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PHOTOMETRY OF THE VARIABLE STARS IN THE GLOBULAR CLUSTER NGC 6712

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ABSTRACT

Photometry in B and V is reported for ten RR Lyrae variables, four long-period semiregular variables, and two variables of unknown type in and near NGC 6712. Seven of the RR Lyrae stars are Bailey-type a, b variables, while three are of type c. The mean period of the a, b stars is $\bar{P}_{a,b} = 0.55$ days. This value and the similarity of the group characteristics of the variables with those in M3 identify NGC 6712 as an Oosterhoff type I cluster, contrary to an expectation that $\bar{P}(6712) < \bar{P}(\mathrm{M3})$. The variables in NGC 6712 therefore provide no solution to the longstanding problem of the origin of the field variables of low ΔS and large amplitude in the period range of $0^{\mathrm{d}}30$–$0^{\mathrm{d}}44$. Variables of this type have not yet been found in globular clusters.

The three long-period variables that are considered to be members have absolute visual magnitudes at maximum of -3.1, -3.1, and -2.3, respectively, for V2($P = 105^{\mathrm{d}}$), V8($P = 117^{\mathrm{d}}$), and V10($P = 174^{\mathrm{d}}$).

I. PURPOSE

In 1939 and again in 1944, Oosterhoff pointed out that globular clusters divide naturally into two groups according to the mean period of the RR Lyrae stars. All subsequent work, especially that of Helen Sawyer (1955), has confirmed this division. Arp (1955) showed in 1955 that the separation into the Oosterhoff groups also segregates clusters according to metal abundance. Variables in clusters with low metal abundances have mean periods of the Bailey a, b variables near $\bar{P}_{a,b} = 0^{\mathrm{d}}65$, while variables in metal-richer clusters have $\bar{P}_{a,b} = 0^{\mathrm{d}}55$. The discovery of very metal-rich clusters by Mayall (1946) and Morgan (1956, 1959) raises the question if a third period group exists.

This question was made more urgent by Preston's study (1959) of field RR Lyrae variables where large-amplitude a, b variables of low ΔS were shown to exist with periods between 0.30 and 0.44 days. Such variables are presently unknown in globular clusters, and the natural presumption was that, if they do occur in clusters, they should be found in the Morgan classes VI–VIII. However, clusters of this metal richness contain few, if any, RR Lyrae stars, and the hypothesis cannot be checked. But variables do occur in clusters as rich as class V, such as NGC 6171 and NGC 6712, and the question can be asked if the mean periods of variables in class V clusters are shorter than 0.55 days.

The period-amplitude relation is also known to differ between clusters of the two Oosterhoff groups (Belserene 1954). Equal amplitudes occur in the two groups at periods which are in the ratio 0.65/0.55. Does a larger ratio apply to class V cluster variables?

These questions were unanswered when the present investigation was begun because periods had not been determined for many variables in clusters of Morgan class V and later. We therefore undertook a study of the variable stars in NGC 6712.

II. THE OBSERVATIONS

Ninety-nine plates were taken with the 200-inch telescope between 1955 and 1961 (Julian days between 2435255 and 2437518). The plates were equally divided between blue and yellow wavelengths, defined by the usual plate and filter combinations of 103aO + GG13 for B and 103aD + GG11 for V. In an effort to find more variables

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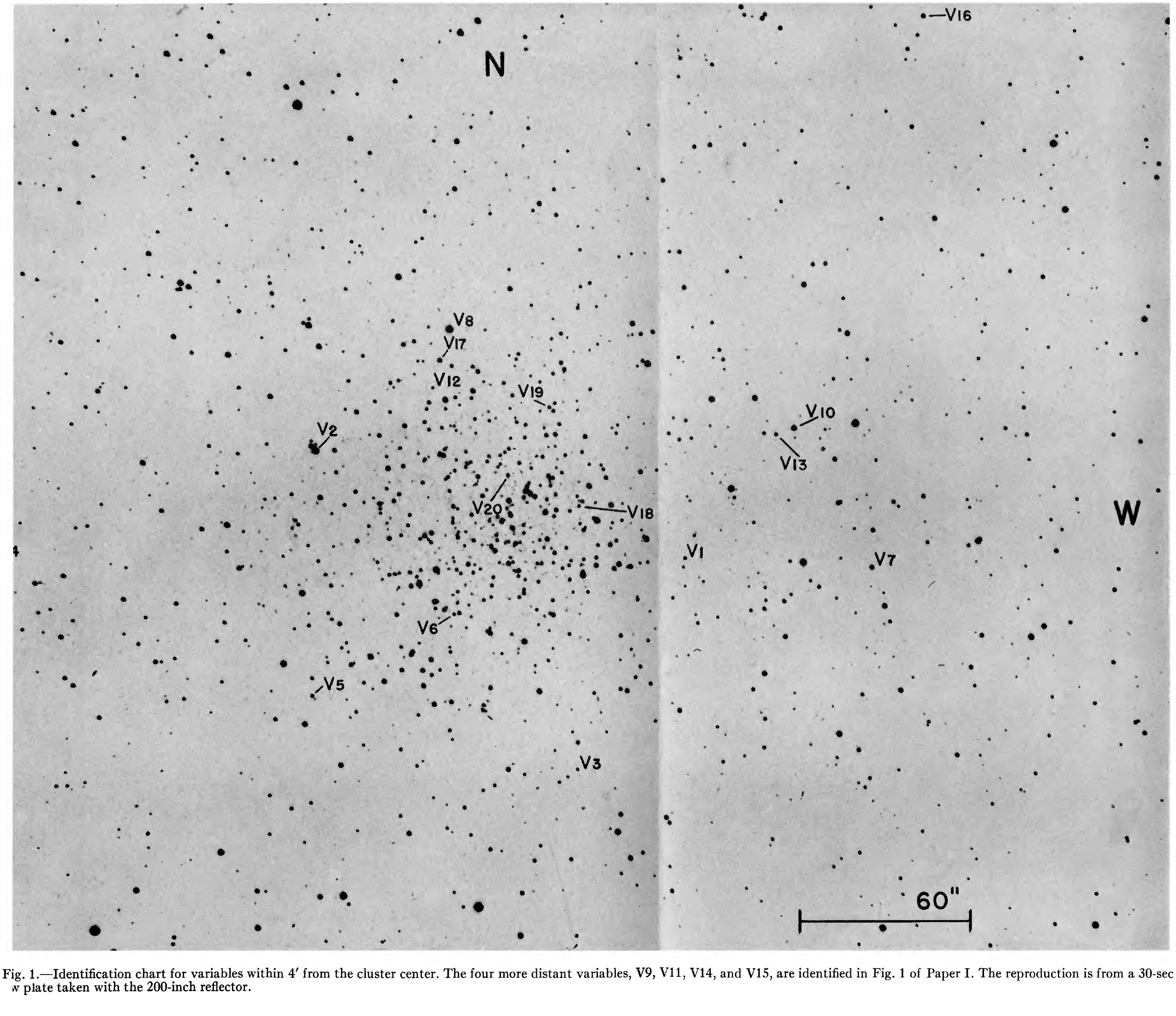


Fig. 1.—Identification chart for variables within 4′ from the cluster center. The four more distant variables, V9, V11, V14, and V15, are identified in Fig. 1 of Paper I. The reproduction is from a 30-sec w plate taken with the 200-inch reflector.

than listed by Helen Sawyer (1955) in her *Second Catalogue of Variable Stars in Globular Clusters*, fifteen pairs of plates were blinked and forty stars were marked as suspected variables. Subsequent investigation showed that most of these do not vary. We have found only four confirmed variables not listed by Sawyer, to which we have assigned numbers 13, 18, 19, and 20. This system continues the numbers of Sawyer, which stopped at V12. V13 was discovered independently by Rosino (1966) in his investigation of the cluster. The other three new ones, V18–V20, are small-amplitude variables near the cluster center. For completeness, we have added four variables (V14–V17) to the list, but the first three of these are almost certainly field stars in the surrounding Scutum Cloud. V14 is star F1 of Sawyer (1953). It is also variable number 131 of Harwood (1962), who gives a period of 201 days. V15, V16, and V17 are listed by Harwood by Nos. 160, 141, and 151, respectively. Our plates do not show V17 to vary, although four maxima and minima have been observed by Harwood. The star is labeled as No. 7 in ring B in the preceding paper (Sandage and Smith 1966; hereinafter called "Paper I"), and has values of $V = 14.98$, $B - V = 0.58$. If it actually varies, it is not an RR Lyrae member of the cluster because it is too bright and too blue.

All 20 variables are identified in Figure 1 of this paper if they are within 4.0 minutes of arc from the cluster center, or in Figure 1 of the preceding paper for the four more distant ones.

B and V magnitudes were determined for sixteen of the variables either by (1) direct reference to the photoelectric sequence of Paper I from measurements made with an iris-diaphragm photometer, or (2) by eye estimates for variables on dense background near the cluster center by reference to the magnitudes of selected stars of Table 2 of Paper I. The results are given in Tables 1 and 2 for the ten RR Lyrae stars and for V11, which is of unknown type. Table 3 gives data on the four long-period variables in or near the cluster, together with V15, which is of unknown type. Magnitudes with colons were determined from eye estimates made to ±0.05 mag.; all other magnitudes were determined from iris-photometer measurements. The magnitudes were originally estimated using an early version of Table 2 of Paper I before a small color equation was applied. These were later corrected for color equation, which explains the non-integral values tabulated for the eye estimates of B in Table 1.

The distribution of the plates was favorable for period determination because fifty-three of the ninety-nine were taken in a three-night interval in 1955, and the remainder were spread over a much longer interval. We were also fortunate in knowing Rosino's results on periods, which he kindly communicated to us before publication. The periods determined from our material for the ten RR Lyrae stars are given in Table 4, which also lists the photometric elements for all variables studied. The periods for the long-period variables could not be found anew from our data because the time coverage was inadequate. We have adopted Rosino's period for V2 (AP Sct), and have changed slightly Harwood's periods for V7 (CH Sct), V8, and V10 to fit our observations. Phases given in the tables were computed with the periods and adopted epoch of maximum light given in Table 4.

The light-curves from these data are shown in Figures 2 and 3. (Our data for V11 and V15 were not extensive enough to determine the nature of the light-curves.) These curves were converted to intensity units, planimetered to find the mean intensity, which was then converted back to magnitudes to give $\bar{V}$, $\bar{B}$, and hence $\bar{B} - \bar{V}$, as listed in Table 4. Also tabulated are the x and y coordinates on the system of Sawyer (1955), but as measured by us on a single 200-inch plate. Finally, the amplitudes in blue and visual light are given in the fourteenth and fifteenth columns.

The question of cluster membership for the variables cannot be answered unequivocally because radial velocities are not available, but it seems likely from position in the cluster and from the value of $\bar{V}$ and $\bar{B} - \bar{V}$ that all RR Lyrae stars except V4 are cluster members. V4 lies outside the cluster radius, determined to be 2.′3 from inspec-

TABLE 1

B MAGNITUDES FOR THE SHORT-PERIOD VARIABLES IN NGC 6712

H.J.D.	Var 1		Var 3		Var 4		Var 5		Var 6		Var 11	Var 12		Var 13		Var 18		Var 19		Var 20	
2,430,000+	B	φ	B	φ	B	φ	B	φ	B	φ	B	B	φ	B	φ	B	φ	B	φ	B	φ
5255.8150	16.21:	0.025	16.91:	0.110	17.05	0.159	17.21:	0.846	16.63:	0.195	17.33	17.21:	0.360	17.15	0.787	.....	.....	.....	.....	17.14:	0.700
.8966	16.59	.184	17.03	.235	17.26	.293	15.98:	.996	17.11:	.355	16.97	17.42:	.523	16.50	.933	.....	.....	16.59:	0.962	16.64:	.946
.9049	16.74:	.200	17.03:	.247	17.34	.306	15.98:	.011	17.32:	.371	16.93	17.41:	.539	16.49	.947	.....	.....	.....	.....	16.64:	.971
.9688	17.03:	.325	17.13:	.345	17.36	.410	16.34:	.128	17.53:	.496	16.90	17.41:	666	16.20	.061	.....	.....	.....	.....	16.74:	.165
5256.8223	16.18:	.992	17.27:	647	17.61	.805	17.21:	.692	16.61:	.166	16.90	17.11:	.363	17.01	.577	16.64:	0.981	.....	.....	17.14:	.744
.8661	16.35:	.078	17.32:	.713	17.29	.877	17.42:	.773	16.71:	.252	17.01	17.31:	.450	17.20	.655	16.69:	.108	16.73:	.249	16.94:	.876
5284.7678	17.20	.570	17.07	.267	17.57	.488	16.44:	.933	17.50:	.870	17.03	16.41:	.946	16.73	.245	16.64:	.973	16.54:	.071	16.64:	.205
.7817	17.15	.597	17.04	.289	17.48	.510	16.16:	.959	17.40:	.898	16.91	16.18:	.974	16.73	.270	.....	.....	16.34:	.114	16.74:	.247
.7949	17.24	.622	17.11	.309	17.49	.532	16.07:	.982	17.18:	.923	16.99	16.05:	.000	16.80	.293	16.64:	.052	16.48:	.135	16.84:	.287
.8094	17.39	651	17.07:	.331	17.45	.555	15.98:	.008	16.44:	.950	16.94	16.10:	.028	16.90	.318	.....	.....	16.63:	.170	16.84:	.331
.8233	17.26	.678	17.13	.352	17.43	.577	15.98:	.034	16.19:	.978	16.96	16.28:	.056	16.79	.343	16.74:	.133	16.68:	.203	17.04:	.373
.8372	17.33	.705	17.20	.373	17.51	.600	16.06:	.059	15.85:	.005	17.03	16.51:	.084	16.96	.368	16.69:	.173	.....	.....	17.04:	.415
.8865	17.35	.801	17.21	.449	17.51	.680	16.34:	.149	16.39:	.101	16.85	16.74:	.181	17.05	.455	.....	.....	.....	.....	17.14:	.564
.9365	17.21	.899	17.21:	.525	17.70	.764	16.81:	.243	16.63:	.201	16.85	17.08:	.282	17.09	.545	17.13:	.463	16.86:	.470	16.94:	.715
.9629	16.60	.951	17.25	.565	17.64	.806	17.00:	.290	16.87:	.252	17.02	17.11:	.334	17.16	.592	17.18:	.538	.....	.....	16.64:	.794
5285.7254	17.24	.440	17.38	.728	17.12	.052	17.21:	.688	17.50:	.744	16.95	17.53:	.850	16.47	.946	.....	.....	.....	.....	16.74:	.099
.7622	17.33:	.512	17.32:	784	17.13	.112	17.22:	.755	17.55:	.816	16.86	16.96:	.923	16.06	.012	16.84:	.854	16.91:	.417	16.64:	.210
.7817	17.22	.550	17.08	.814	17.18	.145	17.32:	.792	17.45:	.855	16.81	16.28:	.963	16.13	.047	16.60:	.912	16.86:	.463	16.84:	.269
.8032	17.16	.592	16.88	.847	17.19	.179	17.32:	.831	17.31:	.896	16.80	15.99:	.005	16.22	.084	16.65:	.973	16.86:	.514	16.94:	.334
.8233	17.21	.631	16.85	.877	17.24	.212	17.45:	.867	16.91:	.936	16.80	16.33:	.045	16.27	.120	16.69:	.031	17.01:	.562	16.94:	.395
.8831	17.29	.748	16.64	.968	17.33	.310	16.16:	.977	16.21:	.053	16.83	16.64:	.164	16.41	.227	16.69:	.205	16.93:	.703	17.14:	.575
.9136	17.32	.807	16.71	.015	17.49	.361	16.16:	.034	16.64:	.114	16.95	16.79:	.226	16.63	.282	16.84:	.295	16.78:	.775	17.04:	.668
.9379	17.32	.855	16.71	.052	17.41	400	16.46:	.078	16.74:	.161	16.92	16.97:	.273	16.84	.324	16.68:	.364	16.63:	.832	16.84:	.741
.9588	17.27	.896	16.83	.084	17.47	.434	16.54:	117	17.02:	.202	17.01	17.03:	.315	16.89	.362	16.98:	.425	16.53:	.881	16.64:	.804
5286.7213	17.11	.385	17.04	.247	17.63	.680	17.13:	.514	17.55:	.694	16.80	17.54:	.831	17.16	.716	17.26:	.633	16.83:	.680	16.64:	.109
.7414	17.13	.424	17.07	.278	17.64	.713	17.22:	.550	17.60:	.733	16.73	17.53:	.871	17.15	.752	17.26:	.691	16.83:	.727	16.64:	.170
.7623	17.16	.465	17.03:	.309	17.52	747	17.30:	.589	17.67:	.774	16.83	17.36:	.912	17.18	789	17.26:	.752	16.78:	.777	16.84:	.233
.7838	17.28	.507	17.16	.342	17.57	.783	17.21:	.629	17.63:	.817	16.90	16.28:	.956	17.29	.828	17.07:	.816	16.78:	.827	16.84:	.298
.8060	17.26	.550	17.17	.376	17.56	.819	17.23:	.670	17.45:	.860	16.77	16.04:	.000	17.18	.867	16.84:	.880	16.63:	.880	16.94:	.365
.8845	17.32:	.703	17.20	.496	17.07	.946	17.32:	.813	16.20:	.013	17.51	16.76:	.155	16.03	.006	16.64:	.106	16.54:	.065	17.24:	.602
.9241	17.28	781	17.24	.556	16.93	.012	17.32:	.886	16.39:	.091	17.19	16.89:	.235	16.14	.077	16.59:	.222	16.58:	.158	17.04:	.722
5342.7077	17.36	.726	17.31	634	17.39	.201	16.54:	.169	17.06:	.290	16.87	16.80:	187	16.63	.222	16.76:	.894	16.93:	.756	17.04:	.319
5344.7284	17.42:	.673	17.32	.716	17.51	.503	17.40:	.873	16.93:	.244	17.61	16.85:	.204	17.24	.812	17.17:	.748	16.91:	.523	16.94:	.426
.7493	17.42:	.713	17.36:	.748	17.47	.537	16.72:	.911	17.17:	.285	.....	16.93:	.246	17.35:	.849	17.23:	.809	16.91:	.572	17.04:	.489
5345.7082	17.27	.586	16.96	.210	17.08	.105	17.31:	.669	16.83:	.162	16.94	16.66:	.153	17.04:	.554	16.86:	.588	16.63:	.835	16.94:	.387
5638.7987	16.25:	.992	16.97:	.215	17.24	.214	16.35:	.066	.....	.....	17.20	16.47:	.099	16.99:	.464	.....	.....	16.63:	.257	16.84:	.205
5658.8327	16.35:	.118	17.23:	.770	16.93	.964	17.21:	.800	16.24:	.113	17.30	16.54:	.946	16.15	.071	16.59:	.081	16.86:	.519	16.94:	.754
6818.6562	16.83:	.252	17.24:	.667	17.35	.902	17.20:	.393	17.37:	.496	16.97	17.38:	.784	16.74	.424	17.03:	458	17.07:	.629	16.64:	.129
.6621	16.84:	.264	17.29:	.676	17.14	.911	17.10:	.404	17.37:	.507	16.92	17.51:	.796	16.73	.435	17.03:	.476	17.07:	.643	16.64:	.147
6820.6554	16.61	.157	17.32	.716	17.26	.169	16.46	.058	17.17:	.409	16.8 ·	17.39	.760	16.10	.977	16.84	.252	16.88:	.346	16.57	.172
.6561	16.60:	.158	17.33:	718	17.12	.171	16.26:	.060	17.12:	411	16.7 ·	17.24:	.762	16.20	.979	16.84:	.255	16.93:	.347	16.64:	.174
6578	16.65:	.161	17.24:	720	17.12	.174	16.26:	.064	17.12:	.415	16.7	17.38:	.766	16.00	.982	16.84:	.261	16.83:	.351	16.64:	.179
.6592	16.60:	.164	17.32:	.722	17.07	.176	16.26:	.066	17.12:	.417	16.8 ·	17.38:	.768	15.99	.984	16.84:	.264	16.88:	.355	16.64:	.183
7517.7645	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.7652	.....	.....	.....	.....	.....	.....	.....	.....	16.04:	.020	.....	.....	.....	16.38:	.951	.....	.....	.....	.....	.....	.....
.7666	.....	.....	.....	.....	.....	.....	.....	.....	16.14:	.023	.....	.....	.....	16.38:	.954	.....	.....	.....	.....	.....	.....
7518.6832	17.14:	.404	17.07:	.309	.....	.....	16.33:	.928	.....	.....	.....	16.56:	.108	17.34:	.582	16.59:	.263	16.49:	.046	16.64:	.846
.6846	17.04:	407	17.07:	.311	.....	.....	16.29:	.931	.....	.....	.....	16.46:	112	17.34:	.586	.....	.....	16.49:	.049	16.64:	.852
.6853	.....	.....	.....	.....	.....	.....	16.29:	.931	.....	.....	.....	16.56:	.112	.....	.....	.....	.....	16.49	.051	.....	.....

TABLE 2

V MAGNITUDES FOR THE SHORT-PERIOD VARIABLES IN NGC 6712

H.J.D.	Var 1		Var 3		Var 4		Var 5		Var 6		Var 11	Var 12		Var 13		Var 18		Var 19		Var 20	
2,430,000+	V	φ	V	φ	V	φ	V	φ	V	φ	V	V	φ	V	φ	V	φ	V	φ	V	φ
5255.8282	15.6 :	0.051	16.0 :	0.130	.....	.....	16.3	0.870	15.8	0.220	16.40	16.25:	0.386	16.4	0.810	.....	.....	...	.....	16.2	0.740
.9139	15.98	.218	16.25:	.261	16.39	0.320	15.5	.028	16.2 .	.388	15.96:	16.6 ·	.557	15.65:	.963	.....	....	.....	.....	15.9	.999
.9223	16.0 :	.234	16.2 :	.274	.....	.....	15.4	.042	16.35:	404	16.05:	16.5 :	.573	15.55:	.977	.....	.....	.....	.....	15.9	.024
5256.8279	15.6 :	.003	16.4 :	.655	16.64	.815	16.3 .	.704	15.75:	177	15.96:	16.3 :	.375	16.4 .	.587	16.0	0.998	15.9	0.159	16.2	761
.8362	15.55:	.019	16.45:	668	16.46	.945	16.3	.850	15.75:	.334	16.05:	16.4	.534	16.35:	729	16.1	.230	.....	.....	16.3	.786
5284.7629	16.37	.560	16.15:	.260	16.57	479	15.76	.924	16.55:	.861	15.98	15.9 :	.936	16.1 .	.236	15.95:	.959	...	....	16.0	190
.7768	16.36	.587	16.2 :	.281	16.41	.502	15.54	.949	16.45:	.888	15.93	15.6 :	.964	16.1 .	.261	16.0	.999	.....	.....	16.0	.232
.7907	16.46	.614	16.2 :	.302	16.58	.525	15.41	.975	16.4	.916	16.20	15.5 :	.992	16.1	.286	15.95:	.040	.....	.....	16.2	.274
.8046	16.50	.641	16.2 :	.324	16.62	.548	15.39	.001	16.4 :	.943	16.06	15.65:	.020	16.1	.311	15.95:	.080	15.85:	158	16.2	.316
.8185	16.42	.669	16.25	.345	16.57	.569	15.47	.025	15.35:	.969	16.05:	15.65:	.046	16.1 .	.334	16.15:	.118	.....	.....	16.3	.358
.8324	16.47	.696	16.25:	.366	16.65	.592	15.50	.050	15.35:	.996	15.96:	15.8 ·	.074	16.1 :	.359	16.15:	.159	15.85:	.224	16.4	400
.8817	16.60	.792	16.35:	.441	16.60	674	15.86	.142	15.6 ·	.094	15.96:	15.95:	.173	16.2 :	448	16.25:	.304	16.0	.340	16.5	.549
.9317	16.51	.890	16.3 :	.517	16.67	.756	15.86	.234	16.0 .	192	15.90:	16.15:	.273	16.3	.536	16.3	.449	16.0	458	16.3	700
.9588	15.96	.943	16.3 :	.559	16.74	.800	15.95	.283	15.85:	.245	15.96:	16.25:	.326	16.4	.584	16.35:	.527	.....	.....	16.2	782
5285.7213	16.39	432	16.5 :	.722	16.20	.045	16.33	.680	16.5	.736	16.05:	16.8	.842	16.0 .	.939	16.2	.735	15.95:	.321	15.9	.087
.7567	16.40	.501	16.45:	776	16.31	104	16.36	.746	16.5 :	.807	15.96:	16.5 :	.914	15.5 .	.003	16.15:	.840	.....	.....	15.9	194
.7595	16.39	.506	16.45:	.780	16.36	.109	16.41	.752	16.5 ·	.813	15.96:	16.2	.919	15.5	.008	16.1	.848	16.0	411	15.9	.202
.7775	16.48	.542	16.3 :	.807	16.37	137	16.43	.783	16.6	.846	15.90:	15.7 ·	.953	15.65:	.038	16.05:	.898	16.0	454	16.2	.257
.7983	16.39	.582	16.15:	.839	16.30	.171	16.4 :	.821	16.4 ·	.887	15.90:	15.6 :	.995	15.6 :	.076	16.0	.958	16.05:	.503	16.2	.319
.8192	16.42	.623	16.05:	.871	16.45	.206	16.49	.860	16.15:	.928	15.90:	15.75:	.037	15.7	.113	15.85:	.019	16.0	.552	16.2	.382
.8789	16.51	.740	15.9 :	.962	16.47	.304	15.50	.970	15.65:	.046	15.84:	16.0:	.156	16.0 :	.220	15.9	193	16.05:	693	16.4	.563
.9095	16.51	.799	15.9 :	.009	16.50	.353	15.56	.025	15.75:	.104	15.96:	16.15:	.216	16.0 :	.273	15.95:	.280	15.9	765	16.3	.655
.9338	16.64	.847	15.9 :	.046	16.49	.394	15.69	.071	15.85:	.153	16.16	16.15:	.265	16.1	.317	15.95:	.353	15.9	.822	16.1	729
.9407	16.55	.860	15.9 :	.056	16.53	405	15.84	.084	15.9	167	16.31	16.15:	.279	16.15:	.330	16.0	.373	15.95:	.838	16.1	.750
.9546	16.48	.887	16.0 :	.078	16.55	.428	15.76	109	16.0 ·	.194	16.14	16.2	.307	16.2	.355	16.1	413	.....	.....	16.1	792
5286.7171	16.30	.377	16.1 :	.241	16.62	674	16.30	.506	16.65:	686	15.84:	16.9 ·	.823	16.4 ·	.709	16.3	.622	16.05:	670	16.0	.096
.7379	16.35	.417	16.1 :	.272	16.64	708	16.34	.545	16.5	727	15.96:	16.7	.865	16.45:	746	16.35:	.683	.....	.....	16.0	.159
.7588	16.39	.458	16.2 :	.304	16.62	.742	16.3 :	.583	16.5 .	768	15.90:	16.6 :	.906	16.5 :	.784	16.35:	744	15.95:	.768	16.1 .	.282
.7796	16.41	499	16.25:	.336	16.67	.776	16.3 ·	.622	16.55:	.809	15.96:	15.7	.948	16.5 :	.821	16.45	.804	15.9	.818	16.1	.285
.8004	16.50	.539	16.3 :	.368	16.66	.809	16.41	659	16.65:	.848	15.96:	15.45:	.988	16.5 :	.856	16.4	.862	15.8	.867	16.1	.348
.8025	16.52	.543	16.3 :	.371	16.66	.814	16.46	.664	16.5 ·	.854	15.96:	15.6 :	.994	16.55:	.862	16.25:	.871	15.8	.872	16.1	.354
.8789	16.46	.693	16.3 :	.487	16.32	.938	16.5 ·	.804	15.65:	.003	16.39	15.95:	.145	15.4 ·	.997	16.0	.091	15.8	.052	16.3	.585
.9185	16.47	.770	16.3 :	.548	16.11	.002	16.28	.875	15.7 ·	.079	16.32	16.0 :	.223	15.7 ·	.066	15.9	.204	15.95:	.145	16.1	705
5342.7119	16.51	.734	16.45:	.641	16.39	.207	15.75	.176	16.2 ·	.298	15.94:	16.05:	.194	15.9 .	.229	16.05:	.906	16.05:	.766	16.3	.331
5344.7319	16.53	.679	16.45:	721	16.53	.509	16.34	.880	16.2	.252	16.42	16.1	.212	16.4 :	.819	16.3	.760	.....	.....	16.3	.436
.7548	16.45:	.724	16.4 :	.756	16.43	.547	15.6 ·	.922	16.3	.297	.....	16.1 ·	.258	16.4 :	.860	16.4	.826	.....	.....	16.5 ·	.506
5345.7117	16.50	.593	16.1 :	.216	16.22	111	16.3 ·	677	16.2 ·	.170	16.07	16.0 .	.161	16.3 :	.561	16.25:	600	16.0 ·	.843	16.3	.398
5658.8209	15.7 :	.095	16.43	.752	16.33	.944	16.5 :	.778	15.55:	.089	16.26	16.37	.922	15.65	.050	15.9	.047	16.0 ·	491	16.2 .	.719
6818.6666	16.05:	.273	16.50	.683	16.23	.920	16.1 .	.413	16.55:	.517	16.05:	16.6 ·	.806	16.2 :	.445	16.2	.490	16.2	.654	16.0	.161
.6718	16.1 :	.283	16.53	691	16.33	.928	16.1 ·	423	16.55:	.527	16.07	16.7 :	.816	16.2 :	.454	16.15:	.505	16.15:	.666	15.9 .	177
6820.6609	15.85	.168	16.47	.725	16.25	.179	15.73	.070	16.33	.421	15.84:	16.57	.772	15.55:	.989	16.05:	.269	16.06	.359	15.92	188
.6616	15.96	.169	16.47	.726	16.33	.181	15.73	.071	16.33	.423	15.84:	16.63	.774	15.5 :	.991	16.12:	.272	16.0	.360	15.88	.191
.6634	15.92	.172	16.46	.729	16.32	.182	15.6 .	.073	16.4 :	.425	15.84:	16.58	776	15.65:	.993	16.15:	.275	16.0 .	.364	15.9 :	.196
.6647	15.93	.175	16.51	.731	16.33	.186	15.6 :	.078	16.4 :	.428	15.84:	16.56	780	15.55:	.996	16.2	.281	16.05:	.368	15.9 :	.200
7517.7687	.....	.....	.....	.....	.....	.....	.....	.....	15.4 :	.027	.....	.....	.....	15.8 .	.960	.....	.....	15.75:	.888	.....	.....
.7701	.....	.....	.....	.....	.....	.....	.....	.....	15.55:	.029	.....	.....	.....	15.8 .	.962	.....	.....	.....	.....	.....	....
.7706	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7518.6909	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	16.0 .	.124	.....	.....	.....	.....	.....	.....	.....	.....
.6923	.....	.....	.....	.....	.....	.....	15.6 :	.944	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....
.6930	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE 3

V AND B MAGNITUDES FOR FIVE LONG-PERIOD VARIABLES

H.J.D. 2,430,000+	Var 2 V	Var 2 φ	Var 7 V	Var 7 φ	Var 8 V	Var 8 φ	Var 10 V	Var 10 φ	Var 15 V
5255.9.....	12.83	0.375	16.05:	0.584	14.0 :	0.768	13.68	0.820	14.40:
56.8.....	12.95	.384	16.05:	.589	14.03	.776	13.66	.825	14.38:
84.9.....	13.73	.652	14.17	.737	12.50	.016	13.34	.987	14.07:
85.9.....	13.82	.662	14.18	.742	12.62	.024	13.40	.992	13.99:
86.8.....	13.86	.670	14.03	.747	12.49	.032	13.30	.997	13.93:
5342.7.....	12.6	.205	11.65	.040	13.9 :	.510	13.63	.319	13.95:
44.7.....	12.5	.224	11.62	.051	13.85:	.528	13.55	.330	14.05:
45.7.....	.....	.233	11.74	.056	13.95:	.536	13.53	.336	13.95:
5658.8.....	12.9	.218	16.1	.700	12.72	.212	13.42	.135	13.8 :
6818.7.....	.....	.316	14.89	.789	12.47	.125	13.71	.802	.....
20.7.....	12.65	.335	14.71	.799	12.66	.142	13.81	.813	.....
7517.8.....	12.7	.999	16.1 :	.459	12.73	.101	13.67	.819	13.83:
18.7.....	12.7	.008	16.1 :	.464	12.68	.108	13.67	.825	13.87:
8165.0*....	.....	.....	11.91	.857	.....	.....	.....	.....	.....
66.0*....	.....	.....	.....	.....	.....	.....	13.73	.545	.....
73.9*....	.....	.....	.....	.....	14.44	.709	.....	.....	.....

	B	φ	B	φ	B	φ	B	φ	B
5255.9.....	14.9:	0.375	18.09	0.584	15.88	0.768	15.90	0.820	16.25:
56.8.....	15.0:	.384	18.09	.589	15.90	.776	15.94	.825	16.35:
84.9.....	16.0:	.652	15.98	.737	14.54	.016	15.45	.987	16.00:
85.9.....	15.9:	.662	15.90	.742	14.60	.024	15.44	.992	16.01:
86.8.....	15.8:	.670	15.81	.747	14.58	.032	15.50	.997	15.98:
5342.7.....	14.7:	.205	13.77	.040	15.69	.510	15.50	.319	15.90:
44.7.....	14.7:	.224	13.89	.051	15.71	.528	15.59	.330	15.95:
44.7.....	.....	.....	.....	.....	15.80	.528	.....	.....	.....
45.7.....	14.7:	.233	13.89	.056	15.72	.536	15.59	.336	15.90:
5638.8.....	.....	.....	.....	.....	14.60	.041	15.50	.020	15.95:
58.8.....	15.3:	.218	17.44	.700	14.86	.212	15.50	.135	16.05:
6818.7.....	14.9:	.316	16.15	.789	14.45	.125	15.9 :	.802	15.85:
6820.7.....	14.7:	.335	16.15	.799	14.71	.142	15.89	.813	15.85:
7517.8.....	14.7:	.999	.....	.....	14.86	.101	.....	.....	16.15:
18.7.....	14.7:	.008	.....	.....	14.81	.108	15.78	.825	16.02:
8165.9*....	.....	.....	13.74	.857	.....	.....	.....	.....	.....
66.0*....	.....	.....	.....	.....	.....	.....	15.70	.545	.....
73.9*....	.....	.....	.....	.....	16.19	.709	.....	.....	.....

*Photoelectric observation

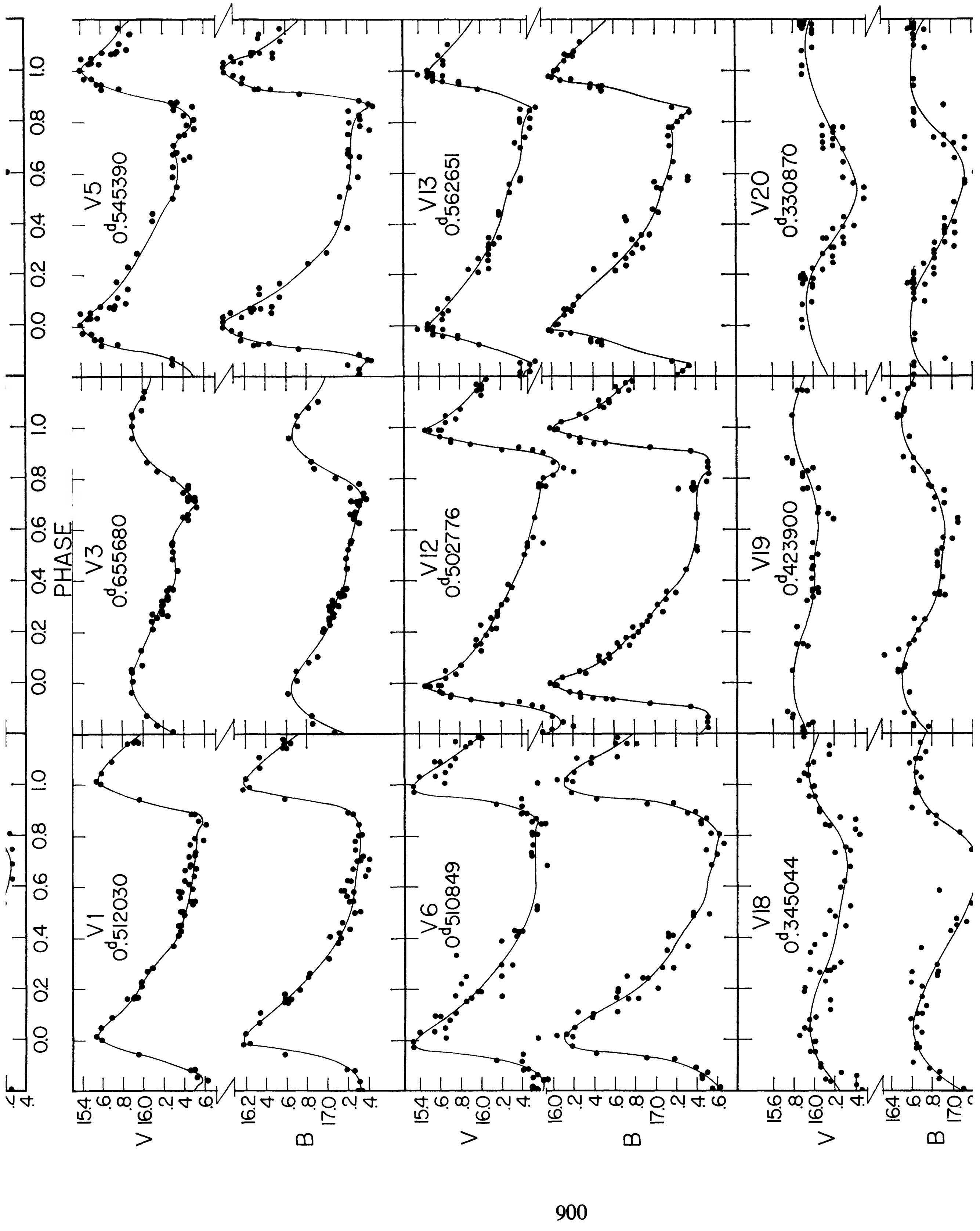
TABLE 4

SUMMARY OF THE ELEMENTS OF VARIABLES IN NGC 6712

No.	Harwood No.	x″	y″	P	Epoch 2,43+	$B_{\max}$	$B_{\min}$	$\overline{B}$	$V_{\max}$	$V_{\min}$	$\overline{V}$	$\overline{B}-\overline{V}$	A_B	A_V	Note
1	146	− 63	− 17	$0^{\mathrm{d}}.512030$	5284.988	16.18	17.32	16.90	15.56	16.60	16.14	0.76	1.14	1.04	
2	AP Sct	+ 69	+ 15	104.6	5007.4	(14.70)	(16.00)	(15.03)	(12.50)	(13.90)	(12.97)	(2.06)	(1.30)	(1.40)	1
3	......	− 28	− 93	0.655680	5285.235	16.66	17.34	17.02	15.89	16.49	16.17	0.85	0.68	0.60	2
4	......	+179	− 27	0.611741	5285.082	16.96	17.62	17.31	16.14	16.68	16.45	0.86	0.66	0.54	
5	154	+ 67	− 71	0.545390	5285.350	16.00	17.40	16.82	15.40	16.48	16.00	0.82	1.40	1.08	
6	......	+ 18	− 41	0.510849	5285.344	16.10	17.62	16.98	15.32	16.56	16.14	0.84	1.52	1.24	
7	CH Sct	−129	− 18	190.48	5327	13.10	18.20	14.66	11.20	16.20	12.72	1.94	5.10	5.00	3
8	149	+ 24	+ 60	117.0	5400	14.55	16.20	15.15	12.55	14.45	13.20	1.95	1.65	1.90	4
9	......	− 4	+285	......	......	.....	.....	.....	.....	.....	.....	....	....	....	5
10	......	− 99	+ 30	174	5287	15.45	15.95	15.65	13.35	13.78	13.56	2.09	0.50	0.43	
11	......	−116	−333	......	......	16.7	17.5	.....	15.8	16.4	.....	~1.0	~0.8	~0.6	6
12	152	+ 29	+ 39	0.502776	5285.298	16.00	17.54	16.96	15.47	16.77	16.20	0.76	1.54	1.30	7
13	144	− 93	+ 25	0.562651	5285.193	15.98	17.36	16.73	15.50	16.50	16.08	0.65	1.38	1.00	
14	131	−426	+ 31	201	......	.....	.....	.....	.....	.....	.....	....	....	....	8
15	160	+247	− 38	......	......	.....	.....	.....	.....	.....	.....	....	....	....	9
16	141	−138	+175	......	......	.....	.....	.....	.....	.....	.....	....	....	....	10
17	151	+ 27	+ 49	......	......	.....	.....	.....	.....	.....	.....	....	....	....	11
18	......	− 25	− 1	0.345044	5285.123	16.64	17.26	16.91	15.94	16.32	16.14	0.77	0.62	0.38	
19	......	− 13	+ 34	0.423900	5285.162	16.50	16.92	16.73	15.80	16.04	15.93	0.80	0.42	0.24	
20	......	+ 1	+ 9	0.330870	5285.031	16.60	17.14	16.83	15.92	16.44	16.15	0.68	0.54	0.52	

Notes to Table 4

1. AP Sct. Epoch and period are by Rosino. Phases in Table 3 were computed with these elements. Our observed maximum does not occur at phase 0.00. Only 75 per cent of our plate material could be used because the bright star ($\underline{V} \sim 14.5$) only 2″0 away contaminates the image.
2. Var 3. Rosino's period of $0^{\mathrm{d}}.655961$ fits all but one of our observations. Our period of $0^{\mathrm{d}}.655680$ satisfies all data of Tables 1 and 2.
3. Var 7: CH Sct. Period obtained from Harwood's last observed maximum at J.D. 2,430,954 and Rosino's quoted maximum at J.D. 2,434,954 with 21 cycles. Phases of Table 3 were computed with these elements. Figure 3 suggests that our maximum occurs at phase 0.960 ± 0.04 in this system, or at J.D. 2,435,327.
4. Var 8. Period from Harwood (1962). The phases of Table 3 were computed with an epoch of maximum at J.D. 2,435,400. Figure 3 suggests that maximum occurs at phase 0.06 in this system, or at J.D. 2,435,407.
5. Var 9. Extremely blue. May be a field U Gem-type star. Good images were seen on only 2 $\underline{V}$ and 4 $\underline{B}$ plates plates.
6. Var 11. Our data suggest an eclipsing binary. Its great distance from the cluster center precludes membership.
7. Var 12. Rosino's period of $0^{\mathrm{d}}.502776$ and our independently derived period of $0^{\mathrm{d}}.502800$ fit our data equally well. We have adopted Rosino's period because, presumably, with Rosino's different distribution of plates it is unlikely that both periods would fit his data even though both fit ours.
8. Var 14. This is F1 of Sawyer (1953). Period is from Harwood (1962).
9. Var 15. Harwood suspects fluctuations within one day and a long period of about 100 days.
10. Var 16. Harwood suspects eclipsing binary of short period.
11. Var 17. Four observed maxima and minima by Harwood. We do not find it variable. This is star B-7 of Paper I at $\underline{V} = 14.98$, $\underline{B}-\underline{V} = 0.58$.


PHASE
0.0
0.2
0.4
0.6
0.8
1.0
V5
0^d.545390
V3
0^d.655680
V1
0^d.512030
V13
0^d.562651
V12
0^d.502776
V6
0^d.510849
V20
0^d.330870
V19
0^d.423900
V18
0^d.345044
V
15.4
.6
.8
16.0
.2
.4
.6
B
16.2
.4
.6
.8
17.0
.2
.4
V
15.4
.6
.8
16.0
.2
.4
B
16.0
.2
.4
.6
.8
17.0
.2
.4
.6
V
15.6
.8
16.0
.2
.4
B
16.4
.6
.8
17.0

tion of a long-exposure yellow plate. Furthermore, it is fainter by 0.3 mag. in $\bar{V}$ than the mean of the other nine short-period variables. The long-period variables V2, V8, and V10 all could be cluster members on the basis of position within the cluster boundary, but V7 (CH Sct) lies just beyond the edge. The amplitude ($A_B = 5.1$ mag.) and period of 190 days for V7 show that the variable is a Mira type. If it is a cluster member at the apparent distance modulus of $(m - M)_{\mathrm{app},V} = 15.6$ (see Paper I), then M_V (max) $= -4.4$ mag., which is about 2 mag. brighter than field Miras at this period

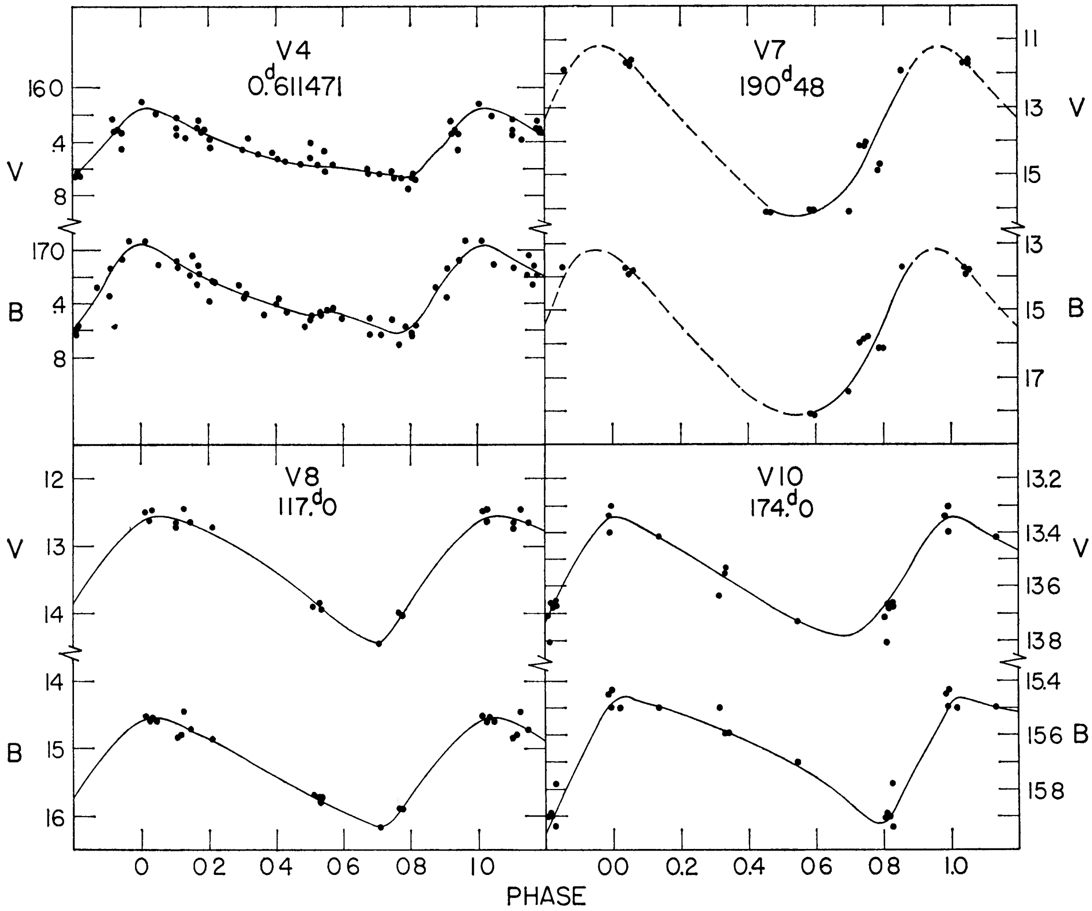


FIG. 3.—Two-color light-curves for the one probable field RR Lyrae star and for three of the four long-period variables

according to the calibration of Wilson and Merrill (1942), and Osvalds and Risley (1961). On the other hand, M_V (max) for V2 ($P = 105^{\mathrm{d}}$), V8 ($P = 117^{\mathrm{d}}$), and V10 ($P = 174^{\mathrm{d}}$) are -3.1, -3.1, and -2.3, respectively; values which agree reasonably well with the calibrations. From these data, V7 is considered to be a field star.

III. DISCUSSION

Although NGC 6712 contains only nine RR Lyrae members, the data are sufficient to show that no very short-period ($0\overset{\mathrm{d}}{.}30$–$0\overset{\mathrm{d}}{.}44$), Bailey-type *a*, *b* stars exist, as was expected by the comments in § I. The mean period for the cluster variables is $\bar{P}_{a,b} = 0\overset{\mathrm{d}}{.}548$ if V4 is excluded, or $P_{a,b} = 0\overset{\mathrm{d}}{.}557$ if V4 is included. Furthermore, the period-amplitude relation, plotted from Table 4, follows the systematic relation for M3 (Roberts and

Sandage 1955, Fig. 6) rather than a relation shifted toward shorter periods. This means that NGC 6712 is an Oosterhoff type I cluster instead of defining a shorter-period group.

These results were unexpected because the Preston ΔS value for this metal-rich cluster, although not yet observed, is certainly less than 5, and may be closer to 2. Preston's 1959 results for the field RR Lyrae stars would then imply that $\bar{P}_{a,b} < 0^{d}.50$ for NGC 6712, and, further, that the period-amplitude relation (Preston's Fig. 5, 1959) should be shifted shortward from the lower-metal clusters such as M15. We are now left with the same mystery as to where the short-period ($0^{d}.30$–$0^{d}.44$), low ΔS RR Lyrae *a*, *b* stars with large amplitudes come from in the general field. Their analogue clusters are not Morgan class V globulars if NGC 6712 is representative. Thus there appears to be a missing class of globular clusters where such variables should exist.

The supposition that the class is Morgan type VI–VIII is probably not tenable because very few RR Lyrae stars occur there due to the characteristic shape of the horizontal branches, which never reach blueward into the RR Lyrae star gap. The type example is 47 Tuc (Wildey 1961). Preston's kinematical solutions (1959) show that these low-ΔS field variables are in an extended disk population with a smaller dispersion in *UVW* velocity space than the more metal-poor variables, which are halo objects (high ΔS). The missing class of clusters might then possibly be of a type which formed early in the history of the Galaxy near the galactic plane, but which has since been dispersed by dynamical dissipative mechanisms in the time of 10^{10} years.

It is a pleasure to thank Dr. Donald Lynden-Bell for the part he played in determining preliminary periods for some of the variables before accurate photometry was available. We also wish to thank Professor Rosino for showing us his early results, before publication.

REFERENCES

Arp, H. C. 1955, *A.J.*, **60**, 317.
Belserene, E. P. 1954, *A.J*, **59**, 406.
Harwood, M. 1962, *Ann. Sterrewacht Leiden*, **21**, 387.
Mayall, N. U. 1946, *Ap. J.*, **104**, 290.
Morgan, W. W. 1956, *Pub. A.S.P.*, **68**, 509.
———. 1959, *A.J.*, **64**, 432.
Oosterhoff, P. T. 1939, *Observatory*, **62**, 104.
———. 1944, *B.A.N.*, **10**, 55.
Osvalds, V., and Risley, A. M. 1961, *Pub. Leander McCormick Obs.*, Vol. **11**, Part 21, p 147.
Preston, G. W. 1959, *Ap. J.*, **130**, 507.
Roberts, M. S., and Sandage, A. R. 1955, *A.J.*, **60**, 185.
Rosino, L. 1966, *Ap. J.*, **144**, 903.
Sandage, A., and Smith, L. L. 1966, *Ap. J.*, **144**, 886 (Paper I).
Sawyer, H. B. 1953, *J.R.A.S. Canada*, **47**, 229.
———. 1955, *Pub. David Dunlap Obs.*, Vol. **2**, No. 2.
Wildey, R. L. 1961, *Ap. J.*, **133**, 430.
Wilson, R. E., and Merrill, P. W. 1942, *Ap. J.*, **95**, 248.