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Precise surface gravitites of A-type stars from Asteroseismology.

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Abstract

δ Sct are one of the most abundant pulsating stars in our Galaxy. In addition, they have moderate to fast rotations and periods of several hours. That makes them the suitable targets for studying the effects of rotation on stellar evolution. In this work, we show how to infer the mean density and the surface gravity of an A-type pulsanting star only from its oscillation frequencies. To do this, we used a separation between frequencies, known as large separation, which is proportional to the stellar mean density. This is the first step towards a reliable mode identification of their oscillation modes.

1 Introduction

Study of stars with solar-type pulsations has reached important milestones during the last decade [1] thanks to space missions dedicated to high-precision photometry, such as CoRoT [2] and Kepler [11]. This has been possible thanks to their relatively simple oscillation spectrum, characterized by a frequency spacing known as large separation ($\Delta\nu$). However, this advance has not been possible in any other kind of pulsators.

δ Sct are a group of well-known pulsating stars, very popular in the 90s. Their popularity is due to the fact that they are bright, very abundant and with periods that allow gathering data during one night. They have masses between M = 1.5-3 $M_\odot$, are in the main sequence or in the phase of burning of H in layer and locate in the classical instability strip. The mechanism that maintains its pulsations is the kappa mechanism (κ), related to the opacity change that takes place in the second He ionization zone (s.e., [14]). They present moderate to rapid rotations [15] and both pressure (p) and gravity (g) oscillation modes [8, 17].

The oscillation spectrum of δ Sct stars is difficult to interpret, due to phenomena such as avoided crossing, non-linear interactions between modes and, above all, the effect of rotation, which modifies the spectrum and multiplies the number of frequencies (see e.g. [7] for a review on the subject). The research presented in this article is a summary of the work published in [5] (from now on, GH2017), which advances in the interpretation of the oscillation spectrum by using $\Delta\nu$. This quantity was recently found for δ Sct (see e.g., [4]) and related to the stellar mean density ($\bar{\rho}$, [6]). In this work, we improved such relation and used $\Delta\nu$ to derive the surface gravity ($\log g$).

This article is divided into the following sections. In Sec. 2, we present the sample and its more relevant characteristics. Section 3 describes the properties of the large separation-mean relation, the methodology carried out to determine $\Delta\nu$ and to fit the data. In Sec. 4, we described the procedure we followed to determine $\log g$. And Sec. 5 details the conclusions of this work.

2 Data sample

Testing a relationship between $\Delta\nu$ and $\bar{\rho}$ requires obtaining a mean density that does not rely on any stellar evolution model. One of the few cases in which this quantity can be obtained is from the determination of masses and radii of eclipsing binary stars. Thus, we looked for such systems with at least one δ Sct component, observed by satellite and with measurements of masses and radii. We found 10 systems that fulfilled these conditions and the only δ Sct that harbour a planet to date (HD 15082).

Table 2 lists the main characteristics of the pulsating components of the systems studied. The stellar mean densities ($\bar{\rho}$) are derived from the masses and radii given by the different authors who studied the systems (see references in GH2017). The surface gravities correspond to the values that these same authors provide ($\log g_{\rm b}$). The surface gravity $\log g_{\hat{\pi}}$ in column 6 refers to the value calculated from large separations and parallaxes. The parallaxes were

Table 1: Characteristics of the systems taken from the literature (see GH2017) and calculated in this work. Columns 3 to 5 are values inferred from the binary analysis, whereas column 6 is calculated from the parallax. The information corresponds to the component showing the large frequency pattern (which is not necessarily the primary).

System	$\Delta\nu$ (μHz)	$\bar{\rho}$ ($\bar{\rho}_\odot$)	Ω (Ω_K)	$\log g_\mathrm{b}$ (cgs)	$\log g_{\hat{\pi}}$ (cgs)	$\hat{\pi}$ (mas)
KIC3858884	29.0 ± 1.0	0.0657 ± 0.0021	0.075	3.740 ± 0.012	3.76 ± 0.04	1.78 ± 0.22
KIC4544587	74.0 ± 1.0	0.414 ± 0.039	0.17	4.252 ± 0.033	4.27 ± 0.08	1.36 ± 0.41
KIC10661783	39.0 ± 1.0	0.1255 ± 0.0039	0.20	3.95 ± 0.011	3.95 ± 0.04	1.94 ± 0.26
HD172189	19.0 ± 1.0	0.0283 ± 0.0061	0.28	3.490 ± 0.082	3.53 ± 0.06	2.27 ± 0.34
CID100866999	56.0 ± 1.0	0.26 ± 0.11	–	4.14 ± 0.14	–	–
CID105906206	20.0 ± 2.0	0.02986 ± 0.00095	0.15	3.539 ± 0.012	3.52 ± 0.10	0.96 ± 0.25
HD159561	38.0 ± 1.0	0.124 ± 0.021	0.60	3.960 ± 0.072	3.93 ± 0.03	67.13 ± 1.06
KIC9851944	26.0 ± 1.0	0.0566 ± 0.0043	0.29	3.691 ± 0.028	3.75 ± 0.25	0.41 ± 0.38
KIC8262223	77.0 ± 1.0	0.423 ± 0.043	0.11	4.287 ± 0.034	4.23 ± 0.10	1.93 ± 0.59
KIC10080943	52.0 ± 1.0	0.205 ± 0.070	0.049	4.07 ± 0.11	4.06 ± 0.08	1.06 ± 0.28
HD15082	80.0 ± 2.0	0.507 ± 0.046	0.20	4.300 ± 0.030	4.31 ± 0.03	8.51 ± 0.24

obtained from the first Gaia data release, DR1 [3], or from Hipparcos [18].

3 The $\Delta\nu$-$\bar{\rho}$ relation

The mean densities were calculated from data of masses and radii obtained from the literature. To calculate the stellar volume, the flattening caused by the centrifugal forces were also taken into account. In this way, a more adequate value of the densities was achieved.

The large separations were obtained following the method described in [4]. First, we selected a group of frequencies with the highest amplitudes and then we applied a Fourier transform taking the amplitudes equal to 1 for all of them. In addition, the histogram of frequency differences was computed and compared to find the correct value of the periodicity. The uncertainty was determined by an échelle diagram, which allows us to measure the deviation for which the pattern disappears. It also allow us to differentiate if the periodicity corresponds to $\Delta\nu$, $\Delta\nu/2$ or another submultiple.

The results of this search are shown in Table 2. Clearly, a linear regression is obtained when these values are represented against the mean densities. This is shown in left panel of Fig. 1. We carried out a fit to the data by implementing a hierarchical Bayesian linear regression. The computation was carried out using the JAGS package (Just Another Gibbs Sampler, [12]). The resulting relationship was:

$$\bar{\rho}/\bar{\rho}_\odot = 1.50^{+0.09}_{-0.10}(\Delta\nu/\Delta\nu_\odot)^{2.04^{+0.04}_{-0.04}}, \qquad (1)$$

where $\Delta\nu_\odot = 134.8$ μHz [10]. This relation is an update of the one found in [6]. It closely follows the relations found using models without ([16]) and including rotation ([13]). Indeed, this relation is independent of the stellar rotation. That makes $\Delta\nu$ a very valuable observable.

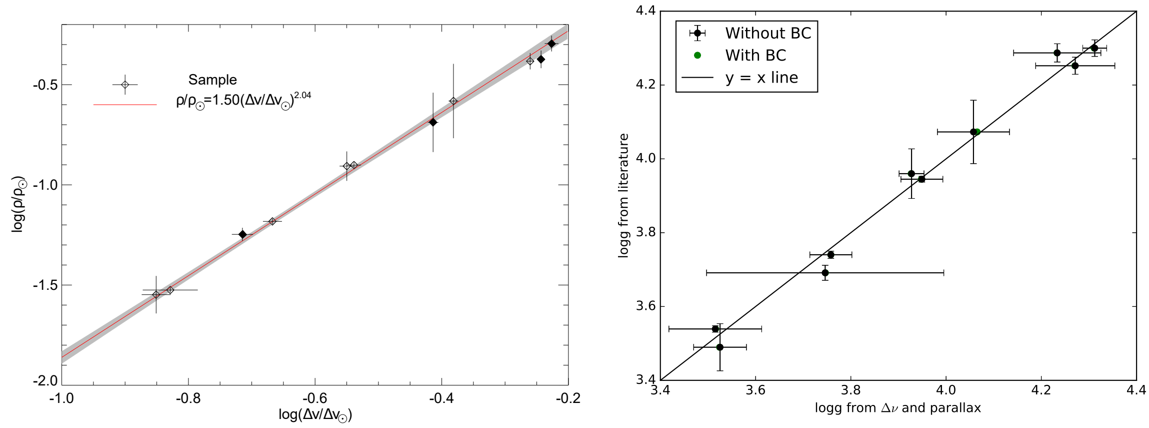

Figure 1: (Left) $\Delta\nu$-$\bar{\rho}$ relation for the 11 stars of our sample. The result of the fit is also shown. (Right) Plot showing the agreement between the $\log g$ from the literature (binary analysis) and that calculated with $\Delta\nu$ and the parallax.

4 Surfaces gravities from $\Delta\nu$ and parallaxes

In order to find if it was possible to determine the surface gravity of the δ Sct stars from $\Delta\nu$, it was necessary to have, at least, an estimation of the stellar mass. In the case of eclipsing binary stars, this is directly determined using Kepler's laws, but we wanted to test a valid method even for isolated stars. Therefore, we decided to take advantage of the recent Gaia data release (DR1) to obtain a measurement of the stellar parallax. This together with a mass-luminosity relation would allow us to find the masses of our objects.

The parallaxes found are shown in Table 2. We did not find parallaxes in the Gaia's DR1 for all the stars, so we completed the data with Hipparcos. Only for CID 100866999 we did not find any measure of parallax, so we did not include this star in our study.

We used the mass-luminosity relationship by [9], obtained from detached Algol binary systems. Although A-type stars have a small bolometric correction, we wanted to check its effect on our calculations. The results of calculating surface gravities with and without bolometric corrections are shown in the right panel of Fig. 1. In the plot, surface gravities obtained from the literature are shown versus values calculated with $\Delta\nu$ and the parallaxes. Line y = x is also plotted as a guide. It can be noticed that values determined by the method presented in this work coincide, within the uncertainties, with values from the literature. In addition, the $\log g$ calculated by applying the bolometric correction is represented in green. In most cases, these points are hidden by those considered without correction. And in the cases where a difference can be appreciated, the deviation is minimum.

In most cases, the uncertainties in $\log g$ from $\Delta\nu$ and parallaxes are of the order of those obtained from the literature. It can be clearly seen that the uncertainty depends directly on the errors coming form the parallax. It is noteworthy that the masses calculated from the mass-luminosity relation could not correspond to the masses obtained from the binary analysis. However, the weight of the calculation is in the radius obtained from the mean density, which has less dispersion than the mass. To check this case, we also made a simple calculation obtaining $\log g$ using random masses. We uses values in the range of M = [1,3] $M_{\odot}$, where the δ Sct starsare located. The result was that the uncertainties in $\log g$ for an incorrect determination of the mass was 0.1 dex, at most. This is below the typical errors obtained by spectroscopy.

5 Conclusions

In this work a methodology has been presented to determine mean densities and surface gravities from only the asteroseismological parameter known as large separation, $\Delta\nu$. For this, a sample of eclipsing binary stars with a δ Sct component was used. This allowed a determination of masses and radii independent of any modelling. The sample consisted of 10 binary systems and a star harbouring a planet.

We improved the relation $\Delta\nu$-$\bar{\rho}$ in [6], demonstrating that it is independent of the rotation of the star. In addition, from the mean densities it was possible to calculate the surface gravities. To do this, parallaxes and a mass-luminosity relation were used to estimate stellar masses. The values of $\log g$ thus obtained showed, in most cases, an uncertainty of the same order as the data obtained from the literature. The uncertainty is directly related to the errors in the parallaxes, so the measurement of $\log g$ could be improved thanks to the accuracy of Gaia.

In any case, the uncertainties in $\log g$ have a limiting value, as shown by its calculation using random masses. Calculating the gravities from these masses and $\Delta\nu$ only, the maximum dispersion of the values only reaches 0.1 dex. Therefore, this is the maximum uncertainty that must be considered when calculating $\log g$ from $\Delta\nu$.

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