Stellar oscillations induced by a planetary companion

Going off on a tangent

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Introduction

Both the Radial Velocity (RV) and transit methods for detecting exoplanets have been successful, but both are limited – characterising the planetary system's mass is a particular difficulty due to degeneracy with the inclination or the density, respectively. Understanding other ways in which the planet and the star interact could break these degeneracies.

Given their mass, size and proximity to their host star, Hot Jupiters have a stronger interaction with their host star than other planets. The first-order effect of their presence is what is used to detect them in both the RV and transit method – the motion of the star around the common centre of mass, and the light blocked by their presence respectively. The tidal potential due to the planet is a second-order effect which changes the amplitude and wavelength of the star's light.

Whilst modelling this interaction for the non-adiabatic case has been undertaken before [6], a detailed analysis of the tangential displacement has been lacking, or has otherwise been done assuming that the change due to non-adiabaticity is small [7].

This work particularly focusses upon the behaviour at the very surface, where non-adiabatic effects are prominent. Comparison between the modelled behaviour and analytical results under the conditions present at the very surface show good agreement.

Method

Numerical method

To model the oscillations, the linear non-adiabatic stellar oscillation equations were solved in the case that the star is perturbed by a regular tidal potential, due to the planet. The variables directly solved for are: ξ_r, the radial displacement; F'_r, the perturbation to the radial radiative flux; p', the perturbation to the pressure; and T', the perturbation to the temperature.

The equations solved are:

$$\frac{1}{r^2}\frac{\partial}{\partial r}(r^2\rho_0\xi_r) + \left(\frac{\rho_0}{\chi_\rho p_0} - \frac{l(l+1)}{m^2\omega^2 r^2}\right)p' - \frac{\rho_0}{T_0}\frac{\chi_T}{\chi_\rho}T' = \frac{l(l+1)}{m^2\omega^2 r^2}\rho_0\Phi_P \tag{1}$$

$$\left(i\rho_0 m\omega c_p + \frac{l(l+1)}{r^2}K_0\right)T' - \left(im\omega c_p\nabla_{ad}\rho_0 T_0\right)\frac{p'}{p_0} + im\omega\rho_0 T_0\frac{\partial s_0}{\partial r}\xi_r + \frac{1}{r^2}\frac{\partial}{\partial r}(r^2F'_r) = 0 \tag{2}$$

$$-\frac{F'_r}{K_0} + \left(-\frac{\partial}{\partial r} + \frac{1}{T_0}\frac{\partial T_0}{\partial r}\left[-3 + \frac{1}{\kappa_0}\left(\frac{\partial\kappa}{\partial\ln T}\right)_\rho - \frac{\chi_T}{\chi_\rho}\left(1 + \frac{1}{\kappa_0}\left(\frac{\partial\kappa}{\partial\ln\rho}\right)_T\right)\right]\right)T' + \frac{\partial T_0}{\partial r}\frac{1}{p_0\chi_\rho}\left(1 + \frac{1}{\kappa_0}\left(\frac{\partial\kappa}{\partial\ln\rho}\right)_T\right)p' = 0 \tag{3}$$

$$-m^2\omega^2\rho_0\xi_r + \left(\frac{\partial}{\partial r} + \frac{\rho_0}{\chi_\rho p_0}\frac{\partial\Phi_0}{\partial r}\right)p' - \frac{\partial\Phi_0}{\partial r}\frac{\rho_0}{T_0}\frac{\chi_T}{\chi_\rho}T' = -\rho_0\frac{\partial\Phi_P}{\partial r} \tag{4}$$

which correspond to the continuity equation, entropy equation, radiative diffusion equation, and the momentum equation respectively.

The boundary conditions are:

$$\xi_r \equiv 0 \text{ at } r = 0 \tag{5}$$
$$F'_r \equiv 0 \text{ at } r = 0 \tag{6}$$
$$\Delta p \equiv 0 \text{ at } r = R \tag{7}$$
$$4\frac{\Delta T}{T_0} - \frac{\Delta F_r}{F_{r_0}} \equiv 0 \text{ at } r = R \tag{8}$$

which correspond to the displacement and perturbed flux vanishing at the centre to ensure continuity, and the surface boundary conditions ensure that the pressure at the perturbed surface is unchanged, and that the star remains a blackbody.

The Henyey method [1] was used to solve these equations, using a solar-type model produced using MESA [2] [3] [4] [5] as the equilibrium background star which we perturbed.

Analytical solution

For the region at the surface, where $\Delta P \approx 0$, analytical expressions for the relationships between certain variables can be calculated.

Results

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Treatments	Response 1	Response 2
Treatment 1	0.0003262	0.562
Treatment 2	0.0015681	0.910
Treatment 3	0.0009271	0.296

Table 1: Table caption

Nulla ut porttitor enim. Suspendisse venenatis dui eget eros gravida tempor. Mauris feugiat elit et augue placerat ultrices. Morbi accumsan enim nec tortor consectetur non commodo. Pellentesque condimentum dui. Etiam sagittis purus non tellus tempor volutpat. Donec et dui non massa tristique adipiscing. Quisque vestibulum eros eu. Phasellus imperdiet, tortor vitae congue bibendum, felis enim sagittis lorem, et volutpat ante orci sagittis mi. Morbi rutrum laoreet semper. Morbi accumsan enim nec tortor consectetur non commodo nisi sollicitudin.

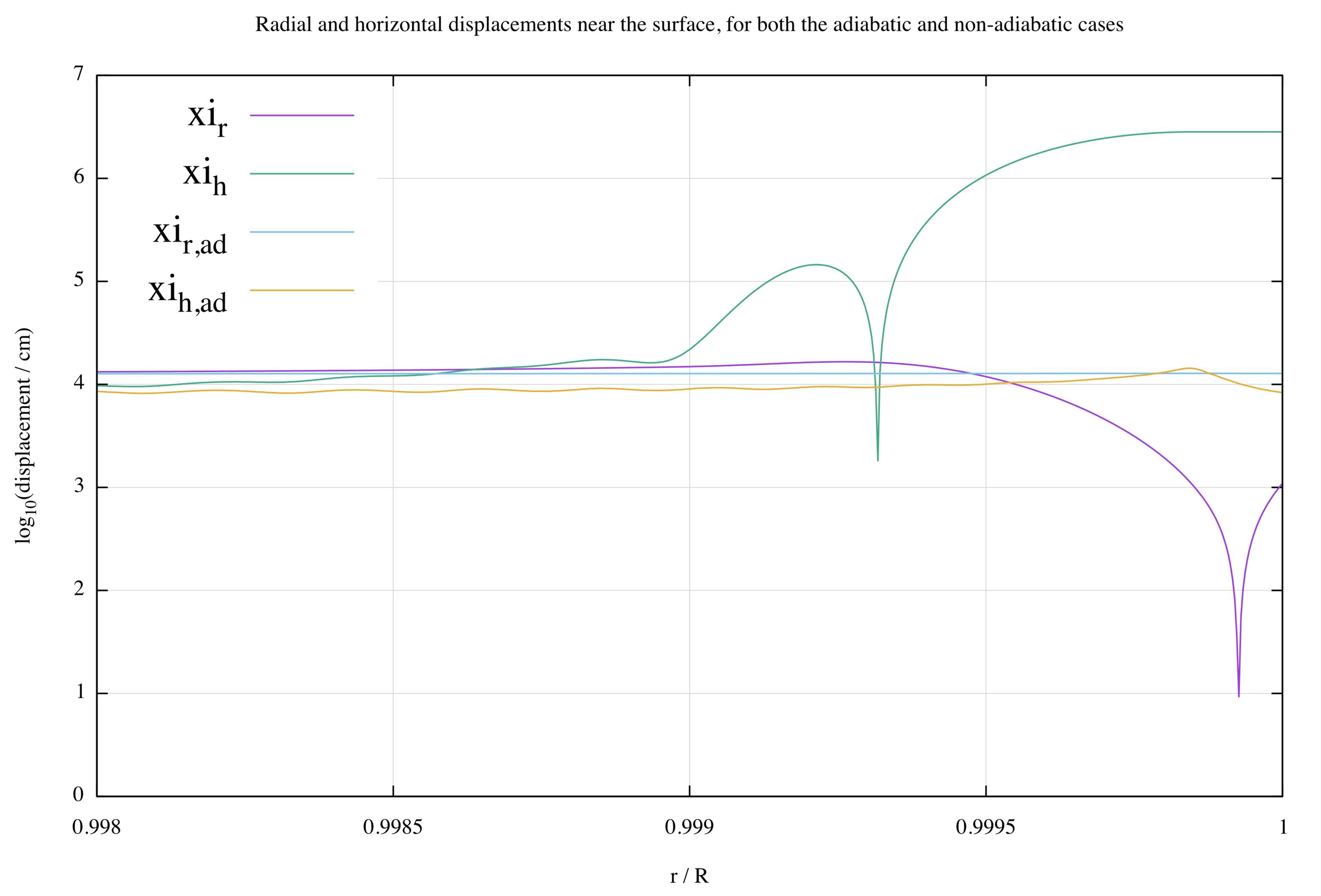

Figure 1: Figure caption

In hac habitasse platea dictumst. Etiam placerat, risus ac.

Vivamus sed nibh ac metus tristique tristique a vitae ante. Sed lobortis mi ut arcu fringilla et adipiscing ligula rutrum. Aenean turpis velit, placerat eget tincidunt nec, ornare in nisl. In placerat.

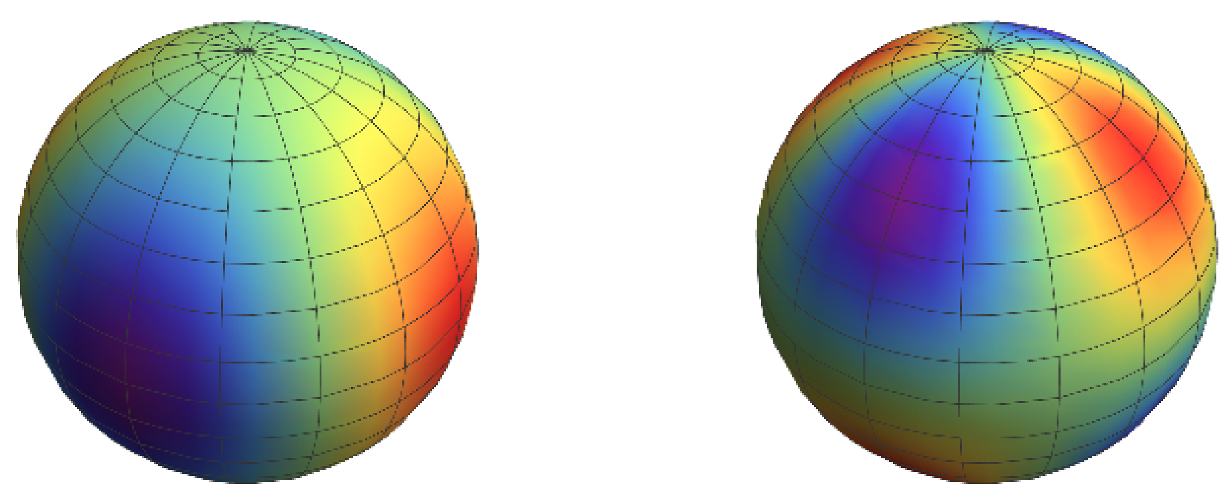

Figure 2: Figure caption

Conclusions

- Pellentesque eget orci eros. Fusce ultricies, tellus et pellentesque fringilla, ante massa luctus libero, quis tristique purus urna nec nibh. Phasellus fermentum rutrum elementum. Nam quis justo lectus.
- Vestibulum sem ante, hendrerit a gravida ac, blandit quis magna.
- Donec sem metus, facilisis at condimentum eget, vehicula ut massa. Morbi consequat, diam sed convallis tincidunt, arcu nunc.
- Nunc at convallis urna. isus ante. Pellentesque condimentum dui. Etiam sagittis purus non tellus tempor volutpat. Donec et dui non massa tristique adipiscing.

Forthcoming Research

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Etiam fermentum, arcu ut gravida fringilla, dolor arcu laoreet justo, ut imperdiet urna arcu a arcu. Donec nec ante a dui tempus consectetur. Cras nisi turpis, dapibus sit amet mattis sed, laoreet.