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Combining asteroseismology and spectroscopy for obtaining precise abundances: CoRoT-GES and K2-RAVE

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Abstract. The spectroscopic analysis of red giant stars is hampered by difficulties in determining the surface gravity, $\log g$. The presence of degeneracies, few lines sensitive to $\log g$, limited spectral coverage and bad signal-to-noise, can affect the precision and accuracy of $\log g$ and, as a consequence, the quality of the element abundances. We show how the adoption of the seismic surface gravity can improve the spectroscopic analysis of red giants. As examples, we adopted the seismic gravity in the analysis of spectra taken by two different surveys: GES (high resolution) and RAVE (intermediate resolution). The results of this technique were the lifting of the $\log g$-$T_{\rm eff}$ degeneracy and more accurate and precise atmospheric parameters and abundances.

Keywords. stars: fundamental parameters, stars: abundances, surveys

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1. Introduction

In recent years asteroseismology has become a strategic tool in spectroscopic surveys, especially for red giant stars. With the scaling relations, that link two of the easiest seismic observables, $\Delta\nu$ and $\nu_{\rm max}$(plus $T_{\rm eff}$), to the stellar radius and mass, it is possible to obtain a seismic value for the surface gravity:

$$\log g_{\rm seismo} = \log g_{\odot} + \log\left(\frac{\nu_{\rm max}}{\nu_{\rm max,\odot}}\right) + \frac{1}{2}\log\left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right) \quad (1.1)$$

where $T_{\rm eff\,\odot}$, $\nu_{\rm max\,\odot}$ and $\Delta\nu_{\odot}$ are the solar values. This equation provides $\log g$ with a precision better than 0.03 dex and is largely insensitive to $T_{\rm eff}$. Following several tests performed using binary stars, interferometry, and parallaxes, the seismic $\log g$ is accurate to 0.1 dex (Morel & Miglio (2012) and references therein).

Although the scaling relations still need to be tested in the low-metallicity regime, solar-like oscillating red giants observed by CoRoT, *Kepler* and K2 are now an integral part of spectroscopic surveys. Not only they are used for testing the spectroscopic pipelines, but thanks to the information on mass and radius, it is also possible to derive ages and distances for field stars with unprecedented precision (Davies & Miglio 2016). CoRoT targets have been used by GES as calibrators, *Kepler* targets have contributed to calibrate APOGEE and LAMOST stellar surface gravities and GALAH is observing K2 targets for both calibration and Galactic archaeology purposes. RAVE recently used a sample of K2 red giants for calibrating $\log g$. in the next years TESS and PLATO satellites will dramatically increase the number of stars with seismic parameters, and the forthcoming 4MOST and WEAVE spectroscopic surveys will largely take advantage of this.

In this work we summarise the results obtained iteratively using the seismic $\log g$ in the spectroscopic analysis of GES (Section 2) and RAVE (Section 3) spectra, using the GAUFRE pipeline (Valentini *et al.* 2013).

Table 1. Typical errors on atmospheric parameters and abundances obtained with classic technique and the errors on the same values obtained using seismic information for GES spectra using GAUFRE pipeline (Valentini *et al.* 2016).

σ		Spectroscopy	Spectroscopy + Asteroseismology
$T_{\rm eff}$	GIR.	100	65
[K]	UVES	70	55
$\log g$	GIR.	0.20	0.03
[dex]	UVES	0.12	0.03
[Fe/H]	GIR.	0.10	0.08
[dex]	UVES	0.09	0.05
[elem./Fe]	GIR.	0.20	0.08
[dex]	UVES	0.08	0.05

2. CoRoT-GES

The Gaia ESO Survey (GES, Gilmore *et al.* 2013) has observed a sample of 590 CoRoT stars with good seismic parameters in the CoRoT LRc01 field. Spectra were taken using the ESO-FLAMES facility, using two spectrographs working at high (UVES, R=47,000) and intermediate (GIRAFFE, R=20,000) resolution.

For the analysis we used the GAUFRE pipeline, that iteratively derives atmospheric parameters by using Eq. 1.1. The resulting $\log g$, $T_{\rm eff}$, and [Fe/H] , are then used for determining chemical abundances. The accuracy of the method has been tested using the sample of Gaia F-G-K benchmark stars (Valentini *et al.* 2016). The newly determined atmospheric parameters and abundances were then used in the PARAM code (Rodrigues *et al.* 2014), together with seismic parameters, for deriving stellar ages and distances with a precision of 21% and 2% respectively. In Table 1 we compare the precision reached by the use of asteroseismoloy with the precision reached by the standard spectroscopic analysis in both GIRAFFE and UVES resolutions.

3. K2-RAVE

The RAVE survey collected intermediate-resolution spectra (R=7,500), centred on the Ca triplet (8400-8800 Å), providing radial velocities, atmospheric parameters and abundances for about 500,000 stars. The latest data release, RAVE-DR5 (Kunder *et al.* 2017), refined the atmospheric parameters with a calibration sample that, among others, included a sample of 87 red giants observed by K2 satellite in Campaign 1.

The construction of this seismic calibration sample is described in Valentini *et al.* (2017). We analysed RAVE spectra of K2 targets using two pipelines: GAUFRE and SP_Ace (Boeche & Grebel 2016). GAUFRE was used for iteratively deriving atmospheric parameters by fixing the $\log g$ to the seismic value. The resulting $\log g$, $T_{\rm eff}$, and [Fe/H] , have been used for determining atmospheric abundances with SP_Ace . As for GES stars, we derived precise distances, masses, and ages, using an updated version of the PARAM code (Rodrigues *et al.* 2017). This strategy will also be adopted for RAVE red giants observed in the rest of K2 Campaigns, with special attention devoted to metal poor stars (Valentini *et al.* in prep.).

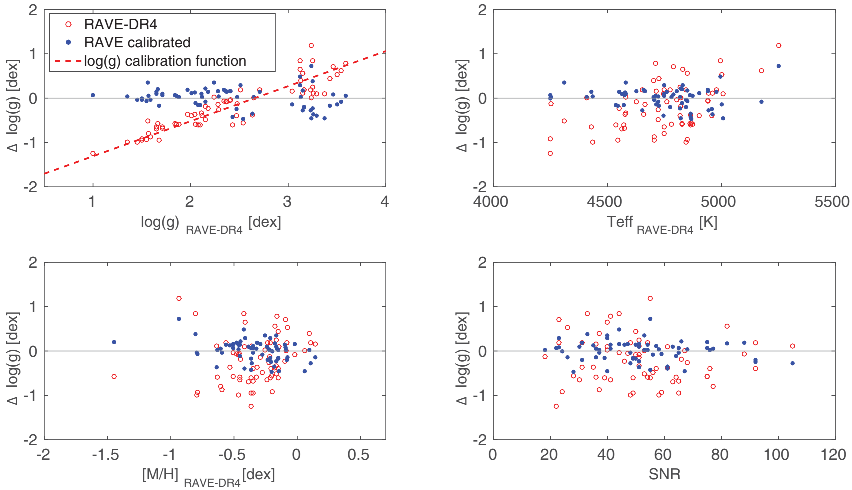

Figure 1. Difference of the spectroscopic $\log g$ (empty circles, from RAVE DR4) and the seismic calibrated one (filled circles) respect to the seismic gravity versus RAVE-DR4 $\log g$, $T_{\rm eff}$, [M/H] and signal-to-noise (SNR) for the 87 RAVE red giants in K2 Campaign 1 (Valentini *et al.* 2017).

By comparing the seismic $\log g$ with the spectroscopically derived one (from RAVE-DR4, see Fig. 1), it had been possible to formulate calibration function for correcting RAVE $\log g$ for red giants (Valentini *et al.* 2017). By comparing the $\log g$ of the targets in common between RAVE and the APOGEE and GES surveys it has been shown that the newly seismic-calibrated gravities are in agreement with those derived by high-resolution surveys.

3.1. *The new version of the RAVE-SC*

The RAVE-DR5 SC catalogue has been constructed using the seismic calibration for red giants and published in RAVE-DR5. For stars with (J-K$_s$)>0.5 mag, new metallicities and abundances have been computed by fixing the $\log g$ to the calibrated one and the $T_{\rm eff}$ to that derived via Infra-Red Flux Method (IRFM). Although RAVE-DR5 SC provides some improvements respect to DR5 version (see Table 2), the $\log g$ and $T_{\rm eff}$ in the catalogue may be not consistent, coming from two different methods. For this reason a new version of the catalogue had been computed, using an updated version of the GAUFRE code that adopts the $T_{\rm eff}$ IRFM only as prior. The new catalogue, together with RAVE-DR5 and RAVE-DR5 SC, had been tested againsts the high resolution sample from (Ruchti *et al.* 2011). Mean difference and dispersion of parameters and abundances are listed in Table 2. There is improvement, even though all sets might suffer of biases introduced by the differences in resolution, wavelength coverage, line lists and the presence of NLTE effects (the Ruchti catalogue contains only metal poor giants). The big difference and dispersion in $\log g$ of the seismic-calibrated catalogues is due to the calibration itself, that forces the stellar gravity to be the 2.1-3.4 dex interval. The new catalogue is available in the RAVE website: *https://www.rave-survey.org/project/*.

4. Conclusions

In spectroscopic surveys the determination of atmospheric parameters and abundances is a fundamental but complex work, especially for red giants. It requires not only the understanding of the behaviour of spectral features, such as updated and correct line

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Table 2. Difference and dispersion in atmospheric parameters and abundances for the stars in RAVE-DR5, REAVE-DR5SC RAVE-SC respect to the values from Ruchti *et al.* (2011).

	RAVE-DR5		RAVE-SC		RAVE-SC new	
	$<\Delta>$	σ	$<\Delta>$	σ	$<\Delta>$	σ
$T_{\rm eff}$ [K]	−1	237	50	85	0	81
$\log g$ [dex]	0.26	0.76	0.65	0.53	0.57	0.50
[Fe/H] [dex]	−0.02	0.23	0.05	0.19	0.01	0.23
[Mg/H] [dex]	−0.11	0.25	−0.10	0.22	−0.09	0.21
[Si/H] [dex]	−0.04	0.20	0.05	0.22	0.01	0.19
[Ca/H] [dex]	-	-	-	-	0.01	0.21
[Ti/H] [dex]	0.11	0.31	0.16	0.23	0.02	0.28

Table 3. Precision required by 4MOST Galactic surveys (based on the Minchev, Chiappini & Martig (2014) model) and the precision achievable at high resolution and low resolution, with and without the seismic information available (source: 4MOST Science Report 2014).

Quantity	Spectroscopy High Resolution			Spectroscopy Low Resolution		
	Model Requir.	No seismo	With Seismo	Model Requir.	No seismo	With Seismo
$T_{\rm eff}$	50 K	75 K	40 K	80 K	110 K	65 K
$\log g$	<0.1 dex	0.12 dex	0.02 dex	0.2 dex	0.3 dex	0.02 dex
[Fe/H]	<0.1 dex	0.1 dex	0.02 dex	<0.1 dex	0.2 dex	<0.1 dex
[αelement/Fe]	<0.1 dex	0.1 dex	0.03 dex	<0.2 dex	0.2 dex	<0.1 dex
[n − capt./Fe]	<0.1 dex	0.1 dex	0.03 dex	<0.2 dex	0.3 dex	<0.1 dex

oscillator strengths or NLTE effects, but also a validation of the spectroscopic pipeline (or methods) adopted. Red giants with asteroseismology significantly improve the situation by providing very precise and accurate values for the $\log g$. Even though covering only a small area of the HR diagram, solar-like oscillating red giants can be used as benchmarks for testing the $\log g$ obtained by spectroscopic pipelines. In addition, when adopting the seismic $\log g$ in the spectroscopic analysis itself, it is possible to construct a stellar sample with very precise and consistent atmospheric parameters, abundances, ages, and distances, useful as training samples for machine learning pipelines and for Galactic archaeology investigations.

The two cases analysed in this work, CoRoT-GES and K2-RAVE, can be considered as examples to understand the improvements that asteroseismology can provide. In particular, our technique will be applied to the seismic targets that will be observed by the forthcoming 4MOST survey (de Jong *et al.* 2016), that will observe not only targets from CoRoT and K2, but also from TESS and PLATO.

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