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"Super" Star Clusters

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Abstract. The production of "super star clusters" (SSCs; luminous, compact star clusters) seems to be a hallmark of intense star formation, particularly in interacting and star-burst galaxies. Their sizes, luminosities, and mass estimates are entirely consistent with what is expected for young Milky Way-type globular clusters (GCs). SSCs are important because of what they can tell us about GC formation and evolution (e.g., initial characteristics and early survival rates). They are also of prime importance as probes of the formation and (chemical) evolution of their host galaxies, and of the initial mass function in the extreme environments required for cluster formation. Recent evidence lends support to the scenario that Milky Way-type GCs (although more metal rich), which were once thought to be the oldest building blocks of galaxies, are still forming today.

1. "Super" or normal?

One of the main contributions to date of the *Hubble Space Telescope (HST)* to the field of stellar populations in nearby galaxies has been the discovery of numerous dense stellar objects resembling star clusters with properties similar to those predicted for the progenitors of the old globular cluster (GC) population in the Milky Way and other nearby galaxies.

These objects are often confusingly referred to as "super star clusters" (SSCs), by virtue of their high luminosities and compact sizes. They have been found in a wide variety of galactic environments, ranging from quiescent dwarf and irregular or amorphous galaxies to large, gas-rich spiral galaxies involved in large-scale gravitational interactions and mergers, and in the star-burst events associated with them (see de Grijs, O'Connell, & Gallagher 2001 for an overview). However, the question arises of whether these objects are indeed "super" star clusters, in terms of either their integrated luminosity or their total mass. If they are indeed the progenitors of Milky Way-type GCs, assuming that they have the potential to survive for a Hubble time, then their high luminosities at their correspondingly young ages (of up to ~ 1 Gyr, in general) are simply conform the expectations of any modern flavor of simple stellar population theory.

Indeed, the mass distributions of most of these young star cluster populations do not extend significantly beyond that of the Milky Way GC population (which is generally used as a benchmark), with a few exceptions (e.g., NGC 7252-W3: Schweizer & Seitzer 1998, Maraston et al. 2001; NGC 6745: de Grijs et al. 2003c; some of the Antennae clusters, e.g., Mengel et al. 2002), although their existence might simply be due to stochastic effects. Nevertheless, the latter objects may therefore truly be super*massive* objects. With the exception of these few clusters, one should perhaps not consider the overall mass distribution of a given cluster population compared to that of the almost universal GC mass function in a wide variety of galaxies hosting such old objects, but instead consider these remarkable clusters in the context of their own parent population. This exercise leads us to realize that in a number of (predominantly) dwarf and irregular galaxies the overall cluster population is host to a few clusters that are significantly more massive than any of the other clusters (although not necessarily more massive than the high-mass wing of the Milky Way GC system), such as observed in NGC 1705 (NGC 1705-I, Ho & Filippenko 1996), NGC 1569 (SSCs A and B; see, e.g., Hunter et al. 2000, and Anders et al 2004 for comparative analysis in the context of the galaxy's overall cluster population), and M82 (M82-F; e.g., Smith & Gallagher 2001). Therefore, the assignation "super" appears to be merely a relative qualification.

In view of the confusing nomenclature, I will henceforth refer to these objects as *Young Massive Star Clusters (YMCs).*

2. Survival to old age?

Although YMC populations are often assumed to be GC-type progenitors, their survival for a Hubble time is by no means guaranteed. In fact, this depends crucially on the slope of the stellar initial mass function (IMF) governing these clusters. High-resolution spectroscopy can – for the nearest YMC systems – be utilized to derive dynamical mass estimates and, combined with integrated luminosity measurements from e.g. *HST* imaging, one can derive mass-to-light (M/L) ratios for a small number of clusters at a time. In their comparison of the M/L ratios at the corresponding ages for a handful of the brightest YMCs, Smith & Gallagher (2001) and Mengel et al. (2002) showed convincingly that a number of them appear to have IMF slopes that are significantly too shallow for the clusters to survive for any longer than roughly the next Gyr. Thus, these objects are unlikely to become GC analogues.

Instead of going through the cumbersome exercise of measuring individual M/L ratios, one can approach this problem statistically, by analyzing the potential of a given cluster population to survive for a Hubble time. The currently most popular models for the dynamical evolution of star clusters predict that the power-law Cluster Luminosity Functions (CLFs) characteristic of YMC systems will be transformed rapidly into the universal Gaussian CLFs of old Milky Way-type GC systems. In a recent paper (de Grijs, Bastian, & Lamers 2003a; see also de Grijs, Bastian, & Lamers 2003b), we provided the first evidence for a turn-over in the intermediate-age, approximately 1 Gyr-old CLF in the center of the nearby star-burst galaxy M82, which very closely matches the universal CLFs of old Milky Way-type GC systems. This is likely to remain virtually unchanged for a Hubble time. We also showed that with the very short characteristic cluster disruption time-scale governing the center of M82 (de Grijs et al. 2003b), its cluster mass distribution will evolve towards a higher characteristic mass scale than for the Galactic GCs by the time it reaches a similar age. We argue, therefore, that this evidence, combined with the similar cluster sizes (de Grijs et al. 2001), lends strong support to a scenario in which the current central M82 cluster population will eventually evolve into a significantly depleted old Milky Way-type GC system dominated by a small number of high-mass clusters. This implies that GC progenitors, which were once thought to be the oldest building blocks of galaxies, are still forming today in galaxy interactions and mergers. However, they will likely be more metal-rich than the present-day old GC systems. This connection between young or intermediate-age star cluster systems and old GCs lends strong support to the hierarchical galaxy formation scenario.

M82's proximity, its shortest known cluster disruption time-scale of any galaxy, and its well-defined peak of cluster formation make it an ideal candidate to probe the evolution of its star cluster system to fainter luminosities, and thus lower masses, than has been possible for any galaxy before.

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