

Asteroseismology of massive stars in the young open cluster NGC 884: a status report

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Abstract

To improve our comprehension of the β Cephei stars, we set up a photometric multi-site campaign on the open cluster NGC 884 (χ Persei). Thirteen telescopes joined the 2005-2007 campaign which resulted in almost 78 000 CCD frames. We present an up-to-date status of the analysis of these data, in which several interesting oscillating stars are pointed out. We end with the future prospects.

Individual Objects: NGC 884

Introduction

Recent progress in the seismic interpretation of selected β Cephei stars was remarkable in the sense that standard stellar structure models are unable to explain the oscillation data for the best-studied stars: HD 129929 (Aerts et al. 2003), ν Eridani (Pamyatnykh et al. 2004, Ausseloos et al. 2004, Dziembowski & Pamyatnykh 2008) and 12 Lacertae (Ausseloos 2005, Handler et al. 2006, Dziembowski & Pamyatnykh 2008). Non-rigid internal rotation and core convective overshoot are needed to fit the measured oscillation frequencies and the standard models have now been upgraded to include these effects, albeit in a crude parametrised

way. Pamyatnykh et al. (2004) have suggested to include in future models radiative diffusion processes as well, in an attempt to resolve the yet unsolved excitation problem encountered for some of the modes detected in ν Eridani.

A next step in asteroseismology of β Cephei stars was undertaken recently, with the study of these stars in clusters. Indeed, with the current CCD cameras we are able to obtain simultaneous measurements of thousands of stars. Another big advantage is the cluster membership of the stars: this gives us much tighter constraints when modelling their observed and identified oscillation modes.

Krzesiński & Pigulski (1997, 2000) discovered one candidate and two bona fida β Cephei stars in NGC 884. The variability study on this cluster conducted by Waelkens et al. (1990) showed that at least half of the brighter stars are variable, while most of them seem to be Be stars.

Observations

To perform ensemble-asteroseismology of NGC 884, we needed time-resolved multi-colour differential photometry of a selected field of this cluster, for which we organised a large-scale multi-site campaign. An international team monitored the cluster with 13 telescopes in the northern hemisphere in the filters U, B, V, I. The data were taken between 2005 and 2007, spread over three observational seasons, spanning in total 800 days. 77 900 CCD images and 92 hours of photo-electric measurements were collected, representing 1290 hours of data taken by about 60 observers. A world map indicating all participating sites and their characteristics (telescope diameter and filters used) and the distribution of the observations in time can be found in Saesen et al. (2008).

The effect of the multi-site character of the campaign is best seen when comparing the spectral windows of the data (see Fig. 1). The spectral window of the Polish data, the site that has the largest contribution to the whole data set, has a high one-day-alias: its amplitude is 90% of the main frequency peak. If we add one site, China, situated at a different latitude, the one-day-alias falls down to 70% of the central peak. Taking all sites into account makes the alias drop to only 55%, which makes it much easier to identify the correct frequency peak.

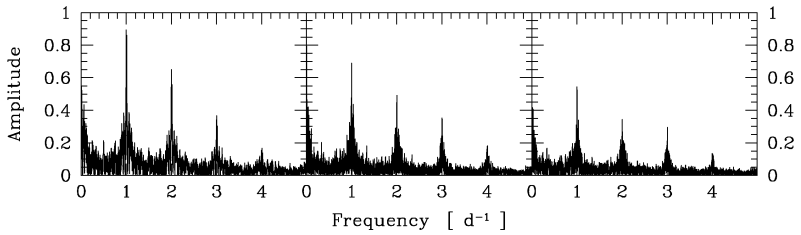


Figure 1: Spectral windows of the Polish data (left panel), the combined Polish and Chinese data (middle panel) and all data (right panel).

To transform the CCD frames into interpretable light curves, we extracted the fluxes of the stars with Daophot (Stetson 1987), in which we combined PSF and aperture photometry. We performed differential photometry in which we correct for atmospheric extinction by taking several reference stars distributed over the CCD frame into account. Currently we are detrending the data with SysRem (Tamuz et al. 2005) to remove the linear systematic effects which are present in a lot of stars. For sites with many data points we obtain an overall

V accuracy of 3-5 mmag over the entire campaign, depending on the telescope. The error on the frequency is smaller than 0.00014 d^{-1} and the detection threshold at high frequencies for Polish data is about 0.3 mmag. Frequencies in the β Cephei range can be accepted if their amplitudes are larger than 1 mmag, but this limit will go down once all data are put together.

Detected variable stars

A preliminary analysis on single-site data led to the confirmation of the two known β Cephei stars, Oo 2246 and Oo 2299, and to the discovery of numerous new pulsators of this type, among which several are multi-periodic (Pigulski et al. 2007, Saesen et al. 2008). However, spectroscopy has shed additional light on two of these newly classified β Cephei stars, Oo 2085 and Oo 2566. They show variations on both short (\sim hours) and long (\sim days) time scales and turn out to have $H\alpha$ emission. As a consequence, Oo 2085 and Oo 2566 are also categorised as Be stars. Oo 2444, Oo 2488 and Oo 2572 remain accepted as β Cephei stars.

The β Cephei stars show at least a double-mode behaviour, except Oo 2299, which seems to show a single, predominant mode. Fig. 2 shows the periodograms in subsequent stages of prewhitening based on dual-site data of two of these oscillators. We clearly detect two frequencies for each of them (first two panels) and after subtracting these variations from the data, there is still power present in the residuals (lower panels). We expect that additional frequencies will peak above the frequency acceptance level after detrending and merging the data of all sites. The case of Oo 2572 also points out that multi-site observations are important to pinpoint the correct frequency peak. In Saesen et al. (2008), which is only based on single-site data, an alias frequency was mistaken for the correct peak.

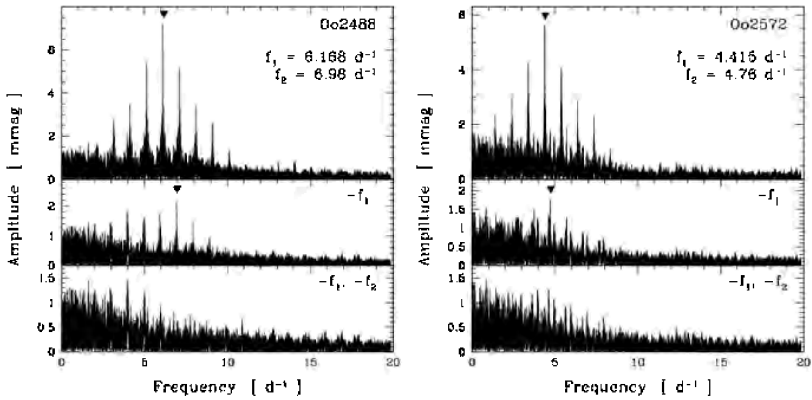


Figure 2: Periodograms of subsequent stages of prewhitening based on Polish and Chinese data of the β Cephei stars Oo 2488 and Oo 2572.

Besides these five established β Cephei stars, we have five more candidates. Three of them show evidence for low frequencies and might turn out to be hybrid oscillators. We have detected seven SPB candidates, amongst which is Oo 2253: three significant frequencies are extracted and shown in the subsequent periodograms of Fig. 3. In addition, the observed field of NGC 884 contains several eclipsing binaries (see Fig. 4 for two newly discovered cases) and other variable stars.

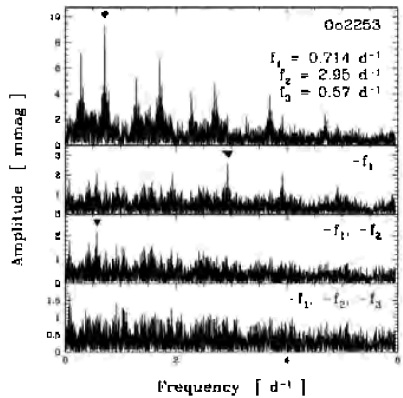


Figure 3: Periododograms of subsequent stages of prewhitening based on Polish and Chinese data of the SPB star Oo 2253.

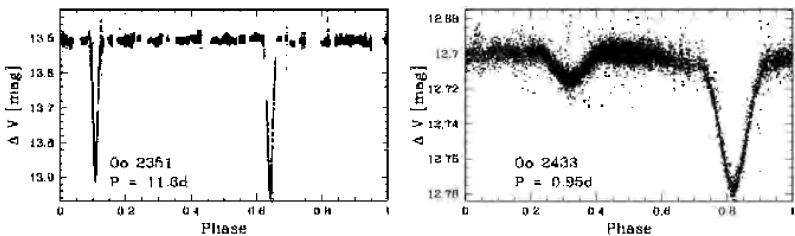


Figure 4: Phase plots of two newly discovered eclipsing binaries Oo 2351 and Oo 2433.

Future prospects

First of all, we will conduct a detailed search for variable stars in the cluster NGC 884. For these variable stars we will do a frequency analysis. We will especially look for B-type pulsators, for which we will perform a mode identification to determine the degree ℓ . The well-known photometric method, which compares the theoretical amplitude ratios with the observed ones at different wavelengths, will be used (Dupret et al. 2003). For this purpose we have observations in different bands at our disposal. The photometric amplitude ratios are going to be combined with radial-velocity amplitudes deduced from simultaneous NOT spectra for the three brightest β Cephei stars. This will make the mode identification more conclusive than only the amplitude ratios (Daszyńska-Daszkiewicz et al. 2005).

In the end we will fit theoretical frequencies to the observed ones and their mode identification, simultaneously for all pulsating cluster members. Indeed, as the stars in a cluster were born out of the same cloud, we can assume that they have the same age and had the same chemical composition at birth. The Liège stellar evolution code CLES (Scuflaire et al. 2008) and the non-adiabatic oscillation code MAD (Dupret et al. 2002) will be applied in this process. Only models that fulfill additional criteria, such as the position in the HR diagram derived from photometry, and the abundances of the stars obtained by NOT spectroscopy,

will be retained.

In any case, the first results are very promising for our future analysis of all campaign data. In-depth evaluation of stellar evolution models seems therefore within reach, now that the technique of asteroseismology has been extensively tested on single field stars.

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