OBSERVATIONS OF CO AND OI IN STARS IN GLOBULAR CLUSTERS

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During the past decade it has been evident that the morphologies of globular cluster color-magnitude diagrams cannot be described by only two parameters, age and metal abundance (Sandage and Wildey 1967, Hartwick 1968). The third parameter is unlikely to be helium because a normal helium abundance is needed to explain the pulsation of RR Lyrae stars (Deupree 1977) and because the helium abundance of the planetary nebula in the metal-poor cluster M15 is normal (O'Dell et al. 1964).

Since studies at classification dispersion and early analyses of high dispersion spectra have yielded little quantitative data on the abundances of C, N, and O in globular clusters we have been endeavoring to establish their abundances in stars in several clusters. We have approached the problem in two ways, by observing the 2.3 micron CO bands and the 6300 Å [OI] line in individual stars in globular clusters.

Observations of CO bands have been carried out by one of us (C.P.) using a photometric system very similar to that of Baldwin et al. (1973). Data have been obtained on the KPNO 2.1 and 4 meter telescopes for 30 stars in 9 clusters with emphasis on M71, M10, M13, M5 and M3. These clusters were selected because M71 has a high metal content while the others show contrasting color-magnitude diagrams. M10 and M13 have extremely blue horizontal branches while M5 and M3 have a mixture of red and blue horizontal-branch stars. The four clusters in question all have [Fe/H] values near -1.4. The results are shown in Fig. 1 where we plot the CO index against (V-K). The continuous line shows the index for standard

A. G. Davis Philip and D. S. Hayes (eds.), The HR Diagram, 173-176.

https://doi.org/10.1017/S0074180900145498 Published online by Cambridge University Press

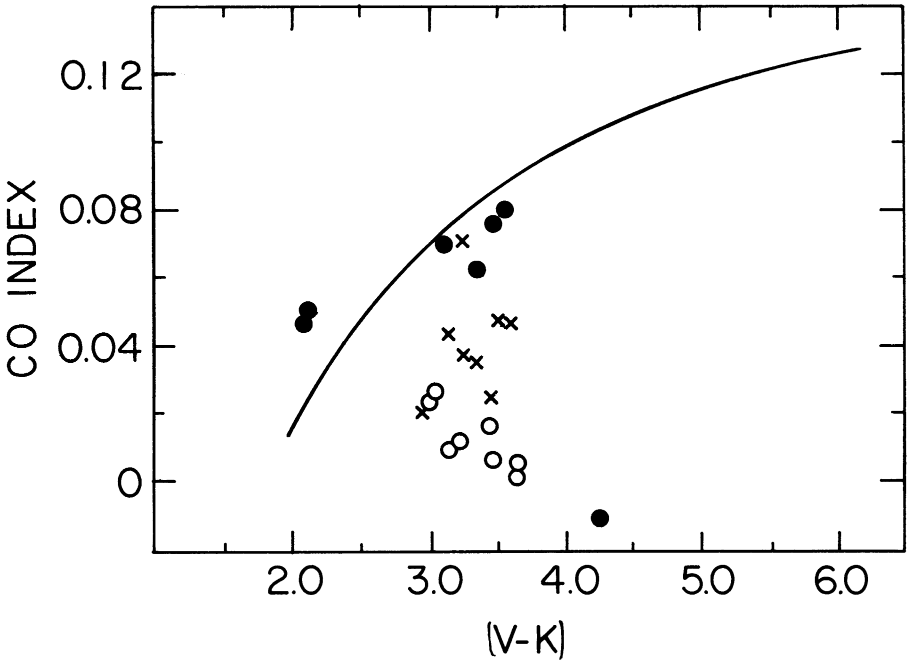

Fig. 1. CO index *versus* (V-K) color index.

stars. The stars in the cluster M71 appear to lie on the line for standard stars. There is a marked difference between stars in M3 and M5 as compared to stars in M10 and M13. The former deviate from the standard line by 0.035 mag while the latter deviate by 0.070 mag. This indicates a higher CO concentration and hence a higher abundance of carbon or oxygen (or both) in M3 and M5 as compared with M10 and M13. To be quantitative we must first determine the abundance of free oxygen in these stars.

From 4m. echelle spectra of one star in M22 and two stars each in M5 and M13 we have derived the ratio of OI to the metals by a curve-of-growth analysis. Our results are of a very preliminary nature for the following reasons. The analysis is by a curve-of-growth for OI as compared with singly ionized iron, titanium, and scandium. Since oxygen is almost entirely neutral and the other three elements are almost entirely ionized, no ionization corrections need be made. No account of association of oxygen in CO is taken since carbon is normally 1/3 of oxygen and hence CO does not greatly deplete the supply of OI. The temperatures were obtained from the colors. Improved temperatures from line intensities will be obtained later and our final analysis will be done by model atmospheres.

TABLE I

DERIVED PARAMETERS FOR THREE GLOBULAR CLUSTERS

Cluster	Star	$\Delta\theta_{eff}$	-log W/λ (OI)	[O/m]
M5	I-68	0.18	4.83	+0.8
	IV-81	0.24	5.12	+0.25
M13	II-67	0.24	5.30	-0.1
	III-56	0.20	5.11	+0.2
M22	IV-102	0.16	5.23	+0.55

Our comparison has been done with the Hyades as standard stars (Helfer and Wallerstein 1968). The results are shown in Table I.

From the table we find that [O/m] is +0.5 for M5 and virtually zero for M13. Hence we see that OI as well as CO is enhanced in M5. The enhancement of CO indicates that carbon is also enhanced since adding O without C will not enhance CO very much. We plan to carry out the necessary model atmospheres, etc. to predict CO enhancement as a function of C and O abundance and the other relevant parameters; but we can conclude from the data available that oxygen and probably carbon are enhanced in M5 relative to M13.

It therefore appears that somehow M5 has retained a higher ratio of helium burning products to metals than has M13. Furthermore the increase in oxygen shows that helium burning occurred in a high temperature, low density environment so as to produce oxygen as well as carbon. This means that the helium burning must have taken place in very massive stars. The lifetimes of stars in the range of 10-100 $M_\odot$ are so short that mass lost from their surfaces during their evolution could easily have been collected by the stars near 0.8 $M_\odot$ that are presently red giants while they were still contracting and hence had a large geometrical cross section to capture intracluster gas.

If the metals and CNO now present in the red giants of globular clusters were formed prior to star formation in the cluster, there is almost no way to speculate as to their mode of formation.

The observations reported upon in this paper were made at the Kitt Peak National Observatory, which is operated under contract with the National Science Foundation. This research was supported by grants from the National Science Foundation. We thank Mr. Bernard Bates for measuring and plotting the equivalent widths and curves-of-growth.

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DISCUSSION

BUTLER: For all of the clusters studied, what does the plot of [Fe/H] vs. [O/H] look like?

WALLERSTEIN: We really don't have enough data to say anything about this.

BUTLER: I just want to comment that a group of us are in the process of analyzing oxygen-line (7774 Å) strengths in a sample of field RR Lyrae stars known to have a large range in [Fe/H]. We do not find the scatter which appears to be present in the [Fe/H], [O/H] diagrams for clusters.

WALLERSTEIN: In M13 the horizontal branch is so blue that there are only 2 or 3 RR Lyrae stars. It may be that in the general field as well as in M13 there are so few RR Lyrae stars with low [CNO/Fe] that you haven't observed any.

ZINN: I would like to remark that Leonard Searle and I have made a survey of 19 globular clusters for metal abundance. We find that M5 is more metal-rich than M13 by approximately 0.4 dex. Perhaps this difference can explain the disagreement between the results discussed by Wallerstein and Butler.

CASTELLANI: I agree that nobody, at present, believes in globular cluster stars without helium. Nevertheless, I wish to point out that a variation in the original helium as low as $\Delta Y \sim 0.03 - 0.06$ can produce strong consequences in the expected morphology of HR diagrams. So, even if we accept "regular" helium in globular clusters ($Y \gtrsim 0.22$), one cannot exclude the occurrence of such kind of variations in determining the observed "peculiarities".

KRAFT: Did you find any variation in [O/Fe] for the stars in a given cluster?

WALLERSTEIN: Not a significant difference. We have only two stars in each cluster.