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THE COLOR-MAGNITUDE DIAGRAM FOR THE GLOBULAR CLUSTER NGC 5897

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ABSTRACT

The color-magnitude diagram of NGC 5897, derived from two-color photometry of 254 stars relative to a photoelectric sequence extending to $V = 17.15$, is characteristic of a globular cluster with low metal abundance. The magnitude difference, ΔV, between the giant branch at $(B - V)_0 = +1.4$ and the horizontal branch is 2.75 mag; the color of the subgiant branch at the magnitude level of the RR Lyrae gap is $(B - V)_{0,g} = +0.78$—values which suggest a metal abundance intermediate between extremely weak-lined clusters (Deutsch group C, Morgan class I) and moderately weak-lined clusters (Deutsch group B, Morgan classes II–III)

Two new RR Lyrae stars and a new red variable near the top of the giant branch have been isolated, bringing the total number of known variables to seven.

The RR Lyrae gap occurs near $V = 16.20$. The apparent visual distance modulus is $(m - M)_{\text{app},V} = 15.70$ if the gap has $M_V = +0.5$. The estimated reddening is $E(B - V) = +0.11 \pm 0.02$. If $A_V/E(B - V) = 3$, the true modulus is $(m - M)_0 = 15.37$, the distance from the Sun is 11900 pc, and the height above the plane is 6000 pc. The absolute magnitude and linear diameter are $M_V = -7.3$, $D = 54$ pc, which require the average surface brightness to be 14 times smaller than that for M3. The low central concentration and large linear size are taken to mean that NGC 5897 has not suffered appreciable tidal evaporation by passage close to the galactic nucleus.

NGC 5897 ($\alpha = 15^h14^m.5$, $\delta = -20°50'$ [1950]; $l^{II} = 343°$, $b^{II} = +30°$) is a globular cluster of large angular size, small central concentration, and abnormally low surface brightness. As part of a continuing program, we have made photometric observations to obtain the color-magnitude (C-M) diagram.

The surface brightness is so low that integrated spectra are not available from the programs of Mayall (1946) and Morgan (1959). However, Deutsch (Kinman 1959) has obtained spectra of individual stars from which he classifies the cluster as extremely metal poor in his group C, which also contains M92 and M15 of Morgan metallicity class I. No other prior data on chemical composition were available, such as the photometric indices ϕ, Δ, ψ, and γ of van den Bergh (1967*a*), van den Bergh and Henry (1962), and Gascoigne and Koehler (1963). The present work was undertaken to determine if NGC 5897 obeys the correlations between chemical composition and the morphology of C-M diagrams suggested by previous studies (Arp 1955; Sandage and Wallerstein 1960; Sandage and Smith 1966; Sandage and Wildey 1967).

I. PHOTOMETRIC DATA

A skeleton photoelectric sequence of twenty stars was established over the range $11.34 \leq V \leq 17.15$ with the 100-inch reflector in the 1956 and 1958 observing seasons. Although the sequence is sufficient for the present reconnaissance, it is not definitive, since only one or two observations of each star were generally made. Furthermore, the brightness of the Mount Wilson sky made precise observations difficult fainter than $V \simeq 16$. The systematic accuracy of the colors for stars fainter than this limit is certainly better than ± 0.10 mag, but it is not of the order of ± 0.01 mag.

The photoelectric values are listed in Table 1, together with smoothed magnitudes obtained by reading the standard stars back through the photographic calibration curves of four plates in each color. The random accuracy of the photographic data is ± 0.021 mag for V and B, as discussed later.

The sequence stars are identified in Figure 1, which is reproduced from a plate of 15-min exposure with the 100-inch reflector diaphragmed to 58 inches, on Eastman 103aD emulsion behind a Schott GG11 filter. Also identified are the seven known variable stars discussed later. The scale of the print can be found from the diameters of the two circles, which are 4′42″ and 9′8″. The cluster extends beyond the outer circle, according to the measurements of Kron and Mayall (1960), which indicate $d_{0.9} = 15\overset{\prime}{.}4$ for NGC 5897.

In total, 254 stars, contained within the outer circle of Figure 1, were measured with an iris photometer on four 200-inch plates in each color that had been obtained in June 1966. Standard plate and filter combinations were used, consisting of Eastman 103aO+GG13 for B and 103aD+GG11 for V. Half of the plates in each color had exposure times of 1 min, and the remaining half, 2 min.

The program stars are identified in Figure 2 following a numbering system originally established by Maarten Schmidt in an early unpublished study of the cluster. The cluster is divided into twelve horizontal strips (not shown), each about 45″ wide. Within the topmost strip the numbers increase from west to east, with star 1 and photoelectric

TABLE 1

PHOTOMETRIC VALUES FOR THE SEQUENCE STARS

STAR	PHOTOELECTRIC				PHOTOGRAPHIC	
	V	$B-V$	$U-B$	n	V	$B-V$
A	11 34	+0 86	0 63	1	.	.
B	12 39	+0 71	30	3	12 36	0 61
	12 45	+0 68	40	4		
C	13 13	+1 15	96	1	13 14	1 16
D	13 65	+0 98	65	1	13 69	1 04
E	13 86	+1 01	67	1	13 82	0 99
F	14 10	+0 77	43	1	14 12	0 76
G	14 33	+0 99	74	1	14 36	0 93
H	14 45	+0 73	28	1	14 44	0 73
I	14 78	+0 75	43	1	14 78	0 75
J	15 04	+0 75	09	1	14 96	0 81
K	15 24	+0 98	.49	2	15 30	0 98
	15 33	+0 64				
		+0 87	45	1		
L	15 70	+0 74	. .	2	15 66	0 71
	15 64	+0 69	18	1		
M	16 16	+0 68	20	1	16 08	0 64
N	16 38	+0 23	37	2	16 47	0 18
O	16 63	+0 75:	. .	2	. . .	. .
P.	16 80	+0 09	18	2	16 78	0 16
Q	16 92	−0 02	35	2	16 99	0 14
	16 68	+0 13	28	1		
R	16 87	+0 16	33	2	16 86	0 09
	16 79	+0 06	0 14	1		
S	17 14	+0 73		1		. .
T	17 15	+0 82		1		
V5 .	Red variable near top of giant branch				13 28	1 62

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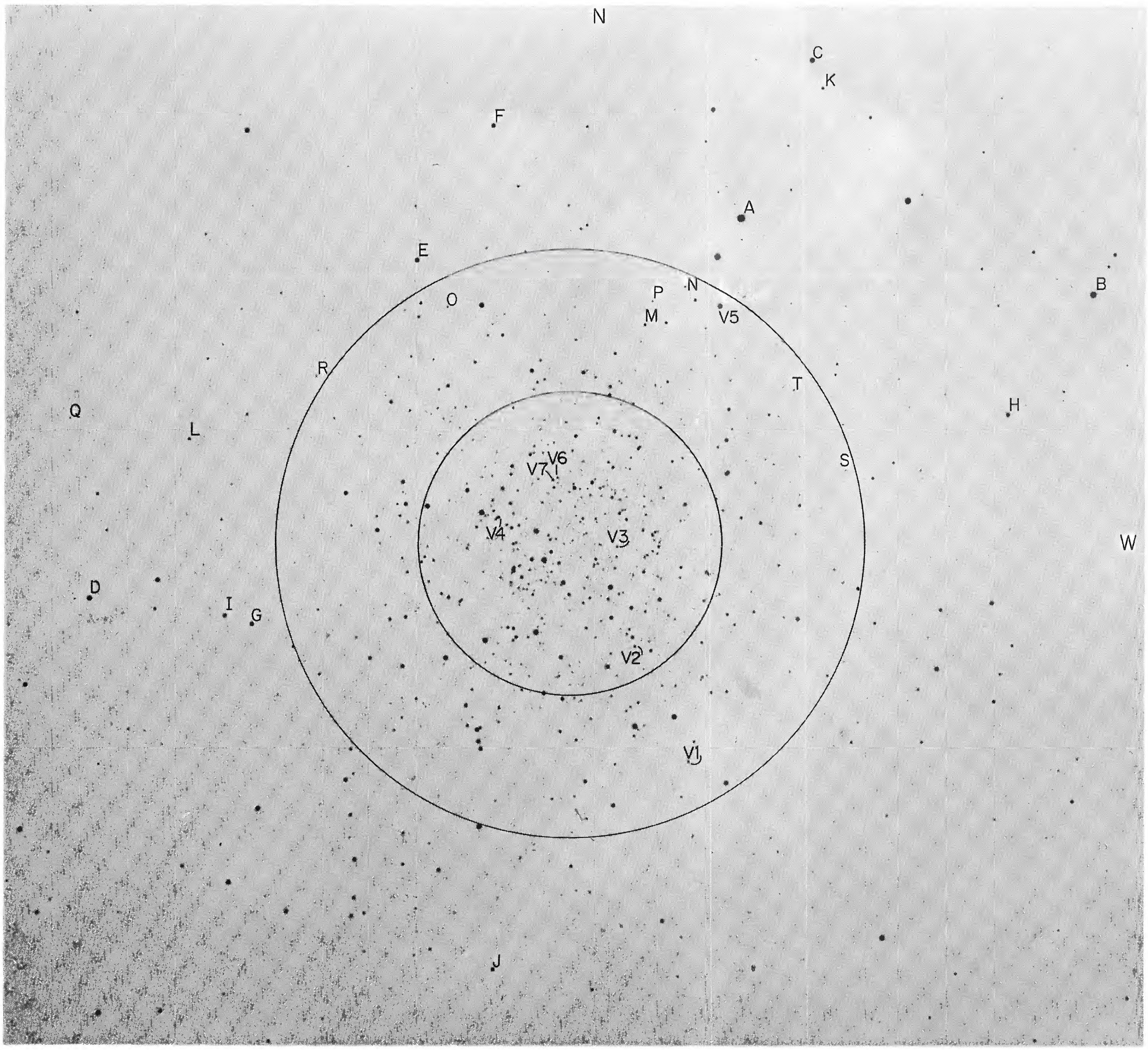

FIG. 1.—Identification chart for the photoelectric sequence and the seven known variables in NGC 5897. Reproduction is from a 15-min exposure on Eastman 103aD+Schott GG11 taken with the 100-inch reflector diaphragmed to 58 inches. The diameters of the two circles are 4′42″ and 9′8″.

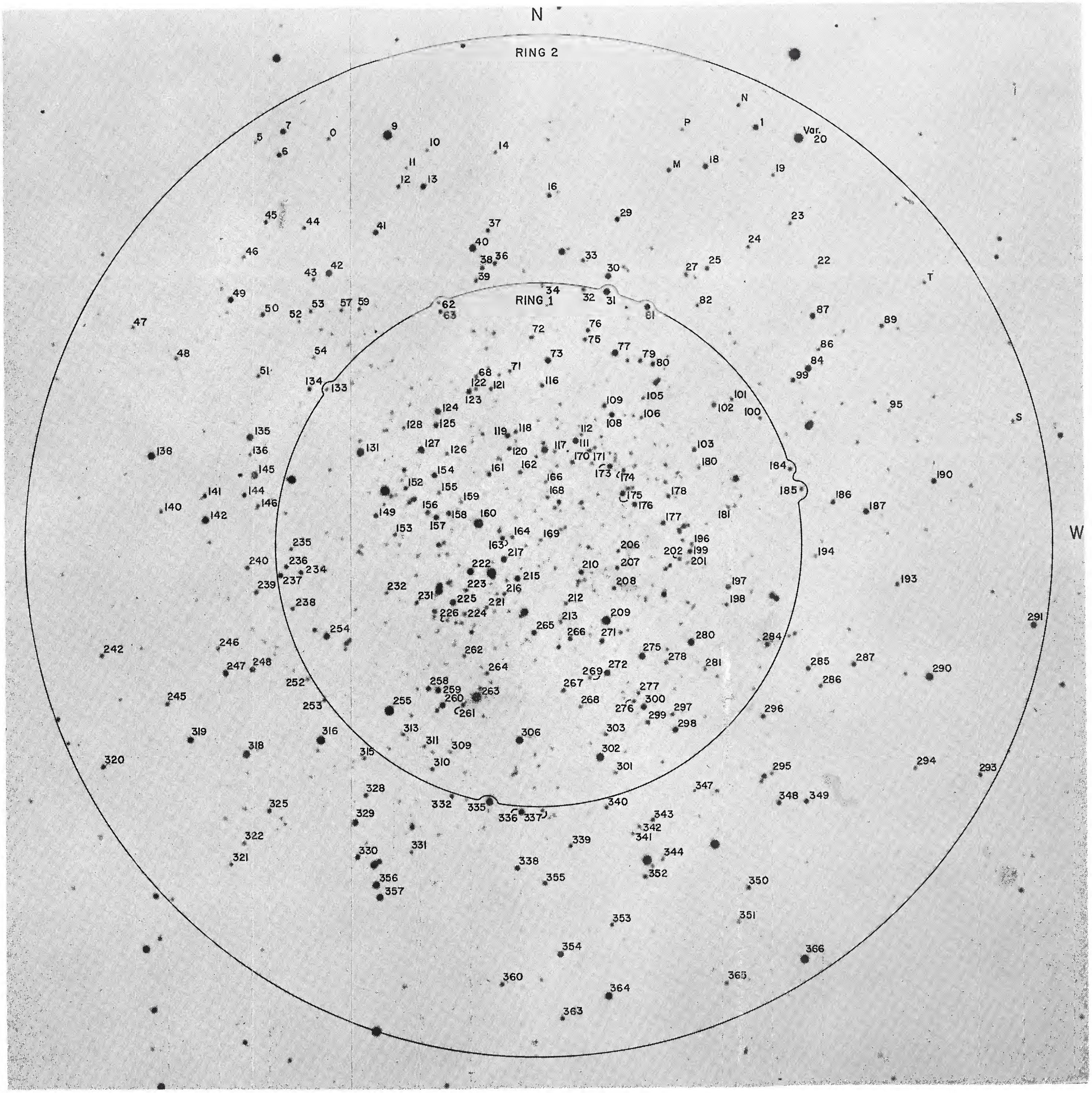

FIG. 2.—Same as Fig. 1 but with 254 program stars identified

standards N and P as the only stars within the strip. The numbering proceeds from east to west in the second strip, starting with star 5 and ending with star 20. This criss-cross numbering is continued, alternating in direction for each successive strip and ending in the southwest corner with star 366.

Not all numbers are represented because only stars with $V < 17.0$ were finally retained due to the steepness of the calibration curves and uncertainty of the magnitudes fainter than this limit.

The final mean data are listed in Table 2. Analysis of the residuals of each star shows the formal probable error of the tabulated values to be ± 0.021 mag in V and ± 0.030

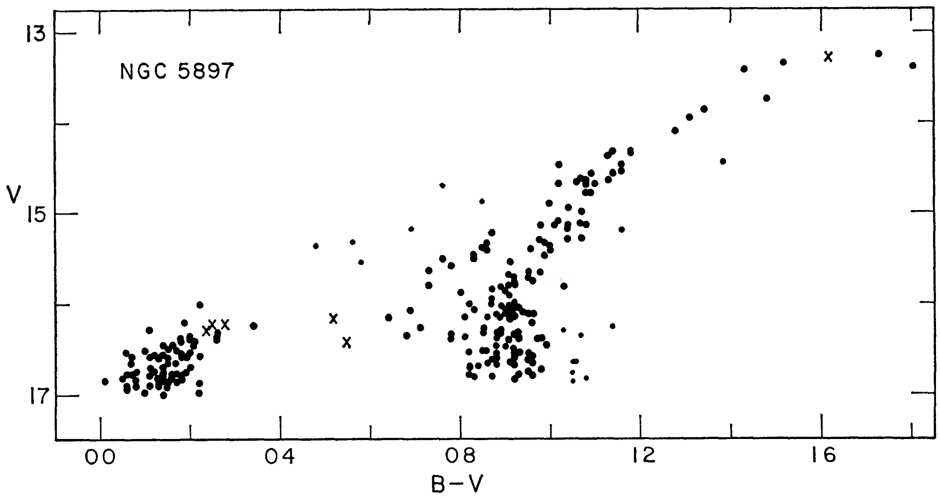

FIG. 3 —The C-M diagram from the data of Table 2 Small circles are presumed to be mostly field stars. Crosses are six of the seven known variables plotted with their instantaneous magnitudes and colors at the time of observation. No light curves are available to obtain mean values.

mag in $B - V$. To within the accuracy of the data, the colors in Table 2 are on the $B - V$ system, as shown from an absence of a systematic color equation between the photoelectric and photographic values of the standards listed in Table 1.

II. THE C-M DIAGRAM

The color-magnitude diagram is shown in Figure 3 as plotted from Table 2. Six of the seven known variable stars (see § III) are shown as crosses. Stars which fall off the principal sequences are plotted as small circles. These are presumed to be field stars because their frequency in ring 2 is three times that of ring 1, which is close to the ratio of the two areas. Field stars of nearly constant surface density should occur with this areal ratio, whereas cluster stars will be more concentrated in ring 1 due to the steep negative density gradient for cluster members.

The C-M diagram has characteristics of a moderately low-metal-abundance cluster, midway between M92 (Morgan class I, Deutsch class C) and M3 (Morgan class II, Deutsch class B). The parameter which has invariably correlated with metal abundance is the magnitude difference, ΔV, between the level of the RR Lyrae stars and the giant branch, read at $(B - V)_0 = +1.4$. According to Demarque and Geisler (1963), the helium abundance, which may be the second parameter controlling certain other characteristics of the diagram (Sandage and Wildey 1967; van den Bergh 1967*b*), has no appreciable effect on ΔV.

To find ΔV we must know the reddening $E(B - V)$. Two methods are available, one from the present data and one from the results of Kron and Mayall (1960). Assuming

TABLE 2

PHOTOGRAPHIC VALUES FOR 254 PROGRAM STARS

Star	V	B − V	Ring	Star	V	B − V	Ring	Star	V	B − V	Ring	Star	V	B − V	Ring
1	15 38	0 48	2	101	16.66	0 91	1	190	15 65	0 98	2	286	16 54	0 82	2
5	16 98	0 10	2	102	16 04	0 91	1	193	16 53	0 06	2	287	16 04	0 89	2
6	15 88	0 90	2	103	16.04	0 92	1	194	16 90	0 06	2	290	14 54	1 16	2
7	15 35	0 86	2	105	16 62	0 88	1	196	16 75	0 18	1	291	15.40	0 98	2
9	13 35	1 52	2	106	16.68	0 14	1	197	15 89	0 80	1	293	16 40	0 97	2
10	16 70	0 93	2	108	15 52	0 83	1	198	16 58	0 14	1	294	16 87	0 19	2
11	16 84	1 08	2	109	16 05	0 90	1	199	16 01	0 82	1	295	16 77	0 19	2
12	16 40	0.78	2	111	15 14	0 98	1	201	16 84	0 01	1	296	16 13	0 91	2
13	15 34	0 99	2	112	16 68	0 92	1	202	16 42	0 18	1	297	16 69	0 84	1
14	16 76	0 95	2	116	16 33	0 26	1	206	16 20	0 25	1	298	15 30	0 98	1
16	16 14	0.86	2	117	16 69	0 20	1	207	16 45	0.14	1	299	16 20	0 28	1
18	15 52	0 76	2	118	16 39	0 55	1	208	16 40	0 98	1	300	15 14	1 08	1
19	16 71	0 11	2	119	15 82	0 89	1	209	13 74	1 48	1	301	16 76	0 17	1
22	16 90	0 15	2	120	16 26	0.34	1	210	15.85	0 87	1	302	14 10	1 28	1
23	16 66	0.17	2	121	16 53	0 86	1	212	16 59	0 14	1	303	16 67	0 13	1
24	16 61	0 16	2	122	16 56	0 88	1	213	16 72	0 20	1	306	14 32	1 18	1
25	16 12	0 91	2	123	15 60	0 78	1	215	15 32	0 56	1	309	17 00	0 14	1
27	16 51	0 18	2	124	15.13	1 07	1	216	16 56	0 12	1	310	16 39	0 88	1
29	15 66	0 95	2	125	15.72	0 95	1	217	15 14	1 01	1	311	16 78	0 93	1
30	15 10	1 02	2	126	16 62	0 88	1	221	16.49	0 15	1	313	16 78	0 11	1
31	14 69	1 08	1	127	14.88	0.85	1	222	14 69	1 02	1	315	16 86	0 17	2
32	16 41	0 91	1	128	16 90	0 13	1	223	16.50	0.92	1	316	13 86	1 34	2
33	16 34	0 92	2	131	14 33	1 14	1	224	16 66	0 86	1	318	14 58	1 14	2
34	16 88	0 15	1	133	16 86	1 05	1	225	15 23	0 87	1	319	15 18	1 07	2
36	16 19	0 96	2	134	16.30	1 03	2	226	16 80	0 87	1	320	16 06	0 93	2
37	16 46	0 21	2	135	14 80	1 09	2	231	16 38	0 81	1	321	16 70	0 82	2
38	15 99	0 92	2	136	16.83	0 18	2	232	16 80	0 19	1	322	16 54	0 93	2
39	16 61	0 93	2	138	14 35	1 18	2	234	16.27	0 13	1	325	16 18	0 91	2
40	14 37	1.13	2	140	16 88	0 13	2	235	16 59	0.96	1	328	16 37	0 68	2
41	15 42	0 86	2	141	16 29	0 85	2	236	16 10	0.94	1	329	14 79	1 09	2
42	14 90	1 00	2	142	14 58	1 09	2	237	15.76	0 97	1	330	15 82	1 03	2
43	16.55	0 92	2	144	16 12	0 96	2	238	16 48	0 99	1	331	16 80	0 18	2
44	16 60	0 92	2	145	14 69	1 10	2	239	16 16	0 92	2	332	16 25	1 14	2
45	16 38	0.20	2	146	16 58	0 22	2	240	16 28	0 71	2	335	14 48	1 16	2
46	16 66	0 15	2	149	16 08	0 83	1	242	16 56	0 18	2	336	15 18	0.69	2
47	16.90	0 11	2	152	16 30	0 89	1	245	16 36	0 22	2	337	16.59	0 13	2
48	16.82	0 05	2	153	16 58	0 16	1	246	16 66	1 05	2	338	15 78	0 92	2
49	15 29	1 06	2	154	15 48	0 99	1	247	15 55	0 58	2	339	16.62	0 87	2
50	16 06	0.93	2	155	16 77	0 06	1	248	15 37	1 00	2	340	16 58	0 11	2
51	16 72	0 82	2	156	16 36	0.20	1	252	16 82	0.13	2	341	16 84	0 08	2
52	16 98	0 22	2	157	15 69	0 91	1	253	16 66	0 96	2	342	16 77	0 14	2
53	16 64	0.07	2	158	15 91	0 91	1	254	14 94	1.04	1	343	16 34	0.88	2
54	16 93	0.06	2	159	16 78	0.11	1	255	13 40	1 80	1	344	16 83	0 19	2
57	16 68	0 22	2	160	13 43	1 43	1	258	15.80	0 92	1	347	16 63	0 95	2
59	16 61	0.19	2	161	16.27	0 24	1	259	15 46	0 83	1	348	16 06	0 92	2
62	16 83	0 16	1	162	16 57	0 18	1	260	15.40	1.00	1	349	16 10	0 84	2
63	16 35	0 26	1	163	16 06	0 69	1	261	16 58	0 07	1	350	16 35	1 07	2
68	16 48	0 88	1	164	16 56	0.14	1	262	16 75	0 12	1	351	16 14	0 50	2
71	16 66	0 88	1	166	16 77	0 07	1	263	13 26	1 73	1	352	16 39	0 93	2
72	16.46	0 16	1	168	16 80	0 82	1	264	16 56	0 14	1	353	16 56	0 95	2
73	15 14	1.04	1	169	16 77	1 05	1	265	15.71	0 92	1	354	15 20	1 16	2
75	16 32	0 89	1	170	16 34	0 78	1	266	16 02	0 87	1	355	16 12	0 95	2
76	16 16	0.89	1	171	16 82	0 05	1	267	16 28	0 85	1	356	14 48	1 02	2
77	14.67	1.06	1	173	15 64	0 73	1	268	16 74	0 08	1	357	14 70	0 76	2
79	16.16	0 81	1	174	16 39	0 26	1	269	16 85	0 92	1	360	16 54	0.20	2
80	16 02	0.91	1	175	15 54	0.91	1	271	15 81	0 91	1	363	16 31	0.93	2
81	15.16	1.04	1	176	15 80	0 73	1	272	14 99	1 07	1	364	14 64	1 13	2
82	16 73	0 98	2	177	16 02	0 22	1	275	14 79	1 08	1	365	16.81	0 96	2
84	14 64	1 08	2	178	16 52	0 10	1	276	16 59	0.15	1	366	13.95	1.31	2
86	16 86	0 17	2	180	16 68	0.88	1	277	16 49	0.90	1				
87	15 29	1 04	2	181	16.81	0 14	1	278	16 43	0.21	1				
89	16 32	0 85	2	184	16 50	0 17	1	280	14 63	1 07	1				
95	16 90	0 08	2	185	16 52	0.85	1	281	16.78	0.16	1				
99	16 01	0 93	2	186	16 12	0 88	2	284	15.96	0 87	1				
100	16 90	0 15	1	187	15 38	0 85	2	285	16.06	0 90	2				

the shape and intrinsic color of the blue end of the horizontal branch to be invariant from cluster to cluster, justified by results on M92, M15, M3, and M13 (see Sandage and Smith 1966, Fig. 4), Figure 3 can be fitted to clusters of known reddening and the displacement along the $(B - V)$-axis determined. This gives $E(B - V) = +0.10 \pm 0.02$ for NGC 5897 by comparison with M92, $+0.12 \pm 0.02$ with M3, $+0.14 \pm 0.03$ with M15, and $+0.09 \pm 0.03$ with M13, for a mean $E(B - V) = 0.11$ with an uncertainty of about ± 0.02 mag. The method is relatively sensitive to the assumption of where the edge of the RR Lyrae instability region occurs, and, although not well defined from Figure 3, we have assumed the color of this feature to be $B - V = 0.28$ in NGC 5897.

Our value of $E(B - V)$ should be compared with Kron and Mayall's results of $+0.11$ and $+0.12$ from their two assumptions of intrinsic integrated colors. While it is true that these authors had to *assume* an integrated spectral type of F5, this does appreciably affect their answer—providing that the true type is not *later* than F5—because the function $(P - V)_0 = f(\text{sp. type})$ is nearly flat for types between A6 and F6 (Kron and Mayall 1960, Fig. 12). We adopt $E(B - V) = +0.11 \pm 0.02$ for NGC 5897 in the subsequent discussion.

If the horizontal branch occurs at $V = 16.2$, estimated from Figure 3, then $\Delta V = 16.2 - 13.45 = 2.75$, obtained by reading the magnitude of the giant branch at observed $B - V = +1.52$. This value is intermediate between the Deutsch B-type clusters (Morgan II–III group) with $\Delta V = 2.54 \pm 0.06$, and the Deutsch C group (Morgan I) with $\Delta V = 3.01 \pm 0.08$, summarized elsewhere (Sandage and Wallerstein 1960, Table 4). On this basis alone we classify NGC 5897 as intermediate in metal abundance between M92 and M3. However, the same conclusion follows from the color of the subgiant branch because this sequence lies between the schematic lines for M92 and M13 (or M3) in a calibrated diagram (Sandage and Smith 1966, Fig. 4) which shows the progressive redward shift of the subgiant branches of clusters with increasing metal abundance.

The same point can be made from the color index, $(B - V)_{0,g}$, defined as the unreddened color of subgiant sequence at the magnitude level of the RR Lyrae gap. The value $(B - V)_{0,g} = 0.89 - 0.11 = 0.78 \pm 0.03$ replaces an earlier result of 0.69 mag quoted by Sandage and Smith (1966) from the unpublished preliminary, and now superseded, data of Sandage and Schmidt. The new value is intermediate between the Morgan class I and classes II–III clusters, although it is somewhat closer to the latter, as seen by inspection of a table given elsewhere (Sandage and Smith 1966, Table 3). Although we are pleased with the consistency of these results, which show no anomaly with previous correlations of morphology and metal abundance, we do not consider the colors of Figure 3 to be established beyond doubt at the ± 0.05-mag level because of the marginal nature of our photoelectric sequence, discussed earlier.

Another feature of the C-M diagram is the near, or perhaps total, absence of the horizontal branch redward of the RR Lyrae gap, and the strong concentration of stars blueward of the gap. The density gradient along the horizontal branch is known to be a function not only of the metal abundance but also of a second parameter. That the NGC 7006 anomaly is not present here shows that the strength of the second parameter in NGC 5897 is more like that in M92 and M15 rather than in either M13 or in NGC 7006—two clusters that bracket the presently observed range of this parameter (Sandage and Wildey 1967; van den Bergh 1967*b*).

Finally, the presence of a moderately well-developed asymptotic branch, similar to that in M13 (Arp 1955; Arp and Johnson 1955) and in M92 (Sandage and Walker 1966), should be noted.

III. THE VARIABLES

Four RR Lyrae stars discovered by Helen Sawyer (1953, 1955) were previously known in NGC 5897. From a short series of twelve plates, taken on different nights with the 100- and 200-inch reflectors between 1956 and 1966, we have confirmed all of

Sawyer's stars and have added three new variables, to which numbers V5, V6, and V7 are assigned. The seven variables are identified in Figure 1. Six of the seven are also marked in Figure 2 with their program numbers as V1 = 351, V2 = 299, V3 = 206, V5 = 20, V6 = 118, and V7 = 119. We discovered star V5 to be variable by inspection of the photoelectric measurements on seven nights in 1956. It is a red star near the top of the giant branch and is plotted at $V = 13.28$, $B - V = 1.62$, which are the instantaneous values for June 9/10, 1966, the date on which the photographic plates for Table 2 were taken. We have no information on the regularity or the period of this star, but it undoubtedly belongs to the well-defined class of red semiregular variables found in this region of the C-M diagram in other clusters.

The other two new variables were found from a special inspection of ten horizontal-branch stars which lay close to or in the variable-star gap of Figure 3. Program stars which were checked for variability but found to be constant on our few plates were stars M, 116, 120, 163, 174, 240, 328. Star 63 may possibly vary, while star 118 = V6 and star 119 = V7 are variable without doubt. Six of the seven variables are shown in Figure 3 as crosses and are plotted at their instantaneous values. No light curves are available to determine mean values. Sawyer variable V4 is the western component of a close double and could not be measured. Of particular interest is program star 120 near the center of the RR Lyrae gap. Special effort was made to detect variability, but the star was constant to within ± 0.1 mag on our short series of twelve plates.

IV. DISTANCE, DIAMETER, AND ABSOLUTE LUMINOSITY

If the RR Lyrae star gap in Figure 3 occurs at $V = 16.20$, and if $M_V = +0.5$ for such stars, then the apparent visual modulus is $(m - M)_{\mathrm{app},V} = 15.70$. Adopting $E(B - V) = 0.11$ and $A_V/E(B - V) = 3$ gives a true modulus of $(m - M)_0 = 15.37$, corresponding to a distance of 11900 pc from the Sun and a height above the galactic plane of 6000 pc. It is not expected that strong-lined clusters would be present at this height above the plane (Kinman 1959, Fig. 6; Eggen, Lynden-Bell, and Sandage 1962, Fig. 5)—a fact quite consistent with the weak-line nature of NGC 5897.

The angular diameter within which nine-tenths of the light is contained is 15.′7 (Kron and Mayall 1960), which corresponds to a linear diameter of 54 pc.

The asymptotic visual magnitude of the cluster is estimated to be $V_t = 8.4$ by Kron and Mayall. With $(m - M)_{\mathrm{app},V} = 15.70$, the absolute magnitude is $M_V = -7.3$. A convenient comparison is the cluster M3, whose apparent modulus is $(m - M)_{\mathrm{app},V} = 15.77$ if the RR Lyrae stars are again assumed to have $M_V = +0.5$. The asymptotic visual magnitude for M3 is $V_t = 6.38$ (Kron and Mayall 1960), giving $M_V = -8.79$, which is 1.49 mag brighter than NGC 5897. Kron and Mayall's diameter for M3 is $d_{0.9} = 9.'3$, which gives a linear diameter of only 29 pc. These numbers are consistent with the abnormally low surface brightness of NGC 5897 relative to M3. The ratio of linear diameter for the two clusters is 1.86, and NGC 5897, which is the larger aggregate, is 1.5 mag fainter intrinsically. For similar surface density distributions, the surface brightness of NGC 5897 will then be $(1.86)^2 \times 4 = 14$ times fainter than that of M3. This explains why the cluster can be resolved to the very center without photometric crowding, as evidenced by Figures 1 and 2, in contrast to the usual situation in M3, M15, M92, and most other globular clusters.

The low central concentration and large linear diameter are characteristic of clusters that have not passed close to the galactic center and have not, therefore, suffered tidal evaporation which cools the cluster and causes subsequent contraction. The effect is evident in the extremely remote clusters isolated by Abell (1955). Particularly good examples are Palomar 3 and Palomar 4 (the 10- and 11-hour clusters), discussed elsewhere (Burbidge and Sandage 1958), where it was shown that these clusters have probably always been more remote than 9000 pc from the central region of the Galaxy.

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