Periodic modulation of pulsation in Cepheids

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Modulation in classical fundamental mode Cepheids

We searched for periodic modulation of pulsation in fundamental mode Cepheids observed by the OGLE project in the Magellanic Clouds (Soszyński et al., 2015). Small amplitude modulation was detected based on the analysis of the frequency spectra, as illustrated in Fig. 1. In a few cases, modulation is visible directly in the light curve – Fig. 2. The effect was detected in only 22 and 29 Cepheids of the LMC and SMC, respectively (∼1 % of the sample). However, in some period ranges the effect is very common – Fig. 3. The incidence rate is nearly 40 % for pulsation periods in between 12 and 16 d in the SMC and is around 5 % for pulsation periods in between 8 and 14 d in the LMC. Interestingly, in frequency spectra of nearly all stars, peak at the modulation frequency is detected (Fig. 1) which corresponds to the modulation of mean brightness. Fortunately, the amplitude of the modulation is always very low, below 10 mmag (except in one star) – Fig. 4; top. Relative modulation amplitude is typically below 6 % (Fig. 4; bottom). These results were published in Smolec (2017). Periodic modulation of pulsation was also detected in V1154 Cyg, the only Cepheid in the original *Kepler* field (Derekas et al., 2017).

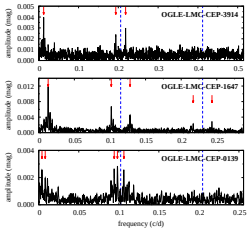

Fig. 1. Frequency spectra for three modulated Cepheids from the LMC after pre-whitening with the fundamental mode and its harmonics (dashed lines). Modulation side peaks are marked with arrows. Note the pronounced peaks at the modulation frequency (in the low frequency range).

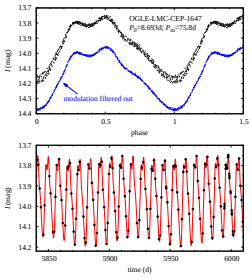

Fig. 2. Light curve for OGLE-LMC-CEP-1647. Phased light curve is plotted in the top panel (black points). For comparison, we also plot the light curve with modulation filtered out (blue points, shifted by 0.2 mag). In the bottom panel we show the section of the light curve with fitted model overplotted (solid line). Time is expressed as $t = \mathrm{HJD} - 245\,0000$ d.

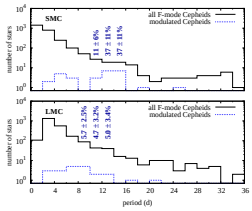

Fig. 3. Period distribution of all (black solid line) and modulated (blue dotted line) fundamental mode Cepheids in the SMC (top) and in the LMC (bottom). Incidence rate of the modulated stars is given only if it exceeds ≈5 per cent in a bin with significant statistics (at least 10 Cepheids). Note the logarithmic scale on vertical axis.

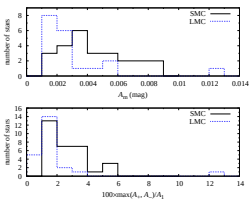

Fig. 4. Distribution of the amplitudes of mean brightness modulation (top) and of the relative modulation amplitude of the fundamental mode (bottom).

Amplitude of the mean brightness modulation is always very low. In addition, the modulation averages out in observations of longer time base. Consequently, modulation has no significant inluence on the use of Cepheids as standard candles.

Modulation in type II Cepheids (BL Her / W Vir / RV Tau stars)

We searched for periodic modulation of pulsation in type II Cepheids observed by the OGLE project in the Galactic bulge (Soszyński et al., 2017). The search was motivated by nonlinear convective models of Smolec & Moskalik (2012) and of Smolec (2016) which predict that periodic modulation of pulsation may occur, in narrow ranges of physical parameters, in type II Cepheids. Just as in the case of classical Cepheids, small amplitude modulation was detected based on analysis of the frequency spectra (Smolec et al., sumbitted to MNRAS).

In total, modulation was detected in 16 BL Her, 9 W Vir and in 7 RV Tau stars. Exemplary light curves and frequency spectra for modulated stars of each class are shown in Figs. 5, 6 and 7. It is interesting to note that in BL Her and W Vir variables significant peak at the modulation frequency is also detected, in agreement with model predictions. It implies that mean brightness of these stars is also modulated, just as in the case of classical Cepheids.

Modulation is particularly interesting in seven RV Tau stars. All are confined to relatively narrow period range, $\approx 30 - 35$ d. Frequency patterns are similar, namely, additional peaks (beyond fundamental mode frequency, its harmonics and sub-harmonics) located at frequencies which are always slightly larger than $5f_0/4$, $9f_0/4$ and $13f_0/4$, are detected. The most likely interpretation is periodic modulation of pulsation with periods slightly shorter than $4P_0$. The less likely interpretations are period-4 pulsation or excitation of additional non-radial modes.

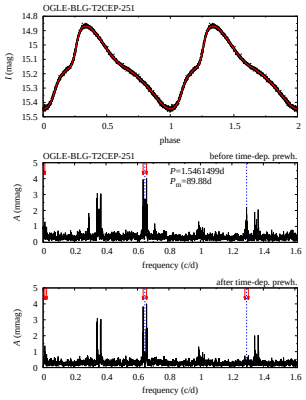

Fig. 5. Quasi-periodic modulation of pulsation in BL Her-type star. Light curve in the top panel and frequency spectra after prewhitening with the fundamental mode and harmonics (dashed lines) in the middle and bottom panels. Modulation side peaks are marked with arrows. Time-dependent prewhitening was used in the bottom panel.

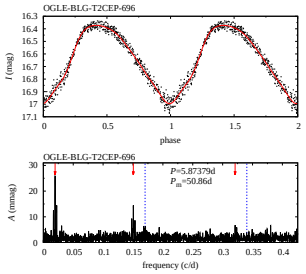

Fig. 6. Quasi-periodic modulation of pulsation in W Vir-type star. Light curve in the top panel and frequency spectrum after prewhitening with the fundamental mode and harmonics (dashed lines) in the bottom panel. Modulation side peaks are marked with arrows.

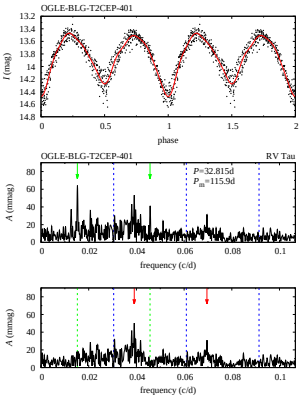

Fig. 7. Quasi-periodic modulation of pulsation in RV Tau-type star. Light curve in the top panel and frequency spectra after prewhitening with the fundamental mode and its harmonics (blue dashed lines) in the middle panel. Sub-harmonics are marked with green arrows. After prewhitening (bottom panel), modulation side peaks become well visible (close to $5f_0/4$ and $9f_0/4$; red arrows).

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