

The light curves of the short–period variable stars in the Carina dwarf Spheroidal galaxy

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Abstract. The light curves of the high–amplitude, short–period variable stars discovered by Mateo et al. (1998) in the Carina dwarf Spheroidal Galaxy were re-analyzed to refine their properties and compare them with those of galactic stars. In spite of a different pulsation mode established by means of different *PLM* relationships, the Fourier parameters did not reveal a separation between the two groups; however, they are slightly different from those of galactic stars. The possibility that some of these stars are double–mode pulsators is suggested.

Key words: methods: data analysis – stars: luminosity function, mass function – stars: oscillations – stars: variables: δ Sct – galaxies: dwarf – galaxies: individual: Carina dwarf Spheroidal

1. Introduction

In the recent years there has been a dramatic increase of the number of known variable stars (galactic and extragalactic) thanks to the results obtained in the framework of large–scale projects as MACHO, EROS and OGLE. As a complementary work, some teams started a survey of variable stars in other Local Group Galaxies. These projects mainly provide light curves and standard *B* and *V* magnitudes. It is quite evident that these curves have to be investigated by means of alternative analysis in order to extract all the scientific information they contain.

Recently, Mateo et al. (1998) reported on the discovery of 20 pulsating stars in the Carina dwarf Spheroidal Galaxy. Their periods are ranging from 0.048 d to 0.077 d and their amplitude is above 0.30 mag in *V*. Similar stars are known also in the Galaxy and they are called δ Sct stars if Pop. I objects or SX Phe stars if Pop. II objects; the old definition “Dwarf Cepheids” (without distinction between Populations) was dropped. The analysis of their light curves by means of the Fourier decomposition was firstly made by Antonello et al. (1986) and then continued by Poretti et al. (1990).

After obtaining the Fourier parameters, we shall compare the light curves of the pulsating variables in the Carina dSph galaxy with those of the galactic variables.

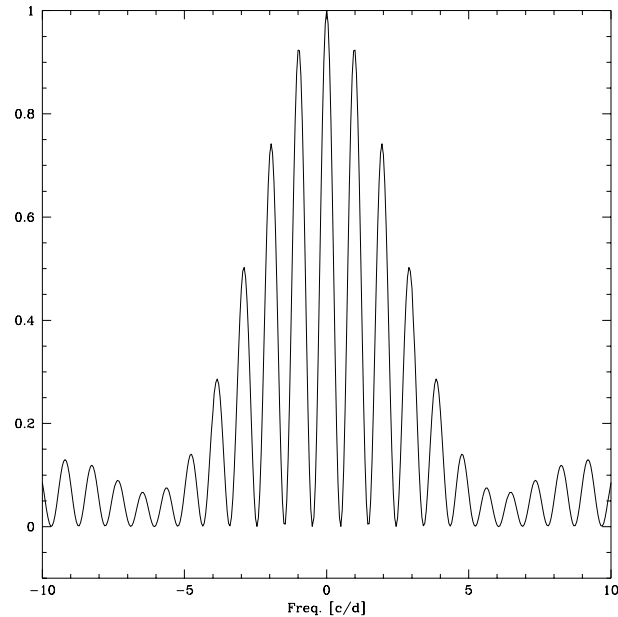


Fig. 1. The spectral window related to the data of the best observed stars

2. Period verification and refinement

The mean magnitude of the variables was about $V=23$ and even if observations were carried out with a 4–m telescope, the single measurements are affected by an error of 0.06 mag or more. Since the number of points is 30 in the best cases (stars 1 to 12), the mean light curves are of limited accuracy and large uncertainties remain.

To determine their period, Mateo et al. (1998) used a method based on the minimum string (Dworetzky 1983), which may not be optimum for noisy data sets with a limited amount of points.

Fig. 1 shows the spectral window as obtained from the data related to stars 1–12, which were observed for a longer time in the two consecutive nights of the sample. However, a night length of about 0.15 d is not sufficient to reduce the aliases at ± 1 cd^{-1} and indeed their height is very similar to that of the central peak; this fact clearly suggests that an ambiguity between the selected frequency and these aliases is always possible.

Table 1. New frequency values for the variables in Carina dSph galaxy; if no value is reported in the right part of the table, no improvement of the fit was introduced by the new approach. Frequencies are in cd^{-1} ; the standard deviations of the fits are in 10^{-2} mag; phase differences ϕ_{21} are in radians; R_{21} is the ratio between the amplitudes of $2f$ and f

Var.	$\langle V \rangle$	Refined elements					Mateo et al. (1998)				
		Freq.	$\log f$	s.d.	ϕ_{21}	R_{21}	Freq.	$\log f$	s.d.	ϕ_{21}	R_{21}
7	23.20	20.52	1.312	11.3	–	–					
8	23.23	17.90	1.253	11.4	3.20	0.24	18.94	1.277	12.0	2.85	0.21
4	23.02	17.60	1.246	8.8	4.49	0.53	16.69	1.222	10.0	3.54	0.25
10	23.03	16.95	1.229	8.2	4.13	0.53					
5	23.06	16.92	1.228	7.2	4.08	0.14					
17	22.95	15.40	1.187	12.8	4.63	0.40	16.58	1.219	13.8	4.19	0.41
13	22.93	14.89	1.173	7.1	3.01	0.36					
20	22.84	14.84	1.171	10.6	4.19	0.39					
15	22.97	14.45	1.160	11.9	3.97	0.37	17.30	1.238	12.9	3.76	0.47
6	22.79	14.29	1.156	7.1	4.07	0.43					
11	22.75	13.95	1.145	7.3	3.58	0.39	13.04	1.115	9.1	3.64	0.33
3	22.92	13.90	1.143	7.1	5.06	0.43	12.99	1.114	7.4	5.34	0.16
9	22.79	13.26	1.122	5.6	–	–					
16	22.81	15.38	1.187	13.2	2.92	0.28					
2	23.10	21.90	1.340	7.7	4.57	0.33	20.88	1.320	8.2	4.49	0.34
12	22.83	18.05	1.256	5.4	4.39	0.28	17.09	1.233	6.1	3.97	0.31
18	22.74	17.05	1.232	8.4	3.88	0.57	18.12	1.258	8.8	3.82	0.57
14	22.45	16.90	1.228	7.4	4.23	0.32	15.97	1.203	8.4	3.99	0.34
1	22.70	15.78	1.197	5.9	–	–	16.78	1.225	6.1	–	–
19	22.63	15.45	1.189	3.9	4.69	0.19					

To test this possible ambiguity, we repeated the analysis by using the least-squares iterative method (Vaniček 1971) to verify if changing the algorithm also changes the results; Table 1 summarizes the results. In 9 cases the two approaches detected the same frequencies, in 6 cases we preferred the $f + 1 \text{cd}^{-1}$ alias of the term reported by Mateo et al. (1998), in 4 cases the $f - 1 \text{cd}^{-1}$ one; in one case (V 15) our method detected a peak related to the $f - 3 \text{cd}^{-1}$ alias. As can be seen from the columns listing the standard deviations, the fit is obviously better in our approach since it is the goal of our search.

Some stars show a standard deviation greater than 0.10 mag (V 7, V 8, V 17, V 20, V 15 and V 16), while the others cluster around 0.07 mag. Such high values can be due to observational errors, but the possibility that they (or part of them) could be double-mode pulsators should be investigated. Since the $F/1O$ double-mode pulsators are expected to be more easily observed, the fact that all the stars (except the doubtful case of V 16) with large residuals are in the group of the F -mode pulsators is a good hint. Unfortunately, owing to the limited data the frequency analyses could not give convincing evidence of a second period.

Of course, it is not possible to state that the frequencies listed in the right panel of Table 1 are the true ones, since also in this case the selection between adjacent peaks is very delicate and the scatter of the light curves plays an important role; however, we can see what happens by using these new refined values and looking at the corresponding PLM relationships. Fig. 2 shows how they changed. The solid lines for fundamental (F ; lower line) and first overtone ($1O$; higher line) pulsators are calculated

as in Fig. 5 in Mateo et al. (1998), i.e. by using $m-M=20.09$, $E(B - V)=0.025$ mag, $[\text{Fe}/\text{H}]=-2.0$; the dashed lines represent the uncertainty of 0.06 mag in the distance modulus.

As regard the $1O$ pulsators, the set of new frequencies gives related points which are closer to the PLM line; in particular Mateo et al. (1998) reported an uncertain classification for the star V 2, which now seems to belong to the group of $1O$ pulsators. On the other hand, the brightest star (V 14) still lies far from the line. It is important to note that the five $1O$ -pulsators are confirmed despite the fact that a wrong choice between a peak and its $\pm 1 \text{cd}^{-1}$ alias can introduce a horizontal shift of 0.03 (for $f=15 \text{cd}^{-1}$) in the $\log f$ value.

The components of the F -pulsator group are confirmed; note however that in the Mateo et al.'s sample we have three stars with $1.1 < \log f < 1.12$, while in our sample only the star V 9 maintains such a long period. Hence, the observed periods of the Carina galaxy stars are in average much shorter. Between the two groups the “half-the-way” position of the star V 16 remains unchanged; as noted above, it may be a double-mode pulsator and its period only roughly known.

3. Fourier parameters

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

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

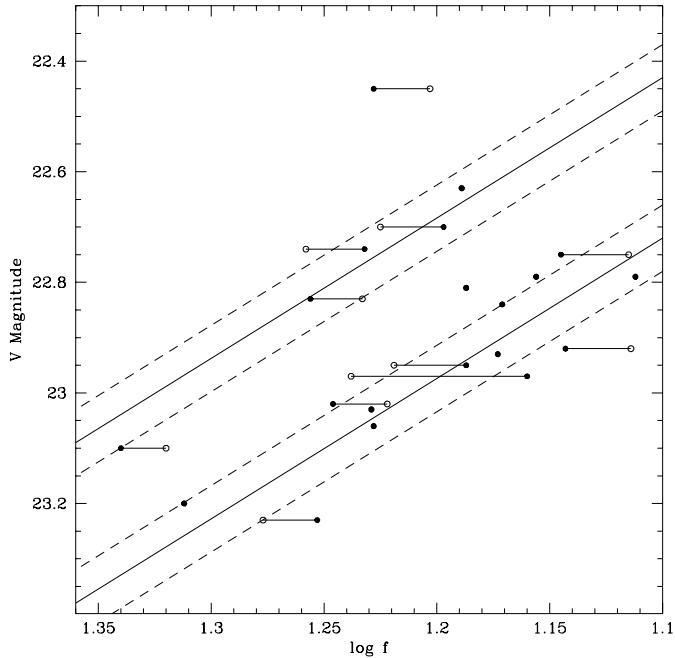


Fig. 2. The *PLM* relationships for *F*-pulsators (lower line) and *1O*-pulsators (upper line) are shown together with the frequency values determined by Mateo et al. (1998; open circles) and in the present work (filled circles). Horizontal lines connect points related to the same star.

where f is the frequency. From the least-squares coefficients we calculated the Fourier parameters $R_{21} = A_{2f}/A_f$ and $\phi_{21} = \phi_{2f} - 2\phi_f$. Typical error bars are ± 0.6 rad for ϕ_{21} values and ± 0.15 for the R_{21} ones. In three cases (V 1, V 7 and V 9) the scatter and/or the phase coverage did not allow us to obtain a satisfactory fit; hence, we cannot propose a reliable Fourier decomposition.

The goal was to obtain some hints about the trends of such parameters when plotted versus the period. In the case of Cepheids and Double-Mode Cepheids the ϕ_{21} parameter provide a powerful tool to discriminate between fundamental (*F*) and first overtone (*1O*) pulsation modes. Recently, Musazzi et al. (1998) summarized the results on the galactic stars, confirming the bimodal distribution of the R_{21} ratio (although the need to increase the sample was emphasized) and the fast increase of the ϕ_{21} values for periods between 0.05 and 0.10 d, followed by a flattening for longer periods. All the short period variable stars discovered in the Carina galaxy lie in the region where the fast increase of the ϕ_{21} values was observed.

In the case of the Carina galaxy the approach to the discussion of light curves is the opposite as compared with our Galaxy. Indeed, the $P - L$ relationships allow us to separate in a straightforward way the *F*-pulsators from the *1O* ones, which is the final goal of investigations in our Galaxy.

As regards the ϕ_{21} values and *1O* pulsators, the range covered by the 5 stars is 3.88–4.69 rad; frequencies are in the range 15.45–21.90 cd^{-1} . In the same frequency interval, the *F*-stars display ϕ_{21} values ranging from 4.08 to 4.49 rad; only considering the strong deviating point related to star V 8 this interval

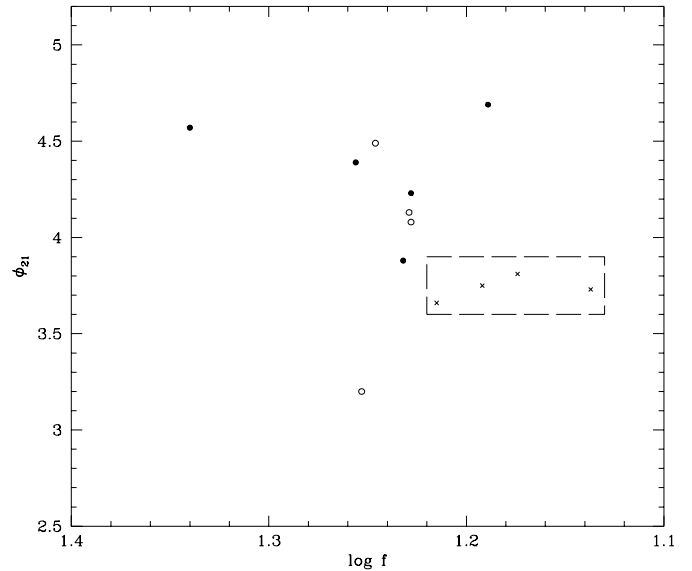


Fig. 3. ϕ_{21} values versus period for galactic pulsators (crosses), Carina galaxy *1O*-pulsators (filled circles), Carina galaxy *F*-pulsators (open circles). Note the narrow box of the galactic pulsators.

is extended to 3.20 rad as an upper limit. As shown in Fig. 3, there is no clear separation between the two groups of stars, at least toward short periods. More precise measurements are necessary to find such a separation. This cannot be immediately interpreted as a failure of the ϕ_{21} differences as mode discriminator, since in the case of Cepheids there is also a region where the ϕ_{21} values are very close each other even if the stars are pulsating in a different mode. Perhaps a different behaviour could be seen toward longer period, but no such star was observed up to now in the Carina galaxy.

We have four galactic variable stars in the same period range: CY Aqr, ZZ Mic, DY Peg and V831 Tau. The Fourier decomposition of their light curves yields a very narrow ϕ_{21} range between 3.66 and 3.81 rad, i.e. values smaller than those observed in the Carina galaxy (Fig. 3). Explaining this difference is far from obvious; for example, it cannot be related to the metallicity, since in the Galaxy there is no separation between Pop. I and Pop. II stars in the $\phi_{21} - P$ plot.

4. Conclusions

The re-analysis of the data reported by Mateo et al. (1998) allowed us to obtain a partially different set of frequencies for the 20 short period variable stars discovered in the Carina dSph galaxy. They are subdivided into 6 *1O*-pulsators, 13 *F*-pulsators; 1 case remains uncertain.

The analysis of the light curves was conducted star by star and the first Fourier parameters were obtained for 17 variables. No clear separation between pulsation modes is discernible in the $\phi_{21} - P$ plot, but the very narrow range of the observed periods hampered us to consider that statement as a definitive one. A more extensive observational study is recommended, since a preliminary comparison with galactic variable stars displays

small differences in the ϕ_{21} values. Owing to the high standard deviation of the fit, the possibility that some stars are double-mode pulsators is also suggested.

It should be also noted that a more accurate standard V magnitude calibration is necessary. Indeed, the V magnitudes used in the PLM relationships were obtained by means of deep survey frames (longer exposures, better S/N) and they can differ up to 0.15 mag from the values obtained in the frames used to study the variability.

More accurate measurements of these stars in the framework of a dedicated project could greatly contribute to solve the matter, allowing us a more reliable analysis. It is of paramount importance to quantify the differences respect with the galactic stars since we could possibly relate them to differences in physical quantities.

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