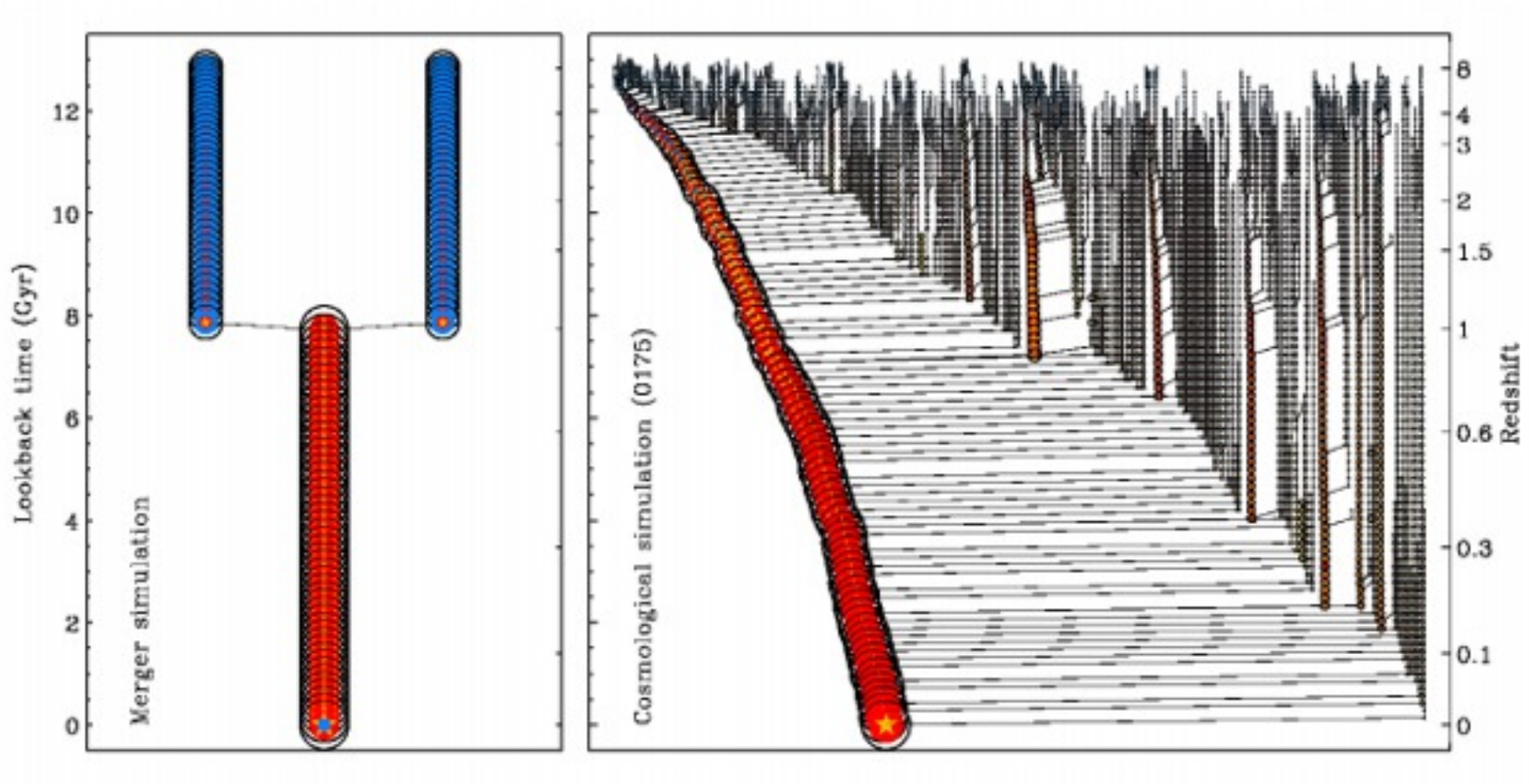
# Probing the mass assembly of massive galaxies with fine structures (and deep imaging)

*Los Andes, 17/11/2013*



Pierre-Alain Duc

# Context: the formation of galaxies within a hierarchical cosmological model

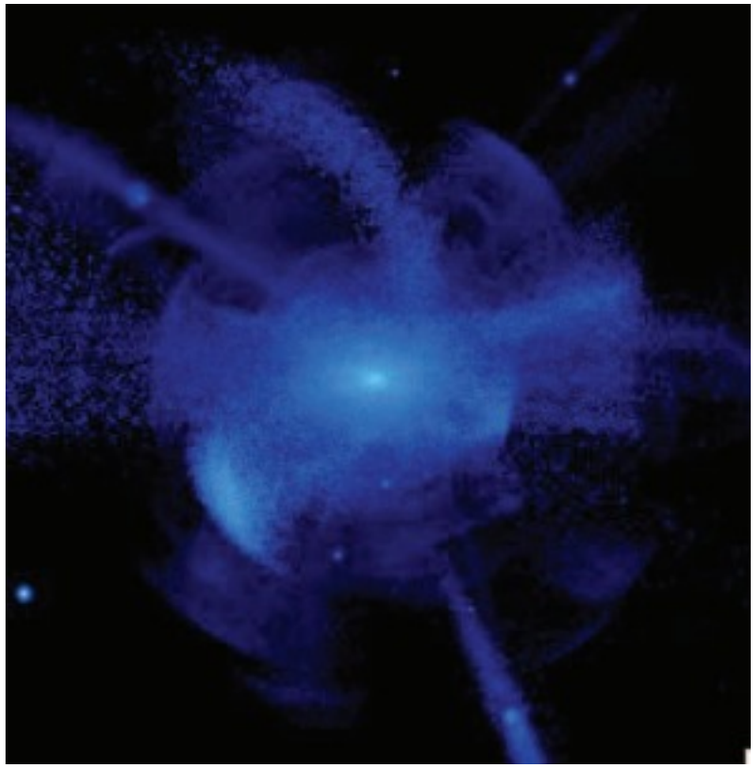



- A fundamental role given to mergers

Naab et al., 2013

- An active debate on the role of
- major vs minor mergers
- gas rich vs gas poor mergers vs cold gas accretion
- on their relative importance as a function of morphological class, environment, redshift

- This talk: fine structures, as probed by deep imaging, can tell something about this



Bullock & Johnston, 2005

# Fine structures and mass assembly: predictions from simulations

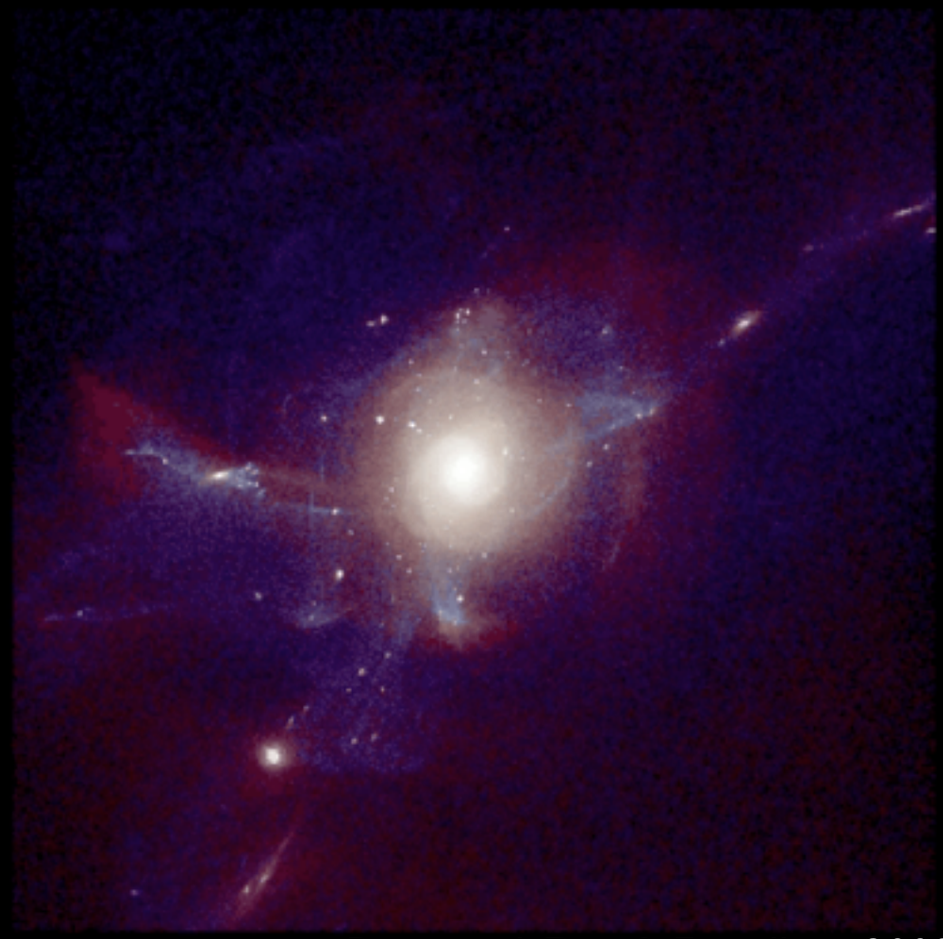
✓ Major mergers between (gas-rich) spirals

➡ Produce gas-rich long, stellar tidal tailS, with structures within them

✓ Major mergers between (gas-poor) early-type galaxies

➡ Do not produce any tidal tails....

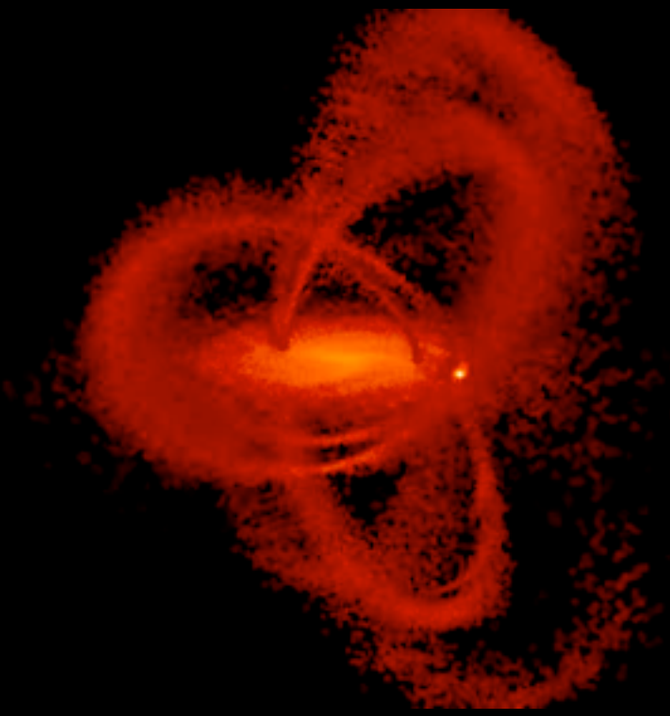
➡ The identification of a prominent *tidal tails* with a mixture of young/old stellar populations reveal a gas-rich major merger



Bournaud, Duc & Emsellem, 2008

✓ Minor mergers involving (gas-poor) dwarf satellites

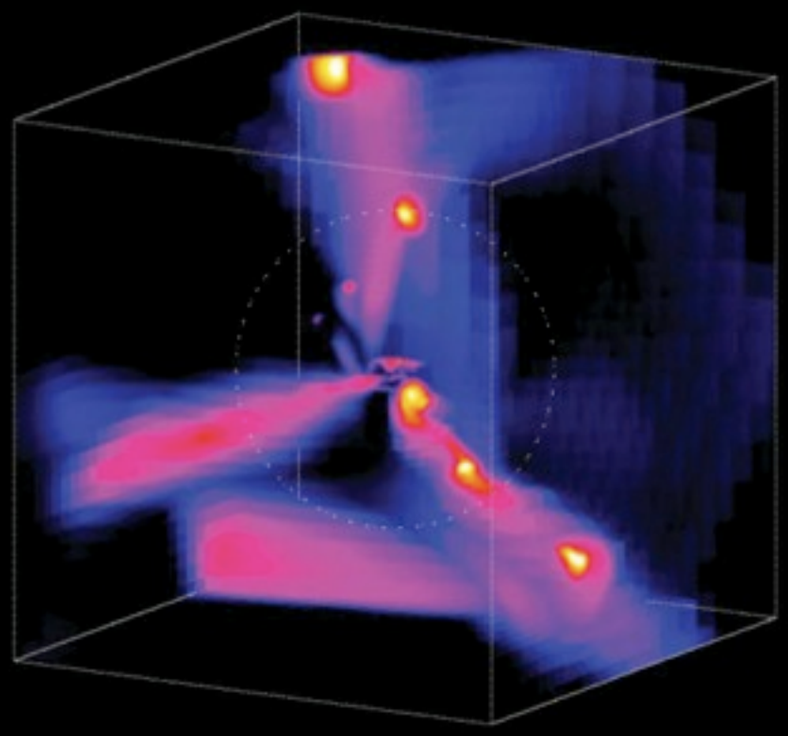
➡ Produce gas-poor, narrow, tidal tails wrapping along their host



© Martin et al.

➡ The presence of narrow stellar *streams* with a possibly a massive condensation within it (the progenitor) favors minor mergers

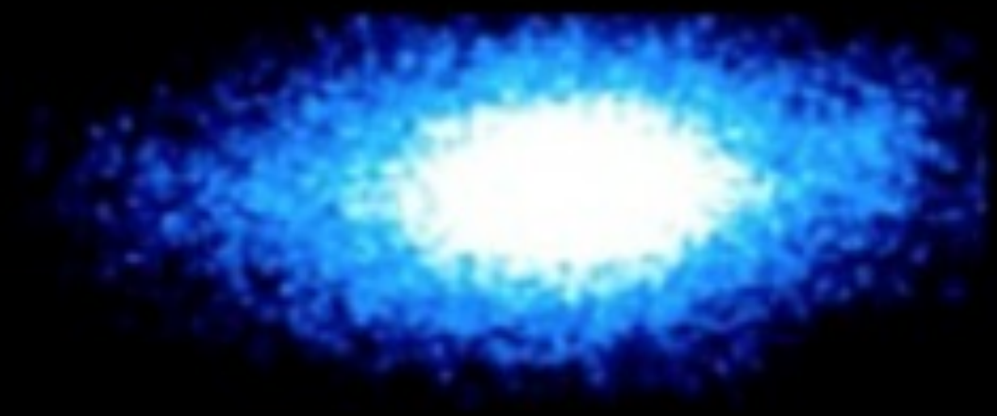
# Fine structures and mass assembly: predictions from simulations



© Dekel et al.

✓ Cold gas accretion, violent disk instabilities, and secular evolution

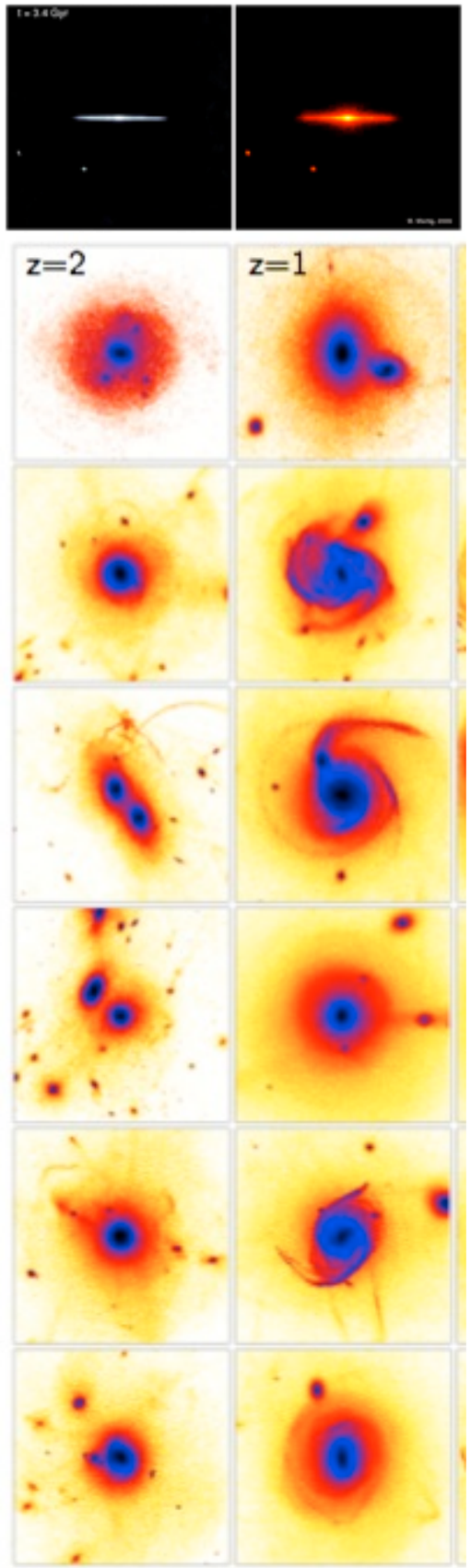
➡ induce morphological transformations but do not produce any fine structures



➡ The absence of fine structures may favor VDIs ... or lack of sensitivity to detect them, or old mergers, or hostile environments for their survival....

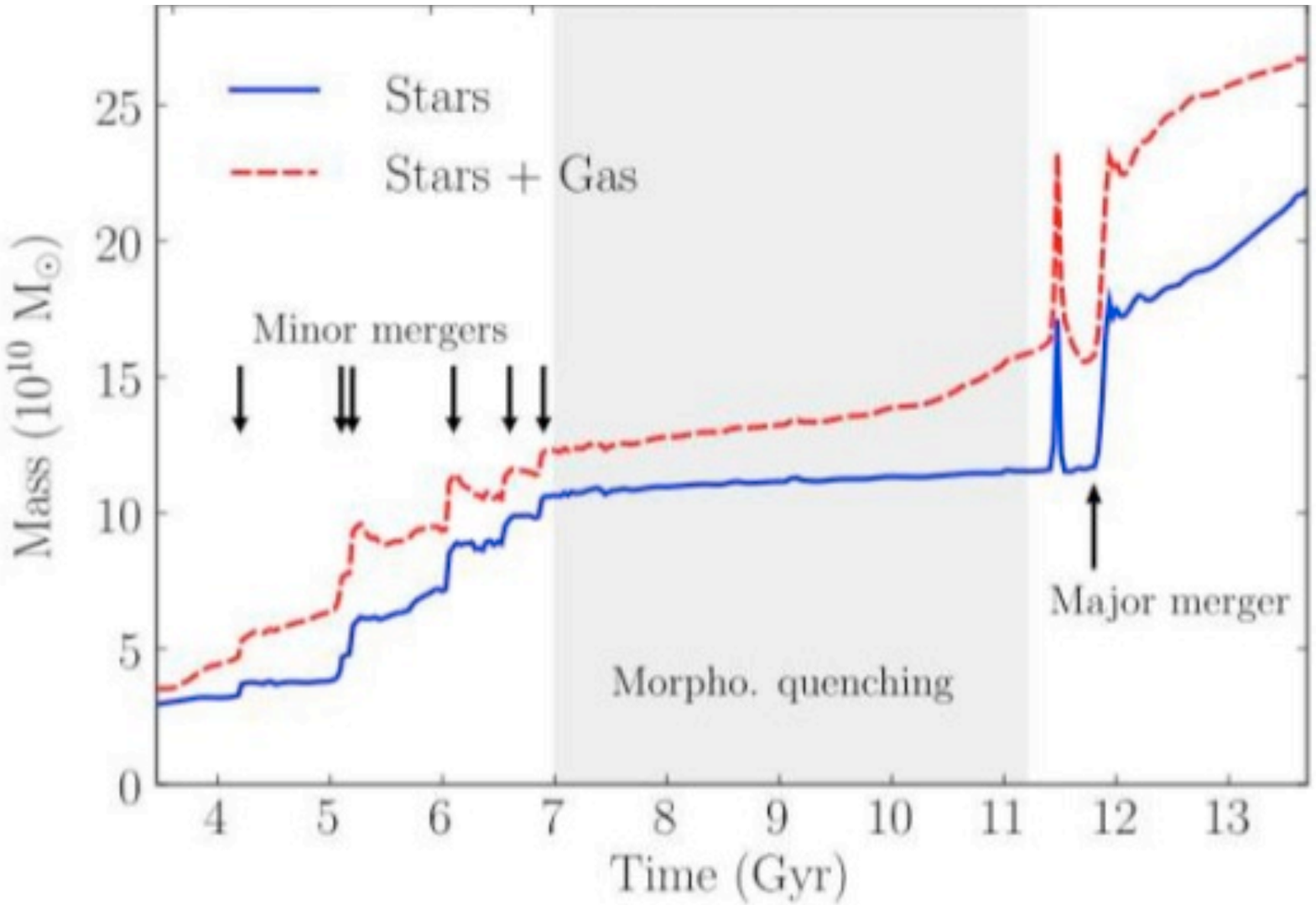
© Bournaud, Elmegreen et al.

# Reconstructing the mass assembly with fine structures



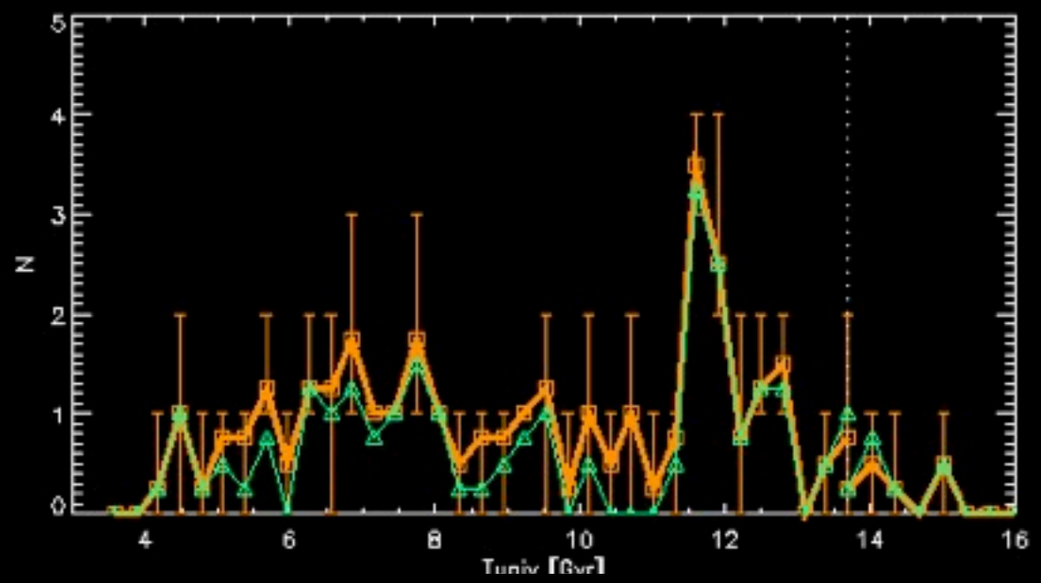

Martig et al., 2009

- Survival time of fine structures probed by numerical simulations in cosmological context

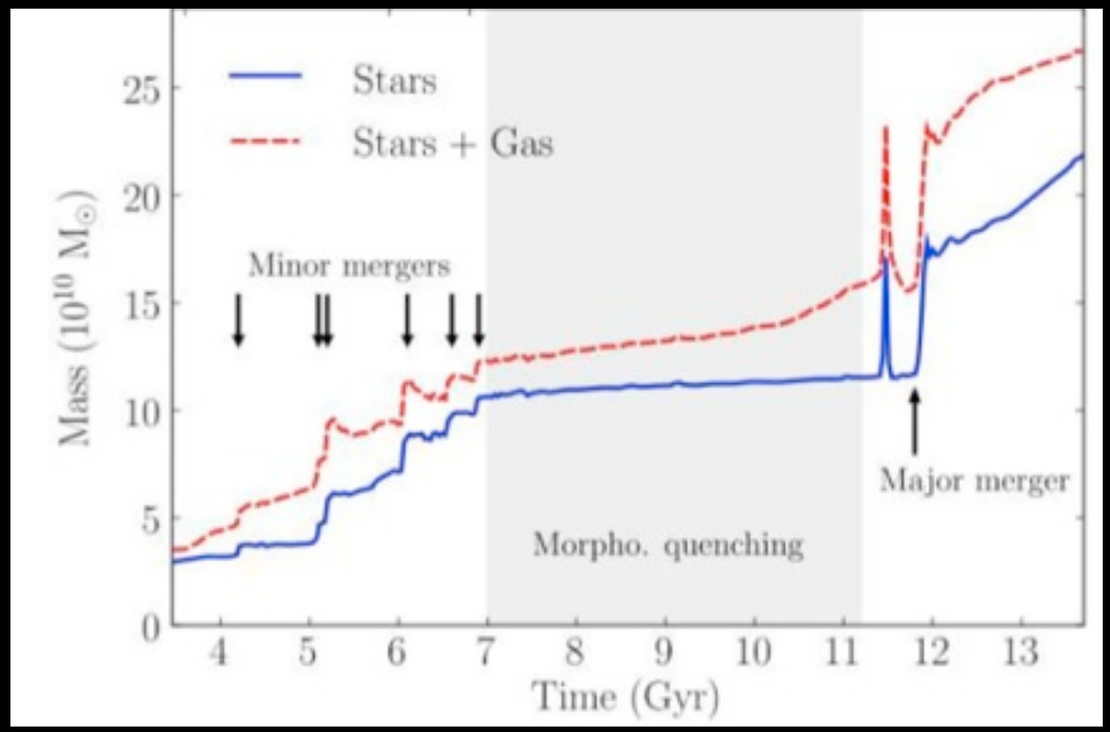



Michel-Dansac et al., in prep.

# Reconstructing the mass assembly with fine structures

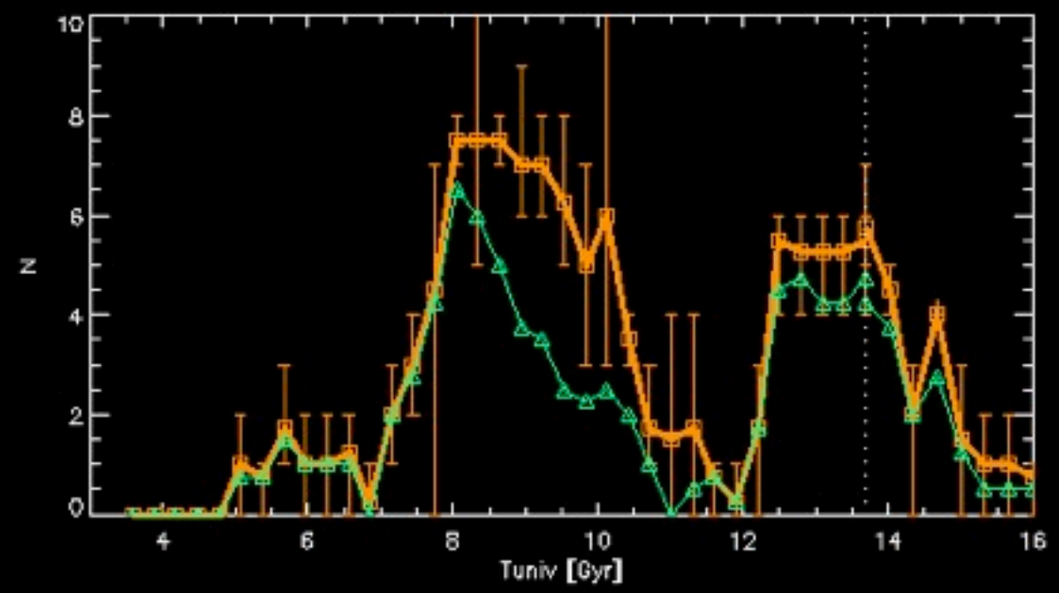



Tidal tails



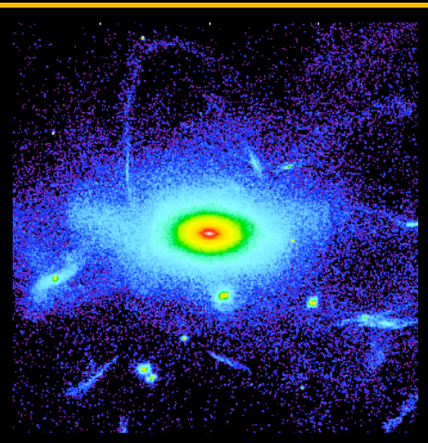

- Tidal tails associated with major mergers remain visible for about 2 Gyr

Shells




- Shell signature (intermediate mass 1:5 merger) rather long lived (3-4 Gyr)

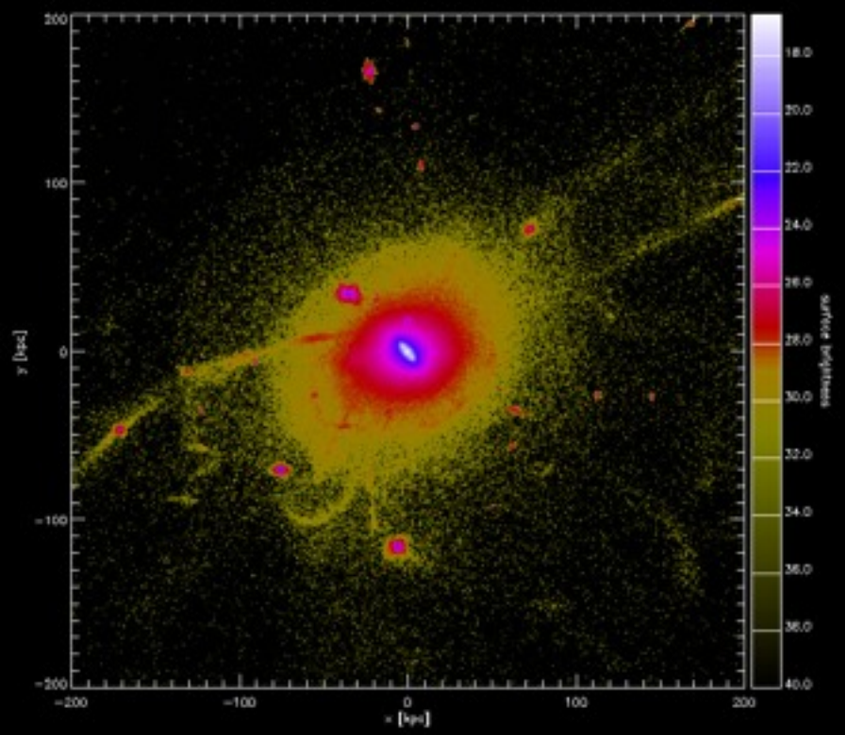
# Surface brightness limitations



✓At unlimited sensitivity

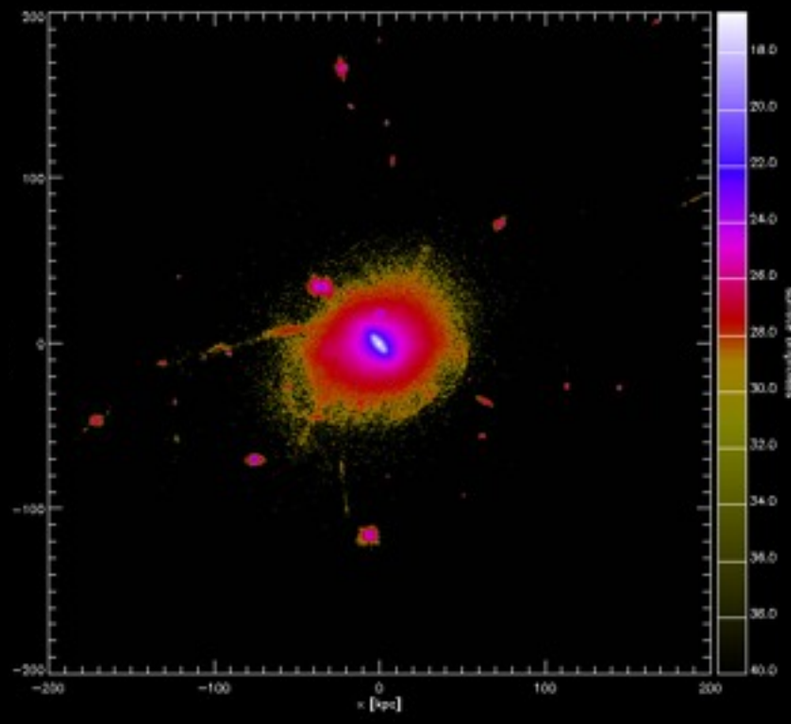
- *Simulated surface brightness maps*

Michel-Dansac et al, 2013



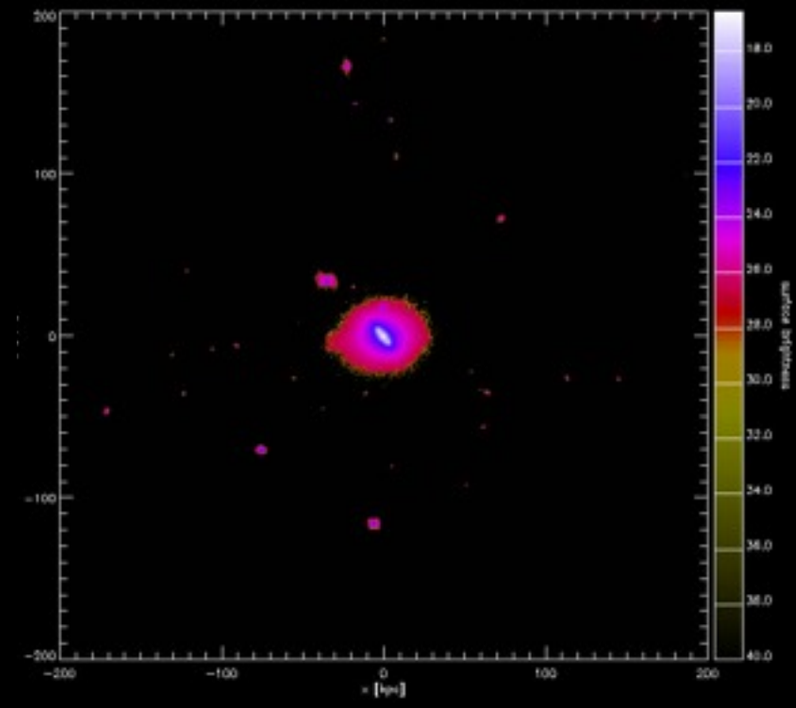

✓ At 32 mag/arcsec$^2$

• Surface brightness maps which are reached from star counts (e.g. PAndAS)
For Local Group galaxies




✓ Cutting at 29 mag/arcsec$^2$

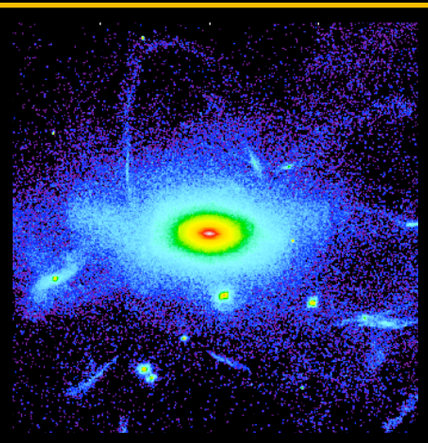
• Surface brightness limit of on-going ultra-deep surveys probing the integrated diffuse light of nearby galaxies




✓ Cutting at 27 mag/arcsec$^2$

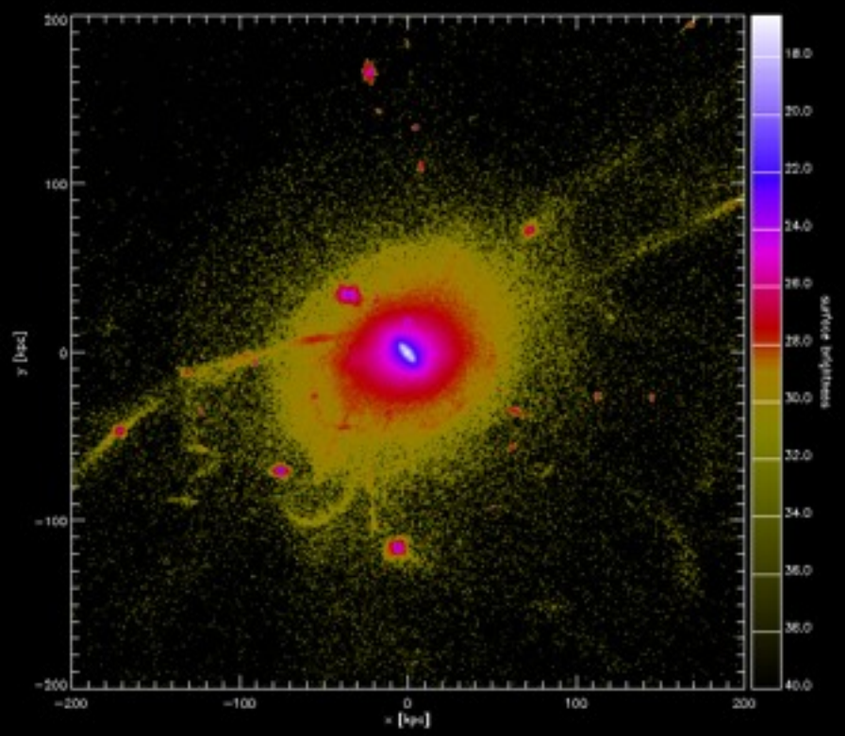
• Surface brightness limit of traditional images of nearby galaxies (SDSS, CFHTLS)

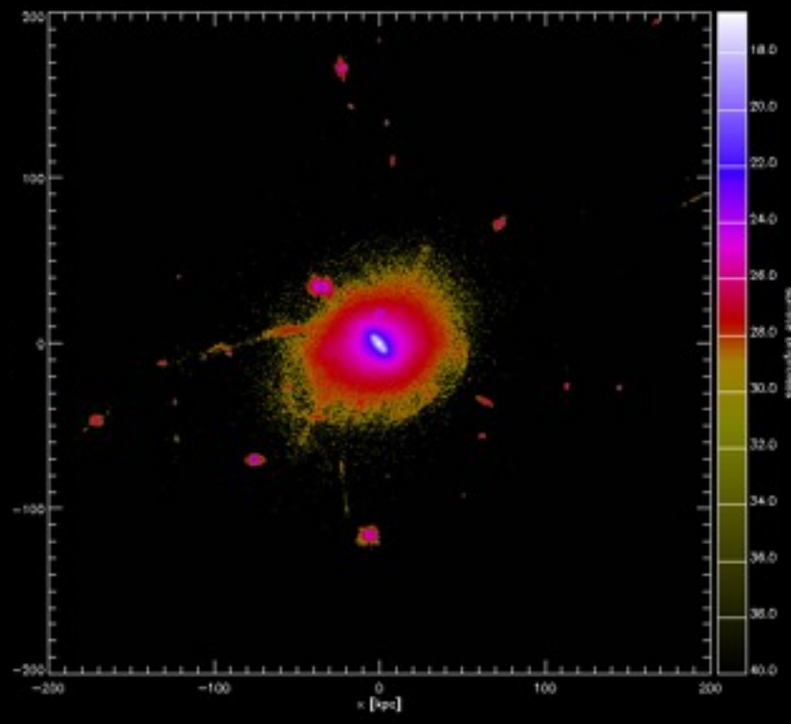
# Surface brightness limitations

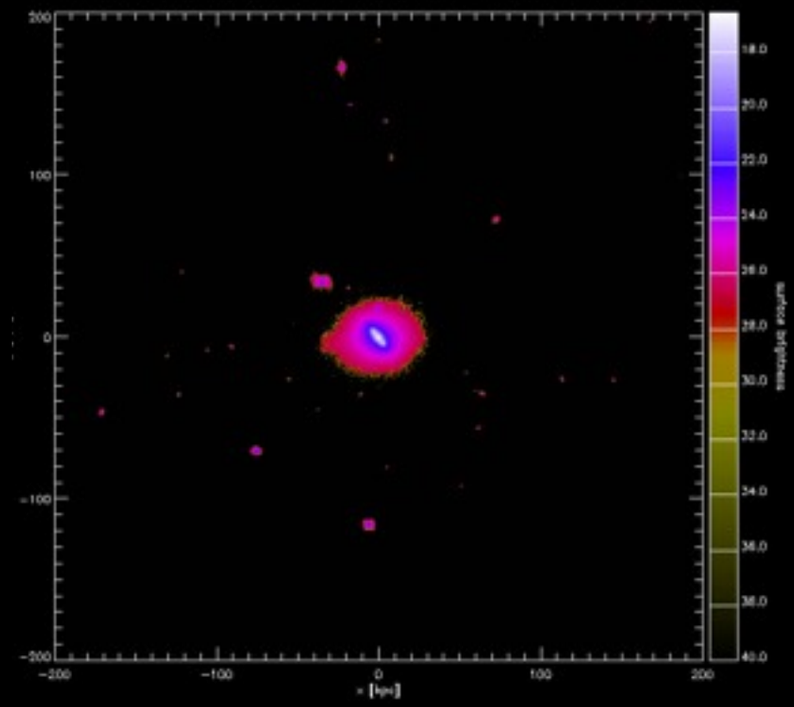


- *Simulated surface brightness maps*

Michel-Dansac et al, 2013




✓ At 32 mag/arcsec$^2$

• Surface brightness maps which are reached from *star counts* for *Local Group* galaxies (e.g. PAndAS)

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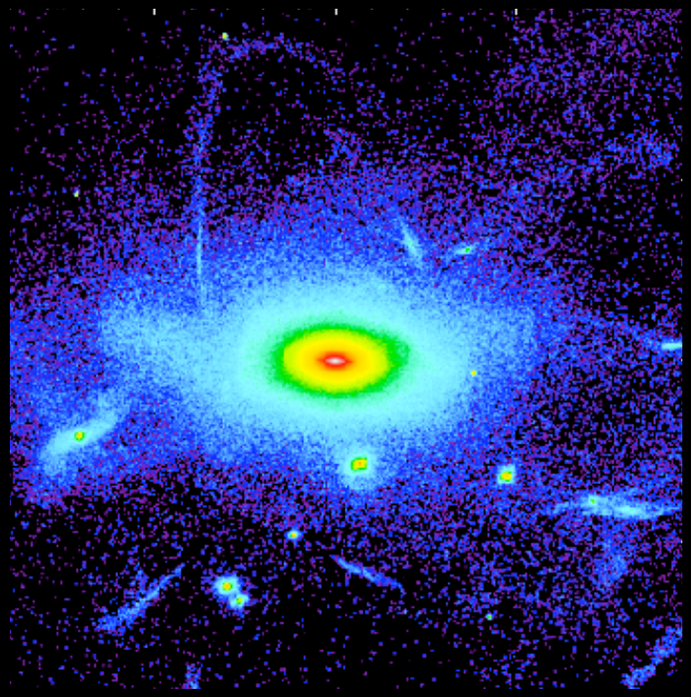
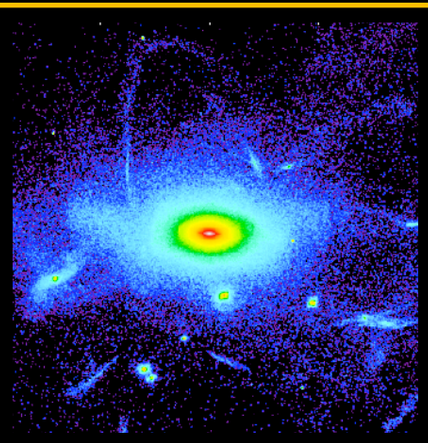


• *Andromeda as seen by PAndAS*

McConnarchie et al, 2011

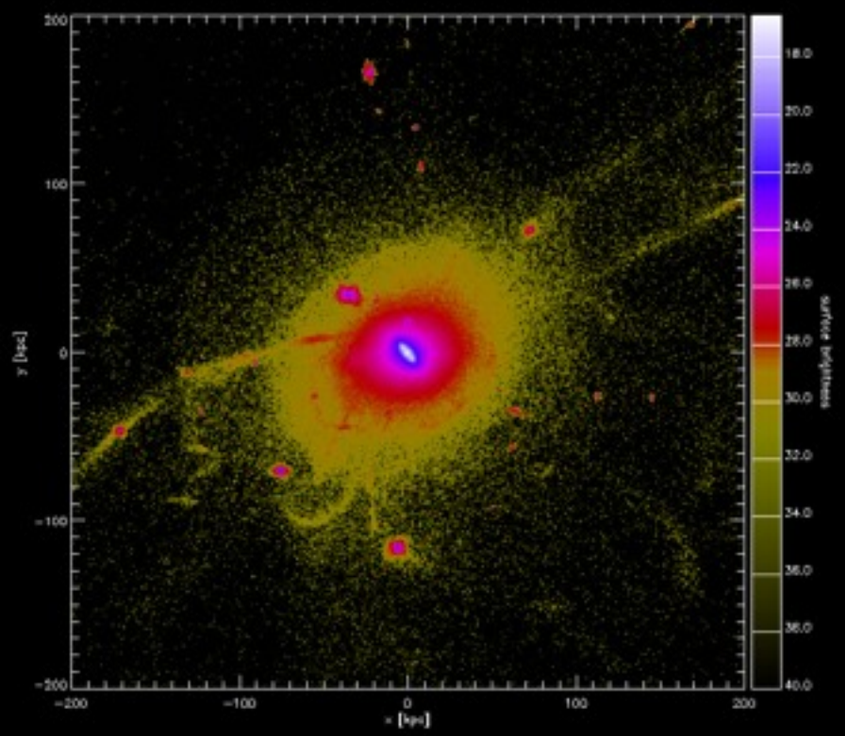
• Should all evolved/massive galaxies ressemble M31 at 32 mag.arcsec$^{-2}$?

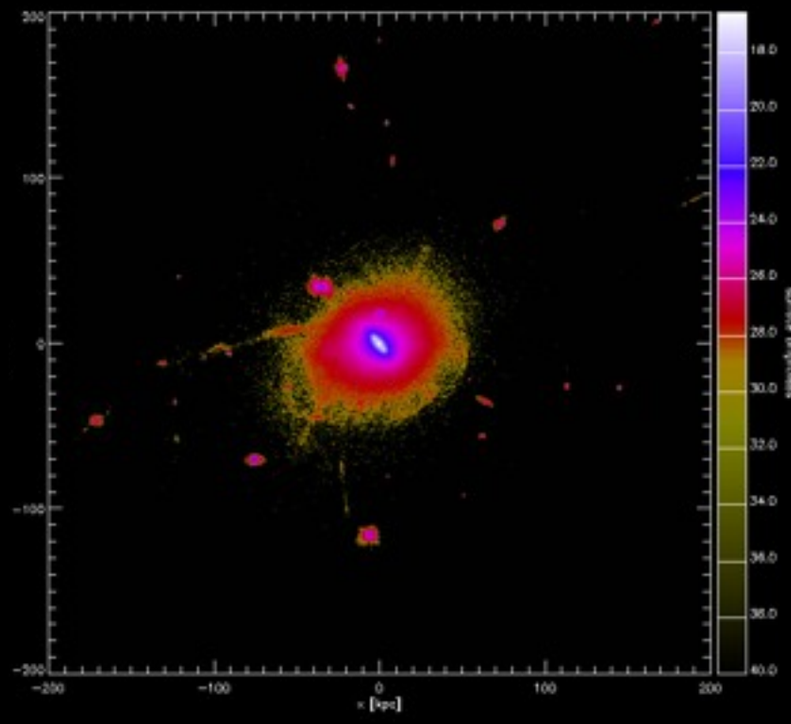
# Surface brightness limitations

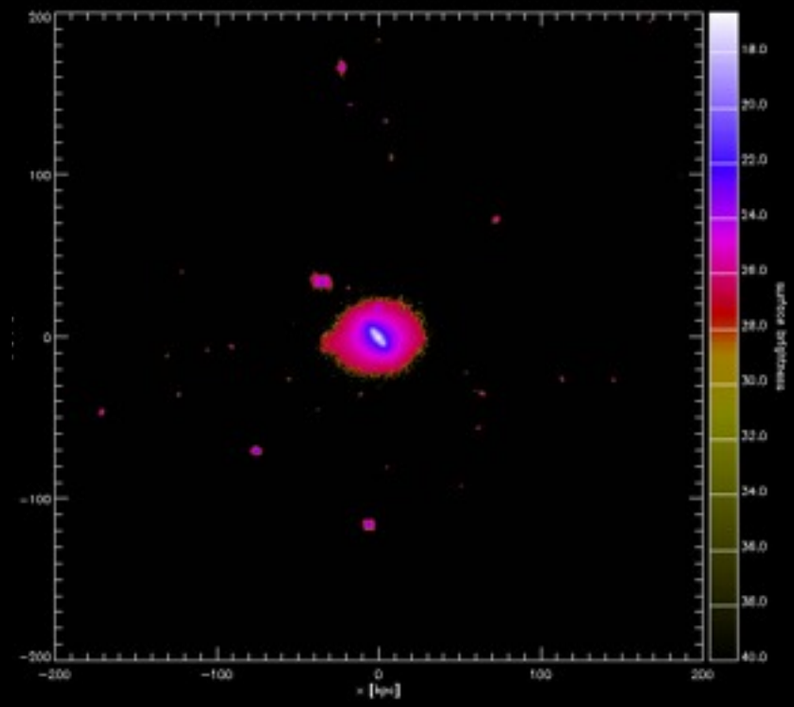


- *Simulated surface brightness maps*

Michel-Dansac et al, 2013

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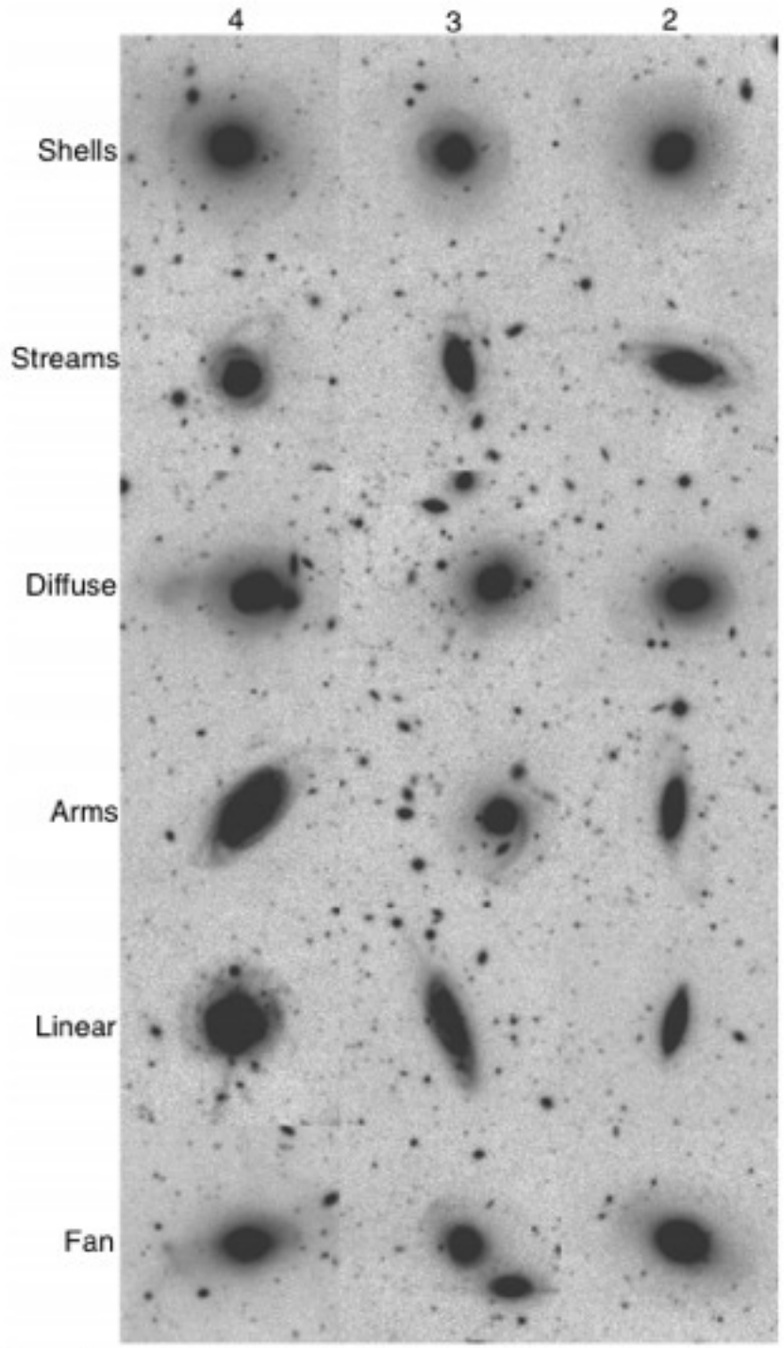
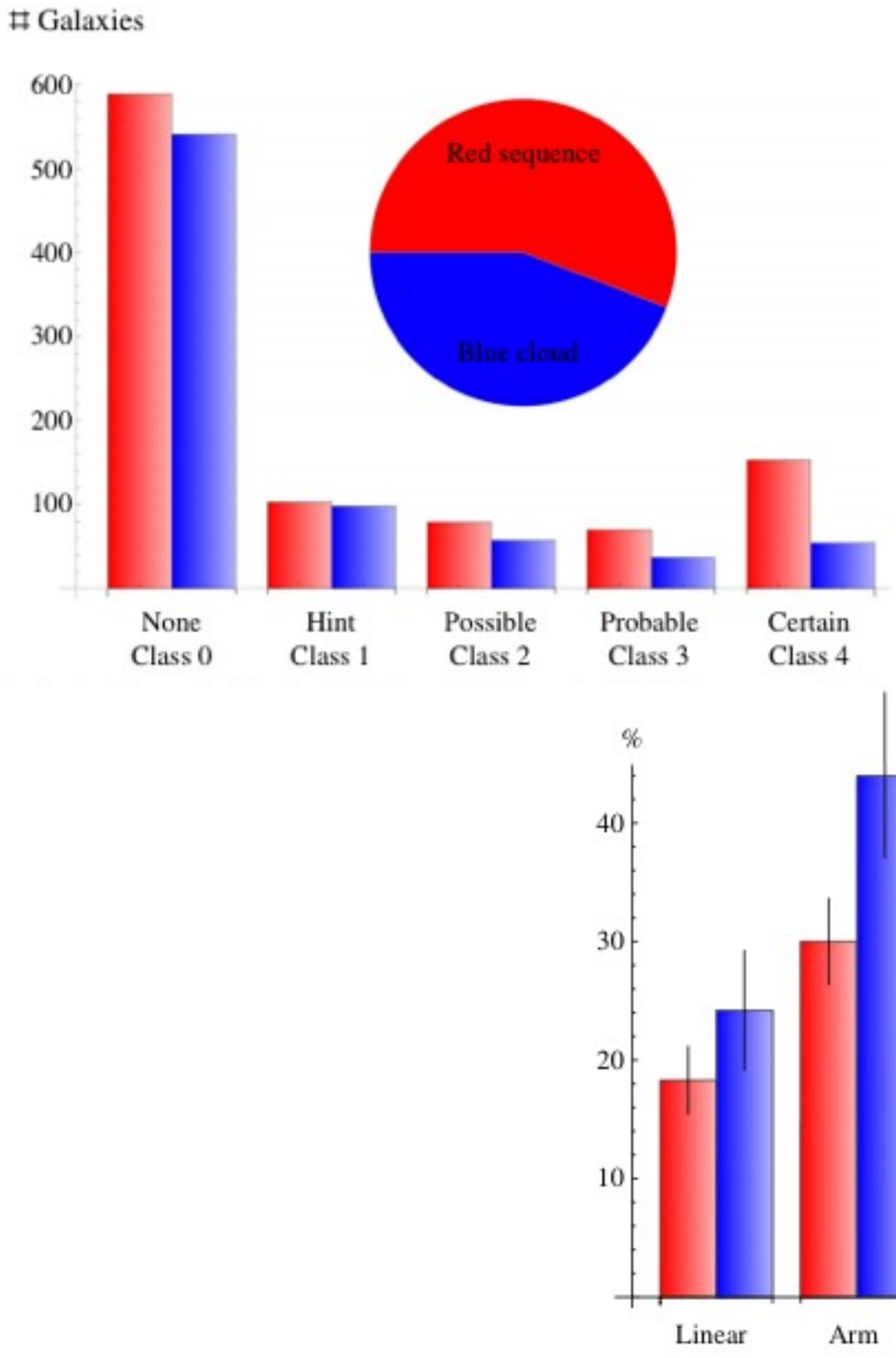
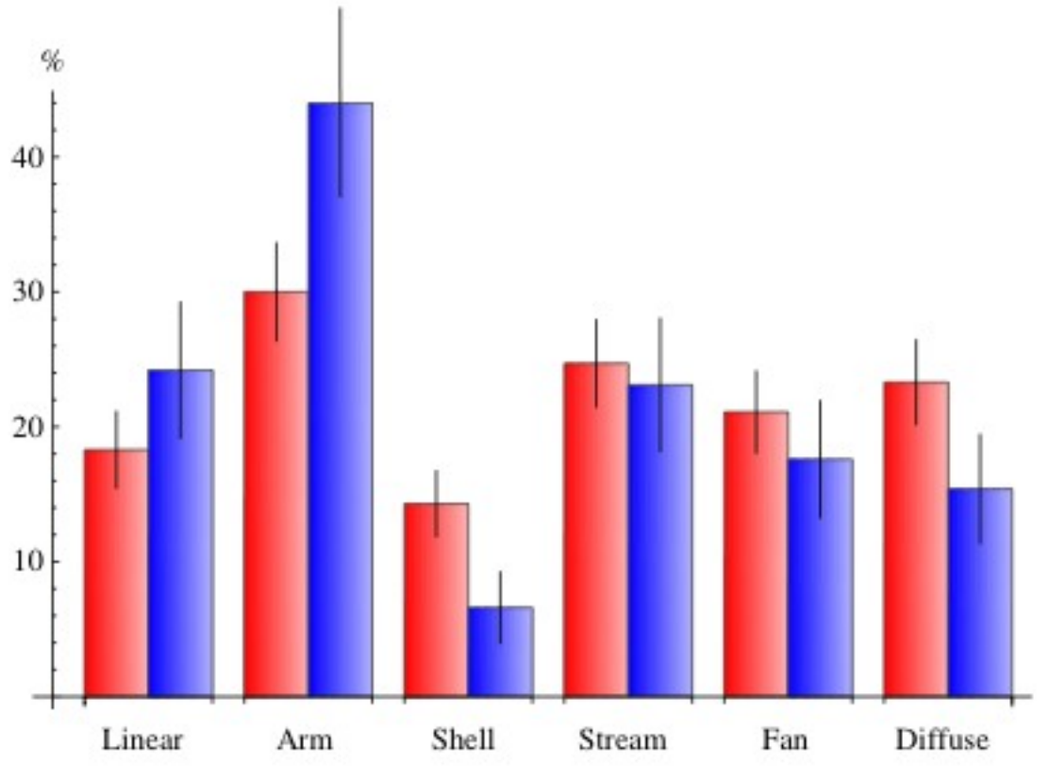
# Surface brightness limitations

CFHTLS



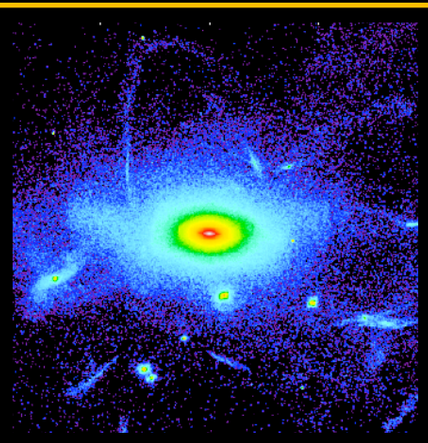

Atkinson et al., 2013



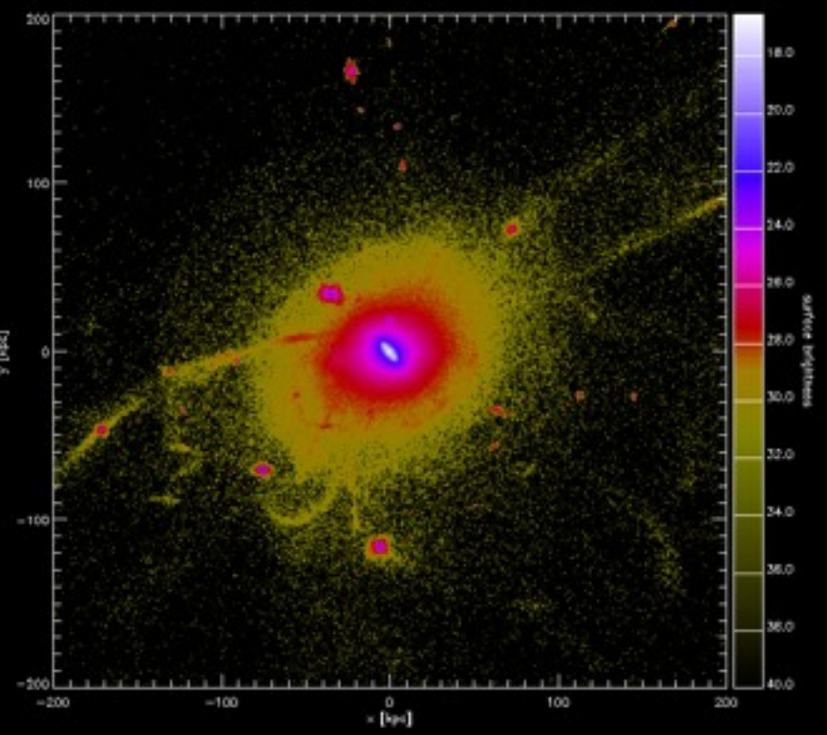

- 12% galaxies with Mr<-19.3 show tidal features

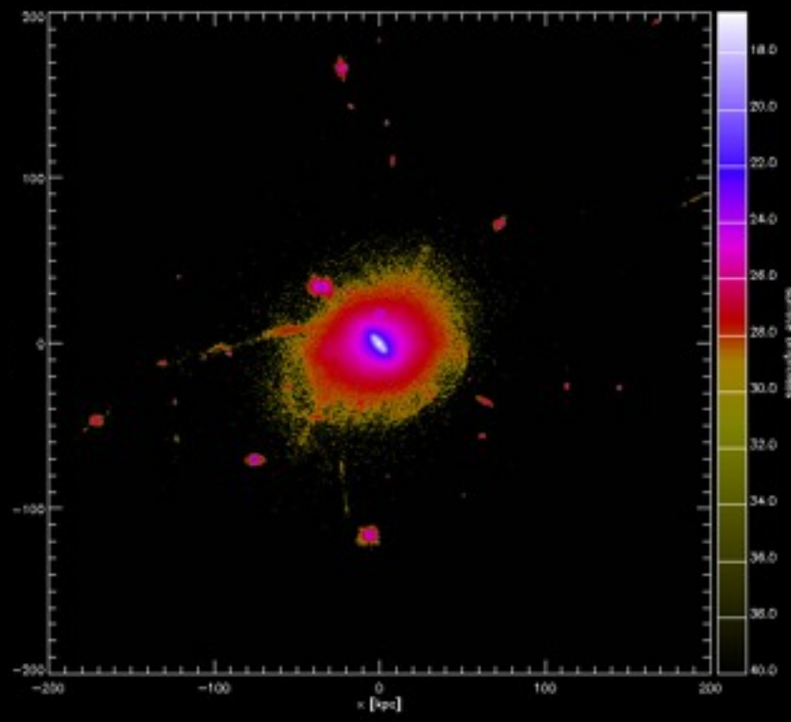
# Surface brightness limitations

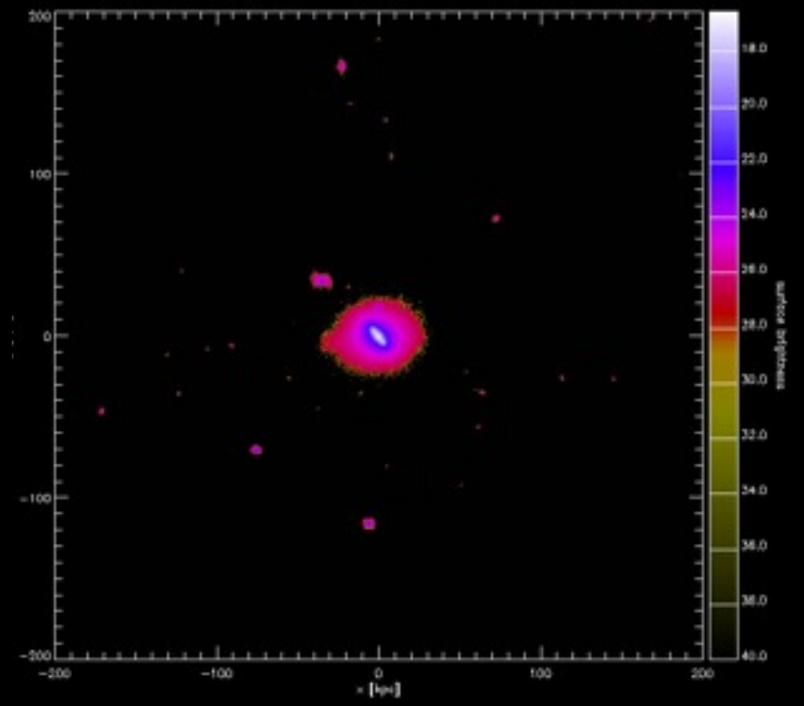


- *Simulated surface brightness maps*

Michel-Dansac et al, 2013

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• Surface brightness limit of on-going *ultra-deep surveys* probing the integrated diffuse light of nearby galaxies

✓ Cutting at 27 mag/arcsec$^2$

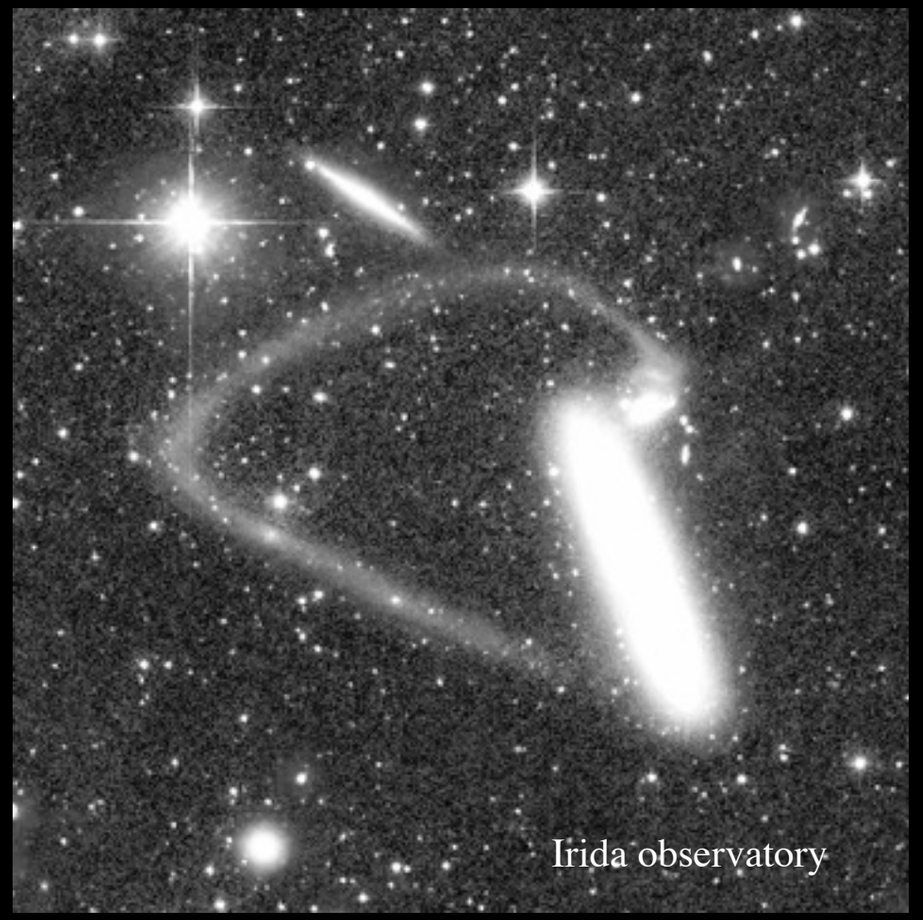
• Surface brightness limit of traditional images of nearby galaxies (SDSS)

# Surface brightness limitations

Blackbird telescope

- Getting to 29 (?) mag.arcsec$^{-2}$ with amateur telescopes

Martinez-Delgado et al., 2010



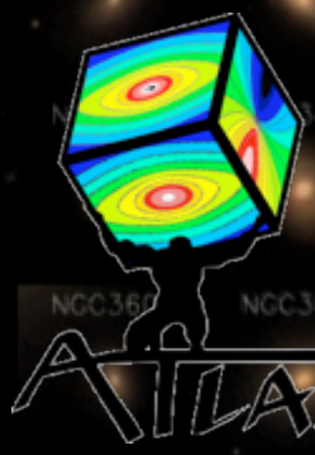
Irida observatory

- Clean, large field of view, images
- Very broad filters, not allowing precise photometry
- Very long exposure times
- No systematic survey

# Extreme deep imaging with MegaCam on the CFHT

A volume-limited sample of 260 massive ETGs with
D < 42 Mpc (Altas$^{3D}$)


Ferrarese et al, 2011




Cappellari et al, 2011


Duc et al, 2013

- Observed with the large field of view camera MegaCam (multiband:u,g,r,i) on the CFHT, as part of NGVS for the Virgo ETGs, and MATLAS for the other ones

# Extreme deep imaging with MegaCam on the CFHT

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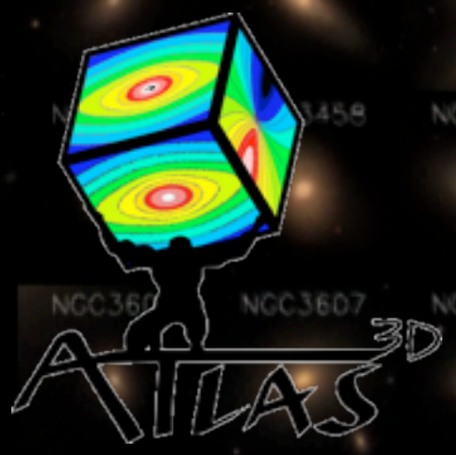
Ferrarese et al, 2011




Cappellari et al, 2011


Duc et al, 2013

- With specific observing strategy (large offsets, sky subtraction) and data reduction technique (Elixir-LSB) to optimize the detection of low surface brightness features

# The Hubble diagram as seen with SDSS-like observations

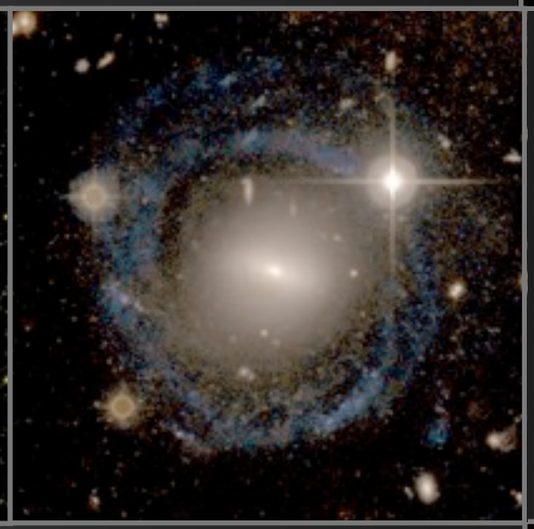
©SDSS

- blue star-forming spirals

- read and dead ellipticals

# The Hubble diagram as seen with LSB mode of MegaCam

©Duc/MATLAS/NGVS

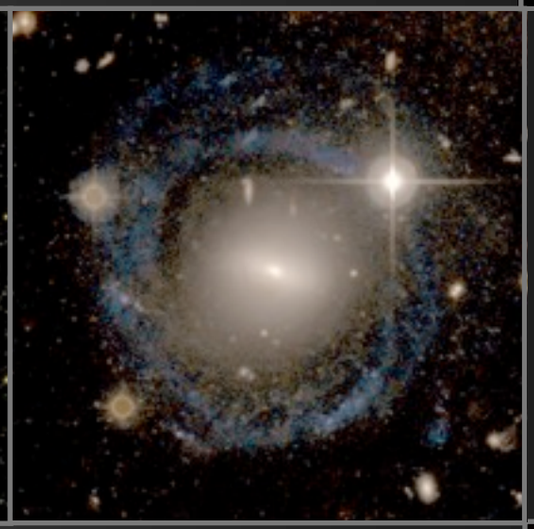


- spirals with a red halo

- ellipticals with star-forming disks

# The Hubble diagram as seen with LSB mode of MegaCam

©Duc/MATLAS/NGVS



- spirals with a red halo

- ellipticals with star-forming disks

Morphological classification depends on image depth -> need for other criteria

©SDSS

# Massive galaxies as seen with the SDSS

Relaxed, with only weak signs of tidal perturbations

©Duc/MATLAS/NGVS

# Massive galaxies as seen with LSB mode of MegaCam

http://irfu.cea.fr/Projets/matlas

Paudel et al., 2013

Duc et al., 2011

Same galaxies show a (recent) complex mass accretion history


• Shells reveal intermediate mass mergers, with specific orbital parameters

• Gas poor stellar streams drawing a S-shape wrapping around the host: an on-going minor merger

• 2 major long tidal tails on each side of the host, revealing a gas-rich major merger

Duc et al., 2011

Paudel et al., 2013

Same galaxies show a (recent) complex mass accretion history

# Fully relaxed, unperturbed, boring ETGs, even at MegaCam depth

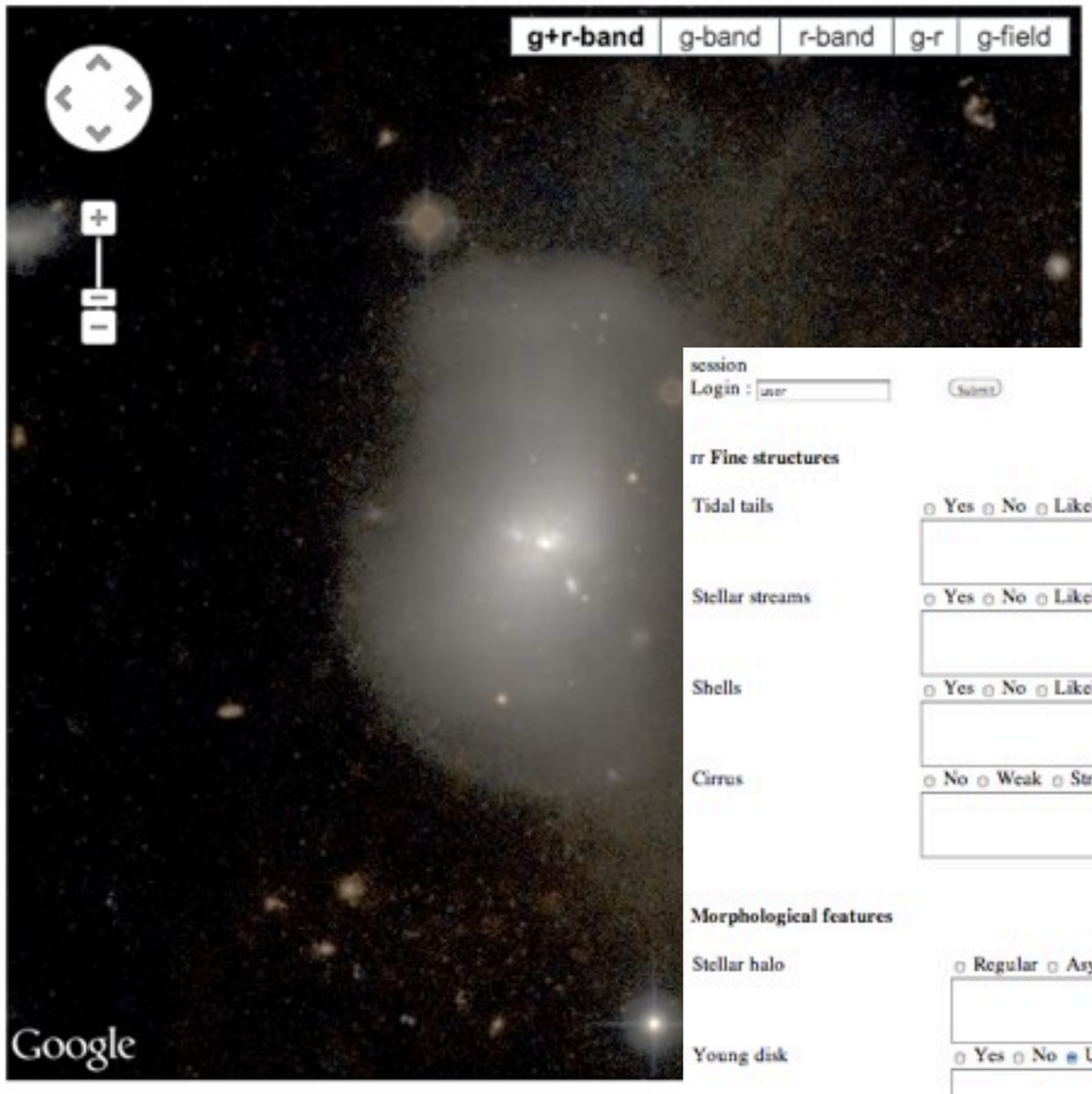
• Not all massive ETGs/ spirals show tidal features (contrary to simulations?)

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/Atlas3D projects

# Classification of galaxies based on fine structures




session
Login : user Submit

rr **Fine structures**

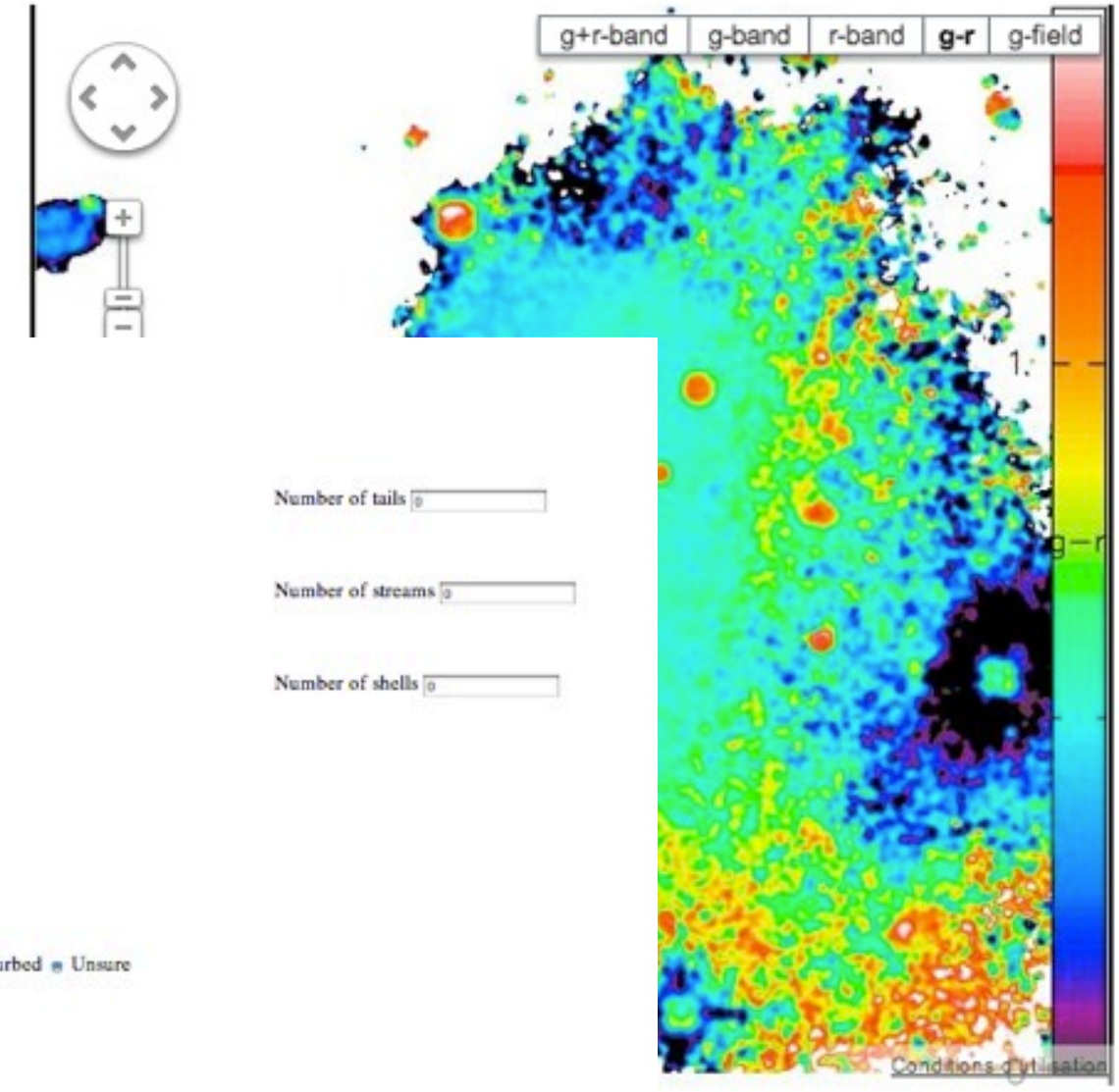
| | | |
|---|---|---|
| Tidal tails | ○ Yes ○ No ○ Likely ● Unsure | Number of tails 0 |
| Stellar streams | ○ Yes ○ No ○ Likely ● Unsure | Number of streams 0 |
| Shells | ○ Yes ○ No ○ Likely ● Unsure | Number of shells 0 |
| Cirrus | ○ No ○ Weak ○ Strong ● Unsure | |

**Morphological features**

| | |
|---|---|
| Stellar halo | ○ Regular ○ Asymmetric ○ Disturbed ● Unsure |
| Young disk | ○ Yes ○ No ● Unsure |
| Stellar bar | ○ No ○ Weak ○ Strong ● Unsure |
| Dust lanes | ○ No ○ Weak ○ Strong ● Unsure |

**Environment**

| | |
|---|---|
| Local | ○ Isolated ○ Overlapping Pair ○ Close Pair ● Unsure |
| Large scale | ○ In field ○ In group ○ In cluster ● Unsure |




- Eye classification

- Statistics à la galaxy / Candels zoo

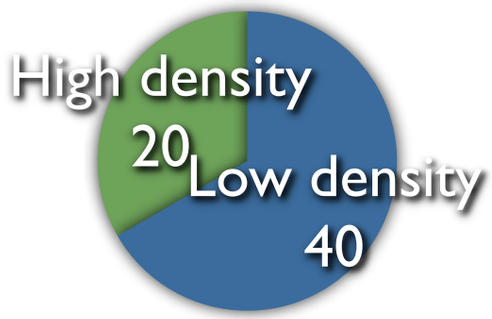
## Correlating fine structure index with:

Preliminary

Sample uncomplete and still biased

### ✓ Environment

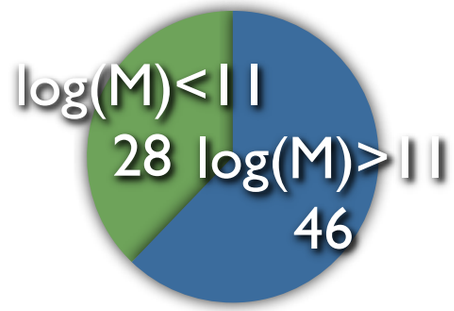
• Galaxies in denser environments (Virgo Cluster) have a lower fine structure index (older or fine structures destroyed)




### ✓ Mass and Size

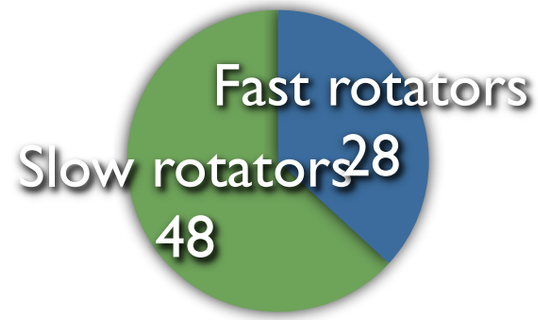
• Massive, extended, galaxies are more tidally perturbed

*% tidally perturbed*

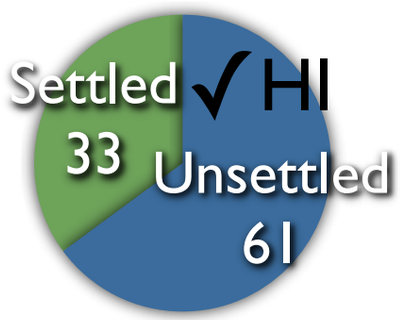



### ✓ Stellar kinematics

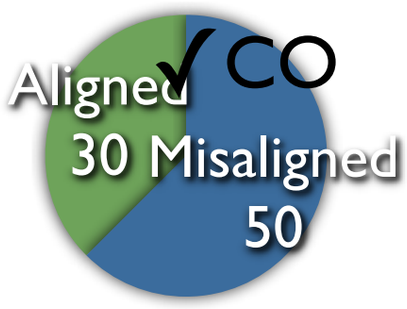
• Slow rotating ETGs have a higher fine structure index than fast rotating ETGs




### ✓ gas content




• Gas-rich ETGs slightly more tidally pertubed. alaxies with unsettled HI (irregular morphology) or CO not kinematically aligned with stars more tidally perturbed



# Conclusions

- Fine structures give hints on the recent mass assembly of galaxies, but have usually a very low surface brightness

- On going deep imaging programs ‘(NGVS, MATLAS) at CFHT with optimized observing and data reduction techniques reach a high surface brightness limit (29 mag.arcsec$^{-2}$) allow us to detect a variety of fine structures.

- New structures found changing our vision of (some) massive galaxies: blue spirals structures around ETGs, tails, streams and shells telling about past mergers below z=1. But not in all ETGs (at our mimiting magnitude)! Depends on galaxy property (mass, kinematics)

- A variety of color profiles is observed in the very outerskirts, also telling about various assembly mechanisms