Correlations of Baryons and Dark Matter During Galaxy Formation

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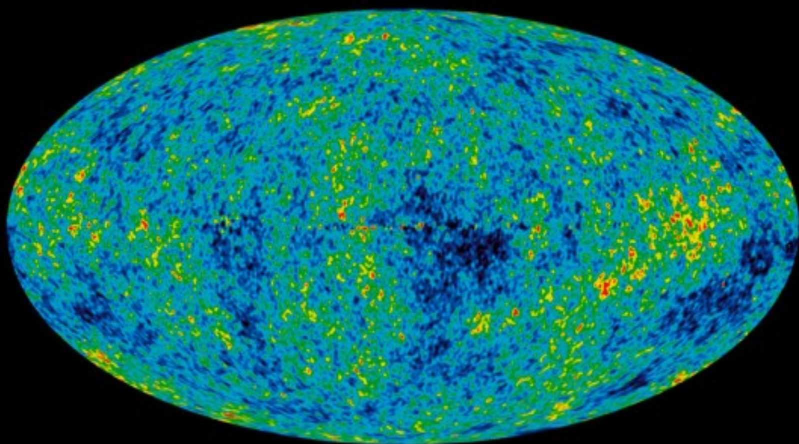
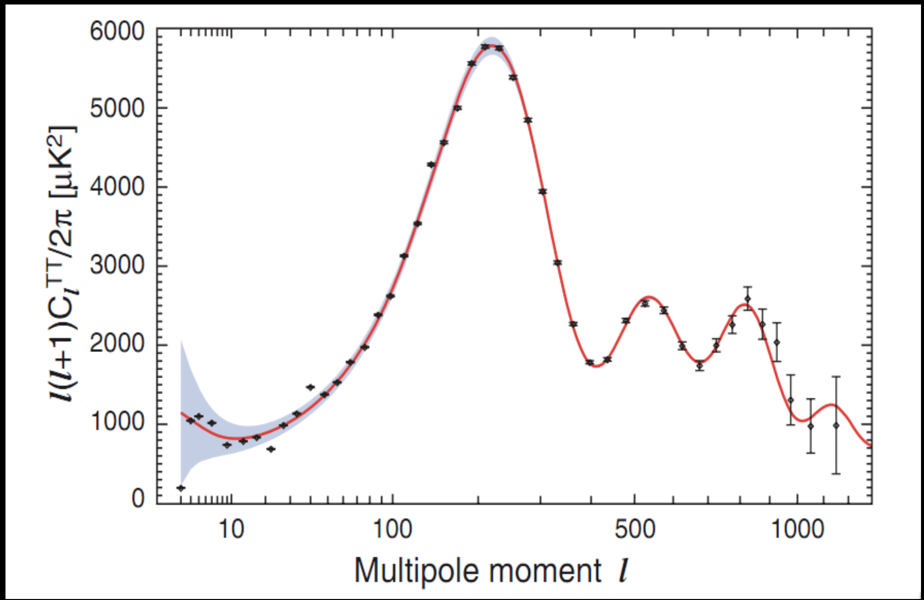
Cosmic Background Radiation – cosmological parameters

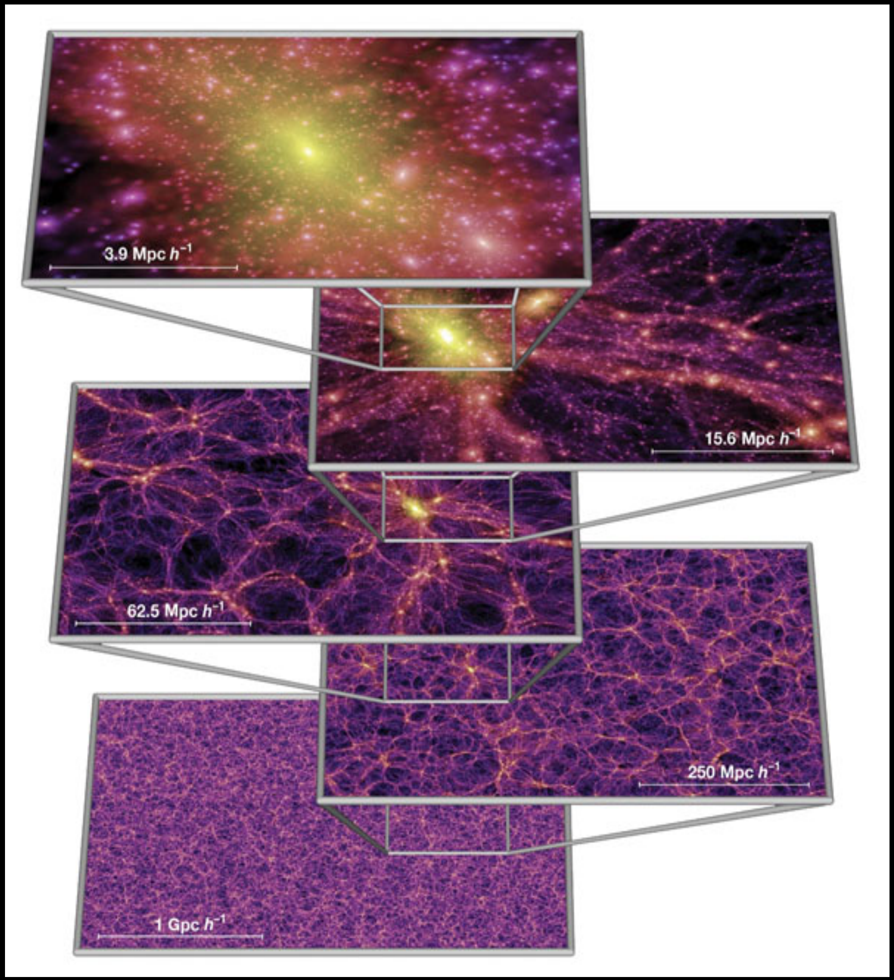




WMAP7

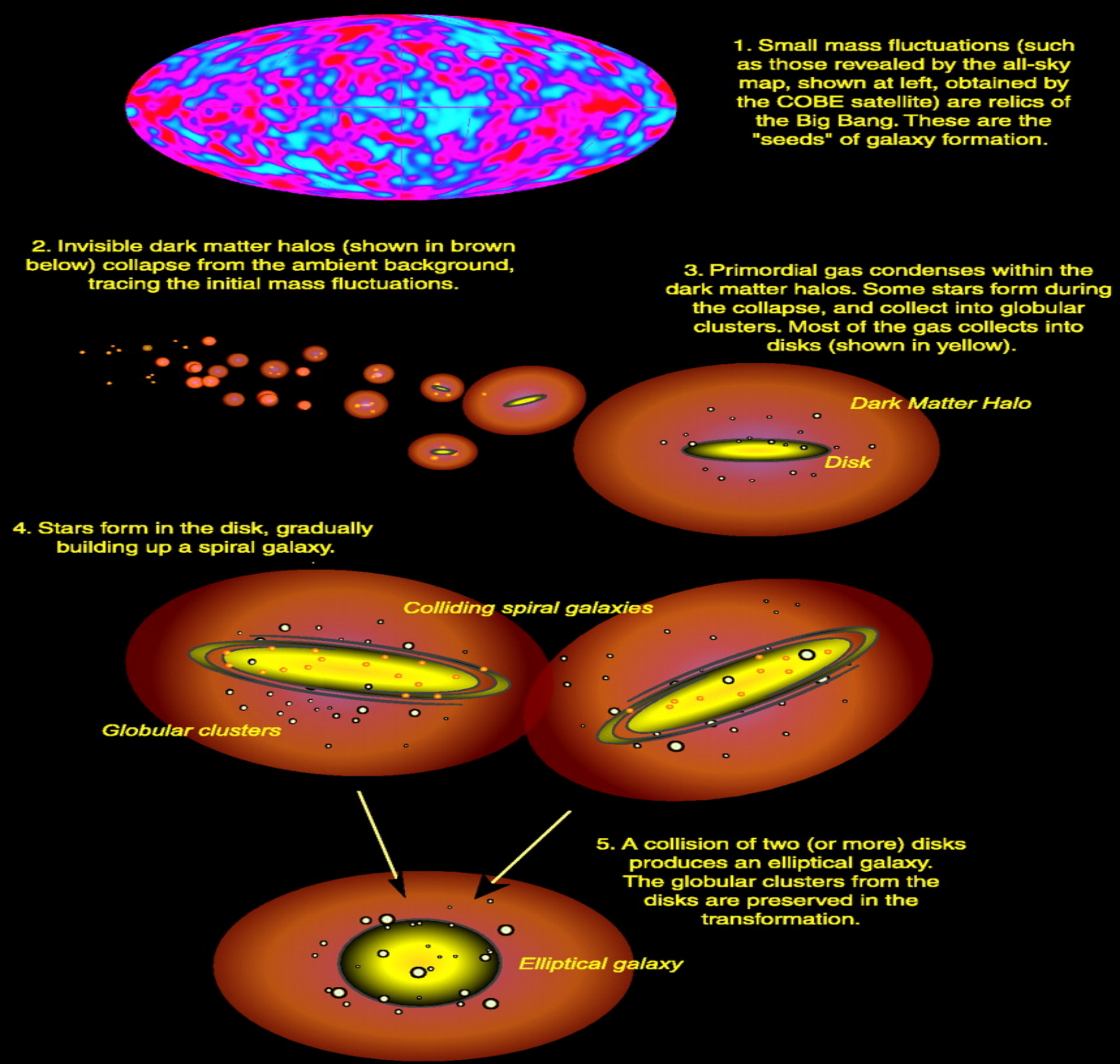
However, nature of dark energy, gravity, etc. can be addressed through observing the evolution of the universe – i.e., galaxies

Galaxy formation – cosmology, dark matter, dark energy and baryonic physics mixed together



Springel
et al. 2005

Traditional Idea for How Galaxies Form



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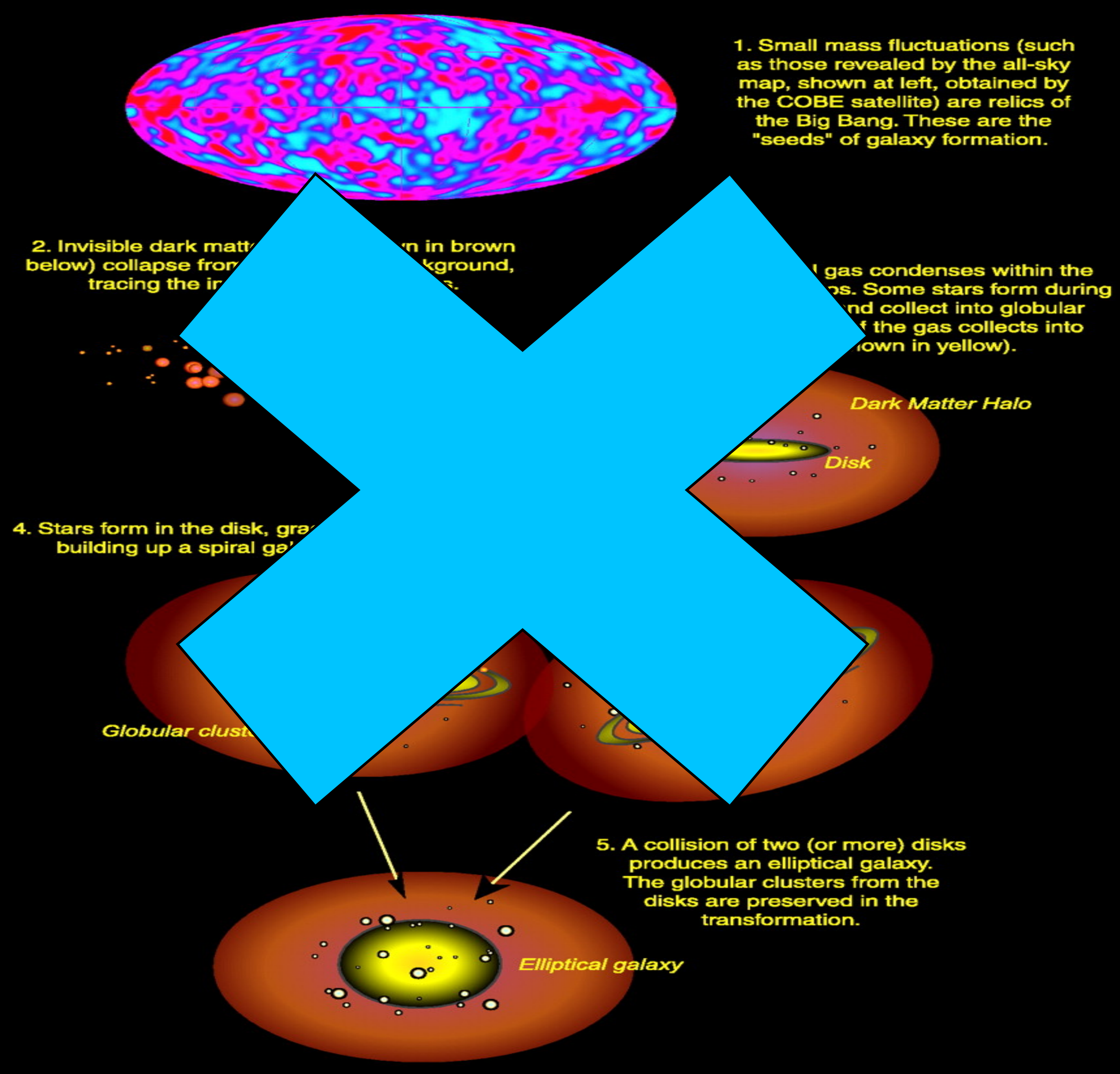
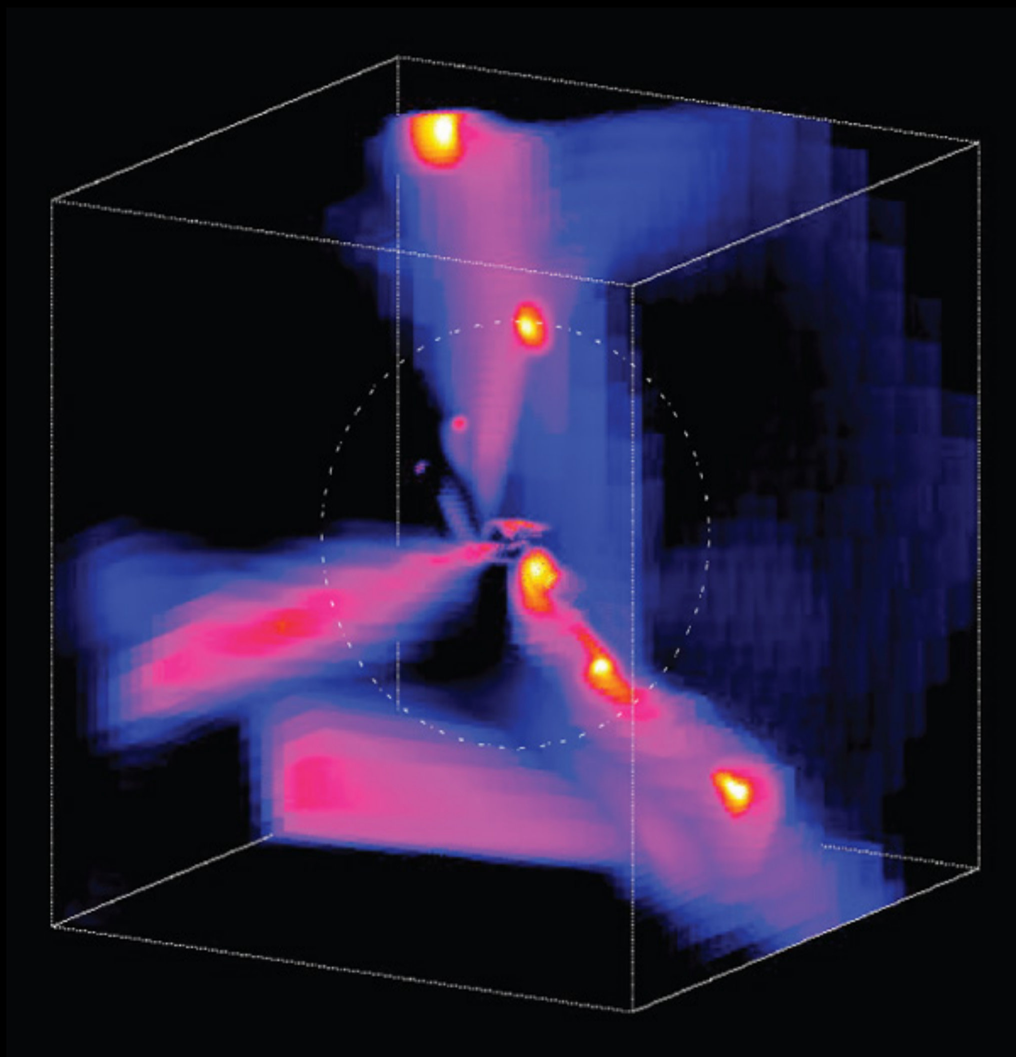
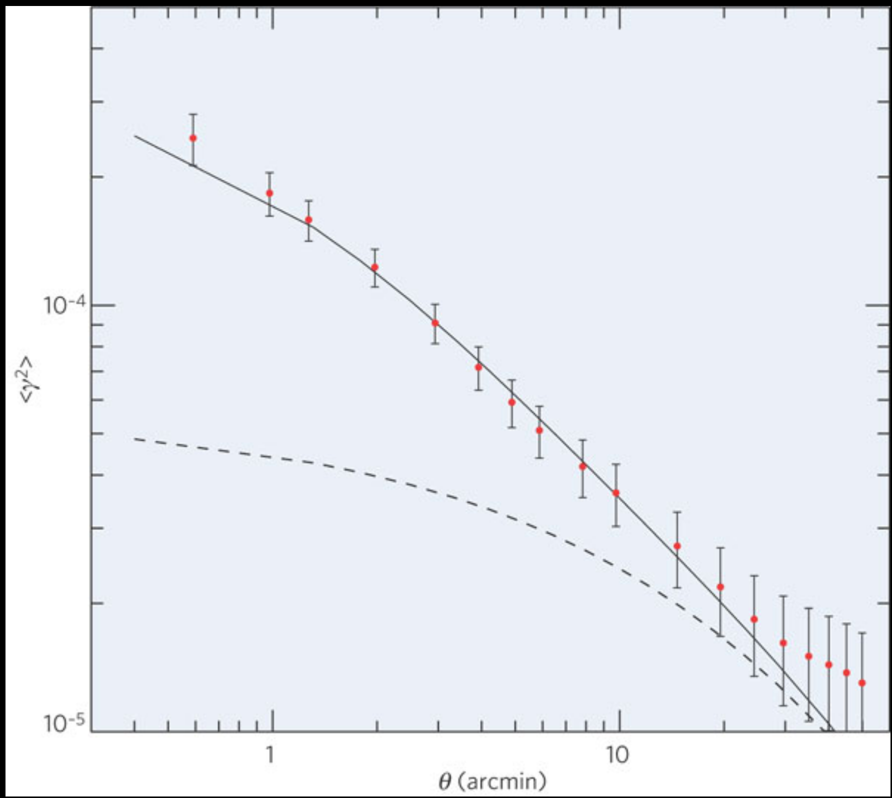
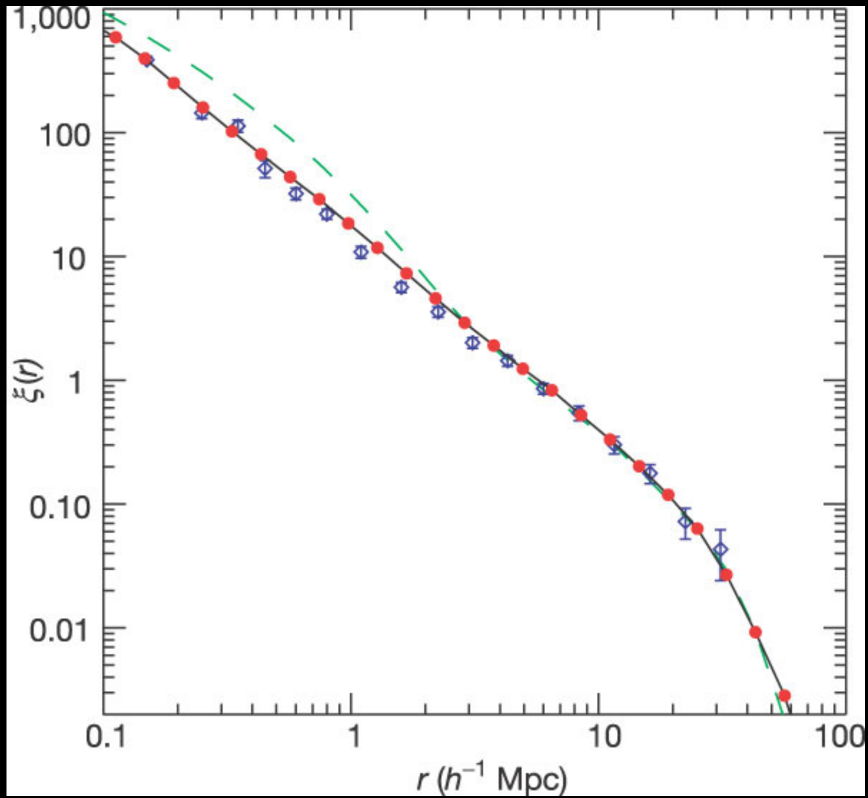


Cold gas accretion is a popular theoretical idea – but little obs. eviden



Dekel et al. 2008

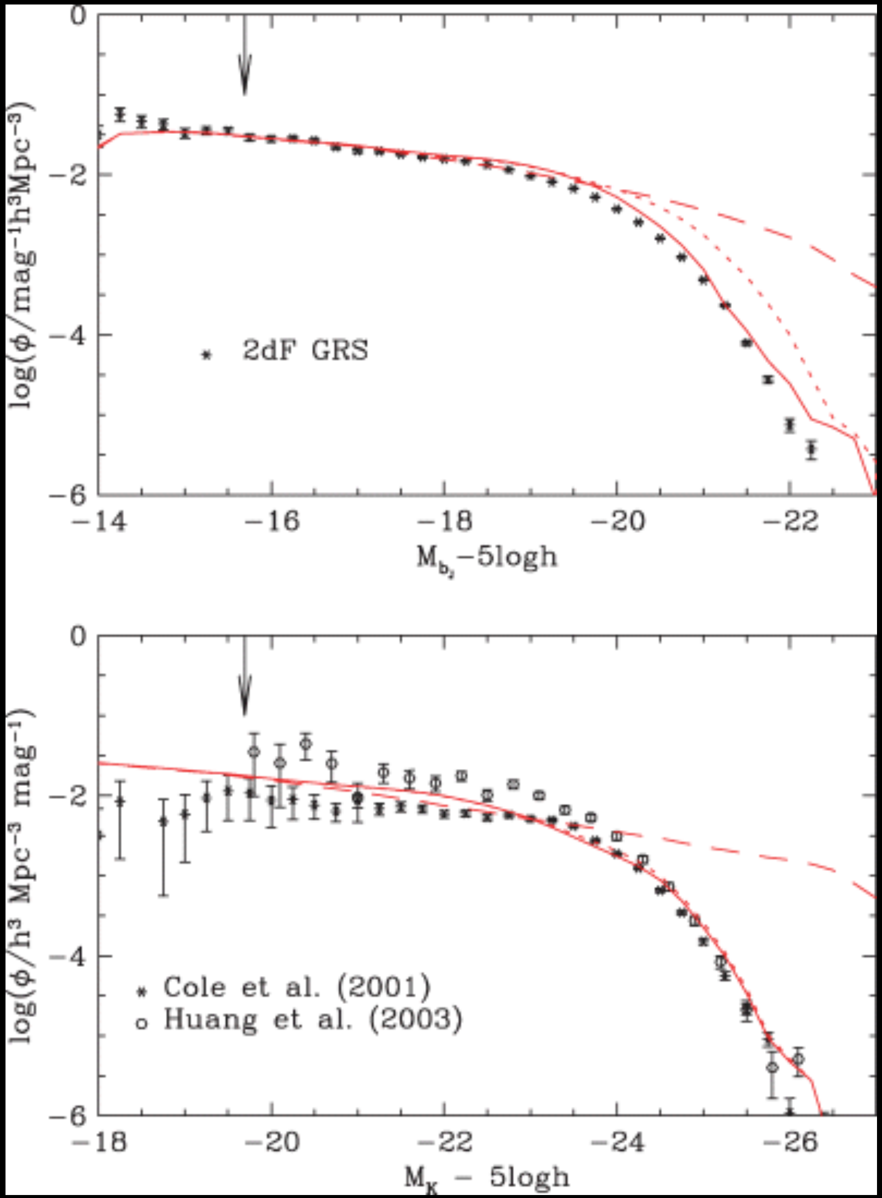




Lensing shear

Galaxy clustering

Models using LCDM
match well the large scale
features of the universe



Bower et al. (2006)

With added physics and feedback, LCDM models can match *some* z = 0 galaxy properties very well

Including:

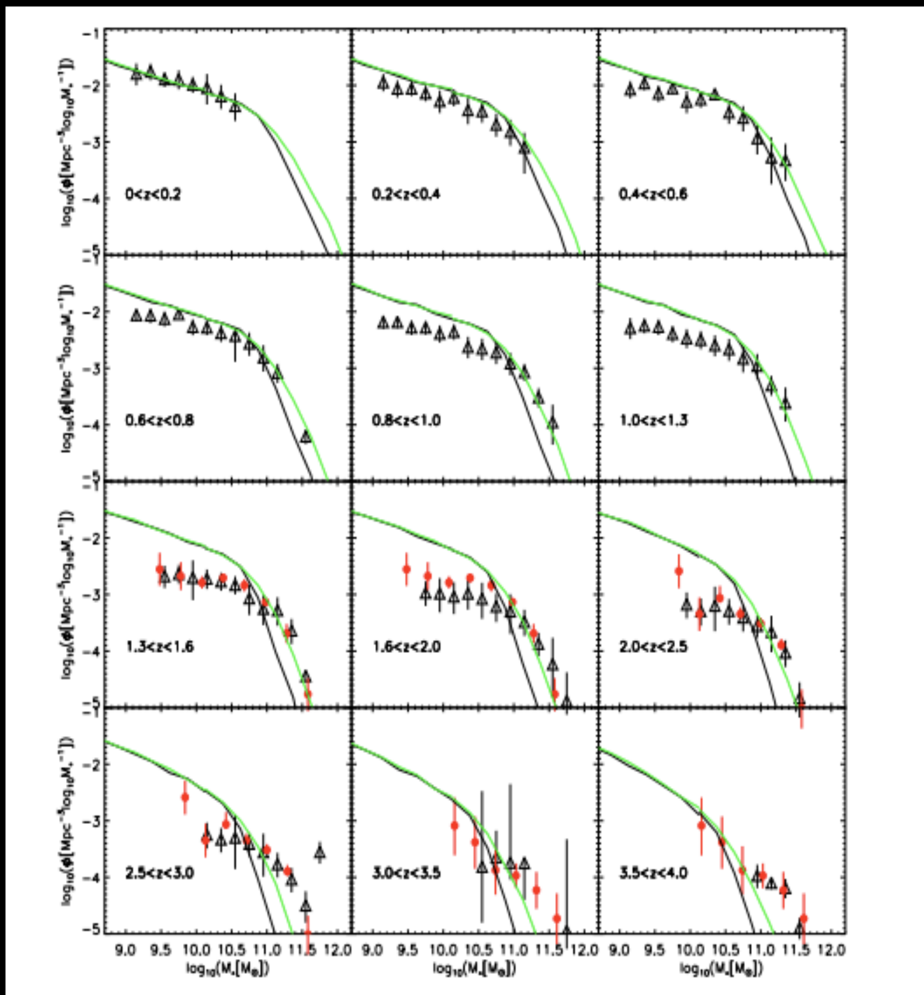
Luminosity functions

Mass functions

Galaxy colors and distributions

Scaling relations: Tully-Fisher, etc.

Traditional method: Make a model to predict or match observatio



Dark matter based models are good, but not perfect at predicting galaxy properties – observations of dark matter at high-z needed to further test LCDM model

problems at high-z: Guo et al. (2010)

Key part of the galaxy formation process involves dark matter, yet we are just starting to observationally determine its role

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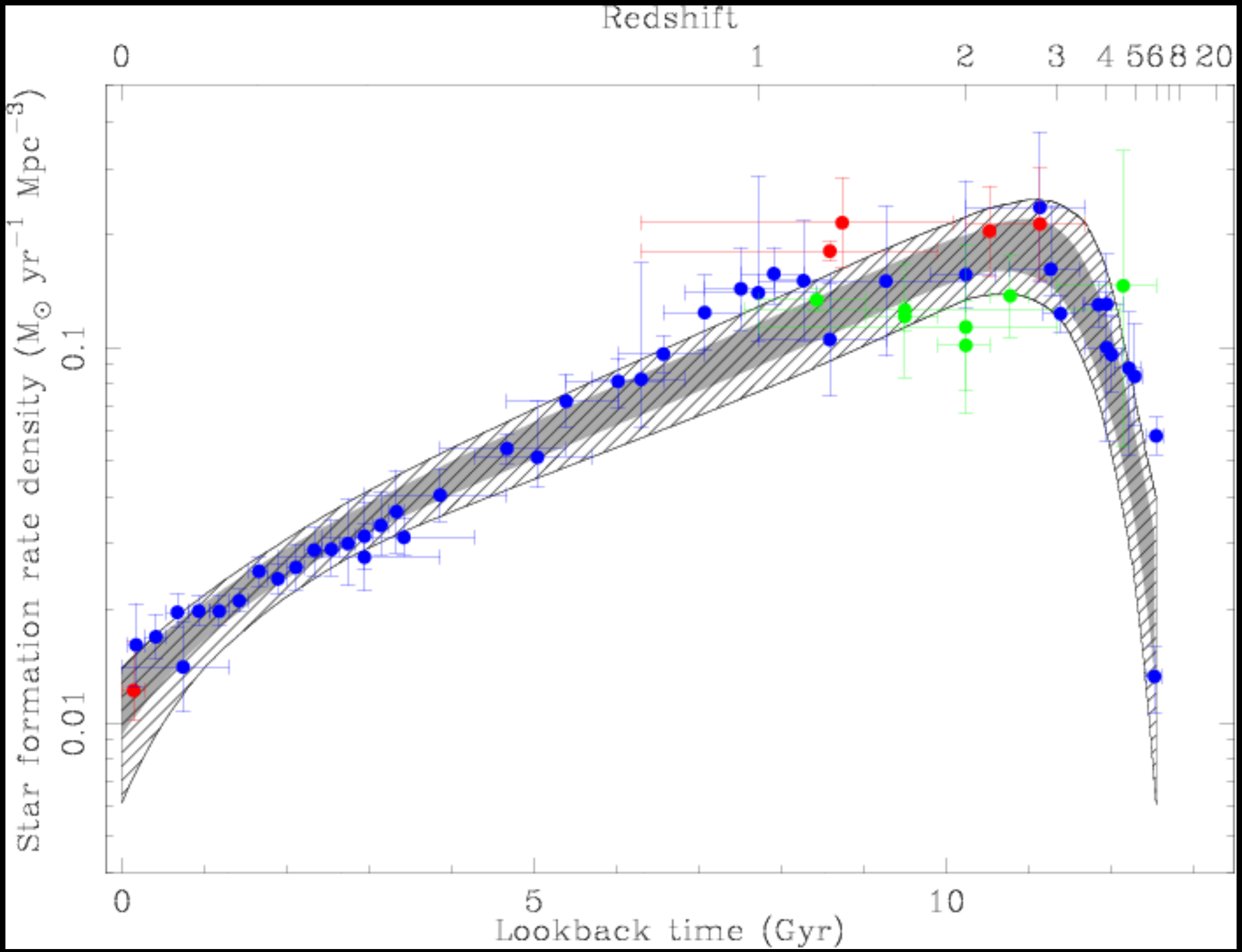
Outline of talk:

1. Evidence for galaxy formation/evolution over time

2. How to trace dark matter with baryonic assembly:

   a. Kinematics of galaxies
   b. Galaxy clustering
   c. Galaxy lensing

The universe is different at high-z

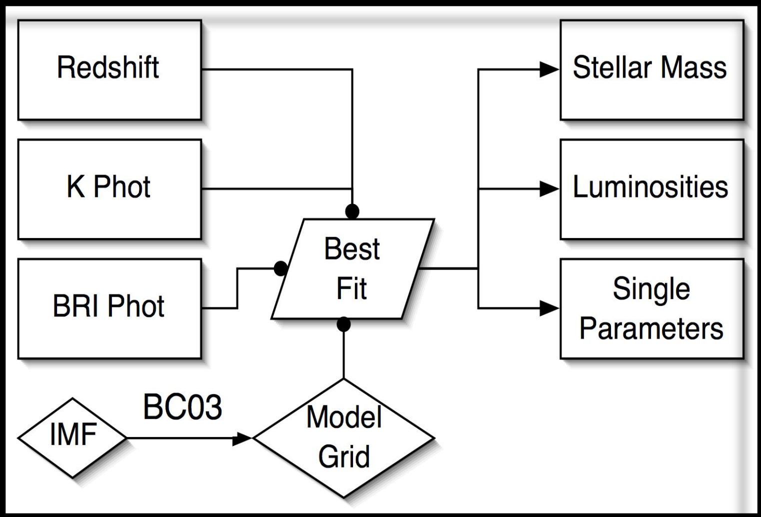


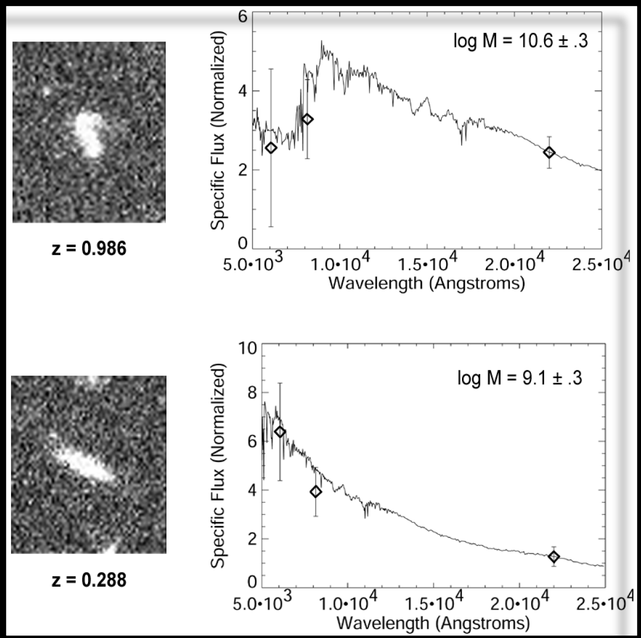
Hopkins (2006)

Star formation is observed to be more common in the past than today

Stellar Mass Computations

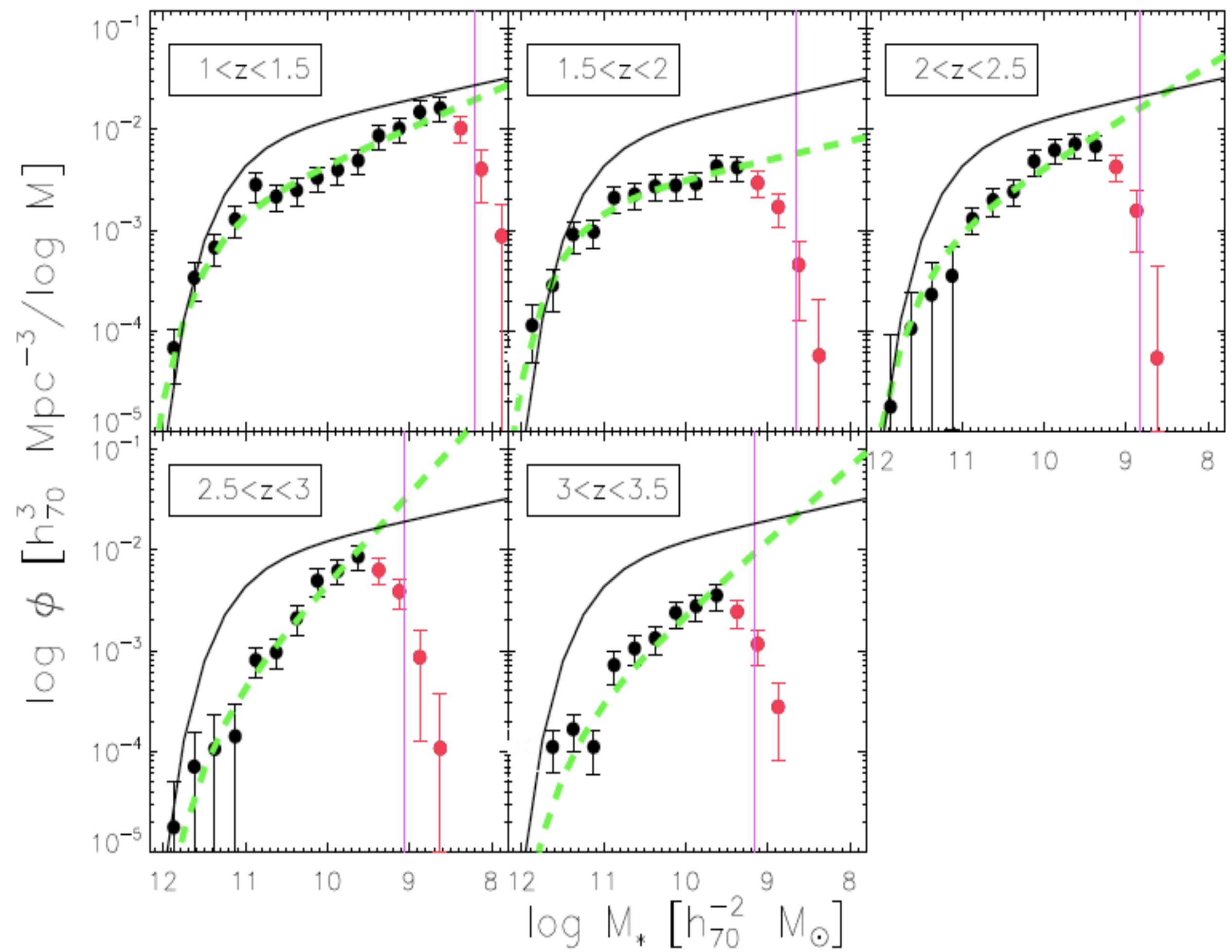
Optical BRI + K-band → M/L ratio → Stellar Mass





Use optical light for M/L ratio and NIR for stellar mass

One way to quantify evolution is though stellar mass functions

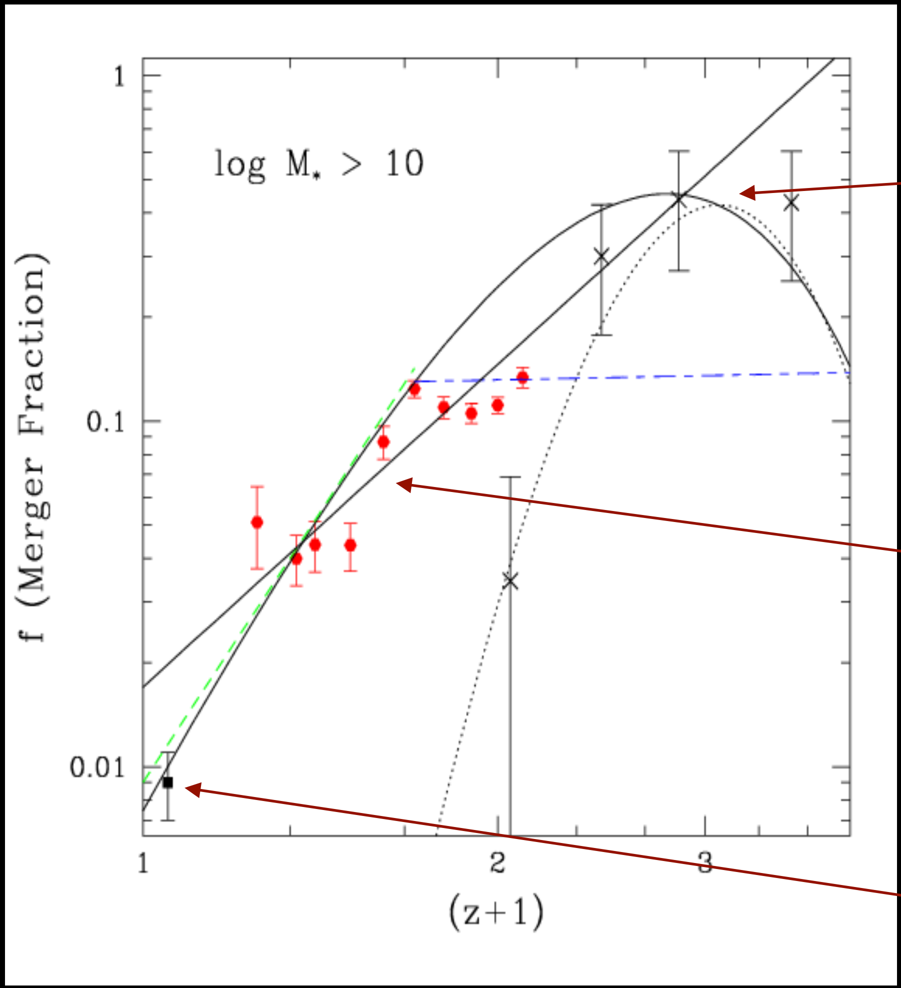


Mortlock et al. (2010)

Direct test of the ΛCDM model of galaxy formation

Why : Cold dark matter is becoming the accepted model for galaxy formation, yet in a sense it is difficult model to test, and its basic prescription should be directly tested – galaxy formation through merging.

New CDM test – the merger history of galaxies



UDF+HDF
(z = 1 - 3)

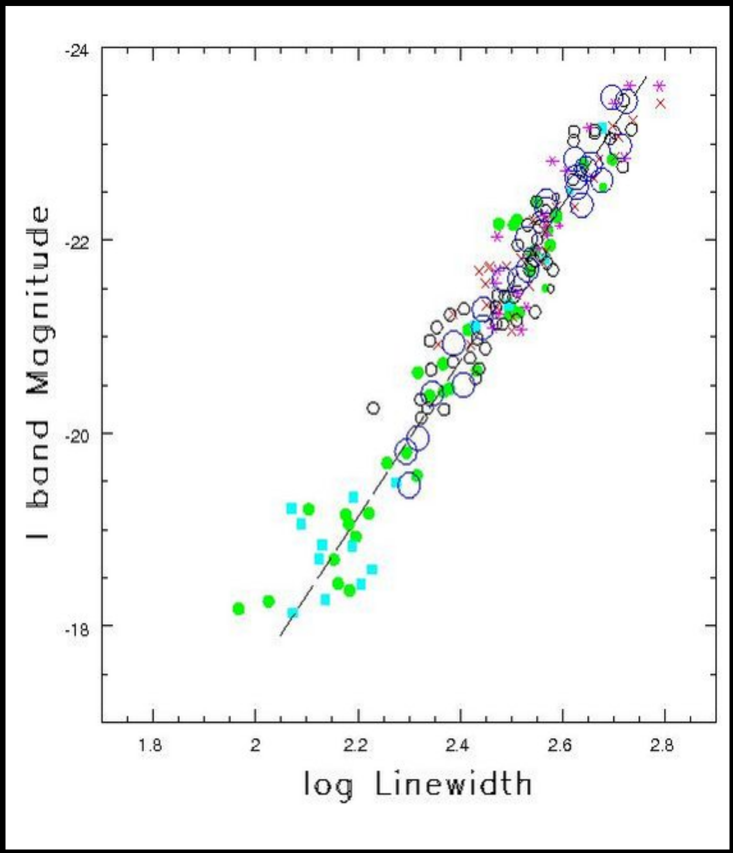
EGS+COSMOS
(z = 0.2 - 1.2)

Millennium Galaxy
Catalog (z = 0)

Evolves as (1+z)^3 to z = 1.5

Conselice et al. (2009)

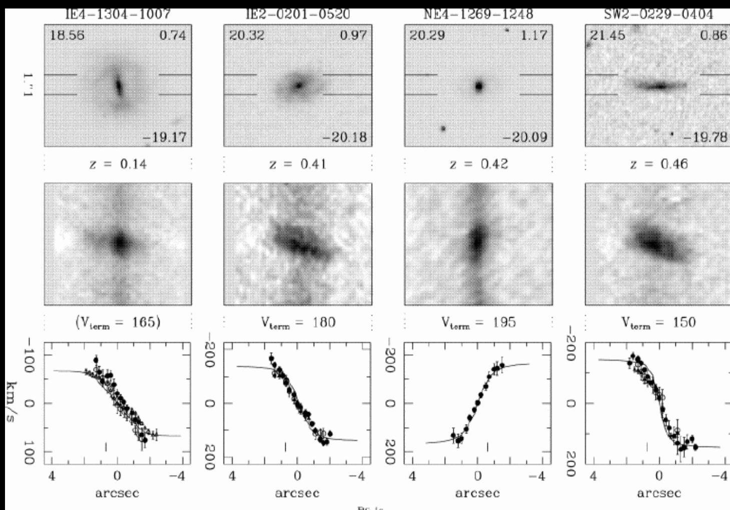
How to measure dark matter in galaxies? Traditional approach through Tully-Fisher and Fundamental plane relations



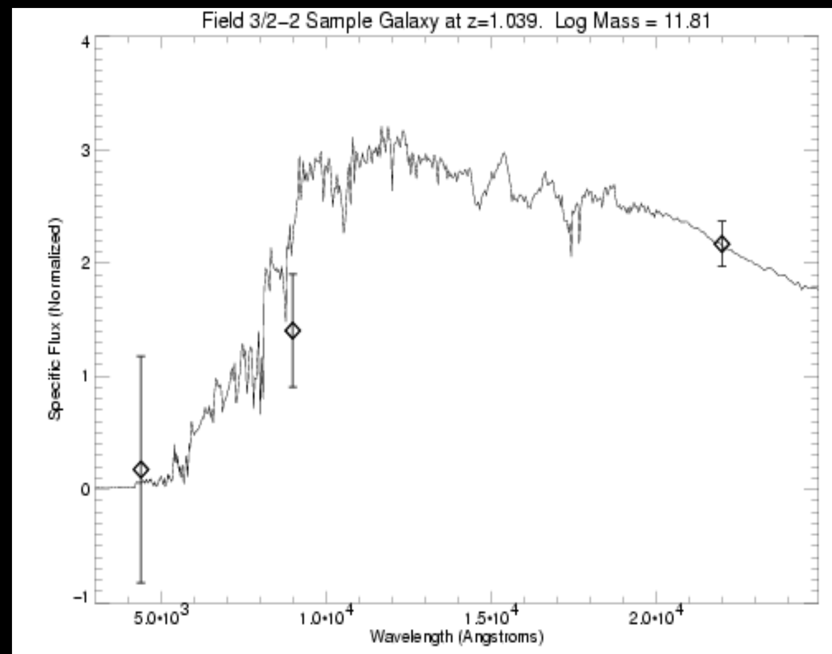
$$L \propto W^{\alpha}$$

The Evolution of Dark Matter

Rotation Curves



Vogt et al. (1997)

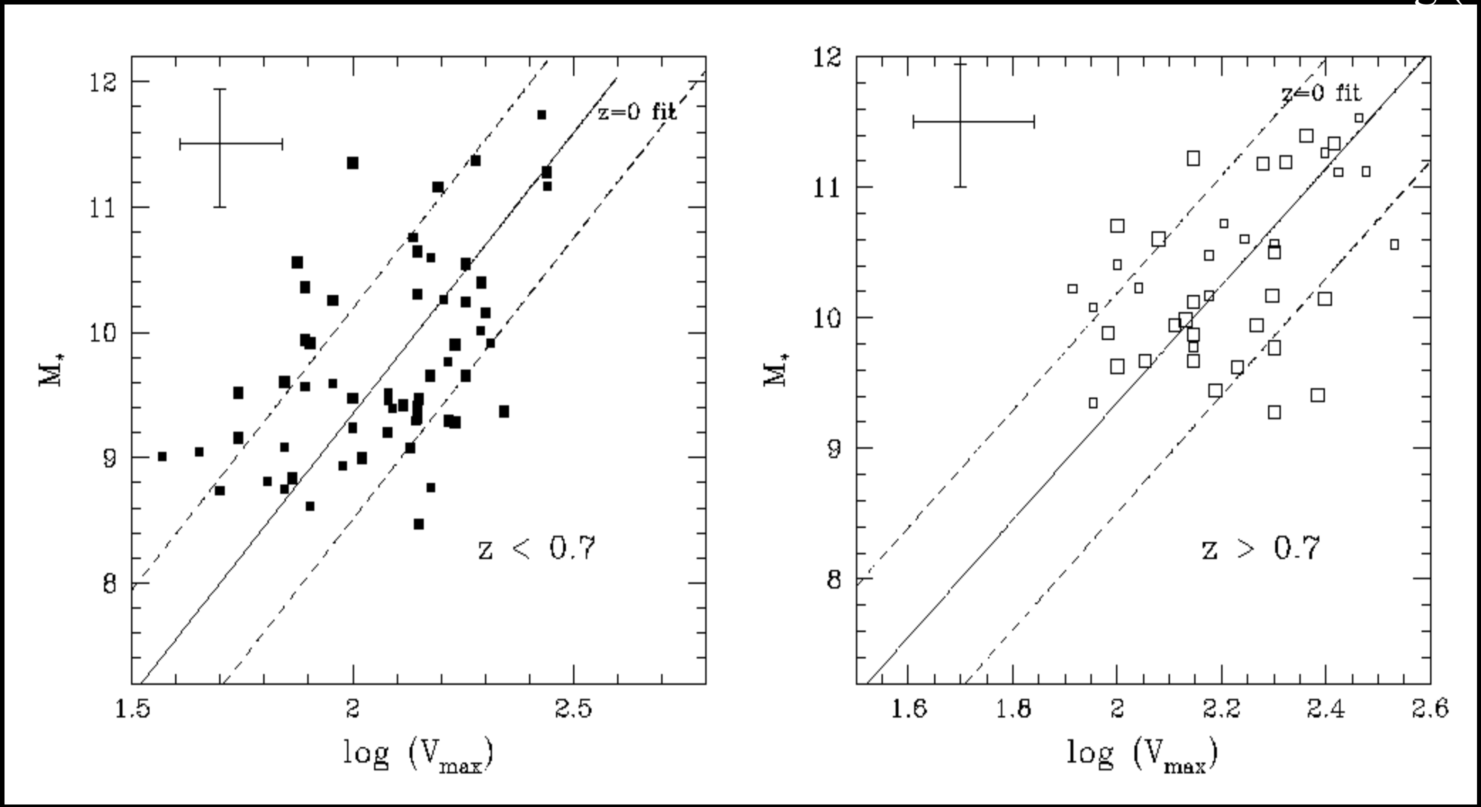


SED fitting for stellar masses

Current and only sample consists of ~100 galaxies from z = 0.2 to 1.2

Stellar Mass Tully-Fisher Relationship – M_* vs. V_{max}

z=0 fits from Bell & de Jong (2001)

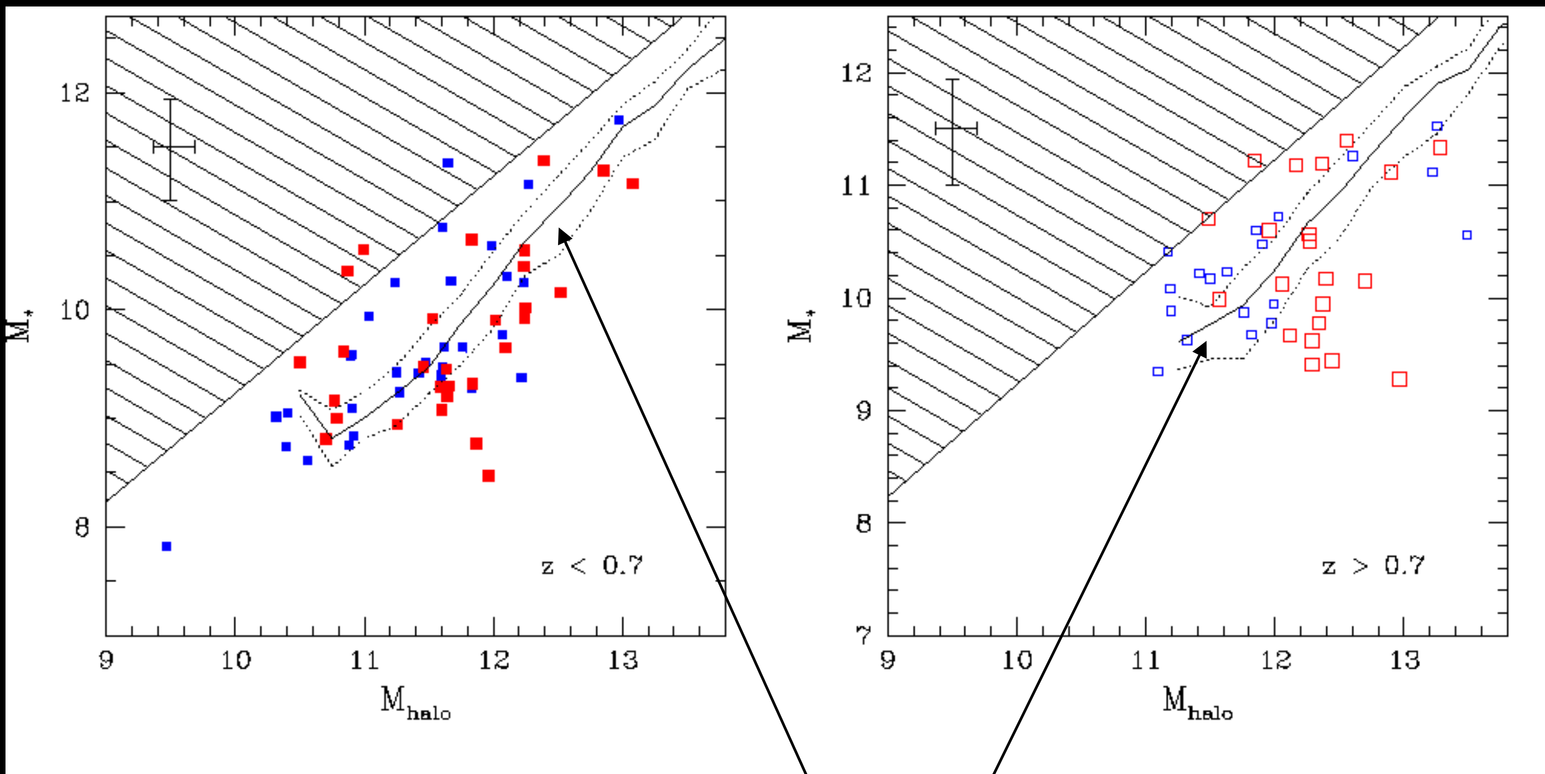


Little to no evolution in the z=0 relationship to z~1.2:

Dark matter and stellar mass appear to assemble together up to z~1.2

Total Masses vs. Stellar Masses

Shaded region is where the stellar fraction is larger than the universal baryon fraction



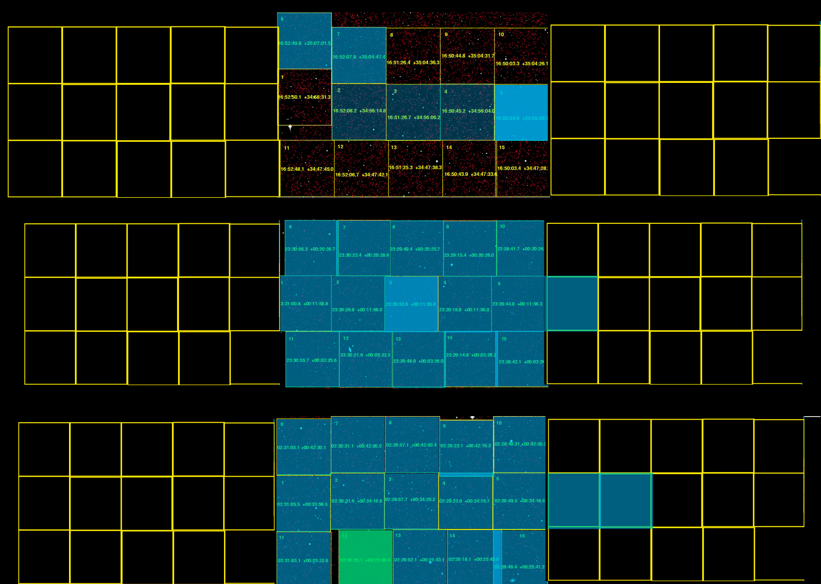
Semi-analytic model predictions from Benson et al. (2002)

Conselice et al. (2005)

Disk galaxy formation at z < 1 is hierarchical in nature

The Palomar Observatory Wide-field Infrared (POWIR) survey

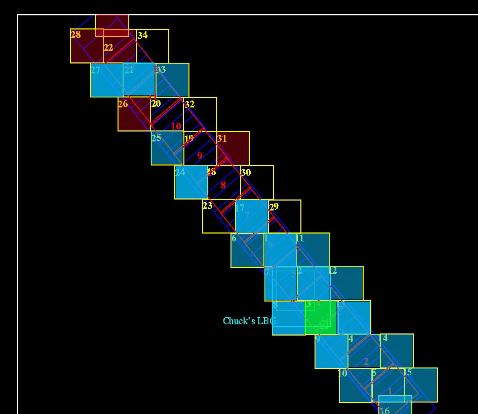
> 70 nights of Palomar IR time (2002-2005) 1.5 sq. degrees
K′ and J band with Spitzer Fields: e.g., Groth, GOODS, DEEP2
Median K~21 (Vega), K > 21 in several images, seeing ~1″
~12,000 redshifts with K mags and stellar masses



Field 2
16:52 +52

Field 3
23:00 +00

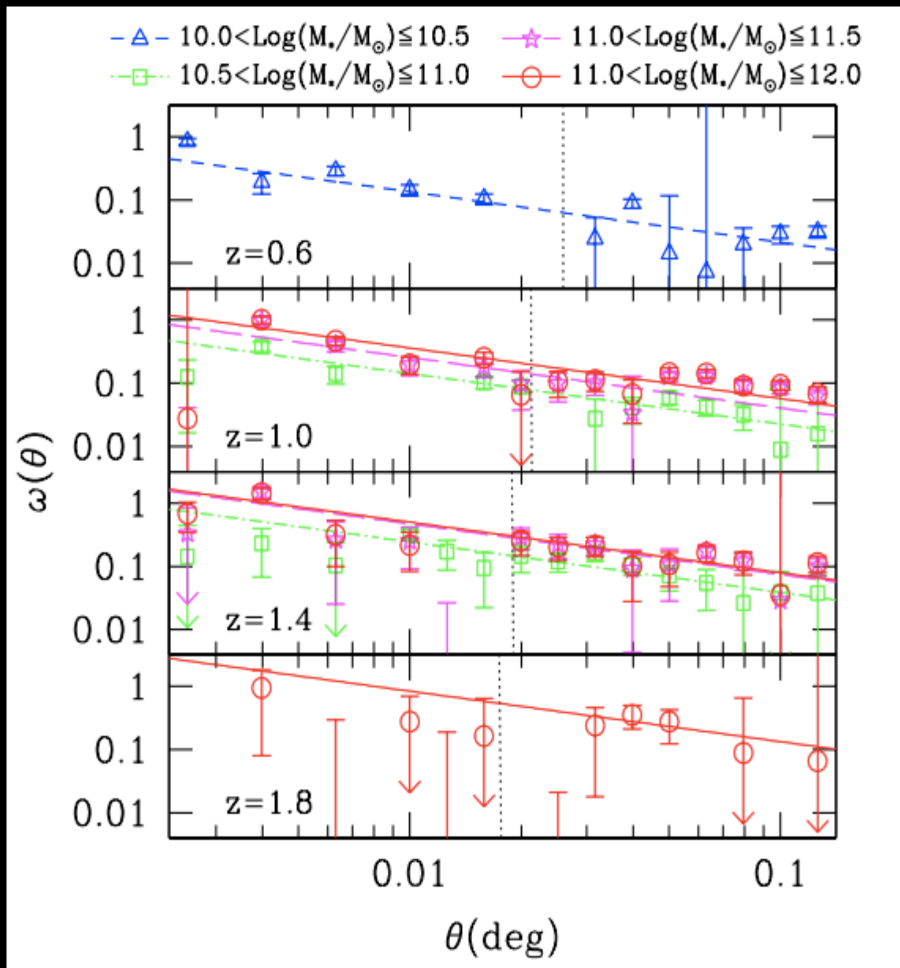
Field 4
02:30 +00



Groth Strip
14:16 +52

1.5 sqr deg survey to K = 20.5 (Conselice et al. 2008)

Galaxy Clustering – need large area surveys to measure



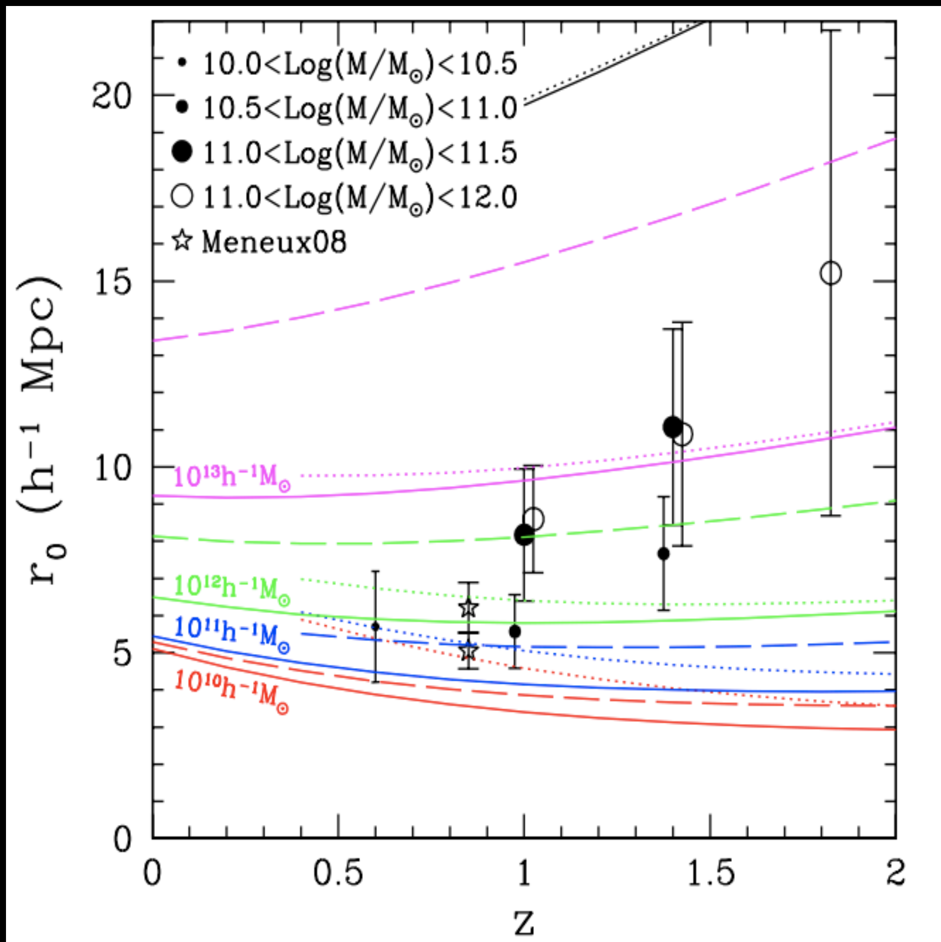
$$\omega(\theta) = \frac{DD - 2DR + RR}{RR}$$

$$\omega(\theta) = A_\omega(\theta^{-\delta} - C_\delta)$$

POWIR survey results

Foucauld, Conselice et al. (2010)

The clustering gives a measure of the correlation length r_o

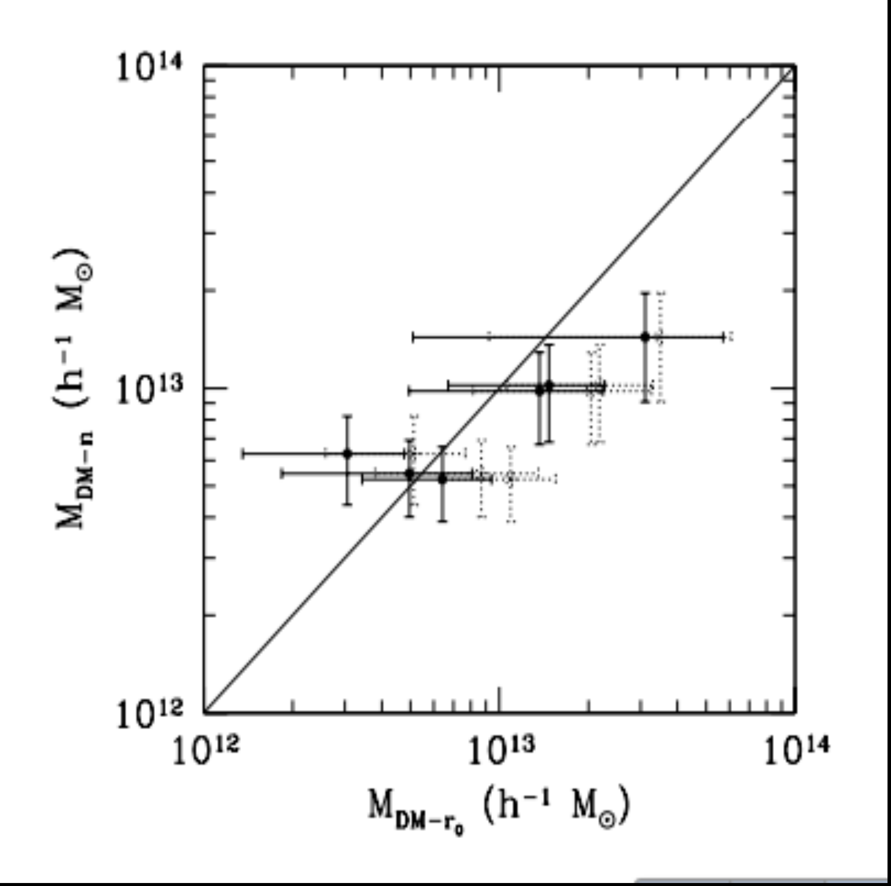


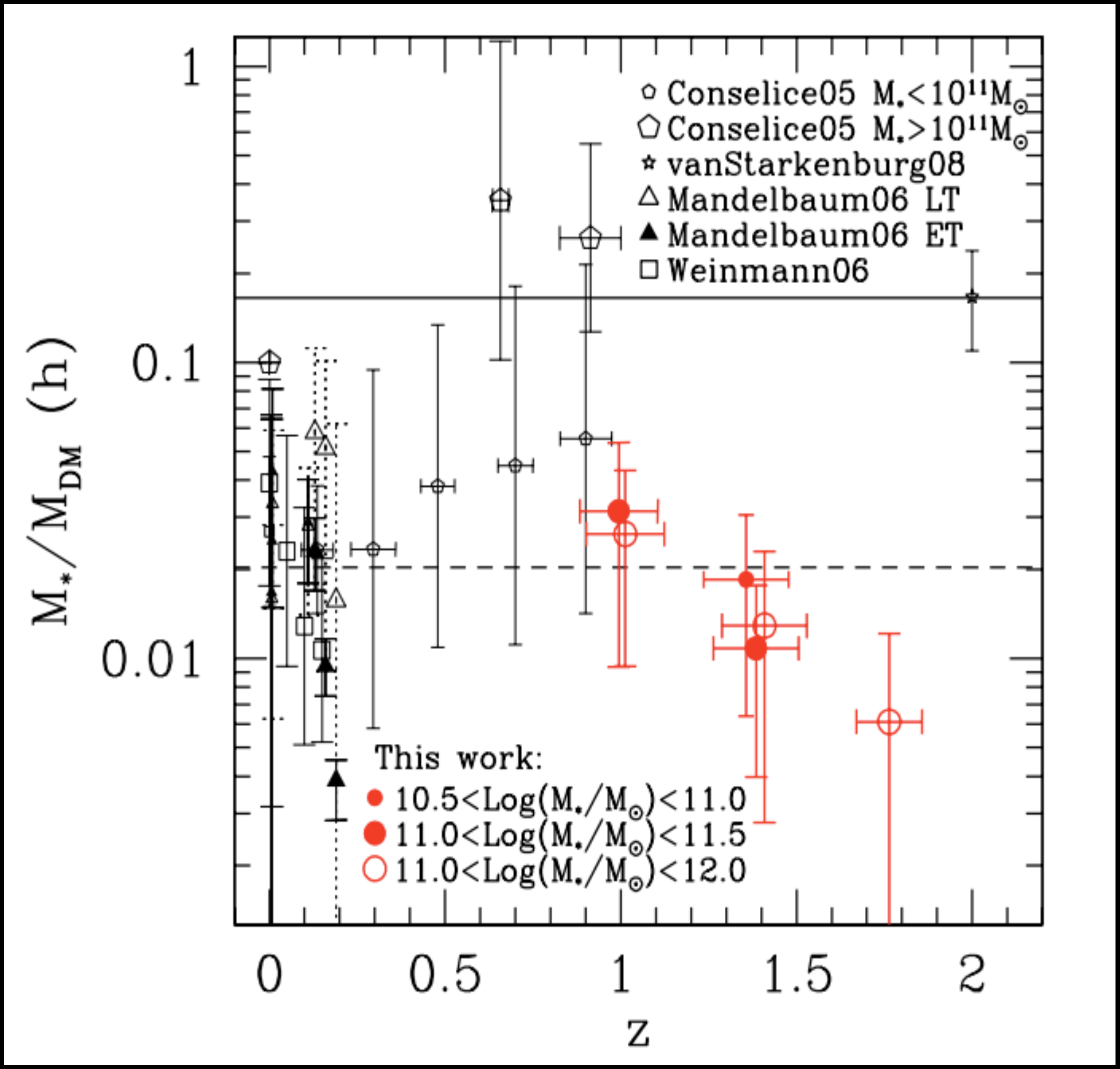
$$\xi(r, z) = \left(\frac{r}{r_0(z)}\right)^{-\gamma}$$

Can use Limber equation and amplitude of correlation functio to calculate the correlation lengt

Foucauld, Conselice et al. (2010)

Agreement between dark matter masses calculated with clustering and abundances





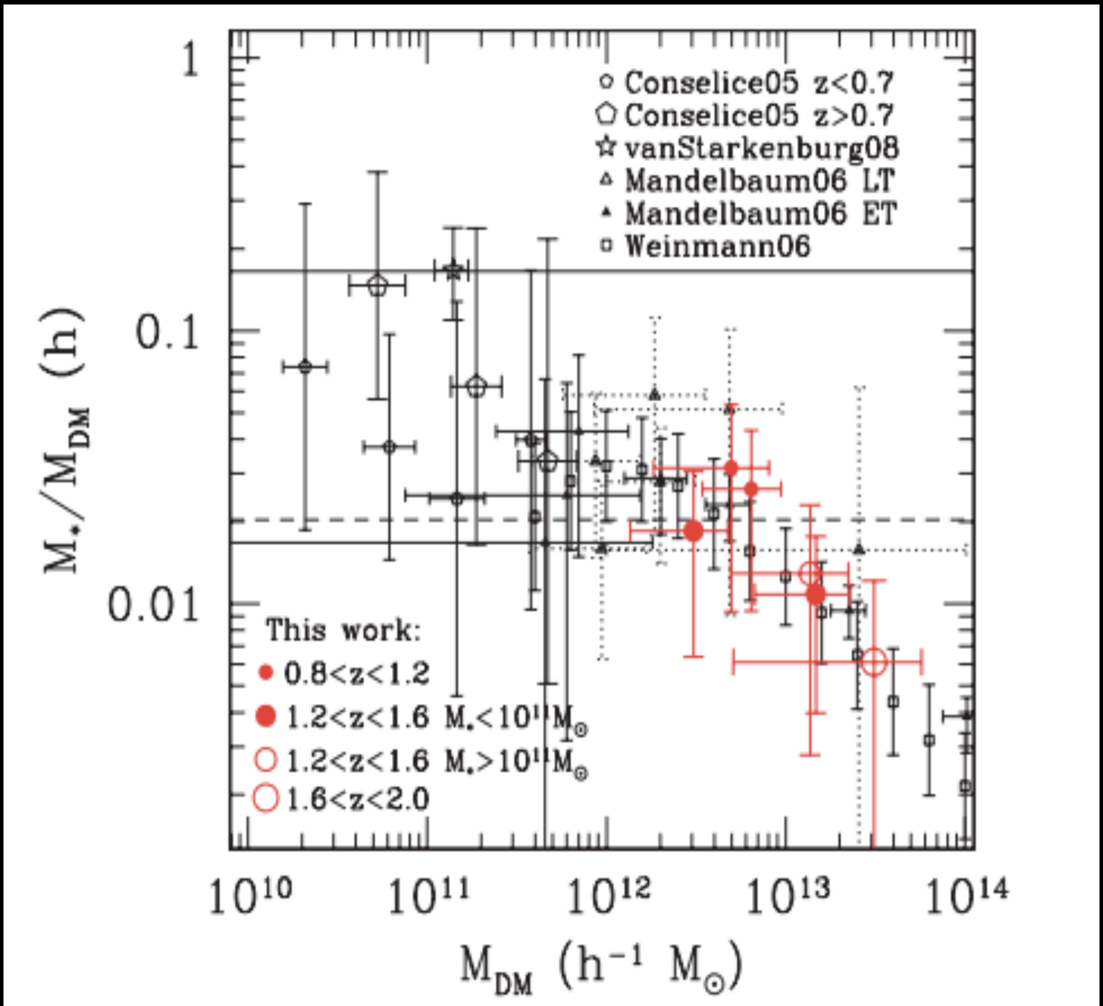
Use clustering to measure galaxy halo masses

Reveals the first masure of how stellar and halo mass evolve at $z > 1$

Ratio evolves slightly at lower redshifts

Foucauld, Conselice et al. (2010)

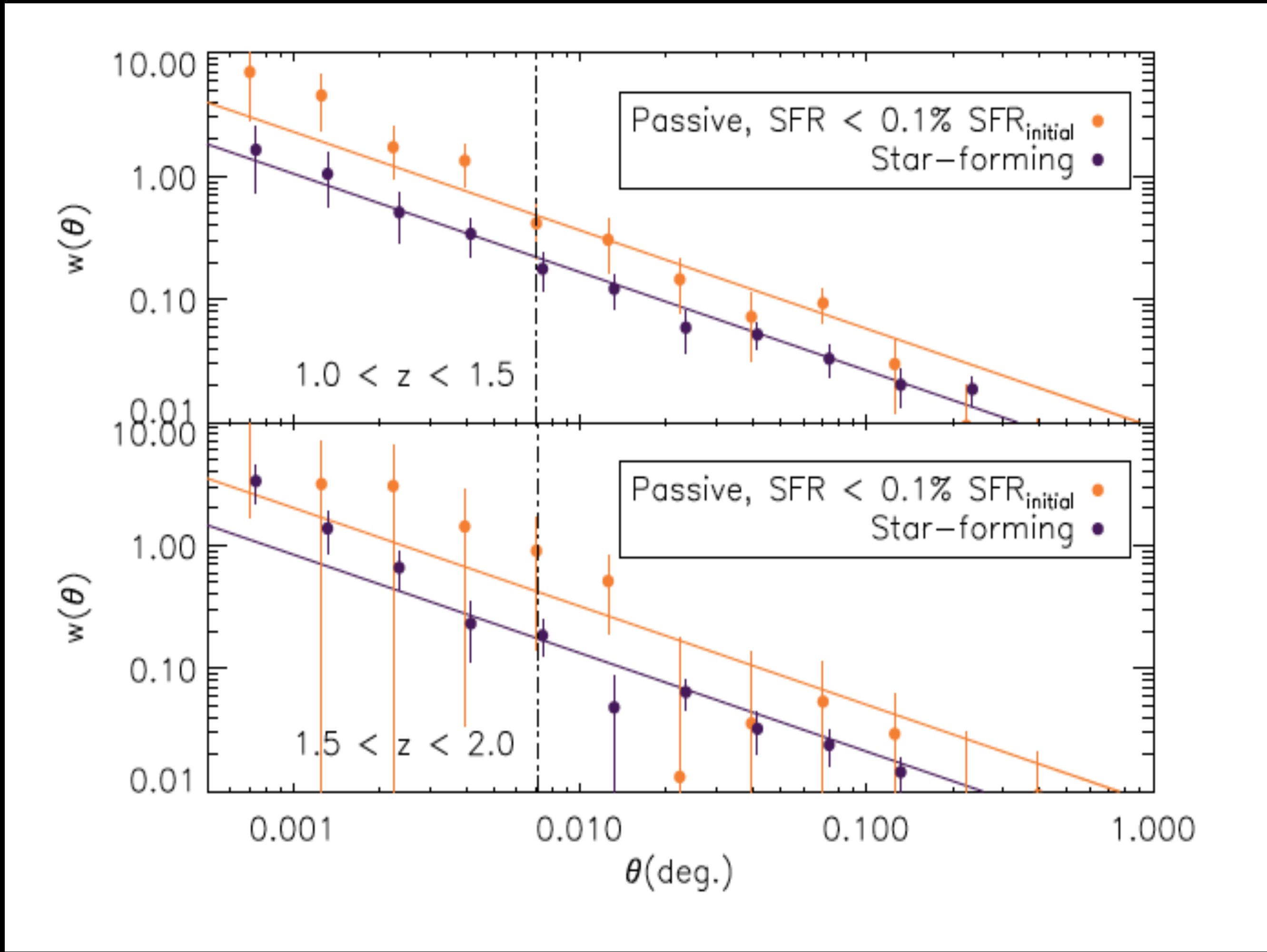
How does the ratio of stellar to dark matter mass change with halo m



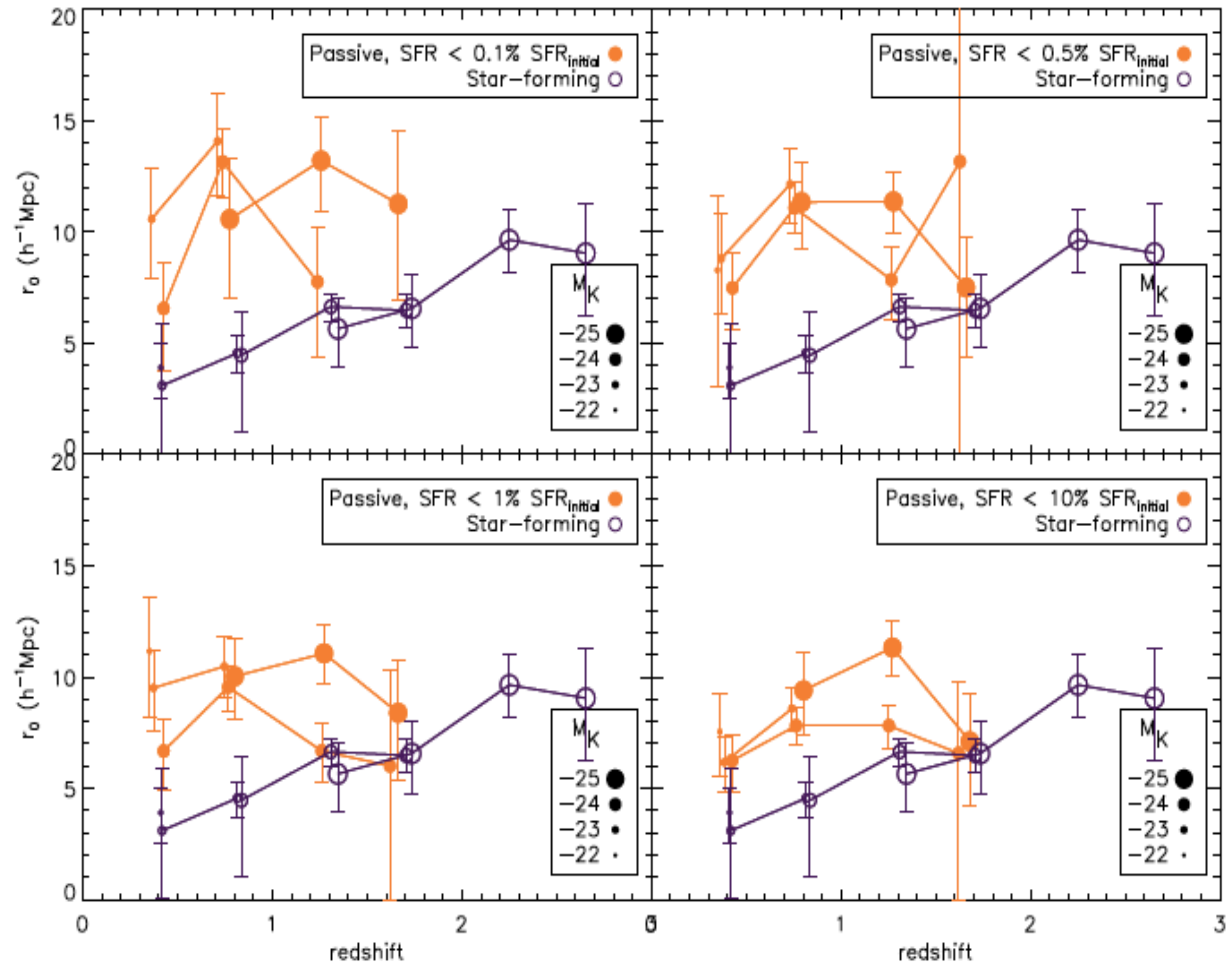
Relation between the stellar to halo mass and halo mass – most massive halos have the lowest fraction of stellar mass

Foucauld, Conselice et al. (2010)

How does clustering change for different galaxy types?

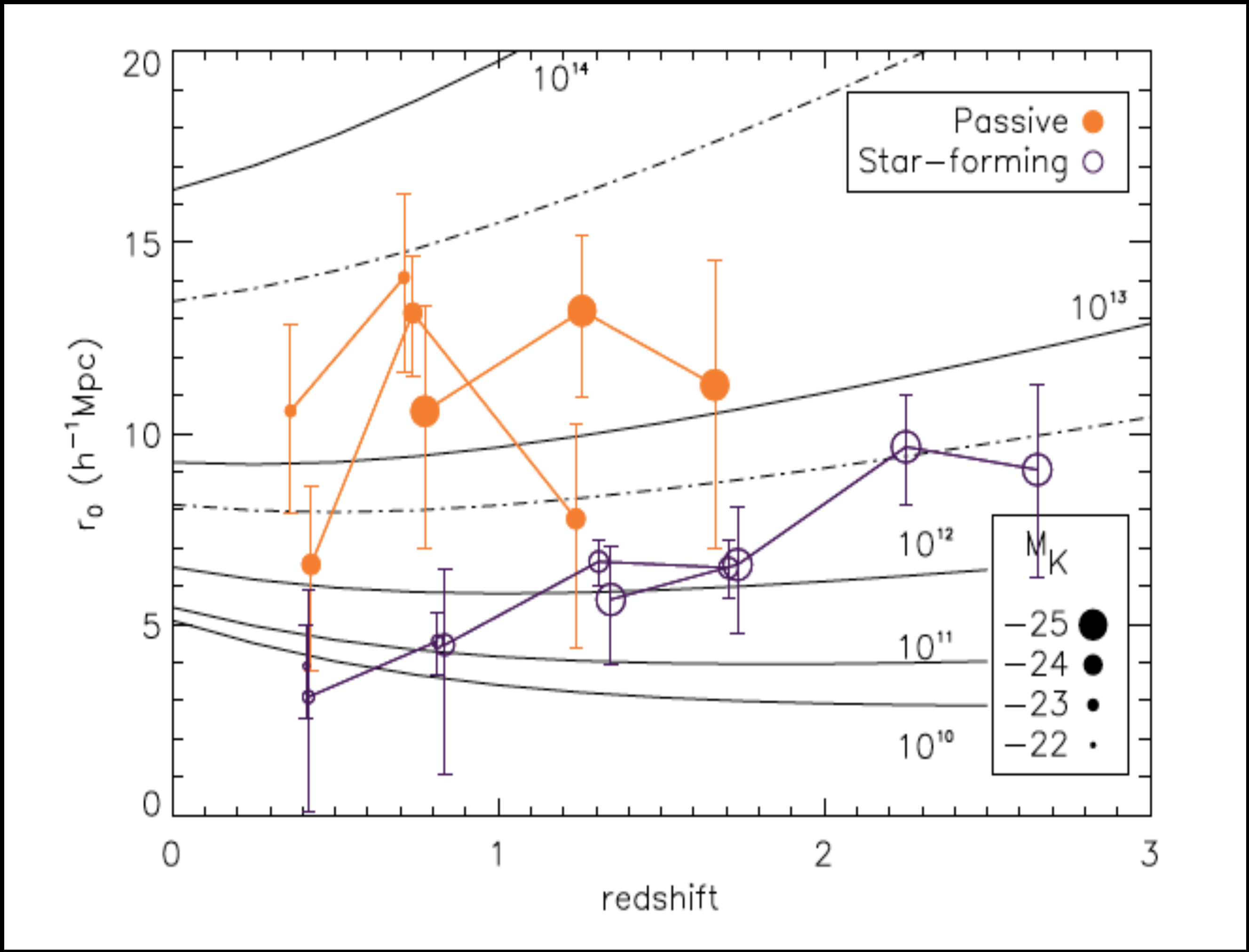


Hartley et al. (2011) UKIDSS UDS



More passive galaxies are in more massive dark matter halos

The correlation length vs. redshift – clear differential up to z = 2



Hartley et al. (2011) UKIDSS UDS

Can we measure total masses vs. total baryonic mass?

Need: dark, stellar and gaseous masses

$$S_{0.5}^2 = 0.5V_{\rm rot}^2 + \sigma_g^2$$

S quantity of Kassin et al. (2007) for total kinematics

$$M_{\rm vir}(R_e) = \frac{5S_{0.5}^2 R_e}{G}$$

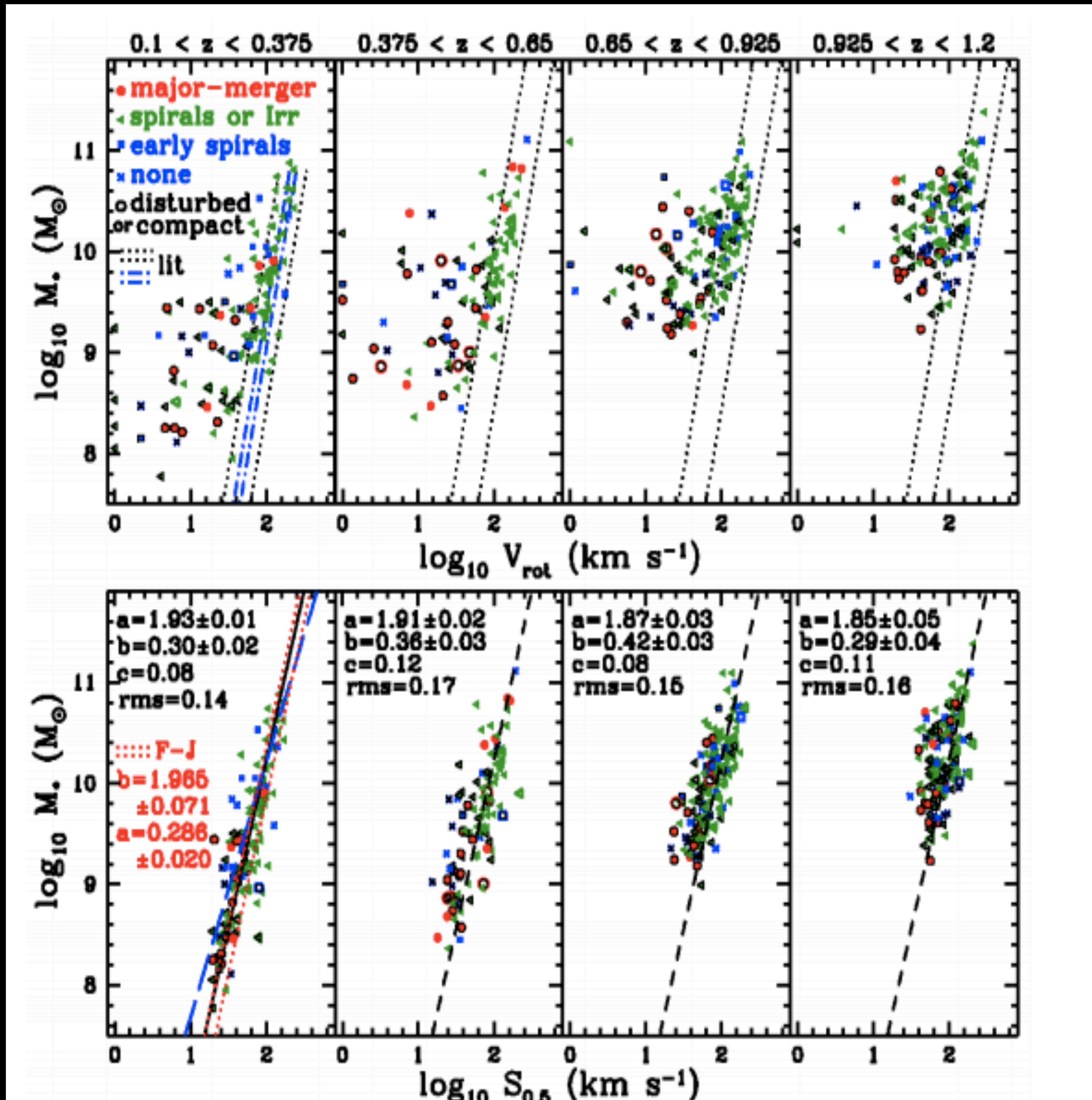
Viral mass within effective radius

$$\log\left(\frac{\Sigma_{\rm SFR}}{\rm M_\odot\ yr^{-1}\ kpc^{-2}}\right) = 1.42\log\left(\frac{\Sigma_{\rm gas}}{\rm M_\odot\ pc^{-2}}\right) - 3.83$$

Cold gas mass from Schmidt law

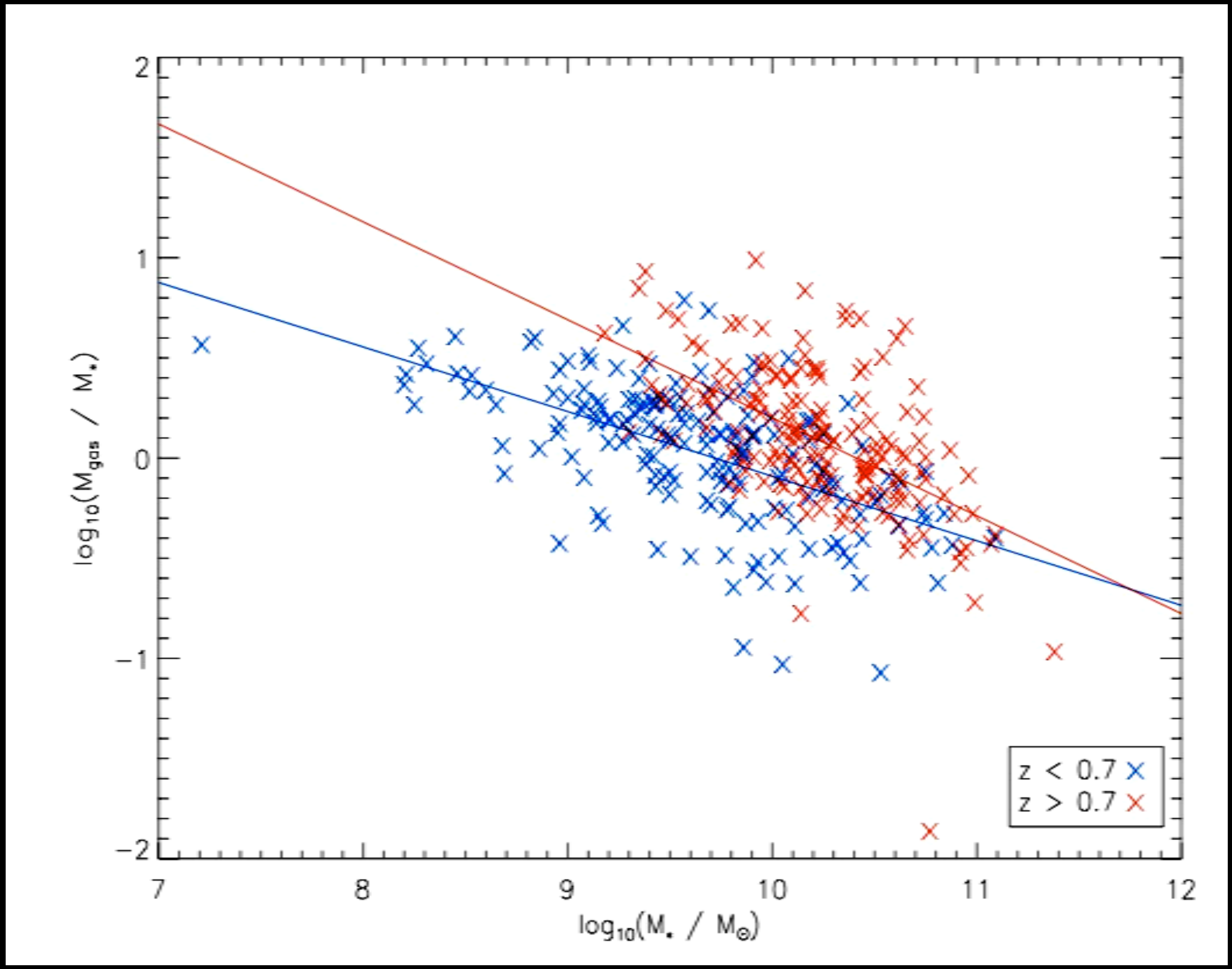
$$M_{\rm halo} = M_{\rm vir}/\Re$$

Total halo mass – calibrated with models



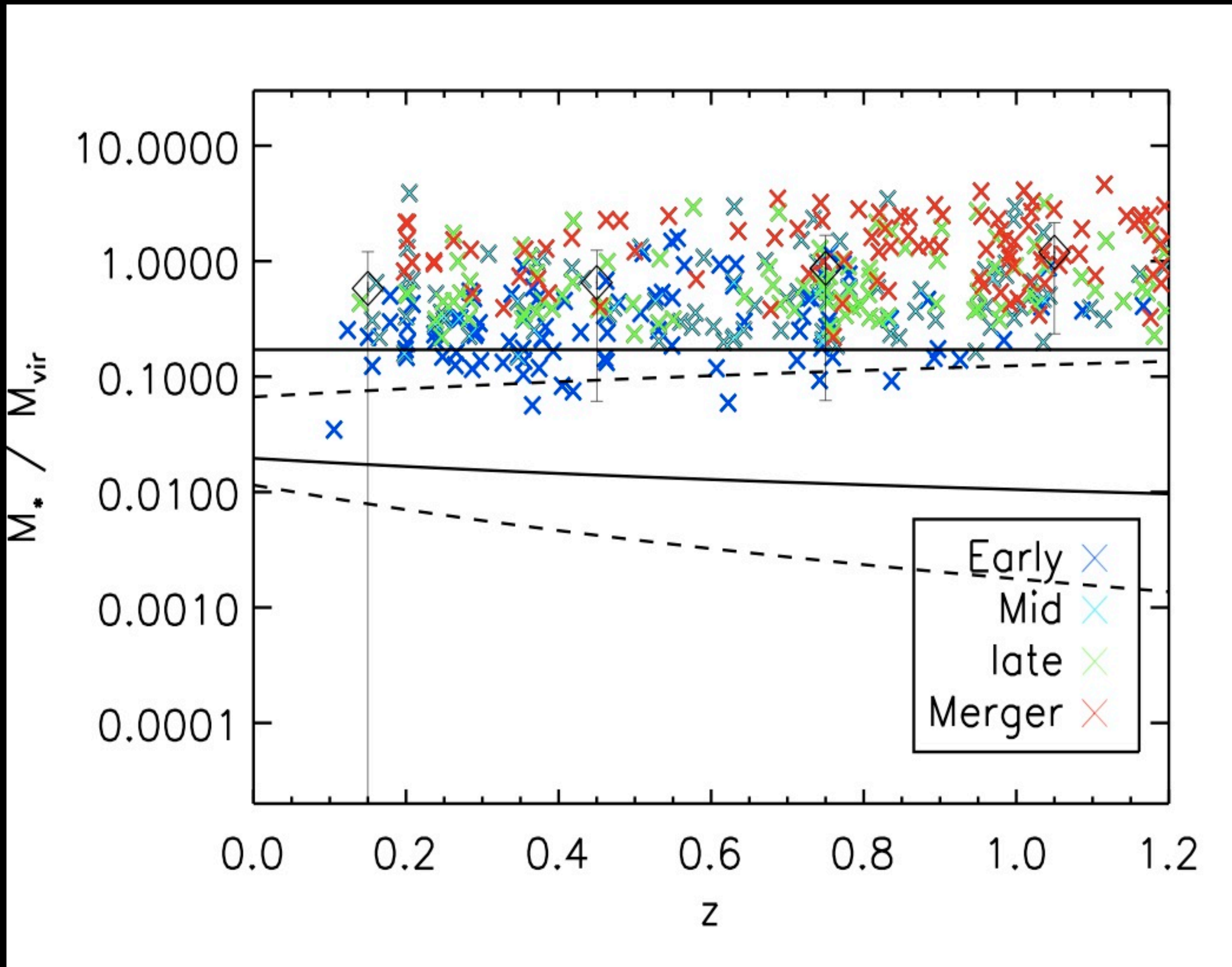
0.1 < z < 0.375
0.375 < z < 0.65
0.65 < z < 0.925
0.925 < z < 1.2
major−merger
spirals or Irr
early spirals
none
disturbed
or compact
lit
log10 M* (M⊙)
log10 Vrot (km s−1)
a=1.93±0.01
b=0.30±0.02
c=0.08
rms=0.14
F−J
b=1.965
±0.071
a=0.286
±0.020
a=1.91±0.02
b=0.36±0.03
c=0.12
rms=0.17
a=1.87±0.03
b=0.42±0.03
c=0.08
rms=0.15
a=1.85±0.05
b=0.29±0.04
c=0.11
rms=0.16
log10 S0.5 (km s−1)

How does the gaseous mass correlate with the stellar mass?

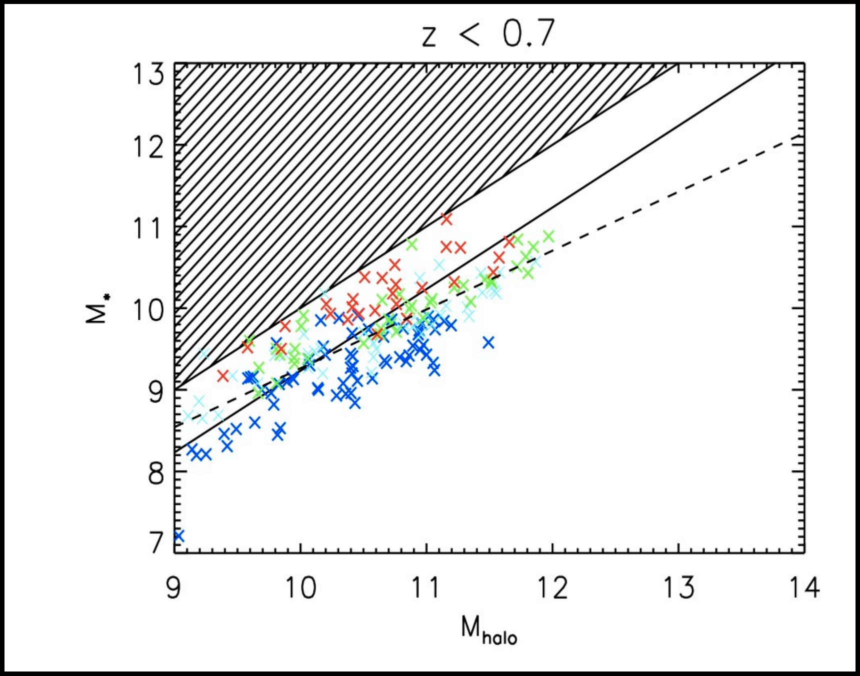


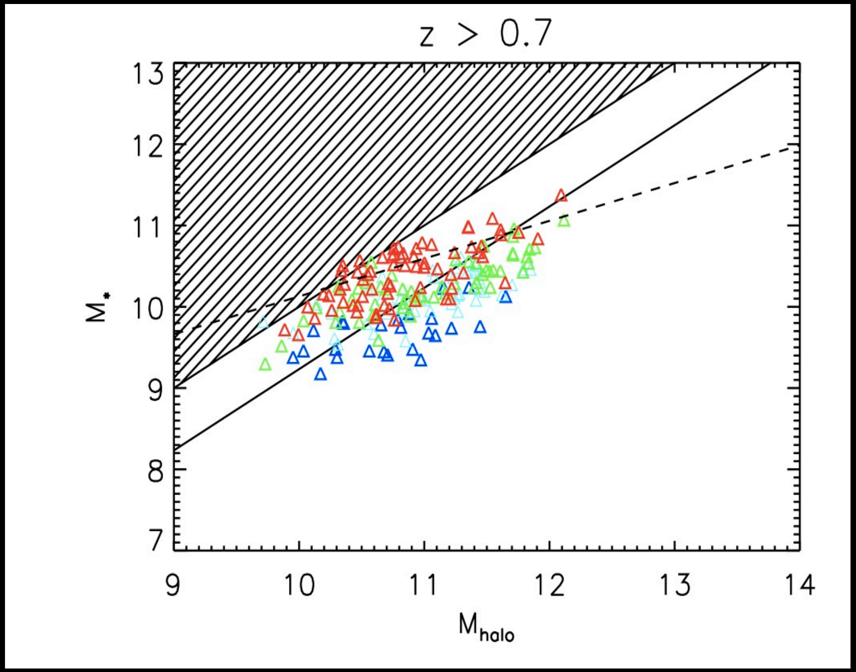
Twite, Conselice et al. (in prep)

Within the effective radius stellar mass is similar to viral mass

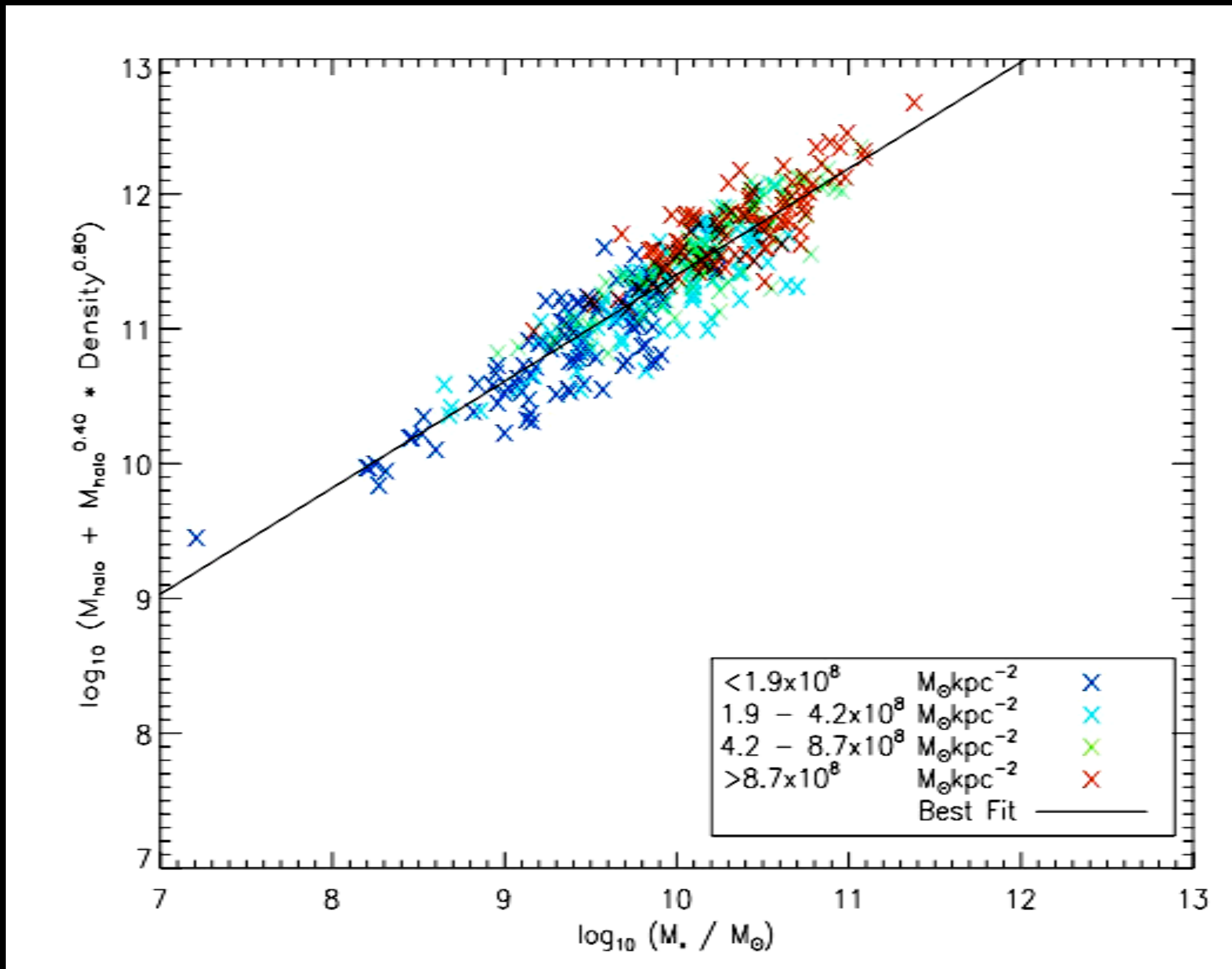


Find between halo mass and stellar mass



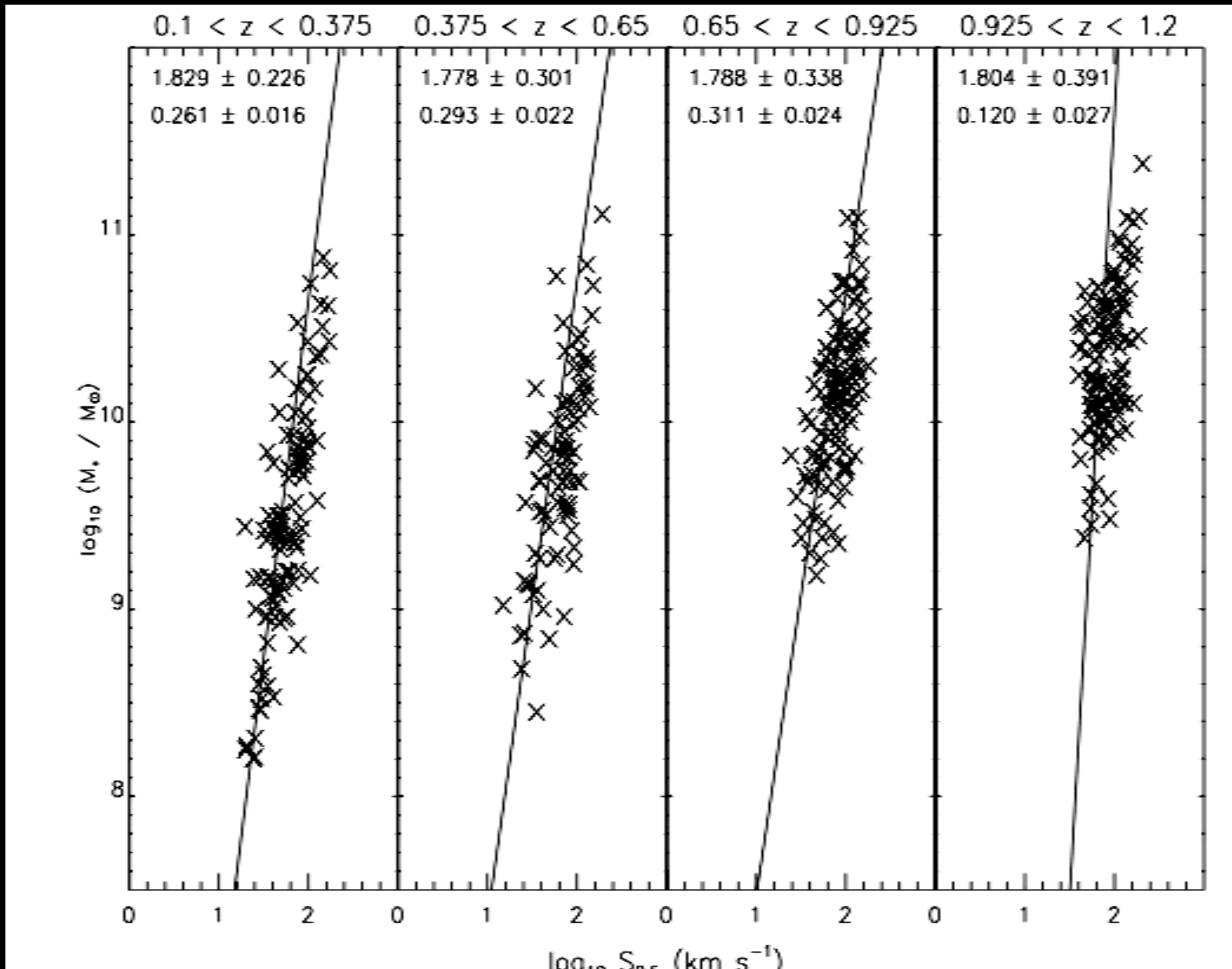


Relation between stellar mass and halo mass and stellar density

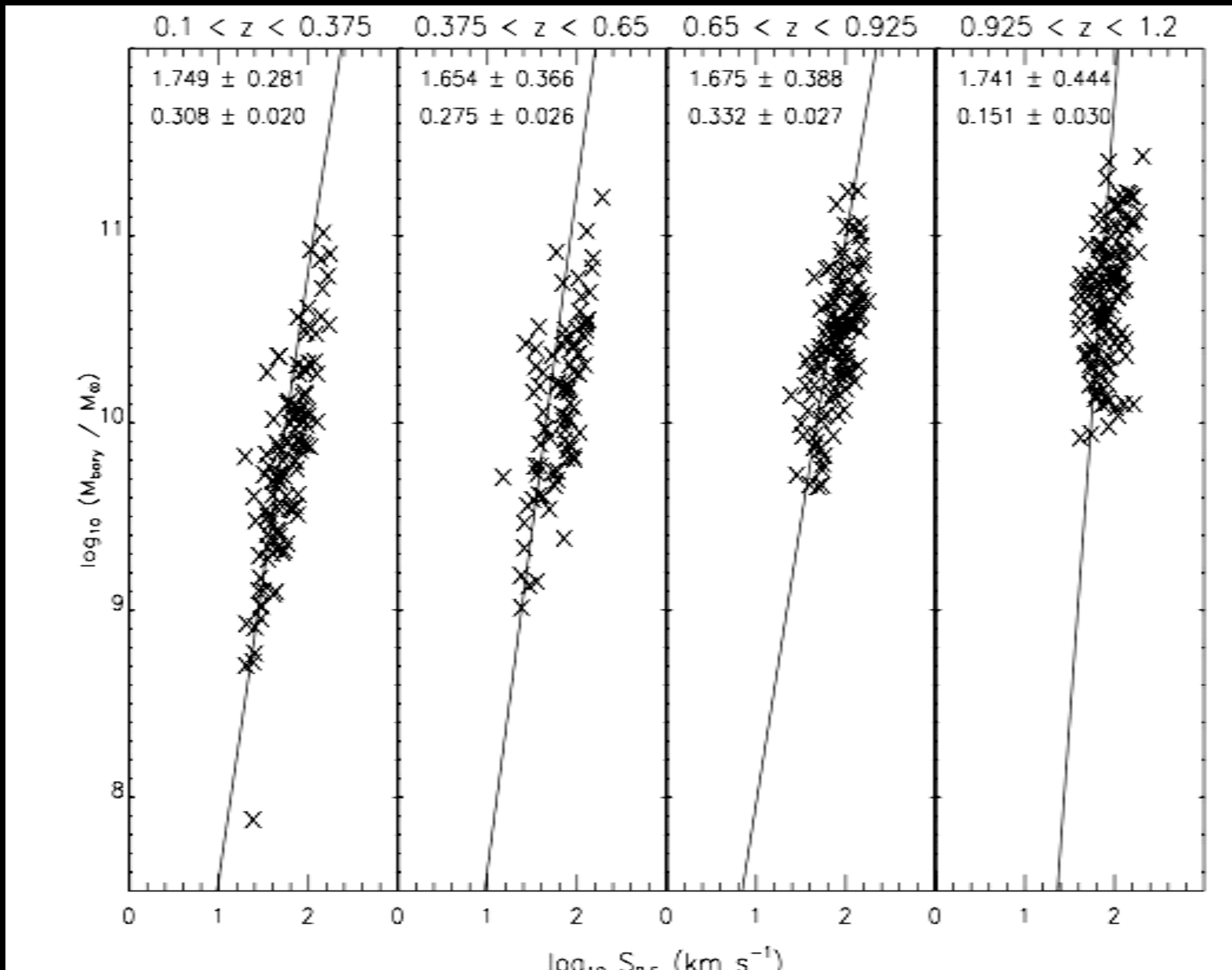


Twite, Conselice et al. in prep

Stellar mass vs. S values

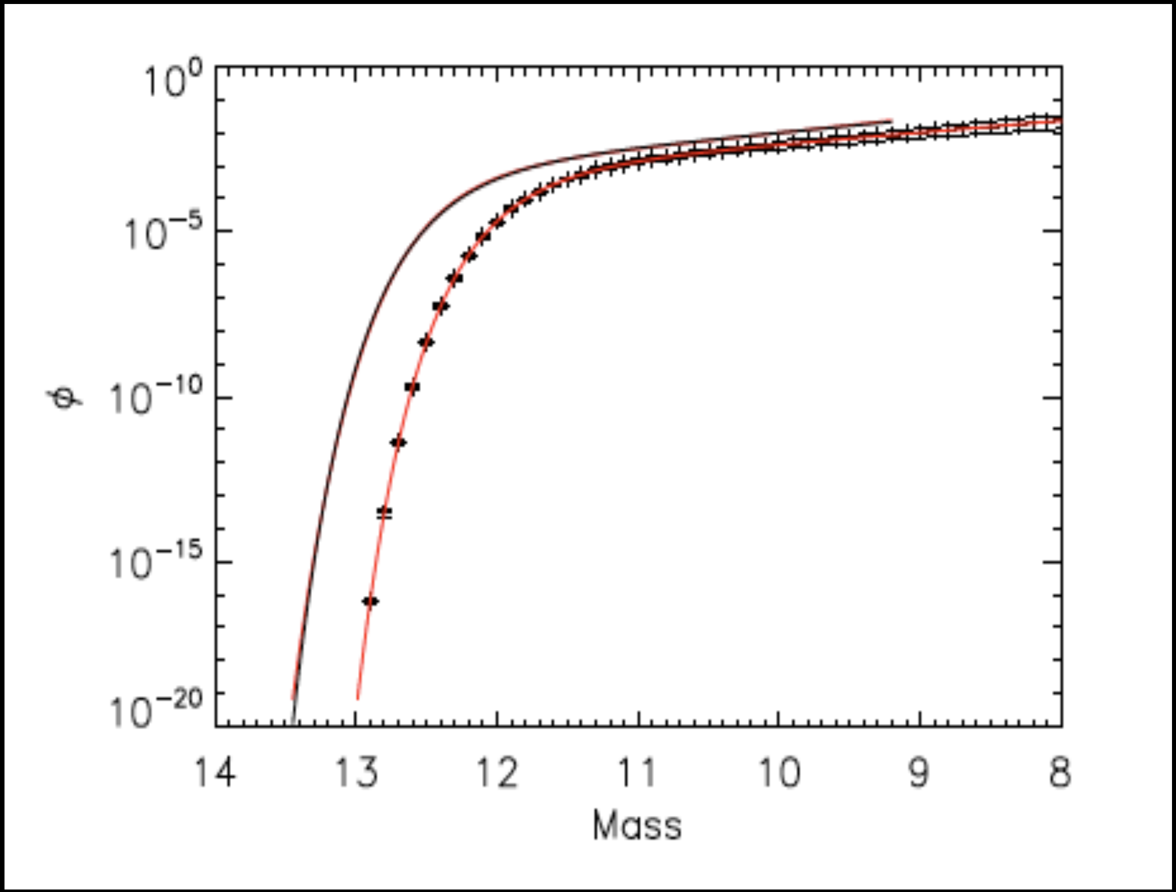


Baryonic mass vs. S values

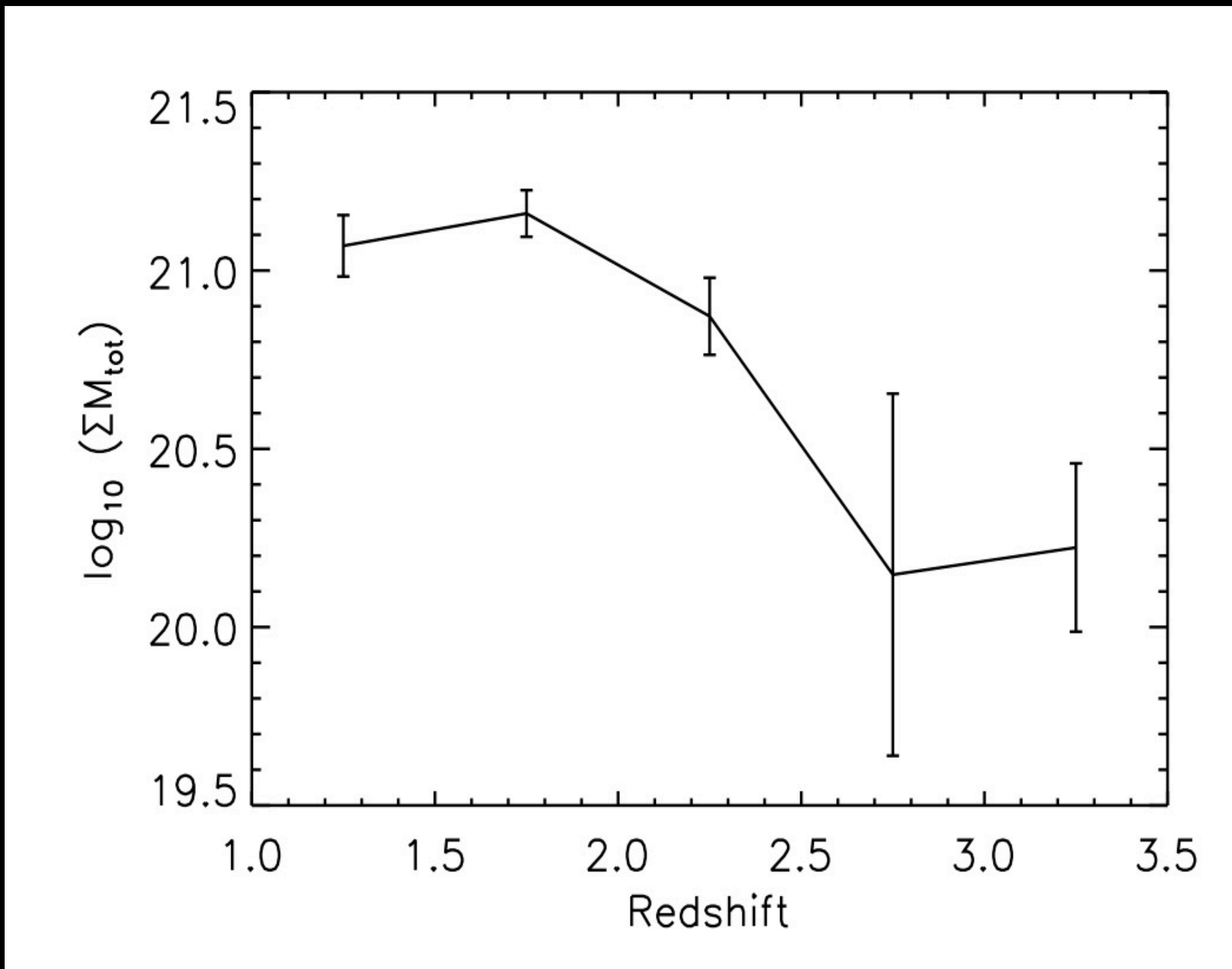


Slightly steeper slope

Can calculate dark matter mass functions for galaxies



The total amount of dark matter attached to galaxies with redshift



very preliminary

Summary

1. Can measure dark matter properties up to $z = 2$ and how this correlates with stellar masses. At $z > 2$ observations much less certain

2. Galaxy evolution is clearly hierarchical with galaxy mergers a dominate process. Driven by dark matter and dynamical friction

3. Can now trace reliably the halo and dark matter masses of galaxies high redshift through clustering analysis – agrees with kinematics

4. We can now measure all types of masses – gaseous, stellar and dark up to $z = 1.4$ using kinematics and star formation rates

5. The dark matter density within galaxies declines at higher redshifts