Multiperiodic RR Lyrae Stars in Omega Centauri

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Abstract

We have conducted a systematic search for multiperiodic pulsations in the RR Lyrae-type stars of the galactic globular cluster $\omega$ Cen. Secondary periodicities close to the primary pulsation frequency have been detected in 17 out of 70 studied fundamental mode (RRab) pulsators and in 35 out of 81 overtone (RRc) pulsators. Because of the observed period ratios, these newly detected periodicities must correspond to nonradial modes. Their beating with the primary radial pulsation leads to a slow amplitude and phase modulation, commonly referred to as the Blazhko effect. The incidence rate of Blazhko modulation in $\omega$ Cen RRab stars ($24 \pm 5\%$) is similar to that observed in the Galactic Bulge. In the case of $\omega$ Cen RRc stars, the incidence rate of Blazhko effect is exceptionally high ($38 \pm 5\%$), more than 3 times higher than in any other studied population.

In addition to Blazhko variables, we have also identified two RR Lyr variables exhibiting first overtone/second overtone double-mode pulsations, and a triple-mode High Amplitude $\delta$ Scuti variable.

1 Introduction

Omega Centauri ($\omega$ Cen) is the largest globular cluster of the Galaxy. It contains about one million stars of which almost 500 are known to be variable (Kaluzny et al. 2004, Weldrake et al. 2007). Recently, precise $B$ and $V$ CCD photometry of variables in $\omega$ Cen were obtained by Cluster AgeS Experiment (CASE) team (Kaluzny et al. 2004). Among others, they published precise light curves of 151 RR Lyr stars belonging to the cluster. These light curves contained from 594 to 761 points and were collected in period from 1999 February 6/7 to 2000 August 9/10.

2 Frequency analysis

We conducted the search for periodicities in individual RR Lyr stars. The analysis was performed in two ways.

We searched for additional signal in $\omega$ Cen RR Lyrae stars with the standard consecutive prewhitening technique. First, the data were fitted with the single frequency Fourier sum of the form:

$$m(t) = A_0 + \sum_k A_k \cos(2\pi k f_0 t + \phi_k)$$

The pulsation frequency $f_0 = 1/P_0$ was also optimized in the fitting process. The fit Eq.(1) was then subtracted from the data and the residuals were searched for secondary periodicities. This was done with the Fourier power spectrum computed over the range of $0 – 5$ c/d. If any additional signal
was detected, a new Fourier fit with all frequencies identified so far and with their linear combinations was performed. All frequencies were optimized anew. The new fit was subtracted from original time-series data and residuals were searched for additional periodicities again. The process was repeated until no new frequencies appeared. At this stage, we performed data clipping, by rejecting all measurements deviating from the fit by more than $5\sigma$, where $\sigma$ is the dispersion of residuals. After removing deviating datapoints, the entire frequency analysis was repeated.

The second method, also based on the consecutive prewhitenings, differed by treatment of the residua. We started from the ANOVA periodogram (Schwarzenberg-Czerny 1996) of the raw light curve and searched it for the peak frequency. Then the light curve was prewhitened with the frequency just identified. Depending on the amplitudes we removed up to 15 harmonics of the frequency from the the prewhitened data of the previous stage. Next we recomputed the ANOVA periodogram for the residuals and the whole procedure was repeated recursively till no feature exceeded ANOVA value of 15.

It is worth to note that both methods produce, within errors, the same results. The only discrepancies appeared when a real period and its alias have similar height and one method preferred one peak and the second the other one. In this case we have chosen the fit with smaller formal error.

3 Results

We detected secondary periodicities close to the primary pulsation frequency in 17 out of 70 fundamental mode pulsators (RRab or RR0 stars) and in 31 out of 81 first overtone pulsators (RRe or RR1 stars). The new frequencies are well-resolved within our dataset and do not result from secular period variability. The derived period ratios are incompatible with those of the radial modes. Consequently, the newly detected secondary frequencies must correspond to nonradial modes of oscillations. The beating between these nonradial modes and the primary radial pulsation leads to a slow modulation of the observed light curve, a phenomenon known as the Blazhko effect.

![Typical examples of different frequency patterns encountered in the RRab variables. A true monoperiodic star is shown in the top panel of the plot.](image)

In RRab variables two nonradial modes were detected in most cases. Together with the primary
peak, they form an equally spaced triplet of frequencies, centered on the primary peak. Following Alcock et al. (2000) we call such stars RR0-BL variables. In 3 RRab stars only one nonradial mode is present (RR0-v1 variables). Finally, an even more complicated pattern was detected in variable V11. In this object we found an equidistant triplet plus an additional peak on the high frequency side of the primary peak. In Fig. 1 we display typical examples of different frequency patterns encountered in the RRab variables. For comparison, we show a true monoperiodic star in the top panel of the plot.

In RRc variables usually only one nonradial mode was detected (RR1-v1 stars). Equidistant triplets were found only in 4 variables (RR1-BL stars). However, more complicated patterns are seen in RRc stars much more frequently than in the RRab stars. In 6 variables we detected nonequidistant triplets of modes. In other 4 RRc stars, even richer frequency patterns with up to 7 nonradial modes were found.

Our findings are summarized in Tables 1 and 2. In ω Cen fundamental mode RR Lyrae stars the incidence rate of nonradial modes is $24.3 \pm 5.1\%$. This is twice the rate observed in the LMC, but identical to the rate in the Galactic Bulge. For ω Cen overtone RR Lyrae stars the incidence rate of nonradial modes is $38.3 \pm 5.4\%$, which is exceptionally high. This is by far the highest rate among all studied RRc populations, being 3 times higher than in the Bulge and 4 times higher than in the LMC.

### Table 1: Incidence rates of nonradial modes in RRab stars in LMC, Galactic Bulge and ω Cen.

|        | LMC Alcock et al. (2003) | Bulge Mizerski (2003) | Bulge Collinge et al. (2006) | ω Cen this work |
|--------|--------------------------|-----------------------|-------------------------------|------------------|
| RR0    | 6158                     | 1942                  | 1888                          | 70               |
| RR0-v1 | 400 6.5%                 | 243 12.5%             | 167 8.8%                      | 3 4.3%           |
| RR0-BL | 331 5.4%                 | 143 7.4%              | 282 14.9%                     | 13 18.6%         |
| RR0-oth| 20 0.3%                  | 86 4.4%               | 75 4.0%                       | 1 1.4%           |
| All NR | 751 12.2%                | 472 24.3%             | 524 27.8%                     | 17 24.3%         |

### Table 2: Incidence rates of nonradial modes in RRc stars in LMC, Galactic Bulge and ω Cen.

|        | LMC Alcock et al. (2000) | LMC Nagy & Kovács (2006) | Bulge Mizerski (2003) | ω Cen this work |
|--------|--------------------------|---------------------------|-----------------------|------------------|
| RR1    | 1143                     | 1161                      | 771                   | 81               |
| RR1-v1 | 24 2.1%                  | 46 4.0%                   | 22 2.9%               | 17 21.0%         |
| RR1-BL | 28 2.4%                  | 53 4.6%                   | 30 3.9%               | 4 4.9%           |
| RR1-oth| 8 0.7%                   | 13 1.1%                   | 41 5.3%               | 10 12.3%         |
| All NR | 60 5.2%                  | 112 9.6%                  | 93 12.1%              | 31 38.3%         |

### 4 Other interesting cases

In the course of systematic frequency analysis of ω Cen RR Lyrae stars we found two double mode pulsators. These are the first double mode RR Lyrae variables identified in this globular cluster. The
period ratios in both stars are close to 0.80, which implies pulsations in the first two radial overtones. Properties of both variables are summarized in Table 3.

### Table 3: FO/SO double mode RR Lyrae stars in ω Cen

| Star  | $P_1$ [day] | $P_2$ [day] | $P_2/P_1$ | $A1$ [mag] | $A2$ [mag] |
|-------|-------------|-------------|-----------|------------|------------|
| V10   | 0.3749761   | 0.2991768   | 0.797856  | 0.18305    | 0.00668    |
| V145  | 0.3732140   | 0.2986517   | 0.800216  | 0.20481    | 0.00894    |

RR Lyrae stars pulsating in the first and second overtone (FO/SO variables) have been previously discovered in the LMC (Alcock et al. 2000). However, Soszyński et al. (2003) have noticed, that all these stars are about 1 mag brighter than typical RR Lyrae stars in the LMC and suggested that they might belong to short-period double mode Cepheids. In contrast, the two FO/SO double mode pulsators discovered in ω Cen belong to the RR Lyrae population of the cluster without any doubt.

In one object, V168, we discovered triple mode pulsations. This star varies with $P_0 = 0.3212979$ day, $P_1 = 0.2465336$ day and $P_2 = 0.1967626$ day. The resulting period ratios are $P_1/P_0 = 0.767305$ and $P_2/P_1 = 0.798117$. These ratios indicate that V168 pulsates in the fundamental mode and the first two radial overtones (FU/FO/SO pulsator). The value of $P_1/P_0$ is too large for RR Lyrae stars, but it is rather typical for High Amplitude δ Scuti stars (HADS), especially for those with longest periods (Poretti et al. 2005). We note in passing, that period ratios of V168 are very similar to ratios observed in two other triple mode HADS, V829 Aql (Handler et al. 1998) and V823 Cas (Jurcsik et al. 2006).

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