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FINDING THE SWEET SPOT: MODELLING OF OSCILLATING RED GIANT BINARIES

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Abstract. Binary stars are essential astrophysical test-beds. As the components of binary systems are formed from the same material and at the same time, they share fundamental properties such as their age and initial composition. Among the different types of binary systems, eclipsing binaries give the most stringent constraints about the stars, such as the stellar mass and radius. In this project, spectroscopic observations from Las Cumbres Observatory (LCO) are combined with high-precision photometry from NASA TESS to obtain radial velocity and multi-wavelength light curves of a peculiar binary system. TIC 293937699 is an eclipsing, double-lined binary system which hosts an oscillating red giant star. We construct a well-constrained binary model and determine precise dynamical masses for both components. The giant's oscillations, present in the TESS photometry, allow for a direct comparison between asteroseismic and dynamical estimates of the star's mass and radius. This binary, which is located on the southern PLATO field, represents a rare and valuable benchmark system for validating asteroseismic scaling relations and testing stellar evolution models in the red giant phase.

Keywords: Asteroseismology – (Stars:) binaries: eclipsing – (Stars:) binaries: spectroscopic – Stars: oscillations

1 Introduction

The mass of a star is the fundamental parameter that determines its stellar structure and its evolution. Understanding stars and their evolution impacts a wide range of astrophysical fields, from exoplanets to galaxies. There are different ways of defining the mass of a star: the dynamical mass (Torres et al. 2010) based on orbital mechanics and only available for binary systems, and the seismic mass using global seismic scaling relations from the Sun (Kjeldsen & Bedding 1995), which can be obtained by performing asteroseismology in solar-like oscillators.

These two masses can be compared to estimate the consistency between both. To perform the comparison, we need specific targets: eclipsing binaries with an oscillating component. As wee see in the left panel of Figure 1, a discrepancy of $\sim 15\%$ exists between the two masses (Gaulme et al. 2016) but this is based on a small sample, so one needs to study more systems. This is the main objective of this work: modelling a new binary system presented in Beck et al. (2024), discovered by Gaia (Collaboration et al. 2023), which fulfills the three conditions above-mentioned.

2 Dynamical mass

The spectroscopic data was obtained with the NRES spectrographs (R $\simeq$ 53 000) on 1m telescopes of Las Cumbres Observatory (Brown et al. 2013), a telescope network that provided a good coverage of the target. It

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allowed us to extract the radial velocity curve for the two components of the binary system, proving that it is a double-lined binary (in other words, both components are detectable in the spectra). Regarding photometric data, we made use of the Transiting Exoplanet Survey Satellite (TESS) light curve (Ricker et al. 2015) corrected using the Py-TADACS software (García et al. 2024a,b). We modelled the system using the `Phoebe` software (Prša et al. 2016). This is illustrated in the right panel of Figure 1. From this, we calculated the dynamical masses of the two components of the binary system: $M_{\text{dynamical, red giant}} = 1.46 \pm 0.1\ M_\odot$ and $M_{\text{dynamical, companion}} = 1.37 \pm 0.1\ M_\odot$.

3 Seismic mass

We used the TESS data to extract the seismic mass of the red giant. From the light curve of TESS transposed to the frequency domain (García et al. 2011, 2014; Pires et al. 2015) we get the Power Spectral Density (PSD), and we can extract the seismic parameters of the red giant (Mathur et al. 2010). Finally we use the scaling relations (Kjeldsen & Bedding 1995) which give the seismic mass of a star combining the global seismic parameters ν_{max} and $\Delta\nu$ with the effective temperature T_{eff}:

$$\frac{M}{M_\odot} \approx \left(\frac{\nu_{\text{max}}}{\nu_{\text{max},\odot}}\right)^3 \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-4} \left(\frac{T_{\text{eff}}}{T_{\text{eff},\odot}}\right)^{3/2}. \tag{3.1}$$

where M is the mass, we recall that ν_{max} is the frequency at which the oscillation power peaks (related to surface gravity), and $\Delta\nu$ the large frequency separation, i.e. the average spacing between consecutive radial oscillation modes (related to the star's mean density). For the red giant we obtain: $M_{\text{seismic, red giant}} = 1.35 \pm 0.4\ M_\odot$.

4 Conclusions

The combination of photometric, spectroscopic and seismic data demonstrates that the target is a well-constrained system, that can be added to the sample of Gaulme et al. (2016), see the left panel of Figure 1. The computation of the relative difference between the two mass results of the red giant leads to a discrepancy of $\frac{\|M_{\text{seismic}} - M_{\text{dynamical}}\|}{M_{\text{dynamical}}} \approx 11\%$. Moreover, it differs from the trend seen in seismic masses.

Apart from already being a peculiar system, the target is also the first and only known to date eclipsing binary system hosting an oscillating red giant in the PLATO long pointing field (Rauer et al. 2025; Magliano et al. 2024; Nascimbeni et al. 2025). In conclusion, these elements establish the target as a benchmark system for exploring the tension between dynamical and seismic masses, contributing to a more precise understanding of stellar masses, and consequently stellar evolution.

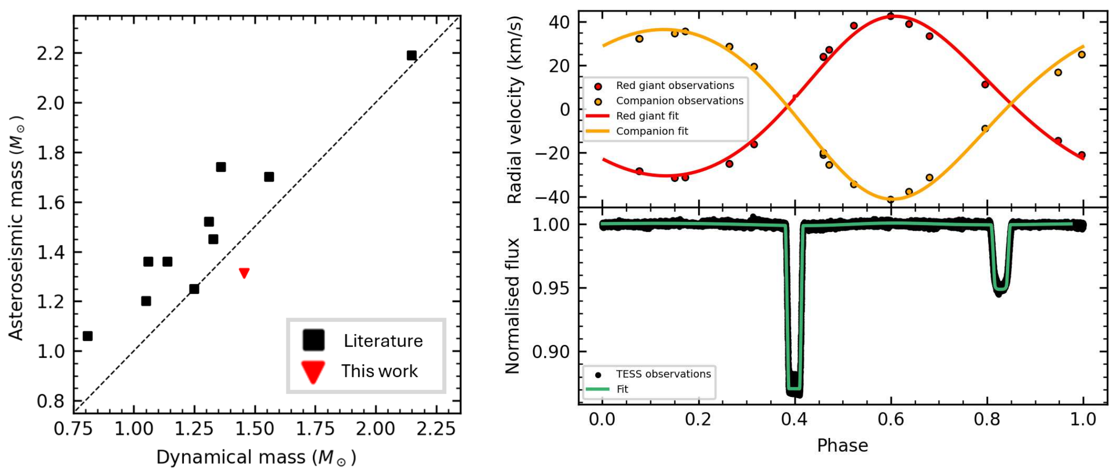

Fig. 1. Left: Comparison between dynamical and seismic masses for eclipsing spectroscopic binaries hosting an oscillating red giant, from the literature (black squares) and adding the target of this study (red triangle). **Right**: Modelling of the binary system with `Phoebe`, including the RV curve (top panel) and the TESS light curve (bottom panel).

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