Simulating acoustic waves in spotted stars

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Abstract

Asteroseismology is a primary tool to provide information and new insights on the relationship between the internal structure of stars and their surface magnetic activity. Numerical simulations are the key to interpret these observations, through the study of the interaction of the acoustic-wave field with 3D perturbations (e.g spots and active regions) to a background model. In this contest we present preliminary results of a parametric study of the effect on selected modes for l=0,1,2 induced by a spot-like perturbation in the sound speed with respect to a convectively stabilised solar Model S. This perturbation is located at the surface and at depths of 0.01 up to 0.03 solar radii, with amplitude changes in the squared sound speed that range from 10% to 100%. For the simulations we used the GLASS code, currently in development, which simulate propagating acoustic waves through a generic full 3D rotating stellar interior, including the center.

1. Motivation

The acoustic wavefield carries a considerable amount of information on the evolution of magnetic fields in active stars. That information however is difficult to extract, due to the non-linear interaction of the waves with the complex magnetic structure. Observational effects (e.g. the inclination angle and limb darkening) also contribute to complicate the analysis [1].

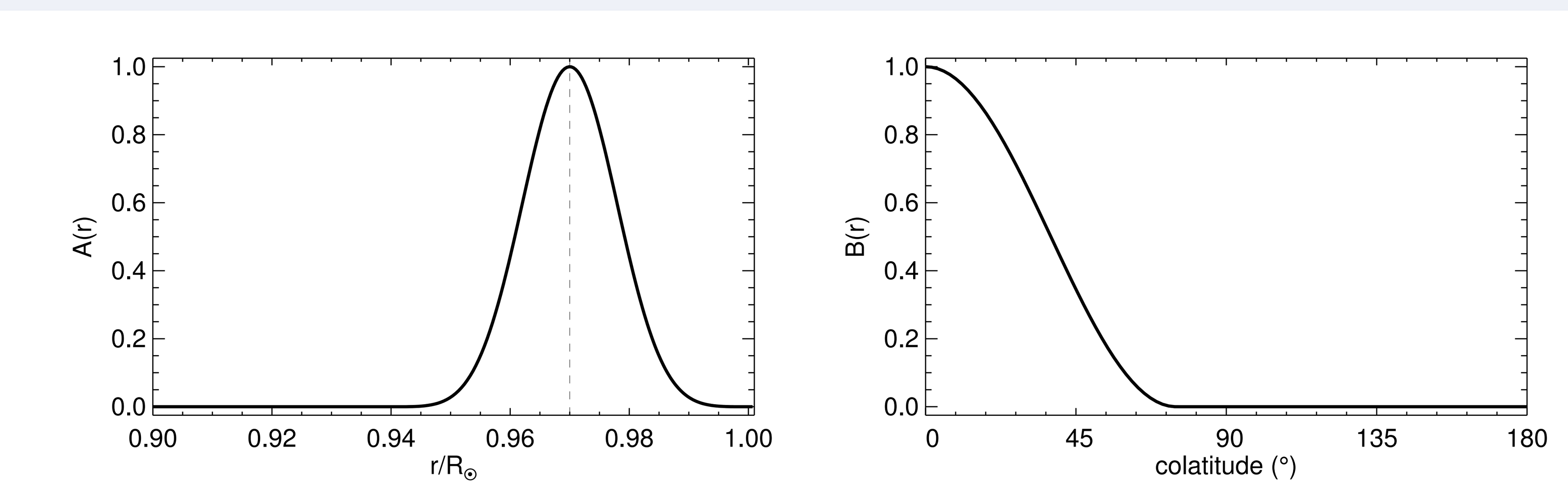
As a first attempt to unravel such a complex problem we focus on a rather simple spot model, in order to investigate the effect on single modes and the coupling between different modes.

2. Method

We consider a full 3D stellar model, and solve the linearized HD equations in the Cowling approximation using the GLASS code.

1. Starting from a convectively-stabilized Model S [2] as a background model, we add a 3D perturbation δc^2 to the soundspeed in the form:

$$\frac{\delta c^2(r,\theta)}{c_0^2(r)} = \epsilon A(r-r_c)B(\theta)$$



where the profiles $A(r-r_c)$ and $B(\theta)$ are chosen to mimick a polar spot, with a surface extension similar to that observed in a young solar analog [3].

2. We perform a parametric study by varying the depth r_c from $0.97\mathrm{R}_\odot$ to $1\mathrm{R}_\odot$ and the amplitude ϵ from 0.1 to 1. We then excite the desired modes, using the eigenmodes solutions given by ADIPLS [4], and let the wavefield evolve with no other forcing for 100 days (solar time).
3. Finally we build synthetic lightcurves and power spectra for different values of the i angle [5].

3. Results

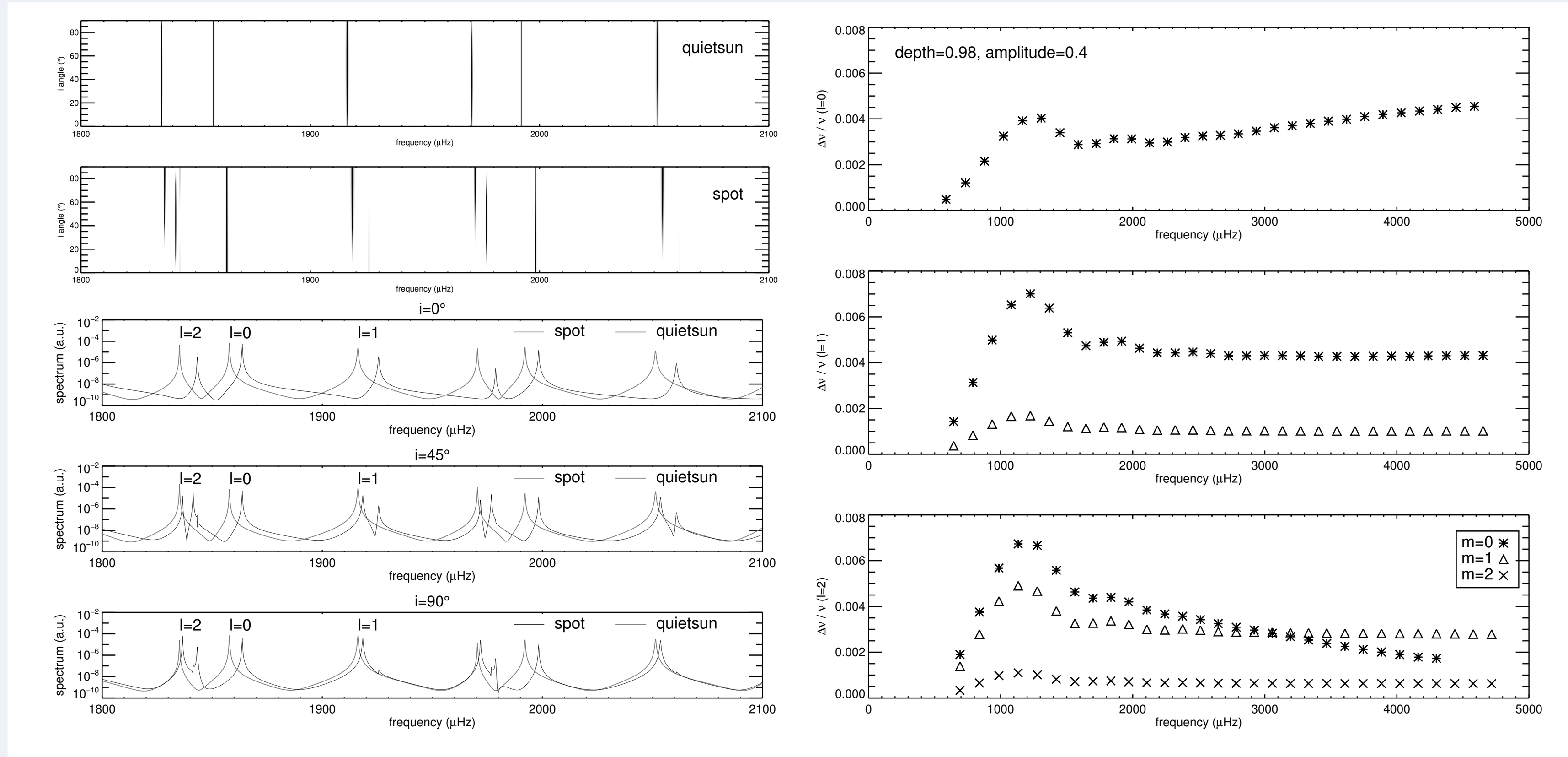


Figure: **Left:** top panels: power spectrum as a function of the i angle, for quiet Sun and a spot with $r_c = 0.98\mathrm{R}_\odot$ and $\epsilon = 0.4$. The bottom panels show the power spectrum (log scale) for quiet Sun (gray line) and the same spot (black line), at i angle values of 0°, 45°, and 90°. **Right:** Relative frequency shifts $\delta\nu/\nu$ induced by the spot for modes with $\ell = 0$ (top), $\ell = 1$ (middle), $\ell = 2$ (bottom), and for $3 \le n \le 32$.

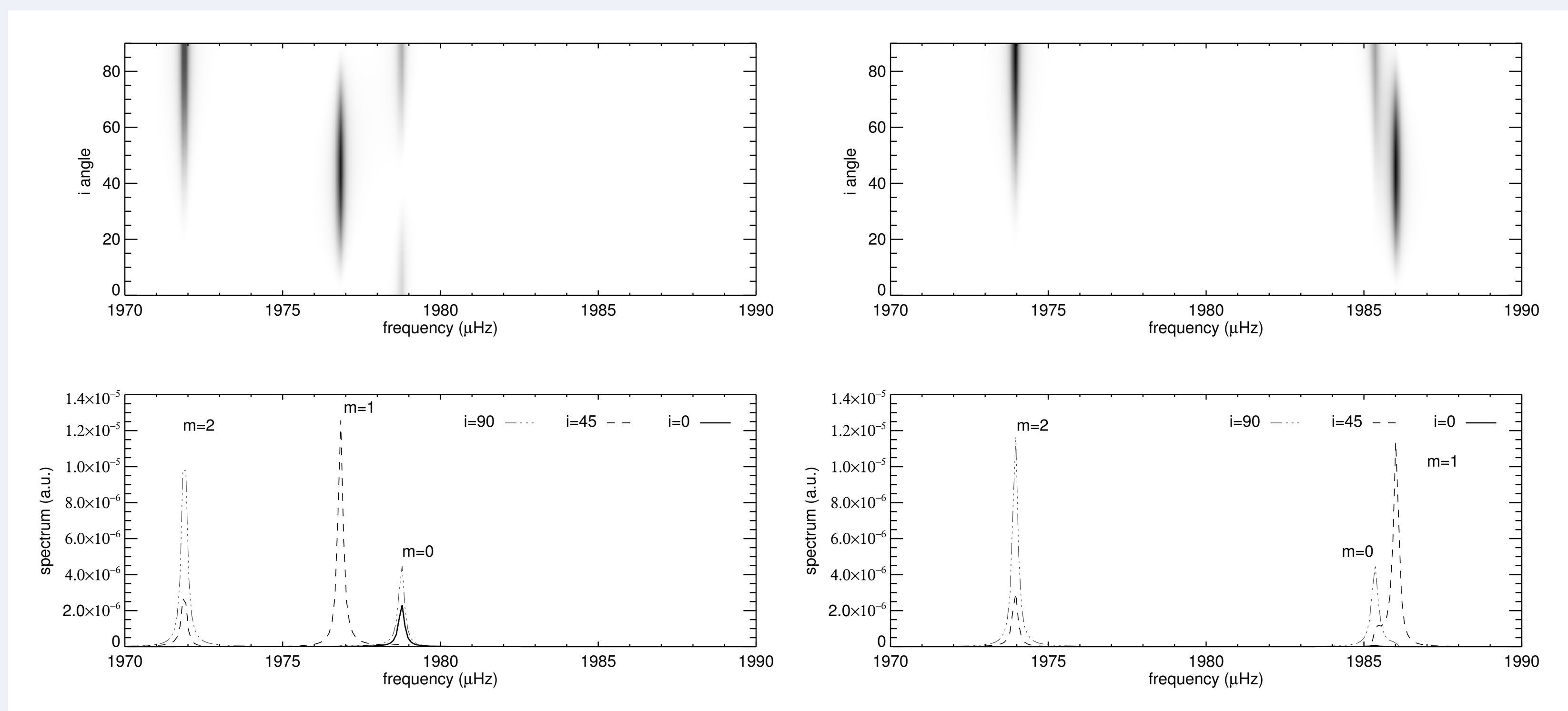


Figure: **Left:** power spectrum of $\ell = 2, n = 12, m = 0, \pm1, \pm2$ as a function of the i angle (top panel), for a spot with $r_c = 0.98\mathrm{R}_\odot$ and for a value of $\epsilon = 0.4$. The bottom panel shows a plot of the spectrum for specific values of $i = 0°$ (solid line), $i = 45°$ (dashed line), and $i = 90°$ (dot dashed line). **Right:** Same as left panels but for $\epsilon = 1$. The plots show the shift for $m = 1$ getting bigger than $m = 0$ in the case $\epsilon = 1$, furthermore, because of the 3D shape of the spot perturbation, the visibility of the modes is no longer determined by the visibility function only.

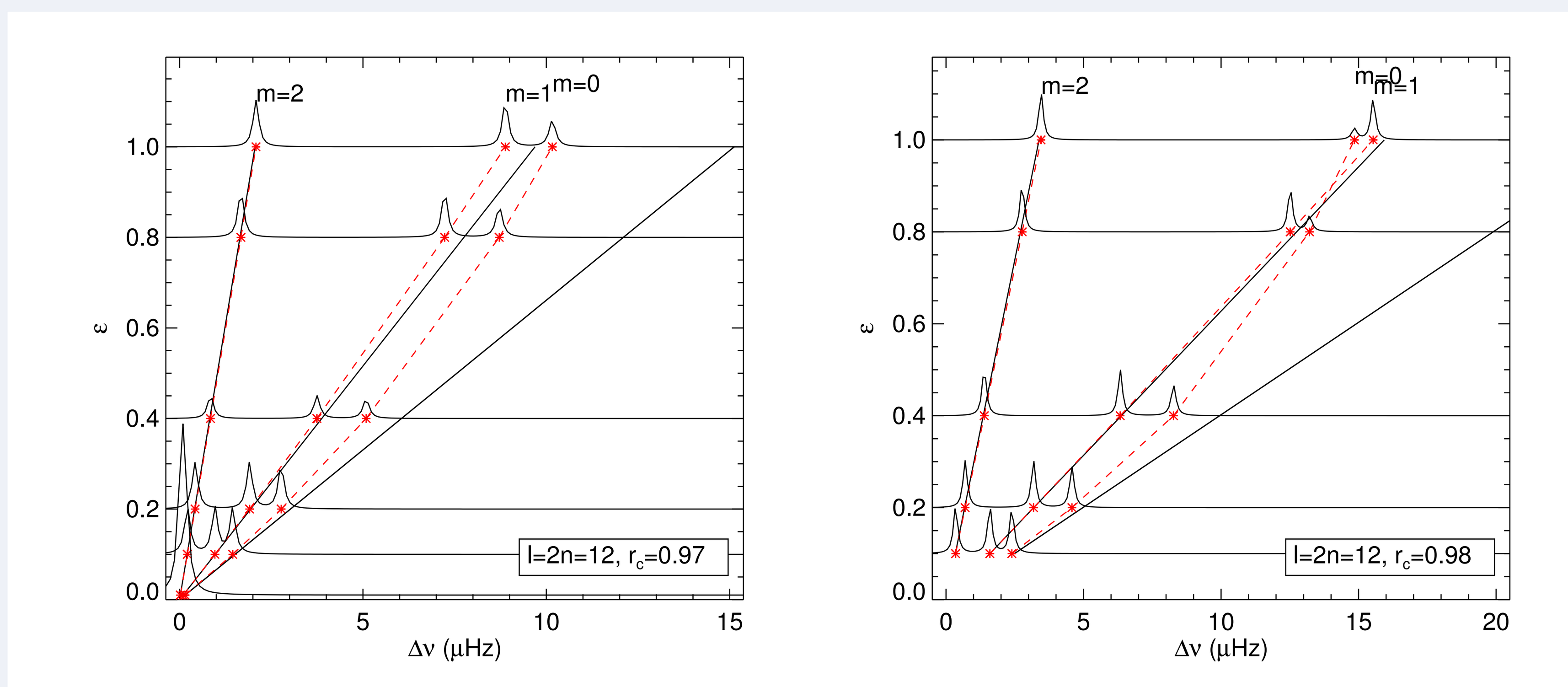


Figure: Spot amplitude ϵ vs. frequency shift for $\ell = 2$, $n = 12$, and $m = 0, \pm1, \pm2$ from simulations (red dashed lines and asterisks) and linear perturbation theory (black solid lines), for two different spot depths of $0.97\mathrm{R}_\odot$ (left) and $0.98\mathrm{R}_\odot$ (right). The superimposed power spectra also show the effect of the spot on the mode amplitudes. The linear theory reasonably reproduces $m = 2$ and $m = 1$, but fails for $m = 0$.

References

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