Satellites of satellites: globular cluster systems as tracers of environmental effects on Virgo early-type dwarfs

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Dynamics of low-mass stellar systems
Santiago de Chile, April 7, 2011
Early-type dwarf galaxies: nature or nurture?

- Most abundant galaxy population in dense environments.
- Low masses and densities → environmental effects?

ACS Virgo Cluster Survey

| NASA, ESA, and E. Peng (Peking University, Beijing) |

Hubble Space Telescope ACS/WFC

| STScI-PRC08-30c |

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**Primordial:** origin at early stages of cluster formation, feedback essential.

**Late origin:** (recent) end-products of physical mechanisms operating in virialized clusters:
- late (< 6 Gyr) red-sequence buildup at low masses.
- spatial and velocity distribution.
- shape, structure and kinematics.
- presence of disc-like components.
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Interactions can drive galaxy transformation in clusters

Kenney et al. (2004)

Hydrodynamical interactions
(Gunn & Gott 1972; Larson+1980)
ISM-ICM ⇒ alter SFR (colours)

Gravitational interactions
(Merritt 1984; Moore+1996)
Galaxy-galaxy and galaxy-cluster potential ⇒ alter colours and structure

Multiple regions and time scales ⇒ degeneracy
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Treu et al. (2003)
GCSs can be excellent tracers of evolutionary mechanisms

- Fossil records of formation and evolutionary processes:
  - Hydro mechanisms don’t alter GCSs properties
  - Gravitational interactions could.

- To compare the properties of Virgo dEs’ GCSs and their potential progenitors with simple predictions from interaction models.
Compilation of dEs and (potential) progenitors GCSs data

$$T_N = \frac{N_{gc}}{(M_*/10^9 M_\odot)}$$ (Zepf & Ashman 1993)

- ACSVCS (Peng et al. 2006, 2008), dEs with $M_V < -15.5$.
- Miller & Lotz (2007), dEs with $-18 < M_V < -12.5$.
- E, S0 and Sp from Spitler et al. (2008).
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2) LSB GCS similar to that of MW (Villegas+08).
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NORMAL GLOBULAR CLUSTER SYSTEMS IN MASSIVE LOW SURFACE BRIGHTNESS GALAXIES

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ABSTRACT

We present the results of a study of the globular cluster systems of six massive spiral galaxies, originally cataloged as low surface brightness (LSB) but here shown to span a wide range of surface brightness values, including two intermediate to LSB galaxies. We used the Advanced Camera for Surveys on-board Hubble Space Telescope to obtain photometry in the F475W and F775W bands and select sources with photometric and morphological properties consistent with those of globular clusters. A total of 206 candidates were identified in our target galaxies. From a direct comparison with the Galactic globular cluster system we derive specific frequency values for each galaxy that are in the expected range for late-type galaxies. We show that the globular cluster candidates in all galaxies have properties consistent with globular cluster systems of previously studied galaxies in terms of luminosity, sizes and color. We establish the presence of globular clusters in the two intermediate to LSB galaxies in our sample and show that their properties do not have any significant deviation from the behavior observed in the other sample galaxies, implying that these properties do not evolve with the surface brightness of the galaxies. Our results are broadly consistent with a scenario in which low surface brightness galaxies follow roughly the same evolutionary history as normal (i.e. high surface) brightness galaxies except at a much lower rate, but require the presence of an initial period of star formation intense enough to allow the formation of massive star clusters.
LSB disc progenitors?
   1) Constraints from GC abundance

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3) Mass loss:
   - from the outside-in.
   - for a given radius, $\dot{M}_{dm} \geq \dot{M}_{gc} \geq \dot{M}_{disc}$
LSB disc progenitors?
1) Constraints from GC abundance

Harassment cannot explain high-$T_N$ dEs.
Fraction of metal-rich GCs decreases towards low-mass galaxies.

Peng et al. 2006
More extended spatial distribution for metal-poor GCs in spirals.

MW (Bica et al. 2006)
LSB disc progenitors?

2) Constraints from GCS metallicity (colour) distribution

Outside-in stripping would increase $f_{red}$

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How would inner dwarfs preferentially retain more GCs? (Peng+08)

**TABLE 7**
BINS OF $R_{3d}$ FOR GALAXIES WITH $M_\ell > -19$

| $R_{3d}$ range (Mpc) | $(R_{3d})$ Mpc | $S_{N,z}$ | $T$  | $S_{N,z,blue}$ | $S_{N,z,red}$ |
|----------------------|----------------|-----------|------|----------------|---------------|
| (0.00, 0.25)         | 0.19           | 1.38      | 11.3 | 1.19           | 0.18          |
| (0.25, 0.50)         | 0.34           | 2.39      | 23.9 | 2.19           | 0.20          |
| (0.50, 1.00)         | 0.71           | 2.13      | 20.8 | 1.87           | 0.26          |
| (1.00, 1.50)         | 1.27           | 1.27      | 13.5 | 1.05           | 0.22          |
| (1.50, 2.00)         | 1.65           | 0.78      | 7.7  | 0.63           | 0.10          |
| (2.00, 2.50)         | 2.14           | 0.50      | 5.2  | 0.47           | 0.03          |
Gas-stripped dIrr progenitors?

1) Constraints from GC abundance

- dlrrs from Georgiev et al. (2010)
- $T_N(dE,N)$ and $T_N(dlrr)$ different at 95% c.l.
- $T_N(dE,nN)$ and $T_N(dlrr)$ different at 85% c.l.
1) Constraints from dEs radial distribution

No simple explanation for negative $T_N$ gradient towards outskirts.

Efficient GC stripping occurs at $r \lesssim 0.2 \, r_{200}$ (Peng et al. 2008).

Clustercentric $M_*$ loss for harassed LMC-like dwarfs (Mastropietro+05)
Evidences for high initial DM masses?

- Clustercentric distribution \(\rightarrow\) total mass segregation?
- High \(T_N\) expected if universal specific formation efficiency as a function of total mass (e.g., Spilter & Forbes 2009; Georgiev+10).
- Very extended spatial distribution down to \(r_{200}/5\).
Evidences for high initial DM masses?

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What about internal mechanisms?

Biased GC formation (Peng+08)

- Inner dEs form earlier $\rightarrow$ high SFR $\rightarrow$ high GC formation efficiency
- High SFR $\rightarrow$ energy feedback $\rightarrow$ thick systems + extended GC distribution + baryon-dominated inner regions.
- Gas-stripping at early stages.

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Perspectives

- Improve numerical simulations, vary orbits, GCSs properties, galaxy masses...
- Extend to non-nucleated and dwarfs with disc features at different clustercentric distances → NGVS
- Intra-cluster GCs? (Lee+10; Peng+11; West+11)
- Spectroscopy of GC candidates (VLT+GTC)
Globular cluster systems can be powerful tools for understanding evolutionary mechanisms in high-density environments.

Skillman & Bender (1995):

"...present day dEs and dIrrs may share a common ancestor, just as humans and apes do, but (most) dEs do not evolve from dIrrs (or LSB discs), just as (most) humans do not evolve from apes."
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Simulations from Aguerri & González-García (2009)

- TID4 → MW-like, B/D = 1:2, only harassment.
- TID2 → B/D = 1:5, only harassment.
- GST1 → B/D = 1:12, harassment + 'gas' loss (10%).
- 500 GCs, $f_{red} = 0.32$
- Metal-rich: $n = 1$, $r_e = 3$ kpc, some rotation.
- Metal-poor: $n = 3 - 4$, $r_e = 8$ kpc, low $v/\sigma$. 

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GCS nor randomly distributed + spectroscopic confirmation (Beasley et al. 2006)
| Quantity          | VCC1261     | VCC1528     | VCC1087     |
|-------------------|-------------|-------------|-------------|
| \( M_B \)         | -17.85      | -16.72      | -16.87      |
| \( v_{\text{grad}} \) (km s\(^{-1}\) arcmin\(^{-1}\)) | -51 ± 46 (-101 ± 42) | 52 ± 17 | 87 ± 29 (74 ± 31) |
| \( v_{\text{max}} \) (km s\(^{-1}\)) | 71 ± 64 (105 ± 44) | 63 ± 21 | 104 ± 35 (49 ± 21) |
| \( v_{\text{rot}} \) (km s\(^{-1}\)) | 47 ± 31 | 68 ± 40 |
| \( \theta_{\text{sys}} \) (deg) | 152 ± 27 | 43 ± 136 | 129 ± 50 |
| \( v_{\text{sys}} \) (km s\(^{-1}\)) | 1865 ± 19 | 1681 ± 21 | 681 ± 19 |
| \( \sigma_{\text{meas.}} \) (km s\(^{-1}\)) | 67 ± 25 | 50 ± 21 | 49 ± 15 |
| \( \sigma_{\text{los}} \) (km s\(^{-1}\)) | 55 ± 13 | 23 ± 9 | 35 ± 16\(^a\) |
| \( \left( v_{\text{rot}} / \sigma_{\text{los}} \right) \) | 1.3 ± 0.7 (1.8 ± 0.5) | 2.7 ± 0.5 | 3.0 ± 0.6\(^b\) (1.6 ± 0.6) |
| \( \gamma \) | 1.9 ± 0.4 | 2.0 ± 0.3 | 2.1 ± 0.4 |
| \( M_{\text{pres}} \) \( (10^{10} M_\odot) \) | 0.52 ± 0.17 (0.53 ± 0.16) | 0.20 ± 0.09 | 0.35 ± 0.15 (0.49 ± 0.23) |
| \( M_{\text{rot}} \) \( (10^{10} M_\odot) \) | 0.56 ± 0.50 (1.67 ± 0.7) | 0.52 ± 0.17 | 2.21 ± 0.64 (0.34 ± 0.15) |
| \( \Gamma_B \) | 5.0 ± 2.5 (10.2 ± 3.3) | 9.5 ± 2.5 | 29.3 ± 8.7 (6.8 ± 2.2) |
### Summary

|                   | Gas stripping                      | Harassment                               |
|-------------------|------------------------------------|------------------------------------------|
| **LSB → dE**      | $N_{gc}$ too high (+bulges, thickness...) | $T_N$ higher in inner regions          |
|                   |                                    | $f_{blue} >> f_{red}$                    |
| **dlrr → dE**     | $T_N$ compatible at low masses      | Radial distribution                     |
|                   |                                    | Too much mass loss ($\downarrow N_{gc}$) |

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