# Origin and fate of the most massive galaxies

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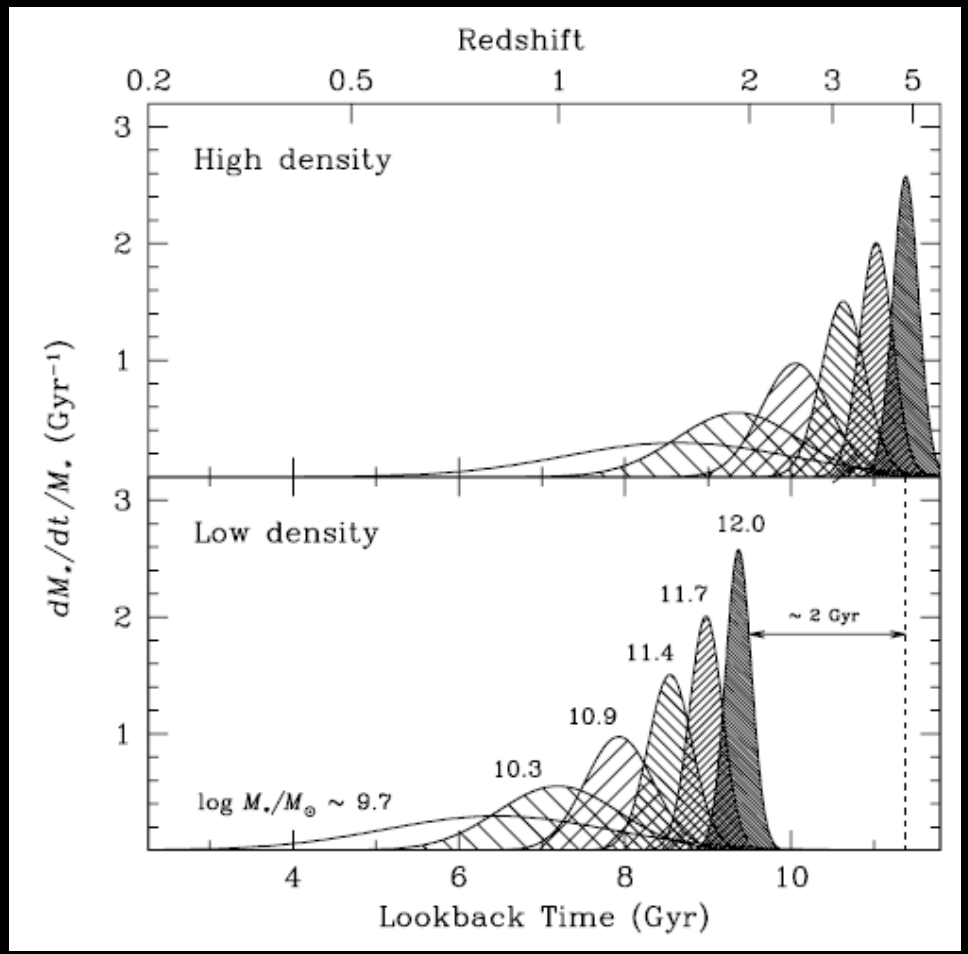
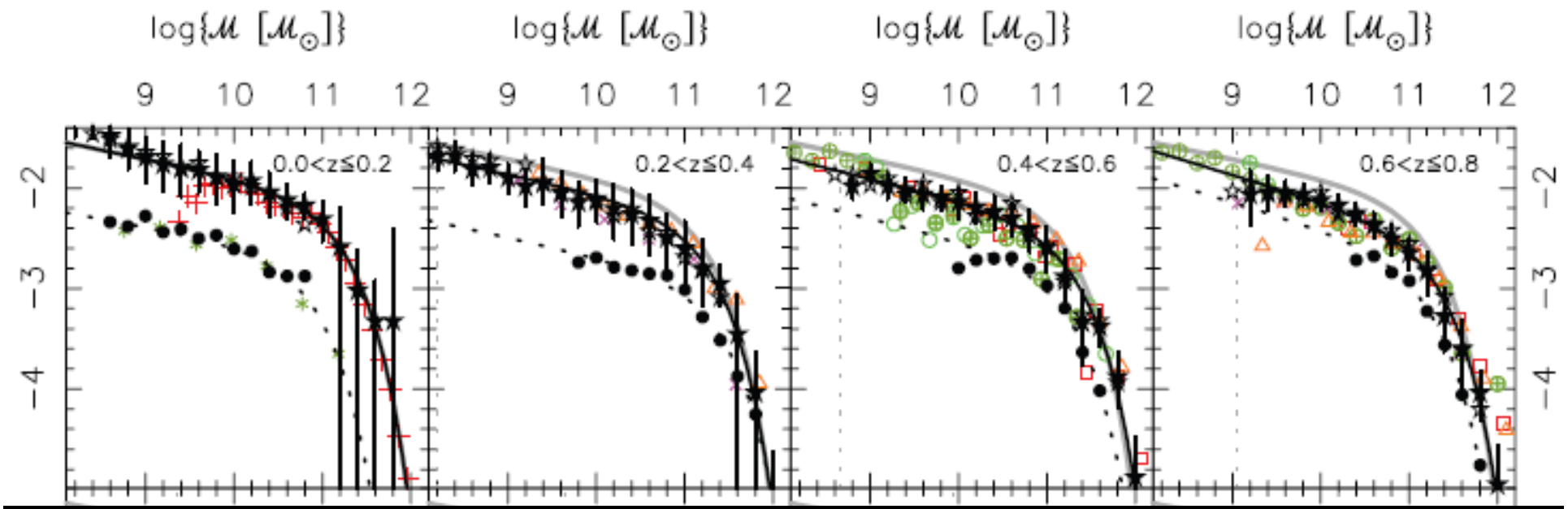
# Massive galaxies today

$M_* \geq 10^{11}$Msun galaxies:

- Morphological Type: 75% early-type
- Stellar populations: old, metal rich, short formation time scale
- Sizes: big objects $r_e$~5 kpc



# Mild stellar mass function evolution for the most massive galaxies since z~0.8




Pérez-González, Rieke et al. (2008)

# Just a passive evolution of the most massive galaxies?

The evidence both from:

-Stellar population analysis in the present Universe

-Number density evolution of massive galaxies

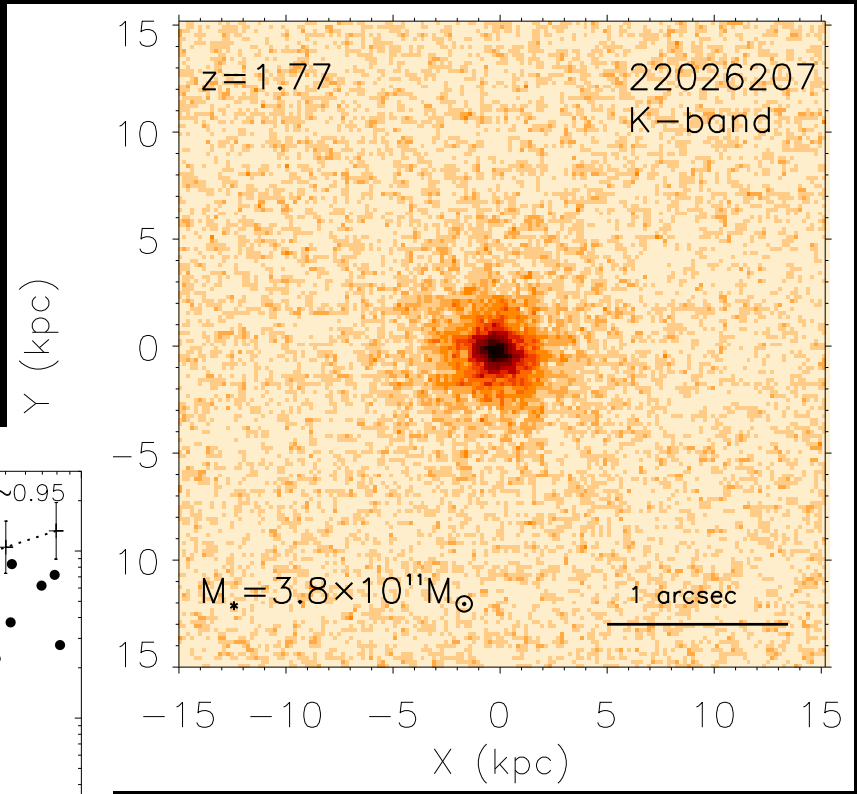
Suggest a monolithic-like formation and passive evolution scenario…

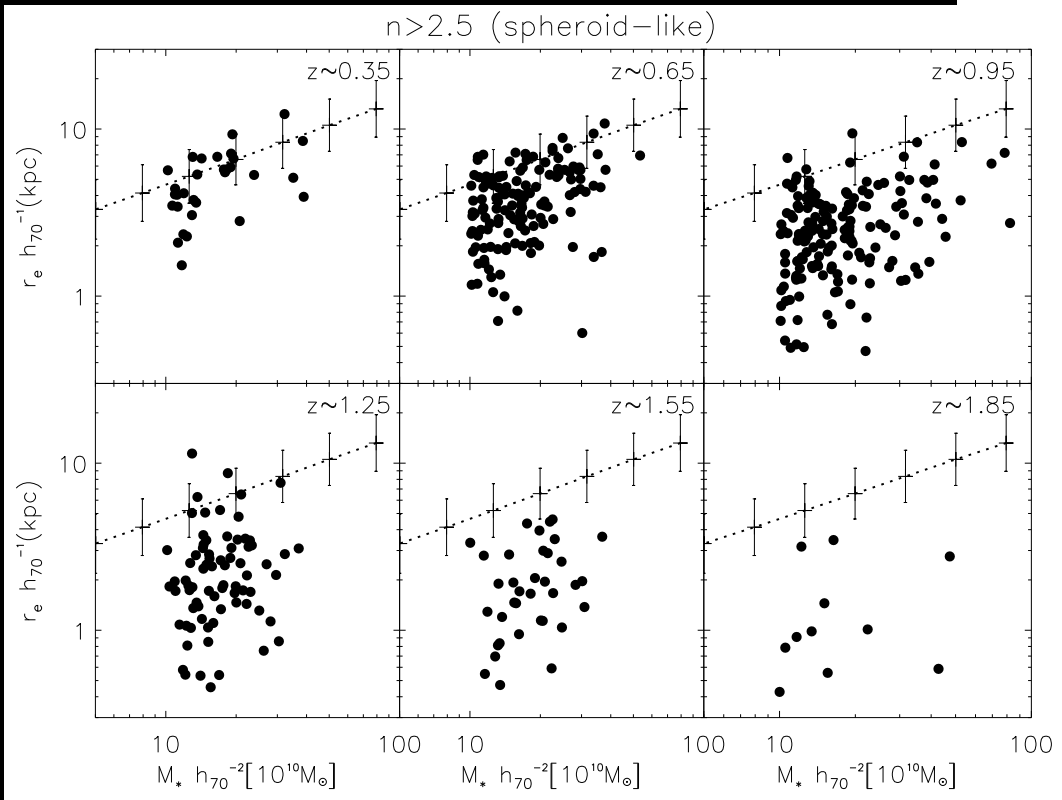
However…

# Massive galaxies at z~1.8

$M_* \geq 10^{11}$Msun galaxies:

- Morphological Type: mixed
- Stellar populations: ~1 Gyr, metal rich?, short formation time scale?
- Sizes: compact objects $r_e$~1.5 kpc




Carrasco, Conselice & Trujillo (2010)

Trujillo et al. (2007)

# Massive galaxies at z~1.8

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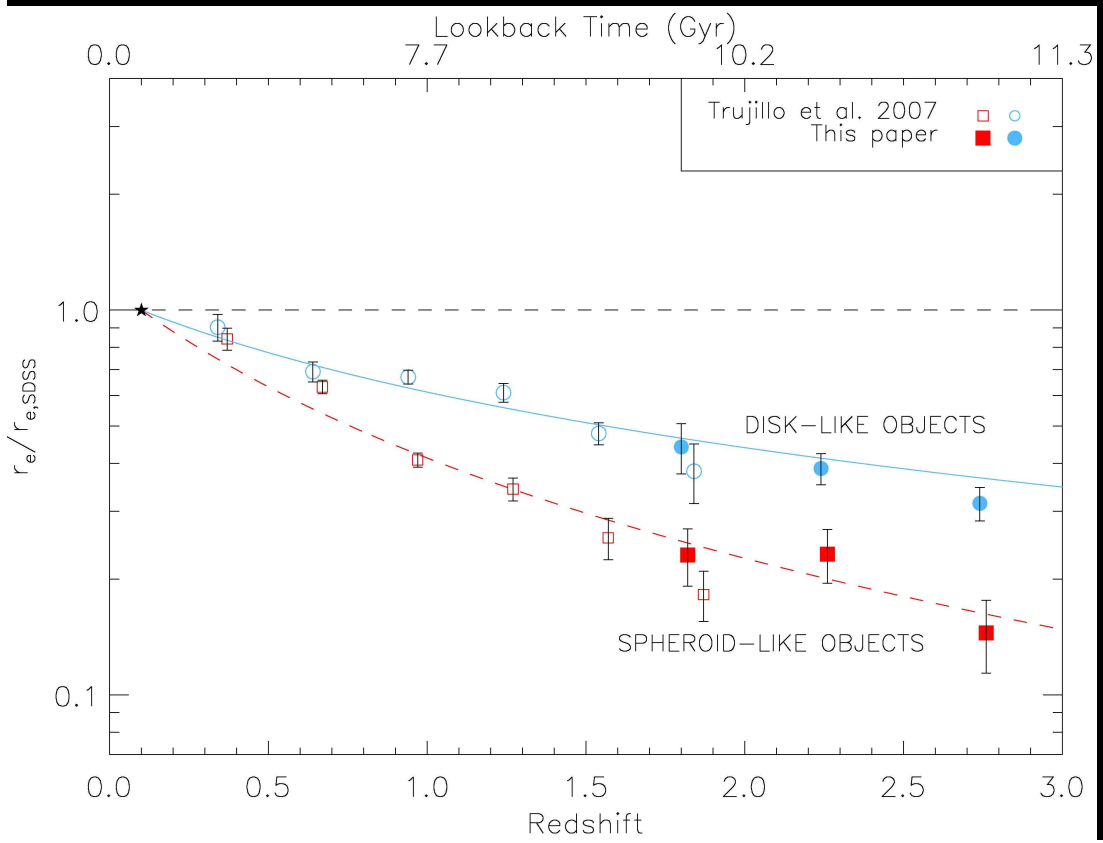



Stellar density at z~2: ~$2 \times 10^{10}$ Msun/kpc$^3$ (Buitrago, Trujillo et al. 2008)

# Models for spheroid size evolution

# Models for spheroid size evolution

Among others (see e.g. Hopkins et al. 2009):

a) There is not size evolution: it is an observational artifact.

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

c) Major dry mergers: spheroid-spheroid re-mergers

d) Minor/Late accretion: more and more minor mergers with low-effective density (e.g. Naab et al. 2009)

How robust is the size evolution result?

# How robust is the size evolution result?

The two possible sources of uncertainty are the size and the stellar mass estimates.

Size estimates:

1. *Repeatability*:

-Daddi et al. (2005); HST ACS (Hubble Ultra Deep Field)

-Trujillo et al. (2006); Ground-based NIR

-Trujillo et al. (2007); HST ACS and NICMOS

-Cimatti et al. (2008); HST ACS

-Zirm et al. (2007); Toft et al. (2007); Longhetti et al. (2007); Damjanov et al. (2008); van Dokkum et al. (2008); Buitrago et al. (2008)… HST NICMOS

-Cassata et al. (2009); WFC3 (Hubble Ultra Deep Field)

-Carrasco, Conselice & Trujillo (2010); K-band Gemini AO imaging

# How robust is the size evolution result?

The two possible sources of uncertainty are the size and the stellar mass estimates.

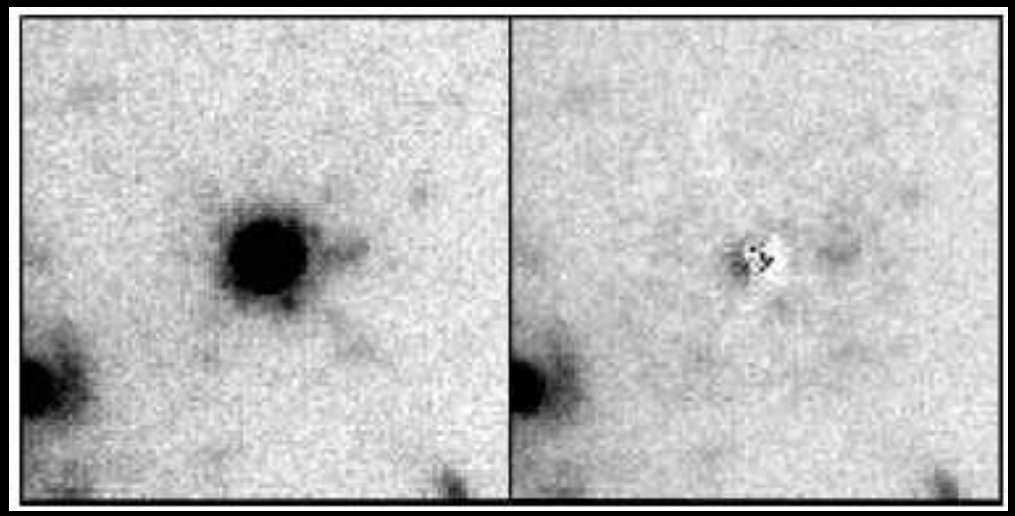
Size estimates:

2. *No evidence for large-scale diffuse halo (after stacking)*:

-Zirm et al. (2007); HST NICMOS 14 objects (~26 mag/arcsec$^2$)

-van Dokkum et al. (2008); HST NICMOS 9 objects (~27 mag/arcsec$^2$)

-Cassata et al. (2009); HST WFPC3 (~26.3 mag/arcsec$^2$ per object)

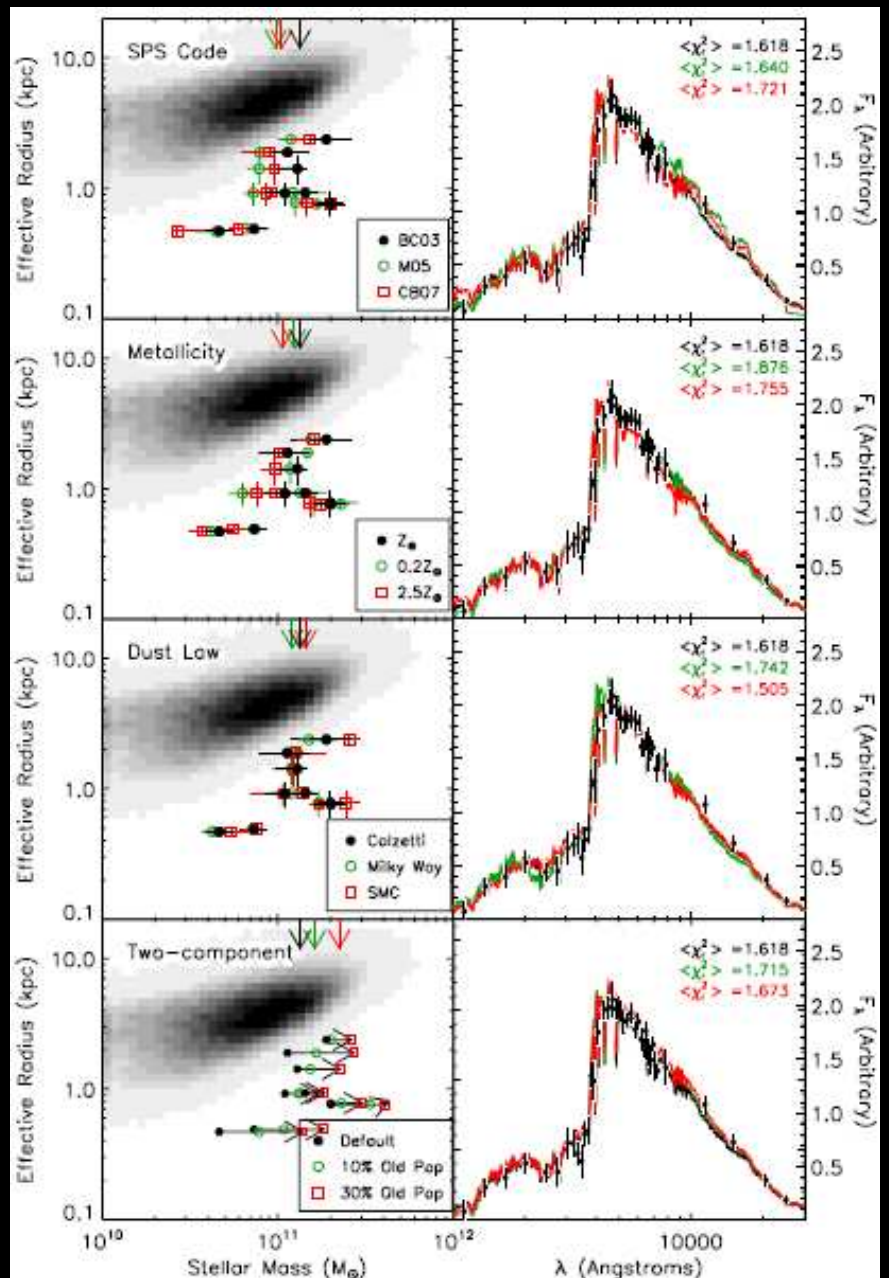


# How robust is the size evolution result?

The two possible sources of uncertainty are the size and the stellar mass estimates.

Stellar mass estimates:

3. *Robust to changes in metallicities, dust laws, different stellar population codes (Muzzin et al. 2009)*



# How robust is the size evolution result?

The two possible sources of uncertainty are the size and the stellar mass estimates.

4. Dynamical mass estimates:

-The first velocity dispersion estimate (Cenarro & Trujillo 2009) found ~240 km/s

-Later estimates has found similar values (Cappellari et al. 2009; Onodera et al. 2010) or extreme (~500 km/s; van Dokkum et al. 2009)

# How robust is the size evolution result?

The observational bias hypothesis seems to be rejected by the best quality (and very deep) data presently available.

# Massive galaxies: velocity dispersion evolution

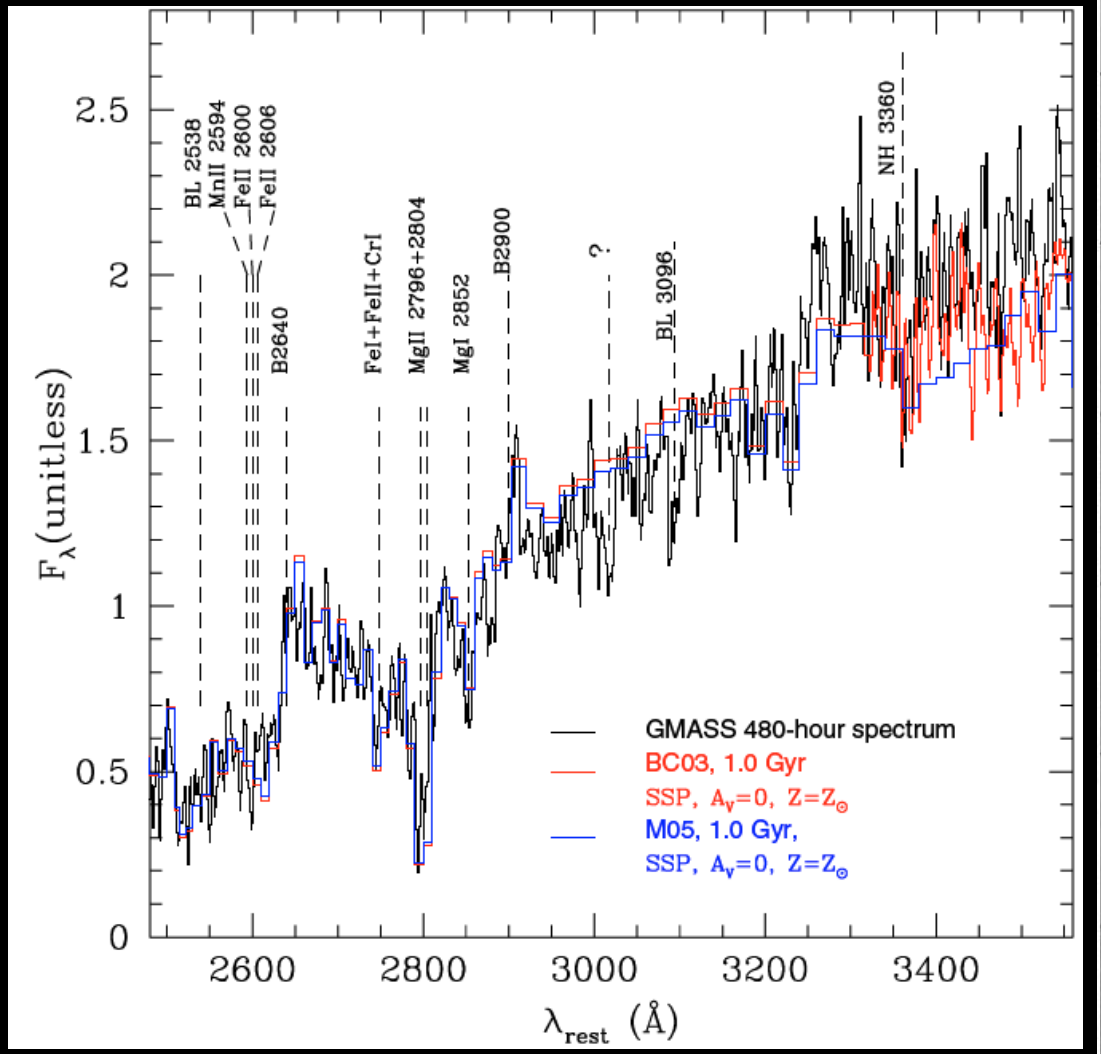
# Observational constraints: velocity dispersion evolution

$$\sigma \propto \sqrt{\frac{GM}{r_e}}$$

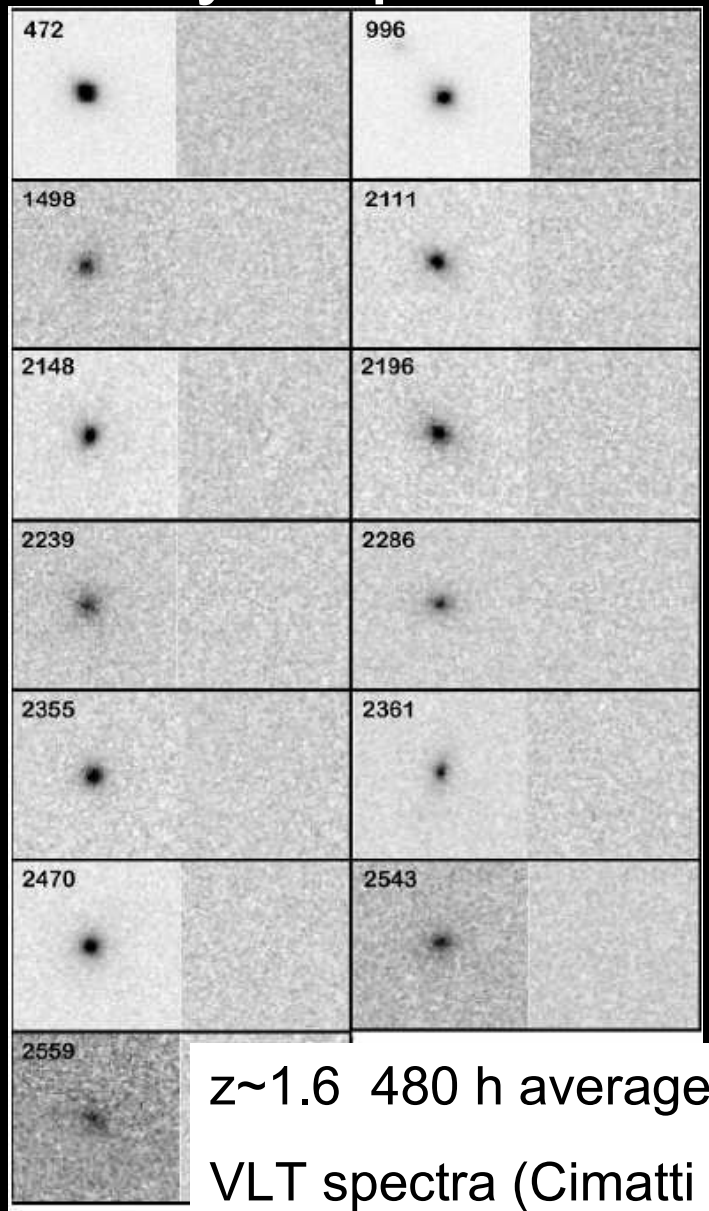
Naïve expectations at a fixed stellar mass:

- $r_e(z=0) = 4\ r_e(z=2) \Rightarrow \sigma(z=2) = 2\ \sigma(z=0)$

# Observational constraints: velocity dispersion evolution



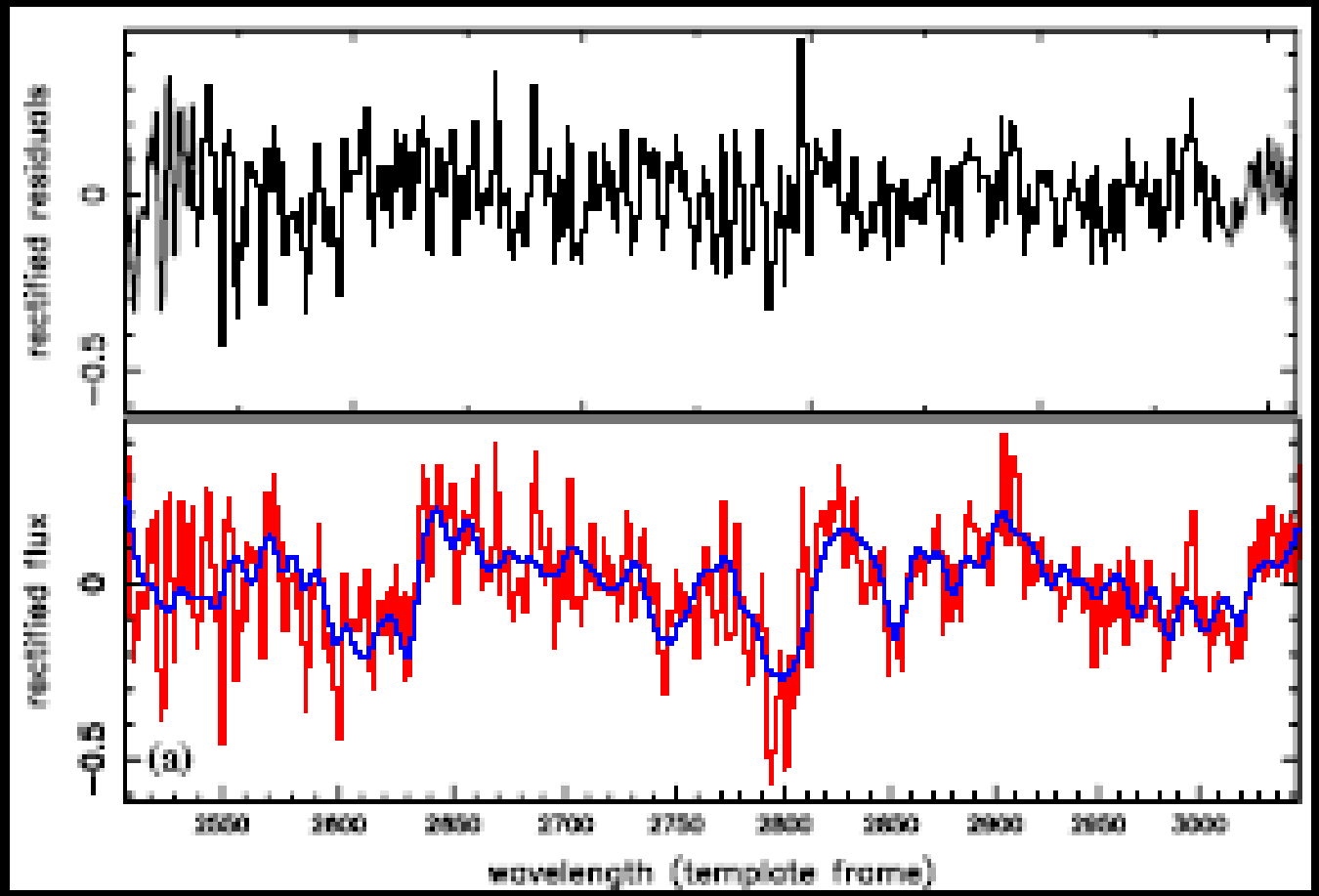

Cenarro & Trujillo (2009)




z~1.6 480 h averaged

VLT spectra (Cimatti et al. 2008)

# Observational constraints: velocity dispersion evolution




Cenarro & Trujillo (2009)

Template:

CoolCAT stars

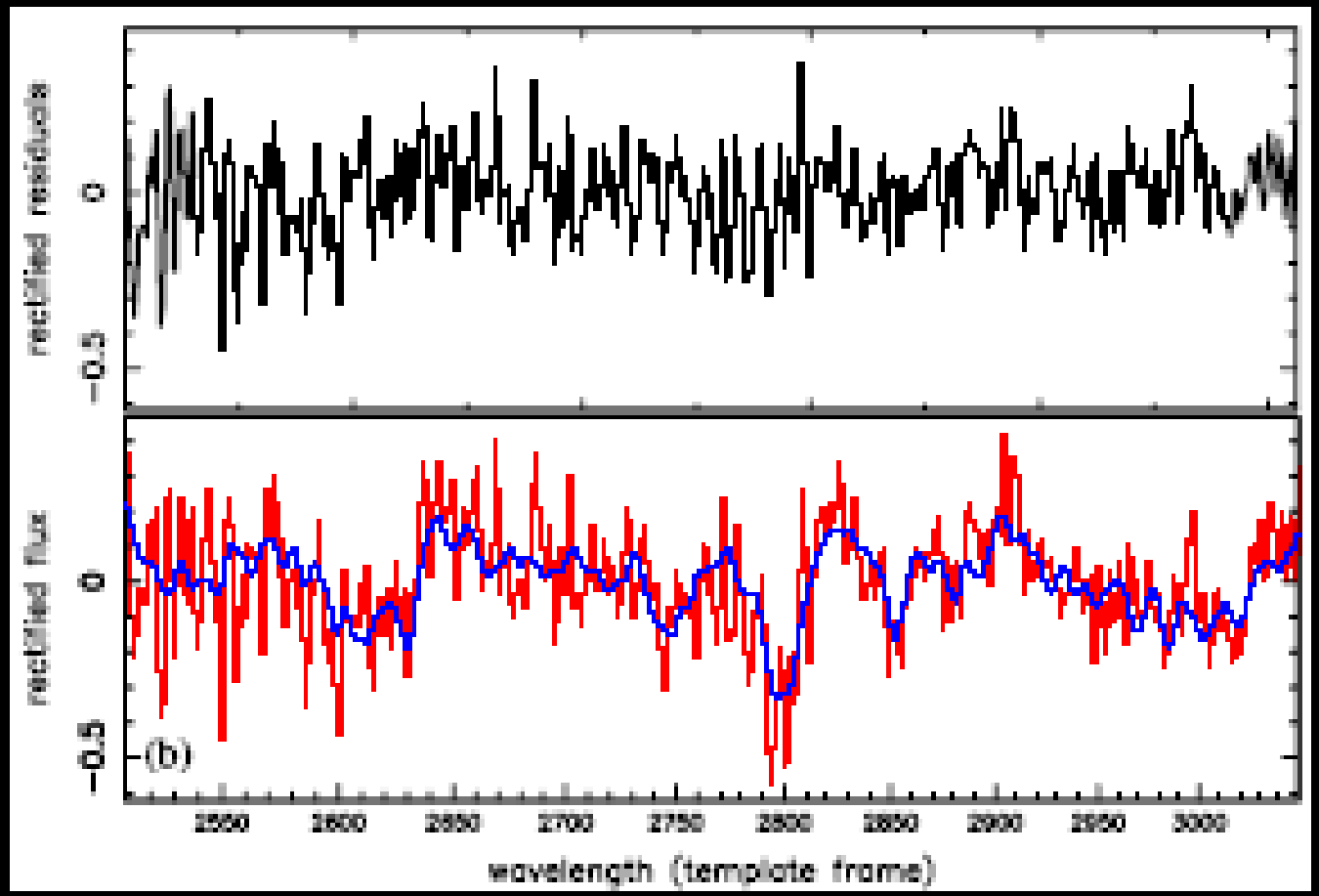
Spectral Range:

2510-3050 Å

$\sigma_*$(km/s):

258±21

# Observational constraints: velocity dispersion evolution




Cenarro & Trujillo (2009)

Template:

BC03+NGSL SSP models

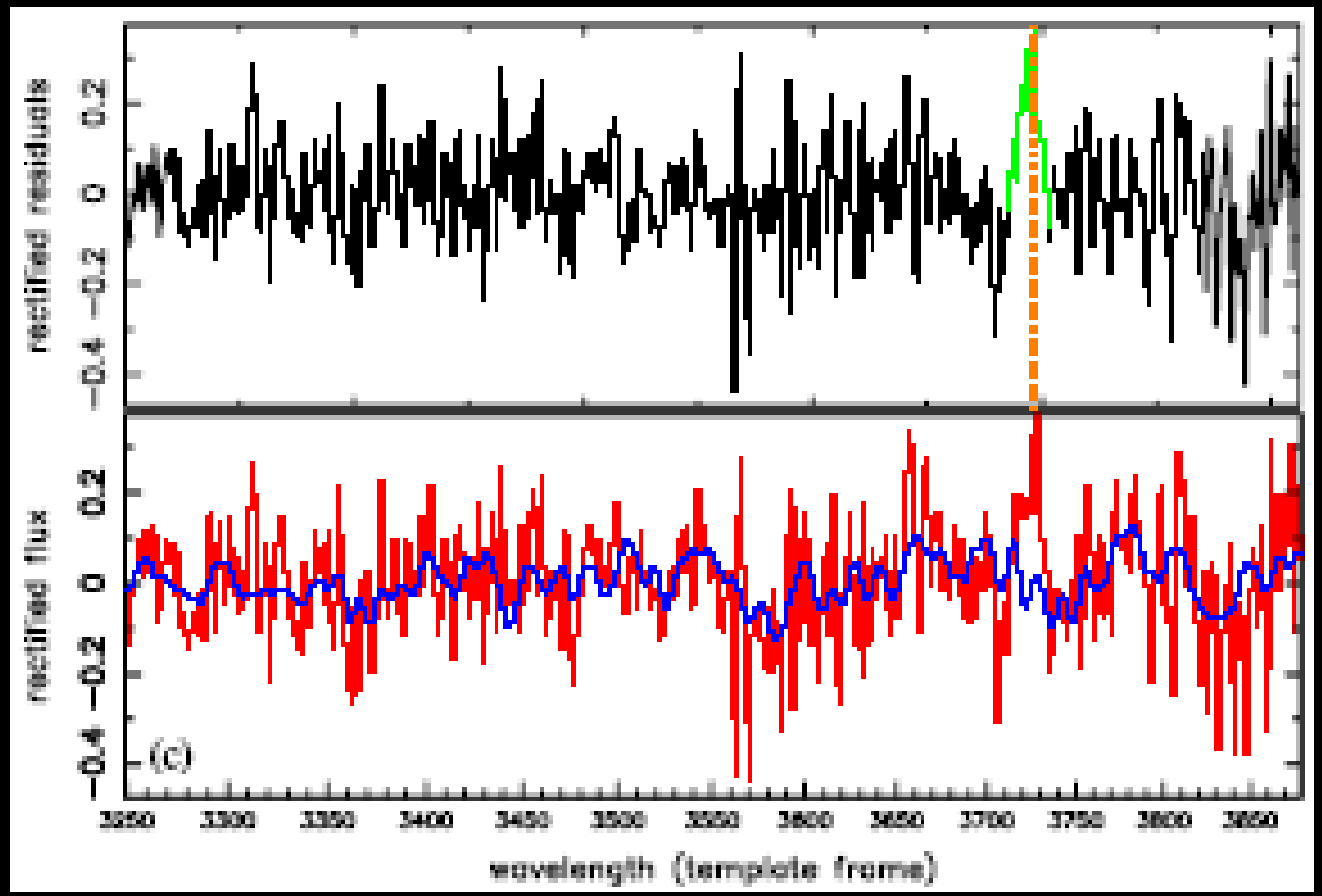
Spectral Range:

2510-3050 Å

$\sigma_*$(km/s):

236±18

# Observational constraints: velocity dispersion evolution




Cenarro & Trujillo (2009)

Template:

Keck/LRIS stars

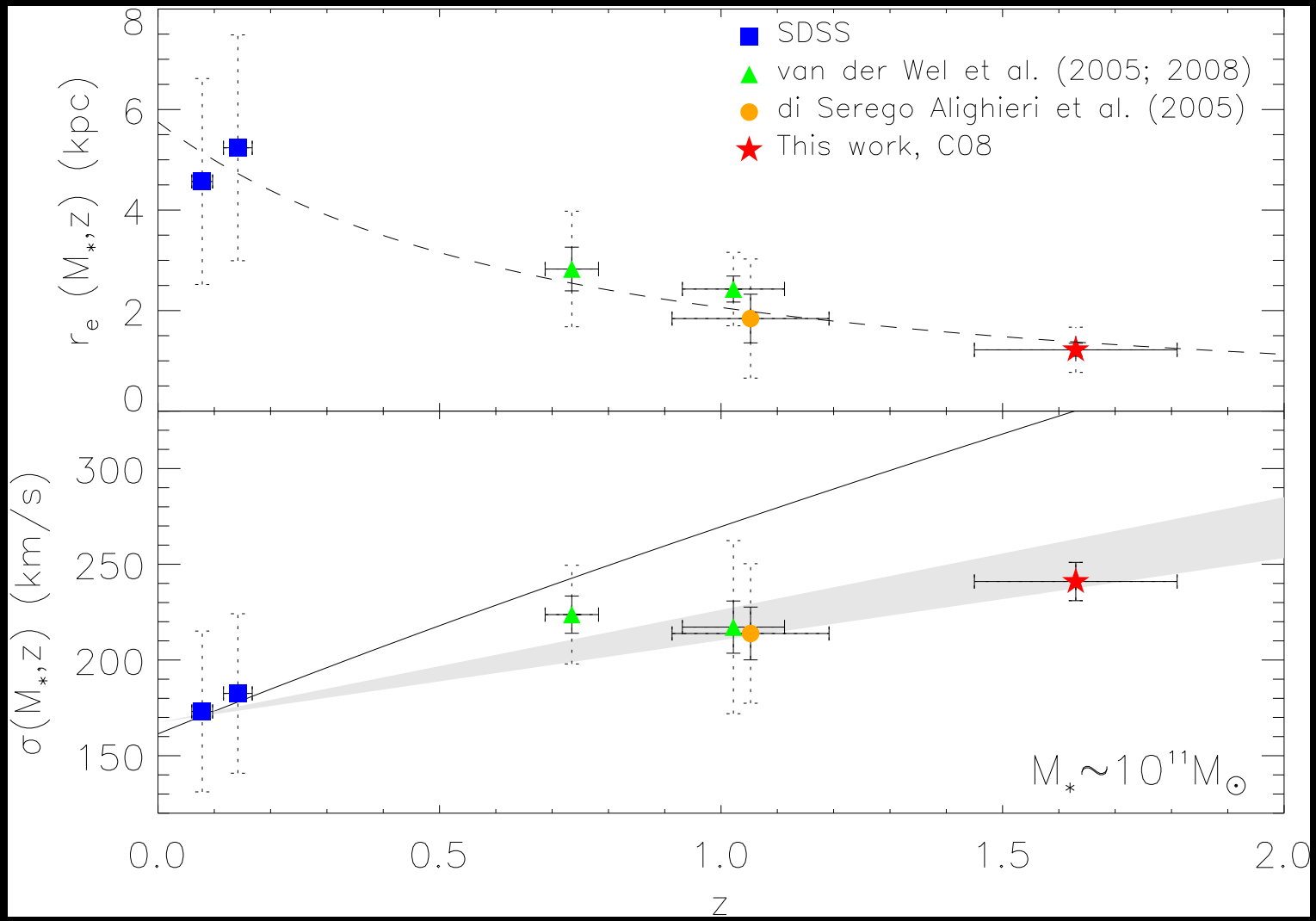
Spectral Range:

3250-3880 Å

$\sigma_*$(km/s):

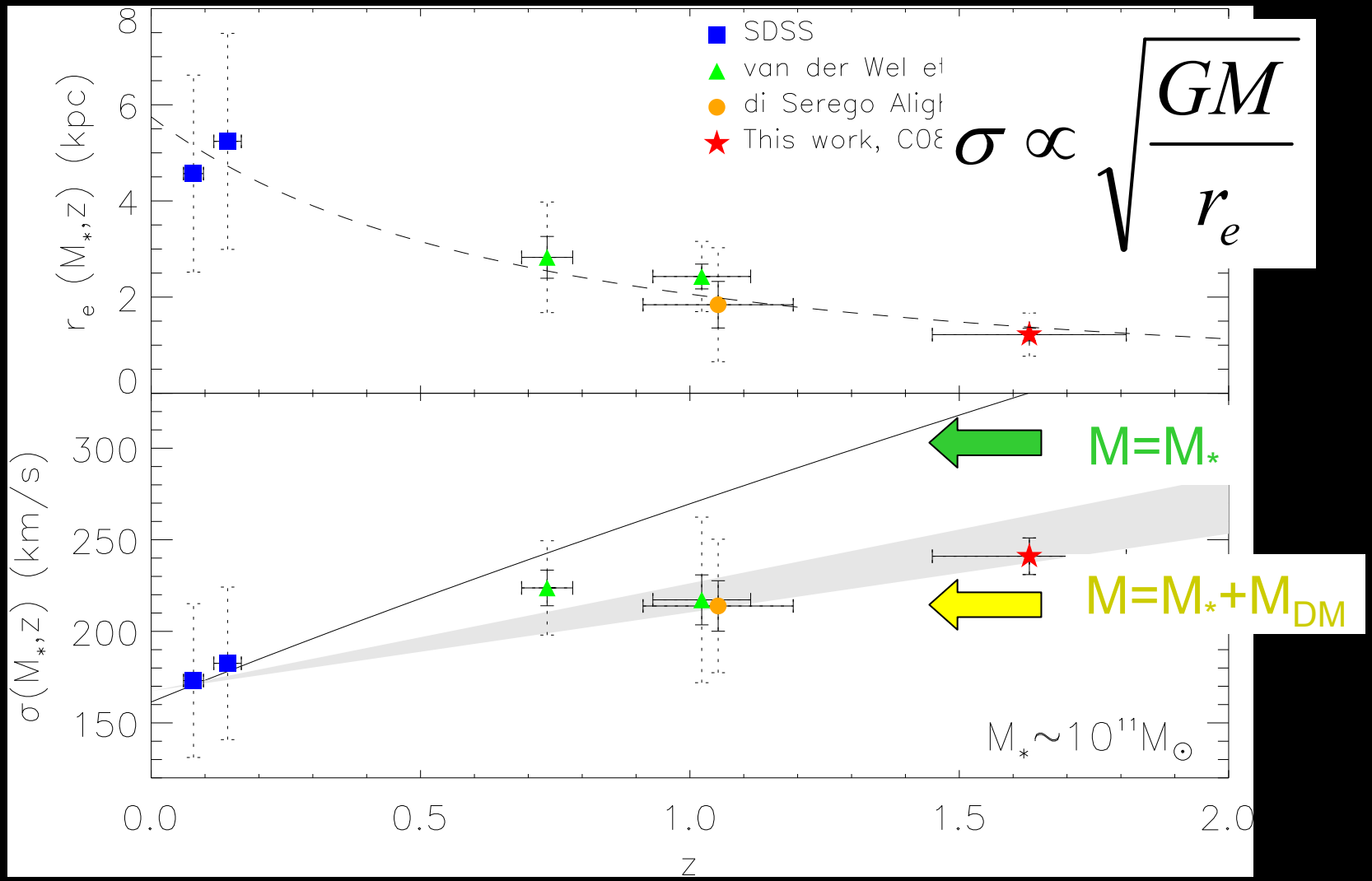
236±15

# Observational constraints: velocity dispersion evolution




Cenarro & Trujillo (2009)

# Observational constraints: velocity dispersion evolution




Cenarro & Trujillo (2009)

# Observational constraints: velocity dispersion evolution

Cenarro & Trujillo (2009):

1. Mild evolution of the velocity dispersion: at a fixed stellar mass only 1.3 larger at z~1.6

a) Compact massive galaxies are *really* massive

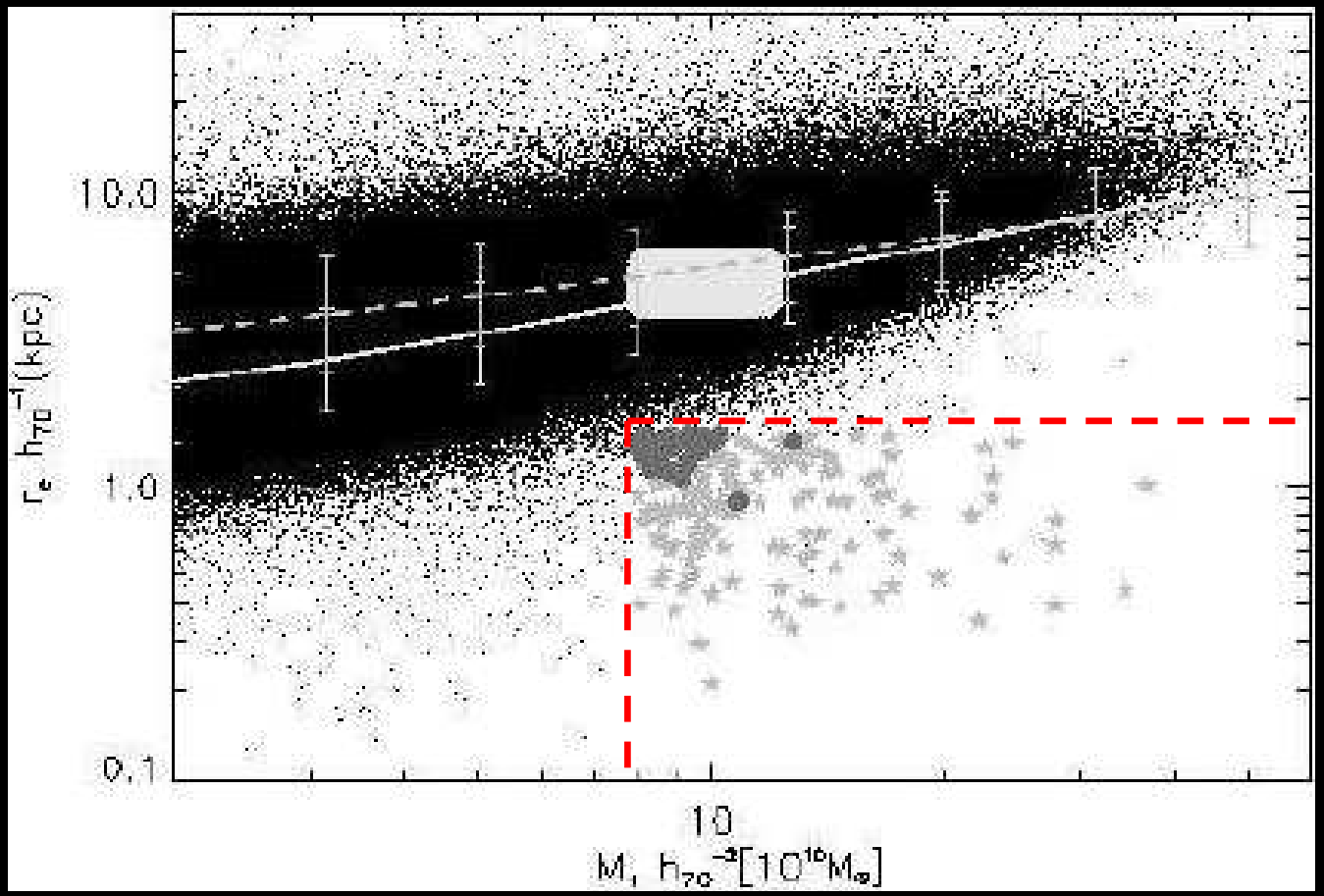
b) IMF evolution do not change dramatically

c) Progressive evolution of the dark matter in settling the velocity dispersion

d) Puffing-up model predicts a strong velocity dispersion evolution at a fixed stellar mass that is not observed

Is there any compact massive galaxies at z~0?

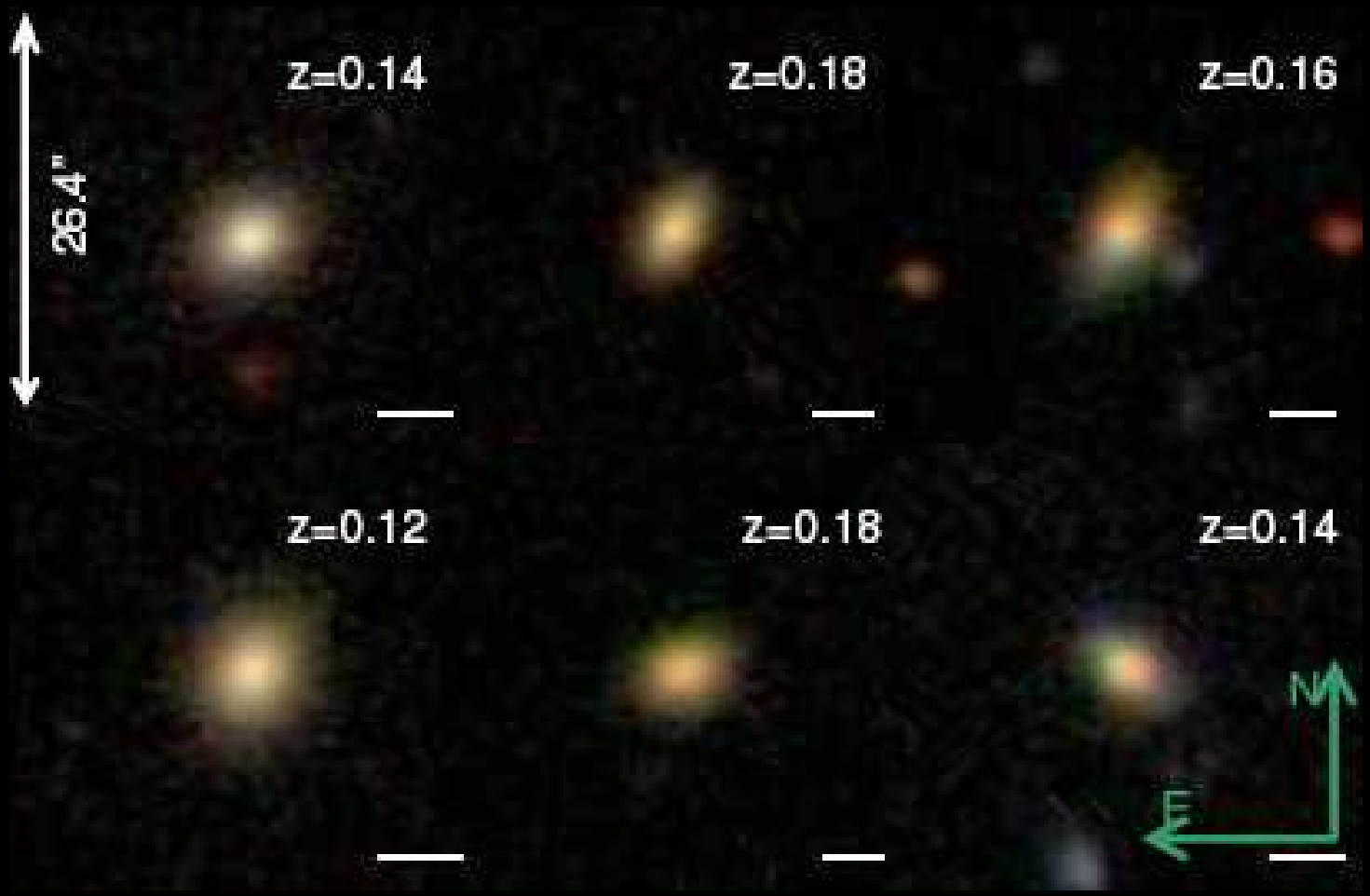
# Observational constraints: is there any compact massive galaxies at z~0?




<0.03% of today massive galaxies are compact

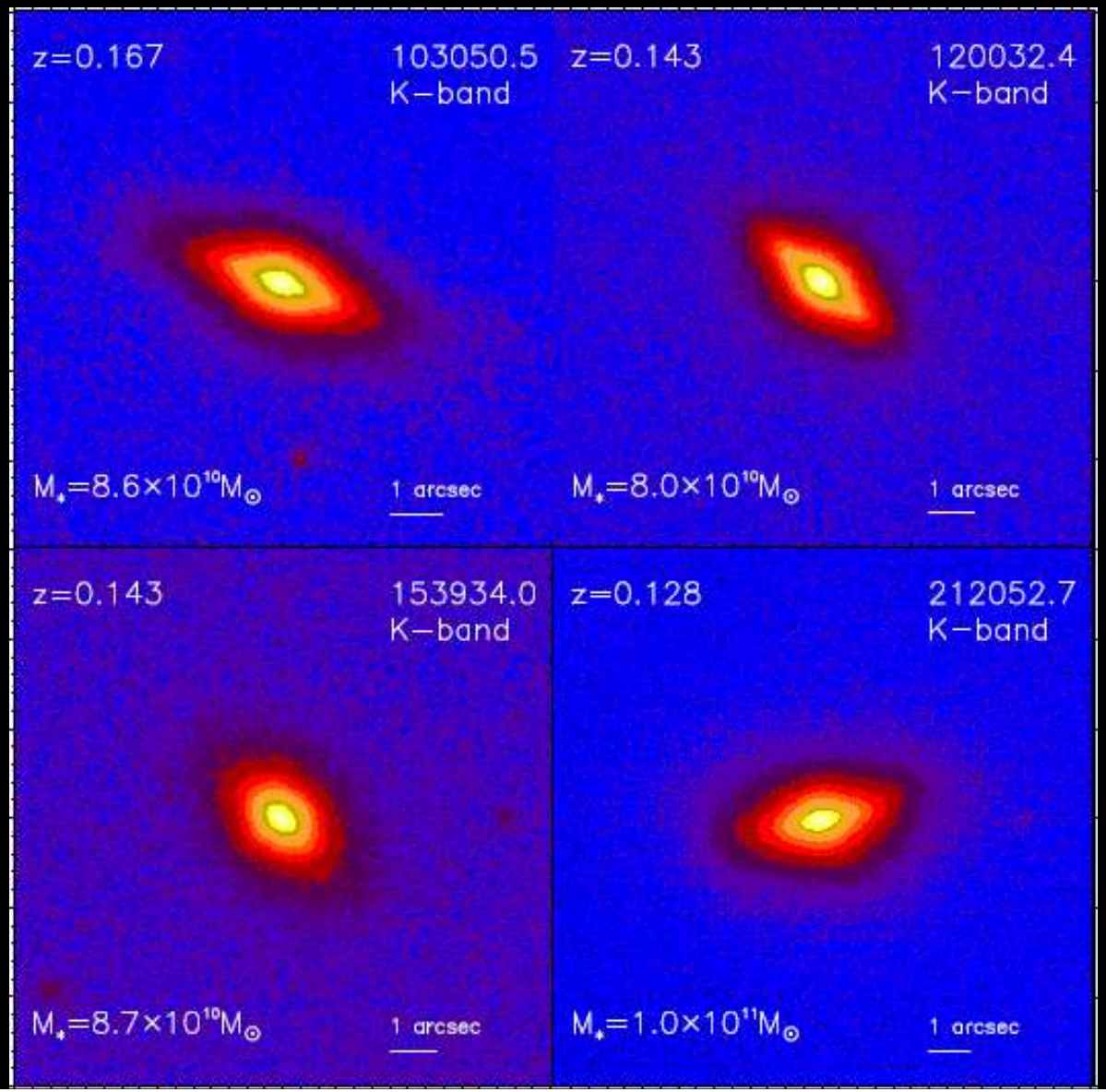
Trujillo et al. (2009)

# Observational constraints: is there any superdense massive galaxies at z~0?




Trujillo et al. (2009)

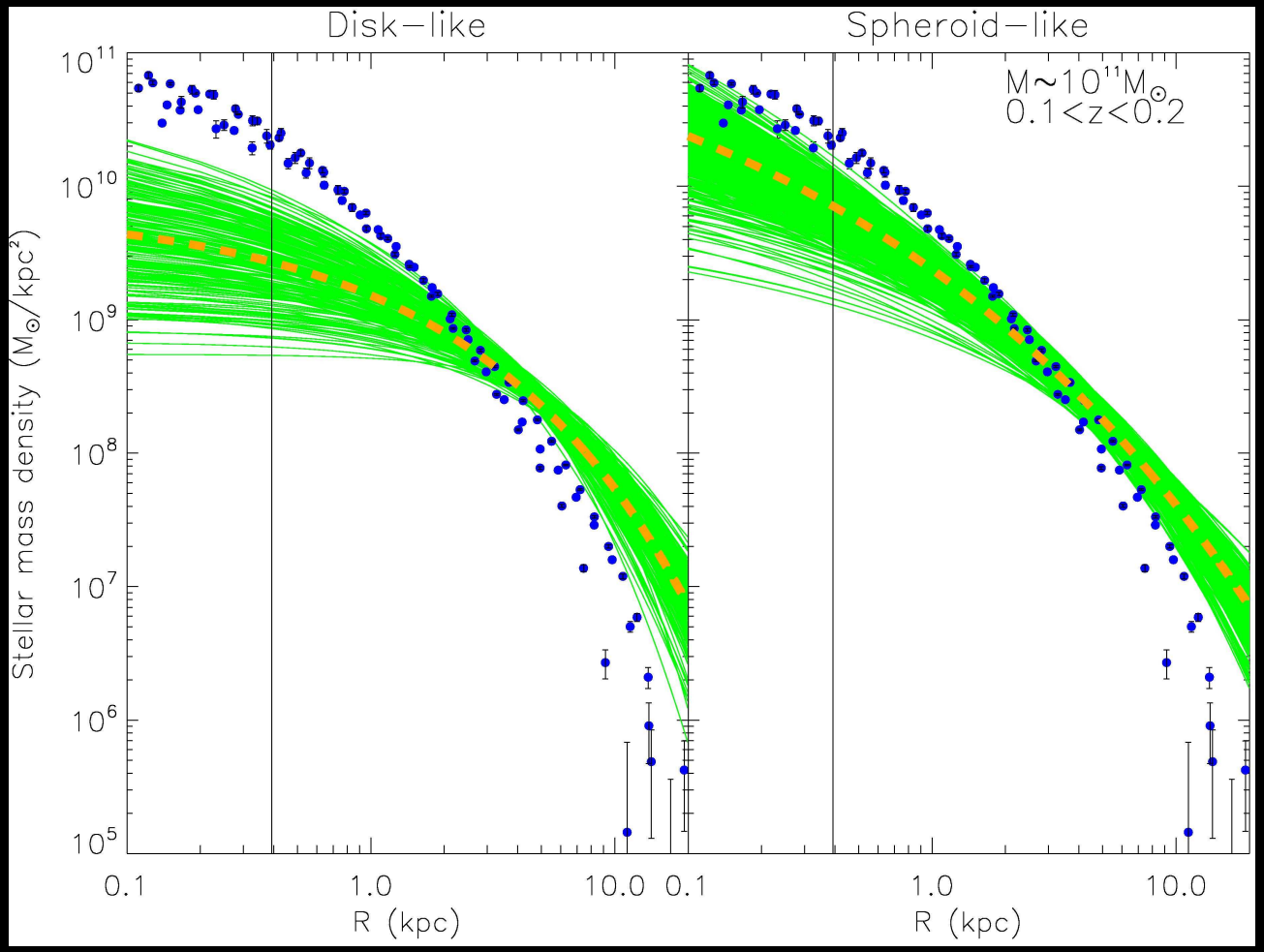
# A high resolution view of local massive compact galaxies




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

Trujillo et al. (2010; in preparation)

# A high resolution view of local massive compact galaxies

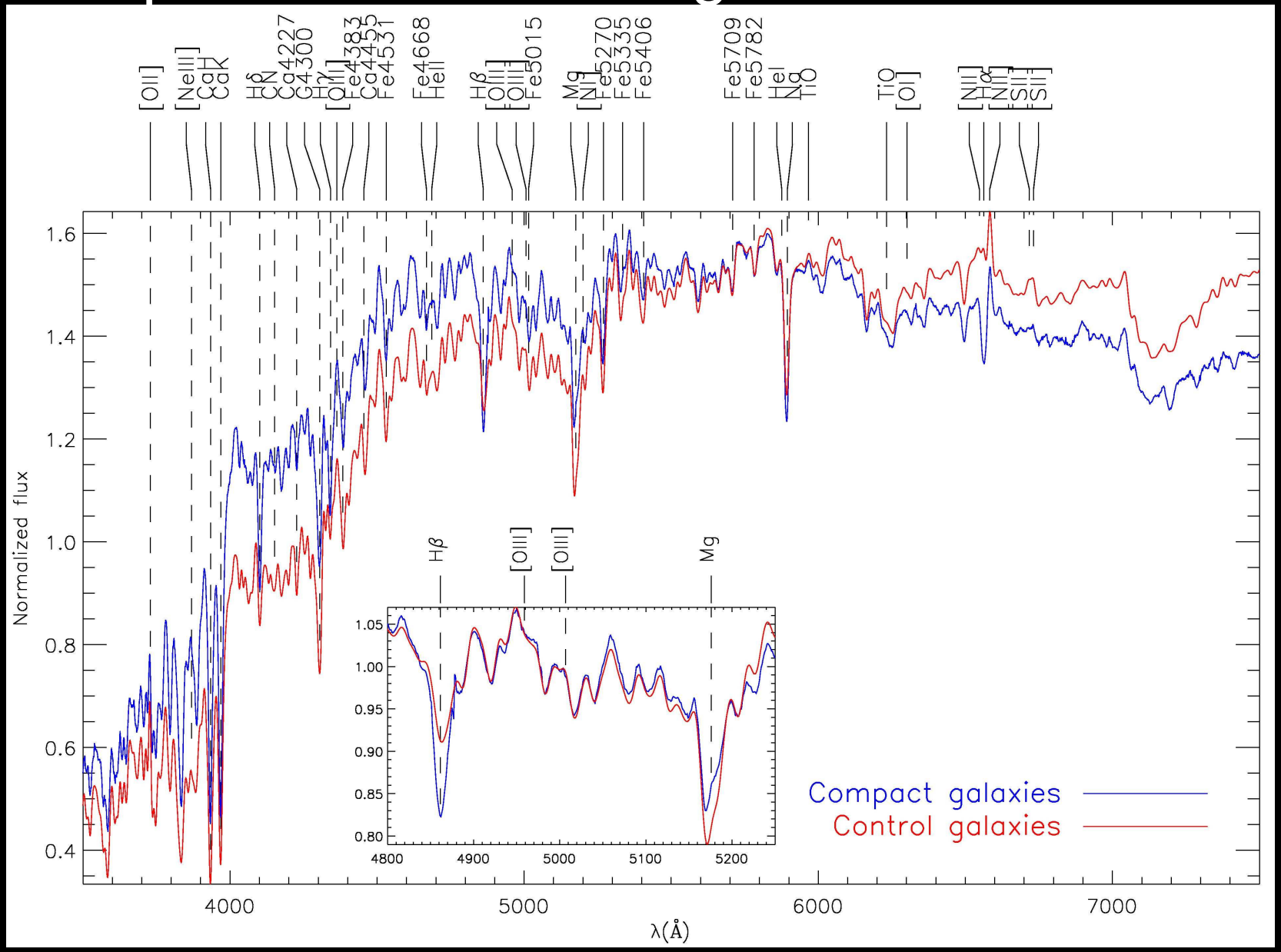



- Stellar mass density profile of massive compact galaxies compared to nearby normal massive galaxies

Trujillo et al. (2010; in preparation)

# Observational constraints: is there any superdense massive galaxies at z~0?

Trujillo et al. (2009)



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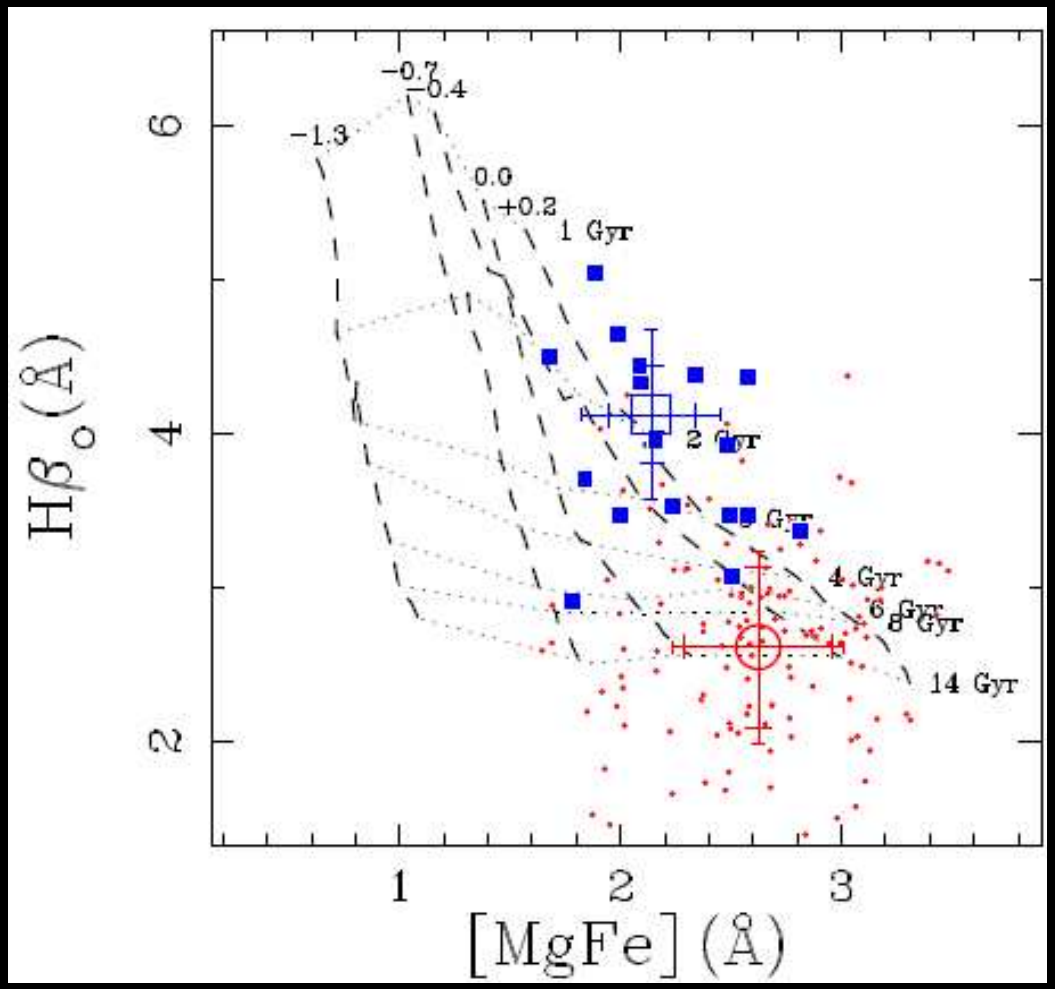



-Superdense massive galaxies at z~0 are surprisingly young (~2 Gyr)

-There are not superdense massive relics today from the early universe

Trujillo et al. (2009); Ferre et al. (2010; in prep)

# Observational constraints: is there any superdense massive galaxies at z~0?

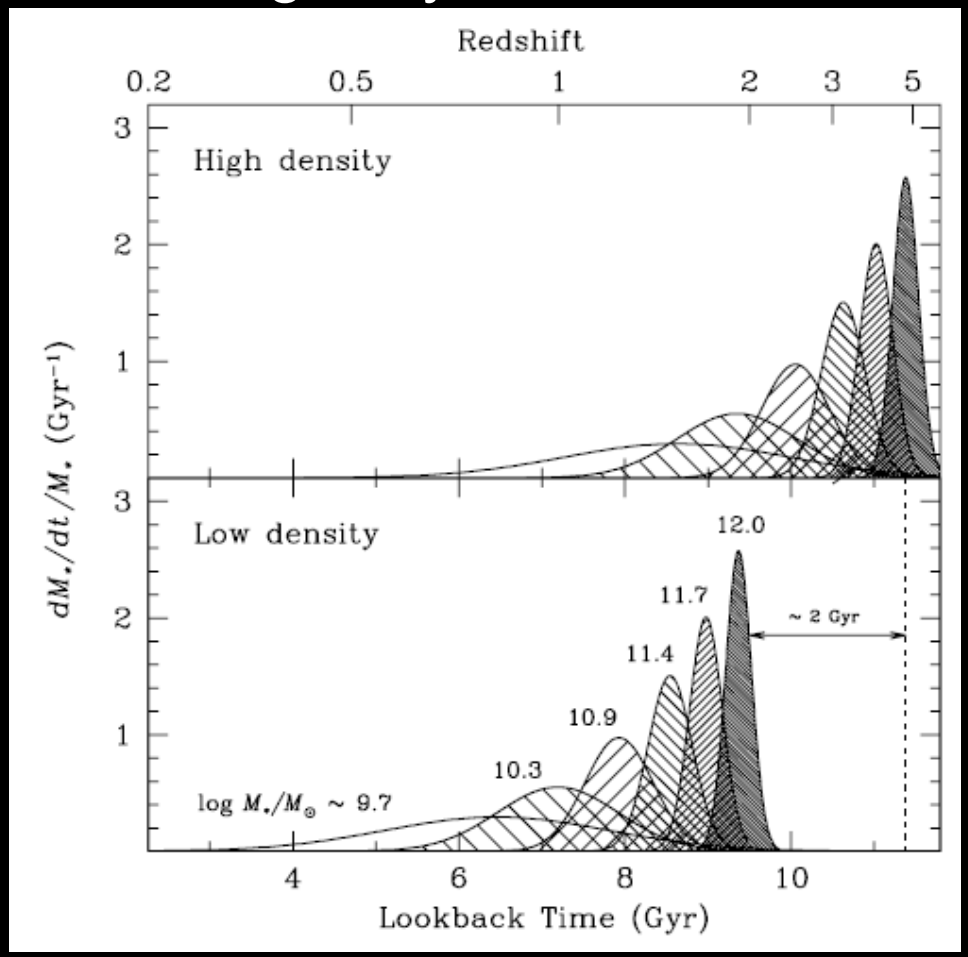
Trujillo et al. (2009):

1. Less than 0.03% of current massive galaxies are superdense
2. These objects are young; NO relics from the early Universe

This result does NOT fit easily in the puffing-up model

# Observational constraints: is there any superdense massive galaxies at z~0?

Are the superdense massive local galaxies then end of the tail of the massive galaxy formation?



Where are the compact massive galaxies today?

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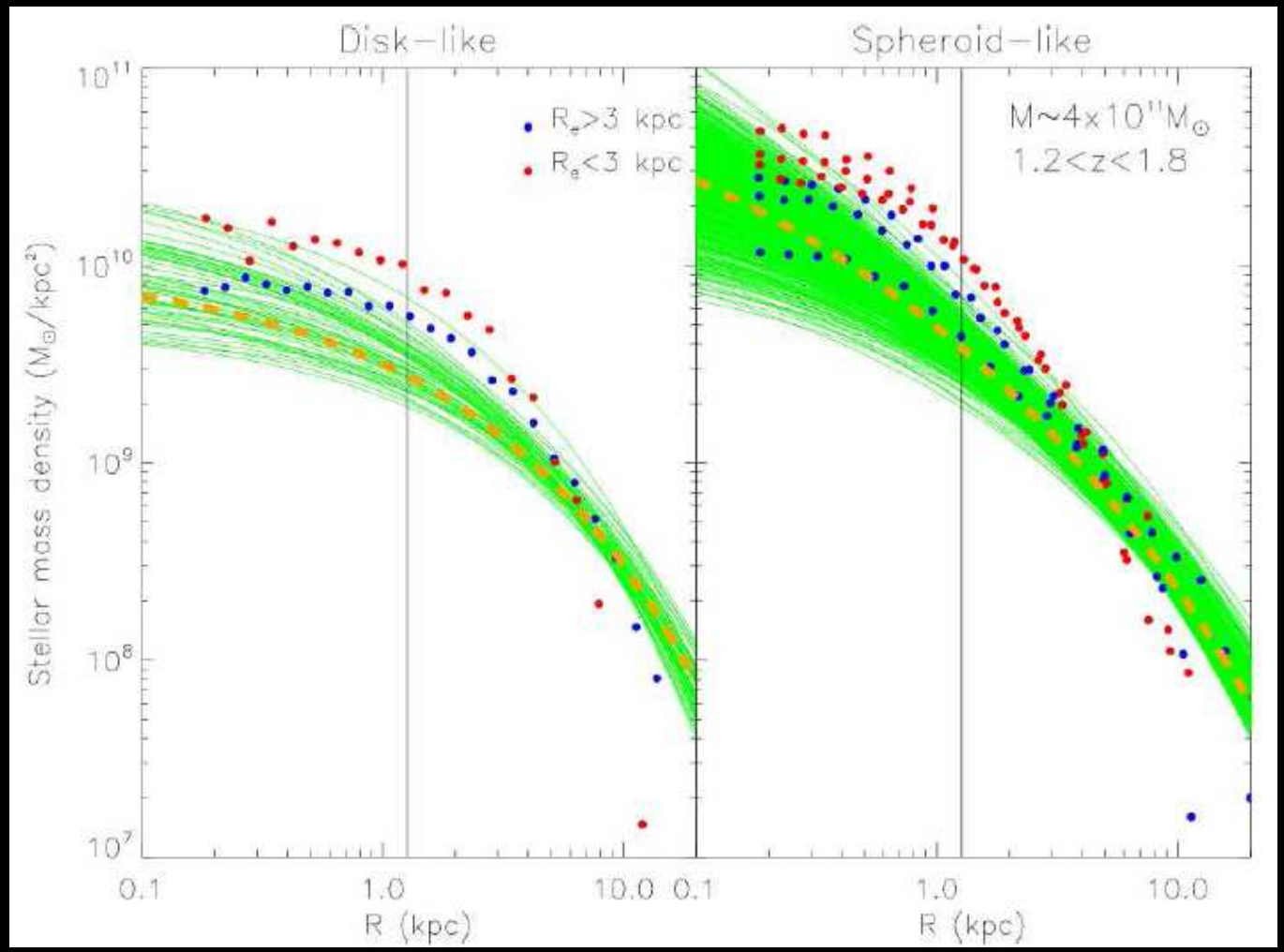
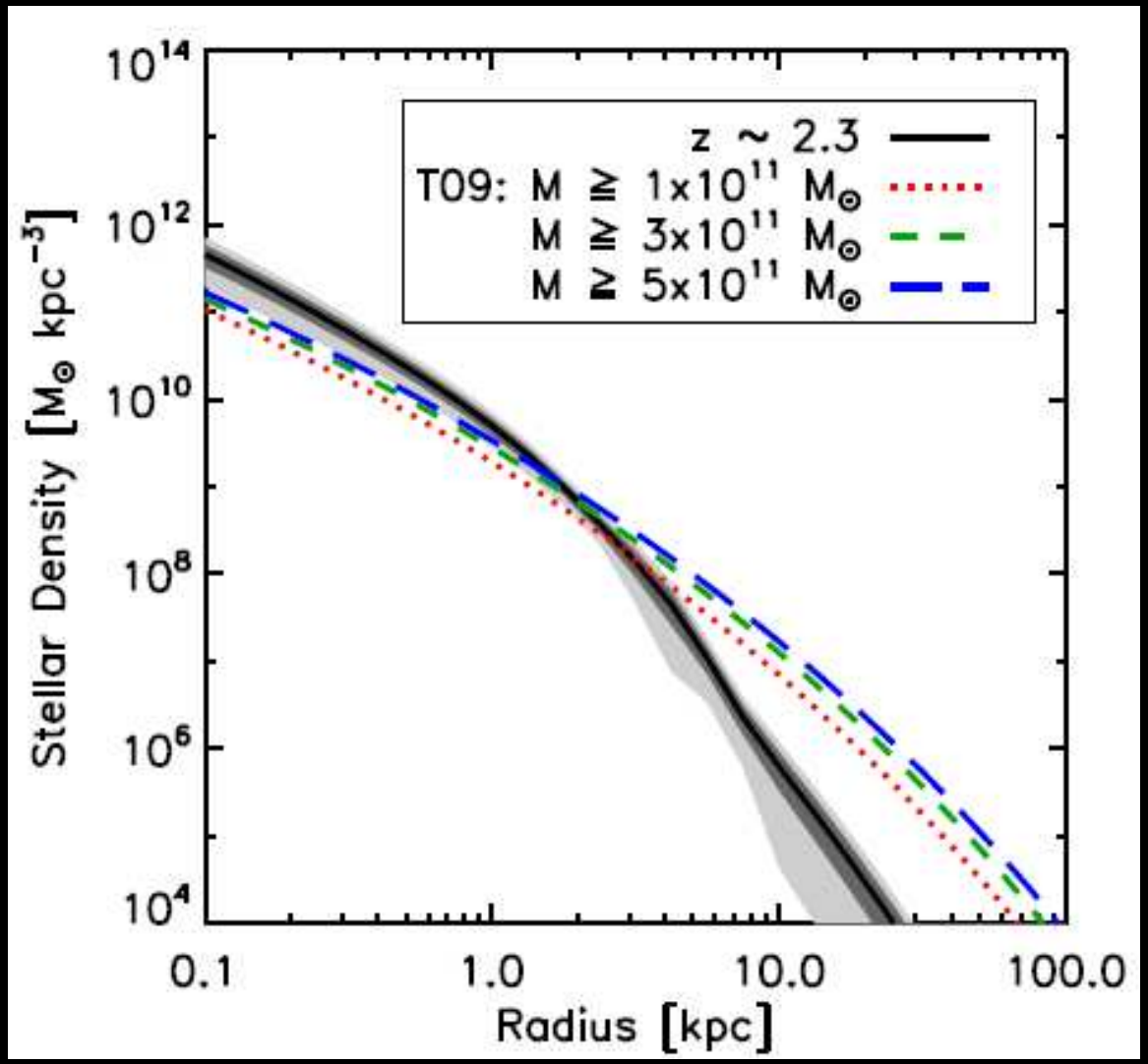



Carrasco, Conselice & Trujillo (2010)

Are the compact massive galaxies today the core of the most massive ellipticals?

# Where are the compact massive galaxies today?

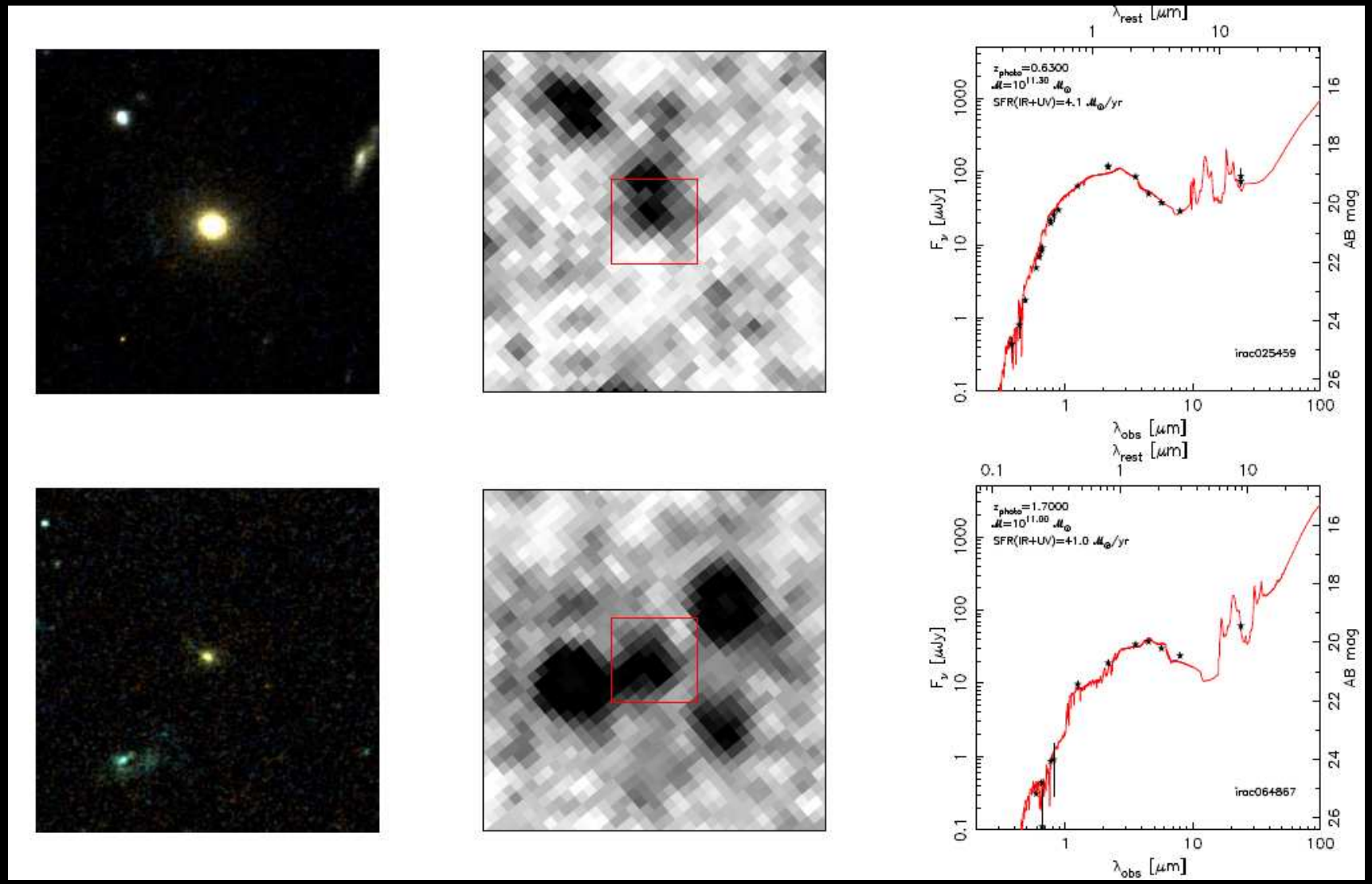



Bezanson et al. (2009); Hopkins et al. (2009)

Are the compact massive galaxies today the core of the most massive ellipticals?

Are the massive galaxies evolving passively?

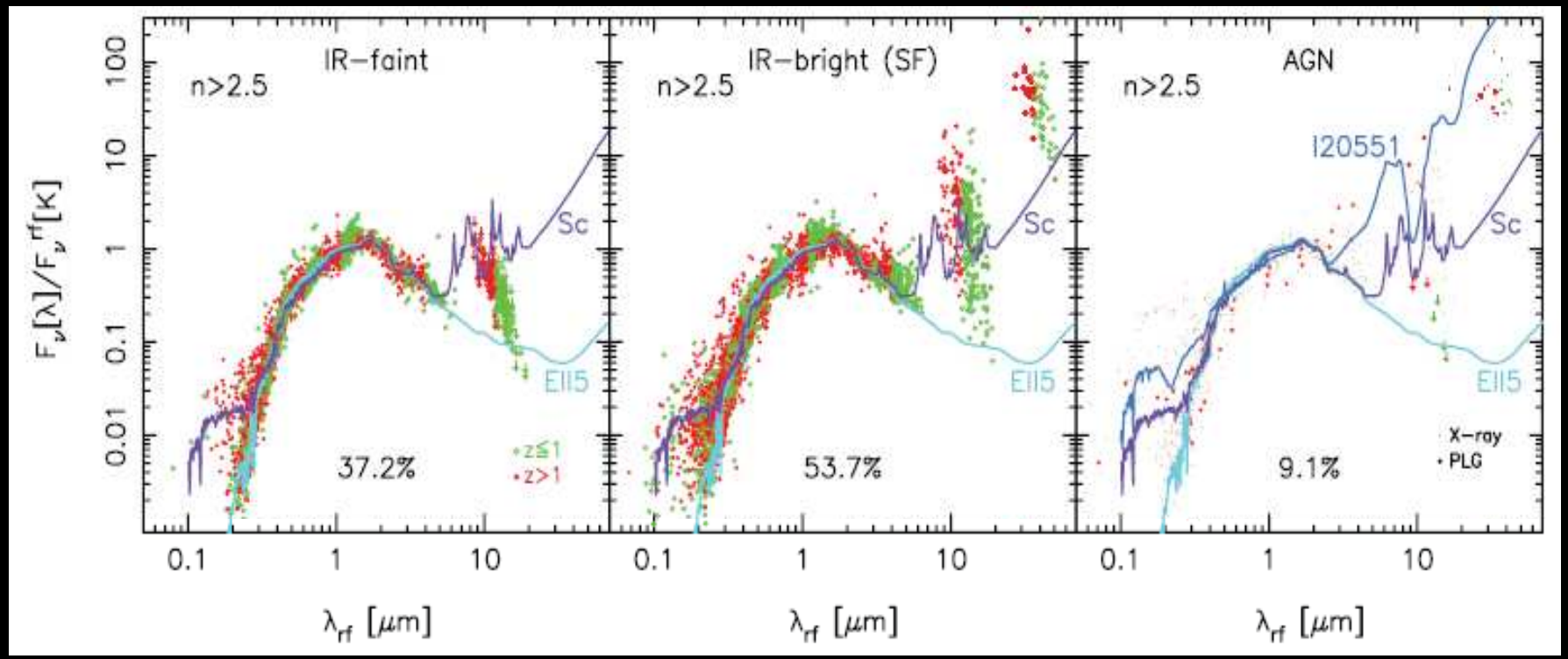
# Observational constraints: star formation histories




Pérez-González, Trujillo et al. (2008)

# Observational constraints: star formation histories

Average SEDs for spheroid-like objects since z~2

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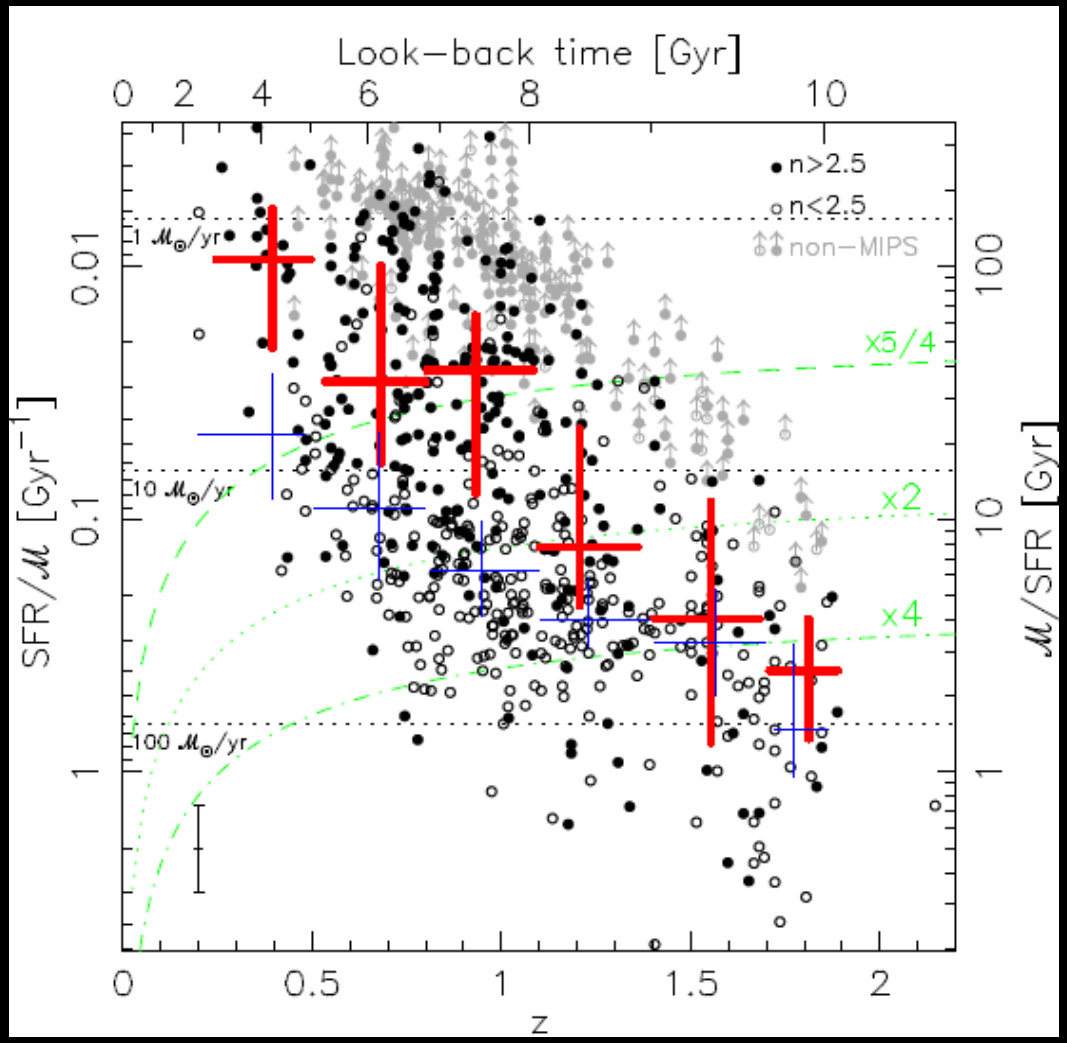
# Observational constraints: star formation histories




Disk-like galaxies:

At the most they have tripled their stellar mass content since z=2

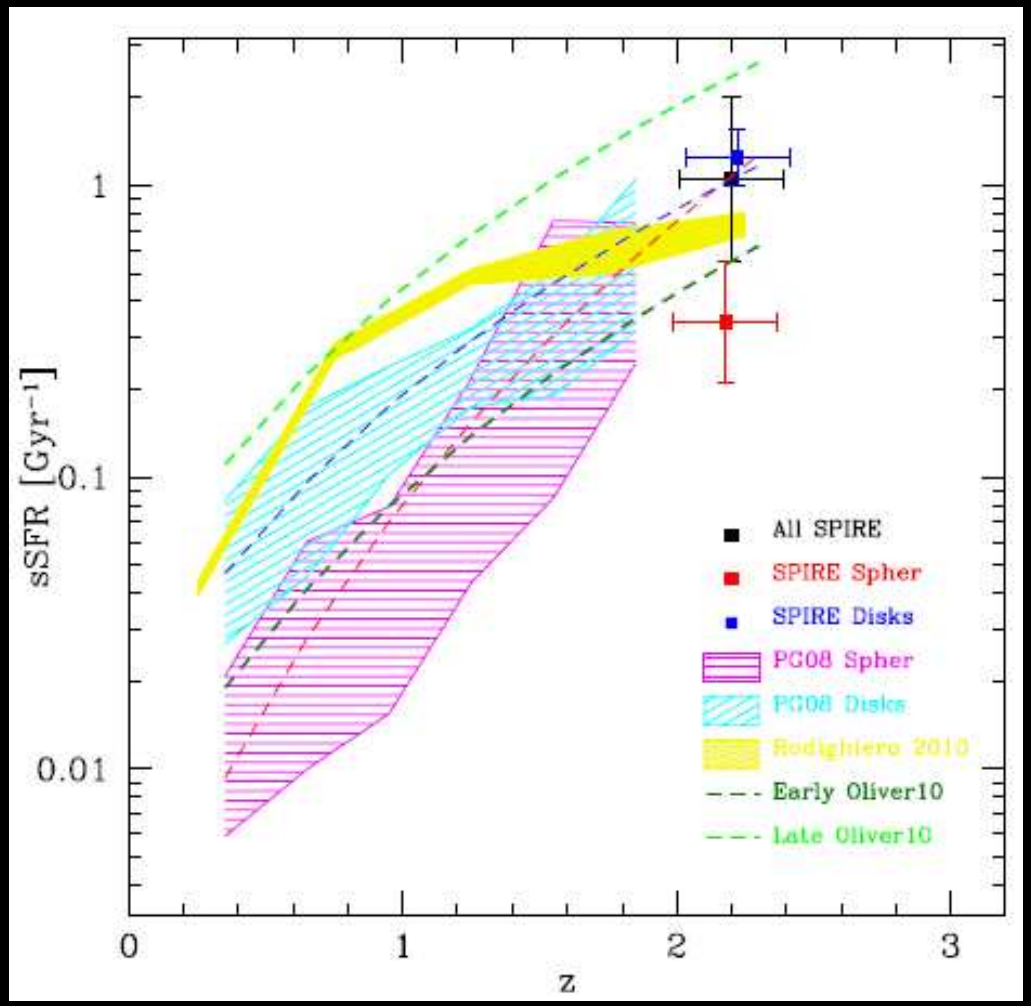
Spheroid-like galaxies:

At the most they have doubled their stellar mass since z=2

Pérez-González, Trujillo et al. (2008)

# Observational constraints: star formation histories

New results at 2<z<3




Cava et al. 2010 (SPIRE at Herschel) and Viero et al. 2010 (Spitzer, BLAST + LABOCA) consistent results:

Disk-like galaxies: ~200-300 M/yr

Spheroid-like galaxies: ~100 M/yr

# Observational constraints: star formation histories

Pérez-González, Trujillo et al. (2008):

1. More than 50% of massive spheroid-like objects are star forming at all z
2. SF declines very quickly
3. Within spheroids star-formation and size are unrelated

This result does not favor either dry merger or puffing-up models

# Models for spheroid size evolution: Likelihood

a) There is not size evolution; It is an observational artifact. X

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

c) Major dry mergers: spheroid-spheroid re-mergers (X; e.g. López-SanJuan et al. 2010)

d) Minor/Late accretion: more and more minor mergers with low-effective density √

How the massive compact galaxies form?

# How the massive compact galaxies form?

Are the massive compact galaxies the final stages of the merging of gas-rich disk galaxies? (Hopkins et al. 2007;2009; Cimatti et al. 2008)

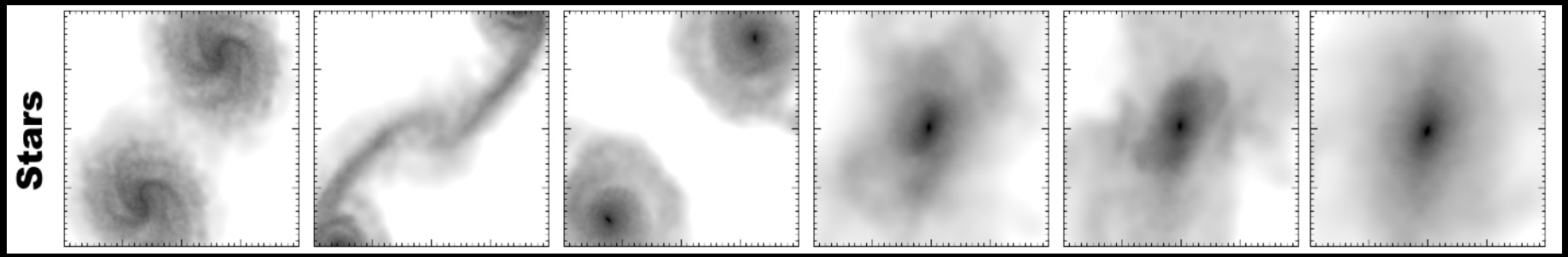



Figure from TJ Cox

# How the massive compact galaxies form?

Characteristics of the candidates to be progenitor of the compact massive galaxies at high-z:

-Gas rich

-Very massive ($M \sim 10^{11} M_{sun}$)

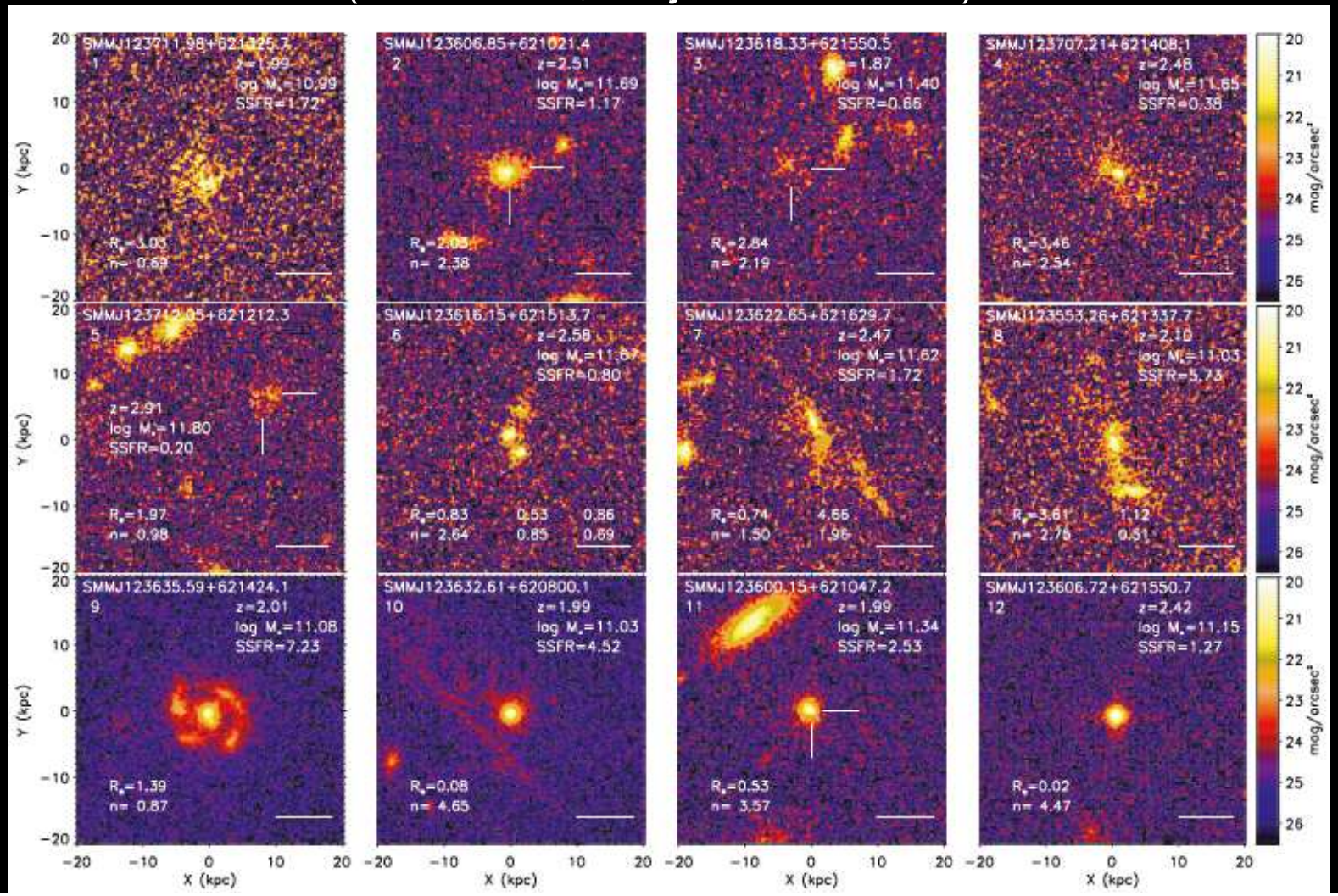
-High redshift ($z>2$)

A likely candidate are the submillimetre galaxies.

We explore whether the morphologies and sizes fit within the theoretical scheme

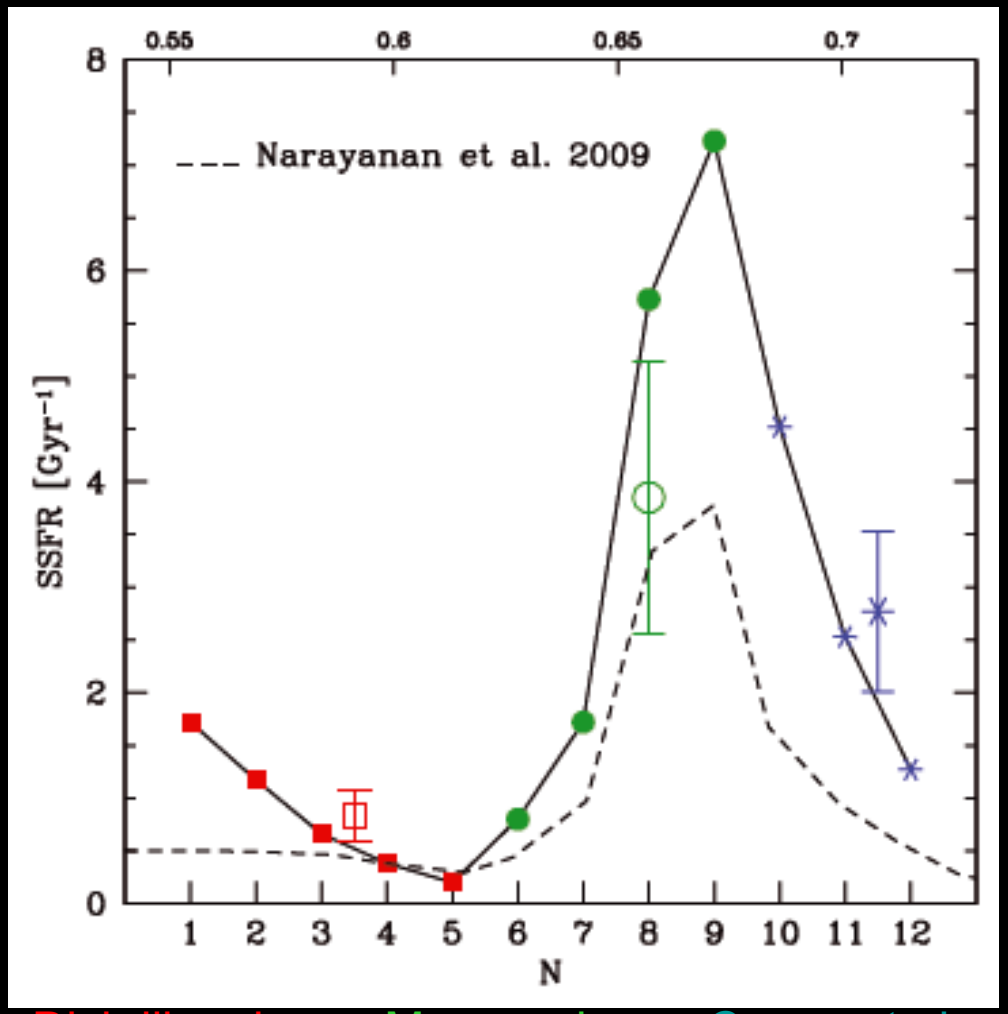
# How the massive compact galaxies form?

Our sample: 12 star forming submillimetric galaxies ($M>10^{11}M_{sun}$) at $1.8<z<3$ observed with NICMOS & ACS @ GOODS-North (Ricciardelli, Trujillo et al. 2010)



# How the massive compact galaxies form?

Can the morphologies of the observed submillimetre galaxies be accommodated into the theoretical scheme?




Disk-like phase Merger phase Compact phase

# Open issues from the observational point of view:

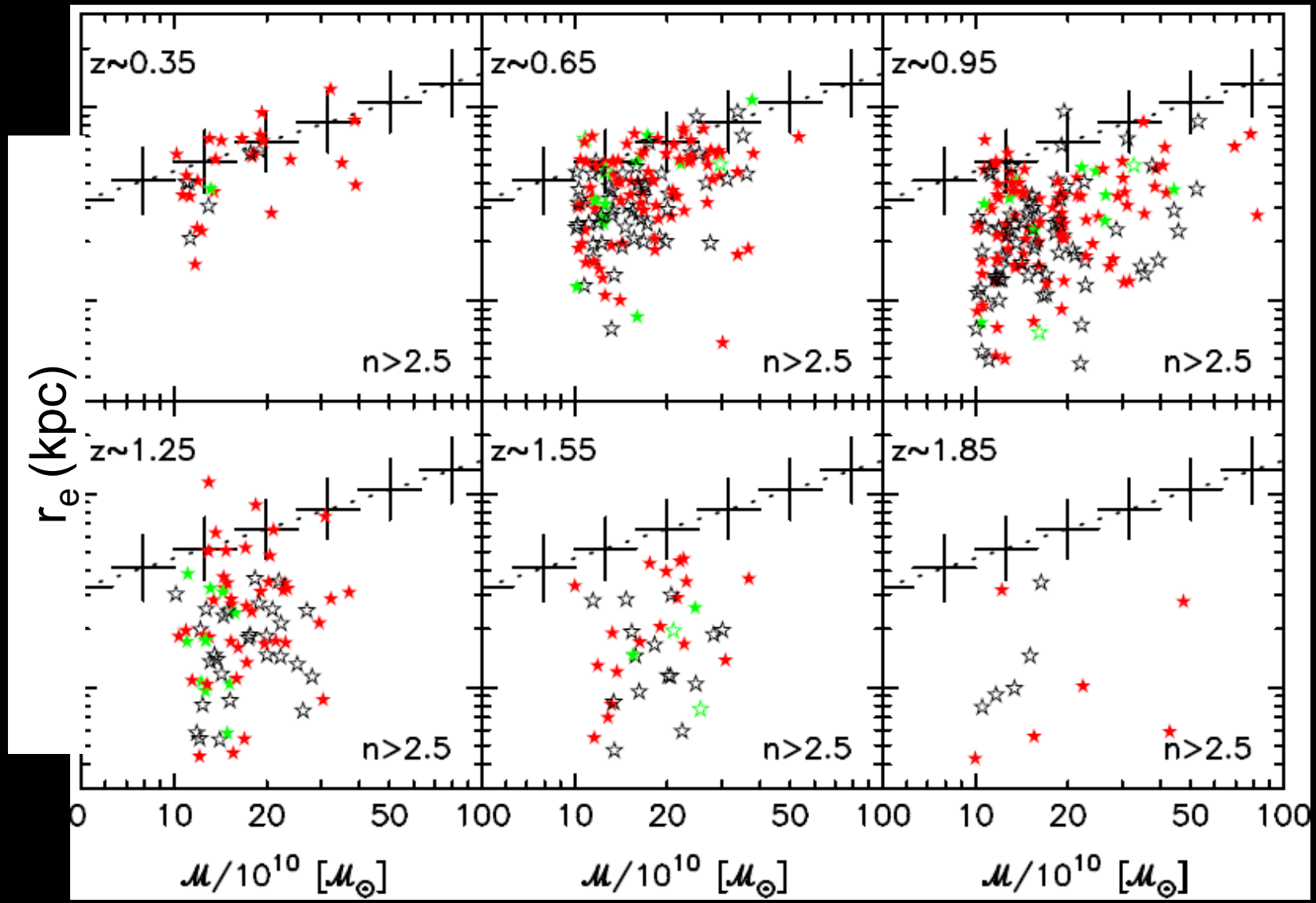
*The most favored evolutionary scenario is the late accretion of minor satellites*, however, still to observationally check:

- An estimation of the velocity dispersion of compact massive galaxies at high-z based on single object spectra with S/N>10 (coming soon)

- An estimation of the evolution of the number of 1:10 satellites of the most massive galaxies since z<2 (coming soon)

- Ages and stellar metallicities gradients of the present-day most massive galaxies to explore the wings properties

# Observational constraints: Star Formation Histories




Pérez-González, Trujillo et al. (2008)