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Probing the mass assembly of early-type galaxies with low surface brightness structures: collisional debris and faint satellites

Semaine de l'Astrophysique Francaise. The Low Surface Brightness Universe

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Nice, May 15th, 2019

CONTENTS

◆ MOTIVATION

- Fine structures observed in galaxy mergers. Major and minor mergers.
- Deep imaging program MATLAS. Tidal tails, stellar streams and shells.

◆ METHOD

- Predictions on fine structures and mass assembly.
- Numerical Simulations.

◆ RESULTS AND DISCUSSION

- Evolution of the stellar mass.
- Identification of fine structures. Mass assembly of a masive galaxy traced by fine structures.
- Comparision with observations (MATLAS survey).

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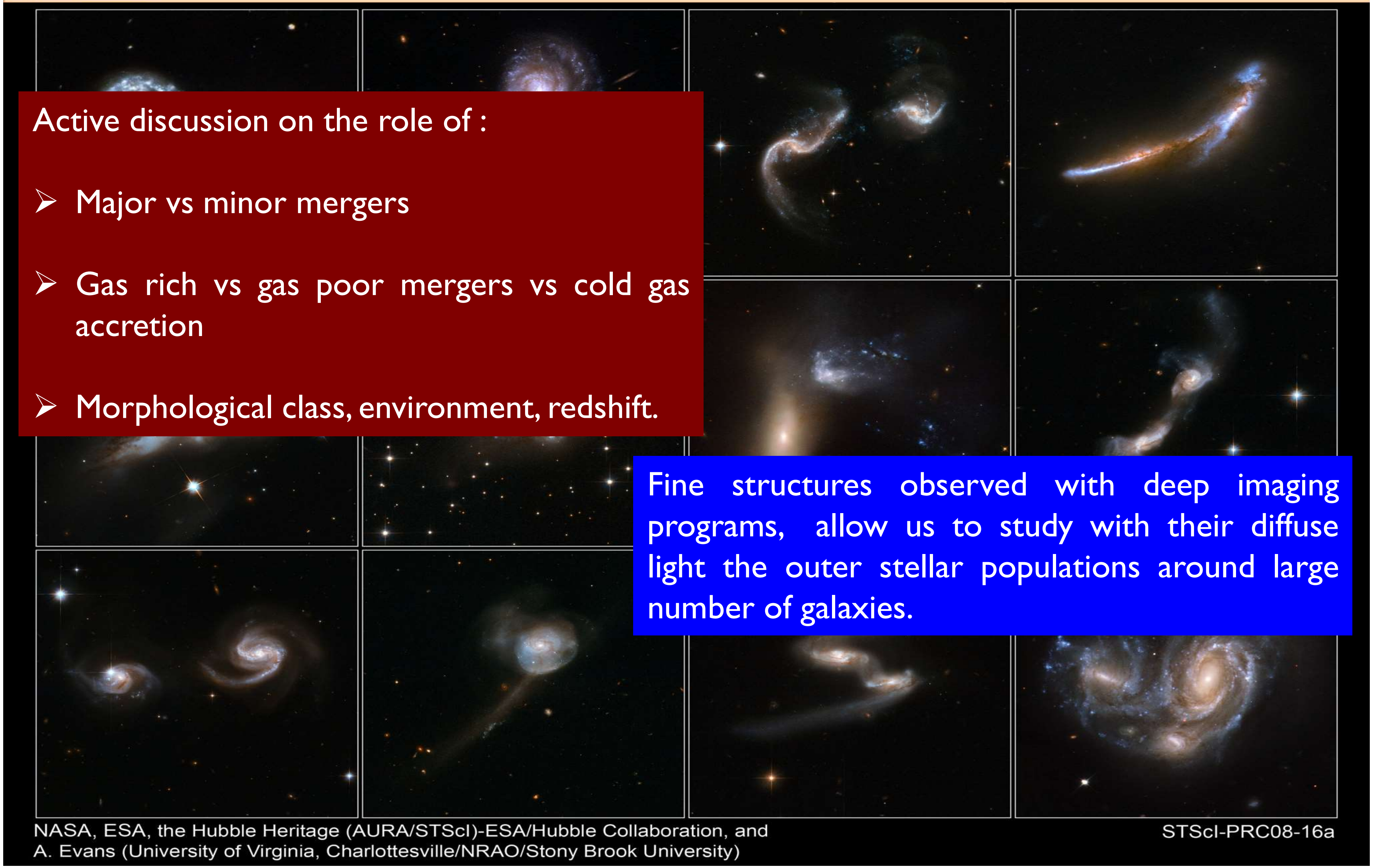
Probing the merger history of red early-type galaxies with their faint stellar structures.

Active discussion on the role of :

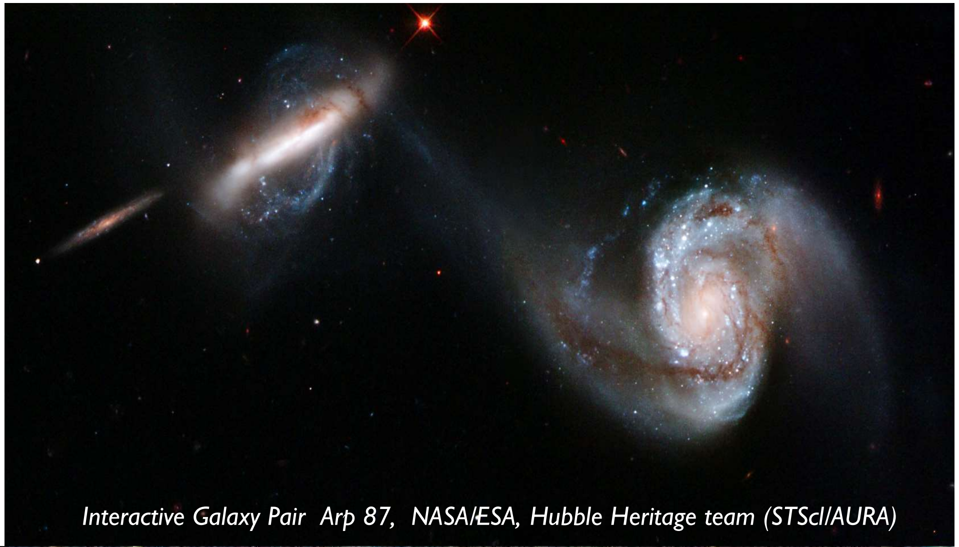
- Major vs minor mergers
- Gas rich vs gas poor mergers vs cold gas accretion
- Morphological class, environment, redshift.

Fine structures observed with deep imaging programs, allow us to study with their diffuse light the outer stellar populations around large number of galaxies.



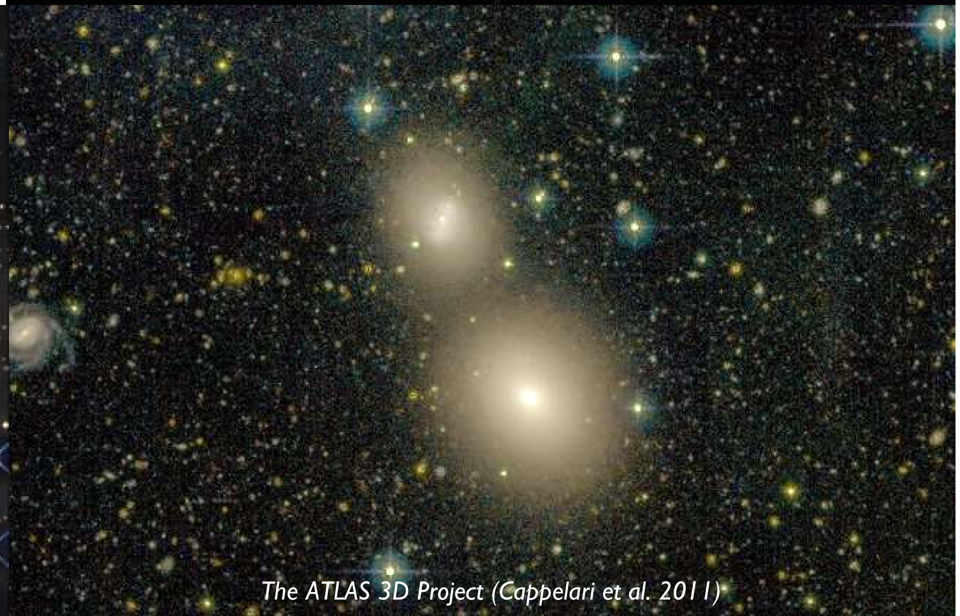
MERGERS

- **Major mergers.**
  - Between (gas-rich) spirals, produce long stellar tidal tails.
  - Between (gas-poor) early-type galaxies, do not produce any narrow tidal tails.



Interactive Galaxy Pair Arp 87, NASA/ESA, Hubble Heritage team (STScI/AURA)

Martinez-Delgado et al. 2010



The ATLAS 3D Project (Cappelari et al. 2011)

- **Minor mergers.**
  - Involving (gas-poor) dwarf satellites, produce narrow tidal tails wrapping along their host.

MATLAS (Mass Assembly of early-Type GaLAxies with their faint Structures)

- The deep imaging program MATLAS (Duc et al., 2017), investigates the mass assembly of ETGs with extremely deep optical images from the MegaCam/CFHT.

- Database of multi-color images for a volume-limited sample of 238 nearby massive ETG and 116 LTG from ATLAS^{3D} sample (Cappellari et al. 2011; Duc et al., 2015). Complemented with NGVS (Ferrarese et al., 2012).

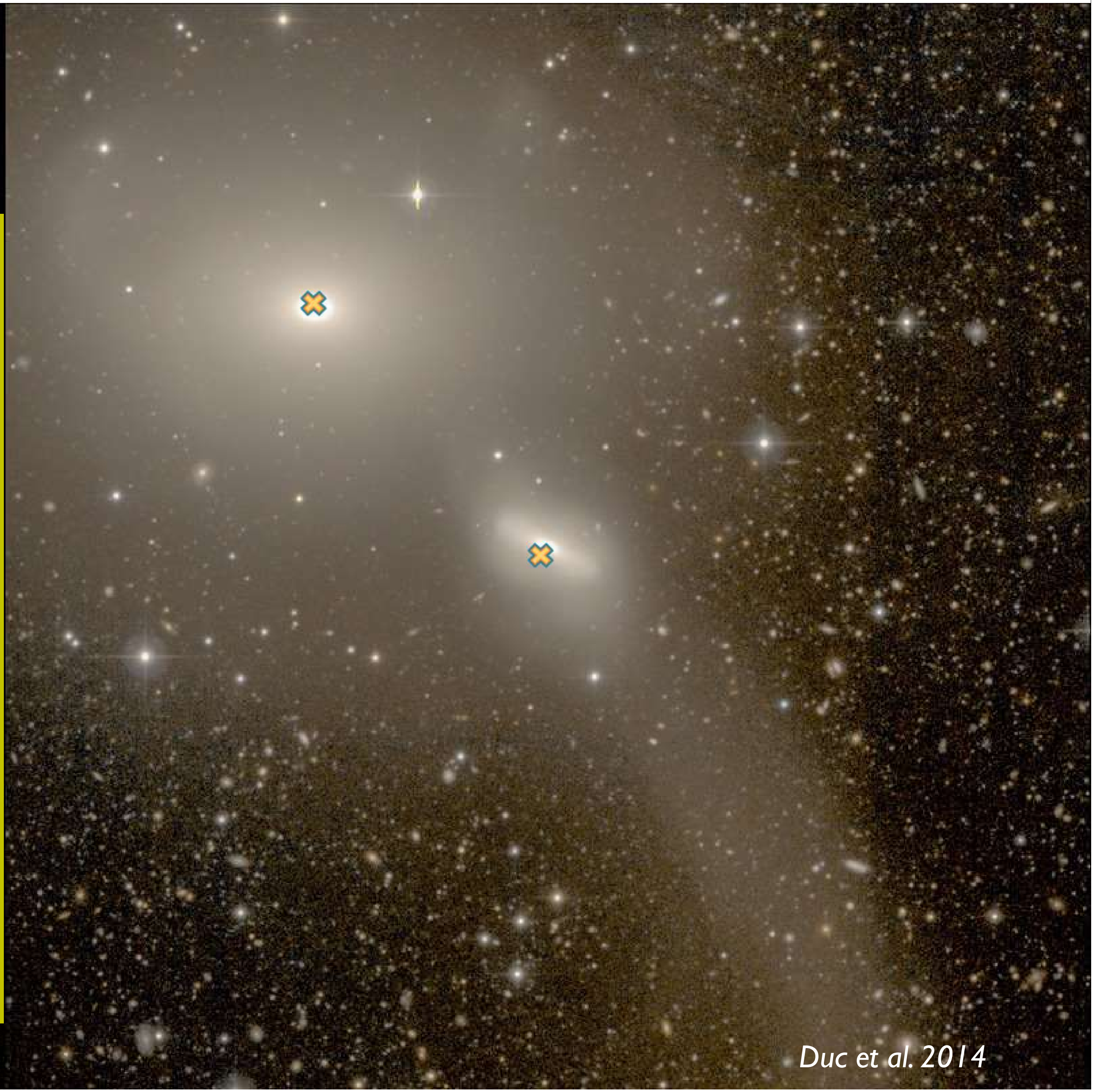
- Surface brightness limit of μ=29 mag arcsec^{-2} in the g-band (reached in 45 min).

- Results: LSB-optimized surveys are detecting new prominent structures that change the apparent morphology of galaxies.

- They provide specific examples of each type of observed structures – tidal tails, stellar streams and shells – and explain how they were identified and classified.

TIDAL TAILS

- Elongated structures shaped by any tidal interaction.
- Surface brightness bellow to 25 mag arcsec^{-2}.
- Made during major mergers.
- Material expelled from the primary galaxy (ETG), following an interaction with a companion massive enough to have significantly perturbed it .



STREAMS

- Narrow and long filaments that trace the orbit of the satellite around its massive host .
- Fainter than μ=26 mag arcsec^{-2}
- Trace past minor mergers.
- Material emanate from a low mass companion orbiting the primary galaxy (ETG).

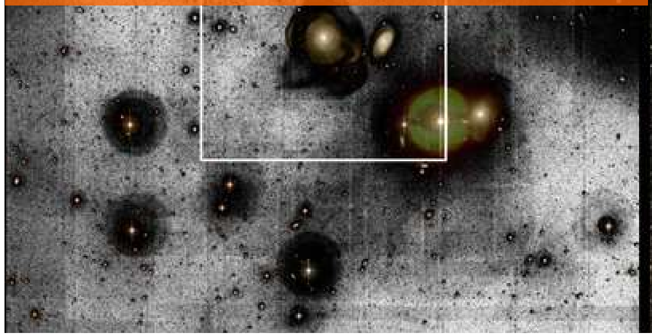
Duc et al. 2014

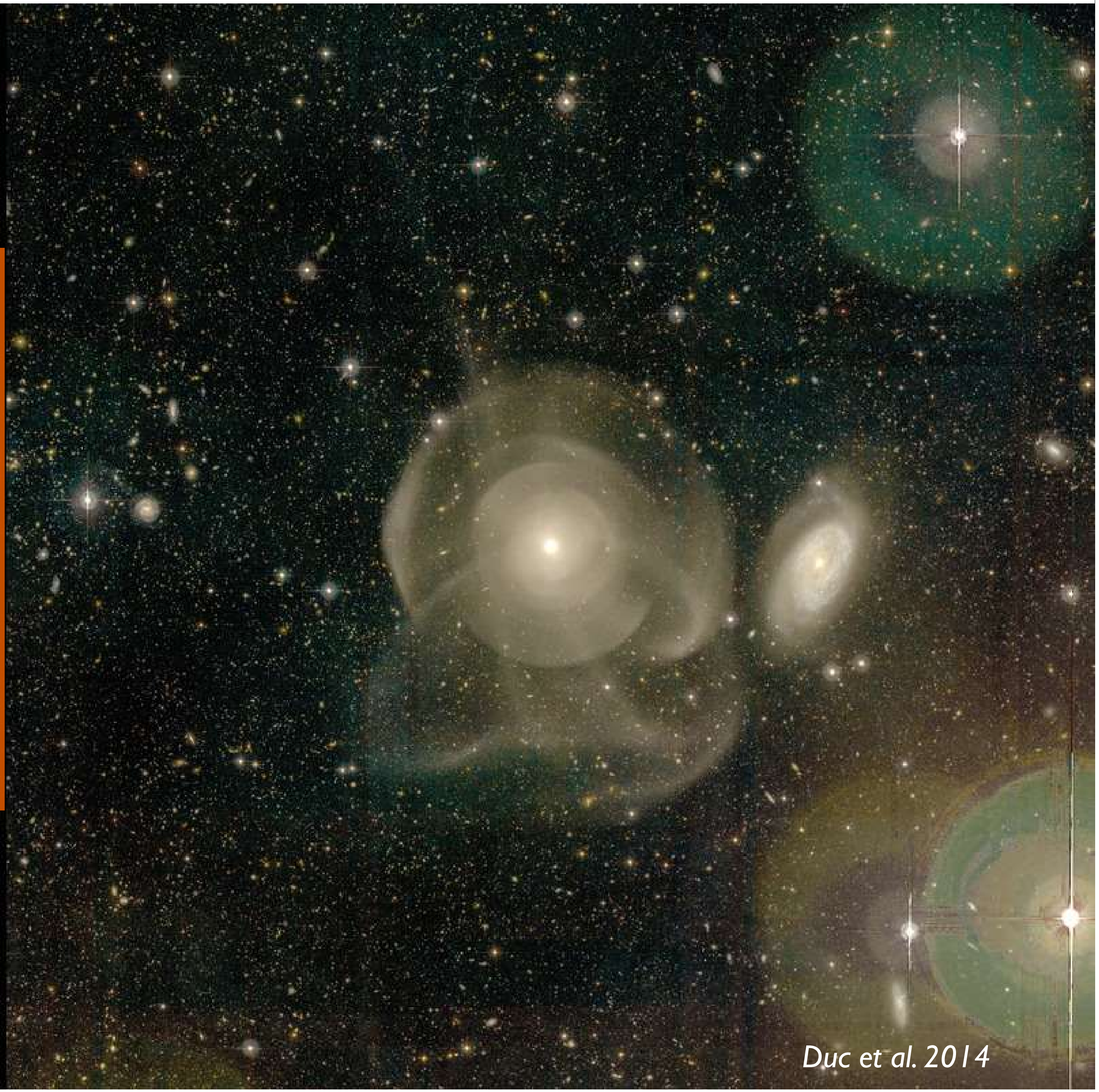
SHELLS

- Circular shapes and shape-edged inner structures.
- Fainter than μ=26 mag arcsec^{-2}.

NGC0474

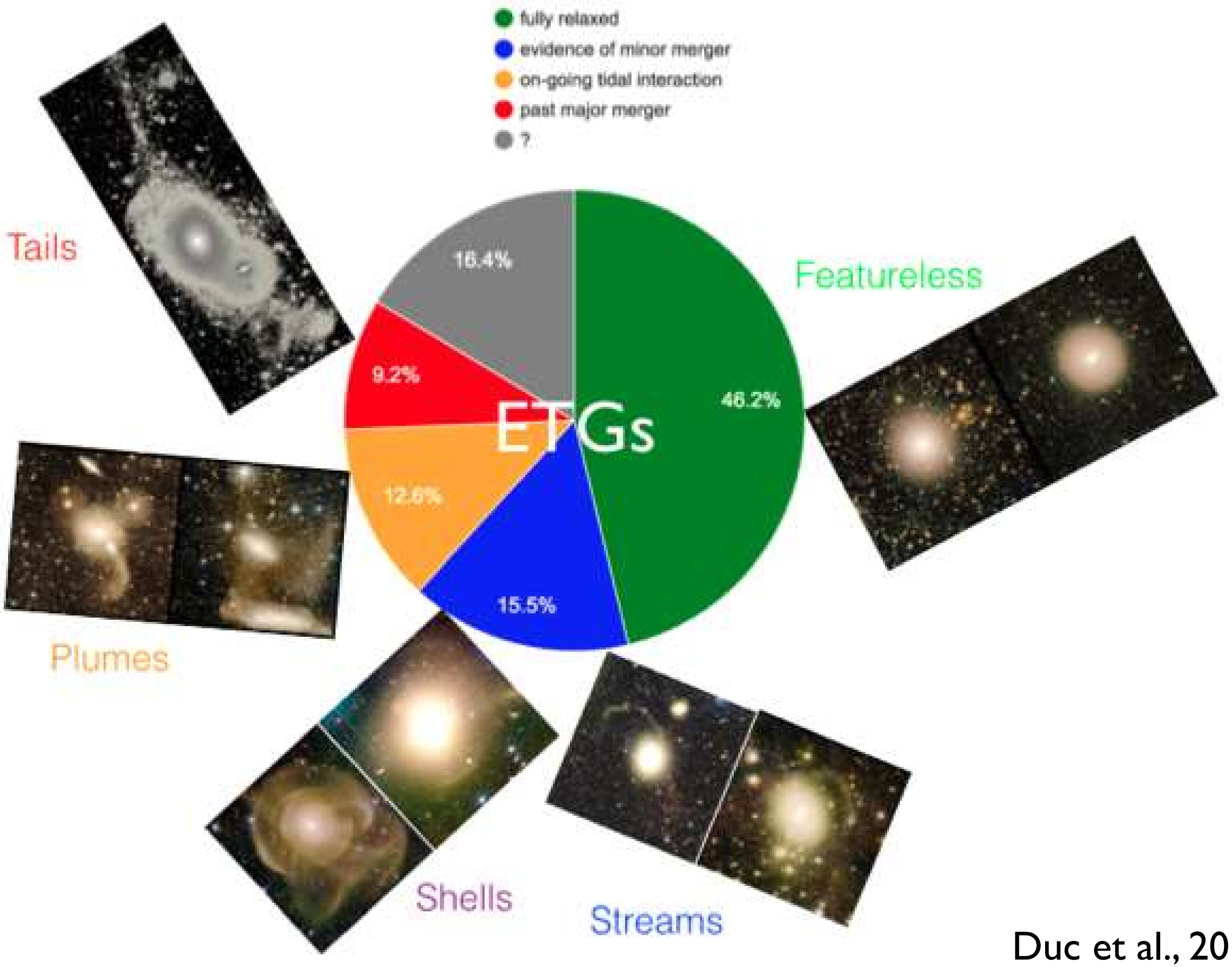
- Usually they are numerous and concentric.
- Intermediate-mass mergers.





Duc et al. 2014

Classification scheme of collisional debris. MATLAS deep imaging survey



Duc et al., 2017

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Numerical simulations

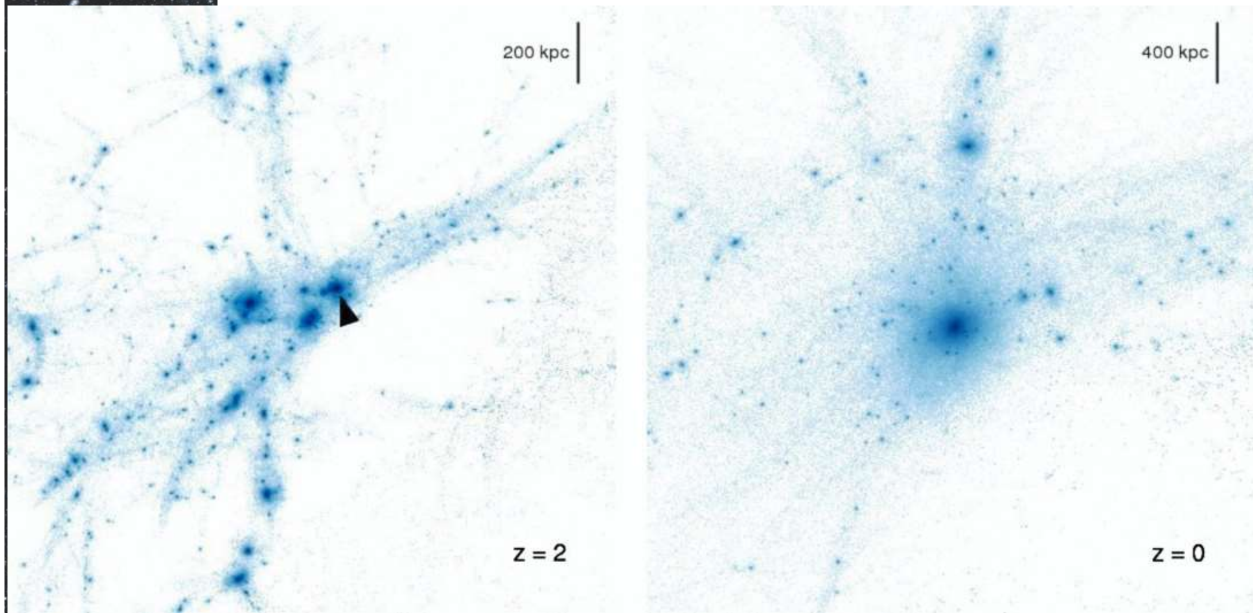
Predictions on fine structures and mass assembly.

- In the hierarchical cosmological context, the accreted mass comes from major and minor merger events.
- Each event generates its own fine structures, which may be destroyed by the following event or preserved in spite of the next accretion event.
- The mass assembly of galaxies may be reconstructed from their fine structures if their survival time is known.
- Furthermore, we can make inferences about the mass assembly history of galaxies if exist a dependence on surface brightness or orientation.
- To what extent surface brightness cuts prevents us from inferring the history of past events?

The galaxy evolution in the cosmological context.

- Numerical simulation to study the "morphological quenching" of star formation in ETGs (Martig et al. 2009).
- Approach: Merger and accretion histories extracted from a ΛCDM halo in a cosmological numerical simulation.
- Accretion histories are re-simulated at much higher resolution. Each halo is replaced by a realistic galaxy containing gas, stars and dark matter.

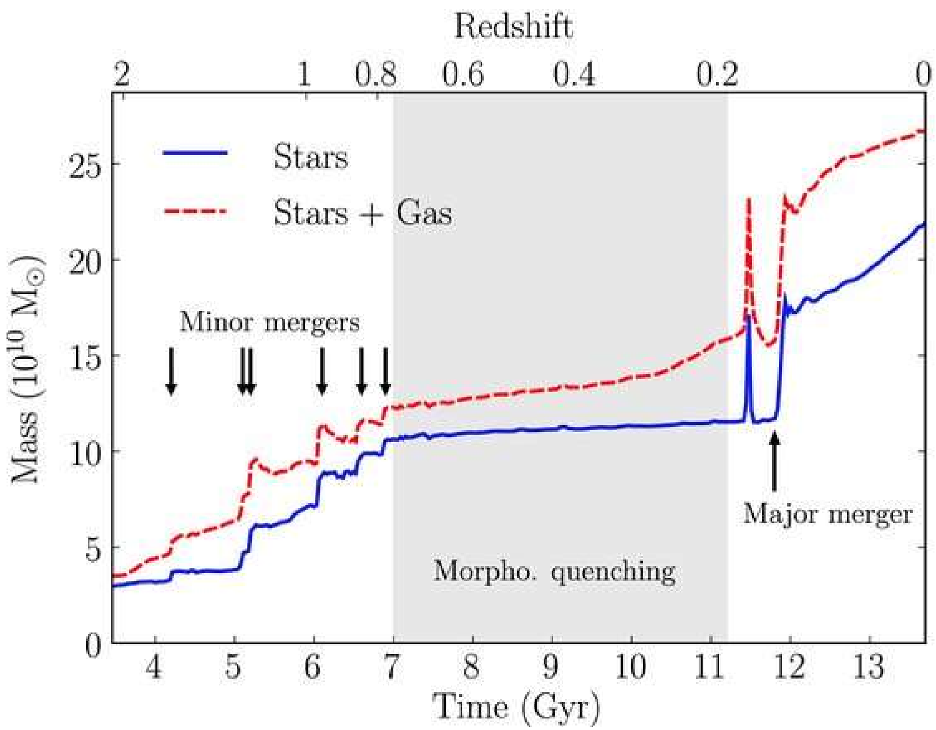
- Cosmological numerical simulation. AMR RAMSES code (Teyssier 2002). Comoving lenght 20 h^{-1} Mpc. Dark mater particles resolution $6.9\times10^6\,M_\odot$
- High-resolution re-simulation. Particle mesh-code (Bournaud & Combes 2002, 2003). Maximal spatial resolution 130 pc. Stellar mass resolution $1.4\times10^5\,M_\odot$ (initially). Stellar and gas mass resolution $2.1\times10^4\,M_\odot$ (during the simulation).



The host halo in the cosmological environment. Large-scale dark matter distribution.

Halo mass growing from $2\times10^{11}\,M_\odot$ at z=2 to $1.4\times10^{12}\,M_\odot$ at z=0

Phases of the galaxy evolution



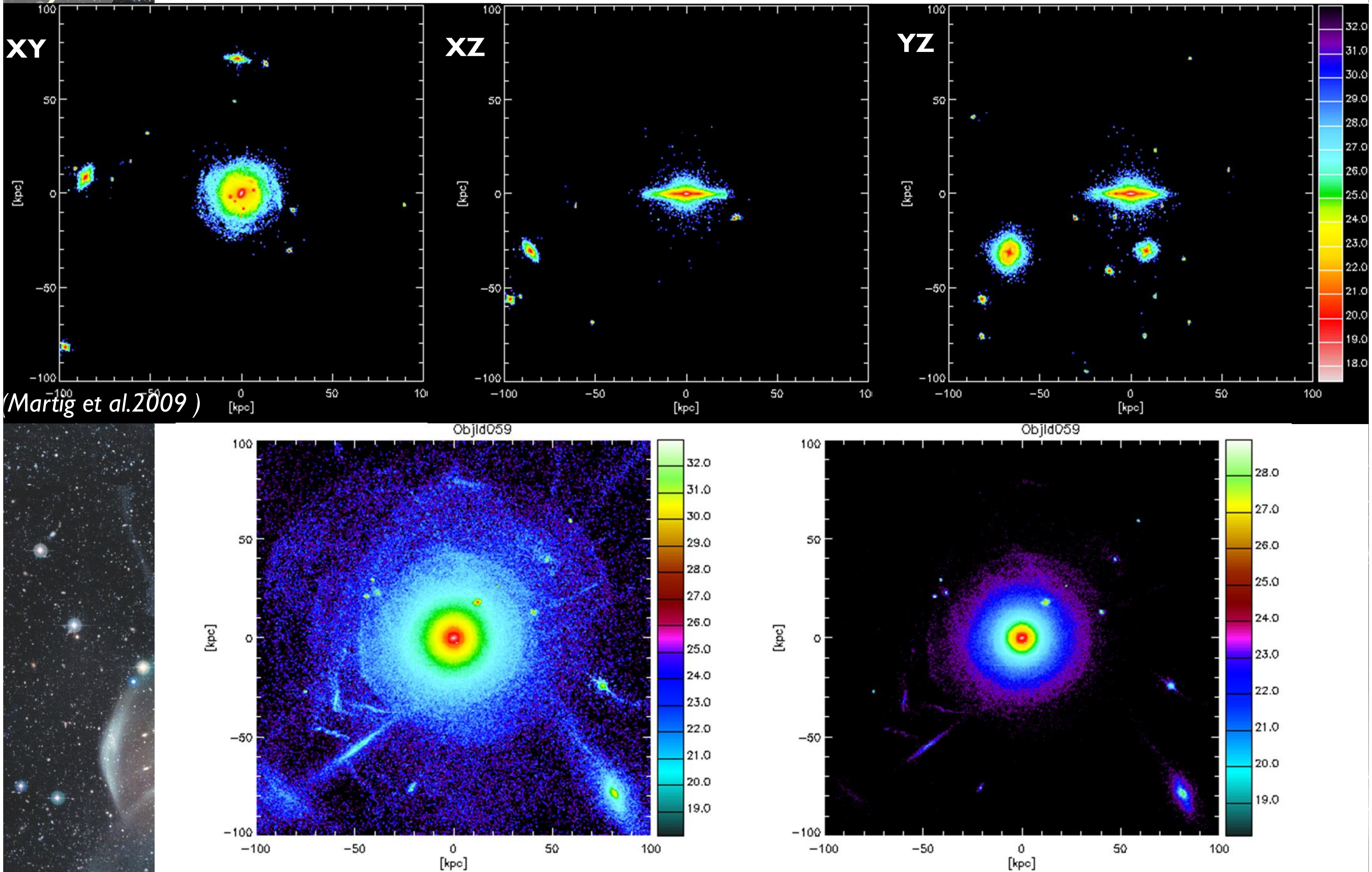
Martig et al., 2009

① Gas disk galaxy and intense phase of minor and intermediate-mass mergers. Mass ratio 4:1 to 10:1. From z=2 to z~1.

② *Morphological quenching.* Star formation suppressed. Very tiny minor mergers (undetectable). Diffuse gas continuosly accreted. From z=1 to z~0.2.

③ Major merger event and increasing gas accretion rate. Mass ratio 1.5:1. From z=0.2 to z=0.

Simulated surface brightness maps



$\mu = 33\ mag \cdot arcsec^{-2}$ $\mu = 29\ mag \cdot arcsec^{-2}$

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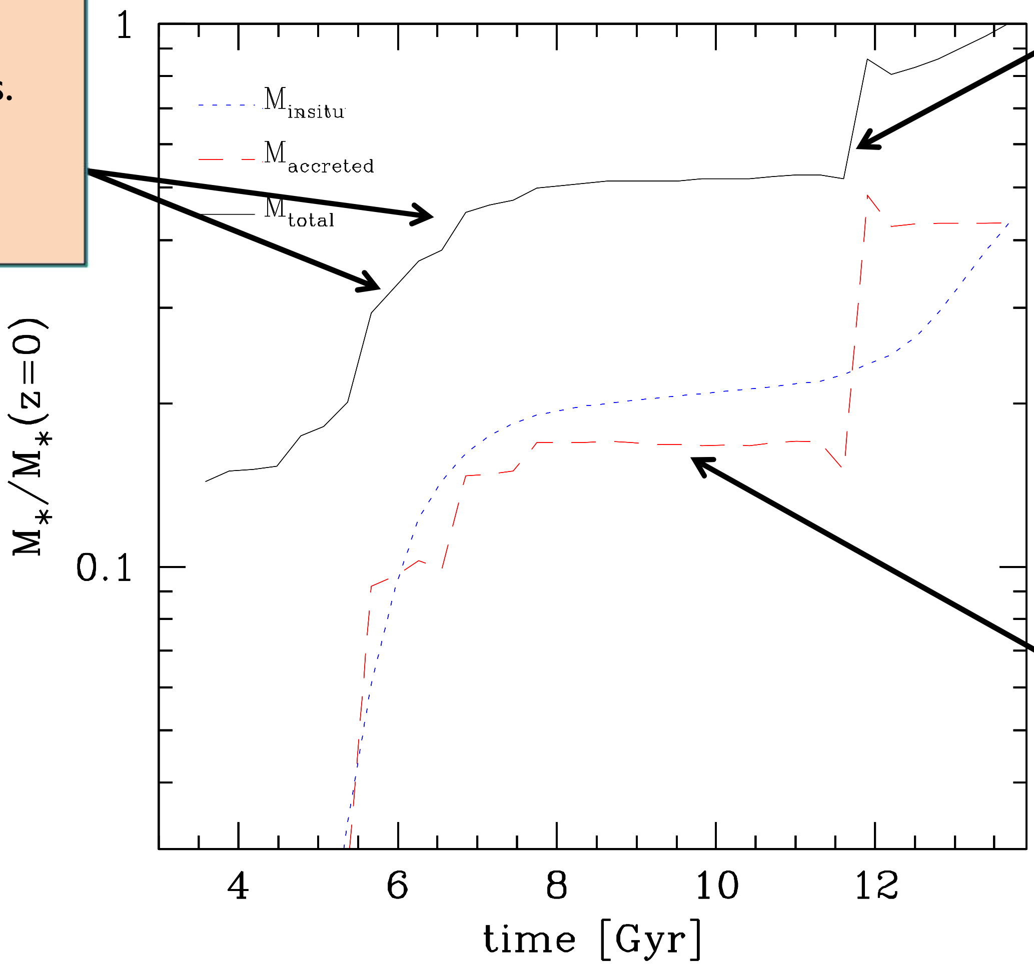
Evolution of stellar mass

Minor and Intermediate mass mergers. Mass ratio 4:1 to 10:1



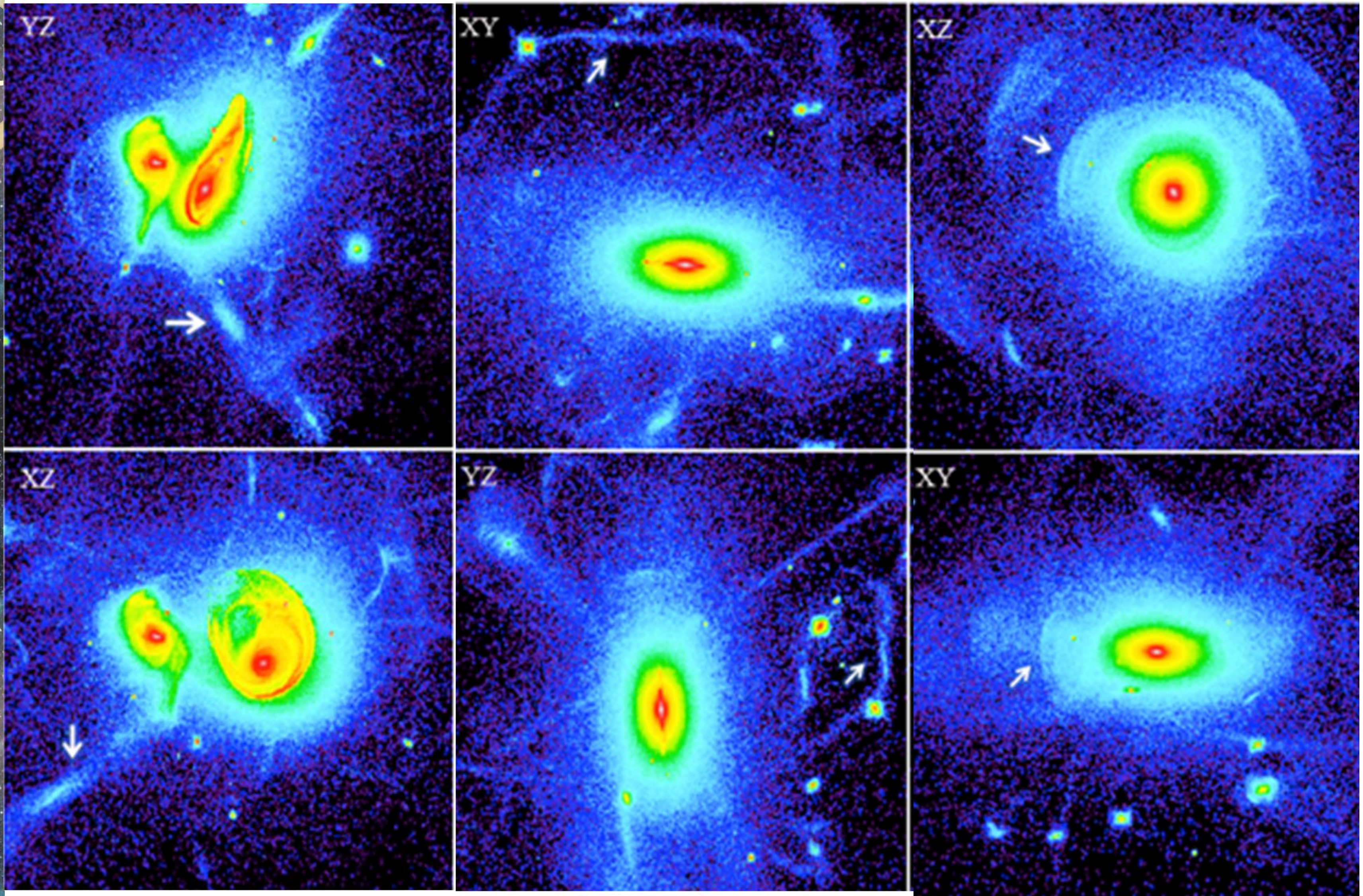
Major merger. Mass ratio 1.5:1

Morphological quenching Phase. Dominated for cold accretion.

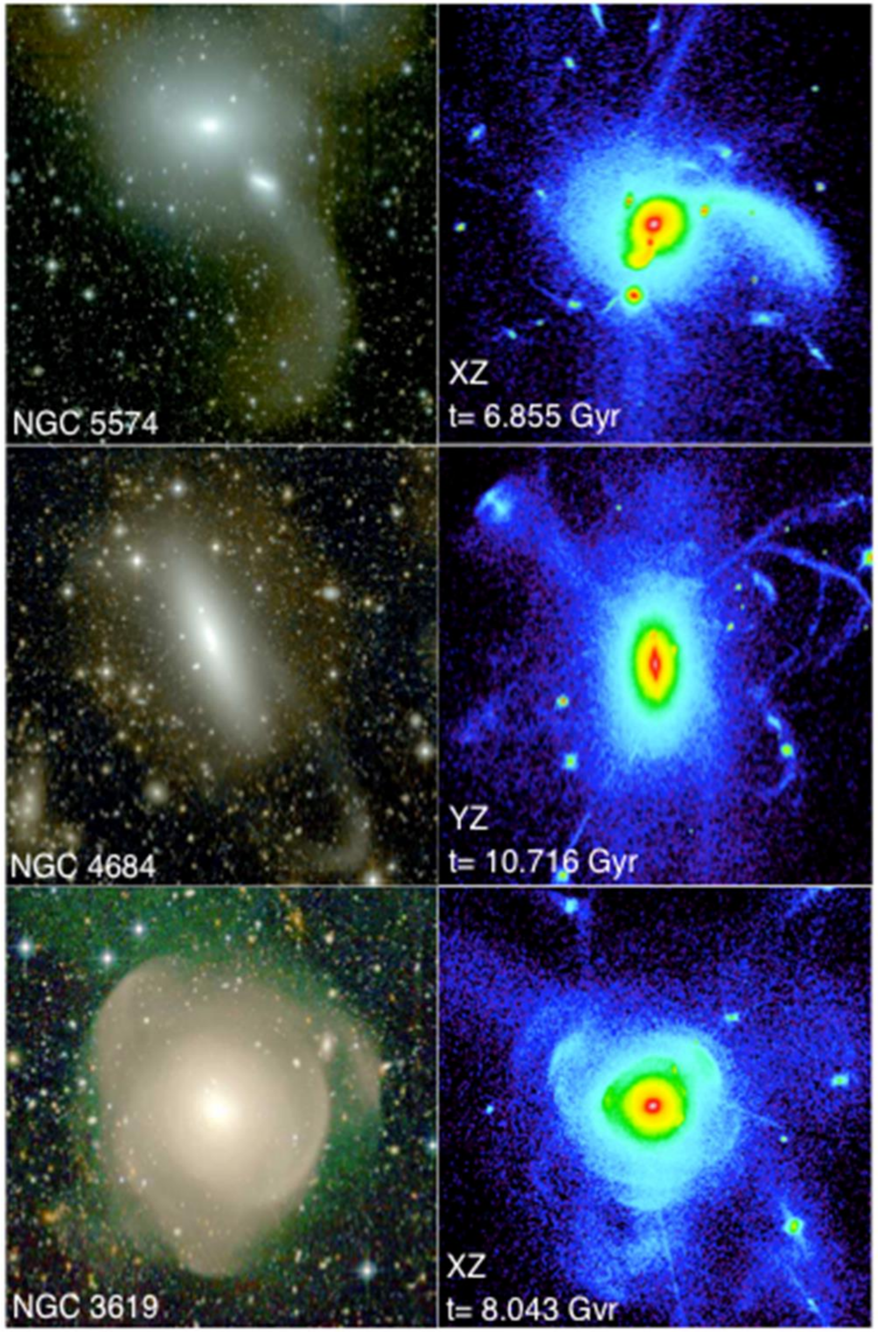
Mancillas et al. in prep. (2019)

Identification of fine structures via visual inspection

Tidal tails **Stellar streams** **Shells**

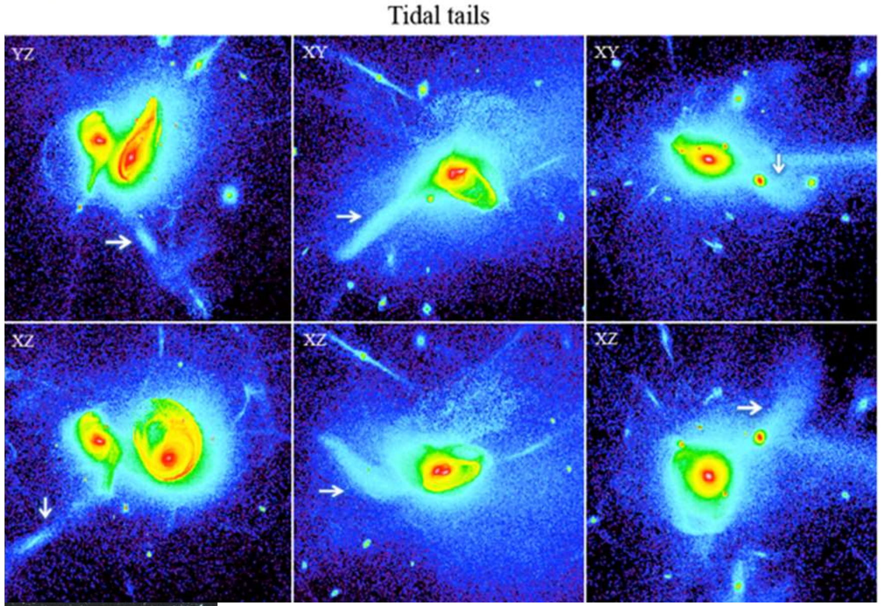


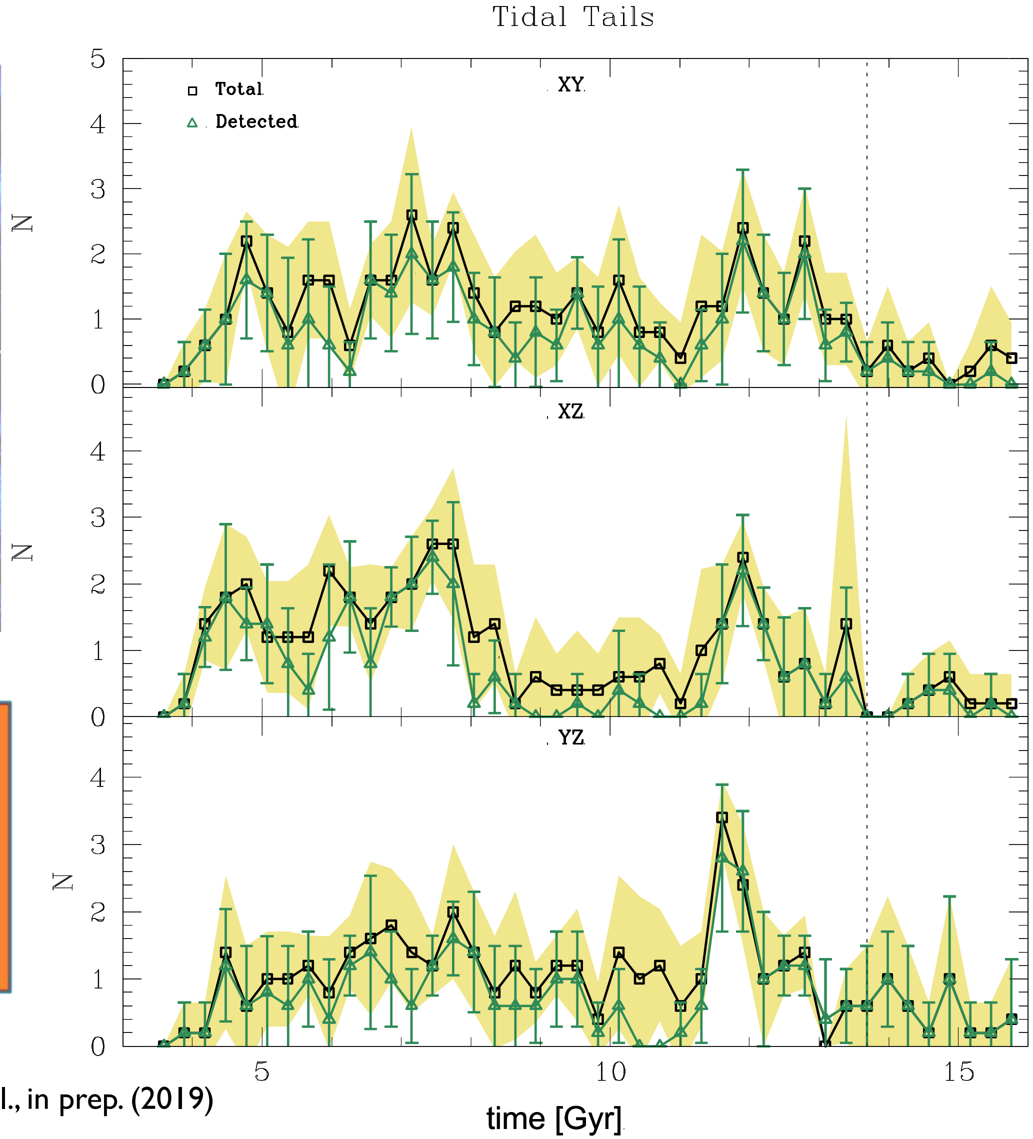
Comparision with observations from MATLAS survey



Mancillas, in prep. (2019)

Evolution of the number of tidal tails



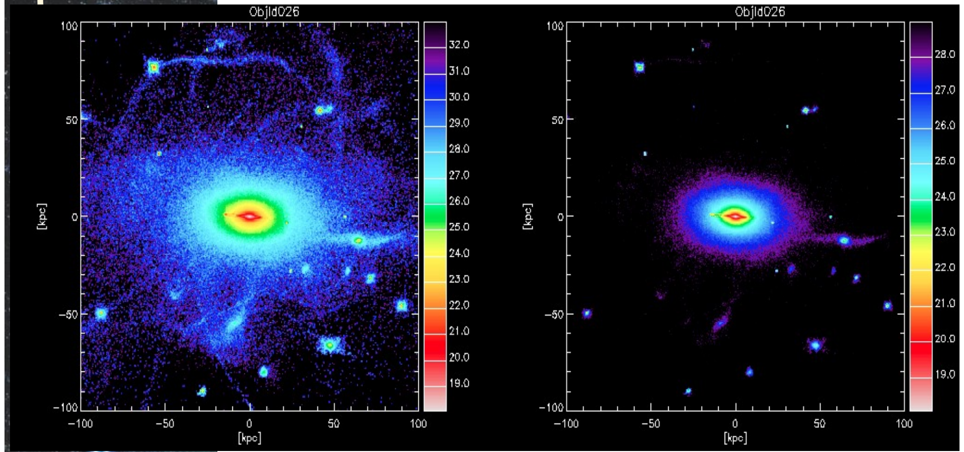


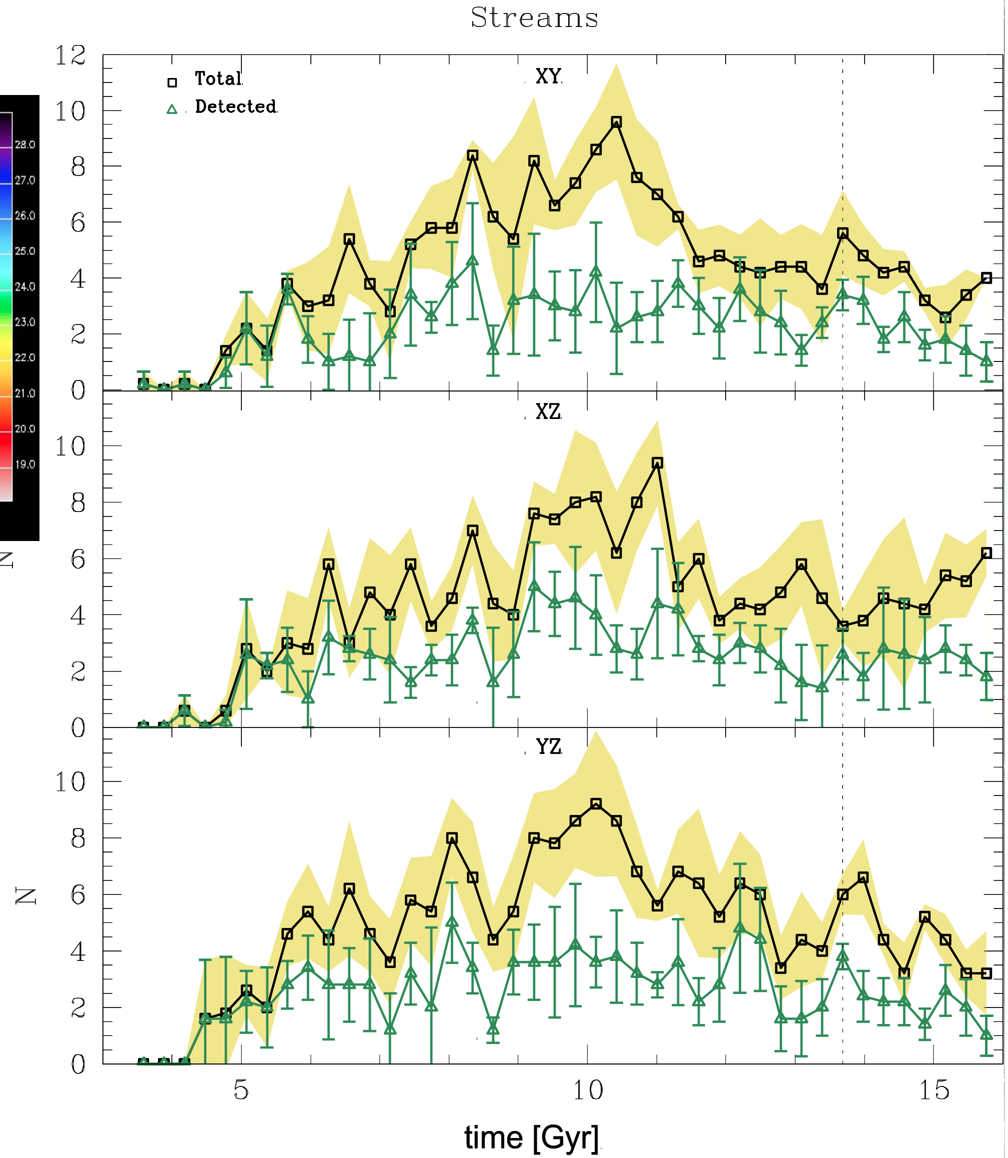
- **Total**: cut in μ=33 mag arcsec^{-2}
- **Detected**: cut in μ=29 mag arcsec^{-2}

Mancillas et al., in prep. (2019)

- **No dependence on surface brightness sensibility.**
- **No strong dependence on projection.**
- **Survival time around 2 Gyr.**

Evolution of the number of stellar streams



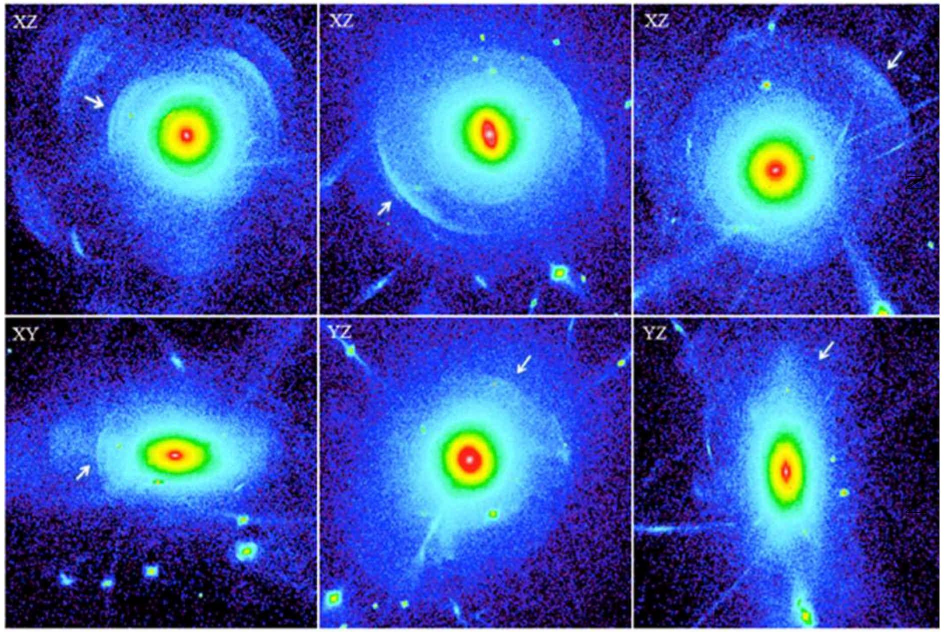


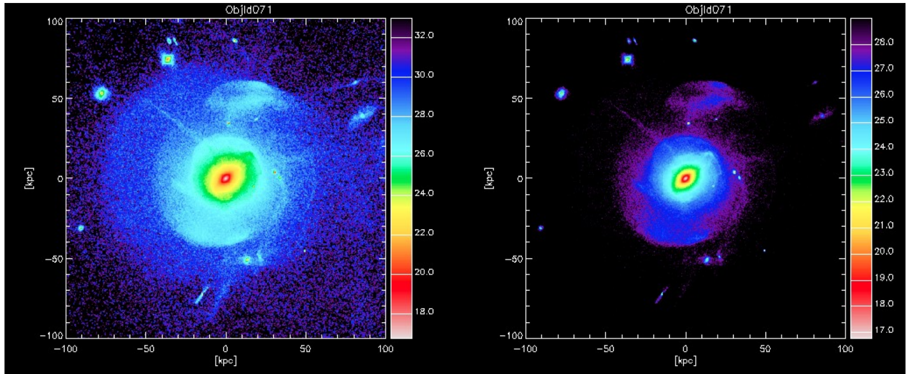
Mancillas et al., in prep. (2019)

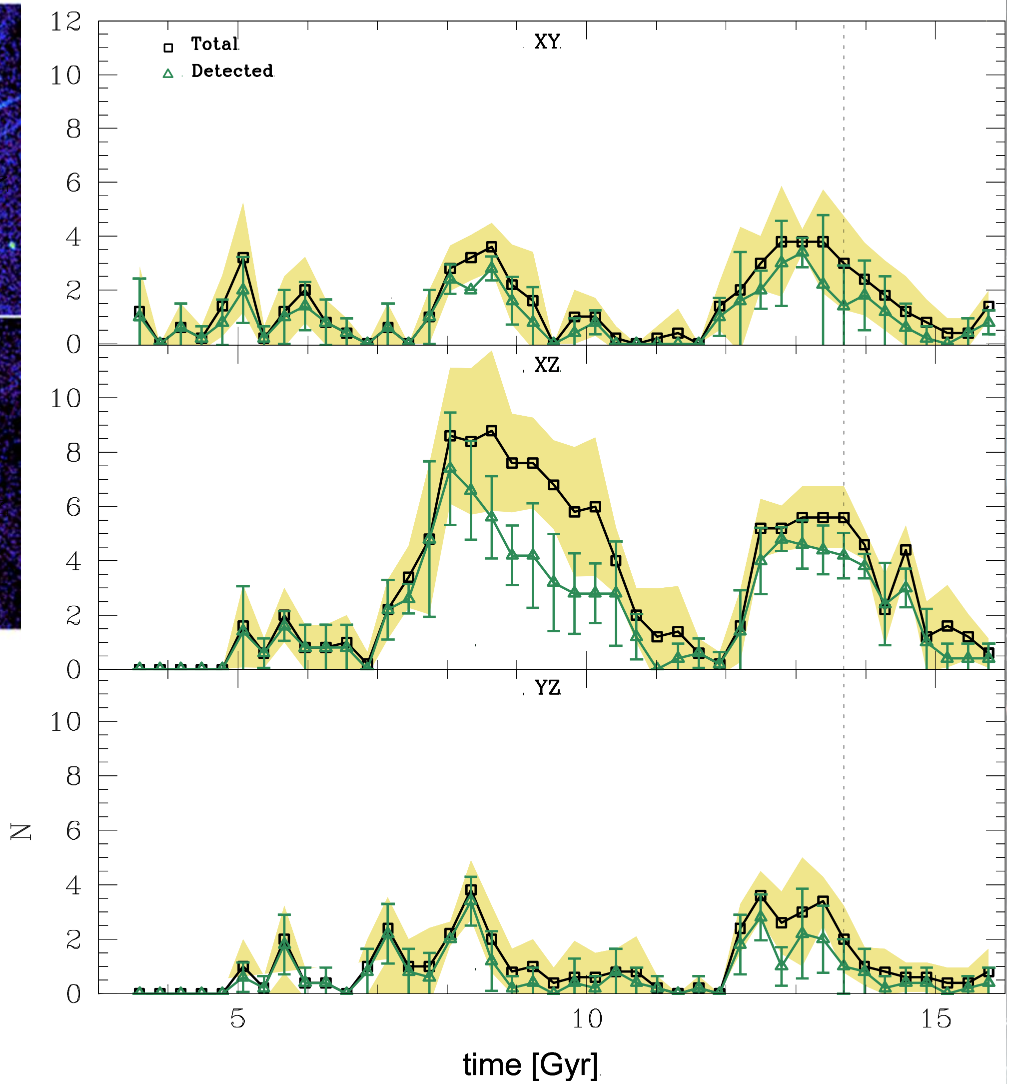
- ✧ **Strong dependence on surface brightness.**
- ✧ **No dependence on the projection. They identified in all directions.**
- ✧ **They are visible during the all evolution of the simulation.**
- ✧ **The peak of incidence is around 10 Gyrs.**

Evolution of the number of shells

Shells







- Strong dependence on the projection.
- Slight dependence on surface brightness limit.
- Survival time around 3 Gyr.

Concluding Remarks

- Tidal tails, shells and streams give us information about past merger events and this fact could be translated in changes on the galaxy properties.

- The census of fine structures in the numerical simulation are a remarkable result from the three diferents phases of the galaxy evolution, where we can make correlations between such structures and their corresponding merger events.

- Tidal tails results from major mergers events (1.5:1), stellar streams from minor mergers (10:1) and shells from intermediate-mass mergers (4:1).

- Tidal tails and shells have long survival times, ~2 Gyr and ~ 3Gyr, respectively, but streams remains visible in all phases of galaxy evolution.

- The detection of stellar streams are strongly dependent on the surface brightness cuts.

- Incidence of shells depends on the projection of the early-type galaxy.

MERCI