Close Non-Radial Modes and Modulation in First Overtone Cepheids

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Close non-radial modes are detected in a significant fraction of first overtone Cepheids. Such modes manifest as additional peaks in the power spectrum, close to the radial mode frequency. We revisit a sample of Cepheids with close non-radial modes previously analysed using OGLE-II data, and check their properties with the more extensive OGLE-III/IV data. The emerging qualitative picture is the same – in all stars we confirm the presence of a single additional peak close to the radial mode frequency. In one of them, we discover an additional peak located symmetrically on the other side of the radial mode frequency. This indicates that the pulsation of this star may be periodically modulated. For other stars, the interpretation in terms of non-radial modes remains the most likely scenario.

For a long time, classical Cepheids were considered as purely radial pulsators. Detailed studies of ground-based data led to the detection of other modes in the first overtone Cepheids, which could not fit the radial mode scenario. Moskalik & Kołaczkowski (2008, 2009) were the first to report non-radial modes in Cepheids using OGLE-II data of the LMC. Two additional types of variability were described: double-periodic stars with additional periodicity very close to the radial first overtone (37 stars) and double-periodic stars with period ratio $P_{\mathrm{x}}/P_{1\mathrm{O}}$ in the $0.6-0.65$ range (7 stars, of which 2 are also in the first group).

We revisit exactly the same stars as studied by Moskalik & Kołaczkowski (2009) (MK09 in the following; 42 stars in total) with recent OGLE-III and OGLE-IV data (Soszyński et al., 2015). Our goals were to check whether signals interpreted as close non-radial modes may in fact correspond to modulation and to check the properties of stars with $(0.6-0.65)$ period ratios.

The most recent editions of the OGLE catalog were used in our data analysis. OGLE-III and OGLE-IV have longer time spans (OII: 1997 to 2000; OIII: June 2001 to May 2009; OIV: March 2010 till now) and higher cadence, which results in typically lower noise level than in OGLE-II data. Our data analysis used a standard consecutive prewhitening technique. First, the significant periodicities were identified using the discrete Fourier transform, and then the light curve was prewhitened with a fitted sine series. After that, the analysis of residuals is performed in order to find additional, low amplitude signals.

From a group of 37 stars analysed by MK09, all the stars show close non-radial modes in the newer data. Only in one star (OGLE-LMC-CEP-0991) was the modulation signature detected. MK09 reported that OGLE-LMC-CEP-0991 has three periodicities: a radial first overtone of $P_1=1/f_1=3.452526\,\mathrm{d}$ and two additional periodicities were located at $\Delta f_2=f_2-f_1=0.016835\,\mathrm{c/d}$ and $\Delta f_3=f_3-f_1=0.007724\,\mathrm{c/d}$.

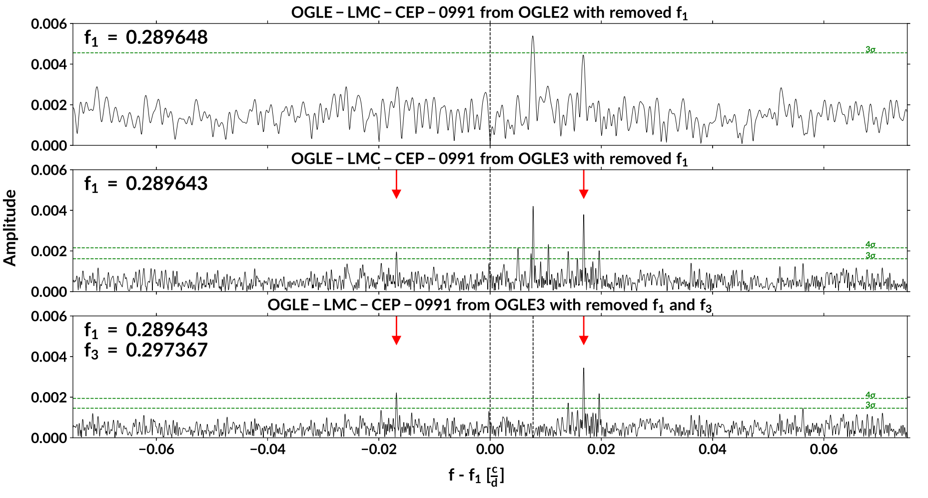

Fig. 1: Frequency spectrum for OGLE-LMC-CEP-0991. Top panel: OGLE-II data with prewhitened 1O signal, middle panel: OGLE-III data with prewhitened 1O signal, bottom panel: OGLE-III data with prewhitened 1O and Δf_3 signals. Green lines mark the 3σ and 4σ noise levels.

In our analysis, the modulation signature was found both in OGLE-III and OGLE-IV data. We detected additional signals at $-\Delta f_2$, which forms an equidistant triplet with f_1 and a signal detected at $+\Delta f_2$ (Fig. 1). After prewhitening, the signal was clearly above the average noise level. The corresponding modulation period would be $P_\mathrm{m} = 1/\Delta f_2 = 59.4$ d. We conclude, that for most of the analysed stars, excitation of close non-radial modes is the most probable scenario. In only one star, the modulation of the dominant periodicity might be present.

We have also found that 16 stars have an additional periodicity with $P_\mathrm{x}/P_{1\mathrm{O}}$ in the $0.6-0.65$ range, of which nine are new detections. In eleven of them, the signals centered at a subharmonic frequency, i.e. at $1/2 f_\mathrm{x}$, are present. The distribution of the discussed stars in the Petersen diagram, in which signals at subharmonic frequencies were detected, supports the model proposed by Dziembowski (2016), which explains the signals at $1/2 f_\mathrm{x}$ as due to non-radial pulsation modes of moderate degrees.

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