Origin of Extended Star Clusters

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Abstract

We have discovered new extended star clusters (ESCs) in a nearby dIrr galaxy NGC 6822. These clusters are the nearest sample of ESCs available to date. The key characteristic of ESCs is their large size compared to typical globular clusters (GC) even though the two cluster populations are rather similar in terms of other parameters, i.e., color and luminosity. Several scenarios have been suggested to explain the formation of ESCs. However, the currently known ESCs may be a mixture of populations with heterogeneous formation histories. Future observational and theoretical studies are expected to better constrain the origins of ESCs as well as to increase their sample size.

1 Observational Characteristics of ESCs

ESCs are one of the new cluster populations being discovered with the advance of observational studies of star clusters. They are characterized by a relatively large size, that is, the half-light radii $R_h \gtrsim 10$ pc, compared to typical globular clusters (GC) with $R_h \sim 2 - 3$ pc. Some examples may include faint fuzzy clusters discovered in SB0 type galaxies (Brodie & Larsen 2002; Hwang & Lee 2006) and extended clusters found in the halo of M31 (Huxor et al. 2005, 2011). Even in the Milky Way galaxy, there are rather extended GCs found in the outer halo (van den Bergh & Mackey 2004). The ESCs in dwarf galaxies had not been known until the discovery of new ESCs in an isolated dIrr galaxy NGC 6822 (Hwang et al. 2005, 2011). Those new ESCs in NGC 6822 are the nearest sample of ESCs available to date ($D \approx 500$ kpc).

Another noteworthy characteristic of ESCs is their spatial distribution. It is shown that the ESCs in NGC 6822 are preferentially aligned along the old stellar halo that lies almost perpendicular to the HI disk like structure (see Fig.1 in Hwang et al. 2011). Faint fuzzy clusters in NGC 5195 and M51 also exhibit elongated spatial distribution, which is not followed by red compact clusters (Hwang & Lee 2006, 2008). This elongated distribution of ESCs is different from the one reported for faint fuzzy clusters in NGC 1023 that are usually found in the galaxy disk (Larsen & Brodie 2000). For ESCs in M31, no distinct
spatial distribution is apparent. However, it is suggested that many ESCs in M31 appear to be associated with stellar streams in the halo (Collins et al. 2009; Huxor et al. 2011).

2 Scenarios at the moment

Figure 1 shows the correlations between $R_h$ and $M_V$ of various types of objects including GCs, LMC, UCDs (ultra compact dwarfs), DGTOs (dwarf globular transition objects), UFDs (ultra faint dwarfs), dSph galaxies, as well as ESCs in M31, M33, and NGC 6822. There are at least two important points to note. Firstly, ESCs are found in almost every type of galaxies ranging from dwarfs (e.g., NGC 6822, Scl-dE1) to giant spirals (e.g., M31) and ellipticals (e.g., NGC 5128). Secondly, there are two subclasses of ESCs with different luminosity: one with $M_V < -9.4$ and the other with $M_V > -8.0$. The bright ESCs are found to occupy the common parameter space with UCDs or DGTOs, while the faint ESCs extend toward UFDs.

Various scenarios for the origins of those ESCs have been proposed and some reviews on each scenario and exemplary ESCs are given in Hwang et al. (2011). A brief summary is as follows: (1) Remnants or cores of tidally stripped dwarf galaxies may form ESCs. (2) Collisions of two or more star clusters in star cluster complexes or super-star cluster may make ESCs. (3) Star clusters are born in various sizes and some ESCs may survive the disruption under the weak tidal field. (4) Another scenario very recently pointed out by Gieles et al. (2011) is that slow expansion of initially compact clusters under the tidal field may have produced ESCs whose size evolution can be explained by adopting a line of constant relaxation time in the mass-radius diagram.

Usually, bright ESCs could be the remnant of disrupted dwarf galaxies or the multiple star cluster collisions, while faint ESCs may have evolved under the optimal tidal field to survive or to expand to their current forms. But no observational evidence is available yet to justify such dichotomy and/or to prefer any scenario over the others. However, every scenario involves the tidal interactions and/or mergers on the scale of star clusters or galaxies that should be the major physical drivers that make ESCs.

For the better understanding and clarification of the ESCs and their possible use for the galaxy evolution studies, future observations with improved photometric depth and spectral resolution as well as wider spatial coverage are required. In view of this expectation, GAIA will play a crucial role to survey even more ESCs in the Milky Way and to reveal their true nature and origin.

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References

Brodie, J. P. & Larsen, S. S. 2002, AJ, 124, 1410

Collins, M. L. M., Chapman, S. C., Irwin, M., et al. 2009, MNRAS, 396, 1619
Figure 1: $M_V$ vs. half light radii ($R_h$) diagram of GCs including the Galactic GCs and LMC GCs \cite{van_den_Bergh_Mackey_2004}, ESCs including M31 ESCs \cite{Huxor_etal_2005, Huxor_etal_2011}, M33 ESC \cite{Stonkute_etal_2008}, Scl-dE1 ESC \cite{Da_Costa_etal_2009} as well as NGC 6822 ESCs \cite{Hwang_etal_2011}. Bright and faint ESCs are separated by a box in dotted lines at the center. Please refer to \cite{Hwang_etal_2011} for more details.

Da Costa, G. S., Grebel, E. K., Jerjen, H., Rejkuba, M., & Sharina, M. E. 2009, AJ, 137, 4361
Gieles, M., Heggie, D. C., & Zhao, H. 2011, MNRAS, 413, 2509
Huxor, A. P., Ferguson, A. M. N., Tanvir, N. R., et al. 2011, MNRAS, 414, 770
Huxor, A. P., Tanvir, N. R., Irwin, M. J., et al. 2005, MNRAS, 360, 1007
Hwang, N. & Lee, M. G. 2006, ApJ Letters, 638, L79
Hwang, N. & Lee, M. G. 2008, AJ, 135, 1567
Hwang, N., Lee, M. G., Lee, J. C., et al. 2011, ApJ, 738, 58
Hwang, N., Lee, M. G., Lee, J. C., et al. 2005, in IAU Colloq. 198: Near-fields cosmology with dwarf elliptical galaxies, ed. H. Jerjen & B. Binggeli, 257–258
Larsen, S. S. & Brodie, J. P. 2000, AJ, 120, 2938
Stonkutë, R., Vansevičius, V., Arimoto, N., et al. 2008, AJ, 135, 1482
van den Bergh, S. & Mackey, A. D. 2004, MNRAS, 354, 713