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PERIODS AND LIGHT CURVES OF 16 CEPHEID VARIABLES IN IC 1613 NOT COMPLETED BY BAADE

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ABSTRACT

New periods and light curves are presented for 16 of the faintest Cepheids in IC 1613 which had not been finished by Baade. Magnitudes have been reduced to Freedman's new photometric scale. The *P-L* relation is extended to periods of 2 days using these new data. Comparison of the total Cepheid data now available in IC 1613 with the data in LMC shows no significant slope difference in the two *P-L* relations for periods of less than 10 days despite the lower metallicity of the young stars in IC 1613. Fifty new faint Cepheid candidates have been found in IC 1613 by blinking plates not used for this purpose by Baade. Most of these stars will have probable periods of less than 2 days, which will eventually permit an extension of the *P-L* relation in IC 1613 to fainter magnitudes when the photometry and period determinations are completed.

Subject headings: galaxies: individual (IC 1613) — galaxies: Local Group — stars: Cepheids

I. INTRODUCTION

The Im V galaxy IC 1613 [RA $1^h02^m16^s$ (1950), decl. $+ 1°52'$ (1950), $l = 130°$, $b = -61°$], at absolute magnitude $M_B = -14.6$, is among the faintest members of the Local Group in which Cepheids have been found. The Small Magellanic Cloud (type Im IV–V) with $M_B = -17.0$ is a factor of 10 more luminous than IC 1613; LMC (type SBm III) at $M_B = -18.4$ is still more luminous by a factor of ~ 30. Hundreds of Cepheids are known in SMC, and more than 1000 in LMC.

Baade found 59 confirmed variables in IC 1613 by blinking 34 plate pairs in his series of 106 plates taken with the Mount Wilson 60 inch and 100 inch reflectors between 1929 and 1937. Light curves for 24 of the confirmed Cepheids had been completed by Baade before his death in 1960. The data for these 24 stars, reduced to a new photometric scale and zero point (Sandage 1971, hereafter S71) showed a very shallow slope of $d\langle B\rangle/d \log P = -1.52$ (S71, Fig. 11) for the *P-L* relation. The slope of the envelope lines for the fiducial *P-L* relation adopted by Sandage and Tammann (1968) from photometry in other galaxies is steeper at approximately -2.4 over the period range of $0.4 < \log P < 1.0$.

The scale and zero point for the 1971 reduction of Baade's data in IC 1613 was based on a photoelectric sequence, transferred to a set of comparison stars over the face of IC 1613, defined in Tables A1 and A2 of Sandage, Katem, and Matthews (1971). Because of the slope anomaly in B for these 24 brightest Cepheids, van den Bergh (1977) queried the reliability of the 1971 magnitude scale and the reduction made by Sandage. His suggestion for a scale error has now been verified by Freedman (1988, Fig. 1), based on her CCD photometry that reaches $B = 23$. Freedman's observations were obtained with the CFHT reflector at Mauna Kea.

Applying Freedman's scale correction to the 1971 photometric elements for Baade's 24 Cepheids has reduced the scale anomaly in the *B* band, but has not removed it (Sandage 1988 [hereafter S88], Fig. 9*a*). However, if the five longest period Cepheids are ignored (justified by noting that these five stars do not adequently sample the area between the envelope lines that themselves are separated by 1.2 mag), the small remaining apparent slope anomaly may not be significant, as will be discussed in the last section.

Because there are apparently no additional Cepheids to be found in IC 1613 with periods longer than $P \sim 15$ days, further study of the slope problem in the *B* band must be done at the short period end of the *P-L* relation. The slope comparison between IC 1613 and say LMC can also be made in the near infrared where the intrinsic spread of the envelope lines is very small, nearly eliminating the stocastic sampling problem just mentioned. Freedman has made this comparison, showing, indeed, no IC 1613 slope anomaly in the near IR *P-L* relation. We also discuss the near infrared comparison in the final section of this paper using additional IR data from the literature.

Before the recent application of near infrared photometry to the problem (see McGonegal *et al.* 1983; McAlary, Madore, and Davis 1984) we began in 1980 to study the fainter Cepheids found by Baade but not completed by him. These stars are labeled TBD (for "to be done") in Table 1 of S71. Our purpose has been to address the slope problem by testing if the effect in B is due to a sampling bias caused by failing to study Cepheids that disappeared below the plate limit at minimum light (S71, S88). To this end, we have used new plate material obtained by Baade between 1950 and 1957 with the Palomar 200 inch telescope, and by one of us with the same telescope between 1958 and 1960, and then with the Las Campanas 2.5 m duPont reflector in a single long run in 1983.

As a first step to increase the IC 1613 Cepheid sample, we have obtained periods for 16 of the 21 variables left in Baade's list of TBD stars. We discuss these new data here so as to finish the photometry of Baade's initial list before carrying the search for additional variables to fainter magnitudes. Although we now have blinked the new plate material and have found ~ 50 fainter definite variables, the determination of their periods is yet in the early stages.

II. PHOTOMETRY

a) New Plate Material

Soon after the 200 inch telescope was commissioned in late 1949, Baade began obtaining plates of the galaxy at Palomar in

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an effort to improve the photometric homogeneity of the Mount Wilson 100 inch data. To this end he took many short-exposure plates centered at different places over the face of IC 1613 to tie the magnitude sequences for individual variables into a common photometric system. Due to the coma-free properties of the Ross field corrector, the flat field of the 200 inch prime focus was an improvement over the noncorrected Newtonian field of the Mount Wilson Hooker reflector. Most of Baade's Palomar plates were of short exposure, made to accomplish this photometric smoothing. However, a number were of 15 minute exposure time, and a few were exposed to the nominal photometric limit reached in 30 minutes on Eastman 103aO emulsion (the high storage capacity Eastman IIIaJ plates had not yet been invented).

For the present study we have used only those plates in the collection that have exposure times of 15 minutes or longer taken on the Eastman blue 103aO emulsion behind either a Schott GG1 or GG13 minus UV filter. The plate scale is 11."1 per mm, and the coma-free field is 15′ in diameter. Between 1950 and 1957, Baade obtained 43 such plates. Six additional long exposure plates were obtained by Sandage between 1958 and 1960 at Palomar, and an additional 10 plates exposed to the photographic limit (sky density of ~0.6) were subsequently obtained at Las Campanas in 1983 with the duPont telescope. The plate numbers and the Julian day times of midexposure are listed in Table 3 below.

b) *Magnitudes of the Comparison Stars*

Freedman's (1988) corrections to the 1971 magnitude scale used by Sandage in his reduction of Baade's photometry is shown in Figure 1 as a function of the 1971 B values. A listing of these corrections is in Table 1, which, when applied in an obvious way to the *B*(1971) magnitudes in Table A2 of Sandage, Katem, and Matthews (1971) give the new magnitudes on the Freedman scale listed in Table 2. Only those comparison stars that have been used in the present photometry of Baade's TBD variables are shown in this table. They are the same stars that are identified on the finding charts in S71.

Several sequences in the 1971 study did not extend faint enough to follow the variables to minimum light. The faintest comparison star in the original list is V41e which has a transformed magnitude onto Freedman's scale of $B = 23.2$. This star also appears to be at the plate limit for most of the plates taken in good seeing used in the present study. Several variables reached this plate limit (none disappeared at minimum),

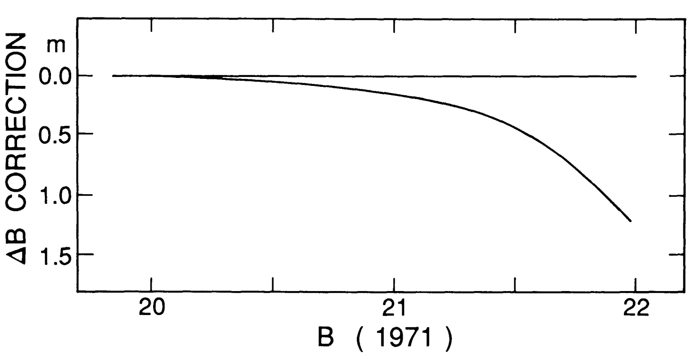

FIG. 1.—Correction of the magnitude scale of the comparison stars used by Sandage (1971) in IC 1613, based on the photometric sequences determined by Freedman (1988).

TABLE 1

ADOPTED CORRECTIONS TO THE 1971 IC 1613 MAGNITUDE SCALE BASED ON FREEDMAN'S (1988) CCD OBSERVATIONS

B(1971) (1)	*B*(1988) (2)	Δ*B* (3)
20.0	20.00	0.00
20.20	20.21	0.01
20.40	20.44	0.04
20.60	20.67	0.07
20.80	20.91	0.11
21.00	21.15	0.15
21.20	21.42	0.22
21.40	21.74	0.34
21.60	22.14	0.54
21.80	22.62	0.82
22.00	23.28	1.28

and were assumed to be at $B = 23.2$ at this phase. This procedure may be the reason for the flat bottom light curves near minimum for V28, V36, V46, V51, V59, and V62 although, as we show in the next section, these six stars themselves have only a minor effect on the slope of the *P-L* relation if they are omitted, showing that the photometry is not significantly affected by possible problems at minimum light.

The faintest sequence stars listed as "faint" in the original 1971 list have been interpreted here to also mean "plate limit" and have been set at $B = 23.2$. The star V46d′ was selected as an additional sequence star for V46 and adopted to be the same brightness as V25/50g. Finally, the magnitudes of stars V28e and V28e′ have been reversed from their 1971 order because e is always fainter than e′ on all plates (see also Plate 5 of S71).

c) *Magnitudes and Light Curves of the Cepheids*

Magnitudes of the 16 Cepheids were measured relative to the Table 2 sequences by the Argelander method of eye estimates. The details are set out in Table 3. The plate numbers in column (1) denote Palomar 200 inch plates if the prefix is PH (for Palomar Hale): the observer's initial is the suffix to the designation. Las Campanas duPont 2.5 m plates are designated as CD (for Campanas duPont). The Julian day at mid-exposure is in column (2). The listing for each variable is the phase (calculated from the finally adopted period, to be discussed), and the measured *B* magnitude. The zero point of each phase is put at maximum light.

The periods were determined by selecting a trial period, estimated from the several long runs on nearly consecutive days in 1956 and again in 1983. Baade had also estimated possible periods for 13 of these stars from his Mount Wilson data, as listed in Table 1 of S71. Starting with these trial periods, the observations were binned into phase intervals of 0.1, and the average scatter of the data in each bin was calculated. The trial period was then incremented, and a minimum in the dispersion per bin was sought as the period range was scanned. Usually several closely spaced minima were found corresponding to cycle count differences within the long time intervals between the more closely spaced observations. Usually, a central minimum in the dispersion versus trial period curve was deeper than the others. The adopted period has been taken to be the one giving this minimum in the dispersion. In a few cases there still remains the possibility of a cycle count error, which will change the adopted period by very small amounts; unimpor-

TABLE 2

Adopted Magnitudes of the Comparison Stars

Region (1)	Star (2)	B (3)	Region (1)	Star (2)	B (3)	Region (1)	Star (2)	B (3)
V7..........	a	20.46	V41..........	a	21.20	V54..........	a	20.89
	b	20.74		b	21.53		b	21.28
	c	21.28		c	21.77		c	21.55
	d	21.64		d	22.80		d	22.14
	e	21.94		e	23.20		e	22.43
V8..........	a	20.75	V46..........	a	21.30	V57..........	a	21.15
	b	21.36		b	21.47		b	21.53
	c	21.66		c	22.14		c	21.94
	d	22.25		d	22.30		d	21.94
				d′	22.60		e = PL	23.20
V28..........	A	20.84		e = PL	23.20			
	a	21.38						
	c	21.72	V47..........	a	20.61	V58..........	a	19.32
	d	22.25		b	21.05		b	19.73
	e′	22.88		c	21.22		c	20.51
	e	23.00		d	21.72		d	21.09
	PL	23.20		e	21.84			
				f	22.63	V60..........	a	21.21
V35..........	a	21.44					b	21.48
	b	21.44	V48..........	a	21.45		c	21.53
	c	21.73		b	21.69		d = PL	23.20
	d	22.30		c	21.89			
	e	22.57		d	22.23	V61..........	a	21.05
	f	23.00		e	23.00		b	21.63
							c	21.88
V36..........	a	20.22	V51/V59.....	α	20.81		d	22.30
	b	20.75		A	21.18		e	22.51
	c	21.03		a	21.36			
	d	21.67		b	21.72	V62..........	a	21.05
	e	22.28		c	22.13		b	21.06
	f	22.81		d	22.49		c	21.01
	PL	23.20		PL	23.20		d	21.82
							e	22.32
V40/V4......	a	20.82	V53..........	A	20.80		PL	23.20
	b	21.05		a	20.90			
	c	21.28		b′	21.35			
	e	21.69		c	21.43			
	f	22.38		d	21.74			
	g	22.66		e	22.35			
	h	23.20						

tant for the present purposes but which should be kept in mind in any future investigations of period changes. In passing, it can be remarked that Baade's estimates of the periods for a number of the present stars were generally quite accurate.

The light curves for the 16 program stars are shown in Figure 2, set out in the order of decreasing period. The photometric elements from these data are listed in Table 4. The adopted period is in column (3). The estimated error in this period, as if there is no cycle count error, is in column (4), based on the assumption that a phase shift of 0.05 could be detected over the 33 yr time interval of the observations. The dispersion of the magnitudes about the mean points, binned in intervals of 0.1 in phase, is in column (5). Maximum, minimum, and (intensity) mean magnitudes are in columns (7), (8), and (9). The amplitude in blue light is in column (10).

d) Photometric Properties of the Non-Cepheids

Besides the 16 Cepheids, five other TBD of Baade's stars were examined in this study, each of which were found to be a non-Cepheid. The very faint star V63 was not variable on the present plate material. We judge V8 and V41 (the southern member of a close double) to be irregular variables; V8 varied between $B = 21.3$ and 21.9 over the 33 yr interval; V41 between $B = 22.0$ and to below the plate limit at $B = 23.2$. V40 has turned out to be a long-period variable of period of ~ 478 days. Baade found the star to be red (denoted RI for red irregular in Table 1 of S71). It ranges in magnitude between $B = 21.7$ to below the plate limit. A further study of this star and of the red variable V19 with a period of 446 days (Fig. 10 of S71) will be made in a future paper in this series when the photometry of the 50 fainter new variables in IC 1613 will be discussed. Finally, V58 is either a long-period variable or an irregular. In 1956 it had $B = 19.3$. A steady decline to $B = 20.0$ occurred in 1957. The magnitudes in other years have been between these two limits. Again, a further study will be made, incorporating data from Baade's extensive Mount Wilson 1929–1937 plate collection. Such bright variables, especially if they are periodic, are of great evolutionary interest because of their bright absolute magnitudes.

III. THE PERIOD–LUMINOSITY RELATION

The period–luminosity relations from the data in Table 4 are shown in Figure 3 for mean light in the upper panel and at maximum light in the lower panel. The 24 data points shown

TABLE 3

B Magnitudes for Cepheids in IC 1613

PLATE	JD 2,430,000+	YEAR	V7		V28		V35		V36		V46		V47		V48		V49	
			PHASE	B	PHASE	B	PHASE	B	PHASE	B	PHASE	B	PHASE	B	PHASE	B	PHASE	B
PH 230B	3512.990	1950	0.54	21.73	0.46	23.20	0.31	22.19	0.93	21.86	0.86	22.01	0.60	21.92	0.20	21.53	0.73	22.18
PH 803B	4624.920	1953	0.30	20.80	0.19	22.70	0.10	21.44	0.77	23.20	0.50	23.02	0.48	22.00	0.70	23.00	0.98	21.69
PH 804B	4624.950		0.31	20.80	0.20	22.70	0.11	21.47	0.78	23.20	0.51	22.90	0.48	22.00	0.71	23.00	....	.....
PH 844B	4628.947		0.85	21.57	....	.....	0.41	22.49	0.42	23.13	0.07	22.36	0.61	22.32	0.21	22.06	0.52	22.11
PH 862B	4633.938		0.53	21.54	....	.....	0.04	21.44	0.46	23.20	0.01	22.30	....	.....	0.08	21.45	0.18	21.41
PH 869B	4679.759		0.79	21.94	0.39	22.98	0.95	22.39	0.20	22.93	0.88	22.27	0.35	21.84	0.29	22.20	0.24	21.57
PH 873B	4680.720		0.92	21.01	0.82	23.20	0.26	22.13	0.60	23.17	0.26	22.54	0.38	22.00	0.65	22.93	0.37	21.83
PH 877B	4681.693		0.05	20.63	0.25	22.88	0.57	23.00	0.00	21.74	0.64	22.60	0.41	21.84	0.02	21.53	0.50	21.97
PH 988B	4980.920	1954	0.89	21.39	0.31	22.93	0.93	22.36	0.40	23.13	0.33	22.66	0.60	22.56	0.37	22.39	0.13	21.53
PH1028B	4984.938		0.44	21.57	0.08	21.94	0.24	22.25	0.04	22.04	0.89	22.36	0.74	22.63	0.88	23.00	0.66	22.11
PH1040B	5005.843		0.30	21.12	0.30	22.93	0.04	21.44	0.59	23.20	0.05	22.36	0.45	22.08	0.73	23.00	0.43	21.90
PH1052B	5006.884		0.44	21.43	0.76	23.20	0.38	22.62	0.02	21.74	0.45	22.72	0.49	21.92	0.12	21.57	0.57	22.04
PH1057B	5007.835		0.57	21.76	0.18	22.76	0.69	23.00	0.41	23.20	0.82	23.20	0.52	22.00	0.47	23.00	0.69	22.18
PH1295B	5371.797	1955	0.24	20.85	0.81	23.20	....	.....	....	.....	....	.....	0.92	21.32	0.13	22.10	....	.....
PH1296B	5371.831		0.25	21.01	0.83	23.20	0.13	21.50	0.30	23.01	....	.....	0.92	21.27	0.14	22.17	....	.....
PH1456B	5688.969	1956	0.53	21.54	0.79	23.20	0.31	22.19	0.03	21.74	0.45	23.02	0.73	22.56	0.22	21.85	0.89	21.83
PH1471B	5690.969		0.81	21.94	0.67	22.98	0.96	21.44	0.85	23.20	0.23	22.54	0.79	22.56	0.97	21.85	0.16	21.41
PH1479B	5691.949		0.94	20.80	0.10	22.15	....	.....	0.25	22.81	....	.....	0.83	22.40	0.34	22.77	....	.....
PH1480B	5691.974		0.95	20.85	0.12	22.25	0.29	22.13	0.26	22.76	....	.....	0.83	22.40	0.35	22.20	....	.....
PH1490B	5692.944		0.08	20.74	0.54	23.20	0.61	22.88	0.65	23.20	0.00	21.74	0.86	22.00	0.71	23.00	0.42	21.76
PH1491B	5692.975		0.08	20.74	0.56	23.20	0.62	22.83	0.67	23.20	0.02	21.74	0.86	22.00	0.73	23.00	0.42	21.83
PH1531B	5717.925		0.49	21.46	0.57	23.00	0.73	22.57	0.87	23.20	....	.....	0.71	22.48	0.09	21.67	0.73	22.25
PH1534B	5717.980		0.49	21.54	0.59	23.20	0.75	22.88	0.90	23.20	....	.....	0.71	22.48	....	.....	0.73	22.25
PH1541B	5718.889		0.62	21.94	0.99	21.66	0.05	21.44	0.27	22.76	0.12	22.48	0.74	22.63	0.46	22.93	0.85	21.90
PH1542B	5718.902		0.62	21.94	0.00	21.55	0.05	21.50	0.27	22.76	0.13	22.54	0.74	22.48	0.46	22.93	0.86	22.04
PH1544B	5718.952		....	.....	....	.....	0.07	21.53	....	.....	....	.....	....	.....	0.48	23.00	0.86	21.97
PH1581B	5803.668		0.19	20.91	....	.....	....	.....	....	.....	....	.....	0.63	22.40	0.29	22.77	0.08	21.37
PH1582B	5803.695		0.19	20.96	0.42	22.94	....	.....	....	.....	....	.....	....	.....	0.30	22.77	0.08	21.69
PH1583B	5803.709		0.20	21.07	0.43	23.20	0.65	23.00	0.96	22.22	0.20	22.39	0.63	22.63	0.30	22.70	0.09	21.41
PH1584B	5803.730		0.20	20.96	0.44	23.20	....	.....	0.97	22.10	....	.....	0.63	22.56	0.31	23.00	....	.....
PH1588B	5807.616		0.73	21.94	0.15	22.63	0.92	22.25	0.56	23.17	....	.....	0.77	22.48	0.77	23.00	....	.....
PH1589B	5807.632		0.73	21.94	0.16	22.76	0.92	22.33	0.57	23.09	0.73	23.02	0.77	22.48	0.78	23.00	0.61	22.11
PH1590B	5807.655		0.73	21.88	....	.....	0.93	22.30	0.58	23.17	0.74	23.02	0.77	22.63	0.79	23.00	0.61	22.04
PH1591B	5807.672		0.74	21.94	0.18	22.76	0.94	22.19	0.59	23.13	....	.....	0.77	22.63	0.79	23.00	....	.....
PH1592B	5807.695		0.74	21.94	0.19	22.90	0.94	21.85	0.59	23.20	0.75	23.02	0.77	22.56	0.80	23.00	0.61	22.04
PH1593B	5807.711		0.74	21.94	0.19	22.76	0.95	21.85	0.60	23.13	0.76	23.02	0.77	22.48	0.81	23.00	0.62	22.04
PH1629B	5836.635		0.69	21.94	0.96	22.04	0.36	22.19	0.43	23.17	0.04	21.94	0.76	22.63	0.67	23.00	0.45	22.11
PH1701B	6040.911	1957	0.80	21.70	0.79	23.20	0.91	22.19	0.67	23.13	0.79	23.08	0.77	22.48	0.01	21.45	0.60	22.18
PH1712B	6041.978		0.95	20.69	0.27	22.98	0.26	22.70	0.11	22.28	0.21	22.48	0.81	22.48	0.41	22.85	0.75	22.25
PH1746B	6103.843		0.16	21.07	0.89	22.96	0.30	22.36	0.74	23.20	0.25	22.54	0.86	22.40	0.00	21.45	0.83	22.18
PH1749B	6103.908		0.17	21.07	0.92	22.96	....	.....	....	.....	....	.....	0.86	22.48	0.02	21.45	0.84	22.25
PH1750B	6103.925		0.17	21.07	0.92	22.63	0.33	22.44	0.77	23.20	....	.....	0.86	22.48	0.03	21.45	0.84	22.25
PH1776B	6162.664		0.19	21.12	....	.....	....	.....	....	.....	....	.....	0.86	22.40	0.08	21.83	0.62	22.25
PH3085S	6455.832	1958	0.20	21.12	0.23	22.93	0.83	22.83	0.72	23.20	0.51	23.08	0.85	21.57	0.16	21.85	0.45	21.83
PH3371S	6814.933	1959	0.22	21.07	0.71	22.98	0.67	22.83	0.61	23.17	0.56	22.66	0.08	21.32	0.99	21.45	0.00	21.05
PH3387S	6817.881		0.62	21.73	0.01	22.04	0.63	23.00	0.82	23.13	0.71	22.90	0.18	21.62	0.10	22.13	0.39	21.76
PH3417S	6819.891		0.89	21.23	0.90	22.04	0.28	22.19	0.64	23.13	0.49	22.57	0.25	21.57	0.85	23.00	0.66	22.18
PH3428S	6846.915		0.58	21.88	0.83	22.98	0.07	21.44	0.69	23.20	0.03	21.81	0.17	22.00	0.00	21.45	0.24	21.76
PH3703S	7203.893	1960	0.31	20.91	....	.....	0.22	22.25	....	.....	0.24	22.30	0.33	22.00	....	.....	0.51	22.25
CD2365S	15578.763	1983	0.39	21.18	0.47	23.20	0.16	21.79	0.52	23.13	0.27	22.54	0.63	22.32	0.58	23.00	0.57	22.04
CD2378S	15579.772		0.53	21.57	0.92	22.88	0.49	22.25	0.93	22.04	0.67	22.72	0.66	22.40	0.96	22.70	0.70	22.32
CD2390S	15580.811		0.67	21.79	0.37	22.98	0.83	22.62	0.36	23.13	0.07	22.22	0.70	22.40	0.35	22.23	0.84	22.04
CD2403S	15581.803		0.80	21.79	0.81	23.20	0.15	21.68	0.76	23.20	0.46	22.66	0.73	22.40	0.72	23.00	0.97	21.69
CD2418S	15582.768		0.94	21.07	0.24	23.00	0.47	22.25	0.16	22.76	0.84	23.08	0.76	22.56	0.08	21.50	0.10	21.83
CD2428S	15583.771		0.07	20.72	0.68	23.20	0.79	22.79	0.57	23.13	0.23	22.42	0.80	22.48	0.46	22.77	0.23	21.76
CD2435S	15584.826		0.22	20.91	0.15	22.38	0.14	21.79	0.00	21.80	0.64	23.08	0.83	22.48	0.86	23.00	0.37	21.90
CD2442S	15585.751		0.34	20.96	0.55	23.20	0.44	22.70	0.38	23.17	0.00	21.74	0.87	22.24	0.20	21.83	0.49	21.97
CD2451S	15586.713		0.48	21.61	0.98	21.78	0.75	22.92	0.77	23.20	0.38	22.60	0.90	21.84	0.57	22.93	0.62	22.18
CD2465S	15589.672		0.88	21.23	0.28	22.98	0.71	22.92	0.98	21.80	0.53	22.60	0.00	21.01	0.68	23.00	0.01	21.26

TABLE 3—*continued*

PLATE	JD 2,430,000+	YEAR	V51 PHASE	V51 B	V53 PHASE	V53 B	V54 PHASE	V54 B	V57 PHASE	V57 B	V59 PHASE	V59 B	V60 PHASE	V60 B	V61 PHASE	V61 B	V62 PHASE	V62 B
PH 230B	3512.990	1950	0.25	22.21	0.48	21.39	0.15	21.28	0.85	22.72	0.58	22.24	0.91	22.04	0.29	21.85	0.44	22.76
PH 803B	4624.920	1953	0.00	21.44	0.60	21.93	0.67	22.38	0.47	22.23	0.28	21.69	0.82	22.70	0.89	22.45	0.78	23.20
PH 804B	4624.950		0.01	21.44	0.61	21.56	0.68	22.41	0.48	22.35	0.29	21.69	0.84	22.70	0.90	22.45	0.79	23.03
PH 844B	4628.947		0.53	23.20	0.64	21.50	0.77	22.35	0.58	22.47	0.06	21.47	0.77	22.70	0.90	22.47	....	.....
PH 862B	4633.938		0.43	23.20	0.92	21.31	0.13	21.49	0.96	21.98	0.26	21.69	0.18	21.87	0.14	21.85	0.71	23.08
PH 869B	4679.759		0.85	23.20	0.72	21.47	0.64	22.29	0.64	22.23	0.53	22.21	0.30	21.87	0.58	22.37	0.60	23.08
PH 873B	4680.720		0.22	22.42	0.96	21.26	0.90	22.02	0.91	22.23	0.95	21.15	0.76	22.87	0.82	22.45	0.91	23.08
PH 877B	4681.693		0.58	23.06	0.21	21.39	0.17	21.49	0.18	21.70	0.38	21.81	0.23	21.51	0.07	21.34	0.23	22.22
PH 988B	4980.920	1954	0.35	22.85	0.21	21.39	0.85	22.08	0.96	21.97	0.70	22.35	0.72	22.70	0.77	22.45	0.46	22.76
PH1028B	4984.938		0.88	23.20	0.24	21.47	0.94	21.09	0.07	21.23	0.48	22.17	0.66	22.87	0.78	22.51	0.77	23.12
PH1040B	5005.843		0.83	23.20	0.62	21.68	0.65	22.43	0.85	22.96	0.72	22.24	0.76	22.70	0.99	21.23	0.56	23.08
PH1052B	5006.884		0.22	22.35	0.89	21.50	0.93	21.31	0.14	21.90	0.18	21.69	0.26	21.70	0.25	22.26	0.90	22.94
PH1057B	5007.835		0.58	23.06	0.14	21.36	0.19	21.78	0.40	22.11	0.60	22.39	0.72	22.87	0.49	22.45	0.21	22.12
PH1295B	5371.797	1955	0.96	21.65	0.79	21.42	....	.....	....	.....	0.55	22.31	0.46	22.70	0.36	22.18	0.49	23.03
PH1296B	5371.831		0.97	21.54	0.80	21.41	0.55	22.43	....	.....	0.56	22.24	0.48	22.87	0.37	22.45	....	.....
PH1456B	5688.969	1956	0.55	23.06	0.41	21.38	0.12	21.49	0.84	22.96	0.80	22.49	0.62	22.87	0.54	22.35	0.56	22.85
PH1471B	5690.969		0.31	22.71	0.92	21.22	0.67	22.43	0.40	22.59	0.69	22.21	0.58	22.70	0.04	21.23	0.21	22.27
PH1479B	5691.949		0.68	23.13	0.17	21.36	0.93	20.97	....	.....	0.12	21.62	0.05	21.52	0.29	22.18	0.53	22.94
PH1480B	5691.974		0.69	23.20	0.18	21.31	0.94	20.89	....	.....	0.13	21.65	0.07	21.70	0.29	22.35	0.53	22.85
PH1490B	5692.944		0.06	21.69	0.43	21.39	0.21	21.90	0.94	21.96	0.56	22.31	0.54	22.87	0.54	22.47	0.85	23.08
PH1491B	5692.975		0.07	21.69	0.44	21.39	0.21	21.52	0.95	21.96	0.57	21.97	0.55	22.54	0.54	22.47	0.86	23.08
PH1531B	5717.925		0.56	23.20	0.86	21.38	0.02	21.13	0.85	22.84	0.61	22.21	0.60	22.87	0.77	22.45	0.97	21.50
PH1534B	5717.980		0.58	23.20	0.87	21.37	0.04	20.97	0.87	22.84	0.63	21.69	0.62	23.04	0.79	22.47	0.98	21.34
PH1541B	5718.889		0.92	22.21	0.10	21.31	0.29	21.96	0.12	21.53	0.03	21.44	0.06	21.53	0.01	21.34	0.28	22.41
PH1542B	5718.902		0.93	21.65	0.11	21.31	0.29	22.14	0.12	21.74	0.04	21.44	0.07	21.50	0.02	21.34	0.28	22.50
PH1544B	5718.952		0.95	21.62	0.12	21.31	0.30	21.96	0.14	21.53	0.06	21.47	0.09	21.87	0.03	21.34	....	.....
PH1581B	5803.668		0.16	23.20	0.92	21.36	0.43	22.43	0.58	22.59	0.52	22.49	0.00	21.40	0.18	21.52	0.83	23.20
PH1582B	5803.695		0.17	23.20	0.93	21.31	0.44	22.43	0.58	22.59	0.53	22.31	0.01	21.87	....	.....	....	.....
PH1583B	5803.709		0.17	22.64	0.93	21.31	0.44	22.43	0.59	21.98	0.54	22.49	0.02	21.87	0.19	21.75	0.84	23.12
PH1584B	5803.730		0.18	22.99	0.94	21.31	0.45	22.08	....	.....	0.55	22.13	0.03	21.87	0.20	21.80	0.85	23.12
PH1588B	5807.616		0.66	23.20	0.94	21.22	0.51	22.08	....	.....	0.27	21.85	0.91	21.87	0.17	21.71	0.11	21.82
PH1589B	5807.632		0.66	23.20	0.94	21.31	0.51	22.43	0.67	22.59	0.28	21.85	0.91	22.37	0.17	21.58	0.12	21.87
PH1590B	5807.655		0.67	23.20	0.95	21.31	0.52	22.43	0.68	22.59	0.29	21.85	0.93	21.70	0.18	21.91	....	.....
PH1591B	5807.672		0.68	23.20	0.95	21.22	0.52	22.08	....	.....	0.29	21.93	0.93	21.87	0.18	21.91	0.13	22.41
PH1592B	5807.695		0.69	23.20	0.96	21.26	0.53	22.43	0.69	22.59	0.30	22.01	0.94	22.04	0.19	21.91	0.14	21.92
PH1593B	5807.711		0.69	23.20	0.96	21.26	0.53	22.43	0.69	22.84	0.31	21.89	0.95	21.87	0.19	21.91	0.14	21.97
PH1629B	5836.635		0.69	23.20	0.40	21.53	0.43	22.02	0.70	22.96	0.10	21.62	0.92	21.87	0.41	22.37	0.54	22.85
PH1701B	6040.911	1957	0.14	22.24	0.94	21.26	0.65	22.43	0.79	22.59	0.14	21.81	0.53	22.87	0.15	21.83	0.00	21.18
PH1712B	6041.978		0.55	23.20	0.22	21.47	0.94	20.89	0.08	21.46	0.61	21.81	0.04	21.87	0.42	22.41	0.35	22.85
PH1746B	6103.843		0.28	23.20	0.16	21.36	0.37	22.02	0.62	22.96	0.26	21.81	0.94	22.04	0.12	21.34	0.38	22.85
PH1749B	6103.908		0.31	22.99	0.18	21.39	0.39	22.02	0.64	22.59	0.29	22.24	0.98	22.04	....	.....	0.40	23.03
PH1750B	6103.925		0.31	23.20	0.18	21.37	0.39	21.90	0.64	22.35	0.30	21.89	0.98	22.04	0.14	21.92	0.40	22.85
PH1776B	6162.664		0.65	23.20	0.30	21.39	....	.....	0.89	22.59	0.27	22.01	0.35	22.70	....	.....	....	.....
PH3085S	6455.832	1958	0.11	22.64	0.74	21.87	0.45	22.02	0.00	21.19	0.91	21.89	0.91	22.37	0.00	21.23	0.76	23.03
PH3371S	6814.933	1959	0.64	23.20	0.14	21.31	0.47	22.38	0.35	21.96	0.71	21.89	0.31	22.04	0.65	22.49	0.46	22.85
PH3387S	6817.881		0.76	23.20	0.90	21.35	0.28	21.96	0.16	21.90	0.01	21.36	0.73	22.70	0.39	22.30	0.42	22.85
PH3417S	6819.891		0.52	23.20	0.42	21.53	0.83	22.02	0.72	22.72	0.90	21.81	0.70	22.87	0.89	22.18	0.07	21.97
PH3428S	6846.915		0.80	23.20	0.37	21.43	0.20	21.78	0.20	21.78	0.85	22.05	0.75	22.70	0.64	22.45	0.85	23.03
PH3703S	7203.893	1960	0.52	23.20	0.23	21.53	....	.....	0.95	21.34	0.71	22.01	0.12	22.37	....	.....	....	.....
CD2365S	15578.763	1983	0.62	23.06	0.26	21.31	0.72	22.26	0.91	22.23	0.09	21.47	0.07	21.53	0.64	22.51	0.41	22.85
CD2378S	15579.772		0.00	21.62	0.52	21.40	0.00	20.89	0.18	21.70	0.54	22.01	0.56	22.70	0.89	21.96	0.74	22.94
CD2390S	15580.811		0.40	22.99	0.78	21.65	0.28	21.66	0.47	21.98	0.00	21.07	0.06	21.70	0.15	21.58	0.08	21.74
CD2403S	15581.803		0.77	23.06	0.04	21.13	0.55	22.08	0.75	22.59	0.44	21.97	0.54	22.70	0.40	22.41	0.40	22.76
CD2418S	15582.768		0.14	22.39	0.29	21.36	0.82	22.20	0.01	21.42	0.87	21.81	0.01	21.53	0.64	22.41	0.71	23.03
CD2428S	15583.771		0.52	23.20	0.54	21.71	0.09	20.89	0.29	21.97	0.31	21.65	0.49	22.70	0.89	22.45	0.04	21.42
CD2435S	15584.826		0.92	21.81	0.82	21.50	0.38	22.02	0.58	22.23	0.78	22.31	0.00	21.53	0.15	21.63	0.38	22.85
CD2442S	15585.751		0.28	22.39	0.05	21.26	0.63	22.43	0.84	22.72	0.18	21.62	0.45	22.54	0.38	22.33	0.68	23.03
CD2451S	15586.713		0.64	23.20	0.30	21.42	0.89	21.78	0.10	21.53	0.61	22.01	0.91	22.37	0.62	22.41	0.99	21.26
CD2465S	15589.672		0.77	22.99	0.06	21.26	0.70	22.43	0.92	22.47	0.92	21.65	0.34	22.37	0.36	22.33	0.95	21.74

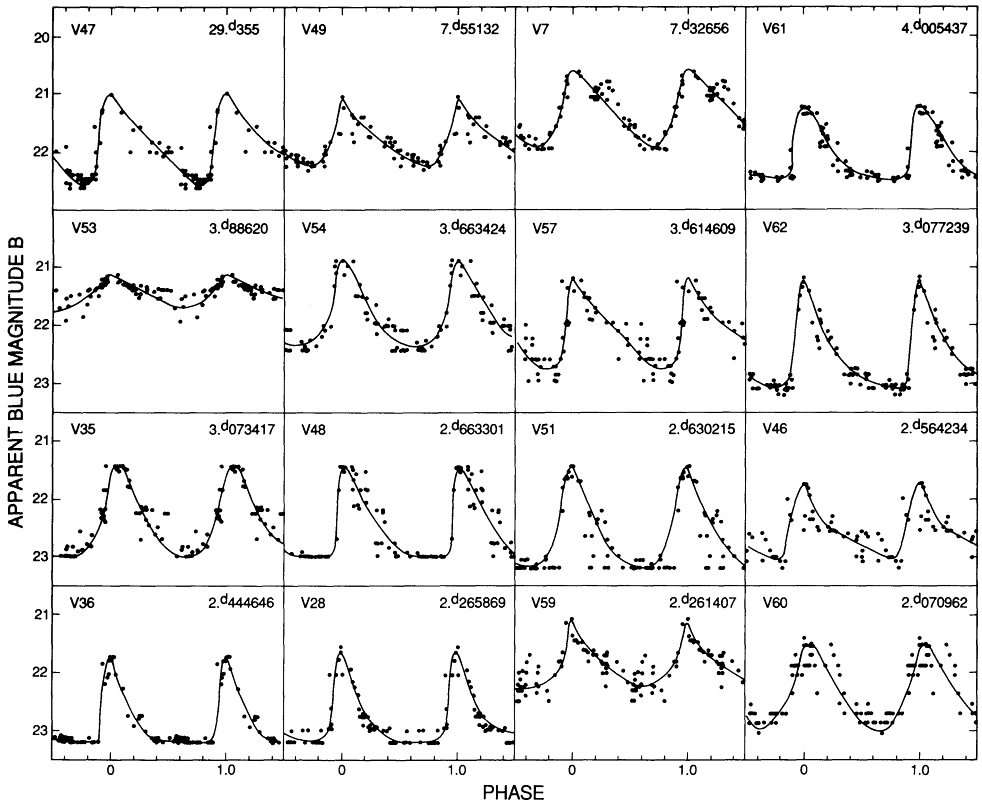

FIG. 2.—Light curves for 16 Cepheids in Baade's original list of IC 1613 variables that were not completed by him. Magnitudes are based on the photometric scale of the comparison stars listed in Table 2. The data are from Table 3.

as solid circles are from the 1971 reduction of Baade's original material, but reduced now to Freedman's photometric scale, with the results listed elsewhere (Sandage 1988, Table III). The 16 stars shown as crosses are the new stars from Table 4 here. The envelope lines are from Sandage and Tammann (1968, Table A1), with the zero points of the ordinates put according to the adopted modulus values shown. These modulus values are based on fitting the 39 cepheids in IC 1613 between the envelope lines, using the absolute magnitude zero points adopted from Table A1 of the reference just quoted. As discussed elsewhere (S88), these zero points are 0.2 mag brighter using mean light, and 0.1 mag brighter using maximum light than the zero points adopted by Feast and Walker (1987). The solid line in each panel is the least squares linear regression using the combined data from Table III of S88 and Table 4 here, discussed below.

The 29 day variable V47, whose light curve closely resembles that of a Cepheid, is 1.4 mag fainter than the ridge lines in Figure 3. The absolute magnitude of V47 is $\langle M_B \rangle = -2.9$ if $\langle B \rangle = 21.8$ at a distance modulus of $m - M = 24.7$. If the star is a W Virginis Cepheid of the globular cluster population, one expects it to be still fainter, at $\langle M_B \rangle = -2.0$ according to the

TABLE 4

PHOTOMETRIC ELEMENTS FOR THE 16 PROGRAM CEPHEIDS IN IC 1613

Number (1)	JD (max) 2,439,500+ (2)	P days (3)	$e(P)$ days (4)	σ mag (5)	log P (6)	B(max) (7)	B(min) (8)	$\langle B \rangle$(mean) (9)	A_B (10)
V7.........	53.474	7.32656	±0.0002	0.09	0.865	20.60	21.92	21.25	1.32
V28.........	50.486	2.265869	0.00002	0.16	0.355	21.65	23.18	22.62	1.53
V35.........	51.293	3.073417	0.00004	0.16	0.488	21.44	23.00	22.27	1.56
V36.........	51.440	2.444646	0.00002	0.07	0.388	21.73	23.20	22.77	1.47
V46.........	51.108	2.564234	0.00003	0.16	0.409	21.74	23.02	22.49	1.28
V47.........	42.542	29.355	0.004	0.18	1.468	21.00	22.57	21.78	1.57
V48.........	50.166	2.663301	0.00003	0.18	0.425	21.45	23.00	22.40	1.55
V49.........	48.511	7.55132	0.0002	0.12	0.878	21.10	22.25	21.78	1.15
V51.........	51.313	2.630215	0.00003	0.19	0.420	21.44	23.20	22.42	1.76
V53.........	50.275	3.88620	0.00006	0.07	0.590	21.13	21.70	21.46	0.57
V54.........	49.776	3.663424	0.00006	0.16	0.564	20.87	22.37	21.71	1.50
V57.........	49.937	3.614609	0.00005	0.21	0.558	21.20	22.75	22.03	1.55
V59.........	51.900	2.261407	0.00002	0.16	0.354	21.08	22.24	21.82	1.16
V60.........	52.109	2.070962	0.00002	0.18	0.316	21.50	23.00	22.25	1.50
V61.........	52.035	4.005437	0.00007	0.13	0.603	21.23	22.50	22.00	1.27
V62.........	52.268	3.077239	0.00004	0.12	0.488	21.26	23.08	22.35	1.82

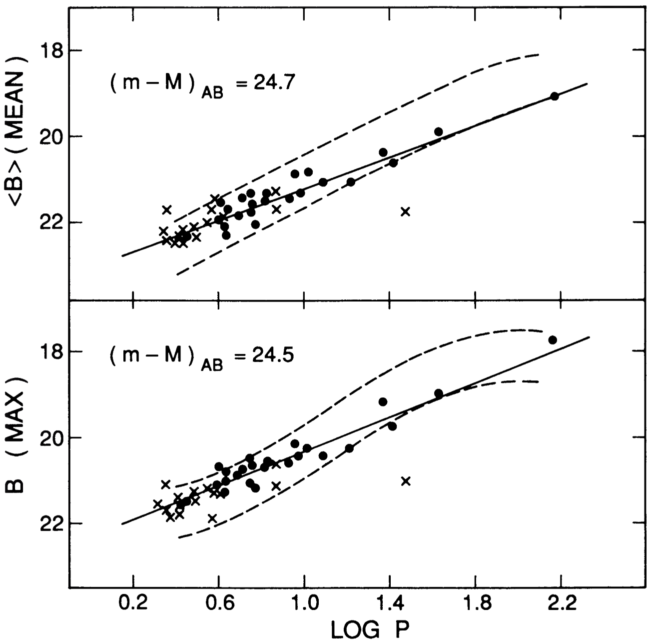

FIG. 3.—*Top:* Period—luminosity relation at mean light. Filled circles are the 24 Cepheids completed in the 1971 study, reduced to the photometric scale of Freedman (1988). Crosses are based on data in Table 4 for the 16 new Cepheids. Envelope lines are from Sandage and Tammann (1968). The modulus value shown is based on their zero point of the *P-L* relation which gives $(m - M)_{AB} = 18.95$ for LMC (Sandage 1988, Table V). The solid line is eq. (1) of the text. *Bottom:* The *P-L* relation at maximum light. The solid line is eq. (2) of the text.

Population II *P-L* relations of Demers and Wehlau (1971, Figs. 7 and 8) and of Demers and Harris (1974, Table I). Furthermore, the scatter of the globular cluster population II Cepheids about the ridge lines in these two investigations cannot accomodate a blue absolute magnitude of $M_B = -2.9$ at $\log P = 1.47$. However, the conclusion that V47 is unusual as a W Virginis star is not quite so clear using the data of Baade and Swope (1963, Fig. 15) where the M31 population II stars at $\log P = 1.47$ have $M_V = -3.2$, which is $M_B = -2.6$ if $B - V = 0.6$. This B absolute magnitude is close to the observed value of -2.9. However, the displacement of the population I and II Cepheid relations in M31 is 2.2 mag at a given period, which again is larger than the 1.4 mag observed in Figure 4 for V47. It may be that the zero points of the population II variables depend on [Fe/H] because of the sensitivity of the position of the evolution tracks that feed the type II instability strip on metallicity (Gingold 1976), in which case V47 in IC 1613 should become important in eventually elucidating the problem.

We now address the central question for which this investigation was planned as to whether the IC 1613 Cepheids show an anomalous slope to the *P-L* relation compared with more metal-rich galaxies. The 39 data points (excluding V47) in both panels of Figure 3 again show a more shallow slope than the envelope lines. However, the greatest weight in this deviation comes from the five longest period Cepheids ($\log P > 1.1$), where, as mentioned, stochastic sampling problems are most severe because of the small numbers.

The regression lines shown in Figure 3, which includes all 39 stars, have the equation

$$\langle B \rangle = -[1.88(\pm 0.12)] \log P + 23.06 \tag{1}$$

in the upper panel, and

$$B(\max) = -[1.99(\pm 0.10)] \log P + 22.29 , \tag{2}$$

in the lower panel.

To test for possible spurious effects due to our photometry, we next eliminate the six stars with flat light curves at minimum (V28, V36, V46, V51, V59, and V62), giving

$$\langle B \rangle = -[1.82(\pm 0.11)] \log P + 22.99 , \tag{1a}$$

for the remaining 33 stars, and

$$B(\max) = -[1.98(\pm 0.11)] \log P + 22.29 , \tag{2a}$$

for the same stars.

Equations (1a) and (2a) are so similar to equations (1) and (2), respectively, that the conclusions concerning the slope of the IC 1613 *P-L* relation are clearly independent of data for the six mentioned stars that are near the plate limits at minimum (note again that none of the six passed below the limit). Furthermore, the more shallow slope of equation (1a) compared with equation (1) is in the opposite sense than would be produced if the $\langle B \rangle$ values of the six stars with flat light curves at minimum were actually *fainter* than listed in Table 4. The conclusion is that the photometry of these stars at minimum is adequate.

We next eliminate the five longest period stars to give

$$\langle B \rangle = -[2.05(\pm 0.23)] \log P + 23.16 , \tag{3}$$

and

$$B(\max) = -[1.77(\pm 0.19)] \log P + 22.15 . \tag{4}$$

Again, eliminating the six stars with flat light curves at minimum in addition to the five longest period stars gives solutions for the remaining 28 stars of

$$\langle B \rangle = -[1.94(\pm 0.26)] \log P + 23.07 , \tag{3a}$$

to be compared with equation (3), and

$$B(\max) = -[1.66(\pm 0.22)] \log P + 22.06 , \tag{4a}$$

to be compared with equation (4). Equations (3a) and (4a) are substantially the same as equations (3) and (4), respectively, again showing a nearly negligible effect on the conclusions by including the six mentioned stars with flat bottomed light curves.

Each of equations (1)–(4) and (1a)–(4a) still show a shallower slope than the envelope lines, both of which have slopes of approximately -2.4 in the relevant period range of Figures 3*a* and 3*b*. The difference between the slopes of the data points and of the envelope lines is evident in these diagrams, and, as before, we attribute the difference to selection effects (S88), not to true differences in slope because of the arguments now to be made in the next paragraphs.

A better comparison than with the slopes of the original envelope lines can be made using recent photoelectric data in LMC (data for Cepheids in SMC are not suitable because of the apparent large tidal elongation of this galaxy in the line of sight; see, e.g., Mathewson, Ford, and Visvanathan 1986). From the listing of 80 Cepheids in LMC given elsewhere (S88, Table I), and by eliminating the six faint deviants, we obtain a linear regression for the LMC variables over the period range of $0.40 < \log P < 2.2$ of

$$\langle B \rangle = -[2.17(\pm 0.09)] \log P + 17.46 . \tag{5}$$

The similar slopes equations (3) and (5) shows that there is, in fact, no measurable slope anomaly in IC 1613 relative to LMC.

As mentioned in the Introduction, the same conclusion has been reached by Freedman (1988) from her discussion of the near IR data in IC 1613 compared with similar data in LMC by Madore (1985) and Walker (1987). A similar comparison can be made using the independent I_V band photometry of LMC by Visvanathan (1985) and by Mathewson, Ford, and Visvanathan (1986), compared with the I band data for IC 1613 by Freedman (1988, Table 5). Although the effective wavelength of the I and I_V band are not identical, the slope of the Cepheid P-L relation is wavelength-independent redward of the R band, justifying the comparison of I and I_V data.

Mathewson, Ford, and Visvanathan show a solution for their near IR data for LMC of

$$\langle I_V \rangle = -[2.90(\pm 0.10)] \log P + 16.36 . \quad (6)$$

The least-squares regression using nine of the IC 1613 variables measured by Freeman (1988, Table 5) also in the near IR [and excluding the very long period cepheid V22 because of its variable light curve (S71) and its large deviation in Figure 6 of Freedman] is

$$\langle I \rangle = -[3.07(\pm 0.10)] \log P + 22.54 , \quad (7)$$

which is clearly the same as equation (6) to within the errors.

Therefore, on the basis of the new data for IC 1613 in the B band discussed here, as added to the earlier data in S71 and compared to the LMC data, (i.e. equation [3] compared to eq. [5]), we conclude that the slope of the IC 1613 P-L relation does not differ from that in LMC despite the apparently large difference in the mean metallicity of their young stars (Cook 1988). This is the same conclusion reached by Freedman from the near IR data used by her. The same conclusion follows here by noting the near identity of equations (6) and (7).

The result has important implications concerning use of Cepheids as distance indicators in galaxies of different metallicity. It is known from Cook's TiO photometry that the young stars in IC 1613 are more metal poor by at least 0.5 dex compared with stars in LMC and are metal depleted by more than 1 dex compared with stars in the solar neighborhood of the Milky Way.

The slope difference, if any, between the P-L relations of IC 1613 and LMC will be investigated further when the study of the 50 new Cepheid candidates in IC 1613 is complete. These new variables are generally fainter than those in Baade's list, and should extend Figure 3 to shorter periods. From the study, now begun, there is also the possibility that more faint, long-period Cepheids like V47 will be found, permitting a test of the hypothesis that such variables are of the Population II. If there is a wide distribution in their periods, a P-L relation presumably can be determined for them. Population II Cepheids are, of course, expected because of the existence of the Baade sheet (S71, Fig. 15) of old red stars in IC 1613.

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