RR Lyrae stars: new discoveries in the OGLE photometry

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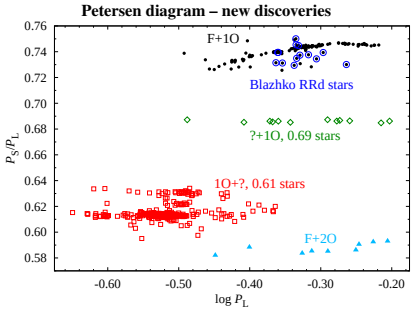
Non-radial modes, Blazhko effect and more...

OGLE data

The space-borne photometry surpasses the ground-based observations in precision and duty cycle, but lags behind when it comes to the number of observed variable stars. Here, massive sky surveys, like Optical Gravitational Lensing Experiment (OGLE, Udalski, Szymański & Szymański, 2015) are hard to beat and allow to detect rare phenomena.

We report the analysis of OGLE photometry of RR Lyrae stars towards the Galactic bulge (Soszyński et al. 2011, 2014). We analysed the full OGLE-III sample of first overtone RR Lyr (RRc) stars and data from only two fields observed in OGLE-IV with high cadence. For stars in these fields we have more than 8000 photometric measurements over 4 years. Our analysis revolutionized the view of the Petersen diagram for RR Lyr stars. We significantly increased the number of double-periodic pulsators of the already known classes and discovered new and intriguing groups of multi-periodic RR Lyr pulsators.

Petersen diagram – new discoveries



Shorter to longer period ratio of the excited modes, P_S/P_L, versus the logarithm of the longer period.

Radial–radial double mode pulsators:
⋆ F+1O (RRd stars); known for years
⋆ F+2O; discovered from space and from the ground; see Moskalik (2013) for review

Radial–non-radial double mode pulsators:
⋆ 1O+? (0.61 stars); discovered since 2007. 261 out of 302 known, i.e. ≈86% **are OGLE discoveries.**
⋆ ?+1O (0.69 stars); **NEW!**

Puzzling double mode pulsators:
⋆ RRd stars with Blazhko effect **NEW!**

Non-radial modes in RRc stars

The non-radial nature of all RRc stars?

The additional mode with characteristic period ratio, $P_x/P_{1O} \approx 0.61$, was first discovered in AQ Leo, RRd star observed with *MOST* (Gruberbauer et al. 2007). Then, 22 additional variables with similar period ratio were detected among RRc/RRd stars observed both from the ground and from space (by *Kepler* and *CoRoT*, see e.g., Szabó et al. 2014, Moskalik et al. 2015, Molnár et al. 2015). Period ratio indicates that **additional mode must be non-radial**. 13 out of 14 stars observed from space show the additional mode, indicating that the phenomenon must be common among RR Lyr stars with first overtone excited. This group of double-periodic radial–non-radial pulsators is called **0.61 stars** in the following.

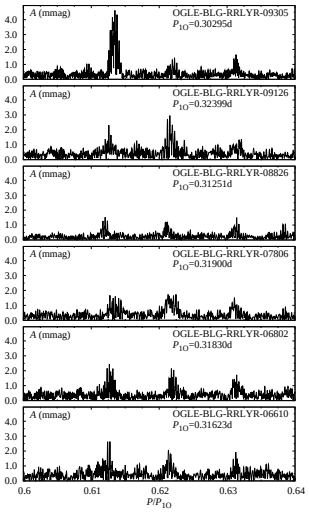
We first analysed all OGLE-III Galactic bulge RRc stars (≈ 5 000) in search for the additional mode and found 147 new 0.61 stars (3 %). Then we analysed the data from two fields towards the Galactic bulge observed in OGLE-IV. The large number of observations reduced the noise level and allowed the discovery of 132 0.61 stars, which is 27 % of the analysed sample. In several stars of this type we detect simultaneous excitation of three non-radial modes, which gives rise to three sequences in the Petersen diagram. The three sequences are detected for the first time. Additional modes and their subharmonics, detected in several stars, display a complex and time-dependent structure in the frequency spectrum. Read more in Netzel, Smolec & Moskalik (2015a,b).

Recently, Jurcsik et al. (2015) published their analysis of dedicated observations of M3. They also find high incidence rate of 0.61 variables, ≈38%.

Gravity modes in RRc stars?

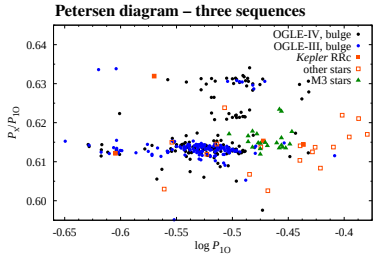
In 11 stars identified in the OGLE catalogue as RRc pulsators, we detect additional longer period variability of low amplitude, in the mmag regime. One additional star of the same type is identified in a published analysis of the *Kepler* photometry. The period ratio between the shorter first overtone period and a new, longer period lies in a narrow range around 0.686. Thus, the additional period is longer than the expected period of the undetected radial fundamental mode. The most probable interpretation is that additional periodicity corresponds to a gravity mode. Read more in Netzel, Smolec & Dziembowski (2015).

Three non-radial modes



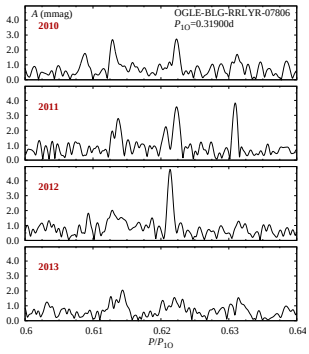
Frequency spectra with normalized period scale, P/P_{1O}, on horizontal axis. In several stars we detect two or three modes with slightly different periods. They give rise to three sequences in the Petersen diagram with slightly different period ratios. The corresponding peaks are non-stationary, in fact clusters of peaks are detected rather than single peaks.

Petersen diagram – three sequences



The diagram shows all known 0.61 variables (302 stars). Three sequences are clear in the OGLE data. Majority of other known stars also fall to one of the sequences.

Season-to-season variation



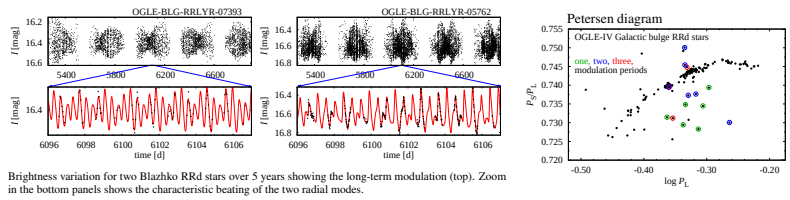
Season-by-season analysis of the data reveals strong time-dependence of the excited modes: their amplitude and phase strongly vary in time. As a consequence, in the frequency spectrum of all data, the modes appear in the form of a cluster of non-coherent peaks.

Discovery of the Blazhko effect in RRd stars

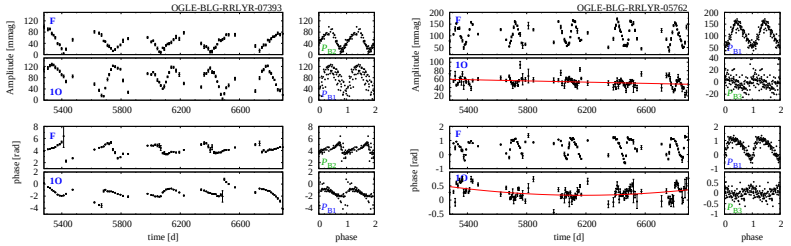
Atypical period ratio, Blazhko effect and more

Using OGLE-IV data we detect Blazhko effect in 15 RRd stars. Most of them have non-typical period ratio of the radial modes. In the Petersen diagram, at a given period of the fundamental mode, they are located significantly below or above the sequence formed by the majority of RRd stars. Multiperiodic modulation is very frequent; two or three modulation periods are detected in eight stars. Modulation periods range from ∼20 d to more than 300 d. Radial mode amplitudes can be modulated by a few to nearly 100 per cent. Both radial modes may be modulated with the same period. More commonly however, dominant modulation for the fundamental mode has different period than dominant modulation for the first overtone. Quite often modulation of only one mode is detected in the data. All the stars share the common feature: their pulsation properties are non-stationary. Amplitudes and phases of the radial modes vary irregularly on a long time-scale of a few hundred or thousand days. The short-term modulations are also irregular. Read more in Soszyński et al. (2014) and Smolec et al. (2015).

Recently, Jurcsik et al. (2014) discovered four modulated RRd stars in M3 that share the same characteristics as Galactic bulge stars.



Brightness variation for two Blazhko RRd stars over 5 years showing the long-term modulation (top). Zoom in the bottom panels shows the characteristic beating of the two radial modes.



Left panels: time variation of radial mode amplitudes and phases; right panels: data phased with the dominant modulation period.

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