Probing the mass assembly of massive galaxies with ultra-deep imaging

CFHT User’s meeting, 2013, Campbell River

Sanjaya Paudel, Etienne Ferriere, Leo Michel-Dansac, Jean-Charles Cuillandre, Michele Cappellari, Richard McDermid, Eric Emsellem, Davor Krajnovic, Frédéric Bournaud, Laura Ferrarese, Patrick Durrell, Eric Peng and the NGVS, Atlas3D and MATLAS teams
Probing the mass assembly of massive galaxies
Probing the mass assembly of massive galaxies

The end product of the hierarchical scenario
Three processes to produce an Early-Type like galaxy

Major merger

Minor merger history

Disk instabilities

Bournaud et al, 2009

Martig et al, 2009

Bournaud et al, 2010
Three processes to produce an Early-Type like galaxy

- Major merger
- Minor merger history
- Disk instabilities

Bournaud et al, 2009
Martig et al, 2009
Bournaud et al, 2010

Producing various types of very low-surface brightness fine structures: tails, plumes, streams, shells
Probing the mass assembly of massive galaxies

- Simulated surface brightness maps

![Image of simulated surface brightness maps]

✓ At 32 mag/arcsec-2

✓ Cutting at 29 mag/arcsec²

- Observed surface brightness maps: from star counts (Pandas), for spirals/dwarfs galaxies in the Local Group

- Observed surface brightness maps from diffuse light, allowing us to access other other types of galaxies, in particular the most massive ones

![Image of observed surface brightness maps]

Michel-Dansac et al, 2013
- A volume-limited sample of 260 massive ETGs with D < 42 Mpc

Cappellari et al, 2011
A volume-limited sample of 260 massive ETGs with D < 42 Mpc

A new classification scheme based on the internal kinematics: the vast majority of ETGs (80%) rotate with available multiwavelength data

Krajnovic et al, 2011

HI: Serra et al, 2011

CO: Alatelo et al, 2012
Extreme deep imaging with MegaCam on the CFHT

A volume-limited sample of 260 massive ETGs with $D < 42$ Mpc

• Observed with the large field of view camera MegaCam, as part of NGVS for the Virgo ETGs, and MATLAS for the other ones
• With specific observing strategy (large offsets, sky subtraction) and data reduction technique to optimize the detection of low surface brightness features
Katey Alatalo, Berkeley, USA; Leo Blitz, Berkeley, USA; Maxime Bois, Obs de Paris, France; Frederic Bournaud, CEA, France; Martin Bureau, Univ of Oxford, UK; Michele Cappellari, Univ of Oxford, UK; Patrick Cote, NRC Herzberg Institute of Astrophysics, Canada; Alison Crocker, UMass, USA; Jean-Charles Cuillandre, CFHT; Roger L. Davies, Univ of Oxford, UK; Timothy A. Davis, Univ of Oxford, UK; Tim de Zeeuw, ESO, Germany; Leiden Univ, NL; Pierre-Alain Duc, AIM, Saclay, France; Patrick Durrell, Youngstown State Univ, USA; Eric Emsellem, Obs de Lyon, France + ESO; Laura Ferrarese, NRC Herzberg Institute of Astrophysics, Canada; Etienne Ferriere, AIM, Saclay, France; Stephen Gwyn, NRC Herzberg Institute of Astrophysics, Canada; Sadegh Khochfar, MPE, Germany; Davor Krajnović, ESO, Germany; Harald Kuntschner, ESO, Germany; Pierre-Yves Lablanche, Obs de Lyon, France; Ariane Lancon, Obs de Strasbourg, France; Richard M. McDermid, Gemini Obs, Hilo, USA; Simona Mei, Obs de Paris, GEPI, France; Leo Michel-Dansac, Obs. de Lyon, France; Raffaella Morganti, ASTRON, NL; Roberto Munoz, Universidad Catolica de Chile, UMI-CFA, Chile/France; Thorsten Naab, MPA, Germany; Tom Oosterloo, ASTRON, NL; Sanjaya Paudel, AIM, Saclay; Eric Peng, Peking Univ, China; Thomas Puzia, Universidad Catolica de Chile, UMI-CFA, Chile/France; Marc Sarzi, Univ of Hertfordshire, UK; Nicholas Scott, Swinburne Univ, Australia; Paolo Serra, ASTRON, NL; James Taylor, Univ of Waterloo, Canada; Anne-Marie Weijmans, Dunlap Inst., Univ of Toronto, Canada; Lisa M. Young, New Mexico Tech, USA
• 60 percent of Atlas3D galaxies with at least deep g-band observations
• 50 percent of Atlas3D galaxies with at least one color available
Requested time as part of MATLAS

For galaxies below 20 Mpc

<table>
<thead>
<tr>
<th>Band</th>
<th>N(ETGs)</th>
<th>N(fields)</th>
<th>Exposure Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>u (field)</td>
<td>37</td>
<td>35</td>
<td>51 hours</td>
</tr>
<tr>
<td>g (field)</td>
<td>98</td>
<td>90</td>
<td>68 hours</td>
</tr>
<tr>
<td>r (field)</td>
<td>116</td>
<td>103</td>
<td>78 hours</td>
</tr>
<tr>
<td>r (Virgo)</td>
<td>58</td>
<td>54</td>
<td>23 hours</td>
</tr>
<tr>
<td>i (field)</td>
<td>173</td>
<td>149</td>
<td>80 hours</td>
</tr>
</tbody>
</table>

To complete NGVS shallow images (to be observed in 2013A)
Changing the way we see Early-Type Galaxies
Changing the way we see Early-Type Galaxies
Changing the way we see Early-Type Galaxies
Disclosing Early-Type Galaxies with star-forming rings
Disclosing Early-Type Galaxies with star-forming rings
Disclosing Early-Type Galaxies with star-forming rings
Disclosing Early-Type Galaxies with star-forming rings
Probing the mass assembly of galaxies with ultra deep imaging: the MATLAS LP

Disclosing Early-Type Galaxies with star-forming rings
Disclosing Early-Type Galaxies with star-forming rings
Disclosing Early-Type Galaxies with star-forming rings
The morphological classification of galaxies depends on the depth of their images...
Disclosing Early-Type Galaxies with spiral structures

The morphological classification of galaxies depends on the depth of their images...
The morphological classification of galaxies depends on the depth of their images...
Disclosing minor mergers

➡ On line feeding of the stellar halo
Disclosing minor mergers

➡ On line feeding of the stellar halo
Disclosing minor mergers

On line feeding of the stellar halo
Disclosing intermediate-mass mergers
Disclosing intermediate-mass mergers
Disclosing intermediate-mass mergers
Disclosing intermediate-mass mergers

Even ETGs may be look pretty
Disclosing intermediate-mass mergers

Even ETGs may be look pretty
Disclosing intermediate-mass mergers

➡ Even ETGs may be look pretty
Disclosing on-going tidal interactions
Disclosing on-going tidal interactions
Disclosing on-going tidal interactions
Disclosing advanced major mergers
Disclosing advanced major mergers

Probing the mass assembly of galaxies with ultra deep imaging: the MATLAS LP

Campbell River, May 2013
Disclosing advanced major mergers
Disclosing advanced major mergers
Disclosing advanced major mergers
Disclosing advanced major mergers
Disclosing minor + major mergers
Disclosing minor + major mergers
Disclosing advanced major mergers

Duc et al., 2011, Paudel et al., 2013

Probing the mass assembly of galaxies with ultra deep imaging: the MATLAS LP

Campbell River, May 2013
Disclosing advanced major mergers

Duc et al., 2011, Paudel et al., 2013
Fully relaxed, unperturbed, boring ETGs, even at MegaCam depth
Not all massive ETGs/spirals show tidal features (contrary to simulations?)

Assembled earlier? In different environments? By different processes?

Need for a statistical analysis over a large number of galaxies

Aim of the NGVS (in Virgo) and MATLAS projects
MATLAS challenges

Stellar streams

Galactic cirrus

Faint foreground stars

Halos of bright stars

Instrumental artifacts

NGVS field
MATLAS challenges: dealing with galactic cirrus

No obvious differences in colors with stellar tails
Identified through complementary observations (FIR/ Herschel, UV/ Galex)

Who is interested with arcsec resolution observations of the Galactic ISM?
The stellar halos of galaxies may be hidden behind the large, complex reflection halos of stars.

But the contamination may be more subtle.
The blueing of the outer color profile consistent with cosmological simulations predicting a mass growing of ETGs thanks to multiple mergers by low-mass, low-metallicity satellites.
Stellar populations in the outermost regions of ETGs

Strong reddening beyond 5 Reff

- Real?
  (also observed in other deep imaging studies)
ABSTRACT

Using SDSS Stripe82 data we have obtained deep radial surface brightness profiles of 7 face-on to intermediate inclined late-type spirals down to $\mu_r \sim 30$ mag arcsec$^{-2}$. We do not find any evidence for a sharp cut-off of the light distribution of the disks but a smooth continuation into the stellar halos of galaxies. Stellar halos start to affect the surface brightness profiles of the galaxies at $\mu_r \sim 28$ mag arcsec$^{-2}$, and at a radial distance of $\gtrsim 4-10$ inner scale-lengths. We find that the light contribution from the stellar halo could be responsible of previous classification of surface brightness profiles as Type III in late-type galaxies. In order to estimate the contribution of the stellar halo light to the total galaxy light, we carried out a Bulge/Disk/Stellar Halo decomposition by simultaneously fitting all components. The light contribution of the halo to the total galaxy light varies from $\sim 1\%$ to $\sim 5\%$, but in case of ongoing mergers, the halo light fraction can be as high as $\sim 10\%$, independently of the luminosities of the galaxies. We have also explored the integrated ($g' - r'$) color of the stellar halo of our galaxies. We find ($g' - r'$) colors ranging from $\sim 0.4$ to $\sim 1.2$. By confronting these colors with model predictions, we encounter problems to fit our very red colors onto stellar population grids with conventional IMFs. Very red halo colors can be attributed to stellar populations dominated by very low mass stars of low to intermediate metallicity produced by bottom-heavy IMFs.
Stellar populations in the outermost regions of galaxies

Halos of bright stars

Halos of galactic nuclei

Redenning of the color profiles in the outskirts of galaxies likely due to the reflection galos of the galaxy nucleus...
Stellar populations in the outermost regions of galaxies
MATLAS challenges: classification of galaxies

Statistics (fine structure index) made by eye

Number of tidal tails

Number of streams

Number of shells

+ presence of diffuse halos, bars, asymmetries, etc..
Classification of galaxies: google + galaxy zoo
Classification of galaxies: google + galaxy zoo

Probing the mass assembly of galaxies with ultra deep imaging: the MATLAS LP
Classification of galaxies: google + galaxy zoo
Future: Automatic detection of tidal structures?
Other science goals: Death and birth of satellite dwarf galaxies

Multiple simultaneous destruction of satellites around a spiral in the Virgo Cluster
**Other science goals:** Death and birth of satellite dwarf galaxies

Multiple simultaneous destruction of satellites around a spiral in the Virgo Cluster
Other science goals: Death and birth of satellite dwarf galaxies

Multiple simultaneous destruction of satellites around a spiral in the Virgo Cluster

NGVS-NGC4216
Paudel et al., 2013
Other science goals: **Death** and birth of satellite dwarf galaxies

Multiple simultaneous destruction of satellites around a spiral in the Virgo Cluster

*NGVS-NGC4216*

Paudel et al., 2013
Other science goals: Death and birth of satellite dwarf galaxies

Multiple simultaneous destruction of satellites around a spiral in the Virgo Cluster

NGVS-NGC4216
Paudel et al., 2013
Other science goals: Death and birth of satellite dwarf galaxies

Multiple simultaneous destruction of satellites around a spiral in the Virgo Cluster

NGVS-NGC4216

Paudel et al., 2013
Other science goals: Death, evolution and birth of satellite dwarf galaxies
Other science goals: Death, evolution and birth of satellite dwarf galaxies.
**Other science goals:** Death, evolution and birth of satellite dwarf galaxies

A disrupted satellite of a satellite

NGC 4216

Paudel et al., 2013
Other science goals: Death and birth of satellite dwarf galaxies

• 3 HI-rich, metal-rich dwarf galaxies along the filamentary structure: Tidal Dwarf Galaxies

Duc et al., 2011
Paudel et al., 2013
Other science goals: Globular Clusters as probe of the large scale environment

Filters chosen to optimize the detection of GCs around the field of ETGs of MATLAS

Work initially started as part of NGVS
Other science goals: Origin of the free floating HI clouds around galaxies

The sensitivity of the survey allows to detect stellar counterparts to HI structures, telling about their origin.
The sensitivity of the survey allows to detect stellar counterparts to HI structures, telling about their origin. 

Other science goals: Origin of the free floating HI clouds around galaxies

Accretion or ejection?

Disclosing the collisional origin of the giant HI ring in Leo

The sensitivity of the survey allows to detect stellar counterparts to HI structures, telling about their origin.

Michel-Dansac et al., 2011
Monsieur et Madame Constantin SIREUIL-ABRAHAM,
Madame Marie-Louise SIREUIL,
Monsieur et Madame Serge SIREUIL-LEFEVRE,

ses enfants;

Joël, Alain, Orslien,
Olivier,
Julia, Laurie, Maud,

ses petits-enfants;

ses arrière-petits-enfants;

Et toute la famille apparentée
ont la profonde douleur de vous faire part du décès de

MADAME

Adrienne MATLAS

veuve de Monsieur Jean-Baptiste SIREUIL
née à Élouges le 25 juillet 1933
et décédée à Gilly le 25 mai 2012.

Les funérailles civiles auront lieu mardi 29 mai 2012
à 14 h 30, caveau familial au cimetière de Dour.
Dans l’attente des funérailles, le corps repose au funérarium
Gobert J.-M., rue de la Victoire, 12, à Frameries.

Les personnes qui désirent rendre un ultime hommage au
defunt pourront se recueillir au funérarium Gobert, rue de la
Victoire, 12, 7080 Frameries, le lundi 28 mai de 17 h à 19 h.

Cet avis tient lieu de faire-part.

P. F. A. DESCHAMPS, Enquêtes, 20 rue A. Deschamps, Tél. 065/65.29.35

Still three years to go: hoping for the best
• From the ground: Extending the survey to other type of galaxies, environments, distances
  ➡ Megacam-red

• From space, with dedicated telescopes: Reaching even lower surface brightness levels: 29 -> 32 mag/arc-2, to reconstruct the mass assembly of galaxies at earlier epoch
  ➡ MESSIER concept