Multiperiodic RR Lyrae stars in the field of NGC6362

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NGC 6362 – observations and data analysis

NGC 6362 is a nearby (μ_V=14.68 mag) globular cluster of Oosterhoff I type. It has a mean metallicity of [Fe/H]$= -0.95$ and belongs to the old halo population (Catelan, 2009). The cluster hosts 35 RR Lyrae-type stars (Olech et al. 2001). In this presentation we revisit these variables, taking advantage of the new photometry accumulated by the Cluster AgeS Experiment (CASE; Kaluzny et al. 2005). The main goal is to conduct a detailed study of dynamical properties of the RR Lyrae stars of NGC 6362, with special emphasis on detecting the Blazhko effect and additional low amplitude pulsation modes.

Our analysis is based on CCD photometry obtained with the 1-m Swope telescope of the Las Campanas Observatory, equiped with the 2048×3159 SITE3 camera with a resolution of 0.425 arcsec/pixel. Observations were conducted from July 8th, 1999 to September 9th, 2009. 3200 V-band images were collected. The images were reduced with the DIAPL package. The frequency analysis of the data was performed with the standard consecutive prewhitening technique. First, the significant frequencies were identified with the discrete Fourier transform. They were included in the sine series which was fitted to the data. The residuals of the fit were then searched for additional low-amplitude signals, which were iteratively included in the fitting formula.

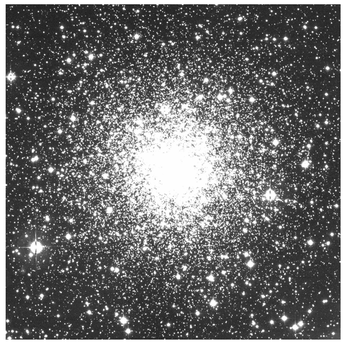

Fig. 1. The V-band reference image of NGC 6362 obtained with the Swope telescope.

RR Lyrae inventory

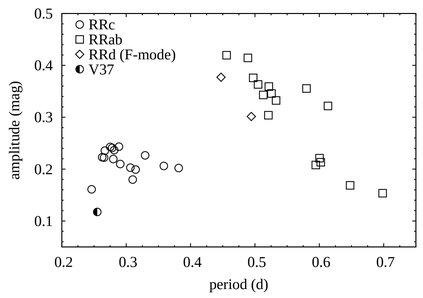

Fig. 2. Period-amplitude diagram for RR Lyrae variables of NGC 6362. Note that Fourier amplitudes are used. Separation of RRab and RRc variables is clear.

RR Lyrae stars are large amplitude, predominantly radial pulsators. In Fig. 2 we present period-amplitude diagram (Fourier amplitudes) for the RR Lyrae stars of NGC 6362. The variables separate in this plot in two distinct groups. 16 stars are fundamental mode pulsators (RRab variables) and 16 are first overtone pulsators (RRc variables). They are marked in the plot by open squares and open circles, respectively. Two objects, previously identified as RRab stars, turned out to be double mode pulsators (RRd stars), with radial fundamental mode and radial first overtone simultaneously excited. These stars are plotted as open diamonds. They are located in the diagram close to the RRab stars, because their pulsations are strongly dominated by the fundamental mode. Finally, V37 is a peculiar variable in which we detect two close high-amplitude periodicities. The star was originally classified as RRc variable (Olech et al. 2001), but lightcurves of both modes are in fact significantly different in shape from typical lightcurves of the RRc stars. The nature of V37 is therefore a puzzle. We will not discuss this variable here any further.

Non-radial modes

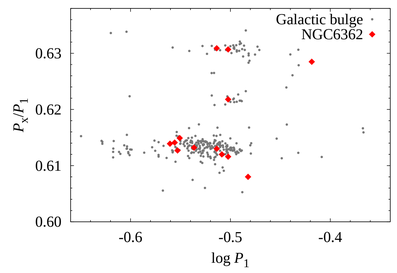

Fig. 3. Petersen diagram for RRc stars with secondary, short-period variability, $P_x/P_1 \in (0.60, 0.65)$. Galactic bulge stars (Netzel et al. 2015) are marked with small grey dots. New detections in NGC 6362 are mareked with red diamonds.

In 10 out of 16 RRc stars of NGC 6362 (63% of the sample) we detect a secondary short period variability, with the period ratio falling in the range of $P_x/P_1 = 0.60 - 0.65$. The amplitudes of these secondary signals are always very low, below 6 mmag. Double-periodic pulsators of this type are not new. Similar stars have recently been discovered in many stellar systems (Netzel et al. 2015 and references therein). Space observations indicate that this form of variability must be very common and most likely occurs in almost all RRc and RRd stars (Moskalik et al. 2015). Detecting it in the ground-based observations is difficult, however, because of the extremely low amplitude of the secondary signal. The incidence rate of 63%, that we report for NGC 6362, is the highest among all stellar system observed from the ground. The properties of the stars identified in NGC 6362 are qualitatively similar to those discovered in the Galactic bulge. In particular, in the period ratio vs. period diagram (so called Petersen diagram; Fig. 3) they fall within the three sequences defined by the Galactic bulge stars.

The period ratios of $0.60-0.65$ cannot be explained by two radial modes. This implies that the secondary periodicities observed in the RRc stars must be due to non-radial modes of oscillation. In the recently proposed model of Dziembowski (2016), these periodicities are identified with the harmonics of non-radial modes of angular degrees of $\ell = 8$ and 9. In this picture, the non-radial modes themselves have amplitudes lower than their harmonics, because of geometric cancelation effects.

The Blazhko effect

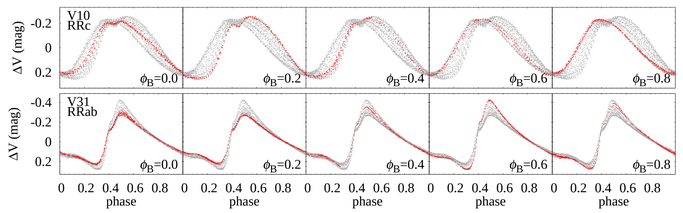

Fig. 4. Illustration of the Blazhko effect in RRc variable V10 (top) and RRab variable V31 (bottom). In consecutive panels, we plot the light curves at five phases of the Blazhko modulation.

Blazhko effect is a periodic (or almost periodic) modulation of pulsation amplitudes and phases. In the frequency domain it manifests itself as a presence of equally spaced triplets (or higher multiplets) centered on the pulsation frequency and its harmonics. The separation of components within the multiplet corresponds the modulation frequency. Sometimes only a doublet is detected, with the other component of the triplet hidden in the noise. The Fourier analysis is the most sensitive method of detecting the Blazhko modulation.

We have found the Blazhko effect in 11 RRab and in 3 RRc stars of NGC 6362. This corresponds to incidence rates of 69% and 19%, respectively, which are among the highest reported in the ground-based observations. The observed modulation periods range from 17.3 day to 216.4 day for RRab stars and from 8.5 day to 15.5 day for RRc stars. In one RRc and in one RRab star we find a rare double-periodic Blazhko effect. The weakest modulation detected in NGC 6362 has a peak-to-peak amplitude of only 7 mmag (in the RRc star V36).

In Fig. 4 we illustrate the Blazhko effect in the RRc variable V10 ($P_{\rm mod} = 8.52$ day) and in the RRab variable V31 ($P_{\rm mod} = 82.27$ day).

Anomalous RRd variables

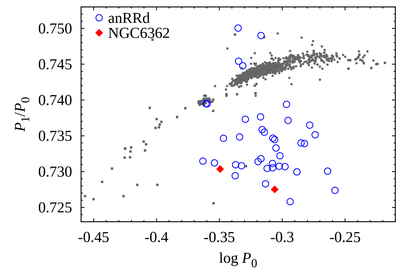

Fig. 5. Petersen diagram with stars classified as 'classical' RRd (small grey dots) and anomalous RRd (blue circles). New detections in NGC 6363 are marked with red diamonds.

Two stars previously classified as RRab variables, V3 and V34, turned out to be double mode pulsators. In addition to the dominant radial fundamental mode we detect a radial first overtone of low amplitude. The period ratios of the two modes in V3 and V34 are 0.730 and 0.728, respectively. These values are significantly lower than for the majority of the 'classical' RRd stars of the same fundamental mode period. In both stars we detect the Blazhko effect, with either the fundamental mode only (V34) or both radial modes (V3) being modulated. Lower than usual period ratios, strong domination of the radial fundamental mode and presence of a long-period Blazhko modulation all indicate that V3 and V34 are not typical RRd stars. These stars must be classified as new members of the recently identified group of the anomalous RRd variables (Soszyński et al. 2016). Indeed, when plotted on the Petersen diagram (Fig. 5) both stars fall comfortably among other anomalous RRd variables identified in other stellar systems.

References

Catelan M., 2009, *Astrophys. Space Sci.*, **320**, 261
Dziembowski W., 2016, *Comm. Konkoly Obs.*, **105**, 23
Kaluzny J., et al. 2005, *AIP Conf. Proc.*, **752**, 70
Netzel H., Smolec R., Moskalik P., 2015, *MNRAS*, **453**, 2022
Moskalik P., Smolec R., Kolenberg K. et al., 2015, *MNRAS*, **447**, 2348
Olech A., Kałużny J., Thompson I., et al., 2001, *MNRAS*, **321**, 421
Soszyński I., Smolec R., Dziembowski W., et al., 2016, *MNRAS*, **463**, 1332

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