Kepler-93: a testbed for detailed seismic modelling and orbital evolution of super-earths around solar-like stars

Jérôme Bétrisey[1], C. Pezzotti, G. Buldgen, S. Khan, P. Eggenberger, S. J. A. J. Salmon, and A. Miglio

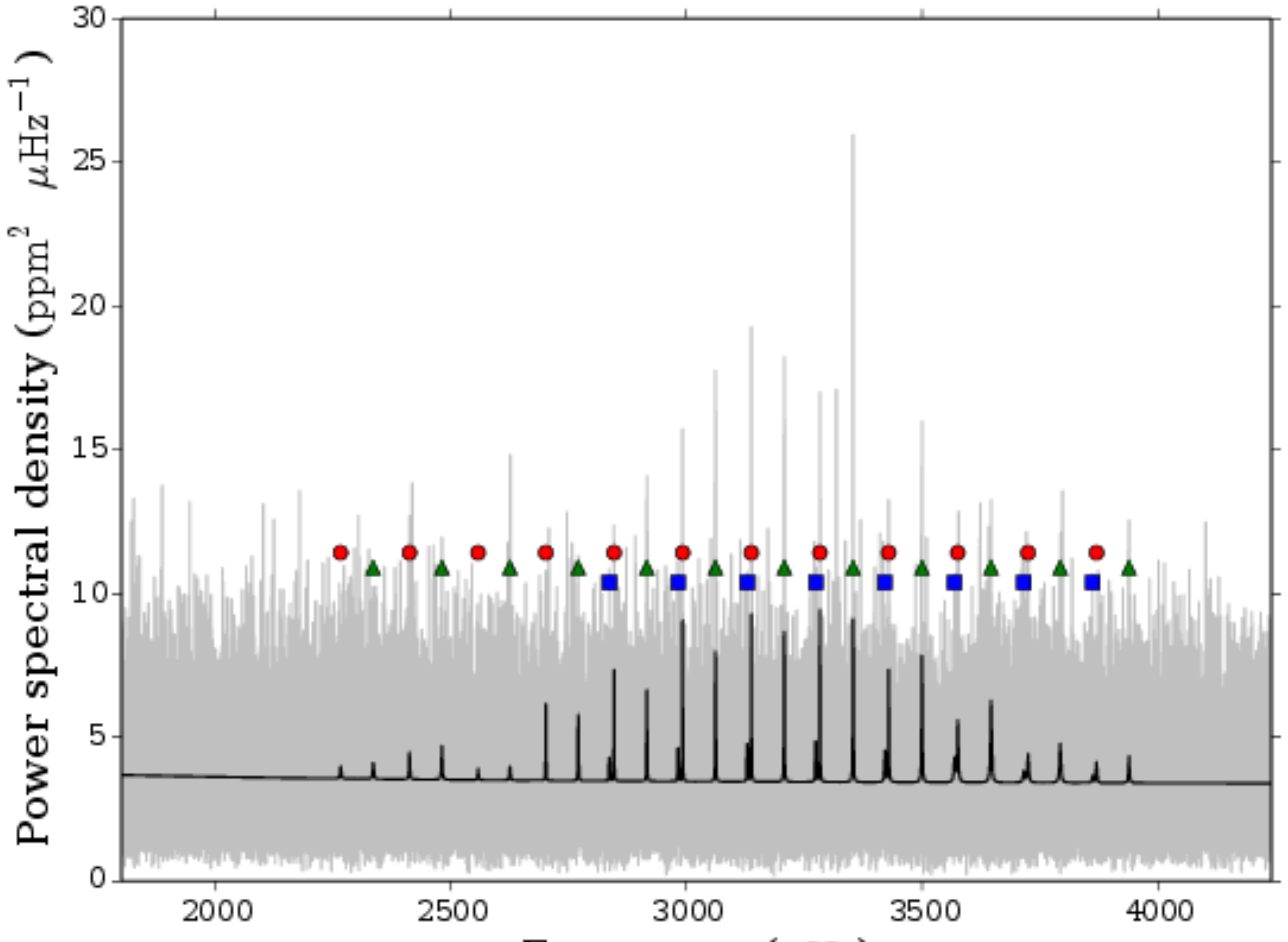
[1] Jerome.Betrisey@unige.ch, Observatoire de Genève, Chemin Pegasi 51, 1290 Versoix, Switzerland

UNIVERSITÉ DE GENÈVE

FNSNF

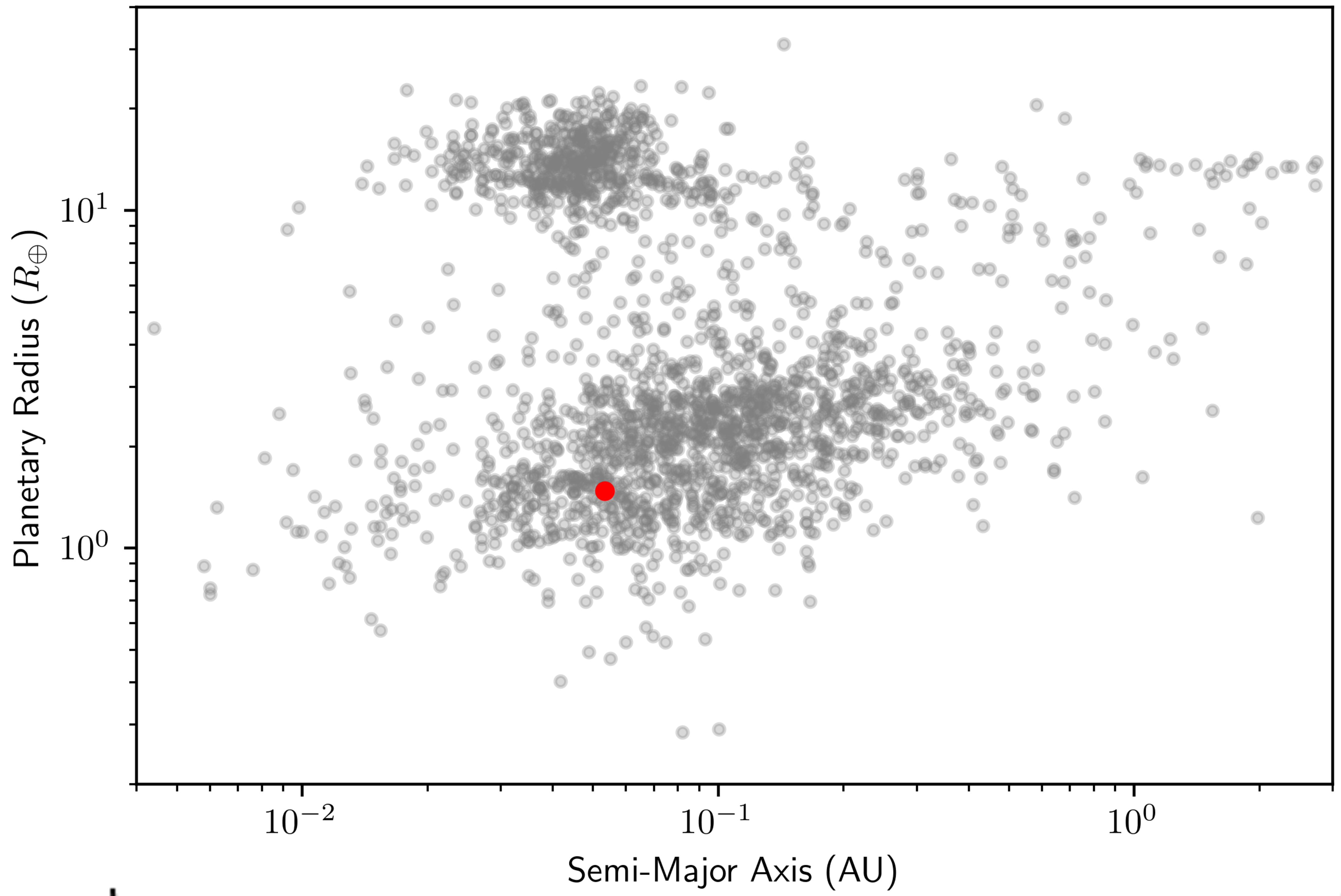
Killing two birds with one stone

Kepler-93



From Davies+2016

Kepler-93b



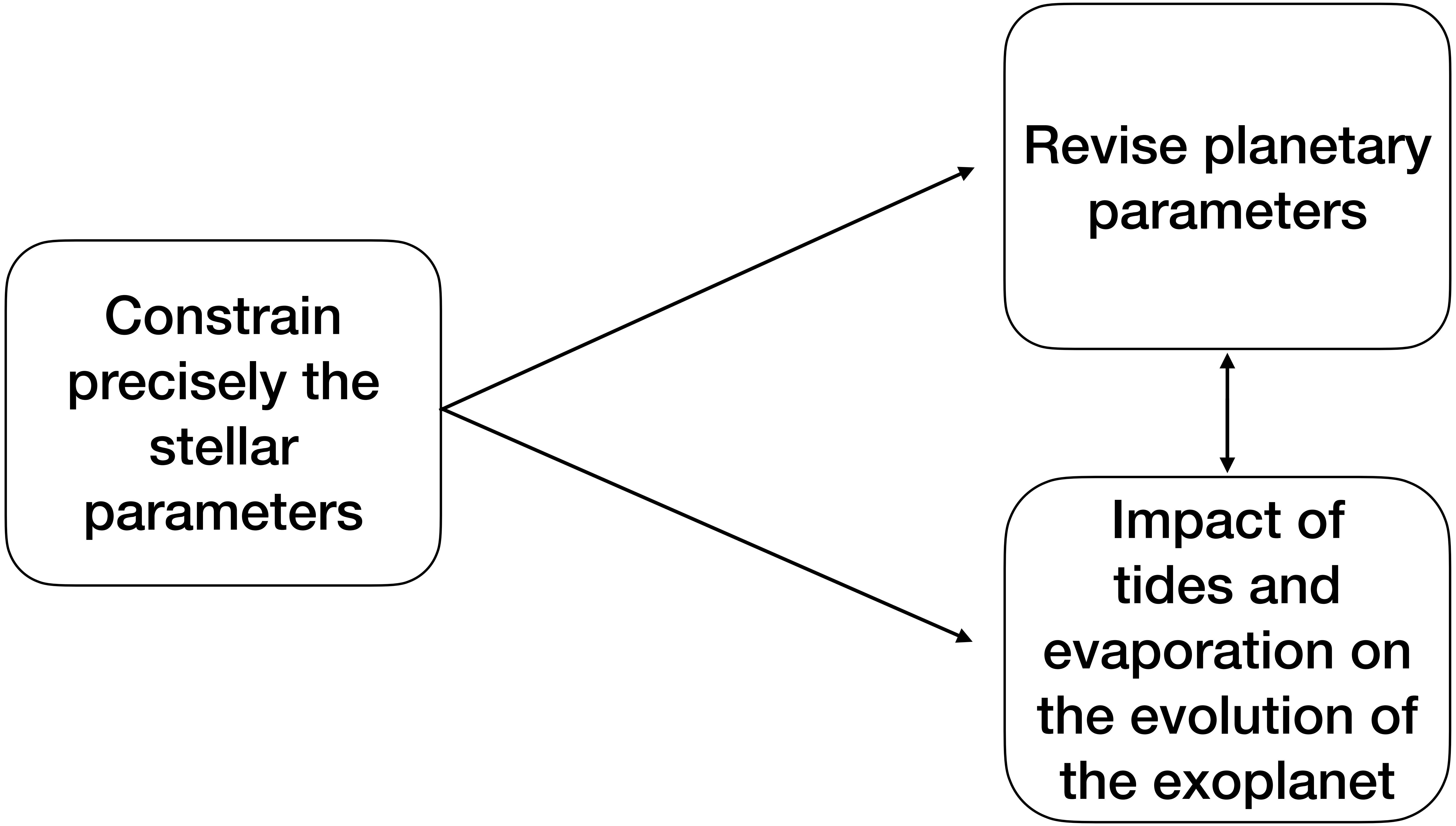
Solar-type star with p-modes precisions similar to expectations for PLATO (Huber+2013, Marcy+2014, Ballard+2014, Silva-Aguirre+2015, Bellinger+2016,2019)

=> benchmark target to test how far we can go with PLATO

Rocky world laying in the lower part of the radius valley, that probably lost its atmosphere during its evolution (Borucki+2011, Marcy+2014, Dressing+2015)

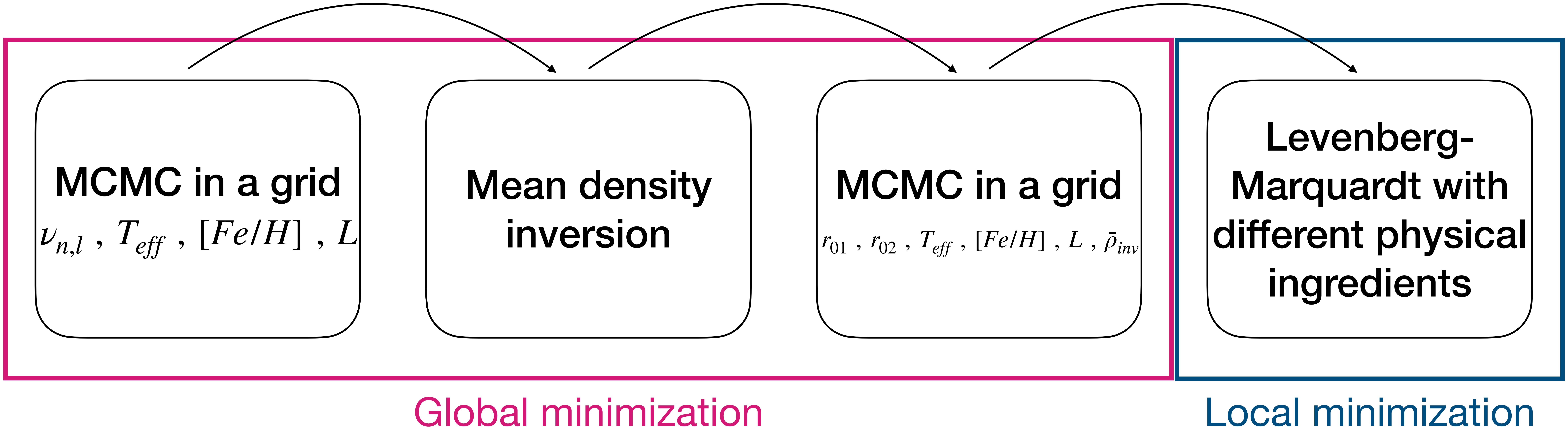
=> good candidate to study the impact of stellar tides and evaporation of the planetary atmosphere

Asteroseismology and Exoplanetology Synergies



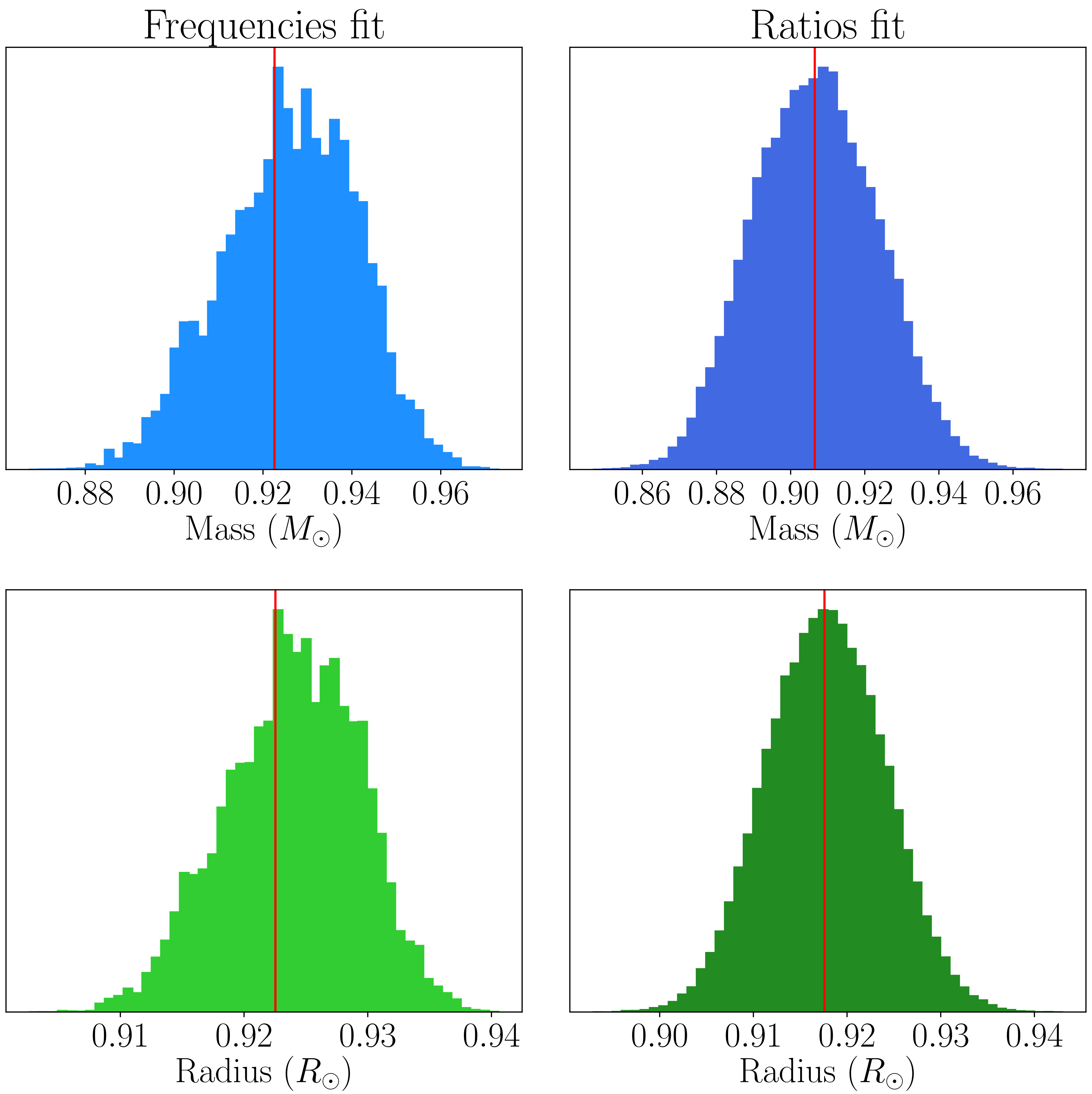
See e.g. Privitera+2016a,b, Rao+2018, Budgen+2019, Pezzotti+2021

The Modelling Procedure



See another application on Kepler-444 in Buldgen+2019

Fitting Frequencies vs Ratios



<u>Frequencies</u>

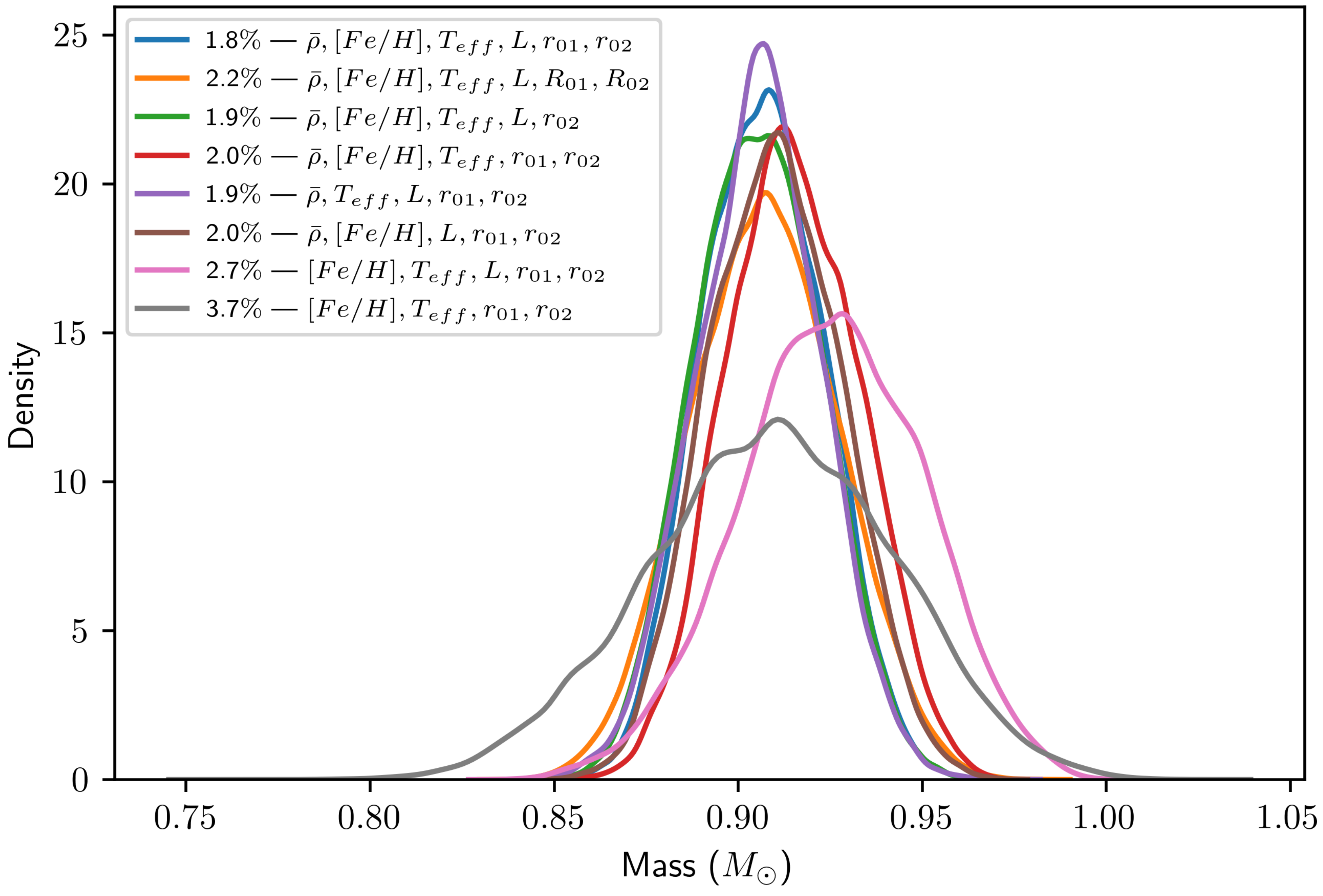
See also Rendle+2019, Buldgen+2019

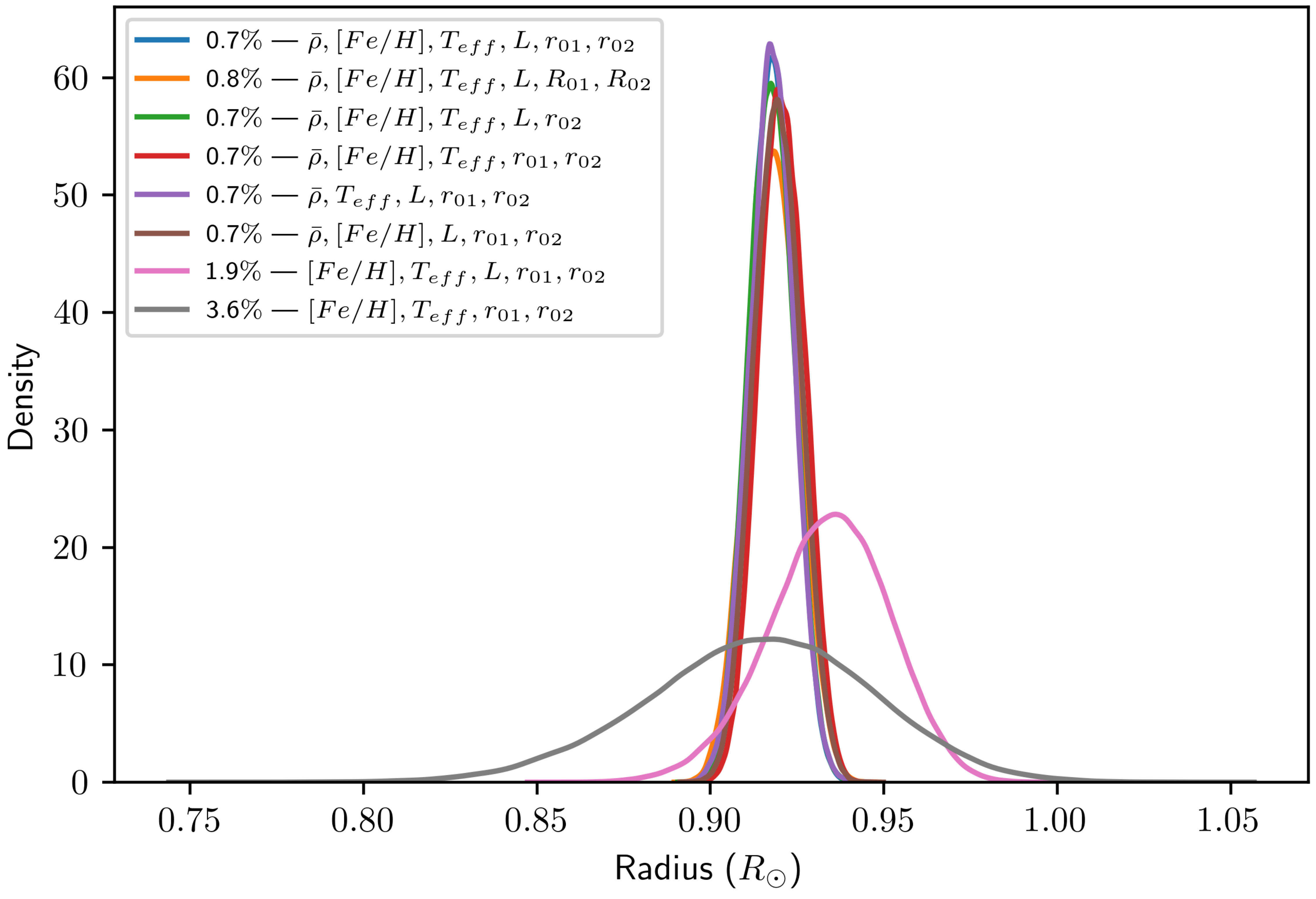
- too many constraints => very peaked histograms and less good interpolation
- Mass overestimation due to the treatment of surface effects

<u>Ratios</u>

- Surface effects damped by definition (Roxburgh&Voronsov 2003)
- Better interpolation

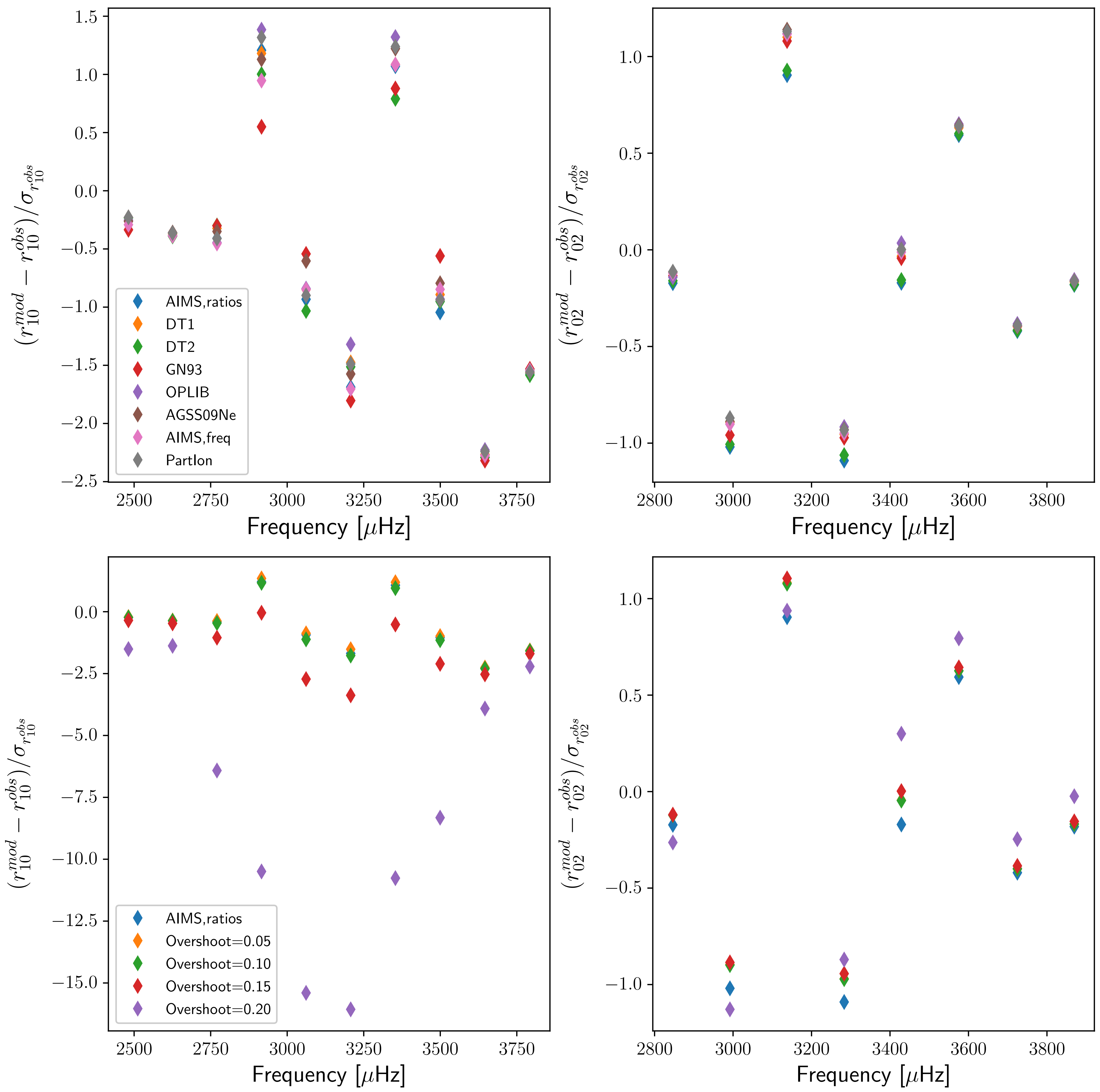
Inverted Mean Density as a Constraint



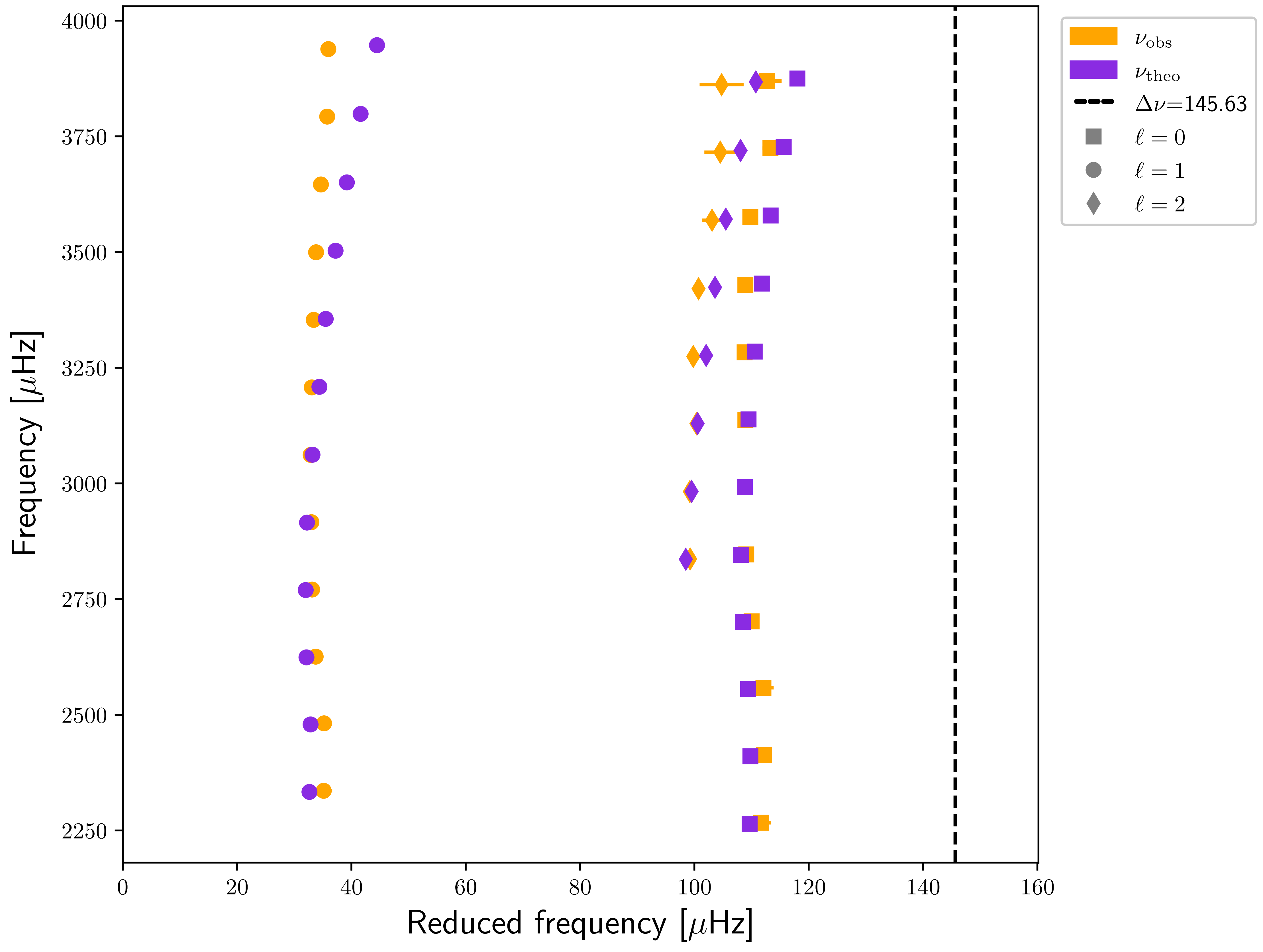


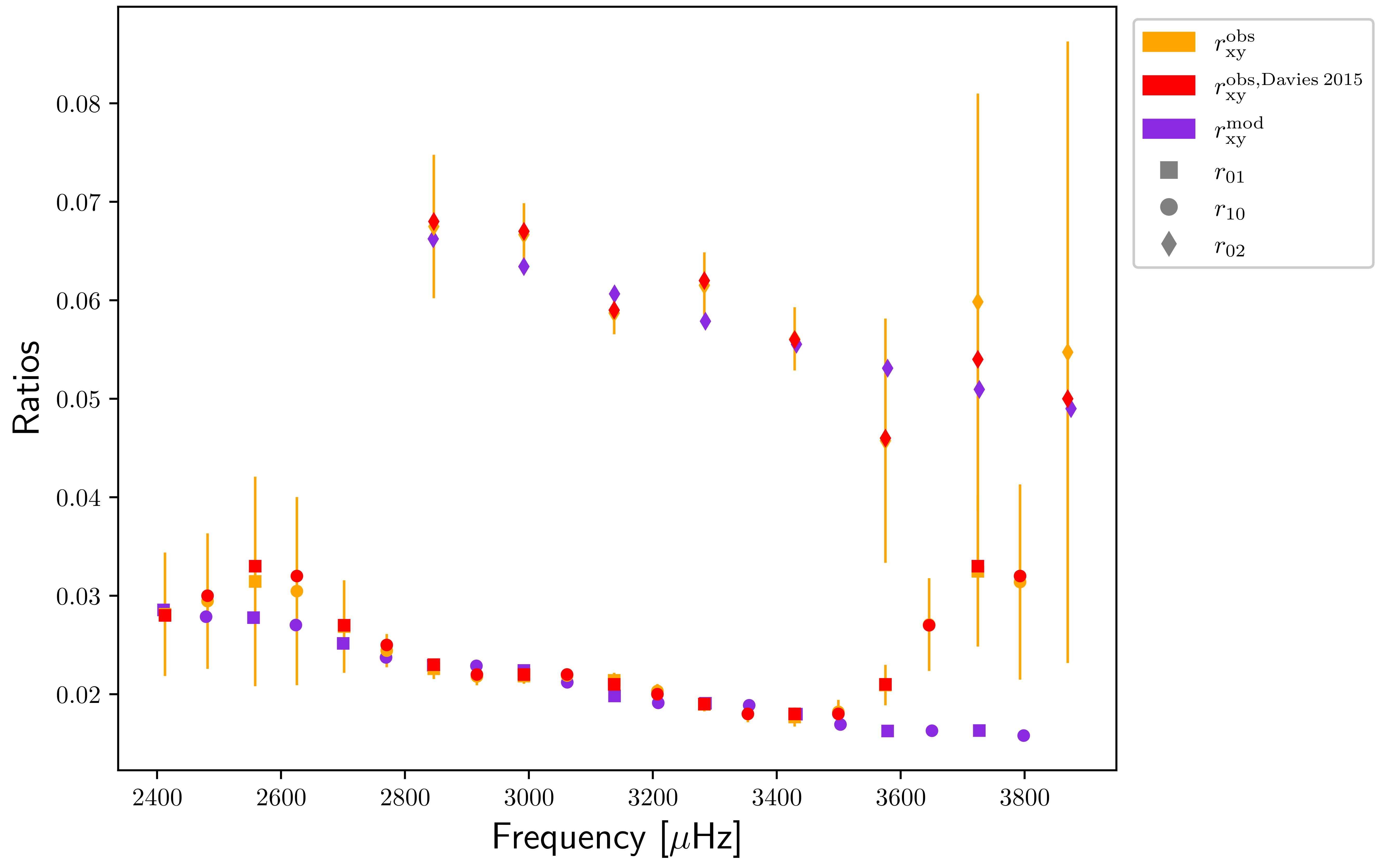
The addition of the inverted mean density leads to better constrained (therefore precise) stellar mass and radius

Revised stellar Parameters

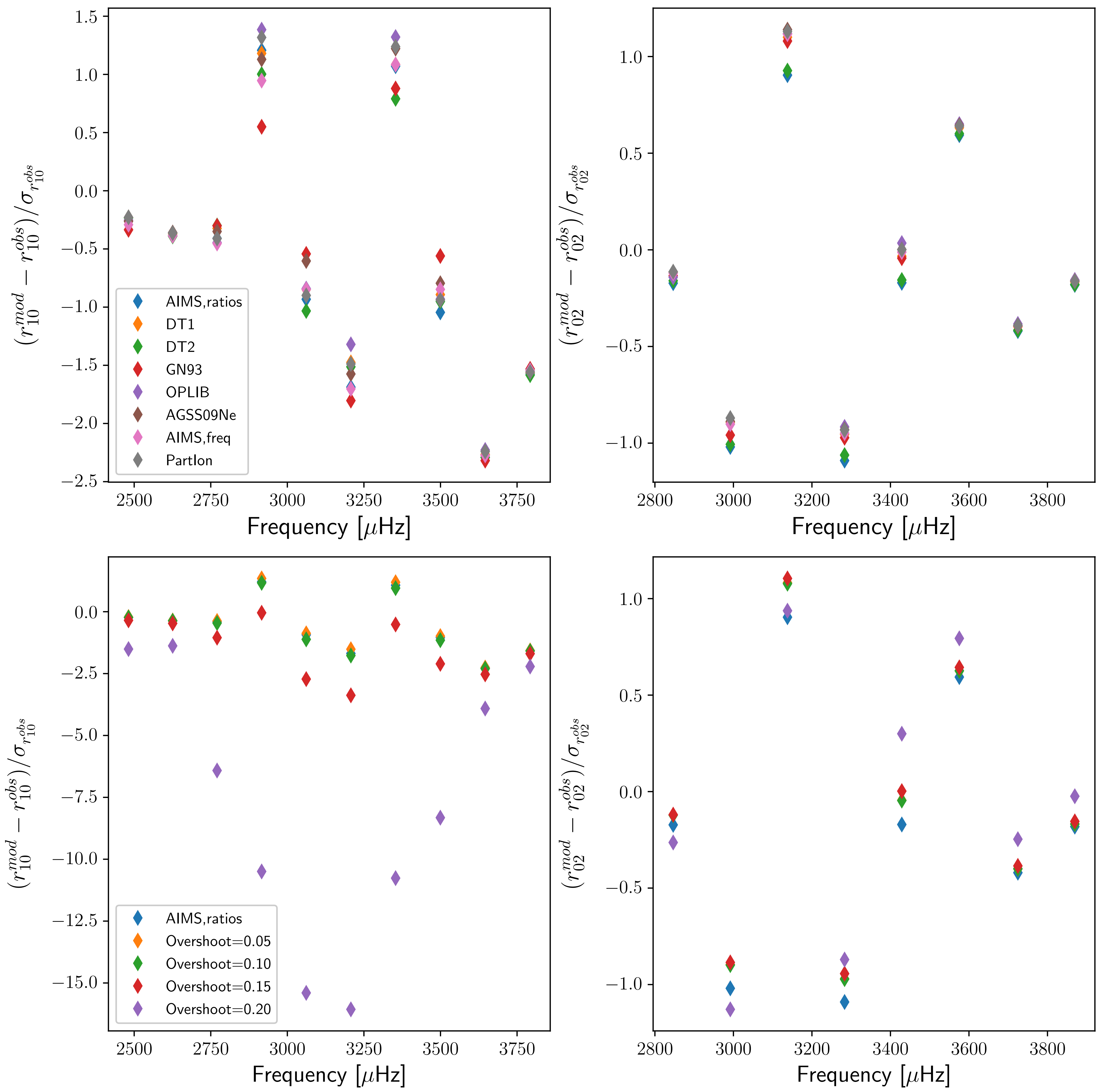


Revised stellar Parameters





Revised stellar Parameters



We reach the PLATO requirements !

(15% in mass, 1-2% in radius and 10% in age)

$$M/M_\odot = 0.907 \pm 0.023 \quad (2.5\%)$$
$$R/R_\odot = 0.918 \pm 0.008 \quad (0.9\%)$$
$$\text{Age [Gyr]} = 6.78 \pm 0.32 \quad (4.7\%)$$
$$\bar{\rho}\ [\text{g/cm}^3] = 1.654 \pm 0.004 \quad (0.2\%)$$

Includes systematics for the choice of the physical ingredients

Mean Density Inversion

Structure inversion equation (Dziembowski+1990):

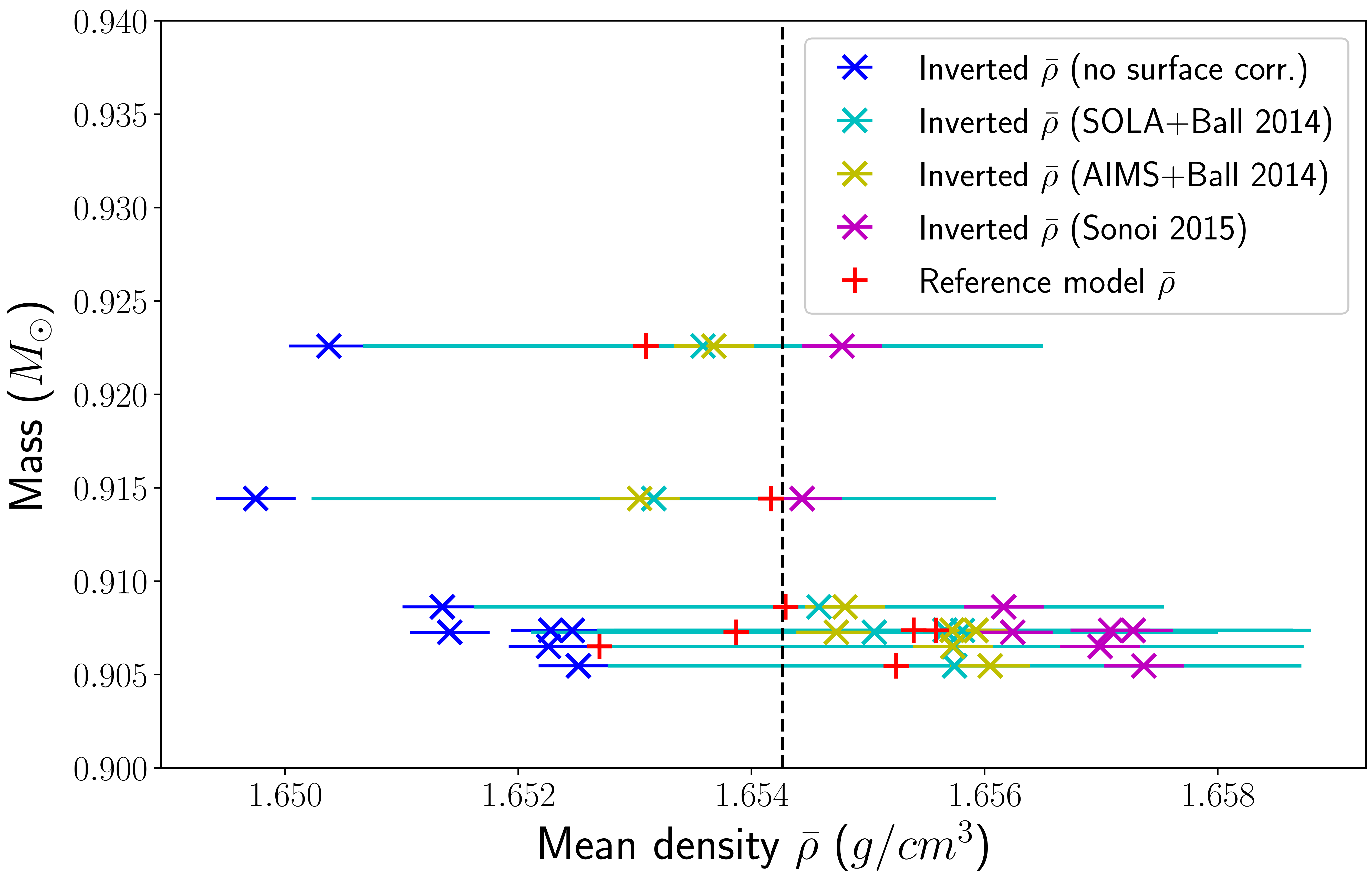
$$\frac{\delta\nu^{n,l}}{\nu^{n,l}} = \int_0^R K^{n,l}_{\rho,\Gamma_1}(r)\frac{\delta\rho}{\rho}dr + \int_0^R K^{n,l}_{\Gamma_1,\rho}(r)\frac{\delta\Gamma_1}{\Gamma_1}dr + \mathcal{O}(\delta^2)$$

SOLA method (Pijpers+1994, Reese+2012):

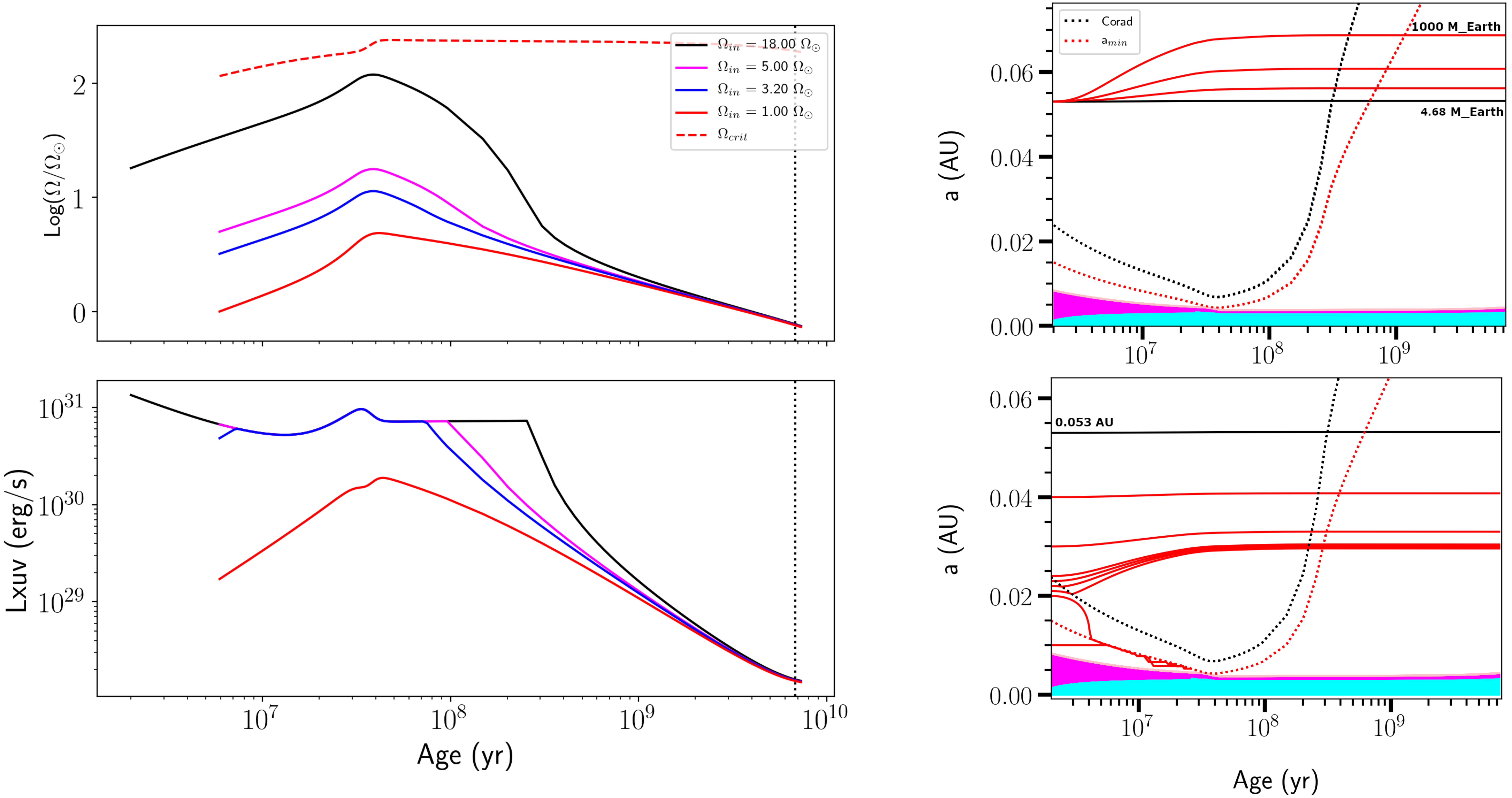
$$\mathcal{J}_{\bar{\rho}}(c_i) = \int_0^1 \left(\mathcal{K}_{\text{avg}} - \mathcal{T}_{\bar{\rho}}\right)^2 dx + \beta\int_0^1 \mathcal{K}^2_{\text{cross}}dx + \lambda\left[2 - \sum_i c_i\right]$$

$$+\tan\theta\frac{\sum_i (c_i\sigma_i)^2}{\langle\sigma^2\rangle} + \mathcal{F}_{\text{Surf}}(\nu)$$

where $\mathcal{T}_{\bar{\rho}} = 4\pi x^2\frac{\rho}{\rho_R}$ and $\bar{\rho} = \int_0^1 \mathcal{T}_{\bar{\rho}}\frac{\delta\rho}{\rho}dx.$



Orbital Evolution of Kepler-93b



Conclusions

- Data quality of Kepler-93 similar to expectations of PLATO -> we can reach the PLATO requirements (15% in mass, 1-2% in radius and 10% in age)
- Mean density inversions can help to get more precise stellar masses and radii
- Mean density inversions are applicable for the majority of the PLATO sample
- Asteroseismology helps to better understand the evolution of exoplanets => limiting factor is the radial velocities follow-up for Kepler-93, not asteroseismology

Thank you for your attention !