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Young Star Clusters in the LMC*

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Abstract

The young globular star clusters in the LMC offer us insights into the formation and early dynamical evolution of globular clusters which are unobtainable from the old globular clusters in our Galaxy. Because these young clusters are so young and populous, they provide an opportunity to measure the upper end of the initial mass function by direct means and also through the dynamical effects of stellar mass loss on the structure of the clusters.

1. Introduction

In addition to the usual modes of star formation (associations, open clusters), the LMC and SMC contain some very young, very luminous clusters which look just like the galactic globular clusters. These young clusters are known as young populous clusters, blue globular clusters or young globular clusters. In mass and binding energy, the brightest examples (e.g. NGC 1831, 1866, 2164, 2214 and the 30 Dor cluster) of these young clusters are like average globular clusters in the Galaxy: their masses are $\sim 10^5 M_\odot$ and their binding energies per unit mass are a few $(\mathrm{km\,s^{-1}})^2$. With ages of about 5×10^6 to 3×10^8 years, these blue clusters in the LMC are much younger than the galactic globular clusters. Although they have no counterparts in the Galaxy, similar young populous clusters objects are found in M33 (Christian and Schommer 1987). These young globular clusters are interesting in many ways. They give us insights into globular cluster formation in the early days of our Galaxy, and they provide a unique opportunity to study the upper part of the IMF and the early dynamical evolution of globular clusters, which is of course no longer possible for the old globular clusters in the Galaxy. The extreme youth of these LMC clusters was not realised until the early 1950s: see for example Shapley and Nail (1951).

2. Integrated Colours

In the (U–B)–(B–V) plane, the young clusters lie on a well-defined track which represents the aging of their stellar content: the cluster age, as estimated from the colour–magnitude diagrams, is closely related to its position along this track (see Elson and Fall 1985). The distribution of the bright clusters in the UBV plane

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is affected by their birthrate history, fading of their integrated light with age, and the disruption of the clusters by various dynamical processes. These effects lead to the observed bimodal distribution of B–V for the bright clusters (e.g. Gascoigne and Kron 1952; van den Bergh and Hagen 1968). The implications of this bimodal colour distribution for the cluster formation rate (e.g. bursts or lapses in the cluster formation rate) are not yet clear.

3. Kinematics

These young clusters are extreme Population I objects, and they have kinematics similar to that of the HI in the LMC. Freeman *et al.* (1983) showed that the systemic velocity, kinematic line of nodes, and the amplitude of the rotational velocity field for the young cluster system in the LMC are all similar to those found for the HI.

4. Direct Measurements of the IMF

The slope of the IMF is an important parameter for understanding the chemical and dynamical evolution of these clusters, and for understanding the impact that these clusters make on their environment. In principle, it is possible to measure the upper part of the IMF (stellar masses $>1M_\odot$) directly from their observed main sequence luminosity functions. Several groups have attempted such measurements, using photographic and CCD techniques, but the results disagree. Each method has its strengths and weaknesses. The photographic method provides a large field which allows accurate background subtraction; however it has the disadvantage of nonlinearity and limited dynamic range. The CCDs used so far are small and it has been necessary to work in the crowded inner regions of the clusters to obtain adequate numbers of stars. Large and uncertain completeness corrections are then needed—see Mateo (1988), Elson *et al.* (1989*a*), Richtler and de Boer (1989) and Richtler *et al.* (1991) for some examples of recent attempts. The estimated power-law slopes of the mass functions for the young LMC clusters range from $x = -0\cdot 2$ to $+3\cdot 5$, with the usual representation of the IMF ($dN \propto M^{-(1+x)}dM$: the Salpeter x is then $1\cdot 35$). These estimates of the IMF slopes cannot yet be regarded as definitive.

In the near future, we can expect that these problems will be overcome by using wide-field CCDs to measure the upper end of the IMF. The lower end of the IMF can be constrained by measuring dynamical masses and M/L ratios for these clusters (see Fischer *et al.* 1991).

5. Dynamical Evolution of Young Clusters

The late stages of the dynamical evolution of globular clusters, including core collapse and post-collapse evolution, have been widely studied: see Elson *et al.* (1987*b*) for a review. The early stages of dynamical evolution are also interesting but are unobservable in the old galactic globular clusters.

Chernoff and Weinberg (1990) computed the dynamical evolution of clusters with a power-law IMF defined as in the previous section. They included collisional relaxation, the galactic tidal field, and stellar mass loss. They showed that weakly concentrated clusters with flat IMFs disrupt in less than 10^8 yr through the effect of stellar mass loss and the galactic tidal field. This stellar mass loss can be very significant: a cluster with $x = 0\cdot 5$ loses about 60% of its mass in

3×10^7 yr. The young LMC clusters have ages $\sim10^7$ to 10^8 yr, central relaxation times several times longer than their ages, and orbital periods around the LMC of about 2×10^8 yr. It follows that:

- their dynamical evolution is dominated by stellar mass loss, rather than by collisional relaxation;
- they should be too young to show the tidal truncation effects seen in the old galactic globular clusters. A recent study of the structure of several young LMC clusters by Elson *et al.* (1987*a*) confirms this expectation. The clusters extend well beyond their eventual tidal radii, as estimated from the cluster masses and the tidal field of the LMC, and show no evidence for a tidal cutoff in their surface density profiles.

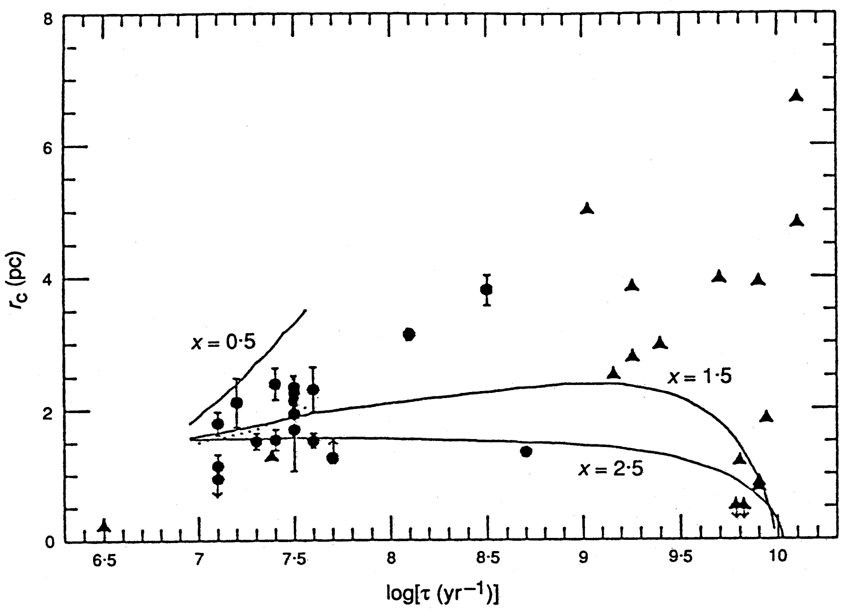

Fig. 1. Core radius r_c against age for the clusters of Elson *et al.* (1989*b*). The curves show the evolution of the core radius for Chernoff–Weinberg models with IMF slopes as shown: see the text for further details.

6. Core Expansion in the Young LMC Clusters

Elson *et al.* (1989*b*) used short exposure CCD images to measure the core radii of 18 young clusters in the LMC by fitting the function $\mu(r) = \mu_0(1+r^2/a^2)^{-\gamma/2}$ to the surface brightness distribution; here a is a measure of the core radius. Fig. 1, which includes another 17 clusters from the literature, shows how the core radii change with age. The main results are:

- the youngest clusters have small cores
- the mean core radius increases with age
- some of the oldest clusters have small cores, indicating that they are approaching core collapse.

These results on core expansion are consistent with the predictions of the Chernoff and Weinberg (1990) models, and can be used as an independent estimate of the slope of the IMFs for these clusters. Fig. 1 also shows the evolution of the core radii for three Chernoff–Weinberg models with different IMFs, all with masses of $6\times10^4 M_\odot$, central potentials $W_0 = 7$ (see King 1966), and located at 3 kpc from the centre of the LMC. The slopes of the model IMFs are indicated. The model with $x = 0\cdot5$, which is rich in massive stars, quickly disrupts through the effect of stellar mass loss and the tidal field. Fig. 1 suggests that the IMF slope is near 1 for some of the clusters and is perhaps closer to 2 for others.

7. Conclusion

These young globular clusters in the LMC are interesting for star formation studies. They provide a useful opportunity to measure the upper part of the IMF by direct and by dynamical means. The mechanism for forming these young clusters is not understood and it would be very interesting to know, even in the most general terms, why globular cluster formation is going on now in the LMC but not in the Galaxy. Several of these young LMC clusters have ages $<10^7$ yr, and it seems likely that the LMC would have several protoclusters in the phase immediately preceding the onset of star formation. It would be useful to find ways to detect such protoclusters.

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