HD 49933 — Seismic Interpretation

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Overview

We report on the seismic interpretation of the frequencies of the star HD 49933.

Global Parameters of HD 49933

- $T_{eff} = 6700 \pm 100$ K
- $M_{bol} = 3.35 \pm 0.10$
- $[Fe/H] = -0.32 \pm 0.10$
- vsini $= 10 \pm 4$ km/s

- Original model produced by Ian Roxburgh
- Time series produced by Caroline Barban
- Frequencies extracted by Thierry Appourchaux

Before the Models ....

Estimation of acoustic depths of base of CZ and HeII ionisation zone

Discontinuities in sound speed derivatives at the HeII ionisation zone and the base of the convective envelope give rise to oscillations in the frequencies.

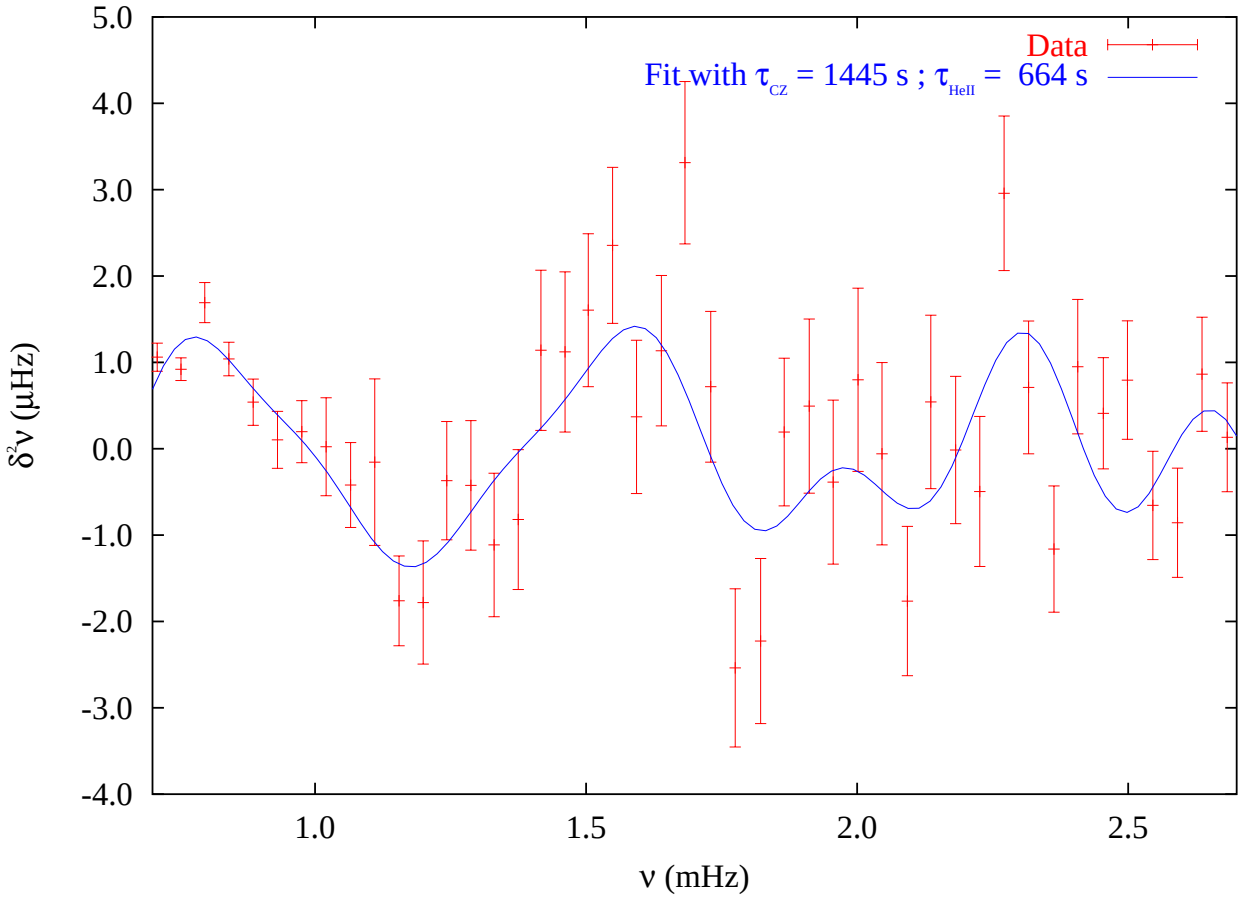
We fit a function of the form

$$\delta^2\nu(n,\ell) = \left(a_0 + \frac{a_1}{\nu_{n,\ell}} + \frac{a_2}{\nu^2_{n,\ell}}\right)\sin(4\,\pi\nu_{n,\ell}\,\tau_{CZ} + \phi_{CZ}) + \left(b_0 + \frac{b_1}{\nu_{n,\ell}} + \frac{b_2}{\nu^2_{n,\ell}}\right)\sin(4\,\pi\nu_{n,\ell}\,\tau_{HeII} + \phi_{HeII})$$

to the second differences of the data, taking into account the errors (Mazumdar & Antia 2001).

Before the Models ....

Estimation of acoustic depths of base of CZ and HeII ionisation zone



The fit provides us with values for the acoustic depths of

- the base of the convective envelope: $\tau_{CZ} = 1445 \pm 68$ s
- the HeII ionisation zone: $\tau_{HeII} = 663 \pm 49$ s

These estimates help to search the closest model.

Stellar Models

Evolutionary tracks were computed with CESAM using

- CEFF and OPAL equation of state
- OPAL opacities
- NACRE nuclear reaction rates
- MLT convection
- Eddington atmosphere
- No diffusion

Frequencies were computed with ADIPLS.

Stellar Models

Variable parameters of models

- Core overshoot (in H_P) : d_{ov} : 0 — 0.2
- Mixing length (in H_P) : α : 1.6 — 1.8
- Metallicity : $[Fe/H]$: -0.42 — -0.22
- Initial Helium abundance : Y_0 : 0.25 — 0.27

All CESAM models are computed with a "high" precision parameter to avoid irregular features at convective zone boundaries
— more accurate models, but very time-consuming!!

- For a particular combination of these parameters we vary the mass of the model to check for overlap between main sequence tracks and the global parameters of HD 49933 on the HR diagram.
- Compare large and small separations of the "data" with the computed values to find the closest possible model.

Nature of the Data

Total of 79 frequencies : $(\ell = 0 : 37, \ell = 1 : 30, \ell = 2 : 8, \ell = 3 : 4)$

Large Separations

$$\Delta_{n\ell} = \nu_{n+1,\ell} - \nu_{n,\ell} \qquad \ell = 0, 1, 2, 3$$

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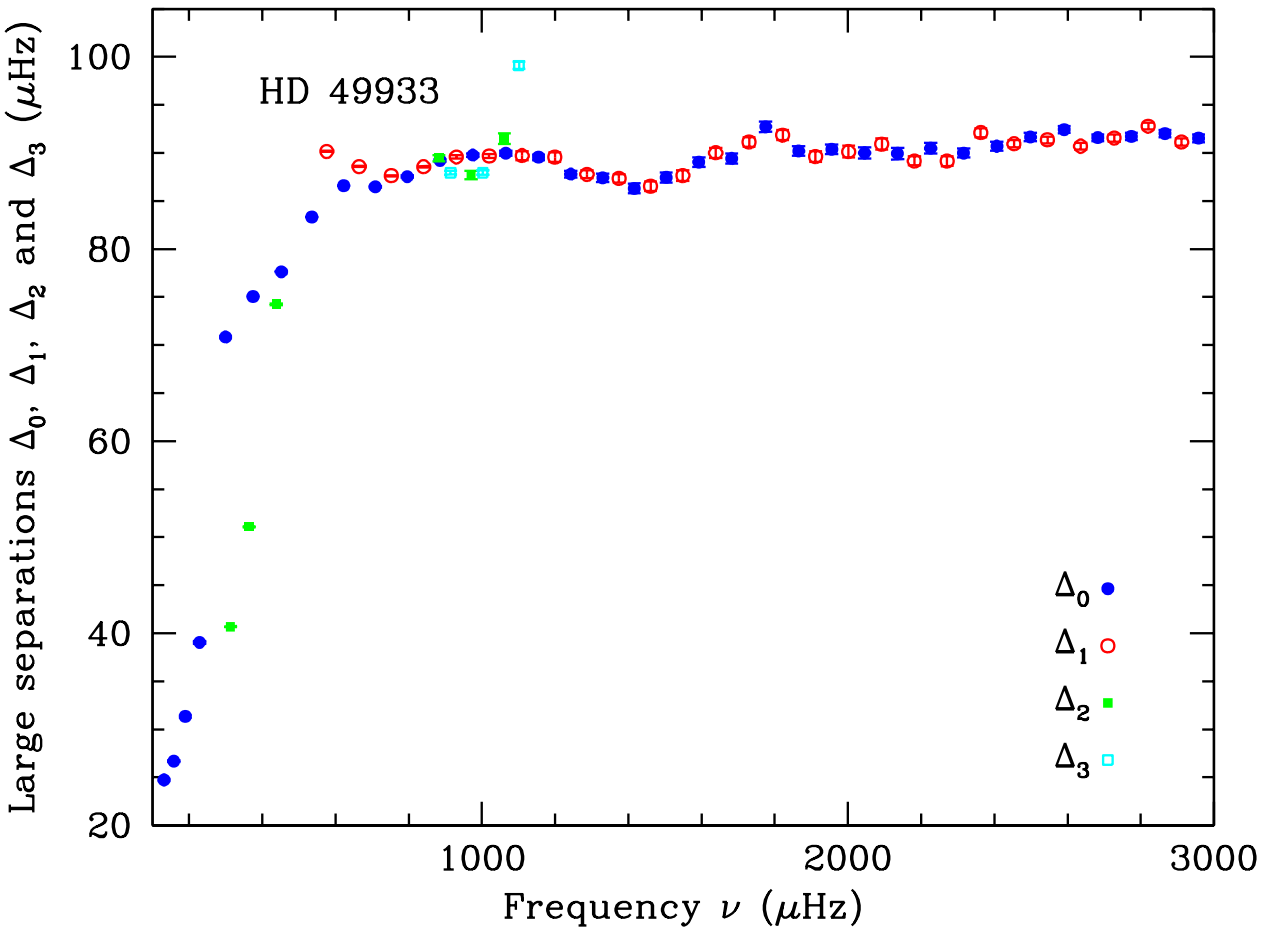


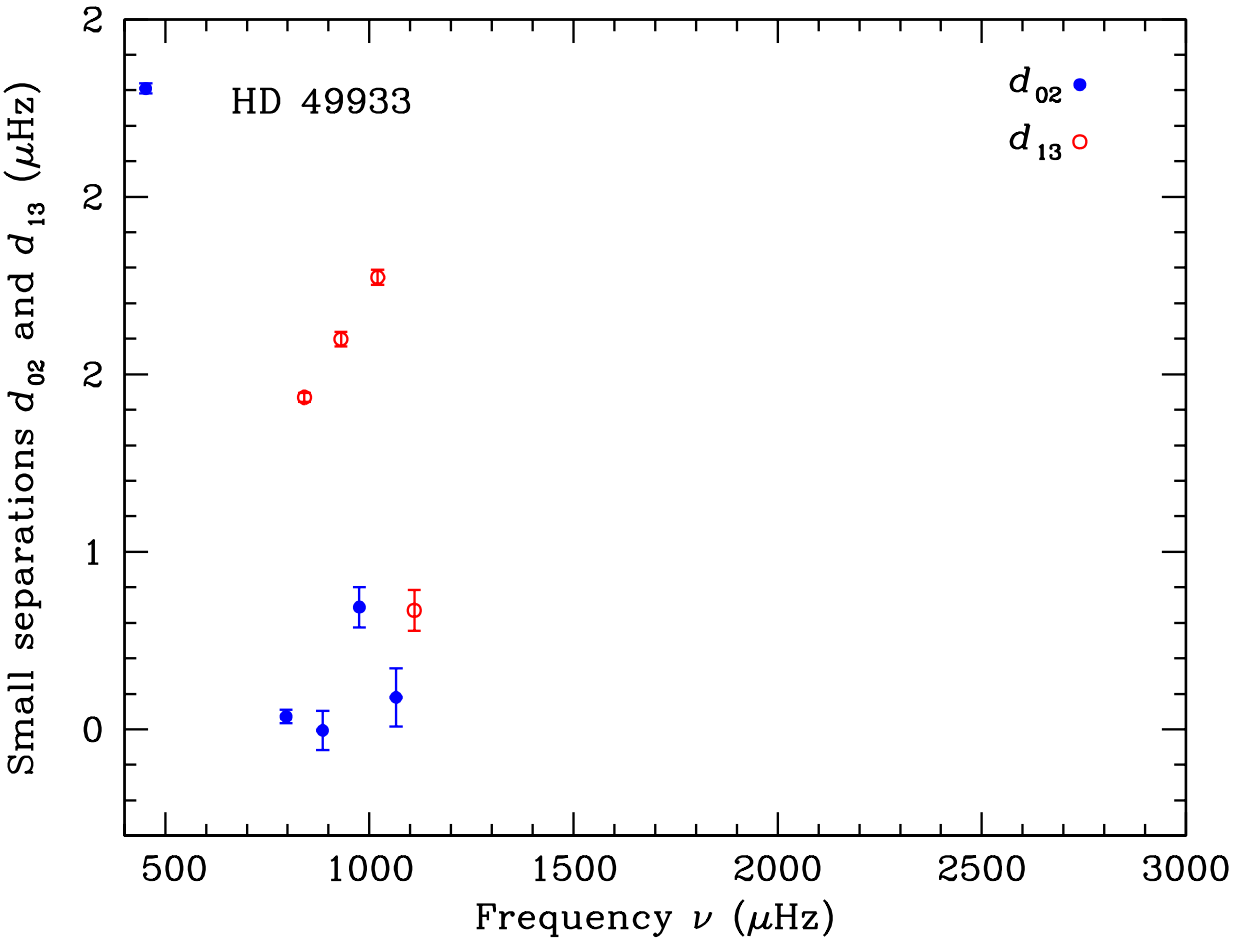
Nature of the Data

Small Separations

- Between $\ell = 0,\ 2$ modes and $\ell = 1,\ 3$ modes:

$$d_{02} = [\nu_{n,0} - \nu_{n-1,2}]/6$$

$$d_{13} = [\nu_{n,1} - \nu_{n-1,3}]/10$$



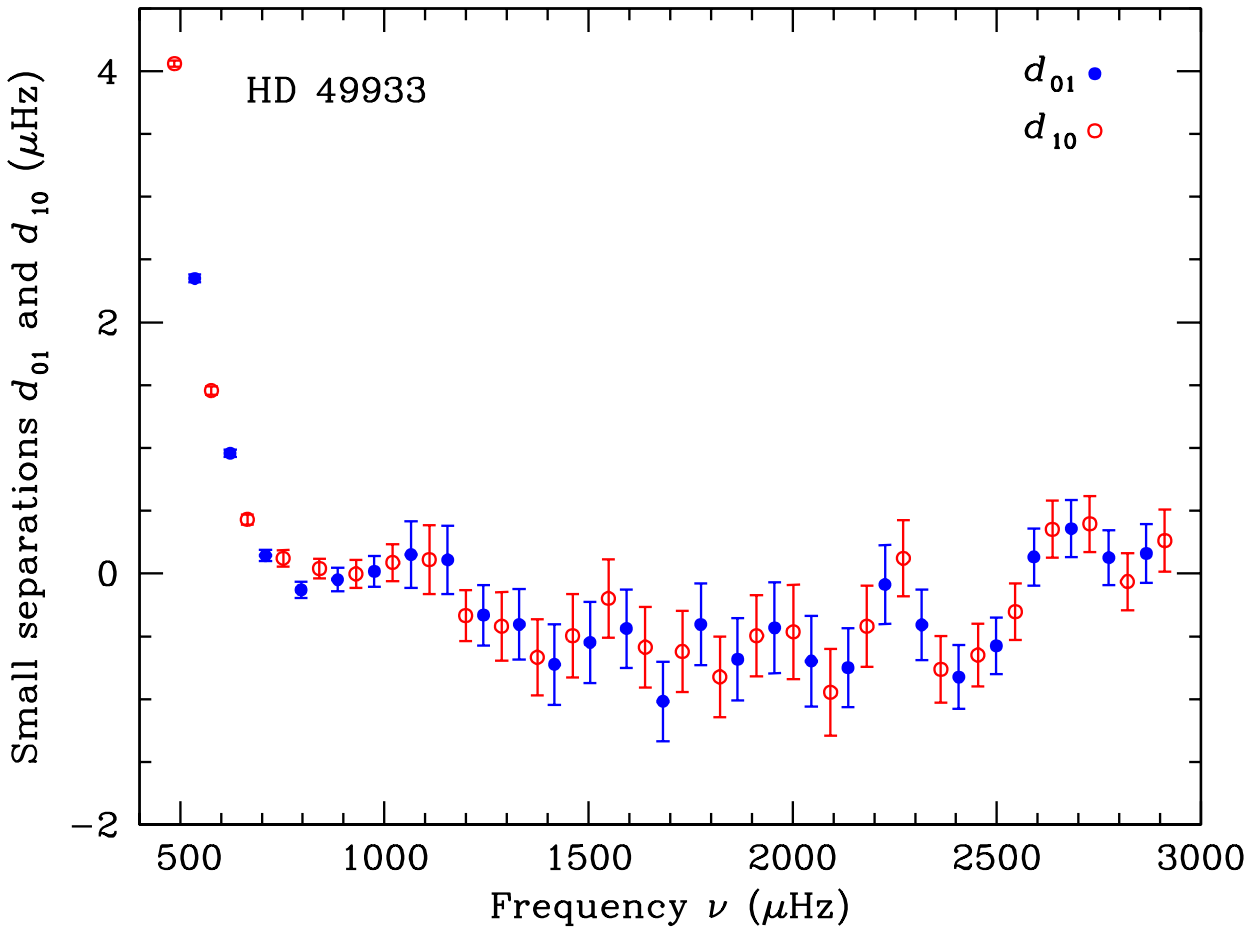
Nature of the Data

Small Separations

- Between $\ell = 0,\ 1$ modes:

$$d_{01} = \quad [\nu_{n,0} - (\nu_{n,1} + \nu_{n-1,1})/2]/2$$

$$d_{10} = -[\nu_{n,1} + (\nu_{n,0} + \nu_{n+1,0})/2]/2$$



Approaching the closest model

- Average value of large separation provides initial estimate of the mean density of the model:

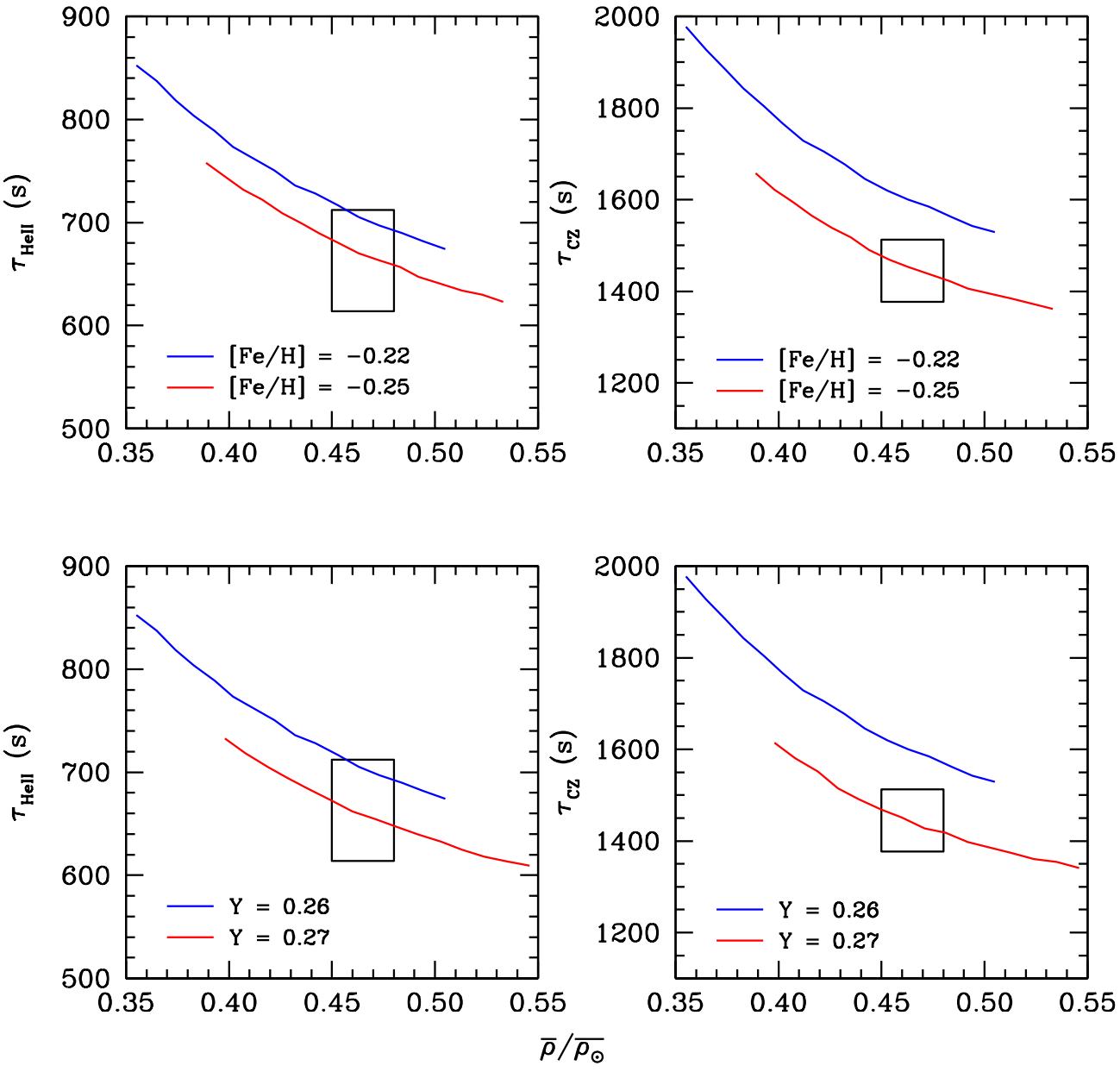
$$\bar{\rho}/\bar{\rho}_{\odot} \sim 0.46$$

- Explore the sensitivity of different features of the large separations to the six model parameters:

$$\mathrm{M}, \mathrm{Age}, \mathrm{Y}, [\mathrm{Fe/H}], \mathrm{d_{ov}}, \alpha$$

- Fitted values of the τ_{CZ} and τ_{HeII} provide strong indication.

Approaching the closest model



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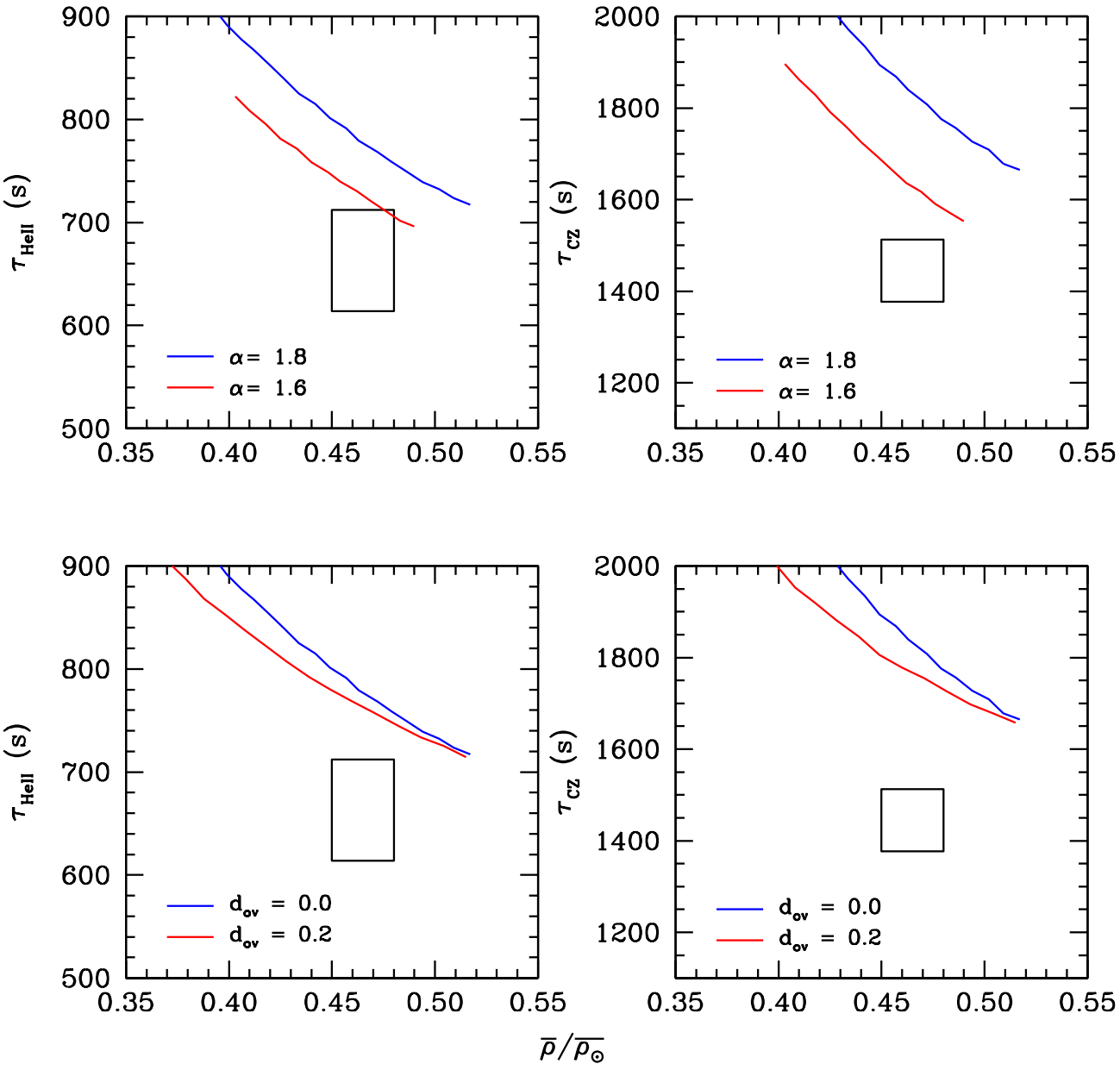
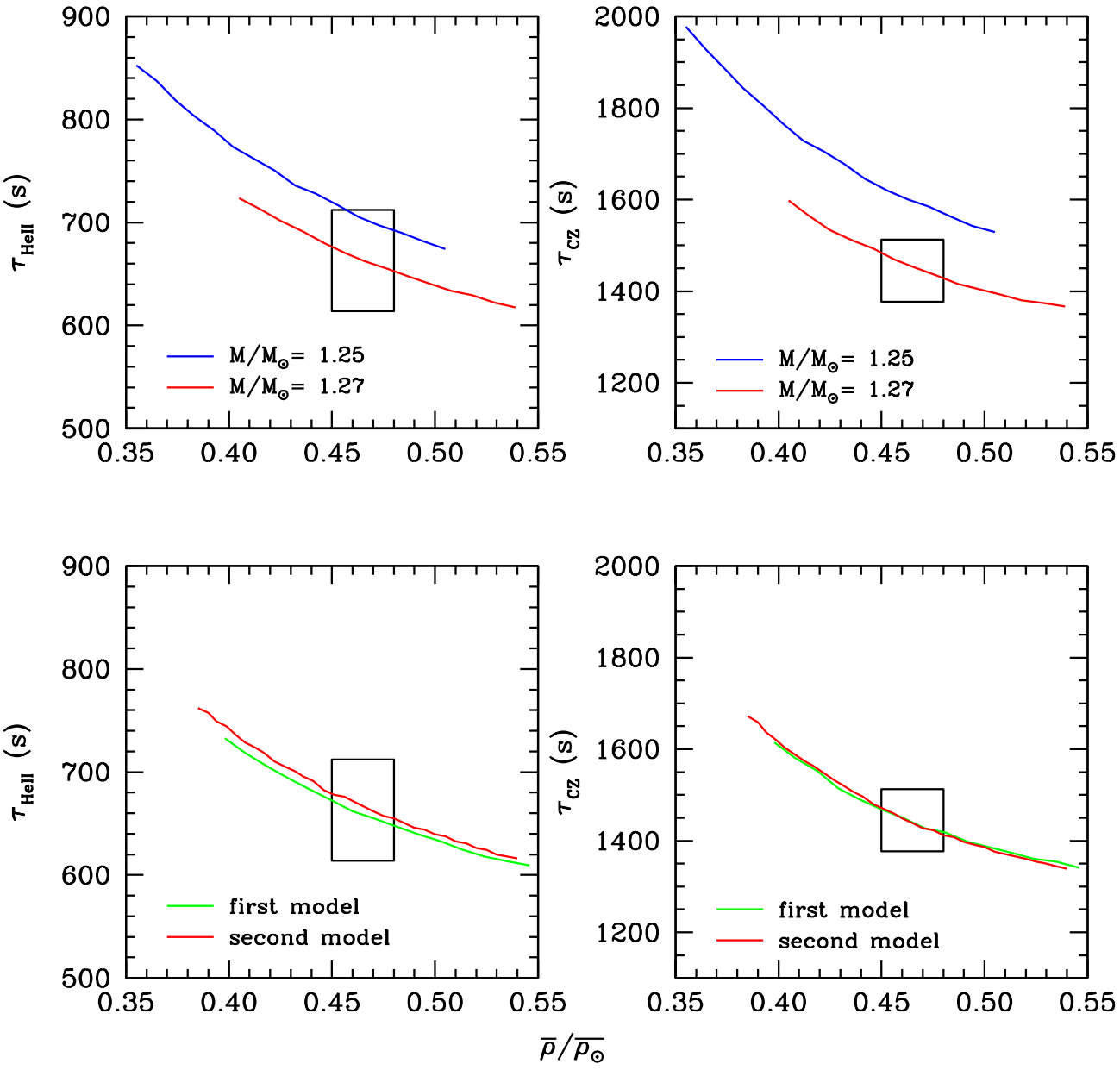


Approaching the closest model

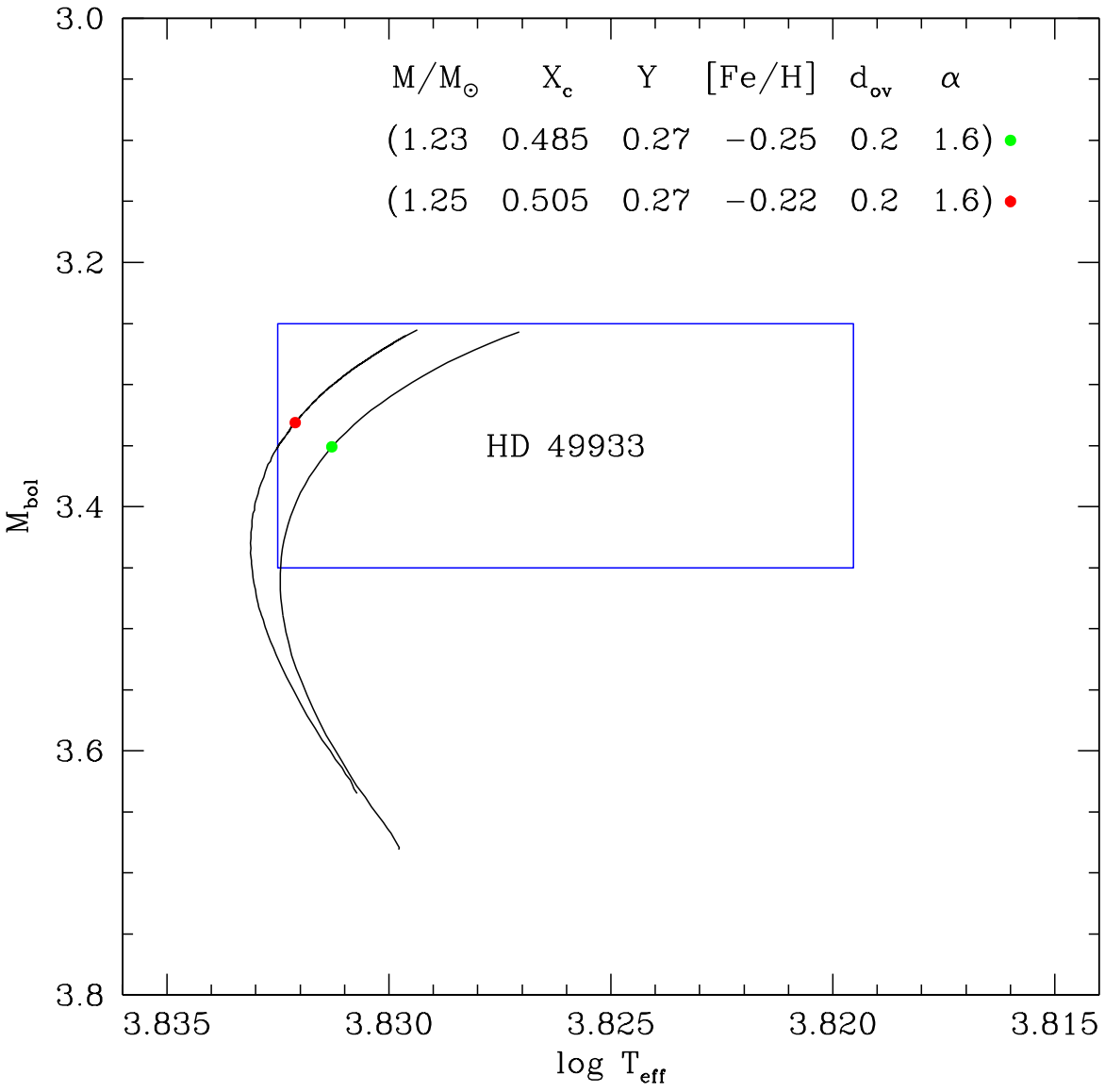


Approaching the closest model

- Small separations between $\ell = 0, 1$ modes in the data have unusually small and even negative values!
- Small separations between $\ell = 0, 2$ modes are hardly available in the data.
- Inability to match the small separations between $\ell = 0, 1$ modes with any combination of parameters.
- Several "best case" scenarios are identified, based on the large separations alone and a comparison of the deviations of the models from the data is made to select the closest model.

Closest Model

We have two close models for HD 49933.



Closest Model

Model Parameters:

- $M/M_{\odot} = 1.23$
- $X_c = 0.485$
- $R/R_{\odot} = 1.383$
- $Y = 0.27$
- $[\mathrm{Fe/H}] = -0.25$
- $\mathrm{d_{ov}} = 0.20$
- $\alpha = 1.6$

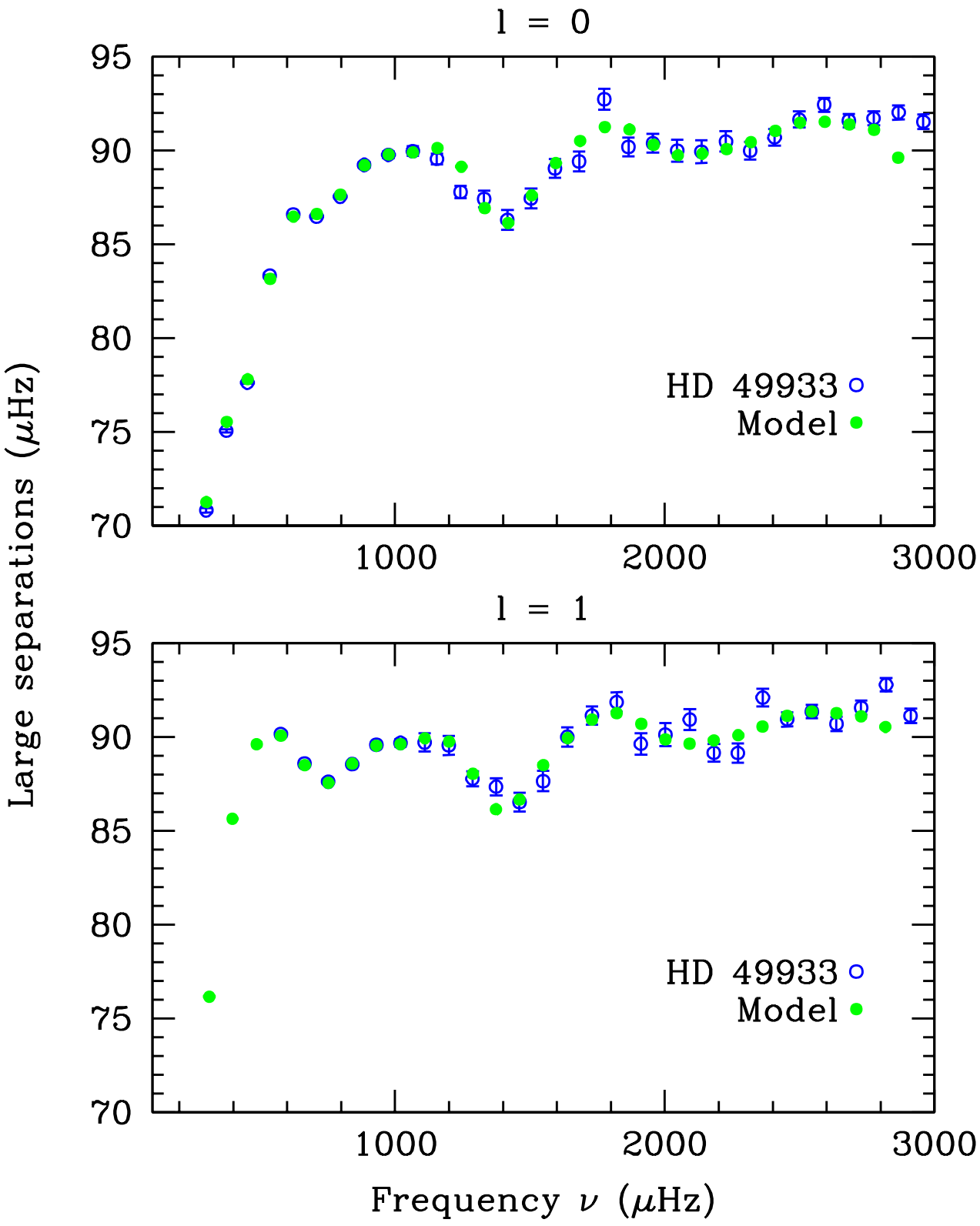
- $M/M_{\odot} = 1.25$
- $X_c = 0.505$
- $R/R_{\odot} = 1.390$
- $Y = 0.27$
- $[\mathrm{Fe/H}] = -0.22$
- $\mathrm{d_{ov}} = 0.20$
- $\alpha = 1.6$

Model values for

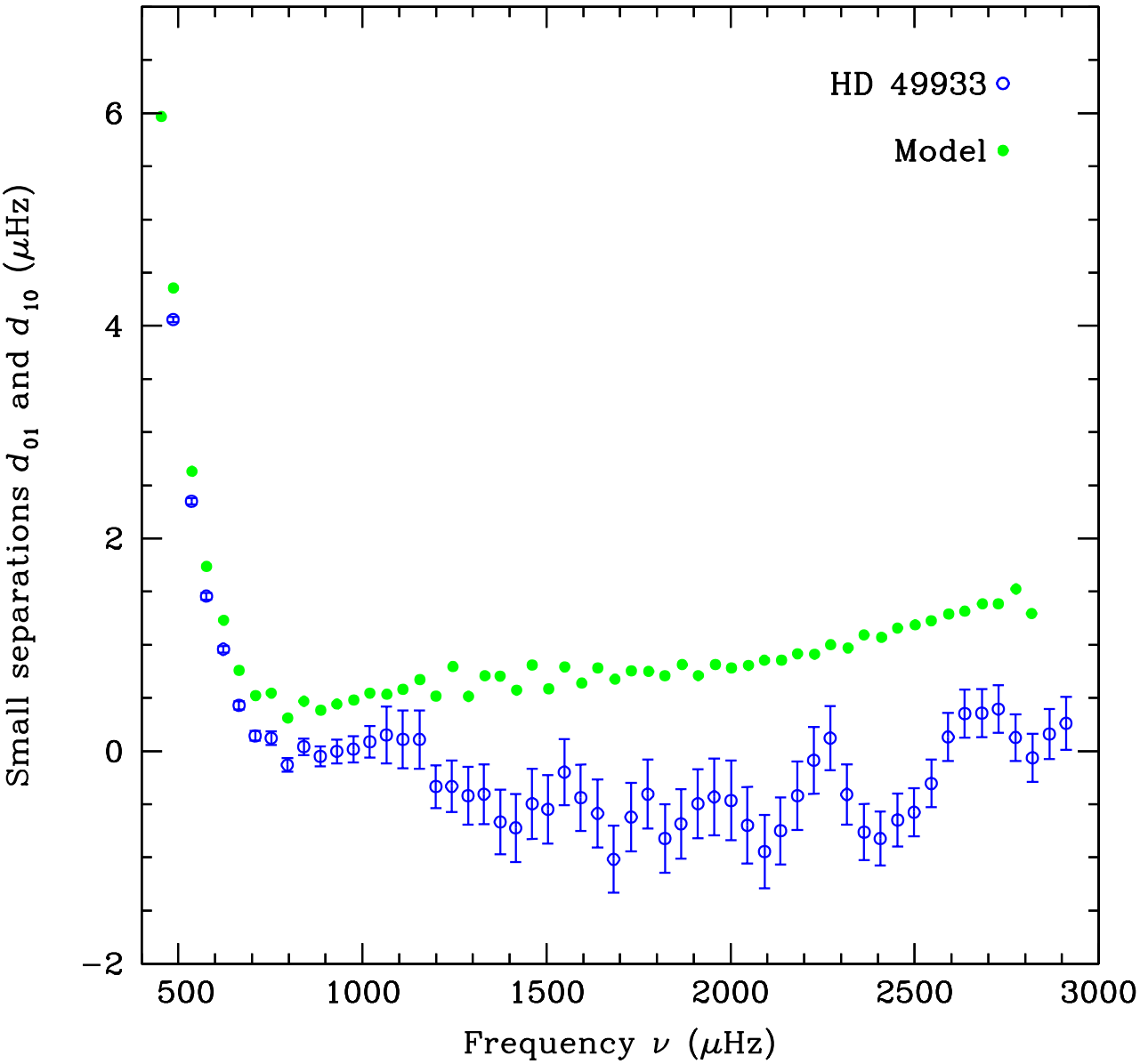
- $\bar{\rho}/\bar{\rho_{\odot}} = 0.465$
- $\tau_{CZ} = 1410$ s
- $\tau_{HeII} = 653$ s

- $\bar{\rho}/\bar{\rho_{\odot}} = 0.465$
- $\tau_{CZ} = 1438$ s
- $\tau_{HeII} = 667$ s

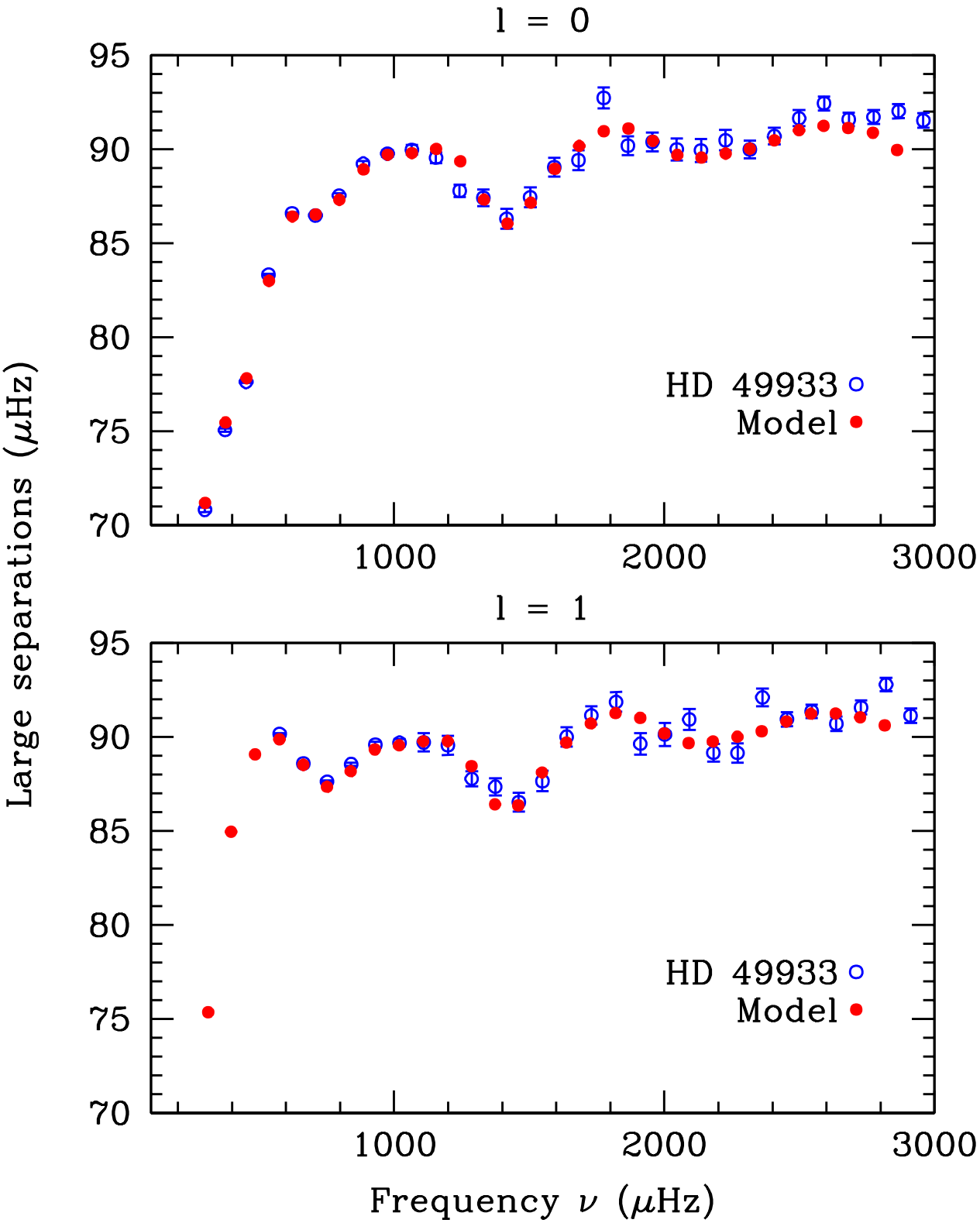
Closest Model



Closest Model



Closest Model



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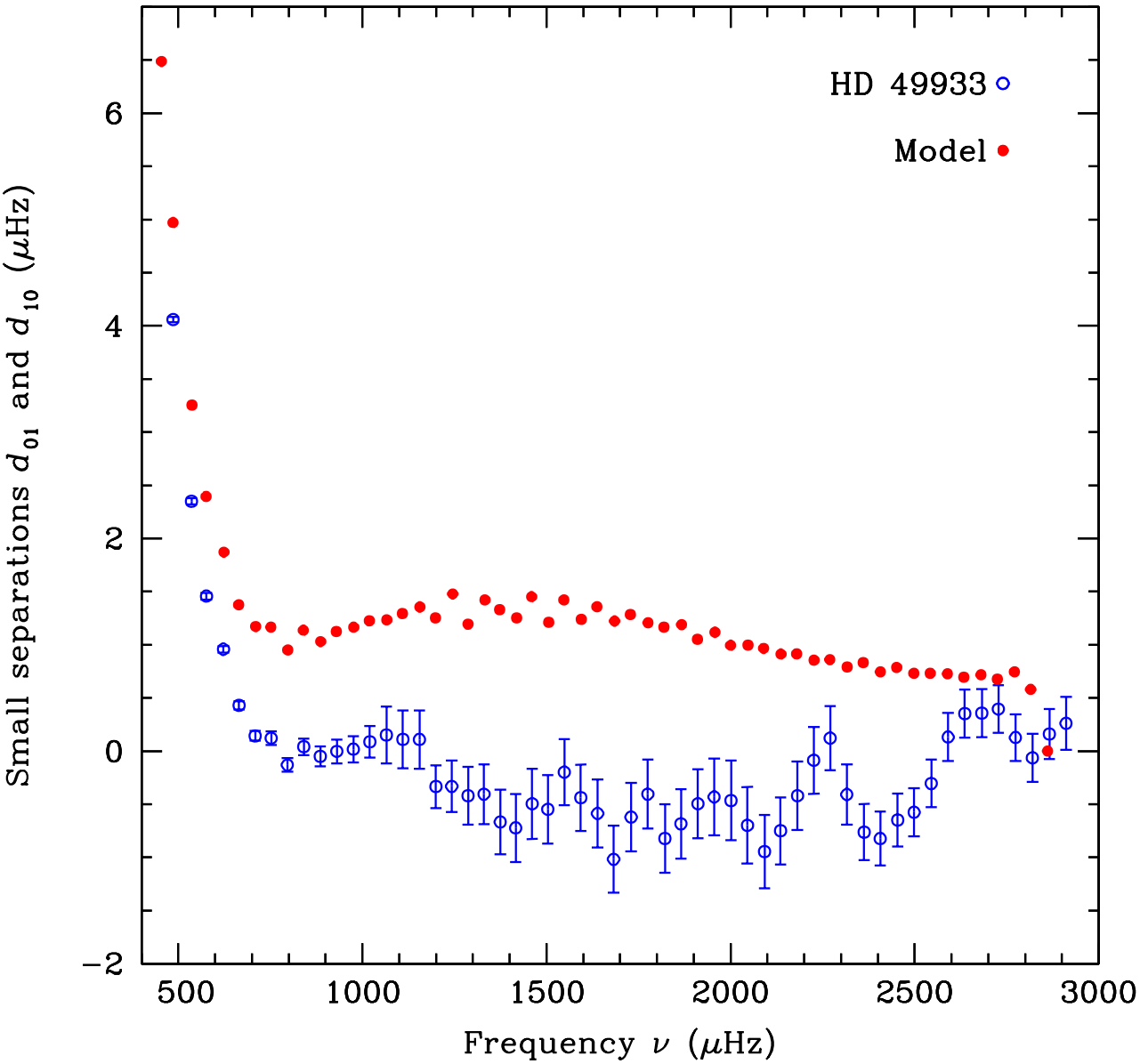

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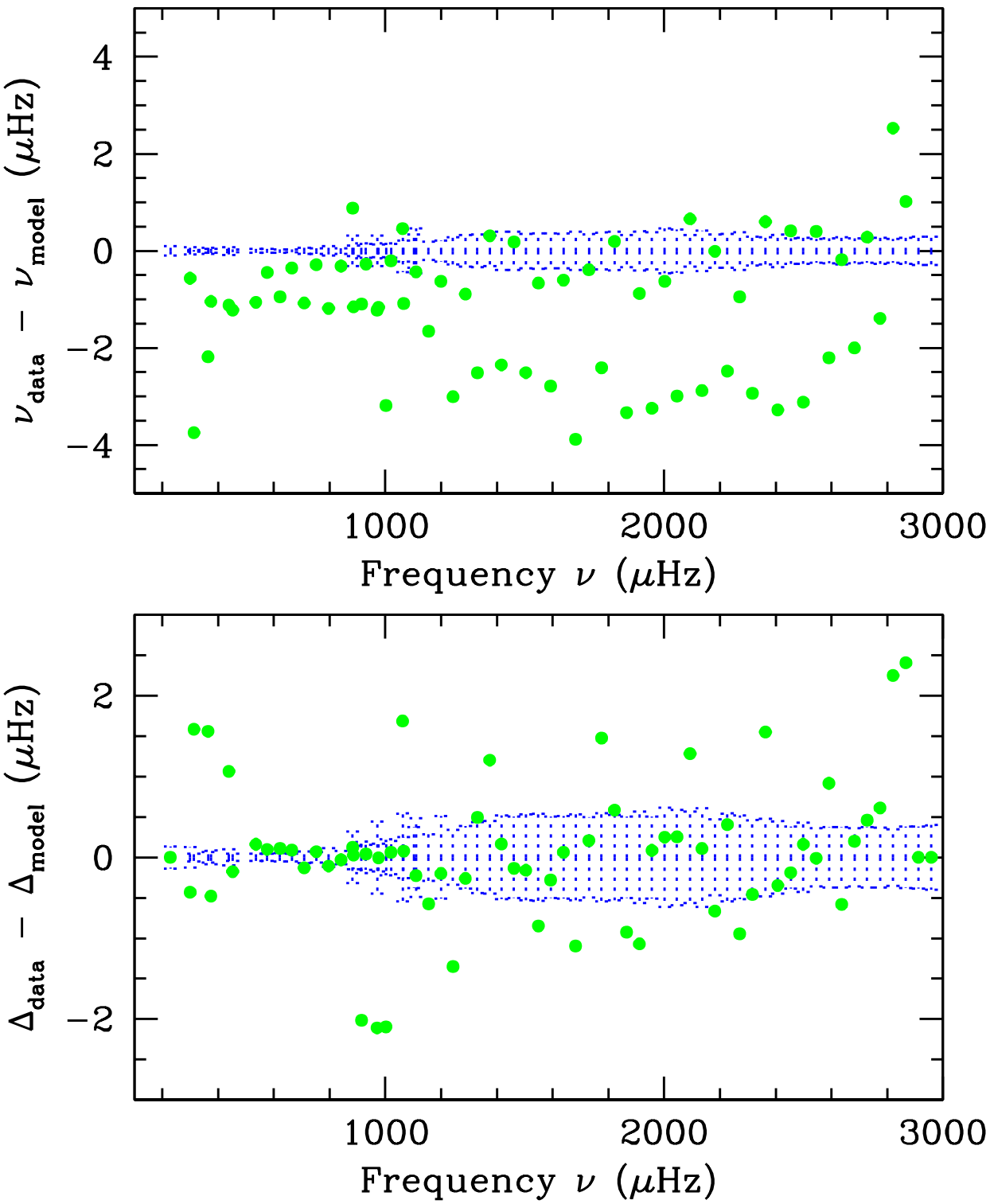
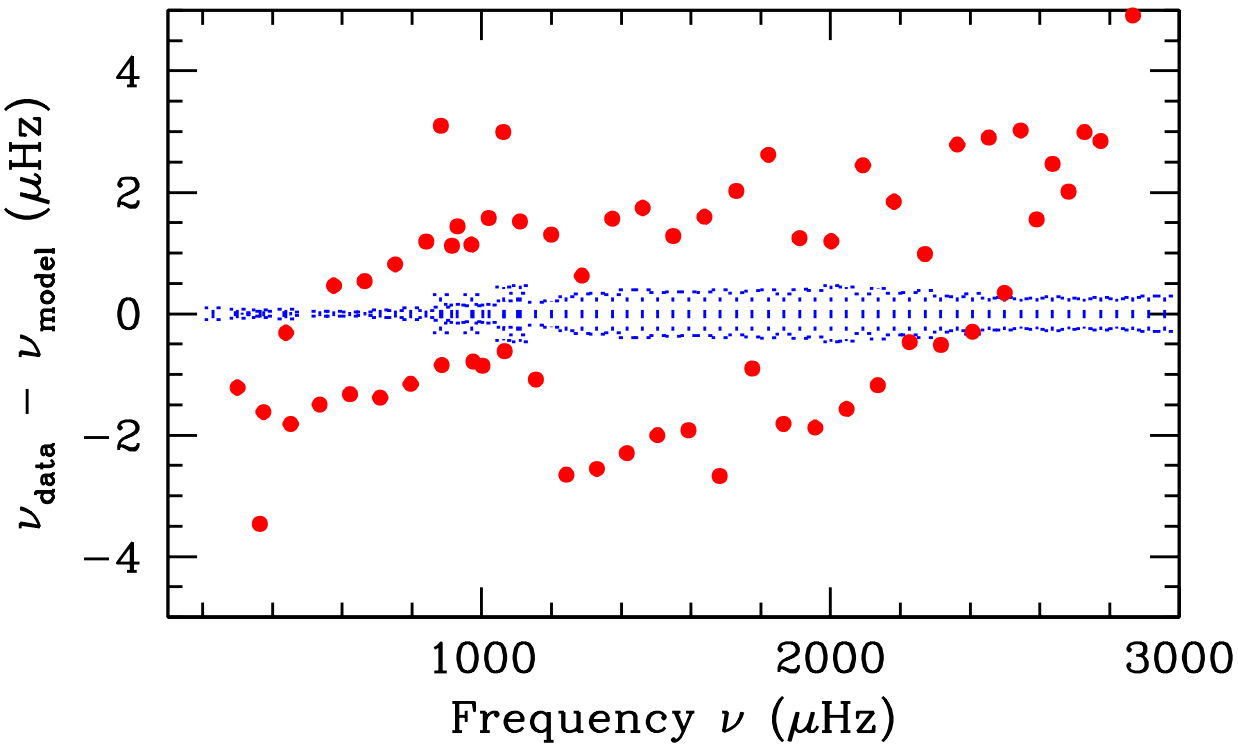
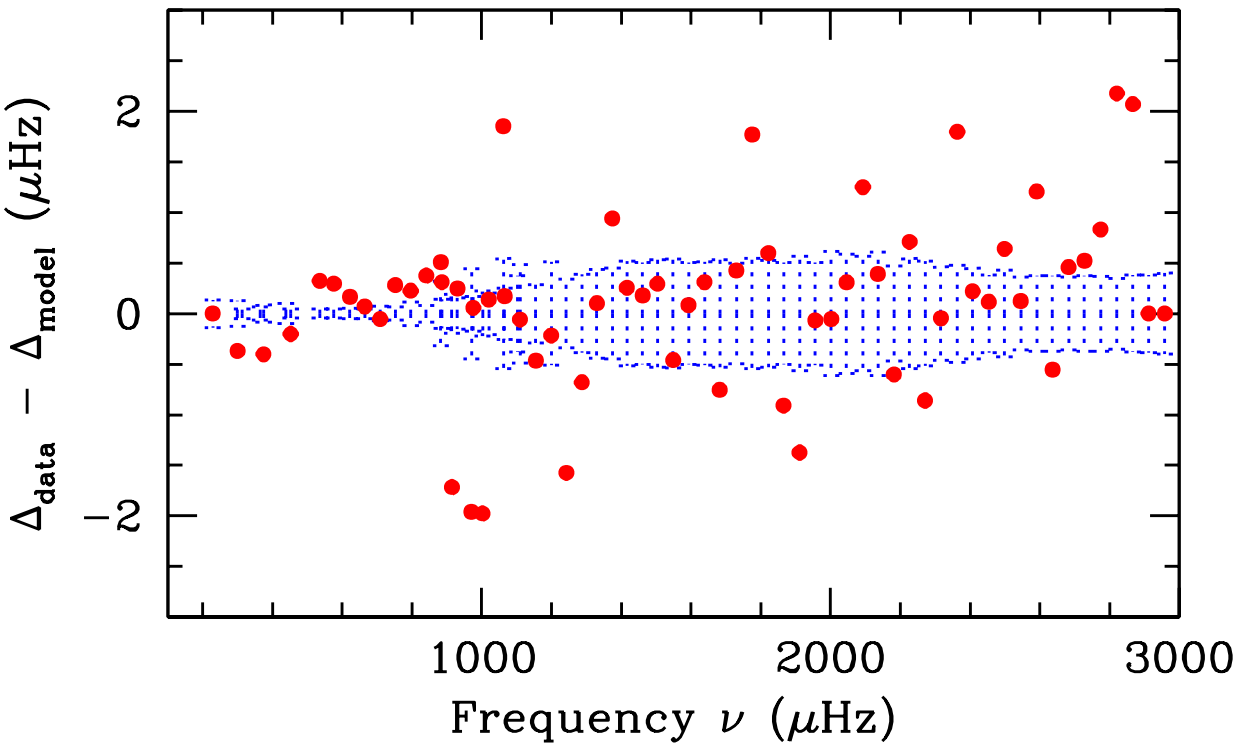


Closest Model





Conclusions

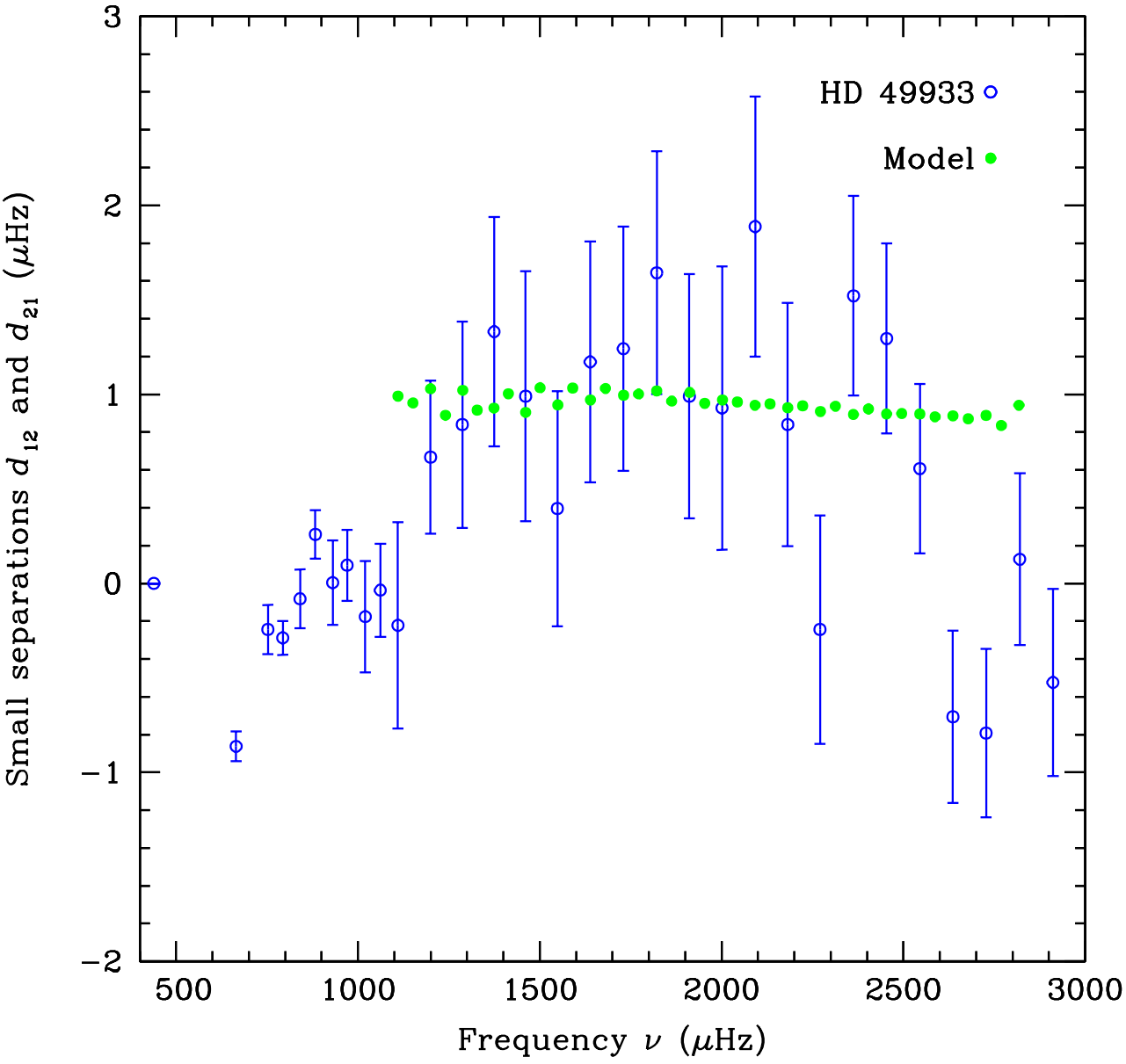
- We could obtain close match between the large separations in the data and a model.
- The small separations of all models that we considered were much higher than the values obtained from the data.
- Our model is likely to be a good approximation of the original model in the outer layers, but lack of constraints from the small separations prevents gaining information about the inner layers.
- The sensitivity of the τ_{CZ} and τ_{HeII} on the model parameters provides good indication of what is to be changed from an initial trial model.
- The unusual values of the small separations might be indicative of misidentification of modes, or model inconsistencies in the inner layers. Or,...

it is a goldmine of information!

Postscript

There might be misidentification of modes between $\ell = 0$ and 2.

In that case, $d_{01} \to -d_{21}/2$ and $d_{10} \to -d_{12}/2$.



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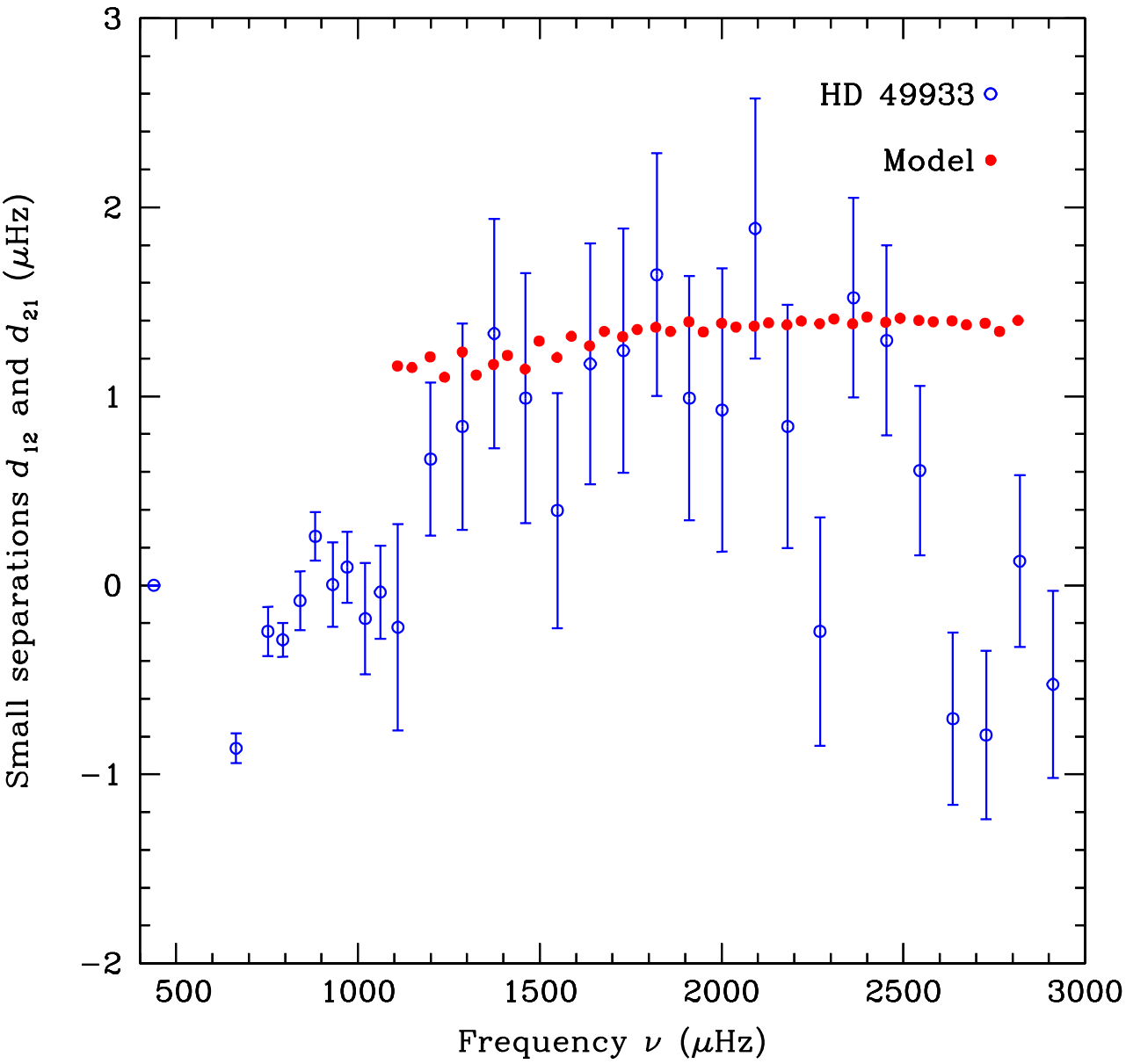
HD 49933
Model
Small separations d_{12} and d_{21} (μHz)
Frequency ν (μHz)
3
2
1
0
−1
−2
500
1000
1500
2000
2500
3000