Periodic modulation and period doubling in type II Cepheids from the OGLE Galactic bulge collection

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OGLE project and type II Cepheids

Optical Gravitational Lensing Experiment, OGLE, is a long-term photometric sky survey led by Warsaw University astronomers (Udalski et al., 1992). OGLE observes with 1.2-m telescope located in Las Campanas Observatory in Chile (Fig. 1, left; Fig. 2). It regularly monitors hundreds of fields in the direction of Galactic bulge, Galactic disc and the Magellanic System. Although its original goal was the detection of gravitational lensing events, with its top-quality and regular observations OGLE contributed to nearly all fields of astrophysics. In particular, it gathered top-quality photometry for thousands of classical pulsators: Cepheids and RR Lyrae stars that revolutionized our knowledge about these variables. Read more at http://ogle.astrouw.edu.pl/.

Cluster AgeS Experiment, CASE (e.g. Kaluzny et al. 2005) is the long-term projects that observes the globular clusters with the goal of determining the clusters' characteristics (eg., age, metallicity) by searching and analysing the variable stars. It frequently uses the 1-m Swope telescope (Fig. 1, right) located at Las Campanas observatory that was also used in the first phase of the OGLE project. CASE collected top-quality, long-baseline photometry for tens of RR Lyr stars in a few globular clusters. Read more at http://case.camk.edu.pl.

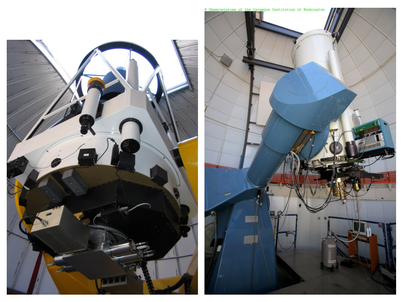

Fig. 1. The 1.2-m OGLE (left) and 1.0-m Swope (right) telescopes.

Fig. 2. The OGLE telescope in Las Campanas Observatory.
Figures 1 & 2 from http://ogle.astrouw.edu.pl/ and http://obs.carnegiescience.edu.

Nonlinear pulsation models for type II Cepheids

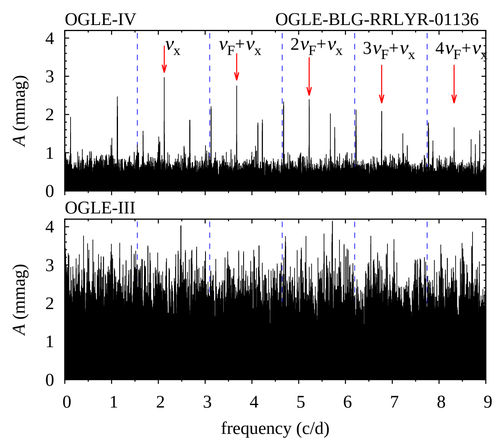

Fig. 3. Frequency spectrum for fundamental mode RR Lyr star (RRab) OGLE-BLG-RRLYR-01136. Spectra for OGLE-IV (top) and OGLE-III (bottom) data are plotted, after prewhitening with the fundamental mode and its harmonics (dashed lines). Additional signals are clearly detected in the OGLE-IV data (arrows), while in OGLE-III their detection is not possible due to much larger noise level, resulting from sparse data sampling. OGLE-IV data consist of 3092 data points gathered over 4 observing seasons, while OGLE-III data counts only 356 points (5 seasons). From Smolec et al. (2016).

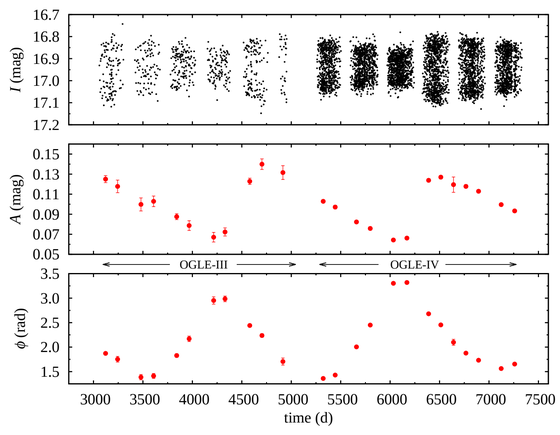

Fig. 4. To detect long-period modulations, long-baseline of the data is necessary. Top panel illustrates the photometric data for first overtone RR Lyr star (RRc), OGLE-BLG-RRLYR-12659, gathered over 12 year during the OGLE-III and OGLE-IV observations. Amplitude modulation is clear. Time-dependent Fourier analysis shows that both amplitude (middle panel) and pulsation phase (bottom panel) vary and are correlated. Modulation period is $\approx$ 1770 d. Adapted from Netzel, Smolec & OGLE (2017, in prep.).

Period Doubling

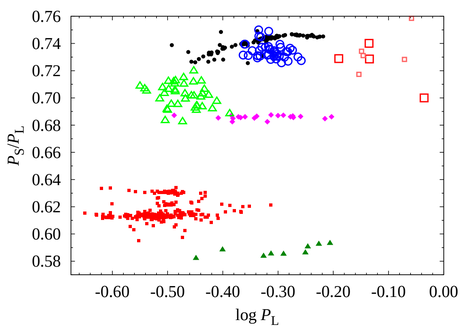

Fig. 5. Petersen diagram, i.e. the ratio of the shorter to longer period, P_S/P_L, versus the log of the longer period, $\log P_L$, for RR Lyrae stars.

A few years ago, only double-mode fundamental mode (F) and first overtone (1O) RR Lyr stars were known (RRd stars, black dots in Fig. 5). Then, a few F+2O stars were discovered, mostly among the Blazhko (modulated) variables (filled green triangles). For the discovery or for understanding of the other classes marked in Fig. 5, exploration of the OGLE data was crucial. These new classes of double-periodic variables are the following:

⋆ $\mathrm{RR}_{0.61}$ stars, with radial 1O and non-radial $\ell = 8$ and 9 modes excited (small red squares). Most of the known stars were discovered in the OGLE data (Netzel, Smolec & Moskalik, 2015a,b).

⋆ $\mathrm{RR}_{0.68}$ stars (magenta diamonds), with radial 1O and additional, long-period variability excited. Discovered in the OGLE data (Netzel, Smolec & Dziembowski, 2015).

⋆ Anomalous RRd stars (open blue circles). F+1O pulsators with anomalous period and amplitude ratios and frequent modulation of the excited modes. Discovered in the OGLE data (e.g., Soszyński et al., 2016).

⋆ Extreme RRd stars (red open squares). F+1O pulsators with extremely long periods. Discovered in the OGLE data (Smolec et al., 2016).

⋆ Double-periodic stars with atypical light curve shape, in between the shapes characteristic for F-mode and 1O mode pulsators (open green triangles). Discovered in the OGLE data (Prudil et al., 2017).

Modulation in BL Her/W Vir stars

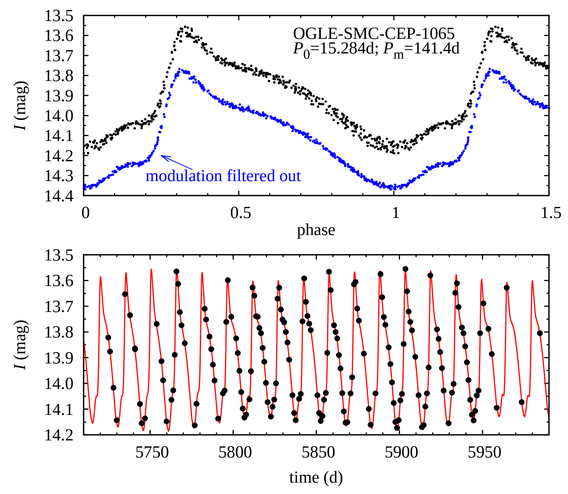

Fig. 6. Illustration of the periodic modulation in OGLE-SMC-CEP-1065. Phased light curve (top) and time-series with model plotted on top (bottom).

In 51 fundamental mode Cepheids of the OGLE collection periodic modulation of the light curves was detected (Smolec, 2017; Fig. 6). Although the overall incidence rate is very low, $\approx$ 1% in each of the Magellanic Clouds, in the case of the SMC and pulsation periods between 12 and 16 d the incidence rate is nearly 40%. Typical modulation periods are between 70 and 300 d. In nearly all stars the mean brightness is modulated, which, in principle, may influence the use of classical Cepheids for distance determination. Fortunately, the modulation of mean brightness does not exceed 0.01 mag in all but one star. Also, the effect averages out in typical observations spanning a long time base. Hence, in studies of sizeable samples of Cepheids with good phase coverage of the light curves, modulation has no practical effect on the distance determinations. It is clear however, that our understanding of the most important astrophysical candles is far from being complete.

Modulation in RV Tau stars

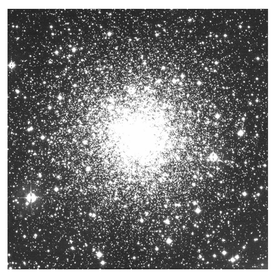

Fig. 7. The V-band image of NGC 6362 observed by the CASE project.

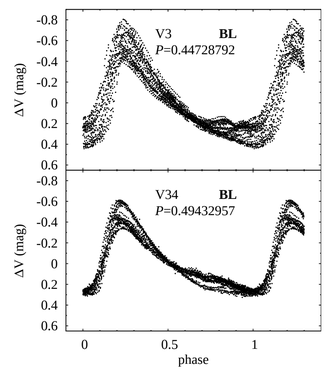

Fig. 8. Light curves of two anomalous RRd stars observed in NGC 6362.

NGC 6362 (Fig. 7) is a nearby globular cluster that was extensively observed by the CASE project with the Swope telescope (Fig. 1) from 1995 to 2009. The top-quality photometry (see Fig. 8) enabled a detailed study of the dynamical properties of its 34 RR Lyr-type variables (Smolec et al., 2017). In many respects, this globular cluster and its RR Lyr sample are record holders:

⋆ The incidence rates of Blazhko phenomenon, 69% in RRab variables and 19% in RRc variables, are among the highest reported in the ground-based observations so far.

⋆ 63% of RRc variables are in fact double-periodic and belong to the $\mathrm{RR}_{0.61}$ class. It is the highest incidence rate of this form of pulsation in the ground-based observations so far.

Other important results are:

⋆ Two stars previously classified as RRab, turned to be anomalous RRd variables. Their light curves, with clear signature of modulation, are plotted in Fig. 8.

⋆ Very rare double-periodic modulations were detected in two stars.

Download:

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