A Parametric Study on the Formation of ECs and UCDs

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ECs and UCDs

- MW GC
- M51 GC
- M81 GC
- NGC1380 GC
- Dwarf gal. GC
- NGC1023 FF
- M31 EC
- Misc. EC
- NGC5128 GC
- Fornax UCD
- Virgo UCD
- Centaurus UCD
- M104 UCD
- Abell S0740 UCD
- Coma UCD

$r_{\text{eff}} [\text{pc}]$

$M [M_{\odot}]$
Cluster Complexes (CCs)

Cluster Complex = cluster of young star clusters
Properties of CCs: diameter: 100 – 1200 pc; mass: $10^5 – 10^8 \, M_{\odot}$
Cluster Complexes (CCs)

Tadpole Galaxy

CC in the disk of M51

Outline of Parameter Study

• Hypothesis:
  ECs and extended UCDs are the remnants of Cluster Complexes.

• Method:
  – Setup of CC models covering a suitable parameter space
  – Placing CC models in the gravitational field of a Milky Way like galaxy
  – Numerical simulations of the evolution of CCs with the particle-mesh Code SUPERBOX++
  – Comparison of structural parameters of evolved CCs with observed ECs and extended UCDs
Initial Setup (1)

Cluster Complex:
- $N_{CC} = 32$ star clusters
- $M_{CC} = 10^{5.5}$ to $10^8 M_{\text{sun}}$
- $R_{pl,CC} = 10$ to $160$ pc
- Plummer distribution
- Virial equilibrium

Star Cluster:
- $N_{SC} = 100,000$ particles
- $M_{SC} = 1/32 M_{CC}$
- $R_{pl,SC} = 4$ pc
- Plummer distribution
- Virial equilibrium
Initial Setup (2)

CC Parameter Space

Orbit

- Polar orbit
- MW-like galaxy
- Initial CC
Time Evolution

\[ M_{CC} = 10^7 \, M_\text{sun}, \quad R_{pl,CC} = 40 \, \text{pc}, \quad T_{cross,CC} = 7.5 \, \text{Myr} \]

Contours: Surface density, lowest level 0.625 \( M_\text{sun} \, \text{pc}^{-2} \), increasing by factors of 3
Number of Mergers and Final Mass
The merger objects cover a significantly smaller parameter space than the input CC models.
Comparison with Observations

- **merger objects**
- **observed ECs and UCDs**

![Graph showing the comparison between merger objects and observed ECs and UCDs. The graph plots $r_{\text{eff}}$ vs. $M$ in units of $M_{\odot}$. The x-axis represents mass in the range from $10^5$ to $10^8 M_{\odot}$, and the y-axis represents $r_{\text{eff}}$ in pc, ranging from 0 to 100.]
Additional Models (1)

- Circular orbit at 60 kpc
- Circular orbit at 20 kpc
- Eccentric orbit
  - $R_{pl} = 240 \text{pc}$
  - $R_{pl} = 360 \text{pc}$

Graph showing the relationship between effective radius ($r_{eff}$) and mass ($M$ in $M_{\odot}$) for observed ECs and UCDs, along with merger objects.
Additional Models (2)

- No external tidal field
- Circular orbit at 60 kpc
Summary

We performed numerical simulations of CC models.

The applied CC parameter space is fully consistent with the range of observed CCs.

The parameter space of the merger objects agrees well with that of observed ECs and extended UCDs.

The merged CC scenario is a likely formation scenario for ECs and extended UCDs.

Wish List to Observers

**Young massive star cluster complexes**
- What is the detailed structure of CCs (e.g. density profile)?
- What is the dynamical state of CCs?
- Is there a general size-mass relation of CCs as found by Bastian et al. 2005 in the disk of M51?

**Databases on ECs and UCDs are incomplete**
- HST surveys cover only a very small fraction of the galactic halo.
- ECs are often excluded from GC catalogs to minimize the contamination with background objects (size limits of <10 pc).
- The luminosity limits of UCD surveys should be adapted to cover medium-mass halo objects like NGC 2419.