SUN-LIKE OSCILLATIONS IN THE POPULATION II GIANT HD 122563

O. Creevey[1], F. Thévénin[1], F. Grundahl[2], E. Corsaro[3], M. F. Andersen[2], V. Antoci[2], L. Bigot[1], R. Collet[2], P. L. Pallé[4], B. Pichon[1] and D. Salabert[5]

Abstract. We have been monitoring the metal-poor Population II giant, HD 122563, for radial velocity variations since 2016 using the SONG telescope on Tenerife. We have detected the global seismic quantity $\nu_{\max}$ which provides information related to the stellar parameters. By combining these data with complementary data, we derive a new precise surface gravity, radius and distance to the star. Our results are corroborated by using the parallax from Gaia DR2. We present these results and some of their implications.

Keywords: asteroseismology, stars: individual: HD 122563, stars: Population II, stars: fundamental parameters

1 Introduction

HD 122563 (V=6.2 mag, $14^{\mathrm{h}}02^{\mathrm{m}}$ 31.8$^{\mathrm{s}}$, +09°41′09.95") is a bright metal-poor [M/H] = –2.4 giant star. As such it can be observed using many independent methods. It was first referenced in the literature over 50 years ago (Pagel 1963), however, despite its brightness and interest as a prototype for similar giants in the Galactic halo, today we still debate some of its most fundamental stellar parameters (for example Creevey et al. 2012; Casagrande et al. 2014; Karovicova et al. 2018; Collet et al. 2018, and references therein).

Analyses presented in Creevey et al. (2012) (C12 hereafter, their figure 4) and Creevey et al. (2014) (their figure 3) clearly indicated discrepancies between observations, interpretation and models. The former indicated that standard evolutionary tracks fail to reproduce the observed position of this star in the HR diagramme and unreasonable assumptions in some tunable parameters are needed. The latter showed a comparison of interferometric with spectroscopic analyses of this star's stellar parameters which hinted towards a potential problem in $\log g$.

Given the current discrepancies along with the fact that this star is a benchmark for distant metal-poor giants, we applied to observe this star using the radial velocity instrument on the Hertzsprung telescope in Tenerife in order to detect oscillations and provide a fresh perspective on this star.

In this work we describe the radial velocity observations of this star (Sect. 2), along with an interpretation using the asteroseismic scaling relation for $\log g$ (Sect. 3). We use the most recent data from Gaia DR2 to test our analysis, and after some brief comparisons, we summarise our conclusions in Sect. 4.

2 Observations

2.1 New observations

We obtained time series radial velocity observations with the 1-m Hertzsprung SONG telescope from April 2016 to December 2017. The Hertzsprung telescope is a node of the Stellar Observations Network Group (SONG) located at the Observatorio del Teide. All observations were obtained using an iodine cell for precise wavelength

[1] Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, France

[2] Stellar Astrophysics Centre, Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, 8000 Aarhus C, Denmark

[3] INAF - Osservatorio Astrofisico di Catania, via S. Sofia 78, 95123-I, Catania, Italy

[4] Instituto de Astrofisica de Canarias, 38205 La Laguna, Tenerife, Spain

[5] Previous affil: IRFU, CEA, Universit Paris-Saclay, F-91191, Gif-sur-Yvette, France

Observations					Derived Parameters				
θ^1	[mas]	0.940	$\pm$	0.011	$\log g$	[dex]	1.39	$\pm$	0.01
$F_{\rm bol}^1$	[erg/cm/s]	13.16	$\pm$	0.36	$\log g_{\rm V17}$	[dex]	1.42	$\pm$	0.01
$T_{\rm eff}^1$	[K]	4598	$\pm$	41	d	[pc]	305	$\pm$	10
$\nu_{\rm max}$	[μHz]	0.35	$\pm$	0.01	$d_{\rm V17}$	[pc]	296	$\pm$	9
$\pi^2_{\rm GDR2}$	[mass]	3.444	$\pm$	0.063	$d_{\rm GDR2}$	[pc]	290	$\pm$	5

Table 1. Properties derived from this work, except for those from [1]C12 and [2]Gaia Collaboration et al. (2018).

calibration. A spectral resolution of 80 000 and an exposure time of 900s was used throughout. The data were reduced using the standard SONG pipeline (Andersen et al. 2014; Grundahl et al. 2017). The radial velocity (RV) time series of 387 data points is presented in Figure 1, left panel and the typical uncertainty on the RV was found to be in the 11-14m/s range.

We used the DIAMONDS Bayesian Inference tool (Corsaro & De Ridder 2014) to model the power spectral density (PSD) of the star. The PSD and the best-fit model are shown on the right panel of Fig. 1, and incorporates a flat noise component, two Harvey-like profiles to account for granulation-driven signal, and a Gaussian envelope to model the oscillation power excess (Corsaro et al. 2015). A clear excess of power due to the oscillations is detected at 3 μHz, this is referred to as $\nu_{\rm max}$. We used the marginal distribution of $\nu_{\rm max}$ from this analysis in our subsequent analysis.
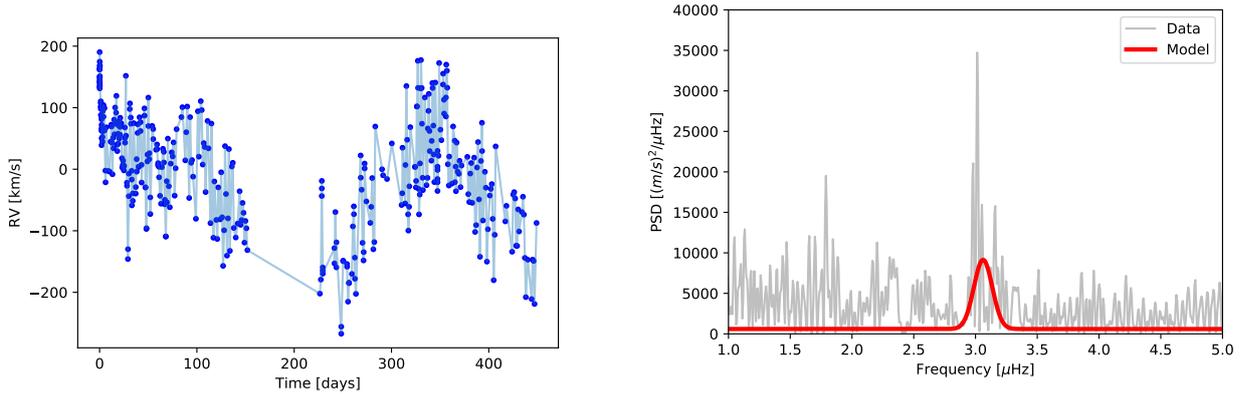
Fig. 1. Left: Time series radial velocities of HD 122563 for the first year of observations. We have subtracted the mean radial velocity and the first observation point is at time T0 = 2457509.38158 Julian days. **Right:** Frequency spectrum of the time series (grey) with a model for the power excess overplotted in red.

2.2 Literature observations

We use the $T_{\rm eff}$ of HD 122563 from C12. This is in agreement with that derived by Karovicova et al. (2018) using independent interferometric measurements, Casagrande et al. (2014) using the infra-red flux menthod, and Heiter et al. (2015) who provide a recommended value based on a compilation of spectroscopic measurements, see Creevey et al. (2019). As we would like to propagate all of the information from the observations, we use the reported bolometric flux $F_{\rm bol}$ and angular diameter θ, where extinction $A_V = 0.01$ mag was assumed.

3 Analysis

3.1 Surface gravity and distance from asteroseismology

The surface gravity of a star can be derived using the so-called *asteroseismic scaling relation* and is given by

$$\frac{\nu_{\rm max}}{\nu_{\rm max\odot}} = f_{\nu_{\rm max}} \frac{g}{g_\odot} \sqrt{\frac{T_{\rm eff\odot}}{T_{\rm eff}}} \tag{3.1}$$

where $f_{\nu_{\max}} = 1$ and $\nu_{\max\odot} = 3050$ μHz in the classic form (Kjeldsen & Bedding 1995) and $f_{\nu_{\max}} \neq 1$ where corrections are proposed. By using the observational data ($\theta, F_{\rm bol}, \nu_{\max}$) along with the solar values of $\log g_{\odot} = 4.438$, $T_{\rm eff\,\odot} = 5772$ K, we performed Monte-Carlo like simulations to derive the stellar parameters ($\log g$, $T_{\rm eff}$), using the methods described in Creevey et al. (2019). By using a prior on the mass between [0.80,0.90] we additionally derived the radius $R_\star$ and distance d (and consequently the luminosity $L_\star$). In Figure 2 the blue contour lines indicate the density distributions of $\log g$ and d from these results. The green contours show the same results but by setting $f_{\nu_{\max}} = (\mu/\mu_\odot)^{1/2}(\Gamma_1/\Gamma_{1\odot})^{1/2}$, where μ and Γ denote respectively the mean molecular weight and the adiabatic exponent, see Viani et al. (2017) (V17 hereon) and references therein. The derived $L_\star$ and $T_{\rm eff}$ are also shown as the blue error box on the right panel, and for comparison we also show the values from C12 as the grey box. We indicate a vector in blue which represents the relative change in the position if we impose $A_V = 0.08$ mag (Lallement et al. 2014).

3.2 Distance and surface gravity from Gaia DR2

We derived d and $\log g$ using the same methodology as above, but by using the set (π, θ) and the mass prior, where π is the parallax from Gaia DR2 (Gaia Collaboration et al. 2018). In Fig. 2 the solution is represented by the black contours (left) and the black box (right).

As can be seen in both figures, similar solutions are obtained using the independent approaches. $\log g$ differs only by $0.02 - 0.04$ dex, and d by less than 1.5σ. Consequently the $L_\star$ agree also to 1σ (1σ error boxes are shown on the right panel). In Fig 1 right panel we also show standard evolutionary tracks from the BASTI models in green (Pietrinferni et al. 2004), and a model from the updated tracks in red (Hidalgo et al. 2018) using solar-scaled canonical models*. Using fine-tuned evolution models from the CESAM evolutionary code (Morel 1997), we could reproduce the observed position but only be reducing the mixing-length parameter by 0.3 from the reference solar value.
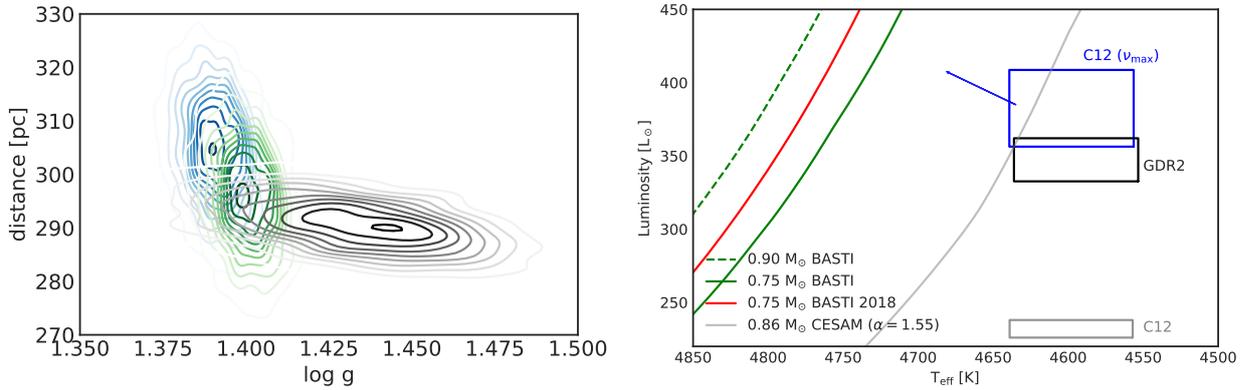
Fig. 2. Left: Density plots of derived distance versus $\log g$ using asteroseismology — without (blue) and with (green) corrections to the seismic relation — and using Gaia DR2 (black) **Right:** HR diagram showing observational position of HD 122563 using different input data (blue, black, and grey), along with standard evolutionary models from BASTI and a tailored CESAM model.

4 Conclusions

- We have detected oscillations in the metal-poor star HD 122563.

- By comparing the distances derived using asteroseismology and that from a parallax from Gaia, we showed that the scaling relations for surface gravity work in the metal-poor and evolved regime.

- We have derived new fundamental parameters for this star using asteroseismology: $\log g = 1.39 \pm 0.01$ and $d = 306 \pm 9$ pc ($d_{\rm GDR2} = 290 \pm 5$ pc).

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*α-enhanced tracks from Pietrinferni et al. (2004) are hotter, and those from Hidalgo et al. (2018) are not yet available.

- By applying corrections to the scaling relations for molecular weight and the adiabatic exponent we derived values of $\log g = 1.42 \pm 0.01$ and $d = 296 \pm 9$ pc.

- The new fundamental parameters imply less tension between evolution models although a discrepancy on the order of 150-200 K still exists. This can be remedied by reducing the mixing-length parameter by 0.3 compared to solar, but further studies with more realistic physics in these models should also be addressed.

- Increasing A_V could also alleviate some of the problem.

- The new surface gravity implies less tension with 3D models, see e.g. Collet et al. (2018) who suggest that a lowering of $\log g$ in their analysis to alleviate discrepancies between their molecular- and atomic-species-derived oxygen abundances.

- We continue to collect data from the SONG Hertzsprung telescope. We aim to detect the mean frequency separation, along with individual frequencies, and a more accurate determination of the width of $\nu_{\max}$ (see Yu et al. (2018) who indicate a trend of width versus $\nu_{\max}$).

- We also aim to understand the long-term trends seen in the time series, see Fig. 1

- The individual frequencies will be very instructive for improving the theoretical models in the metal-poor regime.

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