Spectroscopic and Photometric Observations of Kepler Asteroseismic Targets

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Abstract. We summarize our ground-based program of spectroscopic and photometric observations of the asteroseismic targets of the Kepler space telescope. We have already determined atmospheric parameters, projected velocity of rotation, and radial velocity of 62 Kepler asteroseismic targets and 33 other stars in the Kepler field of view. We discovered six single-lined and two double-lined spectroscopic binaries, we determined the interstellar reddening for 29 stars in the Kepler field of view, and discovered three \( \delta \) Sct, two \( \gamma \) Dor and 14 other variable stars in the field of NGC 6866.

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GROUND-BASED OBSERVATIONS

Our program of ground-based observations of stars selected for Kepler asteroseismic targets has been started in 2005 and is continued since then. We collect high-resolution echelle spectra at the Catania Astrophysical Observatory (Italy, 91-cm telescope, observer: JMŻ), the Harvard-Smithsonian Center for Astrophysics (USA, two 1.5-m telescopes and the 6-m MMT telescope, observer: DWL), the Nordic Optical Telescope (Spain, 2.5-m telescope, observer: TA), the Ondrejov Observatory (Czech Republic, 2-m telescope, observers: EN and JK), and the Poznań University Observatory in Borowiec (Poland, a single telescope with two 0.5-m mirrors, observer: WD). The multicolor CCD and photoelectric data are collected at the Wroclaw University Observatory in Bialków (Poland, 0.6-m telescope, observers: GK, AN, MS and JMJ) and the Catania Astrophysical Observatory (Italy, 91-cm telescope, observer: JMJ).

We aim at the determination of atmospheric parameters of the program stars, i.e., the effective temperature, \( T_{\text{eff}} \), surface gravity, \( \log g \), and metallicity, \([\text{Fe}/\text{H}]\), as well as the projected rotational velocity, \( v \sin i \), and radial velocity, \( v_r \). We use this last parameter to discover and study spectroscopic binaries in the Kepler field of view. A search for new variable stars in the Kepler field of view is our separate study.

RESULTS

Atmospheric parameters

We measured \( T_{\text{eff}}, \log g, [\text{Fe}/\text{H}], v \sin i, \) and \( v_r \) for 62 Kepler asteroseismic targets and 33 other stars in the satellite’s field of view (see [11], [12], and [1]). Most of our program stars are stars of spectral type F, G or K and the luminosity classes V, IV or III. However, our sample includes also around 20 A-type stars, a handful of B-type stars, and one O-type star, HIP 92637, as well as three subdwarfs, HIP 92775, HIP 94704 and HIP 99267, and one supergiant, HIP 97439.

We find that all but one of the stars selected for Kepler asteroseismic targets have solar metallicity or are slightly metal-deficient. The only exception is HIP 92775, sdF8 (see [12]); the other two subdwarfs are not Kepler program stars.

Projected rotational velocity

The projected velocity of rotation of the F, G and K stars observed by us is low, typically below 5 km/s (see [11] and [12]); \( v \sin i \) of the early-type stars observed by us is significantly higher.
We note, however, that several of our early-type program stars, namely, HIP 93522, A7, HIP 93941, B2, and HIP 96762, B9, have $v \sin i$ below 10 km/s (see [1]). This makes them very important and rare targets for an asteroseismic study of early-type stars because for stars rotating so slowly it is possible to perform an unambiguous identification of the modes of pulsation; for stars rotating with $v \sin i \gg 10$ km/s the asteroseismic analysis becomes difficult and may be inconclusive.

**Radial velocity**

In [1] we report a discovery of two double-lined spectroscopic binaries, SB2, HIP 96299 and HIP 98551. The former of these stars, HIP 96299, has been discovered to be an eclipsing binary with a period of 10.0486 days by [6]; the latter, HIP 98551, is not known to show eclipses. Since for SB2 eclipsing binaries it is possible to derive precise masses of the components, which then enter evolutionary and asteroseismic models as one of the fundamental parameters, both stars need further study in order to obtain their radial-velocity curves and find the orbital solutions. For HIP98551, time-series photometry would be needed to find out whether the system is eclipsing.

We have also discovered six single-lined spectroscopic binaries, SB1, namely, HIP 94734 and HIP 94743 discovered by [11], HIP 92132 and HIP 97513 discovered by [12], and HIP 96277 and HIP 97582 discovered by [1]. Since for SB1 stars it is possible to calculate the systems’ mass function, this parameter can be used for estimating the magnitude and color indices of the secondary component of the system, and calculating the duplicity corrections. Neglecting this corrections may lead to incorrect determination of luminosity and effective temperature, and eventually to a wrong asteroseismic model.

**Interstellar reddening**

In [13], we report deriving the interstellar reddening for 29 stars in the Kepler field of view. Having plotted the program stars in several photometric diagrams we conclude that these stars are not reddened. They do not deviate either from the standard relation between $b - y$ and $\beta$ given by [4] and [5] for A7–G2 III–V stars (see Fig. 1) or from the intrinsic relation between $B - V$ and spectral type given by [9] for stars of the luminosity class V and III (see Fig. 2). This result is in a disagreement with the information that can be found in the Kepler KIC-10 catalogue which gives $E(B - V)$ ranging from 0.01 to 0.06 mag for nine of our program stars.

Another result of our photometric study of Kepler asteroseismic targets is finding a discrepancy between effective temperatures derived for stars hotter than 6000 K by means of spectroscopic and photometric methods (see Fig. 3). The spectroscopic temperatures of these stars are around 300 K lower than $T_{\text{eff}}$ derived from photometric methods.
FIGURE 3. The spectroscopic effective temperature \( T_{\text{eff}}^{(1E)} \) derived with the use of the ELODIE archive, which is an on-line database of high-resolution stellar spectra (see http://atlas.obs-hp.fr/elodie), plotted as a function of \( T_{\text{eff}} \) derived from the \((B-V)\) index for Population I stars (points), and \( T_{\text{eff}} \) derived from the \((B-V)\) and \( \delta(0.6) \) indices for the subdwarfs (encircled points). The solid line has unit slope and zero intercept; the short-dashed line runs 311 K below it. (The figure has been originally published in [13].)

The reason for this discrepancy is not clear and will be studied by us in more detail in near future.

Variable stars in open clusters

The open cluster NGC 6866 is one of four open cluster in Kepler field of view. It has been selected for a target in an asteroseismic campaign in summer 2009 in the frame of the activities of the Kepler Asteroseismic Science Consortium (KASC) Working Group#2.1

Between April 27 and July 21 2007, we carried out photometric CCD observations of this cluster with the aim of a search for variable stars. We used the \( BVI_C \) filters of the Johnson-Kron-Cousins \( UBV(RI)_C \) photometric system and collected around 470 CCD frames in each filter during 14 nights.

We discovered 19 variable stars of different types (see [14]). Three of them we classified as \( \delta \) Sct, two, as \( \gamma \) Dor, four, as \( \text{W UMa} \), two, as ellipsoidal variables, one, as an eclipsing binary and seven, as irregular variables. All five pulsating variables are very probable members of the cluster. This makes them promising asteroseismic targets because for stars belonging to a cluster it is reasonable to assume the same age and metallicity, leaving the radii and masses as the only free parameters in asteroseismic modeling. The eclipsing binary is definitely not a cluster member. Consequently, it is not possible to use this star to measure the age and distance to NGC 6866 with the method used by, e.g., [7] and [10].

Having discovered \( \gamma \) Dor stars in NGC 6866, in [14] we discuss the properties of open clusters in which pulsators of this type occur. We show that there is no relation between the age or metallicity of the cluster and the number of \( \gamma \) Dor stars (see Fig. 4). In this way we show that the persisting belief that \( \gamma \) Dor stars occur only in open clusters which are young is unfounded.

FUTURE WORK

Constraining parameters of Kepler targets

Deriving parameters of Kepler targets by means of spectroscopic and photometric ground-based observations is our primary goal. This task is being realized at the observatories already mentioned, as well as at the Telescopio Nazionale Galileo, TNG, (La Palma, Spain) where 19 targets from the KASC Proposal No. 30 (see http://astro.phys.au.dk/KASC) have been scheduled for the AOT20/09B service observations (proposal TAC_71, “Spectral characterization of Kepler asteroseismic targets”, P.I.: G. Catanzaro).

In our study we will focus on a detailed analysis of the stars’ metallicity, the parameter which is crucial for asteroseismic analysis of Kepler data. This has been demonstrated by [15] who showed that the uncertainty in metallicity dominates the uncertainty in the stellar radius.

We plan also a detailed study of selected program stars with the aim of solving the discrepancy between the effective temperatures of hot Kepler targets determined from spectroscopy and from photometry.

Binary stars

Binary stars require a large amount of observing time. First, they need to be confirmed as binaries, then, the orbital period must be determined. Depending on the particular target, the availability of observing time and the weather conditions, such a task can take several days, weeks or months. Therefore, we selected a handful of most promising targets which are scheduled for observing at several observatories. We plan to merge all the data we collect and confirm (or reject) the suspected spectroscopic binarity of these stars, and compute orbital elements for the confirmed ones.
FIGURE 4. \( \gamma \) Dor stars in open clusters coded with shades of gray. The vertical line at 250 Myr indicates a suspected upper limit of the age of an open cluster that can host \( \gamma \) Dor stars (see [8]). (The figure has been originally published in [13].)

**Asteroseismic modeling**

We plan to compute evolutionary and asteroseismic models for selected Kepler asteroseismic targets using the ASTEC and ADIPLS codes (see [2] and [3]). As the input of the modeling procedure, we will use the atmospheric parameters derived by us in [1], [11], [12] and [13]. When possible, we will put additional constraints on the models, e.g., by limiting the possible range of masses of eclipsing SB2 stars using the results from their orbital solution.

**DATA AVAILABILITY**

The echelle spectroscopic observations collected by us at the Catania Astrophysical Observatory are available as the HELAS\(^2\) deliverables at the Wrocław HELAS webpage at http://helas.astro.uni.wroc.pl/deliverables.php.

In the future, we plan to include in our Internet archive the data collected at other observatories.

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