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On the light curve shape of Cepheids in IC 1613 and NGC 6822 *(Research Note)*

E. Antonello

INAF-Osservatorio Astronomico di Brera, via E. Bianchi 46, 23807 Merate, Italy
e-mail: elio@merate.mi.astro.it

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ABSTRACT

Comparison of the Fourier parameters of fundamental mode Cepheids with period near 10 d in galaxies of the Local Group (IC 1613, NGC 6822, Milky Way, Magellanic Clouds) confirms the previous indication of the lack of a spread of ϕ_{21} values in some dwarf irregular galaxies. It is not yet clear whether this is a real effect or if it is just due to the low number of Cepheids in these galaxies. We suspect however that in this period range the Cepheids of IC 1613 and NGC 6822 behave differently from those in the Milky Way and the Magellanic Clouds. The main effect of the different metallicity on the Fourier parameters is confirmed to be the larger R_{21} values of shorter period Cepheids in metal-poorer galaxies. However the metallicity alone should not be enough to explain the various differences among the Cepheids of the four galaxies. The difference between the spread of ϕ_{21} values near 10 d in Milky Way and Magellanic clouds is pointed out.

Key words. stars: variables: Cepheids – galaxies: Local Group – galaxies: stellar content

1. Introduction

In a previous work (Antonello et al. 2000) we tried to verify the possible effects of a very different metallicity on the shape of Cepheids' light curves by comparing stars in IC 1613 with those in the Milky Way. The comparison was made using the *Wh*-band light curves of Cepheids in IC 1613 (e.g. Mantegazza et al. 2001, and references therein) and *V*-band light curves of Milky Way stars. The purpose was to offer new observational results in order to verify the predictions of pulsational models, in particular for different metallicities. Resonances among pulsation modes - such as that between the fundamental and the second overtone mode, $P_0/P_2 = 2$ for a period $P_0 \sim 10$ d – give rise to observable effects on the light curves, which can be exploited to put constraints on the models. New *V*- and *I*-band data are now available for the metal-poor galaxies IC 1613 (Udalski et al. 2001) and NGC 6822 (Pietrzyński et al. 2004), making a better comparison with both Milky Way and Magellanic Cloud Cepheids possible. IC 1613 and NGC 6822 are two dwarf irregular galaxies of the Local Group, with an estimated metallicity of [Fe/H] between −1.3 and −0.7 (Skillman et al. 2003) for IC 1613, and −0.49 (Venn et al. 2001) for NGC 6822. The values of oxygen abundance, 12 + log(O/H), are 7.86 (IC 1613) and 8.14 (NGC 6822), to be compared with 8.02, 8.37, and 8.7 for SMC, LMC, and Milky Way, respectively (van den Bergh 2000).

2. Data analysis

The *V* and *I* data of IC 1613 were taken from Udalski et al. (2001); the known period *P* of pulsation for such stars was slightly improved using other data, as described in Antonello et al. (2006). The *V* and *I* data and the *P* values of NGC 6822 stars were taken from Pietrzyński et al. (2004). Since the Cepheids with the best light curves are those with longer *P*, we took the stars with $P \geq 5$ d into account. The light curves were Fourier-analyzed (cosine series, e.g. Antonello et al. 2000), and the resulting main parameters are reported in Table 1 (*I*-band light curve) and Table 2 (*V*-band light curves). They include the names of Cepheids (those of NGC 6822 with the label "cep" and those of IC 1613 with the label "ogle"), the logarithm of *P*, the amplitude ratio R_{21} and the respective formal uncertainty, the phase difference ϕ_{21}, and the formal uncertainty. The very uncertain Fourier parameters (errors in R_{21} and ϕ_{21} larger than 0.11 and 0.30, respectively) were not considered in the subsequent analysis. As we were interested in a comparison with other galaxies such as the Magellanic Clouds, we considered only the stars with $P \leq 30$ d, since for longer *P* the number of Cepheids per galaxy with available light curves is rather small.

3. Results

The Fourier parameters of the Cepheids in IC 1613 and NGC 6822 are compared in Fig. 1 with those of the stars in the Milky Way (MW) and the Magellanic Clouds (MCs). The data on the MW stars were taken from our previous works (e.g. Antonello & Morelli 1996), while the data on the MCs stars were taken from Udalski et al. (1999a,b). Unlike for the MW, the best photometry of the MCs Cepheids was obtained by OGLE in the *I* band, so we adopted the two different bands *V*

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Table 1. Fourier parameters of the I-band light curves of Cepheids.

Name	$\log P$	R_{21}	$\sigma(R_{21})$	ϕ_{21}	$\sigma(\phi_{21})$
cep001	2.093	0.264	0.011	5.879	0.043
cep002	1.815	0.274	0.025	5.665	0.081
cep003	1.574	0.317	0.035	5.442	0.091
cep004	1.540	0.445	0.047	5.222	0.093
cep005	1.511	0.302	0.016	5.551	0.044
cep006	1.503	0.418	0.021	5.246	0.043
cep007	1.484	0.411	0.031	5.235	0.065
cep008	1.466	0.341	0.021	5.190	0.050
cep009	1.325	0.317	0.022	5.315	0.063
cep010	1.300	0.354	0.025	5.083	0.065
cep011	1.299	0.213	0.034	4.852	0.137
cep012	1.292	0.163	0.023	4.970	0.129
cep013	1.285	0.284	0.026	5.055	0.085
cep014	1.263	0.285	0.038	5.390	0.122
cep015	1.239	0.336	0.069	4.895	0.194
cep016	1.229	0.241	0.027	5.186	0.104
cep017	1.227	0.180	0.032	4.688	0.157
cep018	1.142	0.155	0.045	4.396	0.253
cep019	1.048	0.116	0.070	4.666	0.562
cep020	1.038	0.235	0.029	4.688	0.103
cep021	1.033	0.289	0.035	4.503	0.106
cep022	1.012	0.346	0.065	5.419	0.174
cep023	0.981	0.189	0.036	5.171	0.169
cep024	0.972	0.371	0.040	5.126	0.087
cep025	0.951	0.391	0.116	5.460	0.271
cep026	0.928	0.356	0.040	5.680	0.102
cep027	0.924	0.371	0.074	5.190	0.181
cep028	0.858	0.498	0.057	4.792	0.106
cep029	0.852	0.276	0.105	5.035	0.339
cep030	0.838	0.303	0.067	5.440	0.204
cep031	0.837	0.375	0.059	4.774	0.148
cep032	0.830	0.277	0.056	5.476	0.176
cep033	0.828	0.200	0.086	4.678	0.384
cep034	0.816	0.438	0.075	4.621	0.162
cep035	0.799	0.380	0.089	4.837	0.217
cep036	0.789	0.393	0.087	4.839	0.198
cep038	0.783	0.376	0.071	4.670	0.171
cep039	0.778	0.342	0.102	4.324	0.274
cep040	0.777	0.270	0.082	5.355	0.277
cep041	0.776	0.417	0.067	4.421	0.147
cep042	0.757	0.303	0.057	4.590	0.158
cep043	0.752	0.366	0.093	5.034	0.219
cep044	0.747	0.495	0.097	4.568	0.181
cep046	0.744	0.394	0.108	5.165	0.258
cep047	0.729	0.444	0.058	4.810	0.120
cep050	0.710	0.479	0.118	5.103	0.222
cep051	0.708	0.360	0.067	4.691	0.166
cep052	0.707	0.497	0.077	4.764	0.145
cep053	0.706	0.345	0.101	4.879	0.262
cep054	0.704	0.363	0.090	5.055	0.232
ogle11446	1.623	0.348	0.037	5.304	0.155
ogle01987	1.411	0.398	0.077	5.276	0.152
ogle00736	1.370	0.274	0.034	5.225	0.104
ogle07647	1.219	0.328	0.033	4.658	0.090
ogle13738	1.215	0.159	0.027	4.882	0.152
ogle04861	1.094	0.186	0.047	4.919	0.225
ogle07664	1.018	0.266	0.036	4.467	0.121
ogle00926	0.975	0.307	0.059	5.270	0.167
ogle00879	0.964	0.285	0.047	5.266	0.145
ogle11589	0.928	0.253	0.058	4.688	0.204
ogle13943	0.829	0.378	0.061	5.003	0.146
ogle03732	0.824	0.374	0.084	4.870	0.206
ogle03722	0.765	0.459	0.072	4.874	0.138
ogle13911	0.759	0.453	0.100	4.597	0.209
ogle13780	0.747	0.513	0.119	5.214	0.219
ogle04875	0.711	0.439	0.115	4.560	0.230

Table 2. Fourier parameters of the V-band light curves of Cepheids.

Name	$\log P$	R_{21}	$\sigma(R_{21})$	ϕ_{21}	$\sigma(\phi_{21})$
cep001	2.093	0.345	0.012	5.047	0.037
cep002	1.815	0.318	0.012	5.076	0.034
cep003	1.574	0.459	0.028	4.800	0.055
cep004	1.540	0.467	0.025	4.843	0.049
cep005	1.511	0.354	0.016	4.944	0.037
cep006	1.503	0.460	0.021	4.703	0.039
cep007	1.484	0.431	0.033	4.563	0.068
cep008	1.466	0.399	0.020	4.667	0.041
cep009	1.325	0.331	0.018	4.703	0.048
cep010	1.300	0.336	0.022	4.537	0.059
cep011	1.299	0.257	0.036	4.102	0.126
cep012	1.292	0.223	0.017	4.200	0.069
cep013	1.285	0.366	0.024	4.770	0.059
cep014	1.263	0.324	0.030	4.636	0.084
cep015	1.239	0.338	0.032	4.379	0.080
cep016	1.229	0.276	0.027	4.721	0.090
cep017	1.227	0.164	0.029	4.513	0.142
cep018	1.142	0.122	0.030	4.492	0.212
cep019	1.048	0.074	0.028	5.023	0.349
cep020	1.038	0.227	0.026	4.452	0.099
cep021	1.033	0.209	0.023	3.883	0.099
cep022	1.012	0.276	0.053	5.303	0.171
cep023	0.981	0.228	0.025	4.519	0.099
cep024	0.972	0.437	0.041	4.980	0.078
cep025	0.951	0.275	0.096	5.356	0.309
cep026	0.928	0.354	0.033	5.258	0.083
cep027	0.924	0.352	0.046	5.353	0.119
cep028	0.858	0.500	0.046	4.471	0.085
cep029	0.852	0.228	0.052	4.984	0.189
cep030	0.838	0.482	0.077	4.969	0.154
cep031	0.837	0.418	0.055	4.309	0.117
cep032	0.830	0.372	0.056	4.967	0.146
cep033	0.828	0.256	0.077	4.498	0.242
cep034	0.816	0.480	0.063	4.491	0.124
cep035	0.799	0.459	0.049	4.575	0.100
cep036	0.789	0.423	0.064	4.511	0.139
cep037	0.788	0.320	0.066	4.450	0.189
cep038	0.783	0.549	0.049	4.269	0.084
cep039	0.778	0.469	0.073	4.687	0.150
cep040	0.777	0.432	0.066	4.724	0.141
cep041	0.776	0.402	0.052	4.353	0.114
cep042	0.757	0.392	0.040	4.719	0.089
cep043	0.752	0.556	0.086	4.258	0.146
cep044	0.747	0.489	0.050	4.580	0.092
cep046	0.744	0.342	0.105	4.638	0.283
cep047	0.729	0.446	0.060	4.522	0.119
cep048	0.714	0.411	0.064	4.912	0.143
cep049	0.713	0.468	0.067	4.881	0.133
cep050	0.710	0.522	0.079	4.913	0.135
cep051	0.708	0.437	0.060	4.441	0.128
cep052	0.707	0.599	0.060	4.308	0.097
cep053	0.706	0.462	0.063	4.873	0.130
cep054	0.704	0.368	0.078	4.909	0.196
ogle11446	1.623	0.297	0.039	4.587	0.214
ogle01987	1.411	0.451	0.059	4.725	0.109
ogle00736	1.370	0.302	0.035	4.700	0.103
ogle07647	1.219	0.334	0.035	4.147	0.094
ogle13738	1.215	0.184	0.036	4.405	0.164
ogle04861	1.094	0.234	0.044	4.468	0.169
ogle07664	1.018	0.177	0.025	4.346	0.114
ogle00926	0.975	0.271	0.035	5.206	0.119
ogle00879	0.964	0.265	0.031	4.787	0.102
ogle11589	0.928	0.262	0.042	4.484	0.137
ogle18905	0.831	0.485	0.090	4.775	0.172
ogle13943	0.829	0.330	0.046	4.728	0.123
ogle03732	0.824	0.441	0.059	4.466	0.117
ogle11604	0.766	0.216	0.103	4.507	0.401
ogle03722	0.765	0.487	0.080	4.545	0.134
ogle13911	0.759	0.425	0.058	4.420	0.129
ogle13780	0.747	0.506	0.078	4.560	0.146
ogle04875	0.711	0.508	0.077	4.377	0.135

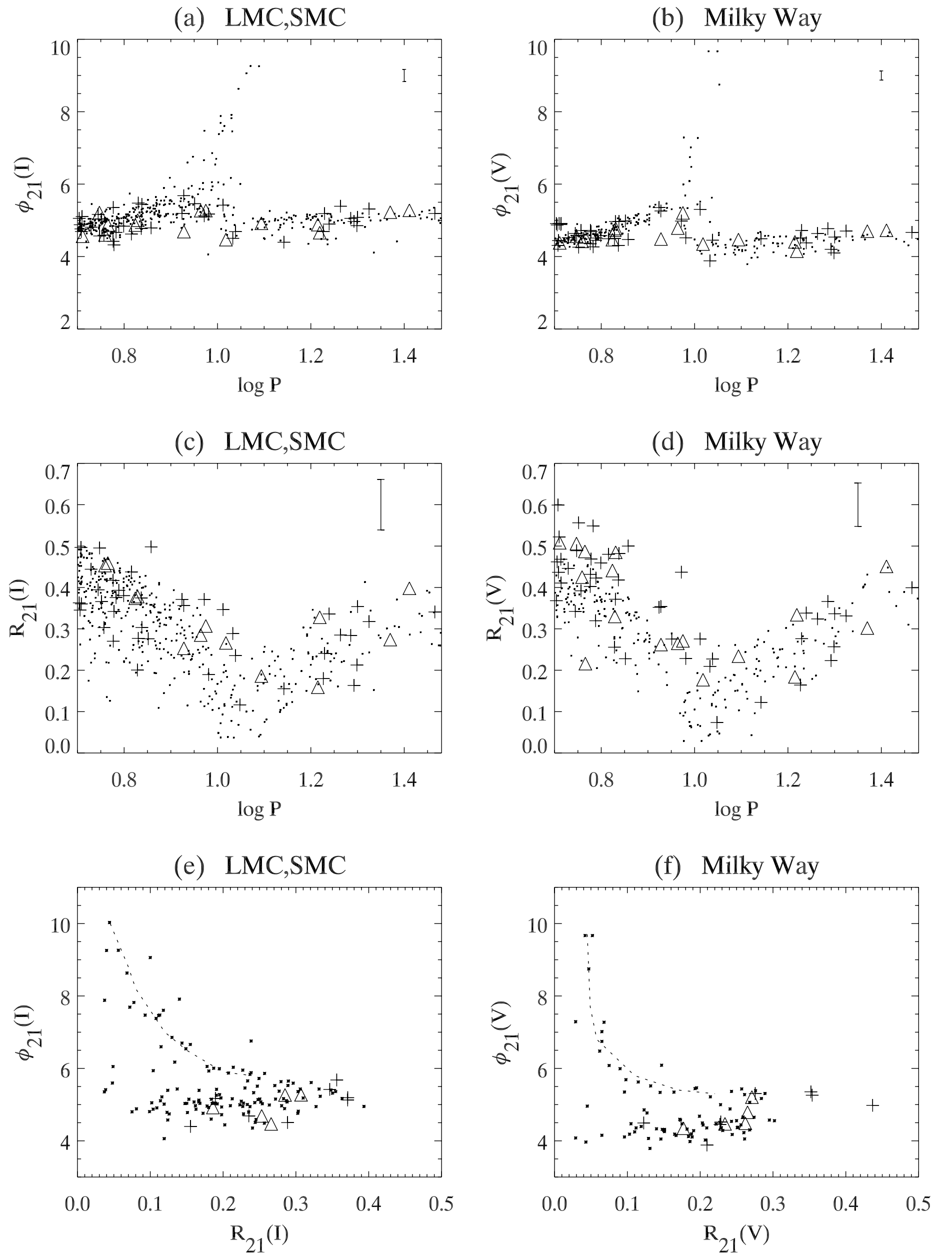

Fig. 1. Comparison of the Fourier parameters of Cepheids in IC 1613 (*triangles*) and NGC 6822 (*plus*) with those of Cepheids in the Magellanic Clouds (*I* band photometry; *dots*) or Milky Way (*V* band photometry; *dots*). The dotted line in panels **e)** and **f)** was drawn by eye (see text). The error bars are the mean formal error of the Fourier parameters of Cepheids in IC 1613 and NGC 6822, that is, ±0.061, ±0.17, ±0.051, and ±0.13, for $R_{21}(I)$, $\phi_{21}(I)$, $R_{21}(V)$, and $\phi_{21}(V)$, respectively.

and *I* for the MW and MCs, respectively. This adoption does not allow direct comparison of the parameters of the Cepheids of the MW with those of the MCs. In general the R_{21} values are not very sensitive to the filter in the optical range (Simon & Moffett 1985). On the other hand, we estimated a systematic difference $\phi_{21}(I) - \phi_{21}(V) \sim 0.33$ between *I* and *V* photometric bands. This estimate was made using OGLE data of some MCs Cepheids with good *V* light curves.

The plots in Fig. 1 show several interesting features.

(1) From the panels (a) and (b) it is evident that the Cepheids with *P* close to 10 d of IC 1613 and NGC 6822 do not show the high ϕ_{21} values ($\gtrsim$5.5 rad) of MW and MCs Cepheids; the result was already known for IC 1613 and is confirmed for NGC 6822. The obvious question is whether this is only due to the poor number of Cepheids in IC 1613 and NGC 6822. If we consider the log *P* range between 0.9 and 1.2, there are 127, 82, and 14 stars in the MCs, MW, and IC 1613 plus NGC 6822, respectively, whereas there are 35 MCs stars with $\phi_{21}(I) \gtrsim 5.7$ in this period range and 13 MW stars with $\phi_{21}(V) \gtrsim 5.4$, that is, about 28% (MCs), and 16% (MW), respectively. These statistics are poor; however, one would also expect about three stars with a high value of ϕ_{21} also in IC 1613 and NGC 6822. We do not think that the lack of such stars is due to a selection effect related to a possibly very small amplitude. For example, in IC 1613 both Antonello et al. (1999) and Udalski et al. (2001) detected the Cepheid V2414-A = OGLE13808 with P = 7.58 d

and amplitude of about 0.2 mag; moreover, only part of the stars with high ϕ_{21} values have a relatively small amplitude. Therefore we think that the lack of Cepheids with large ϕ_{21} values in IC 1613 and NGC 6822 is probably due to some physical reason related to the pulsational characteristics.

(2) In panels (c) and (d) there are no evident differences among the R_{21} values in the various galaxies for $1 \lesssim \log P \lesssim 1.48$. It is known that the Cepheids with $\log P \lesssim 1$ of SMC have progressively higher R_{21} values than do LMC ones. The distribution of Cepheids with $\log P \lesssim 1$ of IC 1613, and in particular those of NGC 6822, is shifted with respect to that of MW Cepheids; a slight shift is possible even with respect to the MCs ones. In order to estimate the possible statistical significance of the shifts, a linear fit was applied to the Cepheids in the range $0.7 < \log P < 1.05$, with average $\log P$ value 0.875. In the panel (d), the MW Cepheids give

$$R_{21}(V) = 0.260(\pm.005) - 0.963(\pm.048)(\log P - 0.875). \quad (1)$$

The mean separation of the Cepheids of NGC 6822 and IC 1613 from this line is 0.084 with $\sigma = \pm.013$; that is, the significance of the shift is larger than 6σ. In the panel (c) the shift with respect to the linear fit of MCs Cepheids

$$R_{21}(I) = 0.287(\pm.004) - 0.831(\pm.041)(\log P - 0.875) \quad (2)$$

is marginal, $0.035 \pm .014$. One could suspect in particular that in the narrower range $0.90 \lesssim \log P \lesssim 1.05$ the stars of NGC 6822 and IC 1613 have higher R_{21} values than those of MW and MCs.

(3) The distribution of the stars with higher ϕ_{21} values in panel (a) shows a different trend from that in panel (b). The different trend is not explained by the different photometric band, and its reality, in spite of the poor number of Cepheids, can also be verified in panels (e) and (f), which only show the stars in the range $0.9 \lesssim \log P \lesssim 1.2$. We have drawn a dashed line by eye to mark the trends. In this context we note that there are no evident differences between the Cepheids of the two Clouds, hence we have not used different symbols for SMC and LMC stars in the plot.

4. Discussion and conclusion

This comparison of the Fourier parameters of Cepheid light curves for different galaxies of the Local Group indicates some possible differences between MW, MCs, IC 1613, and NGC 6822. The physical reason, however, is not completely clear, because such differences do not appear to be a simple metallicity effect. In fact, though IC 1613 is the metal poorest among the four galaxies, and the metallicity of NGC 6822 is slightly larger than that of SMC (Venn et al. 2001), NGC 6822 shows the largest differences with respect to the other galaxies.

Radiative models predict a sensitivity of the Fourier parameters of the light curves to the metal content for P_0 close to the resonance center $P_0/P_2 = 2$ (e.g. Buchler 1998), but this high sensitivity is not confirmed by the observations of Cepheids in the MCs compared to those in the MW; moreover, it seems that including convective transport and turbulent dissipation is not sufficient for improvements. We recall in conclusion that it seems that pulsational models are not yet able to satisfactorily reproduce the light curve features observed in the different galaxies, so we hope that the present results will supply further useful observational indications for comparison with model predictions.

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