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YELLOW GIANTS IN YOUNG CLUSTERS. I. PHOTOMETRIC OBSERVATIONS

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Received 1983 October 20; accepted 1983 December 21

ABSTRACT

To enable a study of the properties of luminous yellow stars, a list has been compiled of 84 stars which appear to be in the appropriate region in the color-magnitude diagrams of 41 young clusters. Proper motions, radial velocities, *UBV* photometry, and spectral types from the literature have been used in those cases where such data are available to assign membership probabilities. DDO and *wby* photometry have also been obtained of most of the stars in the list, and these data are analyzed to remove stars from the sample which have the wrong luminosity or the wrong color excess for cluster membership. In addition, *VRI* photometry is given for many of the stars in the list. Based on these data, 22 of the stars (26%) from the original sample are likely cluster members, while 48 (57%) are not likely to be members. The remainder must be studied further to determine their status but it is probable that some of them are also in clusters.

Subject headings: clusters: open — photometry — stars: late-type

I. INTRODUCTION

Yellow giants and supergiants are potentially of great interest in connection with studies of stellar evolution. Most of these objects are in the helium core burning stage and have evolved back into the yellow giant region from the red-giant branch. Their location in the H-R diagram thus constrains post-main-sequence evolutionary models. Unfortunately, it is difficult to obtain accurate temperatures and luminosities for them except when they are members of clusters.

Although in principle it is possible to infer intrinsic colors, absolute magnitudes, and ages for cluster stars, in practice such information must often be viewed with caution. Membership of individual stars may be uncertain, particularly for those not on the main sequence or for clusters in crowded fields. The effects of reddening can be measured reliably for main-sequence stars, but often the reddening varies substantially over the face of the cluster, giving rise to uncertainties at the location of any particular star. It is also possible that unrecognized composition differences between clusters can affect conclusions drawn from their intercomparison. On the other hand, for many studies it is necessary to resort to using clusters for which little information is available just to have a sufficient sample of objects; often the available studies are limited to three-color photometry.

To improve this situation with respect to the yellow giants and supergiants, a photometric survey of objects in cluster fields which appear to be in the appropriate location in the H-R diagram was carried out. Photometric data on the DDO and four-color systems were obtained since they are capable of discriminating against many field stars, particularly foreground dwarfs and reddened early-type stars. This is not a

substitute for membership studies based on proper motions, but such studies are time-consuming, and we can not anticipate results for a statistically large sample in the near future. The photometric survey will serve to eliminate many objects and narrow the list of potential clusters to those most likely to be of interest for proper-motion studies. In addition, the information from this survey can be used to discuss questions concerning evolution and the properties of these stars.

This paper gives a list of candidate stars, presents the photometric data, and discusses the membership of the stars in clusters. The discussion of this sample of stars in terms of their properties and the theoretical implications will be in Paper II.

II. THE SAMPLE

The 41 clusters studied in this program are listed in Table 1. Of these, 35 were selected by examining the color-magnitude diagrams in Hagen's (1970) atlas and in the Naval Observatory survey of clusters (Hoag *et al.* 1961). Schild (1967) considered several field yellow giants to be members of the η and χ Per association, and four are included in the present program. The remaining five clusters, NGC 2186, NGC 2421, Ru 79, Ly 6, and Stock 14, were selected on the basis of H-R diagrams from the sources indicated in the last column Table 1.

The selection of stars for observation was made solely on the basis of their location in the H-R diagrams. Using published distance moduli and color excesses, the location of stars relative to the Cepheid strip was considered. Within the constraints of feasibility, an attempt was made to include all stars within several tenths of a magnitude in $B - V$ of the strip and brighter than about $M_v = -2$. Some other stars farther away were also included, but no effort was made to obtain a large or representative sample.

The second column of Table 1 lists the apparent distance moduli of the clusters, $V - M_v$, while the third column gives

¹Visiting astronomer at Kitt Peak National Observatory and Cerro Tololo Inter-American Observatory which are operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

TABLE 1
BASIC DATA FOR YELLOW GIANT CANDIDATES

CLUSTER (1)	$V - M_v$ (2)	$E(B - V)$ (3)	STAR (4)	V (5)	$B - V$ (6)	SPECTRAL TYPE (7)	MEMBERSHIP LIKELIHOOD CLASS ^a					OVERALL MEMBERSHIP STATUS ^b (13)	REFERENCES AND NOTES
							Proper Motions (8)	V_R (9)	Spectral Type (10)	DDO (11)	w_{by} (12)		
NGC 129	13.3	0.61	A	8.86	0.96	F5 Ib	2	2	3	...	2	Y	1-4
NGC 225	10.2	0.29	5	9.87	0.89	G6 III	...	...	3	1	...	N	2,5
NGC 654	15.0	0.89	23	11.61	1.22	K2 IV:	1	...	1	1	...	N	6-8
			80	10.93	1.44	...	...	...	...	1	...	N	
			85	10.88	1.35	...	...	...	...	1	...	N	
NGC 659	13.4	0.49	22	11.16P	1.03P	...	...	...	...	1	...	N	9
NGC 752	8.3	0.03	208	9.61	0.98	K1 IV	3	...	2	1	...	N	10-13
			213	9.01	0.99	K0 III	3	...	2	3	...	Y	
			295	9.30	0.96	G9 III	3	...	3	3	...	Y	
			311	9.04	1.03	K0 III	3	...	3	3	...	Y	
h and χ Per ...	13.8	0.56	HD 11544	6.82	1.15	G2 Ib	...	...	2	1	...	N	14,15
			HD 14662	6.27	0.85	F7 Ib	...	...	2	...	...	?	
			HD 17971	7.75	1.06	F5 Ia	...	...	2	...	...	?	
			HD 18391	6.89	1.95	G0 Ia	...	...	2	2	...	?	
NGC 1502 ...	12.2	0.74	2	7.93	1.19	...	3	...	...	1	2	N	2,16
NGC 1528 ...	10.6	0.30	4	9.97	0.92	...	...	...	...	1	...	N	2
NGC 1545 ...	10.9	0.36	4	8.09	0.99	G6 III	...	...	1	1	...	N	2,5,17
NGC 1647 ...	10.2	0.39	4	9.34	0.90	K0 V	...	...	1	1	...	N	2,5
			8	10.33	0.90	G8 III	...	...	2	1	2	N	
			11	11.11	0.85	...	...	...	...	1	...	N	
NGC 1664 ...	11.4	0.20	2	7.50	0.97	G5 III	...	...	1	1	...	N	2,18
NGC 1893 ...	14.8	0.56	2	9.15	1.21	...	...	...	...	1	...	N	19
			111	11.10P	1.12P	...	...	...	...	2	...	?	
NGC 1907 ...	12.4	0.47	HD 35519	6.14	1.46	K2	...	...	...	1	...	N	2,20
NGC 2168 ...	10.7	0.23	101	8.57P	1.13P	G2 II	3	...	3	3	...	Y	19,21
NGC 2186 ...	12.6	0.31	2	9.82	1.09	...	...	...	...	2	...	?	22
NGC 2251 ...	11.8	0.24	2	9.65	0.56	...	...	...	...	1	...	N	2
NGC 2287 ...	9.4	0.00	a	7.28	0.58	G, B9	2	2	...	...	...	?	23-25
			f	7.77	1.15	G8 II-III	2	2	3	2	...	Y	
			21	6.90	1.51	K3 II	2	2	3	2	2	Y	
			75	7.47	1.22	K1 II-III	2	2	3	2	...	Y	
			92	8.10	1.00	K0 II-III	1	2	3	1	2	N	
			97	7.65	1.15	K0 II-III	2	2	3	3	...	Y	
NGC 2421 ...	13.2	0.47	5	10.45	0.95	...	...	...	...	1	2	N	22
NGC 2422 ...	8.9	0.08	4	7.80	1.21	...	1	...	...	2	...	N	19,26,27
			5	7.91	1.03	...	1	...	...	3	...	N	
			109	8.91	0.85	...	1	...	...	1	...	N	
NGC 2467 ...	13.5	0.40	27	10.96	1.10	...	...	...	...	1	...	N	28
			34	9.90	1.10	...	...	...	...	1	...	N	
			42	11.00	1.13	...	...	...	...	1	...	N	
			51	10.39	1.24	...	...	...	...	1	...	N	
			52	10.32	1.15	...	...	...	...	1	...	N	
			71	11.47	1.09	...	...	...	...	1	...	N	
			76	9.86	1.02	...	...	...	...	1	...	N	
			82	11.41	1.05	...	...	...	...	1	...	N	
NGC 2483 ...	13.9:	0.42:	6	10.78	1.00	...	...	...	...	1	...	N	29
			9	11.26	0.99	...	...	...	...	1	...	N	
NGC 2533 ...	12.3	0.26	11	9.04	0.48	G0 V	...	...	1	1	1	N	30,31
NGC 2546 ...	10.2	0.11	99	8.23	1.12	G9 II-III	...	2	3	2	...	Y	32,17
			356	8.24	1.25	K1 II	...	2	3	2	...	Y	
NGC 2670 ...	11.8	0.48	1	7.45	1.16	G2 II	...	...	3	1	...	N	33,17
			5	9.31	1.31	K2 III?	...	...	1	2	2	N	
Ru 79	14.7	0.79	H	11.91	1.55	...	...	...	...	2	...	?	34,22
NGC 3114 ...	10.0:	0.01	1	5.94	0.26	F0 II:	...	2	2	...	3	Y	33,17,35
			2	7.30	0.89	G2 II-III	...	...	2	3	3	Y	
			12	8.93	1.36	G9 III	...	...	2	2	2	?	
			76	8.47	1.24	G9 III	...	...	2	3	2	Y	
			119	7.68	1.25	G8 III	...	2	1	2	...	N	
			159	8.49	1.19	K0 II	...	2	3	3	...	Y	
			184	7.78	1.17	G8 II-III	...	2	2	1	...	N	
Ly 6	15.3	1.34	4	12.52	2.20	G	...	...	...	...	...	?	36,37
Stock 14	13.2	0.26	HR 4511	5.01	0.79	G0 Ia	...	...	3	3	...	Y	38,12,39
NGC 6067 ...	12.2	0.37	7400P	8.25	1.10	G0 Ib	...	2	3	2	3	Y	40,17
			7400F	9.01	0.48	F0 Ib	...	2	3	...	3	Y	
NGC 6204 ...	12.4	0.51	19	9.73	1.11	...	...	...	...	1	...	N	41
NGC 6416 ...	10.8	0.33	I-6	8.58	1.27	K0 III	...	...	1	1	...	N	42,17

TABLE 1—*Continued*

CLUSTER (1)	$V - M_v$ (2)	$E(B - V)$ (3)	STAR (4)	V (5)	$B - V$ (6)	SPECTRAL TYPE (7)	MEMBERSHIP LIKELIHOOD CLASS ^a					OVERALL MEMBERSHIP STATUS ^b (13)	REFERENCES AND NOTES
							Proper Motions (8)	V_R (9)	Spectral Type (10)	DDO (11)	<i>wby</i> (12)		
NGC 6475	7.2	0.04	58	5.56	1.08	K0 III	...	2	2	3	...	Y	43, 17, 44
M25	10.7	0.50	150	7.39	1.59	G6 II	2	2	3	2	...	Y	45, 17, 46, 47
			193	7.04	1.50	G3 III	...	2	2	2	...	?	
NGC 6649	15.7	1.37	19	12.11	1.78	...	...	...	...	...	...	?	48
NGC 6664	12.6	0.64	C	10.33	1.96	G8 II:	...	2	2	2	...	?	49, 17, 50
			29	10.68	1.72	...	...	...	...	3	...	Y	
NGC 6694	13.1	0.60	102	10.30P	1.49P	G8	...	...	...	1	1	N	19, 17
			103	10.43P	1.18P	G0	...	...	...	1	...	N	
			108	11.75P	1.40P	...	...	...	...	2	...	?	
NGC 6755	14.1	0.95	2	10.92	1.47	...	...	...	...	1	...	N	19
			101	10.23P	1.22P	...	...	...	...	1	...	N	
			109	11.28P	1.18P	...	...	...	...	1	...	N	
NGC 7063	9.5	0.08	3	9.71	0.46	...	...	...	...	...	...	?	2
NGC 7235	16.3	0.98	4	11.39	1.49	...	...	...	...	1	...	N	2
			12	12.85	1.41	...	...	...	...	1	...	N	
NGC 7510	15.9	1.1	8	12.03	1.50	...	...	...	...	1	...	N	2
			15	12.80	1.36	...	...	...	...	1	...	N	
NGC 7654	13.1	0.62	2	8.22	1.16	F7 Ib	...	2	3	...	...	Y	2, 51

^a(1) Unlikely member; (2) possible member; (3) likely member.

^b“Y” indicates likely and “N” an unlikely member, based on all available criteria. Insufficient or conflicting information is indicated by a question mark.

REFERENCES AND NOTES.—(1) Arp, Sandage, and Stephens 1959. (2) Hoag *et al.* 1961. (3) Kraft 1958. (4) Lenham and Franz 1961. (5) Svolopoulos 1962. (6) Pesch 1960*b*. (7) Turner 1976. (8) Stone 1977. (9) McCuskey and Houk 1964. (10) Heinemann 1926. (11) Eggen 1963. (12) Roman 1955. (13) Ebbighausen 1939. (14) Argue 1966. (15) Bidelman 1957. (16) Vegt 1966. (17) Harris 1976. (18) Hoag and Applequist 1965. (19) Hoag *et al.* 1961. Star numbers greater than 100 refer to stars measured photographically by Hoag *et al.* They are counted sequentially in the list of photographic data for each cluster starting at 101. (20) Hoffleit 1964. (21) Cudworth 1971 gives $V = 7.00$ and $B - V = 2.15$, while Hoag *et al.* 1961 give $V = 8.57$ and $B - V = 1.13$, although an error in their table makes identification uncertain. The latter value is more consistent with our data and is adopted. (22) Moffat and Vogt 1975*a*. (23) Cox 1954. (24) Eggen 1974. (25) Feinstein, Cabrera, and Claria 1978. (26) Smyth and Nandy 1962. (27) van Schewick 1966. (28) Loden 1966. (29) Lindoff and Johansson 1968. (30) Lindoff 1967. (31) Fitzgerald *et al.* 1979. (32) Lindoff 1968. (33) Lynga 1966. (34) Harris and van den Bergh 1976. (35) Jankowitz and McCosh 1963. (36) Moffat and Vogt 1975*c*. (37) Lynga 1977. (38) Moffat and Vogt 1975*b*. (39) Houk and Cowley 1975. (40) Thackeray, Wesselink, and Harding 1962. (41) Whiteoak 1962. (42) The and Stokes 1970. (43) Koelbloed 1959. (44) Buscombe and Kennedy 1968. (45) Sandage 1960. Star 193 is not marked on Sandage's chart. It is the bright star 15 mm from the lower edge and 23 mm from the right edge of his chart. (46) Landolt 1964. (47) Wallerstein 1960. (48) Madore and van den Bergh 1975. (49) Arp 1958. (50) Kraft 1958. (51) Pesch 1960*a*.

the color excesses. These are from the compilation of Becker and Fenkart (1971) for all except seven clusters. For the clusters not listed there, NGC 2186, NGC 2421 Ly 6, Stock 14, NGC 6516, NGC 6649, and Ru 79, *UBV* photometry from the literature (cited in the last column of Table 1) has been reanalyzed with Becker and Fenkart's zero-age relations to obtain the tabulated values. The distance moduli were increased by 0.3 mag over the Becker and Fenkart scale to make them consistent with the current Hyades distance $V - M_v = 3.3$. The choice of these moduli and color excesses was made because it represents a large and homogeneous compilation.

The individual stars are identified in column (4) of Table 1. The first reference cited in the last column is the source of the designations. Magnitudes, colors, and spectral types taken from the literature are listed in columns (5)–(7). For some clusters, proper-motion or radial velocity studies give information on cluster membership. This is indicated in columns (8) and (9) as follows: 1, unlikely member; 2, possible member; 3, likely member. When there is a spectral type and luminosity class available, it can be used to infer the absolute magnitude and color of the star. The distance modulus and color excess derived from this were then compared with the values of the cluster and the likelihood of membership assessed. This is

indicated in column (10). Columns (11) and (12) are based on data from the present program and are discussed below.

The selection of objects for observation was somewhat subjective, and many marginal cases were encountered; it is not clear how much bias was introduced by this and by observational constraints such as the limiting magnitude. To investigate, we will assume that the clusters in the Hagen atlas and the Naval Observatory survey are representative unbiased samples. Apparent yellow supergiants were counted in intervals of absolute magnitude and color on these H-R diagrams for all the clusters in each set. For this we have assumed a Hyades distance modulus of 3.0 to be consistent with Hagen's distance moduli. The limits of the interval can easily be adjusted to make them conform to a larger distance scale. We also noted how many of these stars are included in the present sample. The results are displayed in Table 2. For each absolute magnitude and color bin, the upper left-hand number is the count from Hagen's sample, while the upper right number is the count from the Naval Observatory sample. Below each we list the number of these stars which are also in our sample. In constructing her diagrams, Hagen deleted some stars on the basis of radial velocities, proper motions, or location (but not on account of photometric properties). This has resulted in

TABLE 2
STATISTICAL DISTRIBUTION OF SAMPLE

ABSOLUTE MAGNITUDE RANGE	SOURCE	COLOR RANGE IN $B - V$											
		0.2-0.4		0.4-0.6		0.6-0.8		0.8-1.0		1.0-1.2		1.2-1.4	
		H	N	H	N	H	N	H	N	H	N	H	N
-5 to -6 ...	H-R diagrams	0	0	0	0	0	2	0	0	0	2	1	1
	sample	0	0	0	0	0	1	0	0	0	1	0	0
-4 to -5 ...	H-R diagrams	2	5	9	6	2	0	2	1	0	0	1	3
	sample	0	0	6	4	2	0	0	0	0	0	0	0
-3 to -4 ...	H-R diagrams	6	4	10	4	1	7	3	2	2	3	0	2
	sample	1	3	7	1	1	3	0	0	1	0	0	0
-2 to -3 ...	H-R diagrams	7	6	10	8	8	3	13	4	7	6	9	4
	sample	0	1	6	2	0	1	4	0	1	0	1	0
-1 to -2 ...	H-R diagrams	22	21	11	13	26	12	20	15	30	20	20	8
	sample	1	1	1	1	0	0	1	1	4	3	1	0
0 to -1	H-R diagrams	46	55	30	14	43	19	73	31	62	18	31	7
	sample	0	0	1	1	0	1	1	1	0	2	1	1

only two stars from our list being omitted and should have no significant effect. Unfortunately, the number of stars in any bin is too small to allow the determination of a completeness correction. However, it can be seen that within the boxed-in area we have included a substantial portion of all the stars, and outside we have included very few. That area of the table roughly corresponds to the region around the Cepheid strip. For the bins in the boxed-in area we have included 70% of the Hagen stars and 40% of the Naval Observatory stars. Every bin lies within one standard deviation of these values. This is consistent with our criterion for choosing stars, so we conclude that our sample within that region should be reasonably representative. However, we must bear in mind that this conclusion is based on a small sample and should not be given high weight.

III. THE OBSERVATIONS

a) DDO Photometry

DDO photometry was obtained for the stars listed in Table 3. Only the four longest wavelength filters of the system were used since these provide adequate information for the present purposes. This photometry was carried out at Kitt Peak National Observatory and Cerro Tololo Inter-American Observatory during 1979 and 1981. The standard stars of McClure (1970) were used to place the observations on the standard system.

The first two columns of Table 3 identify the stars, while columns (3), (5), and (7) list the photometric indices. Column (9) gives the number of nights on which each star was observed. Because there is a large range of brightness among these stars and because a variety of telescopes of different aperture were used, the uncertainties for the various stars differ considerably. Therefore, the standard errors of the mean indices in the table were calculated for each star from the scatter of the individual observations. These are listed in columns (4), (6), and (8) in units of 0.001 mag. The mean standard deviation of a single observation for the brighter stars ($V < 10.$) were 0.012 mag for all three indices. At fainter magnitudes (V near 11.5) the errors rose to ~ 0.025 mag. For

the few stars in Table 3 with a single DDO observation, the standard errors were estimated from the average for stars of similar ultraviolet flux.

Although the majority of stars in Table 3 exhibit scatter consistent with their brightness, a few have larger errors. When the standard error was greater than about twice that expected, the original data were examined. For a number of stars there was no evidence of any difficulty with the photometry, and these are marked in the table as possible variables.

Four stars in NGC 2287 were also observed in the DDO system by Feinstein, Cabrera, and Claria (1978). Their indices and the present results differ by 0.000 ± 0.016 , -0.016 ± 0.005 , and 0.005 ± 0.011 (present values - Feinstein *et al.* values). This is good agreement considering the quoted errors. The stars in NGC 752 have also been observed previously on the DDO system by Twarog (1983). The mean differences from the present values for stars in common are less than 0.007 mag for all three indices. This is also adequate agreement.

b) Four-Color Photometry

Four-color photometry was obtained for many of the stars in our sample. These observations were carried out using telescopes at Behlen Observatory, Kitt Peak National Observatory, and Cerro Tololo Inter-American Observatory between 1979 and 1981. Standard *uwby* filters were used, and the observations were placed on the standard system through observations of stars from the list of Crawford and Barnes (1970) or secondary standards referred to them.

Table 4 displays the four-color indices and their standard errors. Again, there is a range in the accuracy due to the variety of telescopes used and the large range in apparent magnitude and color excess of the stars. However, in general, the standard deviations of single observations are 0.010 mag in $b - y$, 0.018 mag in m_1 , and 0.020 mag in c_1 , except for stars fainter than $u = 12$ where the standard deviations in c_1 increased to ~ 0.035 mag. Estimated errors for stars observed once are based on these values. Again, stars with significantly larger scatter are noted as possible variables. In this case, this judgement is based mainly on $b - y$, which is the most accurate.

TABLE 3
DDO PHOTOMETRY

Cluster	Star	C(45–48)	σ	C(42–45)	σ	C(41–42)	σ	<i>n</i>
NGC 129	A	1.125	2	0.575	6	0.120	3	3
NGC 225	5	1.176	11	0.723	5	0.028	18	2
NGC 654	23	1.240	26	0.846	32	0.166	32	1
	80	1.328	9	0.936	11	0.260	16	4
	85	1.299	17	0.891	17	0.253	6	3
NGC 659	22	1.252	11	0.856	4	0.178	5	3
NGC 752	208	1.131	6	0.922	11	0.136	2	2
	213	1.176	6	0.850	8	0.166	1	2
	295	1.162	4	0.808	3	0.153	18	2
	311	1.184	6	0.870	3	0.179	10	2
h and χ Per	HD 11544	1.272	3	0.832	2	0.204	6	2
	HD 14662	1.112	9	0.587	9	0.119	13	1
	HD 17971	1.203	11	0.603	13	0.108	13	1
	HD 18391	1.636	9	0.998	9	0.232	13	1
NGC 1502	2 ^a	1.244	27	0.760	12	0.189	6	3
NGC 1528	4	1.106	16	0.659	11	0.123	19	1
NGC 1545	4	1.156	10	0.771	7	0.131	7	3
NGC 1647	4	1.119	7	0.839	11	0.047	10	3
	8	1.124	5	0.722	3	0.038	16	2
	11	1.078	14	0.810	7	−0.015	13	2
NGC 1664	2	1.142	17	0.739	4	0.132	6	2
NGC 1893	2	1.247	12	0.852	19	0.272	4	2
	111	1.289	26	0.957	24	0.308	26	1
NGC 1907	HD 35519	1.343	9	1.240	9	0.276	13	1
NGC 2168	101	1.245	9	0.817	4	0.216	2	3
NGC 2186	2	1.234	3	0.754	3	0.142	9	2
NGC 2251	2	0.986	9	0.590	1	0.019	1	2
NGC 2287	a	1.006	4	0.518	2	0.118	5	2
	f	1.248	7	0.903	11	0.312	8	2
	21	1.419	2	1.244	1	0.322	6	2
	75 ^a	1.319	6	0.988	13	0.372	19	2
	92 ^b	1.123	3	0.727	11	0.122	11	2
	97 ^a	1.266	0	0.910	13	0.324	22	2
NGC 2421	5	1.158	2	0.805	8	0.076	5	5
NGC 2422	4	1.296	4	0.928	11	0.321	8	4
	5	1.197	7	0.836	11	0.205	10	3
	109	1.074	5	0.812	7	−0.005	8	4
NGC 2467	27	1.213	14	0.848	9	0.254	8	3
	34	1.219	6	0.862	4	0.287	7	3
	42	1.222	8	0.938	6	0.276	12	3
	51	1.242	12	1.082	9	0.308	9	3
	52	1.229	8	0.977	7	0.262	8	3
	71	1.199	7	0.892	5	0.231	8	2
	76	1.186	24	0.842	4	0.136	19	2
	82	1.202	28	0.897	20	0.185	5	2
NGC 2483	6	1.169	9	0.859	17	0.200	15	3
	9 ^a	1.157	10	0.790	32	0.224	12	3

TABLE 3—*Continued*

Cluster	Star	C(45–48)	σ	C(42–45)	σ	C(41–42)	σ	<i>n</i>
NGC 2533	11 ^a	0.946	65	0.552	156	0.045	40	2
NGC 2546	99	1.284	5	0.900	3	0.302	1	2
	356	1.328	4	0.985	1	0.396	7	2
NGC 2670	1	1.254	6	0.961	6	0.300	11	3
	5	1.286	3	0.759	3	0.143	13	3
Ru 79	H ^a	1.400	8	0.774	12	0.226	79	2
NGC 3114	1	0.864	2	0.376	4	0.057	6	2
	2	1.154	4	0.718	16	0.180	8	2
	12 ^a	1.347	6	1.015	7	0.356	21	2
	76	1.308	8	0.998	6	0.378	9	2
	119	1.324	12	0.928	8	0.352	12	2
	159 ^a	1.271	26	0.882	5	0.293	7	2
	184	1.313	3	0.898	5	0.340	6	2
St 14	HR 4511	1.174	1	0.582	2	0.124	11	2
NGC 6067	7400P ^{a,c}	1.262	32	0.766	76	0.184	51	2
	7400F ^c	0.924	13	0.434	0	0.052	3	2
NGC 6204	19	1.206	20	0.797	11	0.201	7	2
NGC 6416	I-6 ^a	1.321	51	1.106	130	0.340	62	2
NGC 6475	58	1.226	2	0.869	6	0.290	7	2
M25	150	1.457	4	0.996	7	0.347	7	3
	193	1.381	2	0.901	3	0.231	5	3
NGC 6664	C	1.586	2	1.160	2	0.410	7	2
	29	1.470	26	1.062	24	0.297	26	1
NGC 6694	102 ^a	1.519	5	1.112	7	0.451	45	2
	103	1.293	26	0.779	24	0.122	26	1
	108	1.346	26	0.931	25	0.249	32	1
NGC 6755	2	1.321	36	0.928	32	0.270	39	2
	101 ^a	1.305	18	0.989	18	0.286	35	2
	109	1.294	14	0.910	21	0.236	7	3
NGC 7063	3	0.914	12	0.474	11	0.055	15	1
NGC 7235	4	1.345	9	1.073	11	0.187	8	3
	12	1.315	2	0.925	8	0.167	10	3
NGC 7510	8	1.353	12	1.034	15	0.247	7	4
	15	1.288	8	0.927	12	0.139	7	4
NGC 7654	2	1.220	2	0.654	8	0.146	2	2

^aLarger than normal scatter in indices. Possibly variable.^bFaint companion included in diaphragm.^cCrowded field. Colors may be contaminated by nearby stars.

Eggen (1981) observed five of the stars in NGC 2287 on his modified four-color system. The $b - y$ and c_1 indices differ from the present photometry by -0.004 ± 0.008 and 0.000 ± 0.008 mag, while the m_1 indices average 0.033 mag smaller than Eggen's.

c) VRI Photometry

A number of the stars in this program were observed in the Johnson VRI system. The observations of the southern stars were made with the 0.6 m telescope at Cerro Tololo, while the

northern stars were observed with the Behlen Observatory 0.76 m telescope. The colors were transformed to the standard system using stars from the list of Johnson *et al.* (1966). Although there are problems with some of the standard stars in this system (Bessell 1979), and although the filters and photocells used do not exactly match those of Johnson, his system was adopted for consistency with previous work. A relatively large number of standards were observed (15 or more on most nights), and this allowed accurate transformation to the standard system.

TABLE 4
FOUR-COLOR DATA

Cluster	Star	$b - y$	σ	m_1	σ	c_1	σ	n
NGC 129	A	0.709	5	0.051	8	1.026	12	3
NGC 654	23	0.774	4	0.246	5	0.400	7	2
	80	0.936	3	0.308	12	0.450	8	2
	85	0.858	2	0.347	14	0.454	25	3
NGC 659	22	0.812	5	0.282	2	0.254	30	2
NGC 1502	2	0.787	14	0.261	23	0.460	3	3
NGC 1647	4	0.530	3	0.327	4	0.375	4	2
	8	0.582	3	0.199	15	0.418	25	3
	11	0.521	2	0.266	3	0.307	20	3
NGC 1893	2	0.762	4	0.364	2	0.359	13	3
	111	0.807	3	0.453	6	0.404	30	3
NGC 2168	101	0.705	10	0.372	15	0.401	15	2
NGC 2287	a	0.412	10	0.122	18	0.586	20	1
	f	0.687	10	0.486	18	0.334	20	1
	21	0.924	10	0.750	18	0.295	20	1
	75	0.744	10	0.595	18	0.326	20	1
	92	0.581	10	0.251	18	0.559	20	1
	97	0.697	10	0.486	18	0.354	20	1
NGC 2421	5	0.570	10	0.281	7	0.432	12	2
NGC 2422	4	0.750	10	0.478	18	0.298	20	1
	5	0.631	10	0.359	18	0.395	20	1
	109	0.476	10	0.275	18	0.305	20	1
NGC 2533	11	0.401	10	0.178	18	0.341	20	1
NGC 2546	99	0.745	10	0.455	18	0.308	20	1
	356	0.780	10	0.565	18	0.337	20	1
NGC 2670	1 ^a	0.719	26	0.503	27	0.421	8	2
	5	0.815	5	0.220	13	0.583	32	2
Ru 79	H	1.151	10	0.080	18	0.447	35	1
NGC 3114	1	0.172	1	0.132	2	1.461	28	2
	2	0.539	2	0.292	6	0.450	13	3
	12	0.829	9	0.560	8	0.469	30	3
	76	0.775	6	0.560	5	0.384	25	2
	119	0.779	2	0.484	9	0.350	14	2
	159	0.715	2	0.412	14	0.450	20	2
	184	0.740	3	0.496	12	0.341	11	2
NGC 6067	7400P	0.787	3	0.319	28	0.550	12	2
	7400F	0.352	3	0.071	4	1.480	7	3
NGC 6204	19 ^a	0.650	24	0.330	25	0.424	6	2
NGC 6475	58	0.672	3	0.440	0	0.373	0	2
M25	150	1.036	12	0.416	16	0.253	25	3
	193	0.902	5	0.358	5	0.394	6	3
NGC 6694	102	1.169	10	0.499	18	0.818	35	1
	103	0.941	10	0.156	18	0.390	35	1
	108	0.940	10	0.328	18	-0.090	35	1

^aLarger than expected errors. Possibly variable.

The colors of the program stars are listed in Table 5 where we again give the standard errors of the mean values and the number of nights on which individual stars were observed. For stars brighter than about $V=11$ the standard deviations of single observations are 0.009 and 0.016 mag for $V-R$ and $R-I$, respectively. Fainter than this the errors rise to 0.030 and 0.020 mag, respectively. Again for the stars with only one observation the errors have been estimated from their brightness, and again we have marked a few stars which seem to have unusually large scatter.

Six of the stars in Table 5 were previously observed by the present investigator (Schmidt 1976) and $R-I$ colors published. A comparison of the values in Table 5 with the previous values shows that the current colors are larger by 0.010 ± 0.010 mag than the previous values. This seems to be adequate agreement.

d) Variable Stars

A number of investigators have found that stars of the type represented in the present study are frequently variable (see, e.g., Ferro 1981; Percy and Welch 1981). In addition, it is possible that our sample contains unrecognized Cepheids. In Tables 3, 4, and 5 we have noted stars with unexpectedly large scatter. We have also plotted the colors $B-V$, $C(45-48)$, $b-y$, $V-R$, and $R-I$ against each other for all the stars and noted any points which fall away from the mean relations. Deviant stars are regarded as possible variables if an examination of the original data did not reveal any reason to suspect a poor measurement.

HR 4511 in Stock 14 and star 7400p in NGC 6067 were not known to be variable when they were included in the observing list. Both have subsequently been shown to be either Cepheids or Cepheid-like variables (Eichendorf and Reipurth 1979; Eggen 1983), and it is gratifying that both appear to be variable on the basis of inconsistencies among the various colors. Star 11 in NGC 2533 shows unusually large differences between its two DDO observations and some discrepancies in two-color diagrams. It could be a variable with a period of perhaps a few days. Star H in Ru 79 falls away from the other stars in some color-color plots. It is not clear whether this is explained by the fact that it is very faint, especially in the ultraviolet, or whether it is variable. Star 103 in NGC 6694 has inconsistent colors and may be variable.

Clearly this list is likely to be incomplete, given the fact that we have only a few observations of each star. In addition, it is possible that some of the stars listed above appeared to be variables because of poor photometry or photometric peculiarities. Observations to check variability are beyond the scope of this program; the above stars are simply noted as objects which merit further observations.

IV. CLUSTER MEMBERSHIP

The DDO photometry was obtained primarily for the purpose of determining the membership of the giants in the clusters. Janes (1977) presented a method of deriving color excesses from DDO photometry in conjunction with $B-V$ colors. His calibration was extended to lower luminosities and higher temperatures using the standard relations of Osborn (1979). Janes (1975) also developed an absolute magnitude calibration for DDO photometry. Using these calibrations the

TABLE 5
VRI COLORS

Cluster	Star	$V-R$	σ	$R-I$	σ	n
NGC 129 ...	A	0.848	3	0.714	11	2
NGC 654 ...	23	0.928	10	0.728	4	3
	80	1.071	12	0.846	2	3
	85	1.026	12	0.766	8	3
NGC 659 ...	22	0.954	1	0.748	16	2
NGC 1502 ..	2	0.973	3	0.773	2	2
NGC 1545 ..	4	0.780	6	0.582	7	2
NGC 1647 ..	4	0.701	5	0.493	13	2
	8	0.749	30	0.535	19	1
NGC 1893 ..	2	0.889	10	0.704	17	2
	111	0.928	30	0.700	19	1
NGC 2168 ..	101	0.835	4	0.595	26	2
NGC 2670 ..	1	0.874	10	0.548	19	1
	5	1.047	10	0.737	19	1
Ru 79	H	1.464	43	0.967	11	3
NGC 3114 ..	1	0.274	10	0.153	19	1
	2	0.698	11	0.448	2	2
	12	1.030	6	0.635	1	2
	76	0.966	10	0.586	19	1
	119	0.944	10	0.575	19	1
	159	0.893	10	0.554	19	1
	184	0.906	10	0.548	19	1
Ly 6	4	2.190	14	1.454	20	2
NGC 6067 ..	7400P ^a	1.000	21	0.654	28	2
	7400F	0.498	11	0.337	16	2
NGC 6204 ..	19	0.843	10	0.535	19	1
M25	150	1.315	1	0.878	8	2
	193	1.157	1	0.780	5	2
NGC 6649 ..	19	1.751	9	1.276	0	2
NGC 6664 ..	c	1.594	34	1.101	8	2
	29	1.494	50	1.050	14	2
NGC 6694 ..	102	1.417	36	0.945	9	2
	103	1.204	12	0.819	5	2
	108	1.244	22	0.880	11	2
NGC 7235 ..	4	1.186	21	0.915	21	5
	12	1.177	27	0.890	11	3
NGC 7510 ..	8	1.126	1	0.903	27	2
	15	1.055	30	0.842	21	1
NGC 7654 ..	2	0.986	6	0.722	9	2

^aLarger than expected scatter. Possibly variable.

absolute magnitude and color excess of each star in Table 3 which fell within the range of validity of the calibrations was determined. These were then compared with that expected on the assumption of cluster membership. When the agreement was reasonable the star was taken to be a likely cluster

member and this is indicated by a 3 in column (11) of Table 1. Some latitude was allowed in the case of the color excess since this can vary over the area of the cluster.

The four-color photometry can also be used to make a judgement concerning the membership of a particular star in a cluster. For this purpose we have used the relations between the four-color indices m_1 and c_1 derived by Faber (1977). These relations are valid for stars earlier than $\sim G0$, and this method thus applies to stars which are mostly too early for the application of DDO photometry. The luminosity class and spectral type of each star which fell within the calibration was inferred. This was then used to determine the absolute magnitude and color excess of the star. The membership in the cluster as judged from this method is indicated in column (12) of Table 1.

Since the DDO method and the four-color method of inferring cluster membership are complementary in terms of the stars to which they apply, we cannot compare them in detail. However, there are no contradictions between the two for the 12 stars to which both were applicable. A comparison of the membership inferred from proper motions with those inferred from spectra, DDO photometry, and four-color photometry shows that $\sim 10\%$ of the stars are likely members according to one criterion but unlikely members according to another. Some of these are, of course, legitimate in that a star can have the motions of the cluster but not be a member or can be located at nearly the same distance but not be a

member. Thus, the contradictions are not a serious indication of difficulties with the various methods.

Based on the various indications of cluster membership we can now choose those stars which are the most likely to be cluster members. There are 22 stars in Table 1 for which at least one criterion indicates likely membership and no criterion indicates that membership is unlikely. We will regard all of these stars to be likely members of the clusters, and this is indicated by a "Y" in column (13). Thus, of our original sample 26% are likely members. There are 48 stars (57%) for which membership is unlikely based on one or more criteria (indicated by "N" in col. [13]), while for 14 (17%), the membership status cannot be decided on the basis of the information in Table 1. Further study of these stars could be productive.

The discussion of the properties of yellow giants and supergiants will be presented in another paper. That discussion will consider only the 22 stars which appear here to be likely cluster members.

Most of the observations presented in this paper were made at Kitt Peak National Observatory and at Cerro Tololo Inter-American Observatory. The author is grateful to the directors and staffs of those observatories for the use of their facilities and for their assistance. This work was supported by the National Science Foundation under grant AST-7717520.

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