The growing history of massive galaxies

Nacho Trujillo

Instituto de Astrofísica de Canarias

www.iac.es/project/traces

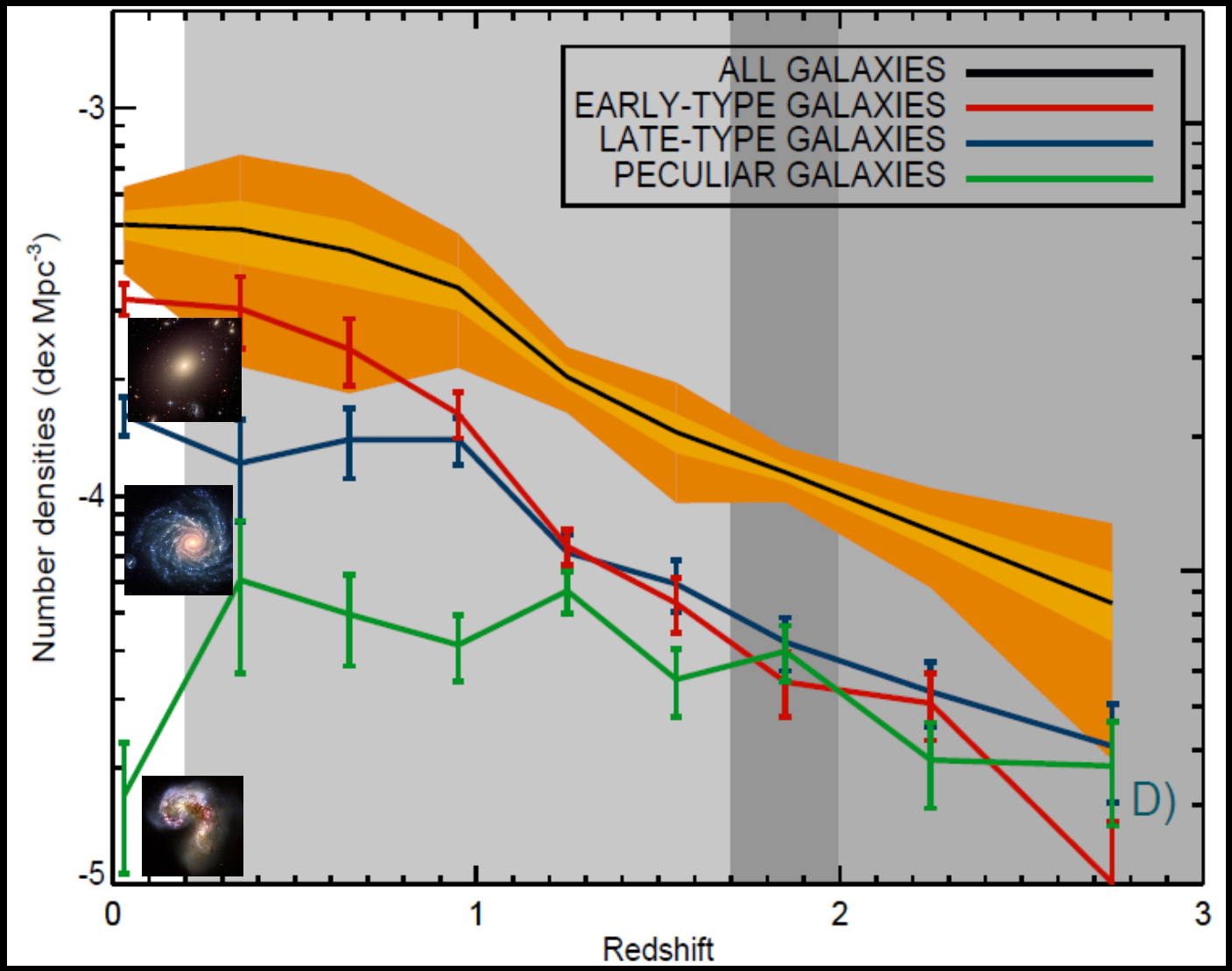
Some clarifying remarks

1. 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

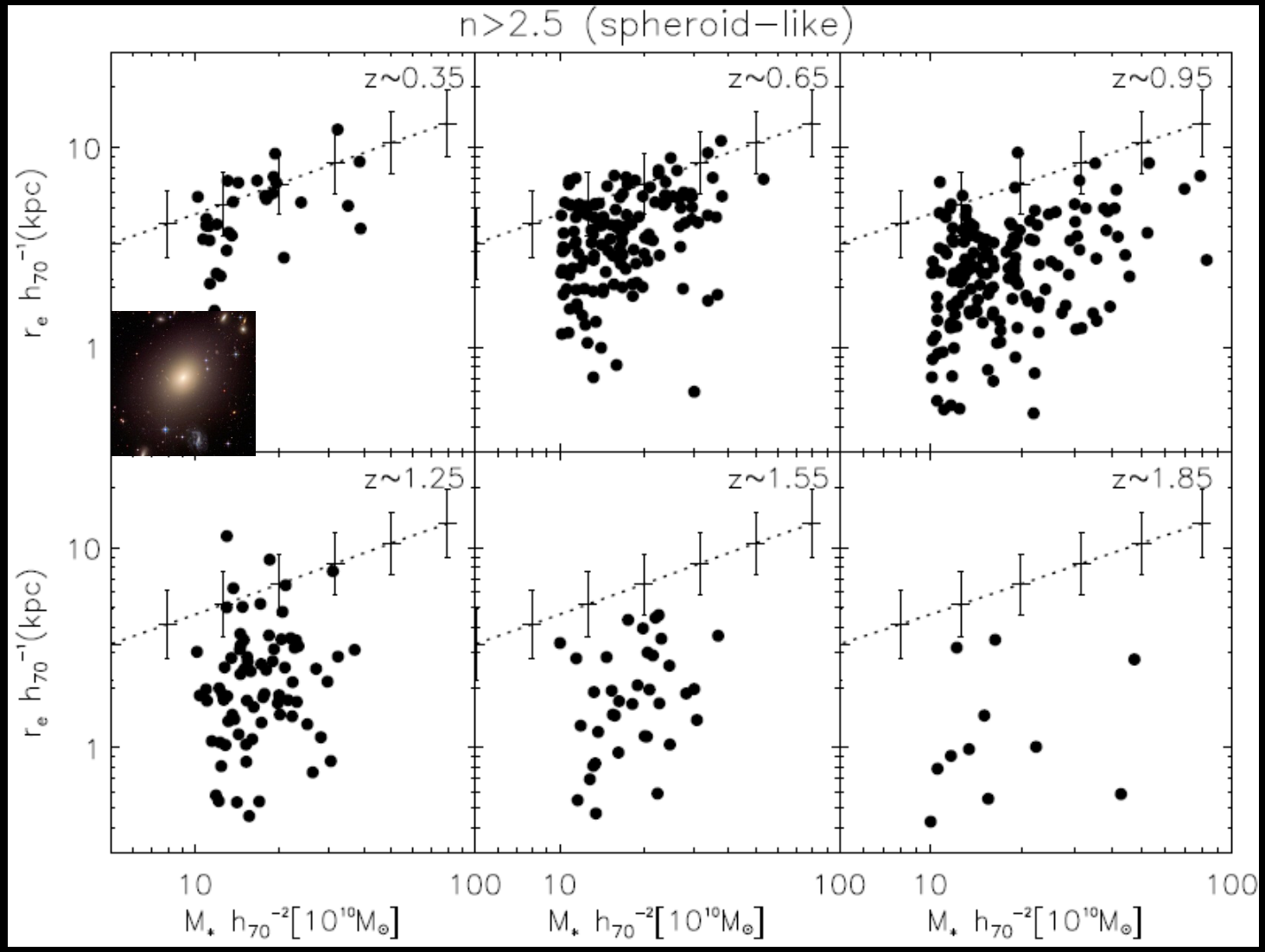
2. The number of massive galaxies has increased by a factor of 10 since z~3



See also: e.g. Drory et al. (2004; 2005), Fontana et al. (2003; 2006), Borch et al. (2006), Pannella et al. (2006), Kajizawa et al. (2009), Bolzonella et al. (2010), Pozzetti et al. (2010), Ilbert et al. (2010), Santini et al. (2012)…

Buitrago et al. (2013); Pérez-González et al. (2008)

3. The stellar mass - size relation has dramatically changed since z~3

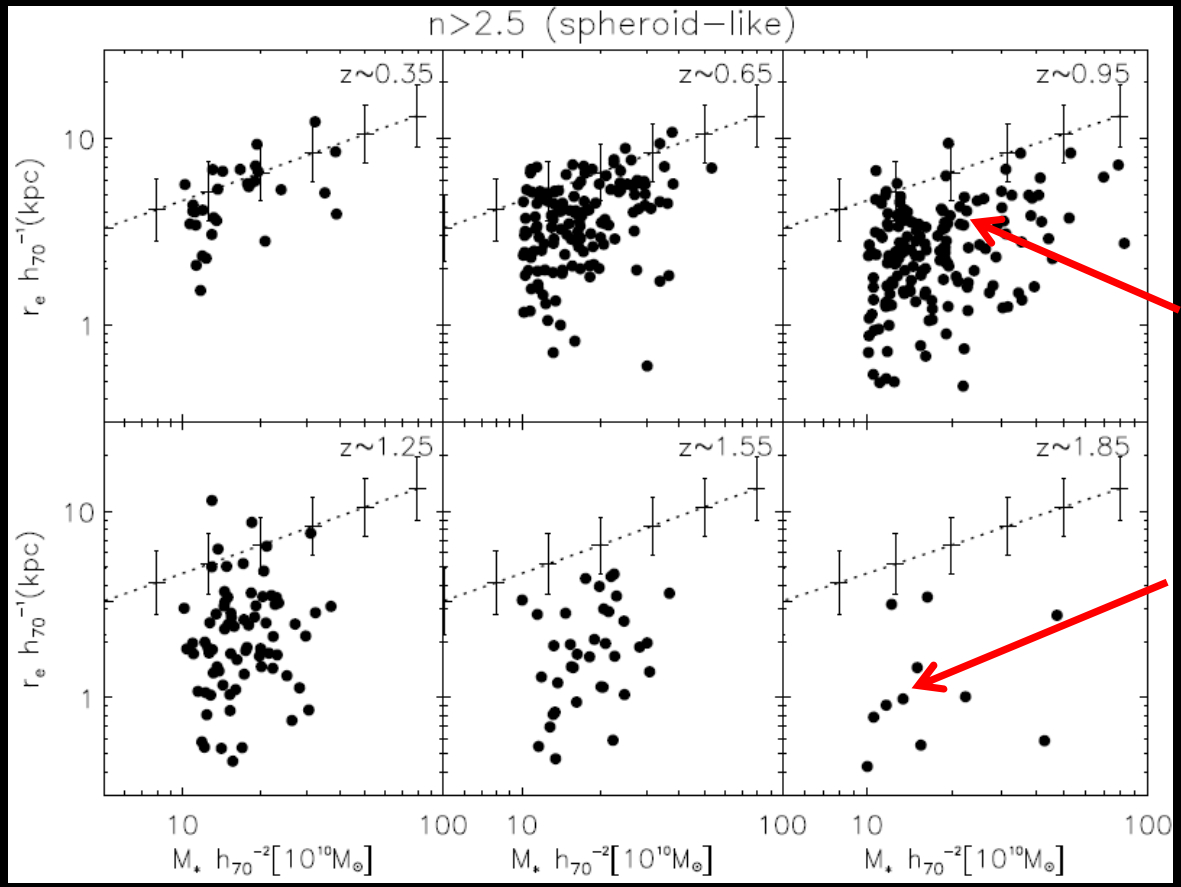


Also found by e.g.: Zirm et al. (2007); Toft et al. (2007); Longhetti et al. (2007); Cimatti et al. (2008); Damjanov et al. (2008; 2011); van Dokkum et al. (2008); Cassata et al. (2009); Saracco et al. (2009); Szomoru et al. (2010; 2012) and many many more…

Trujillo et al. (2007); Buitrago et al. (2008)

4. On the growing history of massive galaxies…

… we have to distinguish among…



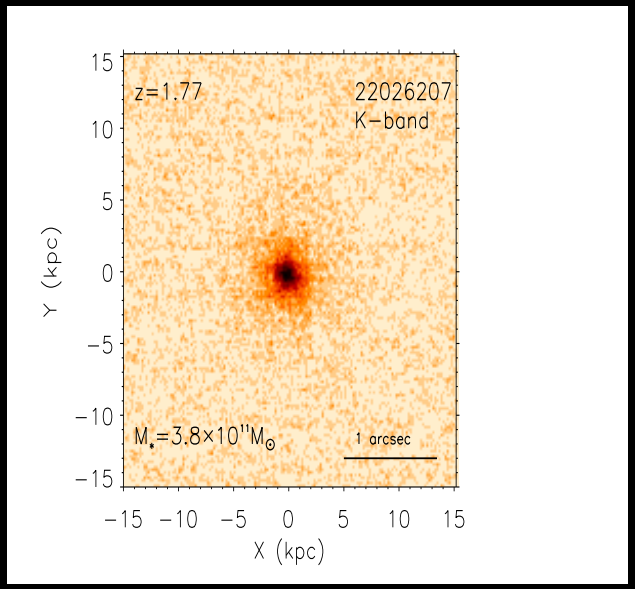
Trujillo et al. (2007)

The mechanisms that:

1. create the newcomers to the stellar mass – size relation
2. make to grow in size the already existed massive galaxies

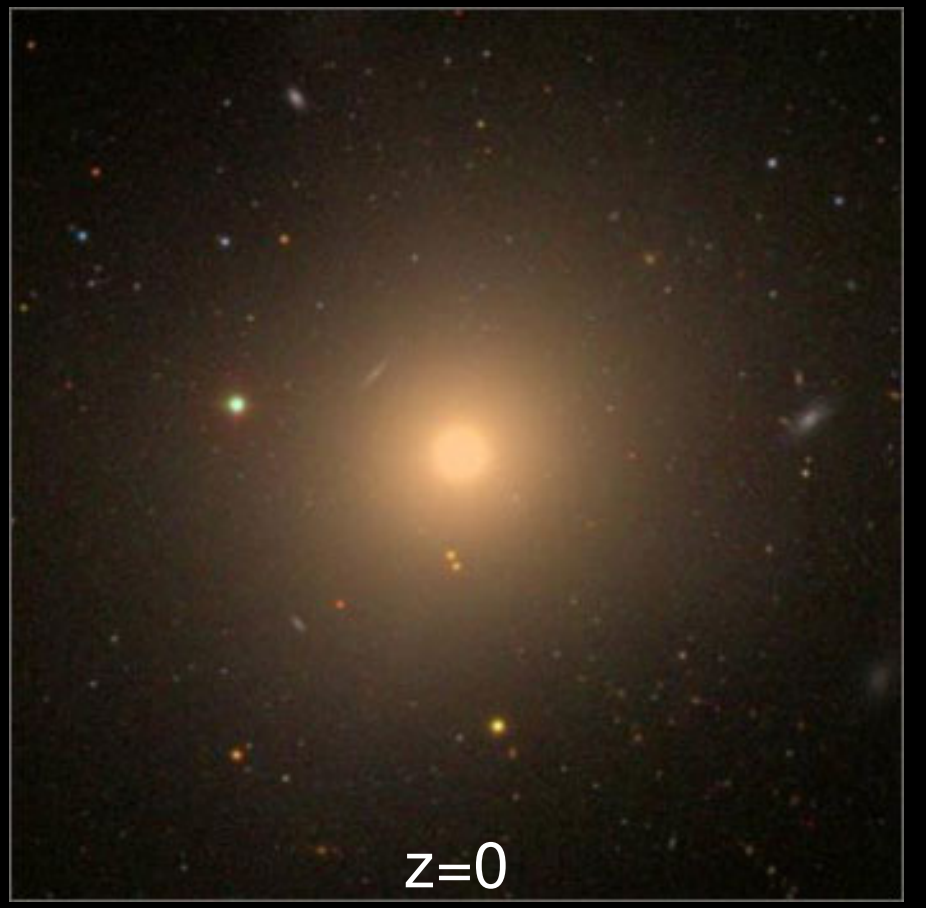
5. This is a talk about the growing mechanisms of already existed massive galaxies

Carrasco et al. (2010)



z=2

?



z=0

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

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

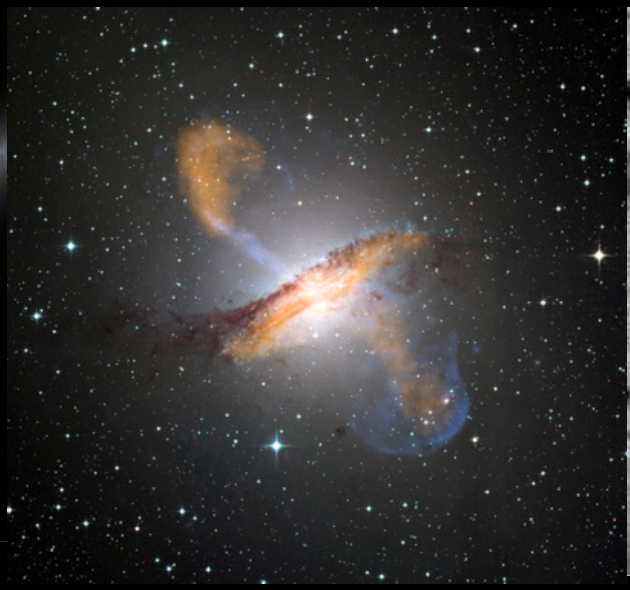
Mass and size growth mechanisms

What is the physical mechanism responsible of the size evolution?

Proposed Models:

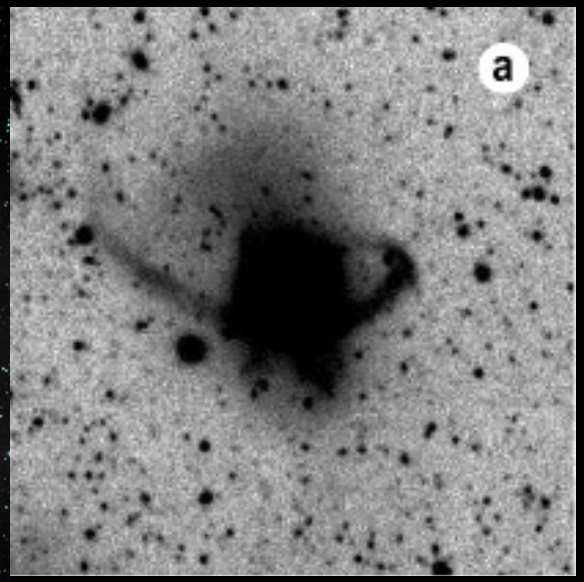
Major Dry Mergers

(e.g. Ciotti & van Albada 2001; Boylan-Kolchin et al. 2006; Naab et al. 2007; Nipoti et al. 2010; 2012)



Puffing up

(Fan et al. 2008;2010; Ragone-Figueroa et al. 2011)



Minor mergers

(Khochfar & Burkert 2006; Maller et al. 2006; Hopkins et al. 2009; Naab et al. 2009; Sommer-Larsen & Toft 2010 ;Oser et al. 2010; Johansson et al. 2012; Oogi & Habe 2013)

What is the physical mechanism responsible of the size evolution?

Predictions:

Major Dry Mergers

- Stellar mass increase
- Continous size evolution
- $\Delta R \sim \Delta M$
- No difference in size between “old” (>1 Gyr) and “young” (<1 Gyr) spheroids at a given redshift

Puffing up

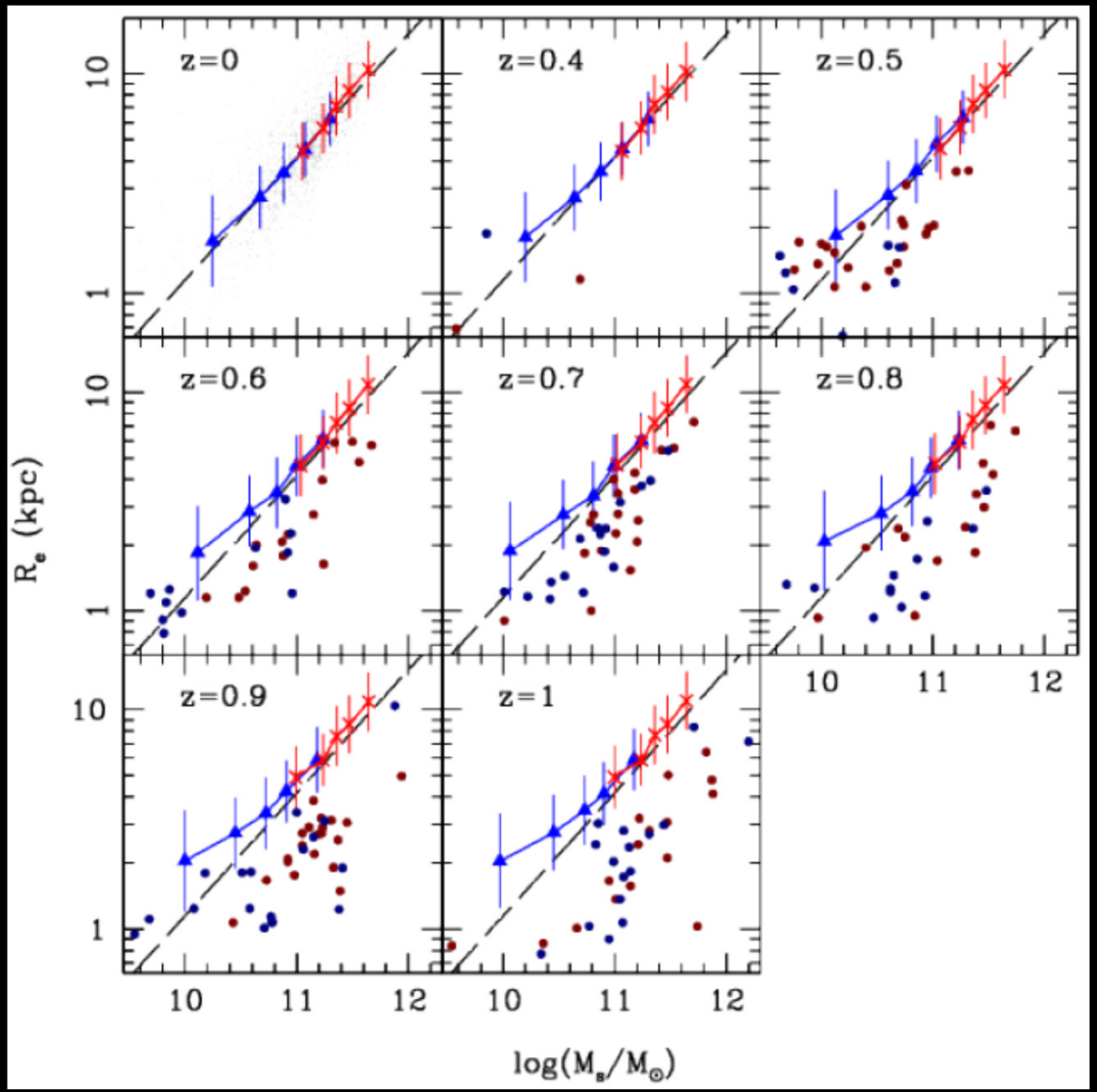
- No stellar mass increase
- Very fast (<1 Gyr) size evolution
- Strong decrease in the velocity dispersion (400 km/s -> 200 km/s)
- Difference in size between “old” (>1 Gyr) and “young” (<1 Gyr) spheroids at a given redshift

Minor mergers

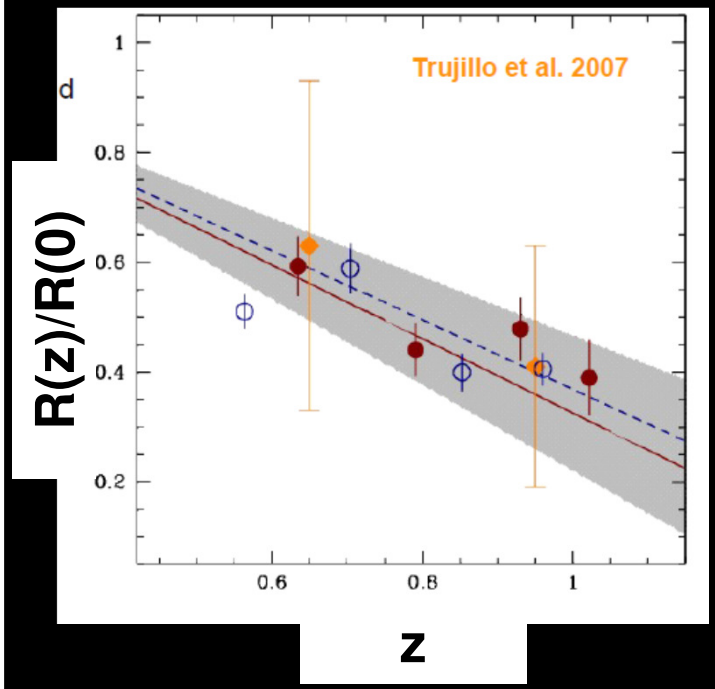
- Stellar mass increase
- Continous size evolution
- $\Delta R \sim \Delta M^2$
- Mild decrease in the velocity dispersion (250 km/s -> 200 km/s)
- No difference in size between “old” (>1 Gyr) and “young” (<1 Gyr) spheroids at a given redshift

Observational constraints

1. Size evolution is age independent

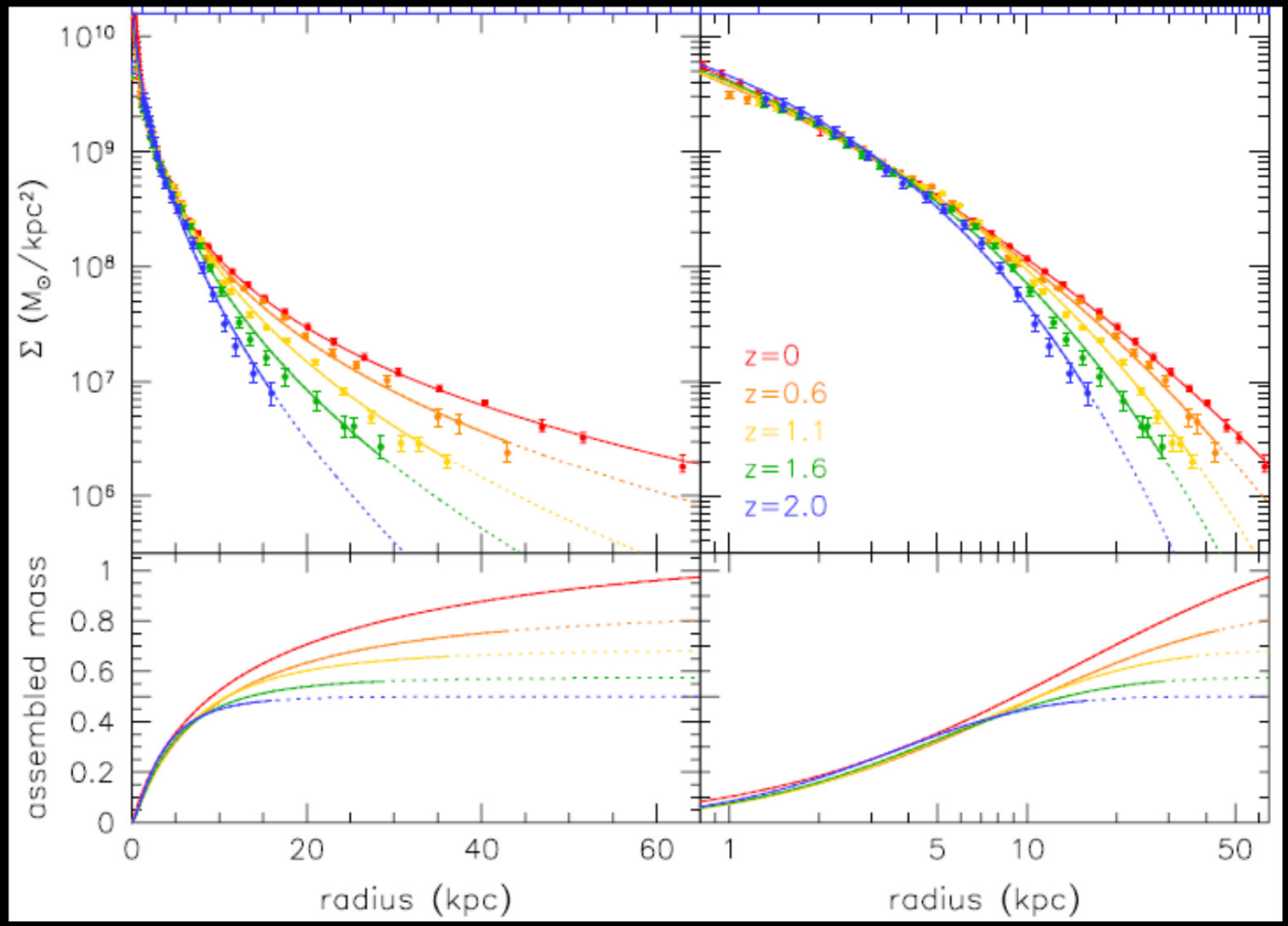


No mean size difference between old and young spheroids at each redshift



Trujillo et al. (2011); see also Saracco et al. (2011) for 1<z<2

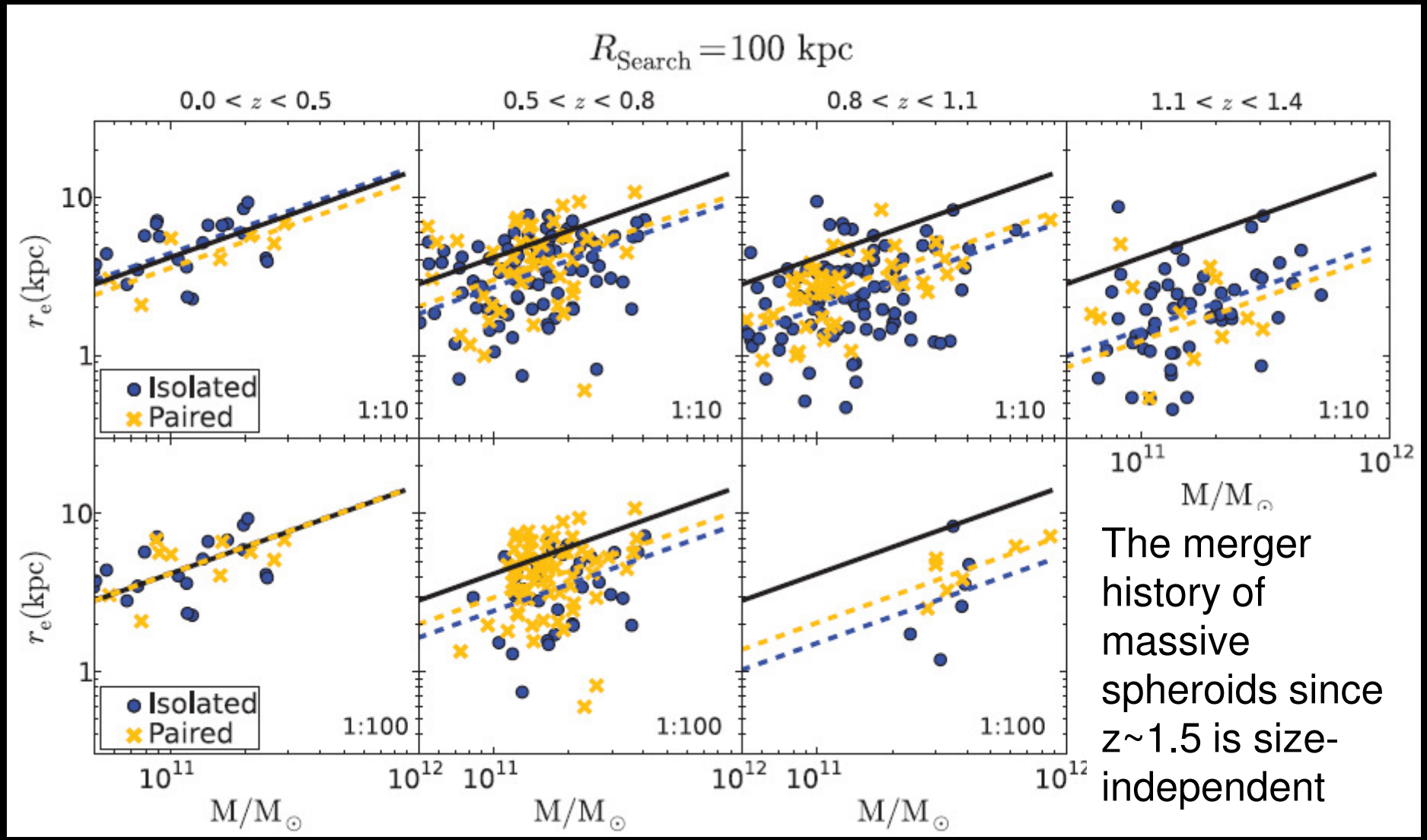
2. Size evolution is a continuous process



Progressive and steady formation of outer galaxy envelopes

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

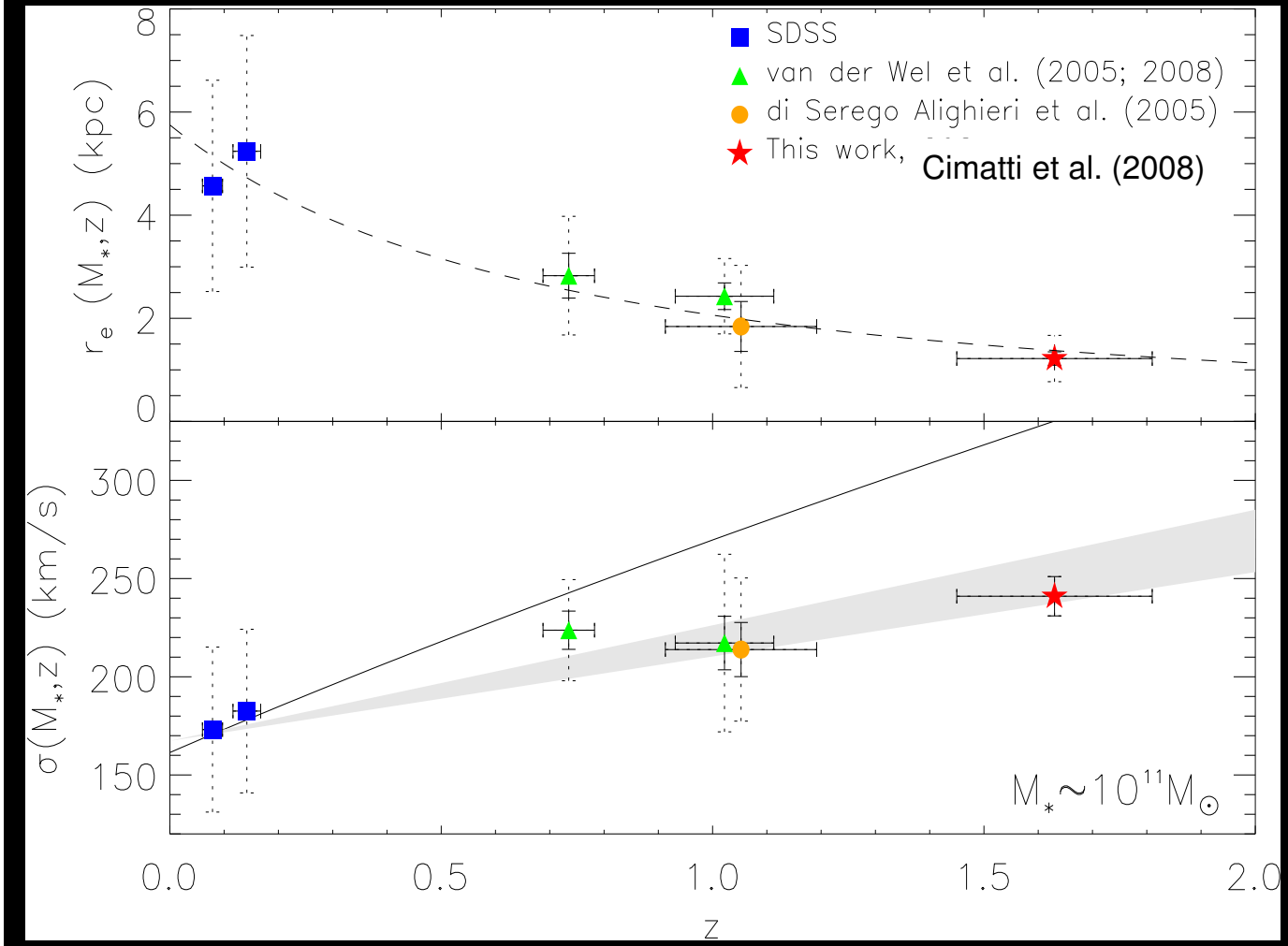
3. Size evolution is size independent



The merger history of massive spheroids since z~1.5 is size-independent

Díaz-García et al. (2013)

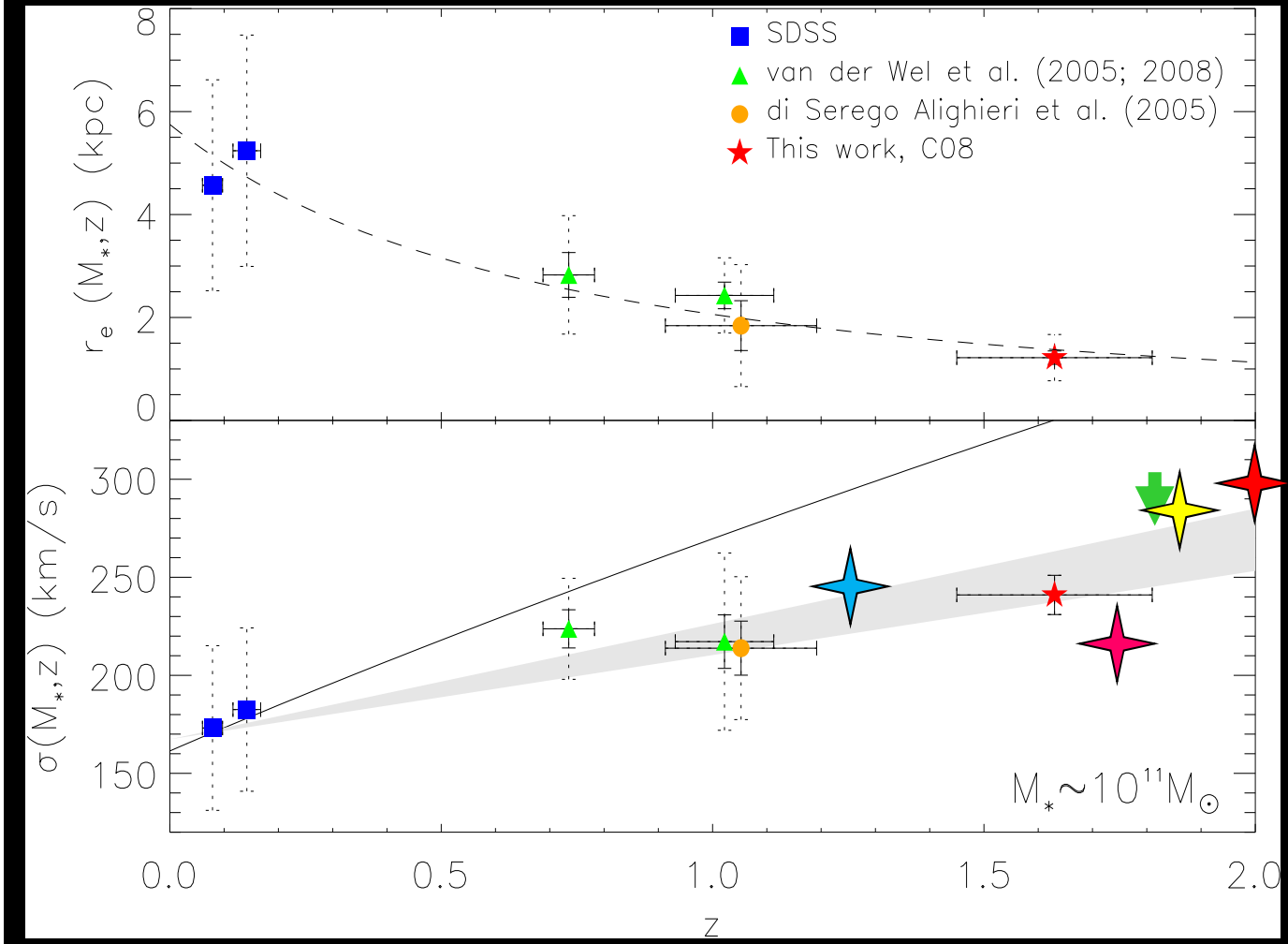
4. Moderate evolution of the velocity dispersion



Mild decrease in the velocity dispersion

Cenarro & Trujillo (2009)

4. Moderate evolution of the velocity dispersion



Mild decrease in the velocity dispersion since z~2

Cenarro & Trujillo (2009); Cappellari et al. (2009); Onodera et al. (2010;2012); van de Sande et al (2011; 2013); Newman et al. (2010), Toft et al. (2012) …

Lessons from the observational constraints

1. Puffing up model is observational disfavor…

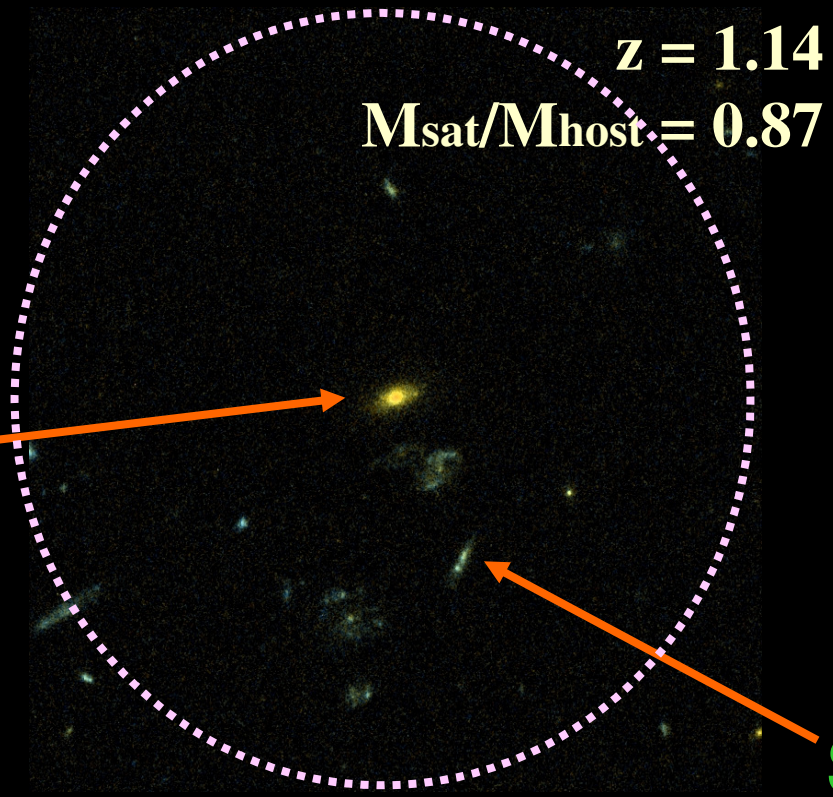
2. Merging model is favored by observations but:

a) Have we got enough number of mergers to produce the size evolution?

b) What is the favorite merger channel of the Nature?

Have we got enough number of mergers to produce the size evolution?

1. Have we got enough number of mergers to produce the size evolution? The role of satellites



Kaviraj et al. (2009)

Jackson et al. (2010)

Nierenberg et al. (2011; 2013)

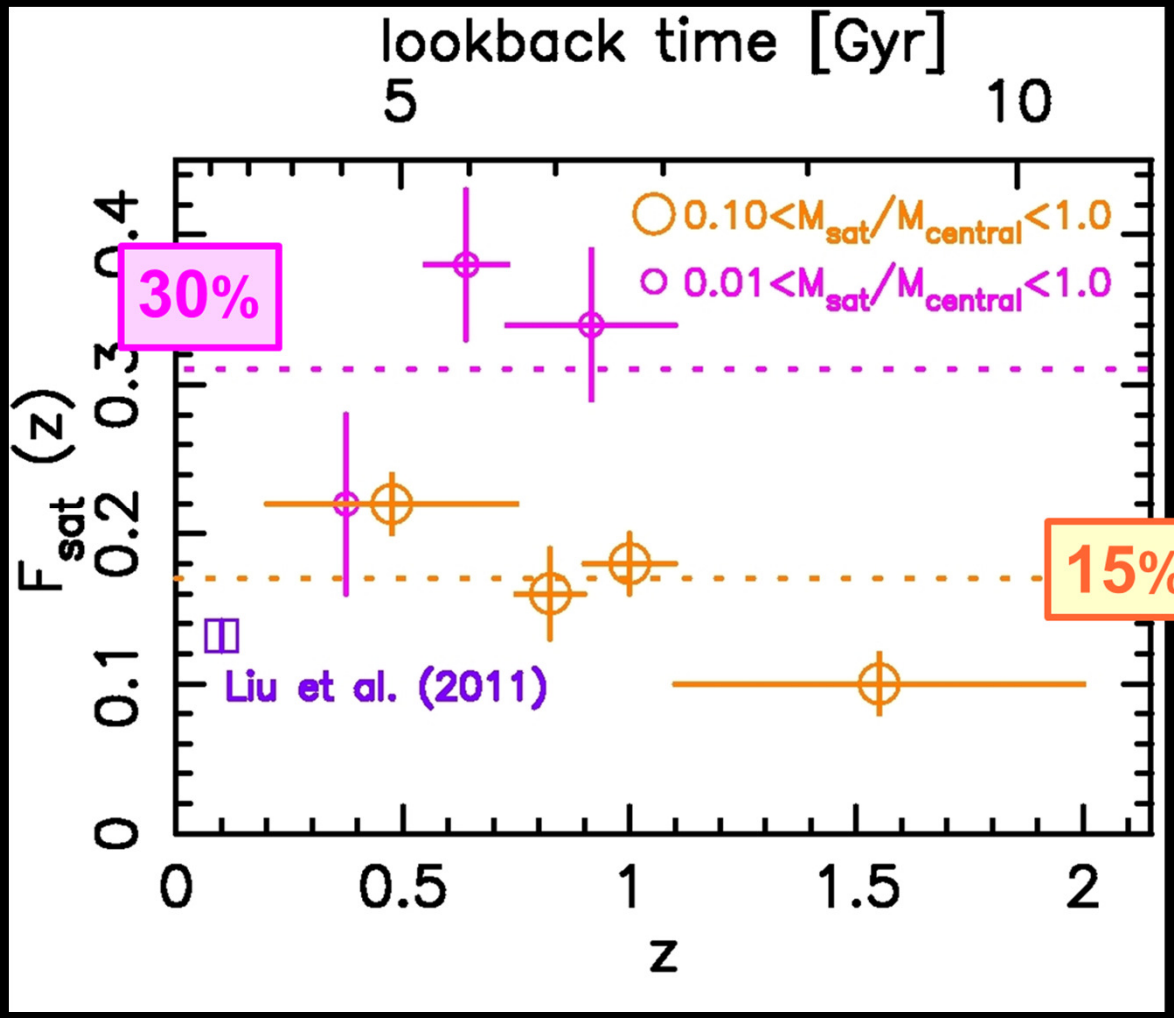
Man et al. (2012)

Newman et al. (2012)

Mármol-Queraltó et al (2012; 2013)

Huertas-Company et al. (2012)

Have we got enough number of mergers to produce the size evolution? The role of satellites



Host galaxies:

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

Search Radius:

100 kpc

Satellite galaxies:

0<z<1

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

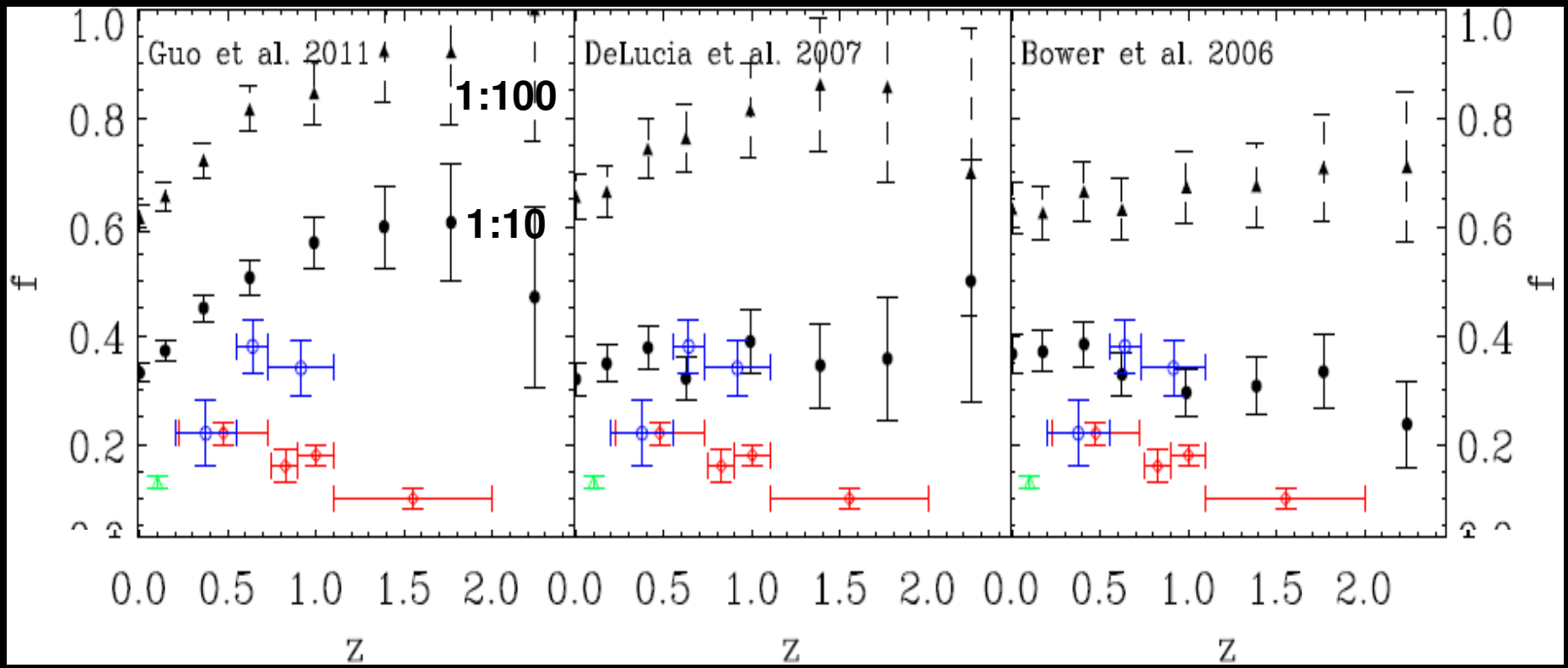
0<z<2

0.1<Msat/Mhost<1

Mármol-Queraltó et al. (2012)

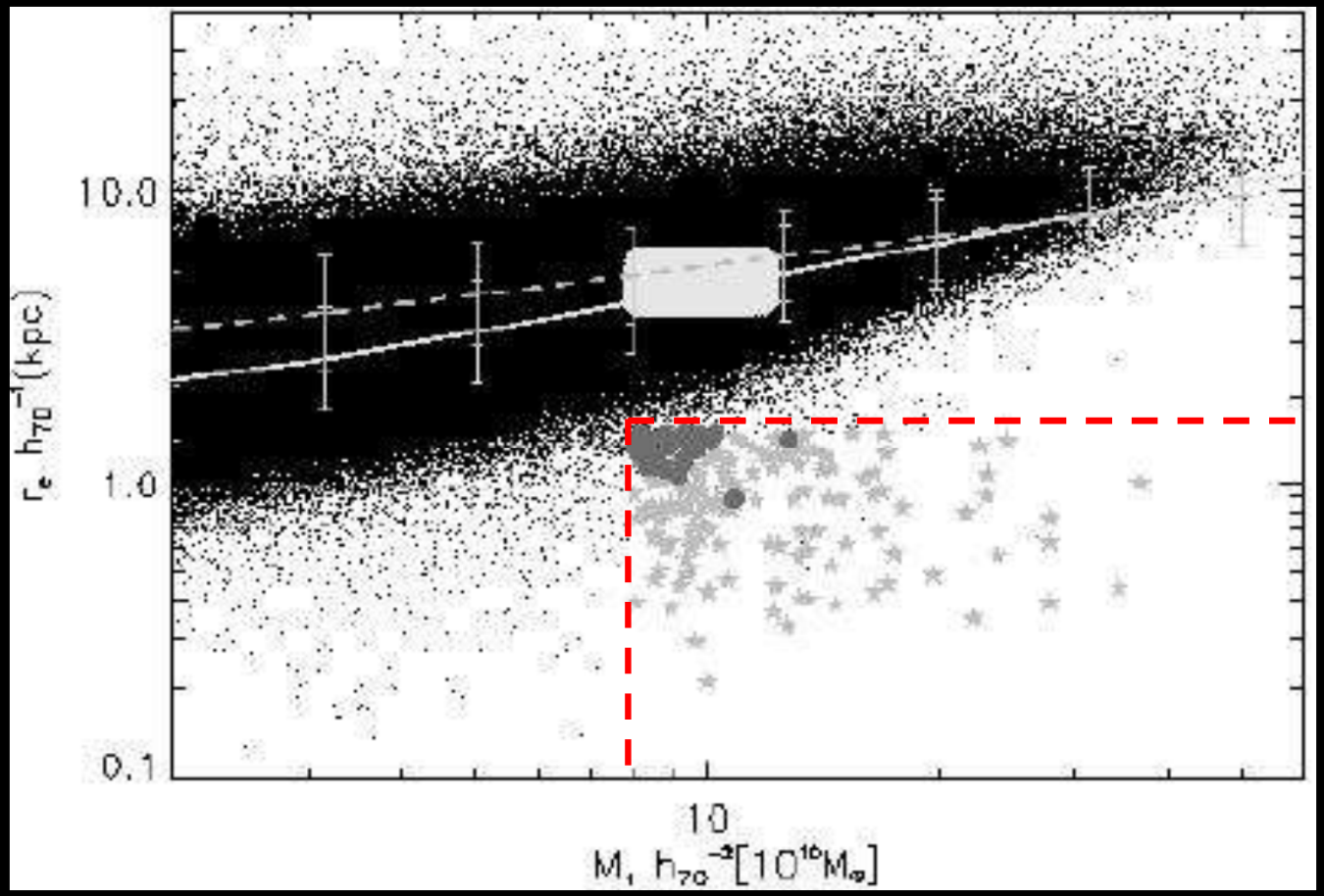
Have we got enough number of mergers to produce the size evolution? The role of satellites

Millennium Simulation vs Observations



Quilis & Trujillo (2012)

Have we got enough number of mergers to produce the size evolution? The number of present-day massive relics



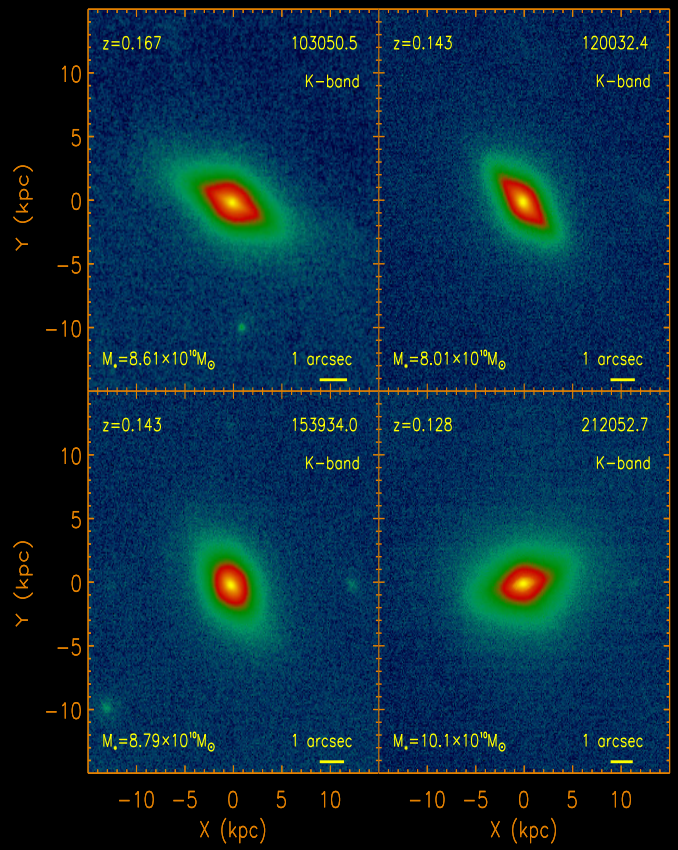
Merging is a ***stochastic*** process

Some massive ***relics*** are expected to survive untouched

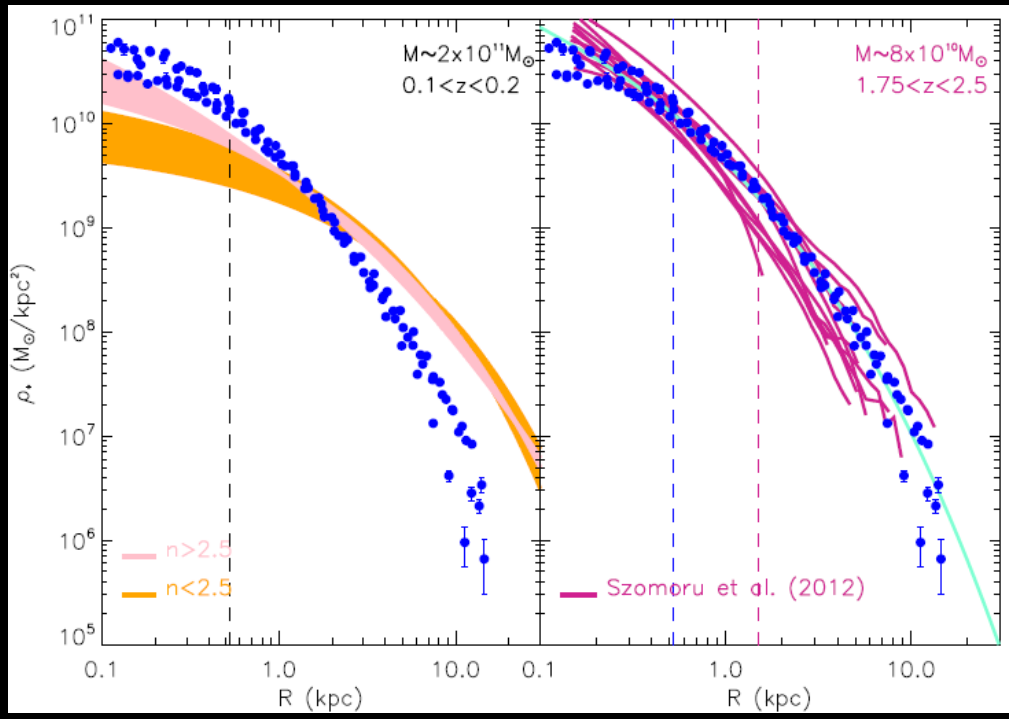
<0.03% of today massive galaxies are compact

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

Have we got enough number of mergers to produce the size evolution? The number of present-day massive relics

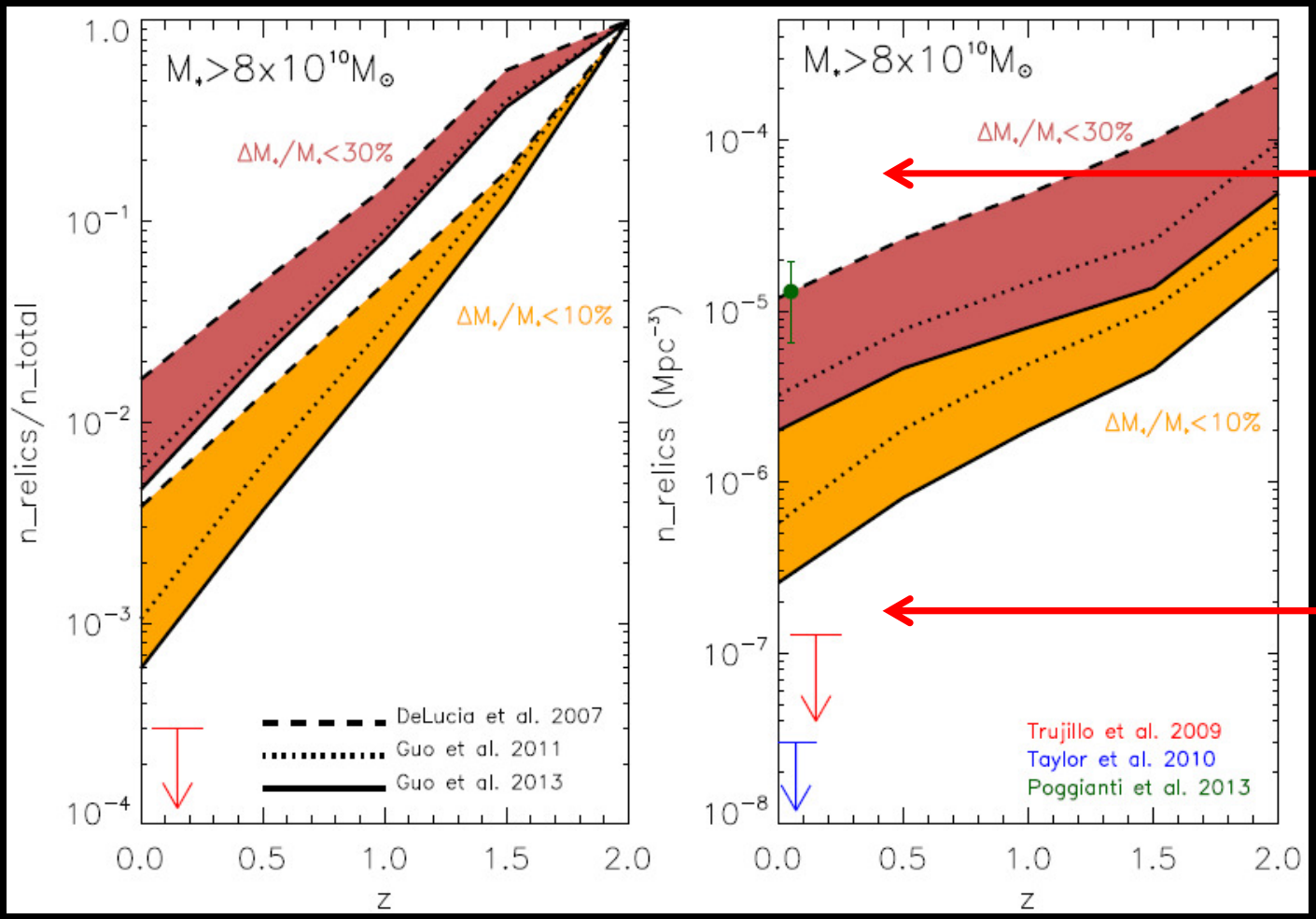


-K-band imaging at 0.15 arcsec resolution with Gemini AO



Trujillo et al. (2012); Shih & Stockton (2011)

Have we got enough number of mergers to produce the size evolution? The number of present-day massive relics



- Infra-merging region

- Over-merging region

- Galaxy growth can not be entirely explain with merging

Quilis & Trujillo (2013)

Have we got enough number of mergers to produce the size evolution?

1. The number of satellites around massive galaxies remains constant since z~2

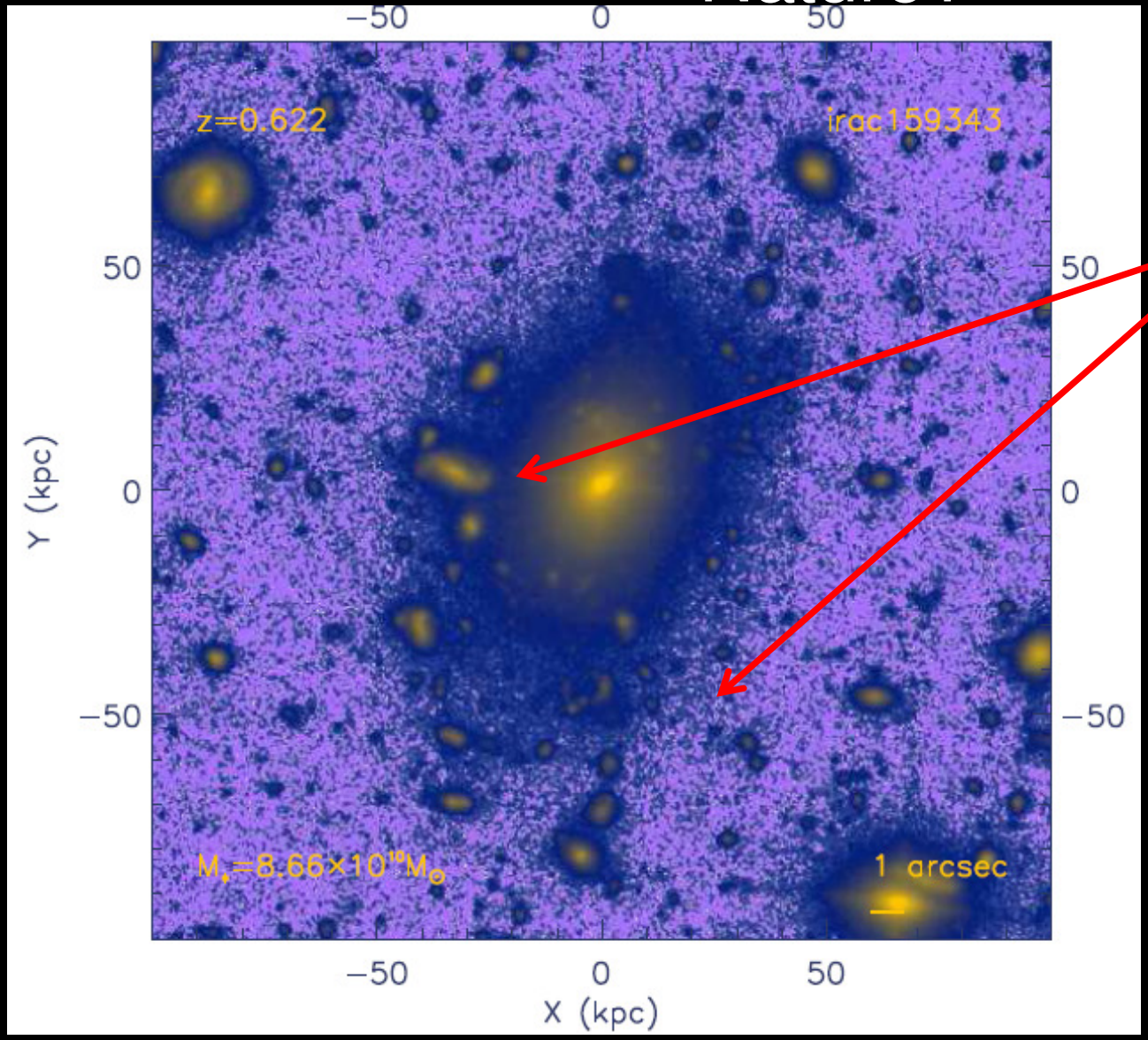
2. Semianalytical ΛCDM models overpredict the number of satellites by a factor of ~2

3. The number of present-day massive relics is pretty uncertain to draw a robust conclusion

4. Semianalytical ΛCDM model predictions fall right in the middle of the observational constraints

What is the favorite merger channel of the Nature?

What is the favorite merger channel of the Nature?

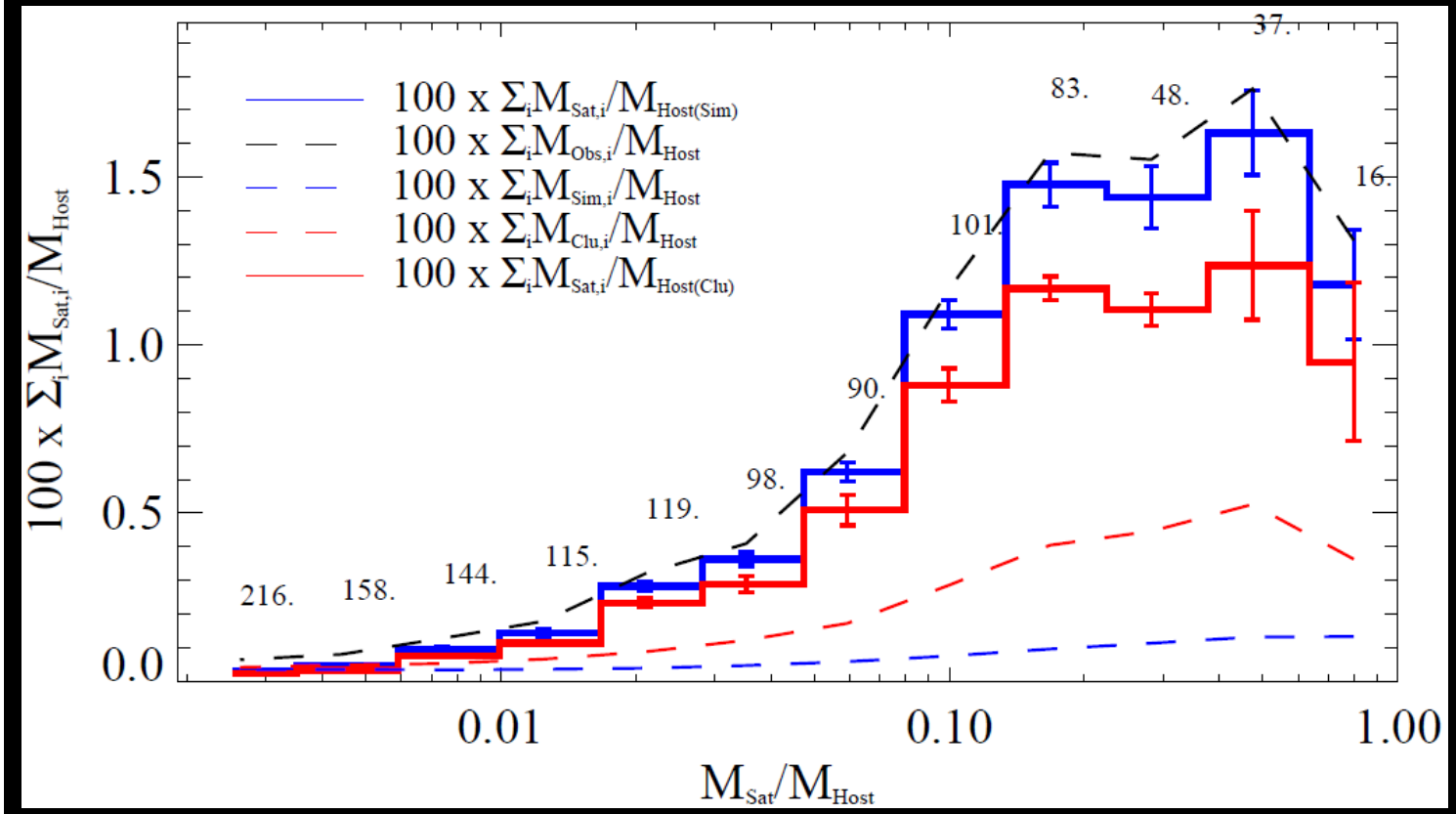


What is the expected mass growth from satellite infall?

Theory favours the 1:5-1:10 merger channel

(Oser et al. 2012; Bédorf & Portegies Zwart 2013)

What is the favorite merger channel of the Nature?

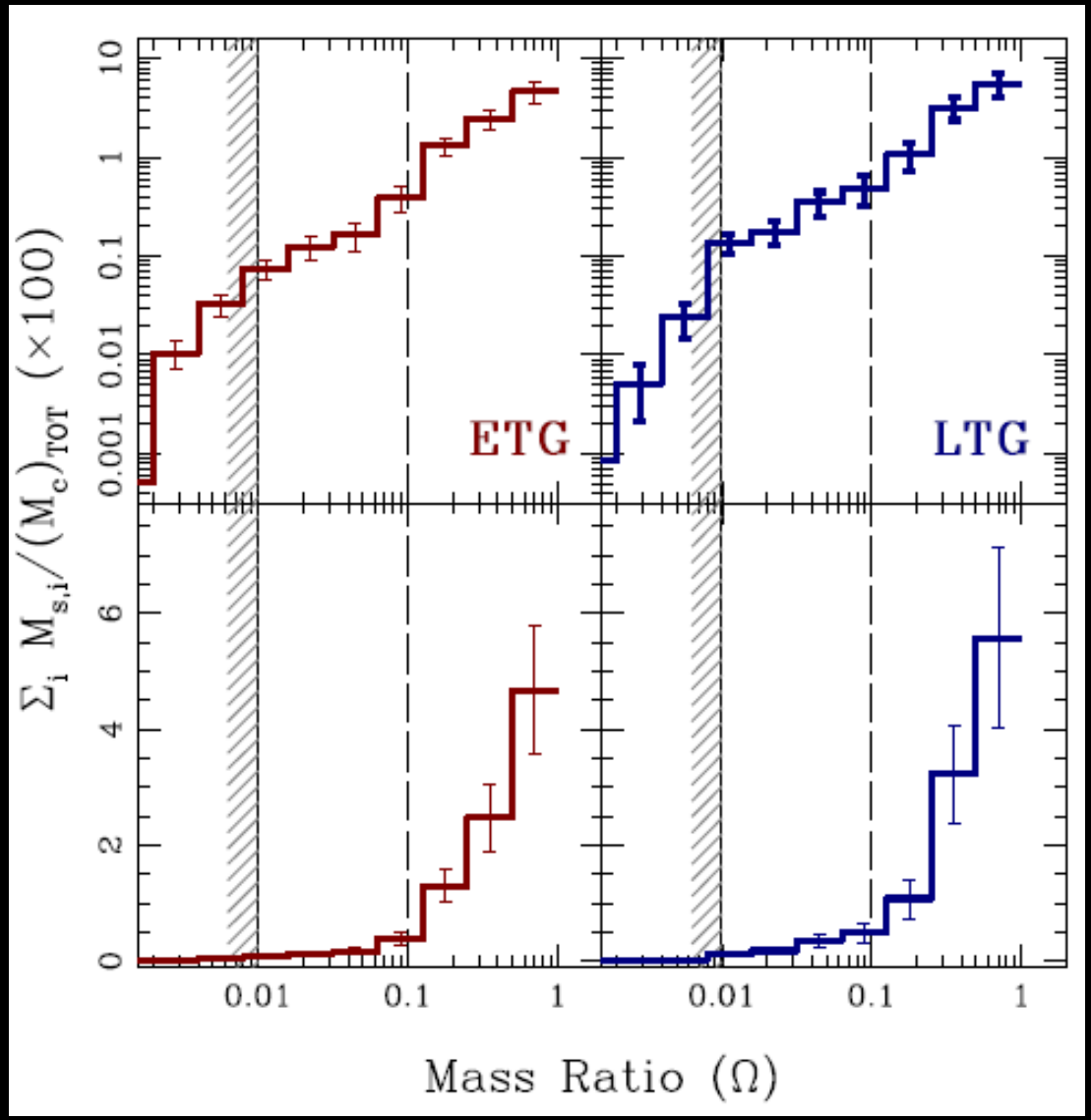


Larger contributor to the mass increase in z=0 massive ellipticals is a satellite with ~1:3

Ruiz et al. (2013)

What is the favorite merger channel of the Nature?

Ferreras et al. (2013; in preparation)



WORK IN PROGRESS!!!

Larger contributor to the mass increase in z=1 massive ellipticals is a satellite with ~1:1

What is the favorite merger channel of the Nature?

1. ***Major mergers alone*** can not drive the size evolution.

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)

2. ***Minor merging alone*** looks also insufficient; We fully discard a significant contribution of 1:10-1:100 merging…

3. ***A combination of major and minor*** merger could work!

(Bluck et al. 2012; Lopez-Sanjuan et al. 2012; Huertas-Company et al. 2013; Ruiz et al. 2013; Ferreras et al. 2013)

A better quantification is still required!

Pending questions: closing the loop

1. Age and metallicity gradients in nearby massive ellipticals: the nature of the envelopes

Coccato et al 2010; Tal et al. 2011; Greene et al. 2012; La Barbera et al. 2012; Montes et al. 2013…

2. Stellar properties of the infalling satellites at high-z

Mármol-Queraltó et al. 2013; Nierenberg et al. 2013; Ferreras et al. 2013…

Summary

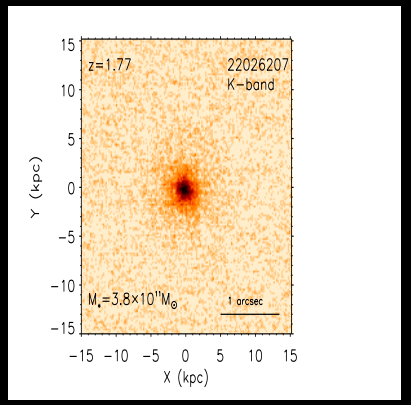
Massive galaxies at z~2-3 were:

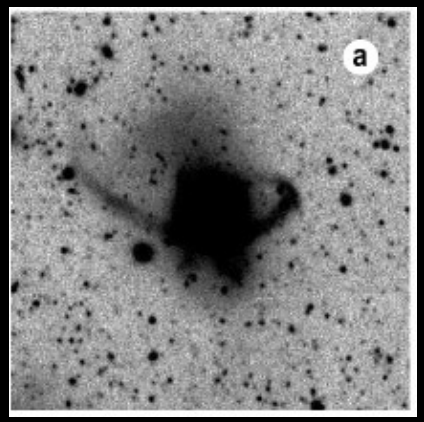
1. 10 times less abundant than today
2. Significantly more compact

Most likely growth mechanism:

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

Global picture seems clear BUT still many unclear aspects! More fun is ahead of us…





Cosmic Time