Formation Efficiencies of Globular Clusters

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Emphasis on small workshops
and visitor programs at KIAA

Please come visit!
Do Globular Cluster Systems Mirror Their Host Galaxies?
Not really...

- Globular cluster are predominantly old (> 8 Gyr) and metal-poor

Brodie & Strader (2006)
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**Issue #1:** Globular cluster formation efficiency is not constant across metallicity and age
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Specific Frequency: number of GCs normalized to $M_V=-15$

$$S_N = N_{GC} \cdot 10^{0.4(M_V+15)}$$

Purpose: “To investigate whether there is in fact a 'universal' and uniform capability for globular cluster formation.” (Harris & van den Bergh 1981)

- Spirals: $S_N \sim 1$
- Ellipticals: $S_N \sim 5$
- Dwarf Ellipticals: $S_N \sim 0-30$
- M87: $S_N \sim 14$

Issue #2: Globular cluster formation efficiency is not constant across galaxy mass and morphology
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Issue #2: Globular cluster formation efficiency is not constant across galaxy mass and morphology

A problem? No! GC systems offer a unique and complementary view on galaxy formation.
The ACS Virgo Cluster Survey

- HST/ACS imaging survey in g and z
- 100 early-type galaxies
- $-22 < M_B < -15$, giants to dwarfs
- Depth: 90% of GC population
- 16 control fields for GC identification and background subtraction
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A homogeneous survey across the mass spectrum of “surviving progenitors” and “merger products”
The ACS Virgo Cluster Survey
Data and Analysis
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- Model underlying galaxy
- Identify GC candidates
- Fit with PSF-convolved King models
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Completeness, GCLF, distances, total magnitudes
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Over 11,000 GCs detected in 100 galaxies
How does GC fraction behave across galaxy mass?

- Narrow range of $S_N$ at intermediate $L$
- High $S_N$ values for both giants and dwarfs
- Reminiscent of $M/L$ vs galaxy mass

Peng et al. (2008)
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Globular Clusters in dEs: The Role of Environment

- Dwarfs only: $M_z > -19$
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- dEs with high GC fractions are within $D_p < 1$ Mpc
- dEs within 100 kpc, stripped of GCs

Peng et al. (2008)
Globular Clusters in dEs: The Role of Environment

Implications

- GC formation in dEs is most efficient in dense regions (biased)

- Low mass halos in dense regions collapse earlier, and are perhaps more efficient at producing GCs

- Earliest collapsing low mass halos in densest regions could build metal-poor GC populations in giants


Rhode, Zepf & Santos 2005 also West (1993)
The Millennium Simulation
(Springel et al 2005, De Lucia et al 2006)

- $2160^3$ dark matter particles
- $500^3$ $h^{-1}$ Mpc volume
- $z=127$ to present
- Galaxies with stellar mass $> 3 \times 10^8$

- 126 massive galaxy clusters
- Select 15,506 simulated early-type dwarfs ($M_z>-19$ at $z=0$) and their progenitors
- 63 snapshots from $z=12$

What are the properties and star formation histories of simulated early-type cluster dwarfs?
The Millennium Simulation:
Early-type cluster dwarfs

Mass-weighted age of central dEs is older
The Millennium Simulation: Early-type cluster dwarfs

Average star formation rate of central dwarfs more peaked with rapid falloff

Star formation in central dwarfs occurs at higher star formation rate density
In local star forming galaxies, higher SFR surface density means a larger fraction of stellar luminosity/mass in massive star clusters.

We can scale the SFR and SFR densities in Millennium semi-analytic models to predict star cluster formation rates.

Cluster Formation Rate $\propto$ SFR x SFR surface density
The Millennium Simulation: Early-type cluster dwarfs

Peak formation of massive star clusters is naturally earlier than peak SFR.

SFR surface density

Star Formation Rate
The Millennium Simulation: Early-type cluster dwarfs

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Star Formation Rate

Cluster Formation Rate

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3. A dependence of massive star cluster formation on SFR density (ISM pressure?) naturally leads to GCs that are older, more metal-poor than their hosts.
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3. A dependence of massive star cluster formation on SFR density (ISM pressure?) naturally leads to GCs that are older, more metal-poor than their hosts

4. GCs of innermost dEs (D<100kpc) already stripped. Central dwarfs with high GC fractions are survivors most similar to the protogalaxies that assembled the M87 GC system