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IMPACT OF UNIFORM ROTATION ON THE STOCHASTIC EXCITATION OF ACOUSTIC MODES IN SOLAR-LIKE OSCILLATORS

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Abstract. We evaluate the impact of the rotation on the stochastic excitation of acoustic (p) modes in solar-like pulsators. First, we derive the forced wave equation taking rotation into account and we compute the source terms, which inject energy into the oscillations. We make use of the Rotating Mixing Length Theory (R-MLT) to assess how the convective root mean square velocities are modified by the Coriolis acceleration. Finally, we use the stellar structure and evolution code MESA combined with the stellar pulsation code GYRE to show that the resulting modes amplitudes are inhibited by rotation.

Keywords: asteroseismology - stars: oscillations - stars: rotation - stars: solar-type - convection

1 Introduction

Acoustic oscillations are stochastically excited by turbulent convection in solar-like pulsators (e.g. Samadi & Goupil 2001; Belkacem et al. 2008). Rotation and magnetic field seem to hinder modes detection (e.g. Garcia et al. 2010; Chaplin et al. 2011). Mathur et al. (2019) witnessed that acoustic modes are not detected in more than 40 % of solar-type stars from the *Kepler* data. As these stars possess a convective envelope, which should drive the oscillations, we explore the hypothesis that the turbulent excitation source is too low to generate oscillations. Rotation and magnetic fields are known to modify convection (e.g. Chandrasekhar 1961). In this work, we extend the theoretical model for the stochastic excitation of p modes (Samadi & Goupil 2001) to include the effects of rotation, through its influence on convection.

2 Stochastic excitation of acoustic modes with rotation

2.1 Stochastic excitation

Even if various source terms can excite acoustic modes, (Samadi & Goupil 2001; Belkacem et al. 2009), only the Reynolds stresses term is non-negligible in solar-like stars. Rotation indirectly modifies the stochastic excitation as it influences turbulent convection (e.g. Brun & Browning 2017). As derived in Samadi & Goupil (2001), the power injected into a given acoustic mode (n, ℓ, m) is

$$\mathcal{P} = \frac{16}{15 I^2} \pi^3 \int_{\mathcal{V}} d^3 x_0 \rho_0^2 \left| \frac{\mathrm{d}\xi_{r,n,\ell}(r)}{\mathrm{d}r} \right|^2 Y_{\ell,m}(\theta, \varphi) Y^*_{\ell,m}(\theta, \varphi) \hat{S}_R \left(r, \theta, \omega_0\right),$$

where I is the mode inertia, ρ_0 the mean density, $\xi_{r,n,\ell}$ the radial component of the oscillation Lagrangian displacement, $Y_{\ell,m}$ the spherical harmonic of orders $\ell, m.$ and $Y^*_{\ell,m}$ its complex conjugate. $\hat{S}_R$ is the contribution of the Reynolds stresses source: $\hat{S}_R\left(\omega_0\right) = \int \frac{dk}{k^2} E^2(k) \int d\omega \chi_k \left(\omega + \omega_0\right) \chi_k(\omega)$, where E is the kinetic energy spectrum and χ_k is the eddy-time correlation spectrum. We find that a Gaussian time-correlation spectrum would not influence the excitation in a rotating framework, so we favour a Lorentzian function (Bessila et al. 2024, under review) since observations (Mathur et al. 2019) show a dependence of the excitation on rotation.

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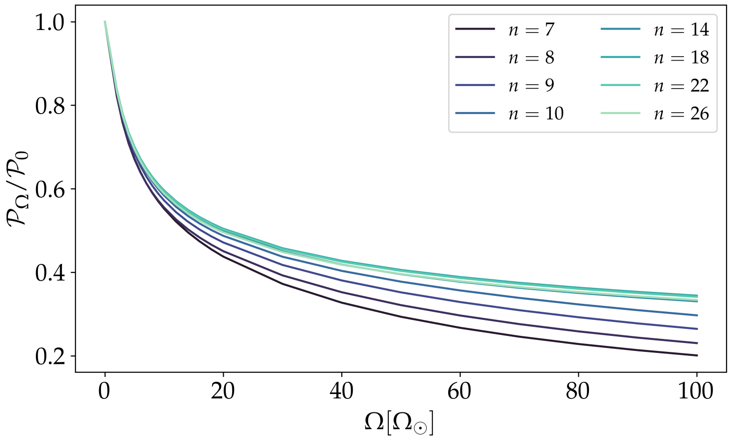

Fig. 1. We represent the power $\mathcal{P}_\Omega$ injected by turbulent convection into the acoustic modes as a function of rotation ($2\pi/\Omega_\odot = 28$ days is the solar rotation rate) normalized by its value $\mathcal{P}_0$ in the non-rotating case. All the modes have the same $\ell = 0$, and different values of radial order n.

2.2 *Rotating convection*

To model rotating convection, we consider the single-mode approach of the Rotating Mixing-Length Theory, developed by Stevenson (1979) and Augustson & Mathis (2019), which is based on the assumption that convection is dominated by the linear convective mode that carries the most heat (Malkus 1954). This model prescribes that the convective velocity scales like $\Omega^{-1/5}$. The R-MLT model succeeds in reproducing the results from local numerical simulations of rotating convection (see e.g. Barker et al. 2014).

3 Numerical results

We assess the impact of uniform rotation on the stochastic excitation making use of the MESA stellar evolution code (Paxton et al. 2011, 2013, 2015, 2018, 2019; Jermyn et al. 2023), as well as the GYRE stellar pulsation code (e.g. Townsend & Teitler 2013). We compute a solar-like model, with a mass $M = 1M_\odot$ and a metallicity $Z = 0.02$. As shown in Fig. 1, the power injected into the oscillations decreases when the rotation rate increases. For a $20\Omega_\odot$ rotation period, the injected power diminishes by up to 50%. In addition, all the modes are not equally influenced by rotation: low n order mode amplitudes are more sensitive to this diminution.

4 Conclusion

We have included rotation in the theoretical model for the stochastic excitation of acoustic modes in rotating solar-like pulsators. We show that the power injected into the stellar oscillations can diminish by up to 50 % for a $20\Omega_\odot$ rotation rate, due to the impact of rotation on the convection. For a given ℓ, low n mode amplitudes are more inhibited.

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