Diffuse Star Clusters and Ultra-Compact Dwarf Galaxies

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Things we “know” about Star Clusters and Galaxies

Old (Globular) Star Cluster

- Single Stellar Population
- No Dark Matter
- Compact ($r_h \sim 3\text{pc}$)
- No size-luminosity relation
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Distinct stellar systems with different scaling relations
Star clusters are discrete components of galaxies
A Menagerie of Hot Stellar Systems

Not all kinds of star clusters are seen in the Milky Way

- Populous (LMC, M33)
- “Faint Fuzzies” and Diffuse Star Clusters
- Nuclear star clusters
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* Populous (LMC, M33)
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Blurring the lines between star cluster and galaxy
* Ultra-compact dwarf galaxies (UCDs)
* Dwarf-Globular transition objects (DGTOs)
A Menagerie of Hot Stellar Systems

Not all kinds of star clusters are seen in the Milky Way
★ Populous (LMC, M33)
★ “Faint Fuzzies” and Diffuse Star Clusters
★ Nuclear star clusters (talk by A. Jordan)

Blurring the lines between star cluster and galaxy
★ Ultra-compact dwarf galaxies (UCDs)
★ Dwarf-Globular transition objects (DGTOs)

DGTO/UCD ➔ GC

dE,N
The ACS Virgo Cluster Survey: Project Team

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The ACS Virgo Cluster Survey

**Sample**
One hundred galaxies, spanning a factor of ~ 500 in luminosity.

**Magnitude limits:** \(9.3 \leq B \leq 16.0\)
\[\Rightarrow -21.8 \leq M_B \leq -15.1\]

**Morphological Types:** E, SO, dE, dE,N, dS0 and dSph

**Membership:** Established by radial velocities.

**Observations**
HST/ACS imaging in g' and z'

Supporting observations:
★ Longslit spectroscopy for kinematic and abundance measurements
★ Imaging (g' z') of Galactic GCs
Diffuse Star Clusters in Early-Type Galaxies

Types of Star Clusters in the Milky Way

<table>
<thead>
<tr>
<th>Globular</th>
<th>Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>✭ Massive: ~200,000 $M_\odot$</td>
<td>✭ Less massive: ~3000 $M_\odot$</td>
</tr>
<tr>
<td>✭ Old: 10-13 Gyr old</td>
<td>✭ Young: 100 Myr</td>
</tr>
<tr>
<td>✭ Metal-poor</td>
<td>✭ Metal-rich</td>
</tr>
<tr>
<td>✭ Halo and bulge</td>
<td>✭ Located in the disk</td>
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Extragalactic

- “Populous” (LMC)
- “Faint Fuzzies”
- Excess faint GCs
- Tracers of star formation
Extended Star Clusters in Stellar Disks

- “Faint Fuzzies” in S0 galaxies NGC 1023, 3384. Not in NGC 3115 (S0) or NGC 3379 (E).
- Red, [Fe/H]~0.6, old (>7 Gyr)

(Larsen & Brodie 2000; Larsen et al 2001; Brodie & Larsen 2002)

Extended, old star clusters in spiral galaxies M81, M83, N6946, M101, M51

(Chandar, Whitmore & Lee 2005)

Also in N5195 (Hwang & Lee 2006)
Diffuse Star Clusters in Early-Type Galaxies

- Globular Cluster selection
- Use Custom control fields
- Knowledge of GC locus in size-magnitude diagram

Some galaxies have excess of low surface brightness objects!

“Diffuse” Star Clusters

Typical Globular Clusters
Twelve galaxies with low surface brightness excess > 3-sigma

![Diagram showing 3-sigma limits and galaxy classifications: Lenticulars, LSB dE, M49 halo.](image)
The Colors of Diffuse Star Clusters
Spatial Distributions of Diffuse Star Cluster Candidates

Red (g-z) > 1.0

Blue (g-z) < 1.0

Red star cluster Candidates follow stellar disk
Ages/Metallicities of Diffuse Star Clusters

![Graph showing the relationship between age and metallicity of diffuse star clusters.](image)
Comparison with Milky Way Star Clusters
Diffuse Star Clusters: Summary

- Some early-type galaxies (lenticulars) have a significant population of “diffuse” star clusters (but why some S0s and not others?)
- Diffuse star clusters appear to be associated with some stellar disks
- They are likely old (>5 Gyr) and metal-rich, like old disks
- Likely very easy to destroy – preserved when unperturbed in disks?
- Closest Milky way analog are old open clusters, but more luminous
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Massive Globular Clusters and Ultra-Compact Dwarf Galaxies:
The Lines Become Blurred

The most luminous globular clusters in the Galaxy and M31: the cores of stripped dwarf galaxies?

“Ultra-compact” Dwarf Galaxies (UCDs)
★ First discovered in surveys of the Fornax Cluster (Drinkwater et al 1999, Hilker et al. 1999)
★ Unresolved from ground ($r_e < 50$ pc)
★ Smaller than dEs ($r_e \sim 300$ pc)
★ Larger than GCs ($r_h \sim 3$ pc)
★ “Dwarf-Globular Transition Objects” (DGTO)
Dwarf-Globular Transition Objects and Ultra-compact Dwarfs in the Virgo Cluster

Hasegan, Ph.D. Thesis
Hasegan et al, in prep

Targeted luminous (-12 < $M_V$ < -11) GC-like objects around M87 and other ACSVCS galaxies to measure velocity dispersions
Comparisons: UCDs, DGTOs, and Globular Clusters
Dwarf Nuclei and DGTOs / UCDs indistinguishable in $M_\nu$-sigma plane

DGTOs / UCDs consistent with extrapolations of both GC and elliptical galaxy (Faber-Jackson) scaling relations

Velocity dispersion alone is insufficient
A “Break” in the Scaling Relations

A break occurs at $M \sim 2 \times 10^6 M_{\odot}$

Above the break, DGTOs and UCDs follow galaxy scaling relations

Below the break, they follow globular cluster scaling relations
How do DGTOs and UCDs form?

- Large, luminous globular clusters – not likely for all


- Remains of massive young star clusters that merged shortly after forming (Fellhauer & Kroupa 2002)
How do DGTOs and UCDs form?


☆ Properties of DGTOs consistent with either merged star cluster complexes or tidally “threshed” dE,Ns

☆ Multiple routes to formation?
High Mass-to-Light Ratios: A Need for Dark Matter?

- UCDs / DGTOs generally have higher mass-to-light ratios than allowed by stellar populations models.

- Those with masses below the “break” (< $2 \times 10^6$) have normal M/L (GC-like), and those above have high M/L (galaxy like).

![Graph showing mass-to-light ratio versus iron abundance (M/L vs. [Fe/H]) with data points and lines indicating different mass regimes.](image-url)
A Connection between UCDs and DSCs?

UCDs

Faint Fuzzies

Fellhauer & Kroupa (2002)

"Faint Fuzzies"
UCDs and DGTOs: Summary

- UCDs may represent a transition in hot stellar systems from star cluster to galaxy at $M \sim 2 \times 10^6 M_\odot$.

- Environment is important: Most are found at center of cluster.

- UCDs in “galaxy” regime have high M/L; dark matter?

- Probing extremes in surface brightness can teach us about both star clusters and galaxies

Hasegan et al (2005)

Hasegan et al, in prep