Evolution of massive galaxies over cosmic time

Nacho Trujillo

Instituto de Astrofísica de Canarias

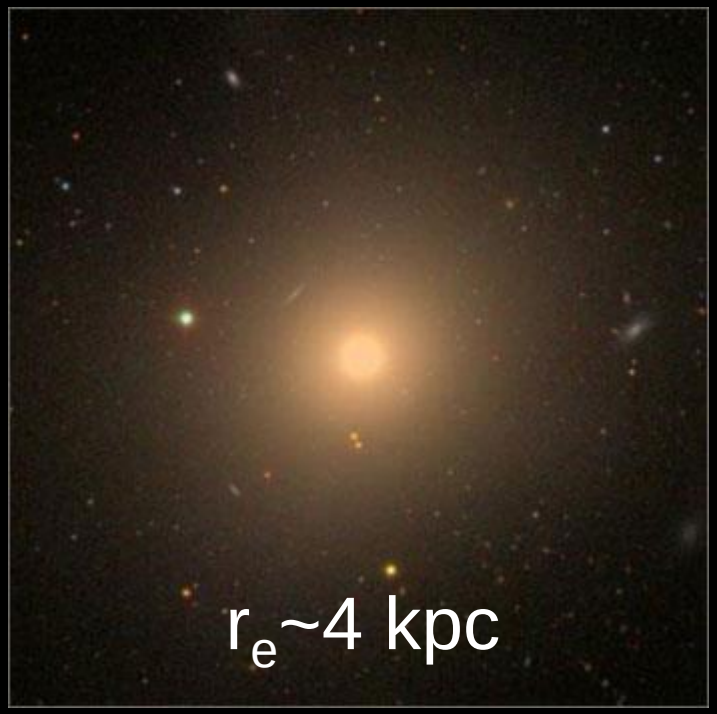
www.iac.es/project/traces

The enormous size evolution: how that it happens?

$M_* \geq 10^{11} M_{sun}$

z=0

z=2



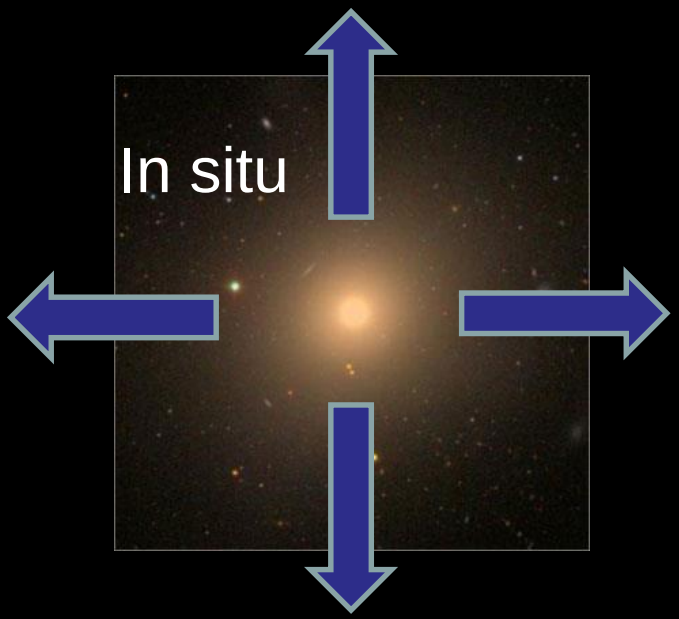
r_e~1 kpc

r_e~4 kpc

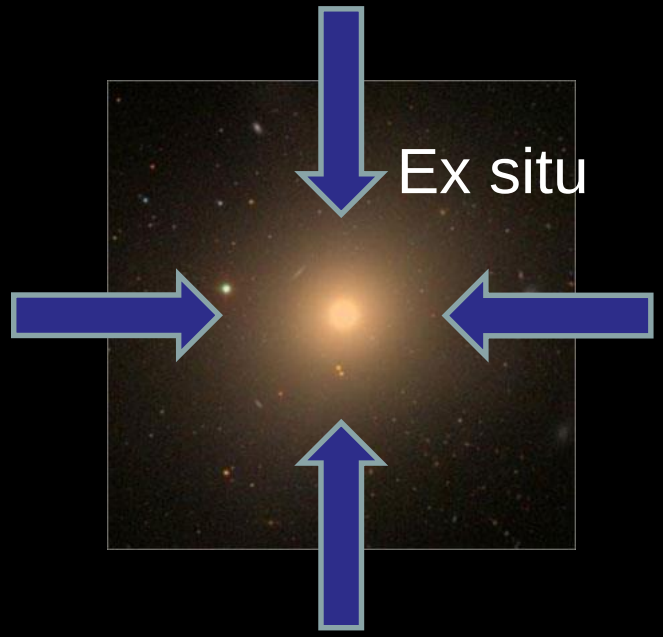
At z~2 they were 4 times smaller!!!

Daddi et al. (2005), Trujillo et al. (2006)

Size growth:
In situ versus *ex situ* scenarios



Puffing-up scenarios



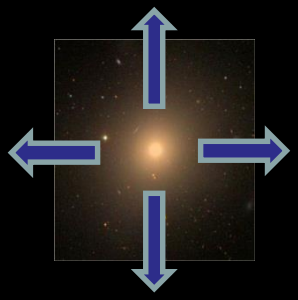
Accretion scenarios

AGN activity Fan et al. 2008; 2010; Ragone-Figueroa & Granato 2011

Supernova winds Damjanov et al. 2009

Major merging Ciotti & van Albada 2001; Boylan-Kolchin et al. 2006; Naab et al. 2007; Nipoti et al. 2010

Minor merging Khochfar & Burkert 2006; Maller et al. 2006; Hopkins et al. 2009; Naab et al. 2009; Sommer-Larsen & Toft 2010; Oser et al. 2010



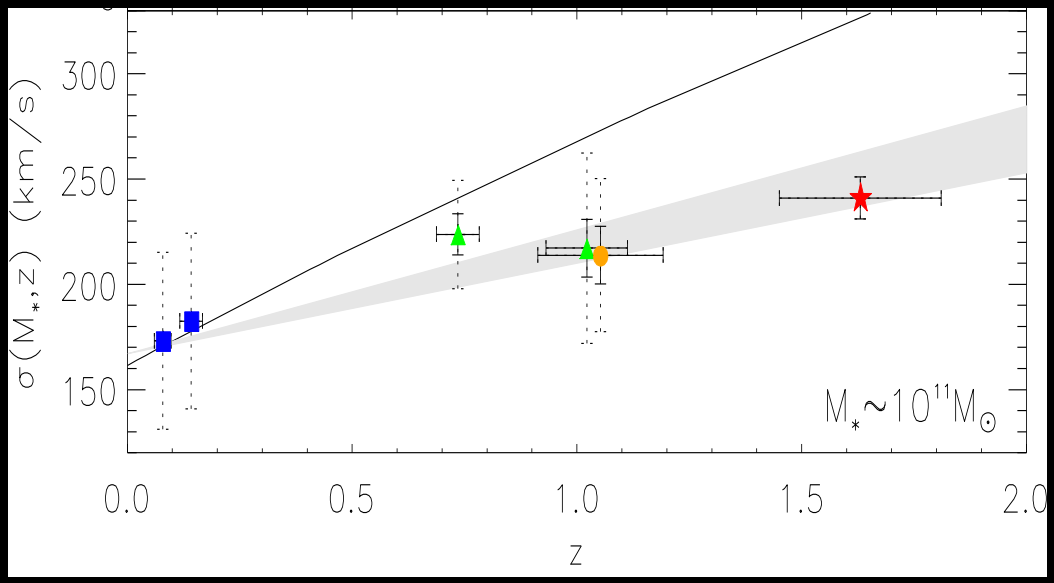
In situ growth: predictions

- Two groups of massive galaxies at every redshift:

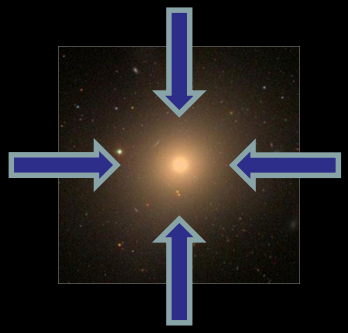
young (<1 Gyr) compact vs old (>1 Gyr) extended

- Strong decrease in the velocity dispersion with cosmic time:

400 km/s -> 200 km/s



Cenarro & Trujillo (2009);
Cappellari et al. (2009);
Onodera et al. (2010);
van de Sande et al (2011);
Newman et al. (2010);
Toft et al. (2012)



Ex situ growth: predictions

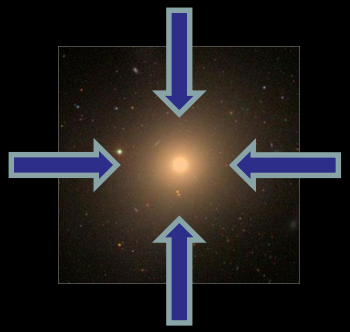
- Stellar mass increase ☑ e.g. van Dokkum+10

- Continuous size evolution ☑ e.g. Trujillo+07; Buitrago+08; Bezanson+08…

- Mild decrease in the velocity dispersion ☑

- No difference in size between “old” and “young” spheroids at a given z ☑
  e.g. Trujillo+11

Qualitative the merging channel seems to work…



Towards a *quantitative test* of the merging channel

The merging channel is a stochastic process…

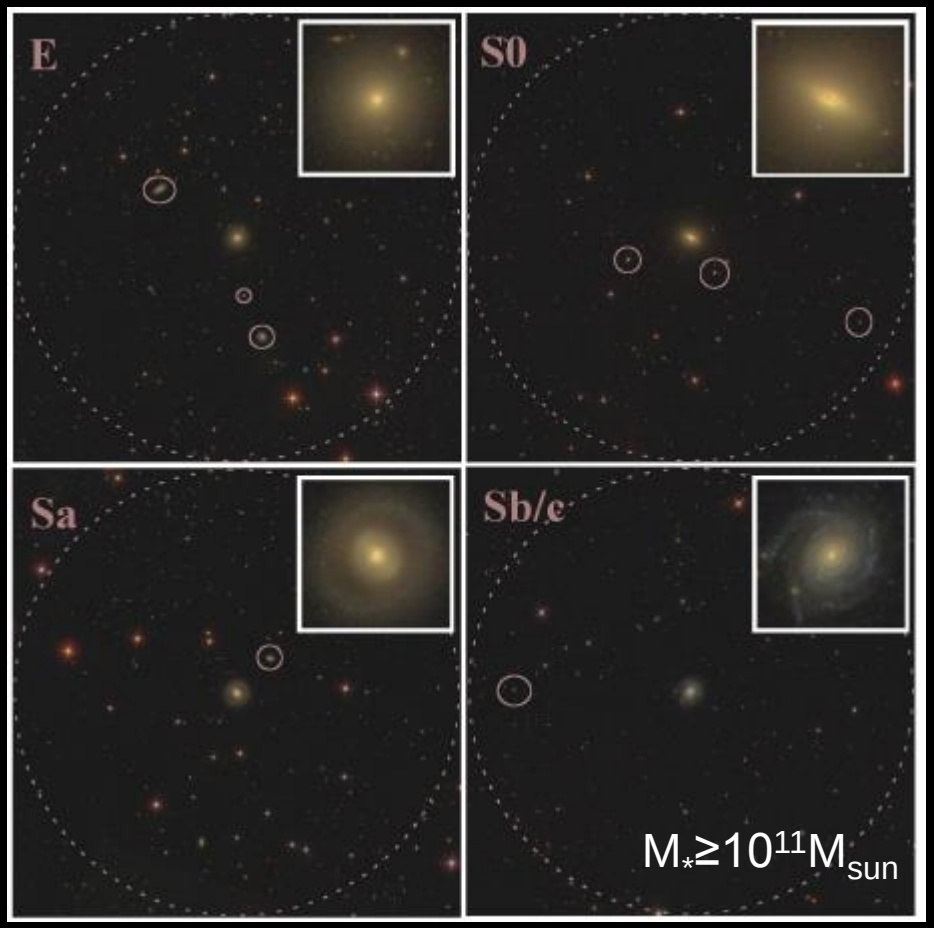
1. Have we got enough number of mergers to produce the size increase?

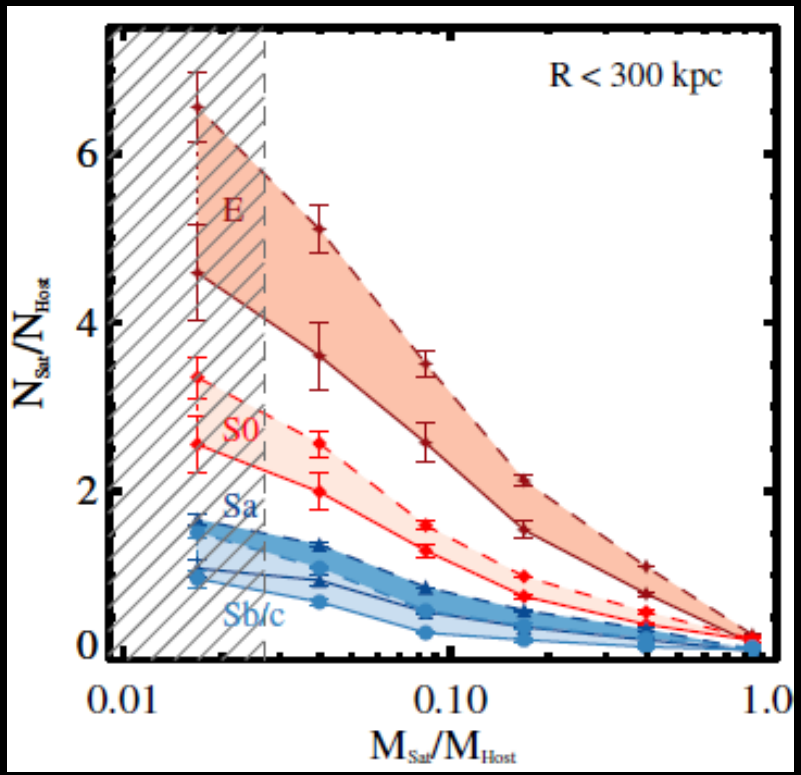
2. Where are the untouched massive "relic" galaxies in the nearby Universe?

Image by P.-A. Duc

I. Have we got enough number of mergers to produce the size increase?

Local Reference: satellite galaxies around massive galaxies today





Ruiz et al. (2015;arXiv:1504.02777)

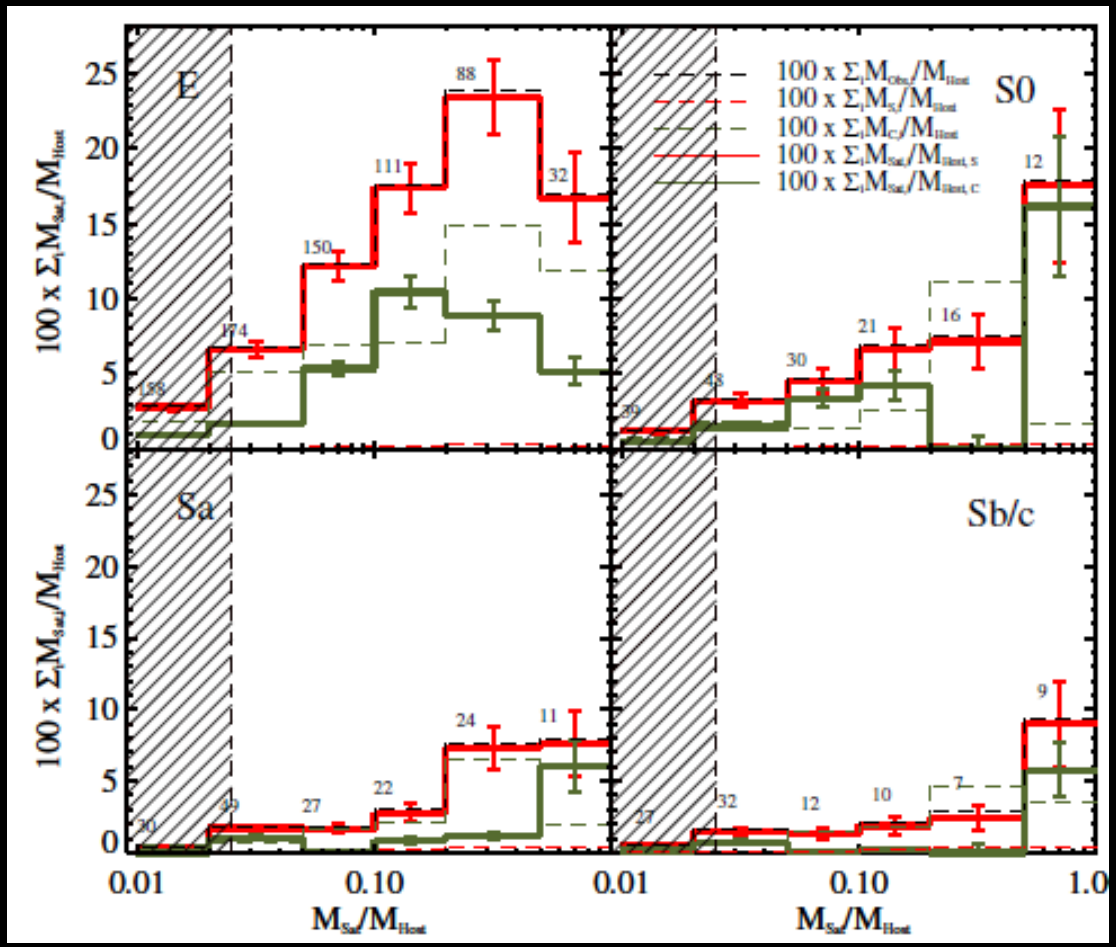
I. Have we got enough number of mergers to produce the size increase?

Local Reference: satellite galaxies around massive galaxies today

Ruiz et al.
(2015;arXiv:1504.02777)

Fracction of mass contained in satellites around massive galaxies today:

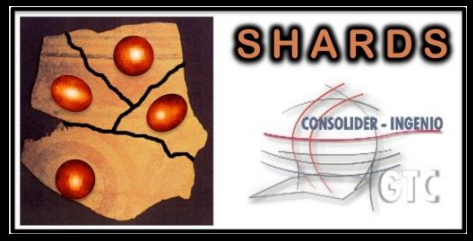
E: ~32%
S0s: ~25%
Sa: ~9%
Sb: ~7%



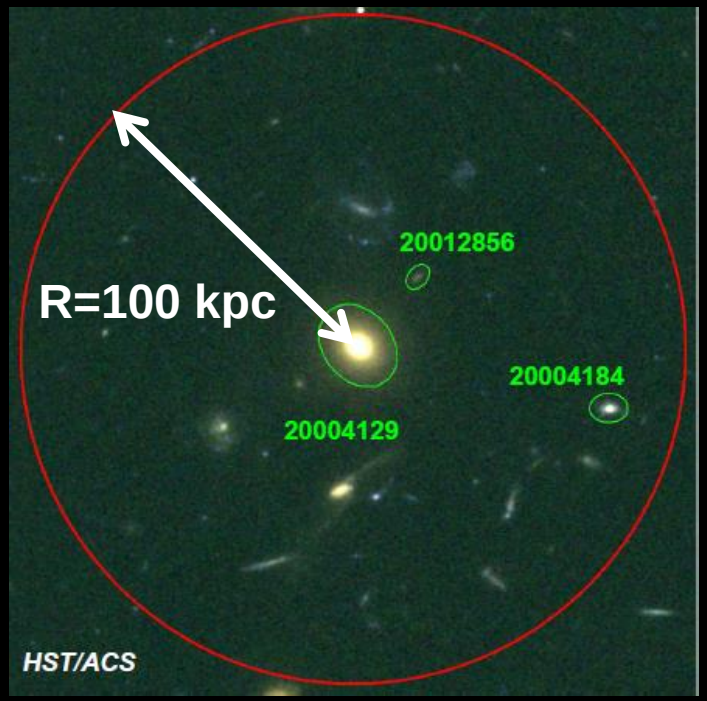
I. Have we got enough number of mergers to produce the size increase?

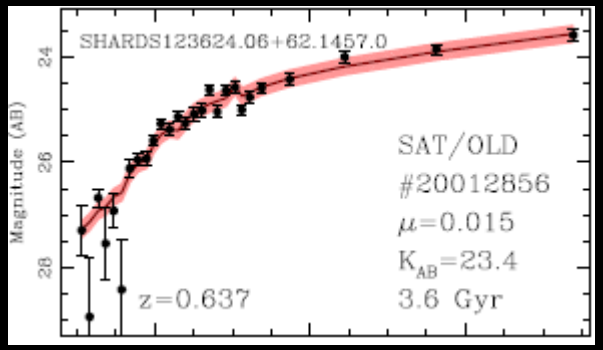
Strategy: counting satellite galaxies around massive galaxies at different cosmic epochs…

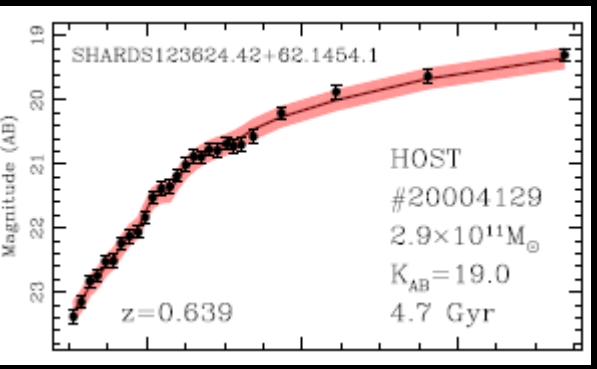
Kaviraj+09; Bundy+09; Jackson+10; Nierenberg+11; Man+12; Newman+12; Mármol-Queraltó+12; Huertas-Company+12; Bluck+12; López-Sanjuan+12; Xu+12

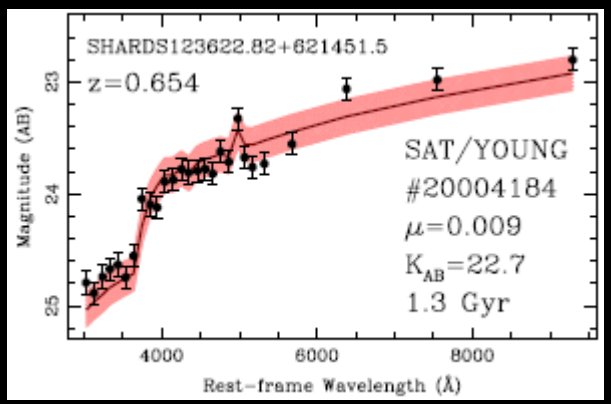


Pérez-González+13









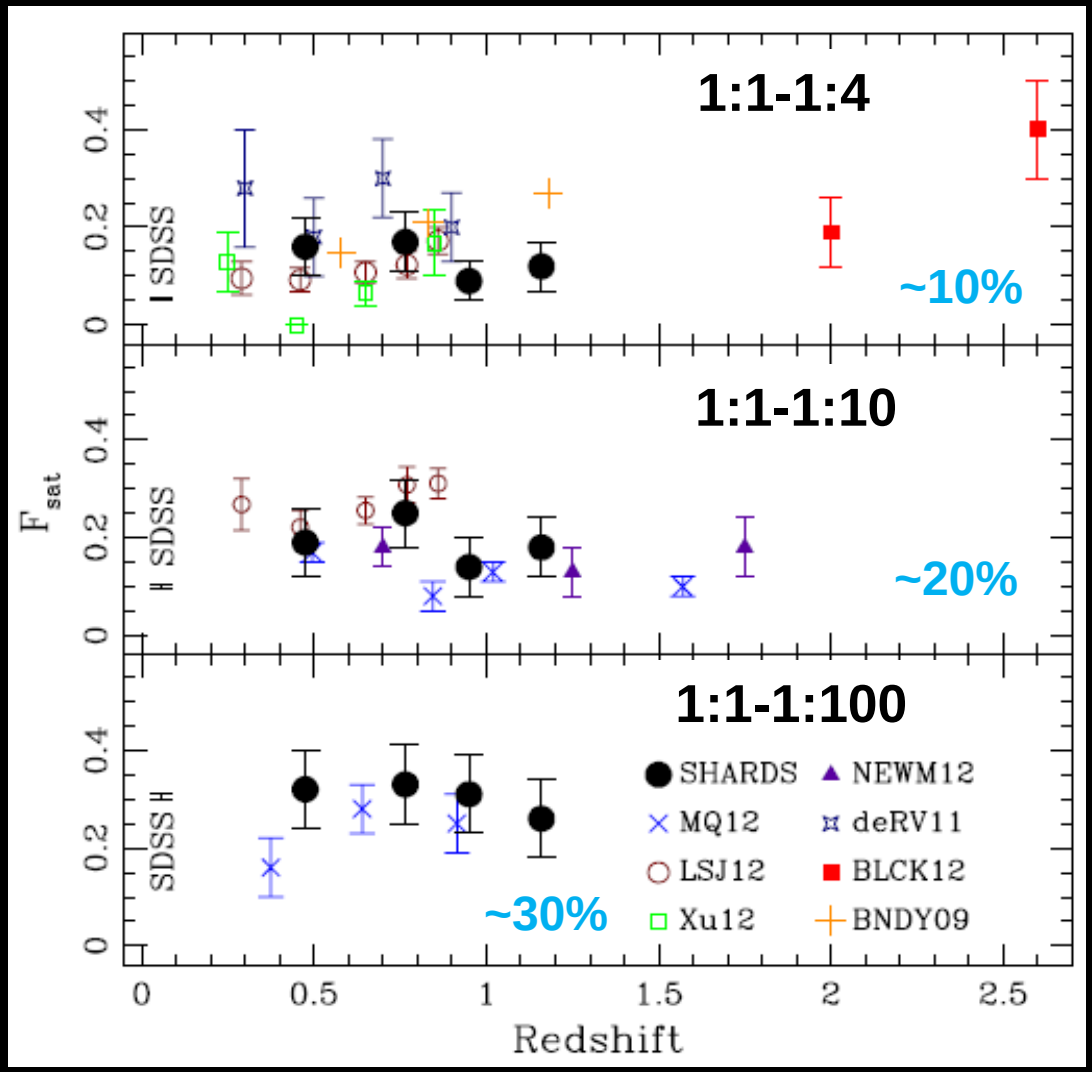
$$\frac{\Delta z}{1+z} = 0.0055$$

Ferreras et al. (2014)

I. Have we got enough number of mergers to produce the size increase?

The number of satellites has remained constant since z~2

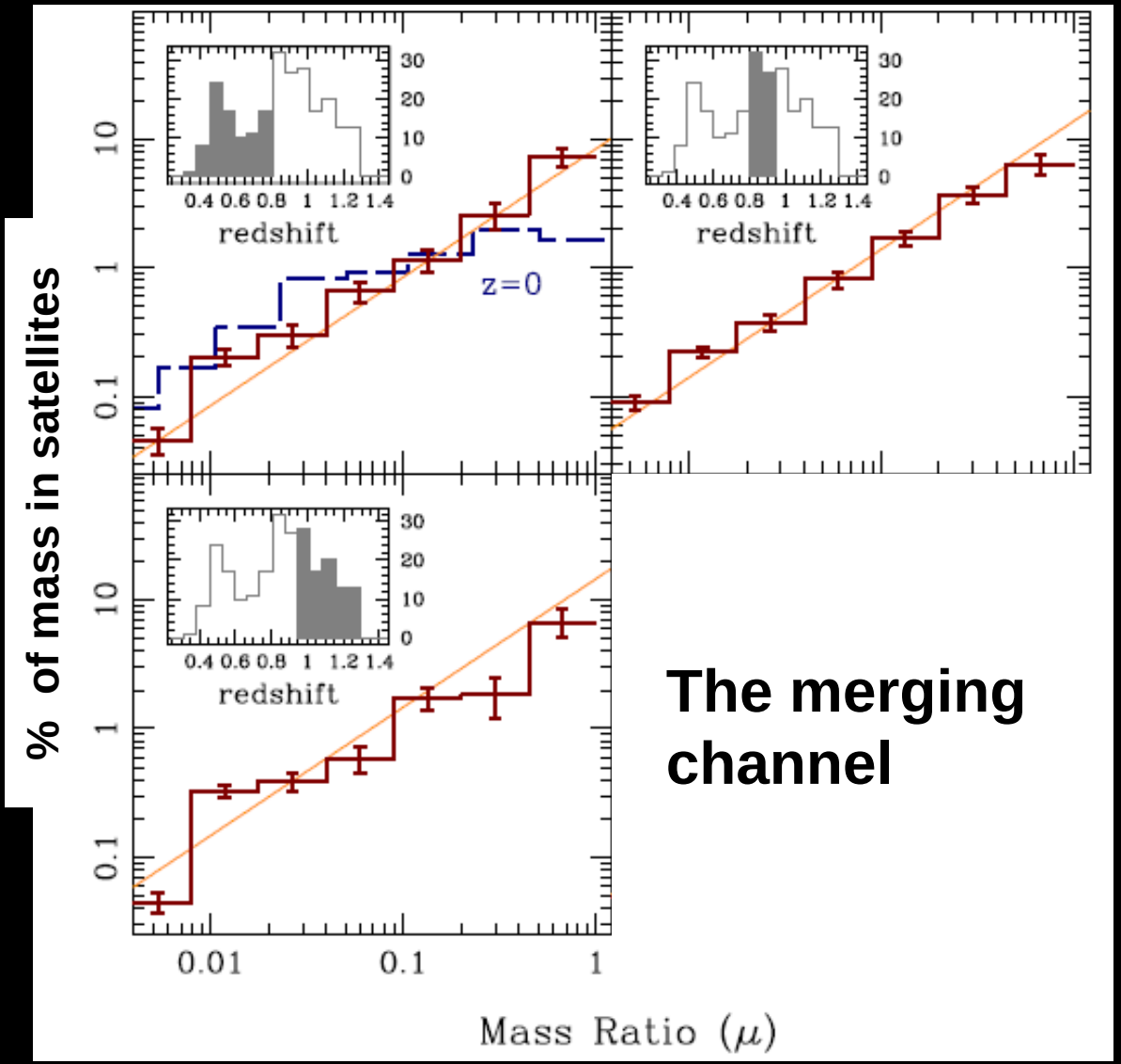
Ferreras et al. (2014)
Ruiz et al. (2014; SDSS z=0)



I. Have we got enough number of mergers to produce the size increase?

The largest contributor to the mass growth are the *most massive* satellites

Ferreras et al. (2014)
Ruiz et al. (2014; SDSS z=0)



The merging channel

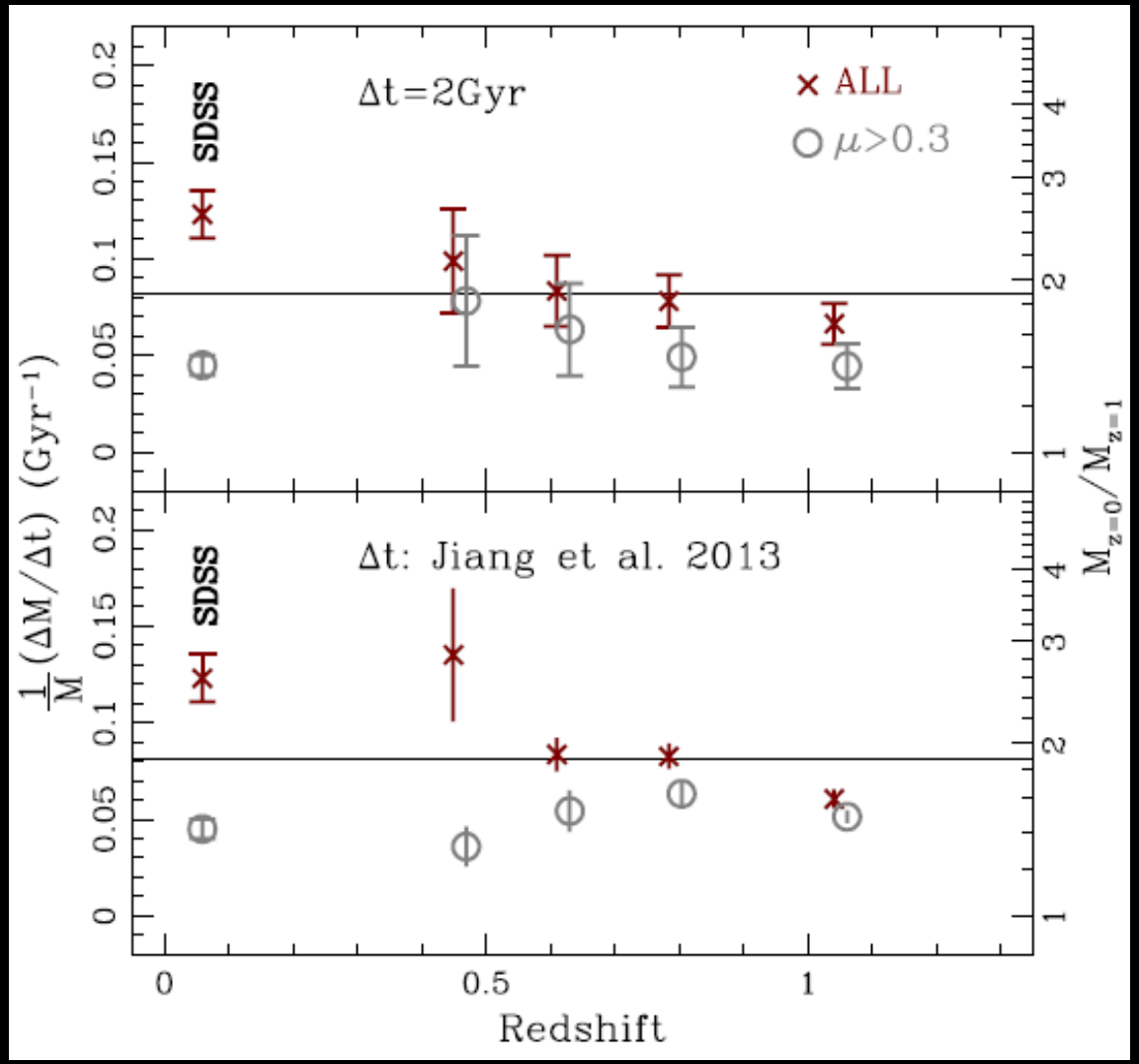
I. Have we got enough number of mergers to produce the size increase?

The average mass growth is 8% every Gyr

Total mass growth since z=1 is a factor of 2

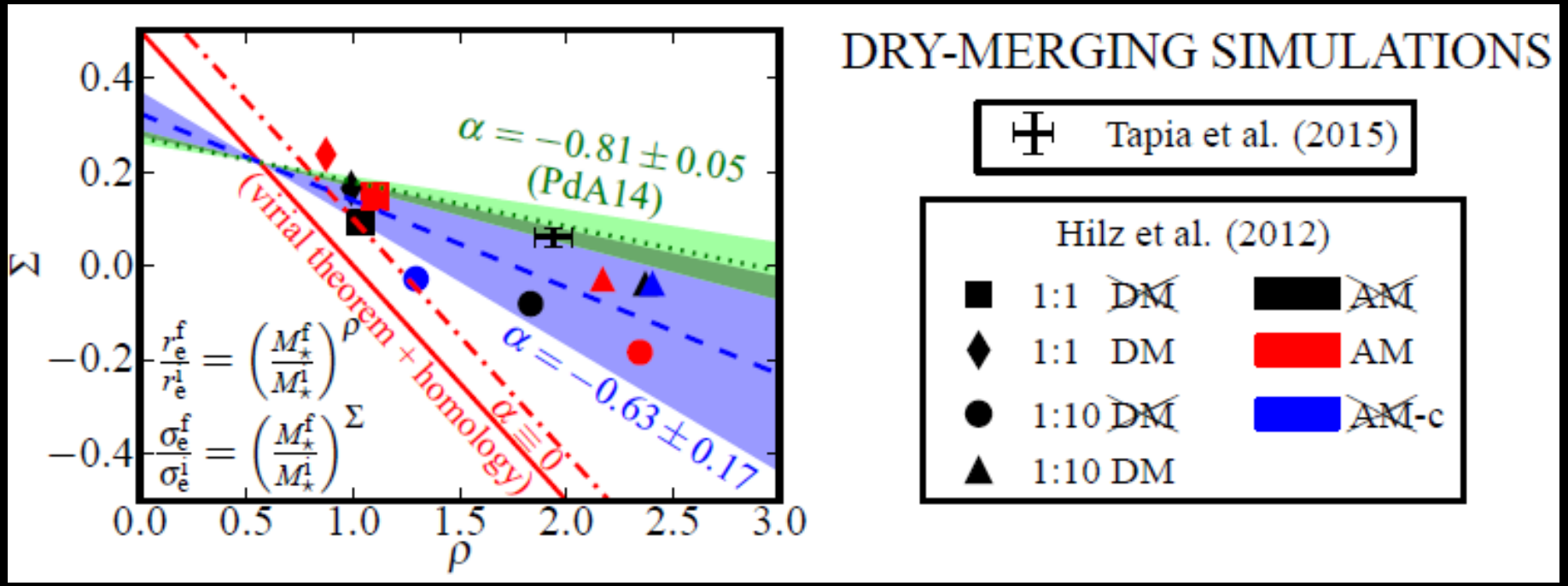
Expected size increase: $\Delta R \sim \Delta M^2$

Ferreras et al. (2014)
Ruiz et al. (2014;
SDSS z=0)



I. Have we got enough number of mergers to produce the size increase?

Dynamical constraints: merging channel compatible with size and velocity dispersion evolution…

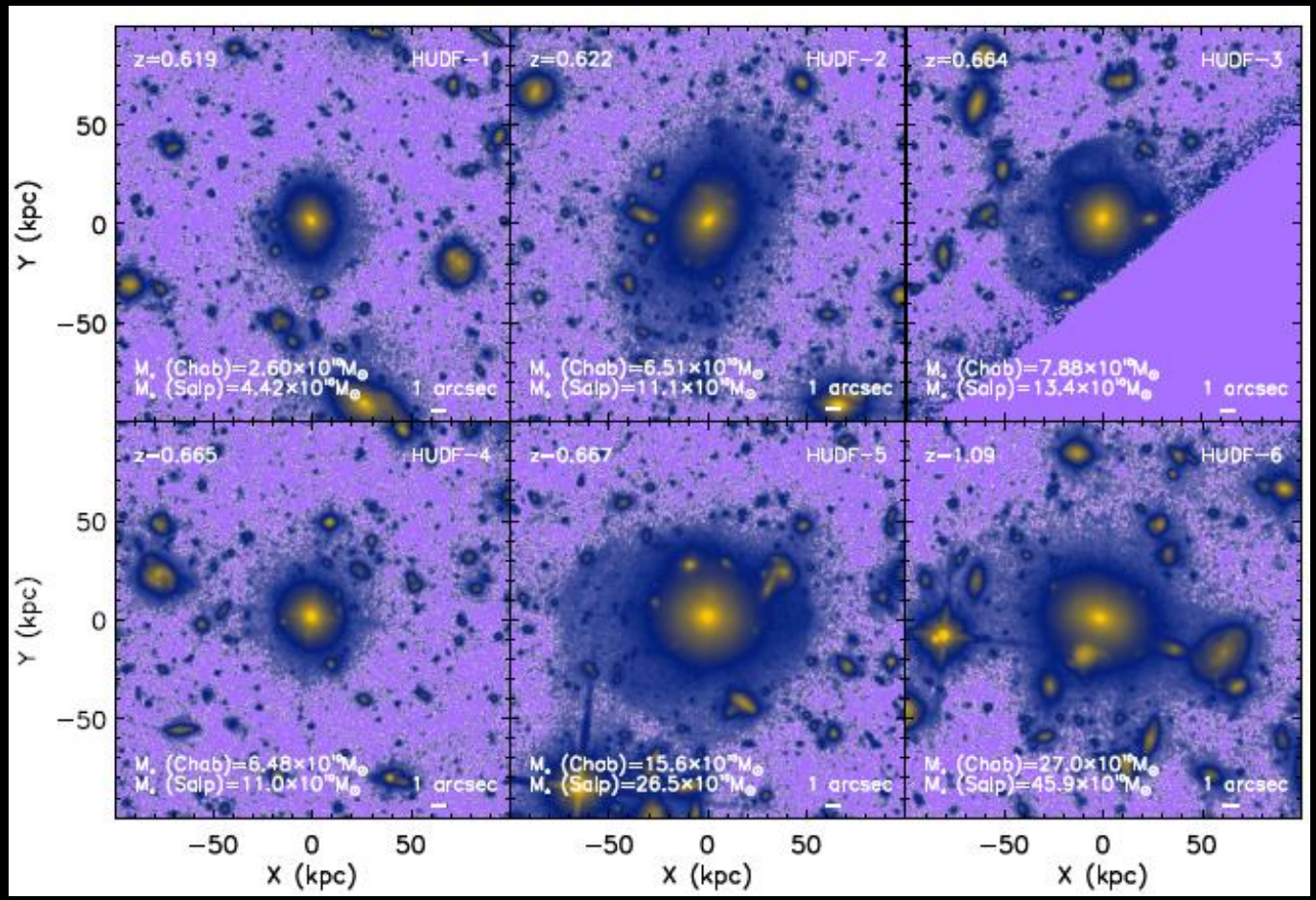


Peralta de Arriba et al. (2015;arXiv:1504.00678)

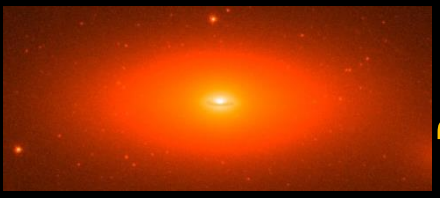
I. Have we got enough number of mergers to produce the size increase?

Direct constraints: characterizing the merging activity with ultra deep imaging..

$\Delta M/M \sim 5\%\ Gyr^{-1}$ in non-symmetric structures

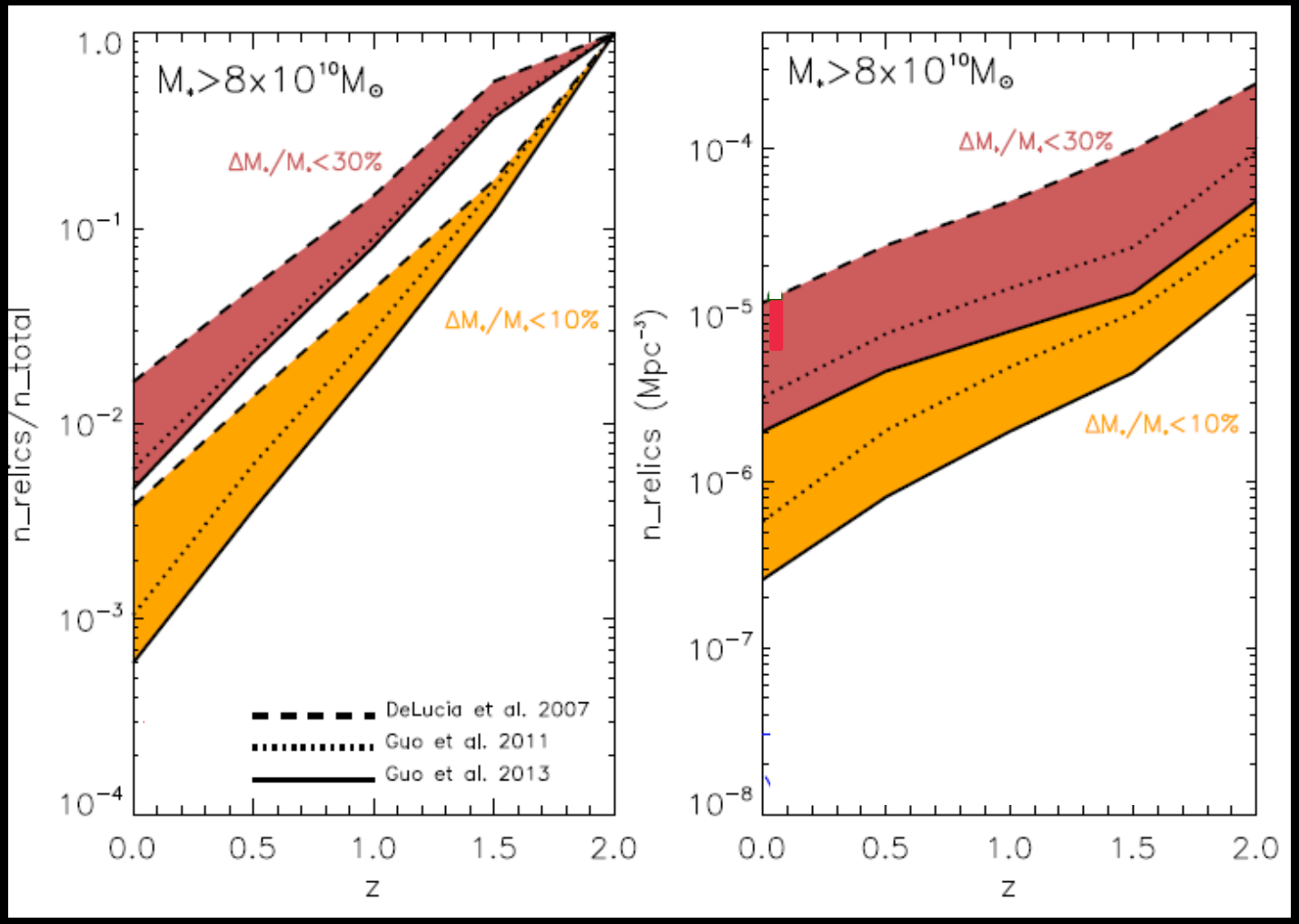


Buitrago et al. (2015)



II. Where are the untouched massive "relic" galaxies in the nearby Universe?

Expected number of "untouched" massive galaxies with cosmic time

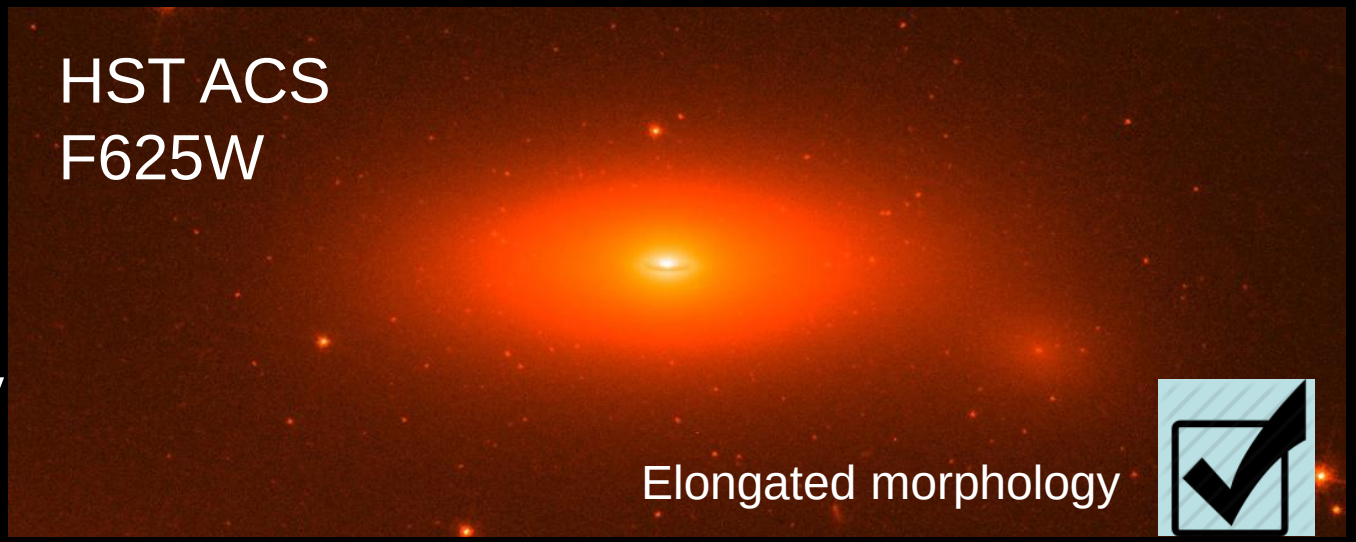


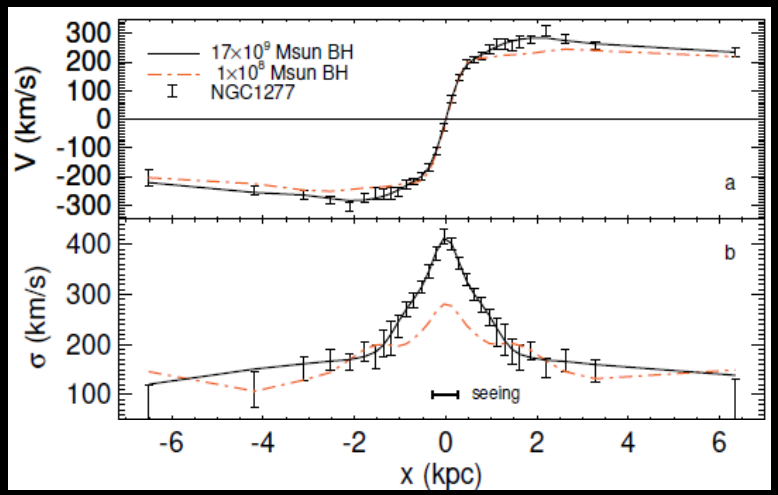
Quilis & Trujillo (2013); See also talk by Damjanov

II. Where are the untouched massive "relic" galaxies in the nearby Universe?

NGC1277:

a massive relic galaxy 70 Mpc away





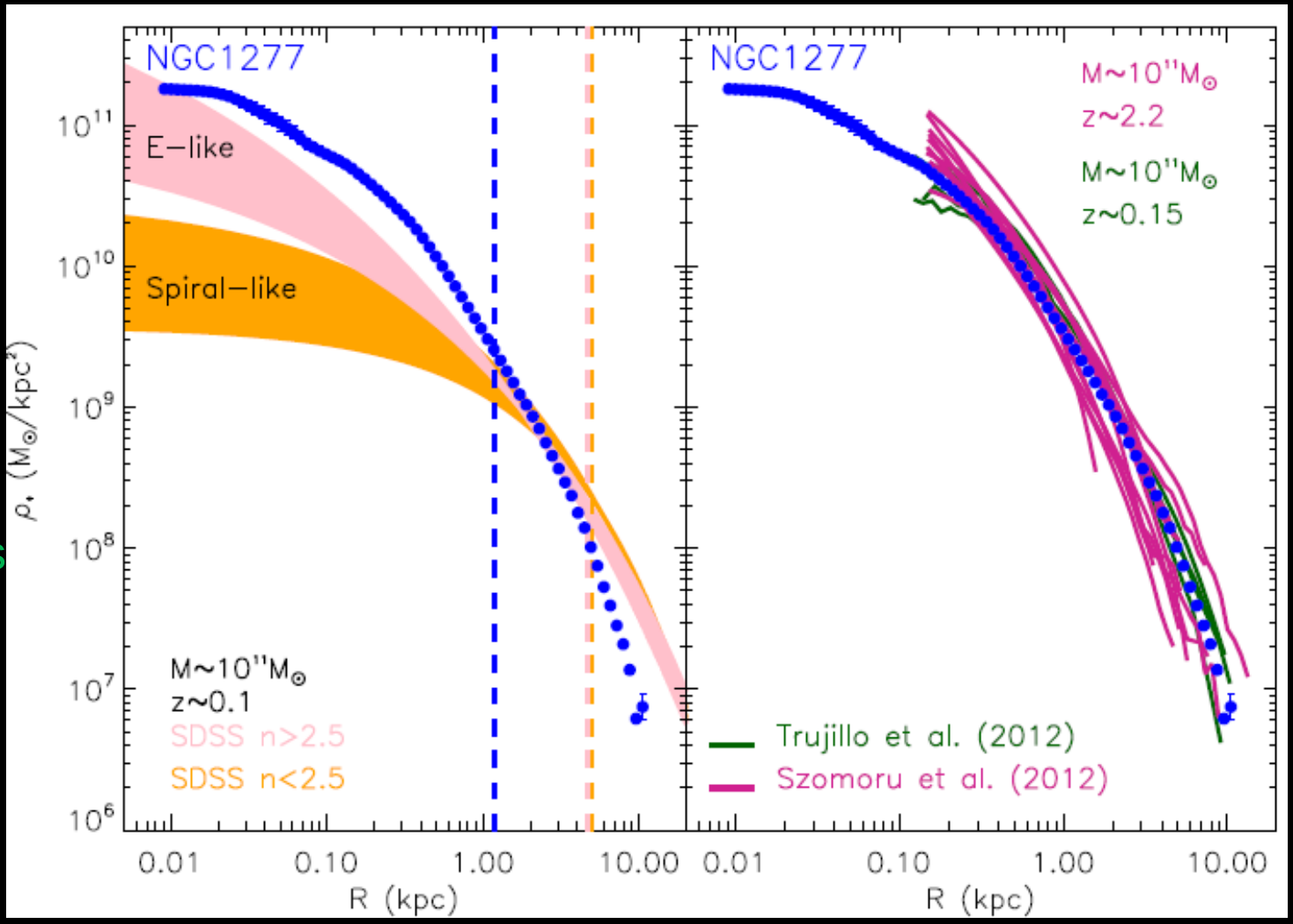
Global properties (van den Bosch et al. 2012):

$M_* = 1.2 \times 10^{11}\ M_{sun}$
$\sigma > 330$ km/s

$R_e = 1.2$ kpc
$V_{rot} > 300$ km/s

II. Where are the untouched massive "relic" galaxies in the nearby Universe?

Stellar mass density profile equivalent to those in high-z massive galaxies

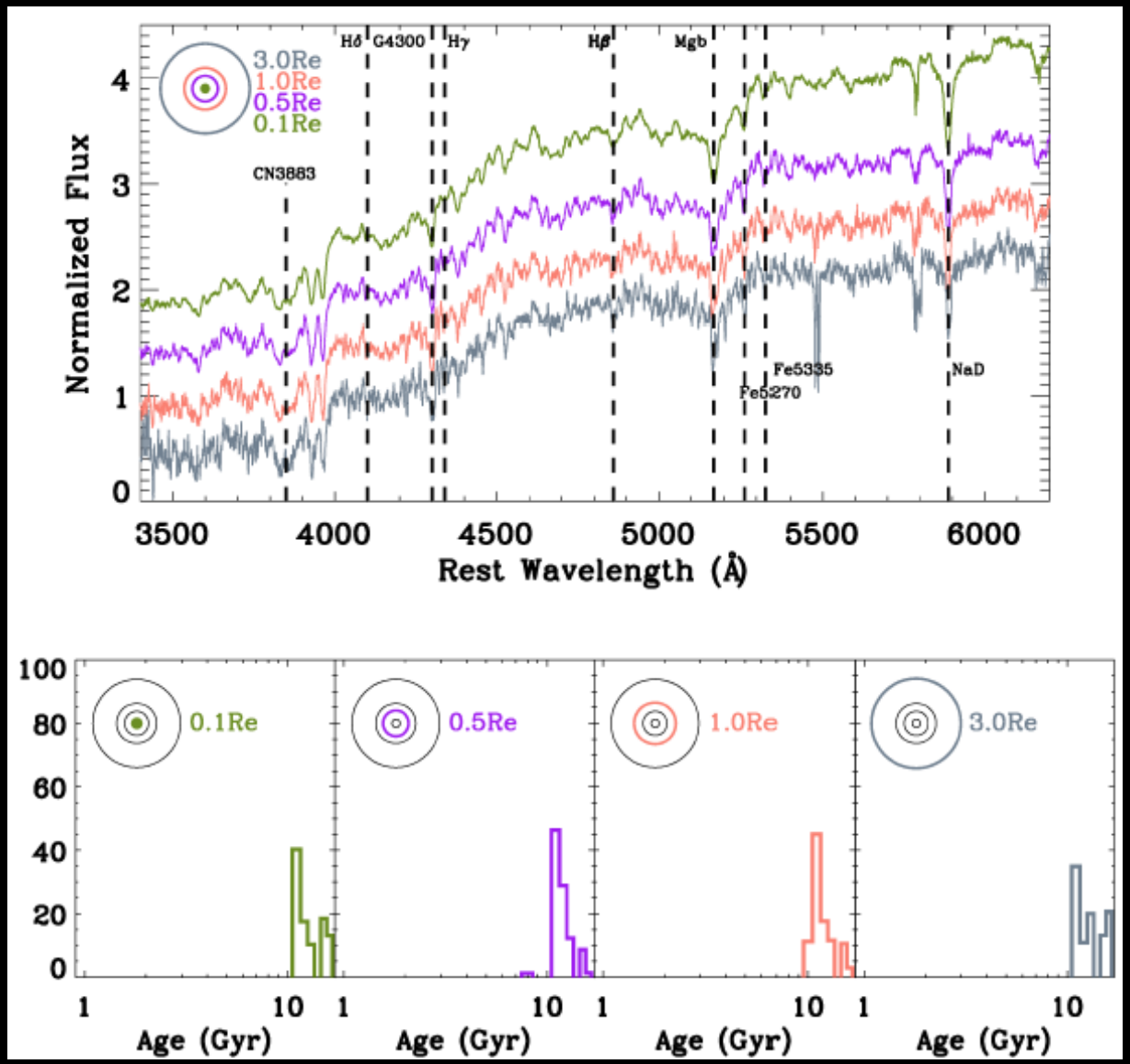


Trujillo et al. (2014)

II. Where are the untouched massive "relic" galaxies in the nearby Universe?

At all radii, Star Formation Histories compatible with no new star formation in the last 10 Gyr…

Trujillo et al. (2014)



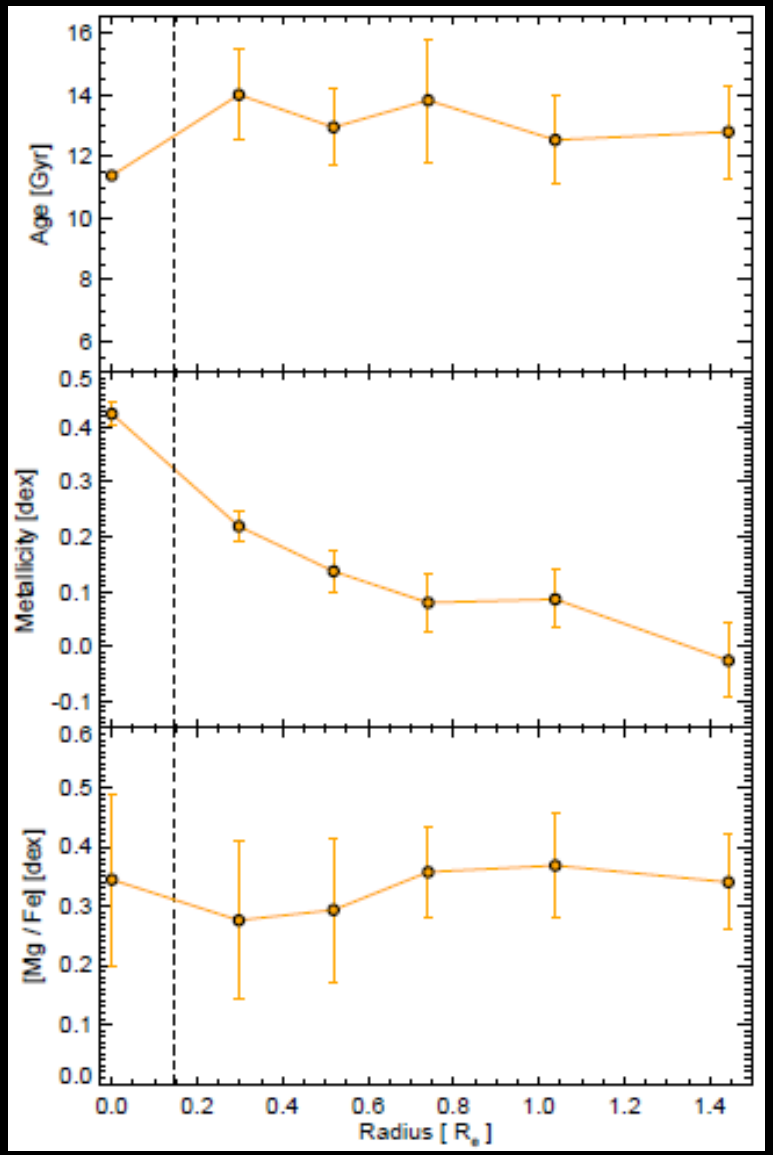
II. Where are the untouched massive "relic" galaxies in the nearby Universe?

Properties:

Age and α/Fe radial profiles are pretty homogenous…

The large α/Fe>0.3 implies an extremely short formation time-scale: ~100 Myr !!!

Star Formation Rate: ~1000 M_{sun}/yr !!!

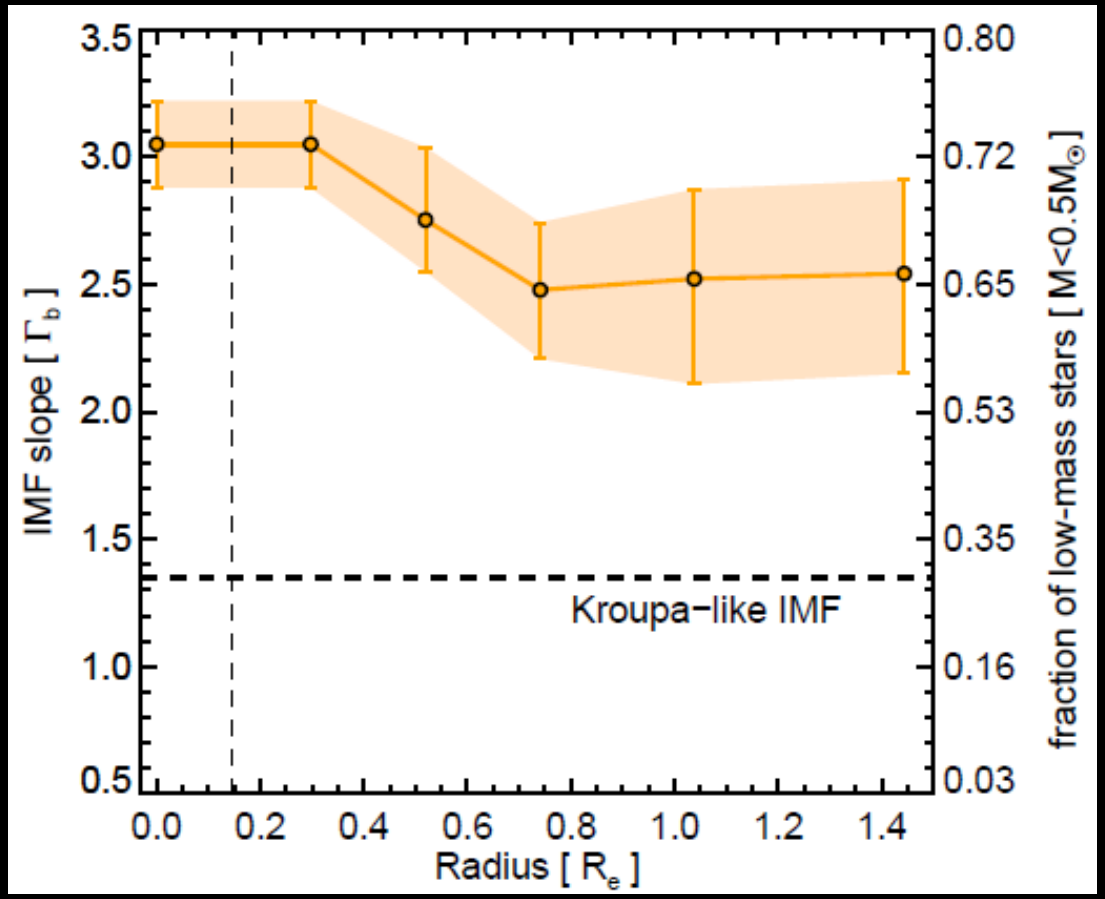


Trujillo et al. (2014);
Martín-Navarro et al. (2015)

II. Where are the untouched massive "relic" galaxies in the nearby Universe?

The primordial IMF of the massive galaxies:

The IMF was bottom-heavy at high-z



Martín-Navarro et al. (2015)

Summary

The merging channel mode of galaxy growth successfully passes two test:

a) The number of satellites around is enough to explain the size and mass growth

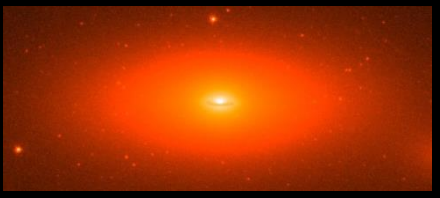
b) There are “unevolved” massive galaxies in the nearby Universe: UNVALUABLE WINDOWS to explore the early Universe

Open Questions

More tests to the merging growth channel:

1. Is the number density of unevolved galaxies in agreement with cosmological predictions?

2. Have the envelopes of nearby massive galaxies the same properties (age and metallicities) than the satellites found at high-z?

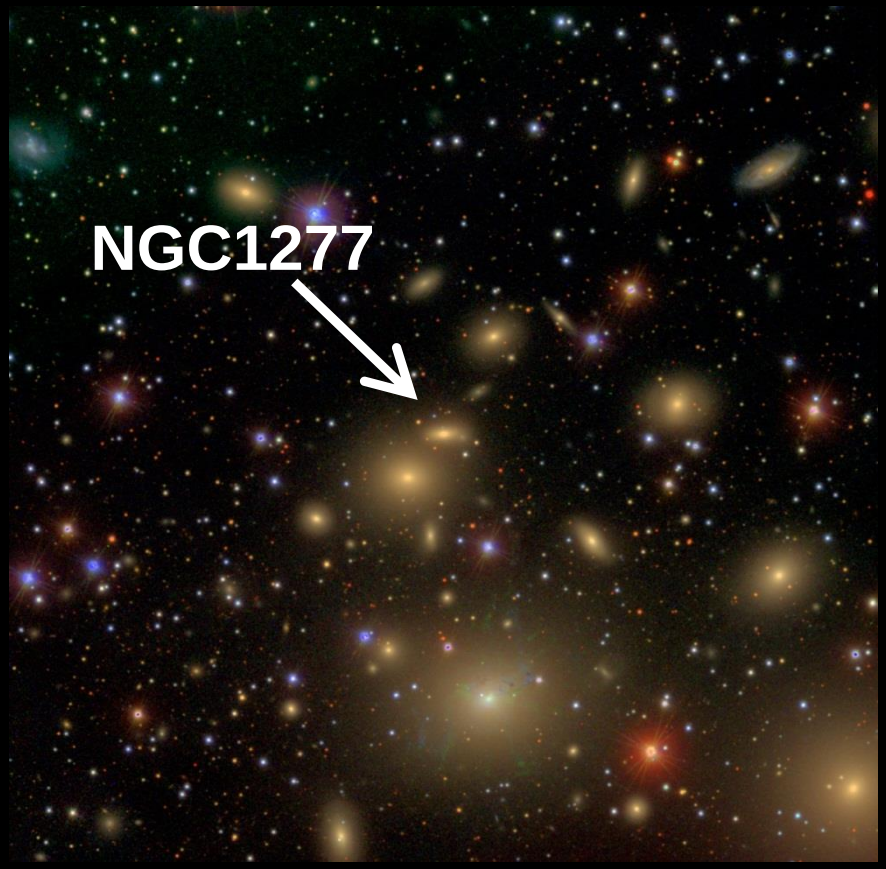


Open questions

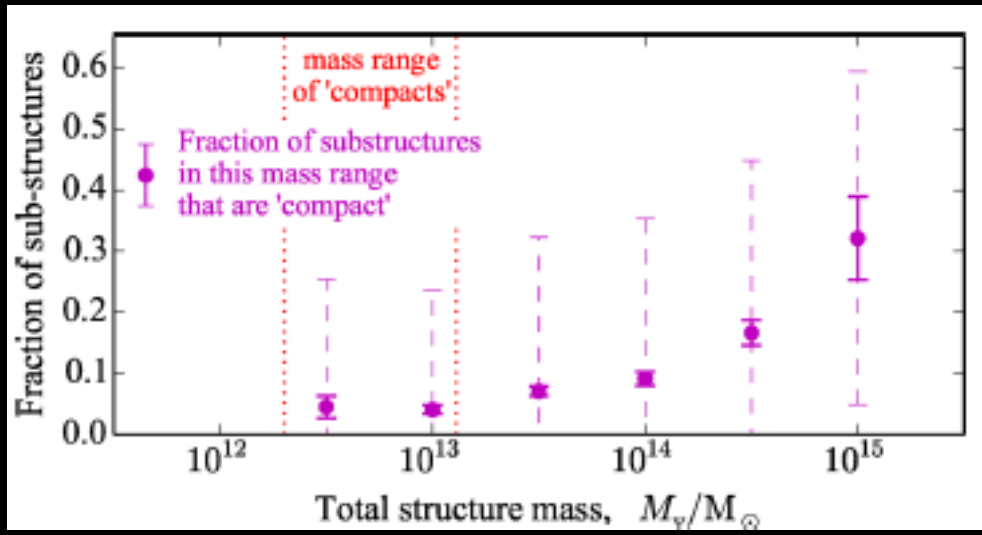
Where are the rest of massive relic galaxies today?

There are some indications that massive relic galaxies are overabundant in dense regions…

Saulder et al. (2015); Ferré Mateu et al. (2015)



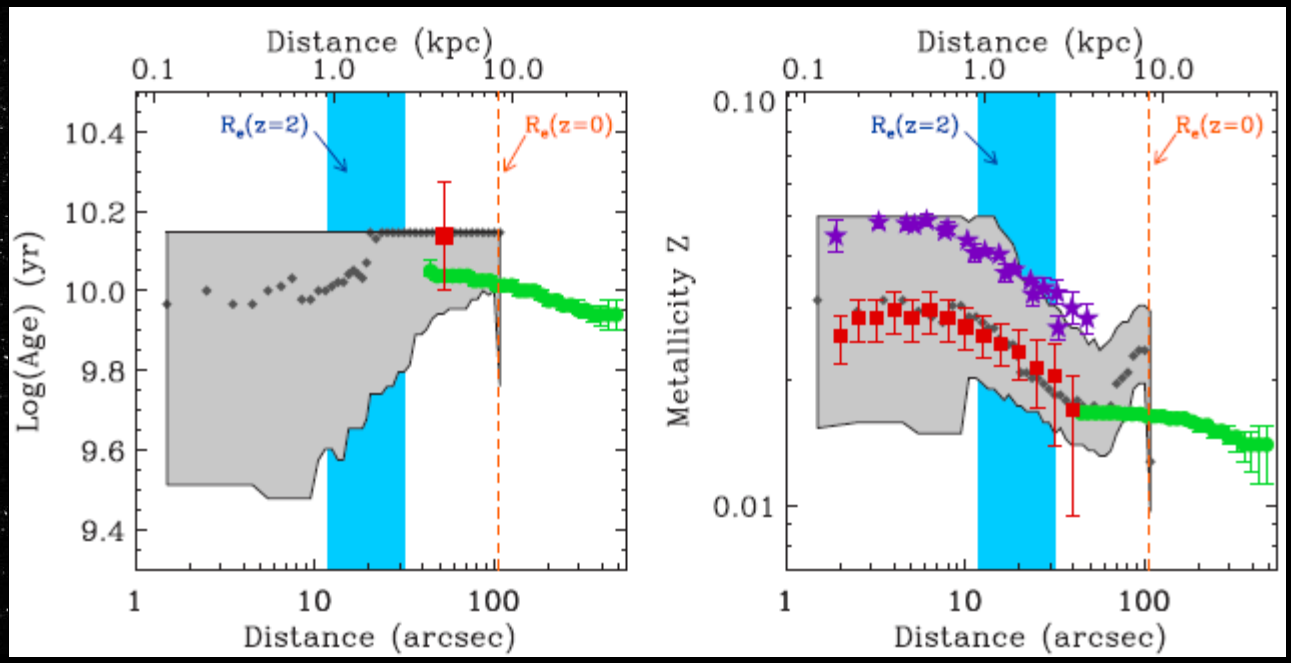
Perseus Galaxy Cluster



Stringer et al. (2015)

Open questions

What are the outer envelopes made of?
Do the stellar populations of the outer region reflects the merging activity?



Montes et al. (2014)

Increasing number of papers exploring the stellar population properties in the outermost regions of massive elliptical galaxies

See also Coccato+10; Roediger+11; Greene+12; La Barbera+12