The Optical Gravitational Lensing Experiment. Cepheids in the Galaxy IC1613: No Dependence of the Period–Luminosity Relation on Metallicity *

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ABSTRACT

We present results of the search for Cepheids in the galaxy IC1613 carried out as a sub-project of the OGLE-II microlensing survey. 138 Cepheids were found in the $14\farcm2\times14\farcm2$ region in the center of the galaxy. We present light curves, VI photometry and basic data for all these objects, as well as color-magnitude diagram of the observed field.

The Period–Luminosity (PL) diagrams for IC1613 fundamental mode Cepheids for V, I and interstellar extinction insensitive index W_I are constructed. Comparison of PL relations in metal poor galaxy IC1613 ([Fe/H]≈-1.0 dex) with relations in metal richer Magellanic Clouds allows us to study dependence of Cepheid PL relations on metallicity in the wide range of metallicities covered by these three galaxies. The slopes of PL relations in IC1613 are identical as in the Magellanic Clouds. The comparison of brightness of Cepheids with the magnitudes of the tip of the red giant branch stars and RR Lyr stars in all three objects provides information on the stability of zero points of PL relations in the I and V-band, respectively. We find that the zero points of PL relations are constant to better than ±0.03 mag over the entire range of covered metallicities. Thus, the most important conclusion of the paper is that the Cepheid PL relations do not depend on metallicity.

Additionally we determine the mean distance to IC1613, based on the common distance scale resulting from four major stellar distance indicators: Cepheids, RR Lyr, TRGB and red clump stars. The distance modulus to IC1613 is equal to $(m-M)_{\rm IC1613}=24.20$ mag with the standard deviation of ±0.02 mag from six measurements and systematic uncertainty of calibrations of ±0.07 mag.

1 Introduction

IC1613 is an intrinsically faint irregular galaxy from the Local Group. It has drawn attention of astronomers for many decades, among others, because of its favorable location on the sky, far from the Galactic plane and therefore small

*Based on observations obtained with the 1.3 m Warsaw telescope at the Las Campanas Observatory of the Carnegie Institution of Washington.

contamination by the interstellar reddening. First search for variable stars in IC1613 was conducted by Baade in 1930s, but its results were published almost four decades later by Sandage (1971). 37 Classical Cepheids were found based on this photographic material allowing first determination of the distance to IC1613 using the Period–Luminosity (PL) relation for Cepheids. Surprisingly, it turned out that the slope of the PL relation in IC1613 was significantly smaller than in other galaxies possessing Cepheids. This led to long lasting discussions on the possible reason of this discrepancy which, if real, would question usefulness of the PL relation for distance determinations. The problem was, at least partially, solved by Freedman (1988a). Much more precise CCD photometry of Cepheids from IC1613 (however, a small sample of only 11 objects) seemed to contradict possibility of different slope of the PL relation in IC1613.

More recently astronomers realized that IC1613 can be a very good laboratory for testing properties of standard candles. Beside of Cepheids, the galaxy contains also the tip of the red giant branch stars (Freedman 1988b) and RR Lyr stars (Saha *et al.* 1992) reachable from ground based observatories. However, for better quality observations of RR Lyr and another standard candle red clump stars HST telescope must be used (Dolphin *et al.* 2001).

It was also realized that IC1613 is a low metallicity object (Freedman 1988b) with metallicity of about 0.3 dex lower than that of the well studied SMC. Therefore, IC1613 may be a crucial object for testing properties of standard candles in low metallicity environment and for calibrating, if present, population effects on their brightness. In particular, precise photometry of Cepheids in IC1613 may shed a light on the possible dependence of the PL relations on metallicity. There is no general agreement in this matter: theoretical modeling leads to contradictory results (Saio and Gautschy 1998, Alibert *et al.* 1999, Bono *et al.* 1999, Sandage, Bell and Tripicco 1999, Caputo *et al.* 2000). On the other hand the empirical attempts to solve this problem were also non-conclusive and with high degree of uncertainty (Sasselov *et al.* 1997, Kochanek 1997, Kennicutt *et al.* 1998). The problem is extremely important, as Cepheid PL relations play the basic role in establishing the extragalactic distance scale.

While ground observations of the red clump and RR Lyr stars require the largest telescopes, it is, however, somewhat surprising that practically no wide extensive search for Cepheids in IC1613 has been undertaken since the Baade's survey in 1930s. Cepheids in IC1613 are reachable from the ground by the medium size telescopes. The only exception here was the survey reported by Antonello *et al.* (1999, 2000) and Mantegazza *et al.* (2001) who discovered about 100 new Cepheids in four fields in IC1613. However, their survey was conducted in white light making their data of little use for studying the Cepheid PL relations and other problems requiring well calibrated photometry.

In this paper we present the results of a sub-project of the OGLE-II microlensing survey (Udalski, Kubiak and Szymański 1997), which was undertaken to fill this gap. We report detection of 138 Cepheids in IC1613 and provide their standard *VI*-band CCD photometry. We show the PL relations for Cepheids in IC1613 and analyze them by comparison with PL relations in the Magellanic Clouds, and comparison of brightness of Cepheids with brightness of other stellar standard candles. The main conclusion of the paper is that the PL relations for the fundamental mode classical Cepheids are universal and do not depend on metallicity.

Additionally we determine the distance to IC1613 based on photometry of standard candles presented in this paper or taken from the literature (Dolphin *et al.* 2001) and calibrations of the common distance scale of major stellar distance indicators provided by Udalski (2000b).

All photometric data presented in this paper are available from the OGLE Internet archive.

2 Observational Data

Observations of IC1613 galaxy presented in this paper were carried out as a sub-project of the second phase of the OGLE microlensing search. The 1.3-m Warsaw telescope at the Las Campanas Observatory, Chile, (operated by the Carnegie Institution of Washington) was used. The telescope was equipped with the "first generation" camera with a SITe 2048×2048 CCD detector working in still-frame mode. The pixel size was 24 μm giving the 0.417 arcsec/pixel scale. Observations were performed in the "medium" reading mode of the CCD detector with the gain 7.1 e^-/ADU and readout noise of about 6.3 e^-. Details of the instrumentation setup can be found in Udalski, Kubiak and Szymański (1997).

The photometric data were collected on 51 nights between August 30 and November 26, 2000. One field centered on the galaxy center (RA=$1^{\rm h}04^{\rm m}50^{\rm s}$, DEC=$2^\circ08'00''$, 2000.0) covering $14\farcm2 \times 14\farcm2$ on the sky was observed. One set of V and I-band observations was obtained on each night. The exposure time was equal to 900 seconds for both V and I-band. Unfortunately, after October 6, 2000 it was not possible to obtain so long exposures because of the autoguider failure. Since then, each V and I-band observation consisted of eight 120 seconds unguided exposures which were then stacked and summed, giving the effective exposure time of 960 seconds.

Observations were usually made at good atmospheric and seeing conditions. However, a few worst quality images obtained at bad seeing and/or with passing clouds were removed from our final dataset. The median seeing of the analyzed images is $1\farcs2$ and $1\farcs1$ for the V and I-band, respectively.

On seven nights when observations IC1613 were obtained, several standard stars from the Landolt (1992) list were also observed during the regular OGLE-II survey. They were used to transform photometry of IC1613 to the standard system.

3 Data Reduction

Collected data were de-biased and flat-fielded in the real time at the telescope using the standard OGLE-II data pipeline (Udalski, Kubiak and Szymański 1997). Before proceeding to further reductions, the observations consisting of eight short exposures were processed. First, seven images of the set were re-sampled to the first (reference) image pixel coordinate system using procedures from the DIA package of Woźniak (2000). Then, the intensity scale of these images was fitted to the scale of the reference frame and all stack of images was coadded using standard IRAF[†] package procedures. This procedure worked very effectively, no significant seeing or photometric quality degradation was noted as compared to the regular long exposure images.

The photometry of stars was derived using the DoPhot photometry package (Schechter, Mateo and Saha 1993) run on 512×512 pixel subframes to account for Point Spread Function (PSF) variations over the frame. Two very good seeing frames – one for V and the other for I-band, were used as the template images whose photometry defined the instrumental VI system. Photometry of each of the remaining images was compared then to the template one and shifted appropriately to the instrumental system.

In the next stage, the photometric V and I-band databases containing photometry obtained from all images were created. They were then calibrated to the standard system by adding corrections resulting from observations of standard stars and the aperture correction to the instrumental photometry averaged from several determinations. Finally, small corrections resulting from imperfect flat-fielding procedure of the standard OGLE-II data pipeline (Udalski 2000b) and mapped from observations of stars of known brightness were applied. The total error of calibration should not exceed 0.02 mag for both V and I-band.

4 Cepheids in IC1613

The IC1613 photometric data in the VI databases were searched for periodic variable objects. All stars with standard deviation of brightness larger than typical for constant brightness objects were selected as potential variable candidates. Their light curves were then searched for periodicity using the AoV algorithm (Schwarzenberg-Czerny 1989). Because the number of collected epochs was similar in the V and I-bands, the search for periodic objects was performed independently for both these bands.

Cepheids in IC1613 were selected from the list of periodic variable objects, by visual inspection of all phased light curves. The main criterion of Cepheid classification was the very characteristic light curve shape and the period in the range of about 1 to 50 days. The latter limit resulted from the total duration of our observations.

[†]IRAF is distributed by National Optical Observatories, which is operated by the Association of Universities for Reaserch in Astronomy, Inc., under cooperative agreement with National Science Foundation.

Table 1

Cepheids in IC1613

Star number	RA (J2000)	DEC (J2000)	P [days]	I [mag]	V [mag]	$V-I$ [mag]	W_I [mag]	Remarks
11446	$1^{h}04^{m}59^{s}.84$	$2^{\circ}05'28''.0$	41.630	17.855	18.801	0.945	16.390	V20
10421	$1^{h}04^{m}58^{s}.12$	$2^{\circ}02'32''.8$	29.310	20.389	21.099	0.710	19.289	V47, PII
1987	$1^{h}04^{m}31^{s}.81$	$2^{\circ}10'06''.7$	25.862	18.554	19.393	0.838	17.254	V11
736	$1^{h}04^{m}32^{s}.23$	$2^{\circ}05'01''.6$	23.450	18.446	19.258	0.811	17.189	V2
7647	$1^{h}04^{m}37^{s}.80$	$2^{\circ}09'08''.1$	16.540	18.515	18.994	0.478	17.774	
13738	$1^{h}05^{m}02^{s}.91$	$2^{\circ}10'34''.8$	16.370	19.113	19.988	0.874	17.758	V18
13682	$1^{h}05^{m}02^{s}.15$	$2^{\circ}10'24''.3$	14.330	17.617	18.851	1.233	15.705	V39
17473	$1^{h}05^{m}05^{s}.86$	$2^{\circ}07'34''.5$	13.120	21.498	21.887	0.388	20.896	PII
4861	$1^{h}04^{m}44^{s}.34$	$2^{\circ}05'29''.0$	12.410	19.451	20.284	0.832	18.163	V37
7664	$1^{h}04^{m}41^{s}.52$	$2^{\circ}08'23''.9$	10.450	19.425	20.064	0.638	18.437	V16
926	$1^{h}04^{m}33^{s}.69$	$2^{\circ}07'45''.3$	9.402	19.637	20.296	0.658	18.617	V6
879	$1^{h}04^{m}34^{s}.54$	$2^{\circ}06'42''.1$	9.193	19.601	20.241	0.639	18.611	V25
11589	$1^{h}04^{m}51^{s}.61$	$2^{\circ}05'33''.2$	8.409	19.997	20.729	0.731	18.865	V34
13808	$1^{h}04^{m}59^{s}.84$	$2^{\circ}08'42''.8$	7.557	20.175	20.945	0.769	18.984	
18919	$1^{h}05^{m}06^{s}.70$	$2^{\circ}12'52''.4$	7.551	19.889	–	–	–	V49
13759	$1^{h}04^{m}52^{s}.61$	$2^{\circ}08'04''.5$	7.333	19.987	–	–	–	V7
18905	$1^{h}05^{m}06^{s}.41$	$2^{\circ}12'33''.6$	6.766	20.226	21.018	0.792	18.998	
13943	$1^{h}04^{m}51^{s}.77$	$2^{\circ}10'54''.7$	6.751	19.960	20.502	0.541	19.122	V24
13709	$1^{h}04^{m}57^{s}.03$	$2^{\circ}08'40''.7$	6.748	19.464	20.556	1.091	17.773	
3732	$1^{h}04^{m}40^{s}.31$	$2^{\circ}01'24''.5$	6.669	20.064	20.680	0.616	19.110	V27
5037	$1^{h}04^{m}49^{s}.24$	$2^{\circ}07'19''.9$	6.310	20.294	–	–	–	
17454	$1^{h}05^{m}16^{s}.39$	$2^{\circ}07'21''.8$	6.111	20.778	–	–	–	
11604	$1^{h}04^{m}56^{s}.72$	$2^{\circ}05'48''.0$	5.885	20.490	21.271	0.780	19.281	
3722	$1^{h}04^{m}43^{s}.93$	$2^{\circ}01'04''.4$	5.818	20.294	20.994	0.700	19.209	V26
17951	$1^{h}05^{m}04^{s}.79$	$2^{\circ}08'50''.3$	5.738	20.013	–	–	–	
13911	$1^{h}04^{m}51^{s}.70$	$2^{\circ}10'10''.2$	5.717	20.169	20.685	0.516	19.369	V17
13780	$1^{h}04^{m}56^{s}.35$	$2^{\circ}08'21''.3$	5.580	20.367	20.991	0.623	19.401	V9
4875	$1^{h}04^{m}49^{s}.08$	$2^{\circ}05'36''.8$	5.138	20.245	20.918	0.672	19.204	V14
11831	$1^{h}04^{m}57^{s}.54$	$2^{\circ}04'44''.4$	5.028	20.757	21.472	0.714	19.650	
15696	$1^{h}04^{m}51^{s}.03$	$2^{\circ}14'30''.3$	5.012	20.565	21.245	0.679	19.513	
15670	$1^{h}04^{m}53^{s}.39$	$2^{\circ}13'30''.3$	4.849	20.386	20.956	0.569	19.504	V13
5574	$1^{h}04^{m}50^{s}.00$	$2^{\circ}06'01''.4$	4.829	20.723	21.512	0.789	19.500	
17805	$1^{h}05^{m}12^{s}.48$	$2^{\circ}07'13''.6$	4.739	20.922	21.683	0.760	19.744	
8146	$1^{h}04^{m}37^{s}.52$	$2^{\circ}08'51''.2$	4.568	20.870	21.558	0.687	19.805	
14287	$1^{h}05^{m}01^{s}.15$	$2^{\circ}09'11''.5$	4.365	20.893	21.655	0.761	19.714	
18891	$1^{h}05^{m}13^{s}.08$	$2^{\circ}12'12''.5$	4.287	20.679	21.300	0.620	19.717	V12
12415	$1^{h}05^{m}00^{s}.12$	$2^{\circ}06'59''.8$	4.264	20.802	21.428	0.625	19.833	
7919	$1^{h}04^{m}49^{s}.10$	$2^{\circ}08'02''.5$	4.264	20.729	21.403	0.673	19.686	V30
5857	$1^{h}04^{m}47^{s}.97$	$2^{\circ}06'48''.9$	4.218	20.520	21.201	0.680	19.467	V15
12109	$1^{h}05^{m}01^{s}.31$	$2^{\circ}05'52''.9$	4.132	20.757	21.359	0.602	19.823	
13784	$1^{h}04^{m}59^{s}.96$	$2^{\circ}08'24''.7$	4.045	20.451	21.046	0.595	19.528	V10
5309	$1^{h}04^{m}43^{s}.24$	$2^{\circ}05'19''.9$	4.029	20.618	21.414	0.796	19.384	
4840	$1^{h}04^{m}43^{s}.20$	$2^{\circ}05'17''.5$	4.013	–	21.310	–	–	V61
1132	$1^{h}04^{m}23^{s}.62$	$2^{\circ}06'11''.7$	4.009	20.834	21.527	0.693	19.759	
5256	$1^{h}04^{m}48^{s}.33$	$2^{\circ}05'05''.5$	4.003	20.875	–	–	–	V3
11743	$1^{h}04^{m}51^{s}.44$	$2^{\circ}07'32''.3$	3.893	20.007	20.830	0.822	18.733	V53
6084	$1^{h}04^{m}46^{s}.55$	$2^{\circ}07'28''.1$	3.872	20.614	21.471	0.856	19.288	
8127	$1^{h}04^{m}40^{s}.38$	$2^{\circ}08'48''.1$	3.856	20.863	21.606	0.742	19.712	
18222	$1^{h}05^{m}06^{s}.02$	$2^{\circ}09'50''.2$	3.803	21.033	21.634	0.601	20.101	
14356	$1^{h}05^{m}02^{s}.44$	$2^{\circ}09'30''.1$	3.666	20.819	21.439	0.620	19.859	V54
961	$1^{h}04^{m}27^{s}.58$	$2^{\circ}04'38''.2$	3.638	21.054	21.812	0.757	19.881	
9928	$1^{h}04^{m}47^{s}.19$	$2^{\circ}14'21''.6$	3.608	20.572	–	–	–	V57
5614	$1^{h}04^{m}45^{s}.33$	$2^{\circ}06'08''.6$	3.434	21.159	21.904	0.744	20.005	
5611	$1^{h}04^{m}43^{s}.76$	$2^{\circ}06'08''.7$	3.255	20.960	21.629	0.668	19.925	
5750	$1^{h}04^{m}44^{s}.52$	$2^{\circ}06'30''.7$	3.247	21.122	21.796	0.673	20.079	
5281	$1^{h}04^{m}38^{s}.39$	$2^{\circ}05'11''.9$	3.144	20.640	21.249	0.609	19.696	
2240	$1^{h}04^{m}34^{s}.84$	$2^{\circ}09'07''.9$	3.074	21.096	21.608	0.512	20.302	V35
342	$1^{h}04^{m}25^{s}.66$	$2^{\circ}03'53''.8$	3.065	21.089	21.711	0.621	20.126	V62
6273	$1^{h}04^{m}50^{s}.43$	$2^{\circ}07'57''.7$	3.019	21.109	21.797	0.687	20.044	
4016	$1^{h}04^{m}40^{s}.08$	$2^{\circ}03'17''.5$	2.957	21.450	22.150	0.700	20.365	
18349	$1^{h}05^{m}05^{s}.34$	$2^{\circ}11'06''.9$	2.869	21.142	21.698	0.556	20.280	V29
19024	$1^{h}05^{m}06^{s}.17$	$2^{\circ}11'52''.3$	2.843	–	21.858	–	–	
16011	$1^{h}04^{m}55^{s}.30$	$2^{\circ}14'49''.9$	2.795	–	22.100	–	–	
12233	$1^{h}04^{m}50^{s}.83$	$2^{\circ}06'20''.8$	2.794	21.175	21.830	0.654	20.160	
12068	$1^{h}04^{m}53^{s}.92$	$2^{\circ}05'41''.1$	2.781	–	21.872	–	–	
7232	$1^{h}04^{m}37^{s}.16$	$2^{\circ}07'01''.7$	2.774	21.306	21.975	0.668	20.271	
2760	$1^{h}04^{m}33^{s}.89$	$2^{\circ}09'18''.5$	2.712	21.297	21.870	0.572	20.410	
1471	$1^{h}04^{m}23^{s}.91$	$2^{\circ}05'17''.6$	2.707	21.320	21.958	0.637	20.333	
7010	$1^{h}04^{m}48^{s}.63$	$2^{\circ}06'30''.2$	2.673	21.273	21.889	0.616	20.319	

Table 1

(concluded)

Star number	RA (J2000)	DEC (J2000)	P [days]	I [mag]	V [mag]	$V-I$ [mag]	W_I [mag]	Remarks
1028	$1^{h}04^{m}28.^{s}26$	$2^{\circ}05'16.''2$	2.664	21.480	22.146	0.665	20.449	
10804	$1^{h}04^{m}51.^{s}05$	$2^{\circ}04'08.''0$	2.662	21.312	21.812	0.499	20.540	V48
4080	$1^{h}04^{m}41.^{s}01$	$2^{\circ}03'49.''5$	2.632	20.934	21.727	0.793	19.705	V51
12526	$1^{h}05^{m}02.^{s}97$	$2^{\circ}07'23.''7$	2.631	–	22.231	–	–	
10263	$1^{h}04^{m}36.^{s}77$	$2^{\circ}14'11.''2$	2.566	21.320	21.967	0.647	20.317	V46
6603	$1^{h}04^{m}48.^{s}56$	$2^{\circ}05'30.''2$	2.564	21.584	22.356	0.771	20.390	
16245	$1^{h}05^{m}00.^{s}75$	$2^{\circ}13'13.''9$	2.561	21.396	21.950	0.554	20.537	
4160	$1^{h}04^{m}42.^{s}16$	$2^{\circ}04'15.''0$	2.542	21.484	22.136	0.651	20.474	
16301	$1^{h}04^{m}55.^{s}64$	$2^{\circ}13'42.''6$	2.533	21.492	22.289	0.797	20.257	
11613	$1^{h}04^{m}55.^{s}51$	$2^{\circ}05'52.''0$	2.476	20.604	21.018	0.414	19.962	
15308	$1^{h}04^{m}51.^{s}20$	$2^{\circ}10'08.''3$	2.460	–	22.221	–	–	
13184	$1^{h}04^{m}50.^{s}69$	$2^{\circ}06'22.''7$	2.455	21.381	22.006	0.624	20.413	
15356	$1^{h}04^{m}53.^{s}34$	$2^{\circ}10'21.''9$	2.447	–	22.107	–	–	V36
14070	$1^{h}04^{m}58.^{s}56$	$2^{\circ}08'23.''2$	2.396	–	21.537	–	–	
1440	$1^{h}04^{m}36.^{s}05$	$2^{\circ}05'05.''6$	2.339	–	22.155	–	–	
7322	$1^{h}04^{m}37.^{s}66$	$2^{\circ}07'13.''7$	2.338	21.347	21.944	0.597	20.421	
4154	$1^{h}04^{m}41.^{s}21$	$2^{\circ}04'12.''6$	2.267	20.932	21.508	0.575	20.041	V59
12659	$1^{h}04^{m}50.^{s}93$	$2^{\circ}07'54.''9$	2.265	21.463	22.031	0.567	20.584	
202	$1^{h}04^{m}34.^{s}73$	$2^{\circ}02'09.''6$	2.264	21.493	22.050	0.557	20.630	V28
6128	$1^{h}04^{m}41.^{s}32$	$2^{\circ}07'34.''4$	2.260	–	21.608	–	–	
14785	$1^{h}04^{m}56.^{s}12$	$2^{\circ}08'17.''4$	2.236	21.567	22.012	0.444	20.879	
1092	$1^{h}04^{m}29.^{s}58$	$2^{\circ}05'46.''9$	2.233	21.398	21.793	0.394	20.788	
4602	$1^{h}04^{m}39.^{s}25$	$2^{\circ}04'08.''9$	2.231	21.457	22.077	0.620	20.497	
14710	$1^{h}05^{m}03.^{s}25$	$2^{\circ}08'04.''4$	2.228	–	22.406	–	–	
15476	$1^{h}04^{m}53.^{s}35$	$2^{\circ}11'02.''8$	2.180	21.568	22.197	0.628	20.594	
6168	$1^{h}04^{m}46.^{s}59$	$2^{\circ}07'40.''2$	2.163	–	21.544	–	–	
2117	$1^{h}04^{m}30.^{s}25$	$2^{\circ}08'06.''5$	2.131	21.300	21.857	0.557	20.437	
5209	$1^{h}04^{m}43.^{s}02$	$2^{\circ}04'53.''4$	2.094	–	21.892	–	–	
8782	$1^{h}04^{m}36.^{s}87$	$2^{\circ}08'22.''6$	2.091	21.480	22.044	0.563	20.607	
5996	$1^{h}04^{m}44.^{s}84$	$2^{\circ}07'14.''1$	2.069	–	21.666	–	–	V60
2389	$1^{h}04^{m}28.^{s}68$	$2^{\circ}10'24.''5$	2.029	–	21.571	–	–	
12044	$1^{h}04^{m}52.^{s}52$	$2^{\circ}05'35.''3$	2.027	21.272	21.786	0.514	20.475	
12747	$1^{h}05^{m}04.^{s}26$	$2^{\circ}04'47.''8$	1.976	–	22.087	–	–	
2342	$1^{h}04^{m}33.^{s}07$	$2^{\circ}09'56.''9$	1.972	21.203	21.751	0.548	20.353	
17400	$1^{h}05^{m}13.^{s}00$	$2^{\circ}06'47.''8$	1.969	–	22.087	–	–	
12929	$1^{h}04^{m}57.^{s}71$	$2^{\circ}05'30.''7$	1.941	–	22.553	–	–	
14790	$1^{h}04^{m}57.^{s}46$	$2^{\circ}08'18.''2$	1.913	–	22.617	–	–	
5674	$1^{h}04^{m}48.^{s}52$	$2^{\circ}06'18.''1$	1.888	20.829	21.448	0.619	19.870	
4475	$1^{h}04^{m}36.^{s}79$	$2^{\circ}03'32.''1$	1.818	21.793	22.361	0.567	20.914	
15230	$1^{h}04^{m}54.^{s}70$	$2^{\circ}09'47.''0$	1.765	–	22.187	–	–	
2124	$1^{h}04^{m}22.^{s}99$	$2^{\circ}08'14.''0$	1.697	21.585	22.177	0.591	20.669	
13481	$1^{h}04^{m}57.^{s}68$	$2^{\circ}07'25.''6$	1.678	–	22.595	–	–	
2818	$1^{h}04^{m}26.^{s}81$	$2^{\circ}09'38.''8$	1.661	–	22.642	–	–	
12401	$1^{h}04^{m}54.^{s}18$	$2^{\circ}06'56.''1$	1.657	21.450	21.979	0.529	20.631	
7018	$1^{h}04^{m}47.^{s}72$	$2^{\circ}06'31.''7$	1.645	–	22.358	–	–	
17545	$1^{h}05^{m}10.^{s}87$	$2^{\circ}04'39.''4$	1.623	–	22.480	–	–	
13192	$1^{h}05^{m}00.^{s}15$	$2^{\circ}06'23.''7$	1.620	–	21.222	–	–	
3897	$1^{h}04^{m}47.^{s}24$	$2^{\circ}01'53.''9$	1.618	–	22.304	–	–	
4195	$1^{h}04^{m}41.^{s}38$	$2^{\circ}04'26.''8$	1.603	–	22.049	–	–	
11130	$1^{h}05^{m}04.^{s}49$	$2^{\circ}02'57.''5$	1.599	–	22.218	–	–	
5197	$1^{h}04^{m}50.^{s}43$	$2^{\circ}04'51.''6$	1.588	–	21.914	–	–	
19479	$1^{h}05^{m}13.^{s}62$	$2^{\circ}12'04.''5$	1.565	–	22.029	–	–	
2197	$1^{h}04^{m}24.^{s}41$	$2^{\circ}08'46.''4$	1.459	–	22.430	–	–	
12070	$1^{h}05^{m}01.^{s}52$	$2^{\circ}05'40.''7$	1.438	–	21.160	–	–	
2751	$1^{h}04^{m}32.^{s}52$	$2^{\circ}09'17.''0$	1.376	–	21.788	–	–	
7028	$1^{h}04^{m}42.^{s}93$	$2^{\circ}06'33.''5$	1.375	–	22.276	–	–	
2771	$1^{h}04^{m}34.^{s}72$	$2^{\circ}09'22.''3$	1.329	–	22.198	–	–	
8173	$1^{h}04^{m}39.^{s}98$	$2^{\circ}08'58.''0$	1.310	–	21.914	–	–	
2909	$1^{h}04^{m}28.^{s}22$	$2^{\circ}10'07.''3$	1.309	–	22.250	–	–	
10862	$1^{h}05^{m}01.^{s}58$	$2^{\circ}01'05.''5$	1.225	–	21.899	–	–	
4173	$1^{h}04^{m}42.^{s}36$	$2^{\circ}04'19.''4$	1.199	–	22.085	–	–	
4555	$1^{h}04^{m}41.^{s}71$	$2^{\circ}03'57.''4$	1.167	–	22.284	–	–	
18698	$1^{h}05^{m}15.^{s}01$	$2^{\circ}10'20.''1$	1.156	–	22.350	–	–	
12167	$1^{h}04^{m}55.^{s}88$	$2^{\circ}06'04.''8$	1.113	–	21.660	–	–	
11221	$1^{h}04^{m}50.^{s}95$	$2^{\circ}03'27.''9$	1.097	–	22.415	–	–	
1383	$1^{h}04^{m}31.^{s}99$	$2^{\circ}04'39.''4$	1.021	–	22.383	–	–	
19350	$1^{h}05^{m}07.^{s}13$	$2^{\circ}14'44.''1$	0.850	–	22.459	–	–	
19304	$1^{h}05^{m}12.^{s}36$	$2^{\circ}14'14.''9$	0.822	–	22.601	–	–	
19725	$1^{h}05^{m}07.^{s}91$	$2^{\circ}13'46.''4$	0.723	–	22.439	–	–	

Independent search in the V and I-band allowed us to find more complete sample of Cepheids in IC1613 and exclude some doubtful cases. Especially, deeper range of the V-band photometry made it possible to identify many more fainter Cepheids falling into noise in the I-band frames.

Altogether we selected 131 light curves in the V-band and 91 in the I-band of 138 Cepheid candidates. Phased light curves of these objects are presented in Appendix A. Table 1 provides the most important observational data for each candidate. In the first column the identification number in the OGLE databases is given followed by the equatorial coordinates (2000.0), period and intensity mean I, V, $(V-I)$ photometry. In the next column the interstellar extinction independent index (Wesenheit index), W_I, defined as:

$$W_I = I - 1.55 \cdot (V - I) \tag{1}$$

is also listed. In some cases remarks are provided in the last column. In particular, cross-identification with Sandage (1971) notation is given. Also Population II Cepheids (PII) are marked in that column.

The mean intensity photometry was determined by fitting the Fourier series of the fifth order to the observed light curves. Formal accuracy of such determined mean magnitudes is of about 0.005 mag for the brightest stars to about 0.04 mag for the faintest ones. Accuracy of the period is about $1 \cdot 10^{-3} \cdot P$.

It is difficult to estimate how complete is the presented sample. Large amplitudes make the Cepheids easy to detect and the sample is very likely complete close to 100% at the bright end. For fainter objects the completeness certainly decreases because of larger photometric noise. Also non-uniform background of the galaxy makes detection more difficult in some regions. Comparison of objects detected in the V and I-bands suggests that down to $P \approx 2.5$ days the sample is reasonably complete – single objects were present only on one list. Objects with shorter periods were detected practically in the V-band only, and for obvious reasons their completeness must be much smaller.

IC1613's location on the sky, as well as its orientation are very fortunate as far as the interstellar reddening is considered. It is commonly accepted that the internal reddening in IC1613 is negligible, and the Galactic foreground reddening in the IC1613 direction is very small. According to Schlegel, Finkbeiner and Davis (1998) $E(B-V)$ toward the galaxy is only 0.025 mag. Thus, to convert the presented photometry to extinction free one, one has to subtract $A_I = 0.05$ mag and $A_V = 0.08$ mag for the I and V-band, respectively, from the data in Table 1.

Fig. 1 presents the color-magnitude diagram (CMD) for stars from our photometric databases of IC1613. 80 classical Cepheids from Table 1, that is those with full VI photometry, are marked by large grey dots in this figure. Open grey circles indicate positions of Population II Cepheids. Asterisk denotes position of the enigmatic object, 13682 (V39 according to Sandage 1971) whose light curve resembles pulsating variable. However, it is very likely not a classical Cepheid (Sandage 1971, Antonello *et al.* 1999) what is confirmed here by its location on the CMD diagram and below on PL diagrams. The remaining Cepheids nicely populate the instability strip located left from the well populated upper part

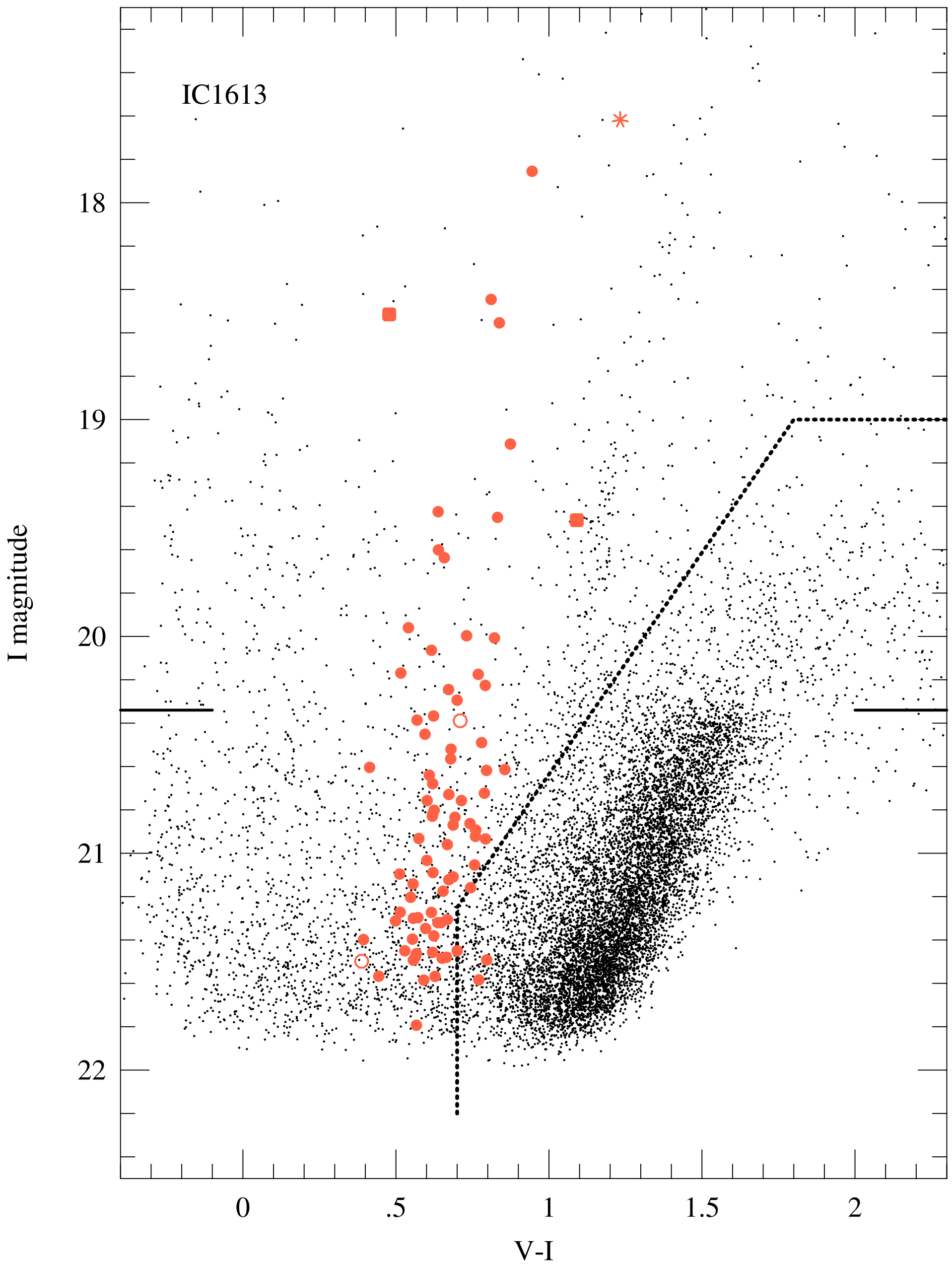

Fig. 1. Color-Magnitude diagram of the observed field in IC1613. Large grey dots indicate positions of classical Cepheids. Gray squares correspond to the positions of blended Cepheids, 7647 and 13709. Open circles mark Population II Cepheids and asterisk an enigmatic variable, 13862. Thick dotted line limits the region used for determination of the TRGB magnitude which is marked by two thick solid lines on the abscissa axes at 20.34 mag.

of the red giant branch. Gray squares in Fig. 1, indicate the classical Cepheids 7647 and 13709. They are located left or right from the main instability strip and are certainly unresolved blends of a Cepheid with another star, what is clearly visible on the PL diagrams, and from the shape (amplitude) of their *VI* light curves.

5 Period–Luminosity Diagrams

Figs. 2–4 present the PL diagrams for Cepheids in IC1613 plotted using the data from Table 1, for the V, I and W_I index, respectively. PL diagrams for all bands look very similar. The main feature is the narrow strip formed by Cepheids pulsating in the fundamental mode. At the faint end, *i.e.*, $\log P < 0.4$ (2.5 days), the strip becomes wider and worse defined what is particularly well noticeable in the V-band. This is caused by the first overtone (FO) Cepheids which become much more numerous in this period range and are by several tenths of magnitude brighter than FU mode pulsators. A few objects are located by about 1.5–2 mag below the main strip. These stars, marked by open circles in Figs. 1–4, are almost certainly Population II Cepheids. Asterisk and filled squares mark the position of variable 13682 (V39), 7647 and 13709, respectively, already described in Section 4.

Table 2

Best least square fit parameters of the PL relations:
$M = A \cdot (\log P - 1) + B$

IC1613 – Fundamental Mode Cepheids				
Band	A	B	N	σ
V	-2.756	20.389	64	0.193
	0.095	0.041		
I	-2.946	19.633	64	0.150
	0.075	0.031		
W_I	-3.256	18.500	56	0.111
	0.057	0.024		

To determine the PL relations for the FU mode Classical Cepheids in IC1613 we followed the same procedure as in Udalski *et al.* (1999) for the LMC and SMC. First, we removed the stars classified as likely Population II objects. Then, we limited our sample of Cepheids to objects with $\log P > 0.4$. There are two reasons for such a limitation. First, in this way we exclude practically all FO Cepheids contaminating the diagrams at shorter periods. It would be difficult to separate them from FU mode objects using standard light curve analysis because of relatively noisy light curves of such faint objects. Secondly, the number of FU Cepheids with periods shorter than the above limit varies

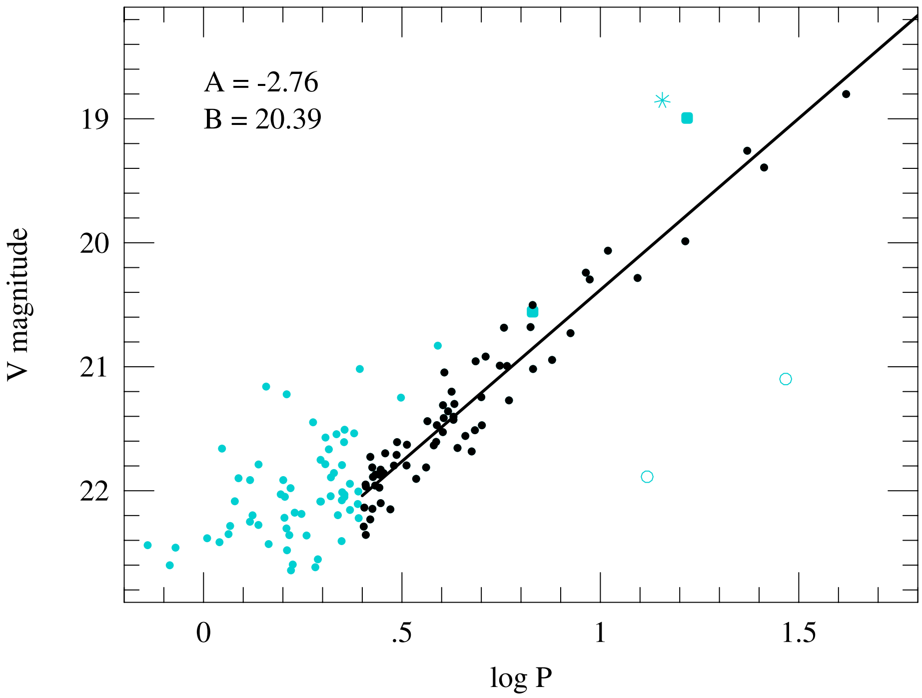

Fig. 2. V-band Period-Luminosity relation for FU mode classical Cepheids in IC1613. Black dots indicate Cepheids used for the final fit of PL relation. Gray dots mark Cepheids with period shorter than $\log P = 0.4$ and objects removed during the iterative fitting of the PL relation. The remaining symbols are as in Fig. 1.

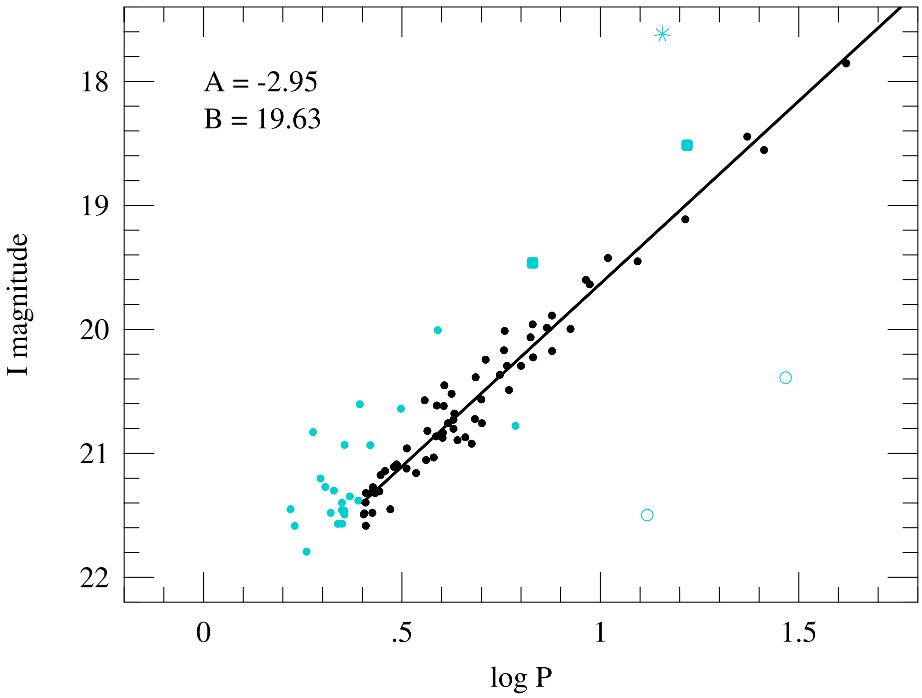

Fig. 3. Same as Fig. 2 for the I-band.

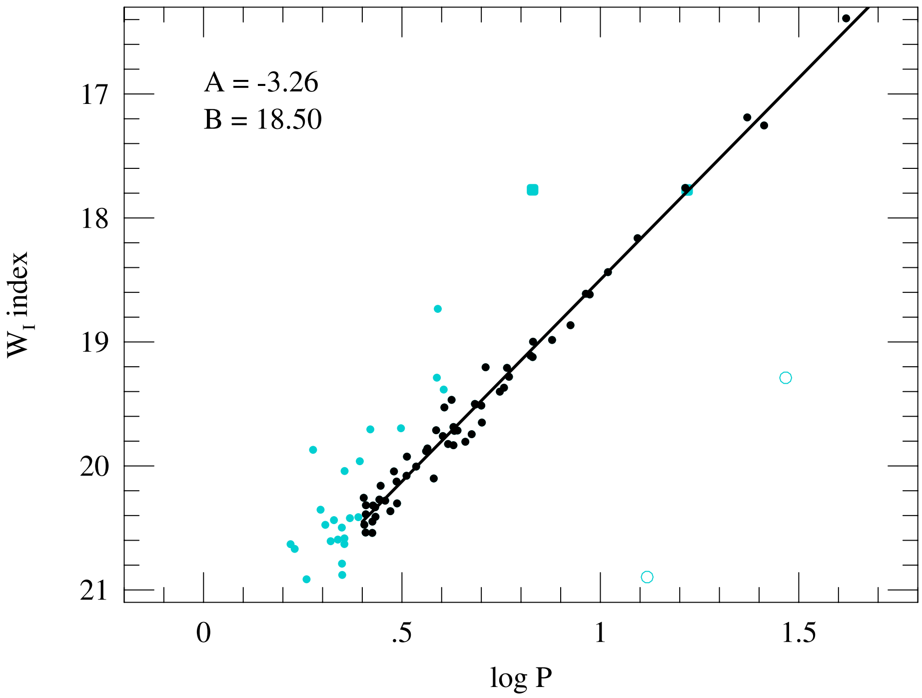

Fig. 4. Same as Fig. 2 for the W_I index.

from object to object. For instance, they are very rare in the LMC and very numerous in the SMC (Udalski *et al.* 1999). What worse, the slope of the PL relation in the SMC for periods shorter than 2 days is steeper (Bauer *et al.* 1999, Udalski *et al.* 1999). Therefore to avoid biases and to have homogeneous material for comparisons with Magellanic Cloud Cepheids we further considered only objects with periods $\log P > 0.4$.

Next, we determined the PL relation in each of the bands. We fitted linear relations in the form:

$$M = A \cdot (\log P - 1) + B \qquad (2)$$

We applied the same iterative fitting procedure with 2.5σ clipping algorithm as for the MC Cepheids. In this manner we removed possible FO pulsators in our sample and/or obvious outliers.

Table 2 lists coefficients of the final PL relations in IC1613 for the V, I and W_I index. The relations are also plotted as thick lines in Figs. 2–4. Cepheids used to the final fit are marked by black dots in these figures. The standard deviation of the fit decreases from V, through I to the W_I index similar as in the LMC and SMC and it is in between of that found in the LMC and SMC.

6 Discussion

Relatively large sample of Cepheids detected in IC1613 makes it possible to study in detail the PL relations in low metallicity environment of [Fe/H] $\approx$ -1.0 dex (Dolphin *et al.* 2001). With so low metallicity, IC1613 is a crucial object for testing the universality of the PL relations and accuracy of the Cepheid distance scale. Cepheids from two remaining objects containing well studied samples of these variable stars, the LMC and SMC (Udalski *et al.* 1999), have the mean metallicity equal to [Fe/H] $= -0.3$ dex, and -0.7 dex, respectively (Luck *et al.* 1998). Therefore comparison of PL relations in these three galaxies can provide basic information on how PL relations depend on metallicity of the environment the Cepheid comes from.

6.1 Dependence of the PL Relation on Metallicity

Udalski *et al.* (1999) presented comparison of the PL relations determined for large samples of FU mode Cepheids in the LMC and SMC. To within uncertainties of determination, the slopes of the PL relations for V, I and W_I index turned out to be consistent in these galaxies. Because of much smaller scatter and better population of the FU mode PL relations in the LMC, their slopes were adopted as universal. The numbers presented in Udalski *et al.* (1999) were slightly corrected in April 2000, due to small recalibration of the OGLE-II photometry and are equal to $A_V^{MC} = -2.775$, $A_I^{MC} = -2.977$ and $A_{W_I}^{MC} = -3.300$ (Udalski 2000b). Comparing these figures with the IC1613 slopes presented in Table 2 one immediately finds the striking agreement for all the presented bands. This result definitively ends the dispute on the possibility of shallower slopes of PL relations in IC1613 started almost three decades ago. The main conclusion from this comparison is that the slopes of the PL relations presented in Udalski (2000b) are indeed universal and do not depend on metallicity.

To study whether the zero points of the PL relations depend on metallicity one needs the reference brightness to which the observed magnitudes of Cepheids could be referenced. Udalski (2000b) proposed the other major standard candles, namely RR Lyr, red clump and tip of the red giant branch (TRGB) stars as possible brightness references and showed that the differences of magnitudes of all major stellar standard candles are very consistent in the LMC and SMC. The TRGB stars seem to be the best for testing the stability of zero points of Cepheid PL relations. First, they are of brightness similar to Cepheids. Secondly, they are usually very numerous and the determination of the TRGB magnitude is very precise (see for instance the TRGB of the LMC and SMC – Udalski 2000b). Finally, it is generally accepted that the TRGB I-band magnitude is practically constant to better than a few hundredths of magnitude for a wide range of metallicity (Bellazzini, Ferraro and Pancino 2001). Also, the old TRGB stars belong to completely different population than young Cepheids so that any correlation of their luminosities seems to be extremely unlikely.

The difference of the I-band magnitudes of TRGB stars and Cepheids with $P = 10$ days for the LMC and SMC was determined by Udalski (2000b) and is equal to: 0.71 ± 0.03 mag and 0.66 ± 0.04 mag for the LMC and SMC, respectively. It is worth stressing at this point that such a determination is fully differential and therefore can be done very precisely, as the majority of possible systematic errors like uncertainty of the zero point of photometry, uncertainty of interstellar extinction etc. cancel out.

There is, however, a possibility that in the case of IC1613 the magnitudes of Cepheids can be systematically affected by blending effect. Mochejska *et al.* (2000, 2001), who first pointed out this effect, found that in M31 and M33 galaxies, located at roughly the same distance as IC1613, some fraction of ground-based detected Cepheids is blended with close physical/optical companions resolved on much higher resolution HST images. This may lead to a systematic overestimate of the brightness of Cepheids up to 0.15 mag for these galaxies when measured from the ground.

Certainly results for M31 and M33, large spiral galaxies, have no direct correspondence to the possible effect of blending in such low luminosity, dwarf galaxy as IC1613. In general, blending for a particular object might be hard to estimate because it may depend on many local conditions etc. To have some information on the possible magnitude of this effect in the case of IC1613 we performed two tests. First we used simulation of Stanek and Udalski (1999) who analyzed how the blending effect would affect the LMC Cepheids when observed at larger distances, *i.e.*, with worse resolution. LMC is certainly more suitable for such a test than spiral galaxies M31 and M33 as both the LMC and IC1613 belong to the same class of galaxies. Still, this test can provide only an upper limit because of much larger brightness, star density etc. of the LMC bar than the faint dwarf IC1613.

Simple calculation yields that at the distance of IC1613 of about 700 kpc, the ground-based resolution of $1''$ corresponds to the LMC Cepheids as seen by the HST (resolution of $0\overset{''}{.}1$) from 7 Mpc. Fig. 4 from Stanek and Udalski (1999) implies that at this distance the blending would affect LMC Cepheids at the 0.03–0.04 mag level only. It seems reasonable then to assume that in the case of IC1613 it will be considerably smaller.

We also looked at HST images of the center of IC1613 retrieved from the Hubble Data Archive, originally obtained by Cole *et al.* (1999). We limited ourselves to Cepheids used for determination of our PL relations, *i.e.*, those with $\log P > 0.4$. Additionally, we also checked whether blending similarly affects other group of stars, *i.e.*, the TRGB stars. We selected a subsample of TRGB stars limiting them to ±0.05 mag around the TRGB mean magnitude (see below). The number of Cepheids and TRGB stars in the field of Cole *et al.* (1999) is small and similar: 10 and 13 objects, respectively. We visually inspected the HST images looking for blending of identified stars. We found significant blending in the case of two Cepheids and five TRGB stars. Although the samples are small we may conclude that both groups of stars seem to be similarly affected in the case of IC1613. Because we will further compare magnitudes of both groups of stars it is safe to conclude that the possible blending cancels in the first approximation and negligibly affects our comparison of standard candles in IC1613 presented below. It will also marginally affect the slopes of the above determined PL relations. Blending is supposed to affect more the shorter period (fainter) Cepheids than the longer period ones. Even if this difference amounts to 0.05 mag, the slopes of the PL relation would be just by similar amount steeper, still in excellent agreement with the slopes of the Magellanic Cloud Cepheid PL relations. Thus, it seems that, apart from the Magellanic Clouds, IC1613 might be an unique object for studying properties of Cepheids not only because of low reddening and low metallicity but also because possible systematic errors like blending are in this case practically negligible contrary to, for instance, M31 or M33 galaxies (Mochejska *et al.* 2000, 2001).

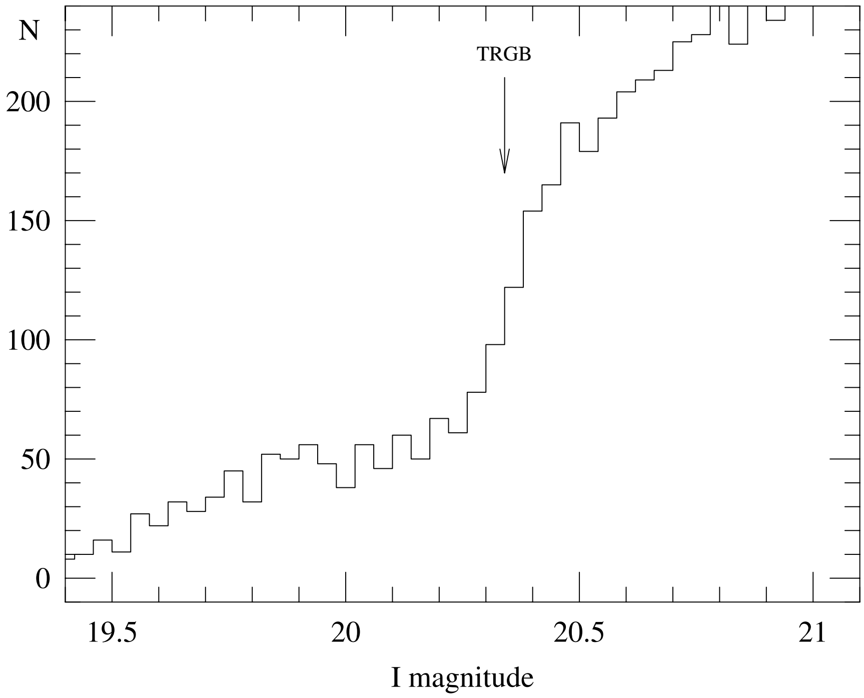

Fig. 5. Histogram of luminosity of the upper part of the red giant branch in IC1613. Bins are 0.04 mag wide. Arrow marks the TRGB magnitude.

CMD diagram of IC1613, presented in Fig. 1, shows that the upper red giant branch is very well populated in this galaxy and the TRGB is easily distinguishable. To determine its magnitude we selected the red giant branch stars from the CMD region limited by dotted line in Fig. 1. Then, we constructed the luminosity function histogram with 0.04 mag bins presented in Fig. 5. The location of the TRGB is clearly seen in this figure and it is marked by the arrow. The TRGB magnitude in IC1613 is equal to: $\langle I^{\rm TRGB}\rangle = 20.34 \pm 0.02$ mag. It is worth noticing that this value is in very good agreement with other recent determinations of the TRGB magnitude (see Section 6.2) for IC1613 (Dolphin *et al.* 2001).

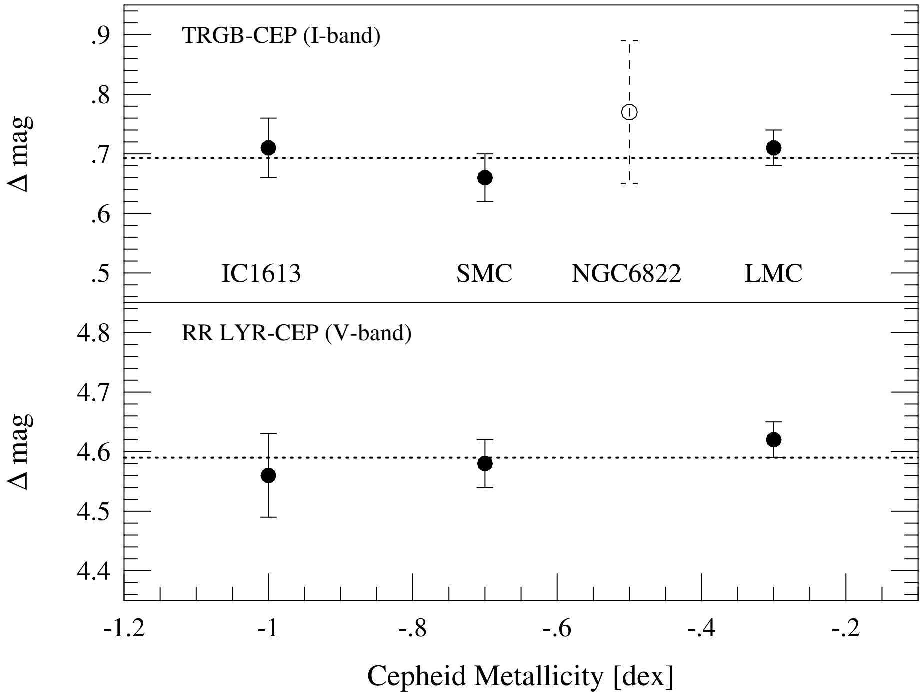

Fig. 6. Comparison of brightness of $P=10$ days Cepheids with brightness of TRGB stars (upper panel) and RR Lyr stars (lower panel).

The I-band PL relation yields the brightness of the $P=10$ days Cepheid in IC1613 of $\langle I^{\mathrm{C}}\rangle = 19.63 \pm 0.04$ mag. Thus, the difference of magnitudes of the TRGB and $P=10$ days Cepheid in IC1613 is equal to 0.71 ± 0.05 mag. Table 3 summarizes comparison of the I-band TRGB and Cepheid magnitudes in the LMC, SMC and IC1613. Upper panel of Fig. 6 visualizes these results. Looking at Fig. 6 one can conclude that in all three objects distributed over wide range of Cepheid metallicities, the mean I-band brightness of Cepheids relative to the reference source, TRGB stars, is constant to ± 0.03 mag.

It should be noted here that at least one additional object could be in principle added to Fig. 6. Another Local Group dwarf galaxy, NGC6288, is known to contain both Cepheids and TRGB stars. With metallicity of $[\mathrm{Fe/H}] \approx -0.5$ dex (Venn *et al.* 2001) it could provide another point in between the LMC and SMC. Unfortunately, similarly to IC1613, NGC6822 still awaits for extensive, standard band search for its Cepheids and determination of precise PL relations. Nevertheless, the rough estimate of the difference of brightness of TRGB stars and Cepheids can be obtained from the data of Gallart, Aparicio and Vílchez (1996). They determine the I-band magnitude of TRGB stars in NGC6822 to be equal to $\langle I^{\mathrm{TRGB}}\rangle = 19.8 \pm 0.1$ mag. They also list the mean I-band magnitudes for six Cepheids from this galaxy. Fitting the universal PL relation ($A_I=-2.98$) to these data gives the brightness of the $P=10$ days Cepheid equal to $\langle I^{\rm C}\rangle=19.03\pm0.07$ mag leading to the difference of 0.77 ± 0.12 mag. It is very encouraging that this value is in very good agreement with the MC and IC1613 data confirming the observed behavior of Cepheids in environments of different metallicity. Nevertheless, we treat this value as very preliminary and mark in Fig. 6 the point for NGC6822 as an open circle with dashed line error bars until a more precise value for NGC6822 is available. One should also remember that a few more nearby galaxies are known to contain Cepheids (*e.g.*, WLM, NGC3109, NGC300). They may also provide additional points to Fig. 6 in the future when accurate and based on many Cepheids standard band PL relations, precise TRGB magnitudes and accurate spectroscopic metallicities are determined.

Table 3

Comparison of brightness of Cepheids with TRGB and RR Lyr stars

Galaxy: Cepheid [Fe/H]:	IC1613 -1.0 dex	SMC -0.7 dex	LMC -0.3 dex
TRGB – CEPHEIDS $\langle I^{\rm TRGB}\rangle-\langle I^{\rm C}\rangle$	0.71 ± 0.05	0.66 ± 0.04	0.71 ± 0.03
RR LYR – CEPHEIDS $\langle V^{\rm RR}\rangle_{\rm [Fe/H]_{LMC}}-\langle V^{\rm C}\rangle$	4.56 ± 0.07	4.58 ± 0.04	4.62 ± 0.03

The comparison of the mean magnitudes of Cepheids and TRGB stars implies no metallicity dependence of the I-band zero point. Although it is unlikely to expect significantly different behavior of Cepheids in shorter wavelength bands, this cannot be in principle excluded. Fortunately, IC1613 also contains RR Lyr stars which V-band magnitude is believed to be a good standard candle. However, contrary to the TRGB stars magnitude, the RR Lyr brightness is known to be dependent on metallicity. The slope of this dependence is usually assumed to be about 0.15–0.20 mag/dex with RR Lyr being brighter in lower metallicity environment.

13 RR Lyr stars in IC1613 were detected by Dolphin *et al.* (2001) on deep HST images. They provide the mean V-band brightness of this sample to be equal to $\langle V^{\rm RR}\rangle=25.00\pm0.04$ mag. They also determined the mean metallicity of this sample to be $[{\rm Fe/H}]=-1.3\pm0.2$ dex.

Udalski (2000b) finds the mean differences of the V-band brightness of RR Lyr stars, converted to the mean metallicity of the LMC RR Lyr stars ($[{\rm Fe/H}]=-1.6$ dex) and $P=10$ days Cepheids in the LMC and SMC to be equal to 4.62 ± 0.03 mag and 4.58 ± 0.04 mag, respectively. Unfortunately, similar comparison for IC1613 cannot be done fully differentially in our case, contrary to the Magellanic Cloud or I-band comparisons, because some shift between the zero points of Dolphin *et al.* (2001) and our V-band photometries is possible. Although, in the case of the I-band TRGB magnitudes the agreement of Dolphin *et al.* (2001) and our determinations is excellent we assume additional uncertainty of ± 0.02 mag for the possible difference of V-band photometries.

Before we compare the V-band magnitudes of RR Lyr and Cepheids we must first convert the former to the metallicity of the LMC. If the IC1613 RR Lyr stars were of the LMC metallicity they would have to be by about 0.05 mag brighter, *i.e.*, $\langle V^{\rm RR} \rangle_{\rm [Fe/H]_{LMC}} = 24.95 \pm 0.05$ mag. With the mean V-band magnitude of P=10 days Cepheids equal to $\langle V^{\rm C} \rangle = 20.39 \pm 0.04$ mag this leads to the difference equal to 4.56 ± 0.07 mag. In the error budget we additionally included 0.02 mag uncertainty of ground-based Cepheid magnitude for possible blending effect. Results of this comparison are also listed in Table 3 and plotted in the lower panel of Fig. 6.

Fig. 6 clearly indicates that brightness of Cepheids in respect to RR Lyr stars in the V-band behaves basically identical to our previous comparison with TRGB stars in the I-band. Again, the brightness of Cepheids is to ± 0.04 mag constant in all objects covering wide range of Cepheid metallicities implying no dependence of the V-band zero point of the PL relation on metallicity.

Summarizing, we can conclude that both VI and W_I slopes and also VI zero points of the Cepheid PL relation are independent of metallicity in the wide range of $-1.0 < {\rm [Fe/H]} < -0.3$ dex. Our tests clearly indicate that the PL relations are universal in this range, so the distance scale based on Cepheids is very reliable and Cepheids are very good standard candles. Of course, we cannot exclude at this moment that some dependence on metallicity occurs outside this range, for instance, for more metal rich object of Galactic metallicity of ${\rm [Fe/H]} \approx 0.0$ dex, or higher. However, analysis of this range will probably have to be postponed until the future space missions (GAIA, FAME, SIM) provide precise absolute magnitudes of large samples of Galactic Cepheids, RR Lyr and TRGB stars.

6.2 Distance to IC1613

Beside Cepheids, TRGB and RR Lyr stars, IC1613 also contains large number of red clump stars. These stars are also believed to be a very good standard candle, the only one which can be directly calibrated with Hipparcos parallaxes (Paczyński and Stanek 1998, Udalski 2000a).

While the observational tests show that the mean I-band magnitude of red clump stars is only slightly dependent on metallicity of environment (the slope of 0.14 mag/dex with red clump stars being brighter in metal poor objects) and practically independent of the age for intermediate age (2–10 Gyr) objects (Udalski 2000ab, Bersier 2000), theoretical modeling predicts its complicated behavior questioning usability of red clump stars as a standard candle (Girardi and Salaris 2001).

The problem is very important because the red clump stars have very reliable calibration based on Hipparcos measurements of nearby stars (Udalski 2000a). Therefore they might be crucial for establishing the precise zero point of the distance scale in the Universe.

Bersier (2000) and Udalski (2000b) presented comparison of the mean I-band magnitudes of red clump stars with TRGB stars. This comparison, fully differential and largely free from systematic errors, showed that after correcting for the above mentioned slight dependence of the red clump brightness on metallicity, the difference $\langle I^{\rm RC}\rangle_{\rm [Fe/H]_{LMC}} - \langle I^{\rm TRGB}\rangle$ is equal to 3.62 ± 0.05 mag for ten galaxies possessing red clump stars of intermediate age and believed to have wide age distribution, different star formation histories etc. (Table 5 in Udalski 2000b). This result clearly indicates that the dependence of the mean I-band magnitude of red clump stars on age in the range of 2–10 Gyr is marginal.

IC1613 offers another opportunity for testing this assumption. Dolphin *et al.* (2001) provide the mean I-band magnitudes for both the red clump and TRGB stars obtained from deep HST images. Again the comparison can be done fully differentially because both kind of stars were observed simultaneously. Dolphin *et al.* (2001) provide data for their field and re-reduced data for another field in IC1613 observed by Cole *et al.* (1999): $\langle I^{\rm RC}\rangle = 23.90\pm0.01$ and 23.86 ± 0.01 mag, respectively, and $\langle I^{\rm TRGB}\rangle = 20.40\pm0.09$ and 20.35 ± 0.07 mag, respectively.

Before making the comparison one has to correct the brightness of red clump stars for the difference of metallicity LMC – IC1613: -0.5 dex *vs.* -1.3 dex (Cole *et al.* 1999, Dolphin *et al.* 2001) by applying correction of $+0.11$ mag (Eq. 14, Udalski 2000b). The final difference $\langle I^{\rm RC}\rangle_{\rm [Fe/H]_{LMC}} - \langle I^{\rm TRGB}\rangle$, very similar for both Dolphin *et al.* (2001) fields, is equal to 3.62 ± 0.07 mag. The main component of the error in this determination is the cited error of the TRGB magnitude. In practice, it is very likely that the real determination error is at least twice smaller – our ground based observations give similar value of TRGB magnitude with much smaller uncertainty.

The comparison of the I-band magnitudes of the red clump and TRGB stars in IC1613 yields identical result as for the remaining ten galaxies from Table 5 of Udalski (2000b). It is worth noticing that according to Cole *et al.* (1999) the age of the red clump stars in IC1613 is about 7 Gyr, rather on the older side of the intermediate age range. Nevertheless, the difference of magnitudes of the red clump and TRGB stars is identical as in objects possessing much younger population of red clump stars like the LMC (2–3 Gyr). Thus, IC1613 is eleventh object confirming that the red clump I-band magnitude is independent of age and only slightly dependent on metallicity. Therefore, there is no empirical evidence to question the Hipparcos calibration of red clump stars for establishing the zero point of the distance scale.

The most likely absolute calibrations of the distance scale for the main stellar standard candles: Cepheids, RR Lyr, TRGB and red clump stars are given in Eqs. 9–14 of Udalski (2000b). They give consistent distances to the LMC, SMC and Carina dwarf galaxy for all the observed there stellar distance indicators. These calibrations are in agreement with differences of magnitudes between standard candles observed in particular objects. They assume only slight dependence of magnitudes on metallicity in the case of RR Lyr and red clump stars (well established empirically) and no other population effects. The calibrations are based on the only direct calibration of standard candles – Hipparcos calibration of red clump stars, but are also in agreement with other less direct calibrations of the remaining distance indicators.

Table 4

Distance moduli to IC1613

STANDARD CANDLE	m_0	$(m-M)_{\rm IC1613}$
CEPHEIDS (V)	20.31 ± 0.05	24.23 ± 0.07
CEPHEIDS (I)	19.58 ± 0.04	24.19 ± 0.07
CEPHEIDS (W_I)	18.50 ± 0.03	24.17 ± 0.07
RR LYR (V)	24.92 ± 0.04	24.18 ± 0.07
TRGB (I)	20.29 ± 0.02	24.20 ± 0.07
RED CLUMP (I)	23.83 ± 0.02	24.23 ± 0.06

In Table 4 we present the distance determinations to IC1613 resulting from four stellar standard candles which photometric data are presented in this paper. The observed magnitudes were corrected for interstellar extinction using the values listed in Section 4 (column m_0 in Table 4). For Cepheids three determination were possible – for the V, I and W_I index.

As can be seen from Table 4, the resulting distance moduli from major stellar distance indicators in IC1613 are very consistent similarly to the LMC, SMC and Carina dwarf galaxy determinations (Udalski 2000b). The distance modulus to IC1613 is equal to $(m-M)_{\rm IC1613}=24.20$ mag with the standard deviation from six determinations of only ± 0.02 mag. The systematic uncertainty, however, can be of the order of 0.07 mag resulting from uncertainty of Udalski's (2000b) calibrations, error of determination of the mean magnitudes and additional possible blending effect in IC1613 in the case of ground-based measurements (estimated at $+0.02$ mag). The distance modulus of IC1613 corresponds to the distance of 690 ± 20 kpc.

The photometric data of IC1613 presented in this paper are available in the electronic form from the OGLE archive:

http://www.astrouw.edu.pl/~ogle
ftp://sirius.astrouw.edu.pl/ogle/ogle2/var_stars/ic1613

or its US mirror

http://bulge.princeton.edu/~ogle
ftp://bulge.princeton.edu/ogle/ogle2/var_stars/ic1613

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