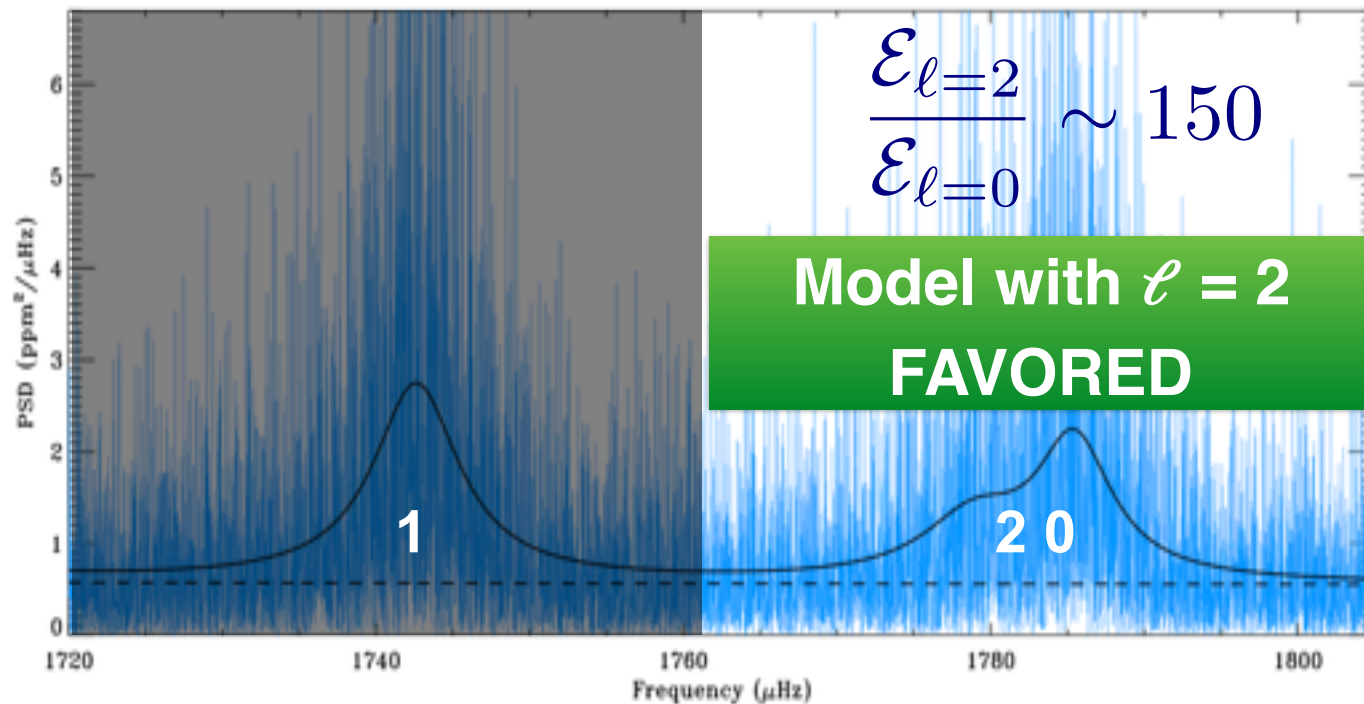
$\mathcal{E}_{\ell=2}$ Bayesian Evidence



Peak significance

$\mathcal{M}_{\ell=2}$ Both $\ell = 2$ and $\ell = 0$

$\mathcal{E}_{\ell=2}$ Bayesian Evidence



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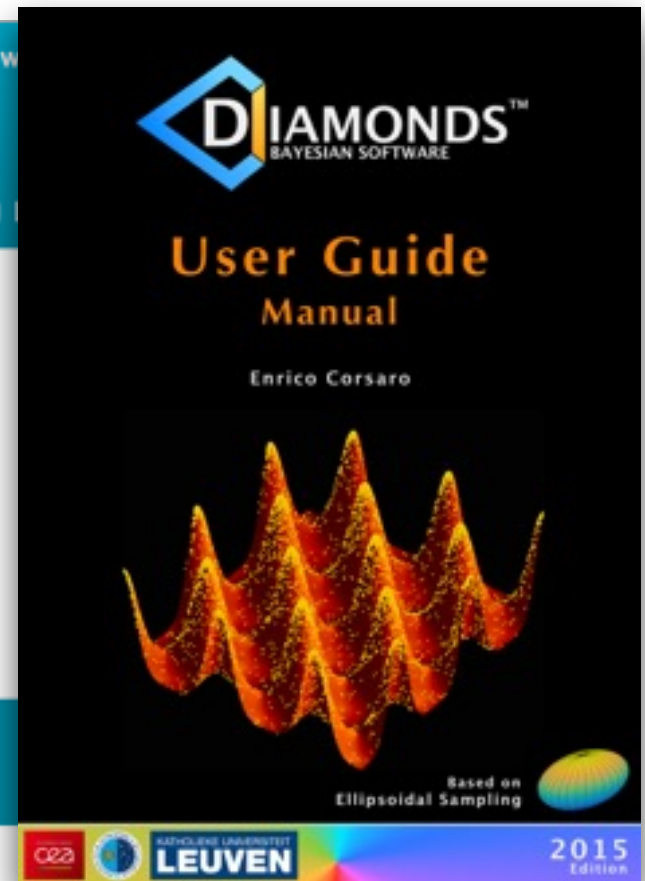
A screenshot of the KU Leuven website. The top navigation bar is teal with white text for 'KU LEUVEN' and links to 'Contact', 'Who's who', 'Organisational chart', 'Libraries', and 'Toledo'. Below this is a secondary teal bar with icons and links for 'EDUCATION', 'RESEARCH', 'ADMISSIONS', 'LIVING IN LEUVEN', and 'ABOUT KU LEUVEN'. On the left, a sidebar menu has a dark grey header 'The DIAMONDS code' with a home icon. Below it are links for 'Download', 'Package Content', and 'Installation Guide'. A red arrow points to the 'Download' link. The main content area has a breadcrumb trail 'Institute of Astronomy → Software → The DIAMONDS code' followed by the title 'The DIAMONDS code'. Under the heading 'Authors', two authors are listed: Enrico Corsaro with email 'emncorsaro(at)gmail.com' and Joris De Ridder with email 'joris.deridder(at)ster.kuleuven.be'. At the bottom, a teal box contains the text 'REFERENCE' followed by 'E. Corsaro & J. De Ridder 2014 A&A, 571, 71'.

Download



<https://fys.kuleuven.be/ster/Software/Diamonds/>

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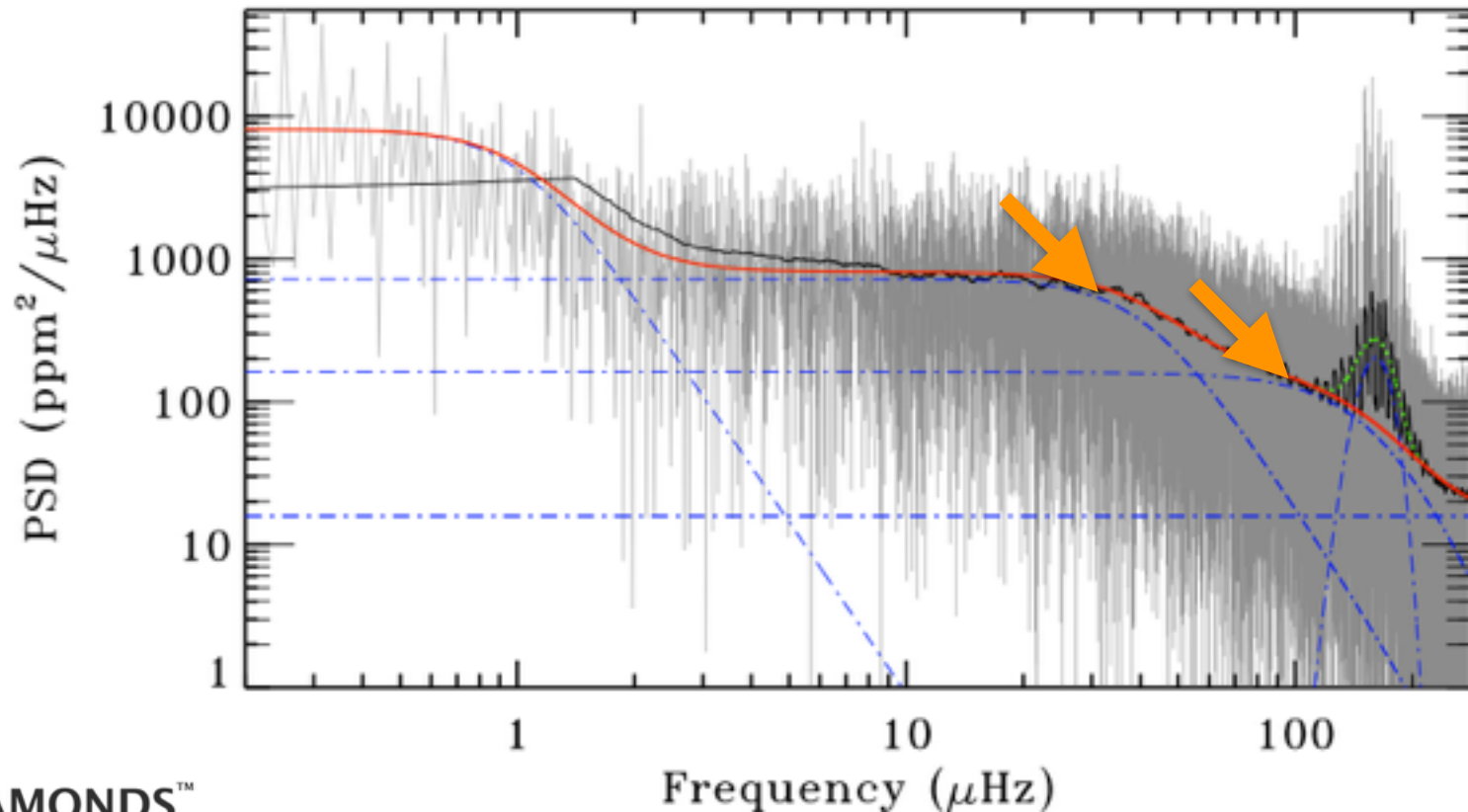


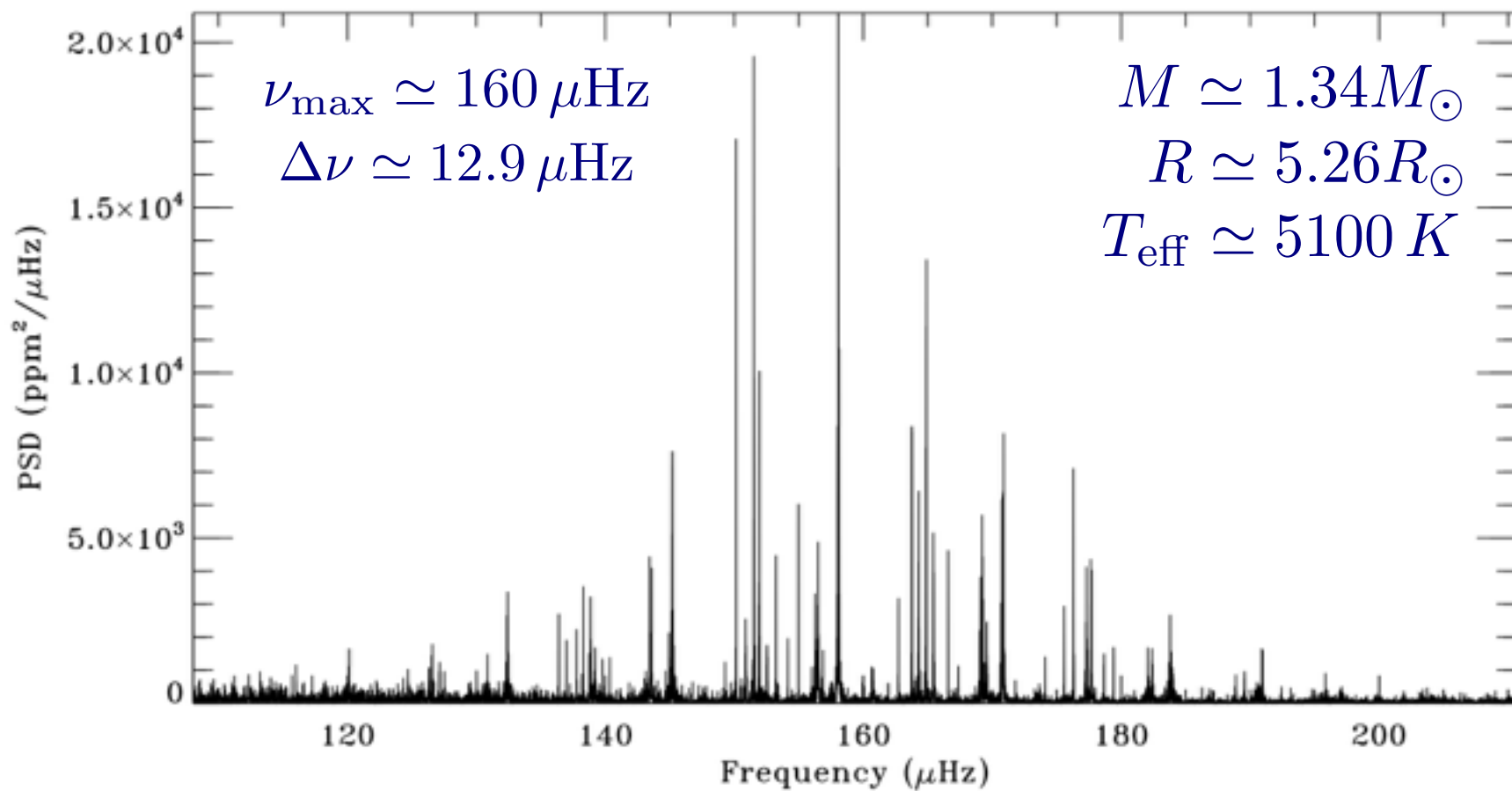
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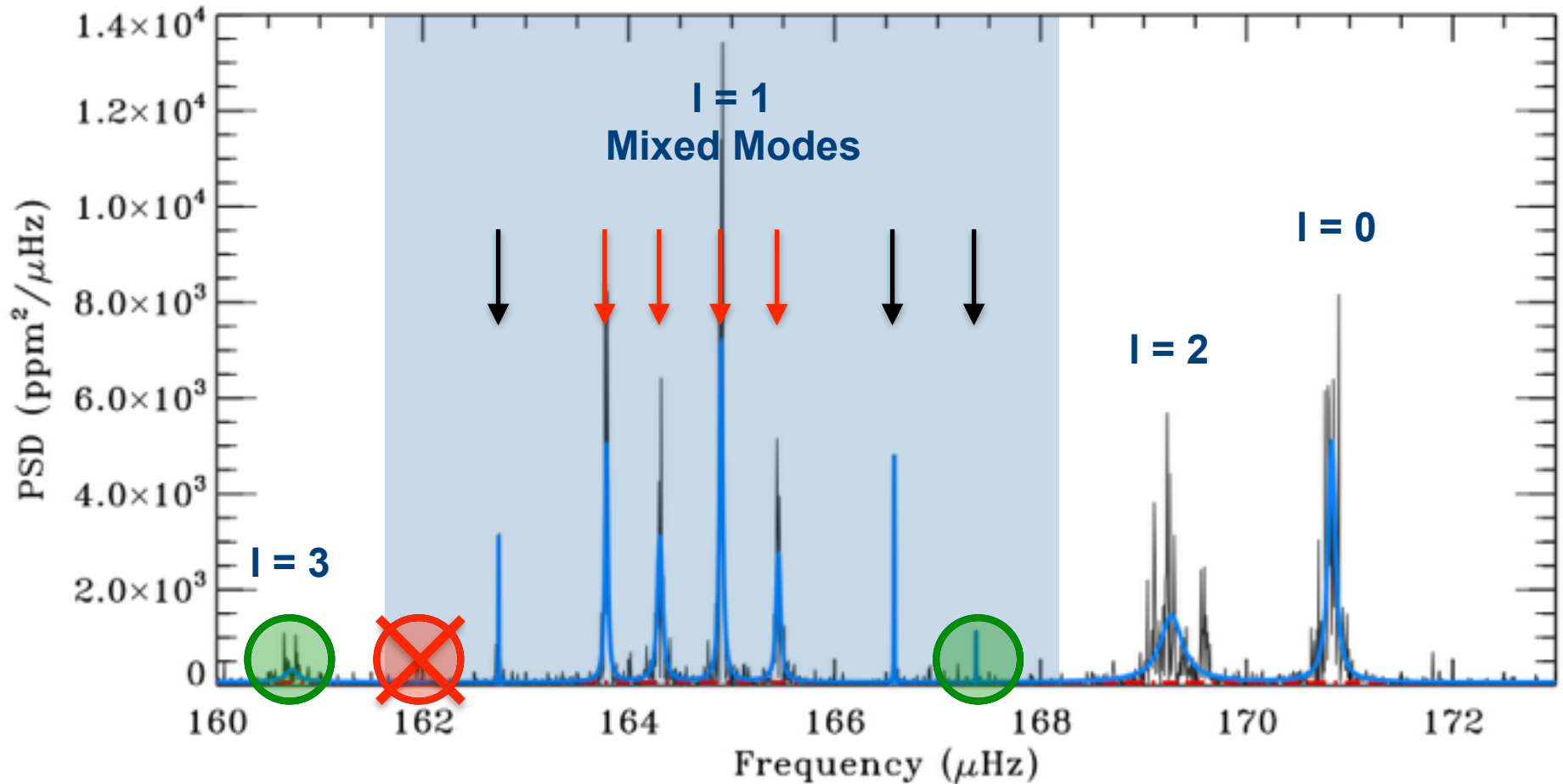
KIC 12008916

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Detection Probability

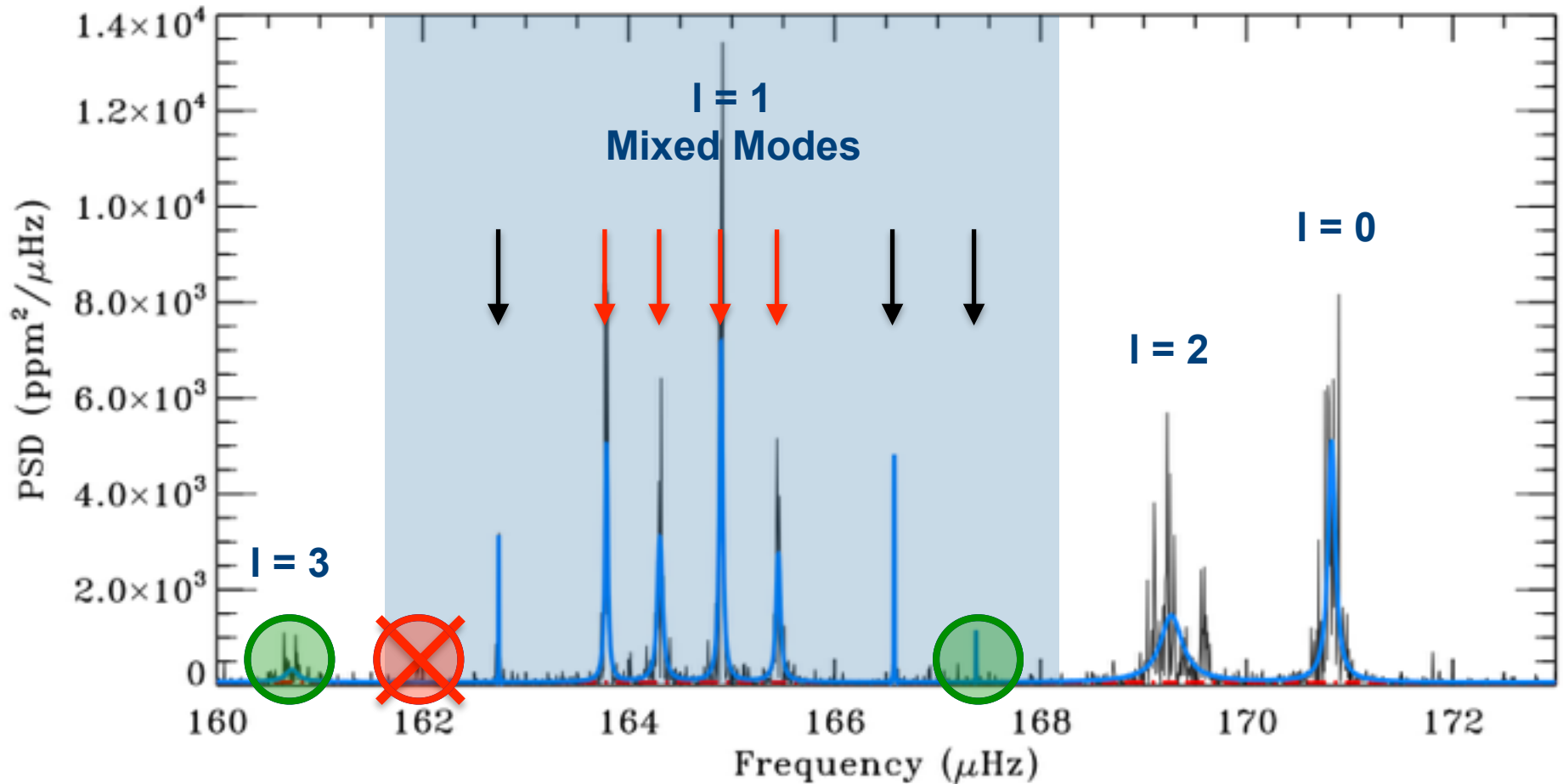
$$p_{\text{peak}} \equiv \frac{\mathcal{E}_{\text{peak}}}{\mathcal{E}_{\text{no peak}} + \mathcal{E}_{\text{peak}}}$$

$$p_{\text{peak}} \gtrsim 99\%$$

Peak detected!

$$B_{1,2} = \frac{\mathcal{E}_1}{\mathcal{E}_2}$$

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