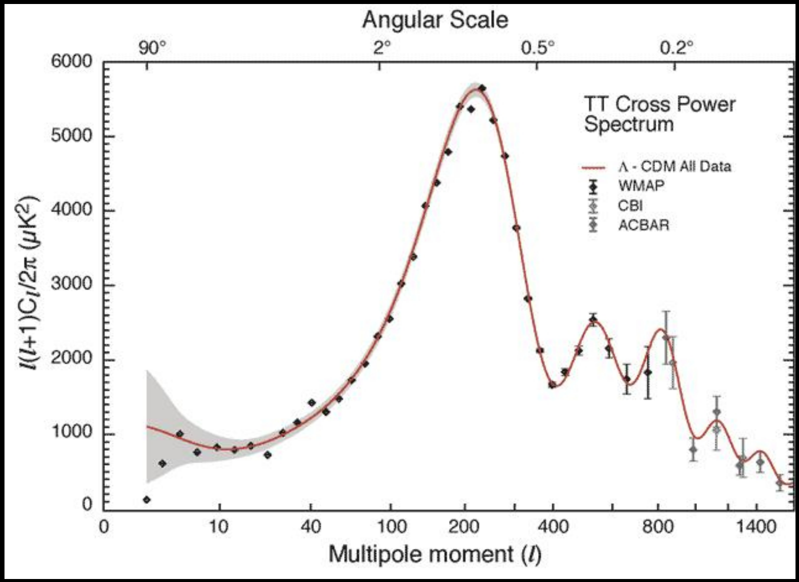
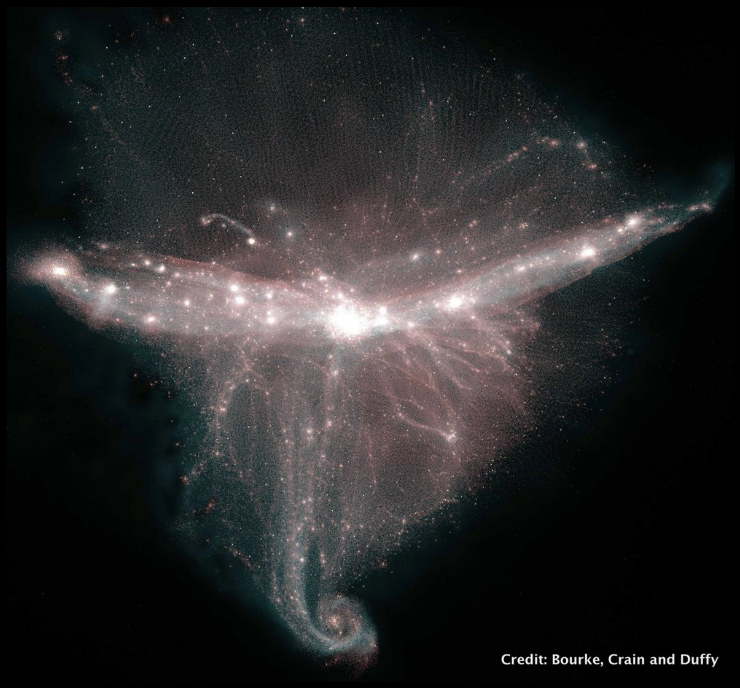
The Role of Mergers in Galaxy Formation and Transformations

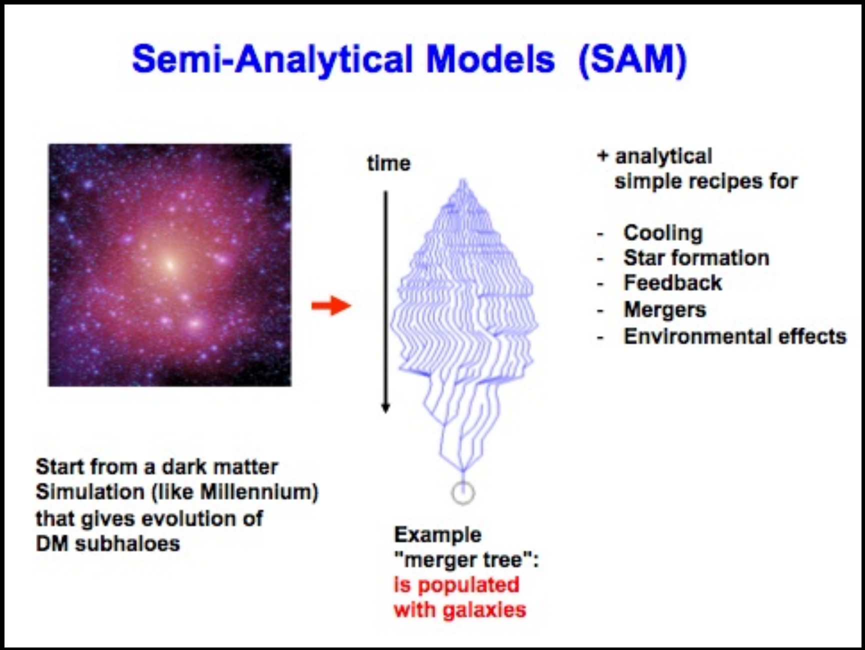
Christopher J. Conselice



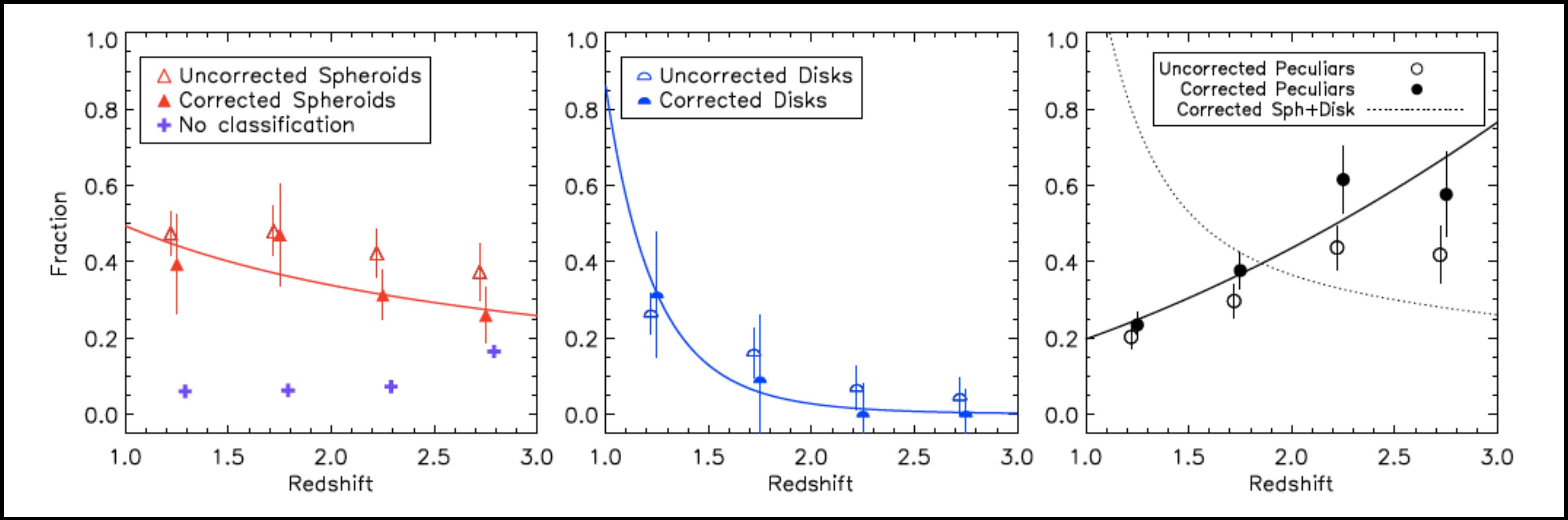
Why find mergers?

Galaxy Formation in CDM predicts a hierarchical formation of galaxies – mergers thus allow a probe of cosmology and galaxy formation





The morphological evolution of galaxies in CANDELS



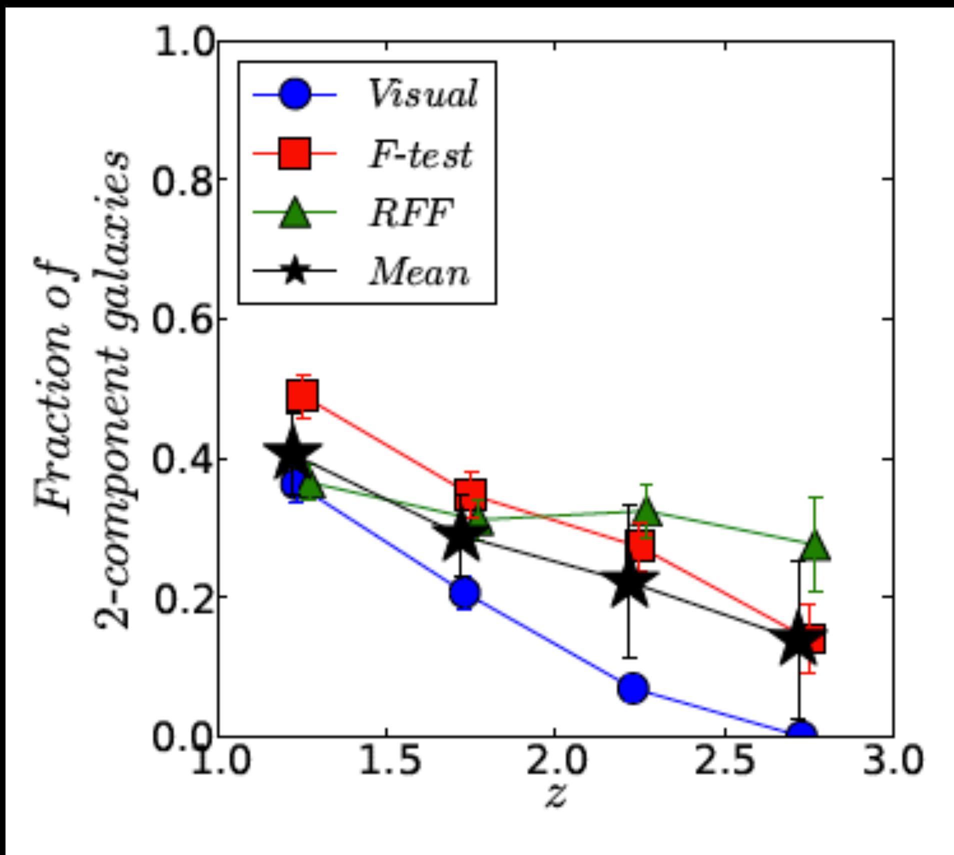
Note that visually determined disks are a very small fraction at z > 2
Peculiar galaxies dominate the population

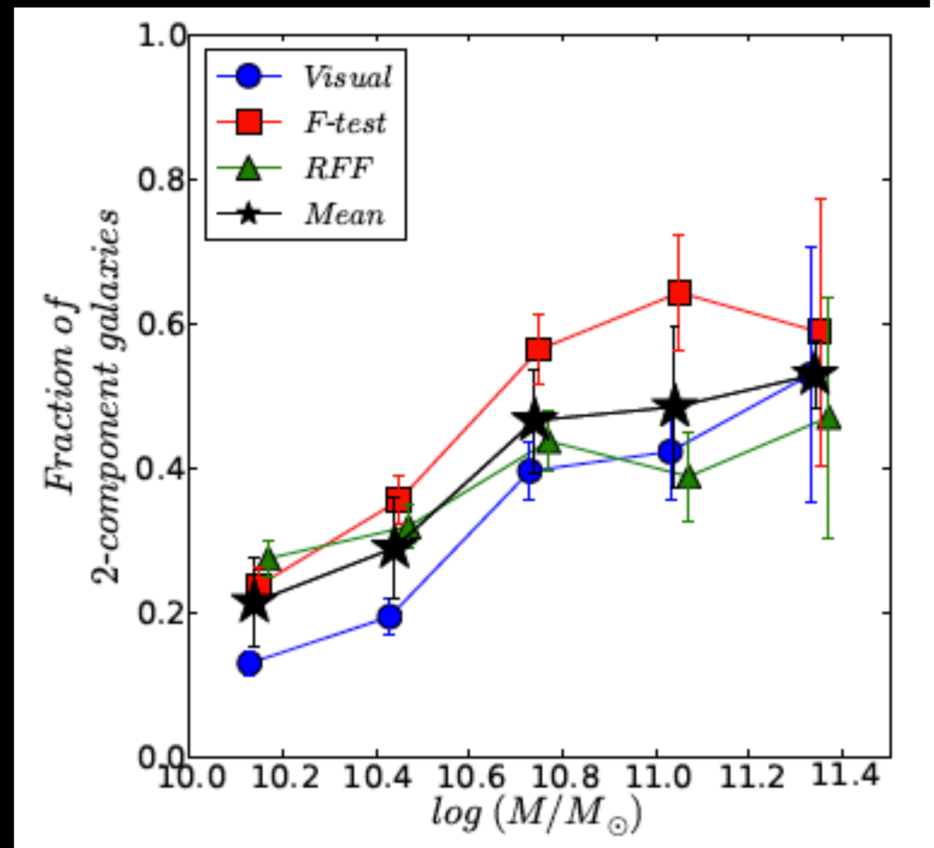
For log M > 10 systems

Mortlock, CC et al. (2015)

Evolution of 2-components and changes with stellar mass

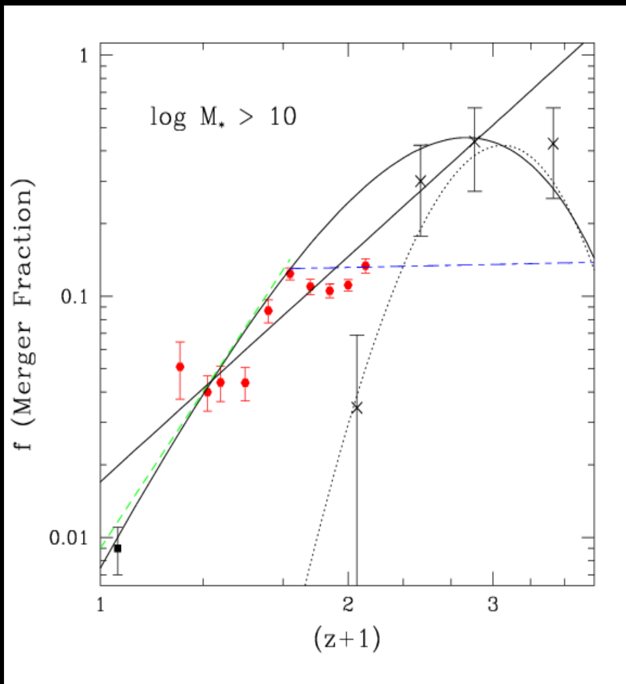
Fewer 2 component galaxies at higher redshift



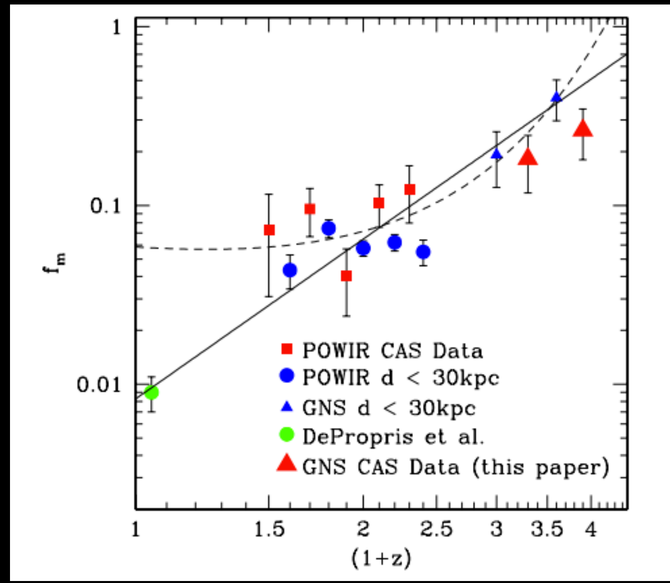


Margalef-Bentabol, CC+16

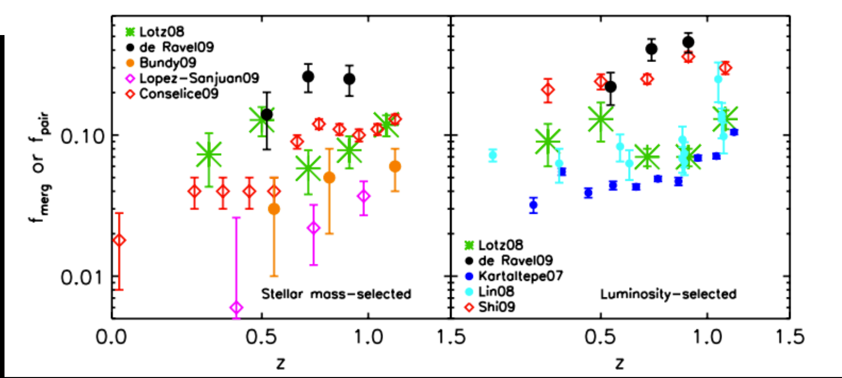
Major mergers – measure with structure



Conselice+09



Bluck+12



Lotz+11

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

Number of Major Mergers

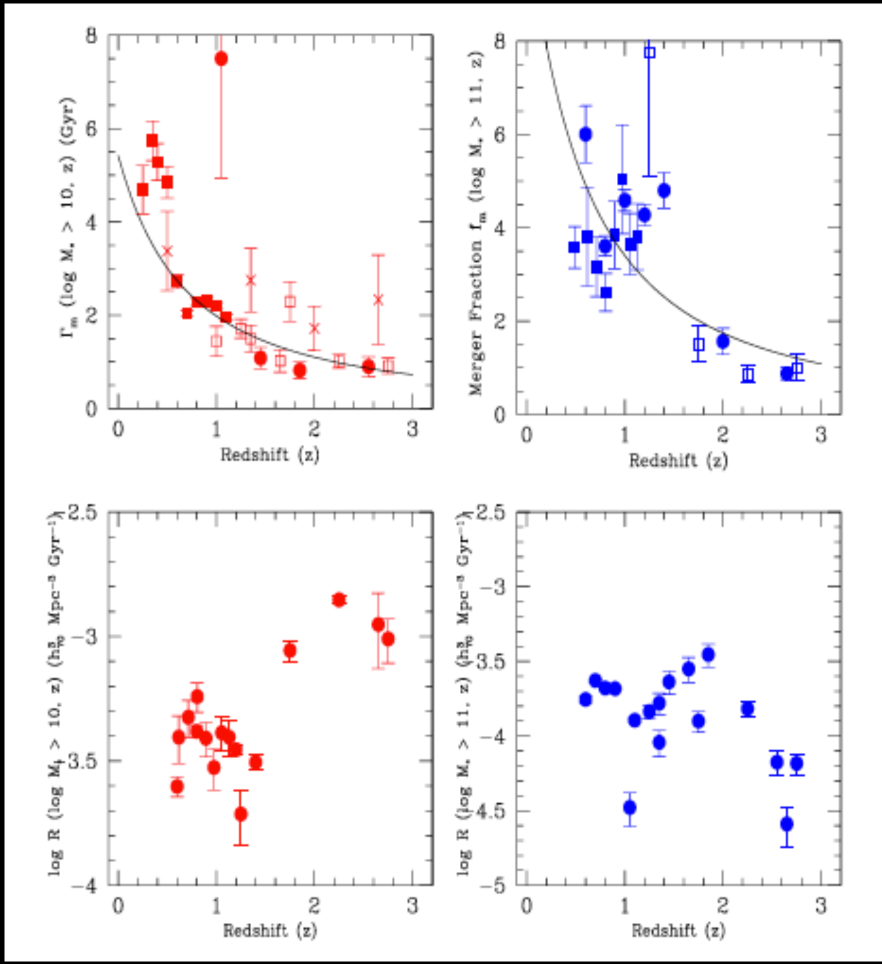
(for stellar mass selected samples, Conselice 2014, ARAA)

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

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

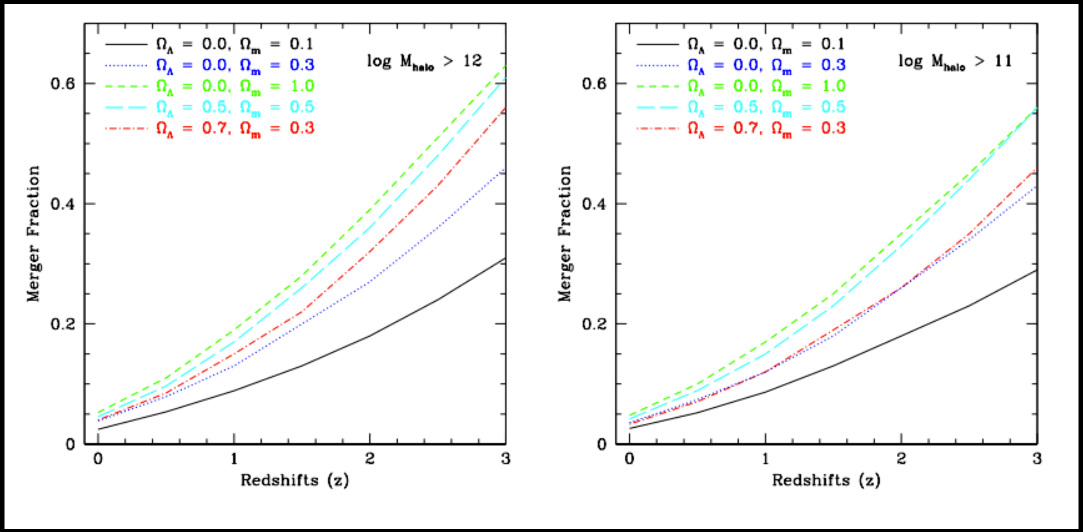
For our best fit for Γ(z), integrating over the redshift range of our galaxies we obtained:

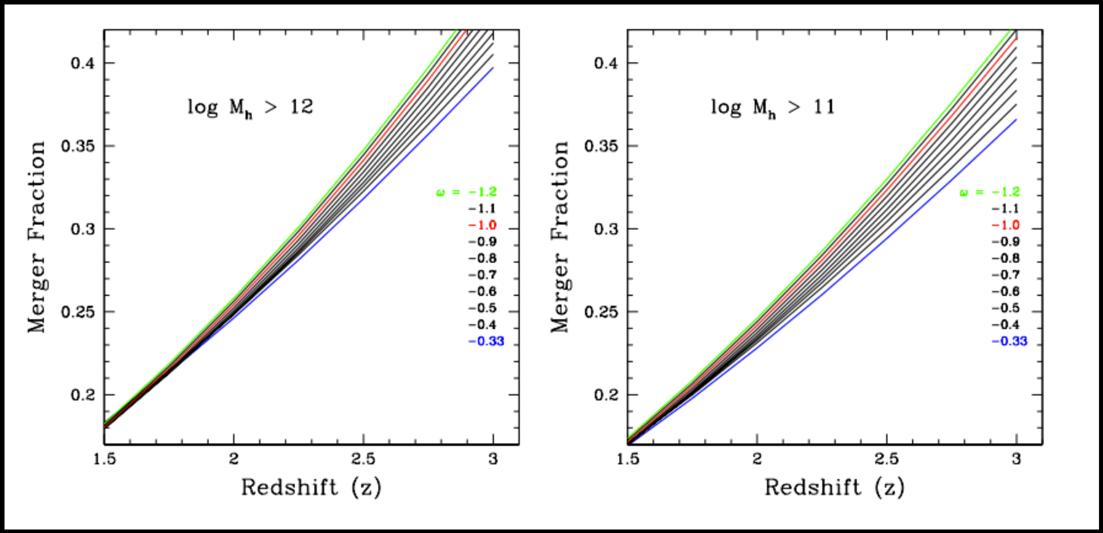
N = 1.7 +/- 0.5
(Major mergers / Galaxy)



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

Mergers as a method of measuring cosmology





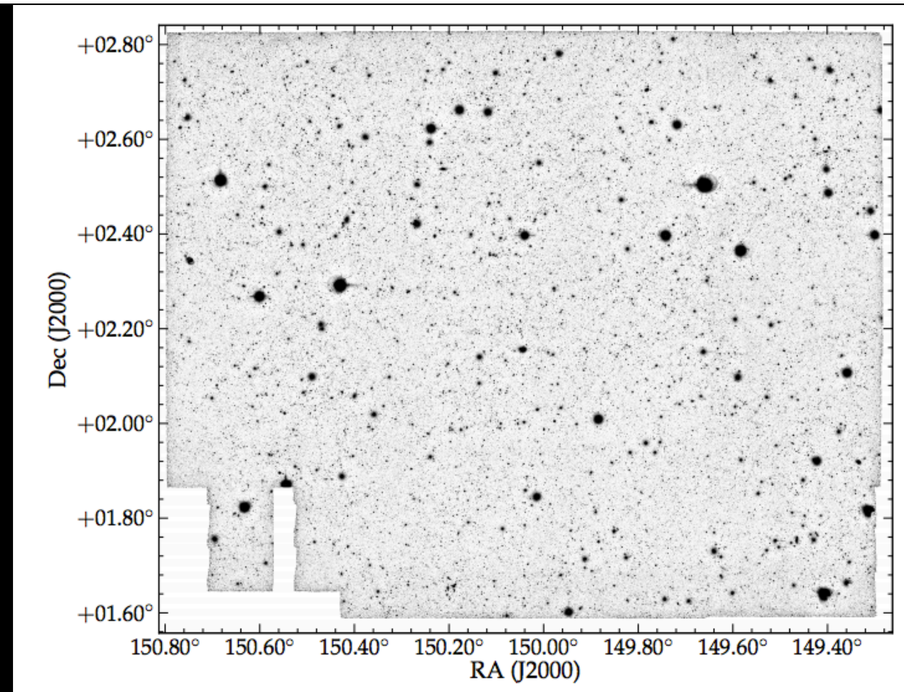
Conselice+14

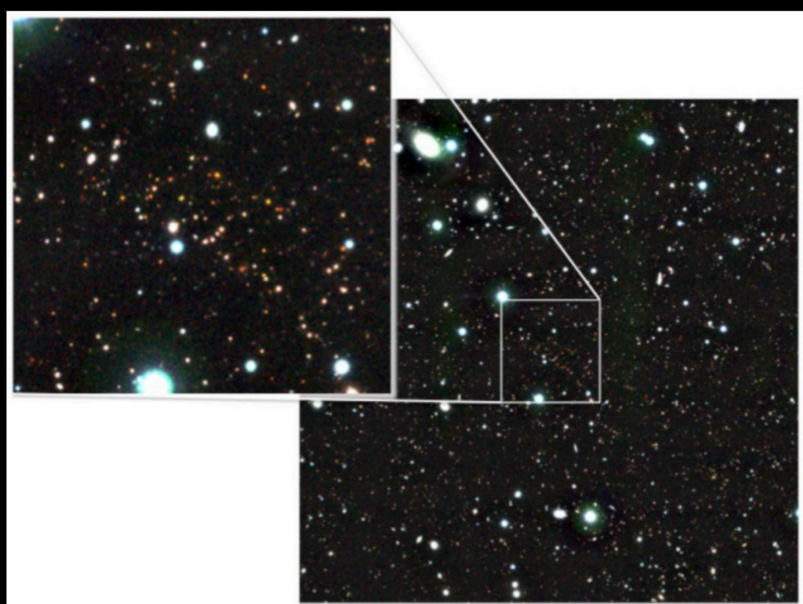
<u>REFINE</u> (Redshift Evolution and Formation in Extragalactic Systems)

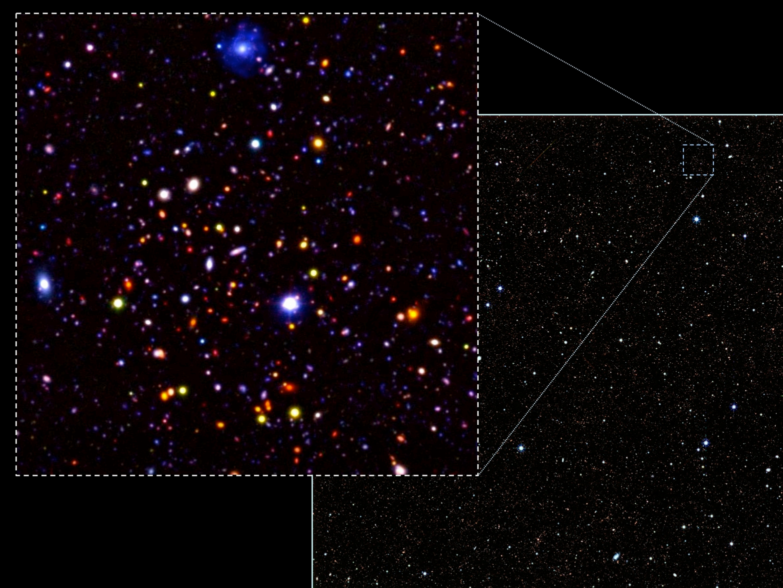
A reanalysis of redshifts and stellar masses for the three IR deep fields:

Ultra-VISTA: K = 23.4, 1.6 sq. degree
UDS: K = 24.2, 0.77 sq. degree
VIDEO: K = 22.5, 1 sq. degree

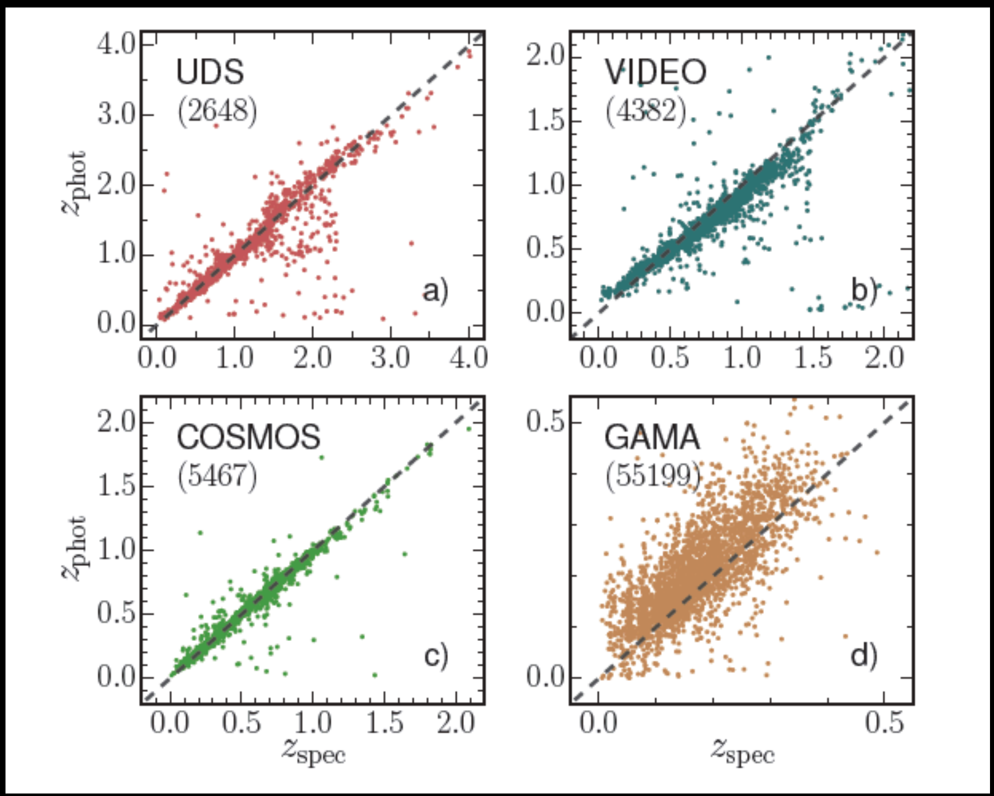
GAMA: 144 sq. degree (nearby uni)

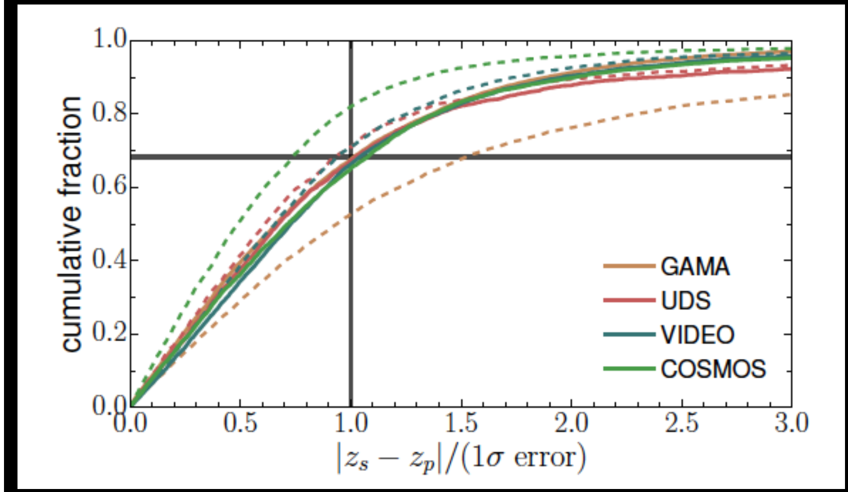






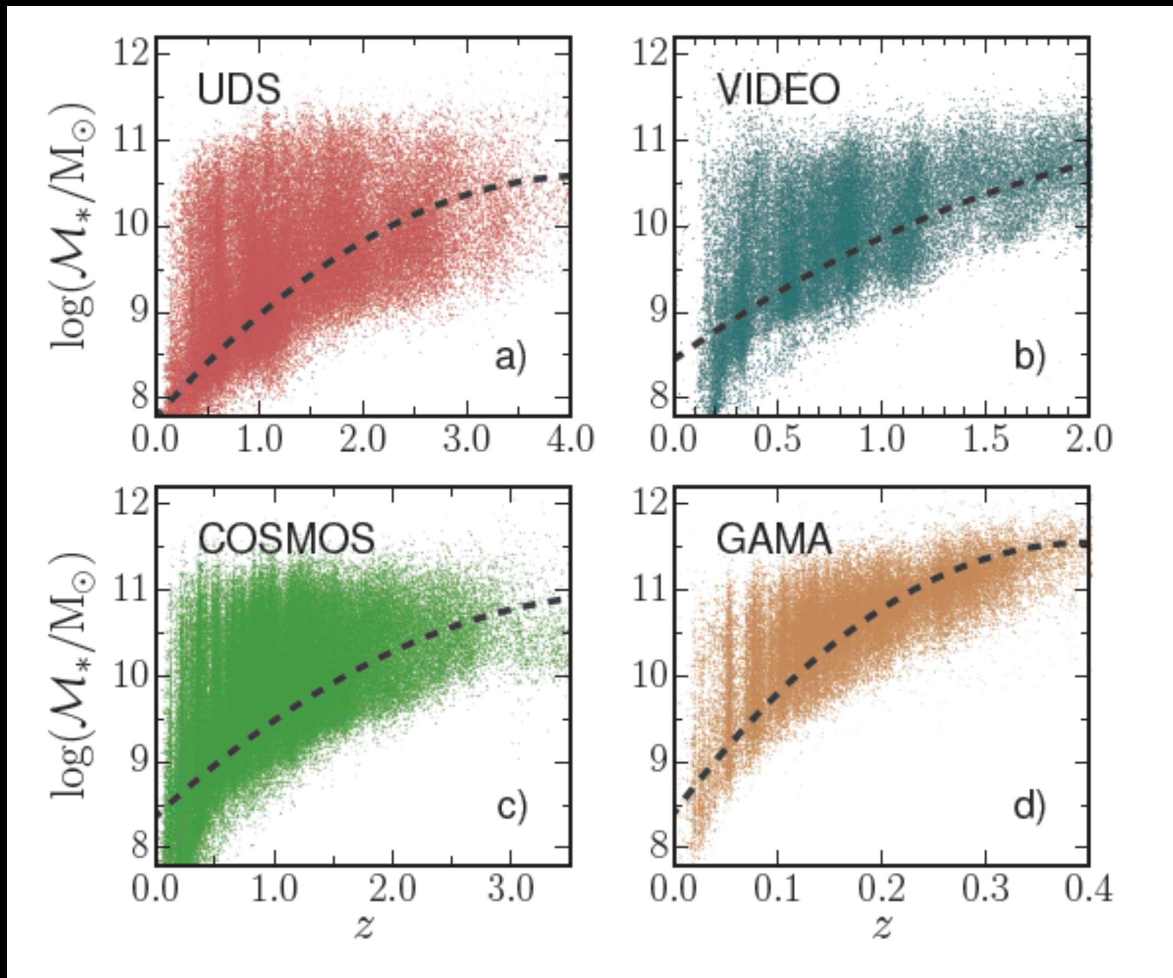
Photometric Redshift Distributions for Each Field





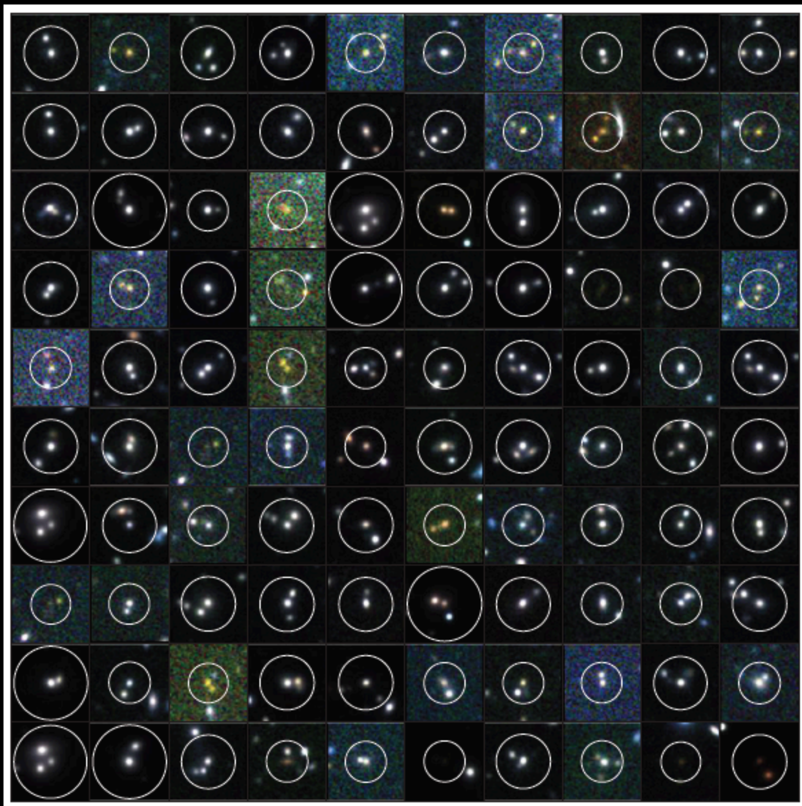
Each z-phot has a PDF from EAZY

Stellar mass distribution

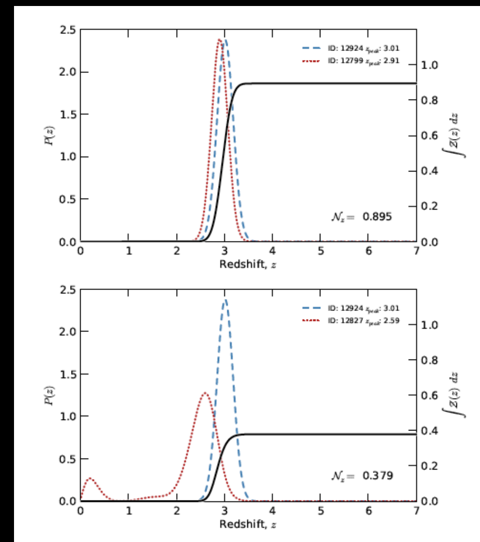


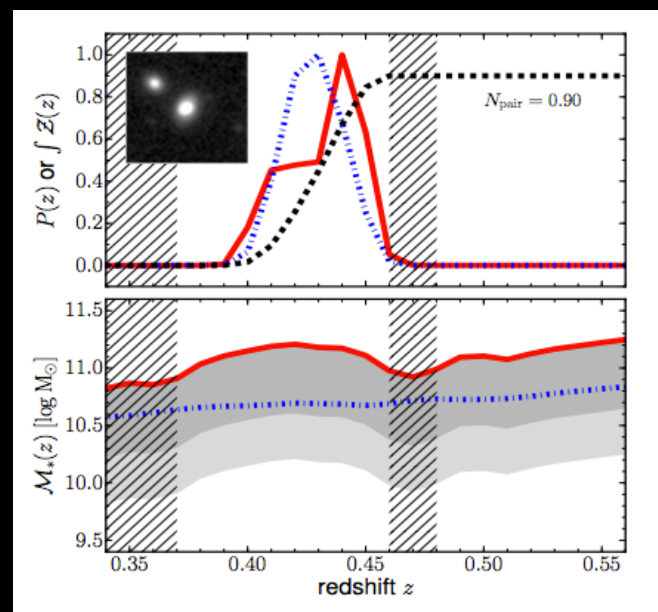
Complete to 10^{10} M_0 out to z = 3

Mergers – though pair counts



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

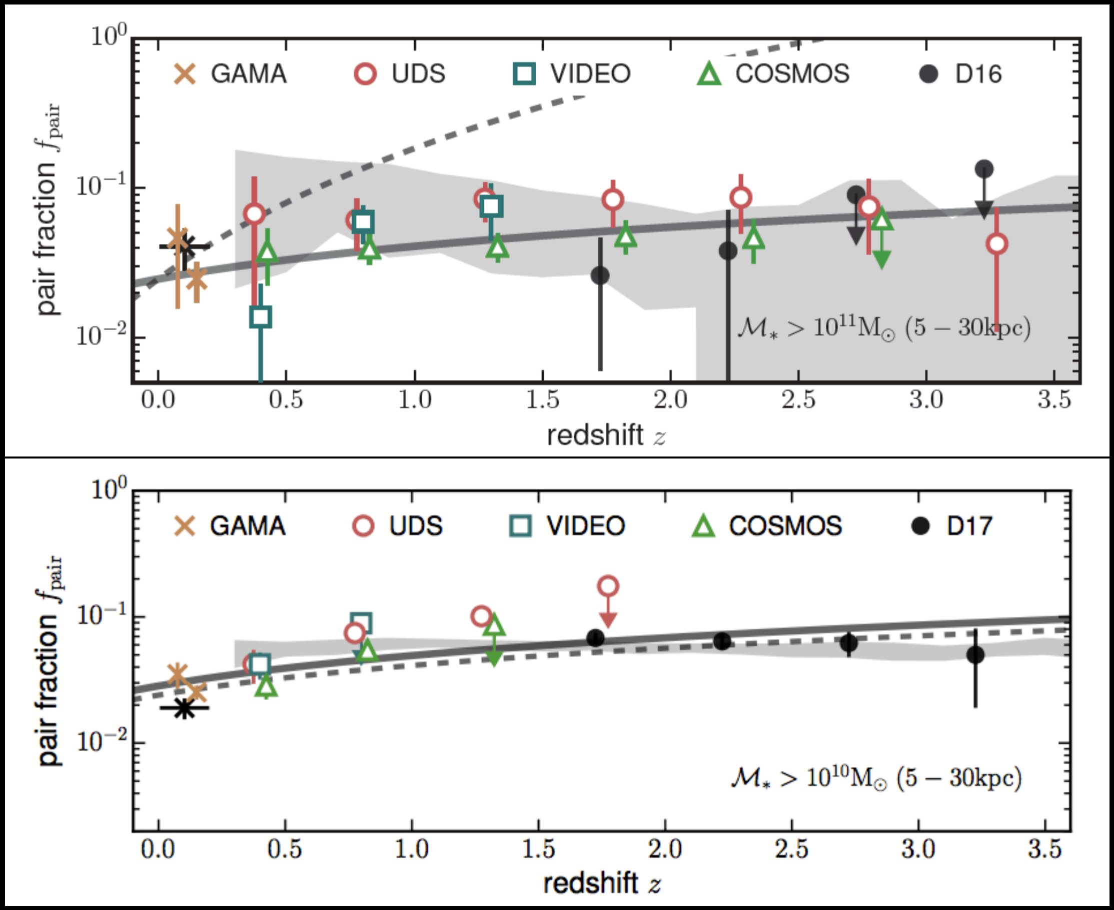




$$\mathcal{Z}(z) = \frac{2 \times P_1(z) \times P_2(z)}{P_1(z) + P_2(z)} = \frac{P_1(z) \times P_2(z)}{N(z)}.$$

New Results

Pair fraction evolution for log M > 10, 11 + < 30kpc + < ¼ mass ratio

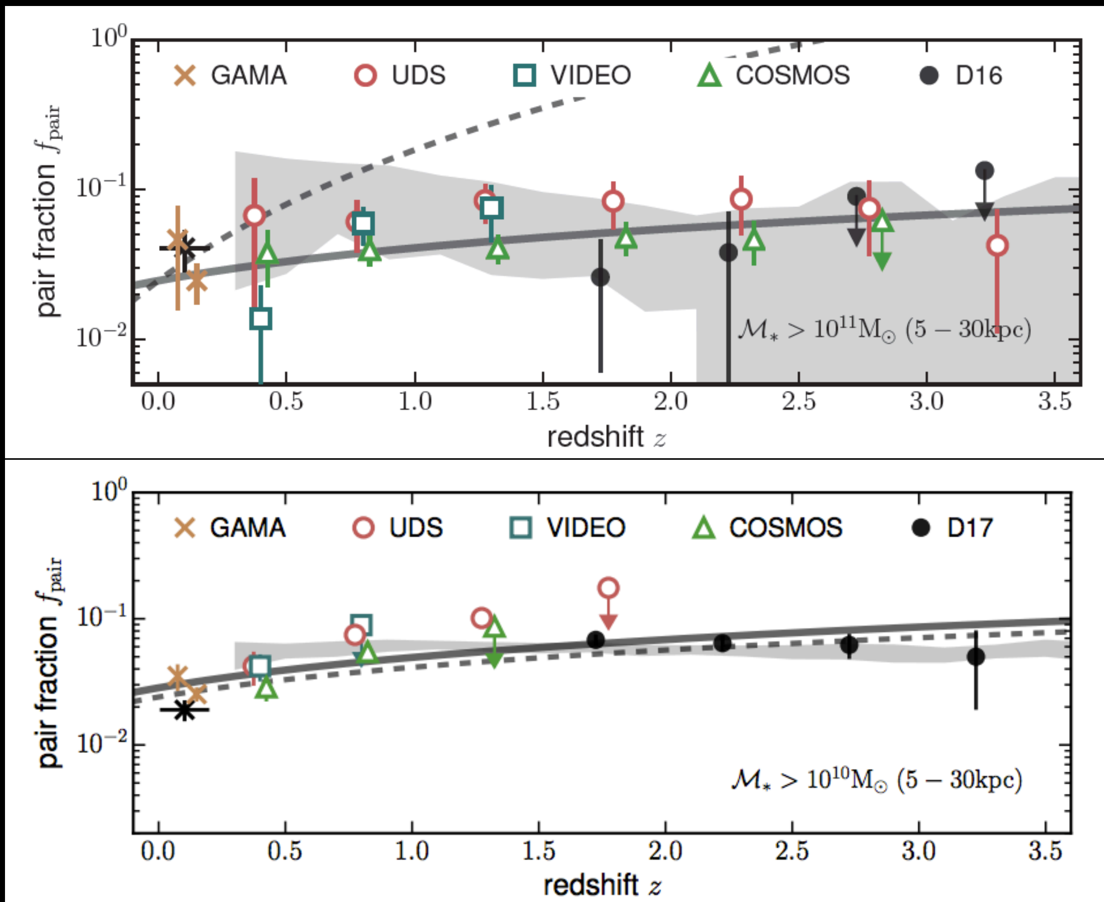


Pair Fractions from three 1 degree sq. deep imaging surveys
VIDEO, UDS, COSMOS and GAMA (for z ~ 0)

Mundy, CC+17, in press: arXiv: 1705.07986

New Results

Pair fraction evolution for log M > 10, 11 + < 30kpc + < ¼ mass ratio

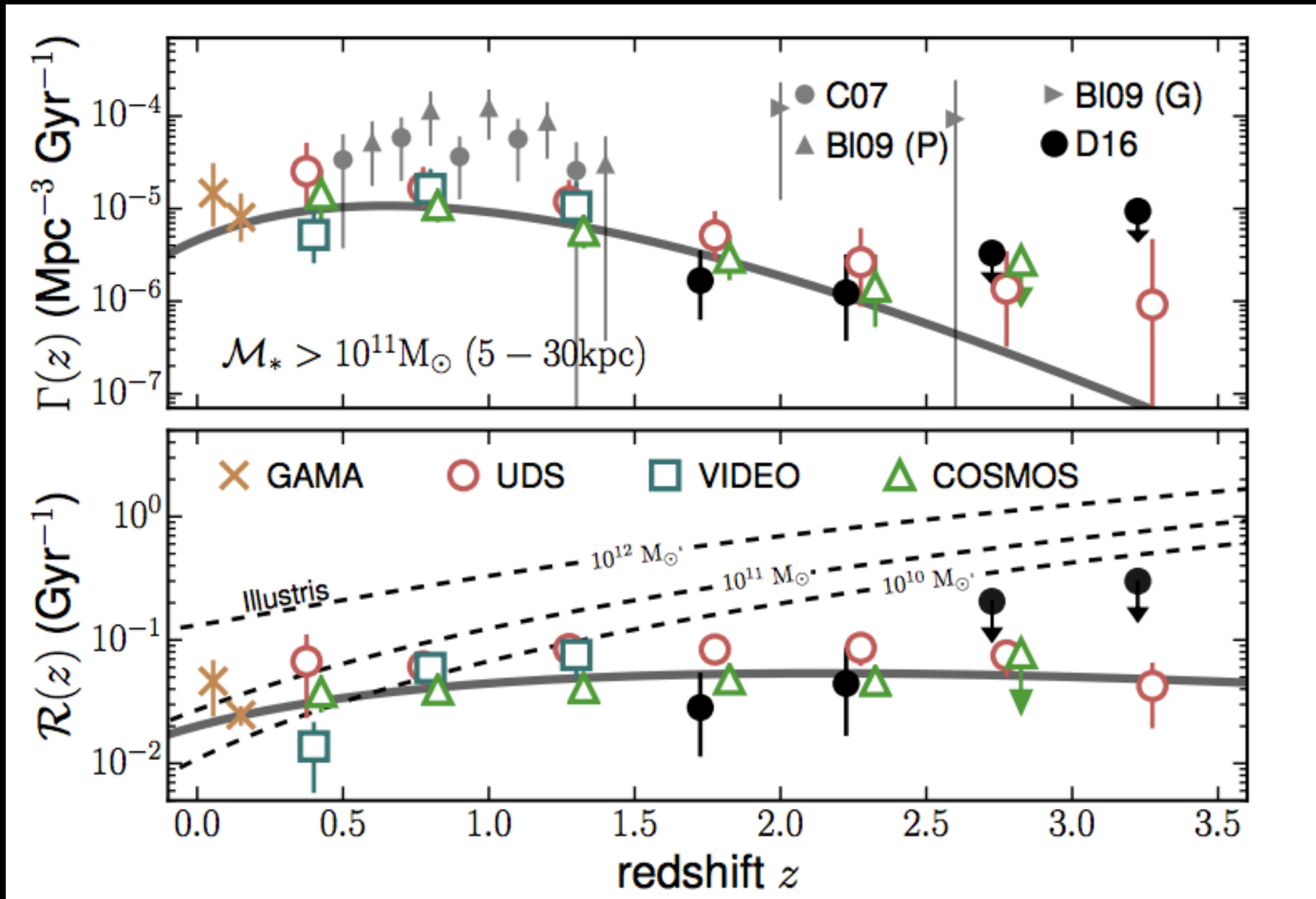


Good agreement with CDM models (Henriques+15)

Not the case previously (e.g., Jogee+09, Bertone+CC 09)

Mundy, CC+17, in press: arXiv: 1705.07986

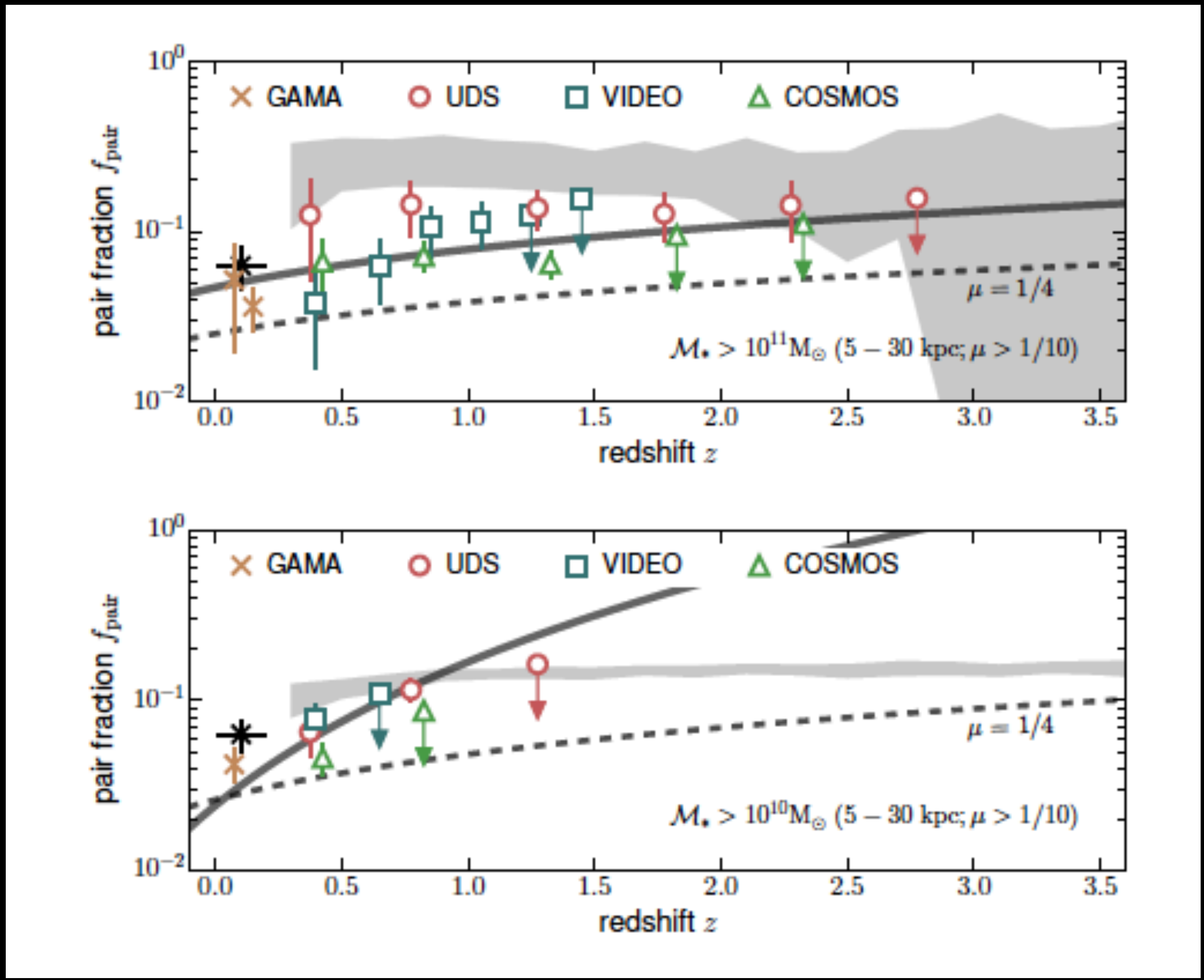
Merger rates, harder to infer – need time-scales



Results show a merger rate which is lower than previous work

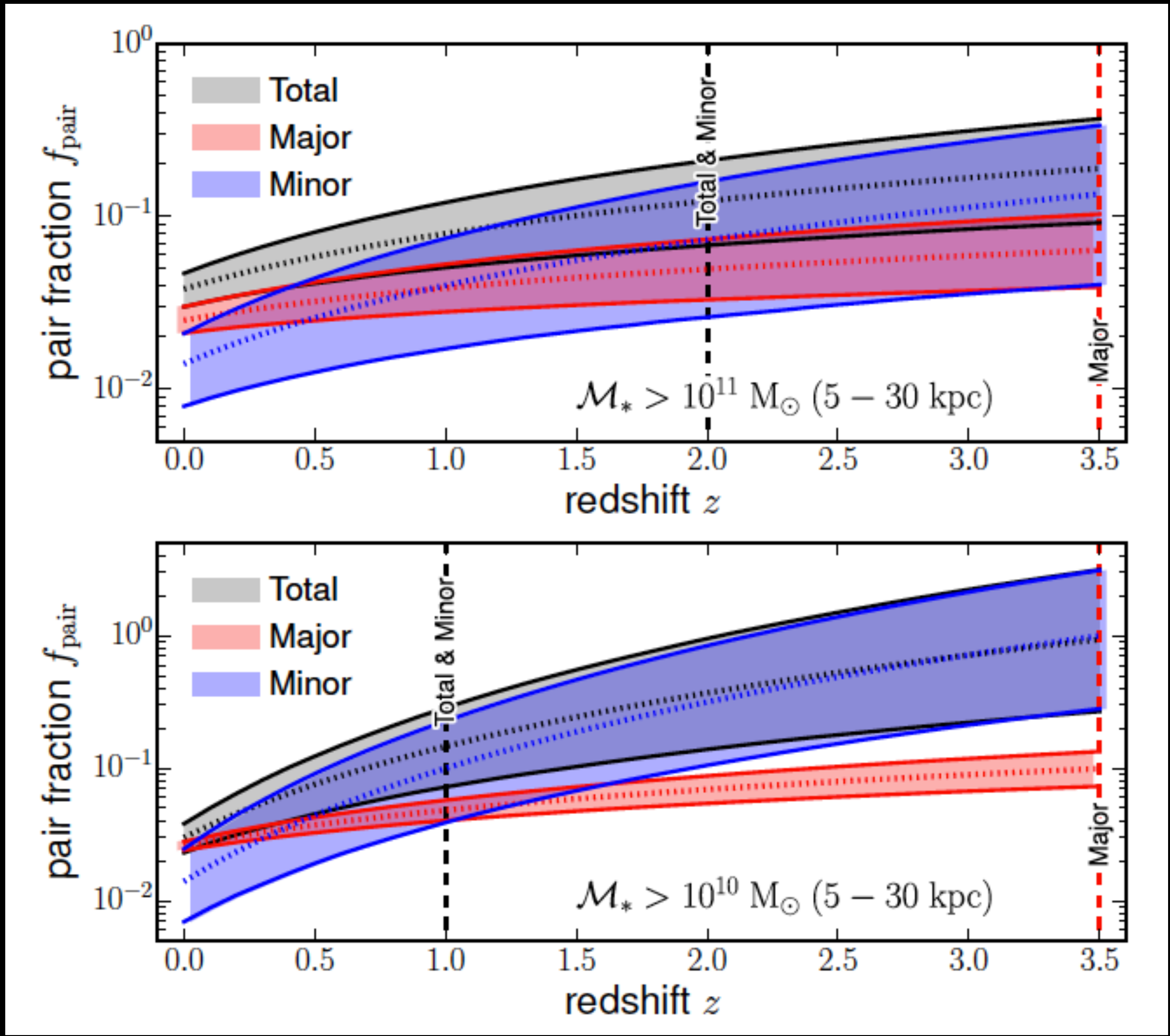
<u>Gives ~1 major merger per galaxy at z < 3</u>

Minor Merger Pair Fraction - ratio > 1/10



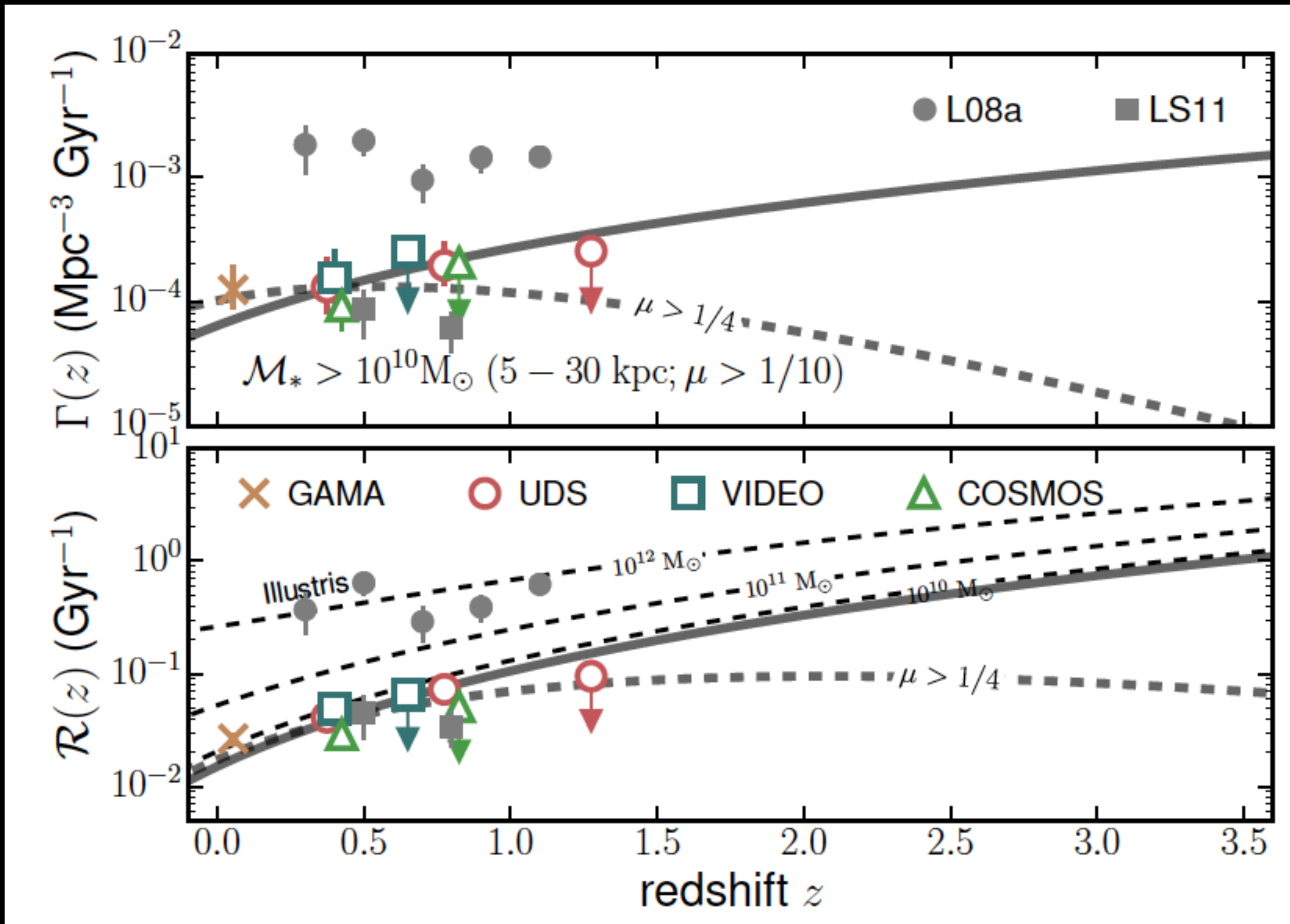
(Models not in agreement)

Comparison between the minor and major pairs



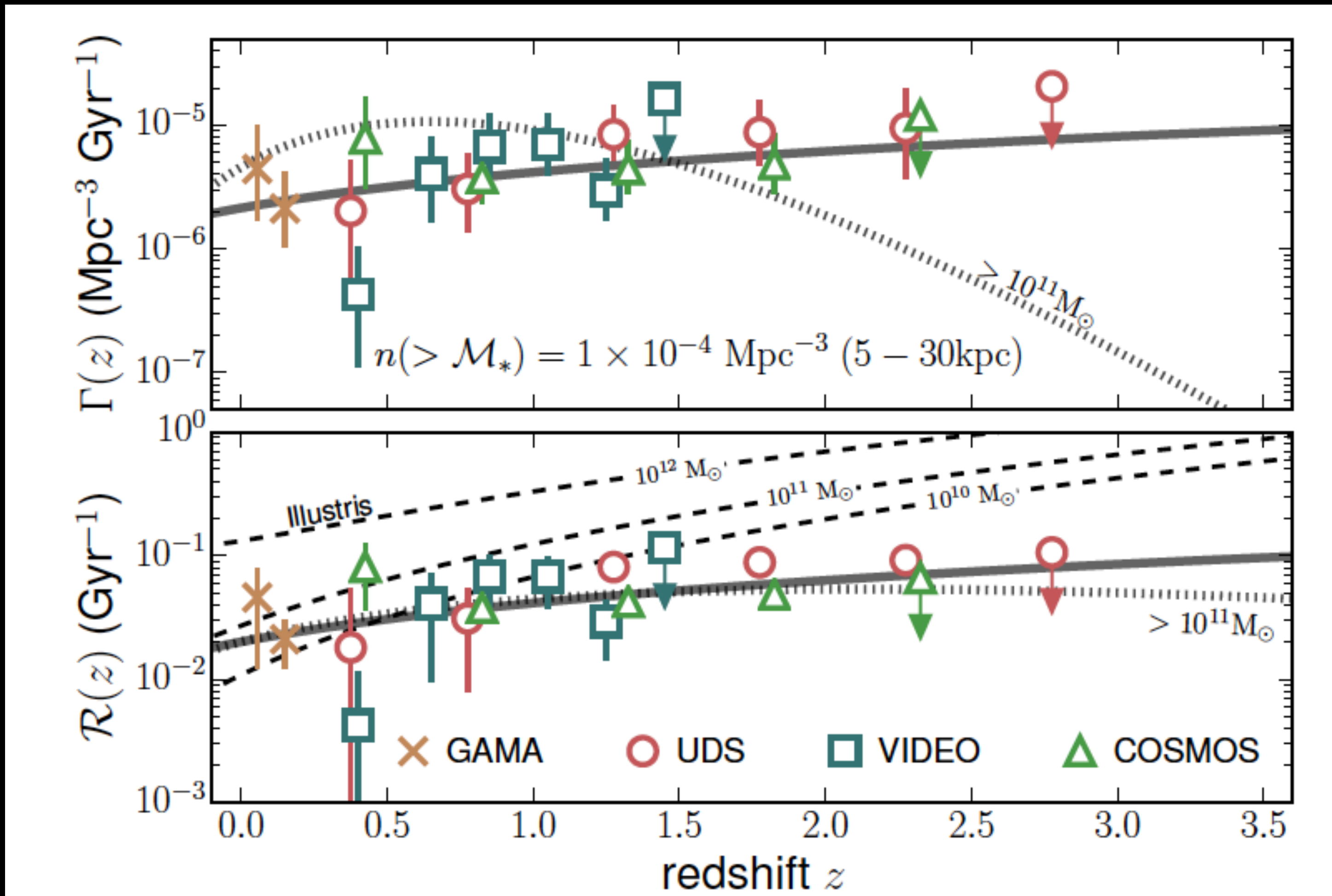
Mundy, CC+17

Minor merger rates comparison – previous results



Mundy, CC+17, in prep

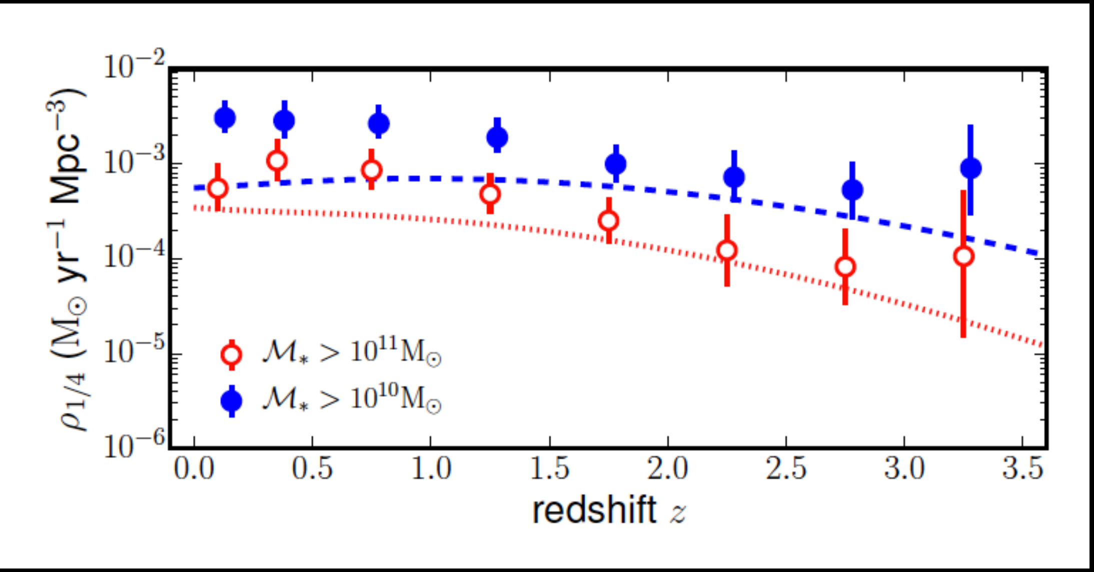
Comparison to Models – not good agreement for minor mergers

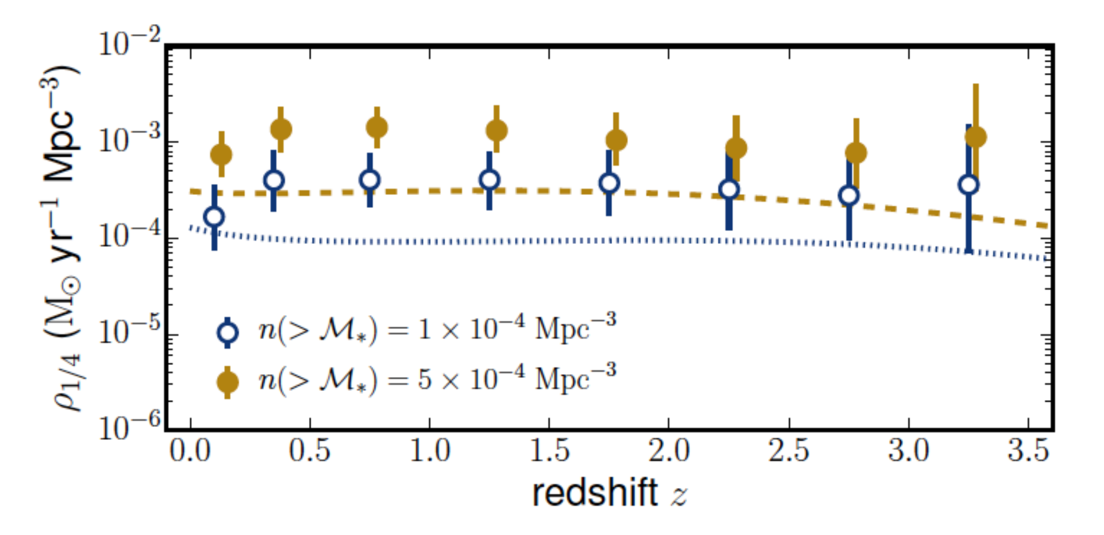


Using same co-moving density – can trace to higher z
Find a higher merger rate for minors than majors at higher-z

Mundy, CC+17 in prep

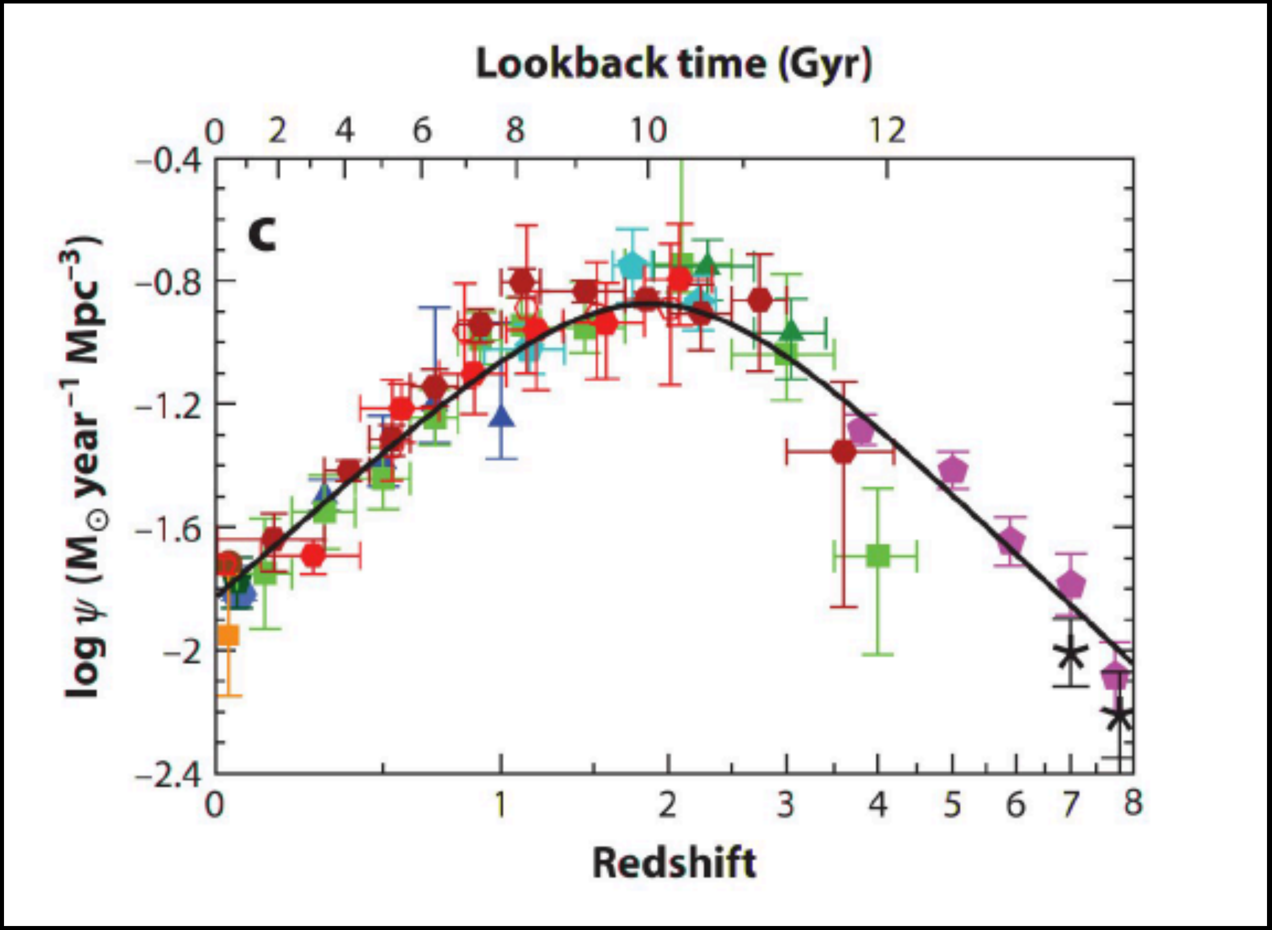
How much stellar mass is added due to mergers?





The mass accretion rate due to major mergers

Can compare with star formation history



<u>At $z = 2$ SFR Peak</u>

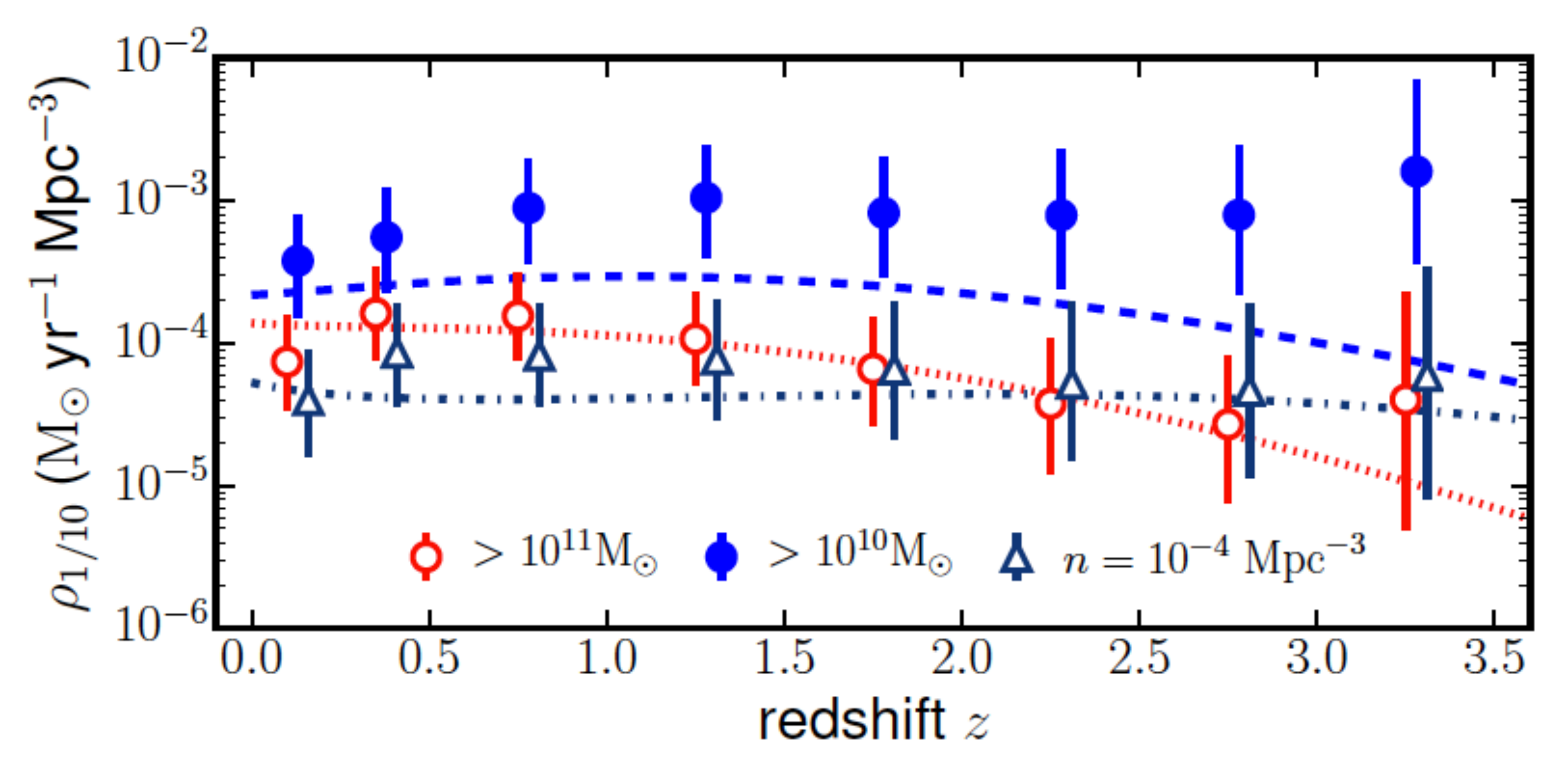
SFR ~ 0.1

Mergers ~ 0.005

<u>But only for log M > 10</u>

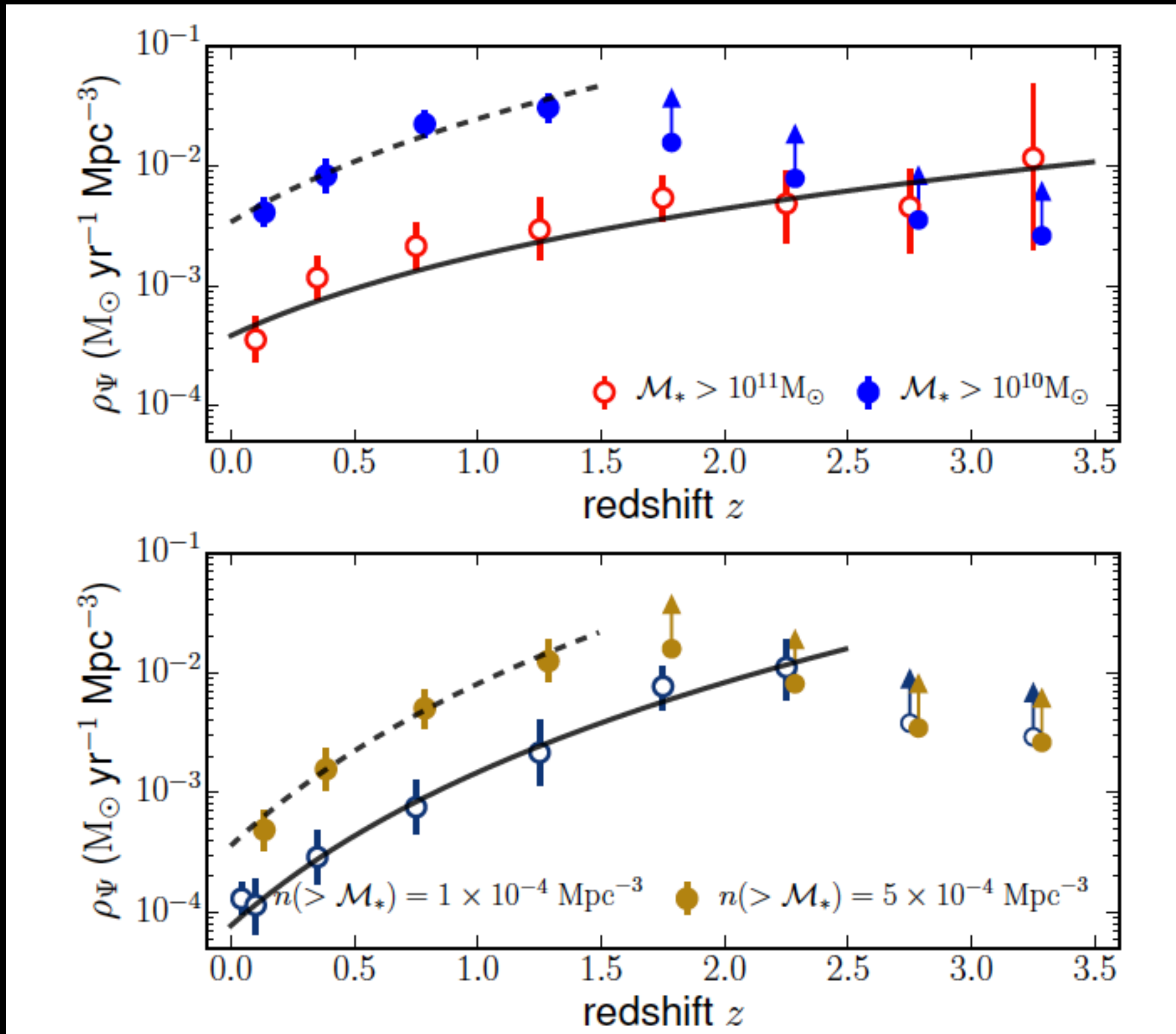
Madau & Dickinson 2014

Mass accretion rate due to minor mergers



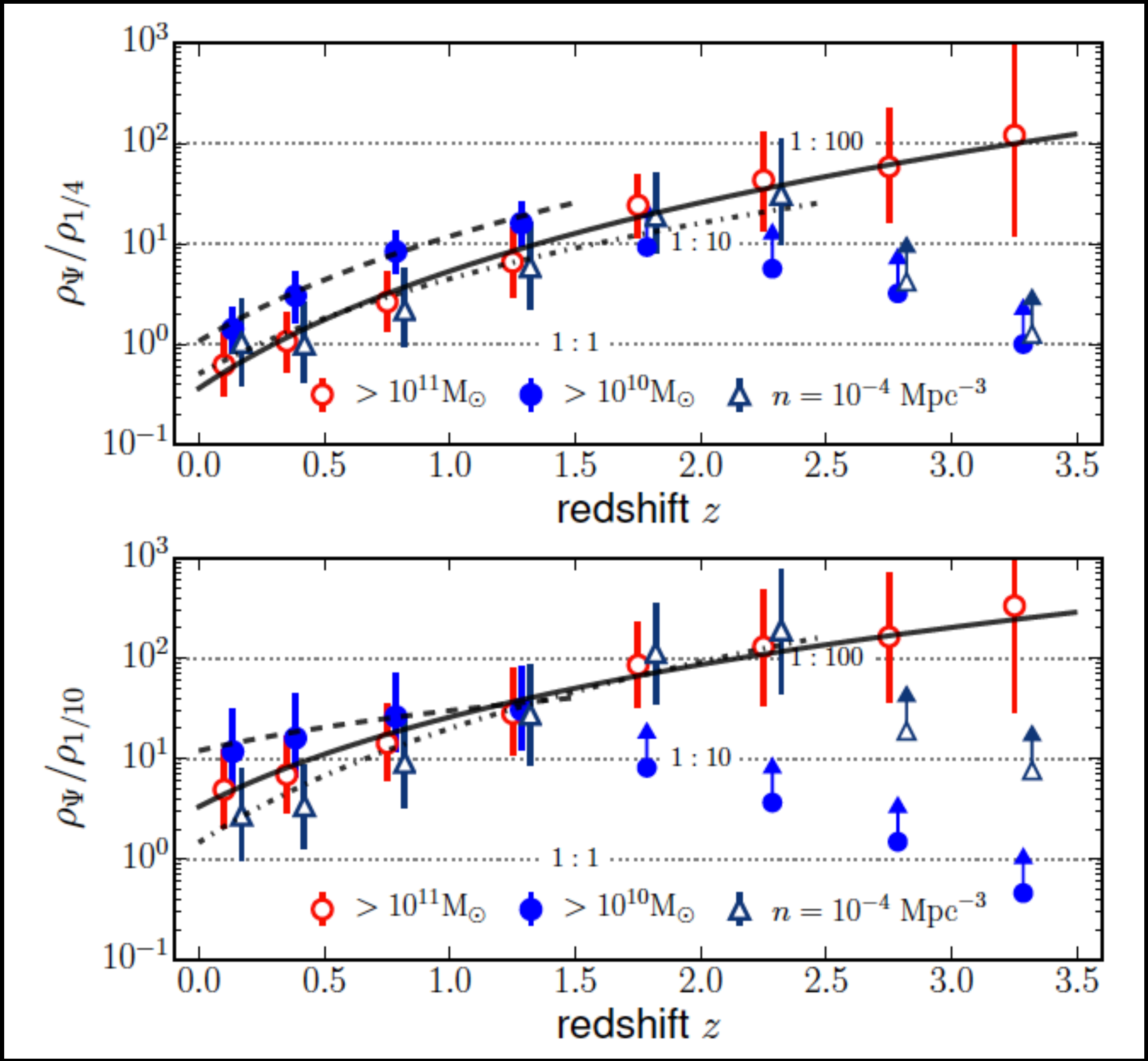
About the same level as the mass accretion from major mergers

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

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

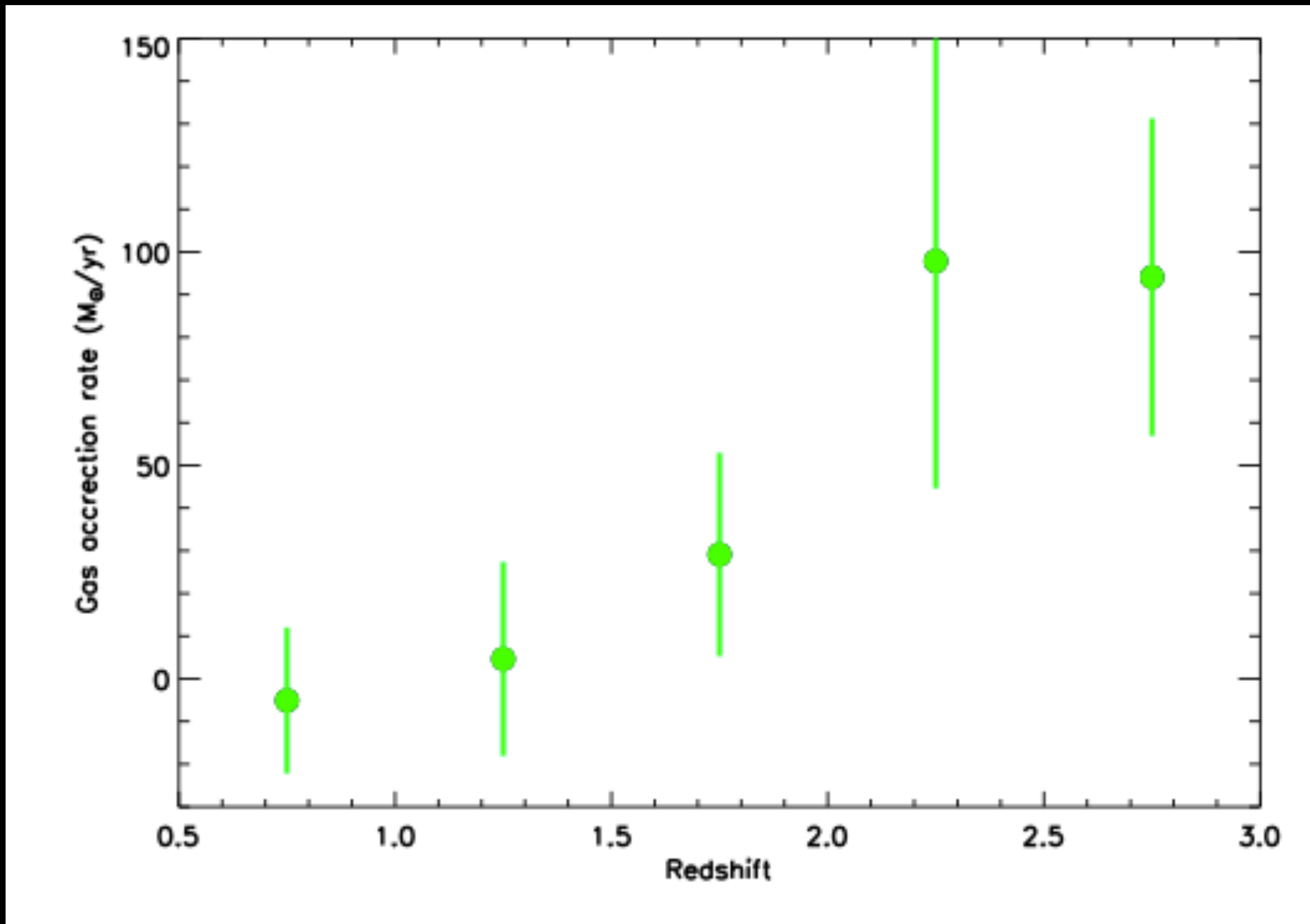
Conselice+13

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

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

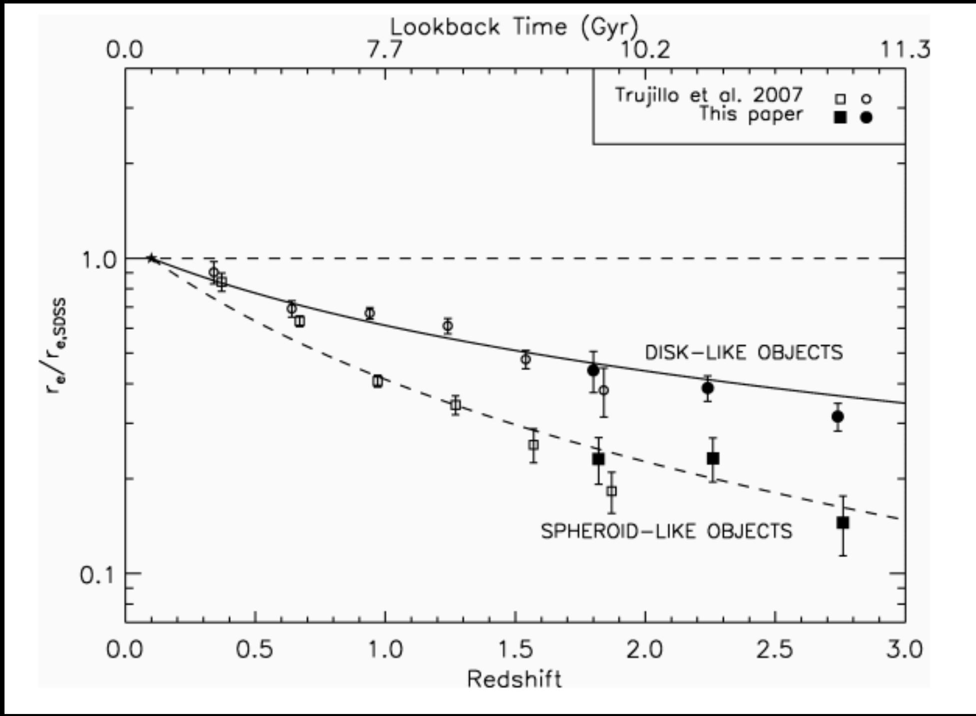
→ *Evidence for cold gas accretion or hot halo gas cooling*

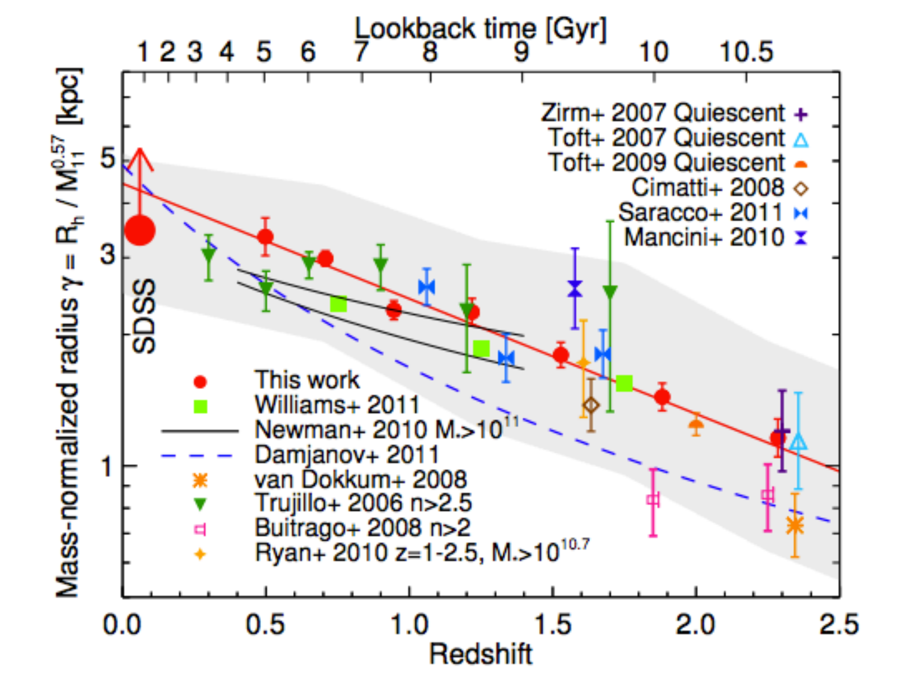
Gas accretion rate history for massive systems over cosmic time



Ownsworth,CC,+14

Size evolution – galaxies get larger with time



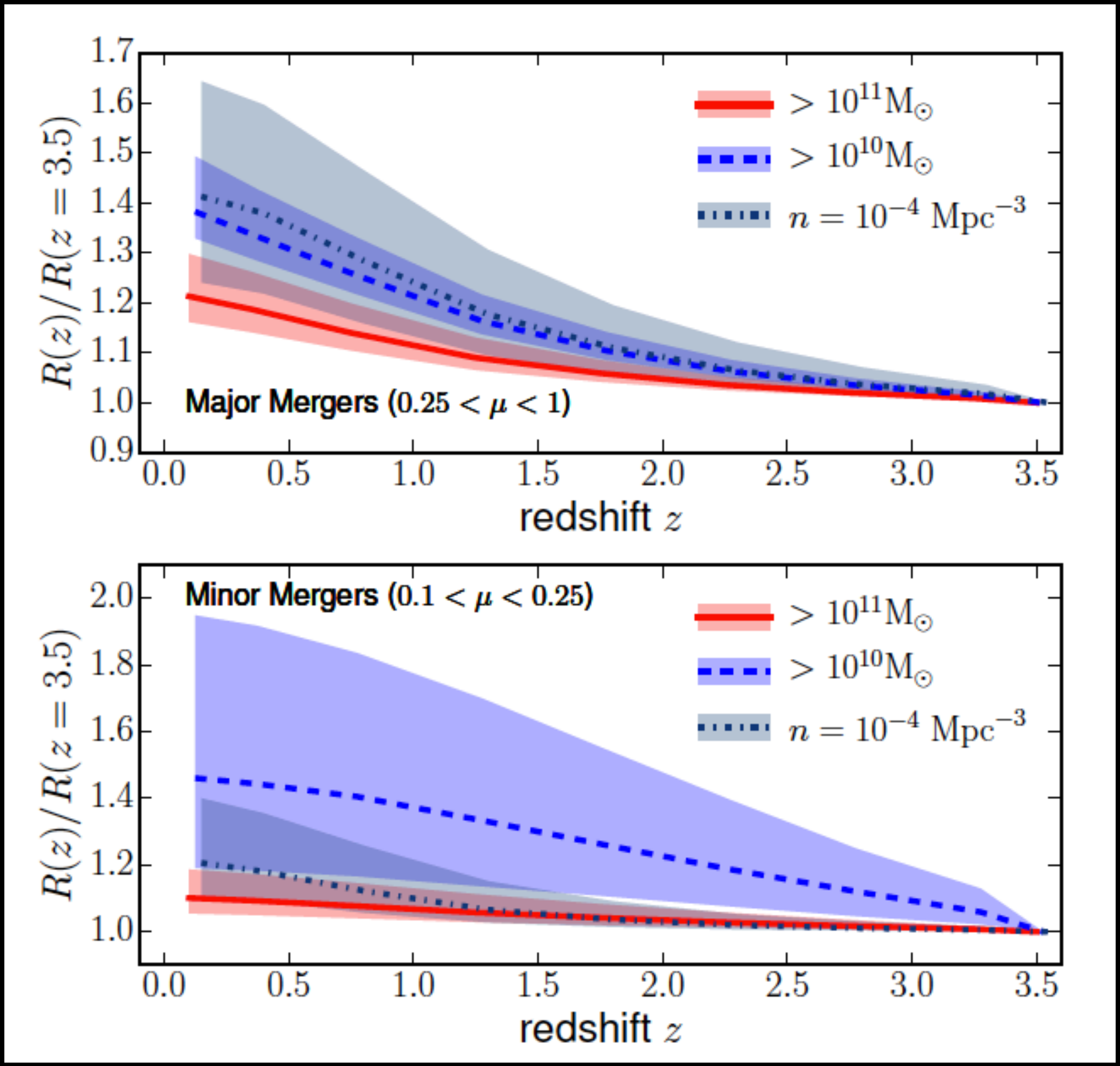


Buitrago+08

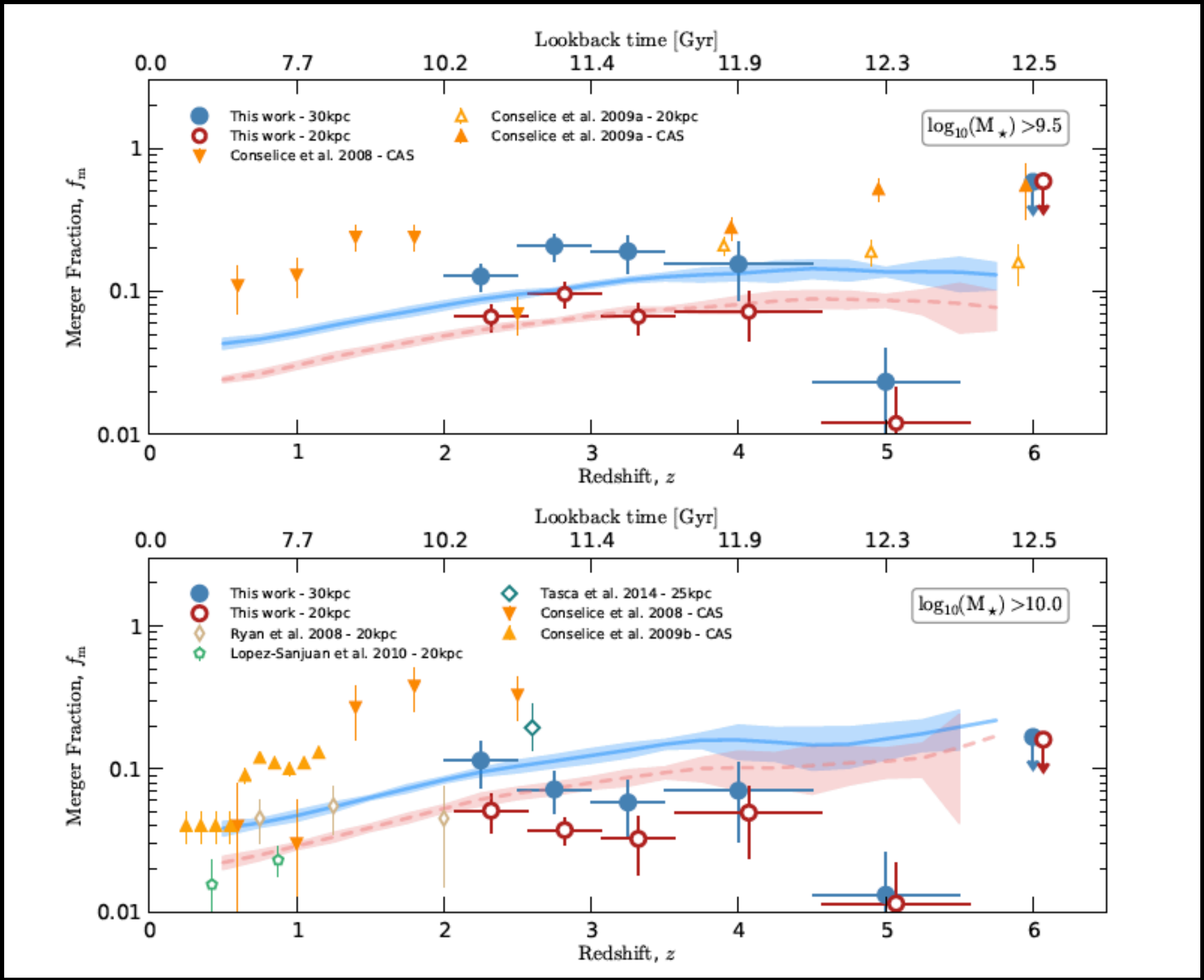
Newman+12

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. Mergers are an important – but not the only – process for galaxy formation. Log M > 10 galaxies undergo ~1 merger at z < 3

2. Major and minor mergers in galaxies up to z=3 contribute at the 30-50% level, with one major merger at z < 1 on average. Need denser (spectra/arcmin) spectroscopic surveys to probe better

3. Mergers are more important for baryonic assembly at late times, whereby at early times star formation is a factor of ~10 more important at z > 1.5

4. Gas accretion/cooling rates are much higher than the merger rate at z~2 and declines at a much faster rate

5. Simulations for major merger pairs agree with simulation, but not for minor mergers, or merger rates for either