Using Patched Models

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Jakob R. Mosumgaard, Jørgen Christensen-Dalsgaard, Victor Silva Aguirre

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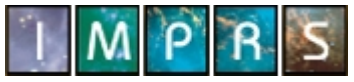

STELLAR ASTROPHYSICS CENTRE

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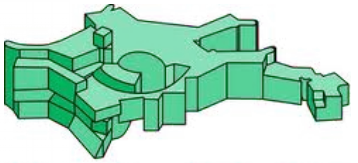

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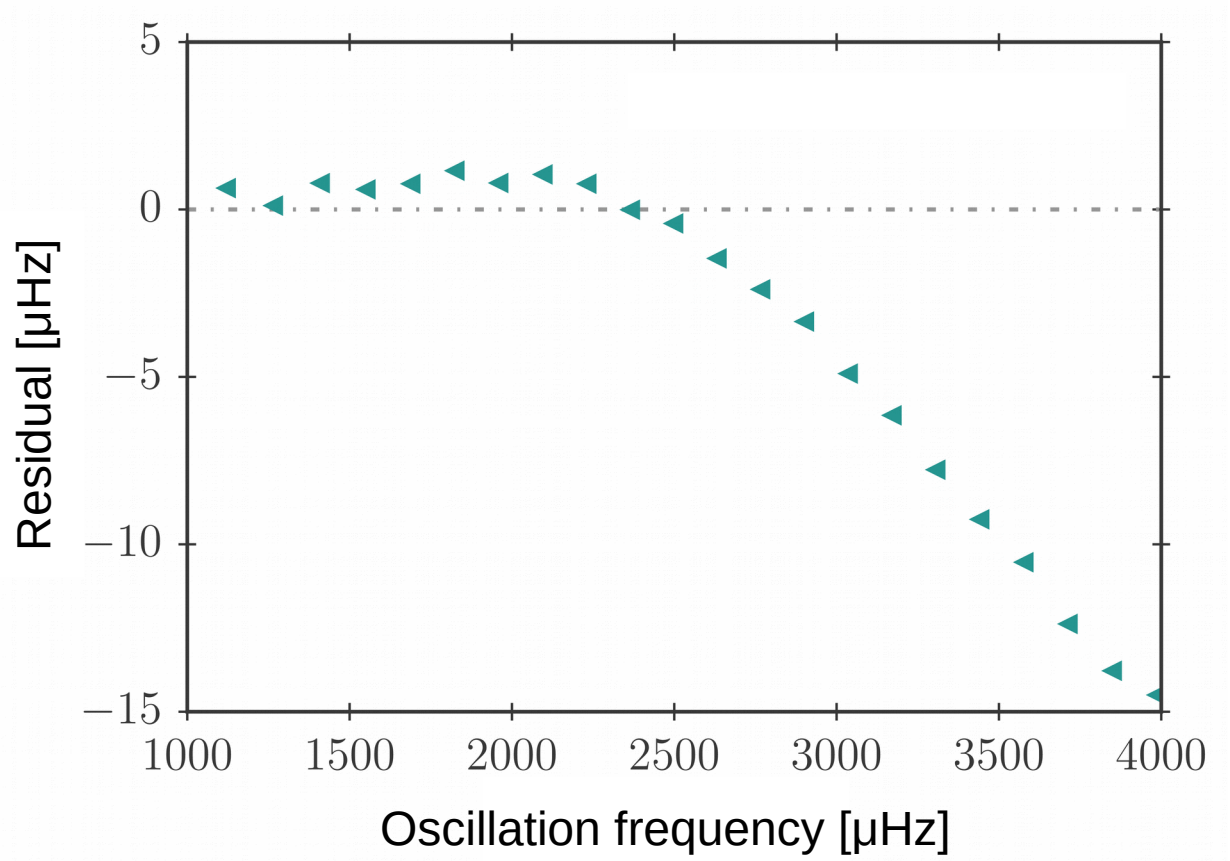
The surface effect



Structural surface effect
(Simplified surface layers, MLT)

+

Modal surface effect
(Adiabatic frequency calculations)

Aims of 1D vs. 3D simulations

Stellar evolution codes:

Holistic picture of evolution

1) 1D, $T(r,t)$

2) MLT, nuclear time-scale

Simplified *superadiabatic* layers

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STRUCTURAL SURFACE EFFECT

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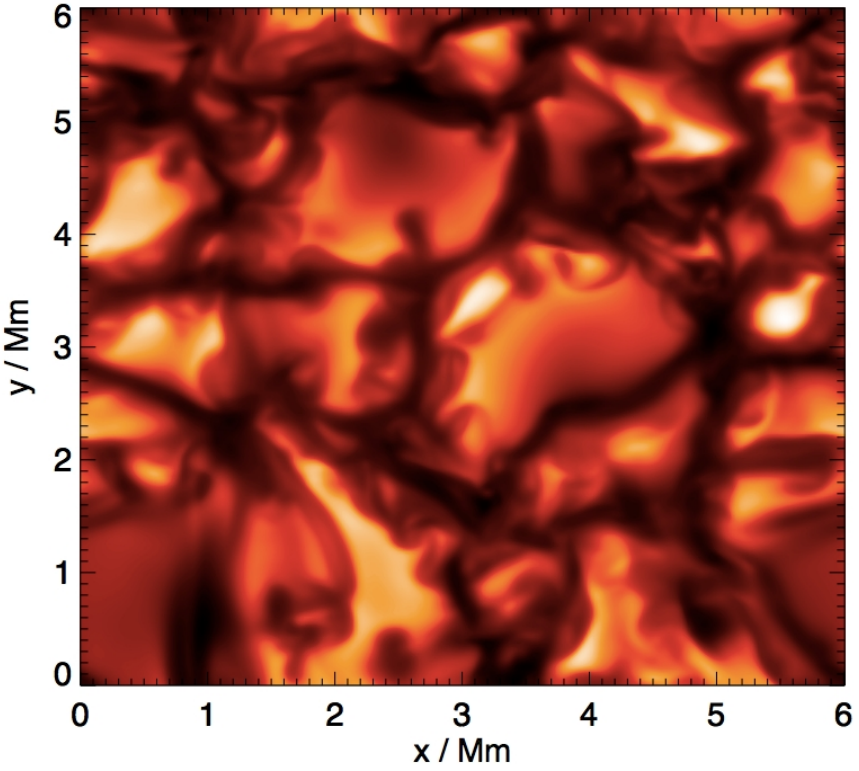
STRUCTURAL SURFACE EFFECT

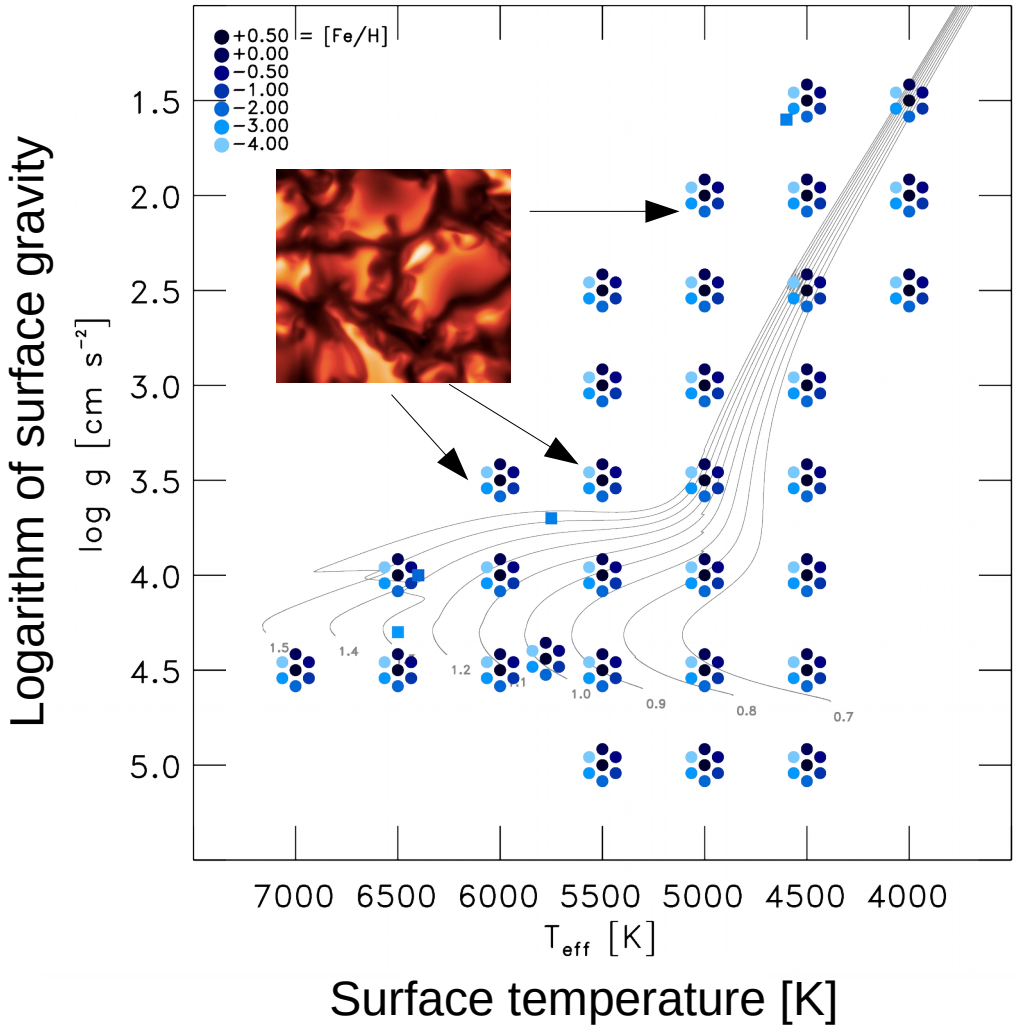


3D simulations are not holistic:

Mm, dynamical time-scale

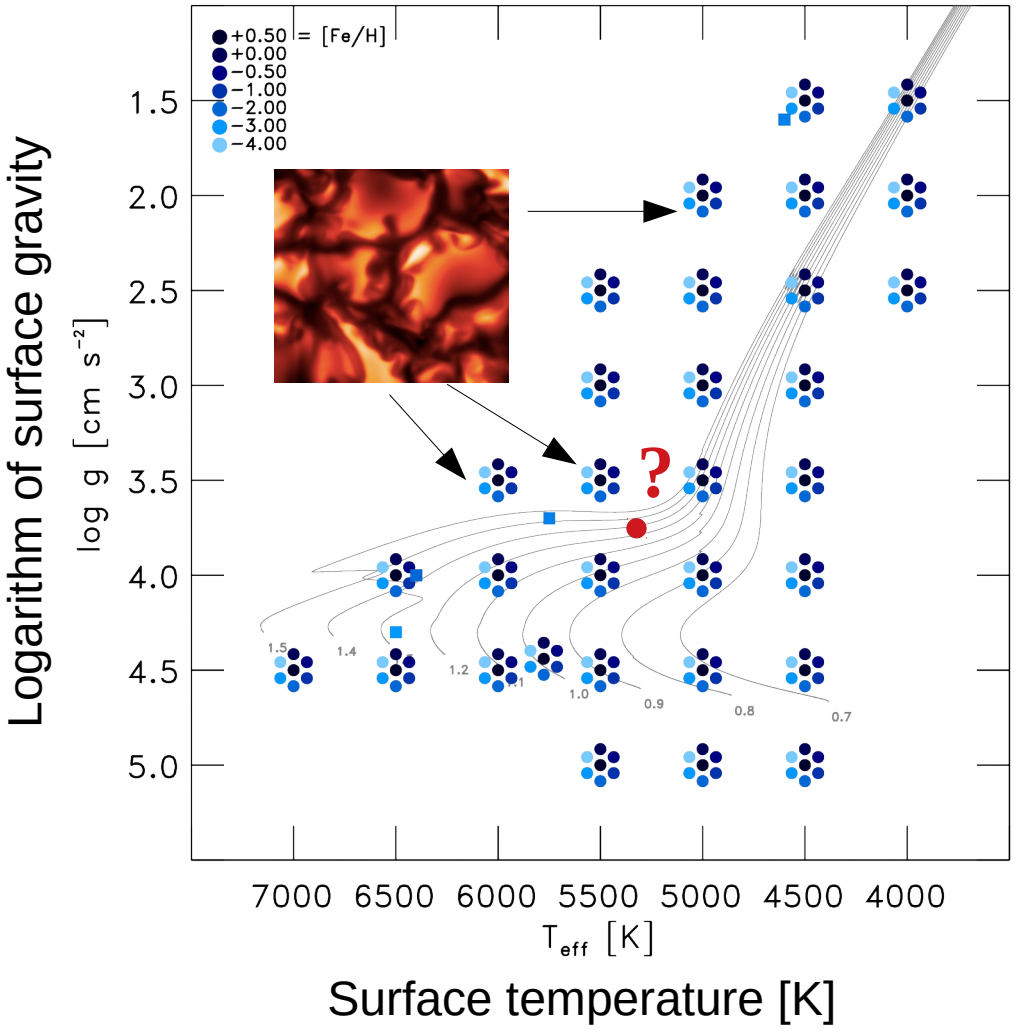
[R. Collet]

3D hydrodynamic models of convection



[Magic et al. (2013)]

3D hydrodynamic models of convection



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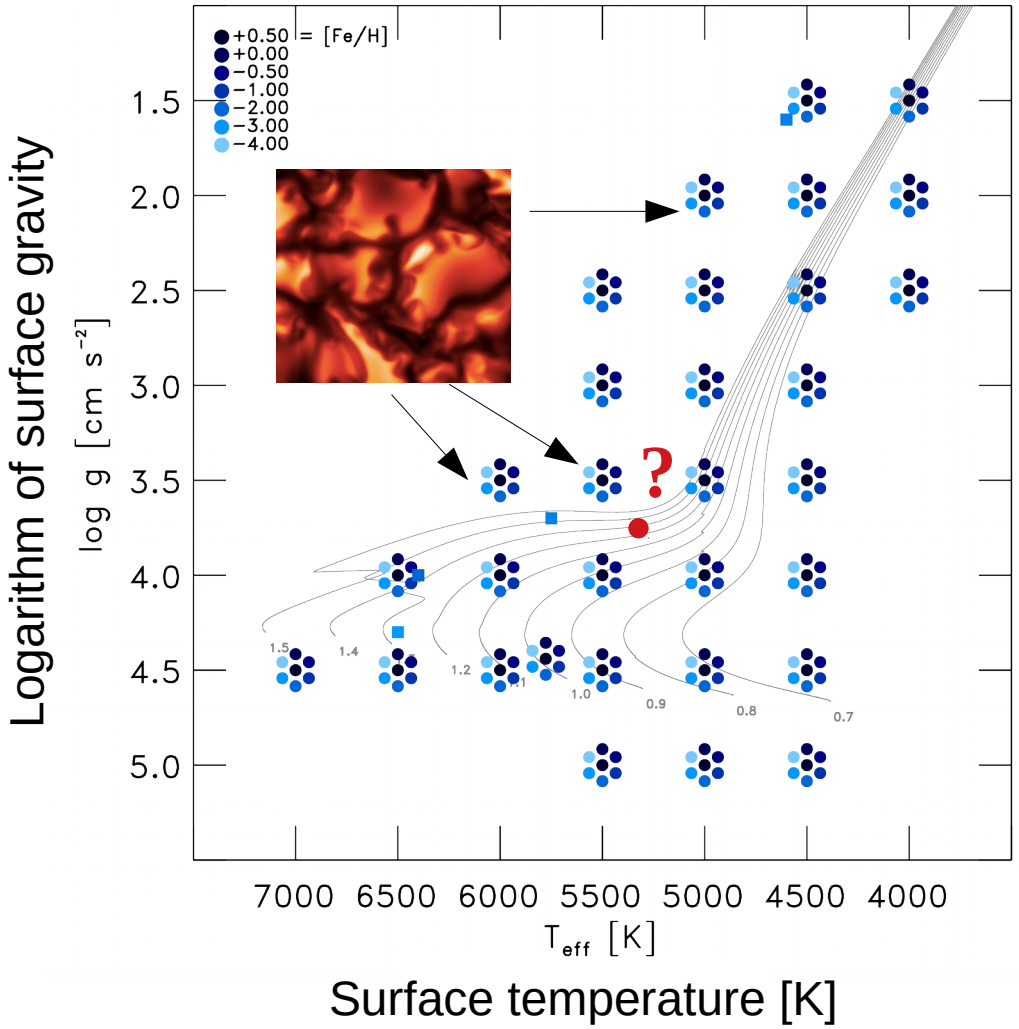
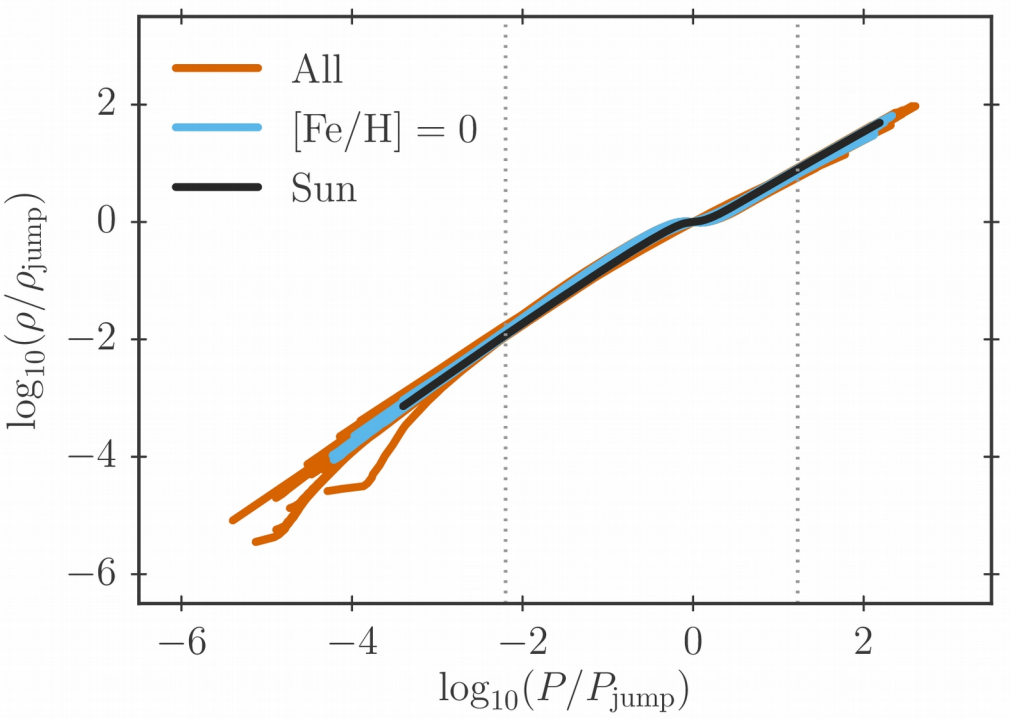


[Magic et al. (2013)]

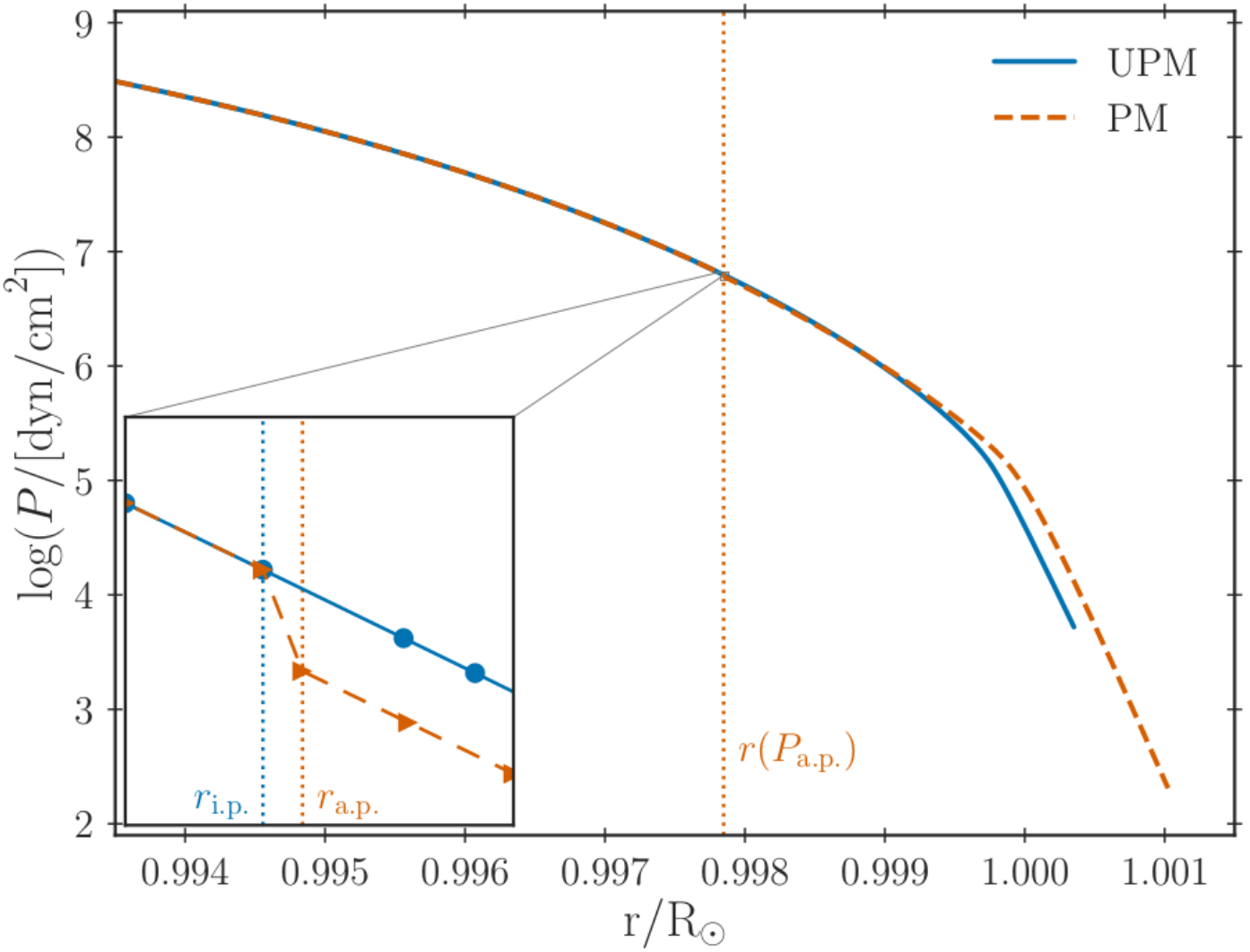
Average 3D structure



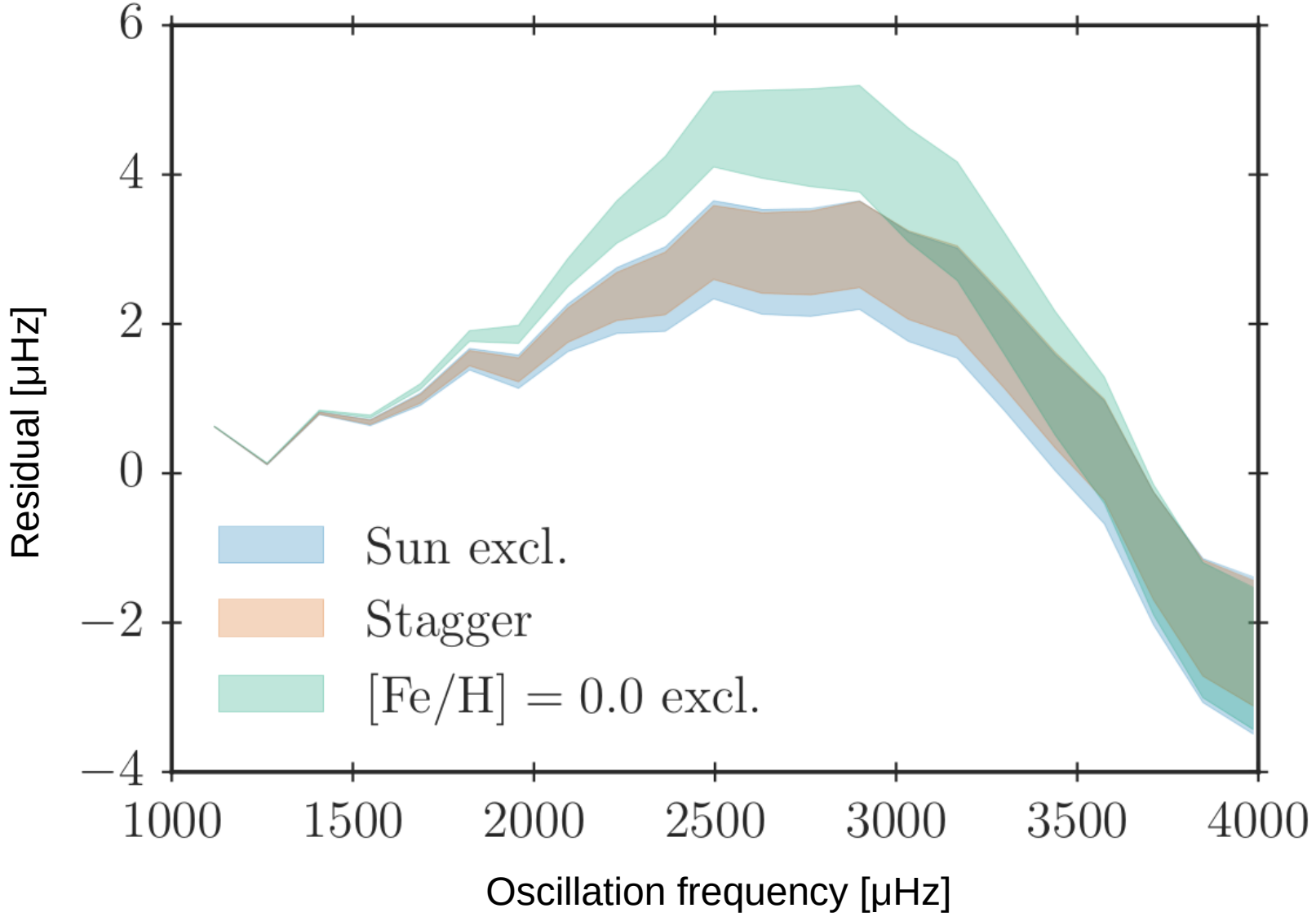
[Jørgensen et al. (2017)]

Patching:

Substitution of the outermost layers of the *final* 1D stellar model with mean 3D simulations

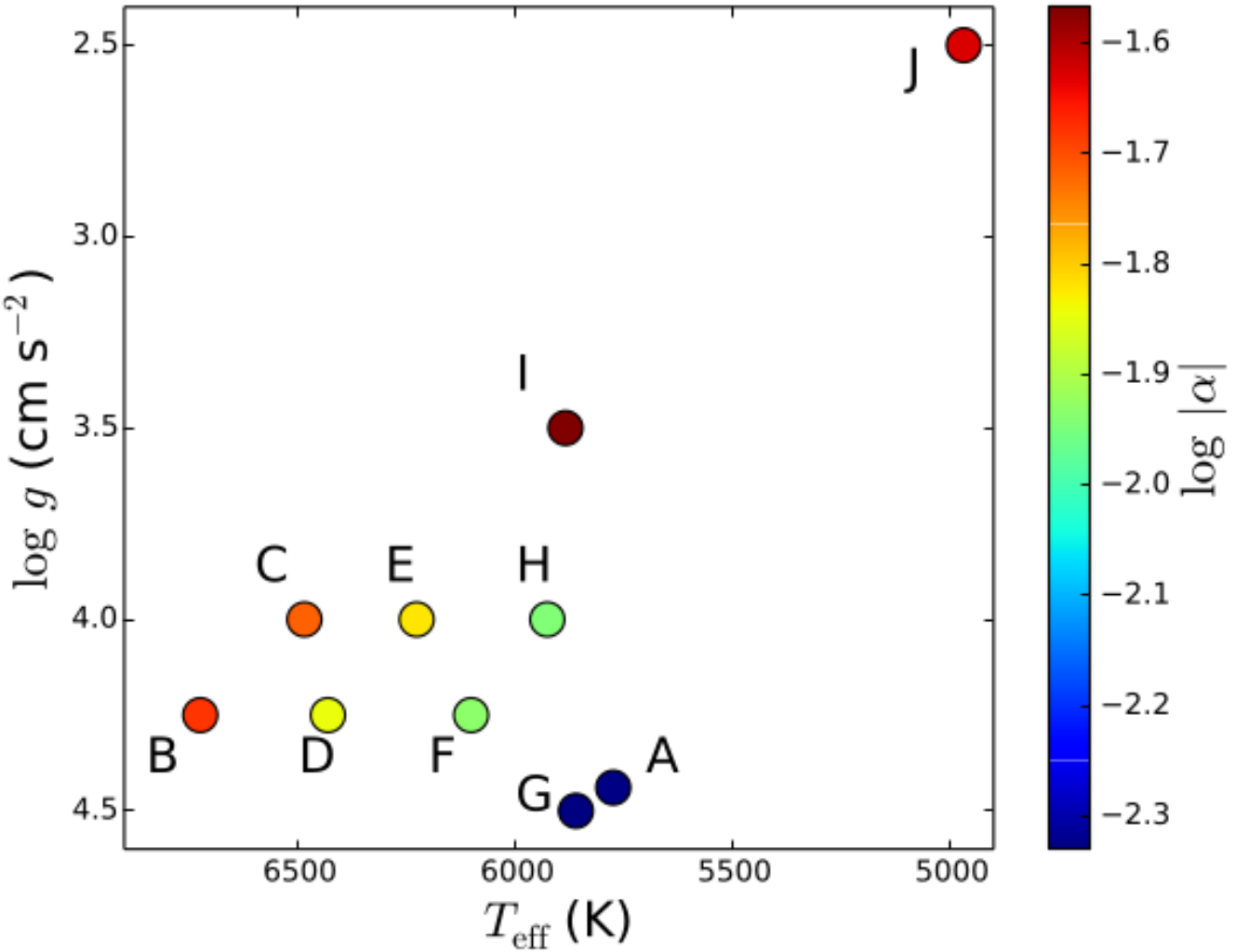


Frequencies (gas Γ_1 approximation)



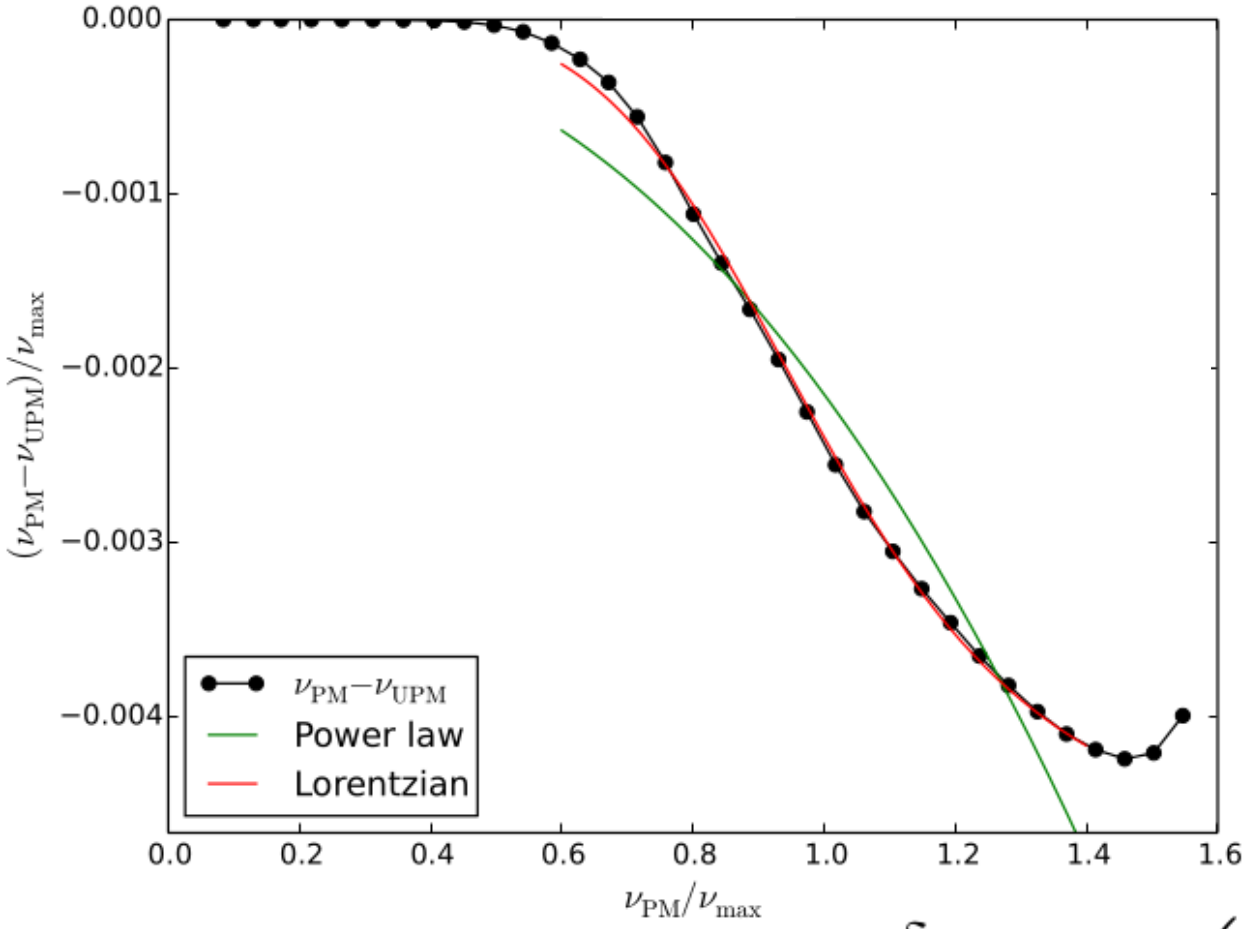
[Jørgensen et al. (2019)]

Induced frequency shift



[Sonoi et al. (2015)]

Induced frequency shift



$$\delta\nu = \nu_{\rm PM} - \nu_{\rm UPM}$$

Kjeldsen et al. (2008):

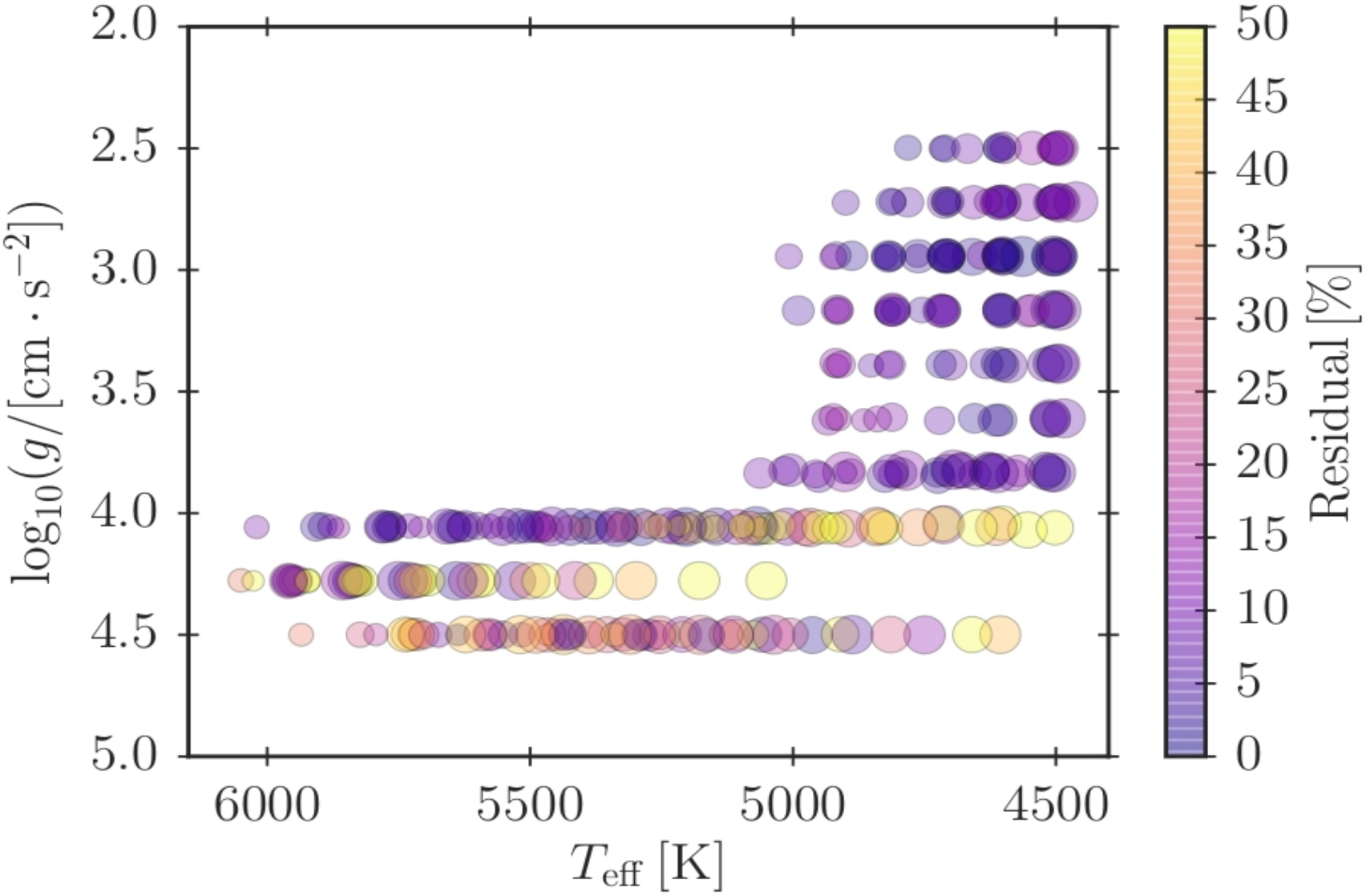
$$\frac{\delta\nu}{\nu_{\rm max}} = a\left(\frac{\nu_{\rm PM}}{\nu_{\rm max}}\right)^b$$

Sonoi et al. (2015):

$$\frac{\delta\nu}{\nu_{\rm max}} = \alpha\left(1 - \frac{1}{1-\left(\nu_{\rm PM}/\nu_{\rm max}\right)^\beta}\right)$$

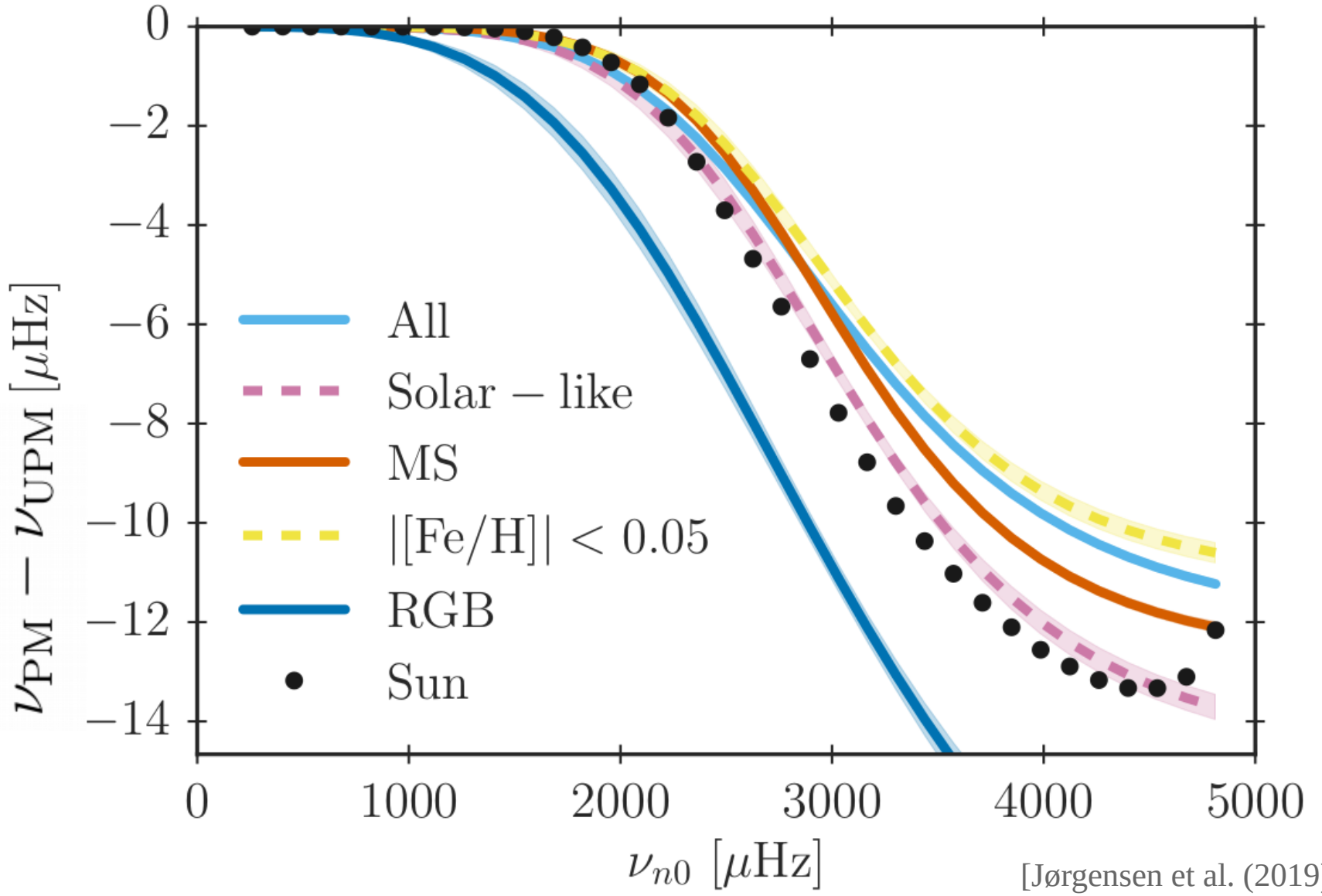
[Sonoi et al. (2015)]

Parameterizations & bias



[Jørgensen et al. (2019)]

Parameterizations & bias

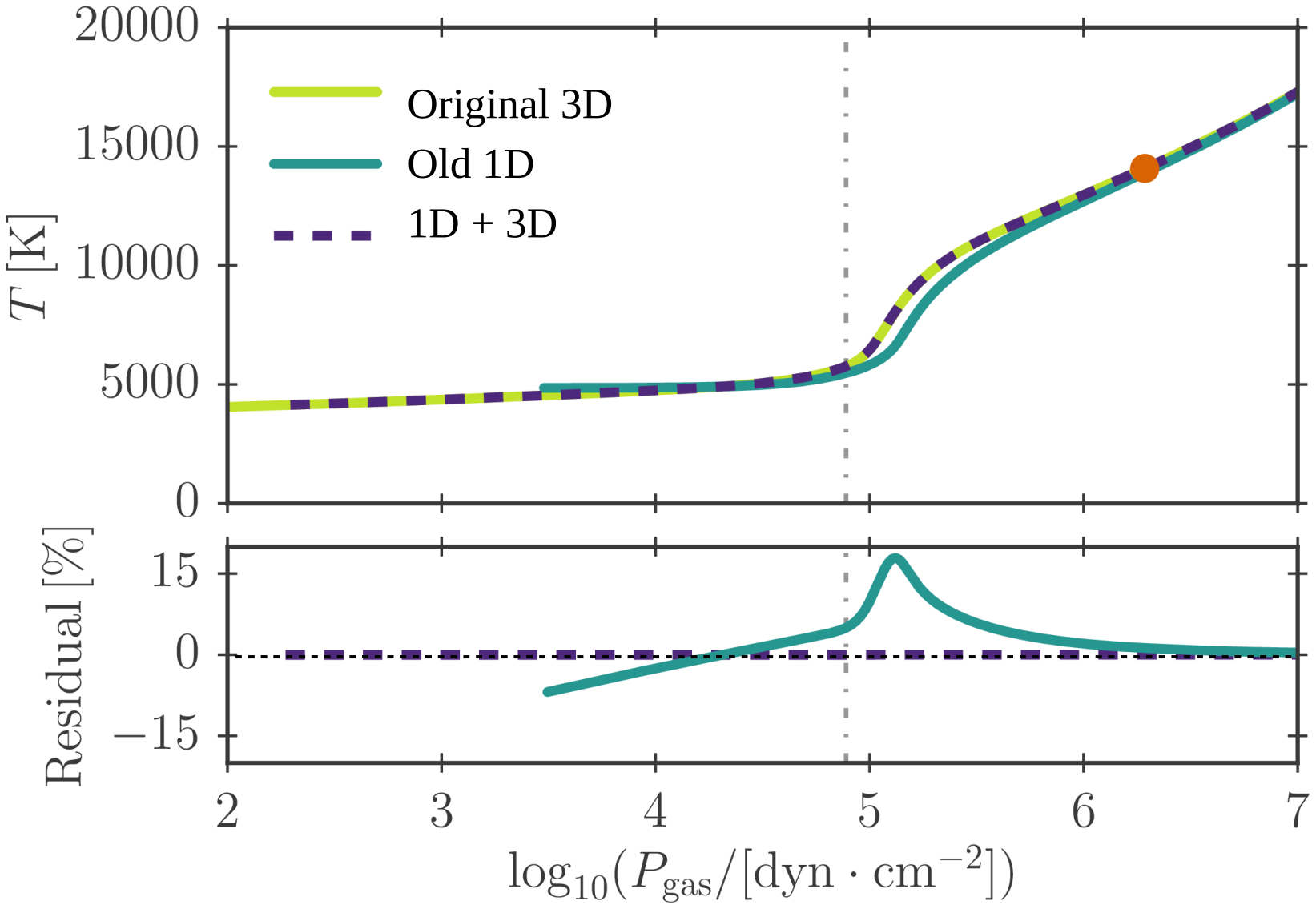


[Jørgensen et al. (2019)]

Coupling:

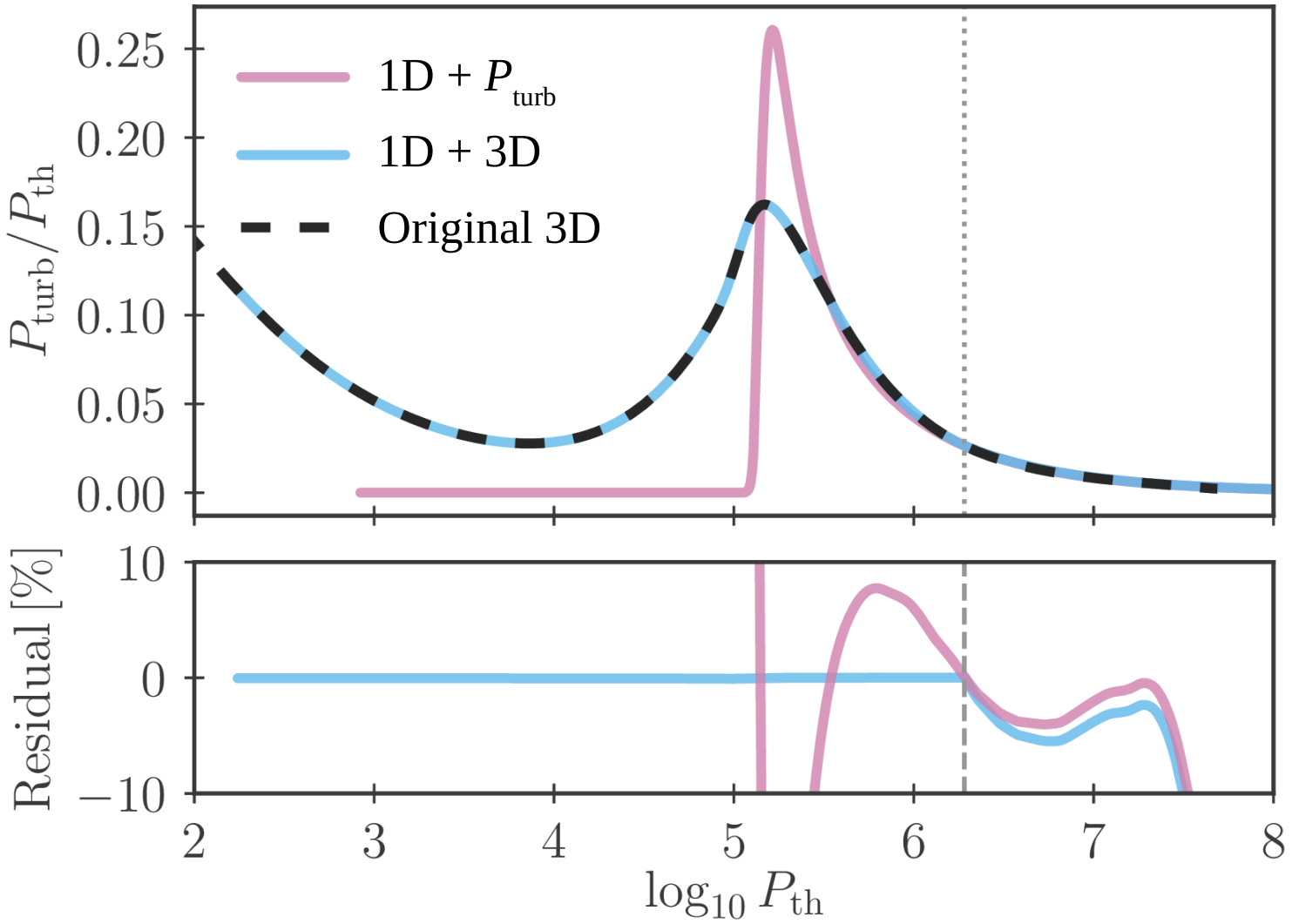
The stellar evolution code uses 3D simulations directly to set the **outer boundary conditions** and appends these at **every time-step**

Does it work?



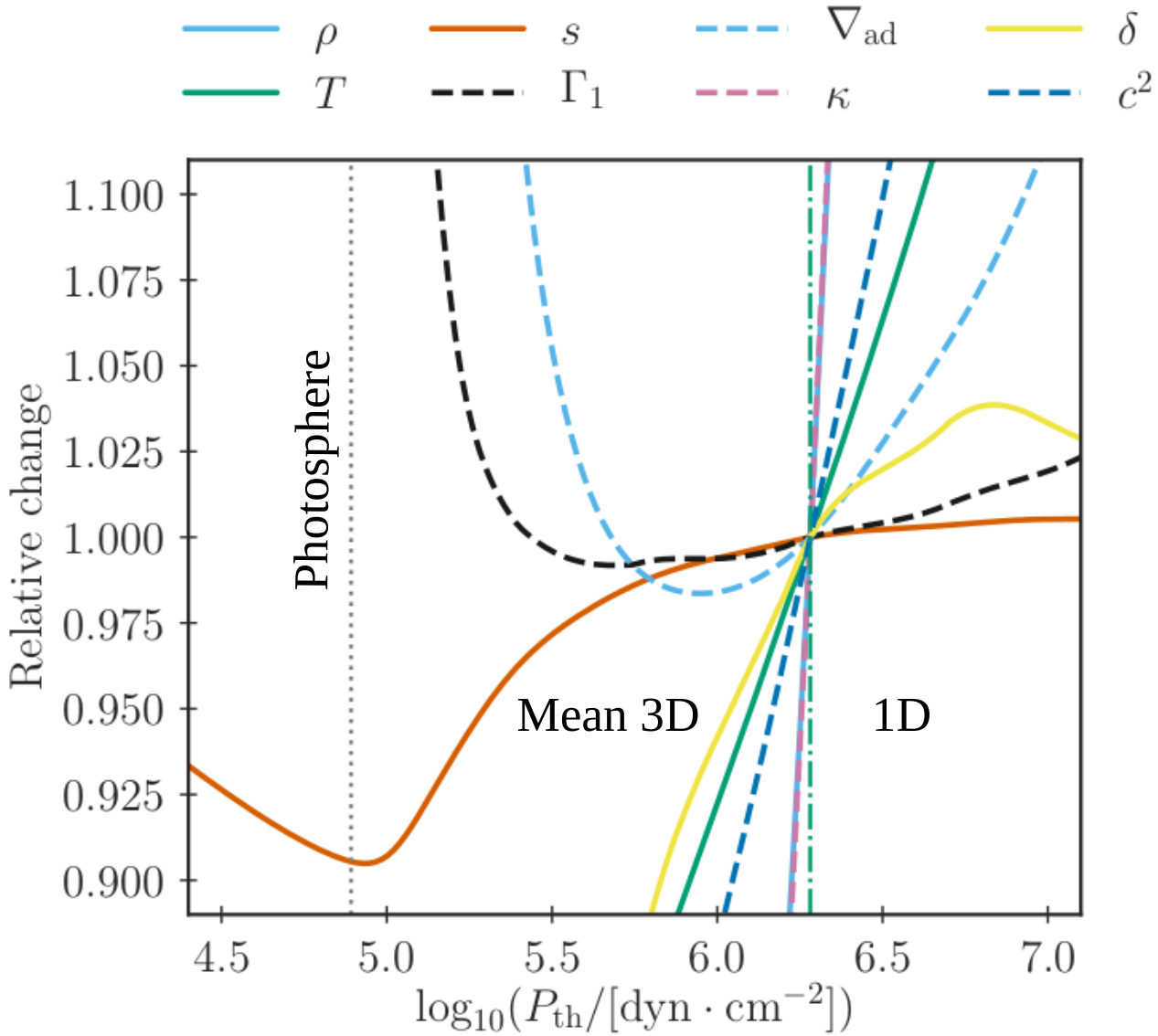
[Jørgensen et al. (2018)]

Turbulent pressure: $P_{\mathrm{turb}} \propto \rho v^2$



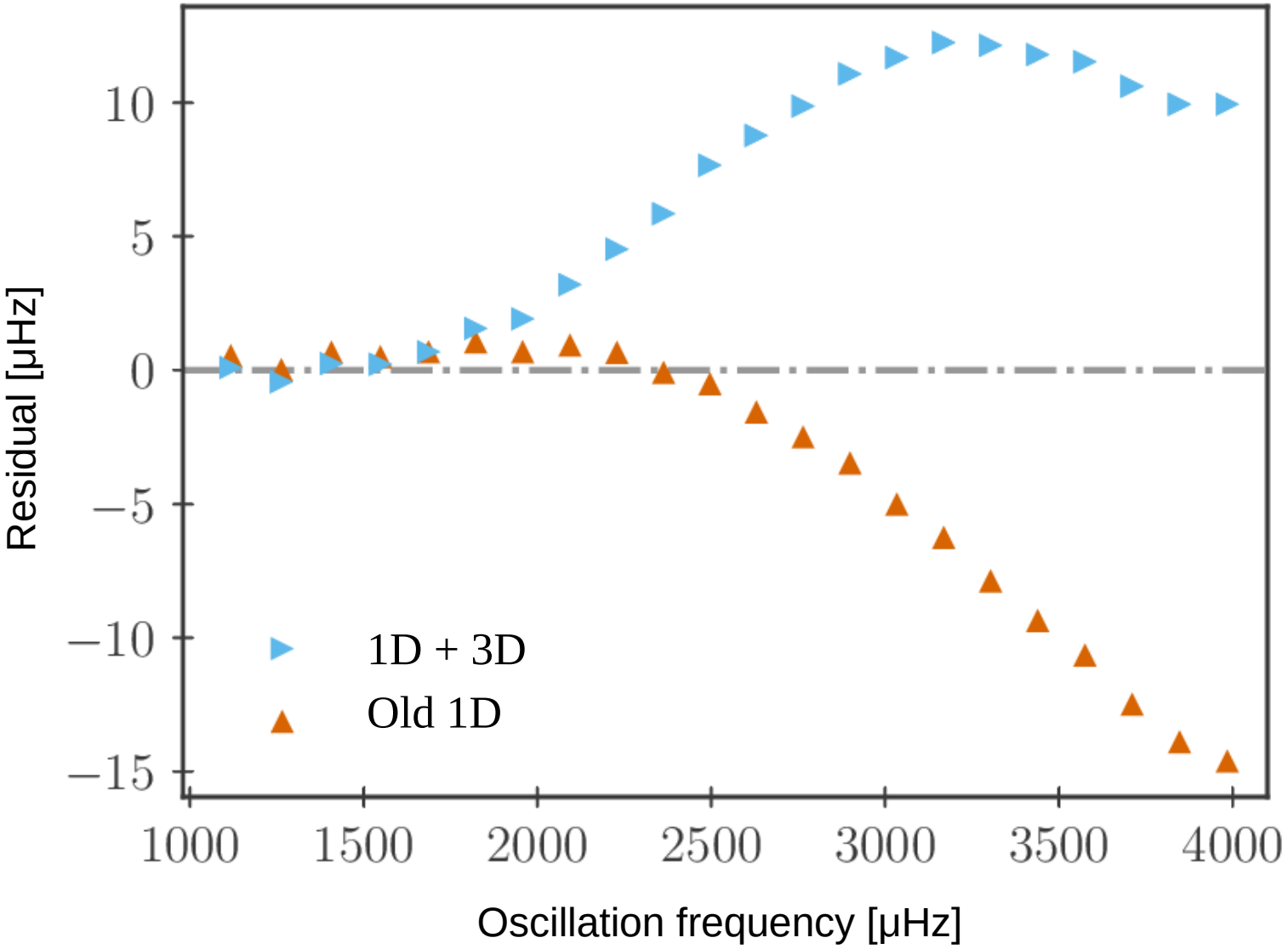
[Jørgensen & Weiss (2019)]

Continuous structures



[Jørgensen & Angelou (2019)]

Frequencies (reduced Γ_1 approximation)



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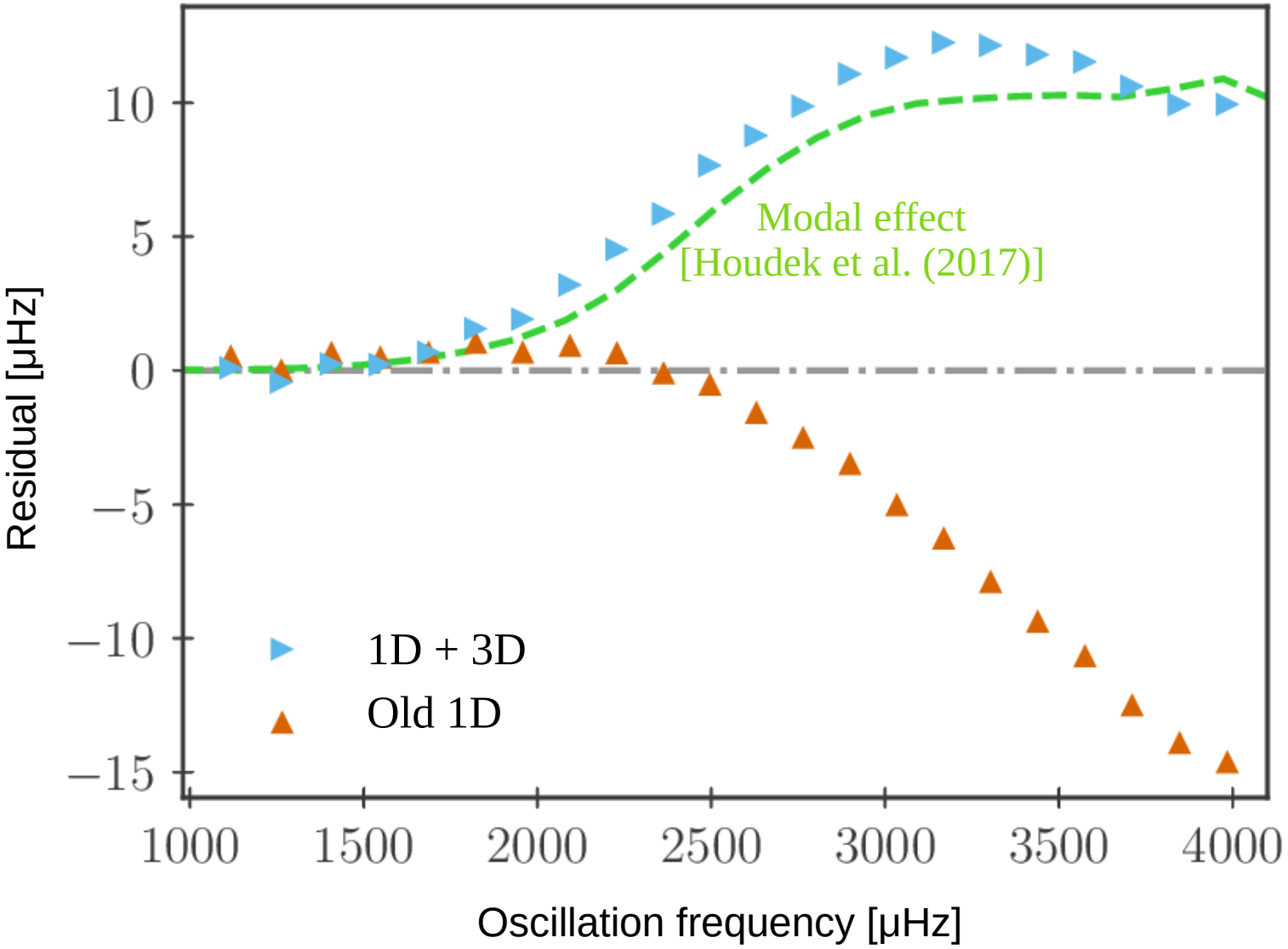
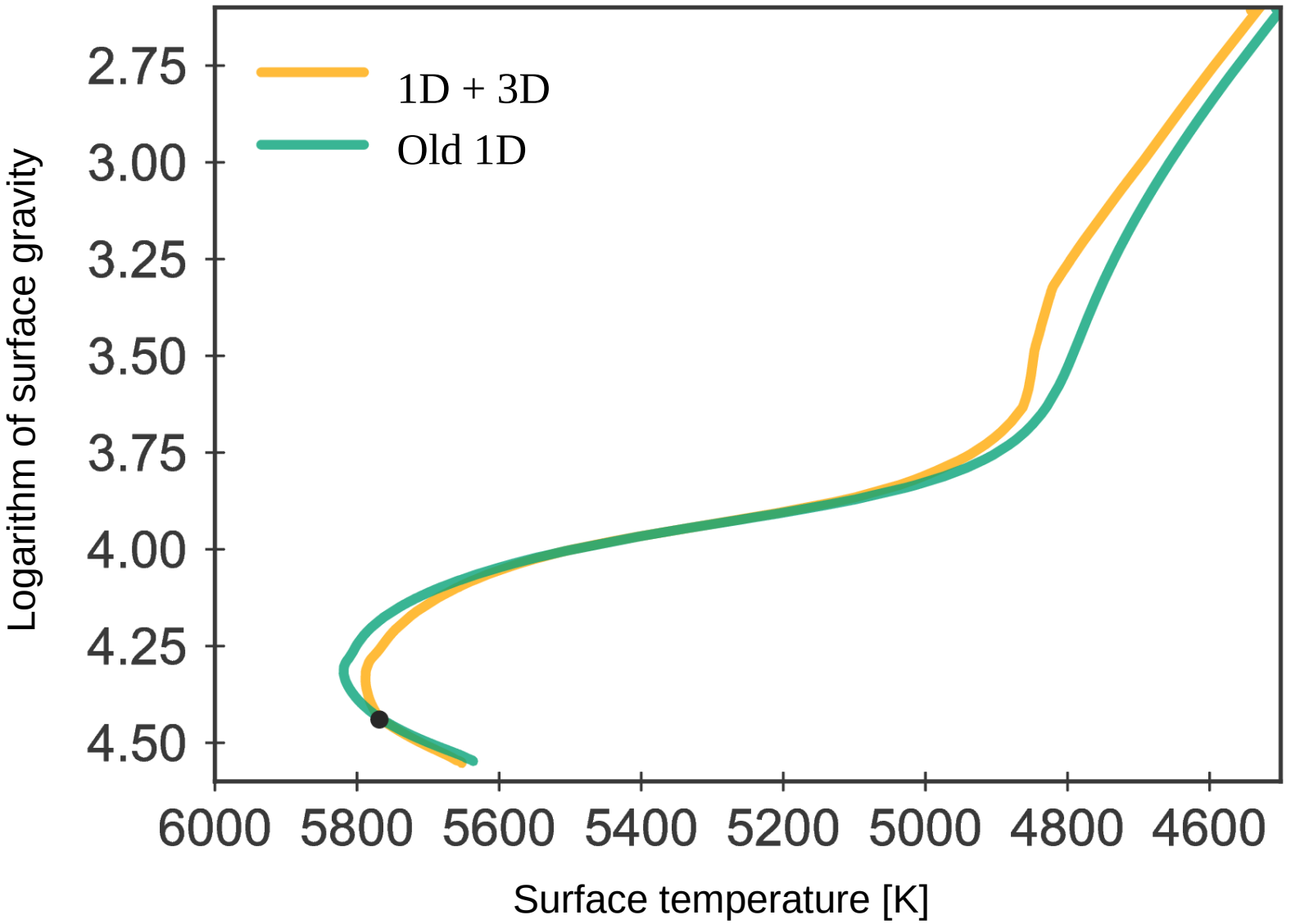


[Jørgensen & Weiss (2019)]

Evolution tracks



[see Jørgensen & Weiss (2019), Jørgensen & Angelou (2019), and Mosumgaard et al. (2019)]

The structural inadequacies that underlie the surface effect affect **the evolution tracks** through the outer boundary conditions

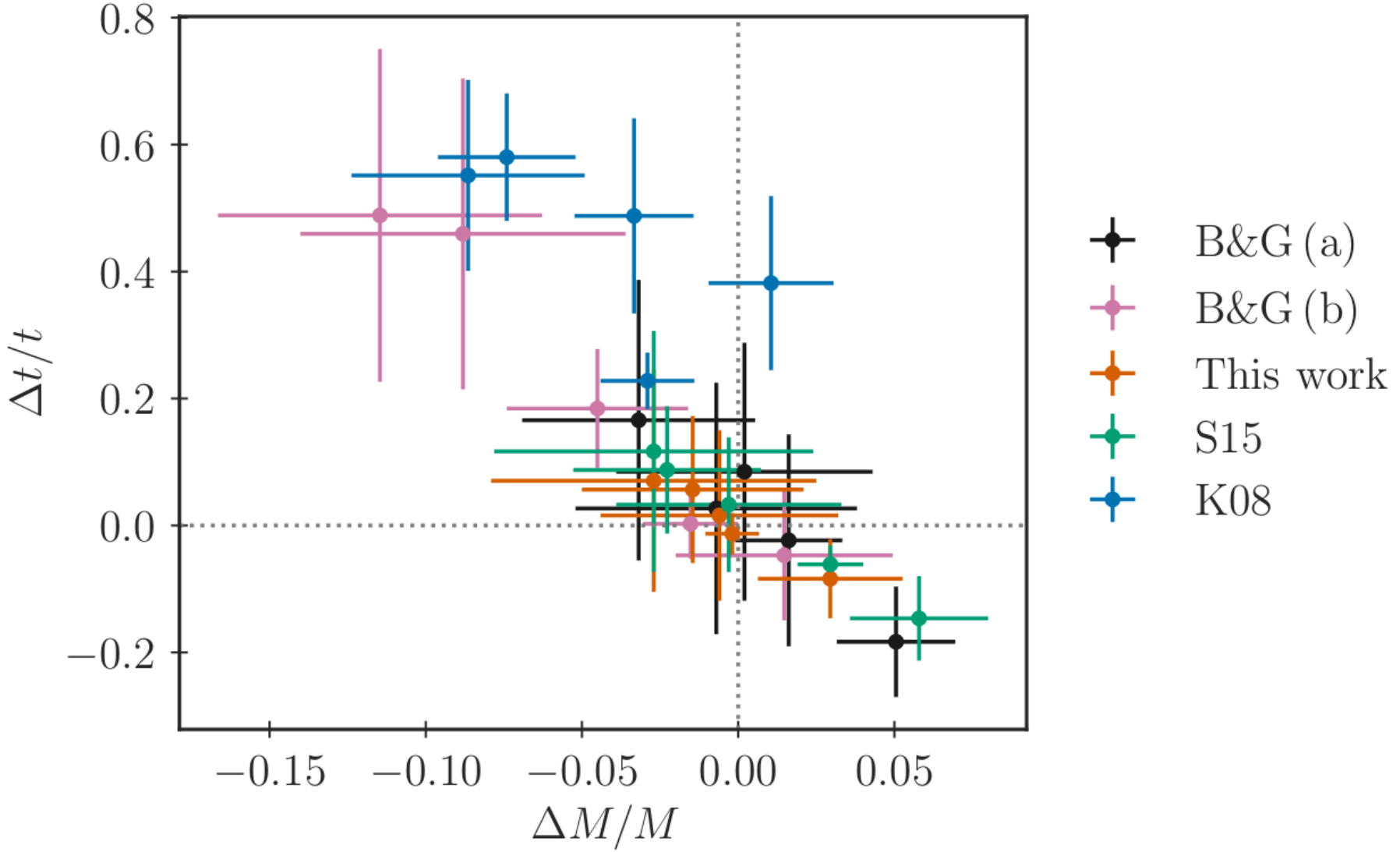
Summary

- We overcome the structural surface effect by including 3D simulations.
- More realistic outer boundary conditions affect the evolution tracks.
- These models are also a diagnostic tool for surface correction relations.

How to deal with the surface effect:

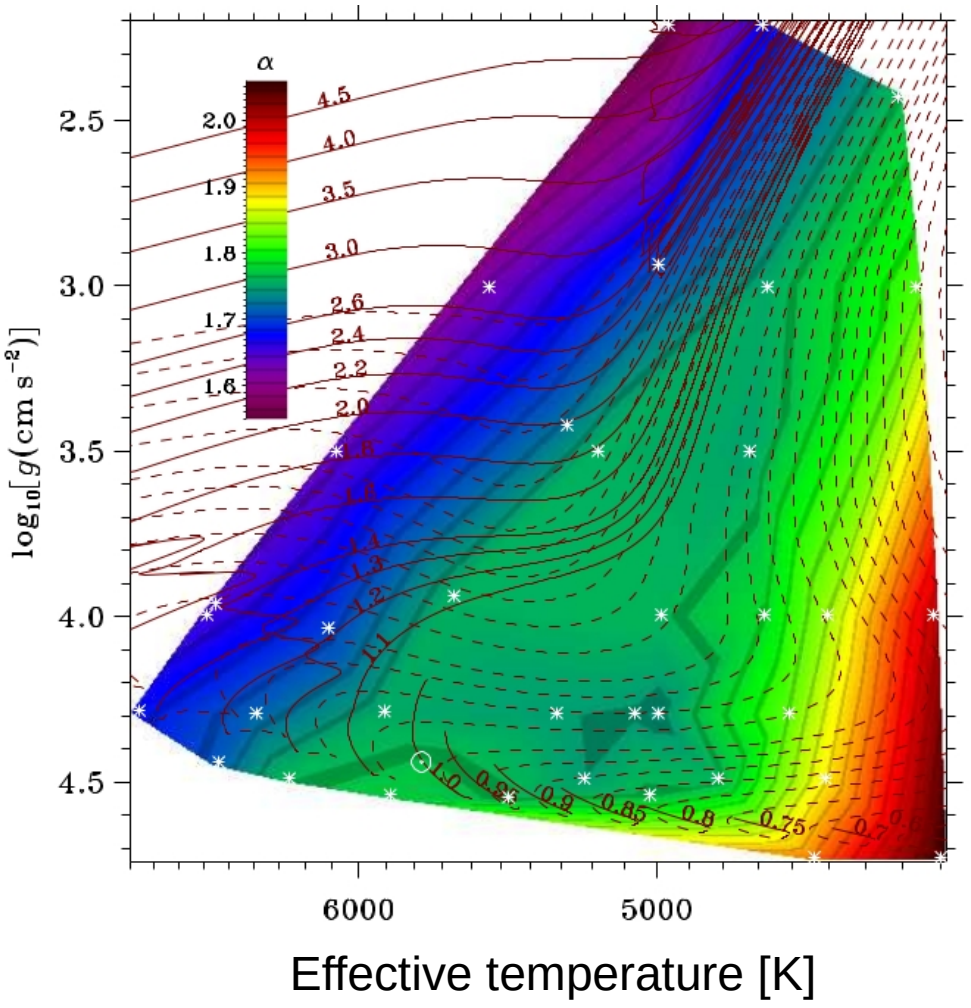
Correcting frequencies	Kjeldsen et al. 2008	(biased)	⊘
	Ball & Gizon 2014	(evolution not corrected)	(✓)
	Sonoi et al. 2015	(biased)	⊘
Circumventing problem	Ratios (r01, r02…)	(evolution not corrected)	(✓)
Correcting structure	Patching, final model	(evolution not corrected)	⊘
	Coupling, all time-steps	(not enough 3D sim.)	(✓✓✓)

Hare & hound exercise

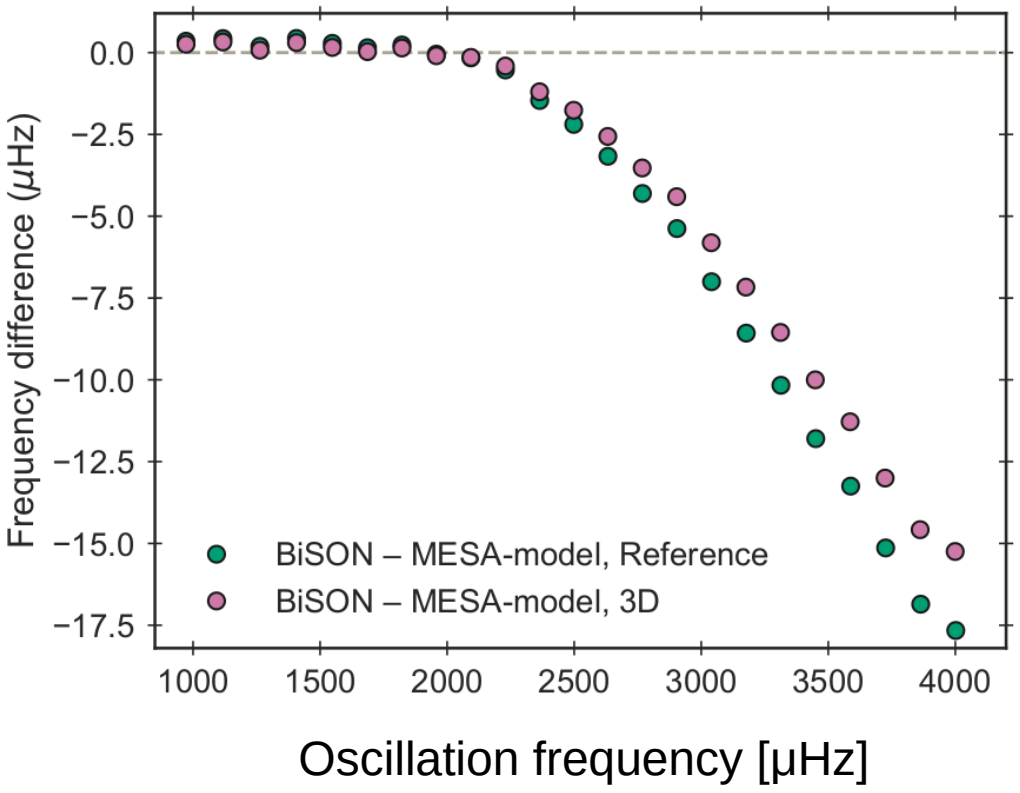


[Jørgensen et al. (2019)]

Parameterizations of patched models

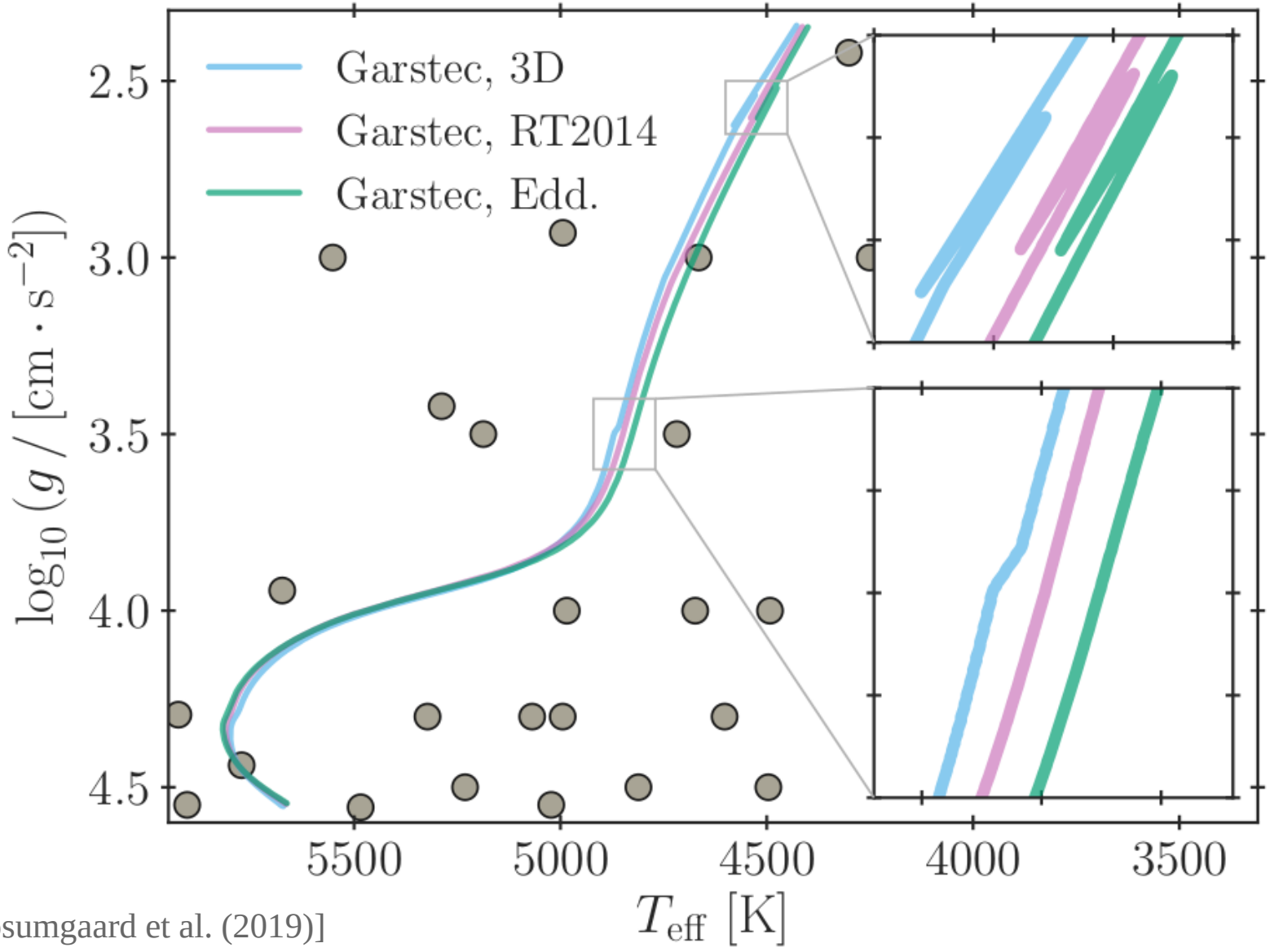


[Trampedach et al. (2014)]



[Mosumgaard et al. (2018)]

Comparison with parameterization



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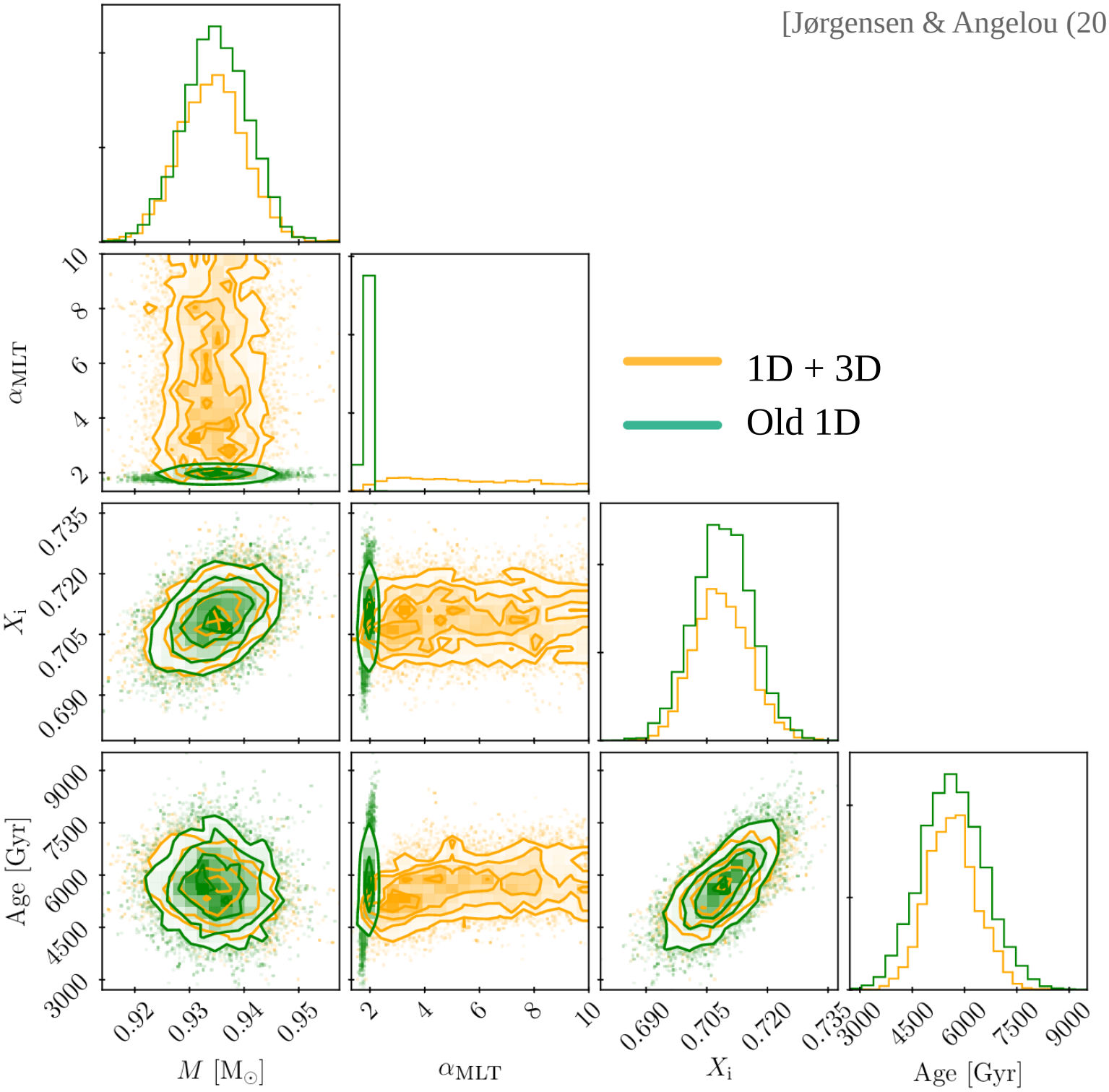

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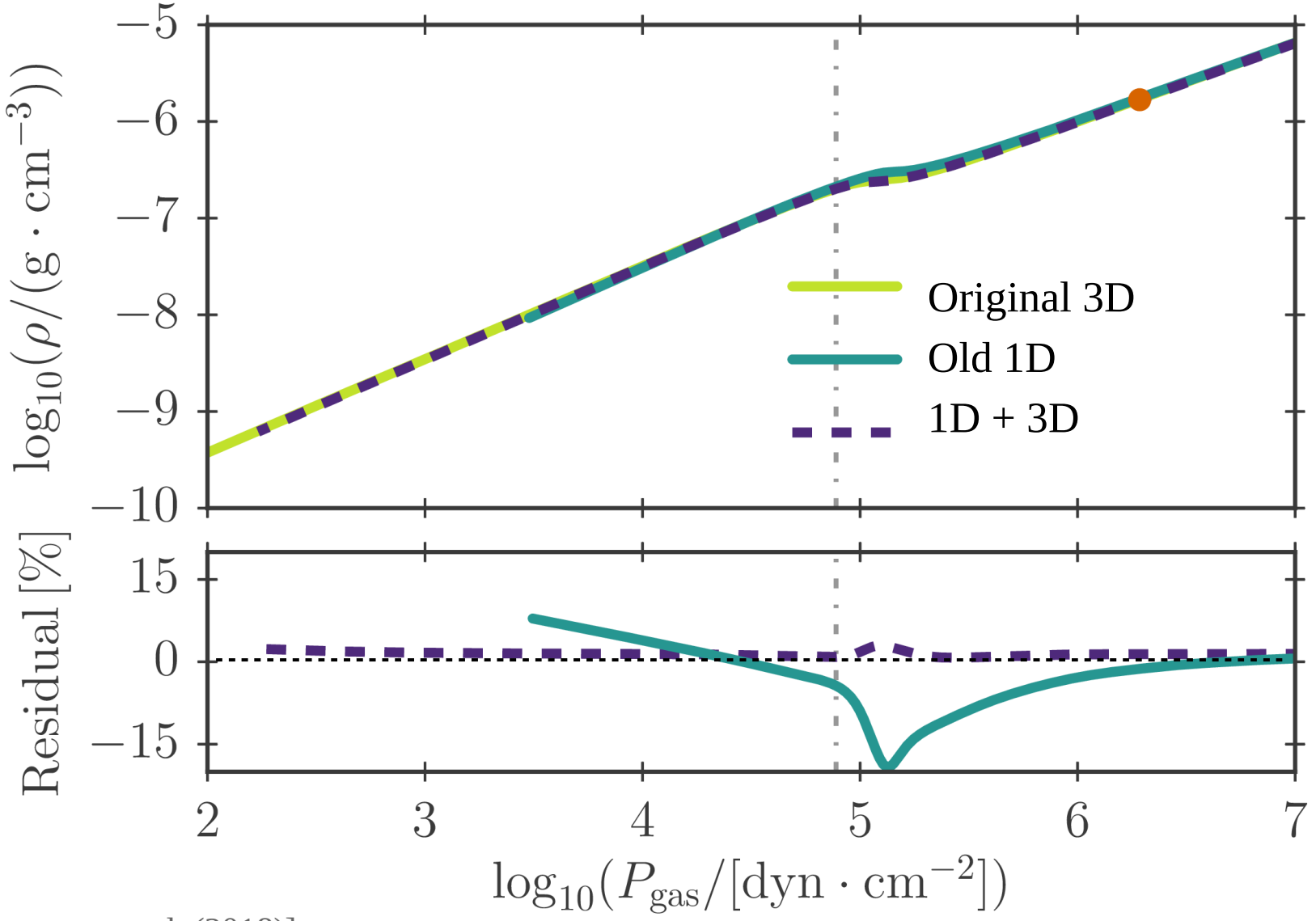
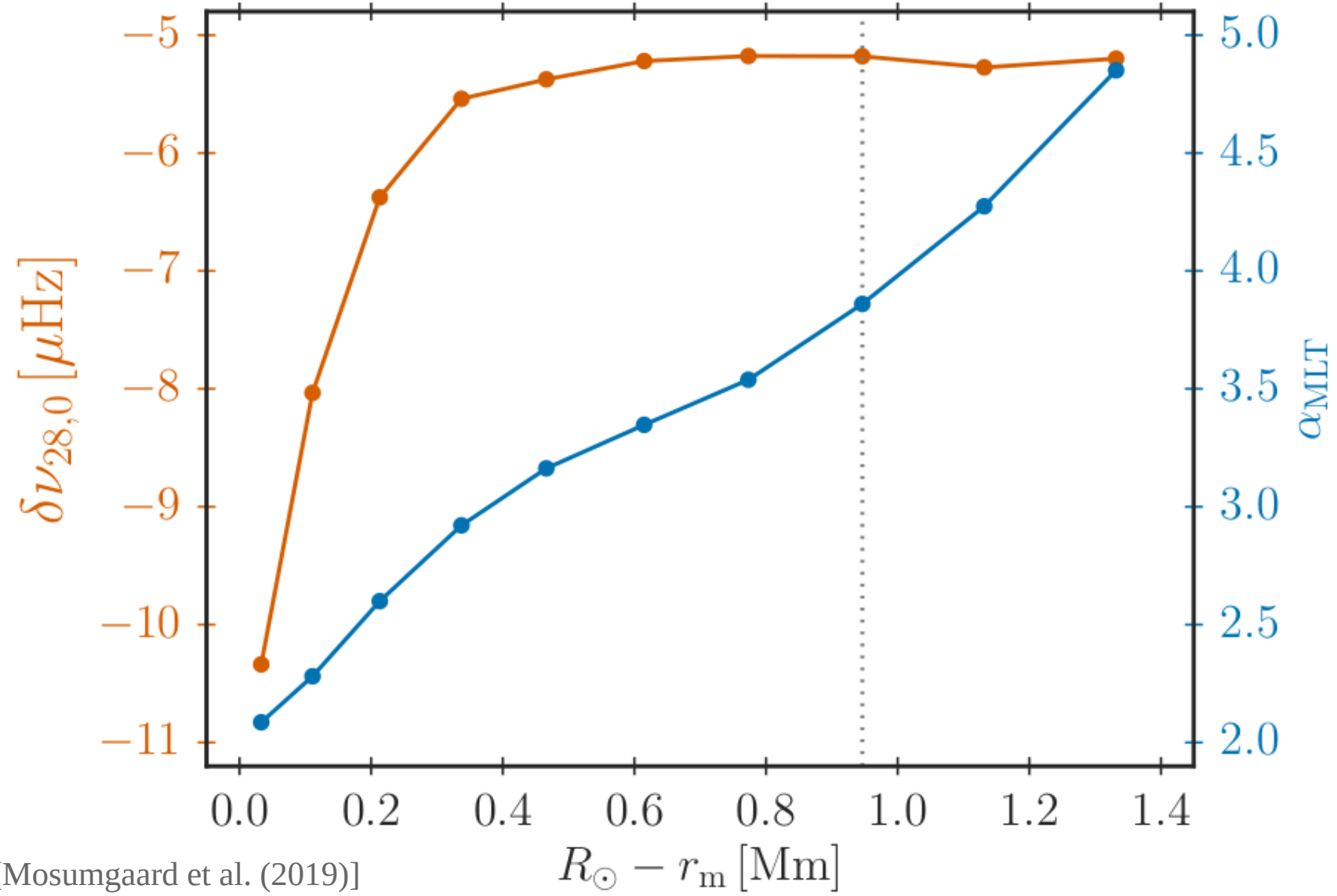


[Jørgensen et al. (2018)]

Depth dependence



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