GLOBULAR CLUSTERS IN THE LMC*

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Because globular clusters are the oldest stellar systems, they should be sensitive probes of the early dynamical and chemical evolution of galaxies. Since some success has been achieved in understanding these problems in our own galaxy, it seems appropriate to see what can be learned from the clusters in the Large Magellanic Cloud (LMC).

Our observations consist of $\sim$90 A mm^{-1} blue spectra of individual giant stars in a number of LMC clusters, calibrated against similar spectra in galactic globular clusters. The reduction of this CTIO data is still in progress, so the abundances are only preliminary values. In Figure 1 we plot a two-color diagram for the red LMC clusters (B-V$\gtrsim$0.5; data from Bernard 1975) with the intrinsic relation for galactic globular clusters (Racine 1973) shown as a dashed line. Note that no clusters lie redward of this intrinsic relation except for NGC 1898 whose colors may be affected by a bright background. Furthermore, bluer than U-B$\sim$0.2 the clusters fall close to the intrinsic relation, whereas redder than U-B$\sim$0.2 the clusters exhibit a large range in B-V color. We hypothesize that the clusters fall into two groups as in our own Galaxy, with the open circles representing a halo population of old clusters and the filled circles a disk subgroup including clusters with all ages up to the halo group. [Gascoigne *et al.* (1976) have found NGC 2209, a proposed disk cluster, to have an age of 8 x 10^8 y.] Table I lists these clusters together with data on their abundance and position in the LMC. Our proposed sample of disk clusters includes only those closest to the intrinsic relation (Fig. 1) and hence presumably examples of the oldest disk clusters. It is interesting to contrast additional properties other than color of the "halo" and "disk" LMC clusters, keeping in mind the analogous subgroups in the Galaxy.

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James E. Hesser (ed.), Star Clusters, 333–337.

The color-magnitude diagram morphology, especially the horizontal branch (HB) structure, is a useful population discriminant. The five halo clusters for which this information is available (see Table I) all show well developed blue horizontal branches typical of the galactic halo clusters whereas the old disk clusters show red horizontal branches as in the Galaxy.

Table I also lists the projected distance of each cluster from the LMC center. The halo group has three clusters well beyond the apparent limit of the disk subgroup. This result is only suggestive because of the small number of clusters in the samples. Recall in the galaxy the halo clusters are found at all distances from the center, whereas the disk clusters extend only to ∿10 kpc.

Finally we consider what little is known about metal abundances from integrated spectra (Andrews and Lloyd Evans 1971), integrated intermediate band photometry (Danziger 1973), photometry of individual stars (Gascoigne 1979), and spectra of individual red giants (Cowley and Hartwick 1979). The two cluster subgroups mimic the behavior of the galactic globular clusters with the halo group being more metal poor than the disk group. Note that the two LMC clusters with greatest distance from the center of the galaxy appear to show a large difference in line strengths, so if there is an abundance gradient in the LMC halo a very large number of clusters will be required to determine it.

The mean metal abundance for the LMC halo clusters may be compared directly with simple models of chemical evolution. From 10 halo clusters listed in Table 1 we find $<[m/H]>=-1.9$ with the standard deviation of the distribution $\sigma=\pm0.3$. (This may be compared with $<[m/H]>=-1.45$, $\sigma=\pm0.37$ for the Galaxy.) Apparently the halo of the LMC is more metal poor than the Galaxy, but we emphasize the result is based on a small sample and assumes the correctness of our choice of LMC "halo" clusters.

Using a simple one-zone model of chemical evolution which allows for mass loss from the star forming region (Hartwick 1976), the expression describing the ratio of the mass of stars with metal abundance Z to those with metal abundance Z_1 is:

$$\frac{S}{S_1} = \frac{1 - \exp\{-[(\alpha+c)(Z-Z_o)]/\alpha p\}}{1 - \exp\{-[(\alpha+c)(Z_1-Z_o)]/\alpha p\}} \qquad (1)$$

where α represents the fraction of mass in each generation of stars which remains locked up in long-lived stars or collapsed remants, p is the yield of heavy elements (the ratio of mass ejected as

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heavy elements to the mass of long lived stars), c is the ratio of mass loss rate to star formation rate, and Z_o is the initial value of Z (primeval metal abundance?). Figure 2 shows a histogram of the observed cluster abundances while the solid line is the predicted frequency histogram for a model with $\alpha = 0.8$, $p = 0.01$, $\log Z_o/Z_\odot = -2.2$, $\log Z_1/Z_\odot = -1.2$, and $c = 56$. This model appears to provide an adequate fit to the data. Interestingly c is found to be 5.5 times larger than in the Galaxy, implying that the relative mass loss rate in the halo of the irregular galaxy (LMC) is much higher than in a more luminous and massive spiral (the Galaxy).

REFERENCES

Andrews, P.J. and Lloyd-Evans, T.: 1971, in A.B. Muller (ed.), "The Magellanic Clouds", Reidel, Dordrecht, p. 88.

Bernard, A.: 1975, *Astron. and Astrophys. 40*, 199.

Cowley, A.P. and Hartwick, F.D.A.: 1979 (in preparation).

Danziger, I.J.: 1973: *Astrophys. J.* 181, 641.

Gascoigne, S.C.B.: 1976, *Astrophys. J. Letters, 209*, L25.

Gascoigne, S.C.B.: 1979, private communication.

Hartwick, F.D.A.: 1976, *Astrophys. J. 209*, 418.

Racine, R. 1973: *Astrophys. J. 78*, 180.

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Table I.

LMC Globular Clusters

Cluster	Distance from center	HB	U-B	U-B	Integrated Spec. Type	[m/H] Gascoigne	Danziger	CH
					HALO CLUSTERS			
NGC	(°)		(mag)	(mag)	G/H			
1466	8.0	B	0.13	0.68	F7/F8	-2.0	-1.41	-1.9±0.1
1754	2.5		0.16	0.73	F5/F7		-2.00	
1786	3.1	?	0.18	0.78	F5/F6		-2.00	
1835	1.7		0.13	0.73	F6-8/G0		-2.00	
1841	14.3	B		0.71		-2.4	-2.00	<2.0±0.3
1898	0.6		-0.03	0.73			-1.64	
1916	0.7		0.18	0.78				
2019	0.8		0.19	0.74			-1.41	
2210	4.3	B	0.12	0.70	F8/F9		-1.64	-1.9±0.3
2257	9.1	B		0.61		-1.3		-1.6±0.3
SL 868= H 11	4.4	B	0.00	0.63		-2.5		<-2.1±0.3
					OLD DISK CLUSTERS			
1652	4.3	R?	0.29	0.82				
1751	2.5	R?	0.38	0.83				
1978	3.6	R	0.24	0.78	F6-7/F7		>1.41	-1.4±0.3
2121	2.6	R	0.25	0.84			>-1.5,<-0.2	
2155	5.6	R	0.23	0.80				-1.1±0.3
2173	4.1	R	0.28	0.83				

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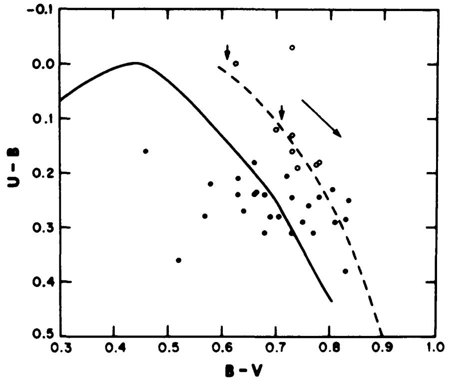

Figure 1. A two-color diagram showing Bernard's observations of red LMC clusters. Open circles and closed circles represent the hypothesized halo and disk subgroups. The solid line shows the position of the Hyades main sequence, the dashed line is the intrinsic relation for galactic globular clusters, the diagonal arrow shows a reddening trajectory, while the two short vertical arrows indicate the (B-V) colors of NGC 1841 and 2257.

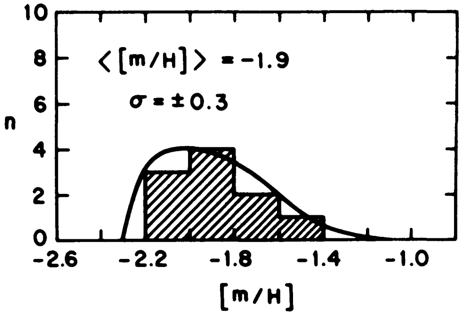

Figure 2. Histogram showing the frequency of [m/H] for 10 LMC halo clusters. The solid line represents the model described in the text.

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