Convective Excitation and Damping of Solar-like Oscillations

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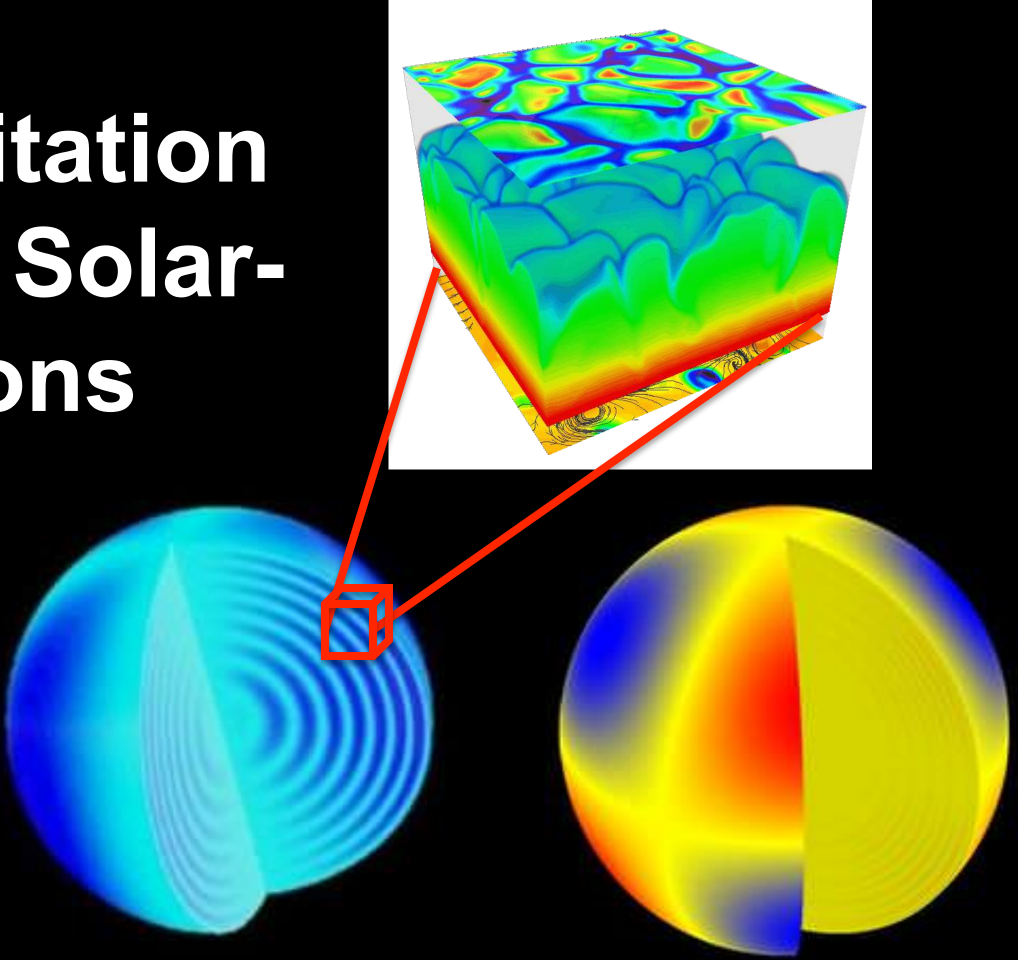
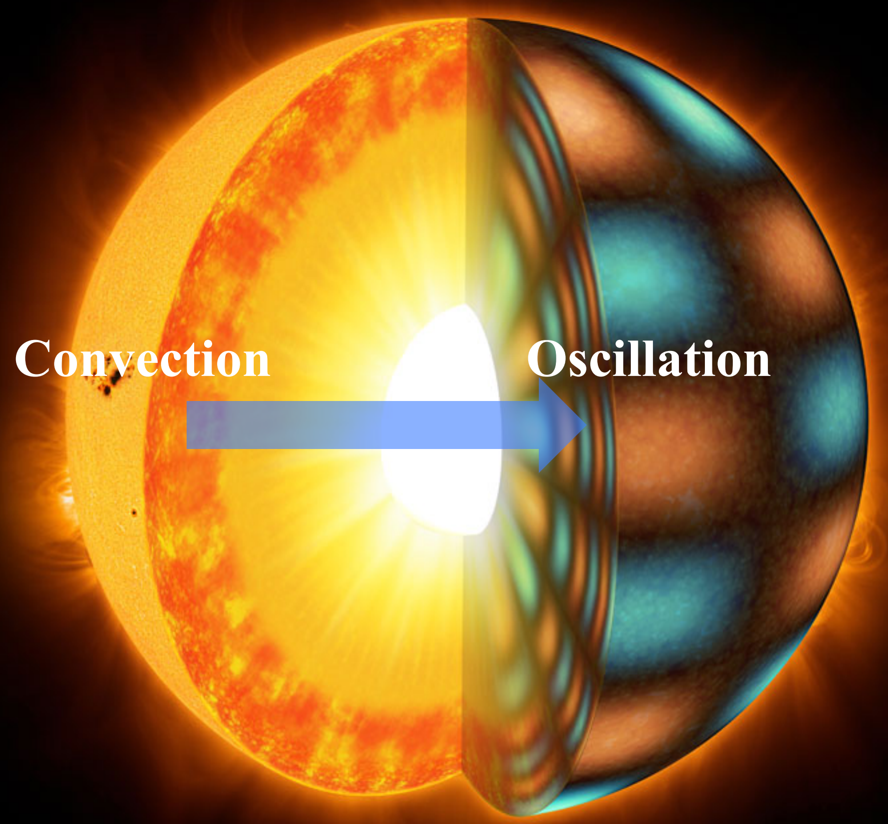
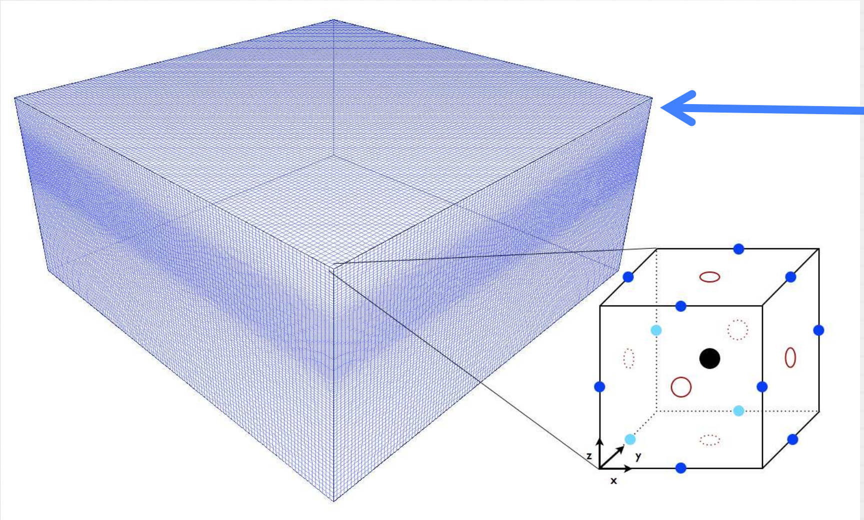
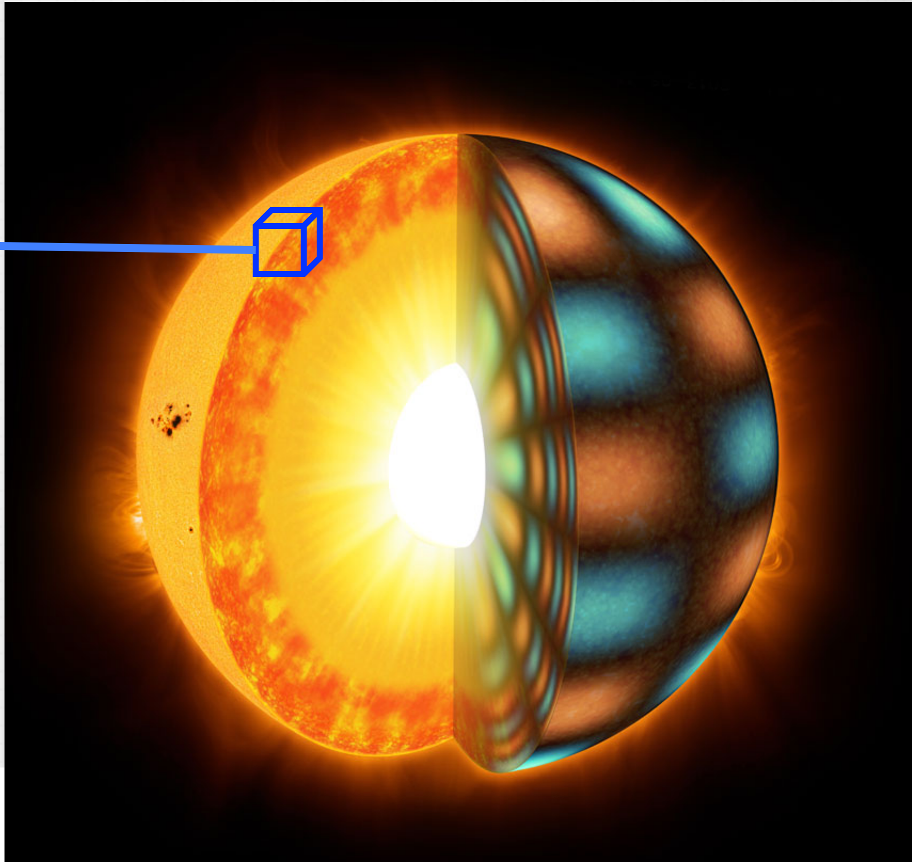


22 Nov, PLATO stellar science workshop


Convection
Oscillation

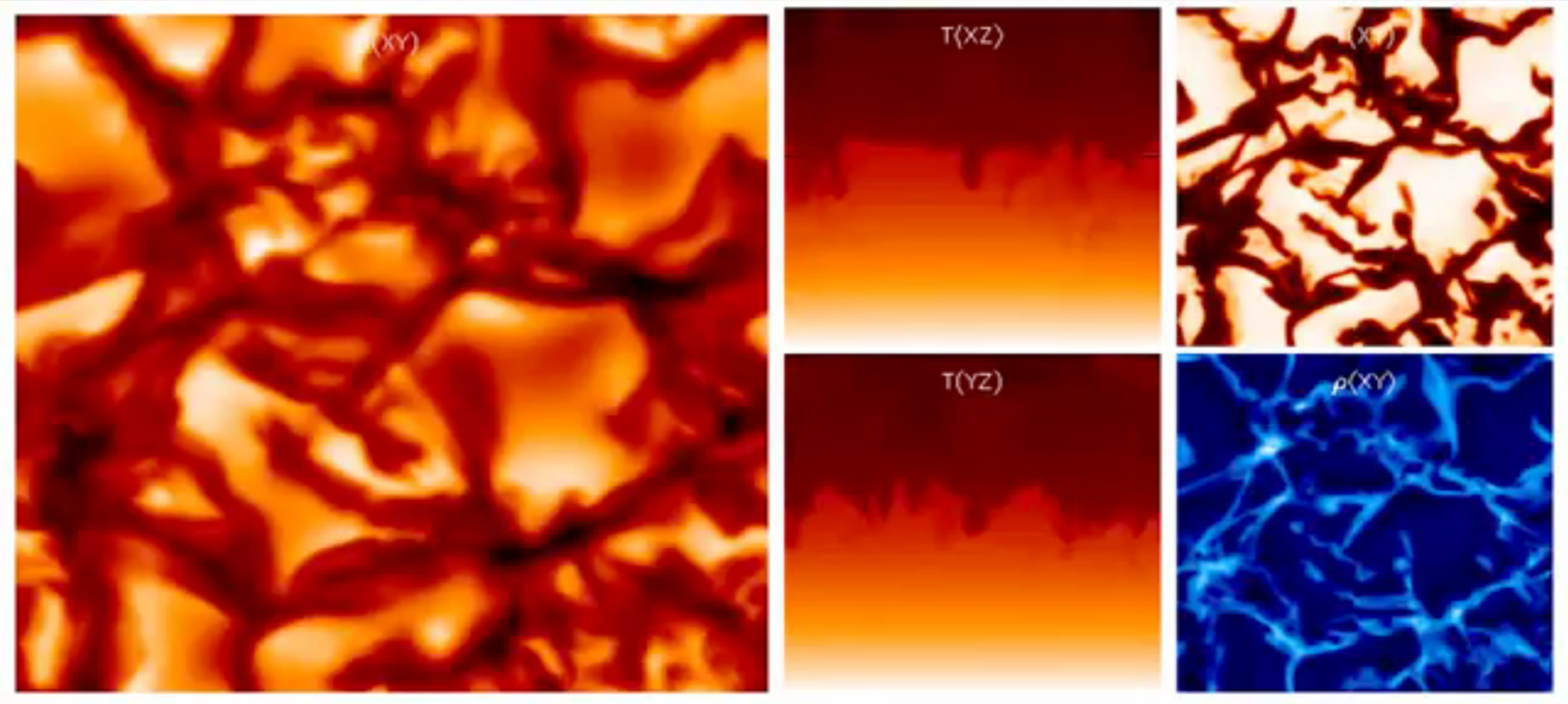
3D Stagger model atmosphere





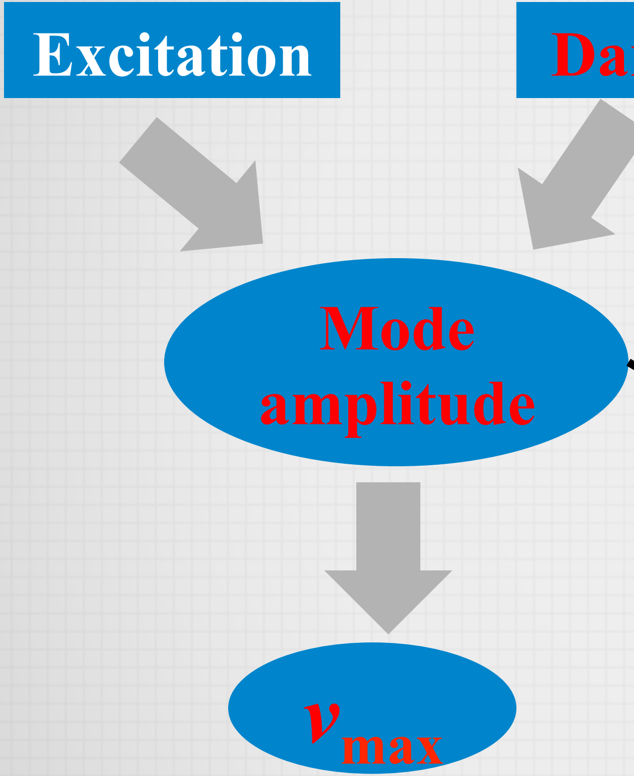
• ρ ∘ $\rho\vec{v}$

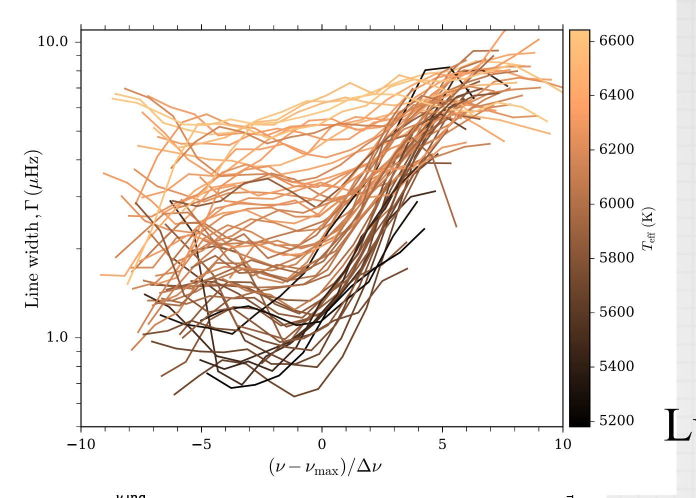
3D model atmosphere



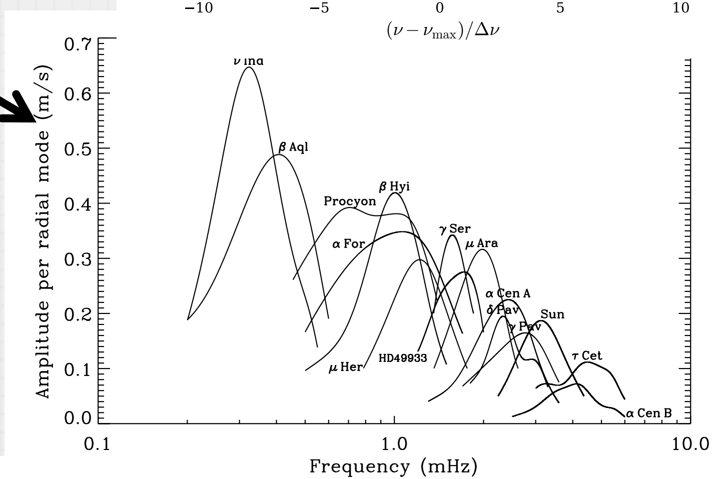
Movie: Zazralt Magic

Interaction between convection and oscillation from 3D model



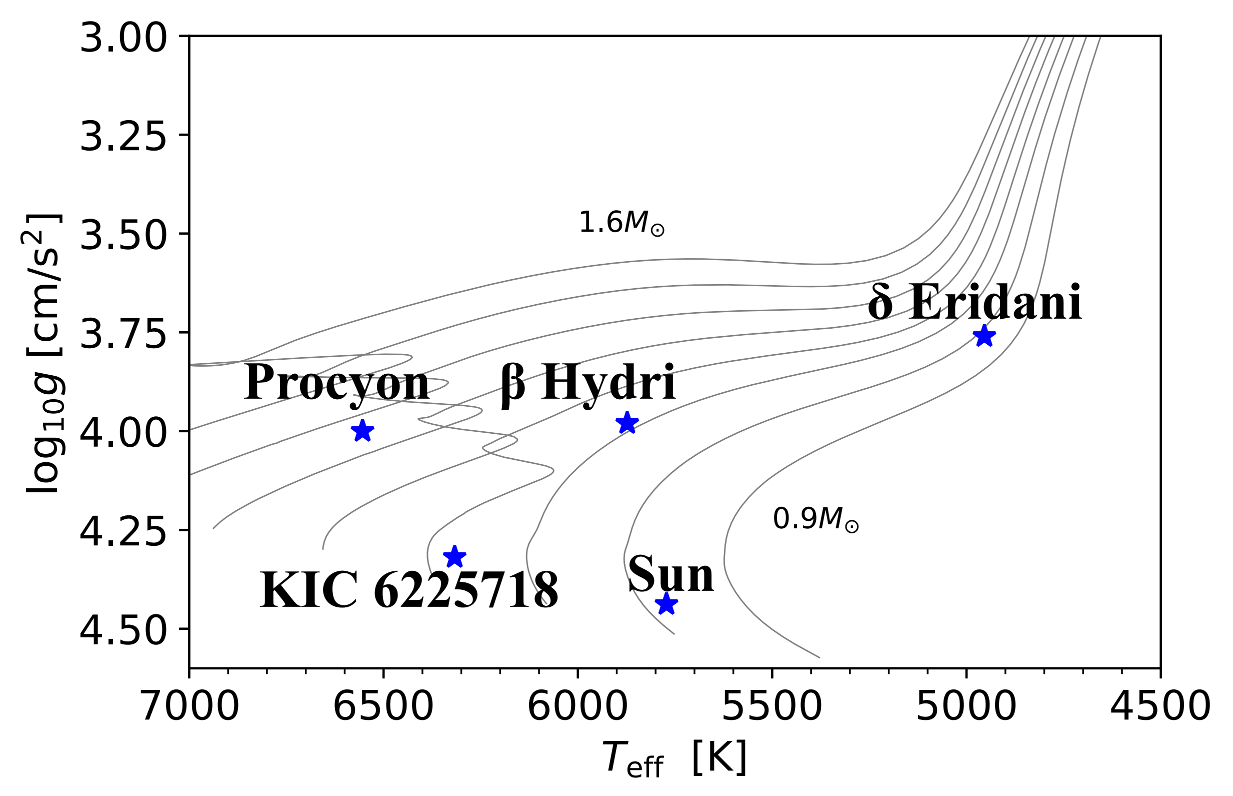


Lund et al. 2017



Arentoft et al. 2008

Apply to solar-like oscillators

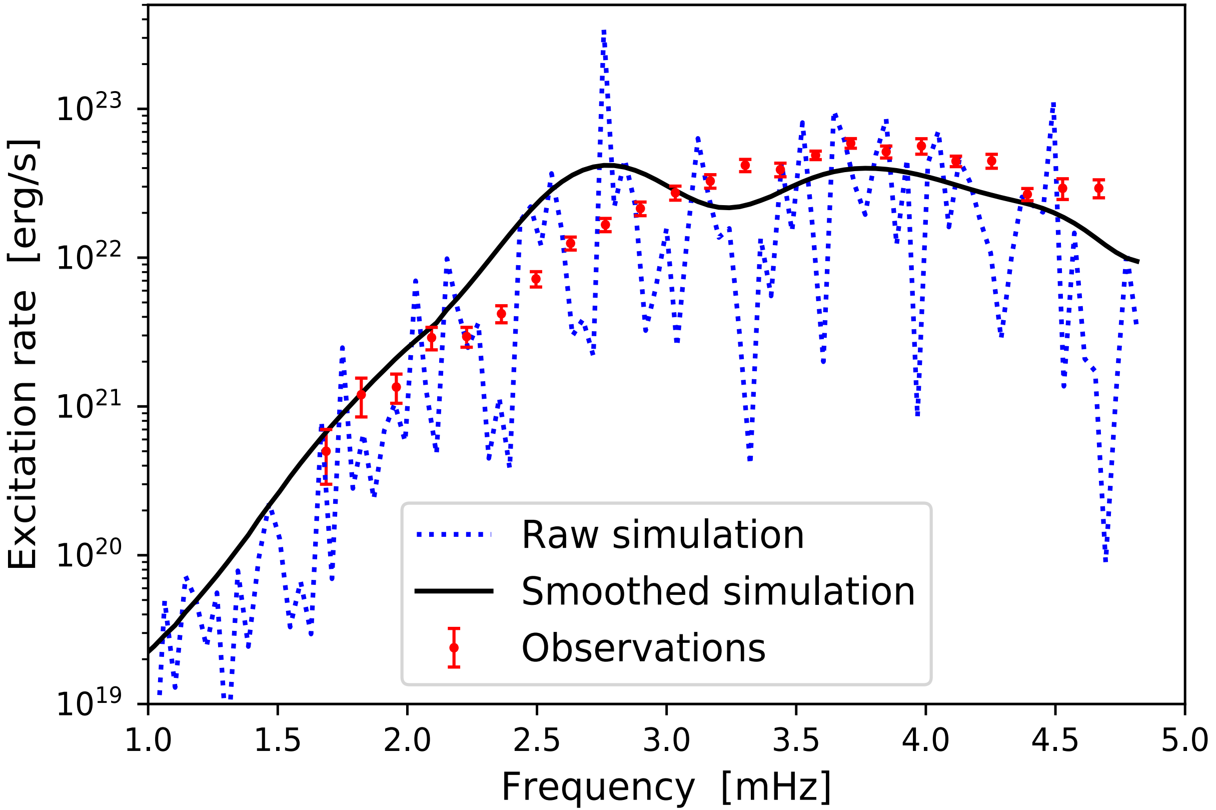


Mode excitation in the Sun

$$\frac{\Delta\left\langle E_\omega \right\rangle_{\rm ens}}{\Delta t} = \frac{\omega^2}{8\Delta t}\left(\int_r \frac{1}{E_0^{1/2}}\frac{\partial \xi_r}{\partial r}\mathrm{Re}\left\{\delta \bar{P}_{\rm nad}(\omega)\right\}dr\right)^2 + \frac{\omega^2}{8\Delta t}\left(\int_r \frac{1}{E_0^{1/2}}\frac{\partial \xi_r}{\partial r}\mathrm{Im}\left\{\delta \bar{P}_{\rm nad}(\omega)\right\}dr\right)^2$$

Oscillation (1D) **Convection (3D)**

Theoretical formulation: Nordlund & Stein 2001



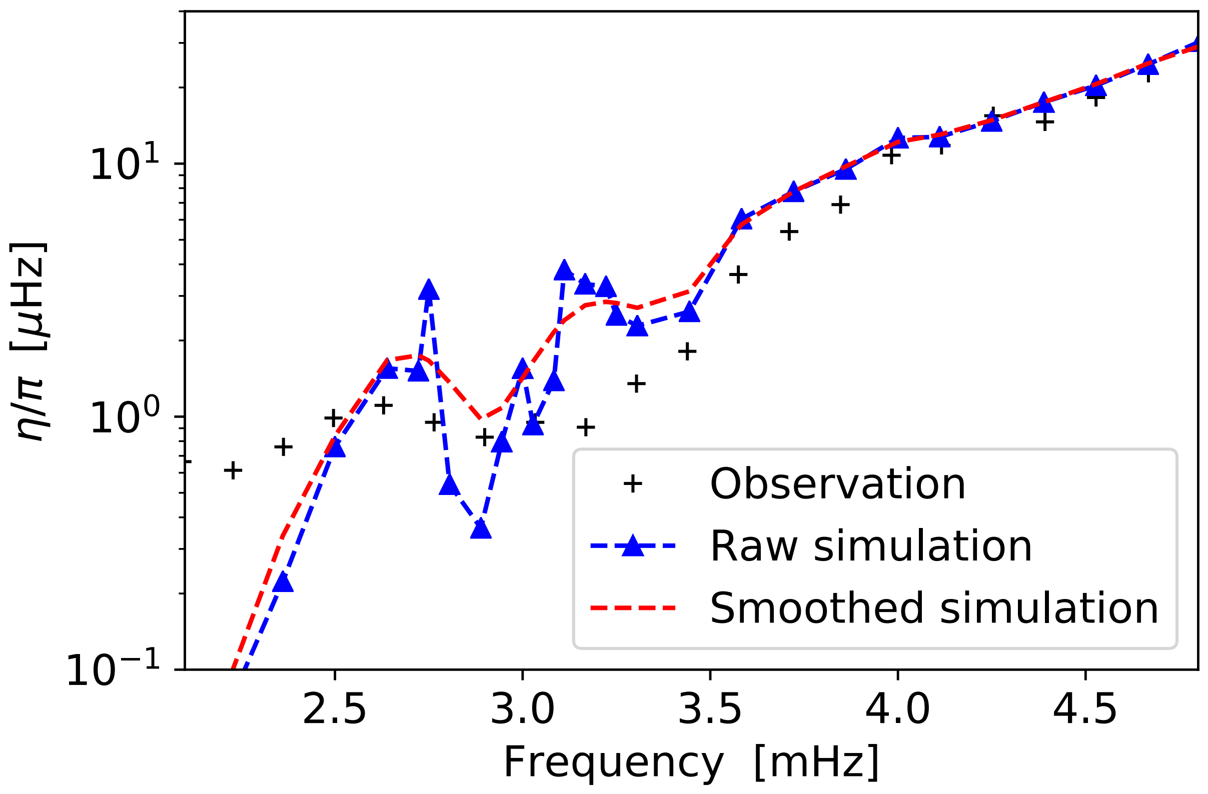
Observation: Chaplin et al. 1998

Solar linear damping rate

$$\eta = \frac{\omega \int_r \mathrm{Im}\left\{(\delta\overline{\rho}^* / \overline{\rho}_0)\delta \overline{P}_{\mathrm{nad}}\right\} dr}{4 m_{\mathrm{mode}} \left| \overline{v}_{\mathrm{vert}}(R_{\mathrm{phot}}) \right|^2}$$

1D

3D models (artificial driving simulations)



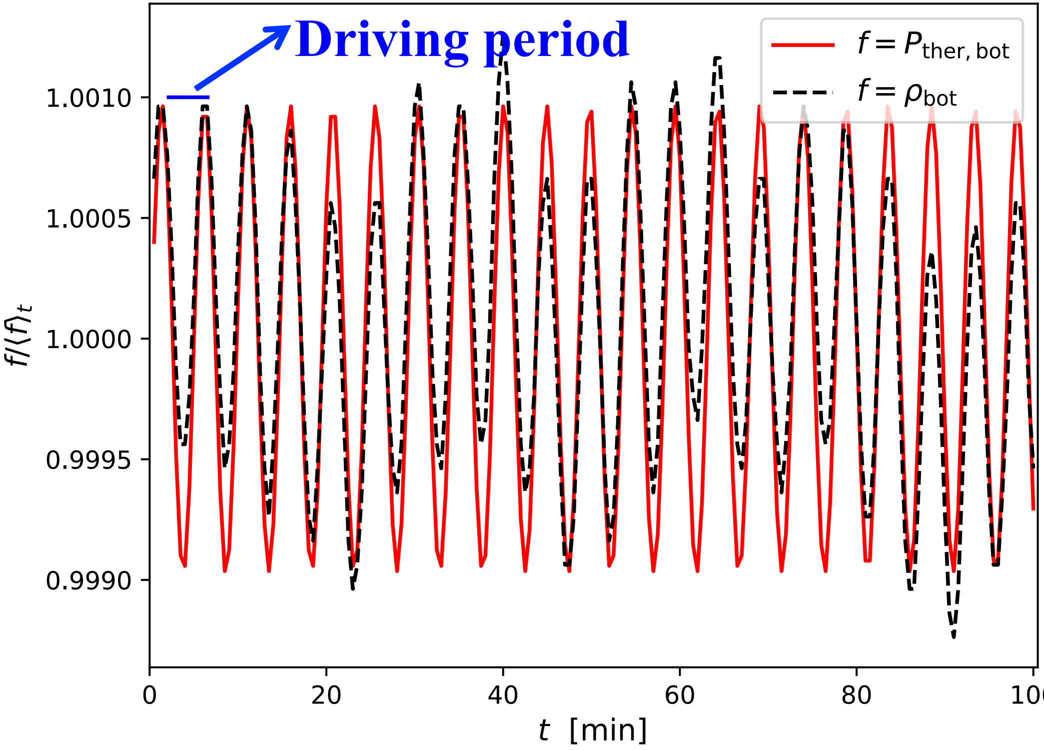
Observation: Chaplin et al. 1998

Artificial driving simulations

Drive a radial mode by perturbing the bottom boundary condition:

$$P_{\mathrm{bot}} = P_{\mathrm{bot},0}\left(1+\varepsilon \sin \omega_{\mathrm{drive}} t\right)$$

$$s_{\mathrm{bot}} = s_{\mathrm{bot},0} + O(\varepsilon^2)$$



Mode velocity amplitude

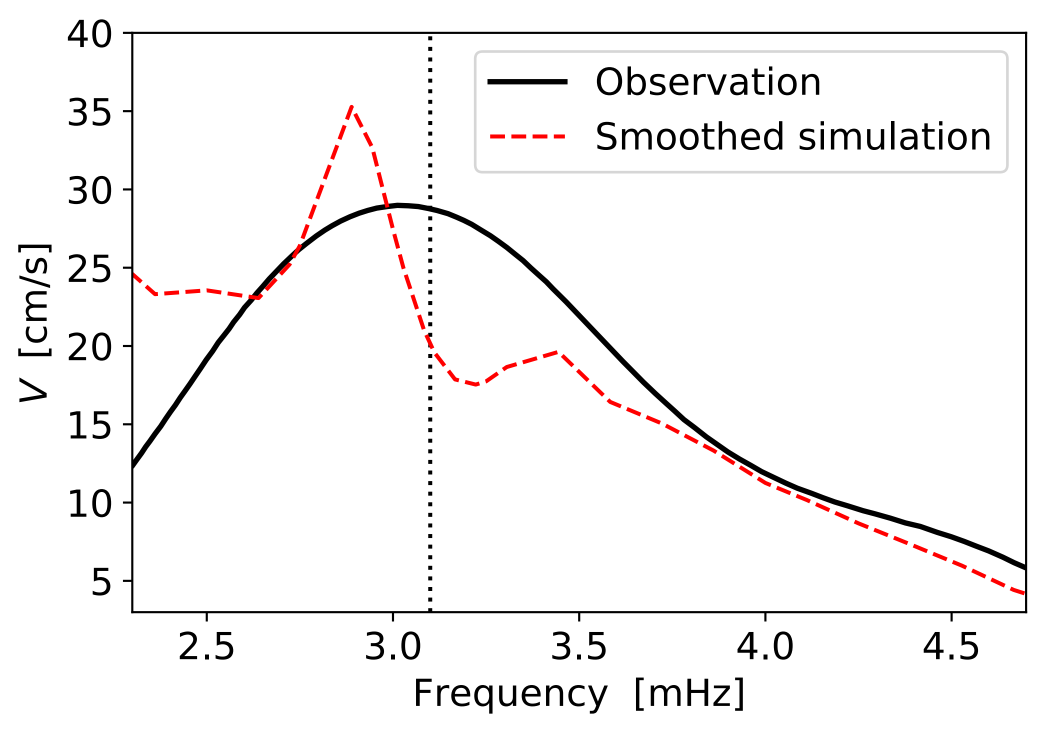
Excitation

Damping

$$V = \sqrt{\frac{2P_{\mathrm{exc}}}{M_{\mathrm{mode}}\eta}}$$

Mode amplitude

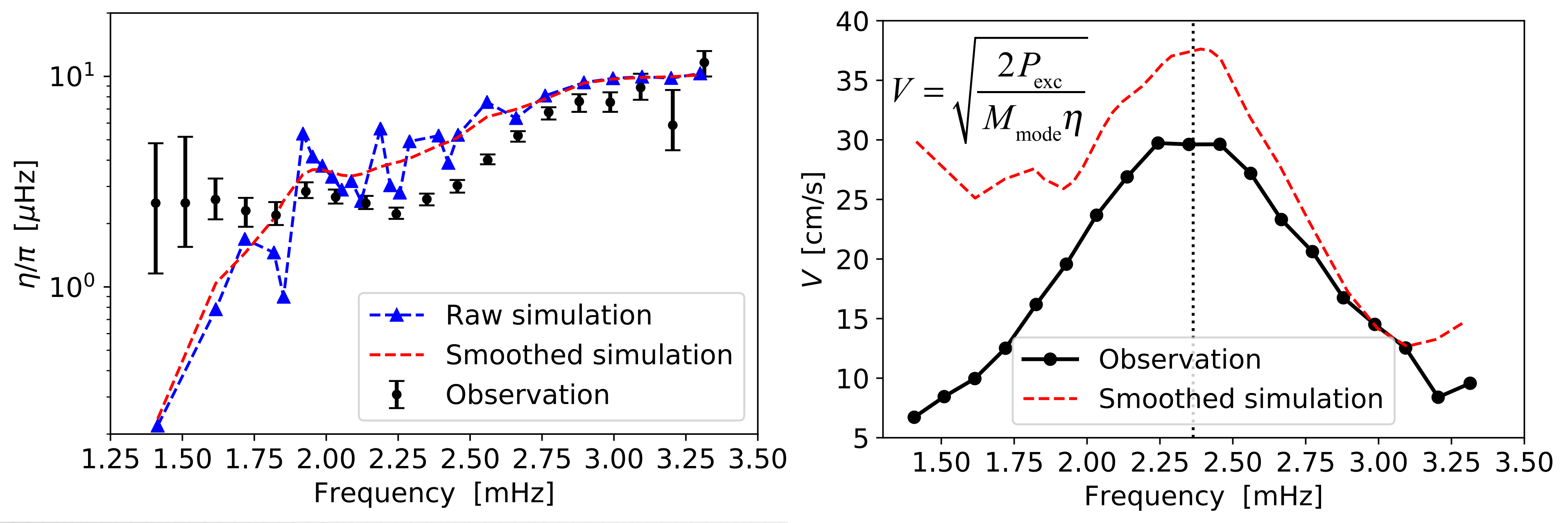
ν_{max}



Observation: Kjeldsen et al. 2008

KIC 6225718

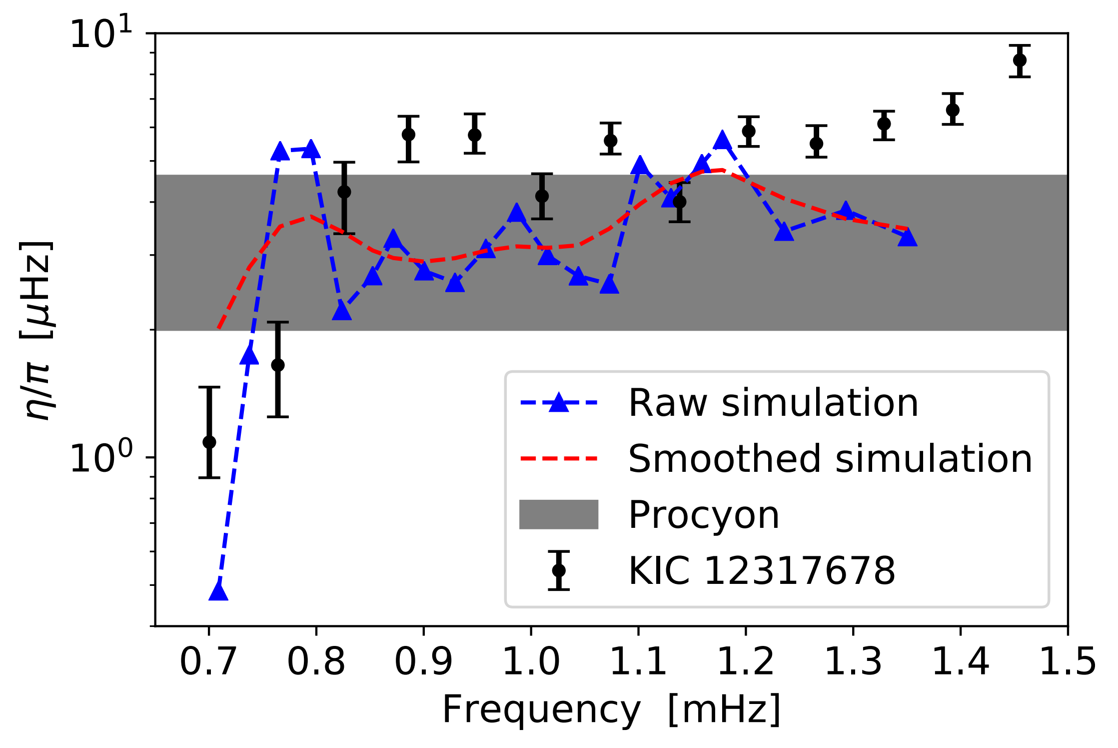
T_{eff} [K]	logg
6230	4.32



Observation: Lund et al. 2017

Procyon

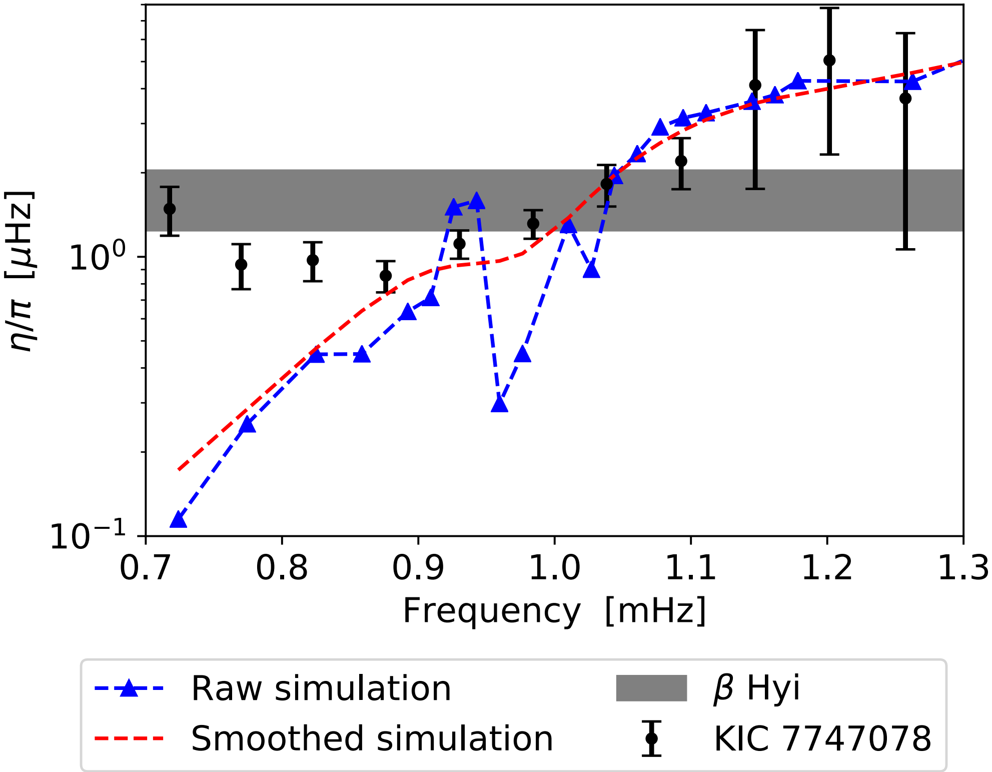
star	T_{eff} [K]	logg
Procyon	6543	4.0
KIC 12317678	6580	4.05

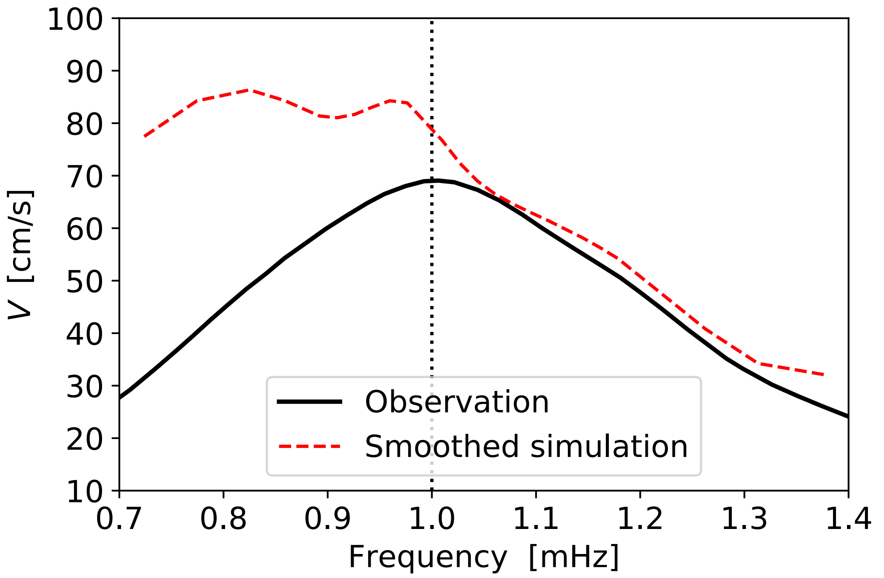


Procyon mean line width: Bedding et al. 2010; KIC line width: Lund et al. 2017

β Hydri

star	T_{eff} [K]	logg
β Hydri	5873	3.98
KIC 7747078	5903	3.91

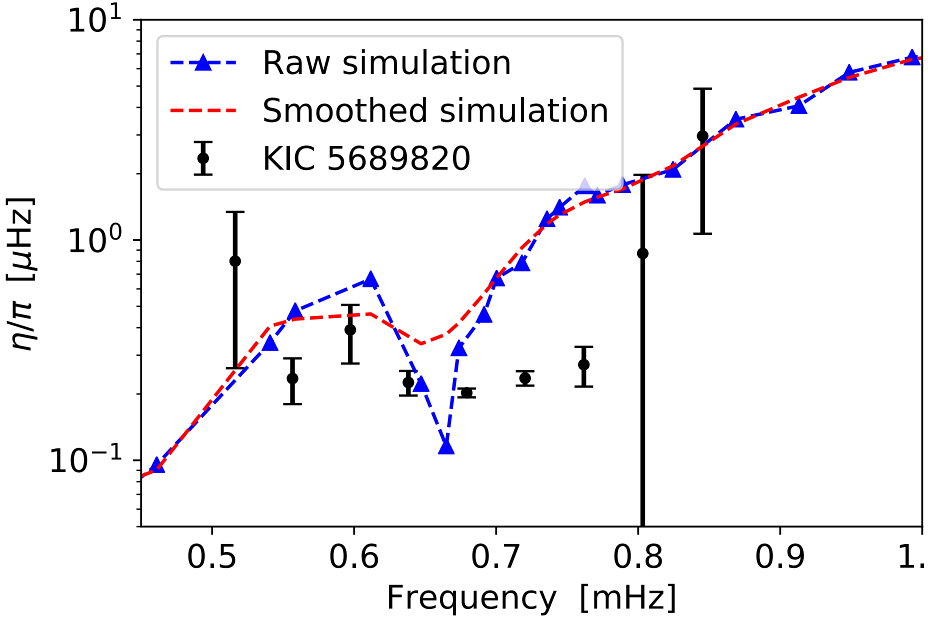




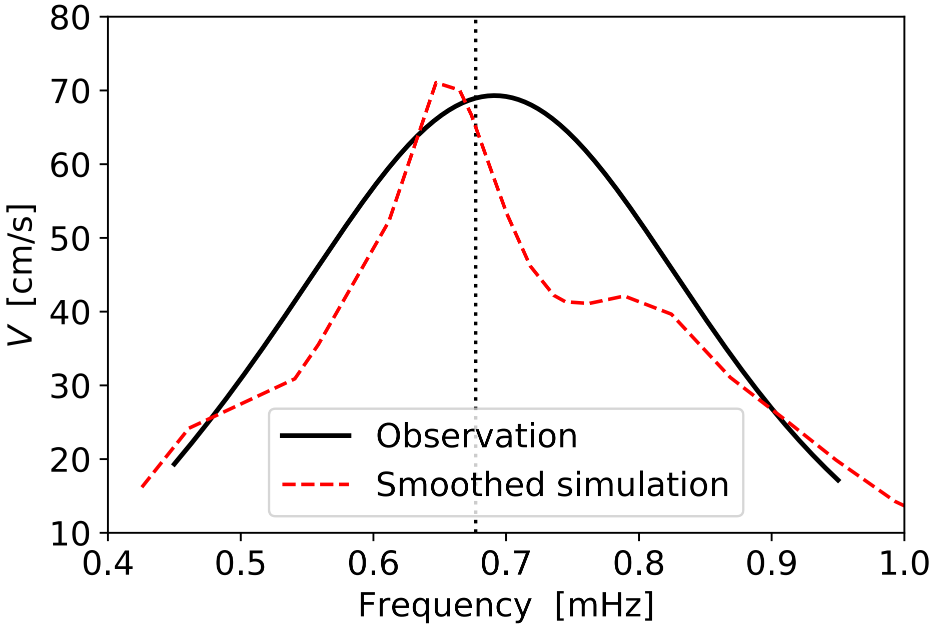
β Hydri Observation: Bedding et al. 2007; KIC line width from Yaguang Li

δ Eri

star	T_{eff} [K]	logg
δ Eri	4954	3.76
KIC 5689820	5037	3.76



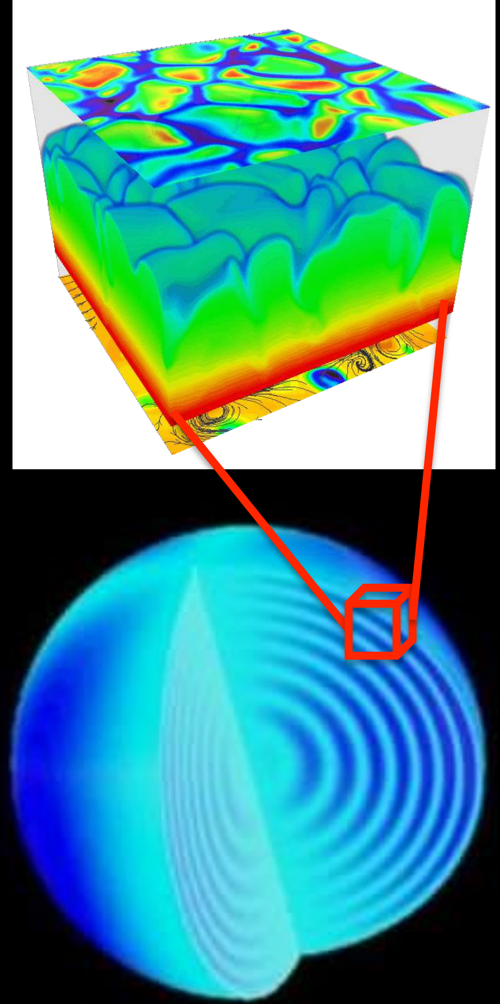
KIC line width from Yaguang Li



Observed mode amplitude data from Torben Arentoft, provided by Earl Bellinger and Tim White

Summary

- Mode excitation, damping & amplitude computed from 3D models
- Relationship between excitation, damping and stellar parameters
- Seismic scaling relations can be quantified from 3D convection modelling

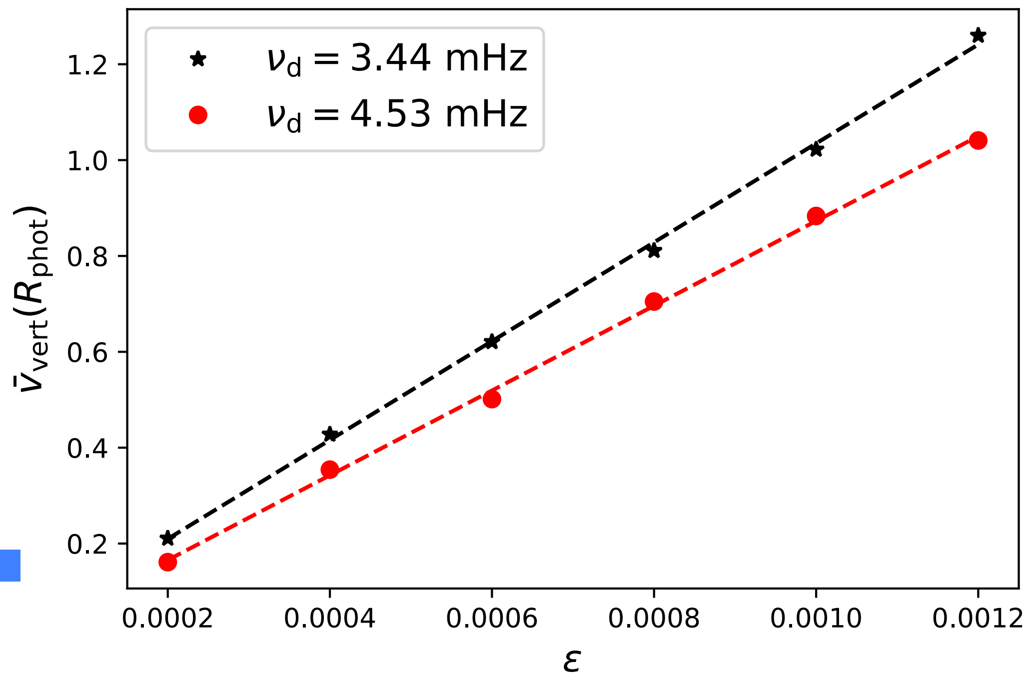


Discussion: trustworthy damping rates from artificial driving simulations?

$$P_{\rm bot} = P_{\rm bot,0}\left(1+\varepsilon \sin \omega_{\rm drive} t\right)$$

$$\eta = \frac{\omega \int_r \mathrm{Im}\left\{(\delta\bar{\rho}^* / \bar{\rho}_0)\delta \bar{P}_{\rm nad}\right\} dr}{4 m_{\rm mode} \left|\bar{v}_{\rm vert}(R_{\rm phot})\right|^2}$$

$$v_{\rm vert}(R_{\rm phot}) \propto \varepsilon$$



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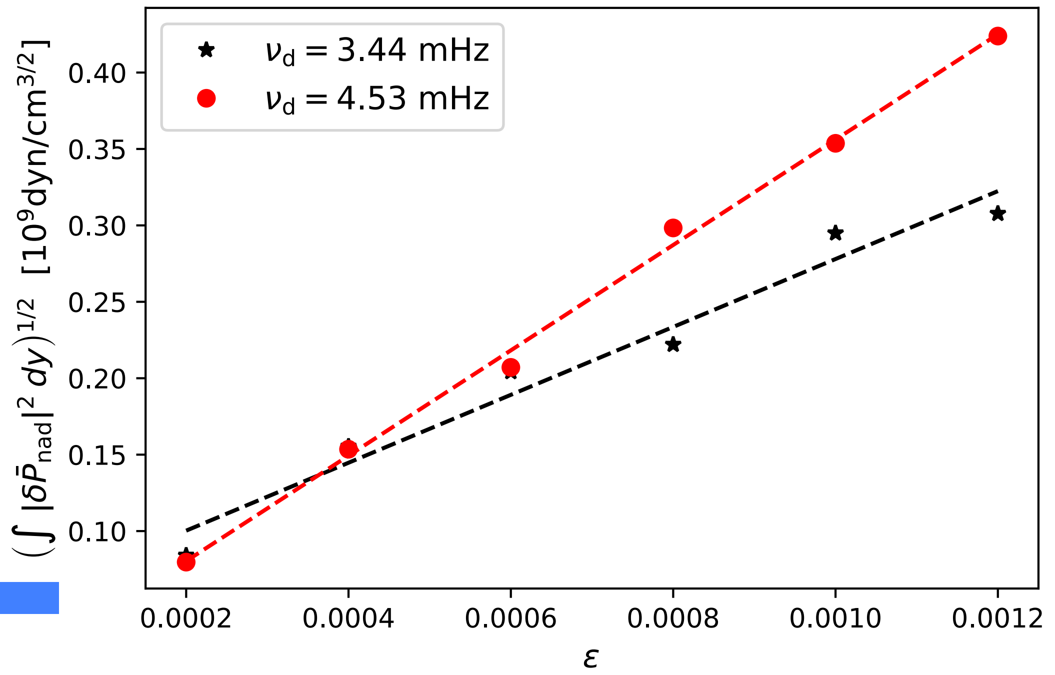
$$\delta P_{\rm nad} \propto \varepsilon$$



Discussion: trustworthy damping rates from artificial driving simulations?

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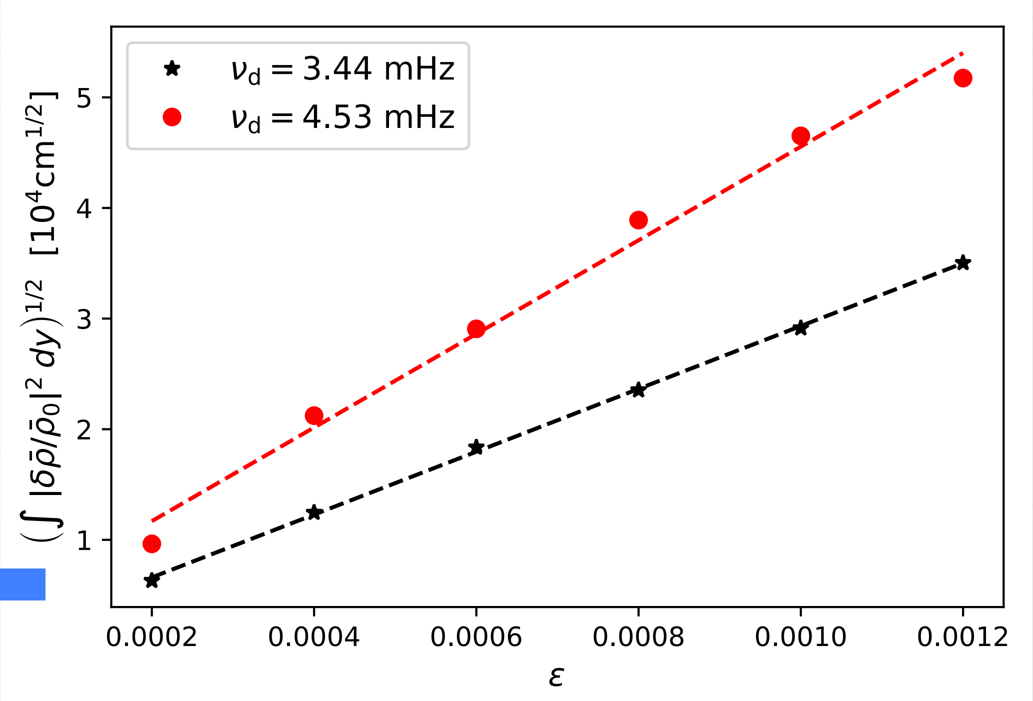
$$\delta\rho \propto \varepsilon$$



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$$v_{\mathrm{vert}}(R_{\mathrm{phot}}) \propto \varepsilon$$

$$\delta P_{\mathrm{nad}} \propto \varepsilon$$

$$\delta\rho \propto \varepsilon$$

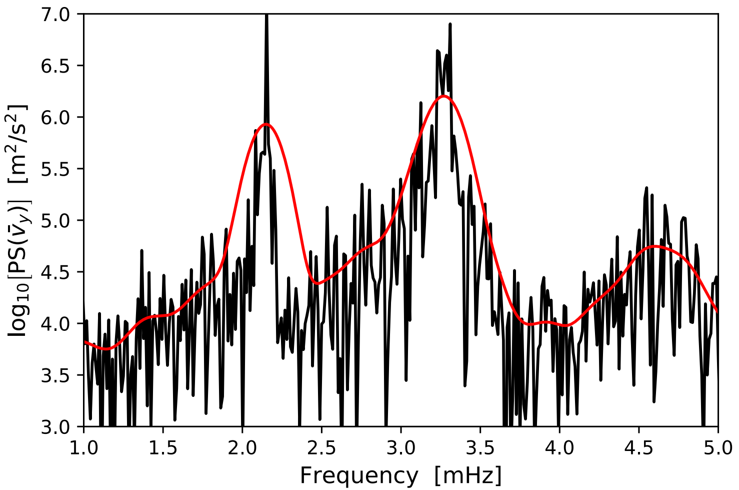
Why so complicated?

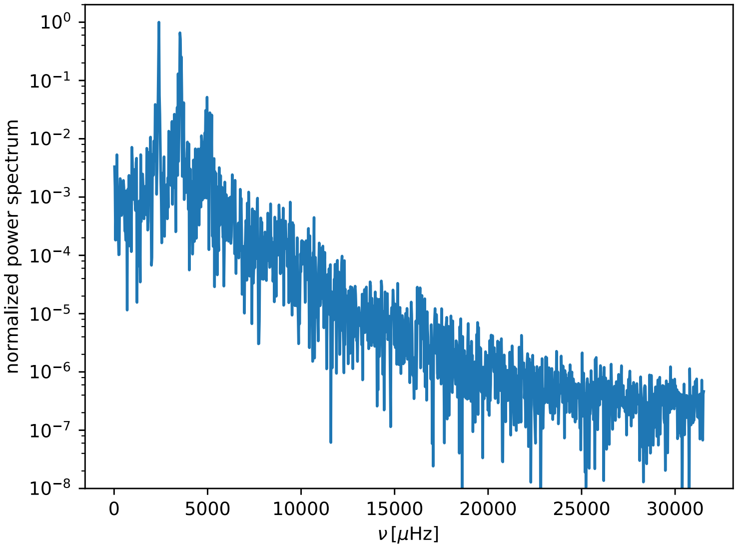
Discussion: line width directly from simulation modes?

Mode	Frequency	Line width
1	2398 μHz	
2	3540 μHz	50 μHz
3	4955 μHz	319 μHz

Too large!

Belkacem et al. 2019





Discussion: line width directly from simulation modes?

Reason: small mode mass (per unit area) in the simulation box

$$\eta = \frac{\omega \int_r \mathrm{Im}\left\{(\delta\bar{\rho}^* / \bar{\rho}_0)\delta \bar{P}_{\mathrm{nad}}\right\} dr}{4 m_{\mathrm{mode}} \left| \bar{v}_{\mathrm{vert}}(R_{\mathrm{phot}}) \right|^2}$$

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Discussion: line width directly from simulation modes?

Conclusion: Yes, but Γ at only 2-3 frequencies.