Ground-based observations of O and B stars

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Abstract

Ground-based observations are a strong tool for asteroseismic studies and even in the era of asteroseismic space missions they continue to play an important role. I will report on the activities of the CoRoT/SWG Ground-Based Observations Working Group, discuss the observational efforts of the Open Cluster campaigns and the search for the origin of extra line-broadening in massive OB stars.

Session: Observed frequencies in pulsating massive stars  Individual Objects: HD 180642, HD 50209, HD 181231, HD 49330, NGC 3293, NGC 6910, NGC 884, NGC 1893, NGC 869

The role of ground-based observations in asteroseismic studies

Over the last decades large observational efforts have been undertaken to carefully monitor the pulsational variability of massive B stars, resulting in a breakthrough in seismic modeling. Also, several observational initiatives are taken to open up new horizons, such as the study of B-type pulsators in clusters and pulsational studies of more evolved massive OB stars. The important key ingredients for an asteroseismic study are precise pulsational frequencies, accurate identified pulsation modes, and strong contraints on physical parameters. To obtain these, a large amount of observing time is required as continuous time-series are needed to unravel beat-frequencies. The best we can do from the ground are multi-site campaigns. Data from space have the additional advantage of a good time sampling and phase coverage, as well as a higher precision. However, the ground-based observations continue to play an important role as simultaneous ground-based data are complementary to the ‘white light’ space
Table 1: Observatories, instruments and telescopes involved in the CoRoT preparatory and simultaneous ground-based observations.

| Obs. | Instrument(s) | Obs. | Instrument     |
|------|--------------|------|----------------|
| ESO  | FEROS@1.52m  | CAHA | FOCES@2.2-m    |
| KO   | V@0.5m       | ESO  | FEROS@2.2m     |
| OHP  | Elodie@1.93m | HARP@3.6m     |
| OPM  | NARVAL@TBL   | MJUO | HERCULES@McLlen|
| ORM  | P7@Mercator  | OHP  | Sophie@1.93m   |
| OT   | CCD@STARE    | OPM  | NARVAL@TBL     |
| SAAO | UBV@0.75m    | SNO  | uvy@0.9m       |
| SLN  | FRESCO@0.91m | SNO  | uvy@1.5m       |
| SMO  | uvy@1.5m     | SMO  | uvy@1.5m       |

Multi-colour photometry provides information on amplitude ratios and phase shifts, which are used to identify the degree $l$, while high-resolution spectroscopy allows the detection of high-degree modes and the identification of both $l$ and $m$ values.

The ground-based CoRoT support observations

The CoRoT/SWG Ground-based Observations Working Group has played an important role in preparing the CoRoT satellite mission. Several mid- and high-resolution spectrographs, multi-colour photometers, and a spectropolarimeter at different observatories\(^1\) were involved (see left panel of Table 1) to characterise and select suitable CoRoT targets (Poretti et al. 2003, 2005).

Now the CoRoT satellite is in successful operation, huge efforts are being made to guarantee the simultaneous monitoring of a handful of selected $\beta$ Cep, $\delta$ Sct, $\gamma$ Dor and Be CoRoT targets from the ground. Large Programme and normal observing proposals have been applied for, and have been approved, with

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\(^1\)CAHA: Calar Alto Astronomical Observatory (E); KO: Konkoly Observatory (HU); ESO: European Southern Observatory, La Silla (CL); MJUO: Mount John University Observatory (NZ); OHP: Observatoire de Haute Provence (F); ORM: Observatoire du Pic du Midi (F); ORM: Observatorio Roque de los Muchachos (E); OT: Observatorio del Teide (E); SAAO: South African Astronomical Observatory (ZA); SLN: Osservatorio Serra La Nave (I); SNO: Sierra Nevada Observatory (E); SMO: San Pedro Mártir Observatory (Mexico)
Table 2: Overview of the amount of spectra obtained from December 2006 until August 2008 in the framework of the simultaneous ground-based observational campaign of CoRoT targets with the FEROS, SOPHIE, FOCES and HERCULES spectrographs. The last column indicates the CoRoT run.

| Type | Target | FEROS | SOPHIE | FOCES | HERCULES |
|------|--------|-------|--------|-------|----------|
| δ Sct | HD 50844 | 216 |       |       | IR       |
| Be    | HD 50209 | 68 |       |       | IR       |
| δ Sct | HD 181555 | 343 | 66 | 285 | LRc1     |
| β Cep | HD 180642 | 213 | 35 |       | LRc1     |
| Be    | HD 181231 | 72 |       |       | LRc1     |
| δ Sct | HD 174966 |       | 134 |       | LRc1     |
| γ Dor | HD 49434 | 409 | 711 | 75 | 194 | LRa1     |
| Be    | HD 49330 | 127 |       |       | LRa1     |
| δ Sct | HD 172189 | 176 |       |       | LRc2     |
| γ Dor | HD 171834 | 193 | 447 | 401 | 55 | LRc2     |
| Ap    | HD 171586 | 12 |       |       | LRc2     |

First ground-based results of B-type CoRoT targets

The β Cep star HD 180642 (B1.5III, M 10 $M_\odot$) was one of the asteroseismic targets in CoRoT’s LRc1. Analysis of a dataset consisting of 507 high-quality multi-colour photometric data, obtained with the Mercator telescope and with photometers at KO, SPMO, and SNO, and 280 high-resolution high S/N spectra (FEROS, SOPHIE, Aurelie) confirmed the presence of a dominant radial mode, and revealed evidence for at least two additional non-radial pulsations modes, including a possible high-order g-mode (Uytterhoeven et al. 2008; Briquet et al. 2009, these proceedings).

No frequencies were found in the 68 FEROS spectra of the late-B type Be star HD 50209 (B8IV, $v\sin i = 209\text{ km s}^{-1}$), observed with CoRoT in LRa1 (Gutiérrez-Soto & Neiner, private comm.). On the other hand, photometric...
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data, consisting of HIPPARCOS satellite data, ASAS3 data and Strömgren uvby data obtained at SNO, reveals one frequency 1.47(2) ± 1d\(^{-1}\) (Gutiérrez-Soto et al. 2007).

No variable signals were detected in the HIPPARCOS data and SNO Strömgren uvby magnitudes of HD 81231 (B5IV) (Gutiérrez-Soto et al. 2007). The Be star was observed with CoRoT in LRc1. A line-profile analysis, based on 72 FEROS spectra, lead to the detection and identification of one \(l = 3\) mode (Gutiérrez-Soto & Neiner, private comm.).

Gutiérrez-Soto et al. (2007) report the detection of frequencies in the 2-3d\(^{-1}\) domain in HIPPARCOS and SNO uvby data for the early-B type Be star HD 49330. From a total of 127 FEROS and 41 NARVAL spectra it seems that this CoRoT target, observed in LRa1, pulsates in several short-period variations (frequencies > 11d\(^{-1}\)), associated to high-degree modes (\(5 < \ell < 7\)), as well (Floquet, Gutiérrez-Soto & Neiner, private comm.). Longer-term variations of the order of 50 days are also detected and can be associated to the envelope of the Be system (Floquet, private comm.).

Future

Analyses of the ground-based time-series in combination with the CoRoT data are in progress, and the preliminary results look promising. To continue the huge observational ground-based effort, there is a need for (time on) high-resolution spectrographs. Even with the current Large Programmes in progress, we need to keep convincing time allocation committees the need for strings of consecutive nights and a huge amount of observing time, which is not always straightforward given the competition and the small amount of available high-resolution spectrographs. Moreover, two of the instruments intensively used for the ground-based support observations so far, FOCES (R=40000) and FEROS (R=48000), will not be available anymore to the community soon. This currently leaves us with the high-resolution spectrographs HARPS (R=80000), SOPHIE (R=70000), HERCULES (R=35000) and FIES (R= 46000 or 67000). Despite the two new spectrographs that will be operational in the near future, HERMES (R=40000–90000) and SONG (R=100000), it will be wise to look for alternatives to secure continuous ground-based high-resolution spectroscopic time-series in the future.

The open cluster campaigns

After successful multi-site campaigns on isolated \(\beta\) Cep stars, a new challenge was found in performing asteroseismic studies of \(\beta\) Cep stars in open clusters. A multi-site campaign using CCD photometry was set up by Andrzej Pigulski
et al. The advantages of such a study are clear: the cluster members are supposed to have the same age and metallicity, which puts serious constraints on the asteroseismic models. Moreover, as the CCD field contains several cluster members, several pulsators can be studied simultaneously. The Open Cluster campaigns are being carried out in two phases: observations in 2005–2007 were dedicated to NGC 3293, NGC 6910 and NGC 884 (χ Per), while NGC 1893 and NGC 869 (h Per) are being observed in 2007–2009.

Preliminary results

The Southern cluster NGC 3293 has been observed in January-May 2006 from seven sites. When combining all the data, a detection level of 0.5mmag is expected. Handler et al. (2007) reported on the first results obtained from the SAAO data only: the cluster contains at least ten multiperiodic β Cep stars and a few faint variable B stars with periods between 8-12 hours. The latter variables are very interesting from a theoretical point of view, as their periods are shorter than typical Slowly Pulsating B(SPB)-type pulsations and longer than the typical periods of β Cep stars.

For the multi-site campaign on NGC 6910 and χ Per, twelve sites in ten countries on three continents were involved. The main telescopes were the 0.6m telescope at Białkowski (PL), the Mercator telescope at ORM (E) and the 0.8m telescope at the Observatory of Vienna University (A). We refer to Saesen et al. (2008; 2009, these proceedings) for a detailed description of all the telescopes involved, as well as for the preliminary results on the cluster χ Per. Analysis of the Białkowski data of NGC 6910 resulted in the confirmation of four known β Cep stars and the detection of five new β Cep variables (Pigulski et al. 2007; Pigulski 2008). For some of them (e.g. NGC 6910 18 and NGC 6910 16) up to ten or more modes are observed (see Fig. 1). Interestingly, both \( p \)- and \( g \)-modes seem to be present in NGC 6910 38 (Pigulski 2008).

Sites involved in the multi-site campaigns of the open clusters NGC 1893 and h Per, executed in 2007-2009, are Xinglong (CN), Białkowski (PL), Baja (HU) and ORM (E, Mercator telescope) observatories. Preliminary results based on Białkowski data, enlarged with older KO data, of h Per include the detection of several variable stars, including three known and six new β Cep stars, some of them seemingly showing \( g \)-modes, and eight Be/SPBe stars (Majewska-Świerżbinowicz et al. 2008).

Discussion

The open cluster campaign is one of the largest asteroseismic observational ground-based efforts currently executed, with many sites and small telescopes involved. Observations, reduction and analysis are in progress. So far, the
campaign has been very successful with several $\beta$ Cep, SPB and Be stars already discovered from isolated datasets. The combined multi-site, multi-colour time-series, free from aliasing effects, promise the detection and identification of several pulsation modes. Moreover, the discovered pulsators are promising targets for future seismic modeling, given the constraints on age and chemical composition dictated by the clustership member.

It seems to be not uncommon to observe high-order $g$-modes in $\beta$ Cep stars. This follows from recent results on the cluster data, e.g. NGC 6910 38 (Pigulski 2008) and some $\beta$ Cep variables in h Per (Majewska-Swierzbinoicz et al. 2008). Also other examples are known (e.g. the CoRoT target HD 180642, see above). Recently, Miglio et al. (2007) theoretically predicted high-order modes to be unstable in $\beta$ Cep stars, which leaves room for nice prospects in asteroseismic studies, as the simultaneous detection of $g$- and $p$-modes enables the mapping of stellar interiors from the core to the surface.

Time-scales of extra line-broadening in massive OB stars

Spectroscopic studies show that a non-negligible extra line-broadening, often called macro-turbulence, plays an important role in the line broadening of OB giants and supergiants. The origin of the broadening, however, is still unknown (e.g. Simón-Díaz & Herrero 2006). One of the possible explanations is in terms of stellar oscillations (e.g. Aerts 2009, these proceedings). Currently a new observational project is set up by Simón-Díaz et al. to investigate this explanation, to explore other origins, to study whether the macro-turbulence in massive OB stars show variability, and if so, to investigate on what time-scales it does. Five nights have been awarded in November 2008 with FIES@Nordic Optical Telescope in low-resolution mode ($R=25000$). Eight OB targets have been selected, and will be observed in different time-intervals, ranging from a few minutes to 3 days. This project is a good step in the direction of exploring possibilities of pulsational and asteroseismic studies of more evolved OB stars.

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Figure 1: Frequency spectra of the nine detected β Cep variables in the open cluster NGC 6910 (taken from Pigulski 2008).