An asteroseismic study of the β Cephei CoRoT main target HD 180642: results from the ground-based campaign

M. Briquet[*], K. Uytterhoeven[†,**], T. Morel[*,‡], C. Aerts[*,§], P. De Cat[¶], P. Mathias[||,††], K. Lefever[*,‡‡], A. Miglio[‡], E. Poretti[**], S. Martín-Ruiz[§§], M. Paparó[¶¶], M. Rainer[**], F. Carrier[*], J. Gutiérrez-Soto[***], J.C. Valtier[||], J.M. Benkő[¶¶], Zs. Bognár[¶¶], E. Niemczura[*,†††], P.J. Amado[§§], J.C. Suárez[§§], A. Moya[§§], C. Rodríguez-López[§§,‡‡‡] and R. Garrido[§§]

[*]Instituut voor Sterrenkunde, Katholieke Universiteit Leuven, Celestijnenlaan 200 D, B-3001 Leuven, Belgium
[†]Laboratoire AIM, CEA/DSM-CNRS-Univ. Paris Diderot; CEA, IRFU, SAp, centre de Saclay, F-91191, Gif-sur-Yvette, France
[**]INAF-Osservatorio Astronomico di Brera, Via E. Bianchi 46, I-23807 Merate, Italy
[‡]Institut d'Astrophysique et de Géophysique de l'Université de Liège, Allée du 6 Août 17, B-4000 Liège, Belgium
[§]Dep. of Astrophysics, University of Nijmegen, IMAPP, PO Box 9010, 6500 GL Nijmegen, the Netherlands
[¶]Koninklijke Sterrenwacht van België, Ringlaan 3, B-1180 Brussel, Belgium
[||]UMR 6525 H. Fizeau, UNS, CNRS, OCA, Campus Valrose, F-06108 Nice Cedex 2, France
[††]Observatoire Midi Pyrenees, Laboratoire d'Astrophysique -LATT, 57 Avenue Azereix, 65000 Tarbes, France
[‡‡]BIRA-IASB, Ringlaan 3, B-1180 Brussel, Belgium
[§§]Instituto de Astrofísica de Andalucía (CSIC), Apdo. 3004, 18080 Granada, Spain
[¶¶]Konkoly Observatory, P.O. Box 67, 1525 Budapest, Hungary
[***]GEPI, Observatoire de Paris, CNRS, Univ. Paris Diderot, place Jules Janssen 92195 Meudon Cedex, France
[†††]Instytut Astronomiczny Wroclawski, Kopernika 11, 51–622 Wroclaw, Poland
[‡‡‡]Universidade de Vigo, Departamento de Física Aplicada, Campus Lagoas-Marcosende, Vigo 36310 Spain

Abstract. The β Cephei star HD 180642 was observed by the CoRoT satellite during a run of 156 days in 2007. The space white light photometry revealed the rich frequency spectrum of the star (Degroote et al. 2009). In the present study, we provide additional information on the target, based on both ground-based multi-colour photometry and high-resolution spectroscopy. We place our object in the ($T_{\rm eff}$, $\log g$) diagram. In addition, we derive the chemical abundances of several elements as well as the metallicity of HD 180642. Finally, we put constraints on the identification of some modes. All these observational constraints will be used to compute stellar models of the target.

Keywords: stars: oscillations – stars: early-type – stars: individual: HD 180642 – stars: abundances
PACS: 90

INTRODUCTION

The B 1.5 II-III star HD 180642 (V1449 Aql, HIP 94793, V = 8.29 mag) was discovered as a candidate β Cephei star by means of Hipparcos measurements (Waelkens et al. [1]). Its β Cephei nature was afterwards confirmed by Aerts [2] who used Geneva photometry to identify its dominant mode as a radial one.

Recently, this object was observed by the CoRoT satellite during a run of 156 days between May and October 2007. A detailed modeling and interpretation of the space white-light photometry was presented in Degroote et al. [3] and revealed the star to be multiperiodic with at least 11 independent frequencies.

To complement the CoRoT information, ground-based multicolour photometry and high-resolution spectroscopy were collected for selected primary and secondary CoRoT targets, and we refer to Poretti et al. [4] and Uytterhoeven et al. [5][6] for a description of this project. In this paper, we report on the analysis results based on the ground-based datasets of HD 180642. A more detailed description can be found in Briquet et al. [7].

The results of both the space-based and ground-based observations will be used to perform an asteroseismic modeling of our studied target. This will be presented in a forthcoming paper (Thoul et al., in prep.).

PHOTOMETRY

Several telescopes with multi-colour photometric instruments are involved in this work. Strömgren *uvby* photometry was collected with the 90cm telescope at Sierra

CP1170, *Stellar Pulsation: Challenges for Theory and Observation*
edited by J. A. Guzik and P. A. Bradley

Nevada Observatory, and with the 1.5m telescope at San Pedro Mártir Observatory; Geneva 7-colour photometry ($UB_1BB_2V_1VG$) with the 1.2m Mercator telescope at the Observatorio Roque de los Muchachos, and with the 70cm Swiss telescope at La Silla Observatory; and Johnson V photometry with the 50cm and 1m telescopes at Konkoly Observatory. A logbook of the observations is shown in Table 2 of Uytterhoeven et al. [5].

To increase the frequency precision, we combined datasets for given filters whenever possible. First, we merged the Strömgren data of both sites. Second, we constructed ultraviolet, blue, and visual ground-based lightcurves (combined U,B,V data hereafter) by merging the Geneva U and Strömgren u, B and v, and V and y data, respectively. Finally, we also constructed a more extensive visual band lightcurve by adding also the Johnson V data to the Geneva V and Strömgren y data.

By applying the SCARGLE (Scargle [8]) method to the combined datasets, we first detected the variations due to the main mode with f_1 = 5.48694 d^{-1}, 2f_1 and 3f_1. The corresponding amplitudes in the combined U filter are 82.7(7), 8.2(7) and 4.3(7) mmag. Afterwards, we also found two additional significant frequencies f_2^p = 0.30818(5) d^{-1} and f_3^p = 7.36673(7) d^{-1} with an amplitude of 4.9(7) and 4.5(7) mmag in the combined U filter, respectively.

To identify the modes, we applied the usual method of photometric amplitude ratios, using the formalism of Dupret et al. [9]. We computed the non-adiabatic eigenfunctions and eigenfrequencies by using the code called MAD (Dupret et al. [10]). To this end, all the models were computed with the Code Liégeois d'Evolution Stellaire (CLES, Scuflaire et al. [11]). We refer to Briquet et al. [7] for details of the input physics adopted. The outcome of the photometric mode identification confirms that the dominant mode is a radial one as already ascertained by Aerts [2]. In addition, we conclude that f_2^p is unambiguously identified as a g-mode pulsation with ℓ = 3. Moreover, f_3^p corresponds to ℓ = 0 or 3, with a preference for ℓ = 0.

SPECTROSCOPY

In the framework of the CoRoT ground-based Large Programme (e.g. Uytterhoeven & Poretti [12]; Uytterhoeven et al. [5][6]), aimed at the follow-up of selected CoRoT targets, HD 180642 was observed with the FEROS spectrograph at the 2.2m telescope at ESO La Silla. The target was also monitored with the SOPHIE (1.93m telescope) and Aurélie (1.52m telescope) spectrographs, both situated at the Haute-Provence observatory. A logbook of the observations is shown in Table 1 of Briquet et al. [13].

The fundamental parameters of HD 180642 and the non-local thermodynamic equilibrium (NLTE) abundances of helium and the dominant metals have been obtained using the codes and methodology described in Morel et al. [14]. We obtained $T_{\rm eff}$=24 500±1000 K, $\log g$=3.45±0.15 dex and a microturbulent velocity ξ=12±3 km s^{-1} . The derived chemical abundances are fully compatible with literature values for nearby main-sequence B stars (e.g., Daflon & Cunha [15]; Gummersbach et al. [16]; Kilian-Montenbruck et al. [17]), except for a possible mild nitrogen excess, also discovered in other β Cephei stars (Morel et al. [14], [18]). The reader is referred to Briquet et al. [7] for the list of the abundance values. The deduced metallicity for HD 180642 is Z = 0.0099±0.0016 (or 0.0126±0.0016 depending on the choice of microturbulence).

A frequency search was carried out by means of a two-dimensional Fourier analysis available in the software package FAMIAS[1] (Zima [19]). Besides the nonlinear radial mode with a peak-to-peak RV amplitude of 90 km s^{-1}, four low-amplitude modes are found: f_2^s=8.4079(2) d^{-1}, f_3^s=0.3046(2) d^{-1}, f_4^s=7.1037(3) d^{-1} and f_5^s=6.3248(3) d^{-1}. The first three frequencies are also detected in the radial velocity measurements and their corresponding amplitudes are 1.5(2), 1.1(2) and 1.0(2) km s^{-1}, respectively. In the radial velocities, the dominant radial mode presents a so-called stillstand but no clear evidence of the existence of shocks was observed.

As explained and illustrated in Zima [20] and Briquet et al. [7], usual spectroscopic mode identification techniques, as implemented in FAMIAS, cannot be applied in case of a large pulsation velocity relative to the projected rotational velocity, i.e., if the radial velocity amplitude is above 0.2 $v\sin i$, as for HD 180642. However, a successful outcome for one of the modes was achieved by means of the moment method of Aerts [21], which we slightly adapted to our case. We used the discriminant of the latter author but taking into account only the amplitudes denoted by C, D, F, and G (see Aerts [21]). In this way we avoid the amplitudes involving the width σ of the intrinsic profile which is not constant in time, in contrast to the assumption in Aerts [21]. The discriminant values for the identified mode are given in Table 1. We found the frequency 8.4079 d^{-1} to correspond to a (ℓ,m) = (3,2). Finally, we derived a value for the equatorial rotational velocity of v_{eq} = 38±15 km s^{-1} .

[1] FAMIAS has been developed in the framework of the FP6 European Coordination Action HELAS – http://www.helas-eu.org/

TABLE 1. The bestfit solutions of the spectroscopic mode identification for the mode with frequency 8.4079 d^{-1} determined by the adapted discriminant Σ, based on the definition in Aerts [21]. The inclination angle i is expressed in degrees; $v \sin i$ is the projected rotational velocity, expressed in km s^{-1}; $v_{r,max}$ and $v_{t,max}$ are, respectively, the maximum radial and tangential surface velocity due to the mode, expressed in km s^{-1}.

$(\ell, \|m\|)$	i	$v \sin i$	$v_{r,max}$	$v_{t,max}$	Σ
(3,2)	81.5	38.5	30.4	3.0	0.93
(3,1)	30.5	39.5	11.4	1.3	4.13
(1,1)	14.5	29.9	11.0	0.4	4.41
(2,1)	14.0	25.2	9.7	0.7	4.42
(2,2)	47.5	38.4	8.4	0.6	4.48
(3,3)	66.5	23.8	14.8	1.7	4.59
(3,0)	23.0	1	20.0	1.7	35.63
(1,0)	83.5	1	24.2	1.0	35.65
(2,0)	63.0	1	23.8	1.4	35.65
(0,0)	90.0	1	2.2	0.0	36.45
(4,0)	3.0	1	86.0	9.1	49.94

SUMMARY

Based on both extensive ground-based multicolour photometry and high-resolution spectroscopy we obtained the following constraints to model the β Cephei star HD 180642. We determined $T_{\rm eff} = 24\,500 \pm 1000$ K and $\log g = 3.45 \pm 0.15$ dex from spectroscopy. The derived chemical abundances were found to be consistent with those for B stars in the solar neighbourhood, except for a mild nitrogen excess. Three modes were detected in photometry. The degree ℓ was unambiguously identified for two of them: $\ell = 0$ and $\ell = 3$ for the frequencies 5.48694 d^{-1} and 0.30818 d^{-1}, respectively. For the third frequency of 7.36673 d^{-1} found in photometry, two possibilities remained: $\ell = 0$ or 3. Four low-amplitude modes were found in spectroscopy and one of them, with frequency 8.4079 d^{-1}, was identified as $(\ell, m) = (3,2)$. Based on this mode identification, we finally deduced an equatorial rotational velocity of 38 ± 15 km s^{-1}.

ACKNOWLEDGMENTS

The FEROS data were obtained as part of the ESO programme 077.D-0311 (PI: K. Uytterhoeven) as well as as part of the ESO Large Programme 178.D-0361 (PI: E. Poretti). This work was supported by the Hungarian ESA PECS project No 98022, by the Research Council of K.U.Leuven under grant GOA/2008/04 and by the European Helio- and Asteroseismology Network (HELAS), a major international collaboration funded by the European Commission's Sixth Framework Programme. KU acknowledges financial support from a *European Community Marie Curie Intra-European Fellowship*, contract number MEIF-CT-2006-024476. EP and MR acknowledge financial support from the Italian ASI-ESS project, contract ASI/INAF I/015/07/0, WP 03170. JCS acknowledges support by the "Consejo Superior de Investigaciones Científicas" by an I3P contract financed by the European Social Fund and from the Spanish "Plan Nacional del Espacio" under project ESP2007-65480-C02-01. SMR acknowledges a "Retorno de Doctores" contract of the Junta de Andalucía and IAA for carrying out photometry campaigns for CoRoT targets at Sierra Nevada Observatory. EN acknowledges financial support of the N N203 302635 grant from the MNiSW. MB and FC are Postdoctoral Fellows of the Fund for Scientific Research, Flanders. AM is Postdoctoral Researcher, Fonds de la Recherche Scientifique – FNRS, Belgium. CRL acknowledges an Ángeles Alvariño contract under Xunta de Galicia.

REFERENCES

1. Waelkens, C., Aerts, C., Kestens, E., Grenon, M., Eyer, L. 1998, *A&A*, 330, 215
2. Aerts, C. 2000, *A&A*, 361, 245
3. Degroote, P., Briquet, M., Catala, C., et al. 2009, *A&A*, in press (arXiv:0906.4057)
4. Poretti, E., Rainer, M., Uytterhoeven, K., Cutispoto, G.,Distefano, E., Romano, P. 2007, *MmSAI*, 78, 624
5. Uytterhoeven, K., Poretti, E., Rainer, M., Mantegazza, L., Zima, W., et al. 2008, in 'HelasII international conference: Helioseismology, Asteroseismology and MHD Connections', Journal of Physics: Conference Series, IOP Publishing, 118, 2077
6. Uytterhoeven, K., Poretti, E., Mathias, P., et al., *American Institute of Physics*, these proceedings
7. Briquet, M., Uytterhoeven, K., Morel, T., et al. 2009, *A&A*, in press (arXiv:0906.3626)
8. Scargle, J.D. 1982, ApJ 263, 835
9. Dupret, M.-A., De Ridder, J., De Cat, P., Aerts, C., Scuflaire, R., Noels, A., Thoul, A. 2003, *A&A*, 398, 677
10. Dupret, M.-A. 2001, *A&A*, 366, 166
11. Scuflaire, R., Théado, S., Montalbán, J., Miglio, A., Bourge, P.-O., Godart, M., Thoul, A., Noels, A. 2008, *Ap&SS*, 316, 83
12. Uytterhoeven, K., Poretti, E., & the CoRoT SGBOWG, 2007, CoAst, 150, 371
13. Briquet, M., Uytterhoeven, K., Aerts, C., et al. 2009, *CoAst*, 158, 292
14. Morel, T., Butler, K., Aerts, C., Neiner, C., & Briquet, M. 2006, *A&A*, 457, 651
15. Daflon, S., & Cunha, K. 2004, *ApJ*, 617, 1115
16. Gummersbach, C. A., Kaufer, A., Schäfer, D. R., Szeifert, T., & Wolf, B. 1998, *A&A*, 338, 881
17. Kilian-Montenbruck, J., Gehren, T., & Nissen, P.E. 1994, *A&A*, 291, 757
18. Morel, T., Hubrig, S., & Briquet, M. 2008, *A&A*, 481, 453
19. Zima, W. 2008, *CoAst*, 157, 387
20. Zima, W. 2006, *A&A*, 455, 227
21. Aerts, C. 1996, *A&A*, 314, 115