BLUE CLUSTERS, POPULOUS CLUSTERS, AND GLOBULARS

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ABSTRACT

The introduction of new photometric techniques for faint objects has tremendously increased our understanding of the MC clusters, especially at the old end of the age spectrum. Many of the well-studied clusters of the past have gone through several transformations, starting as true globulars in 1960, becoming intermediate-age objects in the 1970's, but now returning to the true globular classification in the 1980's. LW 868 is an example of a cluster with such a history. Better photometric accuracy is also greatly improving our understanding of younger clusters, allowing detailed comparisons with theoretical evolutionary models, and a more reliable determination of the age-abundance relationship. The dynamical history of MC clusters can also be examined from the new data. The cluster formation rate, as well as the destruction rate, can be reconstructed from modern, deep cluster surveys.

I. OLD GLOBULAR CLUSTERS

Developing tradition, expanded somewhat by recent experience beyond the local Galactic environment, has held that for a cluster to be a globular cluster it must be luminous, large, massive, very old, and either heavy-element poor or not. Numbers have not yet been set by the IAU for these parameters, but generally all of them are fairly loose, except for age. Most astronomers seem to agree that any cluster younger than about 1.0×10^{10} years is too young to be a genuine globular, regardless of its other properties. Unfortunately, age is the most difficult of these parameters to measure for MC clusters. The only two really reliable methods, among many that have been tried, are searches for RR Lyrae variables and CM diagrams carried out down to the main sequence (MS) turn-off, which unfortunately for the MC's is at $V\sim22$ to 23, a level unattainable until the last year or two.

For the LMC we now have thorough searches for RR Lyrae variables in most, if not all, of the likely true globulars (Graham and Nemec 1984).

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In addition to the well-known outlying cases of NGC 1466, NGC 1841 and NGC 2257, there are well-established RR Lyrae populations in the more central clusters NGC 1786, NGC 1835, and NGC 2210. Nemec (1983) has produced a careful study of those in NGC 2210 and NGC 2257, even finding period changes and several double-mode pulsators among them.

A cluster that apparently does not have RR Lyrae variables but which may belong in this class is SL 868 (sometimes called H11). Originally picked out as a prime candidate for a genuine globular cluster, it was subsequently found to have an anomalous CM diagram (Gascoigne 1966). Later data taken to fainter limits (Freeman and Gascoigne 1977) led to an ambivalent conclusion about its age, while a somewhat later, independent study (Walker 1979) derived an age of only 6×10^8 yr. The latest word, based on much deeper surveys (Hesser et al. 1983 and Andersen et al. 1984), however, indicates a return to the conclusion that it is a genuine globular cluster.

For the SMC, the only certain case of a globular cluster that contains RR Lyraes is still NGC 121, for which Hesser et al. (1983) have a deep CM diagram confirming its old age. K3, long suspected to be old, but with a checkered history not unlike that of SL 868, is not quite old enough to be a true globular, according to the most recent results (Rich et al. 1984). Table 1 is a tentative list of the latest results of which I am aware; it may well need revision very soon.

TABLE 1. Genuine Globular Clusters

Cluster	Criterion: RR Lyraes	Criterion: CM Diagram	Recent References
LMC			
1466*	√	√	Penny 1975, Hesser et al. 1983
1786	√	no	Nemec 1983, Graham et al. 1983
1835	√	no	Graham et al. 1983
1841	√	√	Kinman et al. 1983
2210	√	√	Graham et al. 1983, Nemec 1983, Harris et al. 1983
2257	√	√	Graham et al. 1983, Nemec 1983, Hesser et al. 1983
SL868=H11	no	√	Graham et al. 1983, Hesser et al. 1983
SMC			
121	√	√	Hesser et al. 1983

*Membership questioned (Cowley and Hartwick 1981).

A subject of some considerable disagreement for these clusters (as well as for the blue globulars discussed below) has to do with their projected shape. Geisler and Hodge (1980) found the older clusters of the LMC to be significantly more elliptical than Galactic globulars and Geyer et al. (1983) at least partially confirm this conclusion. Frenk and Fall (1982), however, obtain rather different ellipticities from their measurements. Kontizas et al. (1983) find SMC clusters of both old and young age to be more elliptical than Galactic, or even than LMC, clusters. Because there are interesting possible correlations of shape with age and/or composition (see also Cowley and Hartwick 1982), this is a question that should be cleared up by additional study.

II. BLUE GLOBULAR CLUSTERS

As photometrists have pushed the limits of CM diagrams to fainter and fainter limits, MC globular-like clusters have been found in all age ranges. Among the very young clusters in each Cloud, the most luminous and best studied are NGC 330 in the SMC and NGC 2100 in the LMC. The former was one of the targets of Arp's (1969) pioneer study, and it was investigated again photometrically by Robertson (1974) and spectroscopically by Feast (1972). New, comprehensive, faint-limit photometry is now available from Janes and Carney (1983), who pushed the main sequence photometry down to V = 20. A spectroscopic study in the UV has just been completed for the brighter stars in NGC 330 by Böhm-Vitense et al. (1983a), who find some unexpected properties of the UV extinction and who measure the age to be $2x10^7$ years.

NGC 2100, near the 30 Doradus region and enveloped in dust (Cassatella and Geyer 1983), was found by Westerlund (1961) to be a very young cluster, though it is as large (50 pc) and as luminous (M_V = -9) as a globular. Robertson (1974) measured its CM diagram and more recently Böhm-Vitense et al. (1983b) obtained high and low dispersion IUE ultraviolet spectra of its brightest members. Using these to measure individual stellar extinctions and comparing UV fluxes with models, they determine an age for the cluster of $1x10^7$ yrs.

Integrated UV photometry has also proven helpful in interpreting these clusters (de Boer 1984; Geyer et al. 1983).

The age range between these young values and the ages of genuine globular clusters is becoming fairly well filled out. Table 2 lists a few of the most recent age determinations, finished subsequent to an earlier review (Hodge 1983a). There are still too many data unreduced and too many rich clusters unstudied to reach any firm conclusions about many of the general properties of the system of rich clusters, but three key questions are nearing the point of being definitively answered. First the age distribution of these clusters is not consistent with a historically uniform rate of formation. There is evidence both for periods of enhanced formation and possibly for relatively rapid destruction of these objects. Second, there is at least a rough inverse correlation of age with heavy element abundance (Cohen 1982, and previous references). Third, most of these objects belong to a system that has the kinematics of a disk population (Freeman et al. 1983, Cowley and Hartwick 1982).

Table 2. Some Very Recent Studies of Blue Globulars

Cluster	Age (10^6 yr)	[Fe/H]	Reference
LMC			
NGC 1831	190	-	Hodge & Morris 1983
NGC 1846	intermediate	-	Aaronson et al. 1983
NGC 1856	80	mildly depleted	Hodge & Lee 1983
NGC 1866	86	-0.4	Becker & Mathews 1983, Flower 1982a
NGC 1978	700	-0.5	Olszewski 1982
NGC 2058	120	-	Flower 1982b
NGC 2065	120	-	Flower 1982b
NGC 2100	10	-	Böhm-Vitense et al. 1983b
NGC 2121	400	-1.3	Flower et al. 1983
NGC 2133	130	-1	Hodge & Schommer 1983
NGC 2134	110	-1	Hodge & Schommer 1983
NGC 2190	intermediate	-	Aaronson et al. 1983
NGC 2203	intermediate	-	Hesser et al. 1983
E2	intermediate	-	Aaronson et al. 1983
23 clusters	various	-	Flower 1983
SMC			
NGC 330	20	-	Böhm-Vitense et al. 1983a, Janes & Carney 1983
NGC 339	intermediate	-	Aaronson et al. 1983
NGC 419	intermediate	-	Aaronson et al. 1983
NGC 643	intermediate	-	Hesser et al. 1983
K3	5000	-	Rich and Mould 1983
L 113	4000	-1.4	Mould & DaCosta 1983

III. OTHER MC CLUSTERS

Less attention has been paid to the thousands of clusters in each Cloud that are the obvious counterparts of our Galaxy's open clusters. The Edinburgh group (e.g., Brück 1975, Kontizas 1983, and many other references) has studied the cluster system of the SMC, providing catalogues, CM diagrams, and structural parameters for many open clusters. Less exhaustive open cluster surveys have been carried out for a few SMC fields at the University of Washington (Hodge 1983b, van Duine 1983).

For a series of deep 4-m plates of the LMC, Hodge (1983b) and Olszewski (1982) have made exhaustive searches that should include all possible star clusters of all possible ages, up to the Hubble time.

As expected from dynamical considerations, the number of open clusters decreases dramatically with age. Somewhat surprisingly, considering the very different dynamical environments, the LMC cluster destruction rate is almost identical to that of the Galaxy (Wielen 1971).

I want to thank the many astronomers who sent me information and preprints in advance of publication. There are many important papers relevant to my topic that I could not include because of space limitations and I apologize to their authors. I thank NASA for supporting my IUE spectroscopy of MC cluster stars.

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DISCUSSION

Searle: Do your age distributions for clusters refer to a magnitude-limited sample?

Hodge: Yes. The open clusters in the sample are those with members brighter than about M $\simeq$ 4.0. This should be, therefore, a complete sample of clusters that are younger than the universe. There is also a strong correlation between age and physical size for LMC clusters. Young clusters show a wide range of sizes, while the old clusters are almost all very small.

Mould: It is necessary to distinguish between a limiting magnitude for your Cloud cluster sample and a limiting mass, because the clusters fade with time. Was this taken into account in calculating the formation history for the clusters?

Hodge: Yes. The sample is magnitude limited, which translates into a mass limit in the sense that a cluster so small in population as to have no stars brighter than M $\simeq$ 4.0 will not be detected. By analogy with the Galaxy, I do not believe such clusters exist, as they are disrupted, and thus our sample is probably complete.

van den Bergh: Do you feel that there might be a conflict between your observed distribution of cluster ages in a complete sample and the notion that there was a great burst of star formation in the LMC a few Gyrs ago!

Hodge: No. I believe the age data need to be made more complete and reliable before the clusters can be used to test the burst hypothesis.

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