THE ASTROPHYSICAL JOURNAL, 239:74–77, 1980 July 1

PAL 12—A METAL-RICH GLOBULAR CLUSTER IN THE OUTER HALO

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Received 1979 November 12; accepted 1980 January 7

ABSTRACT

New optical and infrared observations of several stars in the distant globular cluster Pal 12 show that they have CO strengths and heavy element abundances only slightly less than in M71, one of the more metal-rich globular clusters. Pal 12 thus has a metal abundance near the high end of the range over which globular clusters exist and lies in the outer galactic halo. Its red horizontal branch is not anomalous in view of the abundance we have found.

Subject headings: clusters: globular — stars: abundances — stars: evolution

I. INTRODUCTION

The globular cluster Pal 12 has been considered to be an example of a halo cluster, moderately poor in metals, but with a red horizontal branch. The metallicity of Pal 12 has been estimated from photographic spectra of three stars by Cowley, Hartwick, and Sargent (1978, henceforth CHS) and from CMT_1T_2 photometry of four stars by Canterna and Schommer (1978, hereafter CS). The latter authors obtained $[Fe/H] = -1.7 \pm 0.7$, 1.4 dex below their metallicity for M71. The first color magnitude diagram for the cluster indicated that the galactocentric distance was 14 kpc (Harris and Canterna 1979, reported by Harris 1978) and that the globular has a stubby red horizontal branch and a giant branch that lies between those of 47 Tuc and M3. Cohen, Frogel, and Persson (1978, hereafter CFP), and Pilachowski (1978) have suggested that the "second parameter" which determines the horizontal branch (HB) morphology for clusters like Pal 12 is the ratio of the C and/or O abundances relative to that of the heavy metals. In addition, the determination of HB type and metallicity for clusters in the outer part of the galactic halo is important for investigating the early dynamical evolution of the Galaxy (Zinn 1980, and references therein). For these reasons we decided to obtain observations of the infrared CO strengths of the giant stars in this cluster and to better determine their metallicity.

Although Cohen (1979) has offered a recent recalibration of the metallicity scale for "metal rich" globulars such as M71, all our measurements are interpreted via rankings relative to M71 and M5 and, hence, are unaffected by this controversy. In this paper a "high" metallicity will be understood to mean "with respect to other globular clusters" and not necessarily with respect to that of the Sun.

II. OBSERVATIONS AND RESULTS

The three brightest probable members of Pal 12 (stars 13, 14, and 15 from CS) were observed in the IR on both the 4 m telescope at CTIO and the 5 m Hale telescope on Palomar Mountain in 1978 September or October.[2] The faintest probable member (star 20 of CS) was observed from CTIO in 1979 November. The CTIO measurements were made with an f/30 chopping secondary system, while those at Palomar were obtained with a focal plane chopper. The data for Pal 12 were reduced to the same photometric system as the data in CFP and Frogel, Persson, and Cohen (1979) and are given in Table 1. The Palomar data were given only half-weight because of the large air mass of Pal 12 from that site and the mediocre seeing conditions on the night of observations. Nevertheless, the CO measurements from Palomar and CTIO agreed to within the statistical errors of 0.01 mag. The visual photometry and the value of 0.02 for $E(B-V)$ are from Harris and Canterna (1979).

The last four columns of Table 1 give the mean CO strengths for stars having the same de-reddened $(V-K)_0$ colors (or equivalently effective temperatures)

[1] Cerro Tololo Inter-American Observatory is supported by the National Science Foundation under Contract No. AST 78-27879.

[2] Note that the correspondences between the Canterna and Schommer star numbers and those of Cowley, Hartwick, and Sargent (1978) given by CS are incorrect: CS 14 = CHS 5; CHS 3 was not, in fact, observed by CS. These statements have been confirmed by Schommer (private communication).

TABLE 1

PAL 12 PHOTOMETRY

STAR		OBSERVED[c]			REDDENING CORRECTED[d]							FIDUCIAL CO[e]			
CS[a]	HC[b]	K	$(J-K)$	$(H-K)$	K_0	$(B-V)_0$	$(V-K)_0$	$(J-K)_0$	$(H-K)_0$	H_2O	CO	Solar	M71	M5	M3
13	S1	10.87	0.91	0.14	10.86	1.56	3.66	0.90	0.14	0.06	0.14	0.15	0.14	...[f]	...[f]
14	S2	11.38	0.86	0.13	11.37	1.49	3.40	0.85	0.13	0.065	0.11	0.14	0.10	0.09	0.07
15	1128	12.41	0.75	0.11	12.40	1.24	2.89	0.74	0.11	...	...	...	...	...	...
20	1305	13.12	0.77	0.11	13.11	1.08	2.69	0.76	0.11	...	...	...	...	...	...
1 σ	...	0.04	0.03	0.02	...	...	...	...	...	...	...	...	...	...	...

[a] Numbers assigned by Canterna and Schommer 1978.
[b] Numbers assigned by Harris and Canterna 1979.
[c] Typical 1 σ uncertainties are given on the last line. No reddening corrections have to be applied to the CO or H_2O indices.
[d] $E(B-V) = 0.02$ (Harris and Canterna 1979) was used.
[e] Mean CO index at the same de-reddened $(V-K)_0$.
[f] No star as red as Pal 12 Star 13 is present in M5 or M3.

for the mean field giant relationship (CFP) and the globular clusters M71 (Frogel *et al.* 1979), M5 (data to be published), and M3 (CFP). The striking conclusion from Table 1 is that Pal 12 stars have CO strengths at a given $(V-K)_0$ color greater than those of stars in the metal-poor cluster M3 for which [Fe/H] $= -1.8$ (Cohen 1978). In fact, the CO strengths of the two Pal 12 giants approach the mean field relationship for solar metallicity stars as closely as do the stars in the "metal rich" globular cluster M71.

Although the strong CO seen in the Pal 12 stars could be due to an extreme case of the "second parameter effect" in a metal-poor cluster, it could also arise simply from a generally higher metal abundance. In Figure 1 we see that the giant branch of Pal 12 lies to the red of that of M3 by an amount corresponding to nearly 250 K at the tip, indicating a heavy element metallicity closer to that of M71 than to that of M3, although there may be large uncertainties in $(m-M)_V$ to Pal 12 because of its faintness and sparseness.

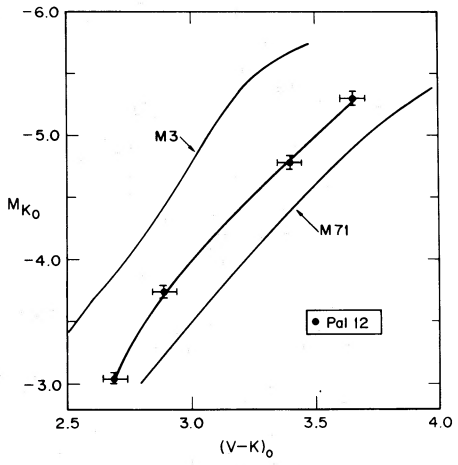

FIG. 1.—Fiducial giant branches are shown for M3 and M71 based on the data of CFP and Frogel *et al.* 1979. The location of the Pal 12 stars is indicated. The uncertainties resulting from photometric errors are indicated for the Pal 12 stars, not including possible (larger) errors in the distance modulus.

In order to better determine the metallicity of Pal 12 we observed stars 13 and 14 in 1979 May on the 5 m telescope at Palomar Mountain using a SIT detector on the digital spectrograph. The spectral region from 4900 Å to 6100 Å was covered with a dispersion in the focal plane of 3.3 Å per pixel, and the comparison lines were 2.5 pixels wide at half-maximum. Comparison stars in M71, M5, and M13 which had a range in $(V-K)_0$ colors corresponding to the Pal 12 giants and which were of approximately the same luminosity (log g varying by less than 0.5 dex) were observed on the same nights. An absorption-line strength index ΣW was formed from the sum of the measured equivalent widths of the 5170 Å Mg I blend, the 5208 Å Cr I–Fe I blend, and the 5270 Å Ca I–Fe I blend. To avoid problems with interstellar lines, the Na I D lines were not considered. In Table 2 we give ΣW (in angstroms) as a function of $(V-K)_0$ for stars 13 and 14 in Pal 12 and for comparison giants in M13, M5, and M71. It is immediately seen that the metallicity of the Pal 12 giants exceeds that of the M5 giants and is close to that of M71.

The above results are at variance with the metallicity determination by CS of [Fe/H] $= -1.7 \pm 0.7$ on a system where [Fe/H] $= -0.3$ for M71. Their result is based on observations of four probable members whose individual metallicities given by the CMT_1T_2 system ranged from solar to -2.5. The high metallicity suggested by Figure 1 and Table 1 is difficult to compare with the qualitative results of Cowley, Hartwick, and Sargent (1978), who found Pal 12 to be of intermediate metallicity with excessively strong CH.

To verify the high metallicity of Pal 12 we observed all four of the probable members with photometry by Canterna and Schommer (1978) using the Cassegrain spectrograph and reticon detector on the 2.5 m du Pont telescope at the Las Campanas Observatory to cover the range from 3900 to 6700 Å. These spectra were used to obtain additional ΣW values listed in Table 2. There were enough stars in common between the Palomar SIT spectra and the Las Campanas reticon spectra to determine that there is a negligible

TABLE 2

ΣW MEASUREMENTS

	CLUSTER										
	PAL 12		M71[b]			M5[c]			M13[d]		
STAR	$(V-K)_0$	ΣW[a]	STAR	$(V-K)_0$	ΣW	STAR	$(V-K)_0$	ΣW	STAR	$(V-K)_0$	ΣW
13	3.66	8.3	46	3.64	9.3:	IV-81	3.45	5.8	IV-25	3.43	4.3
14	3.40	6.8	A4	3.55	7.1	III-78	3.21	4.7	III-63	3.16	3.6
15	2.89	6.1	78	2.87	9.0:	I-68	3.21	5.1	III-73	3.01	4.2
20	2.69	5.1	21	2.84	6.2	I-71	2.98	4.1	II-76	2.95	2.9
			N	2.26	6.9	III-36	2.95	4.9			
						I-25	2.83	4.4			
						I-74	2.83	4.1			

[a] ΣW given in angstroms. Measurement accuracy is ±0.5 Å, except values followed by a colon, where accuracy is ±1.0 Å.
[b] $(V-K)_0$ from Frogel *et al.* 1978.
[c] $(V-K)_0$ from unpublished photometry by Persson, Cohen, and Frogel.
[d] $(V-K)_0$ from Cohen *et al.* 1978.

effect on ΣW in spite of the slightly different dispersions. Figure 2 displays a portion of the spectra (from 3900 to 4600 Å) of Pal 12 star 15, M5 I-25, and M71 star 78 (in the numbering system of Arp and Hartwick 1971). All these stars, according to our IR photometry, have $(V-K)_0$ colors of 2.85 ± 0.04 mag. It is clear that Pal 12 star 15 has line strengths exceeding those of the comparison star in M5 and close to those of the M71 giant. The same ranking is derived when the entire spectral region observed is considered and also when the spectra of the other three stars in Pal 12 are compared to the appropriate comparison stars in other globulars. From these spectra it is also apparent that the high CH strengths of Cowley, Hartwick, and Sargent (1978) are not anomalous (see Fig. 2) for the high metallicity of Pal 12. No evidence for the presence of excessive CN can be seen at this dispersion. We thus find that a high metallicity, comparable to that of M71, is obtained for all the stars observed by Canterna and Schommer (1978).

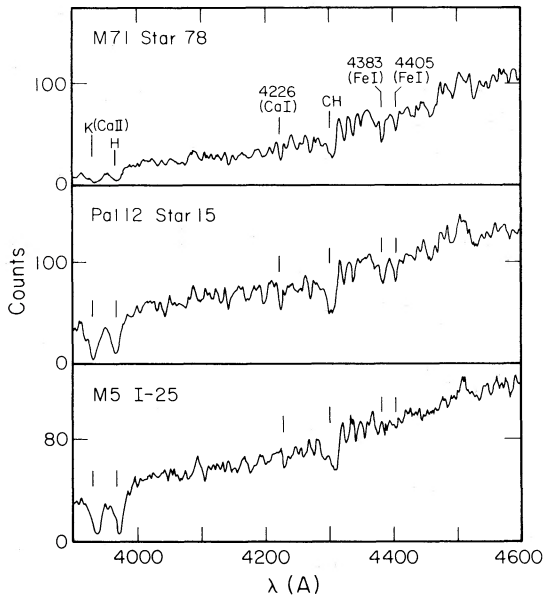

FIG. 2.—The spectrum between 3900 Å and 4600 Å of M71 star 78, Pal 12 star 15, and M5 I-25. Each of these giants has the same dereddened $V-K$ color. The strong falloff toward the blue in the M71 star's spectrum is largely due to the atmospheric dispersion at the high air mass of M71 from Las Campanas Observatory and also to the high reddening ($E[B-V] \approx 0.25$ mag) toward that cluster. The vertical axis is counts per pixel per second multiplied by a constant.

The similar metallicities derived for all the stars and the consistency of the color magnitude diagram shown in Figure 1 provide evidence that the four stars are in fact members of Pal 12. Harris and Canterna (1979) have reached the same conclusion from their more extensive visual photometry. For comparison with previously published data on giants in other globular clusters, we list in Table 3 the bolometric corrections to the K-magnitude, and the values of M_{bol} and effective temperature derived from the observations of Table 1 and the distance modulus of Harris and Canterna (1979).

III. CONCLUSIONS

Our observations show strong CO indices for the two brightest Pal 12 probable members and heavy element abundances close to that of M71 for all four of the stars observed by Canterna and Schommer (1978). Pal 12 is thus a "metal rich" cluster in the outer halo at a galactocentric distance of 14 kpc. Its red

TABLE 3

DERIVED PARAMETERS

Star	B.C.[a]	M_{bol}[b]	T_{eff}
13	2.59	−2.71	3950
14	2.58	−2.19	4050
15	2.35	−1.39	4400
20	2.26	−0.77	4500

[a] Bolometric correction to the K-magnitude.
[b] $E(B-V) = 0.02$ and $(m-M)_v = 16.20$ (Harris and Canterna 1979) were used.

horizontal branch is not anomalous, but is normal for its metallicity.

We are grateful to Barbara Zimmerman for help with the data analysis. We thank Fred Gillett for making the Mark I KPNO chopping secondary available for use at CTIO. Jay Elias assisted with the CTIO observations. This work was supported in part by NSF grant AST 77-20516 and NASA grant NGL 05L002-207.

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