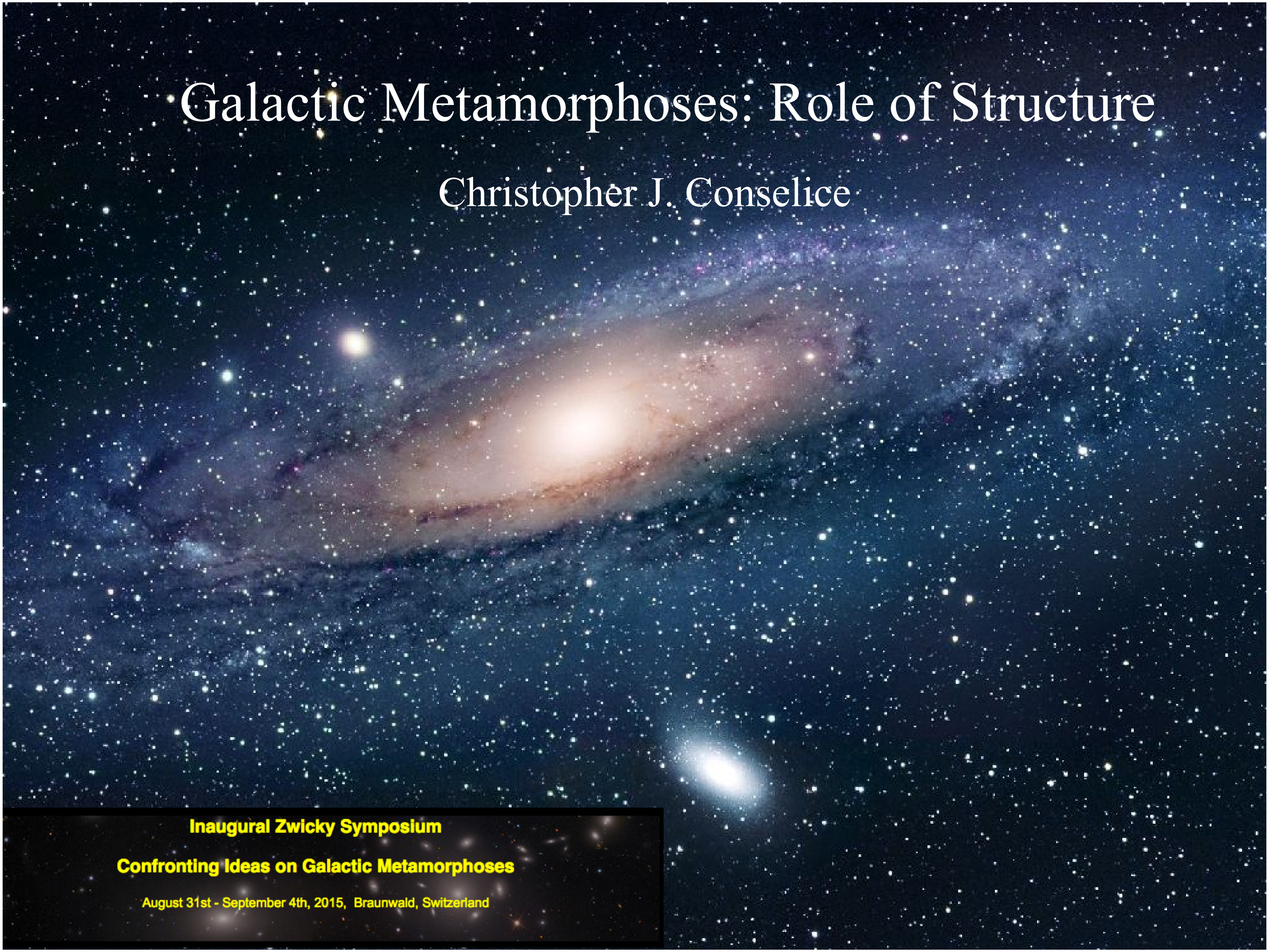
Galactic Metamorphoses: Role of Structure

Christopher J. Conselice



Inaugural Zwicky Symposium

Confronting Ideas on Galactic Metamorphoses

August 31st - September 4th, 2015, Braunwald, Switzerland

Galactic Metamorphoses – What do we mean?

We know galaxies evolution occurs from observations.

Further questions to address are:

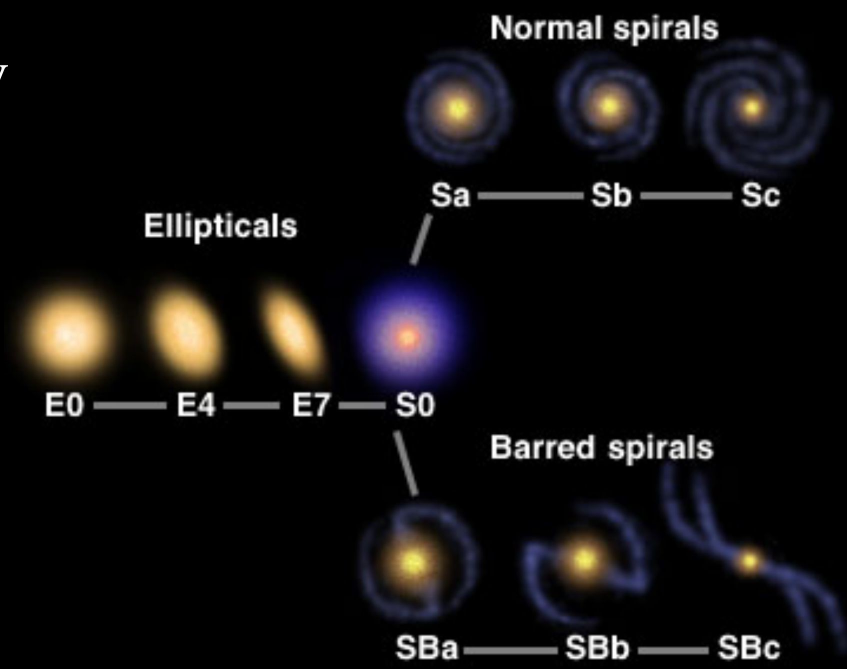
- When/if and how do galaxies transform morphological (i.e., disks/ellipticals/peculiar transformations)
- Size/structure evolution – galaxies compact at high-z
- Stellar mass evolution – what drives the assembly of galaxies? Does it relate to, or is it driven by the structural/morphological changes in galaxies?

Galaxy structure: Galaxy morphology

Local Universe

98% of all nearby bright galaxies can be placed into a Hubble type

Hubble types are the z = 0 final state of bright galaxy evolution

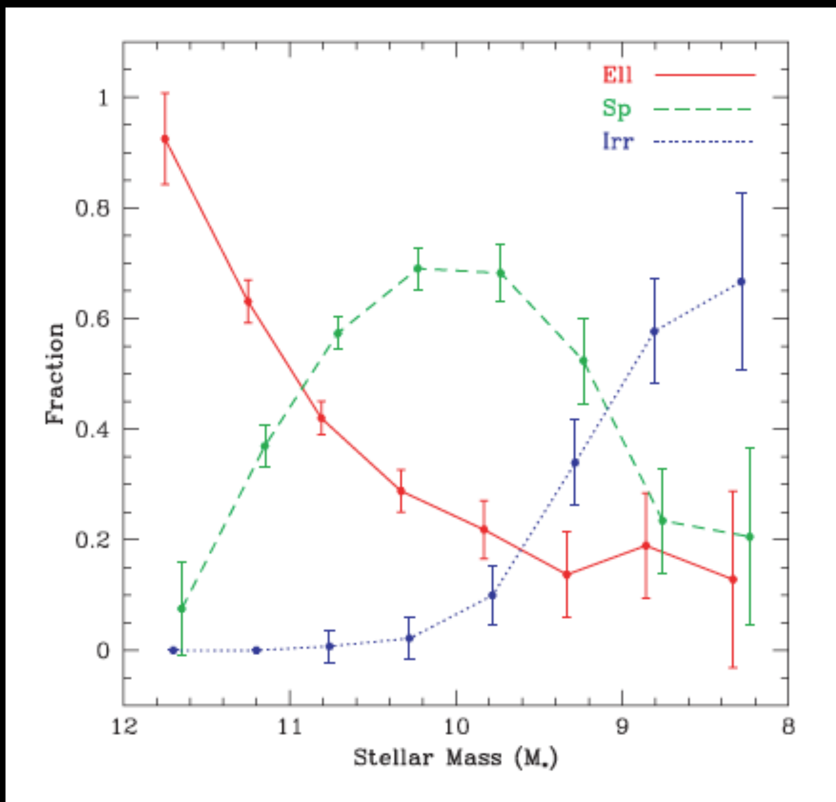


Ellipticals have old stellar populations, spirals have both old and young components while irregulars are dominated by young stars

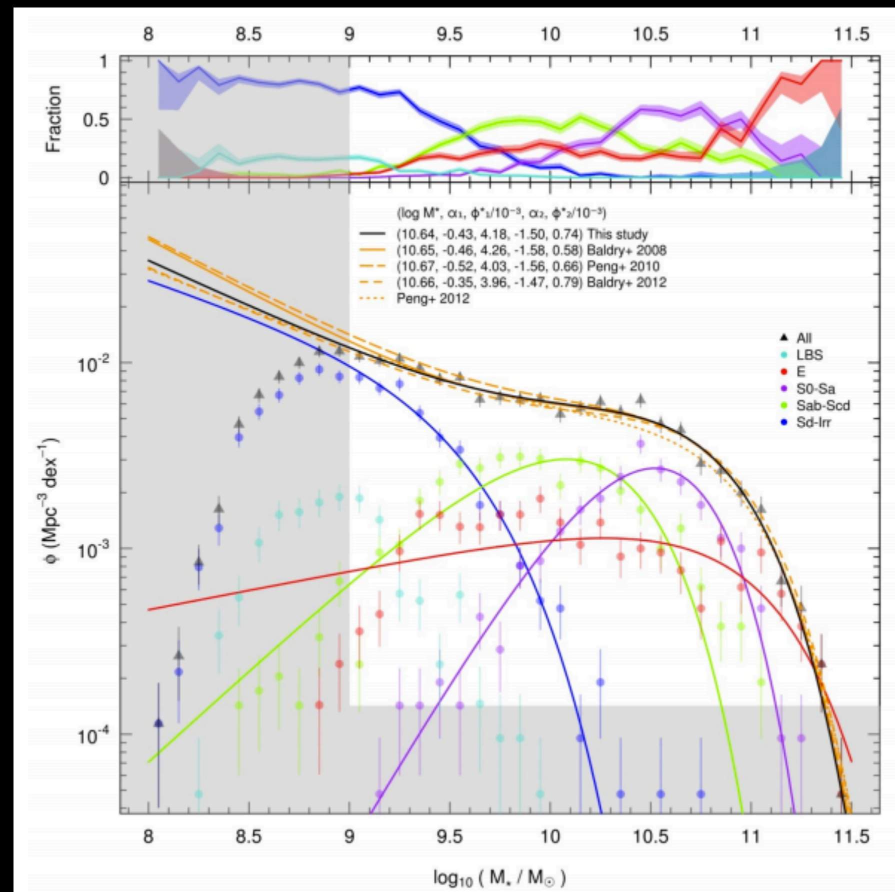
No/little cold gas or star formation

Cooling gas with star formation

End product of galaxy formation highly regulated and dependent on stellar mass for reasons that are not understood

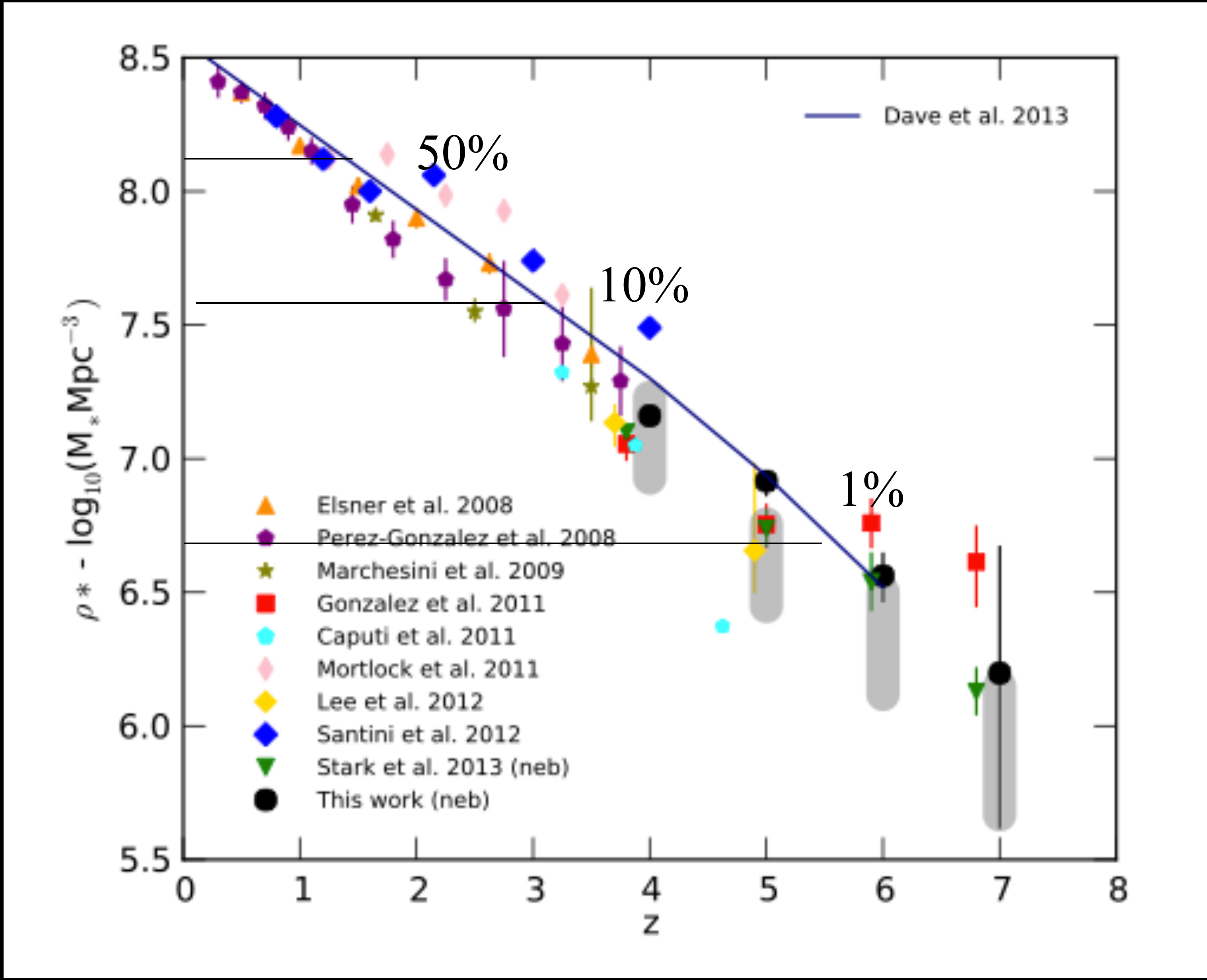


Conselice 06



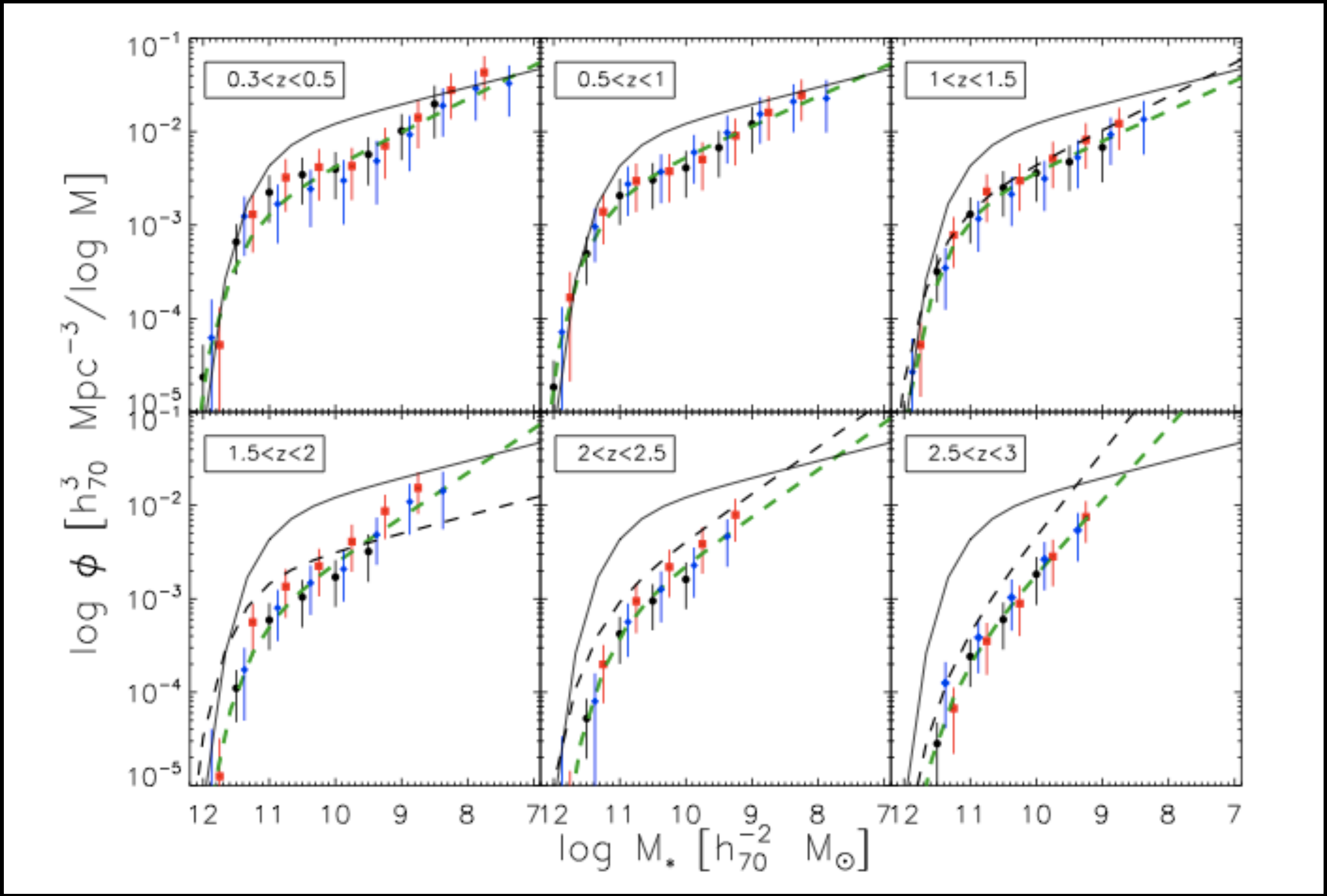
Kelvin+ 2014 (GAMA)

The formation of stellar mass – direct measures



Observed integrated stellar mass density vs. redshift

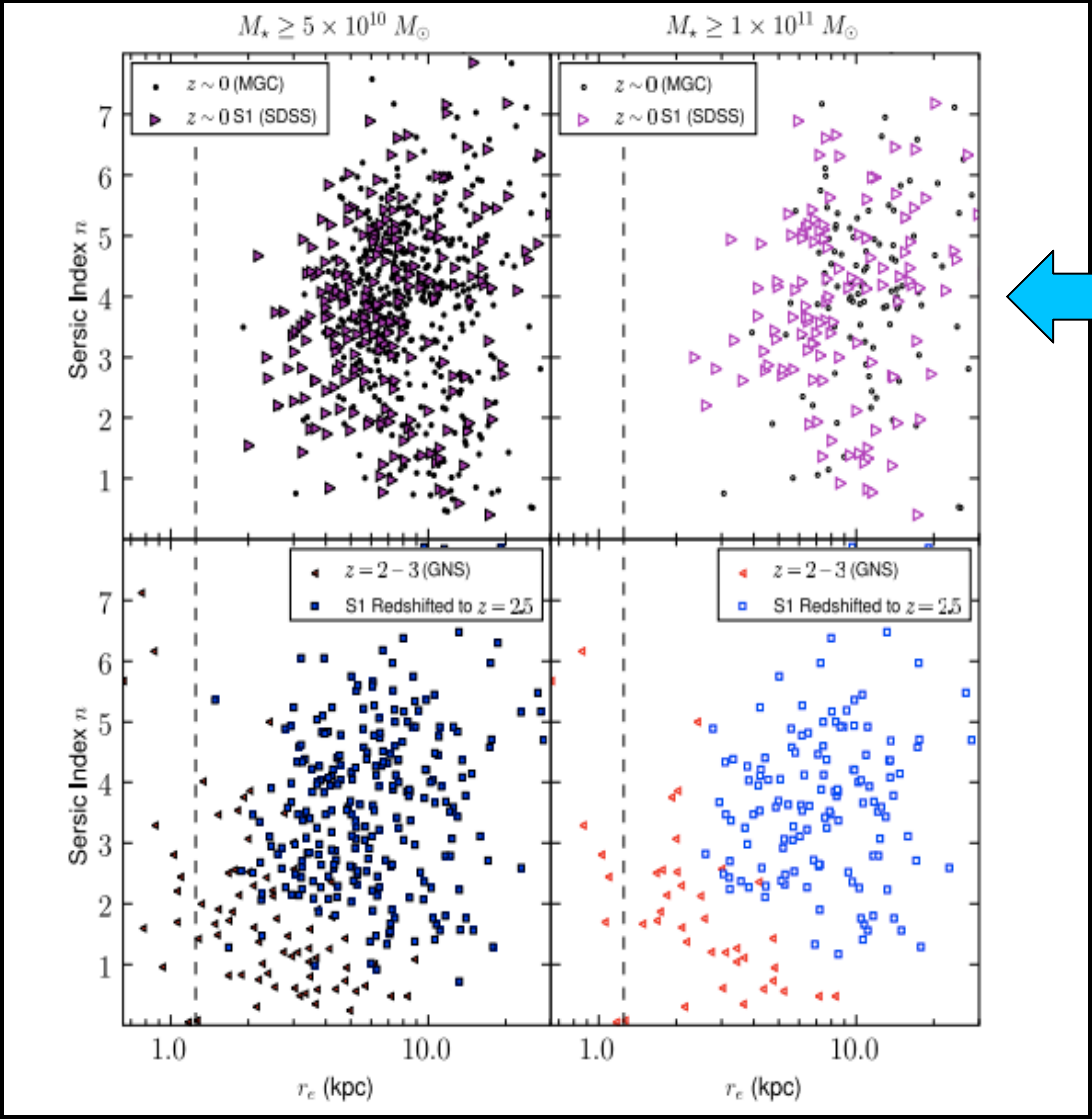
Mass function shows that massive galaxies form quickly



Mortlock+14 (also e.g., Stanfo+15; Muzzin+13; Marchesini+10)

Most massive galaxies are in place by z = 1

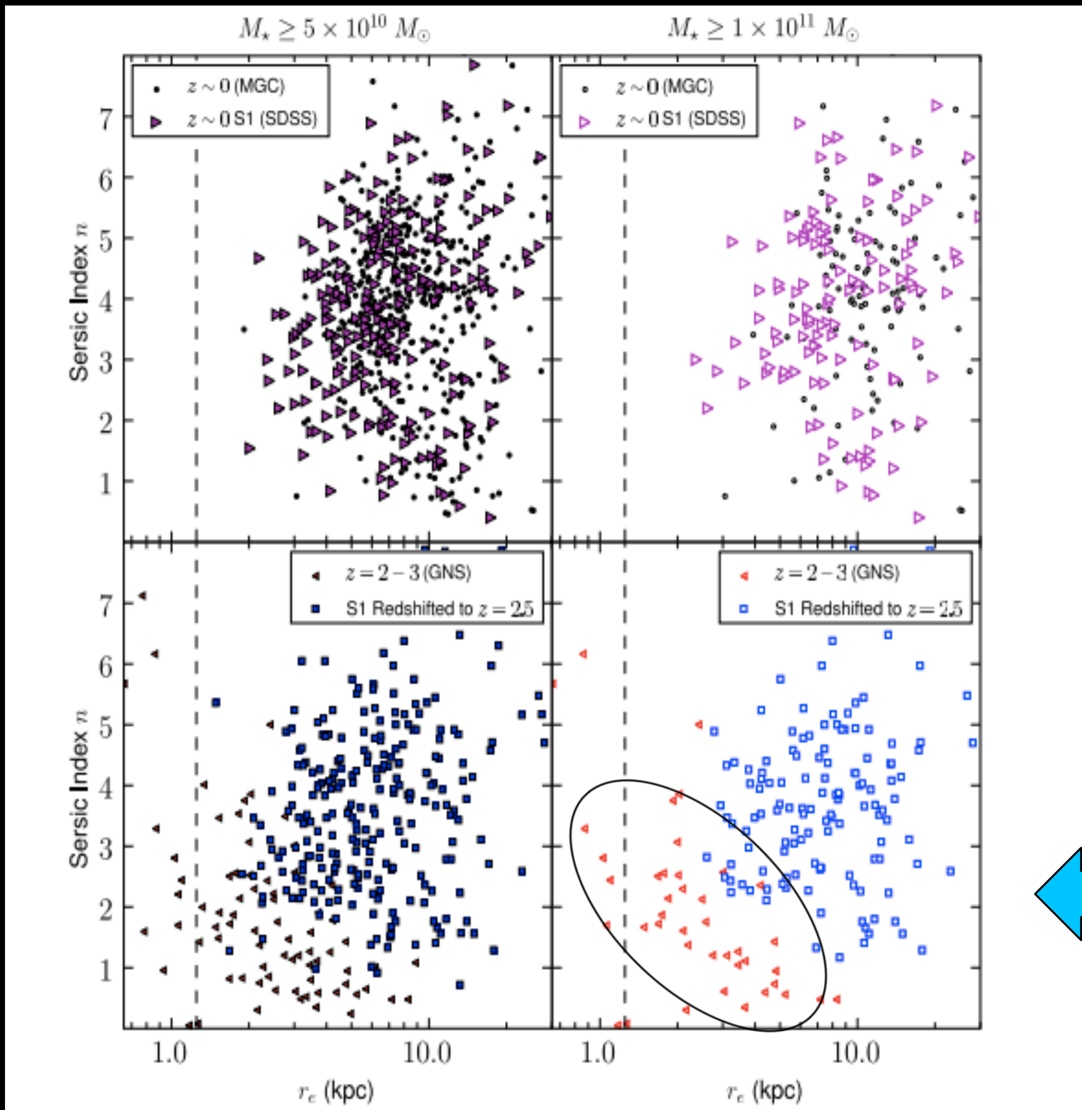
However galaxies at z = 2.5 are different from nearby massive galaxies



Nearby massive galaxies

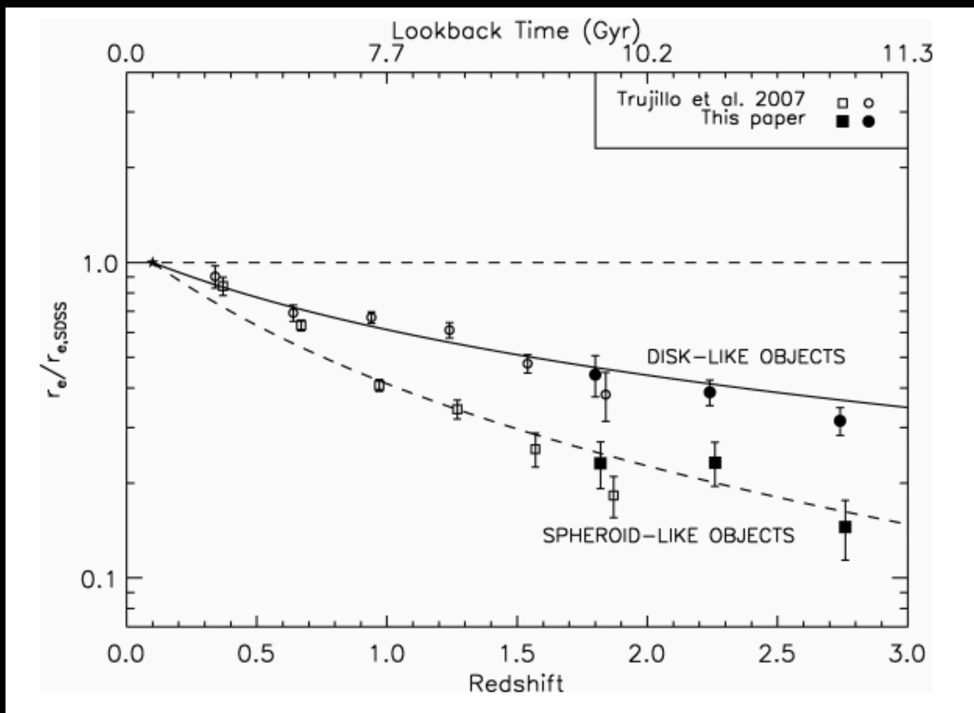
Weinzirl+11

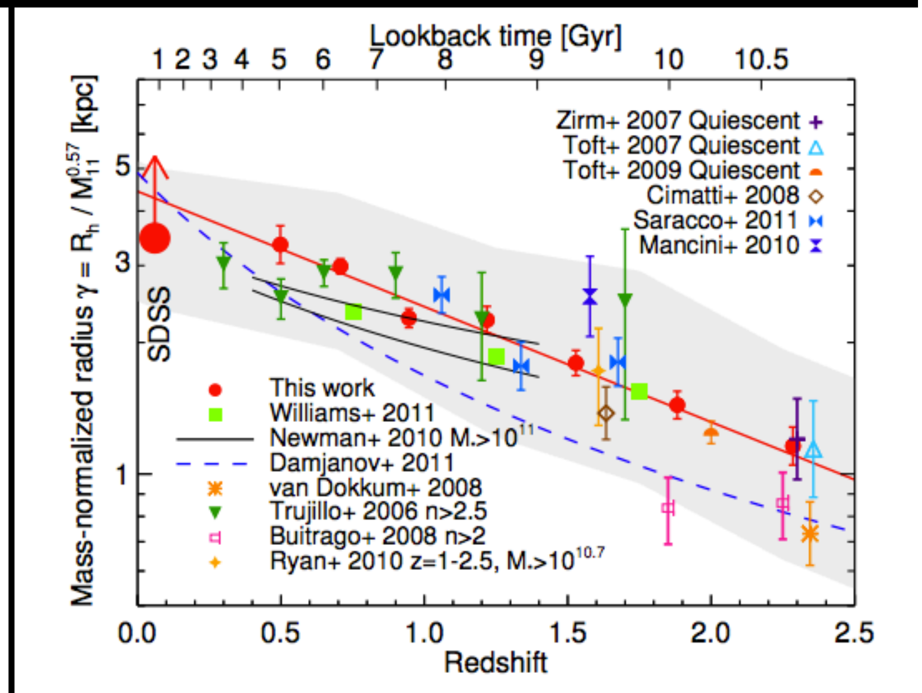
Galaxies at z = 2.5 --- different from nearby massive galaxies



Same mass
but at z > 1

Size evolution – now well established

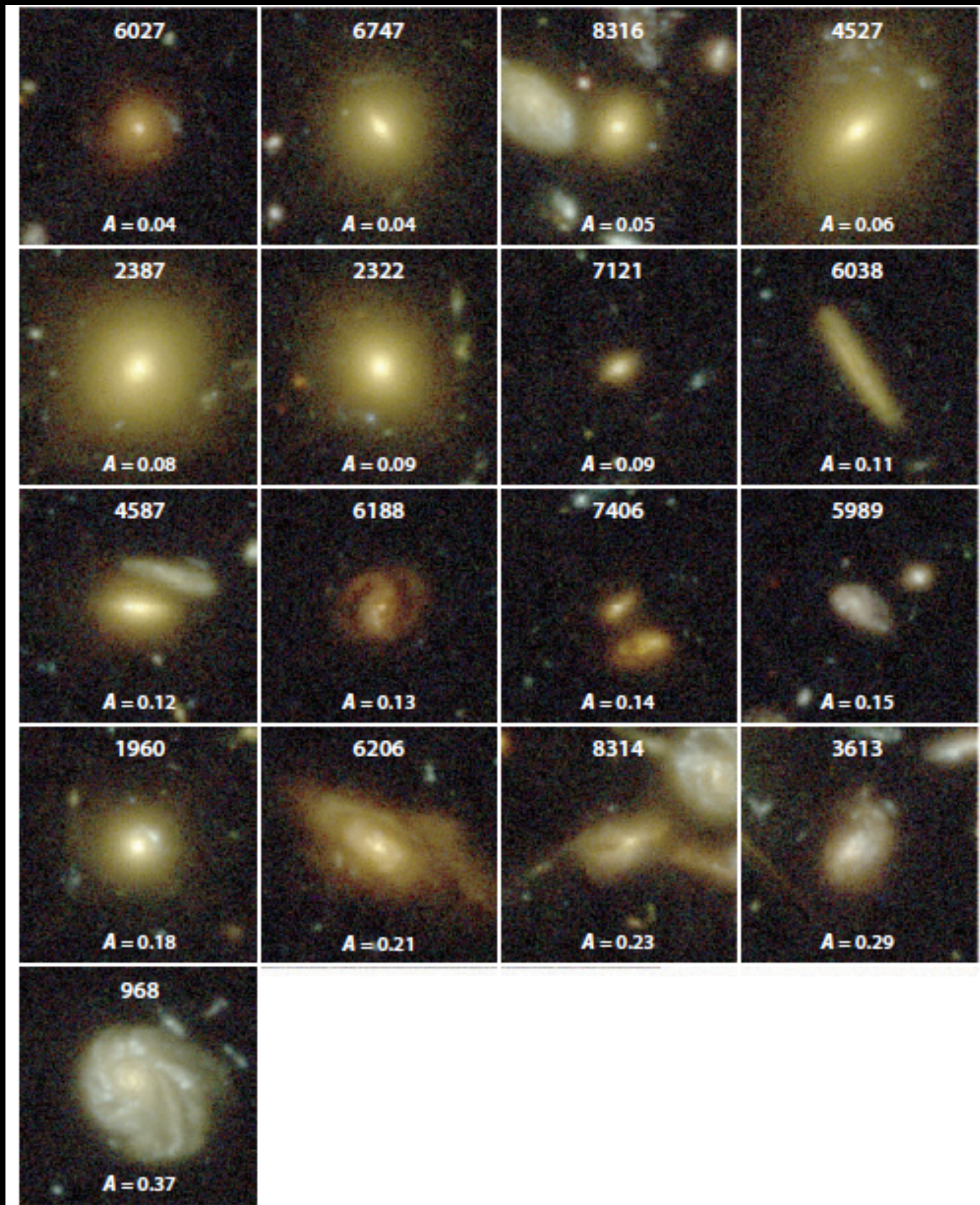




Buitrago+08

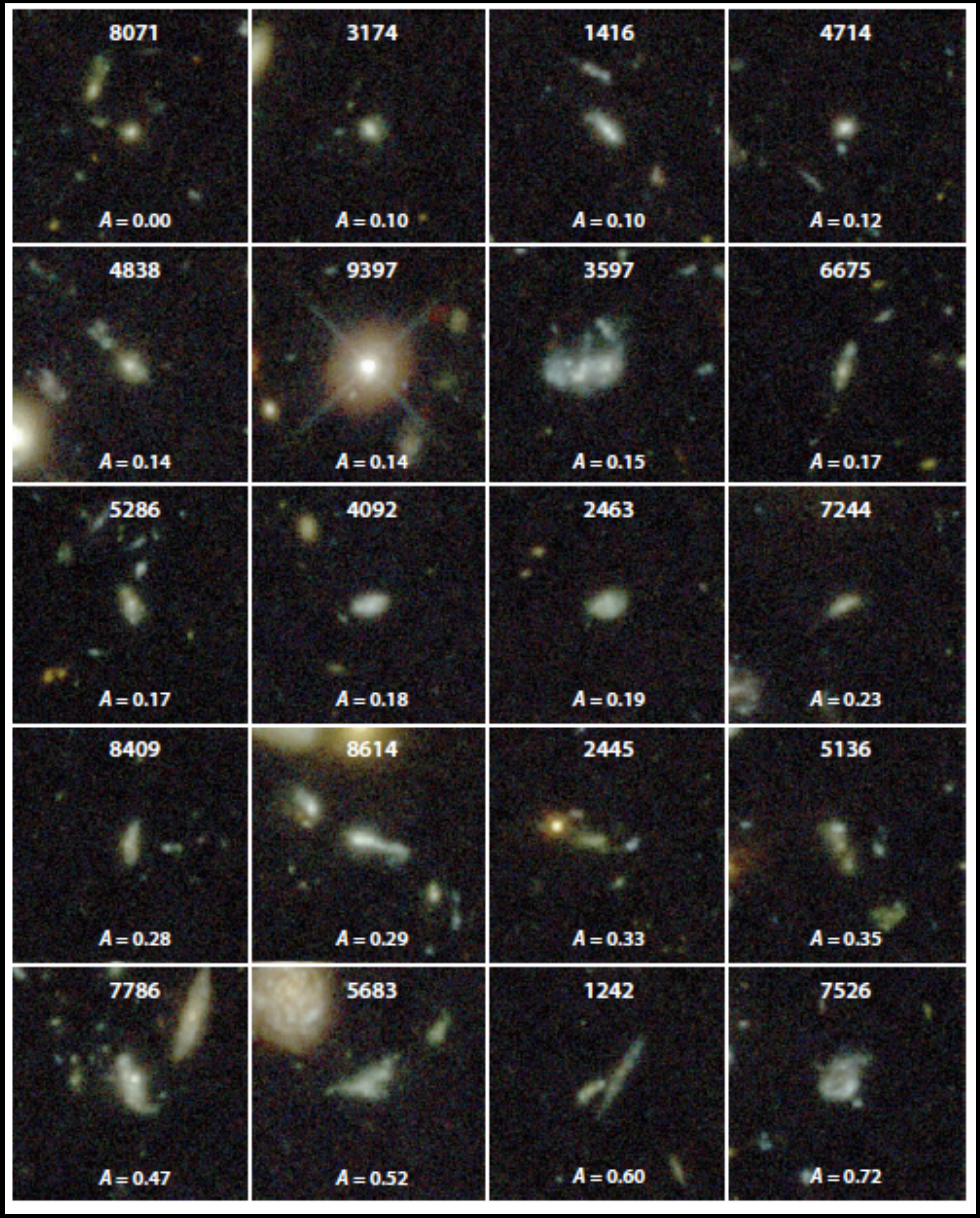
Newman+12

Scales as $\sim(1+z)^{-0.82 \text{ to } -1.5}$



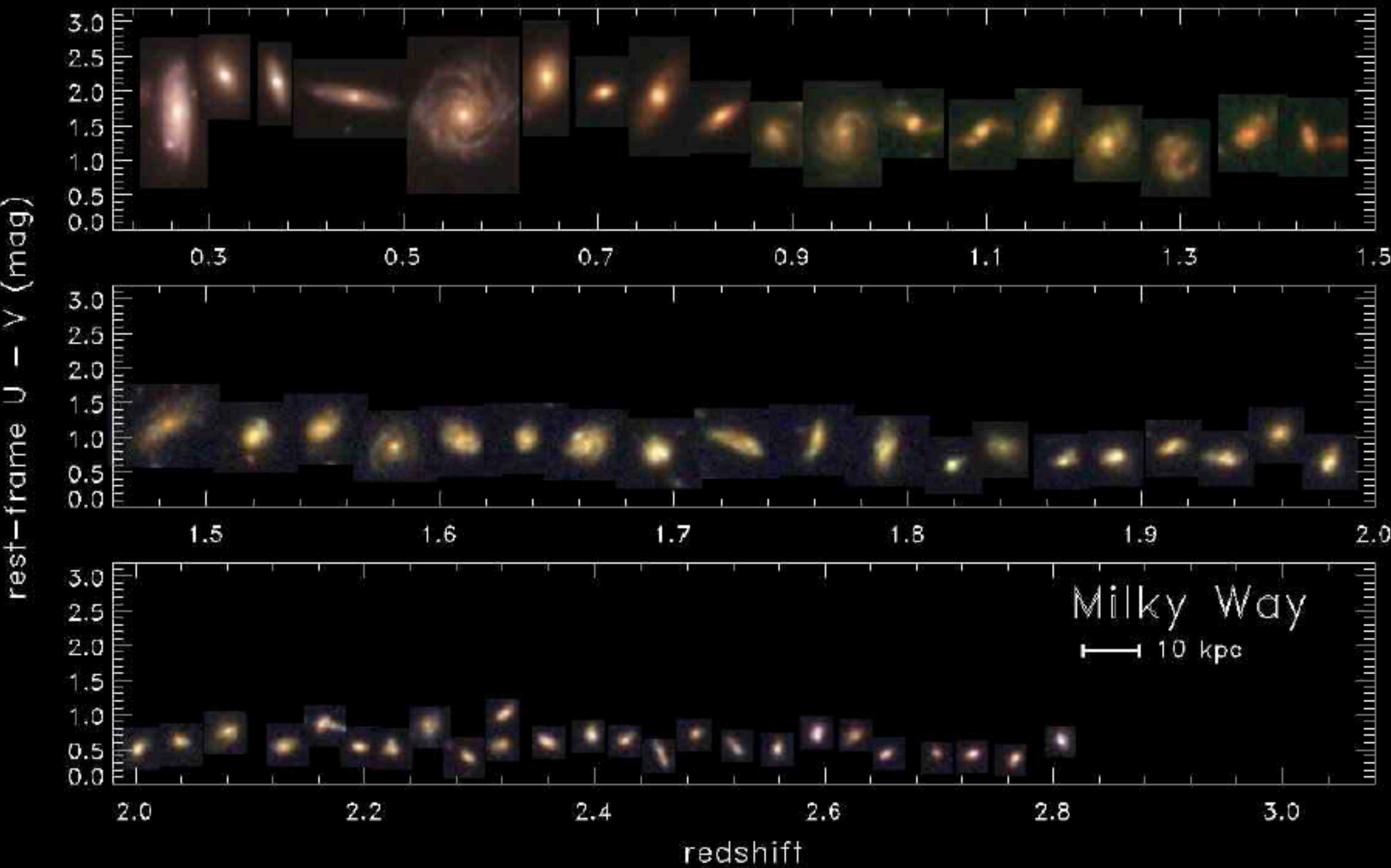
Disk/elliptical/peculiar evolution – visual morphologies

z < 1 massive Galaxies in UDF



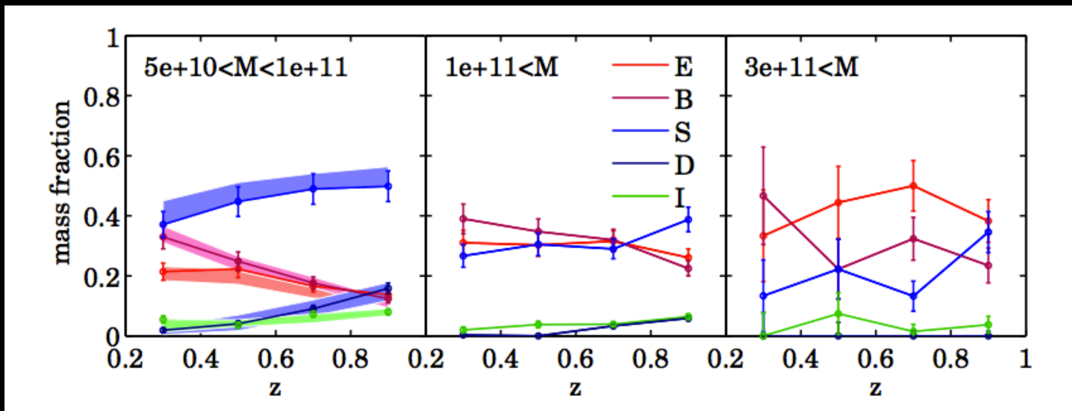
z > 1 massive
Galaxies in UDF

Milky Way mass progenitors

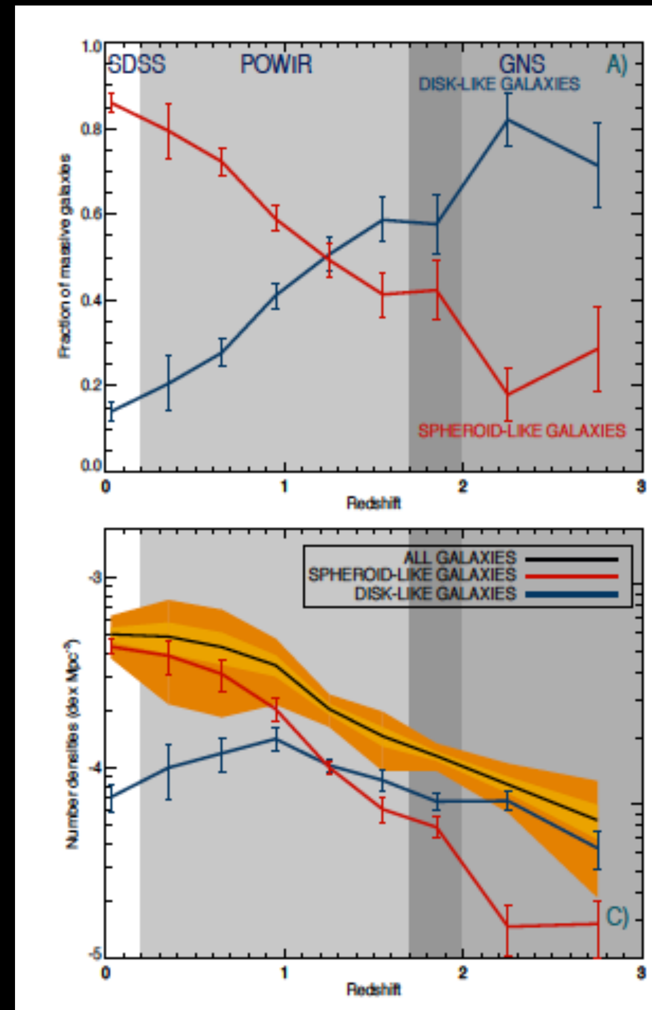


Papovich +15 (CANDELS)

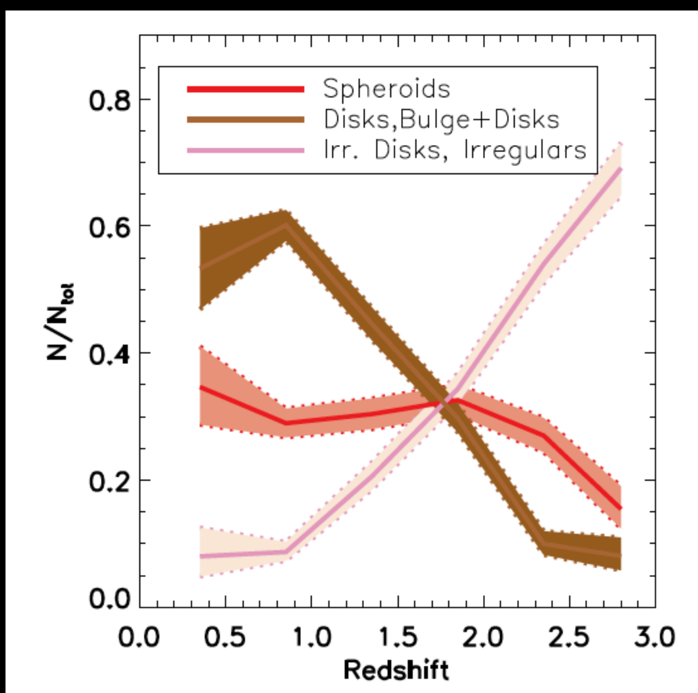
Massive galaxies become more disky/peucliar at higher redshifts



Oesch+10

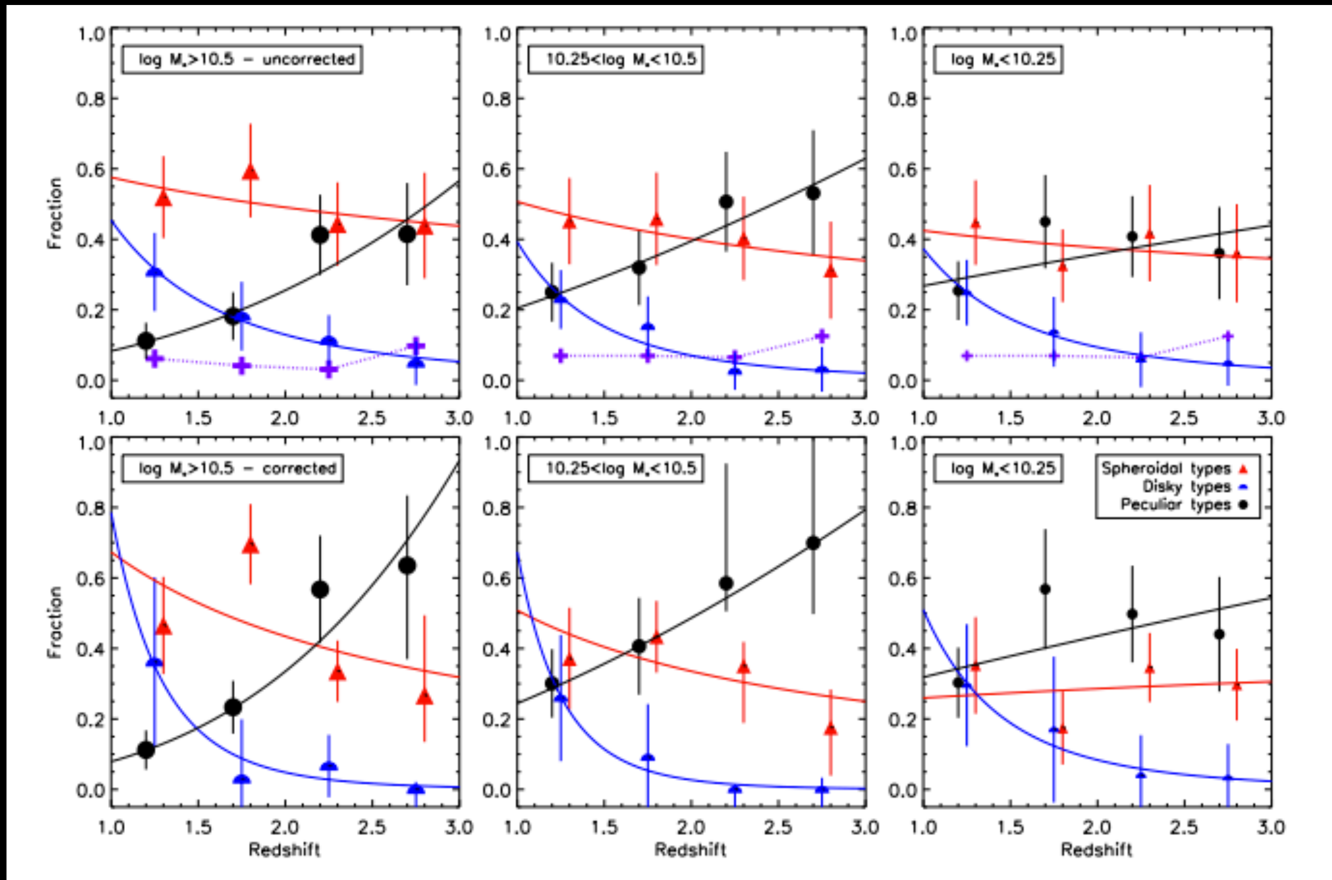


Buitrago+13



Huertas-Company+15

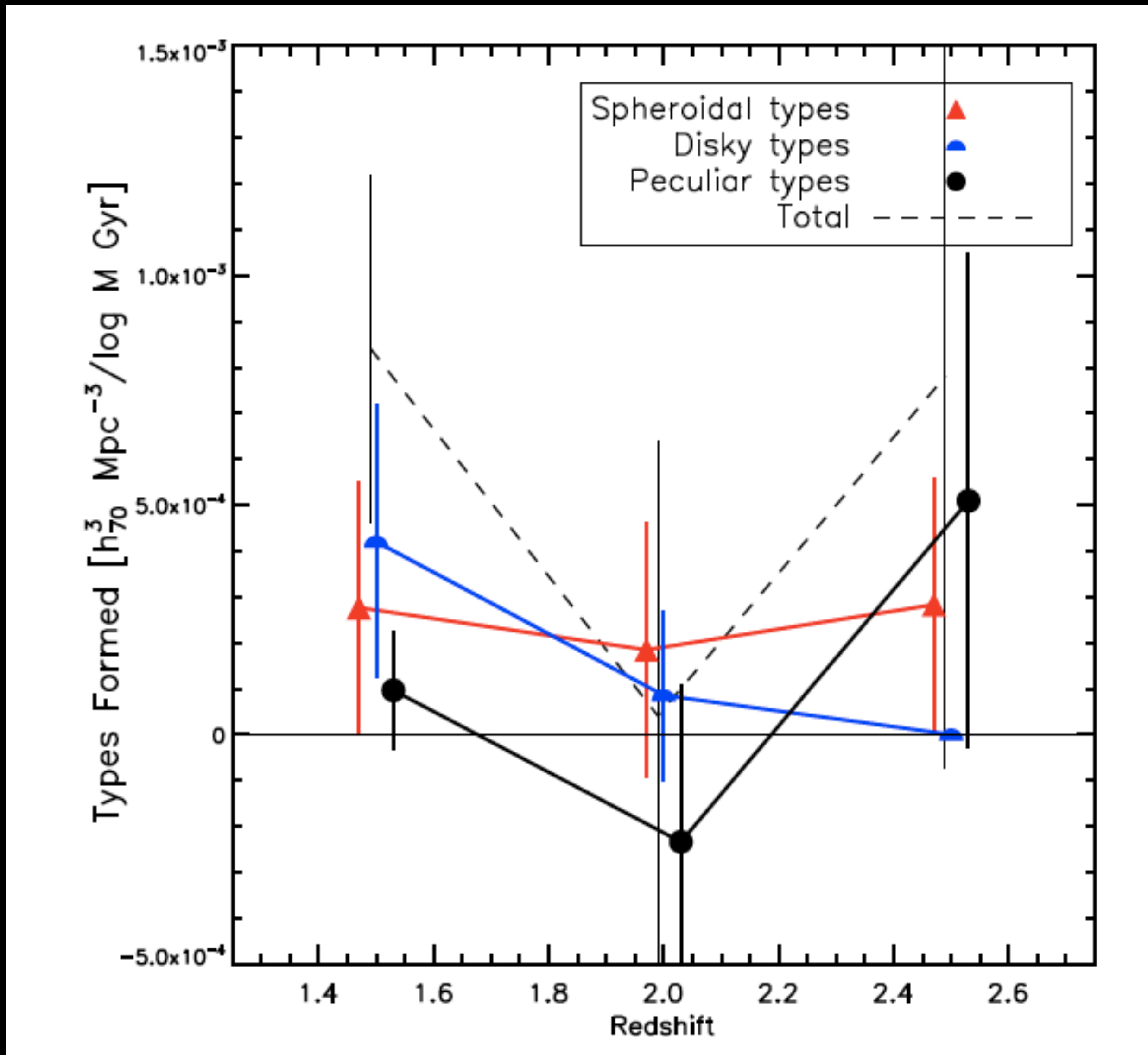
There is a dependence on stellar mass on morphological evolution



More massive systems become ‘Hubble-types’ before lower masses

$Z_{trans} \sim 1.85$

Rate of change in the formation of Hubble types



Roughly constant formation rate for E/Spirals at $1 < z < 3$

How can we form the disk/elliptical bifurcation?

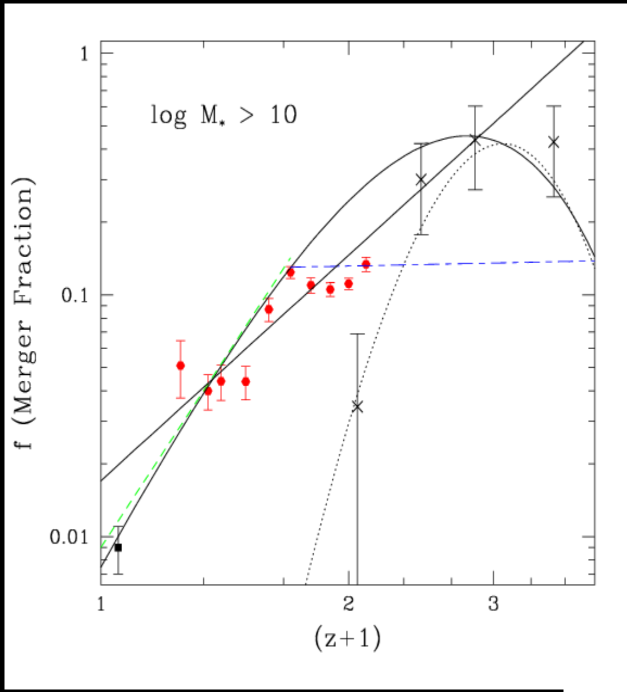
Possible Processes

- Mergers - two or more galaxies colliding to form a more massive system - can halt SF, changes morphology
- Harassment - high speed galaxy interactions removing mass (Moore et al. 1999) - unlikely to be important at low relative velocities (i.e., field galaxies), changes morphology
- Strangulation - removal of hot gas - halts star formation
- Ram pressure stripping - removing gas from disks due to traveling in an intragroup medium, depends upon group σ^2
- Non-gravitational processes (AGN, SNe) - hard to constrain observationally, but likely present

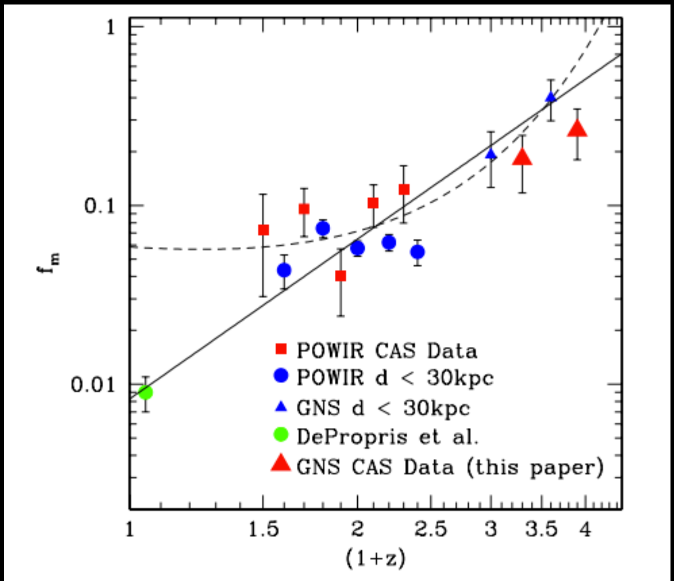
Galaxy Mergers

- Should be common - dynamical friction time-scale goes as (group σ) ^{3}
- ~250 km/s upper limit for dragging galaxies into center of a group over a Hubble time (groups at high-z common)
- Low redshift merger rate expected to be low, around 2% of galaxies in groups merge per Gyr (observed)
- At higher redshift the mass density increases as $H^2 \sim (1+z)^3$. Results in a higher merger rate of $\sqrt{(\rho)} \sim (1+z)^{1.5}$

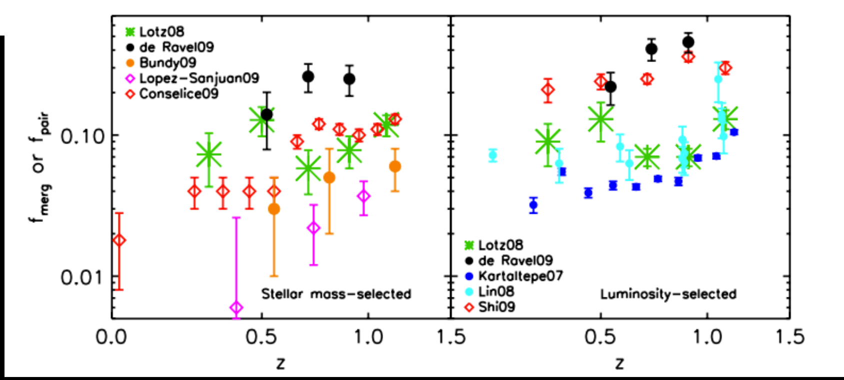
Major mergers – measure with structure



Conselice+09



Bluck+12



Lotz+11

Mergers evolve as $(1+z)^{1\text{-}3}$ to z = 3

Number of Major Mergers

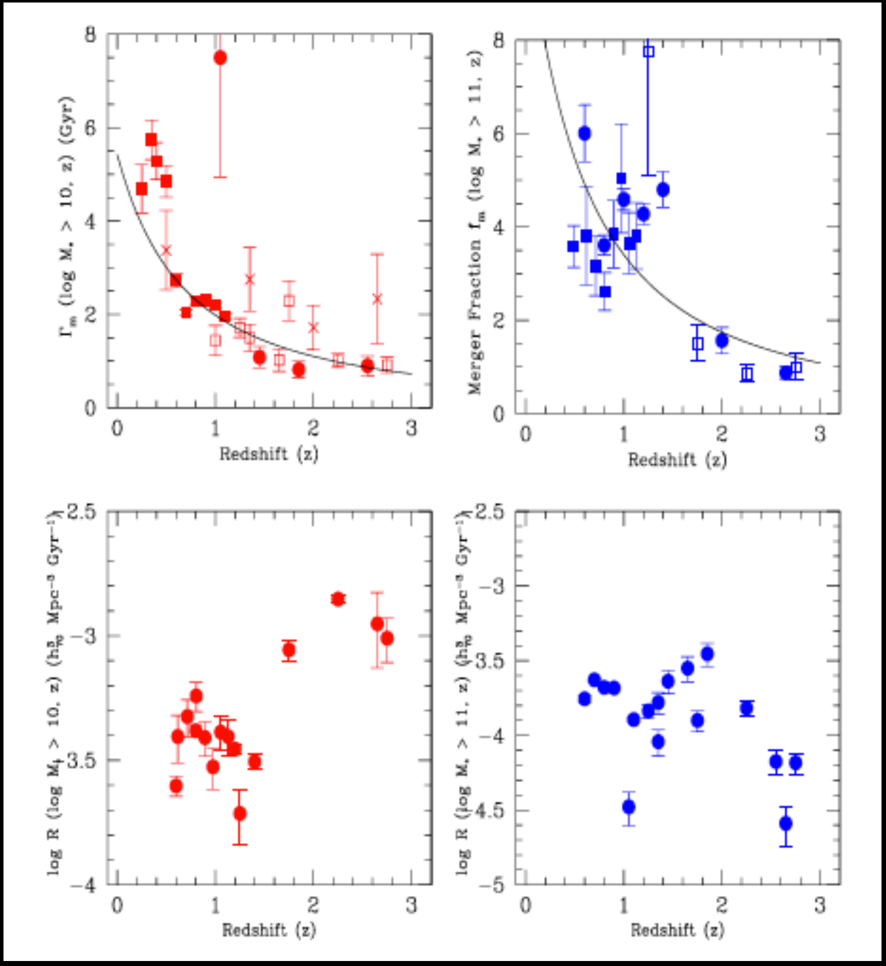
(for stellar mass selected samples, Conselice 2014, ARAA)

The number of mergers an average massive galaxy will undergo from z = 3 to z = 0 can be calculated via:

$$N_m = \int_{t_1}^{t_2} \frac{1}{\Gamma(z)} dt = \int_{z_1}^{z_2} \frac{1}{\Gamma(z)} \frac{t_H}{(1+z)} \frac{dz}{E(z)}$$

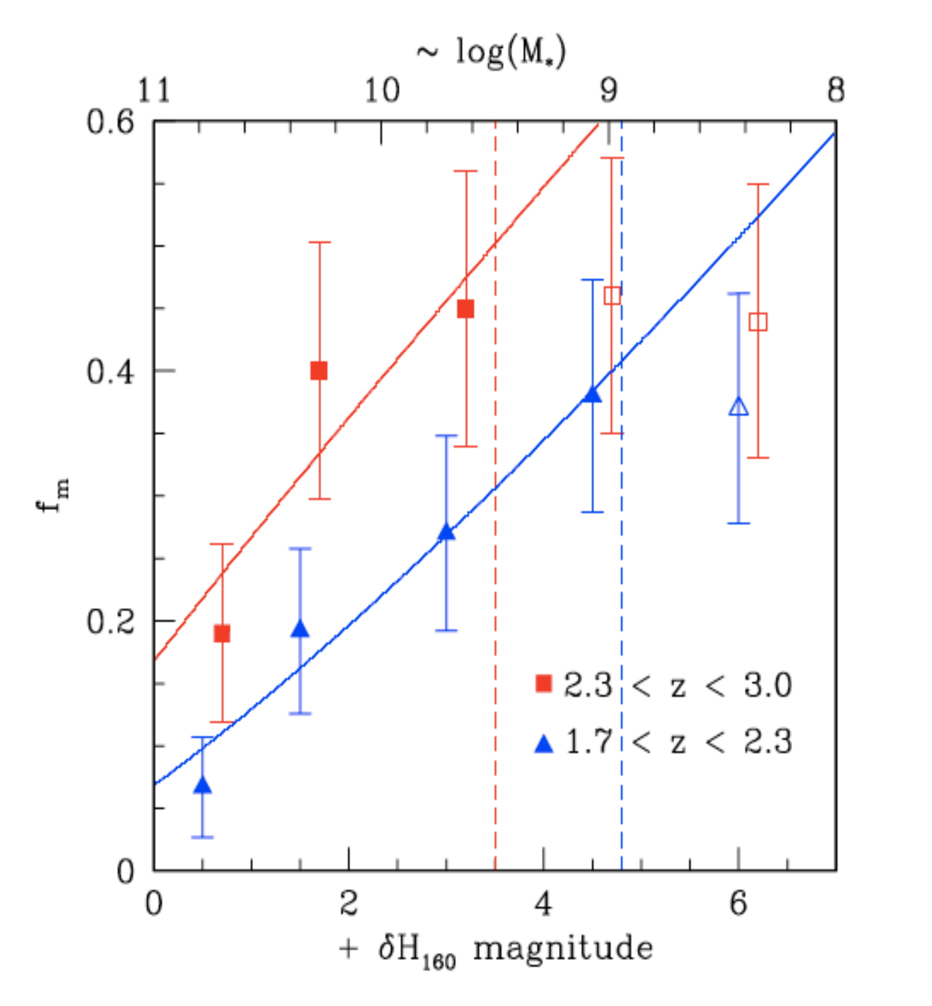
For our best fit for Γ(z), integrating over the redshift range of our galaxies we obtained:

N = 1.7 +/- 0.5
(Major mergers / Galaxy)



Roughly doubles the stellar masses of galaxies from z=0 to 3

Are there minor mergers?

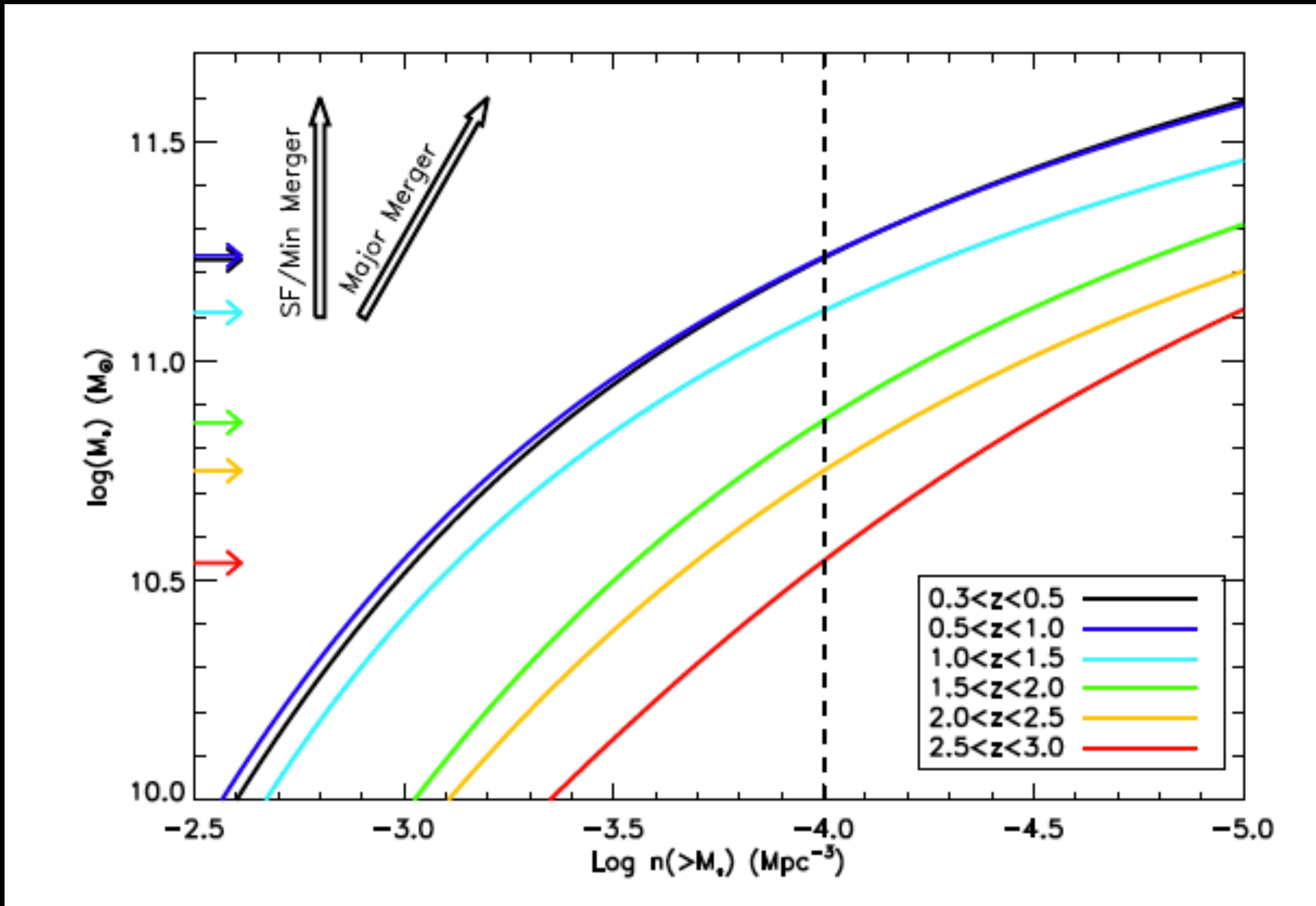


More minor mergers add about the same mass as major mergers

Total mass added from all mergers from 1<z<3 is around 50% for a mass selected sample

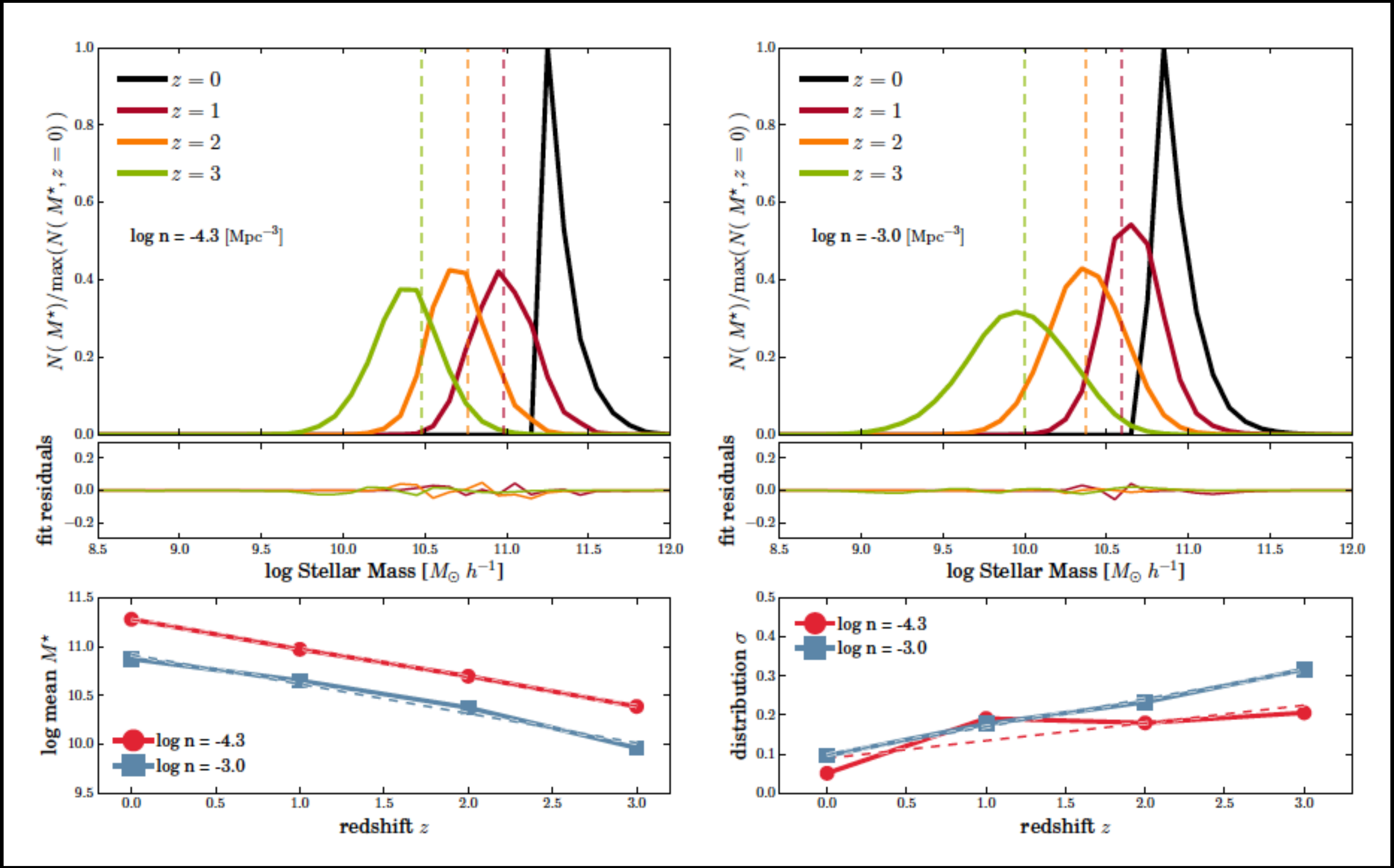
Bluck+12

Want to trace the same galaxies over time



At constant mass selection only 3% of galaxies in a z=0.4 sample would be in a z = 3 selection - a significant progenitor bias

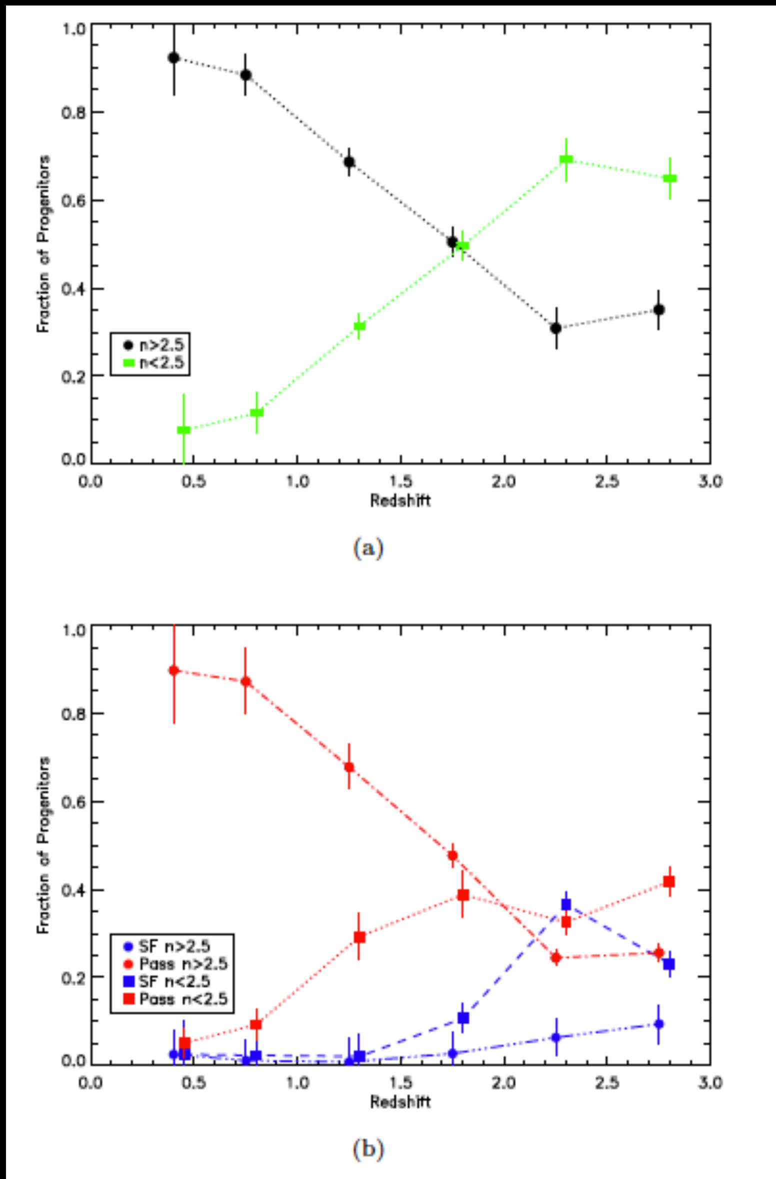
Evolution of z=0 massive galaxy selection



There is no 1:1 mapping, but a large scatter

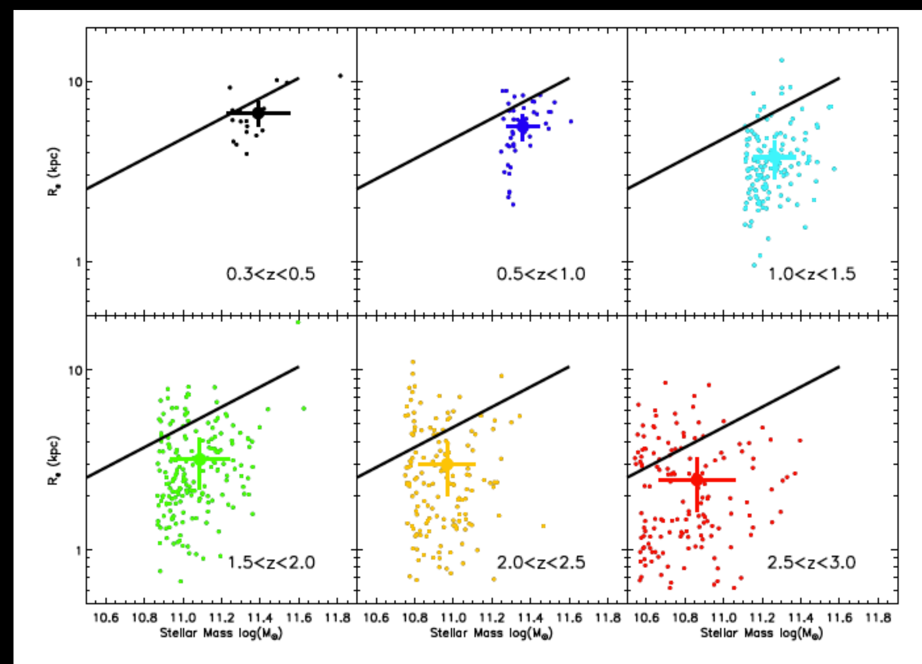
Mundy et al. 2015

Using a constant number density selection



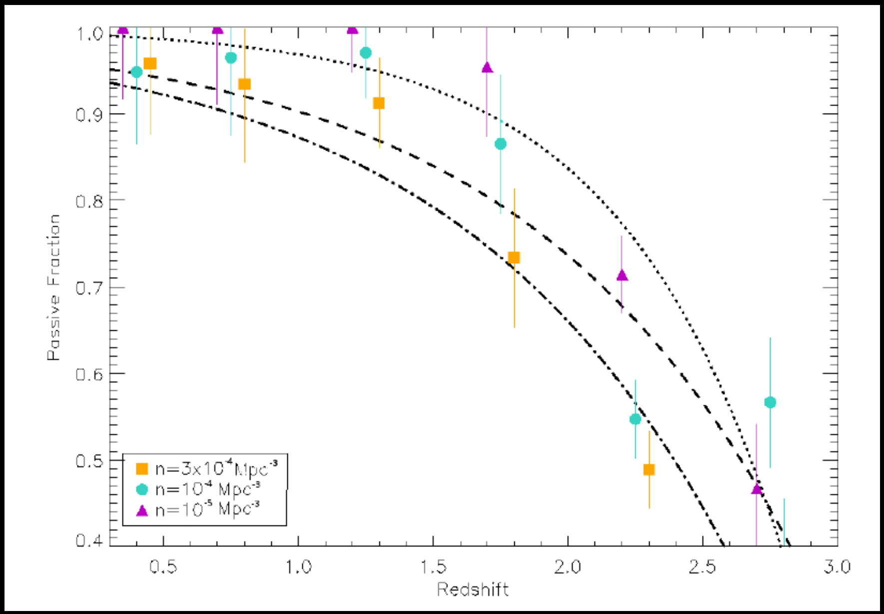
Morphological evolution

Shows strong change in the Sersic indices for any selection and a progression of moving from low n galaxies to high n red systems

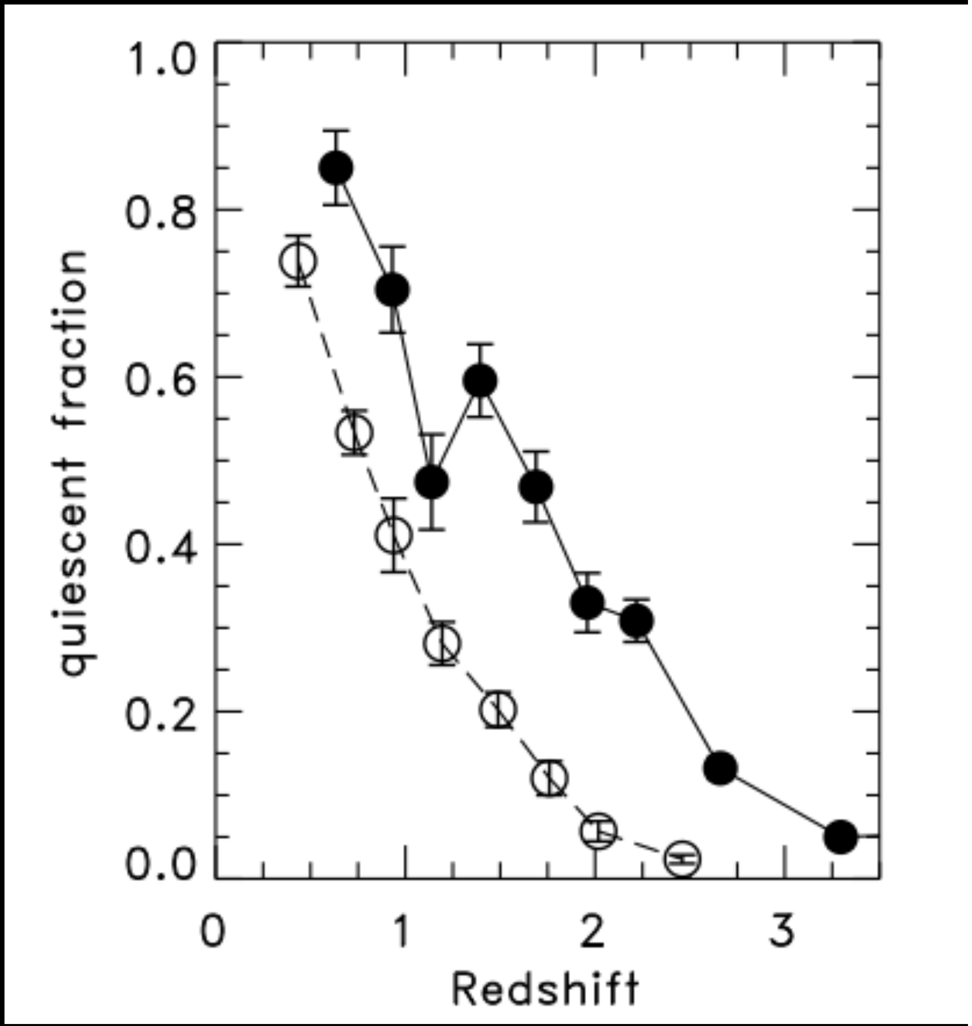


Not as strong size evolution

Passive fraction increases at lower-z

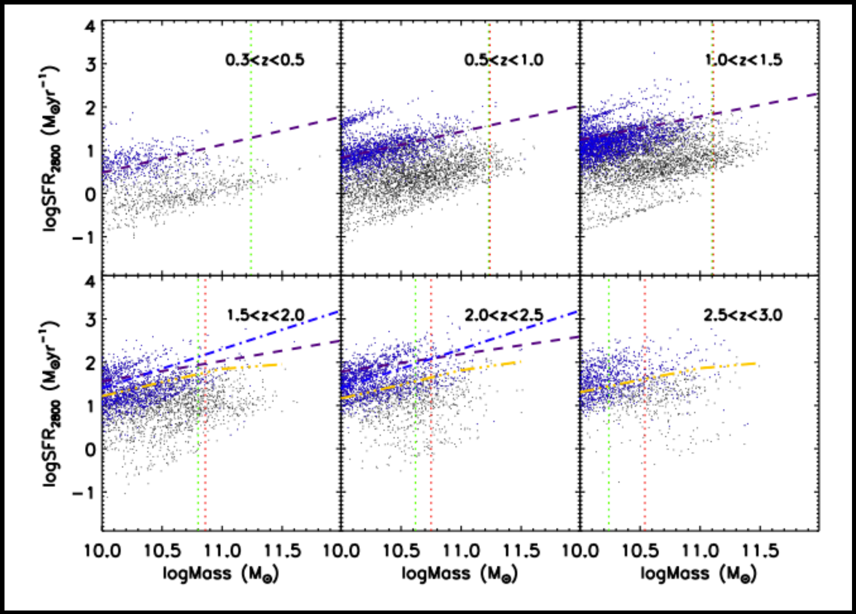


Ownsworth+15

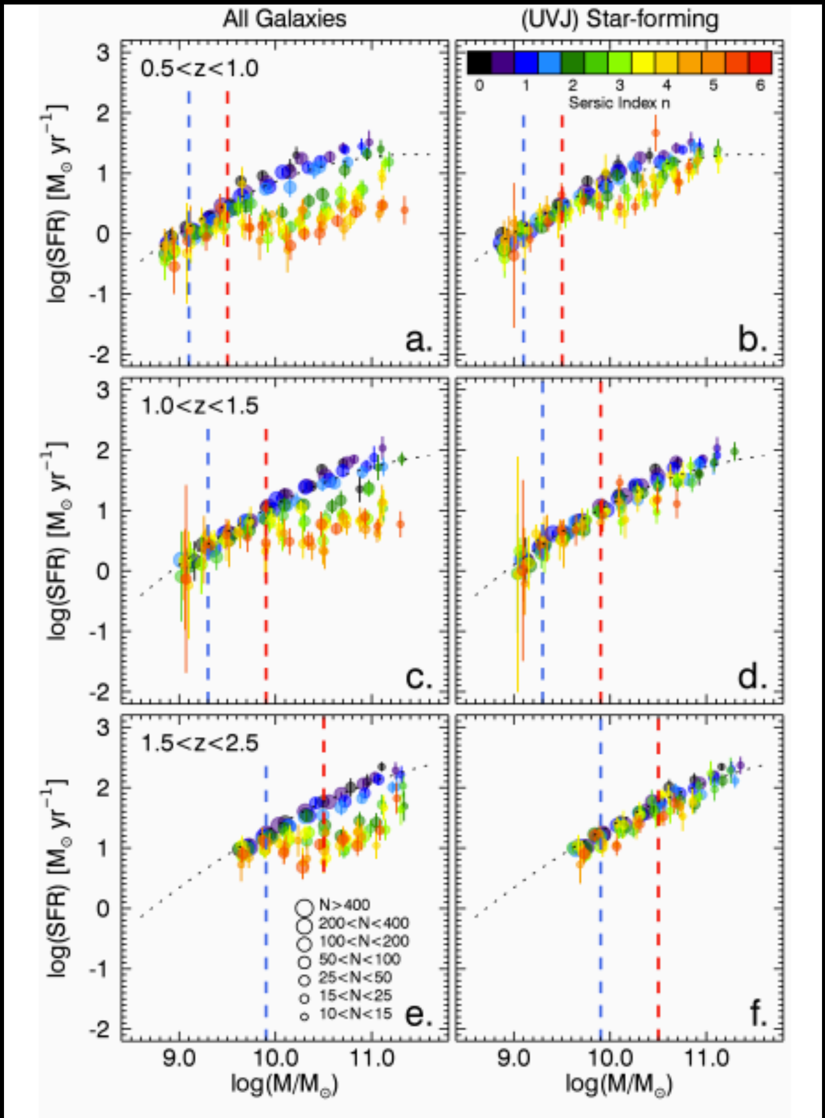


Papovich+15

The star formation rates as a function of stellar mass

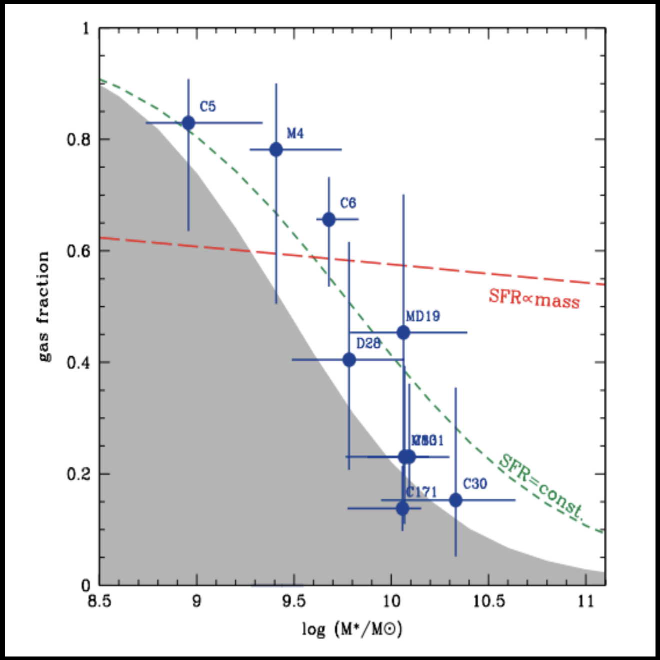


Ownsworth+14

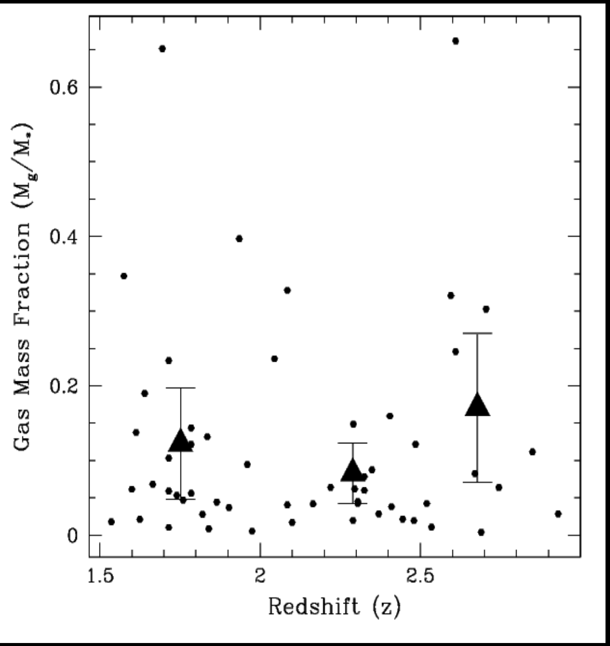


Whitaker+15

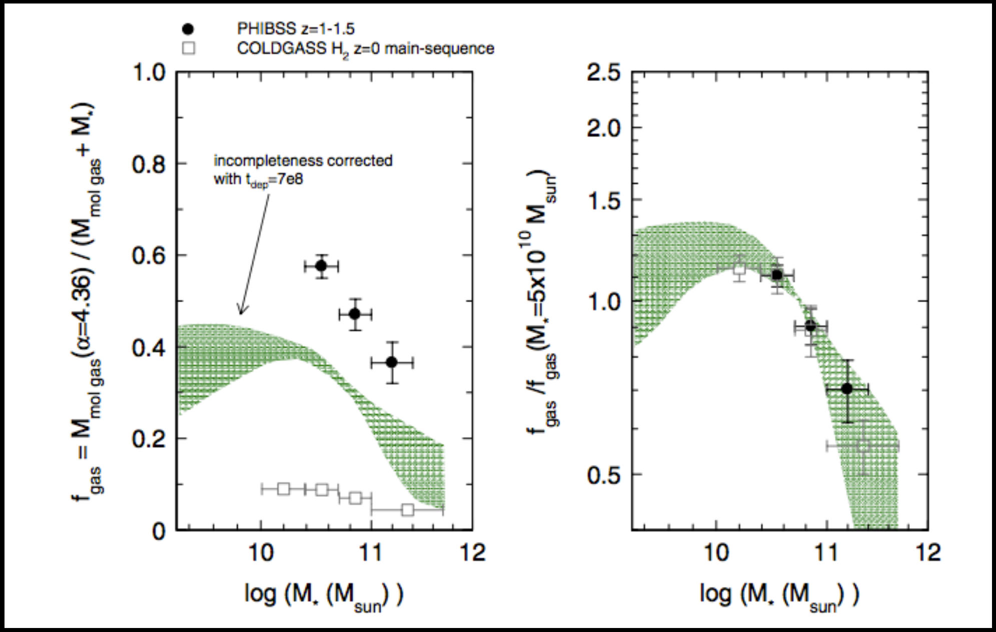
Gas mass fractions



Mannucci+09



Conselice+13



Tacconi+13

Do we have a consensus about how massive galaxies form at 1.5 < z < 3?

$$M_*(t) = M_*(0) + M_{*,M}(t) + <\psi> \delta t$$

Stellar mass evolution

$$M_g(t) = M_g(0) + M_{g,M}(t) + M_{g,A}(t) - <\psi> \delta t$$

Gas mass evolution

$$\frac{M_g(t)}{M_*(t)} \sim \frac{M_g(0)}{M_*(0)}$$

Observed condition

$$M_{g,A}(t) = (1.18 \pm 0.21) \times M_g(0) + <\psi> \delta t - M_{g,M}(t)$$

Amount of gas accreted

Integrate: Mass added from SF ~ Mass added from major merging

However - gas mass fraction for log M > 11 is less than 0.2

The amount of gas added from accretion (or <u>very</u> minor mergers)

$$M_{g,A}(t) = (1.18 \pm 0.21) \times M_g(0) + <\psi> \delta t - M_{g,M}(t)$$

$$\frac{M_{g,A}(t)}{M_*} = \frac{(1.18 \pm 0.21) \times M_g(0)}{M_*} + \frac{<\psi> \delta t}{M_*} - \frac{M_{g,M}(t)}{M_*}$$

$$M_{g,A}/M_*(0) = 0.83 \pm 0.37$$

Over $1.5 < z < 3$ (2.16 Gyr)

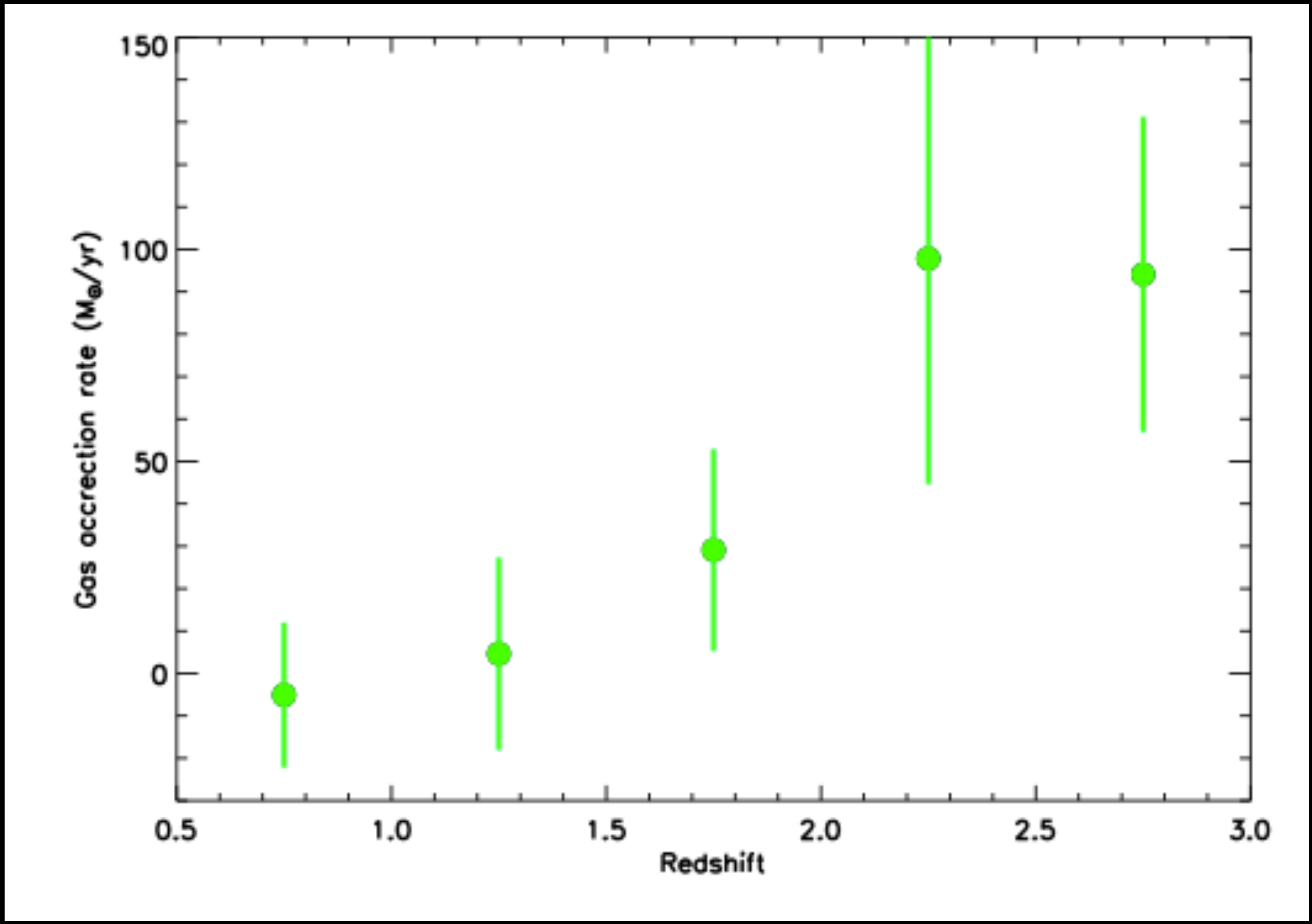
$$(1.6 \pm 0.5) \times 10^{11}\ M_\odot$$

Average amount of gas accreted

Results in accretion rate of

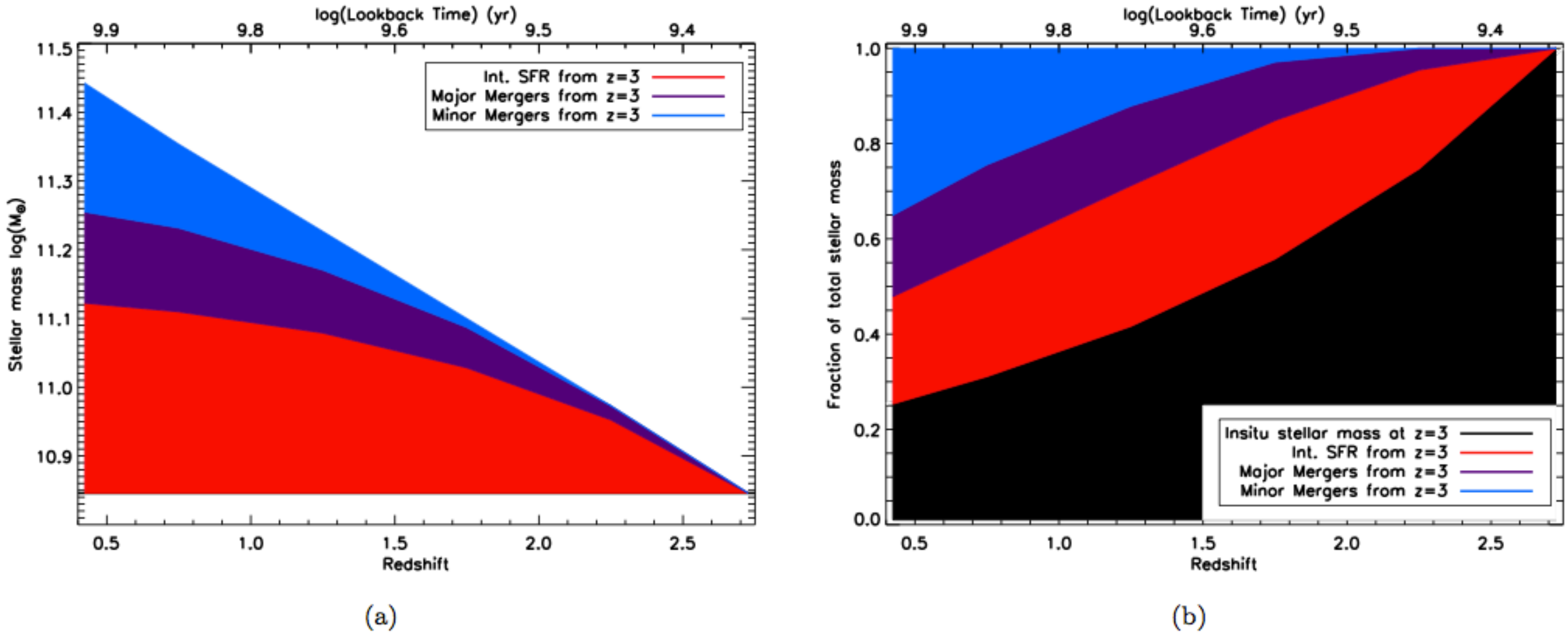
$$\frac{dM_{g,A}(t)}{dt} = \dot{M}_{g,A} = (83 \pm 36)\, M_\odot\, yr^{-1}$$

Gas accretion rate history for massive systems over cosmic time



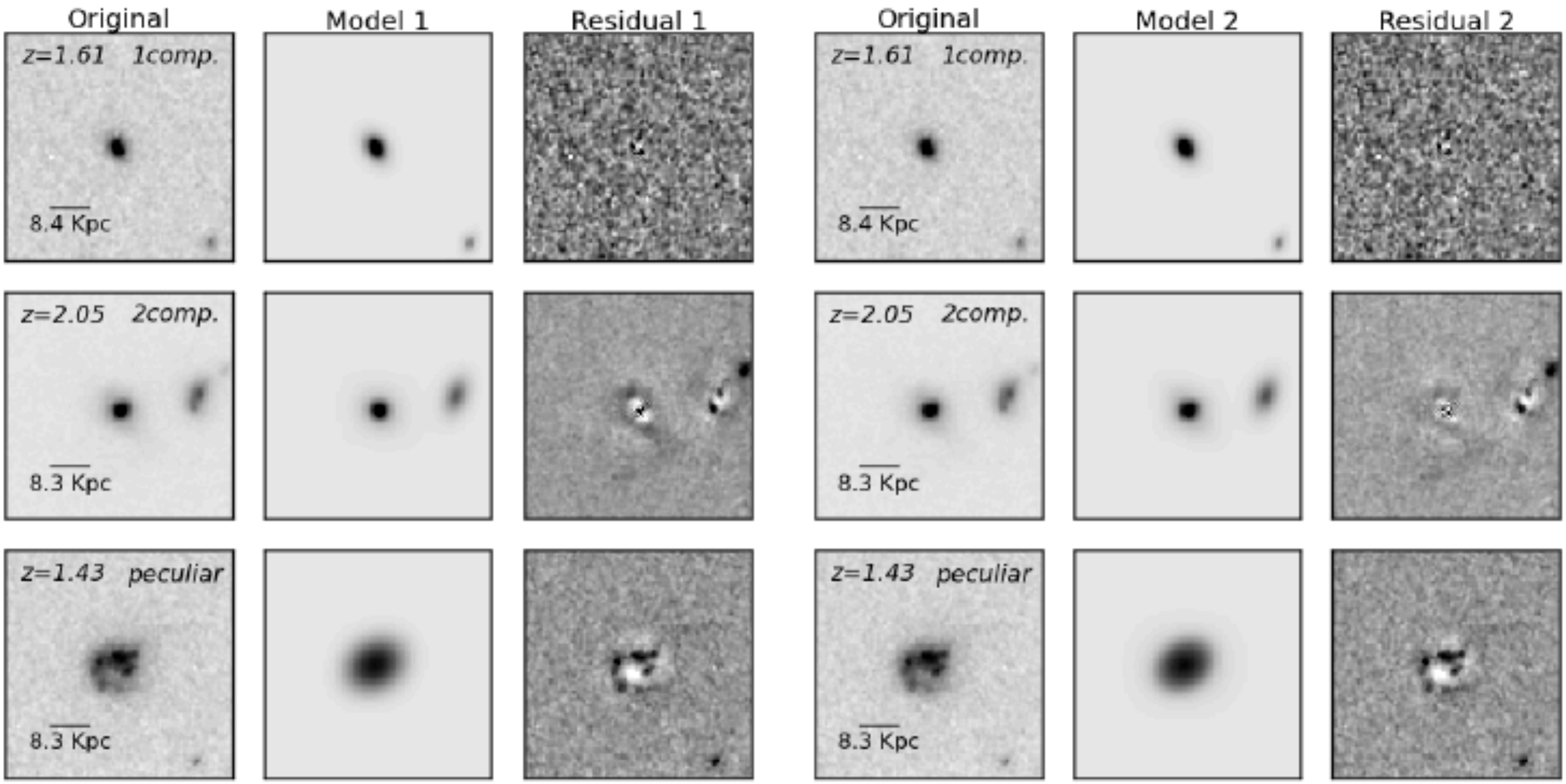
Ownsworth+14

Can determine the relative contributions to massive galaxy formation from z = 3

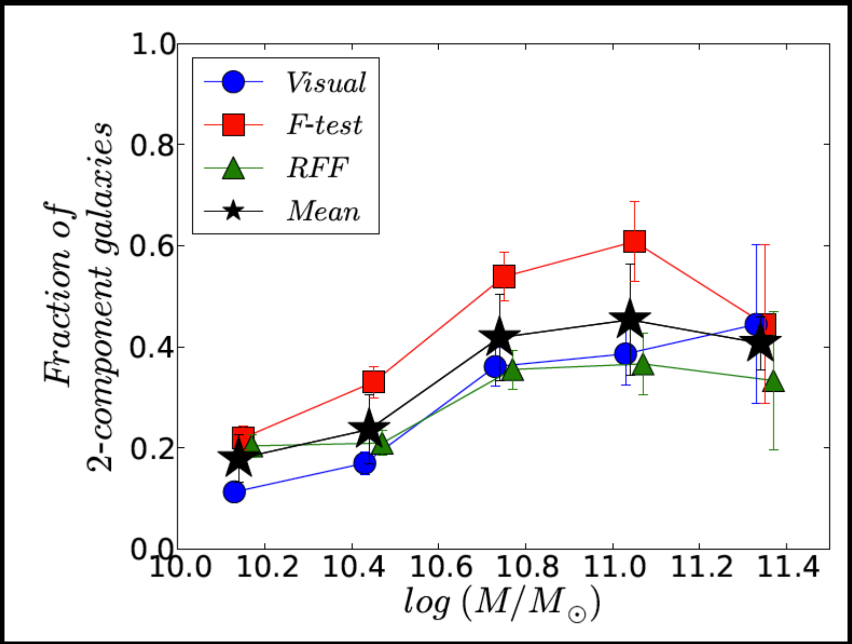


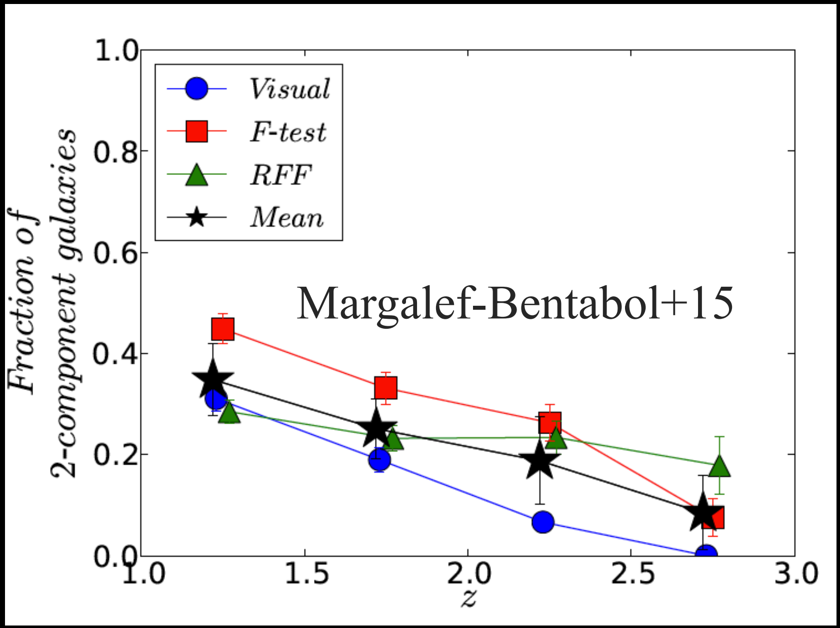
Mergers only ~50% of formation of stellar mass since z ~3

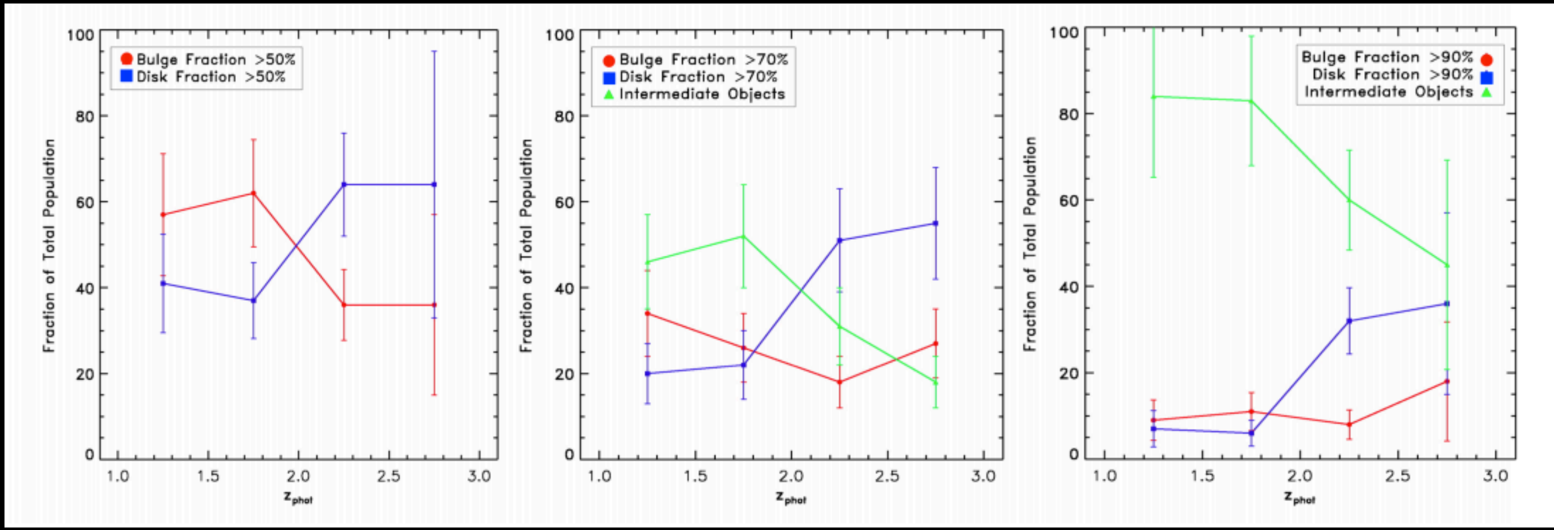
Bulges and disks at high-z



Two component galaxy evolution at 1 < z < 3

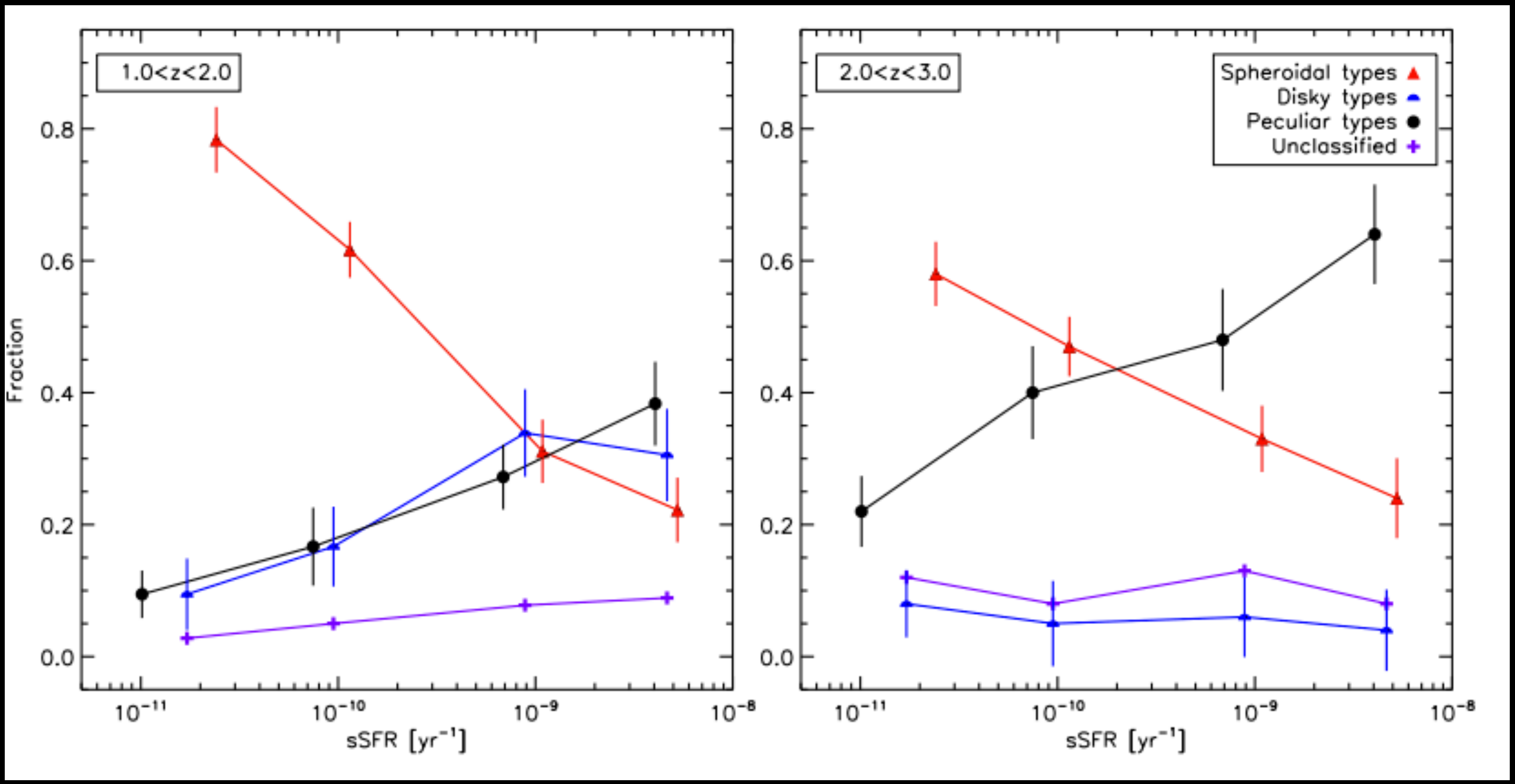




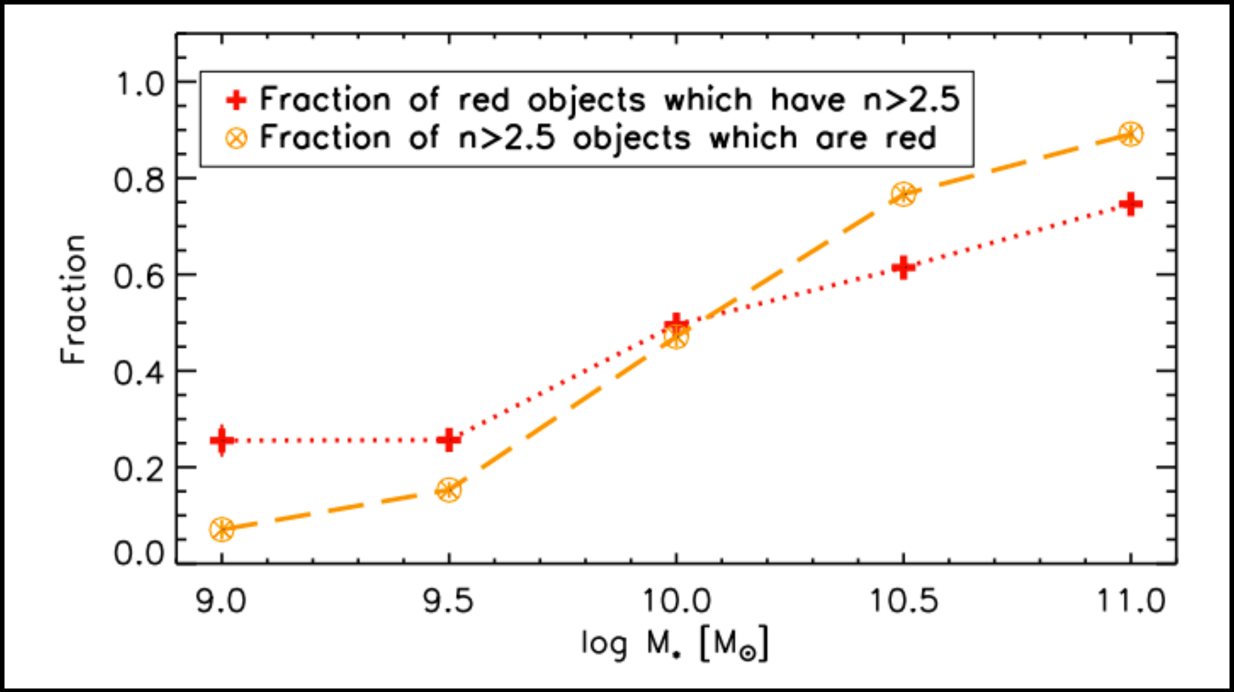


Bruce+12

How does structure drive galaxy assembly?

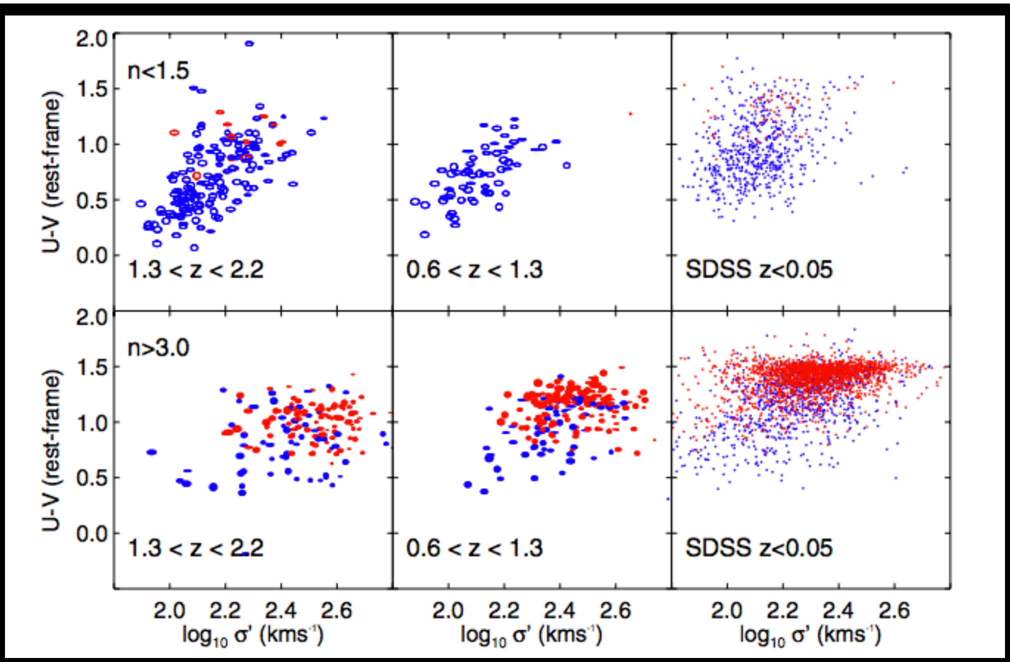


Peculiars dominate the fraction of high sSFR systems at z > 2



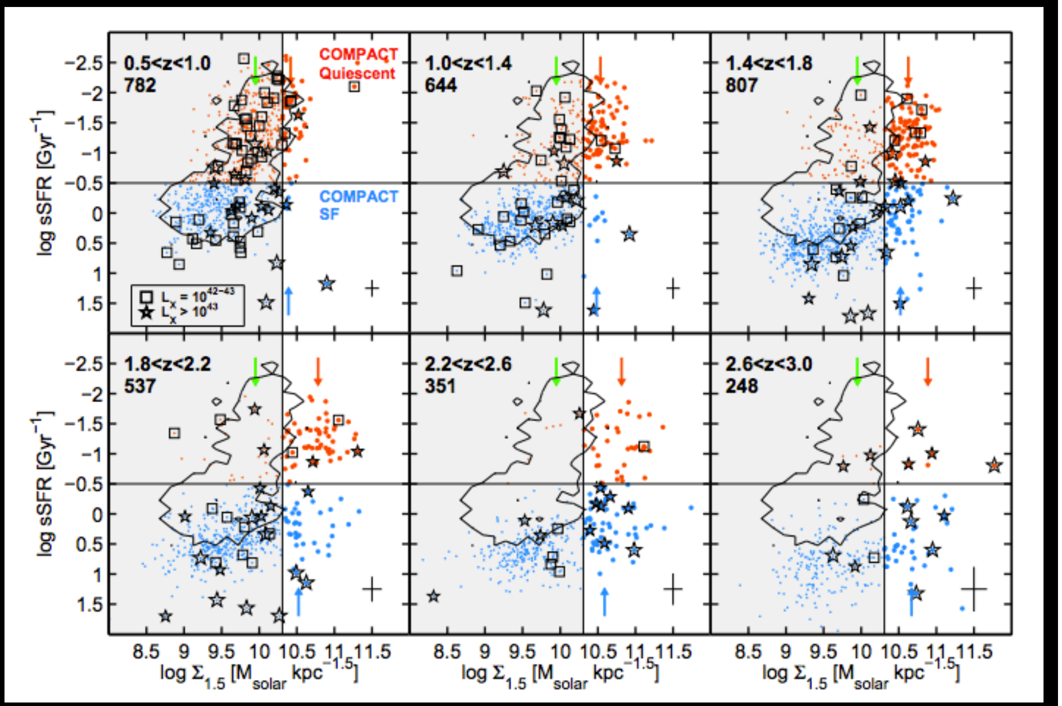
Quenching and structure at z~2

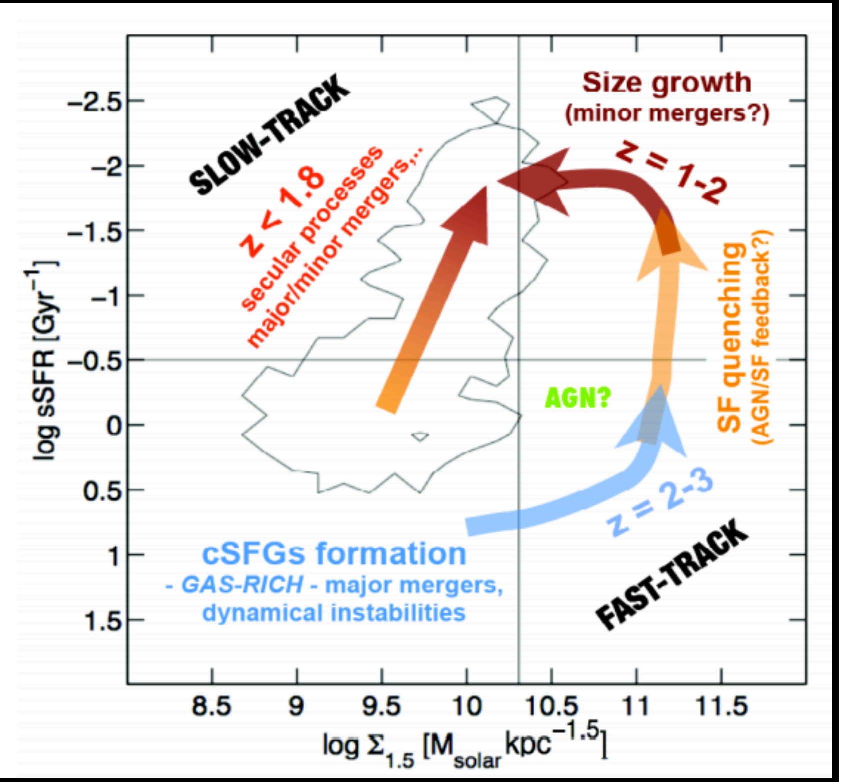
Mortlock+15



Bell+12

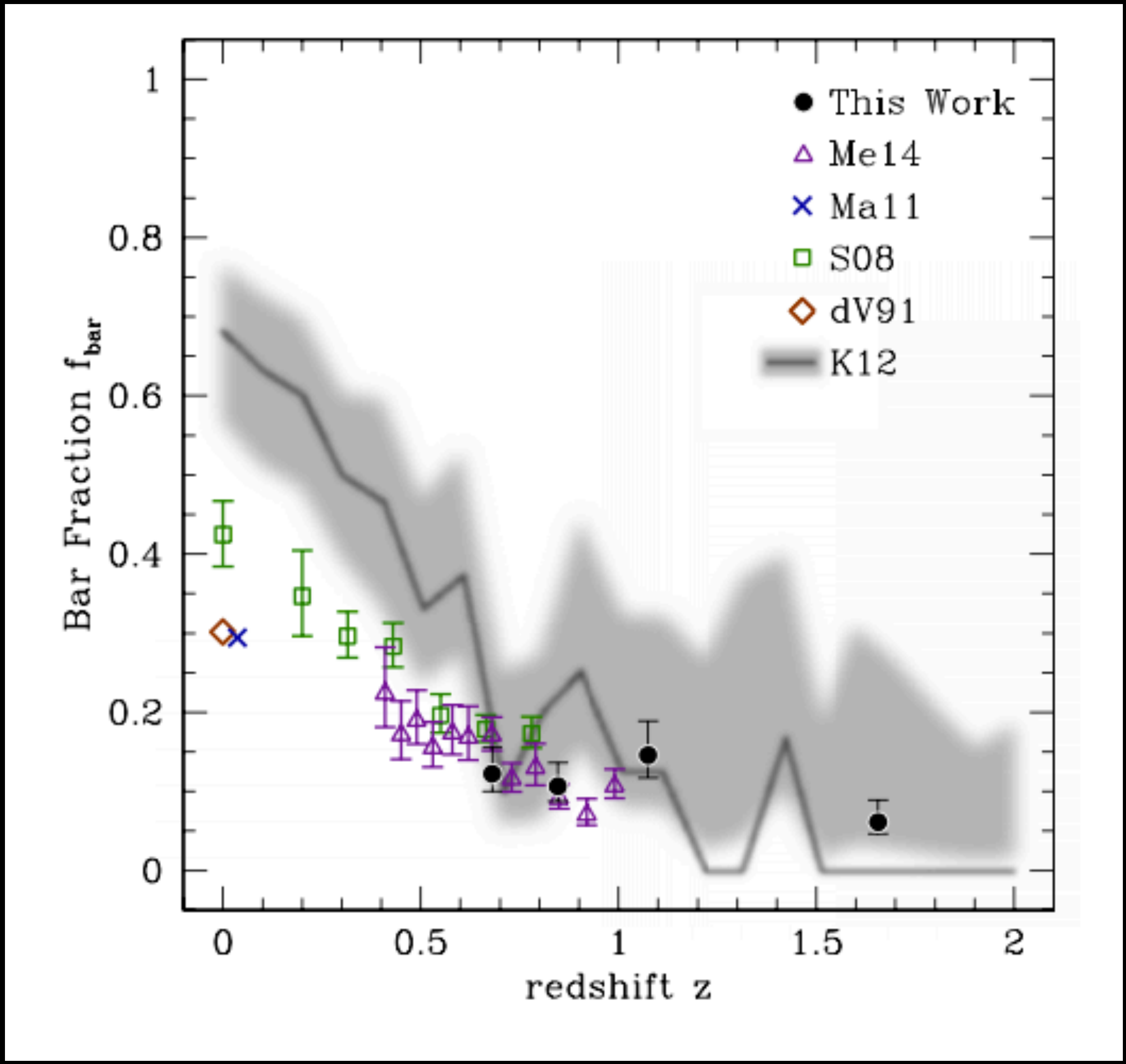
Relation to surface mass density



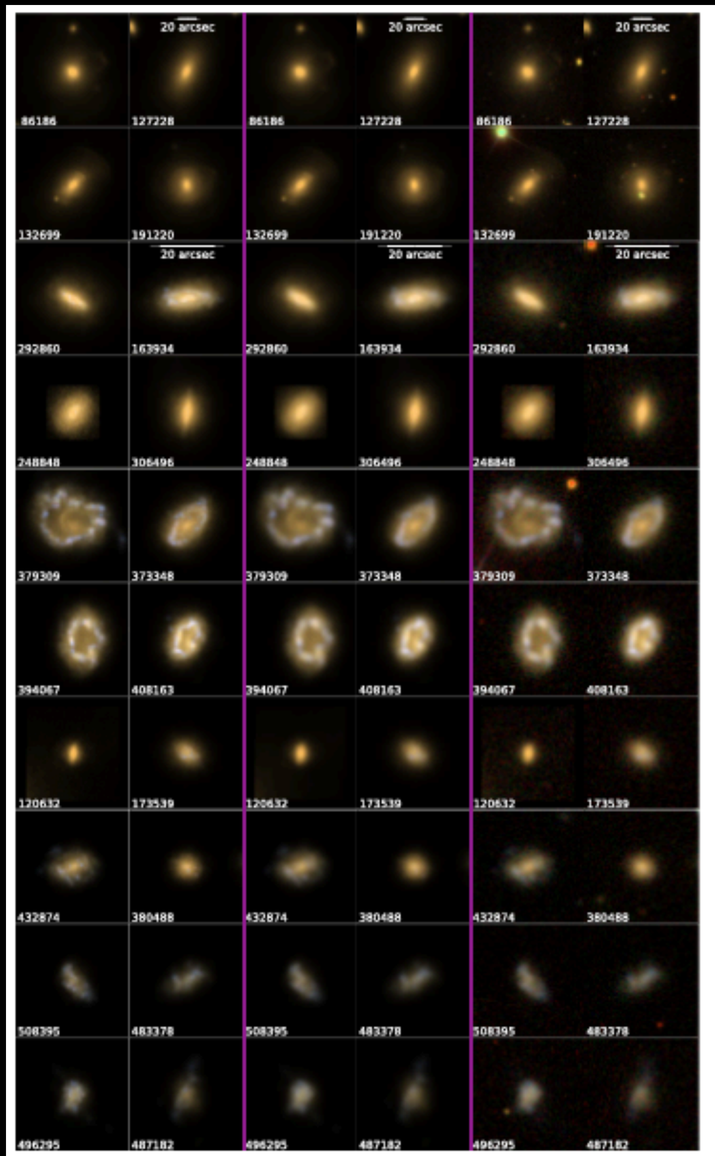


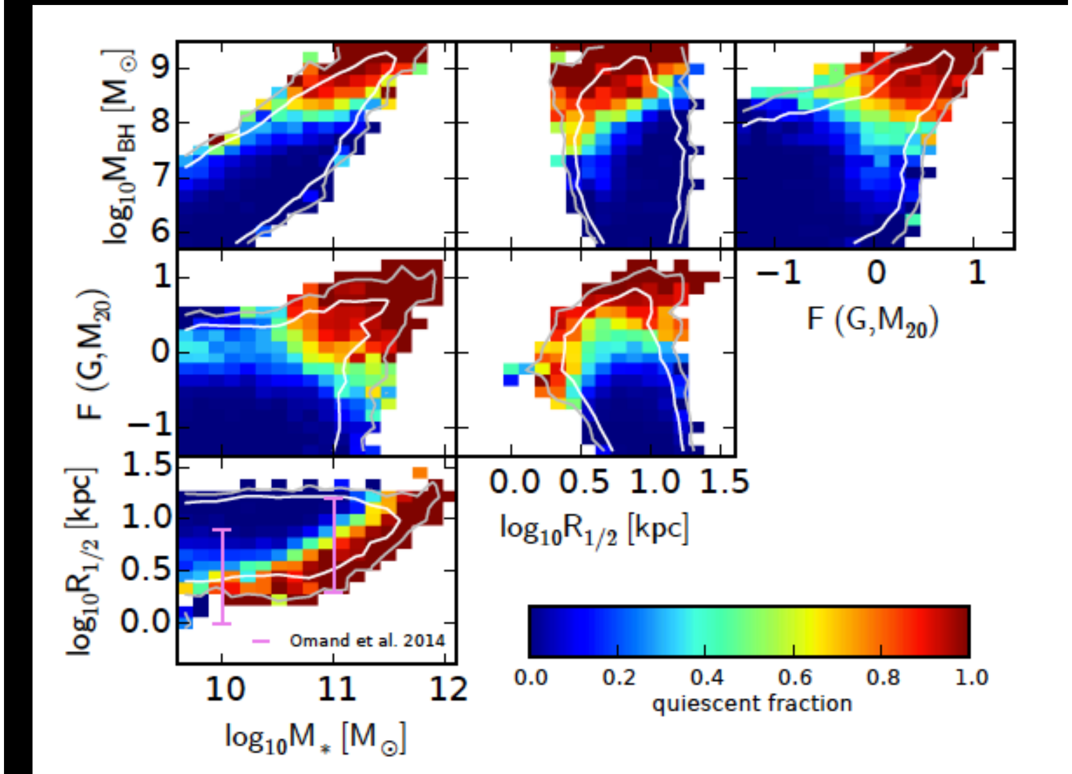
Barro+13

Bars in galaxies at z < 2



Simmons+15





Can almost match distribution
Seen in real galaxies

Illustris simulation (Snyder+15)

Q3: Quenching and morphology/structure

- Is there a disk-spheroid structural dichotomy in most galaxies?
- Can disks be transformed into spheroids except through major mergers?
- Is the stellar mass growth produced in major mergers important?
- Do bars and spiral structure play an important role in galaxy evolution?
- What are the timescales for morphological/structural changes?
- How closely are star-formation activity and morphology/structure correlated?
- How does structure/morphology change when galaxies cease forming stars, and is this just superficial (in light) or profound (involving mass redistribution)?
- Does the structure, e.g. surface density, physically drive the quenching process(es)?
- Is the link between structure/morphology and sSFR cause or effect and how is this linked to size evolution?