Stellar halos & LSB features from deep VST surveys

Enrichetta Iodice
INAF- Astronomical Observatory of Capodimonte
Napoli, Italy

VST color composite image of NGC1316
VST survey of Early-type GAlaxieS (VEGAS) is a deep, multi-band (ugri) imaging survey of early-type galaxies in groups & clusters at VST. VEGAS is based on the GTO assigned at INAF - 2011-2016, PI: M. Capaccioli, ~55 nights - 2016-2021, PI: E. Iodice, ~62 nights. VST is a 2.6m wide-field optical survey telescope, located at ESO Cerro Paranal, Chile. http://www.na.astro.it/vegas/VEGAS/Welcome.html
The Fornax Deep Survey with VST

- joint project based on
  VEGAS (P.I. E. Iodice)
  &
  OmegaCam GTO (FOCUS, P.I. R. Peletier)

- new, multi-imaging (u, g, r, i bands) survey of the Fornax Cluster

- FDS aims to cover 26 deg$^2$ around the core of the Fornax cluster out to the virial radius, including the region of Fornax A
VEGAS & FDS science aims

- map the light distribution and colors out to 8-10 Re and down to the faint surface brightness levels of $\mu_g \approx 31 \text{ mag/arcsec}^2$, $\mu_r \approx 28 \text{ mag/arcsec}^2$, $\mu_i \approx 27 \text{ mag/arcsec}^2$

- study of the galaxy structure and its faint stellar halo, including the diffuse light component, inner substructures as signatures of recent cannibalism events, inner disks and bars

- detection of the external low-surface brightness structures in galaxies, like tidal tails, stellar streams and shells and study the connection with environment

- for those galaxies in the sample with D< 40 Mpc, to census the GCs and galaxy satellites in the outermost regions of the host galaxy and to analyse their photometric properties

- the full sample proposed for VEGAS will provide essential statistical constraints on theoretical models and enable discrimination among competing galaxy formation theories
VEGAS + FDS publications


- **Cantiello M. et al., 2018**, A&A, 611, 93: *VEGAS-SSS II. Comparing the globular cluster systems in NGC3115 and NGC1399 using VEGAS and FDS survey data*


- **Iodice E. et al. 2015**, A&A, 574, 111: *A forming wide polar-ring galaxy at z ∼ 0.05 in the VST Deep Field of the Fornax cluster*
VEGAS + FDS publications

- Iodice E. et al. 2015, A&A, 574, 111: A forming wide polar-ring galaxy at $z \sim 0.05$ in the VST Deep Field of the Fornax cluster

- images from VEGAS
- results on stellar halos & LSB
- observations vs theoretical predictions
NGC5018 group

VEGAS ongoing projects:

Mapping the galaxy structure, interactions and intra-group light in the NGC5018 group

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$L_g (g - r) = 0.8$ mag  ~ similar to the color to the halo of the BCG
VEGAS ongoing projects:

NGC 5018 group

Mapping the galaxy structure, interactions and intra-group light in the NGC5018 group

$L_g (g - r) = 0.8 \text{ mag} \sim$ similar to the color to the halo of the BCG

$\sim 200 \text{ kpc}$
Mapping the galaxy structure, interactions and intra-group light in the NGC5018 group

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$g-r \approx 0.65-0.7 \pm 0.02$ mag
Mapping the galaxy structure, interactions and intra-group light in the NGC5018 group


$g-r \sim 0.65-0.7 \pm 0.02$ mag

$g-r \sim 0.9-1.1 \pm 0.5$ mag
Mapping the galaxy structure, interactions and intra-group light in the NGC5018 group


g-r~0.65-0.7 ± 0.02 mag

ng-r~0.9-1.1 ± 0.5 mag
Fornax Deep Survey with VST

Results & ongoing works
structure of the bright galaxies (m_B<15mag) inside R<R_{vir} 

stellar halos in ETGs

LSB & Dwarf galaxies

science on background objects

GCs distribution
Fornax Deep Survey with VST

observation were completed in Nov 2017 - reduced data will be released on April 2019

Tot int. time/field:

- $u$: 3 hrs
- $g$ & $r$: 2.3 hrs
- $i$: 1.8 hrs
Fornax Deep Survey with VST

observation were completed in Nov 2017 - reduced data will be released on April 2019

Tot int. time / field:
- $u$: 3 hrs
- $g$ & $r$: 2.3 hrs
- $i$: 1.8 hrs

- g, r and i completed in Nov 2016, to be reduced
- u completed in 2017
- g and r completed in Nov 2015 and reduced
- i completed in Nov 2017

- g and r completed in Nov 2016, reduced
- u and i completed Oct 2017
FDS: the ETGs inside $R_{\text{vir}}$

for $R<R_{\text{vir}}$ (~0.7 Mpc) there are ~20 ETGs & ~10 LTGs
the VST mosaic of the Fornax cluster $R<R_{\text{vir}}$ ($\sim 3 \times 3 \text{ sq}^2$)
VST color composite image
https://www.eso.org/public/news/eso1612/
The extended stellar halo of NGC1399

The extended stellar halo of NGC1399

The extended stellar halo of NGC1399


$\mu_g \sim 31 \text{ mag/arcsec}^2$
The extended stellar halo of NGC1399

The extended stellar halo of NGC1399

The intracluster regions: the ICL
The intracluster regions: the ICL

NGC1389

NGC1387

NGC1379

NGC1381

NGC1380B

NGC1380

NGC1399

NGC1404

FCC182

NGC1374
- $10 < R < 40$ arcmin ($\sim 58$-230 kpc)
- $\mu_r \sim 29 - 30$ mag/arcsec$^2$
- $L_g \sim 8.3 \times 10^9 \, L_\odot$
- $g-r \sim 0.7$ mag
ICL vs IC GCs

blue GCs from D’Abrusco et al. 2016

--- blue GCs from Cantiello et al. 2017
The bright ETGs in the $R_{\text{vir}}$ of the cluster
Table 2. Early-type galaxies inside the virial radius ($R_{\text{vir}} \sim 0.7$ Mpc) of the Fornax cluster, brighter than $m_B < 15$ mag.

<table>
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<th>object</th>
<th>$\alpha$ h:m:s</th>
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Notes. Col.1 - Fornax cluster members from Ferguson (1989). Col.2 and Col.3 - Right ascension and declination. Col.4, Col.5 and Col.6 - Morphological type, Heliocentric radial velocity and total magnitude in the B band given by Ferguson (1989). Col.7 - Location in the FDS field (see Fig.1). Col.8 - Other catalogue name.
The bright ETGs in the $R_{\text{vir}}$ of the cluster

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Notes. Col.1 - Fornax cluster members from Morphological type, Heliocentric radial velocity and total magnitude in the B band given by Ferguson (1989). Col.7 - Location in the FDS field (see Fig.1). Col.8 - Other catalogue name.

Surface photometry:
- deep images & isophotal analysis
- total magnitudes & $R_e$ in $ugri$
- $g-r$ & $g-i$ integrated colors, color profiles & 2D colormaps
- stellar M/L
- overview of the galaxy structure (including stellar halos) vs environment

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The bright ETGs in the $R_{\text{vir}}$ of the cluster: RESULTS
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The bulk of the gravitational interactions between galaxies should have happened on the W-NW side of the cluster, where most of the bright ETGs are located and where the intra-cluster baryons are found.
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The bright ETGs in the Rvir of the cluster: RESULTS

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The bright ETGs in the region of the cluster: RESULTS

The bulk of the gravitational interactions between galaxies should have happened on the W-NW side of the cluster, where most of the bright ETGs are located and where the intra-cluster baryons are found.
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asymmetric stellar halos
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$\sum \sim 45 \text{ gal/Mpc}$

$D \sim 0.3 \text{ Mpc}$
The bright ETGs in the $R_{\text{vir}}$ of the cluster: RESULTS

$\Sigma \sim 45 \text{ gal/Mpc}$

$D \sim 0.3 \text{ Mpc}$
stellar halos made by the accretion of rather massive, metal-rich satellite galaxies

\[ \sum \approx 45 \text{ gal/Mpc} \]

D \approx 0.3 \text{ Mpc}

outskirts > 10 -30 kpc

R > 3 R_e

< 1- 3 kpc
stellar halos made by the accretion of rather massive, metal-rich satellite galaxies.

\[ \Sigma \sim 45 \text{ gal/Mpc} \]

\[ D \sim 0.3 \text{ Mpc} \]

blue colors in the outskirts only allow for contribution of minor mergers.
FDS: the SW group

![Diagram showing FCC ETGs + LTGs members m_B<15 mag]
FDS: the SW group

NGC1316
FDS: the SW group

Fornax core
NGC1399

Drinkwater et al. 2001

Fornax SW group
NGC1316

CC ETGs + LTGs members m_B<15 mag
VST color composite image
https://www.eso.org/public/images/eso1734a/
VST color composite image
https://www.eso.org/public/images/eso1734a/
Fornax A: a two-phase assembly caught in act

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Fornax A: a two-phase assembly caught in act

surface photometry out to 33 arcmin (~200 kpc ~15Re)

Caon et al. 1994

Fornax A: a two-phase assembly caught in act

data analysis suggests that we are catching in act the second phase of the mass assembly in this galaxy: accretion of smaller satellites is going on
Observations vs theoretical predictions

the build up of the stellar halo in NGC1316
Observations vs theoretical predictions

The build up of the stellar halo in NGC1316 formed by gradual accretion of several progenitors: similar morphology + total extension.

Cooper et al. 2010
Observations vs theoretical predictions

The build up of the stellar halo in NGC1316 formed by gradual accretion of several progenitors: similar morphology + total extension

- $SB \ (r \ band) = 26.6 - 30.6 \ \text{mag/arcsec}^2$
- exponential profile
- luminous substructures = recent events
Observations vs theoretical predictions for the build up of the stellar halo in NGC1316 formed by gradual accretion of several progenitors:

- Similar morphology + total extension

- SB (r band) = 26.6 - 30.6 mag/arcsec²
- Exponential profile
- Luminous substructures = recent events

\[ L_{(L2+L3)} = 7 \times 10^9 L_\odot \]
\[ g-r = 0.54 \text{ mag} \]

Similar to the total luminosity \((10^7 - 10^9 L_\odot)\)

&

Colors \(0.54 \leq g-r \leq 0.6 \text{ mg}\) of the dwarf galaxies inside the envelope
Observations vs theoretical predictions

Fit of the SB profiles to identify the main components dominating the galaxy light

Observations vs theoretical predictions

Table 6. Total and accreted stellar masses of galaxies in our sample.

<table>
<thead>
<tr>
<th>Object</th>
<th>(u−g)</th>
<th>(g−r)</th>
<th>M/L</th>
<th>M* tot [M⊙]</th>
<th>M* total accreted [M⊙]</th>
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<td>NGC 5018</td>
<td>1.6 ± 0.4</td>
<td>0.7 ± 0.2</td>
<td>1.97 ± 0.9 × 10^{11}</td>
<td>2.7 ± 0.4 × 10^{11}</td>
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<tr>
<td>NGC 5022</td>
<td>1.0 ± 0.4</td>
<td>1.6 ± 0.5</td>
<td>1.48 ± 1.6 × 10^{10}</td>
<td>1.4 ± 0.4 × 10^{10}</td>
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<tr>
<td>MCG-03-34-013</td>
<td>0.6 ± 0.1</td>
<td>1.4 ± 0.1</td>
<td>0.82 ± 0.3 × 10^{9}</td>
<td>3.3 ± 0.3 × 10^{9}</td>
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Note — Columns 2, 3 and 4 show the mean, extinction corrected, u-g and g-r colours of each galaxy and the relative mass-to-light ratios in the g band. Columns 5 is the galaxy stellar mass, while column 6 reports the total accreted stellar masses, derived from the three and two-component fit.

Figure 13. VST g band profiles of NGC 5022 (top), fitted with a three components model, and MCG-03-34-013 (bottom), fitted with a double Sersic model.

Figure 14. Accreted mass fraction vs. total stellar mass for ETGs. The measurement for NGC 5018 is given as red triangle. Black circles correspond to other BCGs from the literature (Seigar et al. 2007; Bender et al. 2015; Iodice et al. 2016; Spavone et al. 2017). Red and blue regions indicate the predictions of cosmological galaxy formation simulations by Cooper et al. (2013, 2015) and Rodriguez-Gomez et al. (2016), respectively. Purple-grey points show the mass fraction associated with the streams from Tab. 1 in Cooper et al. (2015).

The outskirts of NGC 5018 and NGC 5022, which are g−r ∼ 0.9−1.4 for 1≤R≤4 arcm (see Fig. 7). Therefore, we claim that such a feature could be made by a stripped material from the galaxy outskirts in a close passage. In particular, the almost polar half-ring on the East side of NGC 5022 could be formed by the interaction with a high inclined orbit (see e.g. Bournaud & Combes 2003). Moreover, such an interaction might have triggered the new star formation regions.
Observations vs theoretical predictions

Table 6. Total and accreted stellar masses of galaxies in our sample.

<table>
<thead>
<tr>
<th>Object</th>
<th>(u-g)</th>
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Note: Columns 2, 3 and 4 show the mean, extinction corrected, (u-g) and (g-r) colours of each galaxy and the relative mass-to-light ratios in the g band. Columns 5 is the galaxy stellar mass, while column 6 reports the total accreted stellar masses, derived from the three and two-component fit.

Figure 13. VST g band profiles of NGC 5022 (top), fitted with a three components model, and MCG-03-34-013 (bottom), fitted with a double Sersic model.

Figure 14. Accreted mass fraction vs. total stellar mass for ETGs. The measurement for NGC 5018 is given as red triangle. Black circles correspond to other BCGs from the literature (Seigar et al. 2007; Bender et al. 2015; Iodice et al. 2016; Spavone et al. 2017). Red and blue regions indicate the predictions of cosmological galaxy formation simulations by Cooper et al. (2013, 2015) and Rodriguez-Gomez et al. (2016), respectively. Purple-grey points show the mass fraction associated with the streams from Tab. 1 in Cooper et al. (2015).

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Intragroup light in NGC 5018

Table 6. Total and accreted stellar masses of galaxies in our sample.

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Pillepich et al. 2018, R>100 kpc

Pillepich et al. 2018, R<30 kpc center+ICL
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$M_\ast$ total

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Observations vs theoretical predictions

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ETGs in high-density regions of Fornax

massive stellar halos in dense environment?

ETGs in low-density regions of Fornax
Concluding remarks

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- the arcsec-level angular resolution of 0.21 arcsec/pixel
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~ the galaxy structure from the brightest inner regions to the faint outskirts, out to the intracluster regions

~ stellar halos properties (structure, colors, mass fraction) as function of the environment

~ provides observables to be compared with simulations