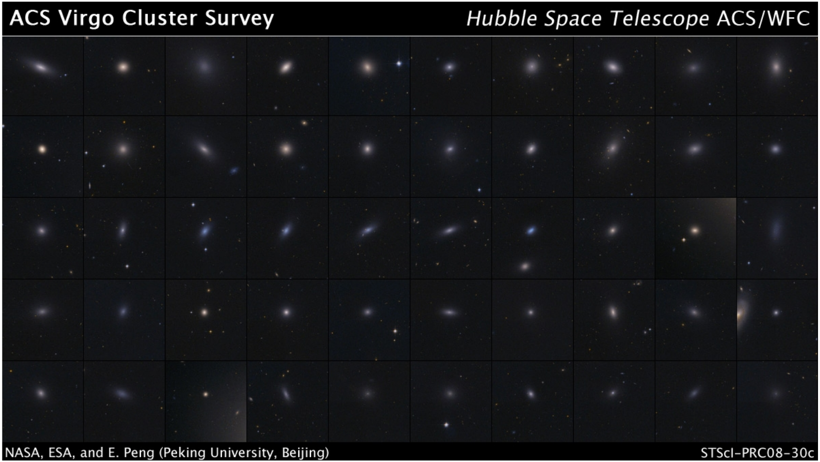
Satellites of satellites: globular cluster systems as tracers of environmental effects on Virgo early-type dwarfs

Rubén Sánchez-Janssen (ESO, Chile)
J.A.L. Aguerri (IAC, Spain)
(MNRAS submitted)

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?



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

STScI-PRC08-30c

Early-type dwarf galaxies: nature or nurture?

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

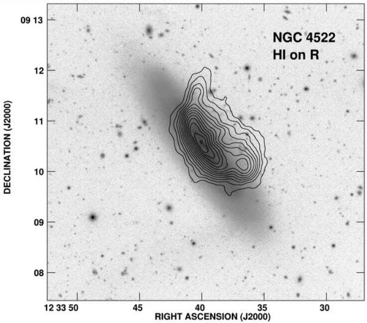
- **Primordial:** origin at early stages of cluster formation, feedback essential.
- **Late origin:** (recent) end-products of physical mechanisms operating in virialized clusters:
  - late (< 6 Gyr) red-sequence buildup at low masses.
  - spatial and velocity distribution.
  - shape, structure and kinematics.
  - presence of disc-like components.

Early-type dwarf galaxies: nature or nurture?

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

- **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.

Interactions can drive galaxy transformation in clusters



Kenney et al. (2004)

Hydrodynamical interactions

(Gunn & Gott 1972; Larson+1980)

ISM-ICM $\Rightarrow$ alter SFR (colours)

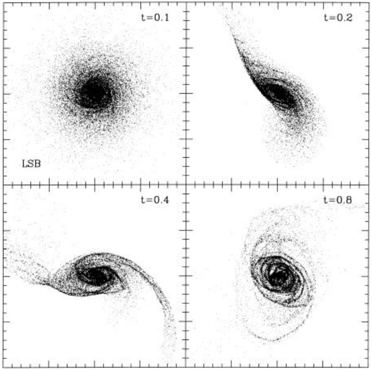
Gravitational interactions

(Merritt 1984; Moore+1996)

Galaxy-galaxy and galaxy-cluster potential $\Rightarrow$ alter colours *and* structure

Multiple regions and time scales $\Rightarrow$ **degeneracy**

Interactions can drive galaxy transformation in clusters



Moore et al. (1998)

Hydrodynamical interactions

(Gunn & Gott 1972; Larson+1980)

ISM-ICM ⇒ alter SFR (colours)

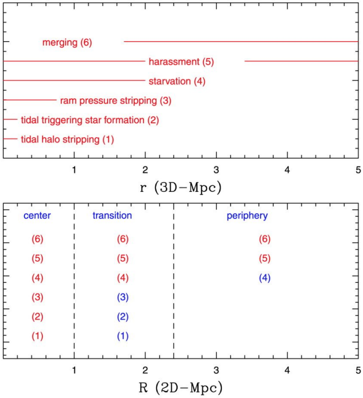
Gravitational interactions

(Merritt 1984; Moore+1996)

Galaxy-galaxy and galaxy-cluster potential ⇒ alter colours *and* structure

Multiple regions and time scales ⇒ **degeneracy**

Interactions can drive galaxy transformation in clusters



Treu et al. (2003)

Hydrodynamical interactions

(Gunn & Gott 1972; Larson+1980)

ISM-ICM ⇒ alter SFR (colours)

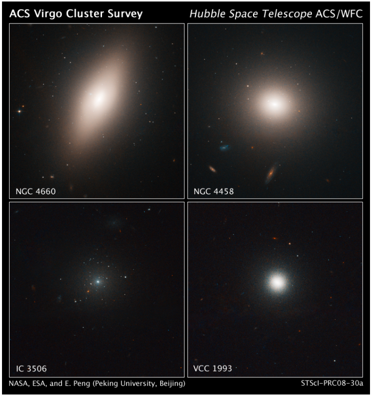
Gravitational interactions

(Merritt 1984; Moore+1996)

Galaxy-galaxy and galaxy-cluster potential ⇒ alter colours *and* structure

Multiple regions and time scales ⇒ **degeneracy**

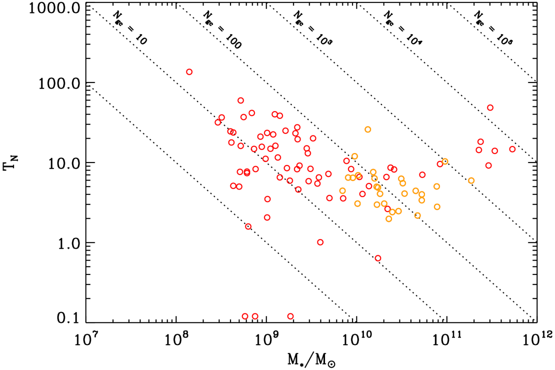
GCSs can be excellent tracers of evolutionary mechanisms



- 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

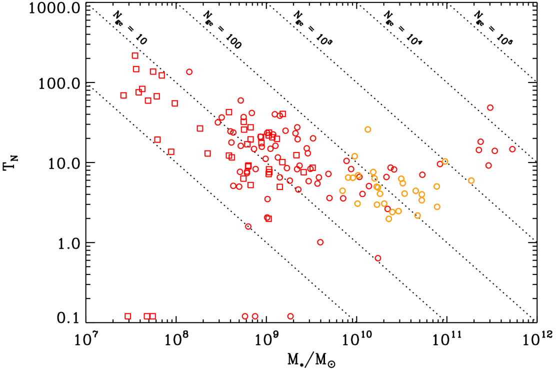
$$T_N = N_{gc}/(M_\star/10^9 M_\odot)$$ (Zepf & Ashman 1993)



- 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).

Compilation of dEs and (potential) progenitors GCSs data

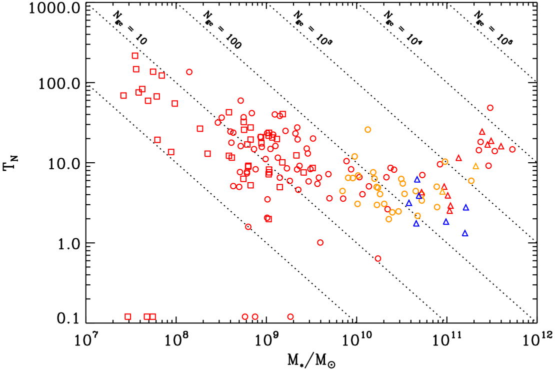
$$\mathrm{T}_N = N_{gc}/(\mathrm{M}_\star/10^9\mathrm{M}_\odot)$$ (Zepf & Ashman 1993)



- 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).

Compilation of dEs and (potential) progenitors GCSs data

$$T_N = N_{gc}/(M_\star/10^9 M_\odot)$$ (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).

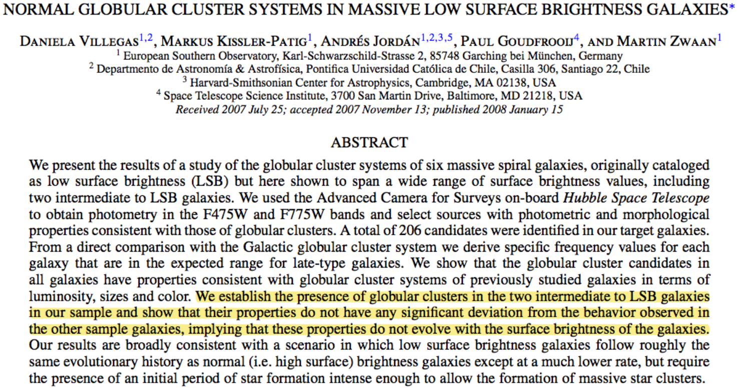
LSB disc progenitors?

1) Constraints from GC abundance

1) A simple scaling of the M$_\star \approx 10^{10}$ M$_\odot$ LSBs simulated by Moore+98.
2) LSB GCS similar to that of MW (Villegas+08).

LSB disc progenitors?
1) Constraints from GC abundance

1) A simple scaling of the M$_\star \approx 10^{10}$ M$_\odot$ LSBs simulated by Moore+98.
2) LSB GCS similar to that of MW (Villegas+08).



NORMAL GLOBULAR CLUSTER SYSTEMS IN MASSIVE LOW SURFACE BRIGHTNESS GALAXIES*

Daniela Villegas[1,2], Markus Kissler-Patig[1], Andrés Jordán[1,2,3,5], Paul Goudfrooij[4], and Martin Zwaan[1]
[1] European Southern Observatory, Karl-Schwarzschild-Strasse 2, 85748 Garching bei München, Germany
[2] Departmento de Astronomía & Astrofísica, Pontifica Universidad Católica de Chile, Casilla 306, Santiago 22, Chile
[3] Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA
[4] Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA
Received 2007 July 25; accepted 2007 November 13; published 2008 January 15

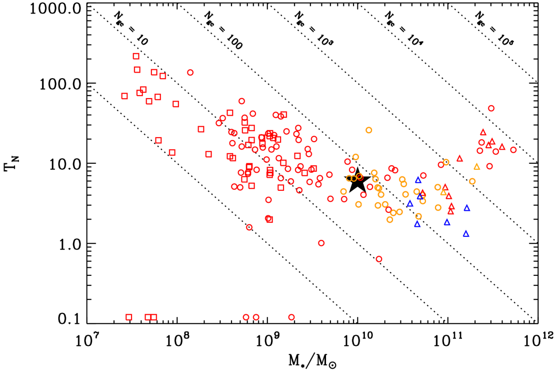
ABSTRACT

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

1) A simple scaling of the $M_\star \approx 10^{10}$ $M_\odot$ LSBs simulated by Moore+98.
2) LSB GCS similar to that of MW (Villegas+08).



LSB disc progenitors?

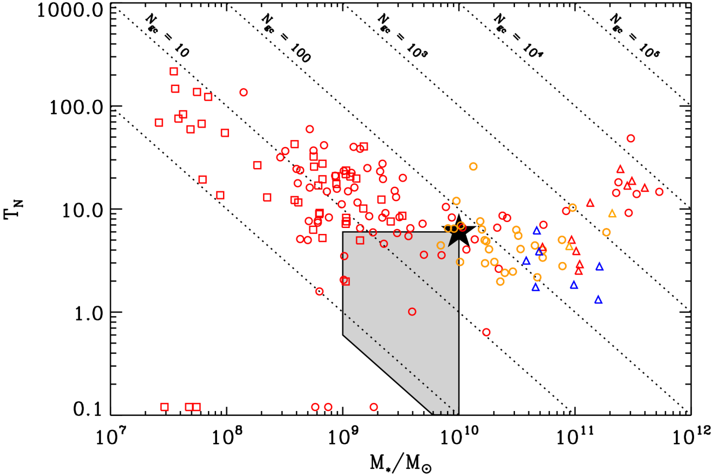
1) Constraints from GC abundance

1) A simple scaling of the $\mathrm{M}_\star \approx 10^{10}$ $\mathrm{M}_\odot$ LSBs simulated by Moore+98.
2) LSB GCS similar to that of MW (Villegas+08).
3) Mass loss:
   - from the outside-in.
   - for a given radius, $\dot{\mathrm{M}}_{dm} \geq \dot{\mathrm{M}}_{gc} \geq \dot{\mathrm{M}}_{disc}$

LSB disc progenitors?

1) Constraints from GC abundance

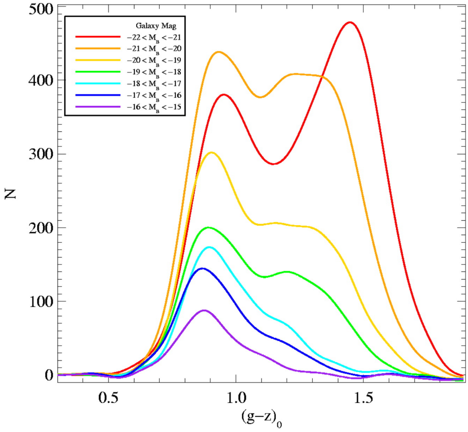
Harassment can not explain high-T$_N$ dEs.



LSB disc progenitors?

2) Constraints from GCS metallicity (colour) distribution

Fraction of metal-rich GCs decreases towards low-mass galaxies.

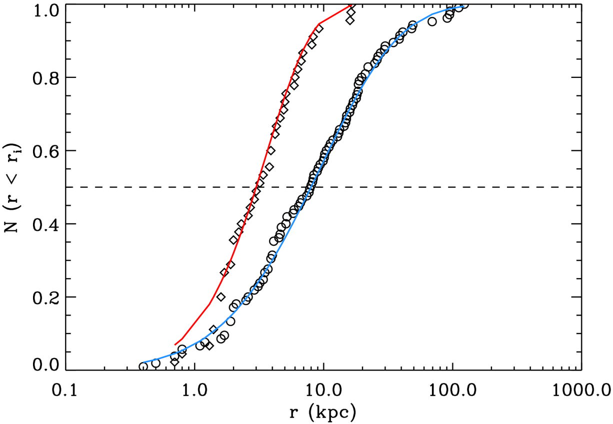


Peng et al. 2006

LSB disc progenitors?

2) Constraints from GCS metallicity (colour) distribution

More extended spatial distribution for metal-poor GCs in spirals.

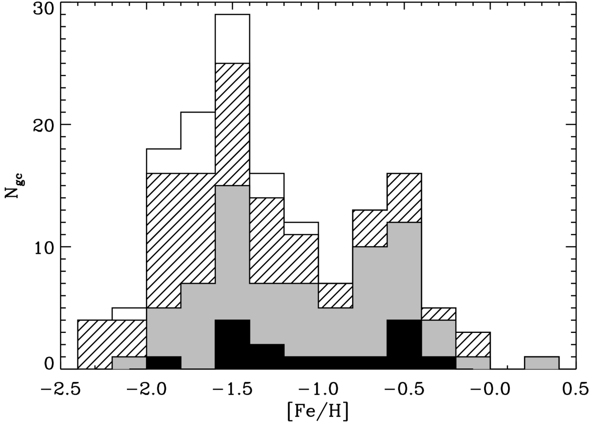


MW (Bica et al. 2006)

LSB disc progenitors?

2) Constraints from GCS metallicity (colour) distribution

Outside-in stripping would increase f_{red}



LSB disc progenitors?

3) Constraints from T$_N$ clustercentric distribution

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

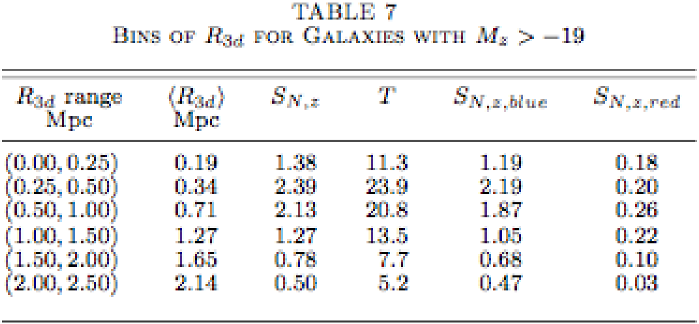
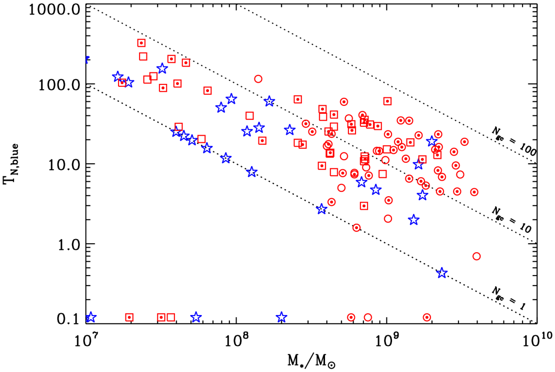


TABLE 7
BINS OF R_{3d} FOR GALAXIES WITH $M_z > -19$

R_{3d} range Mpc	$\langle R_{3d} \rangle$ 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	0.68	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



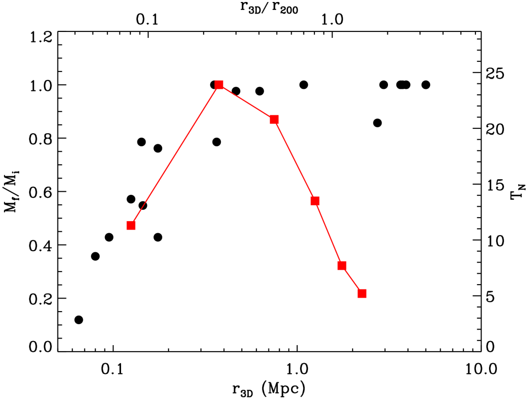
- dIrrs from Georgiev et al. (2010)
- T_N(dE,N) and T_N(dIrr) different at 95% c.l.
- T_N(dE,nN) and T_N(dIrr) different at 85% c.l.

Harassed dIrr progenitors?

1) Constraints from dEs radial distribution

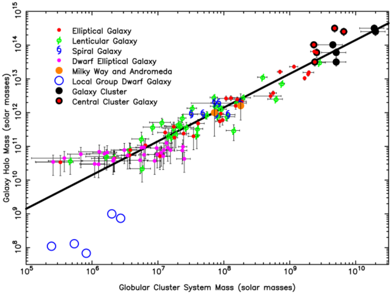
No simple explanation for negative T_N gradient towards outskirts.

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



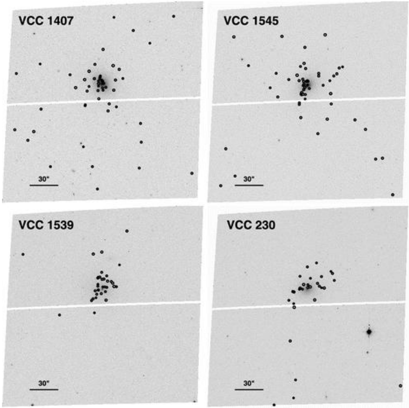
Clustercentric $M_\star$ loss for harassed LMC-like dwarfs (Mastropietro+05)

Evidences for high *initial* DM masses?



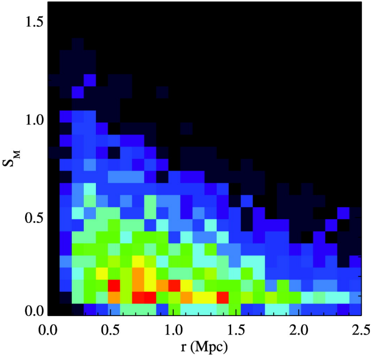
- Clustercentric distribution → *total* mass segregation?
- High T$_N$ expected if universal specific formation efficiency as a function of total mass (e.g., Spilter & Forbes 2009; Georgiev+10).
- Very extended spatial distribution down to r$_{200}$/5.

Evidences for high *initial* DM masses?



- Clustercentric distribution → *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 $\mathrm{r}_{200}/5$.

What about internal mechanisms?



Biased GC formation (Peng+08)

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

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)

To conclude...

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."

To conclude...

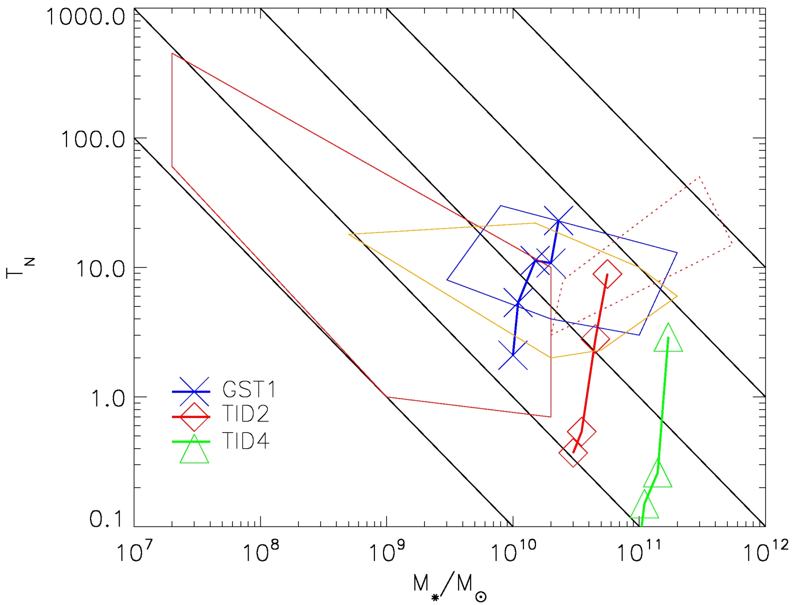
Globular cluster systems can be powerful tools for understanding evolutionary mechanisms in high-density environments.

Skillman & Bender (1995):

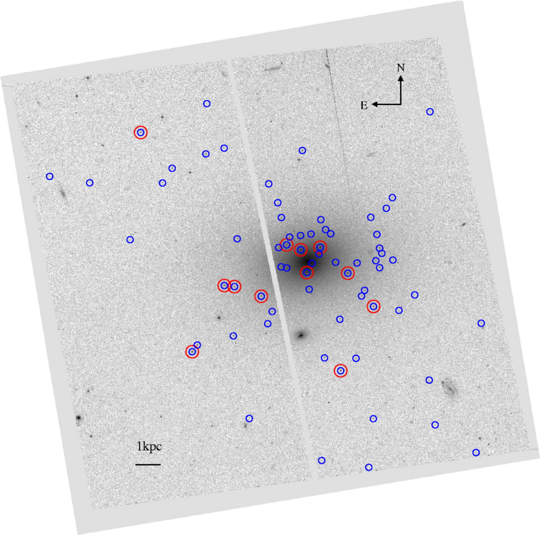
"...present day dEs and dIrrs may share a common ancestor, just as humans and apes do, but (most) dEs do not evolve from dIrrs (or LSB discs), just as (most) humans do not evolve from apes."

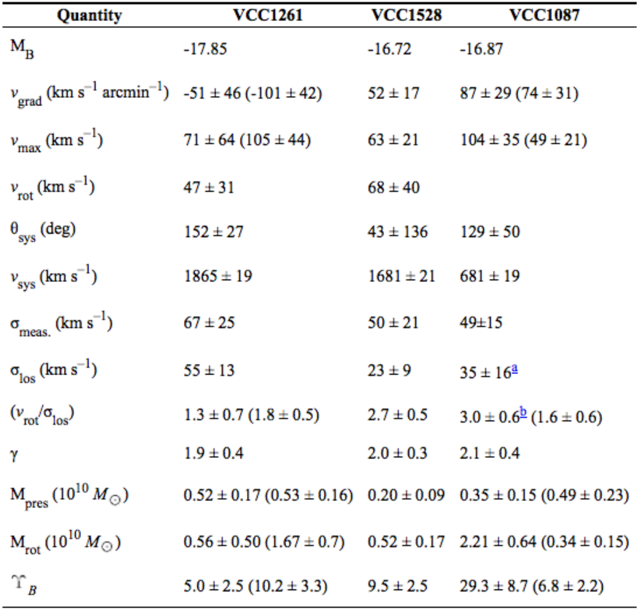
Simulations from Aguerri & González-García (2009)

- 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: $n = 1$, $\mathrm{r}_e = 3$ kpc, some rotation.
- Metal-poor: $n = 3 - 4$, $\mathrm{r}_e = 8$ kpc, low v/σ.


1000.0
100.0
10.0
1.0
0.1
T_N
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
$M_*/M_\odot$
GST1
TID2
TID4

GCS nor randomly distributed + spectroscopic confirmation (Beasley et al. 2006)





Quantity	VCC1261	VCC1528	VCC1087
M_B	-17.85	-16.72	-16.87
v_{grad} (km s^{-1} $arcmin^{-1}$)	-51 ± 46 (-101 ± 42)	52 ± 17	87 ± 29 (74 ± 31)
v_{max} (km s^{-1})	71 ± 64 (105 ± 44)	63 ± 21	104 ± 35 (49 ± 21)
v_{rot} (km s^{-1})	47 ± 31	68 ± 40	
θ_{sys} (deg)	152 ± 27	43 ± 136	129 ± 50
v_{sys} (km s^{-1})	1865 ± 19	1681 ± 21	681 ± 19
$\sigma_{meas.}$ (km s^{-1})	67 ± 25	50 ± 21	49±15
σ_{los} (km s^{-1})	55 ± 13	23 ± 9	35 ± 16[a]
(v_{rot}/σ_{los})	1.3 ± 0.7 (1.8 ± 0.5)	2.7 ± 0.5	3.0 ± 0.6[b] (1.6 ± 0.6)
γ	1.9 ± 0.4	2.0 ± 0.3	2.1 ± 0.4
M_{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_{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)
Υ_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 $f_{blue} >> f_{red}$
dIrr → dE	T_N compatible at low masses	Radial distribution Too much mass loss ($\downarrow N_{gc}$)