Two-dimensional simulations of solar like models with artificially enhanced luminosity

…and more specifically, what impact on **Internal Gravity Waves?**

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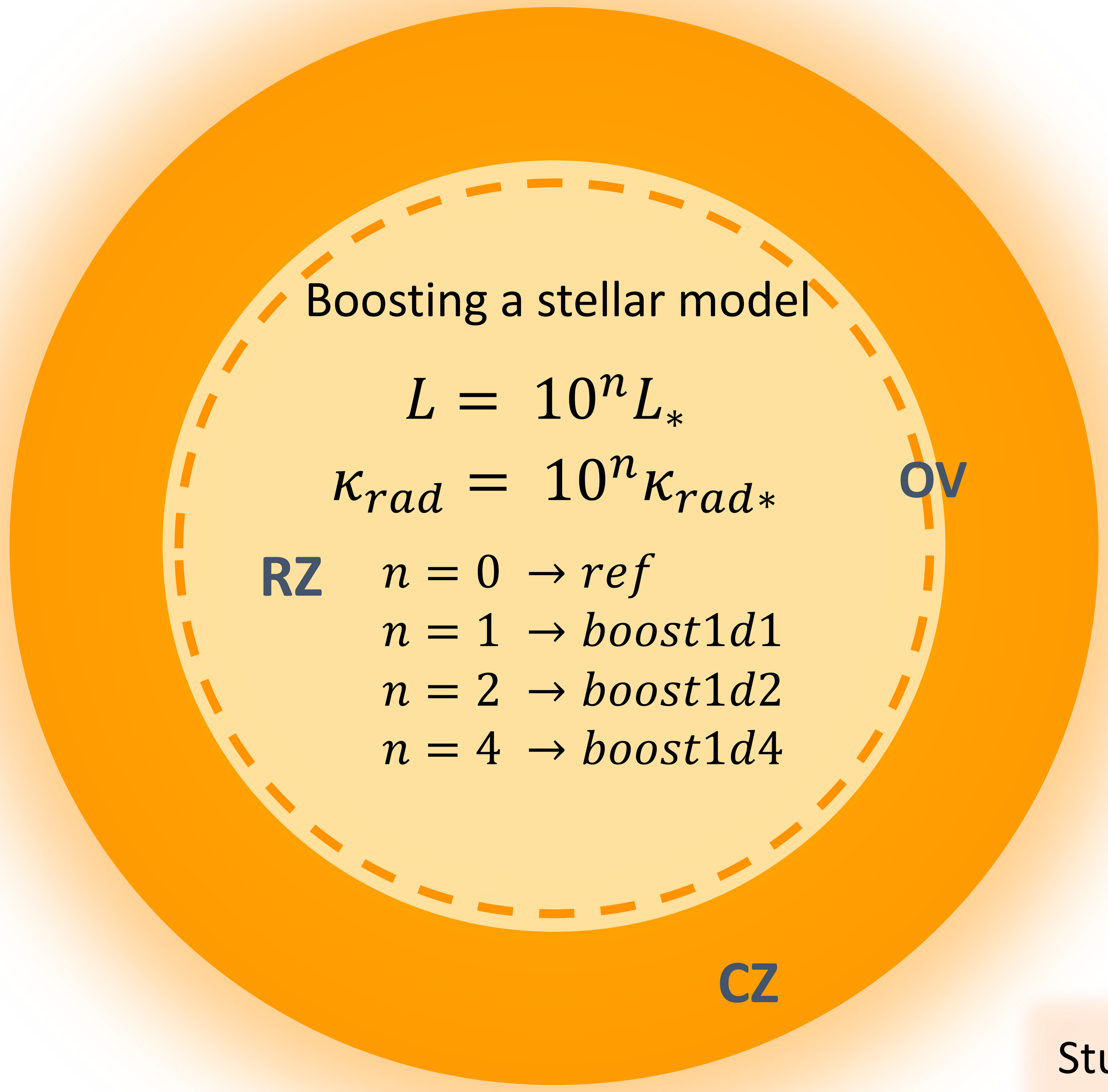
I. Context & Method

- Most current numerical simulations of convection in stars rely on artificially enhanced luminosity L and thermal diffusivity κ_{rad} by several orders of magnitude.
- The reasons for using this artefact is for numerical stability and/or for achieving thermal relaxation.
- How does this workaround impact physical processes like convection, convective overshooting, and internal gravity waves (IGW)?
- We simulate 2D solar-like models using the fully compressible time-implicit MUSIC code [1].
- We study the impact of the artificial boost factor on physical quantities, in particular for IGW.



II. Internal Gravity Waves (IGW)

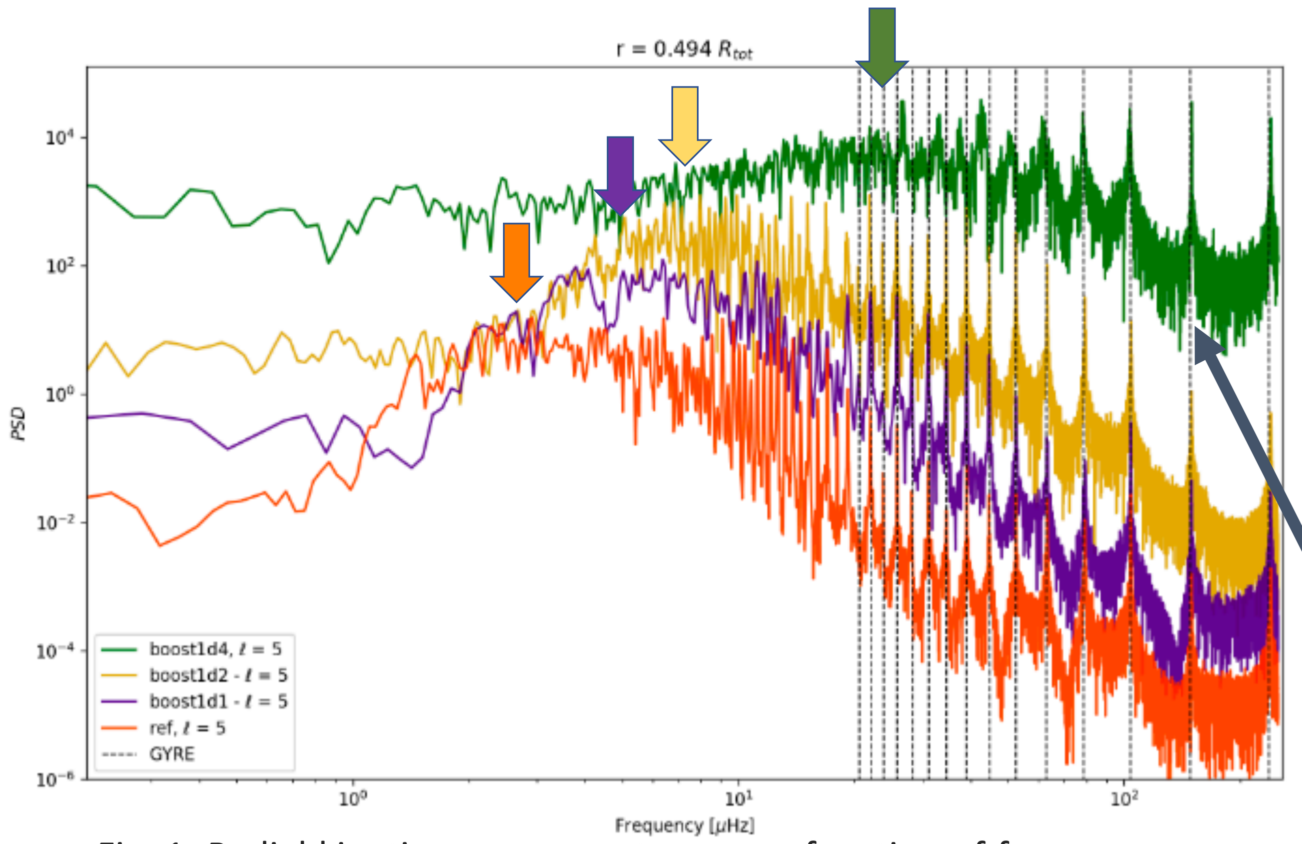


Fig. 1: Radial kinetic energy spectrum as a function of frequency for degree $\ell = 5$ at $r = 0.494$. The vertical dashed lines correspond to the modes frequencies predicted by GYRE [2].

Very good match between linear stability analysis prediction (GYRE [2], dashed lines)) and MUSIC!

Each spectrum presents a peak at a given frequency (coloured arrow), which also mark the beginning of a drop-off in energy at lower frequencies. The energy peak is shifted towards a higher frequency when the enhanced factor increase.

III. Overshooting (OV)

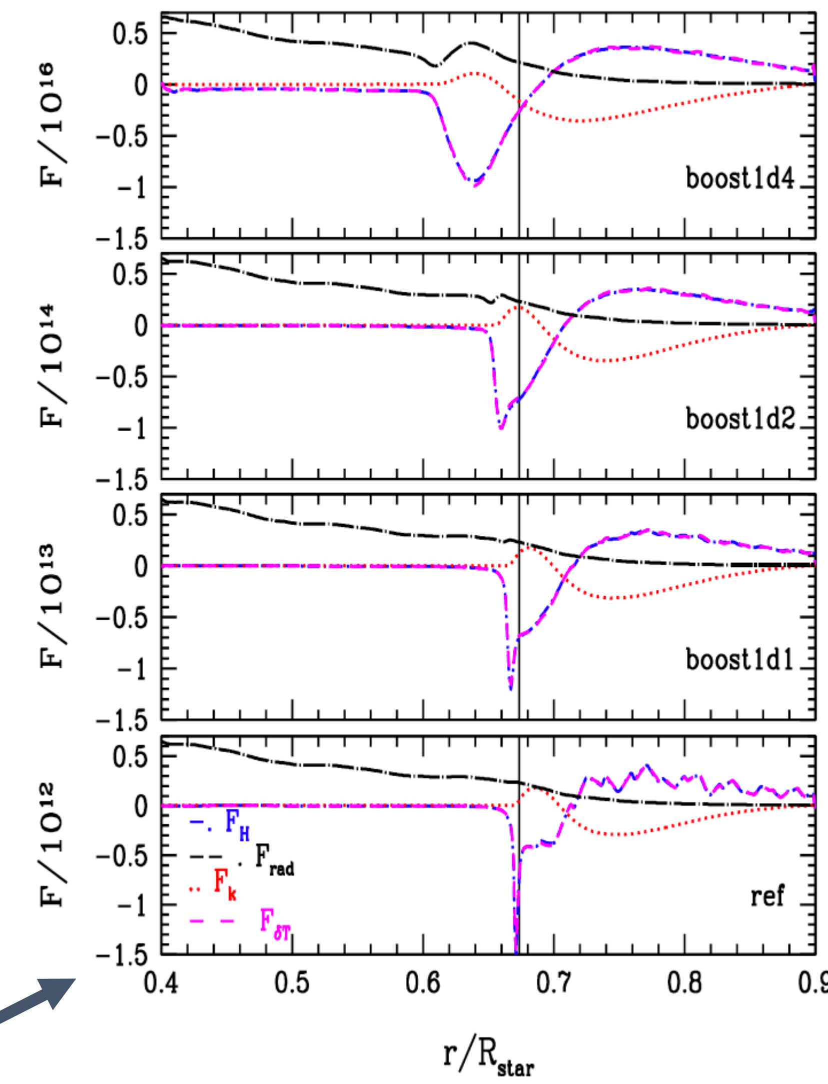


Fig. 2: Radial profile of the vertical enthalpy flux F_H, the radiative flux F_{rad}, the vertical kinetic energy flux F_k and the convective heat flux $F_{\delta T}$ for the four models. Fluxes (in erg.s-1.cm-2) are divided by a constant which is different for each model. The convective boundary is indicated by the vertical solid line.

Enhancing the luminosity impacts the structure and properties of the OV region. More to come soon in Baraffe *et al.* (2021, Submitted)!

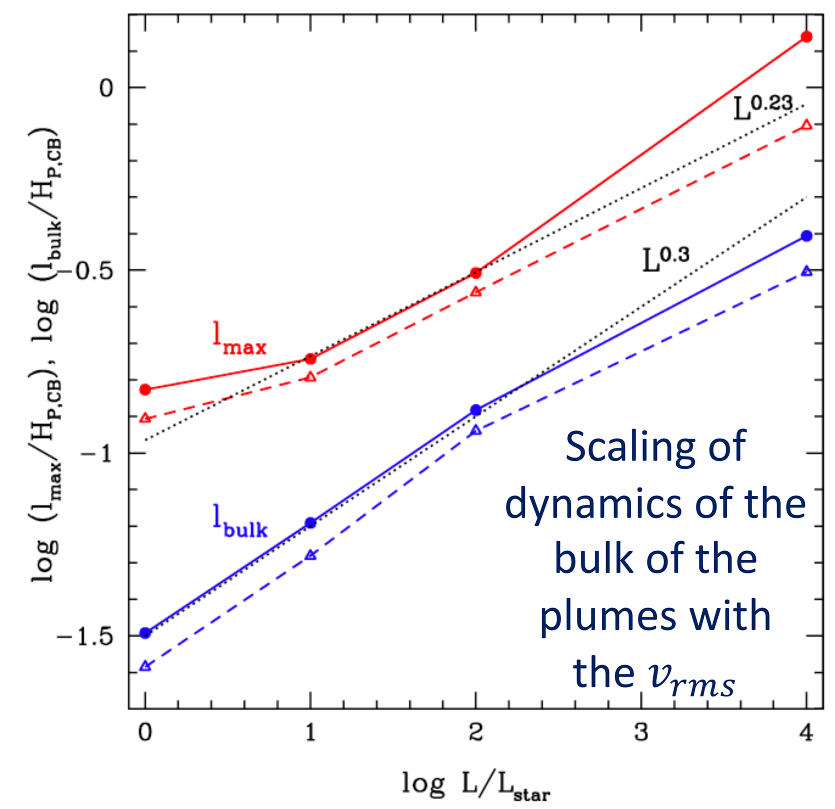


Fig. 3: Maximal penetration length l_{max} (red) and length of the layer where the bulk of the plumes penetrate l_{bulk}(blue curves), in units of the pressure scale height at the convective boundary, as a function of the luminosity of the model.

Studying CZ and OV is also important because they are responsible for IGW excitation [4,5]

IV. Energy Spectra: Can we find a scaling relation?

No scaling because standing IGW (g-modes) frequencies are fixed by cavity geometry

NO

YES

Radiative zone (RZ):

Energy shifted to higher frequency g-modes when the boost factor is increased

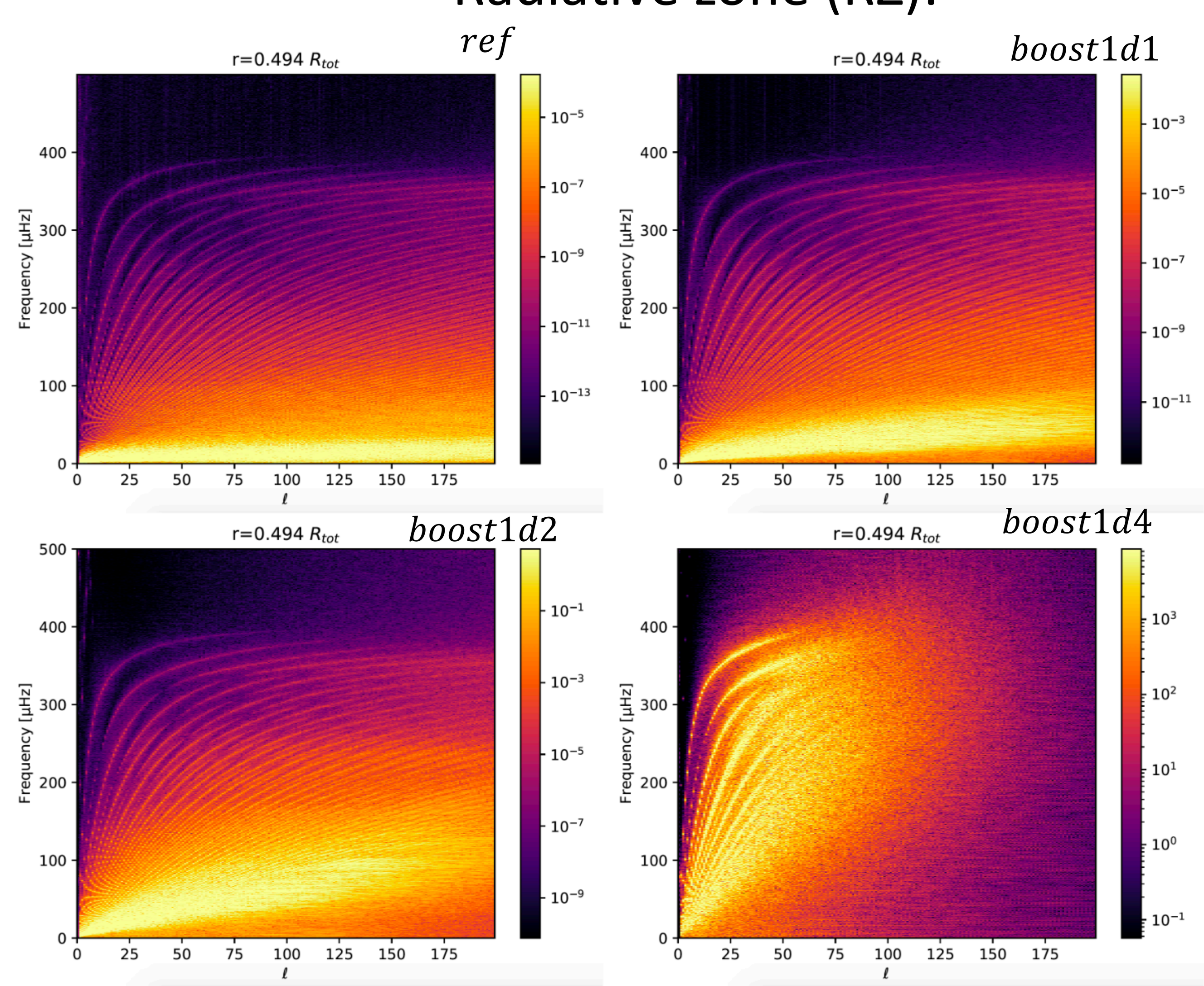


Fig. 4: Energy spectrum of radial velocity at $r = 0.494R_*$

Convection zone (CZ):

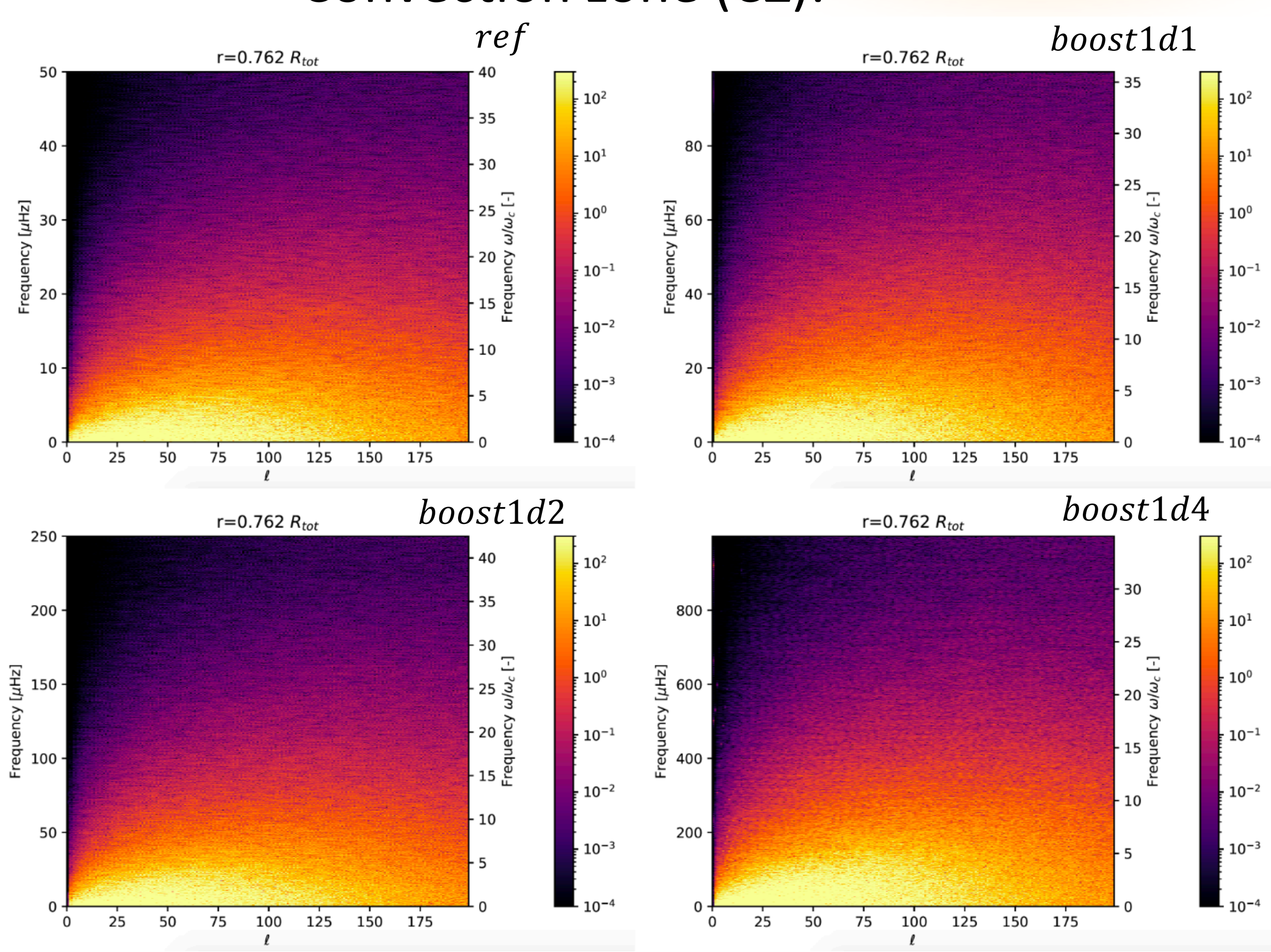


Fig. 5: Energy spectrum of radial velocity at $r = 0.762R_*$

Scaling with the boost in adequation with the Mixing Length Theory [3]

$$v_{rms} \propto L^{1/3}$$

And a convective turnover frequency

$$\omega_c^{-1} = < \int_{r_{conv}}^{r_{out}} \frac{dr}{v_{rms}(r,t)} >_t$$

V. Conclusion

Comparing these models highlights the impact of artificially boosting a stellar model:

- Some of the resulting effects can be compensated for by scaling relations (energy spectrum and velocity in CZ, dynamics of the bulk of the plumes).
- However for some others it is more complex and one has to be careful when using a boosted model. Particularly when studying the OV region, the RZ and/or IGW quantitatively (amplitudes, damping…).

All the results on IGW will be presented in Le Saux *et al.* (in prep)!

[1] Viallet et al. 2011, 2013, 2016; Geroux et al. 2016; Goffrey et al. 2017
[2] Townsend & Teitler, 2013, MNRAS, 435, 3406
[3] Biermann, 1932, ZAp, 5, 117
[4] Press 1981, ApJ, 245, 286, Lecoanet & Quataert, 2013, MNRAS, 430, 2363
[5] Pinçon, Belkacem, & Goupil, 2016, A&A, 588, A122

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