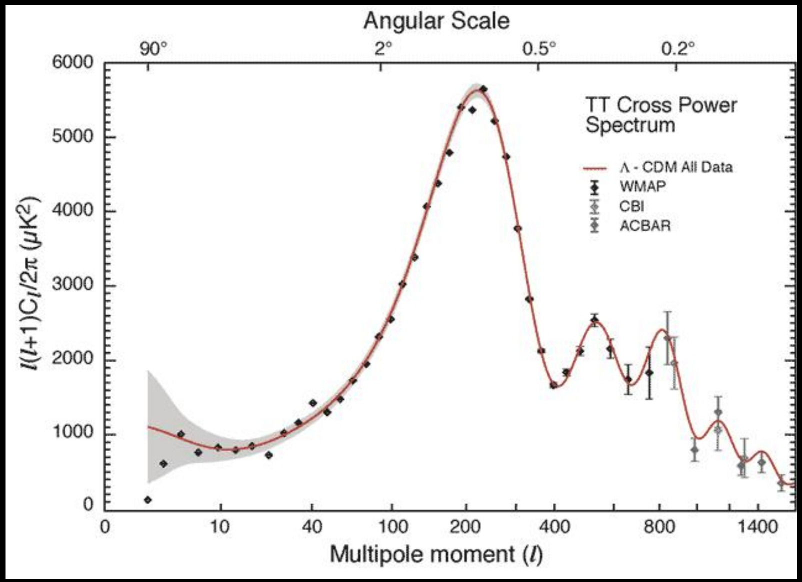
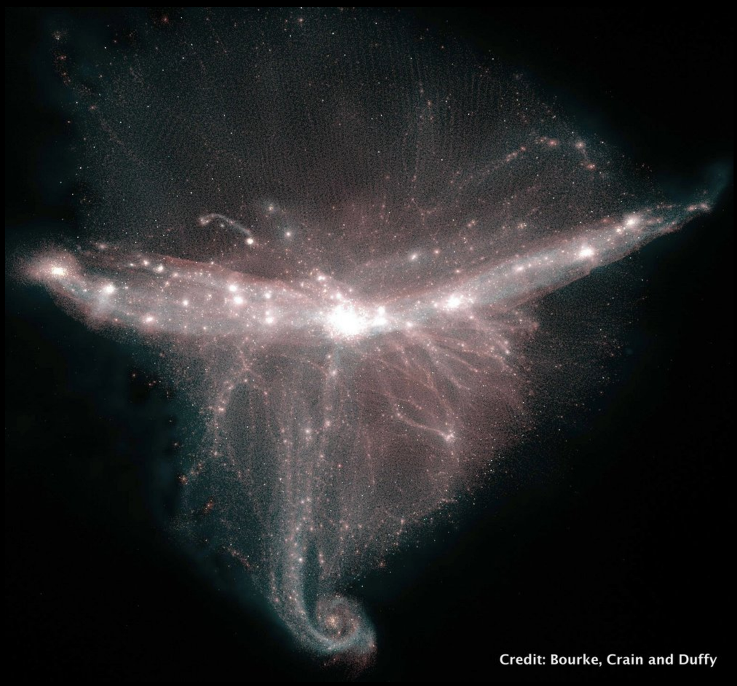
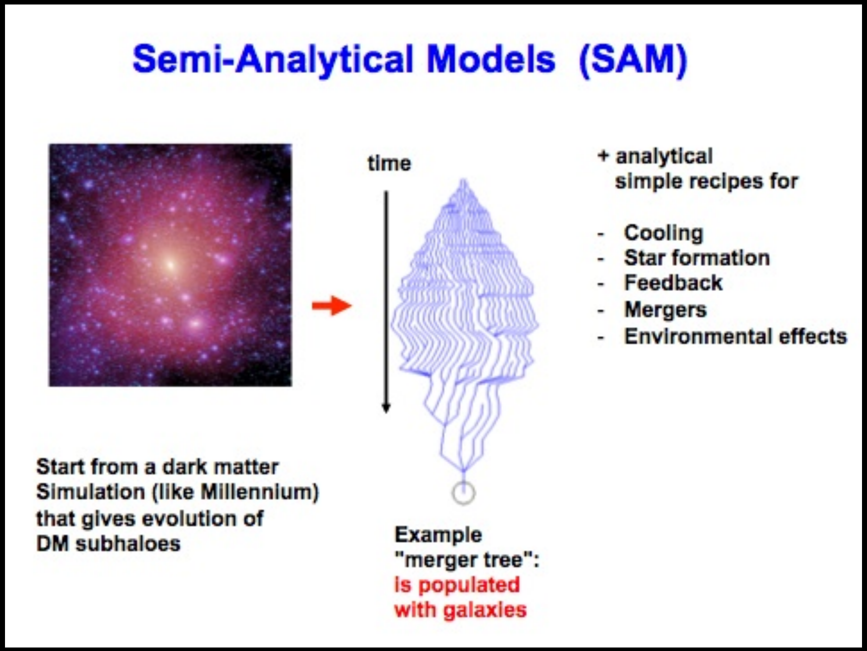
Using Deep NIR imaging to Probe The History of Galaxy Mergers

Christopher J. Conselice

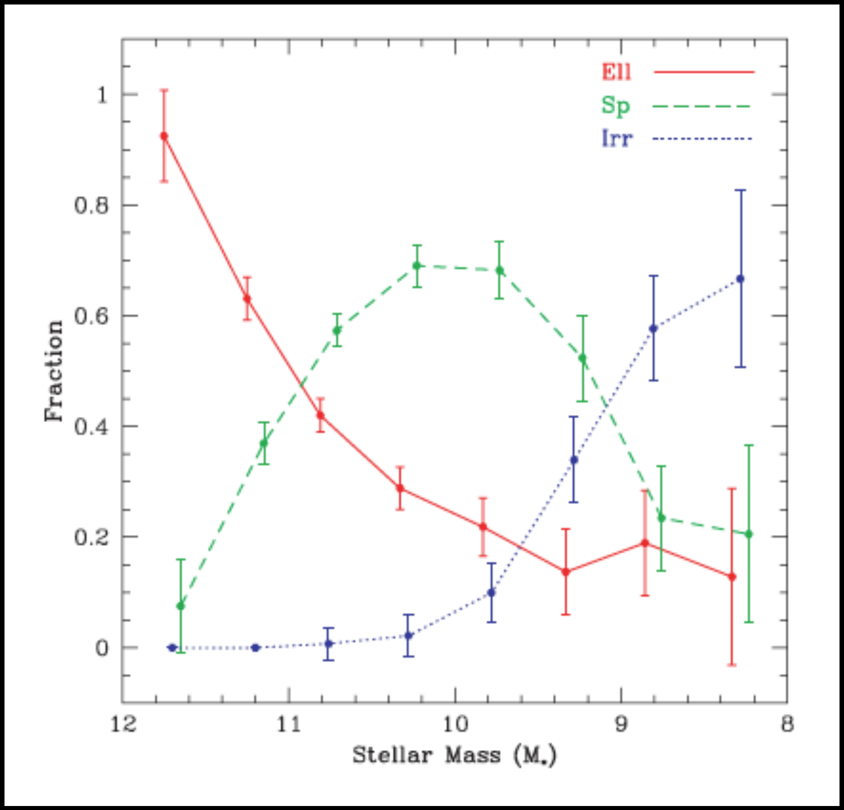


Galaxy Formation in CDM predicts a hierarchical formation of galaxies

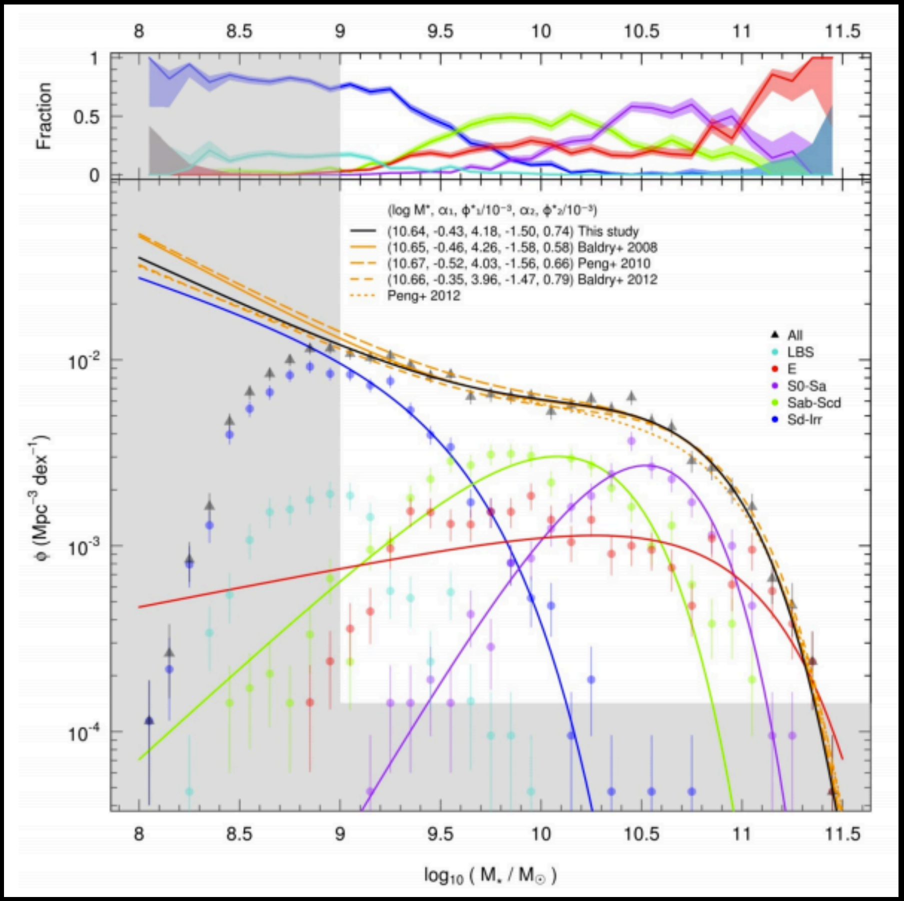




End product of galaxy formation highly regulated and dependent on stellar mass for reasons that are not understood

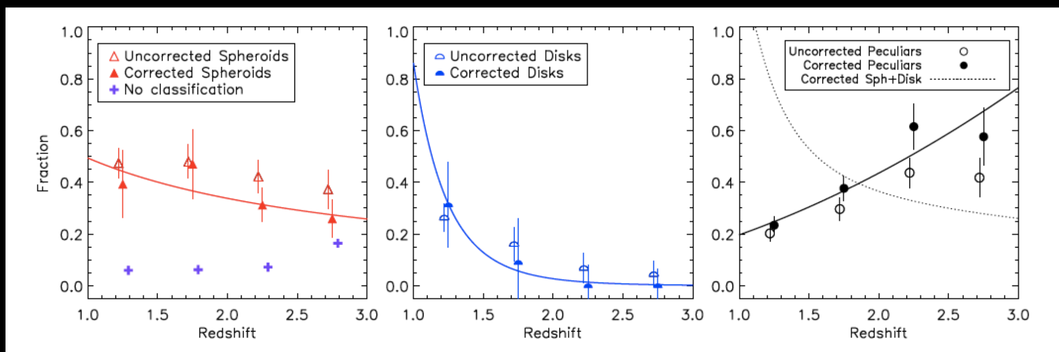


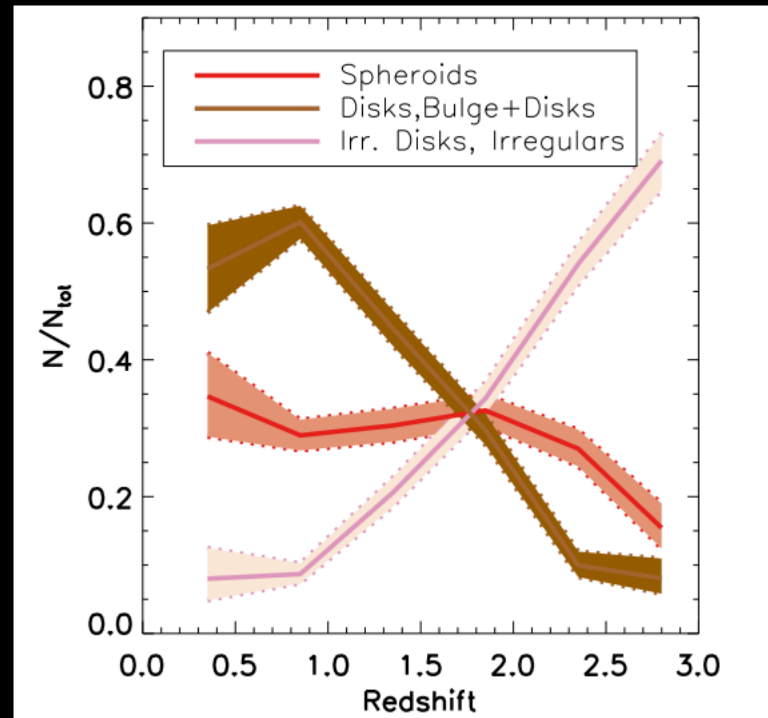
Conselice 06



Kelvin+ 2014 (GAMA)

The morphological evolution of galaxies in CANDELS





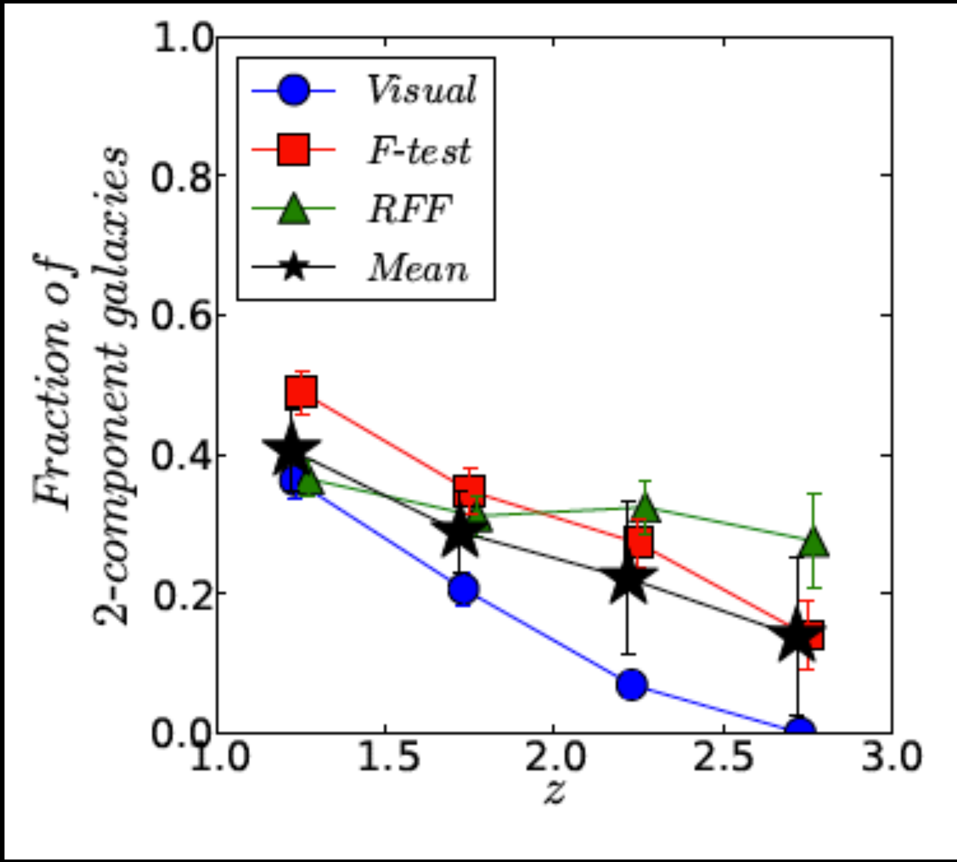
Note that visually determined disks are a very small fraction at z > 2
Peculiar galaxies dominate the population

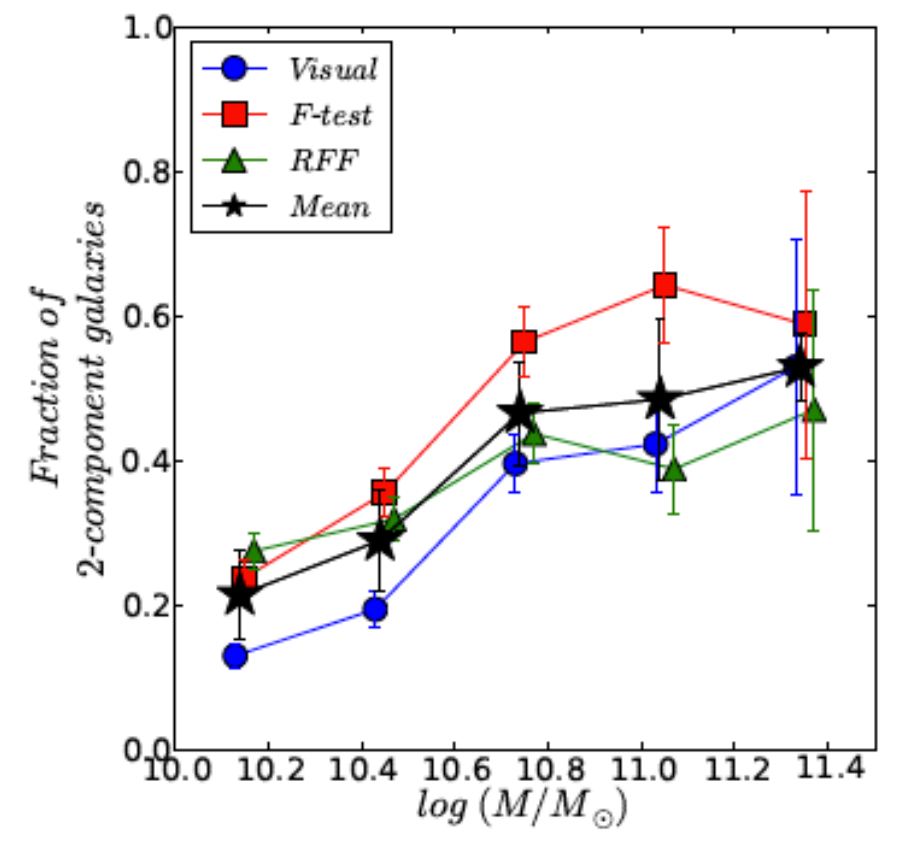
For log M > 10 systems

Mortlock, CC et al. (2015), Huertas-Company+15

Evolution of 2-components and changes with stellar mass

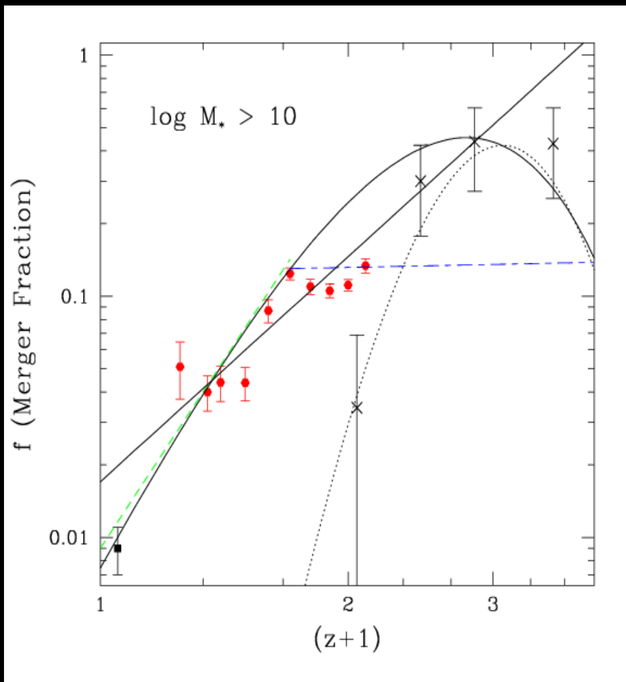
Fewer 2 component galaxies at higher redshift



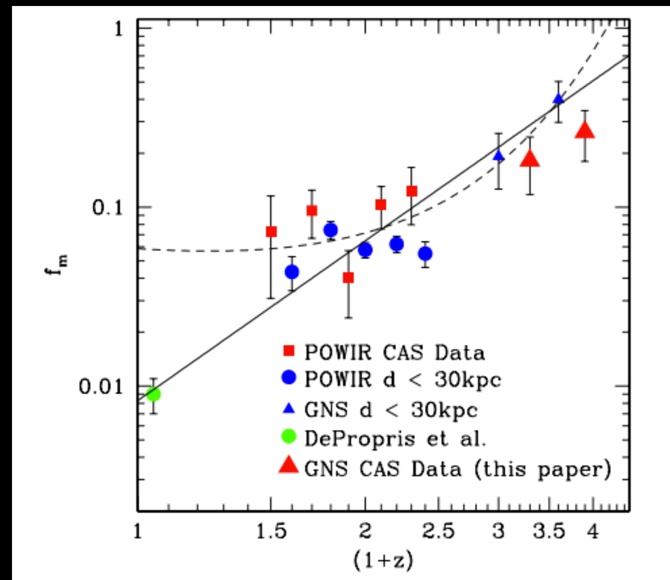


Margalef-Bentabol, CC+16

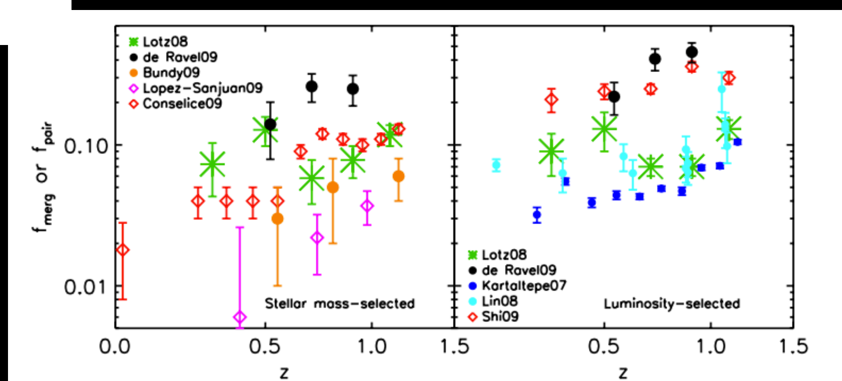
Major mergers – measure with structure



Conselice+09



Bluck+12



Lotz+11

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

Number of Major Mergers

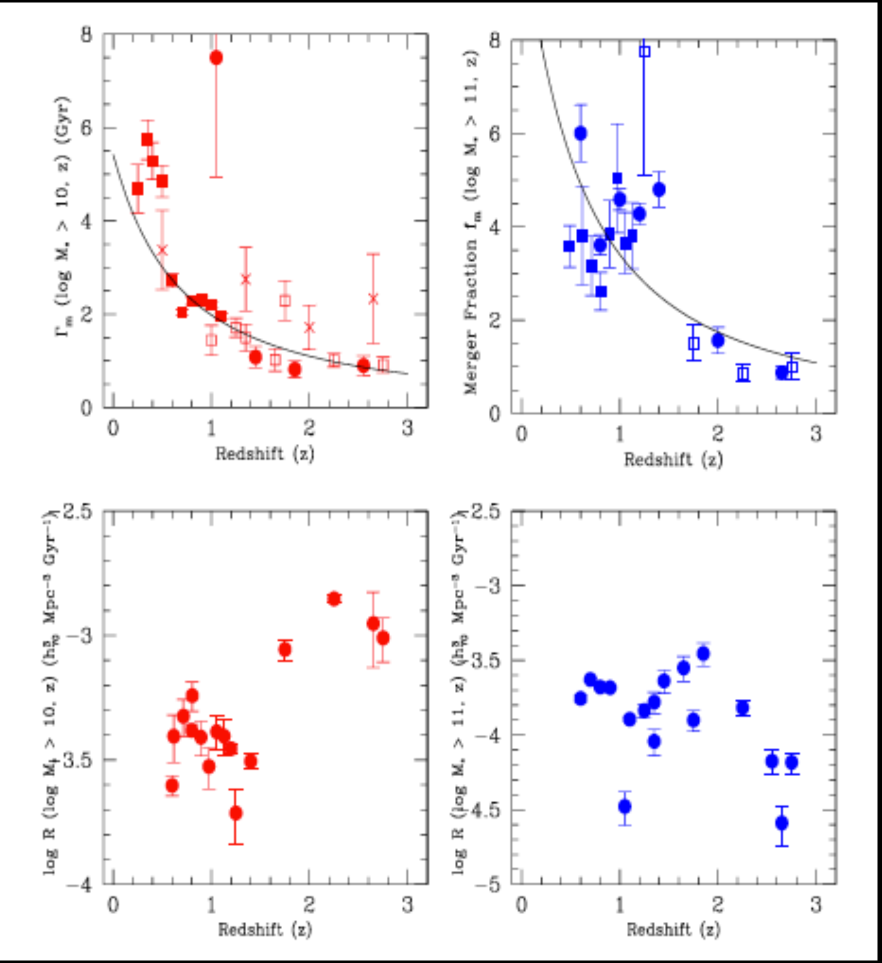
(for stellar mass selected samples, Conselice 2014, ARAA)

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)

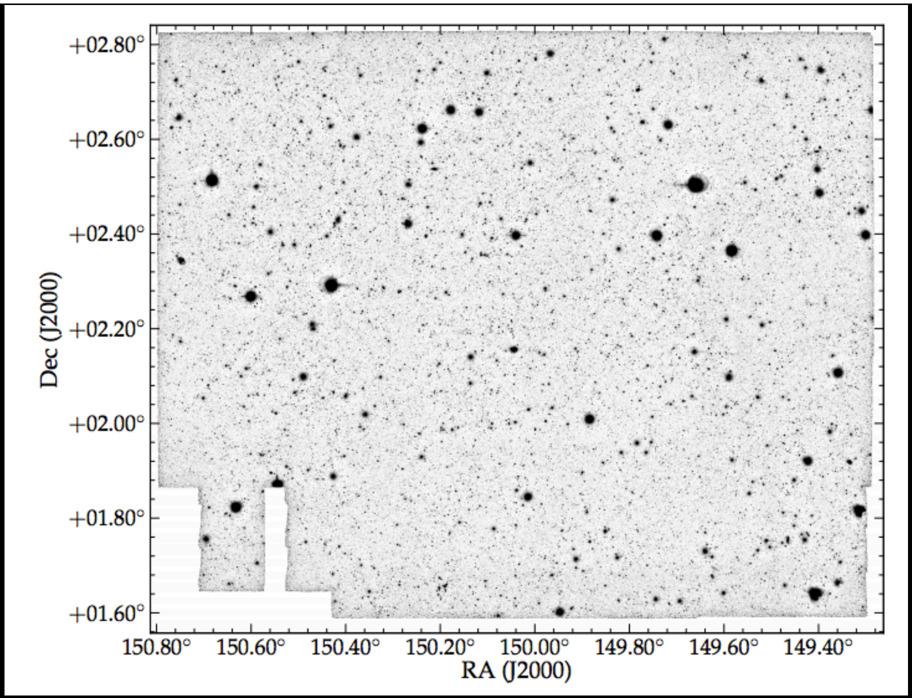


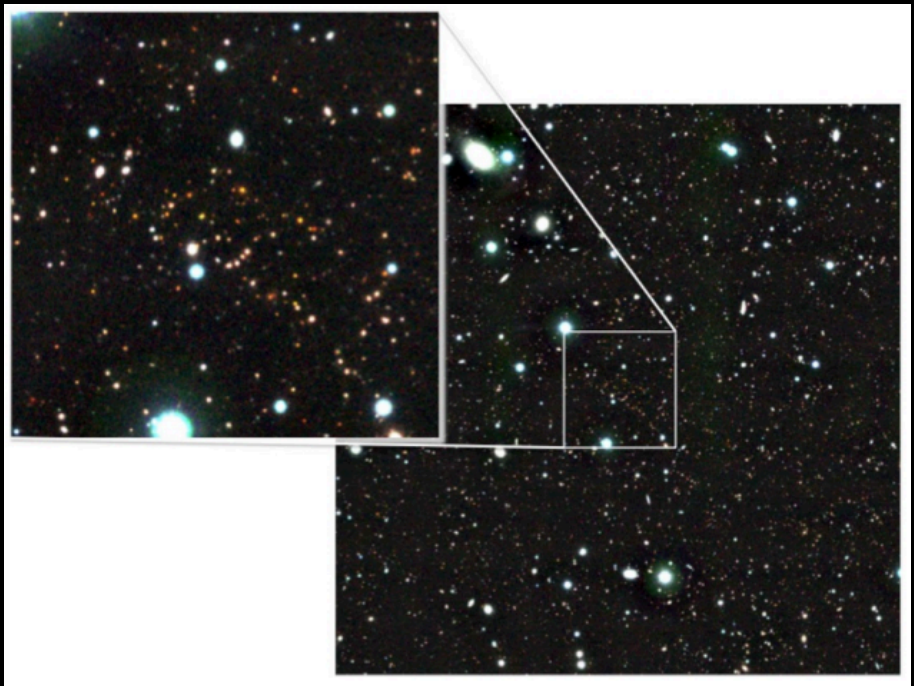
Roughly doubles the stellar masses of galaxies from z=0 to 3

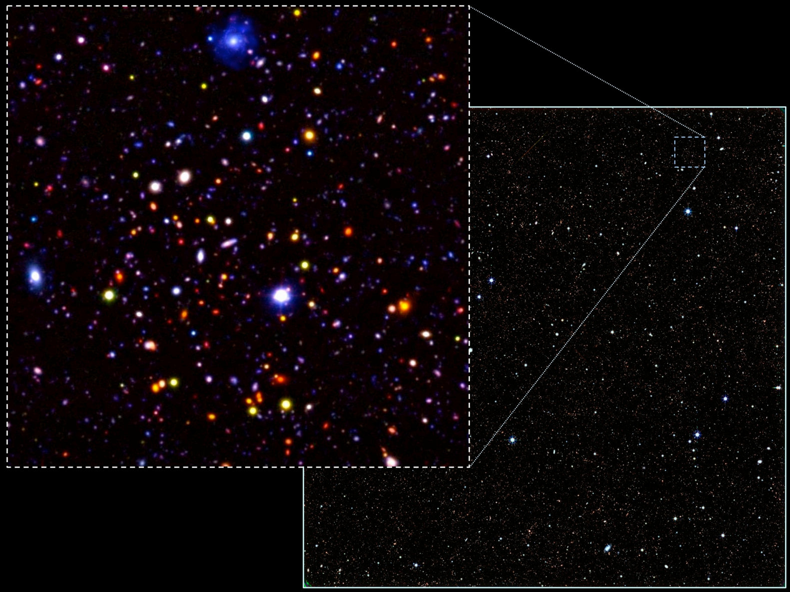
REFINE (Redshift Evolution and Formation in Extragalactic Systems)

A reanalysis of redshifts and stellar masses for the three IR deep fields:

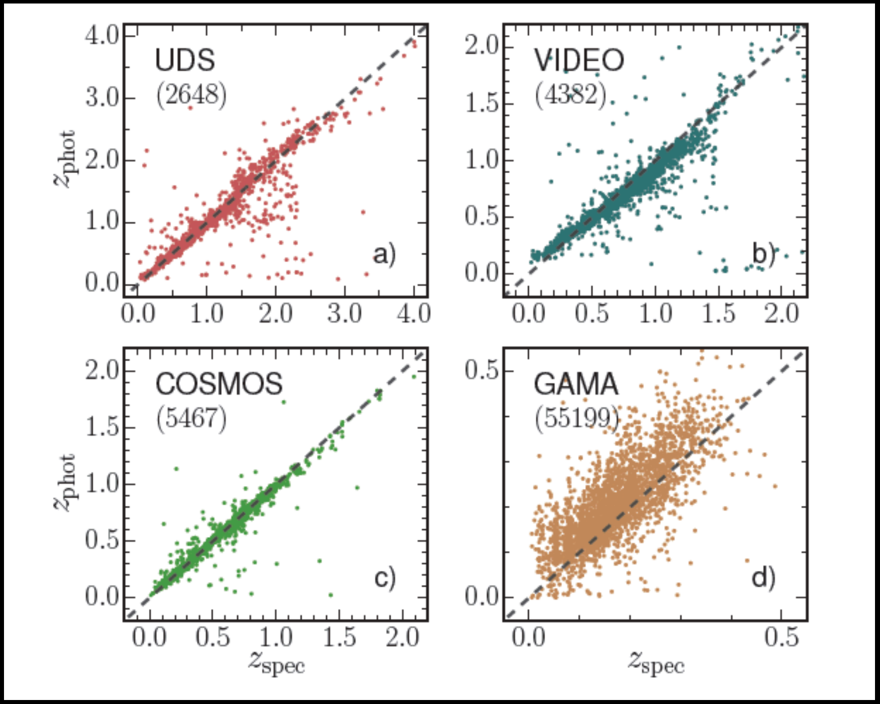
Ultra-VISTA: K = 23.4, 1.6 sq. degree
UDS: K = 24.2, 0.77 sq. degree
VIDEO: K = 22.5, 1 sq. degree
GAMA: 144 sq. degree (nearby uni)

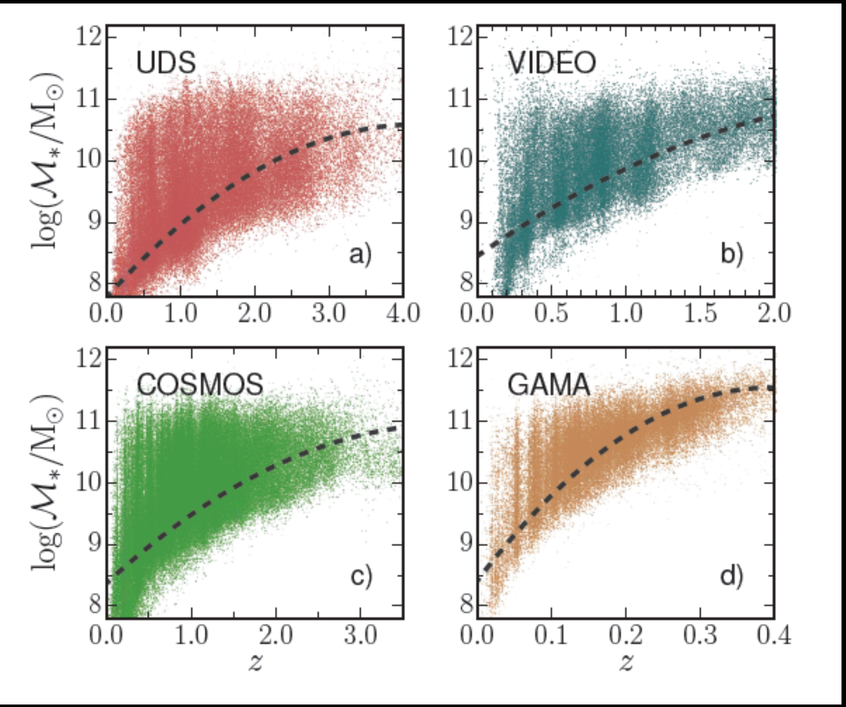






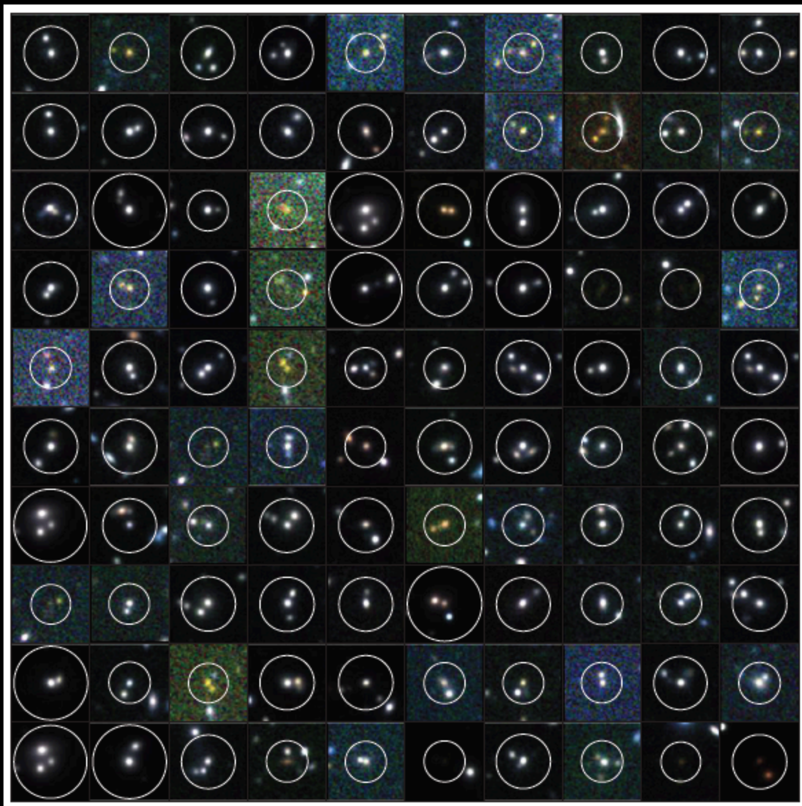
Photometric Redshift and mass Distributions for Each Field



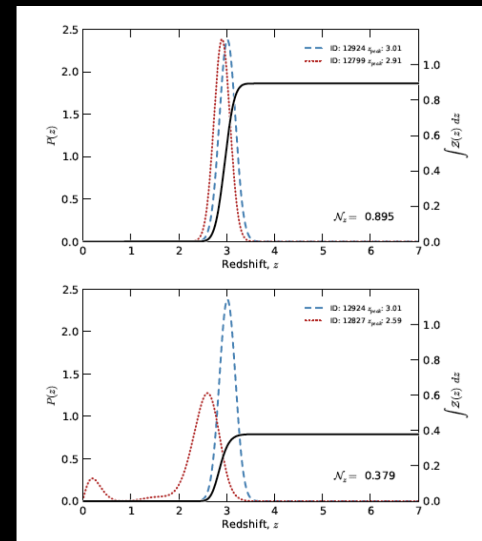


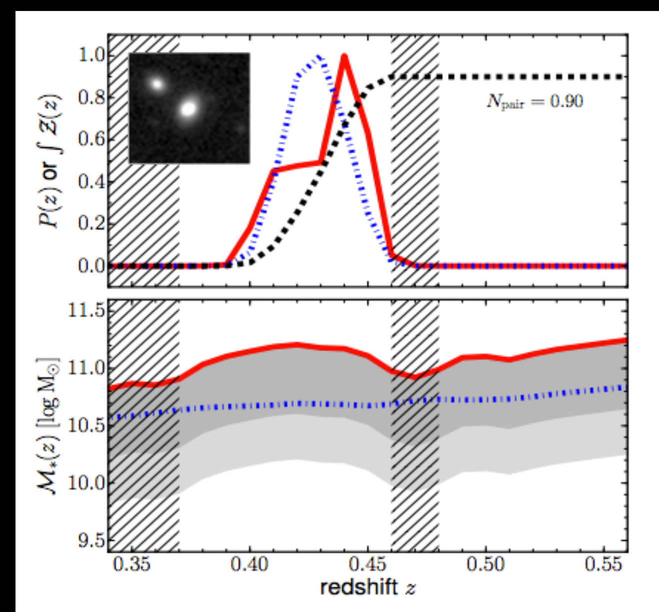
Each z-phot has a PDF from EAZY

Mergers – though pair counts



Find galaxy pairs using the P(z) values for each galaxy

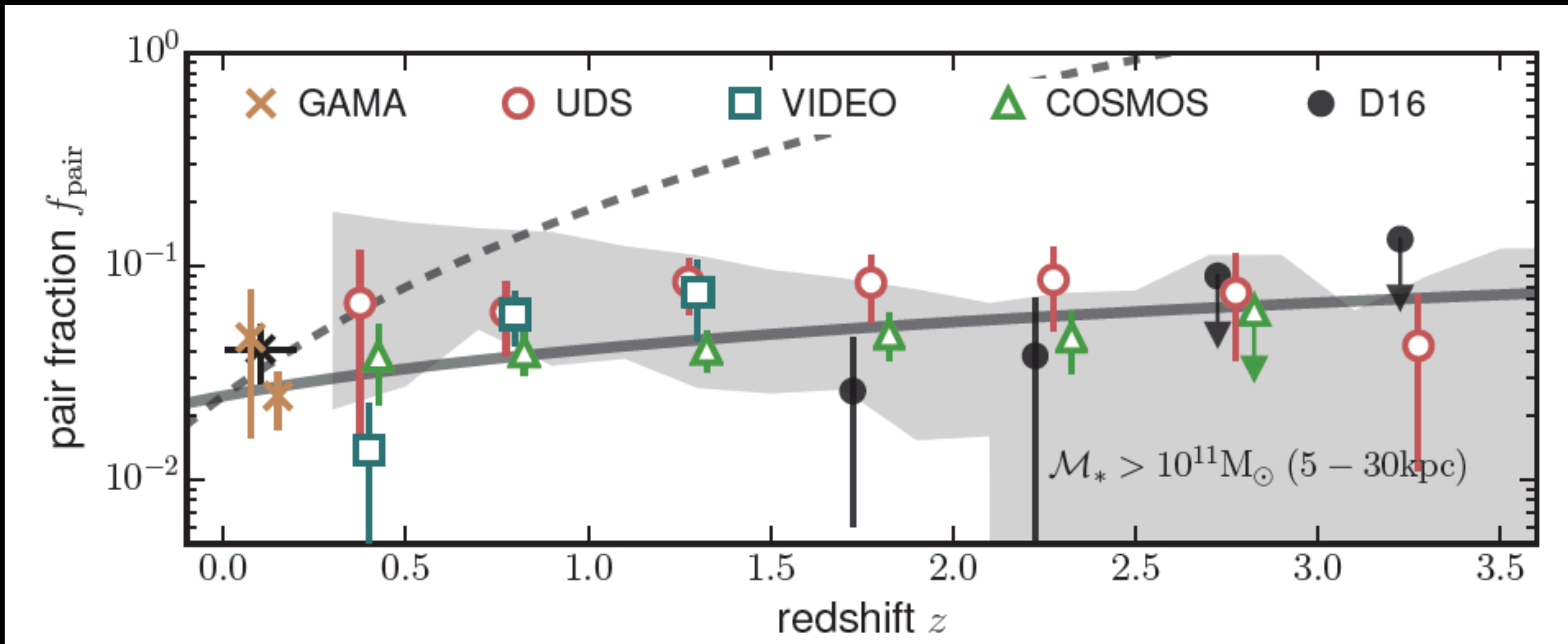




$$\mathcal{Z}(z) = \frac{2 \times P_1(z) \times P_2(z)}{P_1(z) + P_2(z)} = \frac{P_1(z) \times P_2(z)}{N(z)}.$$

New Results

Pair fraction evolution for log M > 11, < 30kpc, < ¼ mass ratio



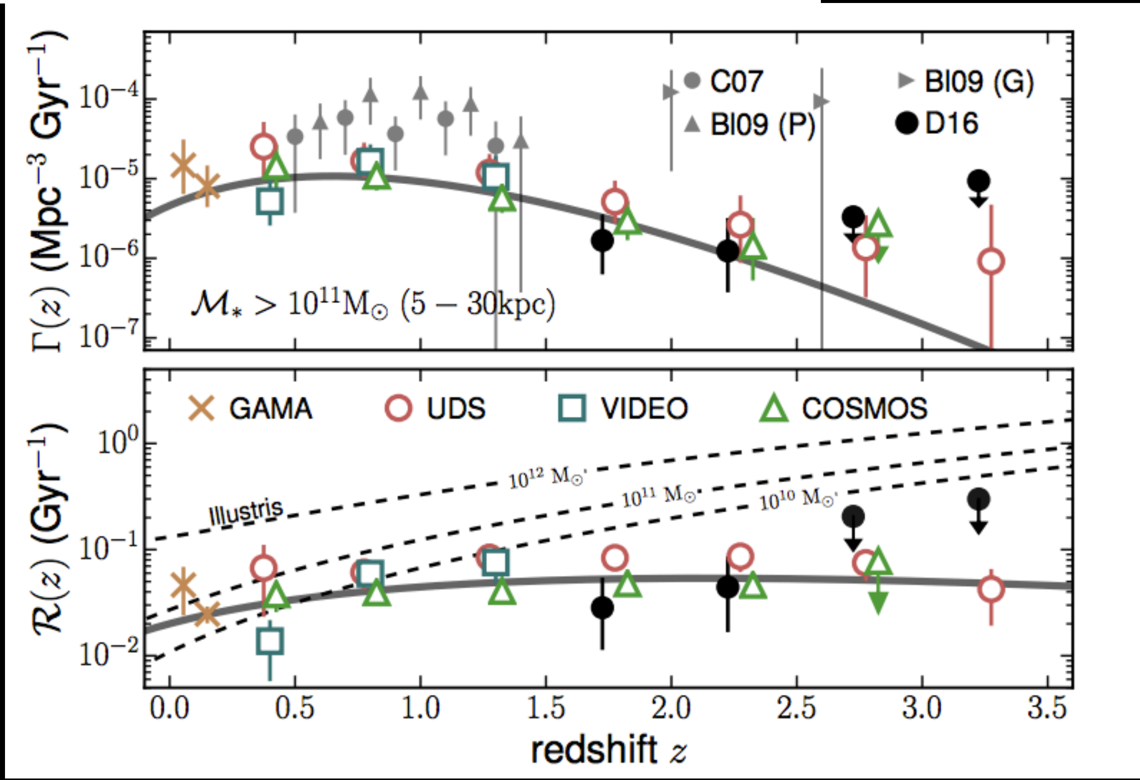
Pair Fractions from three 1 degree sq. deep imaging surveys
VIDEO, UDS, COSMOS and GAMA (for z ~ 0)

Survey Region	f_0	m	$N_{\rm merg}$
$\mathcal{M}_* > 10^{10}\mathrm{M}_\odot$ (5 – 20kpc)			
UDS	$0.012^{+0.005}_{-0.004}$	$1.99^{+0.56}_{-0.51}$	$1.1^{+1.1}_{-0.6}$
COSMOS	$0.009^{+0.006}_{-0.004}$	$1.78^{+1.20}_{-1.02}$	$0.7^{+1.7}_{-0.5}$
All	$0.006^{+0.003}_{-0.002}$	$2.68^{+0.59}_{-0.59}$	$1.1^{+1.3}_{-0.6}$
All + GAMA	$0.010^{+0.002}_{-0.002}$	$1.82^{+0.37}_{-0.34}$	$0.8^{+0.6}_{-0.3}$
$\mathcal{M}_* > 10^{10}\mathrm{M}_\odot$ (5 – 30kpc)			
UDS	$0.029^{+0.012}_{-0.009}$	$1.57^{+0.55}_{-0.50}$	$1.0^{+1.0}_{-0.5}$
COSMOS	$0.014^{+0.008}_{-0.006}$	$2.50^{+1.08}_{-0.84}$	$1.1^{+2.4}_{-0.8}$
All	$0.018^{+0.005}_{-0.004}$	$2.14^{+0.40}_{-0.41}$	$1.1^{+0.8}_{-0.5}$
All + GAMA	$0.020^{+0.003}_{-0.003}$	$1.97^{+0.26}_{-0.25}$	$1.0^{+0.6}_{-0.3}$
All + GAMA + D17	$0.028^{+0.002}_{-0.002}$	$0.80^{+0.09}_{-0.09}$	$0.5^{+0.3}_{-0.1}$

$$f_{\rm m} = f_0 \times (1+z)^m$$

Merger rates, harder to infer – need time-scales

$$\Gamma_{\rm merg}(z) = \frac{\phi_{\rm merg}(z)}{\langle T_{\rm obs}\rangle} = \frac{f_{\rm merg}(z) n_1(z)}{\langle T_{\rm obs}\rangle}, \quad [{\rm Mpc}^{-3}\ {\rm Gyr}^{-1}]$$



$$\mathcal{R}_{\rm merg}(z) = \frac{f_{\rm merg}(z)}{\langle T_{\rm obs}\rangle}, \quad [{\rm Gyr}^{-1}]$$

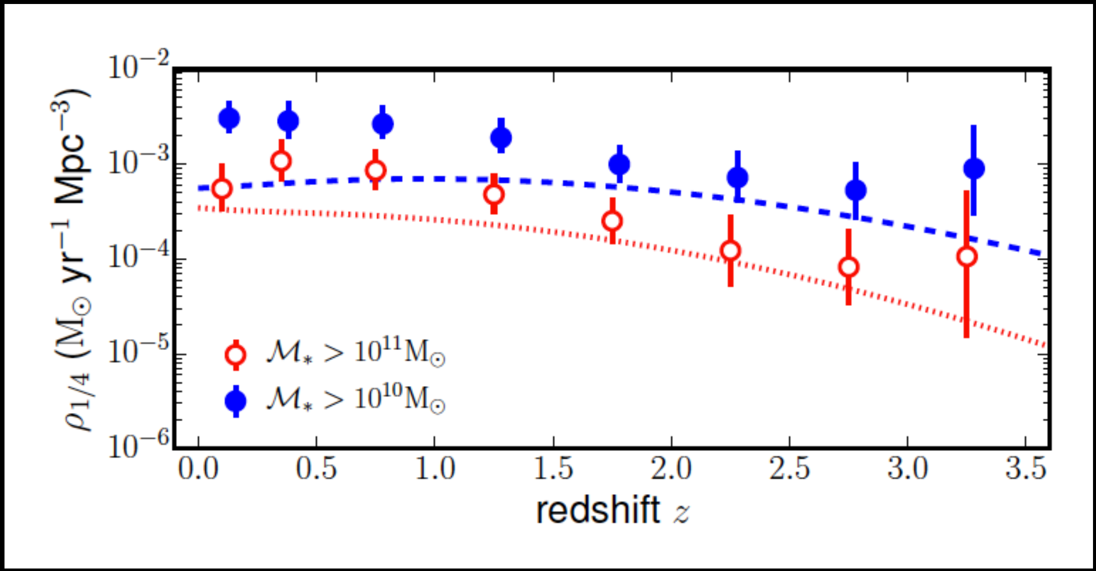
Big Caveat

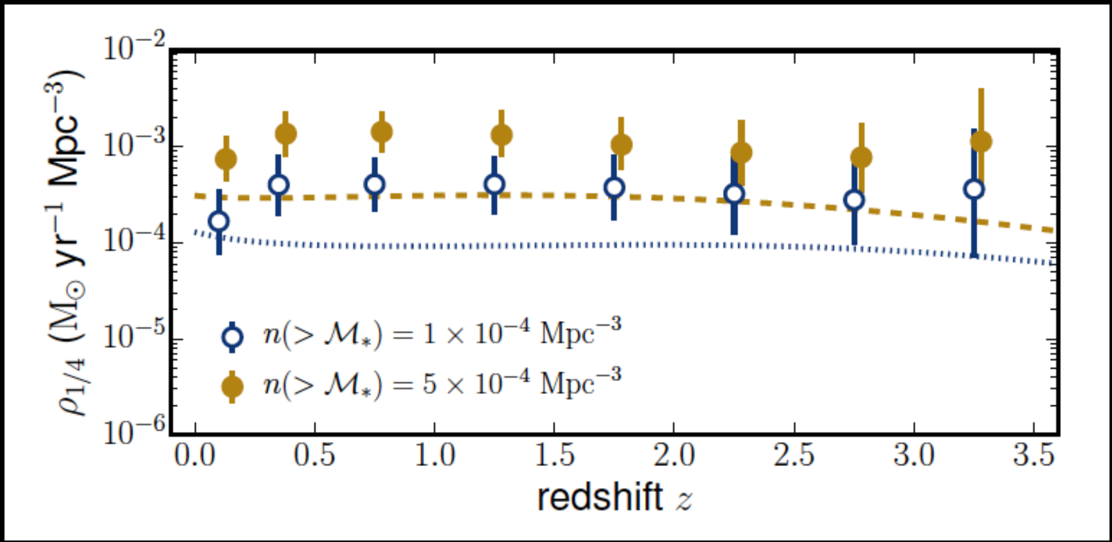
We use the same time-scale at all redshifts. Shorter time-scales at higher z would give more mergers.

Results show a merger rate which is lower than previous work

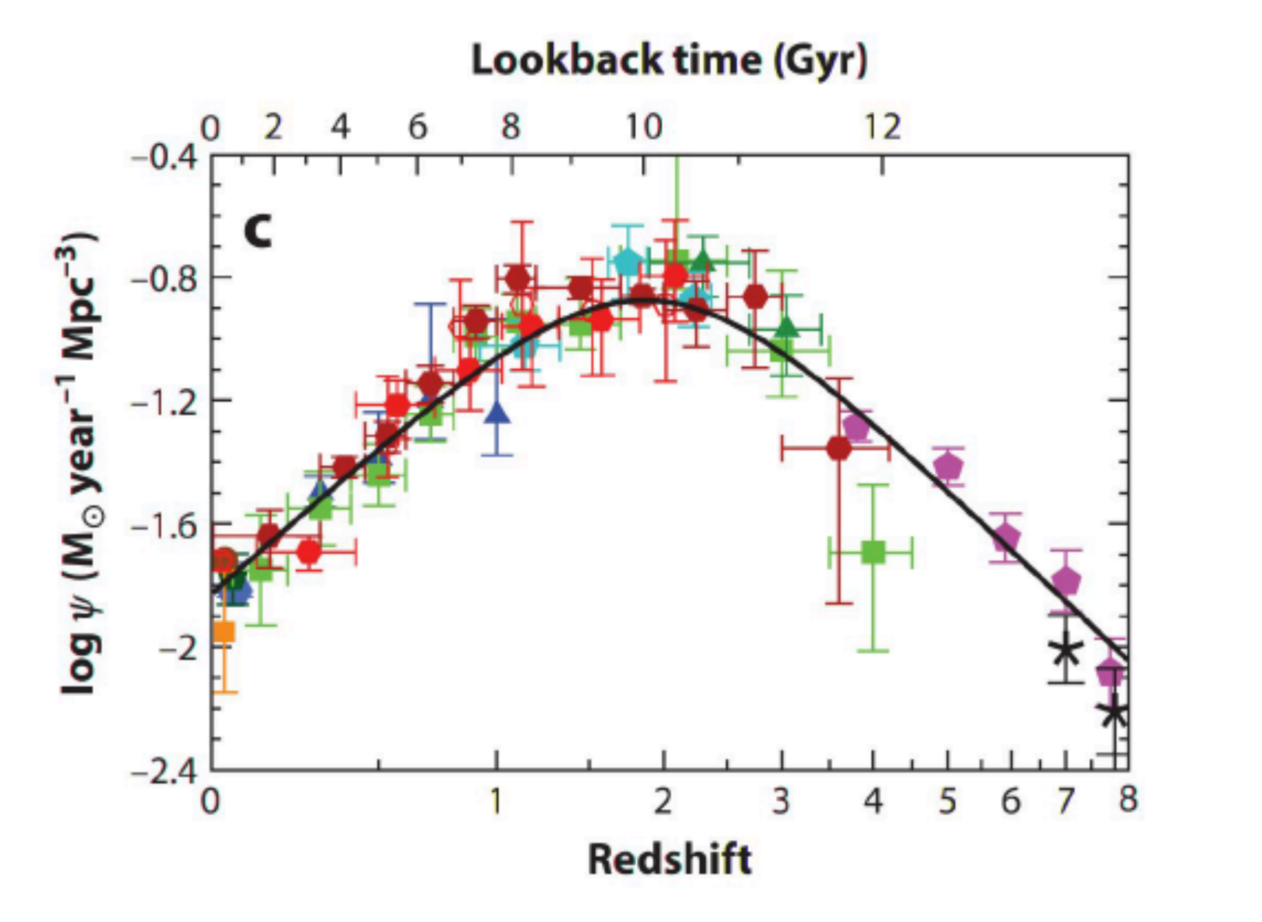
<u>Gives ~1 major merger per galaxy at z < 3</u>

The mass accretion rate due to major mergers





Can compare with star formation history



At z = 2 SFR Peak

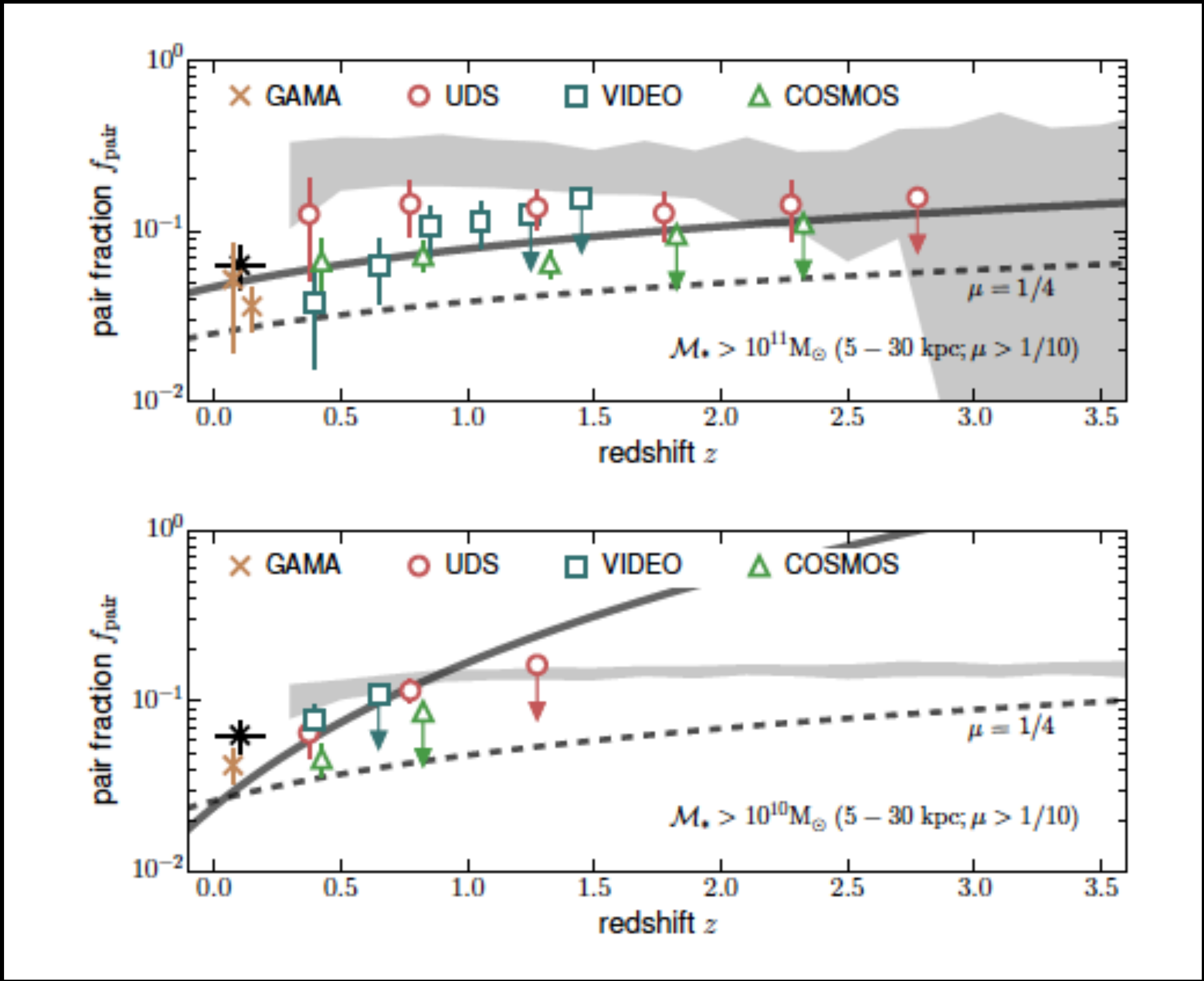
SFR ~ 0.1

Mergers ~ 0.005

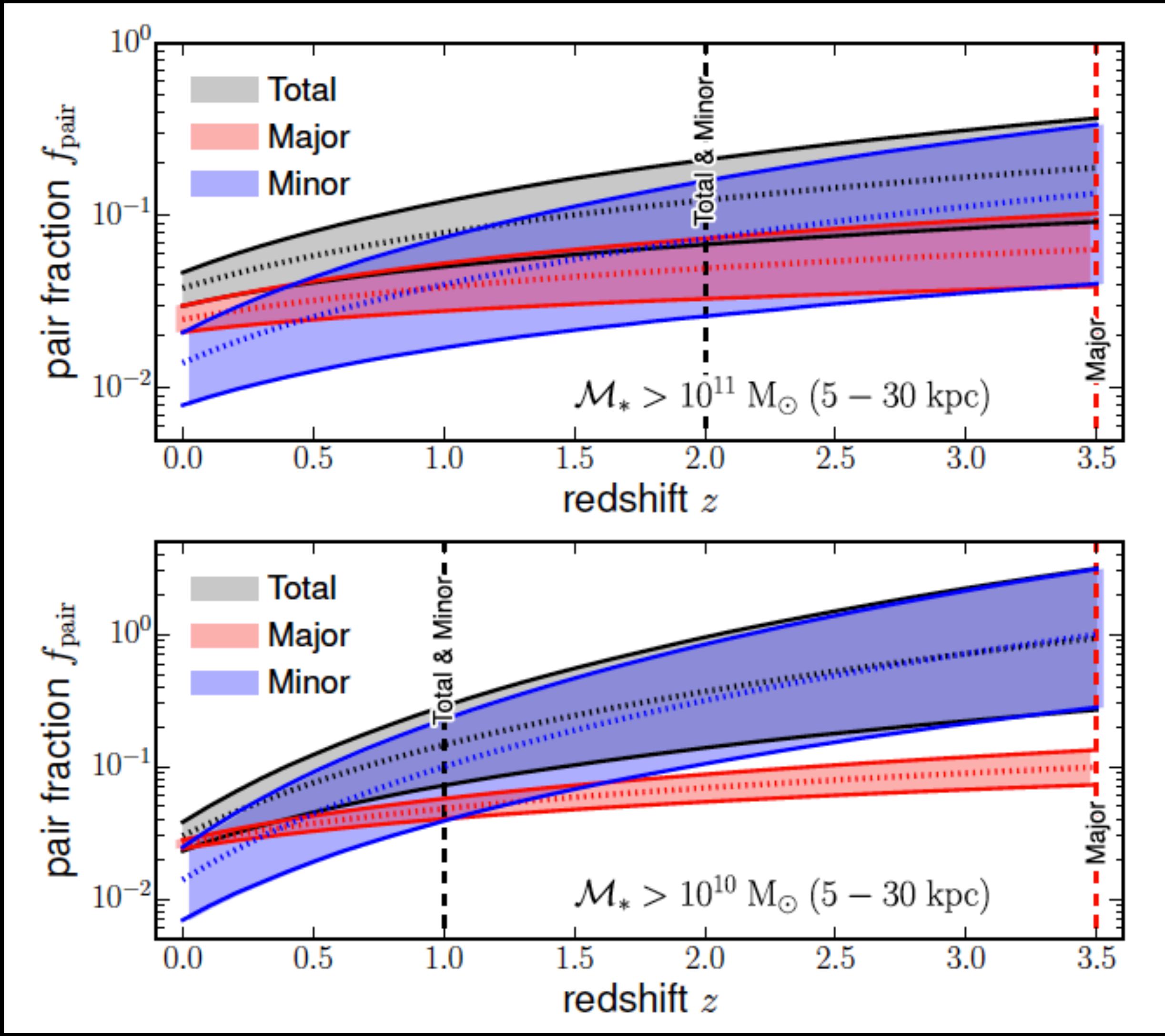
But mergers only for log M > 10, SF integrated over all masses

Madau & Dickinson 2014

Minor Merger Pair Fraction - ratio > 1/10

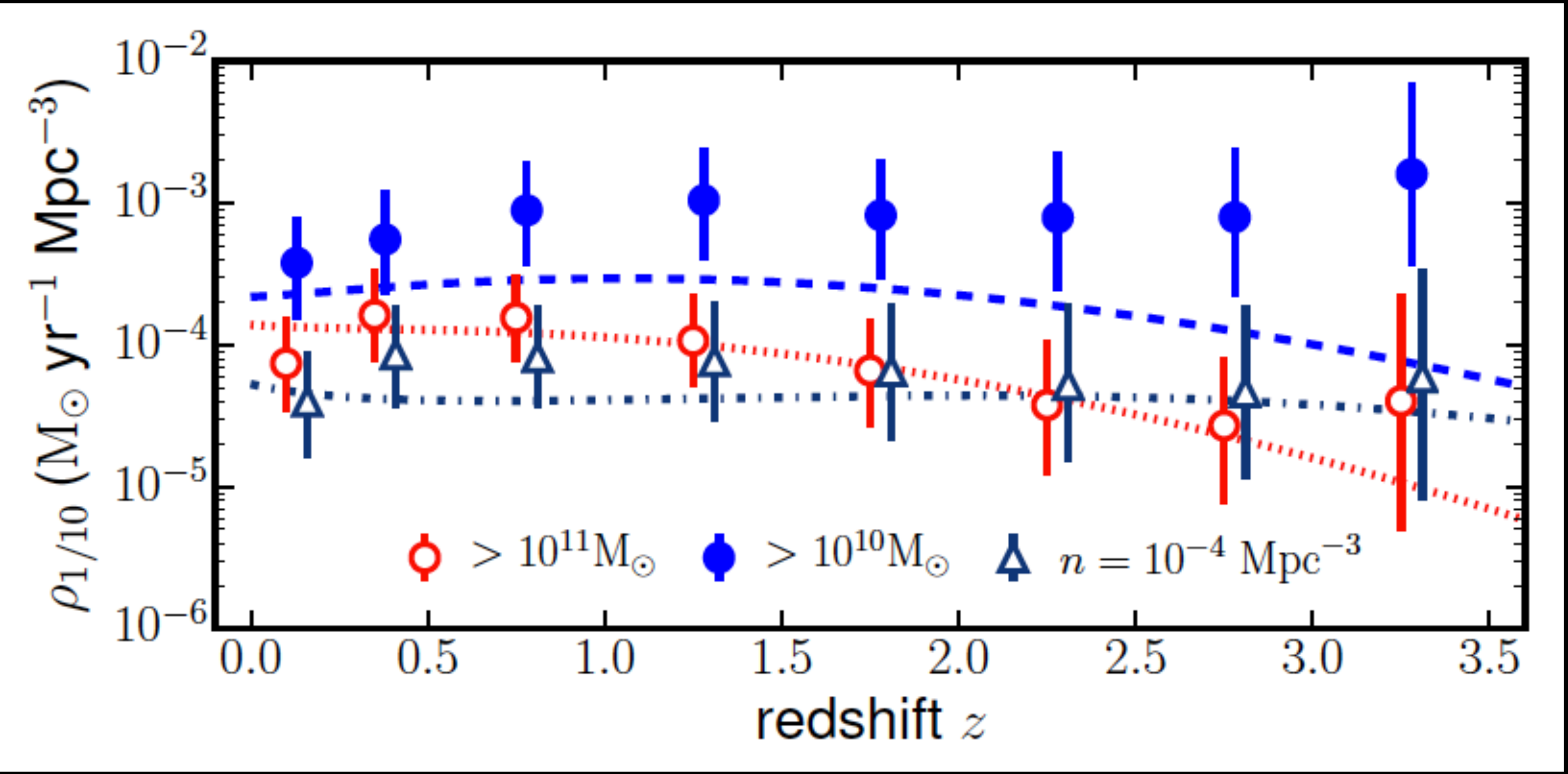


Comparison between the minor and major pairs



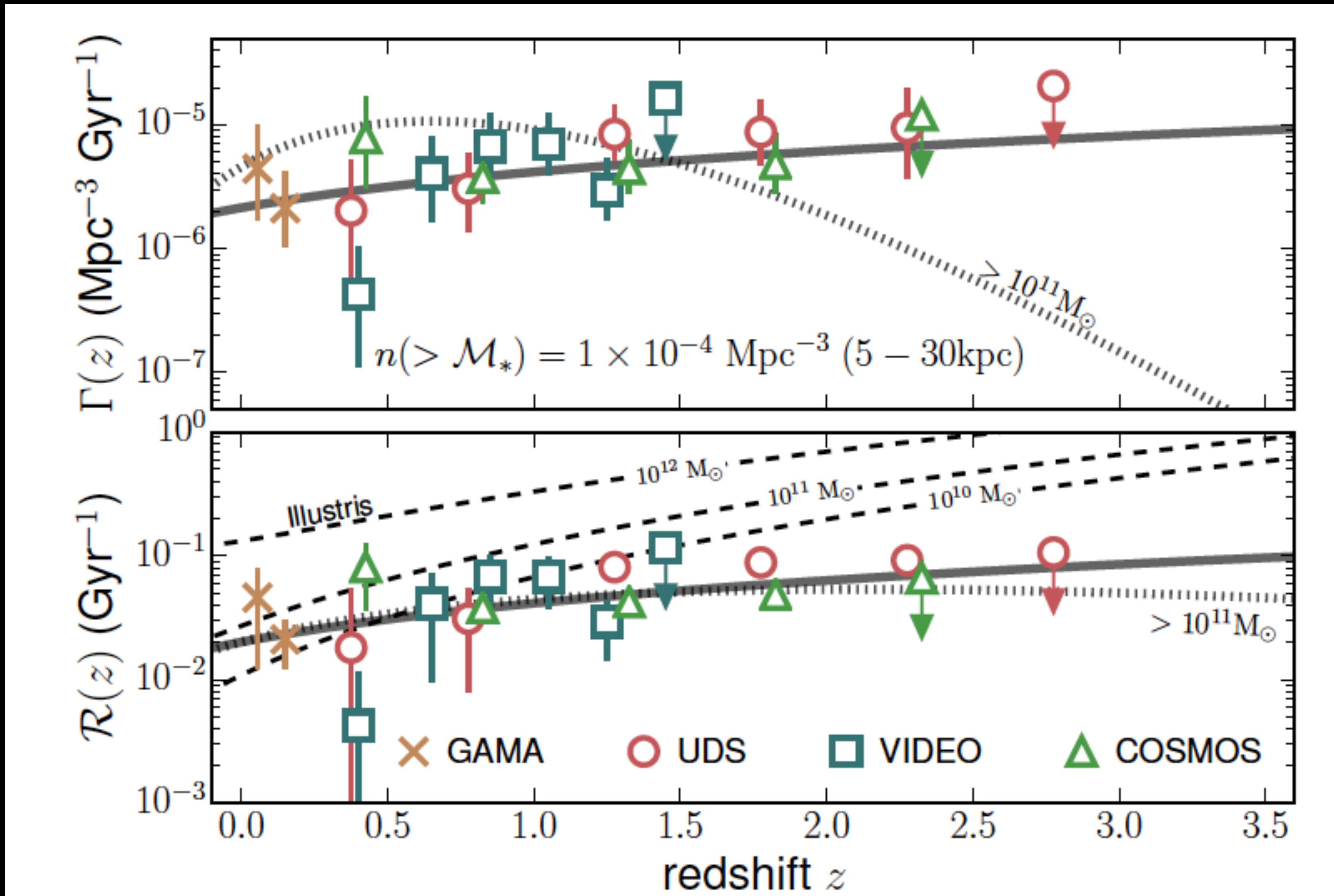
Mundy, CC+17 in prep

Mass accretion rate due to minor mergers



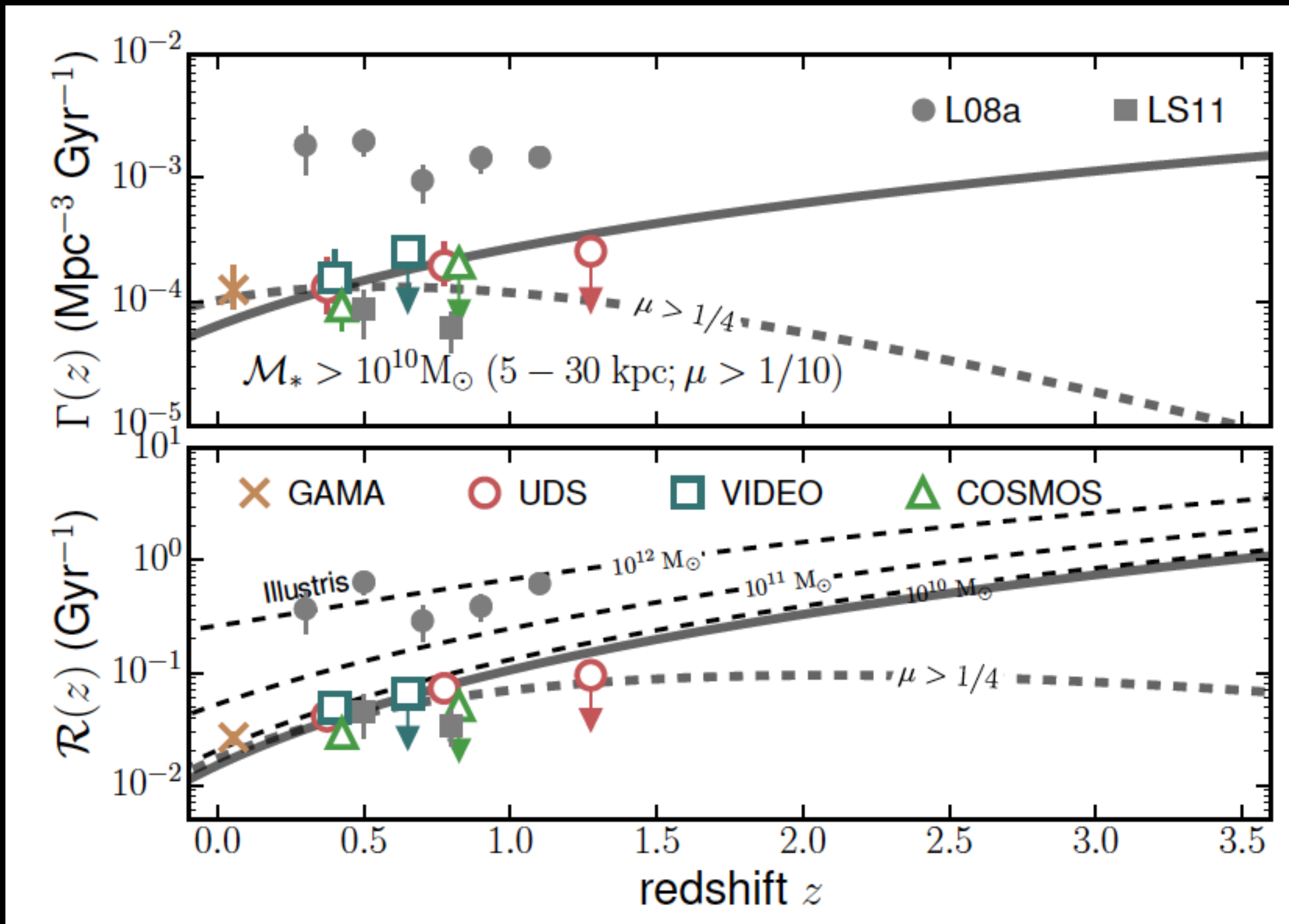
About the same level as the mass accretion from major mergers

Comparison to Models – not good agreement



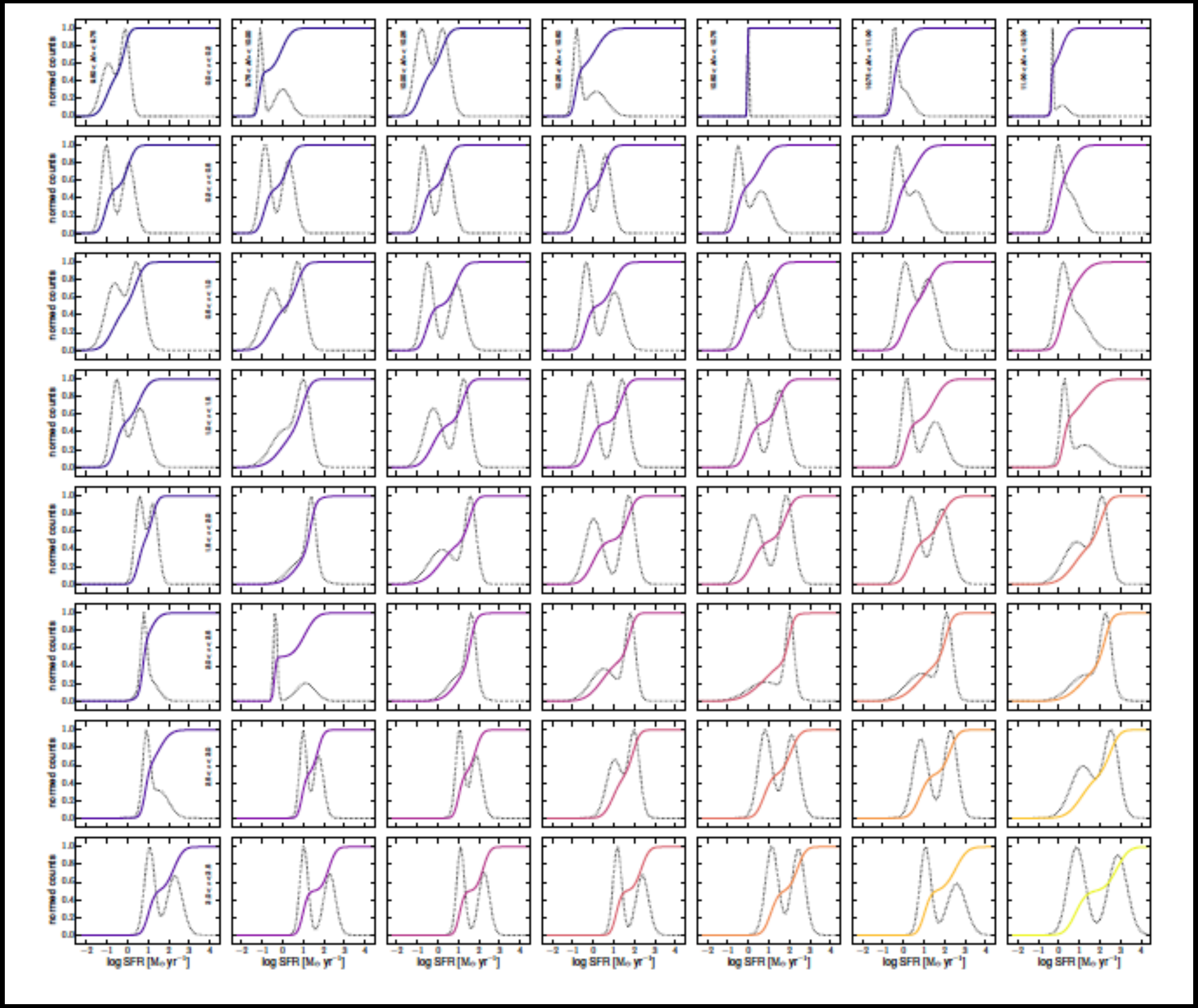
Mundy, CC+17 submitted

Minor merger comparison



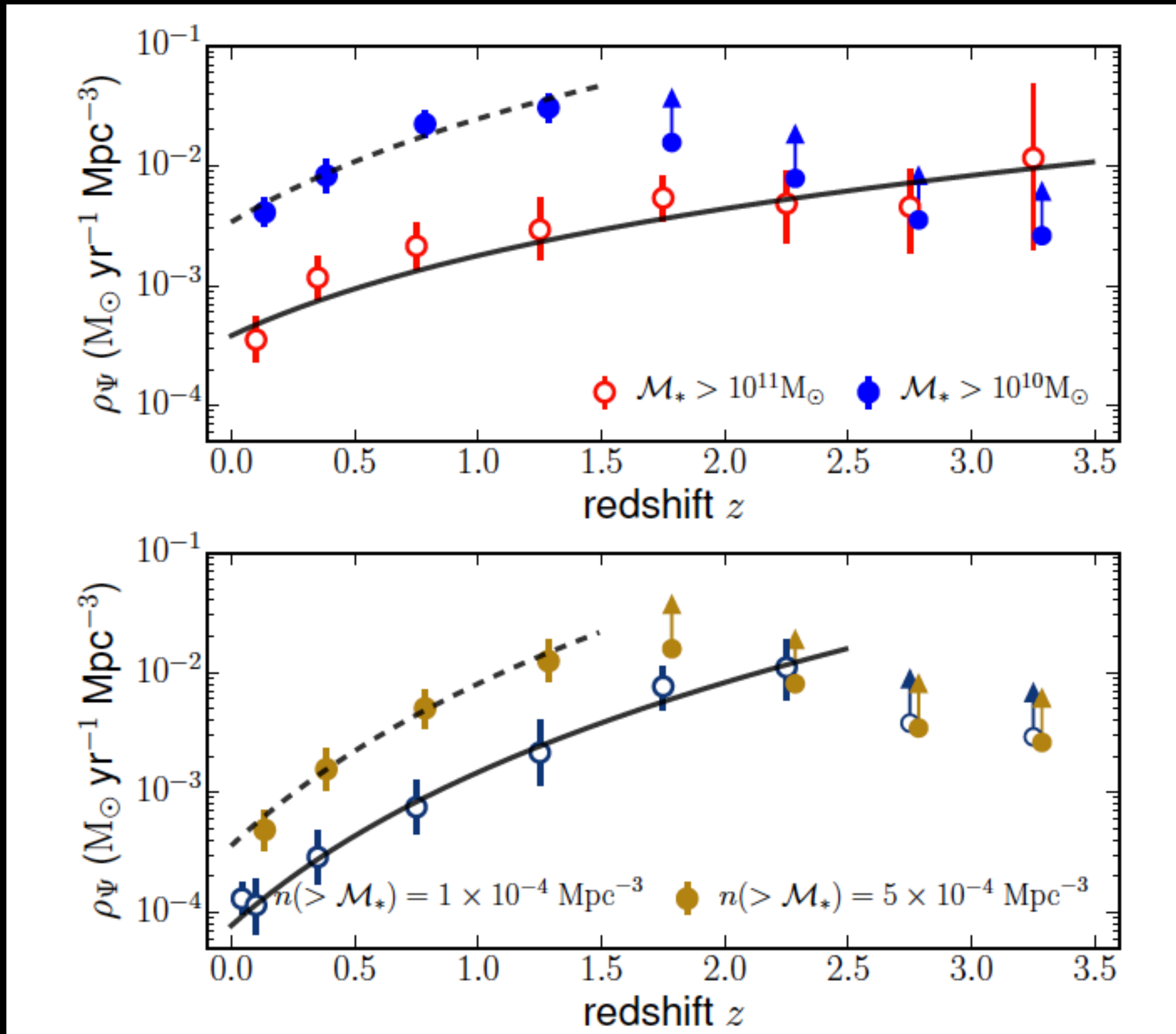
Mundy, CC+17 submitted

How does mass built with star formation compare with mergers?



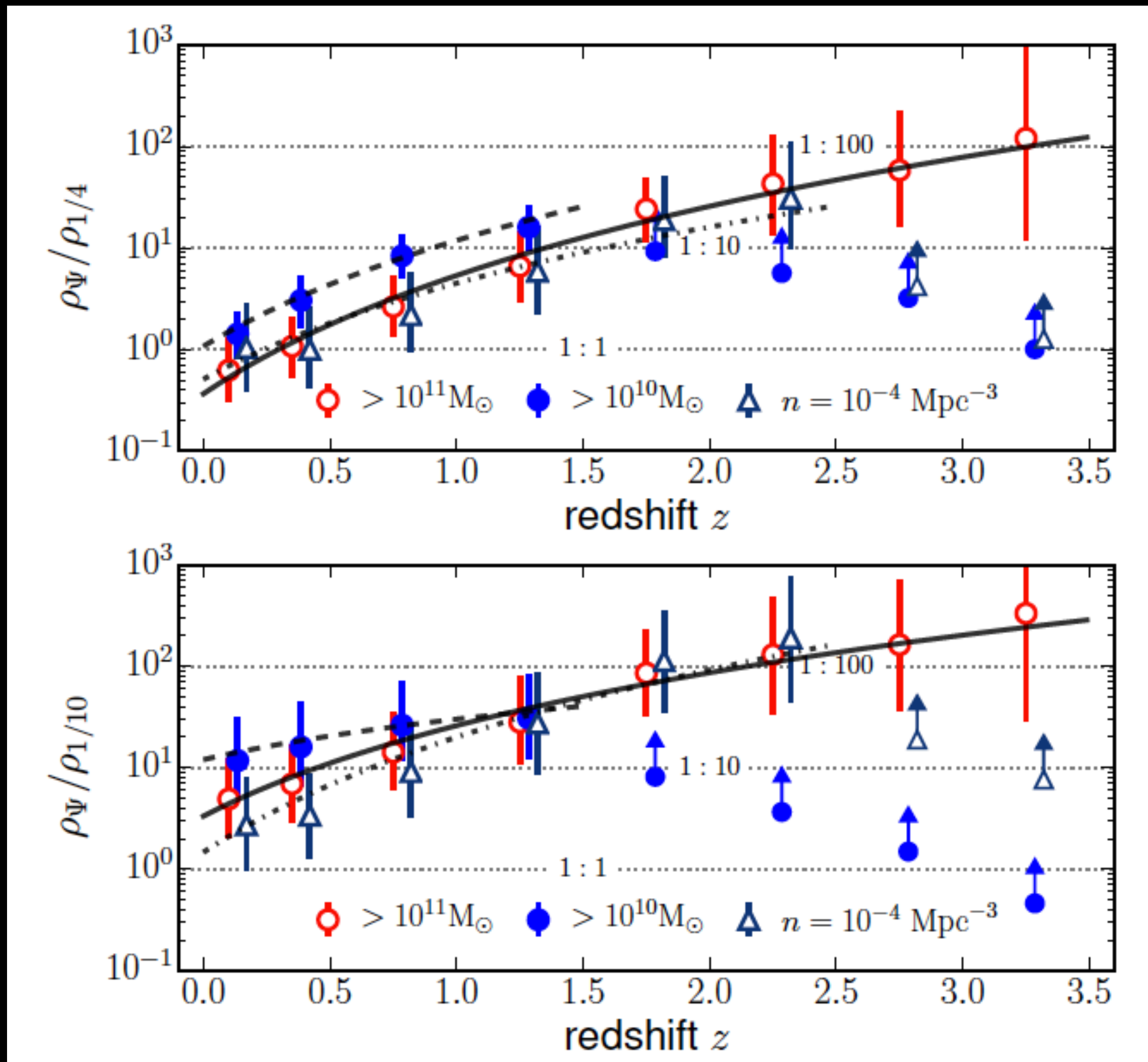
Star formation rate distributions as a function of mass

Resulting star formation rate densities as a function of time/mass



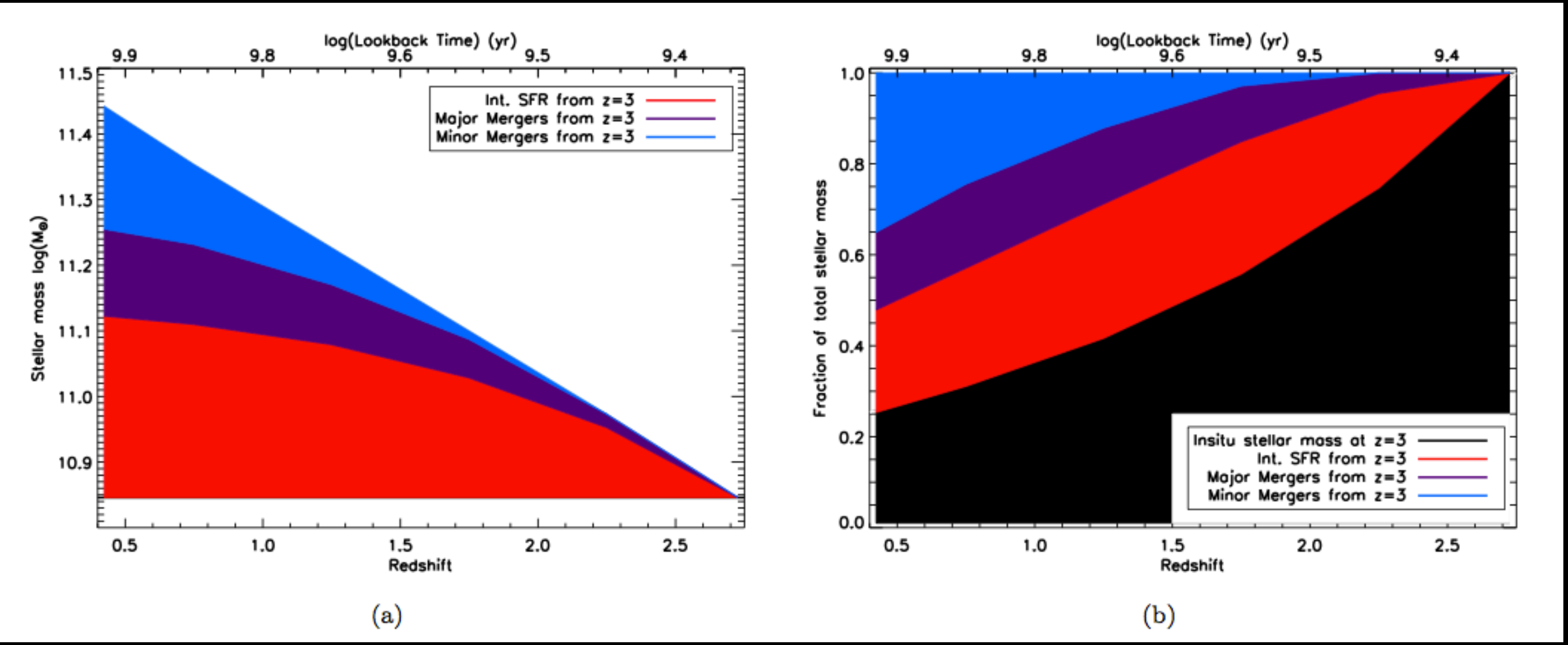
Both for mass selection and number density selected

Ratio of SFR to mass accretion rate due to major mergers



SFR more important at z > 0.5, equal at z ~0.5

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



All mergers ~50% of formation of stellar mass since z ~3

Star formation is not the only way to build mass in galaxies

How much gas do we need beyond what mergers bring?

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

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 very 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)

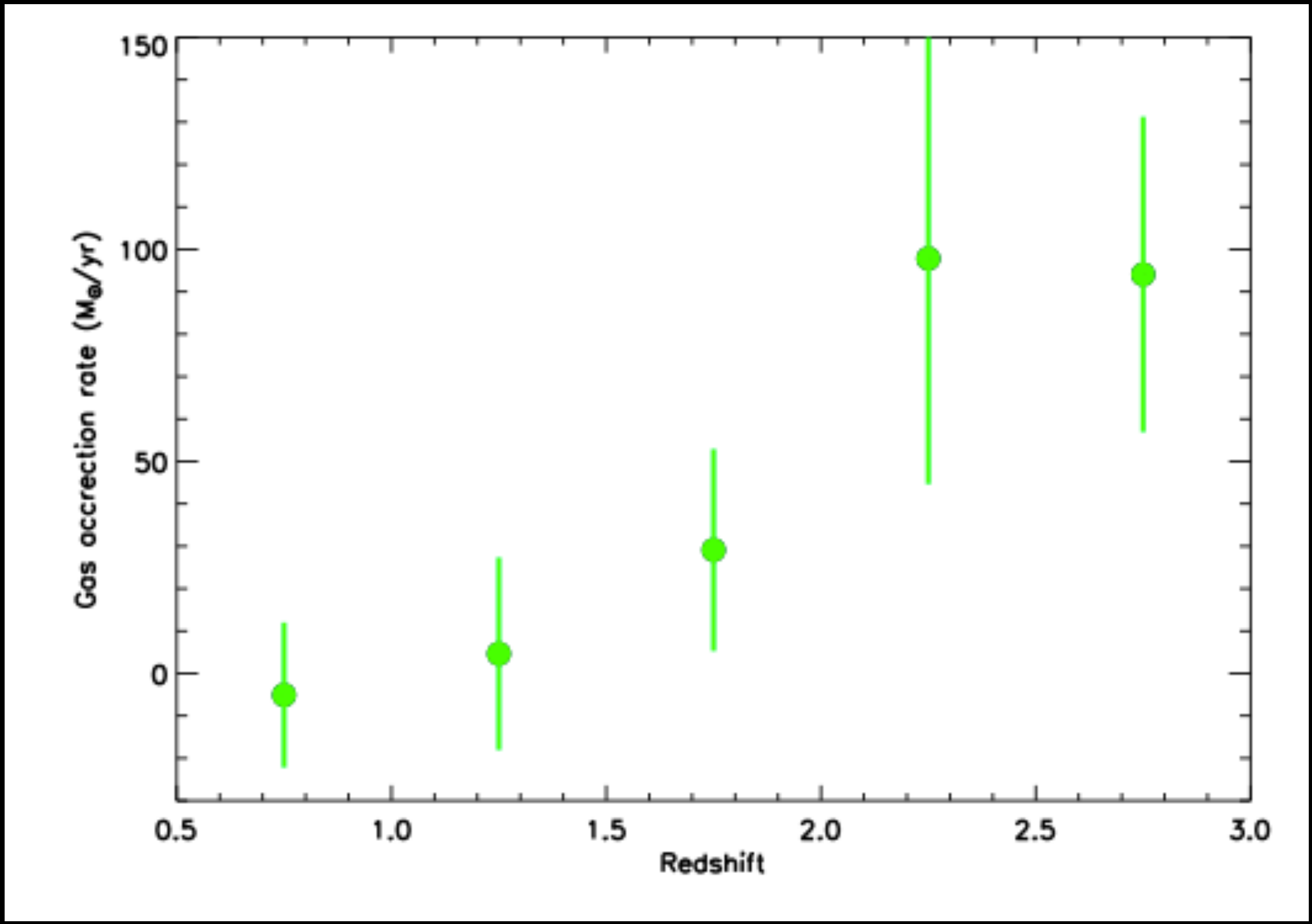
$$(1.6 \pm 0.5) \times 10^{11}\ M_\odot$$

Average amount of gas accreted

Results in accretion rate of

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

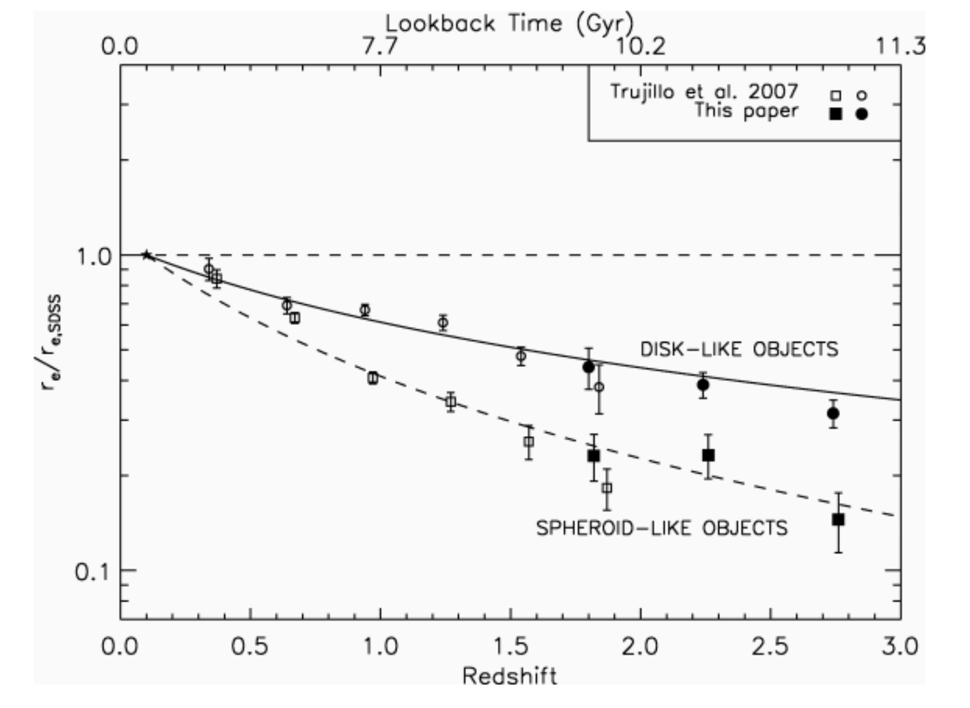
Gas accretion rate history for massive systems over cosmic time

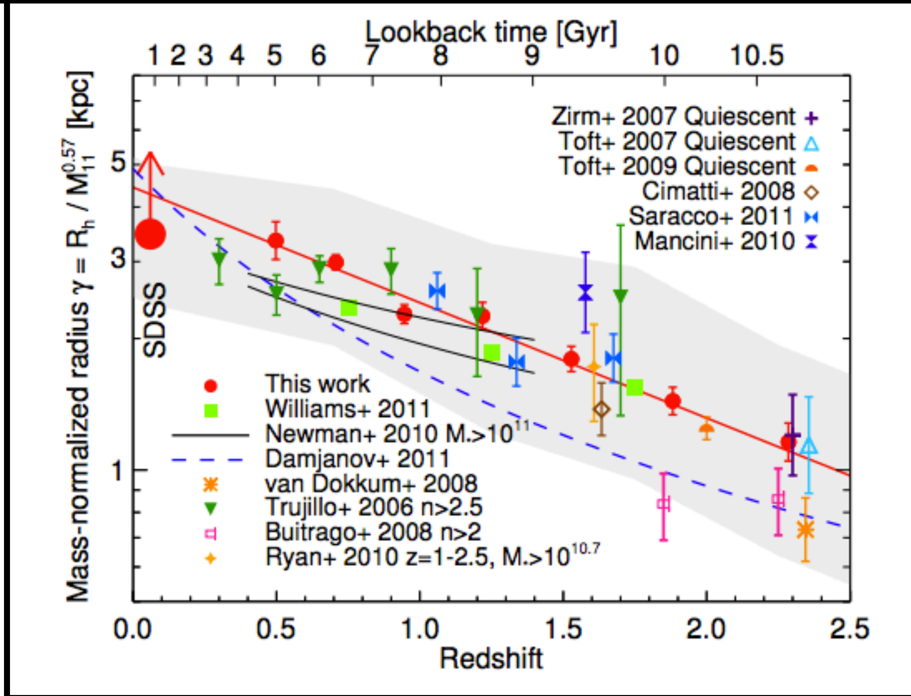


Ownsworth,CC,+14

Decline due to galaxy quenching?

Size evolution – galaxies get larger with time



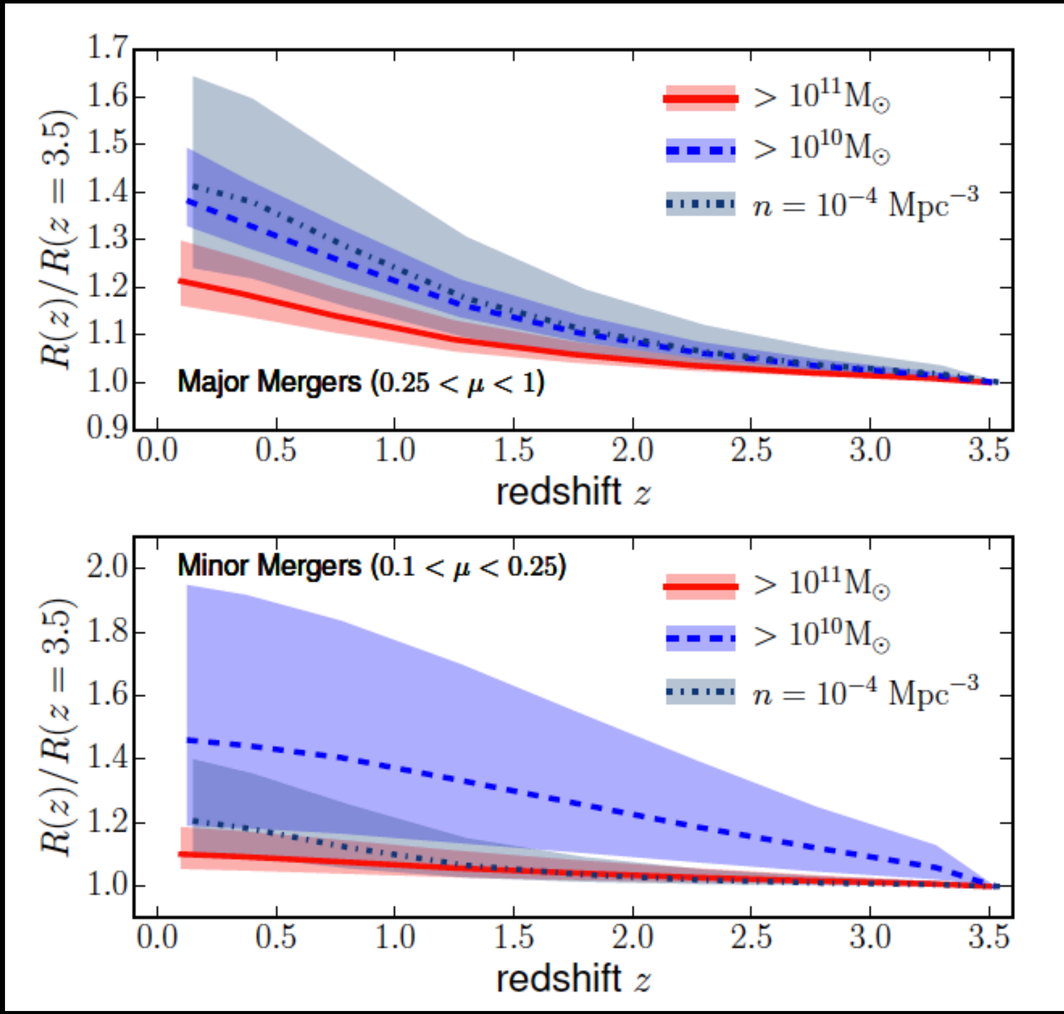


Buitrago+08

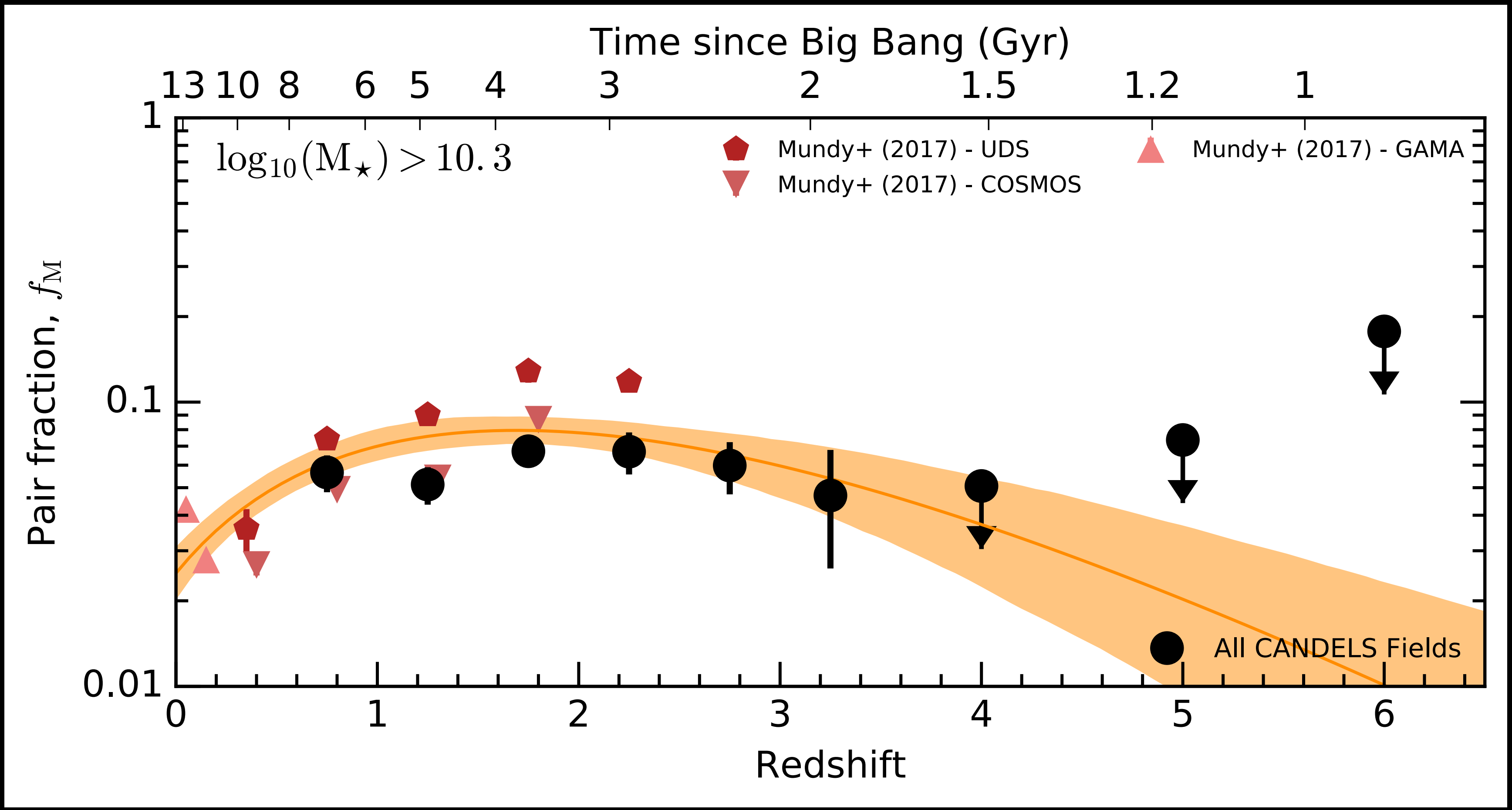
Newman+12

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

Size increase vs. redshift due to merging



Merger history out to z=6



Duncan, CC+17 in prep

Summary

1. Galaxy formation and evolution are driven by mergers in part, but its role is just being quantitatively revealed

2. There are major and minor mergers in galaxies up to z=3. Not the dominant method for formation, but still important at the 25-50% level. Could be higher if merger time-scale evolves.

3. Mergers are relatively more important for galaxy formation at late times, whereby at early times star formation is a factor of 10 more important at $z > 1.5$

4. Gas accretion rates are much higher than the merger rate and declines at a much faster rate.

5. Need more information on merger time-scales at higher redshifts