Expected oscillation parameters for red giants from dynamical masses and radii

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Abstract. Stellar masses and radii of stars with stochastic (solar-like) oscillations can be derived using asteroseismic scaling relations. Here, we predict the asteroseismic observables using the dynamical masses and radii from red-giants in eclipsing binary systems. We show that the predicted frequency of maximum oscillation power (ν_{max}) is generally lower than the observed one, while the predicted large frequency separation ($\Delta\nu$) is in most cases larger than the observed value. This shows that both the scaling relations for $\Delta\nu$ and ν_{max} used with solar references contribute to the observed differences between dynamical and asteroseismically determined masses and radii.

In the era of space missions, in particular *Kepler* and K2, solar-like oscillations have been observed in a large number of stars. The study of these stochastically excited oscillations provides knowledge about physical properties, such as mean density and surface gravity and thus stellar mass and radius. From the Fourier spectrum of red giants it is possible to directly measure two asteroseismic parameters, the frequency of maximum oscillation power ν_{max} and the large frequency separation $\Delta\nu$, i.e. the spacing between modes of the same spherical degree and consecutive radial order. These quantities together with the effective temperature (T_{eff}) of the star can be used to derive stellar masses (M) and radii (R) through the well-known asteroseismic scaling relations ([1, 2]):

$$\frac{\Delta\nu}{\Delta\nu_\odot} \approx \sqrt{\frac{M/\mathrm{M_\odot}}{(R/\mathrm{R_\odot})^3}} \quad \text{and} \quad \frac{\nu_{max}}{\nu_{max,\odot}} \approx \frac{M/\mathrm{M_\odot}}{(R/\mathrm{R_\odot})^2 \sqrt{T_{eff}/\mathrm{T_{eff,\odot}}}}, \tag{1}$$

which are calibrated to the solar reference values $\Delta\nu_\odot$ and $\nu_{max,\odot}$. Here, we use these relations to calculate $\Delta\nu$ and ν_{max} for known double-lined spectroscopic binaries with red-giant components ([3]). For these systems, dynamical masses and radii can be accurately measured from the binary analysis. We use these measurements in equation 1 and vary the solar reference values as follows: $\Delta\nu_\odot = [134.9, 135.0, 135.1, 135.2]\,\mu\mathrm{Hz}$ and $\nu_{max,\odot} = [3025, 3050, 3100, 3125, 3150, 3175]\,\mu\mathrm{Hz}$. This allows us to predict a range of $\Delta\nu$ and ν_{max} values for each star (see Fig. 1). The ratios between the asteroseismic parameters determined from the scaling relations and those directly measured from the oscillations are shown in Figure 2. We find that the predicted ν_{max} ($\Delta\nu$) estimates are lower (higher) than the asteroseismically determined values, with a clear correlation. The right panel of Figure 2 shows $\Delta\nu$ ratio as function of temperature with the metallicity colour-coded. With this small number of stars we are not able to recover the trend in T_{eff} and [Fe/H] that is present in stellar models ([4]).

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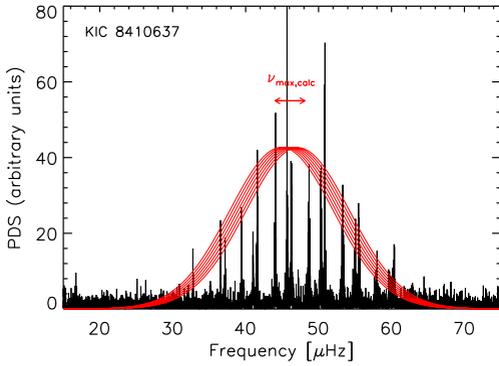
Figure 1. Power density spectrum (in black) of KIC 8410637 centred around ν_{max}. The range of predicted ν_{max} ($\nu_{max,calc}$) values for this red giant is indicated by the red arrow. The corresponding Gaussian fits (multiplied by a factor for visual purposes) are shown in red. No inconsistencies between the predicted and measured values for ν_{max} are apparent.
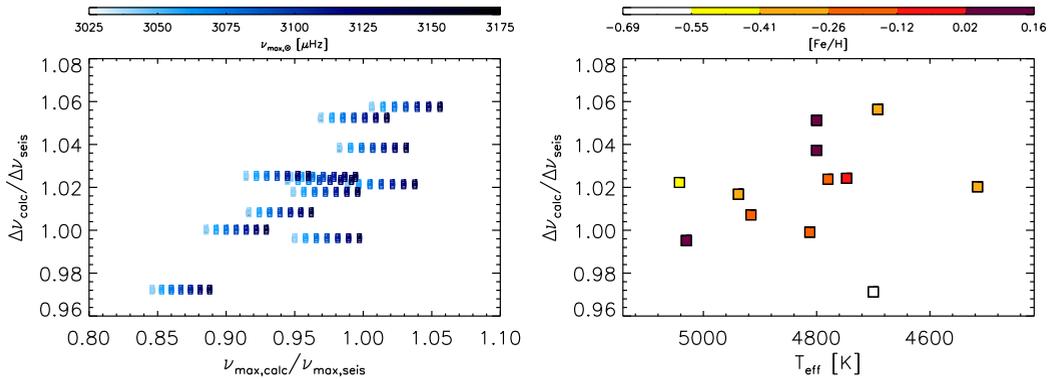
Figure 2. The ratio of predicted $\Delta\nu$ ($\Delta\nu_{calc}$) to the seismically determined $\Delta\nu$ ($\Delta\nu_{seis}$) as a function of the ratio of predicted ν_{max} ($\nu_{max,calc}$) over observed ν_{max} ($\nu_{max,seis}$), left, and as a function of effective temperature T_{eff}, right. The left panel shows all results for the different solar values (see colour bar) and the right panel shows results using a single solar value ($\Delta\nu_{\odot} = 135.1\ \mu$Hz) with the points colour-coded for metallicity (see colour bar).

This pilot study tentatively indicates that for red giants not only the $\Delta\nu$ scaling relation but also the ν_{max} scaling relation suffers from biases in case the solar reference values are used.

References

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