Ground-based observations of Kepler asteroseismic targets

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We present the ground-based activities within the different working groups of the Kepler Asteroseismic Science Consortium (KASC). The activities aim at the systematic characterization of the 5000+ KASC targets and at the collection of ground-based follow-up time-series data of selected promising Kepler pulsators. So far, 36 different instruments at 31 telescopes on 23 different observatories in 12 countries are in use and a total of more than 530 observing nights has been awarded.

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1 Introduction

The Kepler Asteroseismic Science Consortium, KASC, unites hundreds of astroseismologists from institutes all over the world in different topical Working Groups, with the aim of performing seismic studies of all types of pulsating stars across the Hertzsprung-Russell diagram, based on Kepler time-series space photometry. The ground-based observational Working Groups (GBOsWG) take care of the organisation of ground-based observations in support of the Kepler space data. Additional ground-based multi-colour and spectral information are indispensable for a successful seismic modelling (see, e.g., Uytterhoeven et al. 2008a, 2009; Uytterhoeven 2009). The need for ground-based support data is motivated by two objectives: 1) the characterization of all Kepler targets in terms of fundamental stellar parameters, 2) the identification of mode parameters from multi-colour and spectral time-series observations for selected pulsators.

The KASC GBOsWG is making great efforts in organising and planning telescope time on various instruments around the world to meet these objectives and to ensure an optimal seismic exploitation of the Kepler data. So far, 36 different instruments at 31 telescopes on 23 different observatories in 12 countries are involved and a total of more than 530 observing nights has been awarded.

2 Characterization of 5000+ KASC targets

The Kepler space data do not provide information on basic stellar parameters such as effective temperature \((T_{\text{eff}})\), gravity \((\log g)\), metallicity, and the projected rotational velocity \((v \sin i)\), which are important to classify the targets and are crucial for successful asteroseismic modelling. Hence, spectral and multi-colour information are needed to complement the space data. A first effort to compile a catalogue of stellar parameters, derived from Sloan photometry, has been undertaken in the form of the Kepler Input Catalogue (KIC, Latham et al. 2005). However, the accuracy of values of \(T_{\text{eff}}\) and \(\log g\) in KIC is generally too low for seismic modelling. Hence, additional ground-based efforts are required.

The aim of the KASC GBOsWG is to obtain for each of the 5000+ KASC asteroseismic targets a spectrum with a sufficient resolution to derive \(T_{\text{eff}}\), \(\log g\), micro-turbulence, \(v \sin i\) and metallicity (Sousa et al. 2008; Frasca et al. 2006; Bruntt 2009; Niemczura et al. 2009), and multi-colour information to derive reddening, metallicity, and absolute magnitude (Rogers 1995; Kupka & Bruntt 2001).

The systematic characterization of 5000+ targets requires a huge observational effort and involves a long-term project, spread out over several instruments. So far, within the KASC GBOsWG, more than 278 nights have been awarded for the characterization project with 26 different instruments on 17 observatories. More time has been and will be applied for.

The first effort to characterize asteroseismic Kepler targets dates back to 2004. Since then, a project is running to characterize KASC solar-like stars (Molenda-Zakowicz et al. 2007, 2008, 2009b). Nowadays, several observational projects, focussed either on a specific pulsation class or on several classes simultaneously, are ongoing to systematically observe all KASC targets. In Table 1 we present an overview of the awarded observing time for target characterization. Additional information on the observations is given in Uytterhoeven et al. (2010). In addition to the spectroscopic and multi-colour observations, an interferometric project is ongoing with PAVO@CHARA at Mt Wilson Observatory (USA) to measure angular diameters for some of the brightest Kepler targets. Results on the physical parameter determination of a selection of \(\delta\) Sct, \(\gamma\) Dor and hybrid targets are recently presented in Catanzaro et al. (2010).

More observing time has been applied for. Spectropolarimetric observations are planned to investigate magnetic signatures in selected Cepheids, RR Lyr, \(\delta\) Sct, and Be stars with ESPaDOnS@CFHT, Mauna Kea (USA) (P.I. JN, JG-S). An ambitious proposal to observe 95% of all KASC asteroseismic targets with the multi-fiber, multi-object spectrograph LAMOST@4m telescope at Xinglong observatory (CN) has been submitted (P.I. PDC).

3 Time-series observations of selected promising Kepler pulsators

Important key ingredients for an asteroseismic study are precise pulsation frequencies, accurately identified pulsation modes, and strong constraints on atmospheric parameters. Accurate values of the pulsation frequencies will be provided for by the Kepler photometry, while accurate atmospheric parameters will be derived from the ground-based data obtained in the framework of the project outlined in the previous section.

For solar-like oscillators, mode identification relies on the regularity of the frequency pattern in the power spectrum (e.g. Mathur et al. 2010). This method is not directly applicable to larger amplitude pulsators, for which a combination of non-linear effects, rotation, and convection selects the observed modes in a way that is not yet fully understood (e.g. Townsend 2009; Miglio et al. 2008; Suárez et al. (2008, 2009b). Nowadays, several observational projects, focussed either on a specific pulsation class or on several classes simultaneously, are ongoing to systematically observe all KASC targets. In Table 1 we present an overview of the awarded observing time for target characterization. Additional information on the observations is given in Uytterhoeven et al. (2010). In addition to the spectroscopic and multi-colour observations, an interferometric project is ongoing with PAVO@CHARA at Mt Wilson Observatory (USA) to measure angular diameters for some of the brightest Kepler targets. Results on the physical parameter determination of a selection of \(\delta\) Sct, \(\gamma\) Dor and hybrid targets are recently presented in Catanzaro et al. (2010).

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Table 1

Overview of the awarded observing time for target characterization. Information is given on the observatory, the telescope and instrument, the number of awarded nights (N) or hours (h), the type of targets, and the principal investigator (P.I.) of the proposal. Proposals aimed at the characterization of several pulsators (\(\gamma\) Dor, \(\delta\) Sct, \(\beta\) Cep, Be, solar-like, roAp, and Slowly Pulsating B (SPB) stars, and stars in clusters) are labelled “combined”. Spectra that were obtained through a filler programme at the beginning or the end of the night, are indicated as “filler”.

| Observatory          | Telescope            | N  | Target          | P.I.  |
|----------------------|----------------------|----|-----------------|-------|
| Sierra Nevada (E)    | 0.90m photometer     | 8N | combined        | SM-R  |
| San Pedro Martir (MX)| 1.5m photometer      | 5N | combined        | LFM   |
|                      | 2.12m spectrograph   | 2N | combined        | LFM   |
| Tautenburg (D)       | 2m Coudé             | 14N| combined        | HL    |
| Teide (E)            | IAC80 CAMELOT        | 14N| combined        | KU    |
| Piszkésteti (H)      | 1.0m RRC CCD         | 7N | combined        | MP/ZB |
| Calar Alto (E)       | 2.2m BUSCA           | 5N | combined        | KU    |
| La Palma (E)         | INT WFC              | 5N | combined        | KU    |
|                      | NOT FIES             | 3N | combined        | KU    |
|                      | Mercator HERMES      | 7N | combined        | MB    |
|                      | La Palma (E)         | 2.7m e23 | 8N | combined        | PDC   |
|                      | Piszkésteti (H)      | 1.0m RRC CCD | 7N | combined        | MB    |
|                      | Tautenburg (D)       | 2m Coudé  | 14N| combined        | HL    |
|                      | Torrence (E)         | 0.90m photometer | 2N | Be stars       | JG-S  |
|                      | Skinikas (GR)        | 1.3m spectrograph | 4N | Be stars       | JG-S  |
|                      | La Palma (E)         | NOT Alosc | 1N | Be stars       | JG-S  |
|                      | Catania (I)          | 0.9m FRESCO | 3N | \(\delta\) Sct stars | GC   |
|                      | Loiano (I)           | 1.52m BFOSC | 3N | \(\delta\) Sct stars | VR   |
|                      | Asiago (I)           | 1.82m AFOSC | 3N | \(\delta\) Sct stars | VR   |
|                      | La Palma (E)         | TNG SARG  | 2h | \(\delta\) Sct stars | VR   |
|                      | Catania (I)          | 0.9m FRESCO | 15+15+25+12+25N | solar-like stars | JM-Z |
|                      | La Palma (E)         | TNG SARG  | 12N | solar-like stars | JM-Z |
|                      | Mauna Kea (USA)      | CFHT ESPaDOnS | 10h | solar-like stars | HB   |
|                      | Mt Wilson (USA)      | CHARA PAVO | >3N | solar-like stars | DH, MI|
| Steward (USA)        | BOK B&C spectrograph | 10N | compact stars   | EMG   |
|                      | La Palma (E)         | WHT ISIS  | 4.5N | compact stars   | RØ    |
|                      | INT IDS              | 5+4N | compact stars   | RO    |
|                      | NOT FIES             | filler  | compact stars   | JHT   |
|                      | La Palma (E)         | NOT FIES  | 6N+7N | K giants, roAp stars | SF   |
|                      | Mauna Kea (USA)      | CFHT ESPaDOnS | 2h | giants in NGC 6811 | HB   |
|                      | La Palma (E)         | Mercator HERMES | ~45h | binaries with pulsating components | JD   |
|                      | Tautenburg (D)       | 2m Coudé  | filler | SPB, \(\beta\) Cep stars | HL   |
|                      | Haute Provence (F)   | 1.92m SOPHIE | filler | \(\gamma\) Dor stars | PM   |

2005; Degroote et al. 2010). For these targets, the identification of modes observed by Kepler requires ground-based multi-colour and spectral time-series analysis (e.g. Briquet et al. 2009; Poretti et al. 2009; Uytterhoeven et al. 2008b; Rodriguez et al. 2006).

Multi-epoch spectroscopy is also important in the case of (eclipsing) spectroscopic binaries with a pulsating component, because by using spectra one can directly derive the component masses (Tango et al. 2006; Vučkovic et al. 2007; Creevey et al. 2009; Desmet et al. 2010), and it is possible to disentangle the binary components (Harmance et al. 2004) and study the line-profile variability of the components in full detail (Uytterhoeven et al. 2005).

To date, within the KASC GBOsWG, a total of at least 256 nights has been awarded with 15 different instruments on 13 observatories for specific time-series projects. Additional telescope time has been applied for. An overview of the awarded observing time is given in Table 2. We refer again to Uytterhoeven et al. (2010) for a description of the observations. The projects involve RR Lyr stars and Cepheids, Slowly Pulsating B stars, \(\beta\) Cep stars, hybrid \(\gamma\) Dor/\(\delta\) Sct candidates, and pulsators in clusters. The latter concerns a large photometric multi-site campaign on the clusters NGC 6866, carried out in 2009, and NGC 6811, scheduled for 2010. The cluster NGC 6866 is known to host at least three \(\delta\) Sct and two \(\gamma\) Dor candidates (Molenda-Żakowicz et al. 2009a), and there are 12 known \(\delta\) Sct stars in NGC 6811 (Luo et al. 2009).

4 Future plans

The ground-based counterpart of Kepler is crucial for the successful execution of seismic studies. The GBOsWG will continue to organise ground-based observations to comple-
Table 2  Overview of the awarded time for the collection of multi-colour or spectral time-series of selected promising asteroseismic Kepler targets. Information is given on the observatory, the telescope and instrument, the number of awarded nights (N), the type of targets, and the principal investigator (P.I.) of the proposal.

| Observatory           | Telescope         | N  | Targets          | PL            |
|-----------------------|-------------------|----|-----------------|---------------|
| Sierra Nevada (E)     | 1.5m CCD          | 15N| NGC 6866        | RG            |
| Vienna (A)            | 0.8m CCD          | 14N| NGC 6866        | GH            |
| Piszkestető (H)       | 0.9m CCD          | 14N| NGC 6866        | RS            |
| Xinglong (CN)         | 0.85m CCD         | 14N| NGC 6866        | XZ            |
| Białkow (PL)          | 0.6m CCD          | 8+14N| NGC 6866       | JM-Z          |
| Catania (I)           | 0.9m CCD          | 8N | NGC 6866        | KB            |
| Sierra Nevada (E)     | 1.5m CCD          | 15N| NGC 6811        | RG            |
| Vienna (A)            | 0.8m CCD          | 14N| NGC 6811        | GH            |
| Piszkestető (H)       | 0.9m CCD          | 14N| NGC 6811        | RS            |
| Xinglong (CN)         | 0.85m CCD         | 14N| NGC 6811        | XZ            |
| Białkow (PL)          | 0.6m CCD          | 10N| NGC 6811        | JM-Z          |
| Loiano (I)            | 1.52m CCD         | 10N| NGC 6811        | HB            |
| Catania (I)           | 0.9m CCD          | 10N| NGC 6811        | JM-Z          |
| Teide (E)             | IAC-80 CAMELOT    | 10N| NGC 6811        | OC            |
| Apache Point (USA)    | NMSU 1.0m         | 10N| NGC 6811        | JJ            |
| Lulin (TW)            | 0.4m SLT          | 18N| RR Lyr, Cepheids| NCC           |
| Lulin (TW)            | 1.0m LOT          | 3N | RR Lyr, Cepheids| NCG           |
| AAVSONet              | 0.2-0.6m telescopes| >1N| RR Lyr, Cepheids| AH            |
| Sierra Nevada (E)     | 0.9m photometer   | 14N| hybrid γ Dor/δ Sct stars | AOG/SM-R |
| McDonald (USA)        | 2.0m B&C spectrograph | 7N | SPB, γ Dor stars | PDC          |
| La Palma (E)          | Mercator HERMES   | 11N| Cepheids        | HL            |

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