Dynamical effects in type II Cepheids

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Type II Cepheids in the OGLE Collection

Type-II Cepheids are low-mass, typically metal-poor, fundamental mode pulsators. They are divided into three subclasses: BL Her stars ($1\mathrm{d} \lesssim P \lesssim 5\mathrm{d}$), W Vir stars ($5\mathrm{d} \lesssim P \lesssim 20\mathrm{d}$) and RV Tau stars ($P \gtrsim 20\mathrm{d}$). The latter class is characterized by periodic alternations of deep and shallow brightness maxima/minima – a period doubling phenomenon. Exemplary light curves are displayed in Fig. 1. There are over nine hundreds of type II Cepheids in the OGLE-IV Galactic bulge data (Soszyński et al. 2017). Here we report the results of our study of dynamical phenomena in these stars (Smolec et al., *MNRAS*, submitted). These include first double-mode radial BL Her stars, new cases of period doubling among BL Her variables and discovery of quasi-periodic modulations in all subclasses of type II Cepheids.

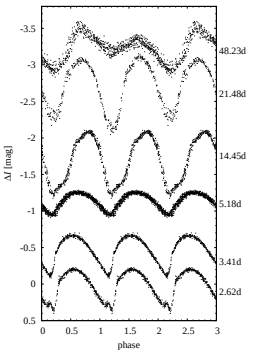

Fig. 1. Exemplary light curves of type II Cepheids from the OGLE Collection.

Double-mode radial BL Her stars

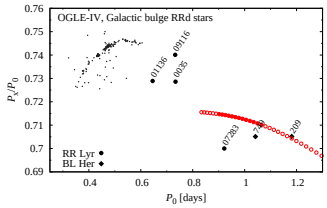

Fig. 2. Petersen diagram showing the location of classical RRd stars (small dots) and of a new group of long-period radial double-mode pulsators which consists of RR Lyrae stars (large dots) and BL Her stars (large diamonds). Linear period ratios, P_1/P_0, calculated for a sequence of models with $M = 0.6\,\mathrm{M}_\odot$, $L = 70\,\mathrm{L}_\odot$ and [Fe/H]=0.0, are plotted with red symbols.

All type II Cepheids are classified as fundamental mode pulsators. Here we report that two BL Her-type stars, T2CEP-749 and T2CEP-209, pulsate simultaneously in the radial fundamental and radial first overtone modes. Although these are the first double-mode BL Her stars, they are also members of the group of double-mode variables identified previously among long-period RR Lyrae stars (Smolec et al. 2016). These stars are characterised by long fundamental mode periods ($P_0 > 0.6\,\mathrm{d}$) as compared to majority of RRd stars, lower period ratios (Fig. 2), low amplitudes of the radial first overtone and characteristic light curve shape corresponding to the dominant fundamental mode (Fig. 3). This class now spans across RR Lyrae and BL Her classes.

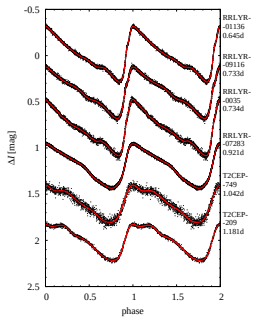

Fig. 3. Light curves for the dominant fundamental mode for the six firm members of the new double-mode group of pulsators. First four light curves are for RR Lyr-type stars, the bottom two are for BL Her type stars. IDs and pulsation periods on the right side of the plot. Note the bump on the ascending branch and its progression with increasing pulsation period.

Period Doubling in BL Her stars

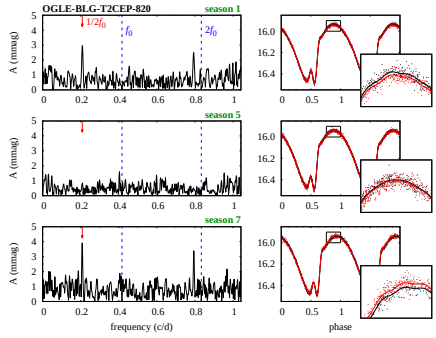

Fig. 4. Illustration of transient period-doubling phenomenon in a BL Her-type star. Left panels show the frequency spectrum after prewhitening with fundamental mode and harmonics. Right panels show the light curve with even and odd pulsation cycles plotted with different colors. Three rows show analysis for three observing seasons.

OGLE-BLG-T2CEP-279 ($P = 2.399\,\mathrm{d}$) was the first BL Her star in which period doubling effect was discovered (Smolec et al. 2012), as predicted earlier by Buchler & Moskalik (1992). The effect is caused by the 3:2 resonance between the fundamental mode and the first overtone, as studied by Moskalik & Buchler (1990). A period doubling domain that extends for $2\mathrm{d} \lesssim P \lesssim 6.5\mathrm{d}$ and covers BL Her and short-period W Vir stars is predicted by recent convective models (Smolec, 2016).

In this study we have found additional period doubling candidates among BL Her stars. Fig. 4 shows the interesting case of OGLE-BLG-T2CEP-820 ($P = 2.401\,\mathrm{d}$). In this star, period doubling is a transient phenomenon. Sub-harmonic, i.e. a signal at $1/2f_0$, which is a signature of period doubling in the frequency spectrum, is clearly detected during observing seasons 1 and 7. It is not detected during season 5. In seasons 1 and 7 the effect is also visible in the light curve, but is weak. In Fig. 4 (right most panels) we show the zooms around brightness maximum. Data are folded with fundamental mode period, but even and odd pulsation cycles and respective Fourier fits are plotted with different colors. It is interesting to note that the period doubling effect reverted in between seasons 1 and 7.

Interestingly, all period doubling BL Her-type candidates have periods in a narrow range around 2.4d, which suggests that the period-doubling domain is much smaller than predicted by the models.

Modulation in BL Her/W Vir/RV Tau stars

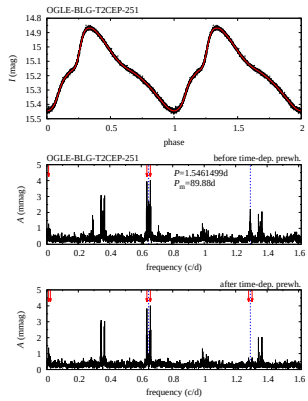

Fig. 5. Quasi-periodic modulation of pulsation in BL Her-type star. Light curve in the top panel and frequency spectra after prewhitening with the fundamental mode and harmonics in the middle and bottom panels. Time-dependent prewhitening was used in the bottom panel.

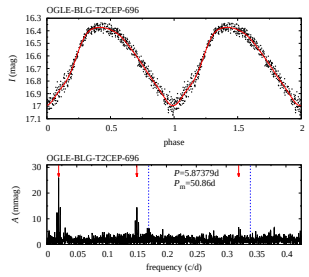

Fig. 6. Quasi-periodic modulation of pulsation in W Vir-type star. Light curve in the top panel and frequency spectrum after prewhitening with the fundamental mode and harmonics in the bottom panel.

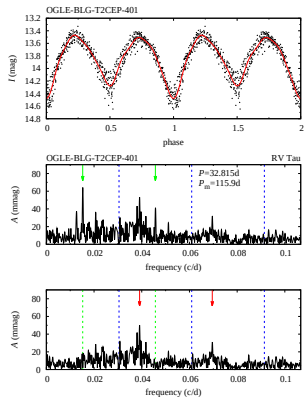

Fig. 7. Quasi-periodic modulation of pulsation in RV Tau-type star. Light curve in the top panel and frequency spectra after prewhitening with the fundamental mode and its harmonics (blue dashed lines) in the middle panel. Sub-harmonics are marked with green arrows. After prewhitening (bottom panel),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

Till recently, periodic modulation of pulsation was detected nearly exclusively in RR Lyrae stars – the famous Blazhko effect. Recently, the effect was also discovered in double-overtone Cepheids (Moskalik & Kołaczkowski 2009), fundamental mode classical Cepheids (Derekas et al. 2017; Smolec 2017) and first overtone classical Cepheids (Soszyński et al. 2015; Kotysz & Smolec 2018). The nonlinear convective models of Smolec & Moskalik (2012) and Smolec (2016) predict that periodic modulation of pulsation may occur, in narrow ranges of physical parameters, in type II Cepheids.

In our analysis we have identified several candidates for modulated type II Cepheids. In Figs. 5, 6 and 7, we show examples of BL Her, W Vir and RV Tau stars, in which modulation signature is clearly detected in the frequency spectrum. Modulation side peaks are marked with red arrows. 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.

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