Low-amplitude periodicities in the first overtone classical Cepheids

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Introduction

Classical Cepheids are variable stars, pulsating mostly in a single radial mode, either in the fundamental (F) or in the first overtone (1O) mode. Recent studies on these stars in the Magellanic System have shown that non-radial modes and other low-amplitude variabilities are not as rare as previously thought. Soszyński et al. (2008) and Moskalik & Kolaczkowski (2009) have discovered additional small amplitude variabilities in the OGLE data for LMC, falling in the period range of $P_{\rm x}/P_{1O} \in (0.6,\ 0.65)$, as well as signals close to the first overtone frequency. The list of the former stars in the SMC, detected in OGLE-III data, was published by Soszyński et al. (2010) and these stars were investigated in detail by Smolec & Śniegowska (2016).

Here we present preliminary results of our analysis of OGLE-IV data for 1O Cepheids both from the LMC and SMC (Soszyński et al. 2015). We focused on looking for signals at $P_{\rm x}/P_{1O} \in (0.6,\ 0.65)$ period ratio, as well as their subharmonics (signals at $0.5\nu_{\rm x}$) and additional low-amplitude periodicities. So far we have analysed 36% and 59% of the LMC and SMC samples, respectively, and detected additional periodicities in 271 stars from the LMC and 231 stars from the SMC.

Analysis

We analyze the OGLE-IV, *I*-band data using consecutive pre-whitening method. First, discrete Fourier transform is performed on the data in order to identify dominant frequencies. Then, the data is fitted with the sine series including aforementioned frequencies and the residuals are scanned for low-amplitude signals. 4σ outliers are removed. Slow trends are subtracted from the data using low-order polynomials or spline functions.

$P_{\rm x}/P_{1O} \in (0.6,\ 0.65)$ signals

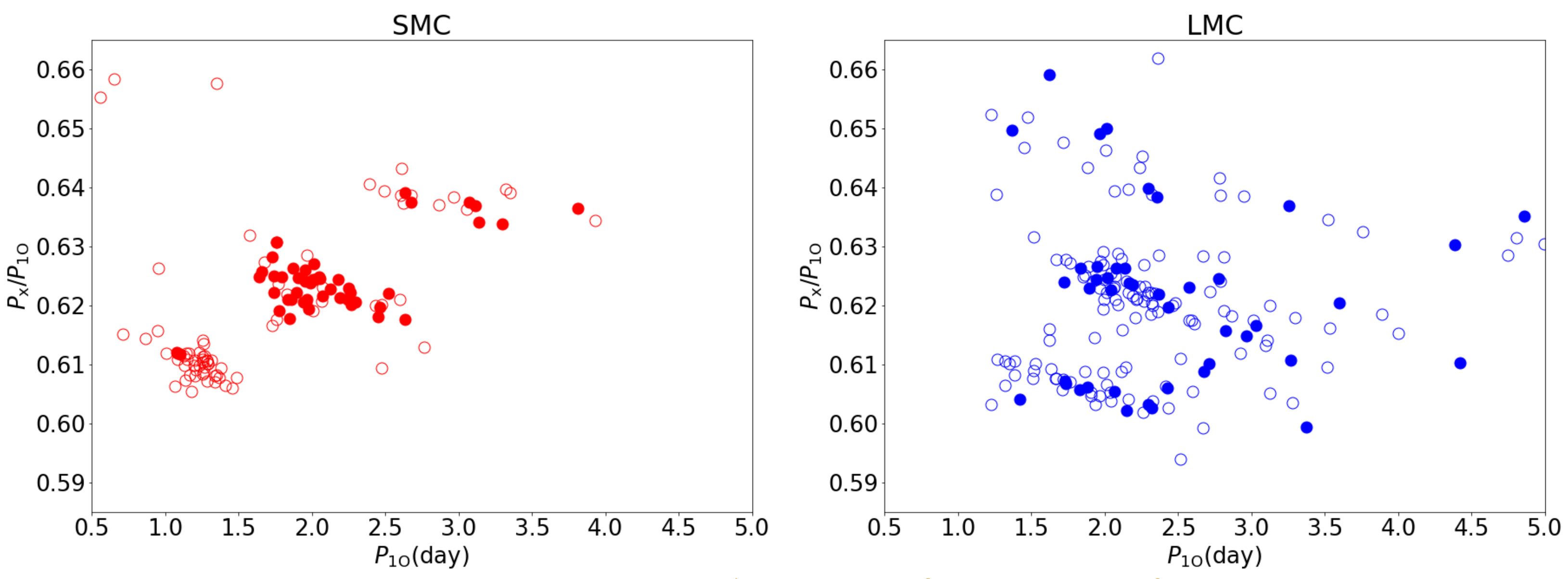

Figure 1. Petersen diagram for $P_{\rm x}/P_{1O} \in (0.6,\ 0.65)$ signals. Stars with detected subharmonic are marked with darker colour

Analyzed stars group in three sequences in the Petersen diagram (Fig. 1), which are better separated in the SMC, but still visible in the LMC. A significant amount of stars, marked with filled symbols, display a power excess centered at $0.5\nu_{\rm x}$. In the SMC these subharmonics are more common (39%) and occur mostly for the middle and upper sequence stars, whereas in the LMC those signals were detected in 25% of the stars and are evenly distributed among the three sequences.

A model proposed recently by Dziembowski (2016) explains these additional variabilities. In the model, signals at $0.5\nu_{\rm x}$ are non-radial modes of $\ell = 7, 8, 9$ degrees, and signals at $\nu_{\rm x}$ are their harmonics. Signals at $0.5\nu_{\rm x}$ are more difficult to observe due to geometrical cancellation. Cancellation is weaker for even-ℓ modes. In the SMC, as expected, we detect the non-radial modes most frequently for the middle sequence, which corresponds to $\ell = 8$ in the Dziembowski's model. This model however, faces difficulty when applied to the LMC.

$\mathrm{P_{1O}/P_x} \sim 0.68$ signals

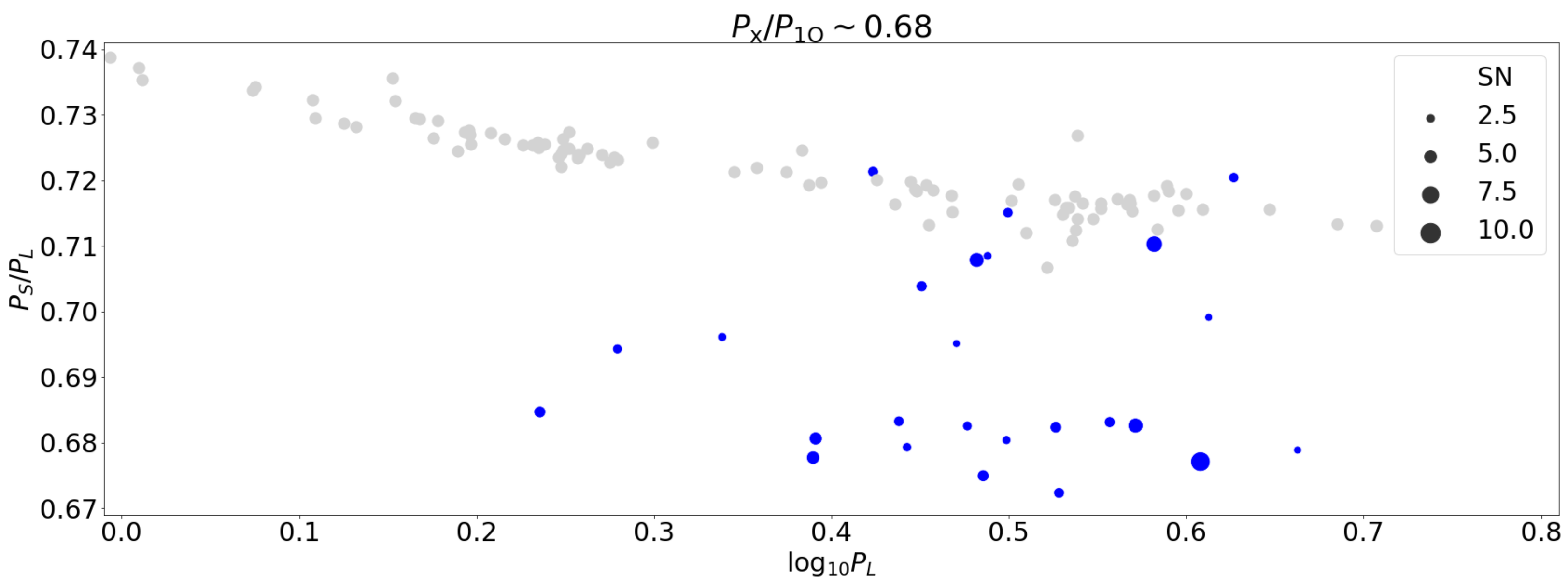

Figure 2. Petersen diagram for $P_{1O}/P_{\rm x} \sim 0.68$ signals (blue). Marker size corresponds to S/N ratio. F+1O Cepheids are marked with grey.

Amidst 271 stars with additional periodicities in the LMC, 14 display variability near $P_{1O}/P_{\rm x} \sim 0.68$ period ratio known for RR Lyrae stars (Netzel et al. 2015). The sample is small and not forming a tight sequence, like in RR Lyrae though. Explanation for such variability, with period longer than expected for the radial F mode, is still missing.

In 7 stars, we also identified signals that may correspond to double-mode pulsations in radial fundamental and first overtone modes. For comparison, in Fig. 2 we plotted F+1O Cepheids from the OGLE-IV catalog in grey.

Signals $\sim$ close to first overtone frequency

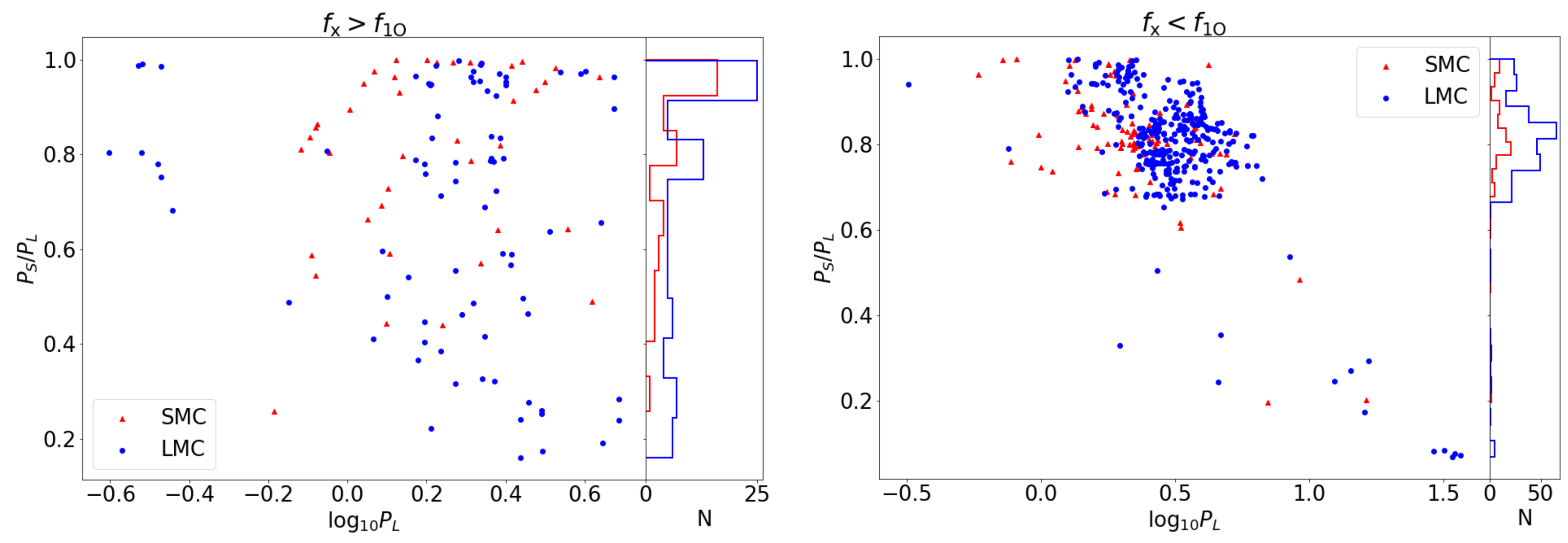

Figure 3. Petersen diagram for additional signals with frequencies higher (left) and lower (right) than the overtone frequency. Shorter-to-longer period ratio, P_S/P_L, is plotted in both panels. LMC and SMC stars are marked with different colors.

Petersen diagrams for additional signals located close to 1O frequency, and other signals that do not fit the two groups discussed previously, are presented on Fig. 3, separately for additional frequencies lower than 1O frequency (right panel) and higher than 1O frequency (left panel). The former are more numerous and constitute 80% and 70% for the LMC and SMC, respectively. For both groups period ratios are concentrated between 0.65-1.0 values, which can be seen in the histograms stacked on the right hand side of the panels. Even lower period ratios are quite frequent for the $f_{\rm x} > f_{1O}$ group and are very scarce for $f_{\rm x} < f_{1O}$ group. There is no commonly accepted explanation for these signals. They may arise due to excitation of non-radial modes. Alternatively, these signals could be interpreted as due to periodic modulation of pulsation, however the characteristic equidistant triplets or quintuplets could not be identified. In principle, for specific modulations, large amplitude asymmetry of multiplet components is possible, however, it seems unlikely, it could be the case for all detected stars. The additional signals remain puzzling.

References

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