Asteroseismic signature of a starspot

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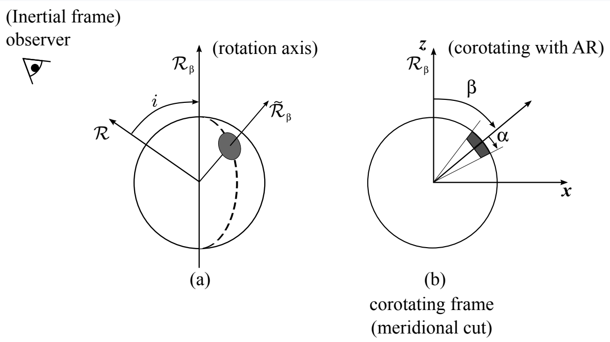
Abstract

Stellar acoustic oscillations are affected by magnetic activity, however it is unclear how a single starspot would affect the power spectrum of oscillations. Since the starspot rotates with the star, it causes a perturbation that is unsteady in the observer's frame. Each (n, ℓ) multiplet appears as $(2\ell+1)^2$ blended peaks in the power spectrum, whose amplitudes depend on the star's inclination and on the latitude of the starspot. We simulate example power spectra using both perturbation theory and numerical simulations.

1. Method: Perturbation theory of a rotating starspot and numerical simulations [6]

Linear theory: We consider a localized 3D perturbation at a colatitude β, mimicking a starspot rotating with the star. For the starspot a simple model is used, that accounts for strength (ε) and surface coverage (α) of the perturbation. For the study we employ the rotation profile of [1], rescaled to a period of $T = 8$ days. We define the observer's inertial frame $\mathcal{R}$ and the frame $\mathcal{R}_\beta$, corotating with the starspot.



Nonlinear regime: With the GLASS code [4], we explore the nonlinear regime of the perturbation by means of 3D numerical simulations, using a convectively stable solar model [5]. A constant rotation profile is used.

1. Starting from the Model S [2] solutions $(\omega_0, \boldsymbol{\xi}_m^0)$ to the stellar oscillation equations of a $n\ell$-multiplet, in $\mathcal{R}_\beta$ we seek perturbed solutions of the form [4]

$$\omega^M = \omega_0 + \delta\omega_M, \quad \boldsymbol{\xi}^M = \sum_{m=-\ell}^{\ell} A_m^M \boldsymbol{\xi}_m^0 ,$$

that solve the eigenvalue problem

$$\left[O^{\mathrm{ROT}}_{\beta,m'm} + O^{\mathrm{SP}}_{\beta,m'm}(\alpha,\varepsilon) - \delta_{m'm}\delta\omega_M \right] A_m^M = 0,$$

where the O^{ROT} and O^{SP} describe the rotation and the starspot perturbations.

2. The observed power spectrum is calculated in the inertial frame $\mathcal{R}$.

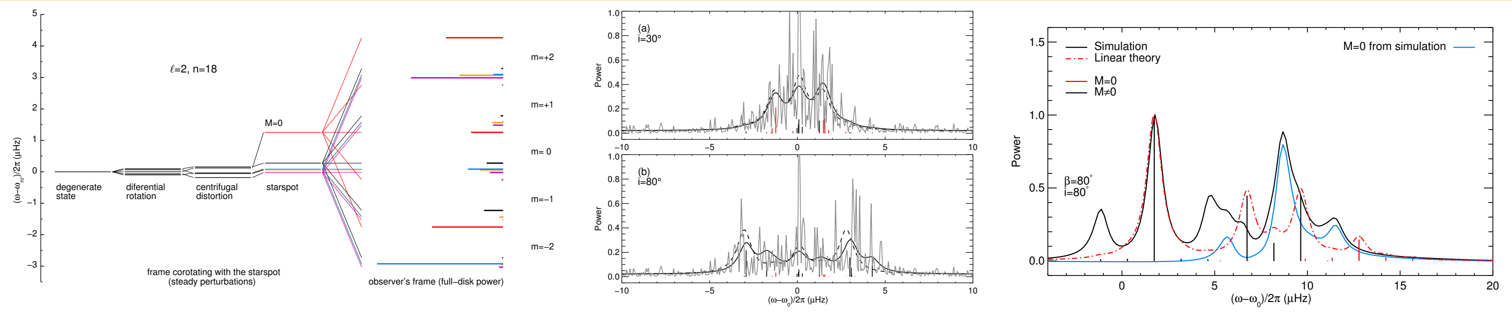
$$P(\omega) \equiv |I(\omega)|^2 = \left| \sum_{M,m=-\ell}^{\ell} \sqrt{P_m^M L(\omega - \omega^M - m\Omega_\beta)}\, \mathcal{N}_M(\omega - m\Omega_\beta) \right|^2$$

$$P_m^M = \frac{(\ell - |m|)!}{(\ell + |m|)!} \left[V_\ell A_m^M P_\ell^{|m|}(\cos i) \right]^2$$

$$E[\mathcal{N}_M(\omega)] = 0, \quad E[\mathcal{N}_M^*(\omega)\mathcal{N}_{M'}(\omega')] = \delta_{MM'}\delta_{\omega\omega'}$$

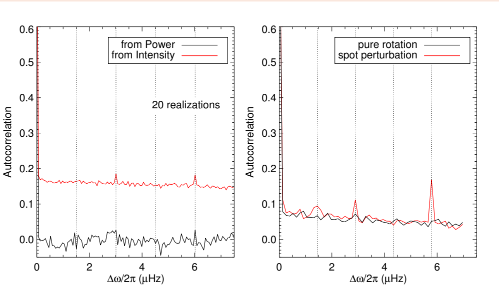
where $L(\omega)$ describes a Lorentzian line profile, and Ω_β is the rotational frequency of the spot. The spectrum is correlated at frequencies separations multiple of Ω_β.

2. Results: Power spectrum



Left: Schematic diagram for the $\ell = 2, n = 18$ multiplet showing the different contributions that remove the degeneracy of the nonrotating nonmagnetic star. In an inertial frame, the observed power spectrum shows $(2\ell+1)^2$ peaks. The Lorentzian profiles generated by the peaks with same color are correlated. **Center:** Realizations of the power spectrum (gray lines) for $\varepsilon = 0.003$, $\beta = 80°$, and $\alpha = 23°$, with $i = 30°$ (a) and $i = 80°$ (b), corresponding to 6 months of continuous observations. A signal-to-noise ratio of 50 has been prescribed. Black solid lines are the limit power spectra. Dashed lines denote the pure rotational spectra. Vertical lines show theoretical peaks from linear theory. **Right:** Power spectrum of the same multiplet from a GLASS simulation with $\varepsilon = 0.02$. Vertical lines show the peaks from linear theory.

3. Results: Correlations



Left: Autocorrelation of 20 realizations of the power spectrum of a $\ell = 2, n = 18$ multiplet from linear theory, for $\varepsilon = 0.003$, $\beta = 80°$, $\alpha = 23°$ and $i = 80°$, calculated by using the power spectrum (black line) and the intensity (red line). **Right:** Autocorrelation of the power spectrum from a GLASS simulation, averaged over the multiplets $\ell = 2, n = 15$ to 30, calculated using the intensity, for a perturbation with $\varepsilon = 0.02$ (red line) and in the case of pure rotation (black line). Vertical dotted lines in both plots denote frequency separations $\Delta\omega$ multiple of Ω_β.

References

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