Structural evolution of Galaxies since z~2, size and mass evolution from Astronomical Observations

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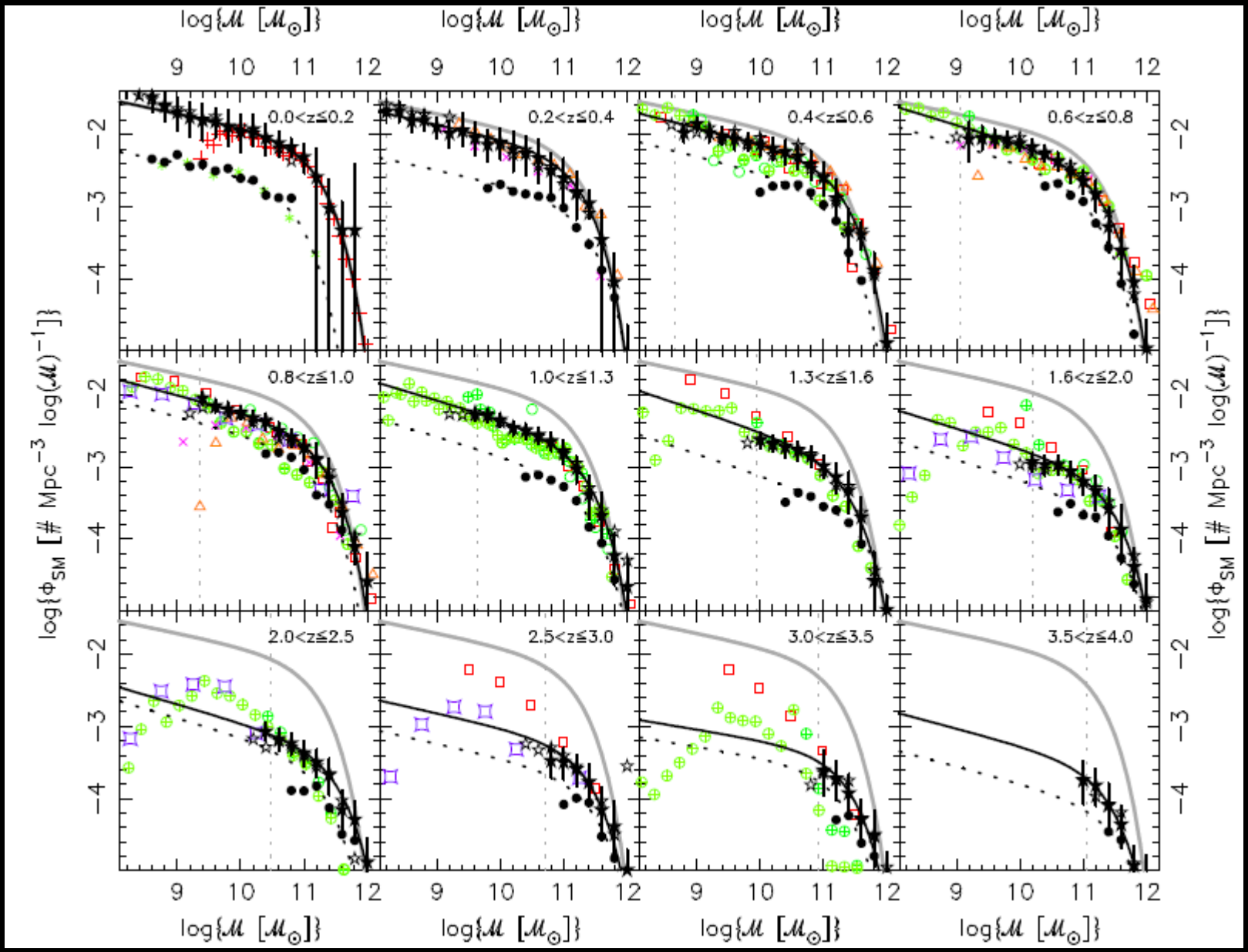
This talk is about massive galaxies

$M_* > 10^{11} M_{sun}$

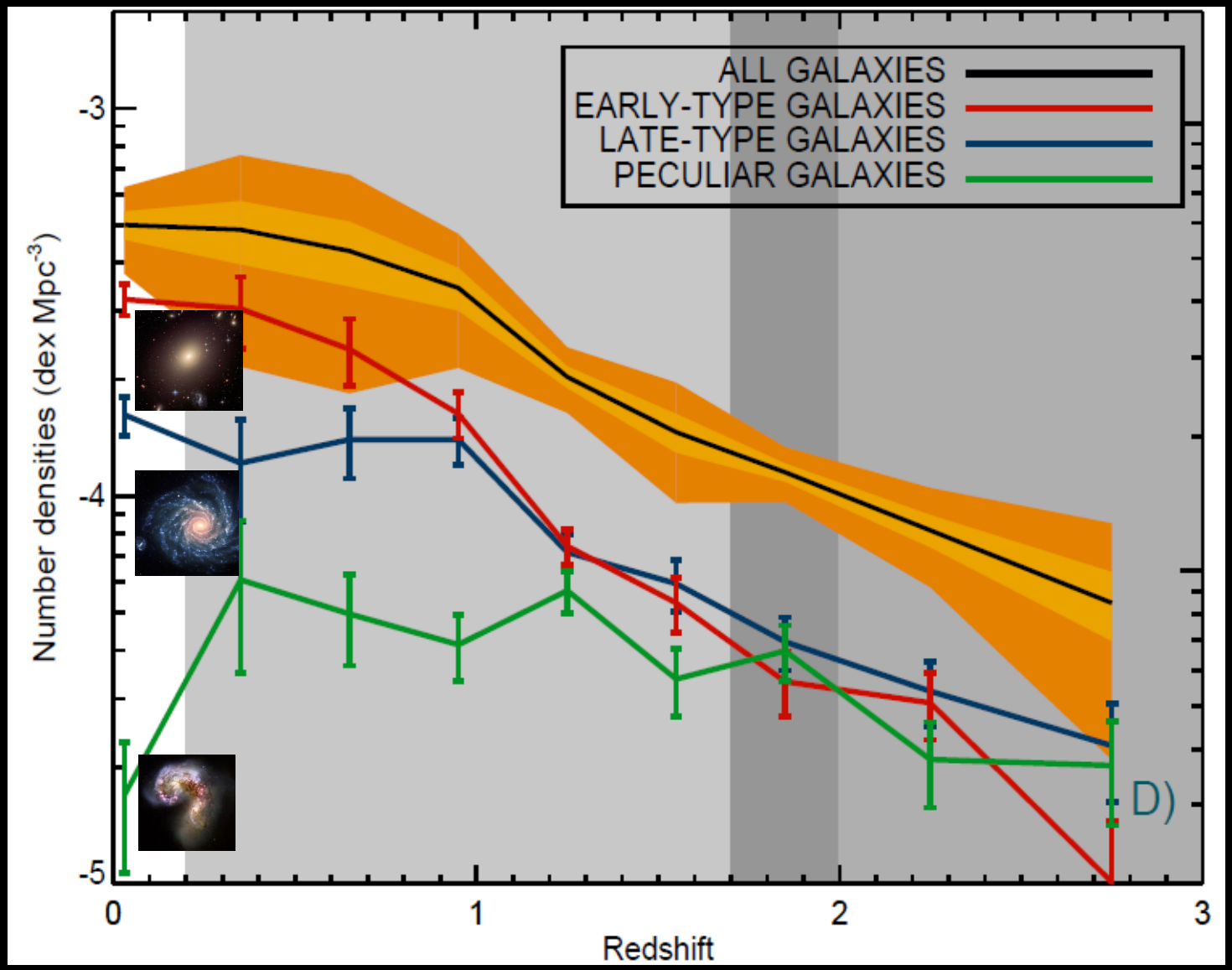
- These are the galaxies we can study with completeness up to z~3 with current telescope facilities

This talk is about massive galaxies



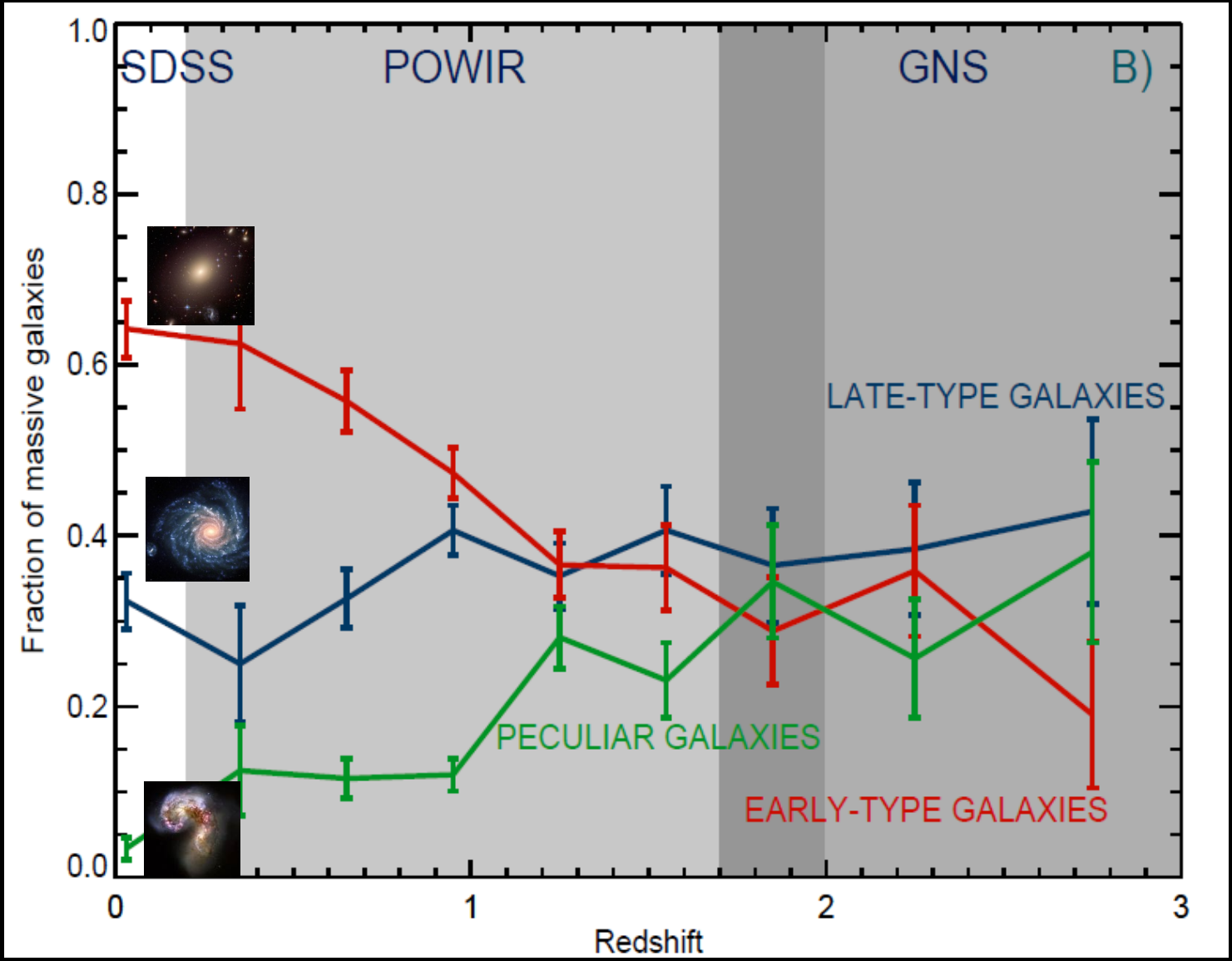
Pérez-González et al. (2008)

The number of massive galaxies has increased by a factor of 10 since z~3



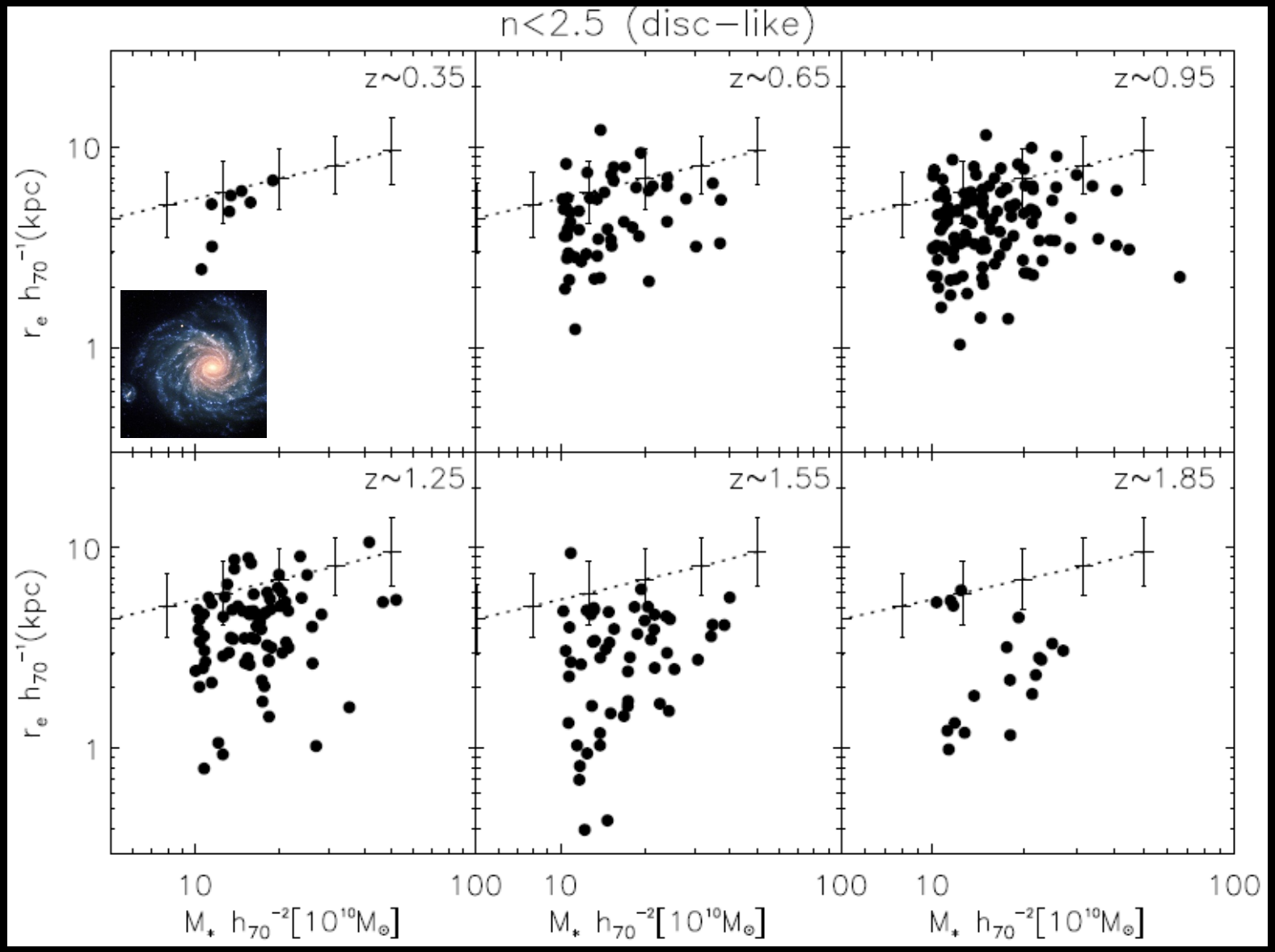
Buitrago et al. (2013)

The dominant morphological type has significantly changed since z~3



Buitrago et al. (2013)

The size of the massive galaxies has dramatically changed since z~3



Trujillo et al. (2007)

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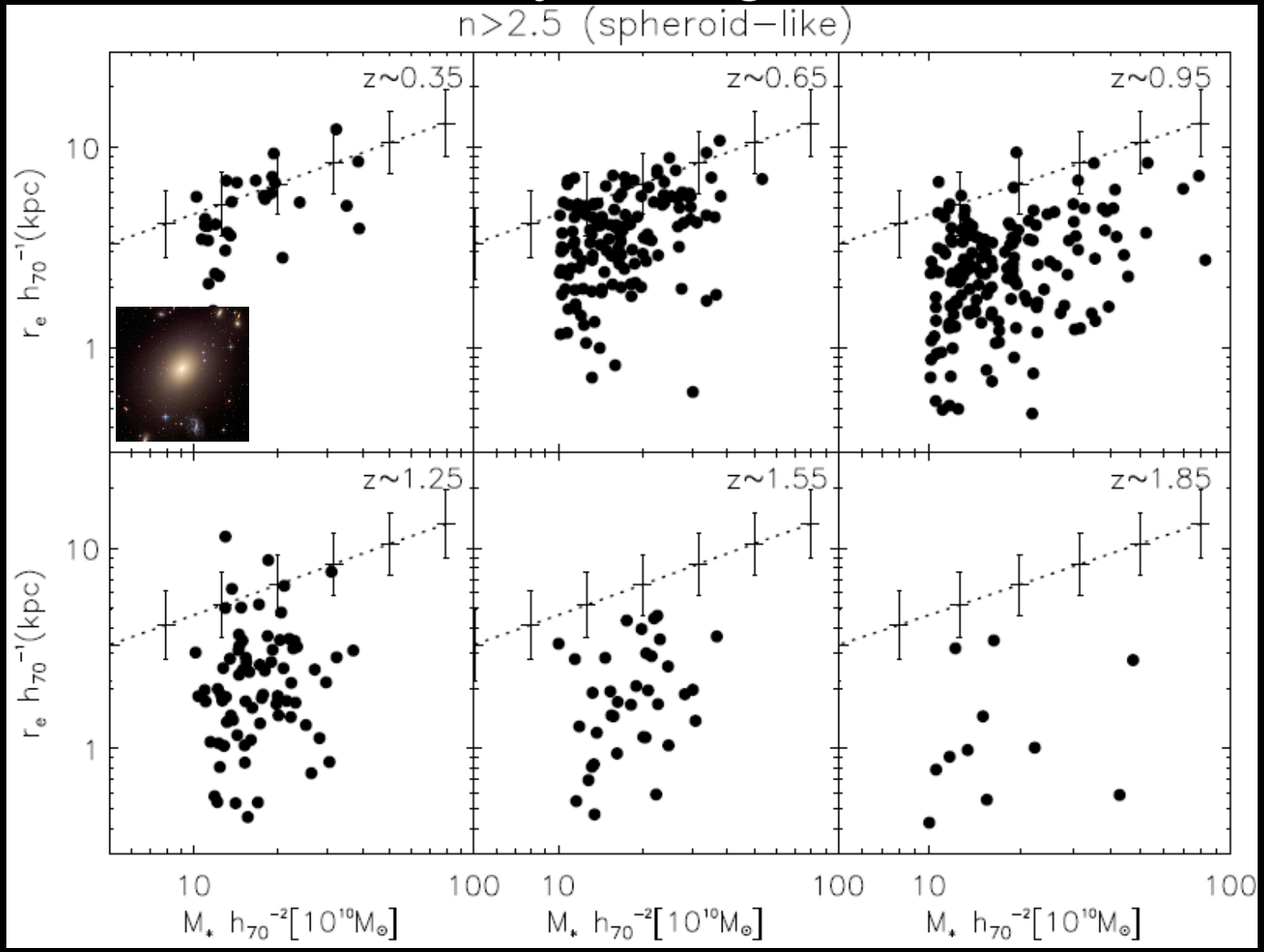
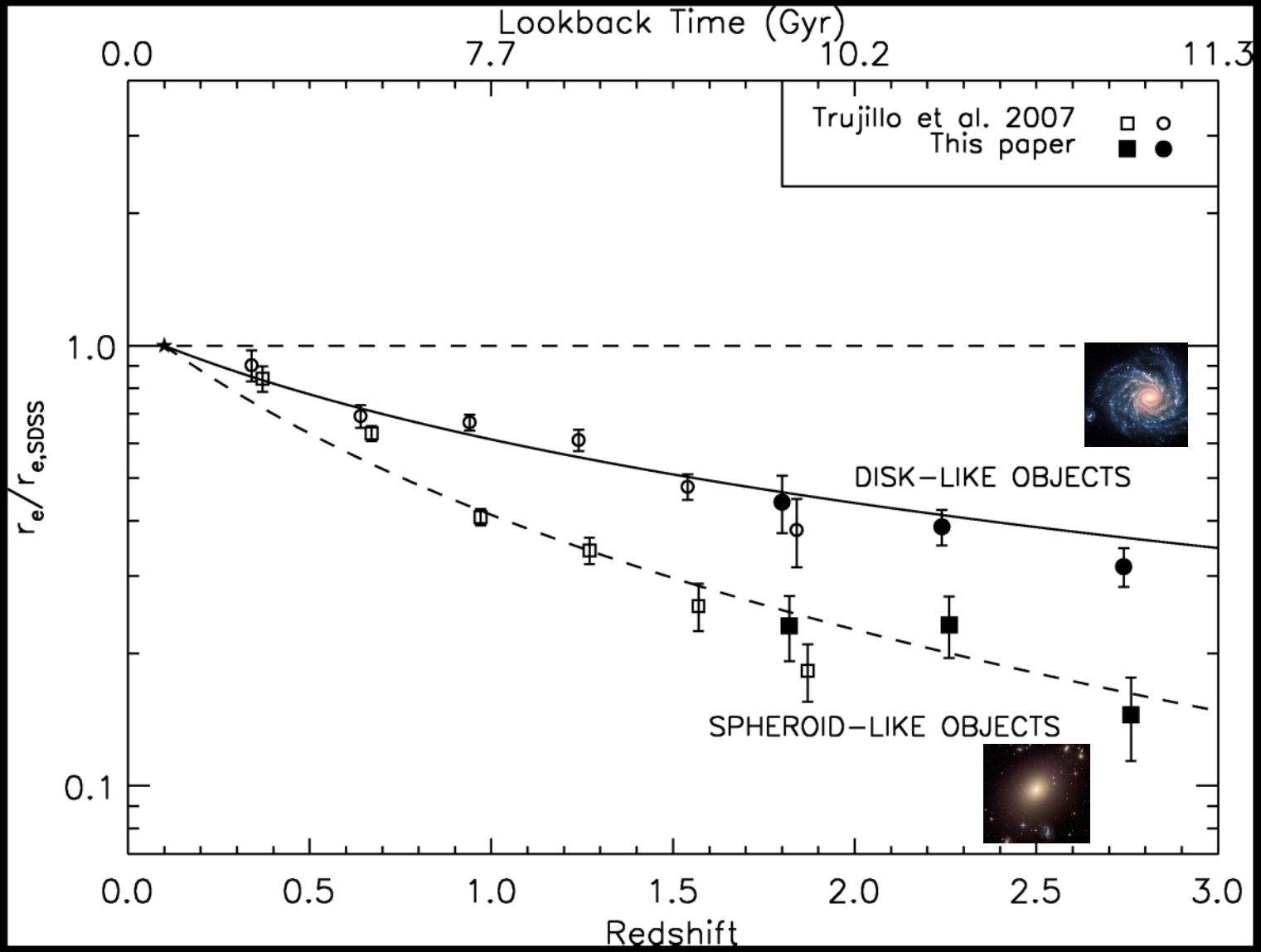


Trujillo et al. (2007)

Massive galaxies: size evolution

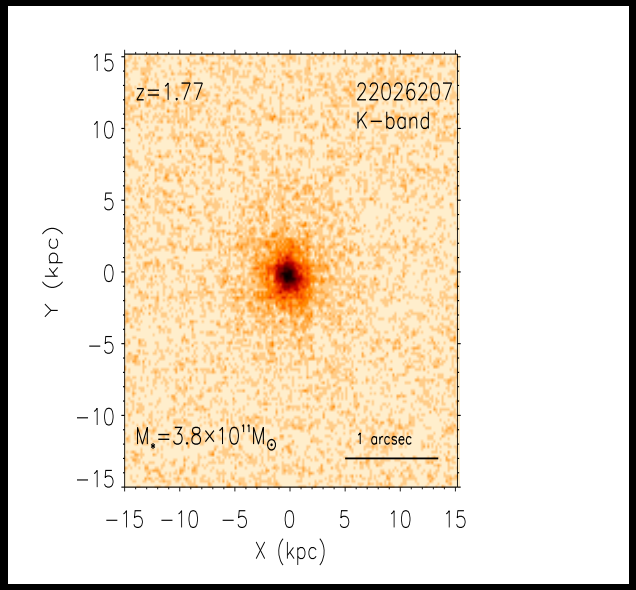
Observed size evolution



Buitrago et al. (2008)

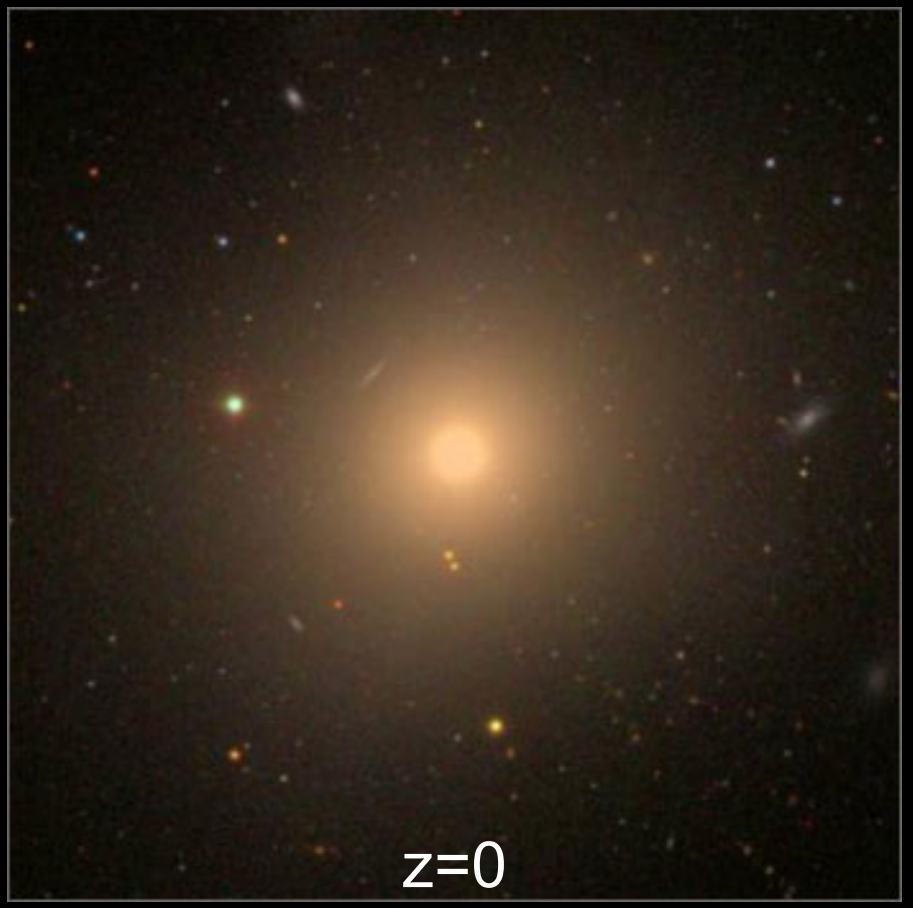
The size evolution of spheroid-like massive galaxies

Carrasco et al. (2010)



z=2

?



z=0

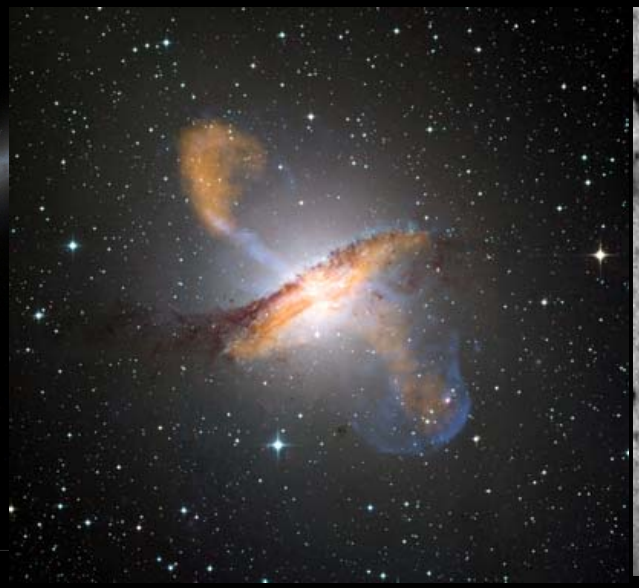
At z~2 they were 4 times smaller!!!

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

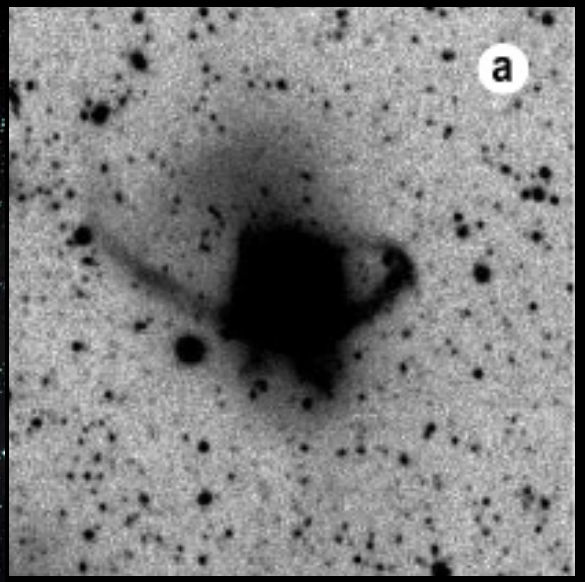
What is the physical mechanism responsible of the size evolution?

Proposed Models:

Major Dry Mergers



Puffing up



Minor mergers

What is the physical mechanism responsible of the size evolution?

Proposed Models:

a) Major dry mergers: (e.g. Ciotti & van Albada 2001; Boylan-Kolchin et al. 2006; Naab et al. 2007; Nipoti et al. 2010)

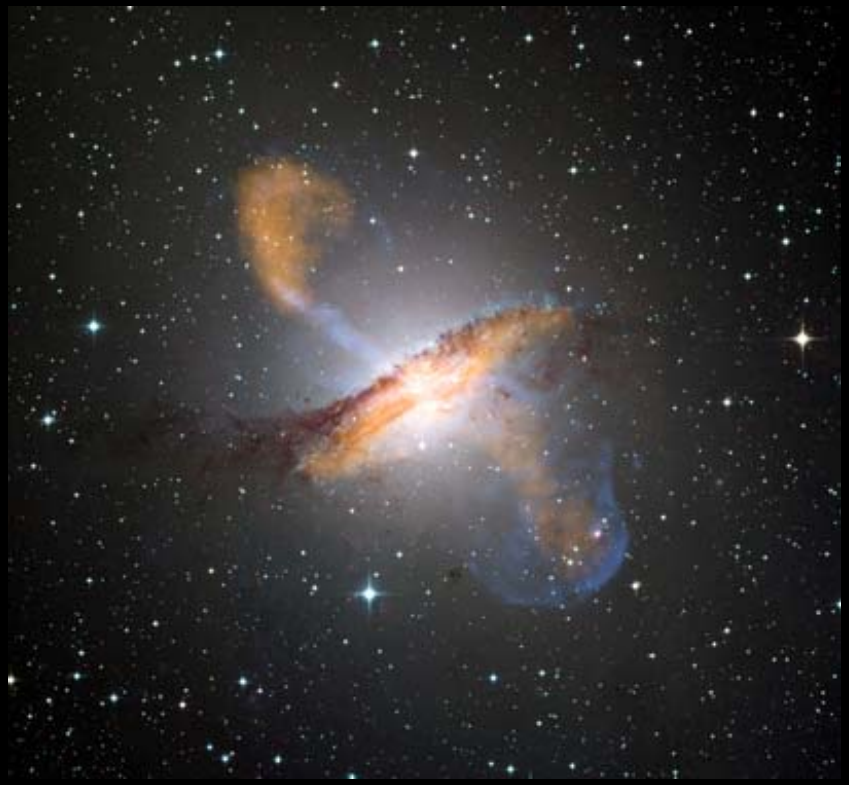
Discarded by observations:

- Not enough number of events (e.g. Bundy et al. 2009; Wild et al. 2009; de Ravel et al. 2009; Bluck et al. 2009; López-San Juan et al. 2010)

What is the physical mechanism responsible of the size evolution?

Proposed Models:

b) Puffing-up: AGN activity removes gas from the galaxies and puff-up their structures (Fan et al. 2008;2010; Ragone-Figueroa et al. 2011)



Predictions:

- No stellar mass increase

- Very fast (<1 Gyr) size evolution

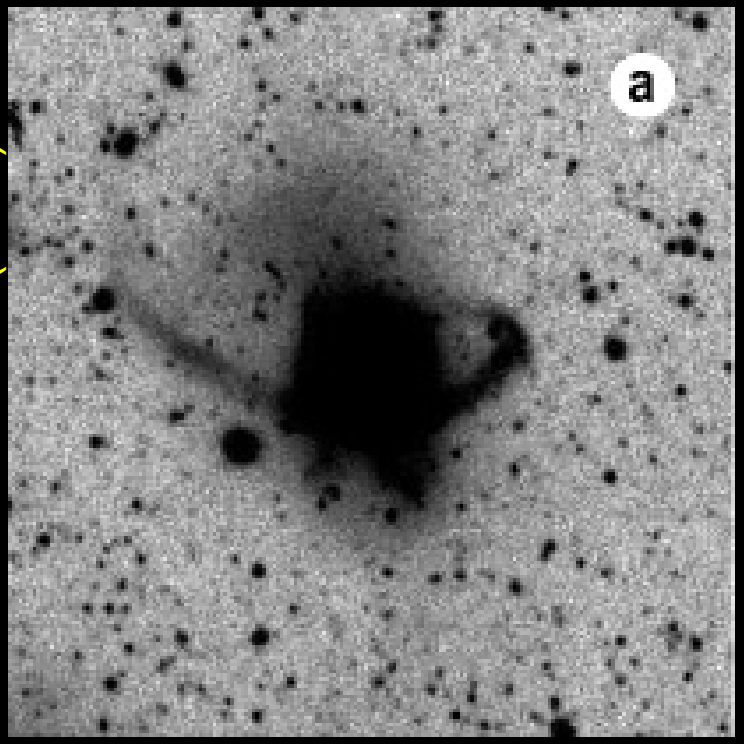
- Strong decrease in the velocity dispersion (400 km/s -> 200 km/s)

- Difference in size between “old” (>1 Gyr) and “young” (<1 Gyr) spheroids at a given redshift

What is the physical mechanism responsible of the size evolution?

Proposed Models:

c) Minor merging: progressive infall of minor satellites with low-effective density (Khochfar & Burkert 2006; Maller et al. 2006; Hopkins et al. 2009; Naab et al. 2009; Sommer-Larsen & Toft 2010 ;Oser et al. 2010)

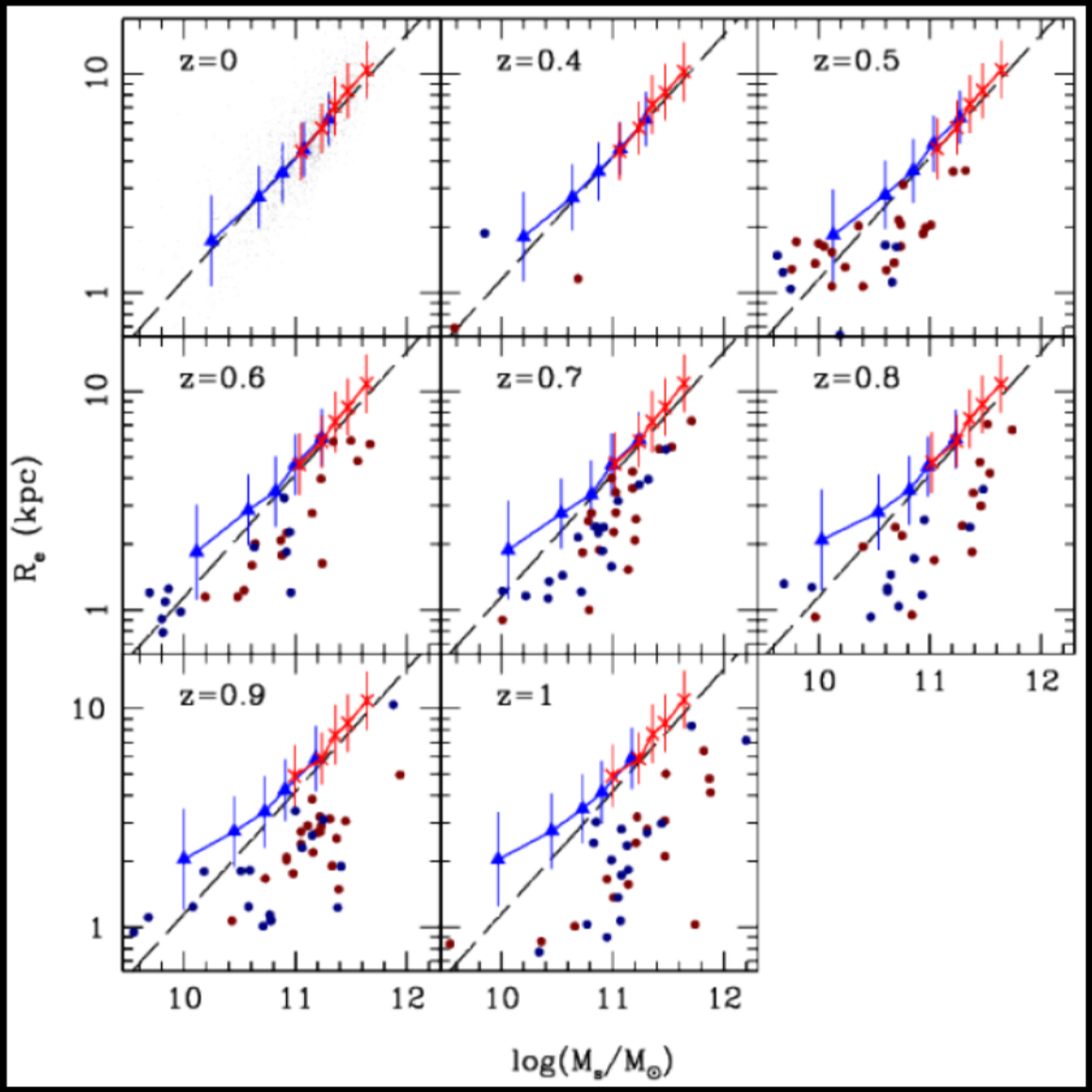


van Dokkum (2005)

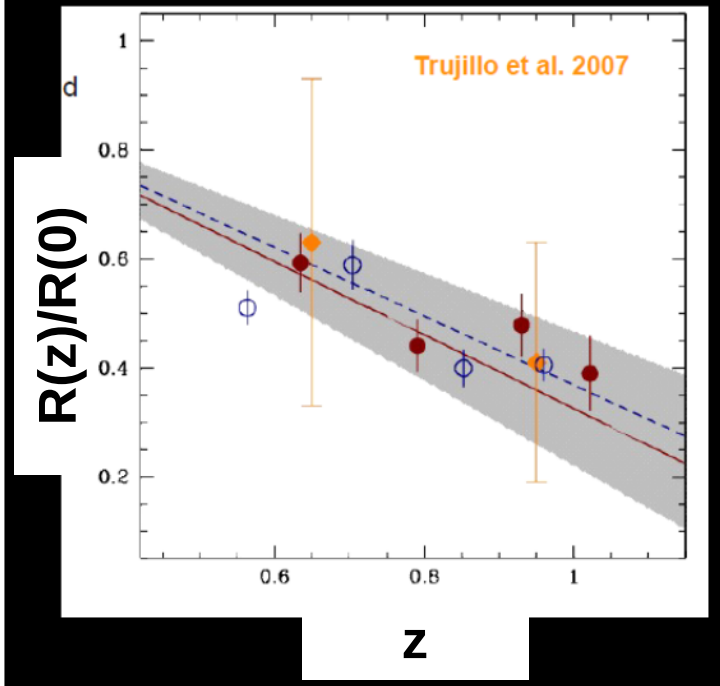
Predictions:

- Stellar mass increase
- Continous size evolution
- Mild decrease in the velocity dispersion (250 km/s -> 200 km/s)
- No difference in size between “old” (>1 Gyr) and “young” (<1 Gyr) spheroids at a given redshift

Observational evidence favors minor merging

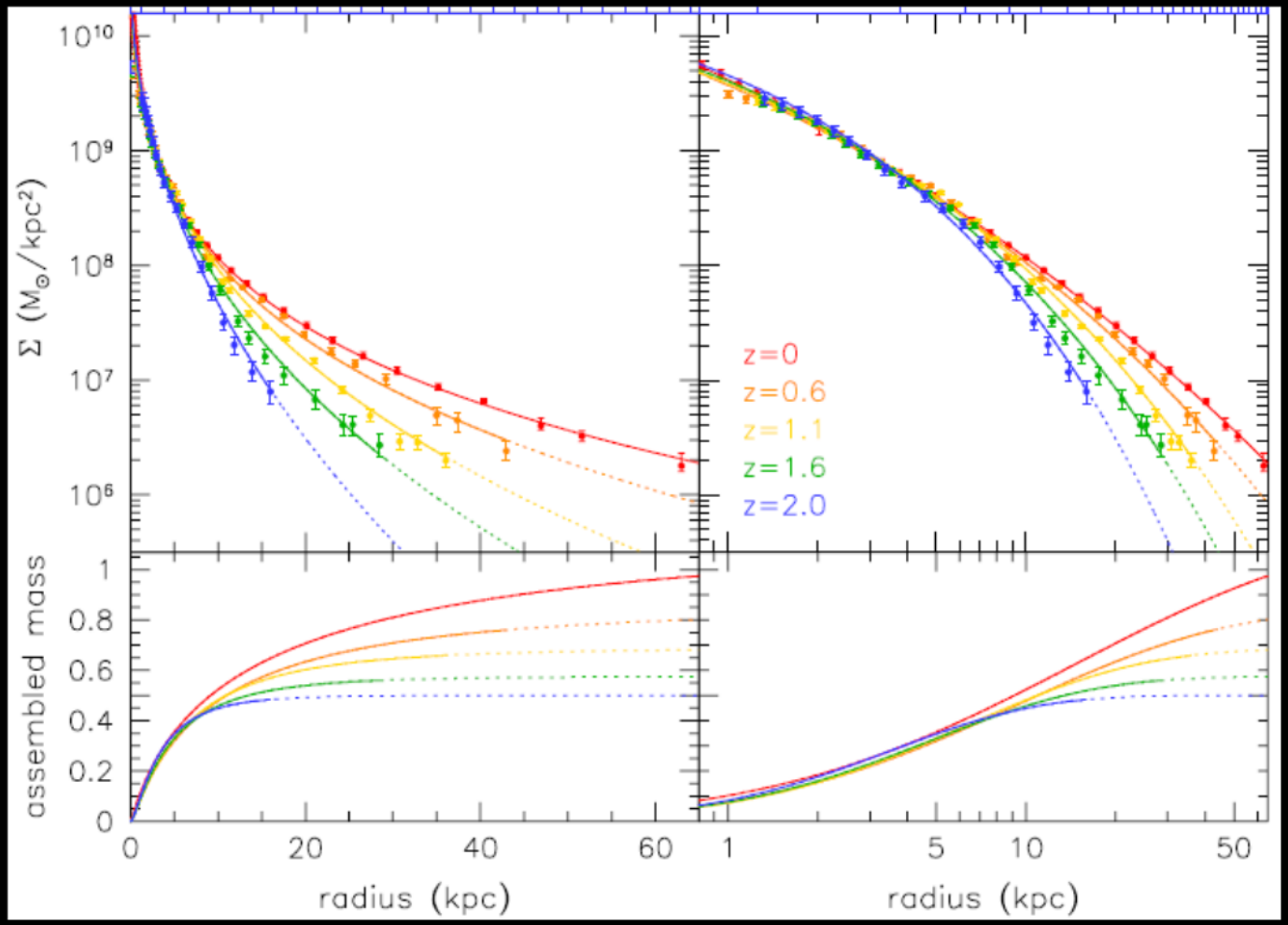


No mean size difference between old and young spheroids at each redshift



Trujillo et al. (2011); but see a critical view in Saracco et al. (2011)

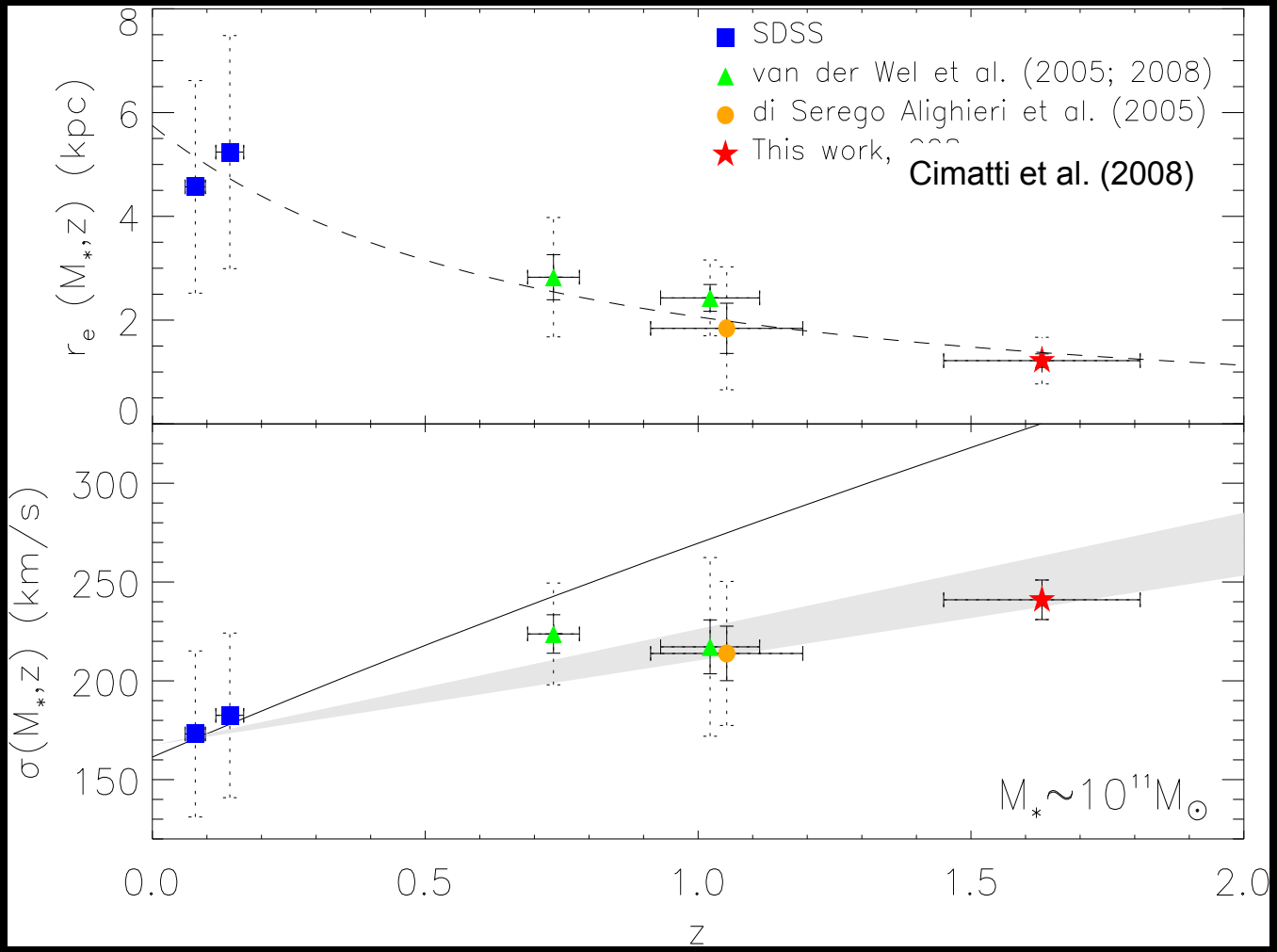
Observational evidence favors minor merging



Progressive and steady formation of outer galaxy envelopes

e.g. Bezanson et al. 2009; Hopkins et al. 2009; van Dokkum et al. 2010…

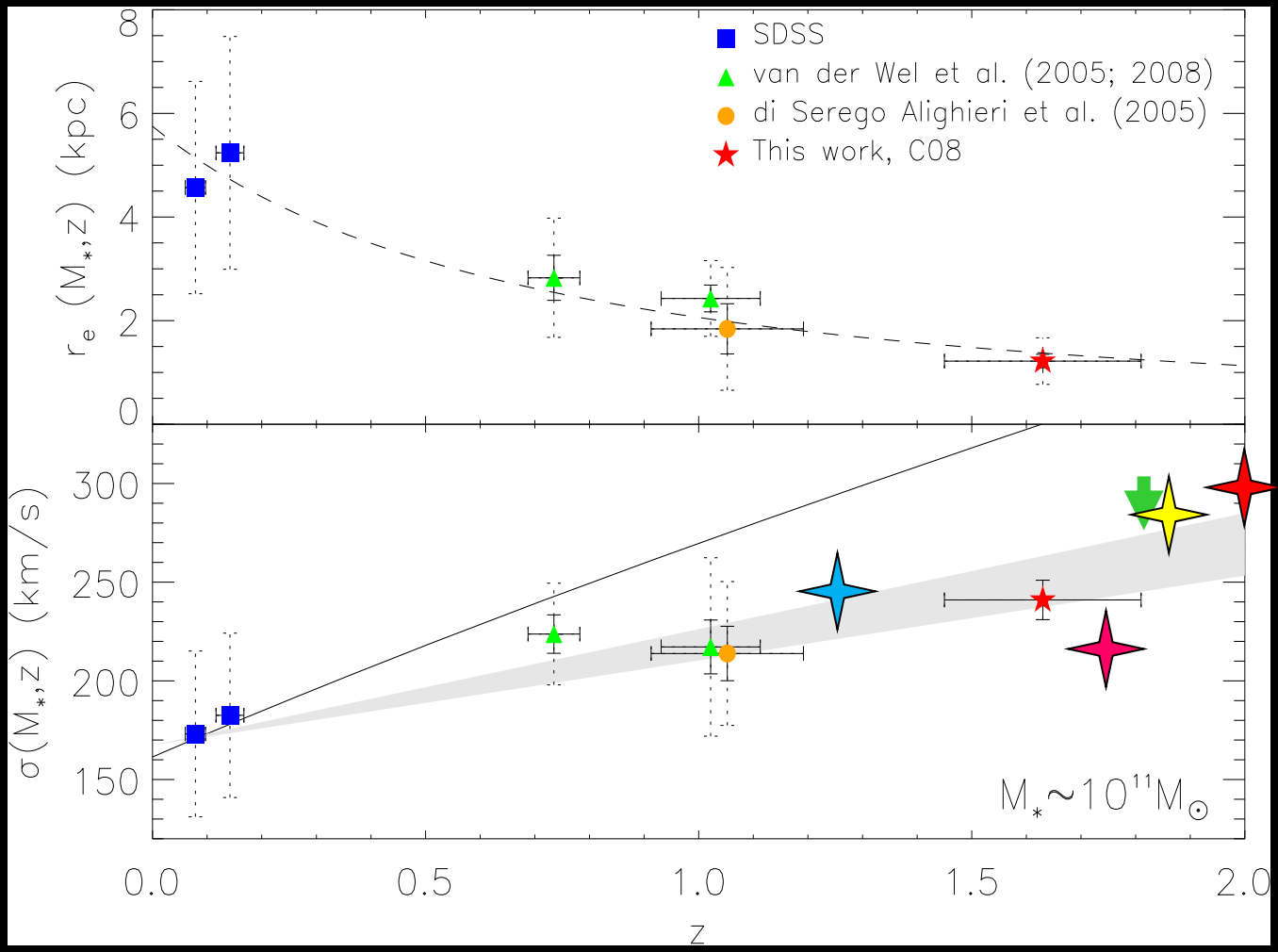
Observational evidence favors minor merging



Mild decrease in the velocity dispersion

Cenarro & Trujillo (2009)

Observational evidence favors minor merging



Mild decrease in the velocity dispersion since z~2

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)

Going into the details: are ΛCDM predictions in agreement with the observations?

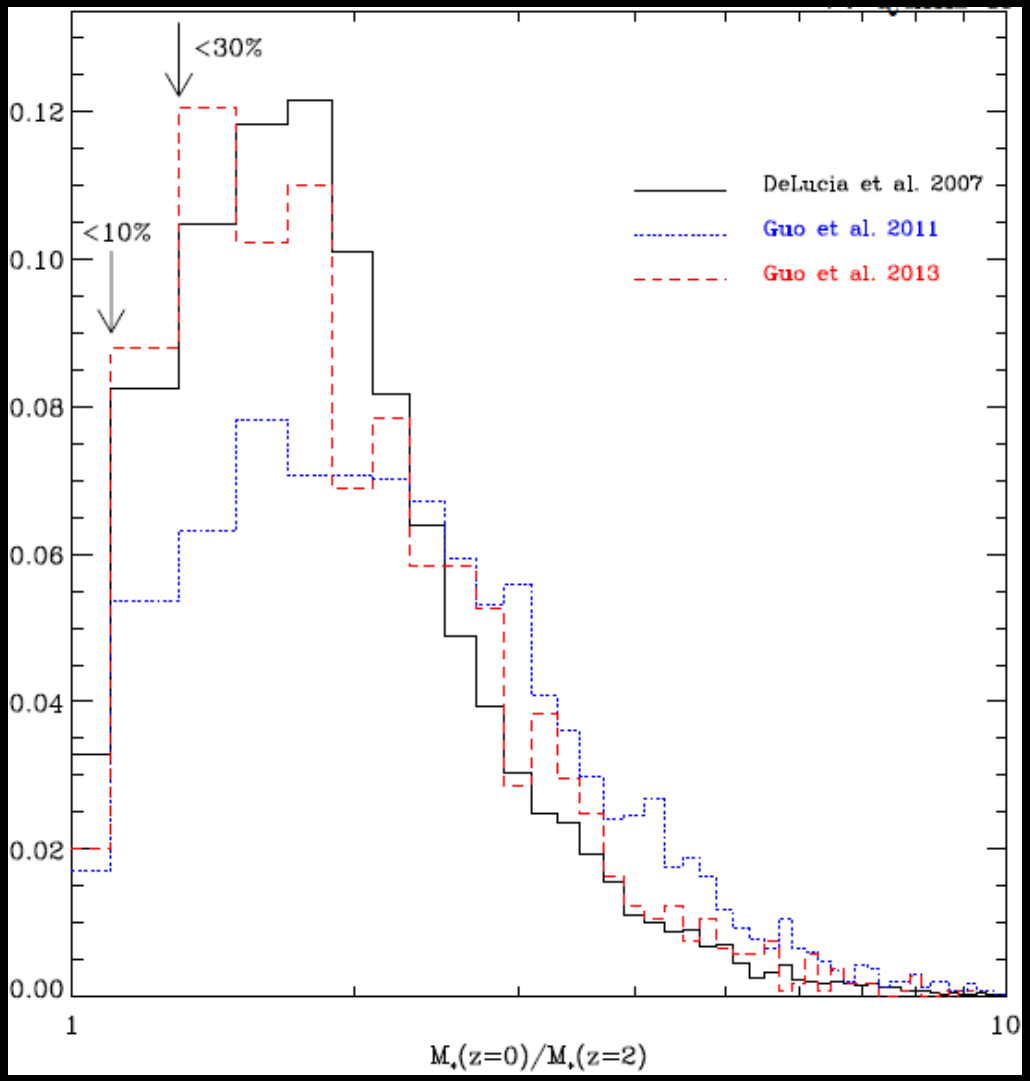
Minor merging model is favored by observations but:

1. On the merger rate; Merging is an stochastic process: how many massive galaxies have survived untouched (i.e. relics) since z~2?

2. On the level of substructure; What is the number of satellites around the massive galaxies?

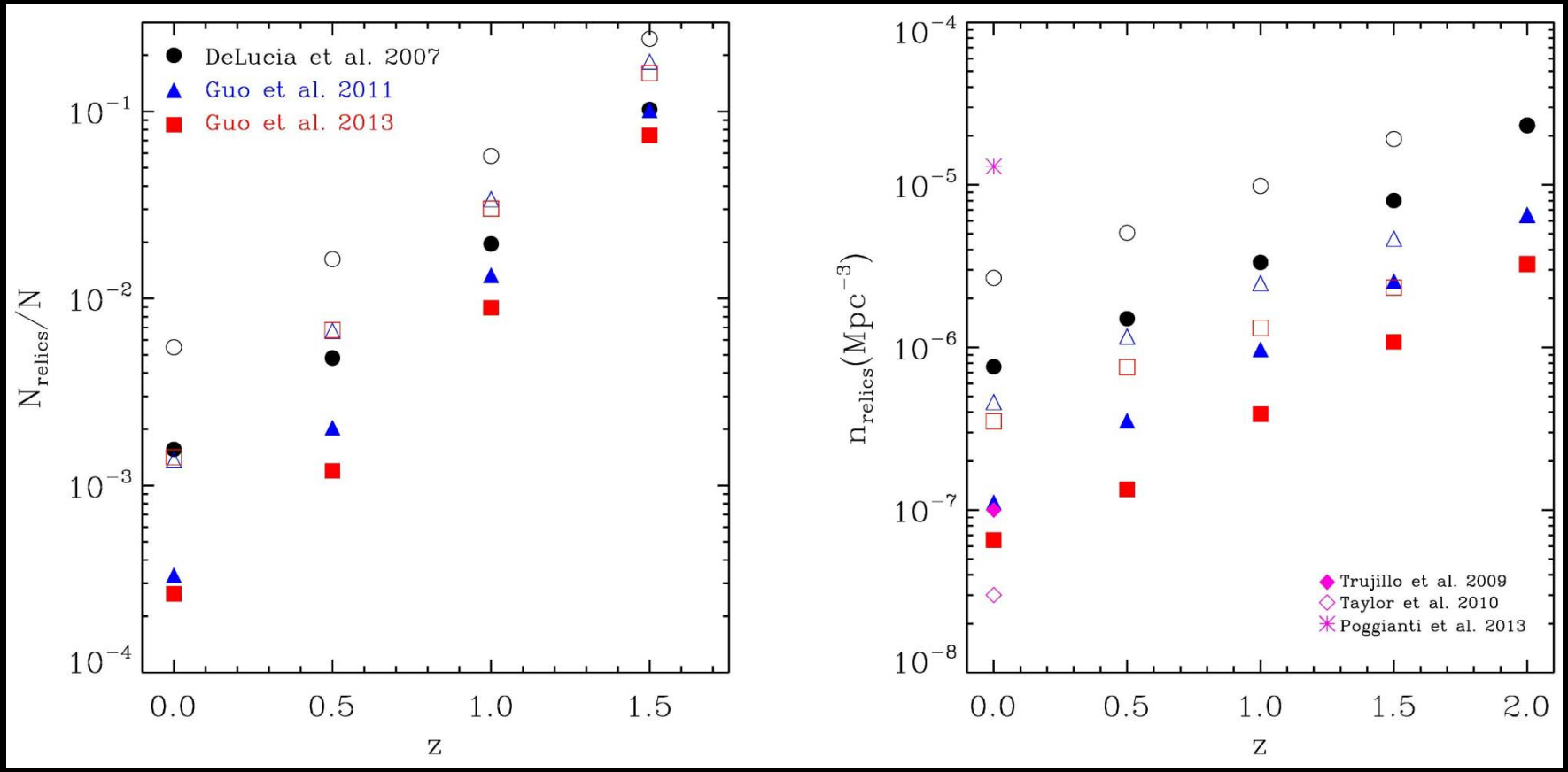
Expected number of massive relics in the present-day Universe

Fraction of massive galaxies form at z=2 as a function of their stellar mass increase



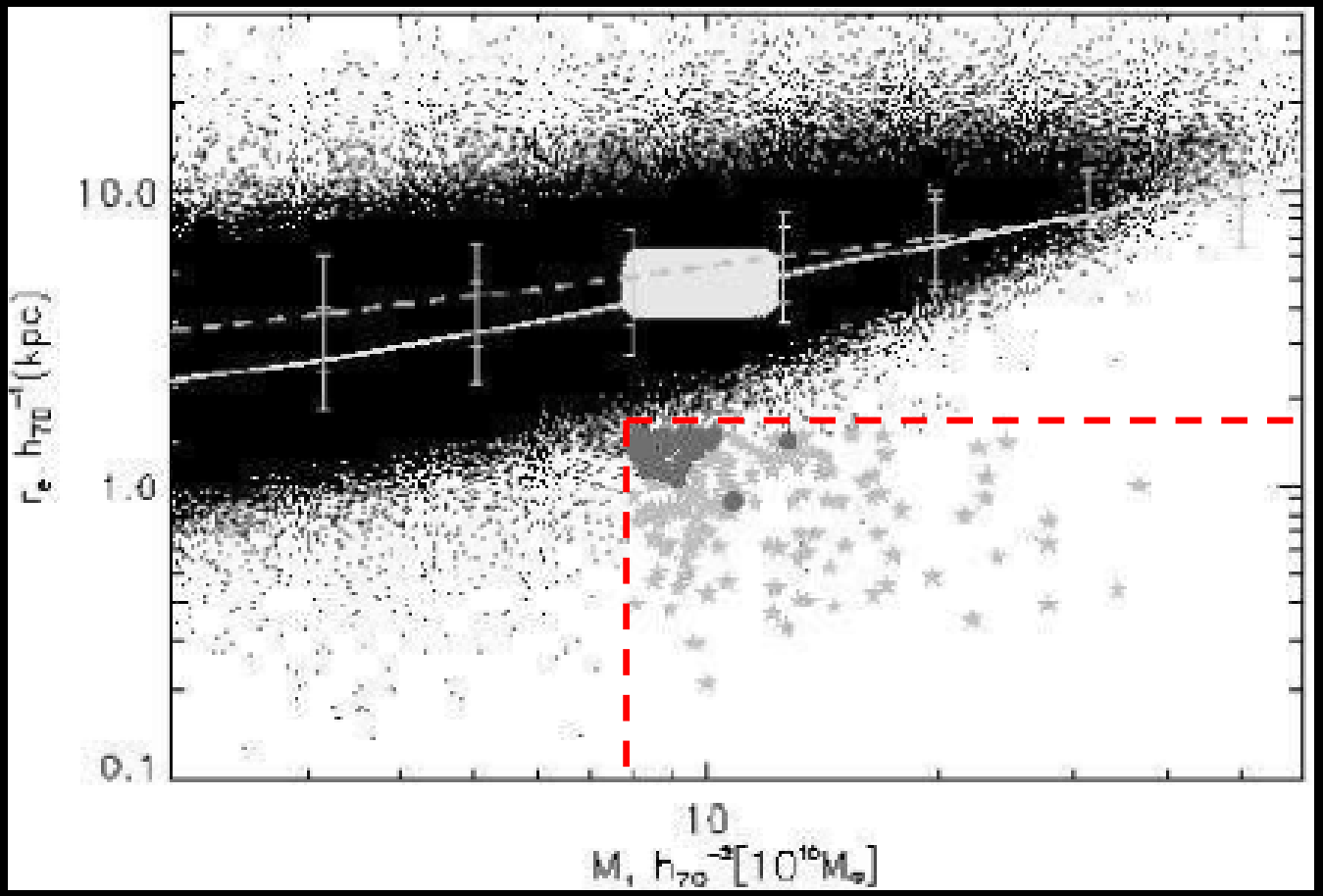
Quilis & Trujillo (2013; in preparation)

Expected number of massive relics in the present-day Universe



Quilis & Trujillo (2013; in preparation)

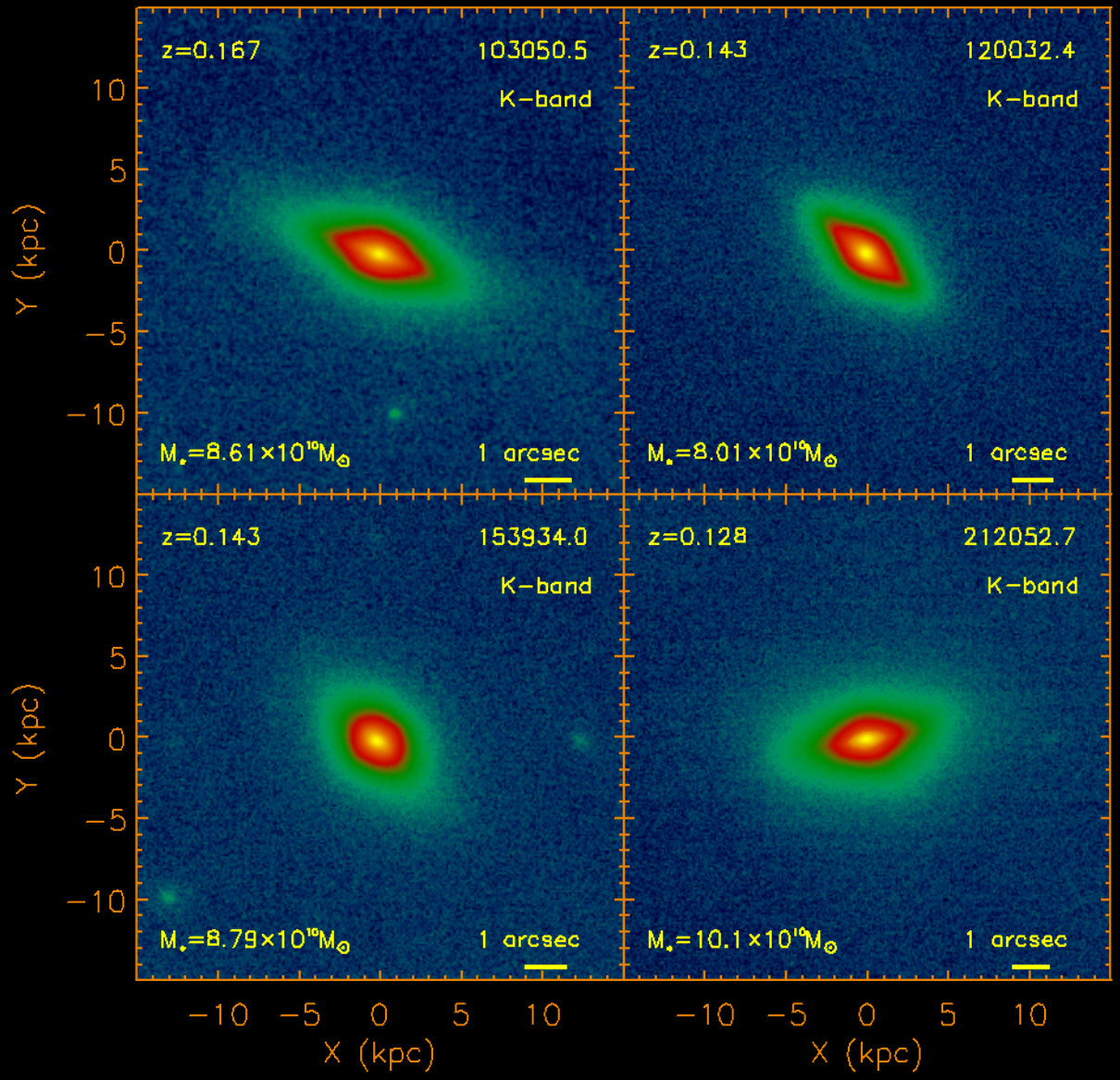
Searching the massive relics of the early Universe



<0.03% of today massive galaxies are compact

Trujillo et al. (2009); Taylor et al (2010); but see Valentinuzzi et al (2010)

Searching the massive relics of the early Universe

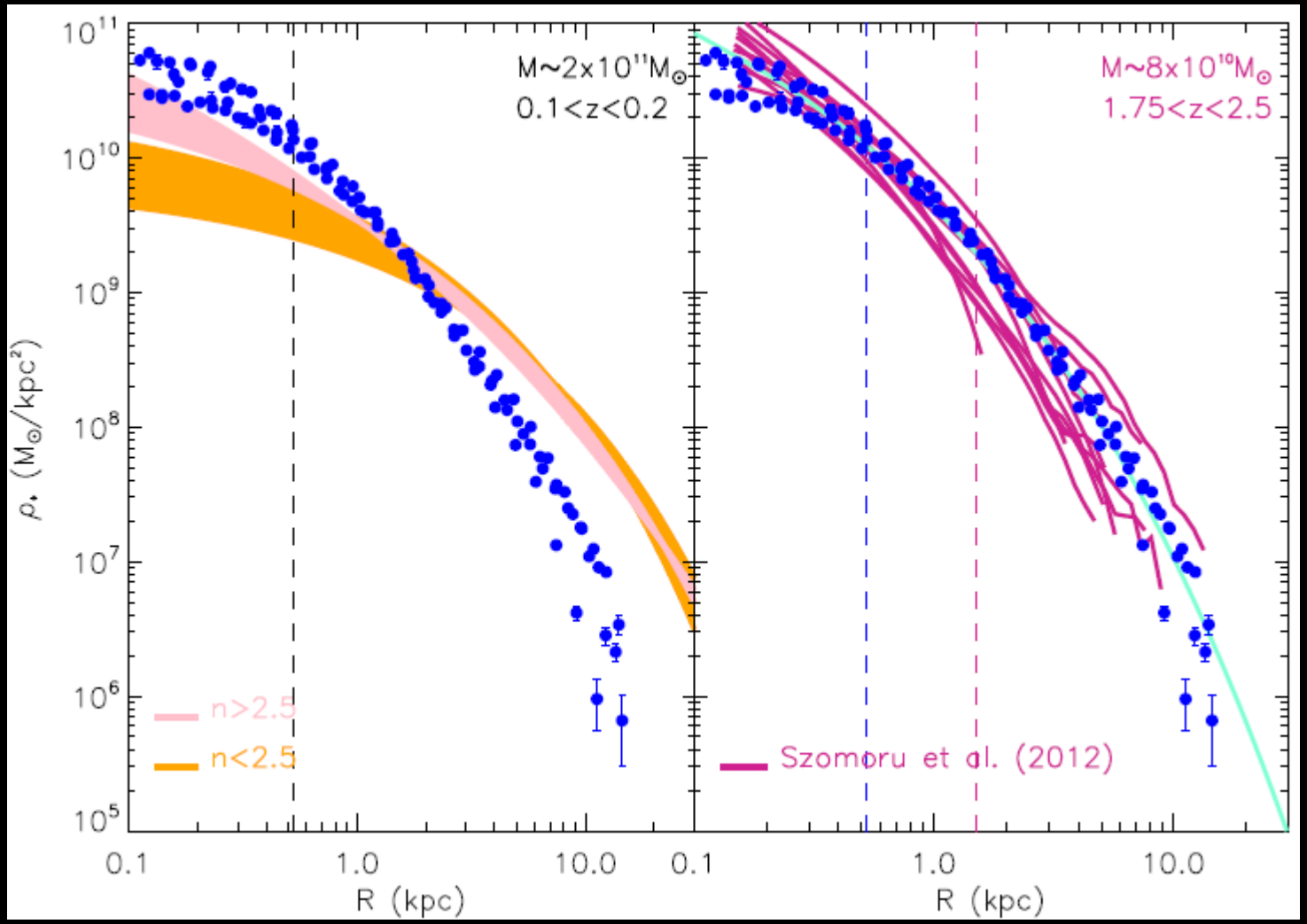


-K-band imaging at 0.15 arcsec resolution with Gemini AO

Trujillo et al. (2012)

See also:
Shih & Stockton (2011)

Searching the massive relics of the early Universe



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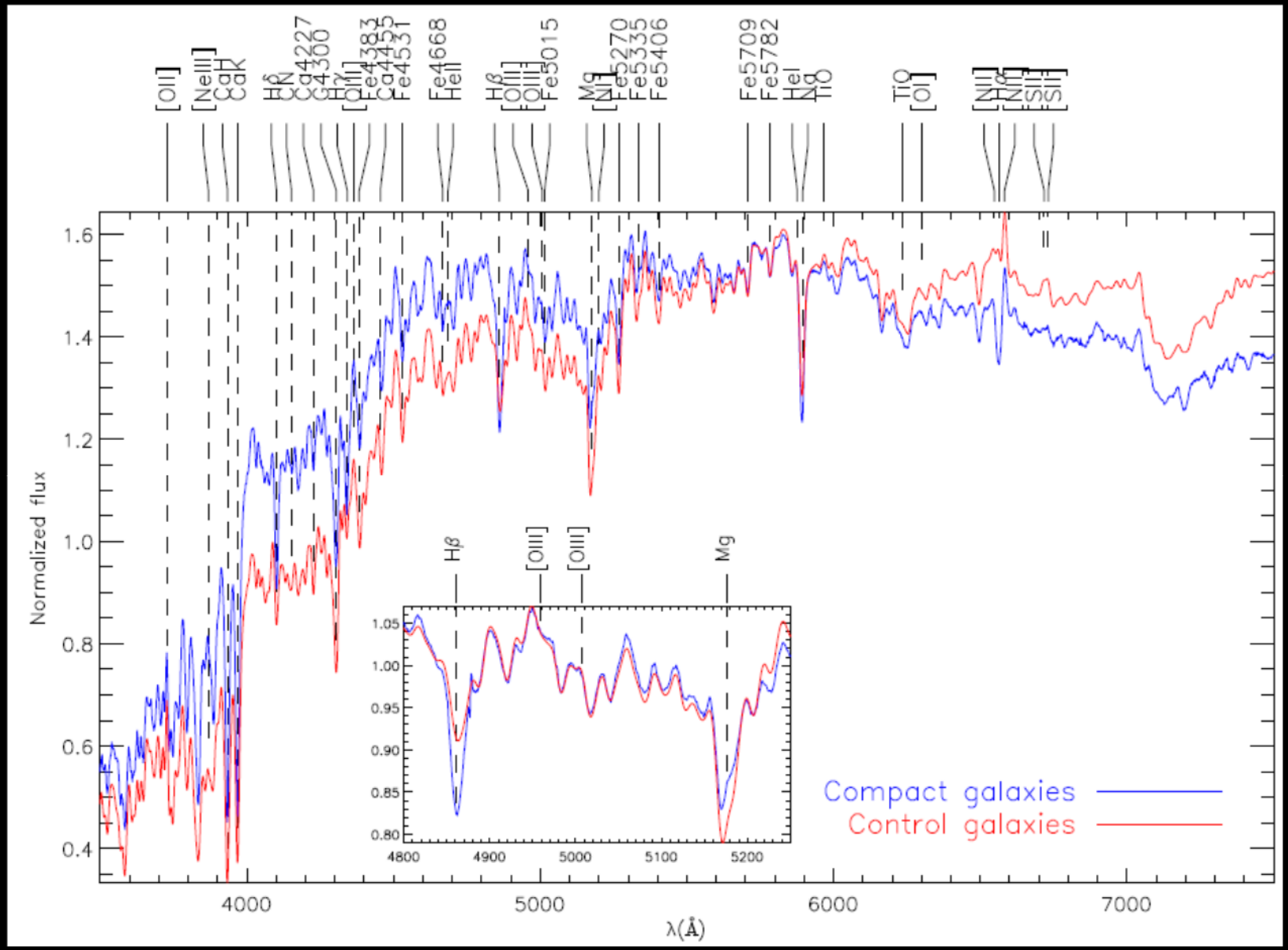

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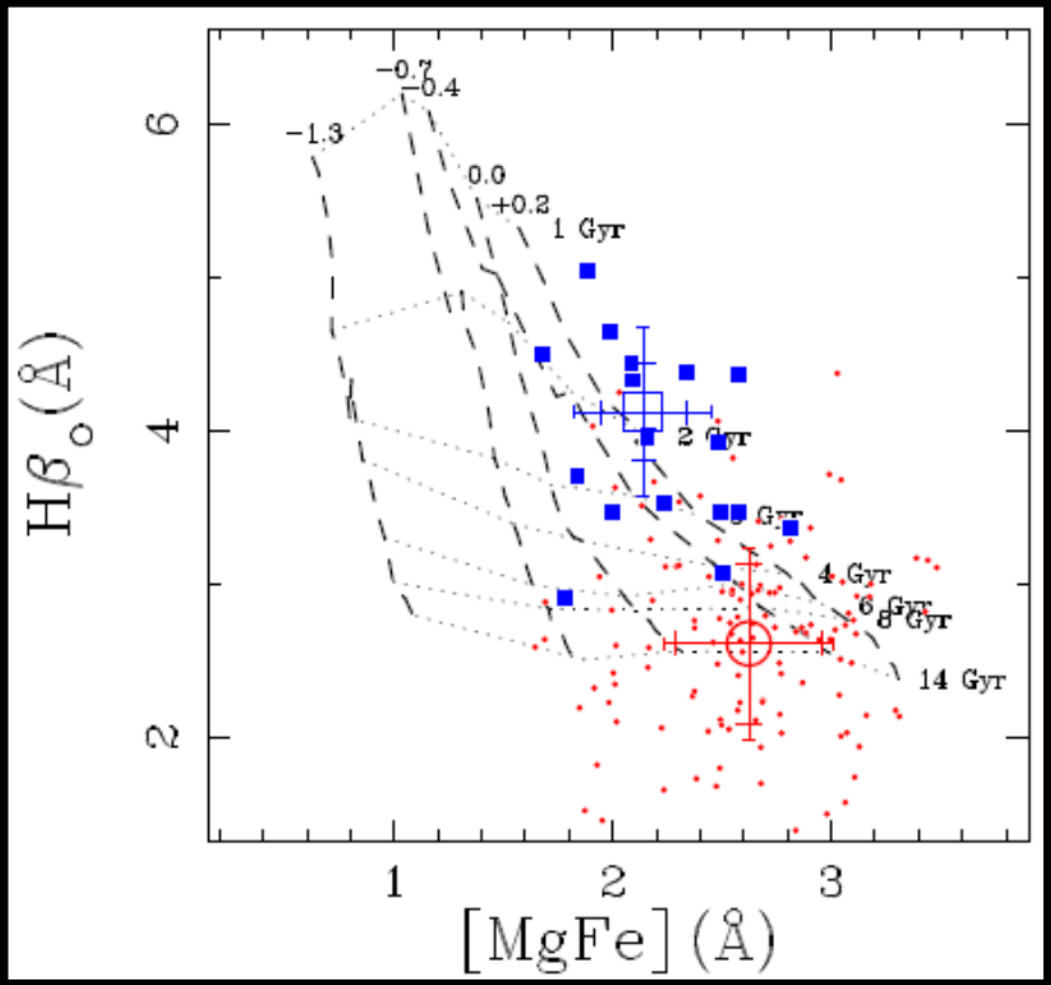


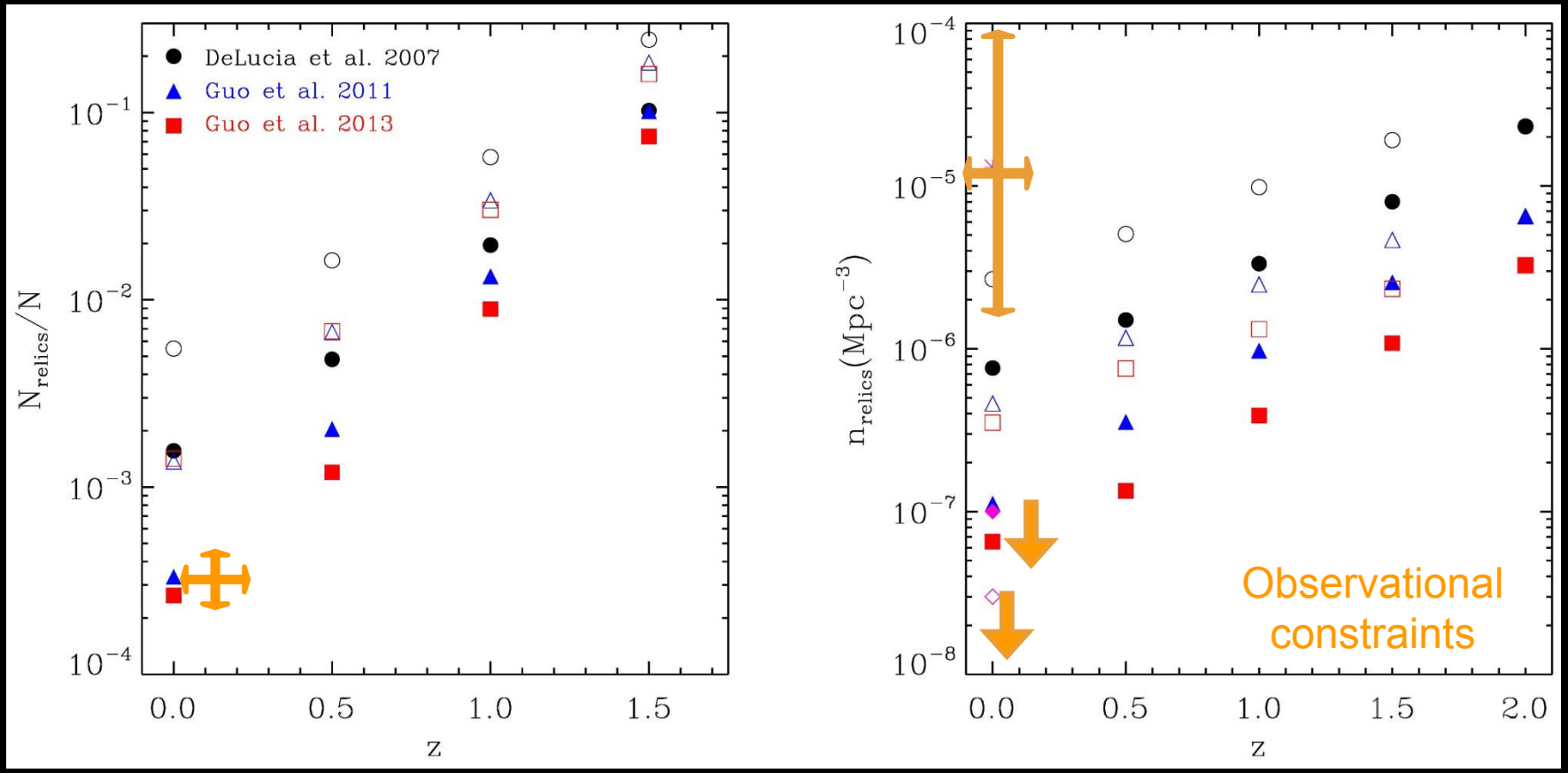
- Most of the massive compact galaxies at z~0 are relatively young (~2 Gyr)

-There are very little (if any) compact massive relics today from the early universe

Trujillo et al. (2009); Ferré-Mateu et al. (2012)

Searching the massive relics of the early Universe

Comparing observations with theoretical predictions



Quilis & Trujillo (2013; in preparation)

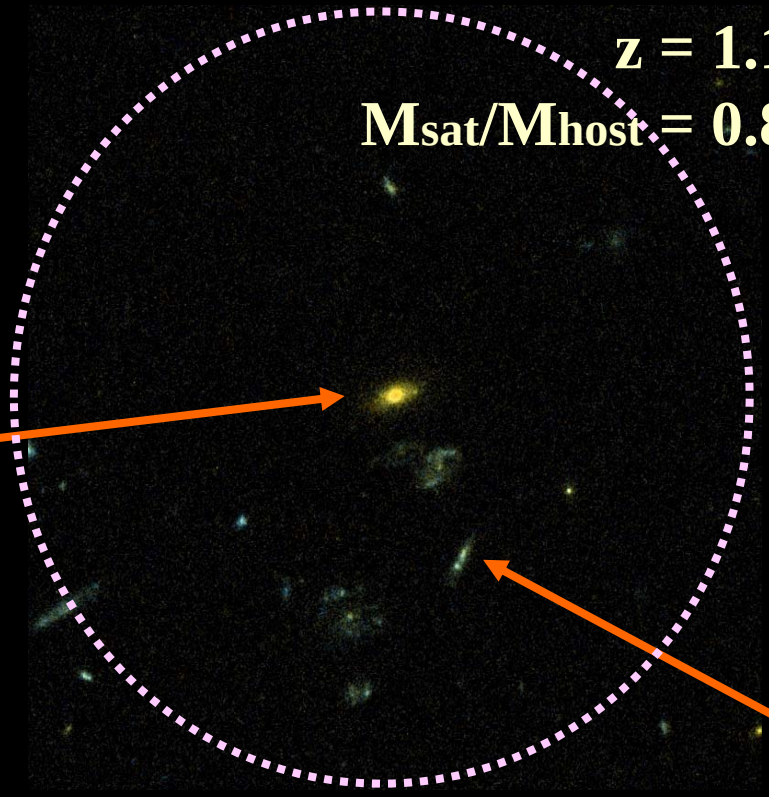
Going into the details: are ΛCDM predictions in agreement with the observations?

Minor merging model is favored by observations but:

1. On the merger rate; Merging is an stochastic process: how many massive galaxies have survived untouched (i.e. relics) since z~2?

There is not an observational clear-cut answer. More work is needed…

The level of substructure around massive galaxies



Kaviraj et al. (2009)

Jackson et al. (2010)

Nierenberg et al. (2011)

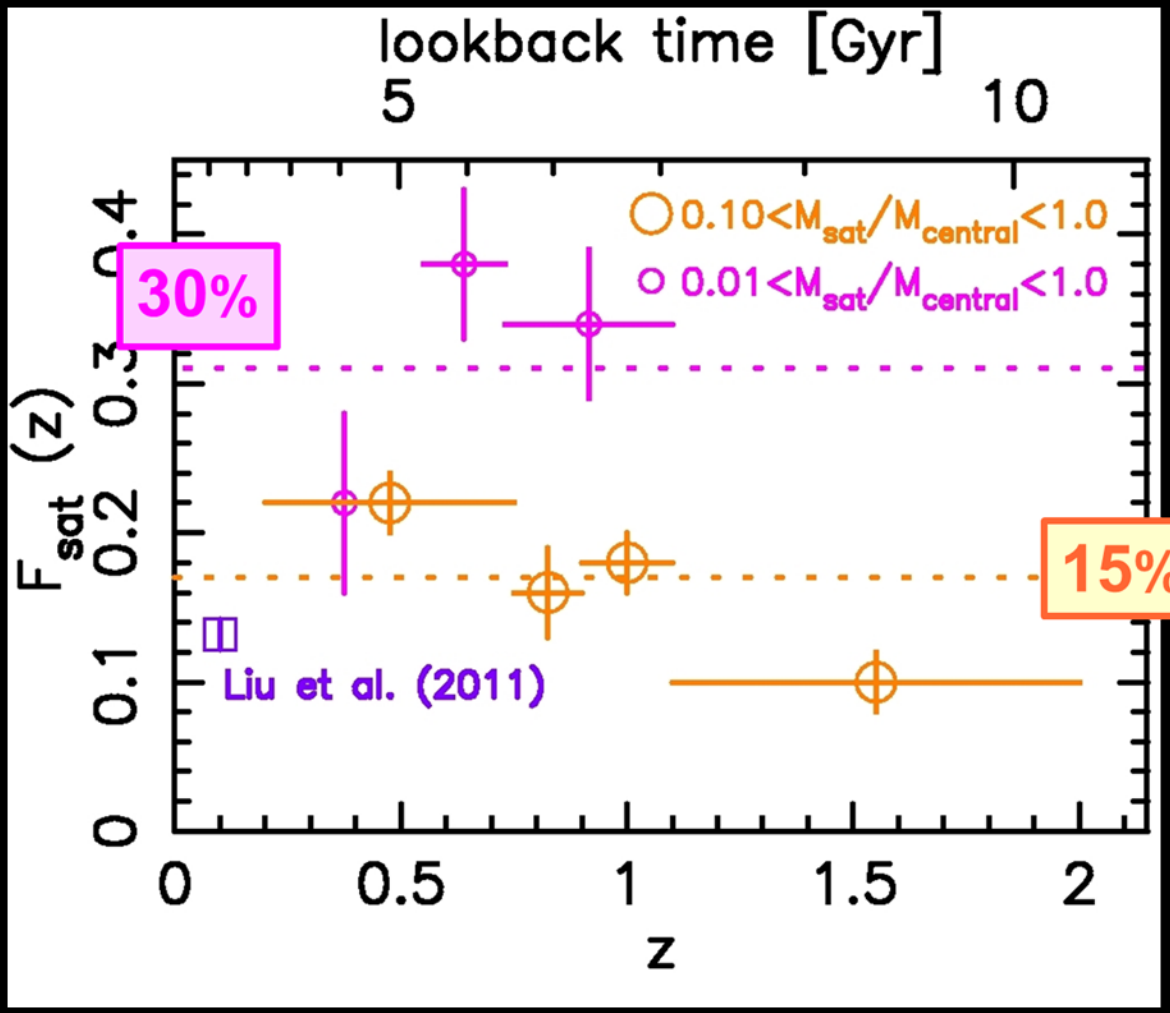
Man et al. (2012)

Newman et al. (2012)

Mármol-Queraltó et al (2012a)

Huertas-Company et al. (2012)

The level of substructure around massive galaxies



Host galaxies:

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

Search Radius:

100 kpc

Satellite galaxies:

$0 < z < 1$

$0.01 < M_{sat}/M_{host} < 1$

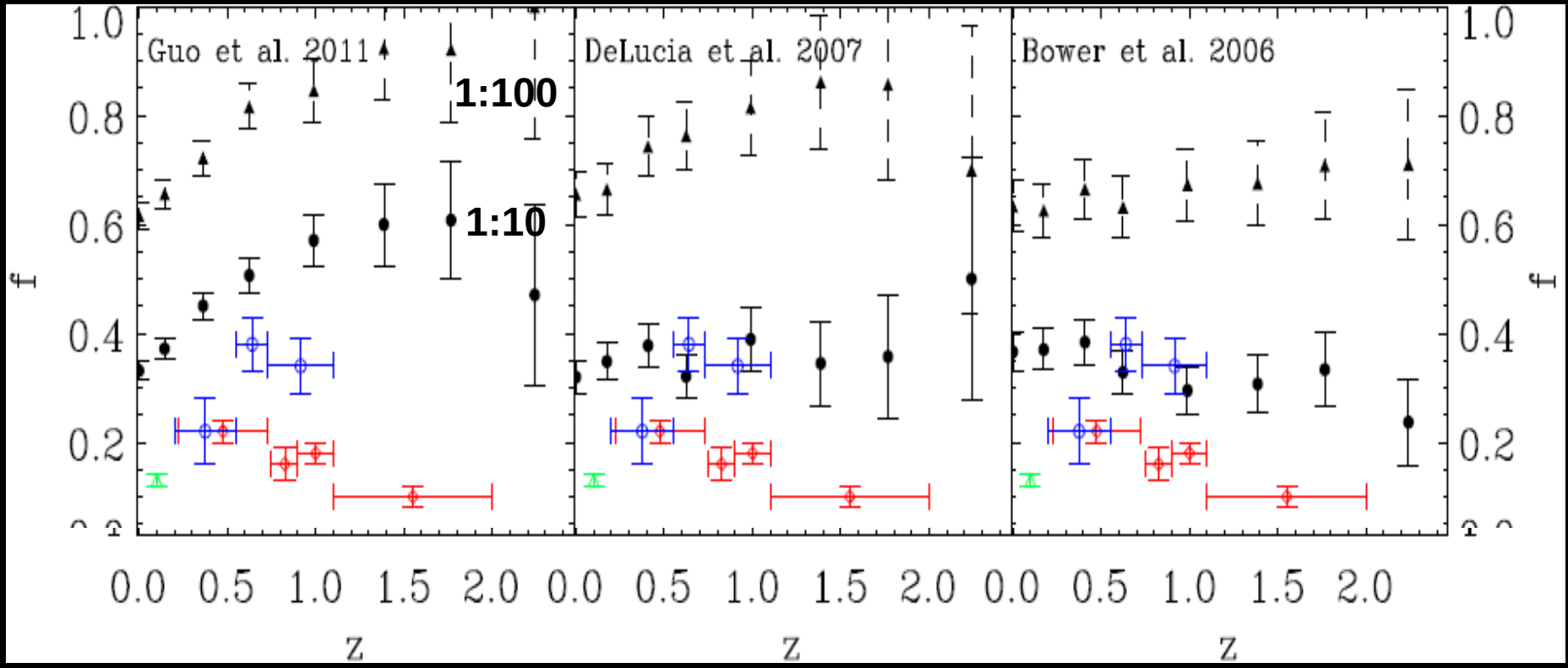
$0 < z < 2$

$0.1 < M_{sat}/M_{host} < 1$

Mármol-Queraltó et al. (2012a)

The level of substructure around massive galaxies

Millennium Simulation vs Observations



Quilis & Trujillo (2012)

Going into the details: are ΛCDM predictions in agreement with the observations?

Minor merging model is favored by observations but:

2. On the level of substructure; What is the number of satellites around the massive galaxies?

a. ΛCDM correctly predicts the constancy of the number of satellites around massive galaxies with redshift
b. ΛCDM incorrectly predicts the exact number by a factor of 2 at all redshift

Future steps

Open questions:

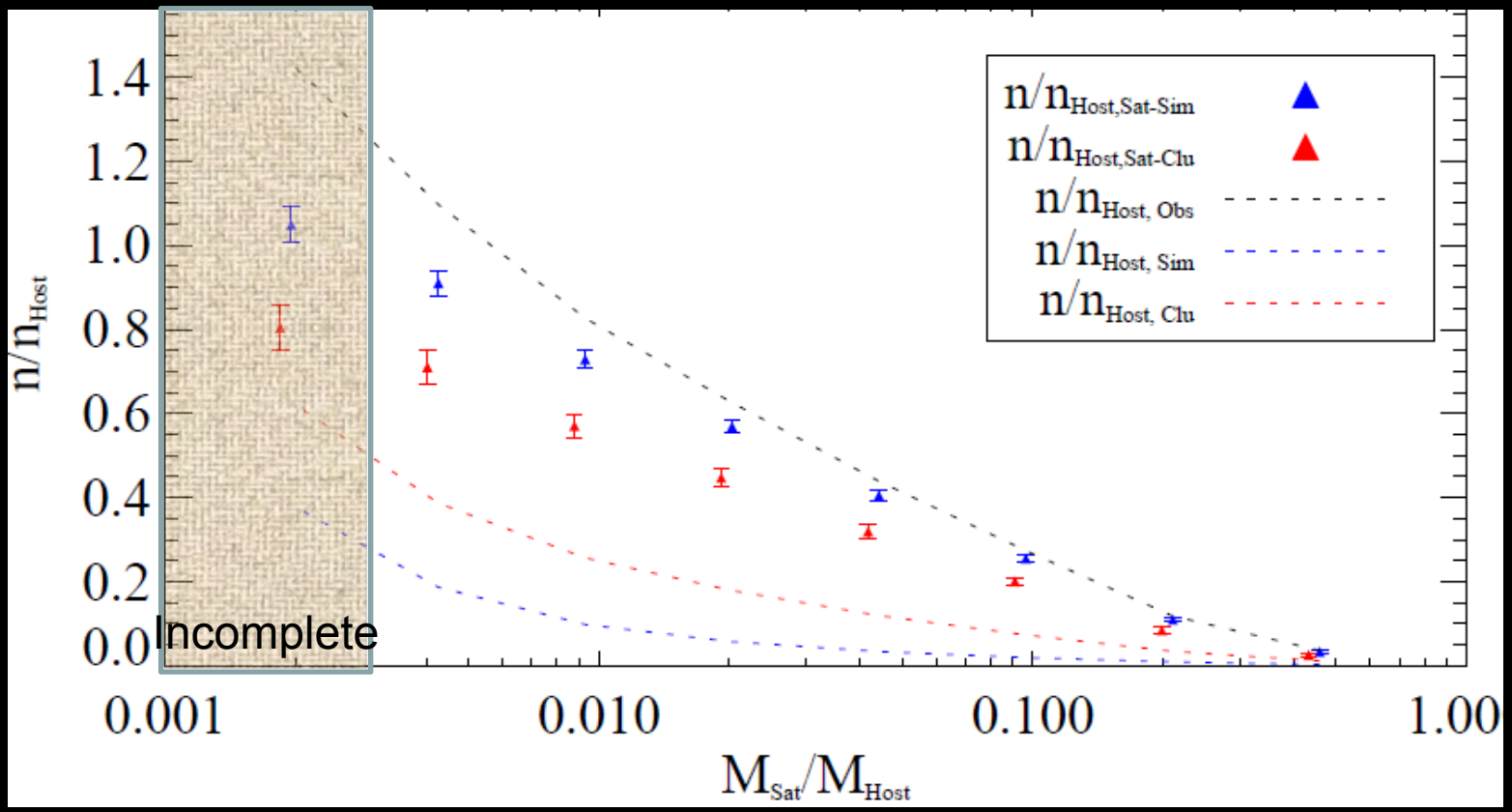
1. What is the number of very low mass satellites around the massive galaxies?

2. What is the most favored channel of growth of the massive galaxies?

What is the number of very low mass satellites around the massive galaxies?

Ongoing work…

Quantifying the amount of satellites down to 1:300 around massive galaxies



Ruiz et al 2013, in preparation

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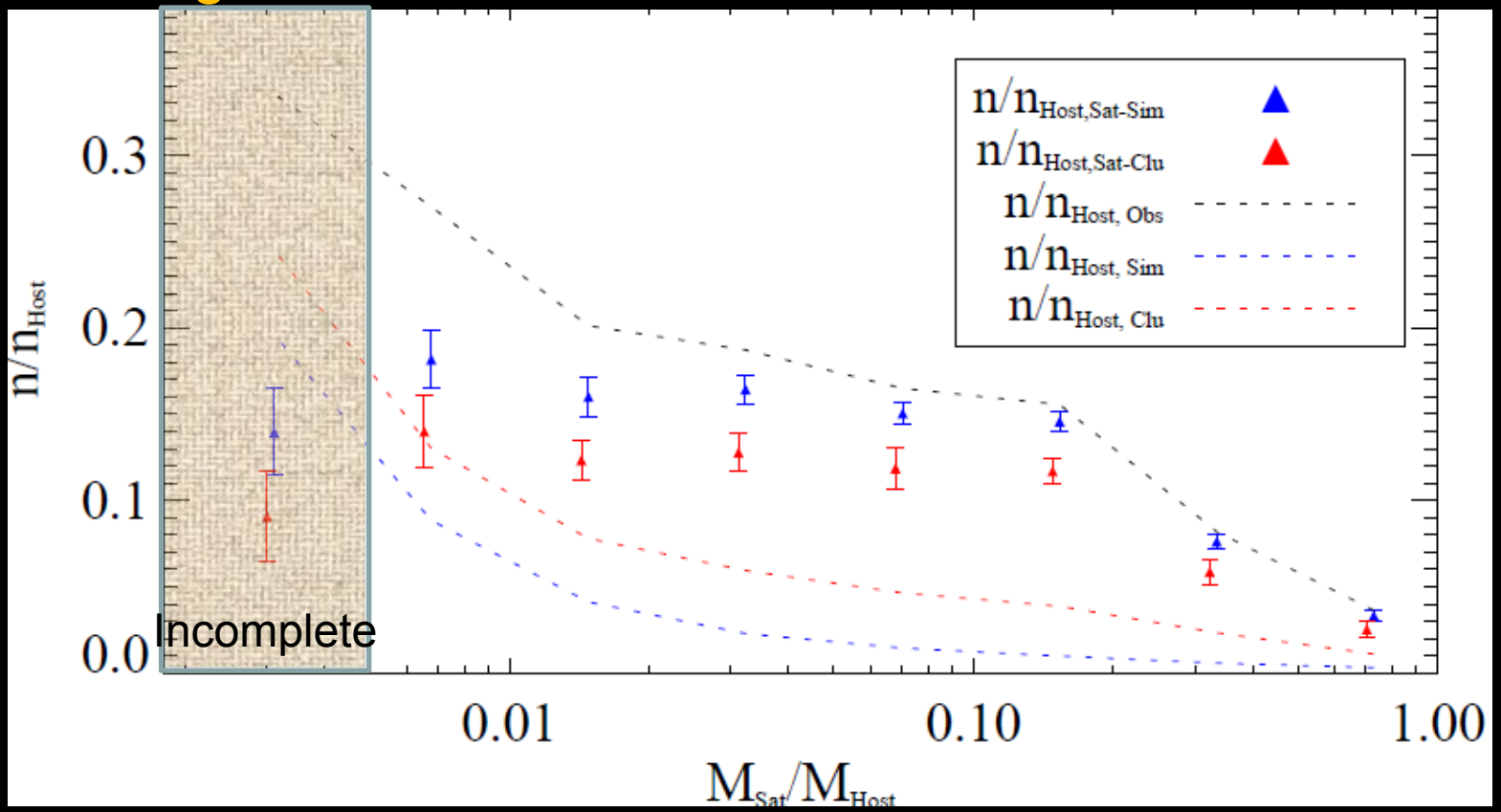

Ruiz et al 2013, in preparation

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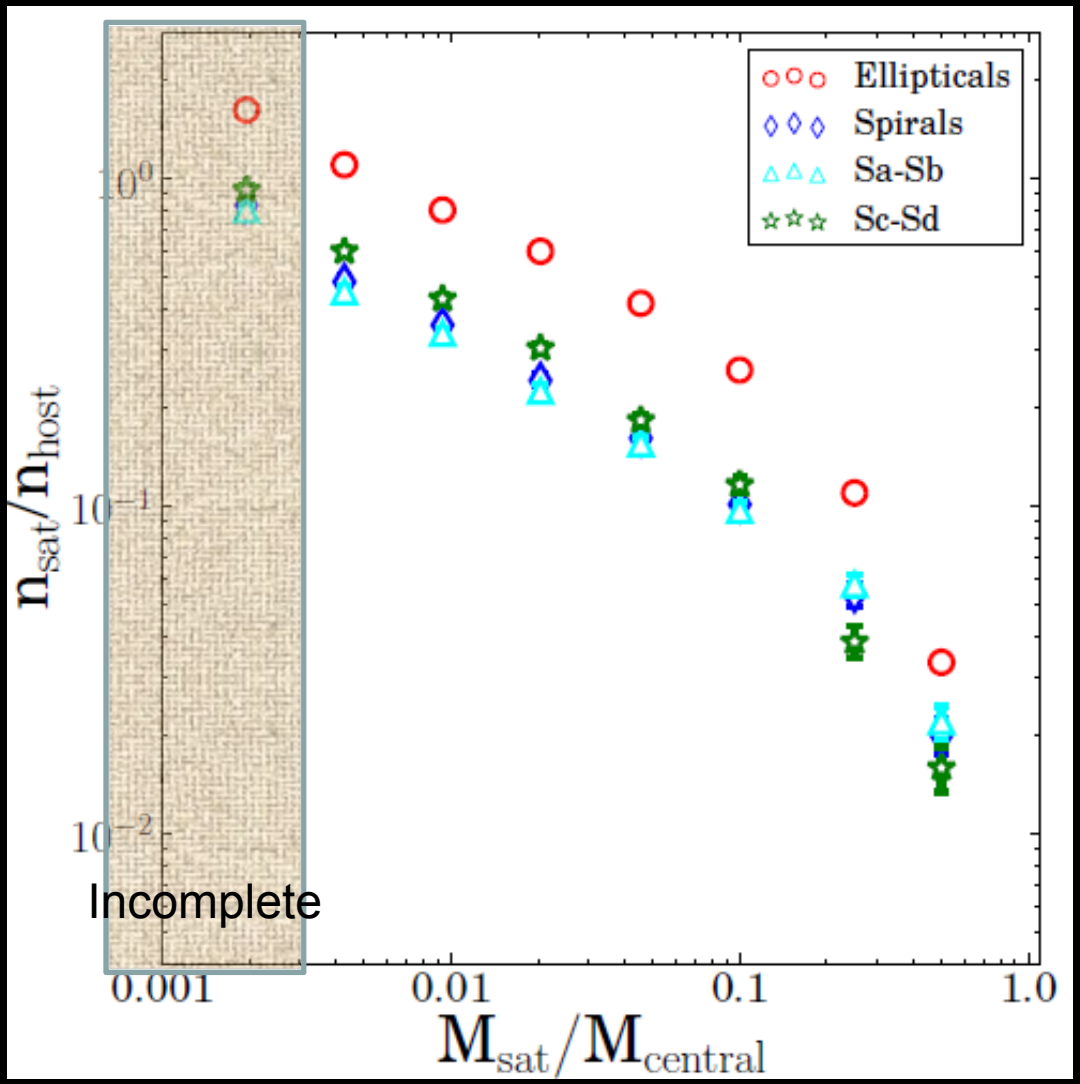
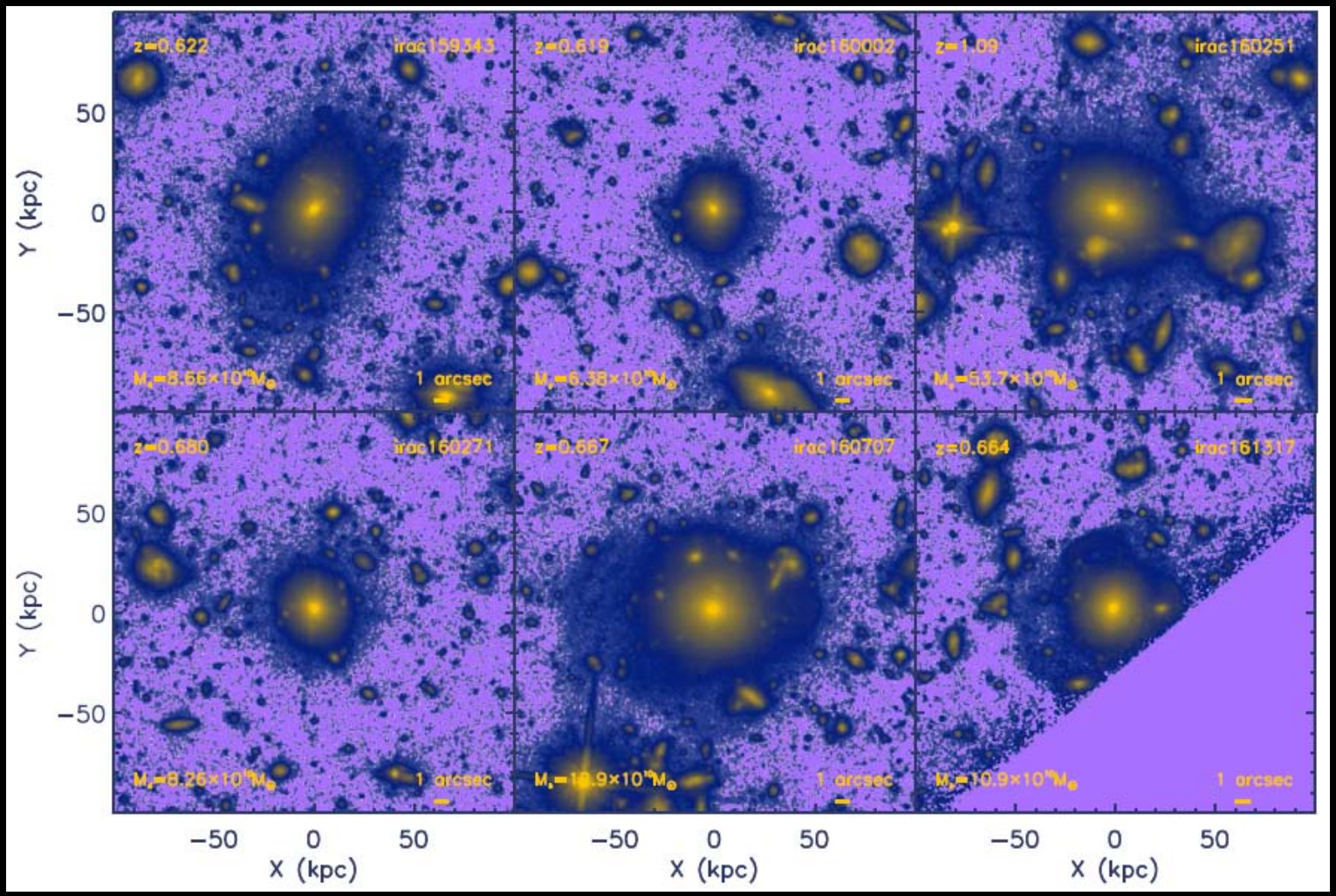


The number of satellites depends on the morphological type…

Mármol-Queraltó et al 2013, in preparation

What is the number of very low mass satellites around the massive galaxies?

Future work

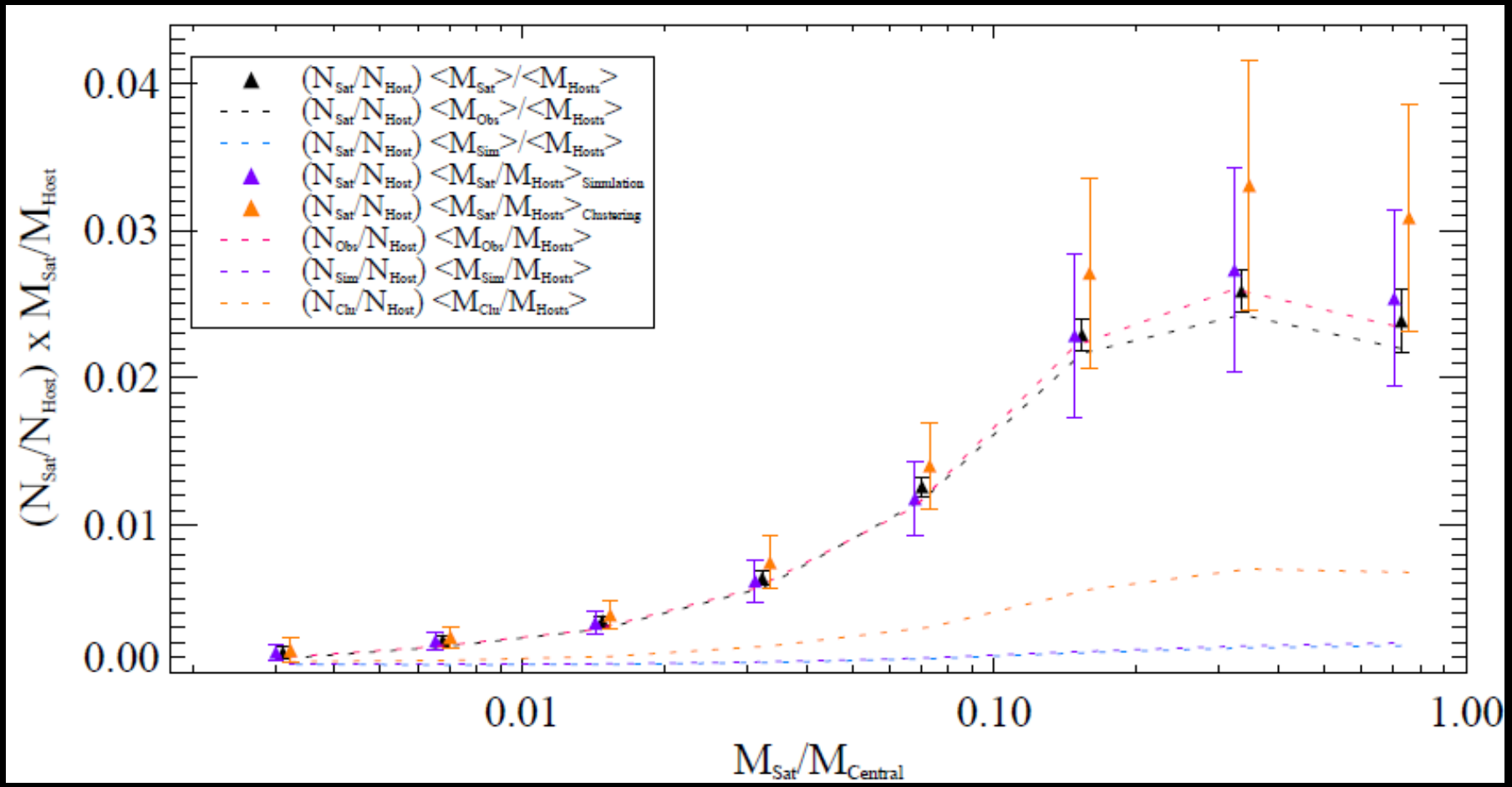


Ultra-deep imaging will allow us to explore the satellite fraction down to 1:3000

(~3×10^7 M_*)

What is mass of the satellite which contribute most to the size and mass growth?

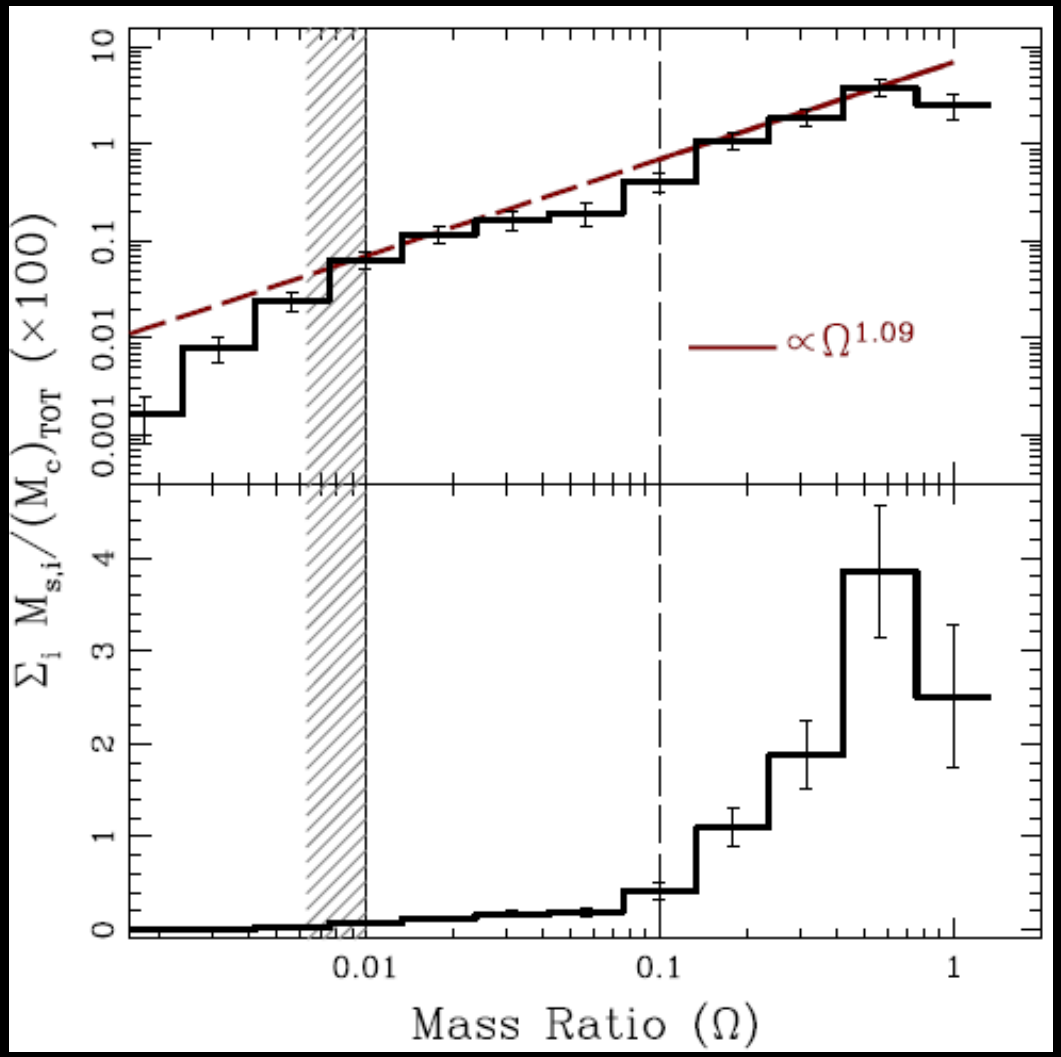
Ongoing work… in the present-day Universe



Ruiz et al 2013, in preparation

What is mass of the satellite which contribute most to the size and mass growth?

Ongoing work… in the z~1 Universe



Ferreras et al 2013, in preparation

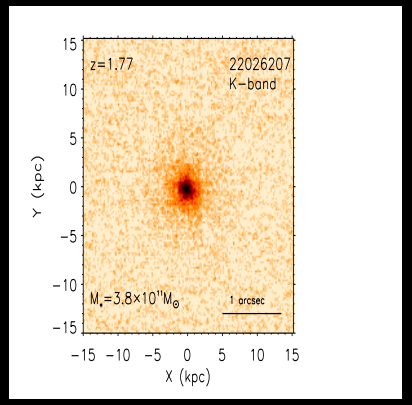
Summary

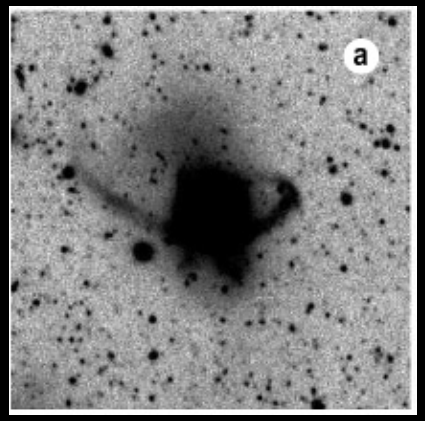
Massive galaxies at z~2-3 were:

1. 10 times less abundant than today
2. Significantly more compact

Most likely growth mechanism:

Continuous accretion of minor satellites that create the outer envelopes and enlarge the size of the galaxies





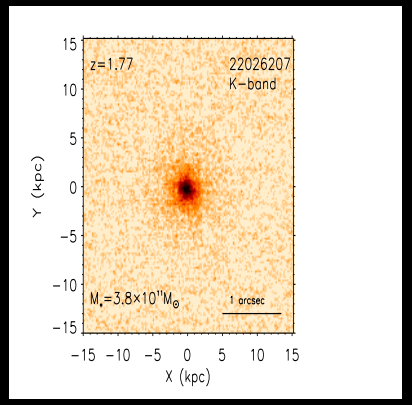
Cosmic Time

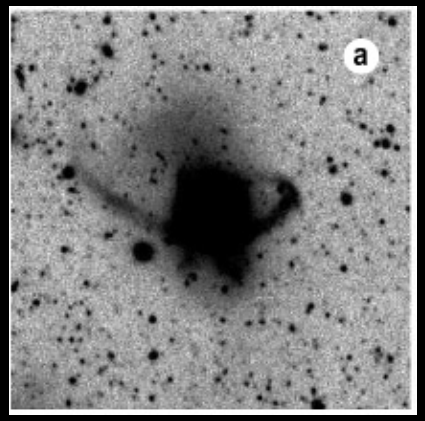
Summary

Still to solve:

1. Is the number of satellites around the massive galaxies enough to produce the size growth?
2. What is the most likely channel of merging?

A detailed confrontation with ΛCDM and ΛWDM simulations is still missing!!!





Cosmic Time