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Seismic analysis of four solar-like stars observed during more than eight months by *Kepler*

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Abstract. Having started science operations in May 2009, the *Kepler* photometer has been able to provide exquisite data of solar-like stars. Five out of the 42 stars observed continuously during the survey phase show evidence of oscillations, even though they are rather faint (magnitudes from 10.5 to 12). In this paper, we present an overview of the results of the seismic analysis of 4 of these stars observed during more than eight months.

1. Introduction

Asteroseismology is the only method that allows us to pierce into stars and thus to obtain information on the structure and dynamics of their interiors (Metcalfe et al. 2010). With the advent of space-based missions performing asteroseismic investigations, during the last decade we have witnessed the rise of a new era in the field of Asteroseismology. The most powerful satellite in operation so far is the NASA *Kepler mission* (Borucki et al. 2010), an exoplanet hunting mission whose long stability and high-precision photometry can also be used to perform asteroseismic investigations (Gilliland et al. 2010a), in particular, for the study of solar-like stars (Chaplin et al. 2011). *Kepler* will observe ~ 150,000 stars in the same field during at least 3.5 years, allowing us to also study stellar cyclic variations (García et al. 2010). Asteroseismic investigations are organized around the *Kepler* Asteroseismic Science Consortium (KASC, Kjeldsen et al. 2010) that decided to perform a survey phase of the solar-like stars, during the first year of operations, by changing the set of observed stars every month. However, 42 stars were continuously monitored in order to test and validate the time series photometry. Some of them showed solar-like oscillations. In this work, we give an overview of the results we have obtained on four of them, two F-type stars (KIC 11234888 and KIC 10273246) and two G-type stars (KIC 11395018, and KIC 10920273). We refer to Mathur et al. (2011) and Campante et al. (2011) for a detailed analysis of these stars.

2. Data Processing & Results

Short cadence (58.85s) time series (Gilliland et al. 2010b) of the four stars were obtained by the *Kepler* photometer from May 2009 to March 2010. Therefore, $\sim$ 320 days of continuous observations with a duty cycle higher than 90% were available for seismic investigations, which is a premiere in this research field. Due to the loss of all the outputs of the third CCD-module on January 9, 2010, only $\sim$ 250 days were available for two of the four stars: KIC 11234888 and KIC 11395018. The raw light curves were corrected for three types of instrumental perturbations: outliers, jumps, and drifts, following the methods described in García et al. (2011). The data of each *Kepler* quarter were concatenated after equalizing their mean values by fitting a 6th order polynomial to each segment. To remove the low-frequency instrumental trends, a high-pass filter was applied.

Several groups inside KASC analyzed the datasets to retrieve the global parameters (mean large frequency separation $\langle\Delta\nu\rangle$, frequency of maximum power $\nu_{\rm max}$, small separation $\langle\delta_{02}\rangle$, mean linewidth $\langle\Gamma\rangle$) as well as the p-mode characteristics. Figure 1 represents the échelle diagrams for two of these stars. We can see the presence of mixed modes with the so-called avoided crossing where modes are "bumped". Mixed modes are very interesting as the evolutionary stage of a star is reflected in their characteristics so they bring strong constraints on the stellar interior and on the age of the star (Metcalfe et al. 2010). From the global seismic parameters and knowing the effective temperature from the *Kepler* Input Catalogue (KIC, Brown et al. 2011) it is possible to have a first determination of the mass and the radius of the star using the scaling relations from solar values as defined by Kjeldsen & Bedding (1995). In Table 1 we summarize the seismic and inferred global parameters of the stars. We used $T_{\rm eff} = 5660$ K, 6240 K, 6380 K, and 5880 K for KIC 11395918, KIC 11234888, KIC 10273246, and KIC 10920273 respectively.

Table 1. Global seismic parameters and inferred stellar properties.

Star	$\langle\Delta\nu\rangle$ (μHz)	$\nu_{\rm max}$ (μHz)	Mass/$M_\odot$	Radius/$R_\odot$
KIC 11395018	47.8 $\pm$ 1.0	830 $\pm$ 48	1.25 $\pm$ 0.24	2.15 $\pm$ 0.21
KIC 11234888	41.7 $\pm$ 0.9	675 $\pm$ 42	1.33 $\pm$ 0.26	2.40 $\pm$ 0.24
KIC 10273246	48.2 $\pm$ 0.5	839 $\pm$ 51	1.49 $\pm$ 0.28	2.27 $\pm$ 0.23
KIC 10920273	57.3 $\pm$ 0.8	1024 $\pm$ 64	1.20 $\pm$ 0.24	1.88 $\pm$ 0.18

3. Conclusions

For the first time, we have more than eight months of continuous asteroseismic data for four solar-like stars. Unfortunately, KIC 11234888 and KIC 10920273 have not been observed after the fourth Quarter of the *Kepler* operations. In the case of KIC 11395018, 22 months will be available with an interruption of around two months due to the failure in the outputs of the third CCD-module. Finally, KIC 10273246, has not been observed in Quarters 6 and 7 but it has been put in the KASC target list from Quarter 8. With the data acquired, we first obtained global seismic parameters such as: $\nu_{\rm max}$, $\langle\Delta\nu\rangle$, $\langle\delta_{02}\rangle$, $\langle\Gamma\rangle$ as well as other parameters like orbital period: $P_{\rm rot}$. Using the scaling relations

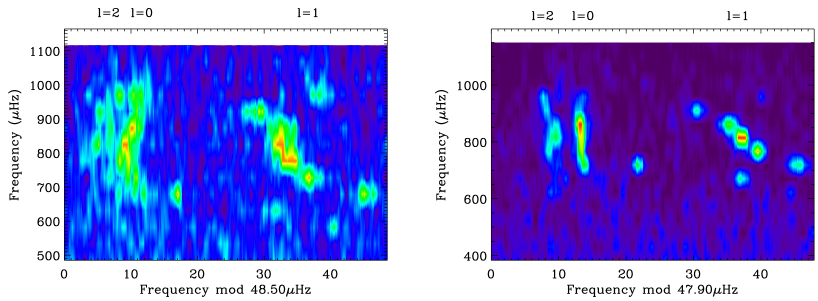

Figure 1. Echelle diagram of KIC 10273246 (left panel) and KIC 11395018 (right panel) obtained with more than eight months of *Kepler* data. We can see the ridges $\ell = 0$, 1, and 2 and the presence of the mixed modes (see the text for more details).

from solar values, we could provide a first model-independent estimation of the mass and radius of these four stars. Then, it was also possible to analyze individual modes. We identified 16 to 30 modes for each star. Detailed modeling is now on going using all these seismic constraints coupled with atmospheric parameters. This will allow to check to a very precise level the physical process involved in the stellar interiors (Creevey et al. submitted; Brandão et al. in prep.; Doğan et al. in prep.).

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