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THE GLOBULAR CLUSTER NGC 6712

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ABSTRACT

New infrared photometry is presented for 15 red giants, including five variables, in the metal-rich globular cluster NGC 6712. From infrared color-magnitude diagrams a value of $[Fe/H]_{IR} = -0.92$ is derived, identical to that for NGC 6171 and in close agreement with optical determinations of the abundance. Nonetheless, the CO indices of the NGC 6712 giants are quite strong—about 0.04 mag greater than for stars in 47 Tucanae.

The long-period variable V7 is the only star in the cluster with a luminosity greater than that predicted for the location of core He flash. Two variables—V2 and V8—are identified as being members of a class of variables characterized by blue colors and high temperatures relative to other giants of the same luminosity.

Subject headings: clusters: globular — photometry — stars: abundances — stars: late-type — stars: variables

I. INTRODUCTION

NGC 6712 is a Galactic globular cluster worth investigating for a number of reasons. First of all, it is one of the few globular clusters with an intermediate value for its metal abundance so that it could be either in Zinn's disk or spheroidal system (Zinn and West 1984; Zinn 1984). Second, it has been identified with a compact X-ray source (Grindlay 1981). Most clusters so identified have quite high central stellar densities. NGC 6712, on the other hand, is quite open in its central region. Finally, in addition to having about one dozen RR Lyrae stars, it may have as many as seven luminous red variables including one long-period variable (LPV) which appears to be a confirmed radial velocity member (Sandage, Smith, and Norton 1966; Feast 1973; Hogg 1973; Lloyd Evans and Menzies 1977).

The first color-magnitude study of NGC 6712 was by Sandage and Smith (1966). They showed its *C-M* diagram to be typical of metal-rich clusters. Lloyd Evans and Menzies (1977) reobserved a number of the stars from Sandage and Smith's lists as well as additional red, luminous stars immediately outside the area examined by the latter authors. Martins and Harvel (1981) also did a *C-M* diagram study of the cluster's central region and claim to have found systematic errors in Sandage and Smith's photometry. Unfortunately, they seem to have overlooked the Lloyd Evans and Menzies paper. These latter authors claim to have found excellent agreement between their V mags and (unpublished) $B-V$ colors and those of Sandage and Smith.

Smith (1983) reviews earlier abundance determinations and uses spectroscopy and photometry of individual giants in NGC 6712 to investigate the cluster's metal abundance. Most recently, Zinn and West (1984) have determined a metallicity for the cluster based on integrated light spectroscopic measurements of $[Fe/H] = -1.01$.

This paper presents infrared photometry for 15 luminous red stars in the cluster, including five red variables. These new data are discussed in the context of previous studies of the infrared properties of red giants in globular clusters (e.g., Frogel, Persson, and Cohen 1983, hereafter FPC; Frogel, Cohen, and Persson 1983, hereafter FCP). The data on the red variables will be discussed in detail elsewhere with the addition of new data on red variables in a number of other clusters.

II. DATA AND CLUSTER PARAMETERS

The observations upon which this paper is based were obtained on 1984 May 13 with CTIO's D3 InSb system on the 4 m telescope. Techniques used for data acquisition and reduction are essentially identical to those discussed in FPC and will not be repeated here, except to note that the standards of Elias *et al.* (1982) were used so that these new data are on the same photometric system as those in FPC.

The brightest and reddest stars from Sandage and Smith (1966) and Lloyd Evans and Menzies (1977) were observed as well as most of the bright red variables. Table 1 gives the reddening and extinction corrected colors and magnitudes for these stars. The last row on the left-hand side of the table lists the corrections applied to the observed values. Notes to Table 1 contain further details concerning the data.

Zinn's (1980) value for $E(B-V)$ is used. This value lies between those given by Harris and Racine (1979) and Lloyd Evans and Menzies (1977) [The latter authors give $E(V-I_K)$ from which an $E(B-V)_0 = 0.45$ is deduced.]

Bolometric magnitudes, effective temperatures, and surface gravities were calculated as in FPC. These physical parameters are listed on the right-hand side of Table 1. As in FPC the value for $(m-M)_0$ of 14.16 is based on $M_{v0}(\mathrm{HB}) = \pm 0.7$ since $[Fe/H] = -1.01$ (Zinn and West 1984).

Various relations between the colors, magnitudes, and CO indices of the NGC 6712 stars are illustrated in Figures 1–4 and will be discussed below. These figures are used to derive the set of parameters in Table 2 which characterize the giant branch of the cluster. Values for NGC 6171 and 47 Tuc are from FCP. $(V-K)_0(\mathrm{GB})$ and $(J-K)_0(\mathrm{GB})$ are determined at an $M_{K_0} = -5.5$. $M_{K_0}(\mathrm{GB})$ is at $(V-K) = 3.0$. CO(GB) is the value at $(V-K)_0 = 3.0$. $\sigma(\mathrm{CO})$ is a measure of the spread in the CO index for stars with $(V-K)_0$ between 3.0 and 3.5.

III. COLOR-MAGNITUDE DIAGRAMS AND CLUSTER METALLICITY

Figures 1*a* and 1*b* show that the NGC 6712 giants have $(V-K)_0$ and $(J-K)_0$ colors similar but not identical to those of NGC 6171 as noted by Smith (1983). The scatter in $(J-K)_0$, which is greater than expected from the photometric uncer-

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TABLE 1

NGC 6712: DATA AND PHYSICAL PARAMETERS

STAR[a]	REDDENING-CORRECTED[b] PHOTOMETRY[c]									PHYSICAL PARAMETERS[d]				NOTES[e]
	K_0	$(B-V)_0$	$(V-I_K)_0$	$(V-K)_0$	$(J-K)_0$	$(H-K)_0$	$(K-L)_0$	H_2O	CO	BC_K	M_{bol}	T_e(K)	log g	
A38	10.67	1.22	1.64	2.90	0.76	0.09	...	...	0.14	2.26	−1.23	4280	1.4	1
A51	9.74	1.42	1.75	3.26	0.83	0.11	...	0.03	0.115	2.40	−2.02	4090	1.0	1
B8	9.74	1.43	1.62	3.15	0.80	0.11	...	0.03	0.175	2.36	−2.06	4150	1.0	1
B66	9.39	1.43	1.77	3.35	0.84	0.12	...	0.04	0.18	2.43	−2.34	4040	0.9	
B108	9.80	1.43	1.78	3.31	0.85	0.14	...	0.03	0.19	2.42	−1.94	4050	1.0	
C59	10.02	1.35	1.42	2.86	0.77	0.11	...	0.04	0.175	2.26	−1.88	4320	1.2	
LM 5	8.71	...	2.11	3.79	0.88	0.16	...	0.06	0.20	2.55	−2.90	3870	0.6	
LM 8	9.07	...	1.95	3.60	0.88	0.12	...	0.03	0.12	2.50	−2.59	3930	0.7	
LM 10	9.09	...	1.94	3.54	0.81	0.12	...	0.08	0.165	2.47	−2.60	3950	0.7	
LM 11	9.99	...	1.82	3.27	0.80	0.10	...	0.03	0.125	2.39	−1.78	4080	1.1	
V2	8.19	1.71	2.24	3.6	0.73	0.18	0.33	0.47	0.185	2.46	−3.51	3930	0.4	2, 3
V7	7.01	1.59	...	4.1	0.96	0.28	0.48	0.35	0.205	2.63	−4.52	3780	−0.1	1, 4, 5, 6
V8	8.30	1.60	2.77	3.0	0.91	0.21	0.26	0.20	0.19	2.36	−3.50	4280	0.5	1, 2, 7
V10	8.07	1.74	2.56	4.4	1.01	0.18	0.18	0.09	0.16	2.71	−3.38	3690	0.3	1, 2, 8
V21	8.22	...	2.26	4.2	0.98	0.15	0.17	0.10	0.145	2.66	−3.28	3750	0.4	9, 10, 11
Correction ..	−0.11	−0.35	−0.14	−1.08	−0.22	−0.08	−0.05	−0.02	+0.015	...	...	...	...	

[a] Identification numbers are from Sandage and Smith 1966 or Lloyd Evans and Menzies 1977. Variable star designations are as in Hogg (1973).

[b] $E(B-V)_0 = 0.39$ (Zinn 1980). For stars with colors of the ones in this table, the appropriate value is $E(B-V) = 0.35$. The last row on the left-hand side of the table gives the corrections applied to the *observed* values in order to get the ones tabulated.

[c] *BV* values are from Sandage and Smith (1966). (*VI*) colors are from Lloyd Evans and Menzies (1977). For the variables *mean* values were used for the $B-V$ and $V-I_K$ colors. Photometric uncertainties in the *JHK* colors, H_2O, and CO indices are ± 0.02 mag or less. The uncertainties in the $K-L$ colors are ± 0.03 mag.

[d] Based on $(m-M)_0 = 14.16$ for $M_{v_0}(\mathrm{HB}) = +0.7$ and $M = 0.8\ M_\odot$.

[e] NOTES.—(1) Probable radial velocity member (Smith 1983). (2) Considered to be member on basis of position (Sandage, Smith, and Norton 1966). (3) $P = 104.6$ days; AP Sct; mean *V* from Sandage *et al.* 1966 used to compute $(V-K)_0$. (4) LPV. (5) Radial velocity member (Feast 1973). (6) $P = 190.5$ days; CH Sct; *V* at phase = 0.14 from Sandage *et al.* 1966. (7) $P = 117.0$ days; *V* data near maximum light used (Sandage *et al.* 1966). (8) $P = 174$ days; *V* at phase 0.6 (Sandage *et al.* 1966). (9) Considered to be a member on the basis of position (Lloyd Evans and Menzies 1977). (10) Mean *V* mag from Lloyd Evans and Menzies 1977. (11) May not be a cluster member (Lloyd Evans 1983).

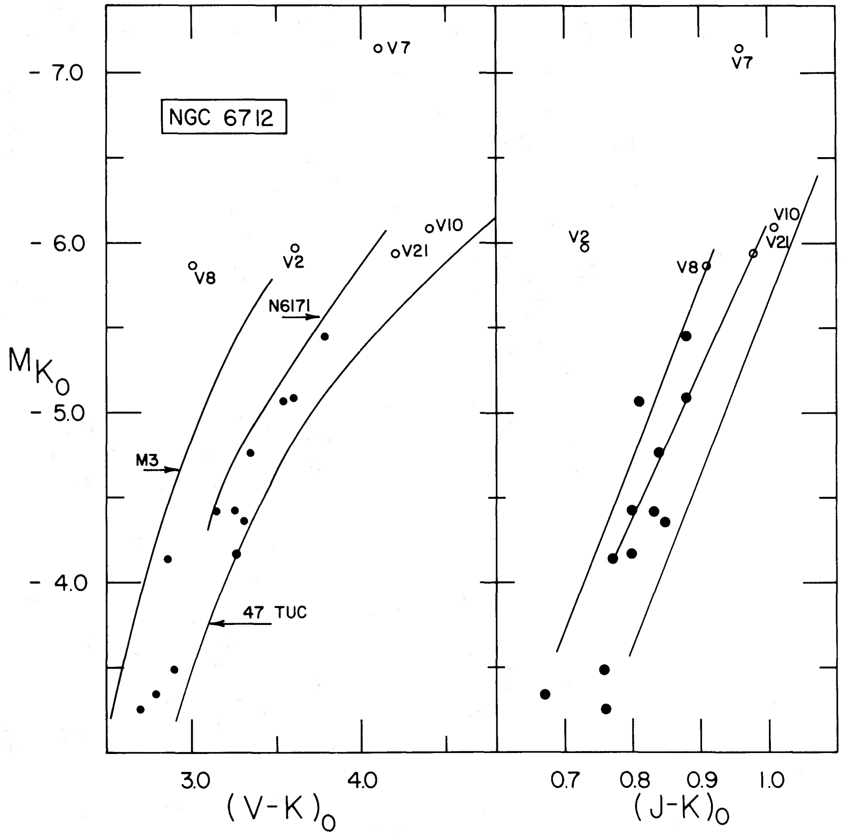

FIG. 1.—Two color-magnitude diagrams for the NGC 6712 stars from Table 1. The two faintest stars are from Smith (1983) with values transformed to correspond to $E(B-V)$ and $(m - M)$ used here. Open circles are variables. Fiducial giant branches from three other clusters are superposed.

tainties, could arise from variable reddening and/or inclusion of asymptotic giant branch (AGB) stars.

With respect to the well-defined giant branches of 47 Tuc and M3, the NGC 6712 stars tend to be somewhat redder in $(V-K)_0$ than in $(J-K)_0$. This is more obvious from inspection of the color-color plot in Figure 2. Although 47 Tuc stars were not used to define the mean cluster line in Figure 2, they do lie quite close to it. A change in the reddening value adopted for NGC 6712 will act primarily to move the stars in Figure 2 parallel to the mean lines. The suggested systematic error in Sandage and Smith's (1966) V magnitudes (Martins and Harvel 1981) would be in the sense that the $(V-K)_0$ values used here have to be made redder still.

In any case, a value for $[Fe/H]_{IR}$ may be derived for NGC 6712 from the values for $(V-K)_0(GB)$ and $(J-K)_0(GB)$ in Table 2 and equations (7a) and (7b) of FCP. This value is -0.92, identical to that for NGC 6171, and not significantly

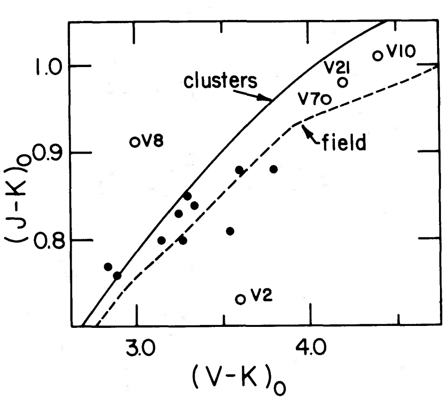

FIG. 2

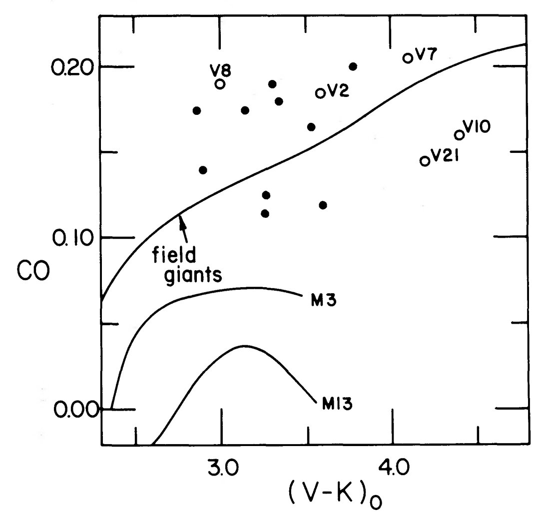

FIG. 3

FIG. 2.—A color-color plot for stars from Table 1. The cluster line is the mean for M3, M13, M92, and M71.
FIG. 3.—The CO indices of the stars in Table 1 are shown as a function of their $(V-K)$colors. Means lines for field giants and two globular clusters are shown.

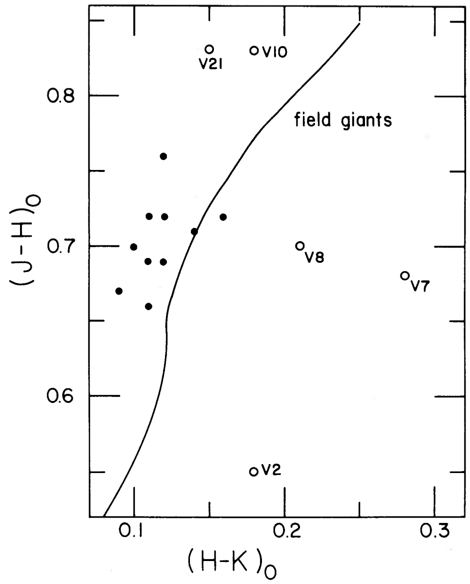

FIG. 4.—A color-color plot for stars from Table 1. The mean relation for field giants is shown.

different from Zinn and West's (1984) value of -1.01 (the dispersion in the fit between the IR abundance scale and Zinn's [eq. (11) of FCP] is 0.24 dex).

From the data presented by FPC one can conclude that the redward extent of a cluster's giant branch in $J-K$ or $V-K$ is a function of the cluster's metallicity. There is a particularly striking difference between clusters in metallicity group A, the most metal rich, and those in group B as may be seen by comparing Figures 5*a* and 5*b* of FPC. Group B clusters have no stars redder than $(V-K)_0 = 4.5$ while group A clusters have a significant number of such stars, especially variables. Figures 1 and 2 here clearly put NGC 6712 in group B, consistent with the quantitative metallicity estimate made above.

There exists a well-defined correlation between the bolometric magnitude of the tip of a cluster's giant branch, excluding any long-period variables (LPVs) which might be present, and its metallicity (FCP). Table 2 gives two values for this quantity—the first assumes that V2 and V8 are first ascent giants. The second excludes these two variables because they might in fact be AGB stars. In either case M_{bol}(1st) is virtually the same as it is for NGC 6171. From equation (4) of FCP the predicted value is -3.56. Although this is nearly 2 σ brighter than the second value tabulated, the difference cannot be regarded as being significant because of variability and residual uncertainties in the reddening and distance modulus.

TABLE 2

GIANT BRANCH PARAMETERS

Parameter	6712	6171	47 Tuc
$(V-K)_0$(GB)	3.82	3.73	4.04
$(J-K)_0$(GB)	0.92	0.93	0.98
M_{K_0}(GB)	-4.0	-4.15	-3.43
M_{bol}(1st)	-3.50 (-3.38)	-3.42	-3.60
CO(GB)	0.16	0.13	0.12
σ(CO)(GB)	0.07	0.03	0.07
[Fe/H]$_{\mathrm{IR}}$	-0.92	-0.92	-0.59
[Fe/H]$_Z$	-1.01	-0.99	-0.71
$(H-K)_0$(GB)	$+0.025$	$+0.02$	$+0.02$

IV. OTHER COLORS AND INDICES

Figure 3 shows that the CO indices of the NGC 6712 giants are, in the mean, as strong as or stronger than those of field giants at the same color (the mean relation for field stars is from Frogel *et al.* 1978). Equation (5) of FCP predicts a CO(GB) of 0.09 for a cluster with NGC 6712's metallicity (see also their Fig. 7), whereas the observed value, given in Table 2, is 0.16. Only NGC 5927 and 6553 have CO indices of comparable value. To further underscore the high CO(GB) value for NGC 6712, note that giants in 47 Tuc with the same color range as those in NGC 6712 have CO indices which are, in the mean, 0.04 lower (Table 2 here or Fig. 4 of Frogel, Persson, and Cohen 1981).

The spread in the CO indices at a given color, σ(CO)(GB) in Table 2, is large but consistent with values for other clusters in FCP's groups A and B.

The blueward displacement of the NGC 6712 giants from the mean field line in the $(J-H)$, $(H-K)$ diagram of Figure 4 is consistent with the behavior seen in most other clusters (Fig. 3 of FPC and col. [15], Table 1 of FCP).

Finally, the H_2O indices of the nonvariable giants in NGC 6712 have the values expected for stars of their colors.

V. THE RED VARIABLES

The five brightest stars in NGC 6712 are all red variables. One of these, V7, is an LPV which means that this cluster is the most metal-poor one known to contain such a variable. As has been found for LPVs in other clusters (FPC and FCP), NGC 6712-V7 has a bolometric luminosity significantly brighter than the point at which core helium flash is expected to occur in first ascent cluster giants and is the *only* cluster member brighter than this limit.

Two of the variables, V2 and V8, have significantly bluer mean colors than other stars of the same brightness on the giant branch (Figs. 1*a* and 1*b*). While one can attribute blueness in $V-K$ to lack of simultaneity of observation, this cannot be the explanation for $J-K$. These two stars also have red $K-L$ colors and strong H_2O absorption for their $J-K$ colors, properties which are typical of other members of a class of variables originally identified because of their relatively blue optical colors, but which also have distinctive infrared properties (Frogel 1983 and references therein). Unlike other members of this class, though, their CO indices are quite strong.

The strong H_2O absorption in V2, V7, and V8 is the probable cause for the displacement of these stars from the fiducial line in Figure 4. Such displacement is typical for these variables (Frogel 1983).

The remaining two variables, V10 and V21, have luminosities, colors, and indices which are quite similar to the small-amplitude red variables V3 and V7 in M69 (Figs. 2, 3, 5, 6, and 7 in FPC).

A subsequent paper will discuss the NGC 6712 variables, along with other recent observations of cluster red variables, in more detail.

VI. DISCUSSION AND SUMMARY

In most respects the infrared properties of bright red giants in NGC 6712 are consistent with what would be predicted from the cluster's metallicity and the mean relations established previously (FPC and FCP). In particular, quantitative and qualitative estimates of its metallicity based on infrared color-magnitude diagrams agree closely, both in an absolute and a relative sense, with independent estimates by Zinn and West (1984) and Smith (1983).

The most deviant characteristic found is the abnormal strength of the CO indices of the giants in the cluster. These indices are greater even than those measured for the CN weak–CO strong giants of 47 Tuc (Frogel, Persson, and Cohen 1981). Unfortunately, there are no published CN measurements for the NGC 6712 giants. These would be most interesting to obtain along with CH band measures. Could the lack of central concentration of this globular have influenced in some way the mixing history of its giants?

The $V-K$ colors of the NGC 6712 giants are clearly too red for their $J-K$ colors when compared to stars in other clusters. Could this be a blanketing effect connected with the strong CO indices? A new determination of the BV magnitudes and colors with a linear detector would help to eliminate a possible source of uncertainty.

This cluster has two stars which can be considered to be members of that class of variables whose colors are considerably bluer than other variable and nonvariable giants of the same brightness.

NGC 6712 has a metallicity which places it on the boundary between Zinn's (1984) disk and halo cluster systems. The strong CO indices of its stars as well as the presence of an LPV clearly support its membership in the disk system, consistent with its location in space and its kinematics.

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