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THE RR LYRAE STARS IN BAADE'S FIELD NEAR NGC 6522

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ABSTRACT

From a reinvestigation of the RR Lyrae stars in Baade's field near NGC 6522 we find:

1. Among 38 variables, 84 percent of the periods originally determined from the hour-angle–limited data of Baade were spurious. The period-frequency diagram for the galactic center variables is similar to that of M5 (NGC 5904), a typical Oosterhoff type I cluster.
2. If the origin of these stars was globular clusters, then the clusters had metal abundances between those of M5 and NGC 6171.
3. Using an absolute magnitude derived from Christy's theoretical relation between $\langle M_V \rangle$ and $P_{\rm trans}$ for RR Lyrae stars, and Baade's luminosity function, we find the distance to the galactic center to be $R_0 = 7.0 \pm 0.6$ kpc. Whether this small value of R_0 should be construed as support for Clube's M_V value or as a suggestion that the theoretical $P_{\rm trans}$ relation needs modification cannot be unambiguously decided from the present data.

I. INTRODUCTION

Many years ago Baade (1951, 1963) discovered over 100 RR Lyrae stars while blinking 27 plate pairs for a study of the variables in a region toward the galactic center around the globular cluster NGC 6522 ($l^{\rm II} = 1°$, $b^{\rm II} = -4°$). Baade concluded that these stars were part of the galactic bulge and from their space distribution obtained a distance to the galactic center of 8.16 kpc. Using Baade's plate material, Gaposchkin (1955, 1956) determined periods and light curves for these stars. NGC 6522 is at a declination of $-30°$ so that with the 100-inch (254 cm) telescope at Mount Wilson, Baade was limited to small hour angles when obtaining plates of this cluster field. This circumstance coupled with the fact that periods of RR Lyrae stars are some fraction of a day leads to the possibility of obtaining a spurious period, or periods, related by the equation

$$\frac{1}{P_2} = \frac{1}{P_1} \pm n \,, \tag{1}$$

where n is an integer sidereal day.

On the basis of quite small samples, both Pavlovskaya (1957) and Alexander (1960) pointed out that some of Gaposchkin's periods were spurious. Later, Pavlovskaya (1960), while still working with the original hour-angle–limited data, showed that a large percentage of the originally determined periods were dubious. In order to obtain

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correct periods for a larger number of stars, we obtained new plate material of the field with the 60-inch (152 cm) telescope at Cerro Tololo Inter-American Observatory for two reasons. First, from the period-frequency or period-amplitude distribution of the RR Lyrae stars and the results of Preston's (1959) work on RR Lyrae stars in the vicinity of the Sun, we can estimate the relative metal abundance of the galactic-bulge stars. Second, using a theoretical relation (Christy 1966) involving the transition period from type *c* to type *a* light curves, we can determine the absolute magnitude of the RR Lyrae variables and then redetermine the distance to the galactic center.

II. OBSERVATIONAL MATERIAL AND REDUCTION OF DATA

In order to find which, if any, of the periods in the Gaposchkin analysis are spurious, data covering a large range in hour angle on a single night are required. We obtained 32 plates, $1^\circ \times 1^\circ\!.5$, of the NGC 6522 field with the Ritchey-Chrétien focus of the 60-inch telescope on Cerro Tololo, whose latitude of -30° is ideal for the study of the galactic center. These plates were obtained on three nights—one in 1969 June, and two separated by approximately one week in 1970 May–June. Most exposures were made for 30 minutes and all were B plates (103a-O + GG 13). The 1969 plates were taken at approximately hourly intervals, while the 1970 plates were exposed consecutively during the ~8.5-hour periods of observation. With such uninterrupted coverage of the light curves of the short-period variables, the danger of incorrect period determinations is minimized.

The RR Lyrae variables were identified from charts given in Gaposchkin (1955, 1956). Difficulty was encountered in making some identifications as the large-scale charts of individual fields (Gaposchkin 1956) did not always resemble the field in the photographic reproduction (Gaposchkin 1955). Approximately 110 stars classified as RR Lyrae were measured with an iris photometer on all of the plates. In addition we measured many of the stars in Arp's (1965*a*) photoelectrically calibrated sequence. The iris readings for each star were then reduced to one plate by using the standard stars. A calibration curve was constructed from a sixth-order polynomial, and individual magnitudes were read off. Table 1 gives the photographically determined B-magnitudes for Arp's standards. The photoelectric values are also included for comparison; the agreement is satisfactory and no difficulties were encountered in the photographic reductions. The photographic B-magnitudes for the variables are given in table 2.

TABLE 1

PHOTOELECTRIC AND PHOTOGRAPHIC DATA FOR ARP'S STANDARDS

Arp Identification*	B_{pe}*	B_{pg}†	Arp Identification	B_{pe}*	B_{pg}†
J.........	14.85	14.85	W........	17.48	17.52
L.........	15.64	15.61	c.........	17.49	18.45
O.........	16.07	16.24	Z.........	17.53	17.68
M........	16.22	16.25	R.........	17.59	17.51
P.........	16.65	16.65	T.........	17.66	17.68
S.........	17.09	17.32	d.........	18.12	18.07
U.........	17.12	16.98	f.........	18.43	18.49
X.........	17.25	17.24	g.........	18.60‡	18.68
Y.........	17.36	17.37	e.........	18.72	18.67
b.........	17.37	17.34			

* From Arp (1965*a*).
† This paper.
‡ Photographic value (Arp 1965*a*, table 2).

We used the periods determined by Gaposchkin to plot light curves from the new data, and it was apparent that most were not the true period. Then, with the new data, we scanned around the spurious periods given by equation (1) in steps of $0^{d}00002$ using a period-finding computer program based on the Lafler and Kinman (1965) techniques. When the program indicated that a particular period might fit the new data, we scanned this same period region using the more extensive Gaposchkin data, which, on account of its longer baseline in time, gives a more definitive estimate of the period. We thus obtained unambiguous periods for the 38 variables given in table 3. Our inability to resolve more periods is due in part to photometric inaccuracies discussed below. In other cases period and amplitude variations, a common feature of the light curves of RR Lyrae variables, may be responsible. From the light curves constructed from the data in table 2, which are based on Arp's photoelectric sequence, we also obtained the $\bar{m}_B = \frac{1}{2}(m_{B,\max} + m_{B,\min})$ and $\Delta m = (m_{B,\min} - m_{B,\max})$ given in table 3. The periods given in table 3 should be accurate to within $\pm 0^{d}00005$. For only six of the 38 stars in table 3 (marked by an asterisk in the table) have we confirmed the Gaposchkin period. Further, for another six stars whose Gaposchkin periods were confirmed in Pavlovskaya's (1960) later work, we obtained different periods. In figure 1, we present sample light curves that illustrate both a relatively favorable and unfavorable case, based on the results of tables 2 and 3.

Before discussing the results, a few comments on the photometric accuracy are in order. The field around NGC 6522 is extremely crowded; however, some estimate of the uncertainty can be obtained from the plate-to-plate scatter in the photographically determined magnitudes of the standard stars in table 1. A typical standard deviation of a single observation is ± 0.04 mag. Arp chose his standards to be as free from crowding as possible in this field, whereas the RR Lyrae stars were not so chosen. However, an estimate of the additional photometric uncertainty can be made from the amplitude of the scatter in the light curves constructed. While some of these curves show virtually no scatter, others shown a dispersion of more than ± 0.1 mag about a mean curve (see fig. 1). This limitation in accuracy is no doubt responsible for our inability to resolve the

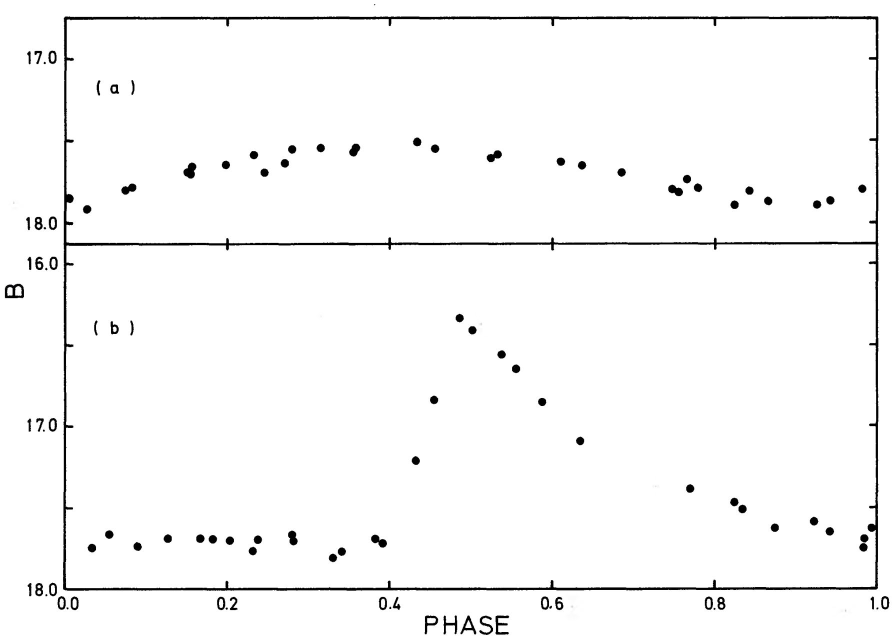

FIG. 1.—Typical light curves constructed from data in tables 2 and 3 for two RR Lyrae stars: (*a*) Star 37, $P = 0^{d}28682$; and (*b*) Star 45, $P = 0^{d}44022$.

TABLE 2

B-MAGNITUDES FOR THE STARS OF TABLE 3

H.J.D. 2,440,000+	1	5	12	14	15	16	17	22
388.5576		16.99	17.94	17.72	17.39	17.79	17.46	17.52
.5891	18.47	17.27	18.09	16.90	17.50	17.77	16.97	17.44
.7048	18.56	17.68	17.16	17.59	17.97	17.84	17.49	17.58
.7296	18.37	17.74	17.29	17.67	18.28	17.58	17.49	17.13
.8509	17.48	17.81	17.72	17.81	18.38	17.68	17.65	17.21
.8986	17.70	17.83	17.95	17.90	18.48	17.99	17.69	17.33
.9219	17.82	17.96	17.88	17.80	18.05	18.00	17.79	17.39
736.5972	17.52	18.06	18.07	16.89		17.67	16.96	17.54
.6202	17.62	17.82	17.59	17.11		17.61	17.00	17.35
.6427	17.62	17.82	17.00	17.27	17.92	17.65	17.20	16.74
.6641	17.69	17.81	17.18	17.45	17.54	17.69	17.34	16.55
.6909	17.65	17.77	17.39	17.59	17.50	17.72	17.35	16.92
.7227	17.75	17.77	17.46	17.61	17.59	17.84	17.53	17.18
.7548	17.80	17.76	17.61	17.75	17.85	17.85	17.59	17.27
.7875	17.78	17.81	17.68	17.70	17.78	17.83	17.60	17.38
.8215	17.84	17.20	17.68	17.68	17.95	17.62	17.59	17.37
.8482	18.11	17.12	17.95	17.91	18.24	17.71	17.78	17.49
.8702	18.19	17.24	17.94	17.83	18.22	17.70	17.81	17.50
.8975	18.02	17.01	17.82	17.78	18.41	17.55	17.70	17.64
744.6150	17.94	17.83	18.11	17.08	18.61	17.68	17.73	17.45
.6373	17.96	17.85	18.01	17.33	18.61	17.61	17.79	17.43
.6616	17.99	17.67	18.02	17.52	18.35	17.57	17.77	17.45
.7022	18.00	16.92	18.11	17.54	17.70	17.59	17.77	17.43
.7240	18.03	17.13	18.13	17.65	17.49	17.67	17.82	17.41
.7459	18.09	17.24	17.88	17.67	17.55	17.70	17.81	17.47
.7676	18.09	17.33	17.40	17.69	17.57	17.76	17.80	17.40
.7905	18.18	17.53	17.23	17.77	17.74	17.82	17.87	16.98
.8122	18.23	17.50	17.25	17.80	17.77	17.86	17.69	16.67
.8366	18.30	17.52	17.33	17.84	17.95	17.84	17.29	16.60
.8593	18.22	17.56	17.47	17.83	17.95	17.79	17.01	16.93
.8816	18.40	17.82	17.63	18.36	18.31	17.81	16.82	17.06
.9013	18.52	17.73	17.67	18.01	18.34	17.60	16.97	17.17

TABLE 2 (Continued)

H.J.D. 2,440,000+	26	29	32	34	37	42	45	46
388.5576	17.83	18.64	17.90	17.87	17.81		17.68	17.34
.5891	17.83	18.70	17.94	17.98	17.87	18.60	17.69	17.46
.7048	17.81	18.69	17.89	17.14	17.64	17.61	16.41	17.67
.7296	17.76	17.83	17.68	17.40	17.57		16.65	17.70
.8509	17.31	18.08	17.57	17.73	17.79	17.90	17.51	17.60
.8986	17.35	18.61	17.70	17.87	17.89		17.65	16.55
.9219	17.41	18.05	17.67	17.79	17.93	18.24	17.63	16.69
736.5972	17.65		18.09	17.93	17.65		17.38	16.62
.6202	17.64		17.96	17.73	17.55	18.65	17.47	17.01
.6427	17.69		17.91	17.80	17.55		17.63	17.14
.6641	17.72		17.94	17.74	17.51	18.38	17.59	17.33
.6909	17.66		17.93	17.82	17.61	18.31	17.75	17.49
.7227	17.69	18.70	17.81	17.73	17.66		17.66	17.54
.7548	17.72		17.99	17.82	17.80	18.28	17.68	17.62
.7875	17.67	18.69	17.85	17.79	17.89		17.70	17.67
.8215	17.69	17.56	17.71	17.57	17.80	18.32	17.66	17.68
.8482	17.79	17.77	17.86	17.67	17.80		17.77	17.81
.8702	17.82	17.75	17.59	17.27	17.70	18.60	17.72	17.72
.8975	17.67	17.83	17.29	16.77	17.70		16.84	17.67
744.6150	17.87	18.70	18.14	17.54	17.67	18.62	17.68	17.69
.6373	17.84		17.88	17.61	17.58	18.46	17.74	17.74
.6616	17.75		17.61	17.71	17.55		17.74	17.22
.7022	17.72		17.46	17.72	17.55	18.62	17.69	16.68
.7240	17.56		17.54	17.79	17.59		17.77	16.83
.7459	17.49		17.55	17.78	17.63	18.14	17.70	17.08
.7676	17.40	18.66	17.57	17.72	17.70		17.81	17.31
.7905	17.24		17.63	17.79	17.74	17.70	17.68	17.39
.8122	17.29		17.63	17.84	17.82	17.62	17.21	17.45
.8366	17.27		17.67	17.87	17.89	17.66	16.34	17.57
.8593	17.32		17.70	17.82	17.85	17.66	16.57	17.59
.8816	17.40	18.48	18.00	18.49	17.78	17.78	16.85	17.61
.9013	17.41	17.65	17.86	18.03	17.71	17.84	17.09	17.63

TABLE 2 (Continued)

H.J.D. 2,440,000+	47	50	59	70	79	91	93	99
388.5576	17.29	17.58	17.98	18.02	17.77	17.68	17.54	
.5891	17.35	17.69	17.97	18.29	17.66	17.63	17.59	18.28
.7048	17.60	17.59	17.98	18.42	17.25	17.90	17.76	18.53
.7296	17.65	17.59	18.01	18.53	17.40	17.85	17.78	18.49
.8509	17.30	16.58	17.31	17.33	17.66	18.04	17.82	
.8986	17.36	17.23	17.53	17.62	17.67	18.13	17.83	
.9219	17.43	17.29	17.63	17.66	17.71	18.12	17.59	
736.5972	17.37	17.61	18.08		17.73	17.43	17.76	
.6202	17.31	17.61	17.81	18.59	17.67	17.48	17.71	
.6427	17.19	17.65	17.92	18.10	17.67	17.52	17.72	18.68
.6641	17.25	17.54	17.91	17.50	17.70	17.62		
.6909	17.46	17.64	17.91	17.47	17.70	17.58	17.72	
.7227	17.45	17.42	17.94	17.58	17.70	17.67	17.73	
.7548	17.59	16.62	18.00	17.80	17.75	17.73		
.7875	17.57	16.30	18.03	17.79	17.71	17.76	17.79	
.8215	17.45	16.72	17.85	17.76	17.20	17.74	17.74	
.8482	17.66	17.11	18.14	18.22	17.00	17.97	18.00	
.8702	17.42	17.18	18.23	18.23	17.16	17.99	17.95	
.8975	17.37	17.24	18.13	18.47	17.01	17.93	17.46	
744.6150	17.34	17.40	18.05	18.50	17.01	17.39	17.74	
.6373	17.34	17.49	18.02	18.46	17.19	17.52	17.76	
.6616	17.40	17.47	18.16	18.40	17.43	17.57		
.7022	17.39	17.66	18.35	18.48	17.45	17.60		18.69
.7240	17.54	17.60	17.90	18.32	17.55	17.69		18.23
.7459	17.56	17.65	17.56	18.29	17.58	17.70	17.82	17.96
.7676	17.56	17.55	17.35	18.27	17.54	17.73		17.95
.7905	17.59	17.62	17.40	18.49	17.69	17.79		18.10
.8122	17.61	17.57	17.47	18.09	17.66		17.86	18.17
.8366	17.50	17.32	17.49	17.42	17.66	17.79	17.85	18.39
.8593	17.43	17.68	17.62	17.26	17.67	17.87	17.59	18.40
.8816	17.42	17.78	17.67	17.55	17.72	18.02		18.66
.9013	17.34	17.62	17.73	17.62	17.70	17.99	17.11	

TABLE 2 (Continued)

H.J.D. 2,440,000+	105	106	114	118	124	127	136	143
388.5576	18.38	17.56	18.17	17.69	17.48	17.90	18.14	18.04
.5891	18.36	17.63	18.25	17.74	17.53	17.81	18.15	17.99
.7048	18.63	17.89	18.68	17.77	16.07	17.65	18.01	18.04
.7296	18.36	17.99		17.74	16.60	17.58	17.97	18.05
.8509	17.79	17.92		17.30	17.20	17.77	17.59	17.89
.8986	18.03	18.26		17.40	17.43	17.81	17.74	17.71
.9219	18.06	17.97		17.47	17.47	17.72	17.82	17.61
736.5972	18.12	17.89		17.46	16.75	17.72	18.33	18.22
.6202	17.85	17.29		17.50	16.98	17.63	18.43	18.24
.6427	17.92	17.11		17.47	17.11	17.60	17.82	18.07
.6641	17.97	17.23		17.58	17.28	17.57	17.49	18.16
.6909	17.91	17.41		17.62	17.14	17.57	17.42	18.07
.7227	17.97	17.54		17.55	17.29	17.67	17.54	18.04
.7548	18.08	17.63		17.66	17.42	17.73	17.65	18.17
.7875	18.12	17.74		17.62	17.20	17.84	17.64	18.01
.8215	18.10	17.73		17.56	17.40	17.74	17.60	17.68
.8482	18.47	17.96	18.60	17.72	17.56	17.86	17.93	17.79
.8702	18.37	17.98	18.28	17.66	17.63	17.80	17.89	17.74
.8975	18.51	17.99	18.19	17.63	17.37	17.79	18.45	17.64
744.6150	18.36	17.74		17.80	16.96	17.67	17.67	18.19
.6373	18.23	17.77		17.74	17.14	17.74	17.72	17.86
.6616	18.27	17.86		17.68	17.29	17.80	17.80	17.71
.7022	18.40	17.91		17.69	17.41	17.83	17.89	17.64
.7240	18.29	17.90		17.75	17.44	17.74	17.84	17.66
.7459	18.28	17.94		17.73	17.49	17.71	17.91	17.76
.7676	18.26	17.91	18.47	17.72	17.46	17.62	17.86	17.68
.7905	18.35	17.95	17.79	17.70		17.60	18.01	17.78
.8122	18.43	17.97	17.81	17.49	17.49	17.59	17.97	17.83
.8366	18.69:	17.99	18.04	17.17	17.26	17.54	18.06	17.83
.8593	18.49	17.89	18.35	17.06	17.43	17.58	18.05	17.77
.8816		18.11	18.64	17.23	17.47	17.61	18.35	17.93
.9013	18.61	18.05		17.30	17.43	17.67	18.44	17.93

TABLE 2 (Continued)

H.J.D. 2,440,000+	155	161	164	194	222	241
388.5576	17.75	17.68	17.57	17.50	17.62	17.66
.5891	17.81	17.75	17.57	17.55	17.41	17.68
.7048	17.62	17.85	17.09	17.63	17.54	17.80
.7296	17.50	17.74	17.28	17.62	17.59	17.62
.8509	17.51	17.59	17.50	17.50	17.43	17.55
.8986	17.59	17.71	17.47	16.43	17.31	17.63
.9219	17.60	17.77	17.17	16.60	17.35	17.69
736.5972	17.78	17.62	17.50	17.83	17.34	17.97
.6202	17.70	17.67	17.37	17.65	17.40	17.71
.6427	17.53	17.63	17.08	17.73	17.45	17.60
.6641	17.54	17.66	17.28	17.76	17.54	17.51
.6909	17.34	17.70	17.16	17.64	17.65	17.46
.7227	17.33	17.77	17.02	17.45	17.61	17.49
.7548	17.43	17.82	17.31	16.76	17.69	17.52
.7875	17.40	17.85	17.24	16.70	17.56	17.60
.8215	17.47	17.69	17.36	17.07	17.31	17.55
.8482	17.63	17.83	17.61	17.32	17.41	17.73
.8702	17.63	17.72	17.57	17.39	17.35	17.83
.8975	17.63	17.58	17.20	17.51	17.53	17.68
744.6150	17.64	18.05	17.57	17.61	17.60	17.62
.6373	17.66	17.92	17.58	17.61	17.55	17.59
.6616	17.62	17.85	17.52	17.66	17.30	17.57
.7022	17.66	17.73	17.43	17.65	17.29	
.7240	17.65	17.65	17.43	17.60	17.44	17.58
.7459	17.70	17.66	17.26	17.59	17.49	17.60
.7676	17.66	17.60	17.22	17.61	17.49	17.59
.7905	17.63	17.67	17.13	17.72	17.58	17.67
.8122	17.70	17.66	17.11	17.63	17.64	17.68
.8366	17.70	17.73	16.88	17.41	17.68	17.70
.8593	17.77	17.72	17.35	16.92	17.69	17.77
.8816	17.79	17.89	17.47	16.37	17.65	17.81
.9013	17.85	17.91	17.57	16.70	17.60	17.84

TABLE 3

DATA FOR 38 RR LYRAE STARS NEAR NGC 6522

Star	Period	$\overline{m}_B$	Δm_B	Baade Group	Star	Period	$\overline{m}_B$	Δm_B	Baade Group
1	0.65495	17.93	1.25		70	0.45410	17.98	1.35	
5	0.46317*	17.45	1.10	II	79	0.51587	17.35	0.80	I
12	0.47864	17.60	1.10	II	91	0.66692	17.70:	0.90:	III
14	0.44445	17.43	1.15	III	93	0.49709	17.55:	0.90:	II
15	0.47362	18.03	1.35		99	0.48652	18.35:	0.90	
16	0.26902	17.78	0.45		105	0.56091	18.20:	0.80:	III
17	0.59084	17.35	1.00		106	0.48967	17.68	1.15	I
22	0.42950	17.08	1.00	II	114	0.46512	18.35:	1.10:	I
26	0.77050	17.55	0.60	I	118	0.55722	17.40	0.70	II
29	0.44856*	18.13:	1.15:		124	0.49910	16.78:	1.55:	
32	0.60023	17.70	0.70	III	127	0.29190*	17.70	0.30	II
34	0.42414	17.35	1.20	III	136	0.49278	17.93	1.05	III
37	0.28682	17.70	0.40	I	143	0.65160	17.91	0.62	II
42	0.60354	18.13	1.05		155	0.59471	17.60	0.50	I
45	0.44022	17.08	1.45	I	161	0.31004*	17.80	0.40	II
46	0.42767*	17.15	1.20	I	164	0.27929	17.33	0.55	II
47	0.29624	17.42	0.35	II	194	0.50709	17.05	1.40	II
50	0.45423	17.08	1.35	I	222	0.26995*	17.50	0.40	I
59	0.52114	17.82	1.00	III	241	0.36203	17.65	0.40	III

* Gaposchkin period

period ambiguity in many of the stars with low amplitudes. Furthermore, the possibility that small field errors exist—perhaps different in 1969 and 1970—cannot be entirely ruled out. Finally, we again note that the time span of the combined observational data is approaching that for which period and amplitude changes might be expected to complicate the analysis.

III. THE RELATIVE METAL ABUNDANCE OF THE RR LYRAE STARS NEAR NGC 6522

Figure 2*a* is the period-frequency plot for all stars in table 3. Also shown in figure 2 is the period-frequency plot for RR Lyrae variables in M5 (NGC 5904) taken from the compilation of Sawyer (1955). From figure 2*b*, and Sawyer (1955), we find that the shortest-period *a*-type variable in M5 has a period of $0\overset{d}{.}43242$. From table 3, the shortest-period *a*-type variable in the galactic bulge has a period of $0\overset{d}{.}42414$, while Dickens (1970) has found the shortest-period *a*-type variable in NGC 6171 is $0\overset{d}{.}41554$. Calculating P_{trans} (the transition period between *c*- and *a*-type variables) by averaging 4/3 of the longest *c*-type period and the shortest *a*-type period (Christy 1966), we find values of P_{trans} of $0\overset{d}{.}465$, $0\overset{d}{.}453$, and $0\overset{d}{.}423$ for M5, the galactic bulge, and NGC 6171, respectively: Thus we conclude that the properties of the RR Lyrae stars toward the center of the galaxy are intermediate between those of M5 and NGC 6171.

In his spectroscopic study of RR Lyrae stars in the vicinity of the Sun, Preston (1959) defined a quantity ΔS as the difference in spectral type determined from the hydrogen lines and the K-line of Ca II at a specific phase. He found values of ΔS ranging from 0 to 10. In a later paper Preston (1961) found a ΔS of 3–4 for the variables in M5. In view of the similarity of the period-frequency diagrams of M5 and the galactic center, we estimate $\Delta S \sim 3$–4 for the galactic-bulge variables.

Preston (1959) also showed that stars with different ΔS were separated in the period-amplitude diagram (fig. 5 of his paper). Based on this figure, Plaut (1970) has computed a quantity

$$p_0 \approx 0.655 - 0.119\Delta m\ , \tag{2}$$

and finds stars with $p > p_0$ have $\Delta S > 5$, while stars with $p < p_0$ have $\Delta S < 5$. Plaut has computed $\langle p_0 - p\rangle$ for RR Lyrae stars at the different galactic latitudes in his surveys (Plaut 1966, 1968*a*, *b*, 1970). He finds a possibly significant systematic variation in $\langle p_0 - p\rangle$ ranging from -0.075 ± 0.011 at $|b^{\text{II}}| = 29°$ to $+0.004 \pm 0.006$ at $|b^{\text{II}}| = 8°$. We find $\langle p_0 - p\rangle = +0.009 \pm 0.013$ for 28 type *a* variables in our table 3 which are found at $|b^{\text{II}}| = 4°$. From our value of $\langle p_0 - p\rangle$ we may crudely estimate that the RR Lyrae variables in the galactic bulge have $\Delta S \sim 2$–3, a value consistent with that derived from the comparison of period-frequency diagrams. We conclude that RR Lyrae variables toward the galactic center are indeed metal rich. They thus plausibly could have originated in clusters with metal abundances between those of the globular clusters M5 and NGC 6171.

IV. THE DISTANCE TO THE GALACTIC CENTER

On the basis of theoretical models of RR Lyrae stars, Christy (1966) found the remarkable result that the transition period, P_{trans}, between *c*-type and *a*-type RR Lyrae stars is a function of the absolute magnitude of the star independent of its mass or chemical composition. Christy's relation, as expressed by Dickens (1970), is:

$$\langle M_V\rangle = -0.46 - 4.17 \log P_{\text{trans}}\ , \tag{3}$$

where the angular brackets imply an intensity mean. If we substitute the value of $P_{\text{trans}} = 0\overset{d}{.}453 \pm 0\overset{d}{.}012$ calculated in the previous section into equation (3), we find $\langle M_V\rangle = 0.97 \pm 0.05$. From a study of the RR Lyrae stars in the globular cluster NGC 6712 by Sandage, Smith, and Norton (1966) we find an average $\langle B\rangle - \langle V\rangle = 0.29$

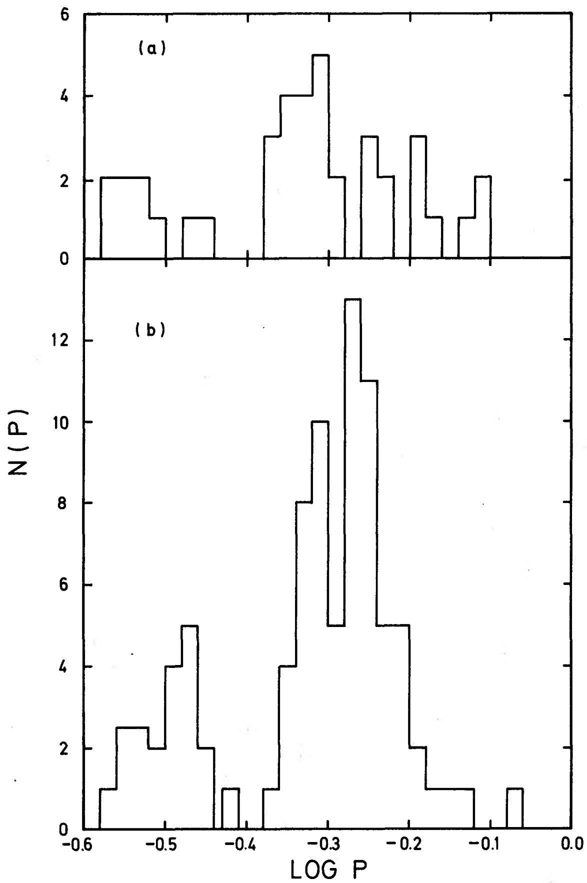

FIG. 2.—Period-frequency distributions for RR Lyrae stars in (*a*) Baade's field around NGC 6522, and (*b*) the globular cluster M5.

corrected for a reddening of 0.48 (Sandage and Smith 1966). The above authors conclude from the period-frequency distribution in NGC 6712 that the variables are similar to those in Oosterhoff type I clusters such as M5. From Dickens's analysis of the variables in NGC 6171 we find an average $\langle B\rangle - \langle V\rangle = 0.37$ corrected for a reddening of 0.28 (Sandage and Katem 1964; Dickens 1970). Using the mean between NGC 6712 and NGC 6171 of $\langle B\rangle - \langle V\rangle = 0.33 \pm 0.03$ for the galactic-bulge variables, we find $\langle M_B\rangle = 1.30 \pm 0.06$. The relation between $\bar{M}_B = \frac{1}{2}(M_{B,\mathrm{max}} + M_{B,\mathrm{min}})$ and $\langle M_B\rangle$ depends on the asymmetry of the light curves. From the data of Dickens (1970) we find $\langle\langle M_B\rangle - \bar{M}_B\rangle = 0.05$ and from Sandage *et al.* (1966) we find 0.07 for the same quantity. Adopting $\langle M_B\rangle - \bar{M}_B = 0.06$, we obtain $\bar{M}_B = 1.24 \pm 0.06$ for the RR Lyrae stars toward the galactic center. Note that the error estimate assumes Christy's relation is correct.

To find the distance to the galactic center, the space distribution of the variables in table 3 was computed following the outline given by Baade (1963). The variables were divided into three groups according to their distance from the center of NGC 6522: Group I, $d < 8'.75$; Group II, $8'.75 < d < 12'.38$; and Group III, $12'.38 < d < 15'.9$. Only those stars in Groups I and II were used in the distance determination. We adopted Arp's (1965*a*) value of reddening, $E_{B-V} = 0.46 \pm 0.03$, so that, assuming a ratio of total-to-selective absorption of 3.0 ± 0.2 (Allen 1963), the blue absorption is $A_B = 1.84 \pm 0.15$ mag. With $\bar{M}_B = 1.24$ the resulting space distribution is shown in figure 3. Also shown in figure 3 is the space distribution computed using the more complete luminosity function of Baade (1963) with the $\overline{M}_B$ and A_B values found above. From figure 3, we find $R_0 = 7.0 \pm 0.6$ kpc to the maximum in the RR Lyrae distribution, which is essentially the distance to the galactic center. The horizontal error bar in figure 3 shows the range in distance corresponding to a difference of ± 0.20 mag in distance modulus. This error takes into account uncertainties in the observationally determined value of P_{trans}, the transformation from $\langle M_V \rangle$ to $\overline{M}_B$, the apparent magnitude of the RR Lyrae density maximum, and the total blue-absorption calculation; but Christy's (1966) relation (eq. [3] above) was assumed to be correct. Regarding the uncertainty in the apparent magnitude of the RR Lyrae density maximum, a plot of the mean apparent magnitudes given by Gaposchkin against the mean apparent magnitudes obtained using Arp's (1965*a*) photoelectric sequence—i.e., those given in table 3—confirms Arp's observation that Baade's original photographic sequence is within ± 0.1 mag of the photoelectric sequence. In view of recent theoretical work by Iben (1971) suggesting a possible helium dependence in the period-luminosity relation, the true error should actually be larger than the ± 0.2 mag quoted above. Finally, we note that a change of -0.5 mag in M_V means a multiplication of the distance by a factor of 1.26.

A value of $R_0 = 7$ kpc is much lower than the conventional value of 10 kpc (Arp 1965*b*). The main reason for our lower value is the adoption of $\overline{M}_B = 1.24$ mag for the RR Lyrae variables, as derived from Christy's theoretical relation and our observationally determined value of P_{trans}. Observational support for the low M_B value comes from the work of Clube (1970), who suggests, on the basis of an apparent systematic error in the secular parallaxes of field RR Lyrae variables, a value of $\langle M_V \rangle \simeq 1.3$ mag for those stars. On the other hand, the uncomfortably large discrepancy of 0.6 mag between theory and observation found by Sandage (1970) from his work on globular clusters, and the work of Iben (1971) referred to above, indicate that modifications to equation

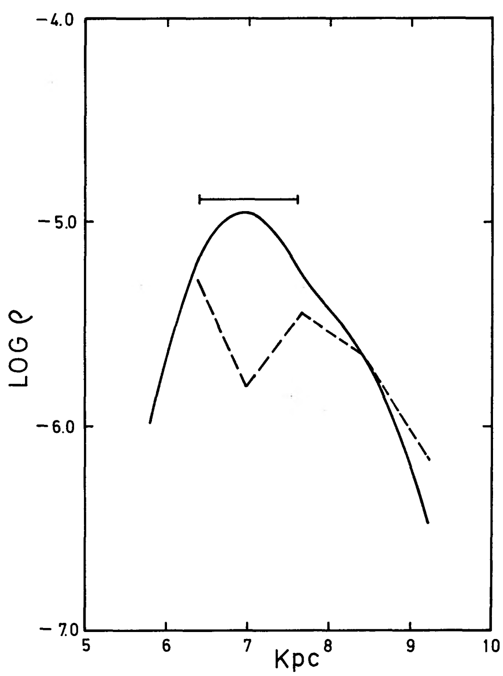

FIG. 3.—The space distribution of RR Lyrae stars around NGC 6522. Plotted is the logarithm of the density of RR Lyrae stars per cubic parsec against distance in kiloparsecs. The solid curved line was constructed from the luminosity function of Baade (1963), and the dashed line is from our less complete data of table 3. The horizontal error bar shows the uncertainty in distance due to an error of ± 0.2 mag in distance modulus.

(3) may be required. The possibility of obtaining R_0 in such a direct manner should be a stimulus for further observational and theoretical work on RR Lyrae stars.

V. SUMMARY

From our reinvestigation of the RR Lyrae stars in Baade's field near NGC 6522, we find the following.

1. Among 38 variables, 84 percent of the periods determined by Gaposchkin from hour-angle–limited data were spurious. This confirms the earlier results of Pavlovskaya (1957, 1960) and Alexander (1960). The variables studied herein are found to closely resemble those in M5 in the period-frequency plane.
2. The variables are metal rich with an estimated $\Delta S \sim 3$–4. If one assumes that the likely origin of these stars was in globular clusters, then the clusters had metal abundances between those of M5 and NGC 6171.
3. Using Baade's luminosity function and Christy's theoretical relation between P_{trans} and M_V, we estimate the distance to the galactic center to be 7.0 ± 0.6 kpc. Our lower than conventional value for R_0 is due to the relatively faint M_B adopted for the RR Lyrae stars.

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REFERENCES

Alexander, J. B. 1960, *Observatory*, **80**, 110.
Allen, C. W. 1963, *Astrophysical Quantities* (2d ed.; London: Athlone Press).
Arp, H. C. 1965*a*, *Ap. J.*, **141**, 43.
———. 1965*b*, in *Stars and Stellar Systems*, Vol. **5**, ed. A. Blaauw and M. Schmidt (Chicago: University of Chicago Press), chap. 19.
Baade, W. A. 1951, *Pub. Univ. Michigan*, **10**, 7.
———. 1963, in *Evolution of Stars and Galaxies*, ed. C. P. Gaposchkin (Cambridge: Harvard University Press).
Christy, R. F. 1966, *Ap. J.*, **144**, 108.
Clube, S. V. M. 1970, *Observatory*, **90**, 147.
Dickens, R. J. 1970, *Ap. J. Suppl.*, **22**, 249.
Gaposchkin, S. I. 1955, *Variable Stars*, **10**, 337.
———. 1956, *ibid.*, **11**, 268.
Iben, I. 1971, *Ap. J.*, **168**, 225.
Lafler, J., and Kinman, T. D. 1965, *Ap. J. Suppl.*, **11**, 216.
Pavlovskaya, E. D. 1957, *Soviet Astr.—AJ*, **1**, 923.
———. 1960, *Variable Stars*, **13**, 8.
Plaut, L. 1966, *B.A.N. Suppl.*, **1**, 105.
———. 1968*a*, *ibid.*, **2**, 293.
———. 1968*b*, *ibid.*, **3**, 1.
———. 1970, *Astr. and Ap.*, **8**, 341.
Preston, G. W. 1959, *Ap. J.*, **130**, 507.
———. 1961, *ibid.*, **134**, 651.
Sandage, A. 1970, *Ap. J.*, **162**, 841.
Sandage, A., and Katem, B. 1964, *Ap. J.*, **139**, 1088.
Sandage, A., and Smith, L. L. 1966, *Ap. J.*, **144**, 886.
Sandage, A., Smith, L. L., and Norton, R. H. 1966, *Ap. J.*, **144**, 894.
Sawyer, H. B. 1955, *Pub. David Dunlap Obs.*, Vol. **2**, No. 2.