Astron. Astrophys. 356, L37–L40 (2000)

ASTRONOMY
AND
ASTROPHYSICS

Letter to the Editor

Metallicity effects on the light curve shape of Cepheids with period close to 10 days*

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Received 14 February 2000 / Accepted 13 March 2000

Abstract. The light curves of population I classical Cepheids with period P in the range between 5 and 13 days in the very metal poor irregular galaxy IC 1613 have been analyzed and compared with those of Cepheids in the Galaxy. Even if there are few Cepheids in this period range in IC 1613, the results are of some importance for the (presently unsuccessful) attempts to reproduce the observed light curves with nonlinear models for low metal content Z. Looking at the shape, there is a general similarity of the light curves in both galaxies, even if $Z \sim 0.02$ for Galaxy and ~ 0.001 for IC 1613, but the same shape occurs in different period ranges. The theoretically predicted sensitivity of Fourier parameters to Z is apparently confirmed just in part by IC 1613 Cepheids, since the observed parameters are compatible with purely radiative model results, but for Z *larger* than 0.01. A comparison with SMC Cepheids ($Z \sim 0.005$) indicates that the partial compatibility could be just apparent owing to the poor number of stars; if this was true, the failure of nonlinear models would be an even more serious problem than it is presently deemed.

Key words: stars: oscillations – stars: variables: Cepheids – galaxies: individual: IC 1613 – galaxies: Local Group – galaxies: stellar content

1. Introduction

Resonances among the pulsation modes in Cepheids give rise to observable effects on the light curves which can be exploited to put constraints on the pulsational models and on the mass–luminosity relations. The best known of these resonances occurs in the fundamental mode Cepheids between the fundamental and the second overtone mode ($P_0/P_2 = 2$) in the vicinity of a period $P_0 \sim 10$ d and it is at the origin of the well known Hertzsprung progression of the bump Cepheids (e.g. Simon and Lee 1981). In the first overtone mode Cepheids another resonance occurs between the first and the fourth pulsation modes ($P_1/P_4 = 2$; e.g. Antonello & Poretti 1986; Antonello, Poretti and Reduzzi 1990). When the resonance effects observed in light curves of Cepheids of Galaxy and Magellanic Clouds are used to constrain purely radiative models, one obtains stellar masses that are too small to be in agreement with stellar evolution calculations (e.g. Buchler 1998). Moreover, the radiative models predict a sensitivity of the Fourier parameters of light curves to the metal content Z, for P close to the resonance center $P_0/P_2 = 2$, but this sensitivity is not confirmed by Cepheids in Magellanic Clouds (low metallicity galaxies). According to Buchler et al. (1999), it has become clear that some form of convective transport and of turbulent dissipation is needed to make progress. However, even this new treatment does not appear to be sufficient for reproducing correctly the main observational features (J.R. Buchler, private communication; G. Bono, private communication). We are therefore compelled to supply theorists with new observational data, in particular of Cepheids in very metal poor irregular galaxies such as IC 1613, to help them in the attempt to solve the problems.

2. Data analysis

Four fields of IC 1613 were observed in the period 1995–1998 at ESO–LaSilla with the Dutch 0.9 m telescope. Owing to the smallness of the telescope, the CCD observations were performed in white light, i.e. with no filter. For a description of the technique, its reliability and a discussion of the results concerning Field A, see Antonello et al. (1999a; Paper I) and Antonello et al. (1999b; Paper II); other two papers on the remaining three fields, B, C and D, are in preparation. In the present note we discuss the Cepheids with $5 < P < 13$ d detected in the four fields. They are listed in Table 1, where we report their identification number for the respective field (column 1), the period (column 2), the amplitude of the white light curve (Wh), and the Fourier parameters, amplitude ratio $R_{21} = A_2/A_1$ (column 3), $R_{31} = A_3/A_1$ (column 4), phase difference $\phi_{21} = \phi_2 - 2\phi_1$ (column 5) and $\phi_{31} = \phi_3 - 3\phi_1$ (column 6), obtained using the fitting formula

$$Wh = Wh_0 + \sum A_i \cos[2\pi i f(t - T_0) + \phi_i]; \qquad (1)$$

the formal errors of the Fourier parameters are also reported.

[⋆] Based on observations collected at ESO-La Silla

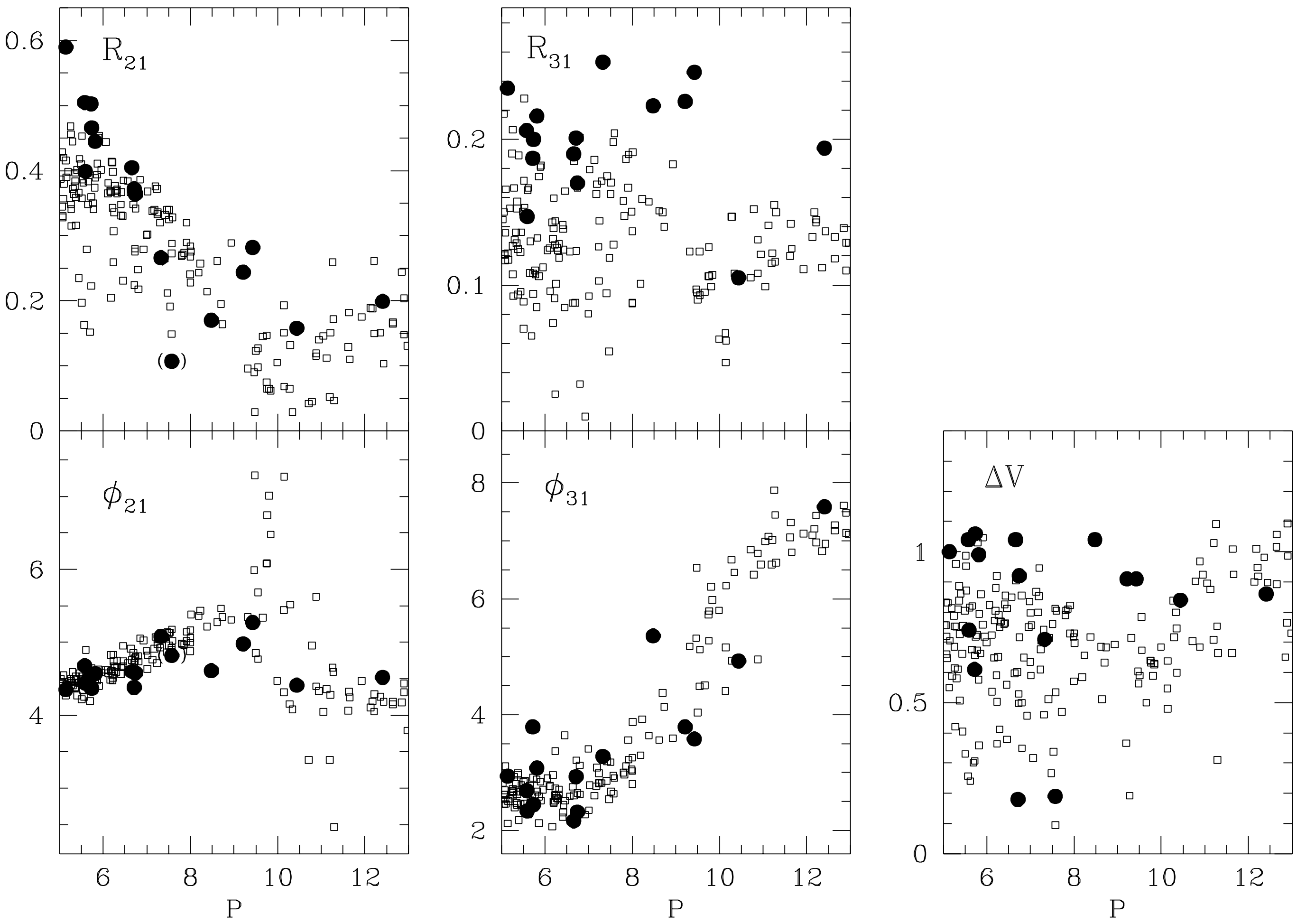

Fig. 1. R_{21}, ϕ_{21}, R_{31}, ϕ_{31} and amplitude ΔV values plotted against P; *squares*: Cepehids in Galaxy; *filled circles*: Cepheids in IC 1613; amplitude values are scaled according to the relation $\Delta Wh \sim 0.8\Delta V$

Table 1. List of Cepheids in IC 1613

Name	P [d]	ΔWh	R_{21}	R_{31}	ϕ_{21}	ϕ_{31}	Name	P [d]	ΔWh	R_{21}	R_{31}	ϕ_{21}	ϕ_{31}
V0129-B	5.1437	.80	.590	.235	4.35	2.94	V1337-A	6.7427	.74	.364	.170	4.58	2.32
			.059	.051	0.14	0.28				.019	.017	0.06	0.11
V0819-A	5.5779	.83	.505	.206	4.68	2.69	V4620-B	7.3266	.57	.253	.116	5.08	3.28
			.045	.044	0.11	0.22				.032	.035	0.12	0.16
V4540-B	5.5924	.59	.399	.147	4.44	2.34	V2414-A	7.5726	.15	.107		4.82	
			.039	.039	.12	.26				.079		.75	
V2221-A	5.7214	.49	.503	.187	4.54	3.79	V1274-B	8.4800	.83	.170	.223	4.61	5.36
			.070	.062	.18	.41				.027	.027	.17	.15
V1734-A	5.7366	.85	.466	.200	4.37	2.45	V1638-C	9.2130	.73	.244	.226	4.98	3.79
			.022	.021	.06	.12				.024	.024	.10	.12
V0024-D	5.8160	.79	.445	.216	4.57	3.08	V1193-C	9.4282	.73	.282	.246	5.27	3.58
			.039	.041	.10	.18				.017	.019	.09	.11
V0078-D	6.6605	.83	.405	.190	4.60	2.17	V0016-B	10.441	.67	.158	.105	4.41	4.93
			.026	.025	.08	.15				.050	.051	.32	.44
V0107-A	6.7135	.14	.372	.201	4.38	2.93	V2952-B	12.411	.69	.199	.194	4.52	7.59
			.111	.107	.35	.60				.026	.025	.13	.15

3. Results

We will compare the light curves of Cepheids in IC 1613 with those in Galaxy. First of all, as remarked in Paper II, we note that the shape of the light curves in the Wh band does not differ significantly from that in the V band, since the effective wavelengths of the two passbands are close; moreover, as regards the observed amplitudes, $\Delta Wh \sim 0.8\Delta V$. According to the study of $BVRI$ light curves of galactic Cepheids made by Simon & Moffett (1985), the R_{i1} values are independent of the filter, while the ϕ_{i1} values increases with the wavelength. ϕ_{21} values for the V band differ by about 0.2–0.3 rad from those for R band. Since Wh effective wavelength is intermediate between V and R ones, we expect that the ϕ_{21} values of Wh light curves are systematically larger by ∼0.1 rad than those of V light curves, which is a negligible quantity in the economy of the present comparative study.

The Fourier parameters are plotted against P in Fig. 1. The R_{21} values for $P < 6$ d tend to be larger in IC 1613; this feature should depend on the metallicity since it is also noted in the Small Magellanic Cloud Cepheids (see Paper II). The values decrease with P, but unfortunately there are no many stars, and hence we cannot identify precisely a minimum at $P \sim 10$ d as in Galaxy. The ϕ_{21} values for $P < 8$ d appear to be essentially the same in both galaxies. For longer periods, the values do not change very much from star to star in IC 1613, and it is possible that, differently from the Galaxy, at 10 d the ϕ_{21} values are rather uniform, i.e. there is no spread.

Differences between the stars with P near 8 – 9 d in the two galaxies are seen also for R_{31} values. In order to understand this point, we have compared the sequence of the curves of the Cepheids in the two galaxies for the limited period range near 8 – 9 d; the curves are plotted in Fig. 2.

Some typical examples of light curves of galactic Cepheids are shown, taken from the paper by Antonello & Morelli (1996). The most evident feature is a double maximum; for $P \lesssim 9$ d the first (in time) maximum is higher than the second, while for $P \gtrsim 9$ either the opposite occurs, or the light curve is featureless (or at most with a small bump on the ascending branch, e.g. FN Aql). Note that the almost sinusoidal light curves have very small R_{21} values, but the amplitude is not negligible. This is generally verified by all the galactic Cepheids with P between 8 and 10 d (Fig. 1). In IC 1613 we find a star, V1274-B, with 8.48 d, whose light curve shape is similar to that of galactic Cepheids with $P \gtrsim 9$ d, while the stars V1638-C and V1193-C have light curve shapes similar to those of galactic Cepheids with $P \lesssim 9$ d. Moreover it is interesting to note that the amplitudes of the Wh light curves of V1274-B, V1638-C and V1193-C are *larger* than those of V light curves of galactic Cepheids with similar P.

4. Discussion

Up to now no complete and detailed study of nonlinear models has been published. Preliminary results for purely radiative models for Z values of 0.020, 0.015 and 0.010 were reported by Buchler (1998): the ϕ_{21} values for P near 10 d depend strongly on Z, in the sense that the spread of the values decreases with decreasing Z. That is, for models with $Z = 0.02$, the ϕ_{21} values vary in a range between 4 and 5.5 rad, while for $Z = 0.01$ vary between 4.5 and 4.8 rad. This trend is confirmed by the radiative models of Aikawa & Antonello (2000), that for $Z = 0.005$ show very uniform ϕ_{21} values. However, the Fourier parameters ϕ_{21} and R_{21} of light curves of Cepheids with $P \sim 10$ d in Galaxy are similar to those of Cepheids with the same P in LMC ($Z \sim 0.01$) and SMC ($Z \sim 0.005$), and do not support the theoretical model predictions; for LMC and SMC, see the results of MACHO (e.g. Welch et al., 1997), EROS (e.g. Beaulieu & Sasselov 1997) and OGLE (e.g. Udalski et al. 1999a) surveys. IC 1613 Cepheids could be compatible with these model predictions, but the average Z value, 0.001, is much lower; in other words, it would seem that the models are too much sensitive to metallicity differences. As regards the models which include convection, the situation does not look much better (J.R. Buchler, private communication); for example, the light curves obtained by Bono et al. (1999) look rather different from those shown in Fig. 2.

In order to verify possible biases, we made a comparison with SMC Cepheids using OGLE database (Udalski et al. 1999b). Most of OGLE observations were performed in I band, whose effective wavelength is quite different from that of V and Wh bands; therefore we considered the V datasets for about 60 stars in the P range between 7 and 11 d, even if the number of data points per set were not large (about 30). An inspection of the V light curves and of the respective Fourier parameters showed that the characteristics of some of SMC Cepheids are not very different from those of IC 1613 with similar period, and therefore the apparent partial compatibility with the theoretical model predictions could be due just to the poor number of Cepheids in IC 1613. In particular, we remark that the observed spread of ϕ_{21} values at $P \sim 10$ d is explained mainly by stars with a light curve shape similar to that of FN Aql, that is a light curve which is rather symmetric or with a small bump on the ascending branch. This kind of stars was not detected in IC 1613.

5. Conclusion

The detailed study of light curve shapes of Cepheids of different metallicities is essential for a progress of our knowledge of the stellar interiors; in fact, the difficulties of nonlinear models (including also the treatment of turbulent convection) to reproduce satisfactorily the observations point towards the need of further improvement of input physics.

Some Cepheids in IC 1613 with P near 10 d show low order Fourier parameters which are apparently compatible with theoretical model predictions for $Z \sim 0.01$. If this was confirmed by further observations, the conclusion would be that the models are just too sensitive to metallicity differences, and therefore simple parameter adjustements would probably suffice to improve the situation. However, a comparison with SMC Cepheids suggests that the partial compatibility is only apparent, and it is due just to the poor number of Cepheids in IC 1613.

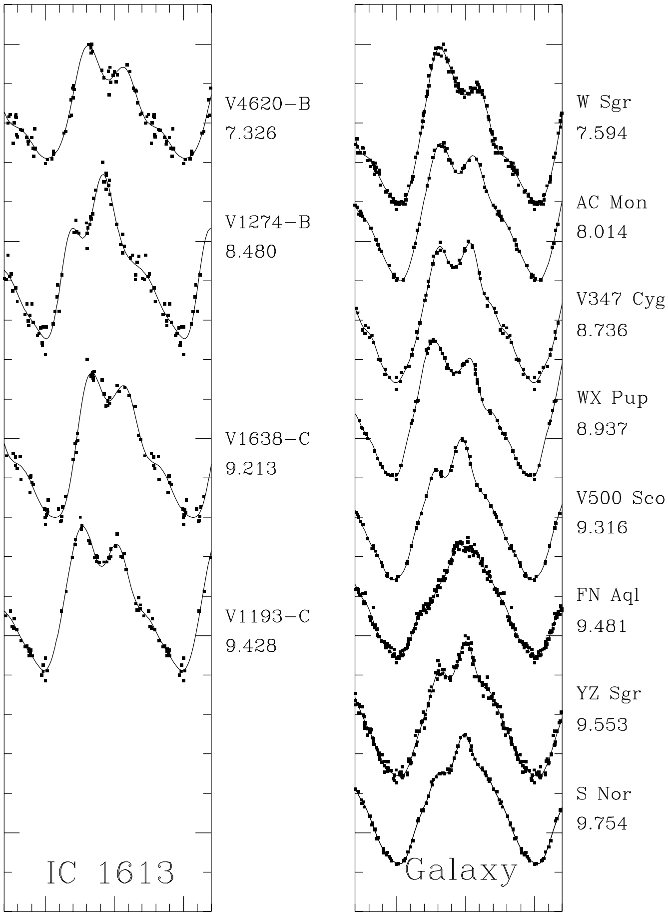

Fig. 2. Comparison of light curve shapes of Cepheids in IC 1613 and Galaxy for a narrow range of P; the P of each star is indicated. The ticksize of ordinatae is 0.2 mag

We stress the importance of observing other very metal poor irregular galaxies, such as NGC 6822, in order to increase the number of stars and verify the sensitivity of the 10 d resonance effects to the metallicity. If also the metal poorest galaxies did not substantiate such a sensitivity (as already done by LMC and SMC), we would remain with an even more serious problem than it is presently deemed.

Acknowledgements. Thanks are due to S. Motta for the help in the treatment of galactic Cepheids data.

References

Aikawa T., Antonello E., 2000, in preparation
Antonello E., Morelli P.L., 1996, A&A 314, 541
Antonello E., Mantegazza L., Fugazza D., Bossi M., Covino S., 1999, A&A 349, 55
Antonello E., Mantegazza L., Fugazza D., Bossi M., 1999, A&A 350, 797
Antonello E., Poretti E. 1986, A&A 169, 149
Antonello E., Poretti E., Reduzzi L., 1990, A&A 236, 138
Beaulieu J.P., Sasselov D.D., 1997, In: Ferlet R., Maillard J.P., Raban B. (eds.) Variable Stars and the Astrophysical Returns of Microlensing Surveys, Editions Frontières, p. 193
Bono G., Marconi M., Stellingwerf R.F., 1999, preprint
Buchler J.R., 1998, In: Bradley P.A., Guzik J.A. (eds.), A Half Century of Stellar Pulsation Interpretations: a Tribute to A.N. Cox, ASP Conf. Ser. 135, 220
Buchler J.R., Yecko p., Kolláth Z., Goupil M.J., 1999, In: Gimenez A., Guinan E.F., Montesinos B. (eds.) Theory and Tests of Convection in Stellar Structure, ASP Conf. Ser. 173, 141
Simon N.R. Lee A.S., 1981, ApJ 248, 291
Simon N.R., Moffett T.J., 1985, PASP 97, 1078
Udalski A., Soszynski, Szymanski M., et al., 1999a, Acta Astron. 49, 45
Udalski A., Soszynski, Szymanski M., et al., 1999b, Acta Astron. 49, 437
Welch D.L., Alcock C., Allsman R.A., et al., 1997, In: Ferlet R., Maillard J.P., Raban B. (eds.) Variable Stars and the Astrophysical Returns of Microlensing Surveys, Editions Frontières, p. 205