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The light curves of the short-period variable stars in ω Centauri

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Abstract. The Fourier decomposition was applied to the light curves of the short period variable stars discovered by the OGLE team (Kaluzny et al. 1996, 1997) in ω Cen. The progression of the ϕ_{21} parameter as a function of the period is extended toward very short periods as the new values connected directly to those of stars located in the Galaxy. However, two groups of stars deviate: the first is located around 0.038 d and it shows rather high ϕ_{21} values; the second is the origin of a small change in the slope around 0.050 d. The reality of the two features is discussed. The peculiarity of the light curve of OGLEGC 26 is also emphasized.

Key words: methods: data analysis – stars: oscillations – stars: variables: δ Sct – Galaxy: globular clusters: individual: ω Cen

1. Introduction

Pulsating variables are being continuously discovered in the course of large–scale projects. The Fourier decomposition describes their light curves in a powerful, synthetic way, supplying information on the pulsational content. As an example, Fourier parameters give the possibility to determine if a Cepheid pulsates in the fundamental or in an overtone mode (see Pardo & Poretti 1997 for an application to double–mode Cepheids) and this could make any Period–Luminosity relationship more clear.

The analysis of the light curve of short–period pulsating variables (P <0.20 d) was carried out firstly by Antonello et al. (1986); then Poretti et al. (1990) and Musazzi et al. (1998) supplied new observational evidence. All these stars are located in the Galaxy and they do not belong to clusters; we shall call them hereinafter "galactic" variables. They are both Pop. I (δ Sct stars) and Pop. II (SX Phe stars) objects; no clear separation of the light curves as a function of the population was detected.

The OGLE project collected a large amount of photometric data while monitoring the globular cluster NGC 5139$\equiv$ ω Cen (Kaluzny et al. 1996, 1997). 34 new SX Phe stars were discovered: 24 are presented by Kaluzny et al. (1996), 10 by Kaluzny et al. (1997). These data can supply original results since galactic stars do not display periods shorter than 0.06 d, while in the ω Cen sample this value is rather an upper limit. Therefore, we have an opportunity to verify if there is a straight connection between the two different samples and, if any, to extend the period baseline.

2. Period verification and refinement

The time baseline covered by the OGLE monitoring is around 120 days (i.e. a single observing season) for most of the stars, but in 9 cases the available data extend over two seasons. In this case, an improvement of the goodness of the fit could be obtained by calculating a solution for each season and then aligning the mean magnitudes (this procedure was applied to the measurements of OGLEGC 3, 4, 5). As a matter of fact, shifts up to 0.048 mag were observed in Field 5139BC, which are surely due to observational or instrumental problems. In two cases (OGLEGC 42, 45), we did not consider the data obtained in one season, as they were a small part of the total and probably affected by a misalignment which was difficult to quantify. In the remaining four cases (OGLEGC 9, 29, 38, 59) the procedure of the re-alignment did not introduce appreciable effects on the fit.

We made an independent period search. Since the baseline and the number of measurements were appropriate, all the values previously known were confirmed. Only the case of OGLEGC 34 deserves some comment. Kaluzny et al. (1996) suspected a double–mode nature on the basis of the period search carried out with the CLEAN algorithm. We performed the frequency search by using the least–squares iterative method (Vaniĉek 1971) and we obtained the power spectra shown in Fig. 1 (upper panel). The peak at f=26.1611 cd^{-1} is the highest, but the difference with respect to the alias at 25.1611 cd^{-1} is very small. When introducing f as a known constituent, the power spectrum did not reveal any significant feature in the range that would be expected for a second period (lower panel). The CLEAN algorithm is probably responsible for the result quoted by Kaluzny et al. (1996): because it cannot match the odd noise distribution, the signal is spread at different peaks. OGLEGC 34 is probably monoperiodic, but the period is uncertain and may be either one of the two values reported above; we have a slight preference for f=26.1611 cd^{-1} because it gives a better fit and a better residual power spectrum. Note also in the lower panel of Fig. 1 the increasing noise at very low frequencies, the fingerprint of night–to–night misalignments.

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Table 1. The phases differences ($\phi_{21}, \phi_{31}, \phi_{41}$) and amplitude ratios ($R_{21}, R_{31}, R_{41}$) obtained from the Fourier decomposition are reported together with period values. The half–amplitude of the light variation is also reported. In 12 cases the $2f$ term (i.e. the first harmonic) was not detected.

OGLEGC	Period [d]	$<V>$	A_1 [mag]	ϕ_{21} [rad]	R_{21}	ϕ_{31} [rad]	R_{31}	ϕ_{41} [rad]	R_{41}
28	0.036134870	16.739	0.03	2.75	0.09				
39	0.036973661	17.558	0.02	4.03	0.12				
38	0.037484631	17.524	0.03	2.73	0.17				
36	0.037533733	17.400	0.04	4.65	0.09				
33	0.037826061	17.437	0.04	2.86	0.10				
26	0.038668115	17.348	0.04	1.28	0.33				
29	0.038911717	17.310	0.02	3.72	0.12				
25	0.043739175	17.143	0.03	3.25	0.13				
62	0.046620047	17.462	0.03	4.13	0.17				
1	0.046120912	17.026	0.06	3.44	0.21				
2	0.048181161	17.404	0.06	3.75	0.48				
6	0.050652146	17.202	0.09	3.50	0.21	0.84	0.05		
27	0.052887667	17.054	0.06	3.22	0.10				
8	0.041784708	16.749	0.16	3.35	0.16				
50	0.047180040	17.050	0.23	3.61	0.29	1.43	0.07		
32	0.048640261	16.995	0.13	3.61	0.27				
9	0.049374914	16.943	0.19	3.71	0.25	1.28	0.06	5.30	0.03
4	0.049520847	16.720	0.15	3.73	0.27				
42	0.057399999	17.006	0.25	3.53	0.25				
3	0.062286809	16.641	0.27	3.60	0.41	1.25	0.20	5.06	0.10
5	0.065491187	16.805	0.16	3.70	0.39	1.24	0.15		
45	0.065600010	16.849	0.11	3.68	0.34	1.15	0.12		

3. Fourier parameters

As a further step, we fitted the V magnitudes by means of the formula

$$V(t) = V_o + \sum_i A_i \cos[2\pi\, i\, f(t - T_o) + \phi_i] \quad (1)$$

where f is the frequency, measured in cycles per day (cd^{-1}). From the least–squares coefficients we calculated the Fourier parameters $R_{ij} = A_i/A_j$ (in particular $R_{21} = A_2/A_1$) and $\phi_{ij} = j\,\phi_i - i\,\phi_j$ (in particular $\phi_{21} = \phi_2 - 2\,\phi_1$). These parameters are reported in Table 1; the mean magnitude of OGLEGC 29 is assumed from Kaluzny et al. (1996) as the values listed in the electronic table are shifted up by 2.5 mag. The period values obtained from the least–squares routine are listed, but they do not differ greatly from those reported by Kaluzny et al. (1996, 1997).

Typical error bars are $\pm$0.33 rad for the ϕ_{21} values and $\pm$0.05 for the R_{21} ones. Note that the amplitudes quoted hereinafter are those of the cosine terms, i.e. the half–amplitude of the light variation. No significant $2f$ term could be evidenced in 12 cases (OGLEGC 7, 24, 34, 35, 37, 40, 46, 59, 60, 63, 66, 70). For these stars the light curves do not deviate appreciably from a sinusoid: that means that if a 2$^{\rm nd}$–order fit is forced on the data, the error bar on the amplitude of the $2f$ term is larger than the amplitude itself. Following the same criterium, in 15 other cases the fit was stopped at the 2$^{\rm nd}$–order, in 6 cases at the 3$^{\rm rd}$ and in two cases at the 4$^{\rm th}$.

Fig. 2 shows the $\phi_{21} - P$ plot: the stars have been subdivided into three groups according to their amplitude and different symbols have been used. As can be noticed, there is a well defined trend in the diagrams. Moreover, the ϕ_{21} values (open squares in Fig. 2) related to the galactic stars CY Aqr, ZZ Mic (Antonello et al. 1986) and V831 Tau (Musazzi et al. 1998) are in excellent agreement with those related to stars in ω Cen.

There are some interesting cases:

OGLEGC 26 – The light curve is noisy (rms residual 0.033 mag), but its shape looks quite strange, with a descending branch steeper than the ascending one (Fig. 3, upper panel). The reality of the asymmetry is even more obvious when considering the mean light curve (Fig. 3, lower panel). In the Galaxy, there are two high–amplitude δ Sct stars with a similar light curve: V1719 Cyg (Poretti & Antonello 1988) and V798 Cyg (Musazzi et al. 1998). Both these stars have a double–mode nature. Since the number of measurements of OGLEGC 26 is adequate (231 on 50 nights), a second period should be revealed by the frequency analysis, but we failed to find it.

OGLEGC 29, 36, 39 and 62 – There are a few cases where the ϕ_{21} values seem to deviate from the progression described by the others (Fig. 2). When considering the error bars, the ϕ_{21} values of the light curves of OGLEGC 29 and 39 (3.72$\pm$0.66 rad and 4.02$\pm$0.82 rad, respectively) are only marginally deviating; in the case of OGLEGC 62 (ϕ_{21} =4.13$\pm$0.56 rad) the line is just within the error bar of the related point. This discrepancy can be explained by observational scatter, since the amplitude

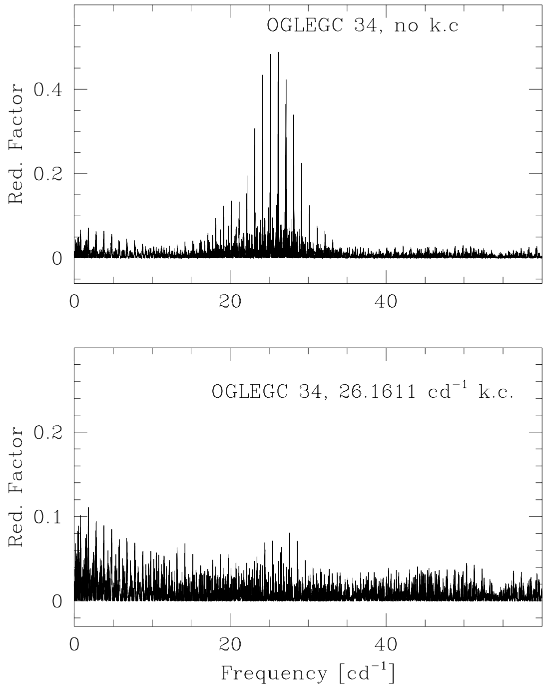

Fig. 1. The power spectra of the OGLEGC 34 measurements. In the power spectrum shown in the *upper panel* the frequency f=26.1611 cd^{-1} is detected as the highest peak, even if the 25.1611 cd^{-1} term is very similar in height. After introducing the former as a known constituent (k.c.), no significant second term is detected (*lower panel*). The star has probably a single period, whose value is still ambiguous (25.1611 cd^{-1} or 26.1611 cd^{-1})

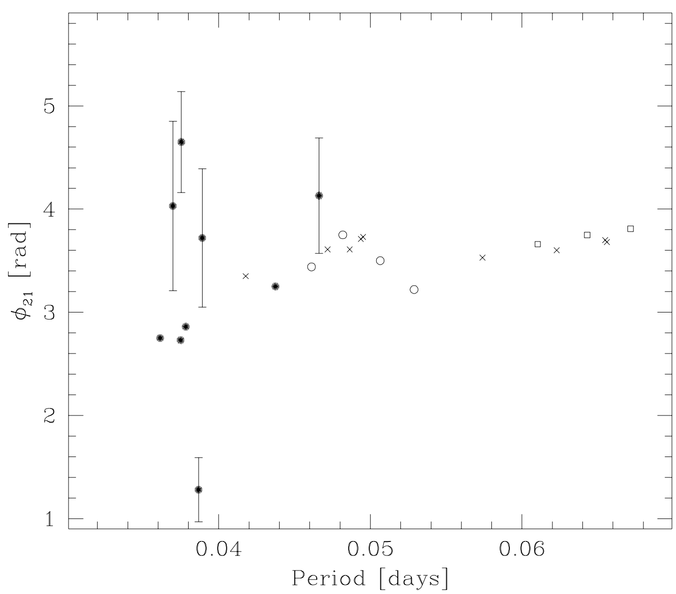

Fig. 2. The $\phi_{21} - P$ progression for short period stars in ω Cen. Different symbols for different amplitudes: filled dots for $A \leq 0.04$ mag, open dots for $0.06 \leq A \leq 0.09$ mag, crosses for $A \geq 0.11$ mag. The three open squares on the right side denote the three galactic stars CY Aqr, ZZ Mic and V831 Tau. Error bars are reported for the individual cases discussed in the text

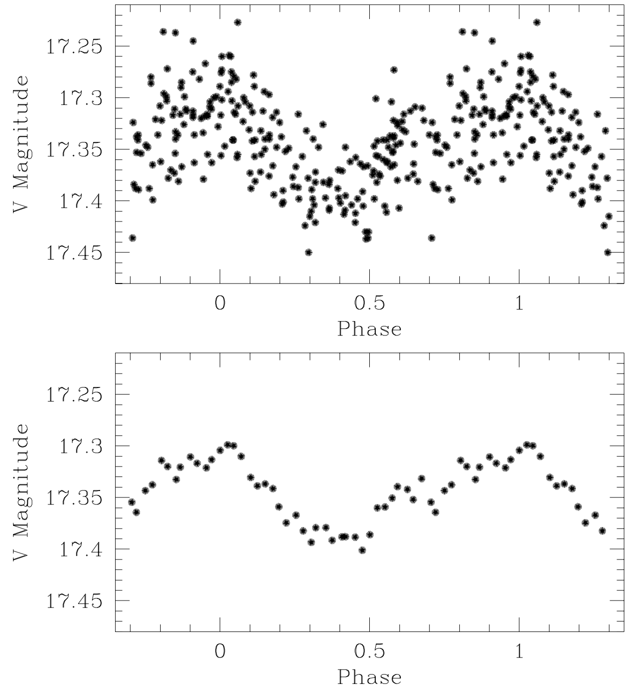

Fig. 3. The star OGLEC 26 shows an asymmetrical light curve, with a descending branch steeper than the ascending one (individual points, *upper panel*). This asymmetry is even more obvious in the mean light curve (*lower panel*)

of the A_2 terms is very small. Moreover, the error bars may be optimistic since they are obtained from the formal error propagation. However, we note that the highest value (4.65±0.49 rad for OGLEGC 36) is the more reliable one and is farther than 3σ from the others.

4. Discussion

The analysis of the 34 short–period variable stars in ω Cen stressed the importance of studying the Fourier parameters. The sample of high–amplitude δ Sct and SX Phe stars is considerably enlarged by these new variables especially toward shortest periods. In general, many variable stars show a very small amplitude, below 0.10 mag. Such a small value is probably responsible for the high number of sinusoidal light curves: since the R_{21} ratios are usually around 0.1, the amplitude of the $2f$ term is very small and observational errors can mask the asymmetry of the light curve.

In spite of that, the ϕ_{21} parameters are confined in a narrow strip for periods between 0.042 d and 0.07 d. Toward longer periods, there is an overlapping with the values obtained in the case of galactic stars. Toward shorter periods, the tendency to decreasing ϕ_{21} values is also verified. It should be noted that there is a strong difference with the results obtained by analyzing the stars in the Carina dwarf Spheroidal Galaxy (Poretti 1999), where the distribution is not as clear as it is here.

As a general consideration, the progression of the ϕ_{21} parameter as a function of the period appears in a clear way. However, a careful analysis should take more details in consideration:

1. Attention should be paid to the scatter in the distribution of the ϕ_{21} parameters around 0.050 d in Fig. 2; in that region the mean error is $\pm$0.20 rad. Hence, this intriguing feature is on the borderline to be considered as a real change in the progression. By analogy to Cepheid light curves (Pardo & Poretti 1997), such a change can be the signature of a resonance between the fundamental mode and a higher overtone.
2. The small bunch of points above the progression at 0.038 d suggests a different light curve family. Since this group of stars shows a very small amplitude, it is possible that they are nonradial pulsators, not necessarily radial pulsators in a higher overtone.
3. The very low ϕ_{21} value (1.28$\pm$0.31 rad) emphasizes the anomalous light curve of OGLEGC 26. The fact that such a light curve is observed in a Pop. II object is quite surprising, since V1719 Cyg and V798 Cyg (whose light curves are similar) are very probably Pop. I stars having a quite normal metallic content. However, their ϕ_{21} values are higher (2.52$\pm$0.05 and 2.64$\pm$0.06 rad, respectively) and hence the light curves are a little different. In many cases, it seems that the phenomenon at the origin of the anomalous brightness increase should be carefully evaluated when dealing with pulsating star models.

It is of paramount importance to obtain very accurate light curves to give more confidence to these results. However, it should be noted that the ϕ_{31} and ϕ_{41} values (Table 1) supply a good confirmation of the reliability of the least–squares fits: indeed, their mean values (1.20 rad and 5.18 rad, respectively) are in excellent agreement with the expected ones on the basis of the results on the galactic variables (see Fig. 2 in Antonello et al. 1986, upper and middle panels).

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References

Antonello E., Broglia P., Conconi P., Mantegazza L., 1986, A&A 169, 122
Kaluzny J., Kubiak M., Szymański M., et al., 1996, A&AS 120, 139
Kaluzny J., Kubiak M., Szymański M., et al., 1997, A&AS 122, 471
Musazzi F., Poretti E., Covino S., Arellano Ferro A., 1998, PASP 110, 1156
Pardo I., Poretti E., 1997, A&A 324, 121
Poretti E., 1999, A&A 343, 385
Poretti E., Antonello E., 1988, A&A 199, 191
Poretti E., Antonello E., LeBorgne J.F., 1990, A&A 228, 350
Vaniĉek P., 1971, Ap&SS 12, 10