New windows on massive stars: asteroseismology, interferometry, and spectropolarimetry
Proceedings IAU Symposium No. 307, 2014
G. Meynet, C. Georgy, J. H. Groh & Ph. Stee, eds.

doi:10.1017/S1743921314006796

An attempt of seismic modelling of β Cephei stars in NGC 6910

D. Moździerski, Z. Kołaczkowski and E. Zahajkiewicz

Asstronomical Institute, University of Wrocław, Kopernika 11, 51-622 Wrocław
email: mozdzierski@astro.uni.wroc.pl

Abstract. We present preliminary results of seismic modeling of β Cephei-type stars in NGC 6910 based on simultaneous photometric and spectroscopic observations carried out in 2013 in Białków (photometry) and Apache Point (spectroscopy) observatories.

Keywords. stars: oscillations, open clusters and associations: NGC 6910, stars: early-type, stars: fundamental parameters

1. Introduction

The recent seismic modeling of bright β Cephei stars (see, e.g. Aerts *et al.* 2003, Pamyatnykh *et al.* 2004, Dupret *et al.* 2004, Daszyńska-Daszkiewicz & Walczak 2010) has brought some constraints on the convective overshooting of the core and an indication that massive star cores rotate faster than their envelopes. The perspectives for doing asteroseismology of these stars are therefore promising.

A new way of using asteroseismology is to simultaneously model many stars of the same pulsation type, which is called ensemble asteroseismology. This type of asteroseismology can be done e.g. for members of an open cluster. A prerequisite of a successful asteroseismology study is mode identification and determination of some global stellar parameters, which can be done much easier for stars in open clusters than for field objects. This is because cluster membership makes that some stellar parameters (distance, reddening, age, chemical composition) can be safely assumed to be the same for all stars, while other parameters (e.g. masses and radii) are strictly related. One of the best candidates for ensemble asteroseismology is the young open cluster NGC 6910 in which Kołaczkowski *et al.* (2004) discovered four β Cephei variables. A new campaign focused on this cluster allowed to detect at least eight β Cephei-type members (Pigulski 2008). The frequency spectra of β Cephei stars in this cluster, arranged according to the decreasing brightness (i.e. mass), show a very interesting progress of frequencies of excited modes. This is exactly what one could expect for p modes in stars located at the same isochrone in a cluster. This is a strong argument for trying ensemble asteroseismology of this cluster.

2. Observations and Results

New observations of NGC 6910 were made in 2013. The photometric observations were obtained in Białków Observatory (Poland) during 21 nights. These observations were carried out with a 60-cm reflecting telescope and the attached CCD camera covering $13' \times 12'$ field of view. About 4000 CCD frames were acquired using the B, V, and I_C filters of the Johnson-Kron-Cousins photometric system. The spectroscopic observations were carried out at the Apache Point Observatory (APO) ARC 3.5-m telescope and the ARC Echelle Spectrograph (ARCES) during five nights. In total, we have taken 36 spectra of NGC 6910-18 and single-epoch spectra of two other β Cep-type stars: NGC 6910-14

Table 1. Atmospheric parameters of analysed β Cep stars in NGC 6910.

Star	$\log(T_{\rm eff}/{\rm K})$ [1]	$\log(T_{\rm eff}/{\rm K})$ [2]	$\log L/L_\odot$	$v \sin i$ [km s^{-1}]
NGC 6910-14	4.447	4.443	4.182	125
NGC 6910-16	4.447	—	—	149
NGC 6910-18	4.398	4.400	4.025	94

Notes:
[1] Based on our spectroscopy.
[2] Based on Strömgren photometry.

and NGC 6910-16. The spectra have a resolving power of 31500 and cover a range between 3200 and 10000 Å. Photometric observations were calibrated in a standard way. For each frame, we calculated aperture and profile magnitudes of the stars using the DAOPHOT II package (Stetson 1987), and then derived differential magnitudes. Spectroscopic observations were reduced with standard IRAF routines.

We determined $T_{\rm eff}$ and $v \sin i$ of the observed stars (NGC 6910-14, -16, -18) using our spectra and the BSTAR2006 grid of non-LTE model atmospheres of Lanz & Hubeny (2007) and the ROTIN3 program. We used also the UVBYBETA code and literature u, v, b, y, and β magnitudes to obtain $\log L/L_\odot$ and $\log T_{\rm eff}$ of NGC 6910-14 and NGC 6910-18. The results are shown in Table 1. In the case of NGC6910-18, we found that the amplitudes of the two dominating modes with frequencies $f_1 = 6.1549\,{\rm d}^{-1}$ and $f_2 = 6.3890\,{\rm d}^{-1}$ remained almost unchanged in comparison to 2005–2007 observations. We performed mode identification for this star with the methods developed by Daszyńska-Daszkiewicz *et al.* (2005) for five stellar models using B, V, and $I_{\rm C}$ time-series photometry. The evolutionary tracks were computed with the Warsaw-New Jersey evolutionary code adopting the OP opacities, the solar mixture, rotational velocity $V_{\rm rot} = 100$ km s^{-1}, hydrogen abundance $X = 0.7$, metallicity parameter $Z = 0.015$ and no overshooting from the convective core. We identified f_1 as an $l = 3$ mode whereas f_2 can be identified as $l = 0$, 1 or 2.

This work was supported by the NCN grant No. 2012/05/N/ST9/03898 and has received funding from the EC Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 269194. The work is based on observations obtained with the Apache Point Observatory 3.5-meter telescope, which is owned and operated by the Astrophysical Research Consortium. Some calculations have been carried out in Wrocław Centre for Networking and Supercomputing (http://www.wcss.wroc.pl), grant No. 219. We thank Dr. J. Jackiewicz for making available telescope time on the APO ARC 3.5-m telescope and for his support during observations. We thank A. Pigulski, P. Bruś, G. Kopacki and P. Śródka for making some observations of NGC 6910 in Białków.

References

Aerts, C., Thoul, A., Daszyńska, J., *et al.* 2003, *Science* 300, 1926
Daszyńska-Daszkiewicz, J., Dziembowski, W. A., & Pamyatnykh, A. A. 2005, *A&A* 441, 641
Daszyńska-Daszkiewicz, J. & Walczak, P. 2010, *MNRAS* 403, 496
Dupret, M.-A., Thoul, A., Scuflaire, R., *et al.* 2004, *A&A* 415, 251
Kołaczkowski, Z., Pigulski, A., Kopacki, G., & Michalska, G. 2004, *AcA* 54, 33
Lanz, T. & Hubeny, I. 2007, *ApJS* 169, 83
Pamyatnykh, A. A., Handler, G., & Dziembowski, W. A. 2004, *MNRAS* 350, 1022
Pigulski, A. 2008, *Journal of Physics Conference Series* 118(1), 012011
Stetson, P. B. 1987, *PASP* 99, 191