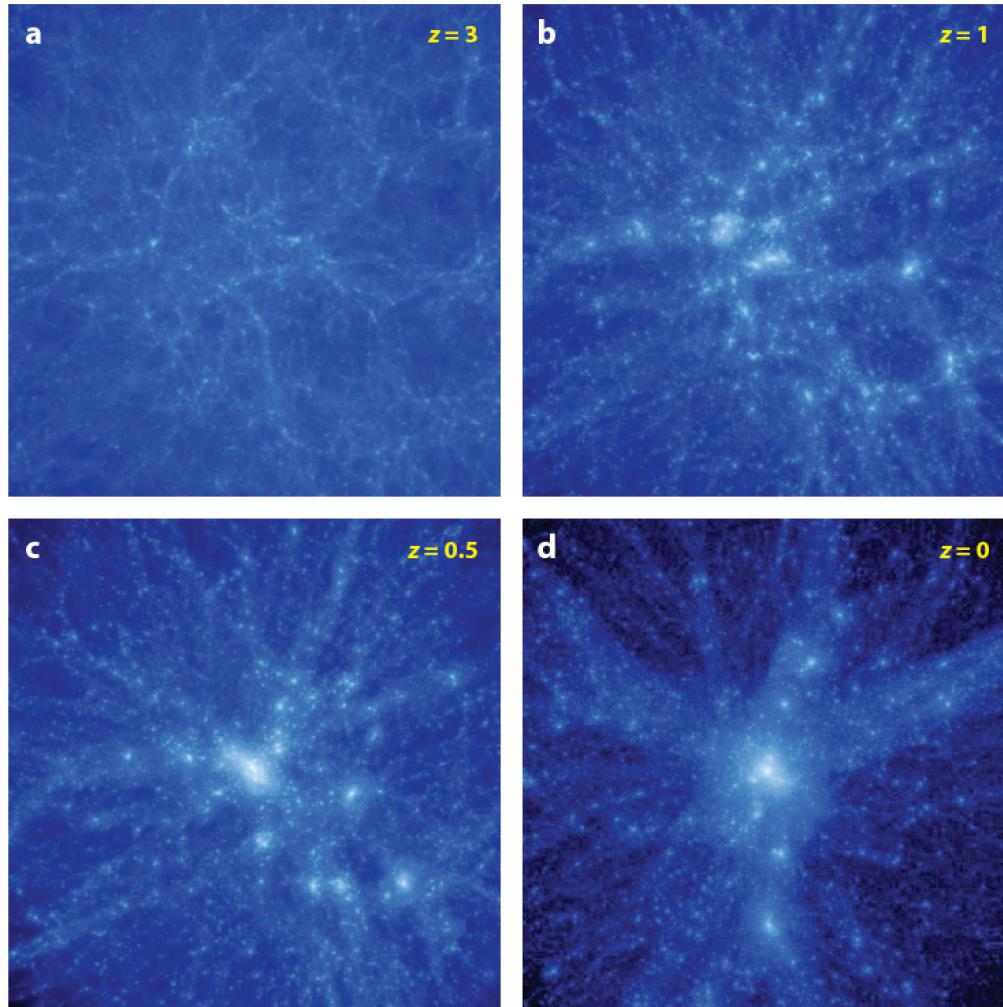


Ay 127

Bias and the Evolution of Clustering



Galaxy Biasing

Suppose that the density fluctuations in mass and in light are not the same, but

$$\text{Or: } (\Delta\rho/\rho)_{\text{light}} = b (\Delta\rho/\rho)_{\text{mass}}$$

$$\xi(r)_{\text{light}} = b^2 \xi(r)_{\text{mass}}$$

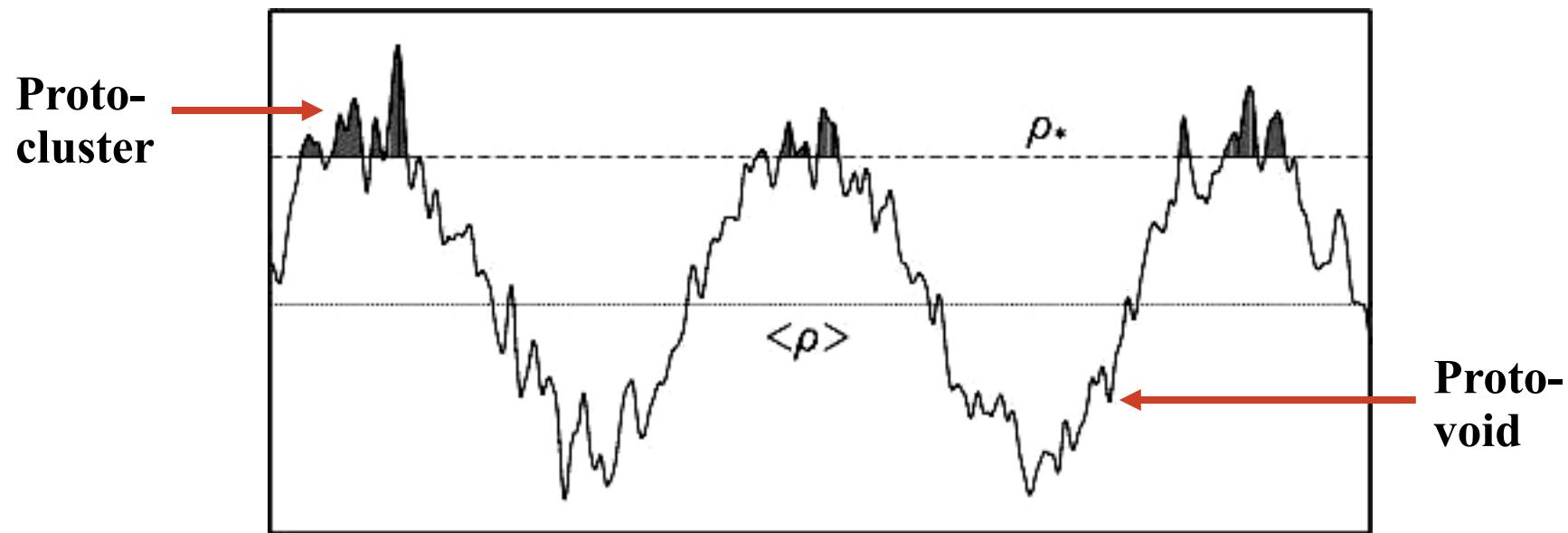
Here b is the *bias factor*.

If $b = 1$, light traces mass exactly (this is indeed the case at $z \sim 0$, at scales larger than the individual galaxy halos). If $b > 1$, light is a *biased tracer* of mass.

One possible mechanism for this is if the galaxies form at the densest spots, i.e., the highest peaks of the density field. Then, density fluctuations containing galaxies would not be typical, but rather a biased representation of the underlying mass density field; if $1-\sigma$ fluctuations are typical, $5-\sigma$ ones certainly are not.

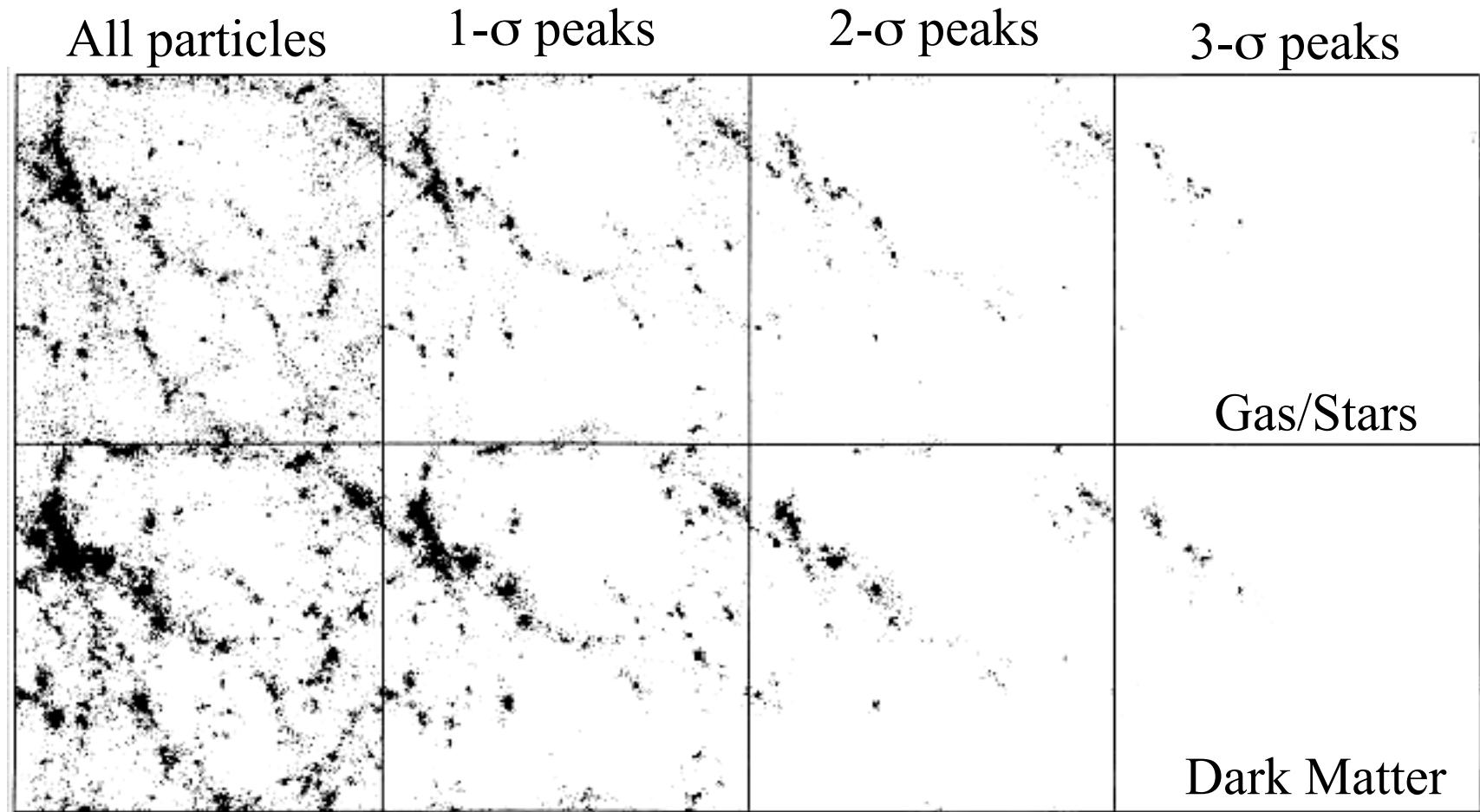
High Density Peaks as Biased Tracers

Take a cut through a density field. Smaller fluctuations ride atop of the larger density waves, which lift them up in bunches; thus the highest peaks (densest fluctuations) are a priori clustered more strongly than the average ones:



Thus, if the first galaxies form in the densest spots, they will be strongly clustered, but these will be very special regions.

An Example From a Numerical Simulation

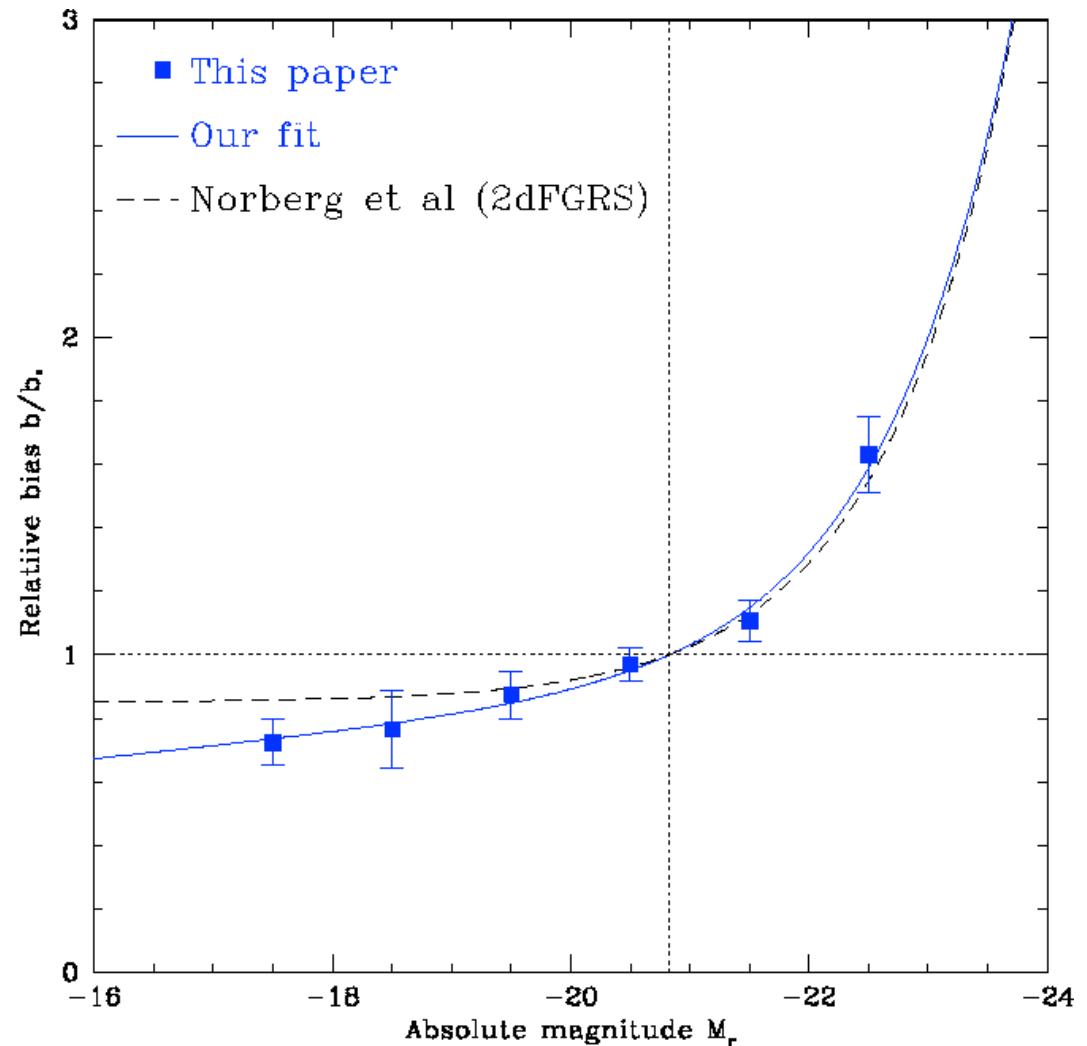


(From an N-body simulation by R. Carlberg)

Galaxy Biasing at Low Redshifts

While on average galaxies at $z \sim 0$ are not biased tracers, there is a dependence on luminosity: the more luminous ones are clustered more strongly, corresponding to higher peaks of the density field.

This effect is stronger at higher redshifts.



Biassing in the SDSS, Tegmark et al (2004)

Evolution of Clustering

- Generally, density contrast grows in time, as fluctuations collapse under their own gravity
- Thus, one generically expects that clustering was weaker in the past (at higher redshifts), and for fainter galaxy samples
- A simple model for the evolution of the correlation function:

$$\xi(r, z) = \xi(r, 0) \times (1 + z)^{-(3 + \epsilon)}$$

and the clustering length (in proper coordinates):

$$r_0(z) = r_0(0) \times (1 + z)^{-(3 + \epsilon)/\gamma}$$

If $\epsilon = -1.2$, clustering is fixed in comoving coords.

If $\epsilon = 0$, clustering is fixed in proper coords.

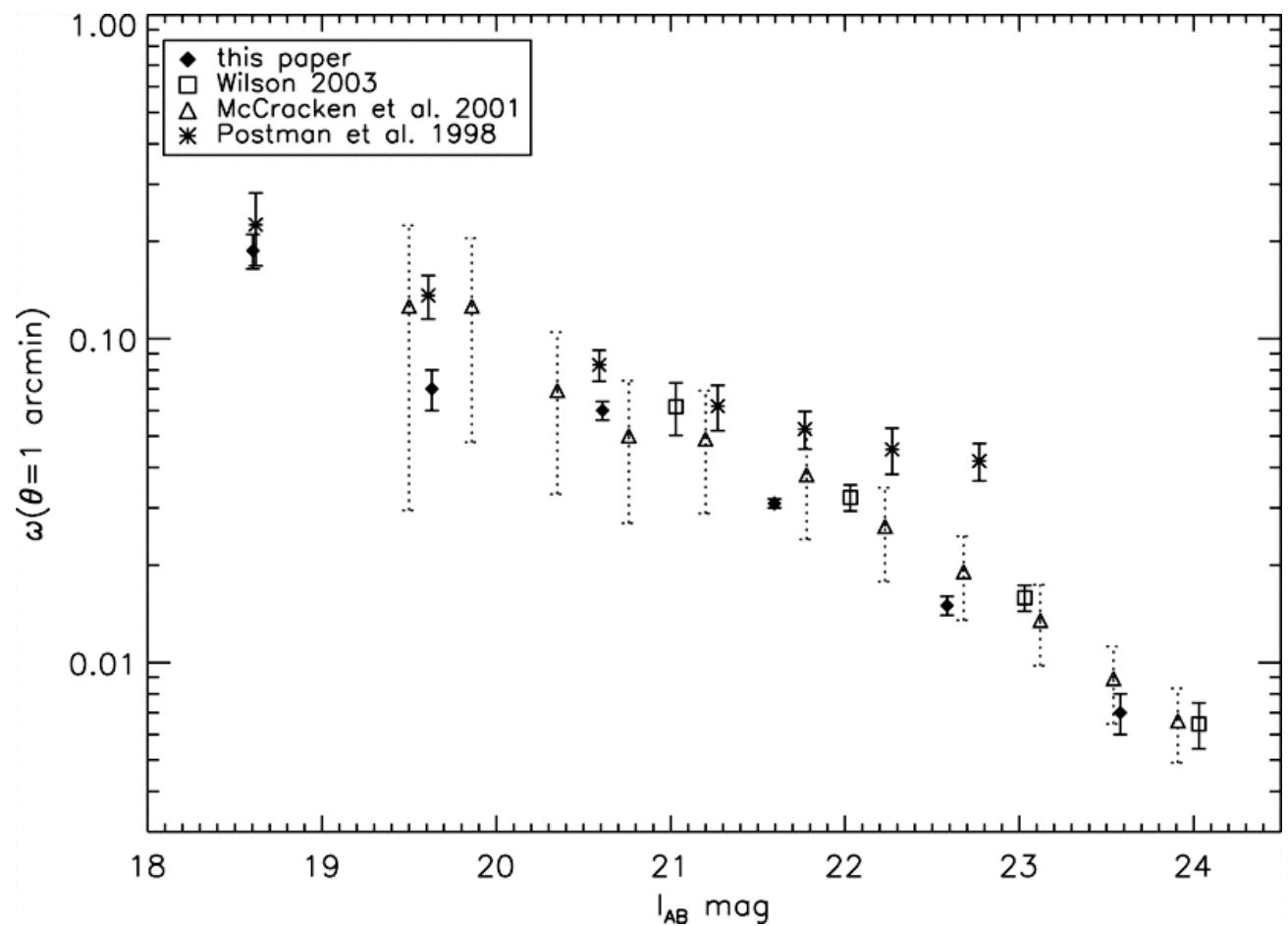
If $\epsilon > 0$, clustering grows in proper coords.

- Observations indicate $\epsilon > 0$, but not one single value fits all data

Evolution of Clustering

- Indeed, the strength of the angular clustering is observed to be weaker at fainter magnitudes (\sim more distant samples)

Amplitude of the angular correlation function on the scale of 1 arcmin, as a function of the survey depth

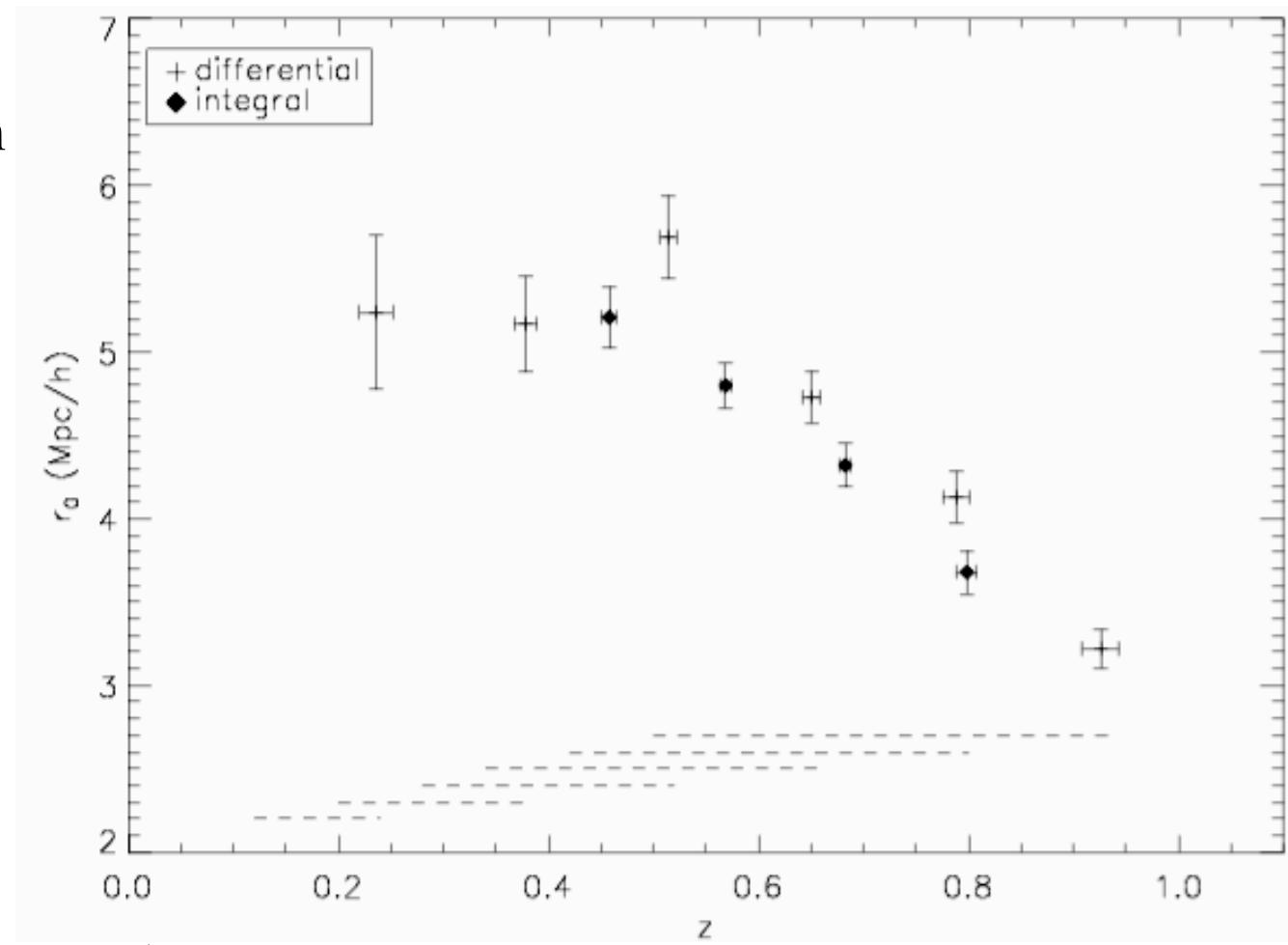


(Coil *et al.*, DEEP survey team)

Evolution of Clustering

- Deep redshift surveys give the same result for the spatial clustering, at least out to $z \sim 1$:

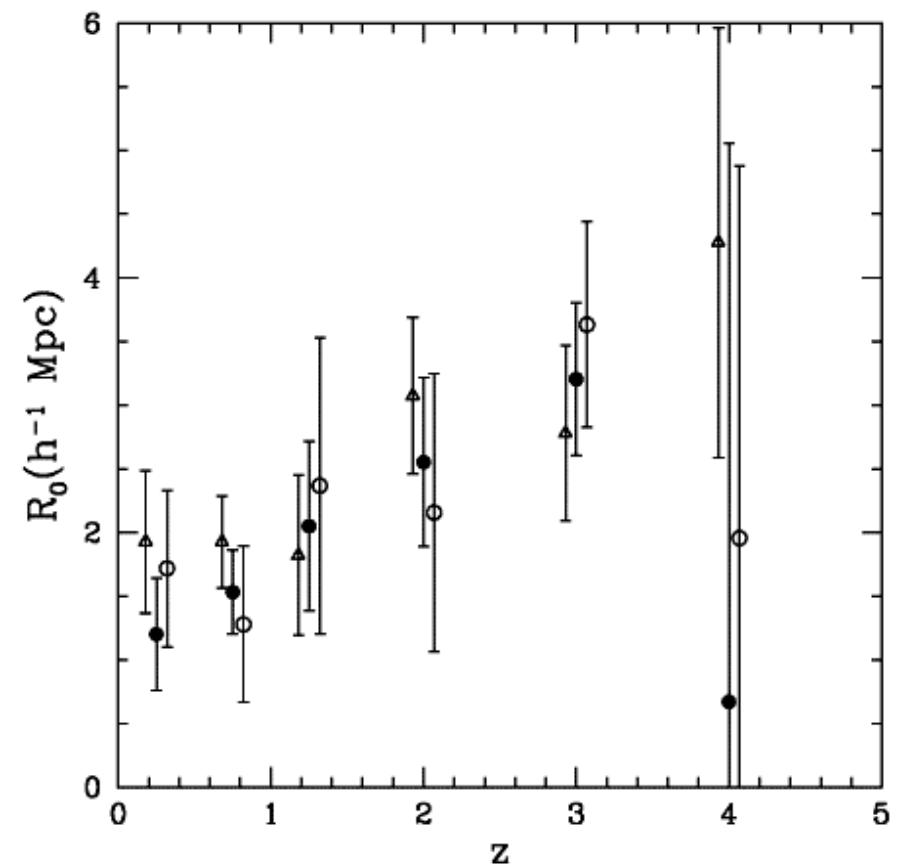
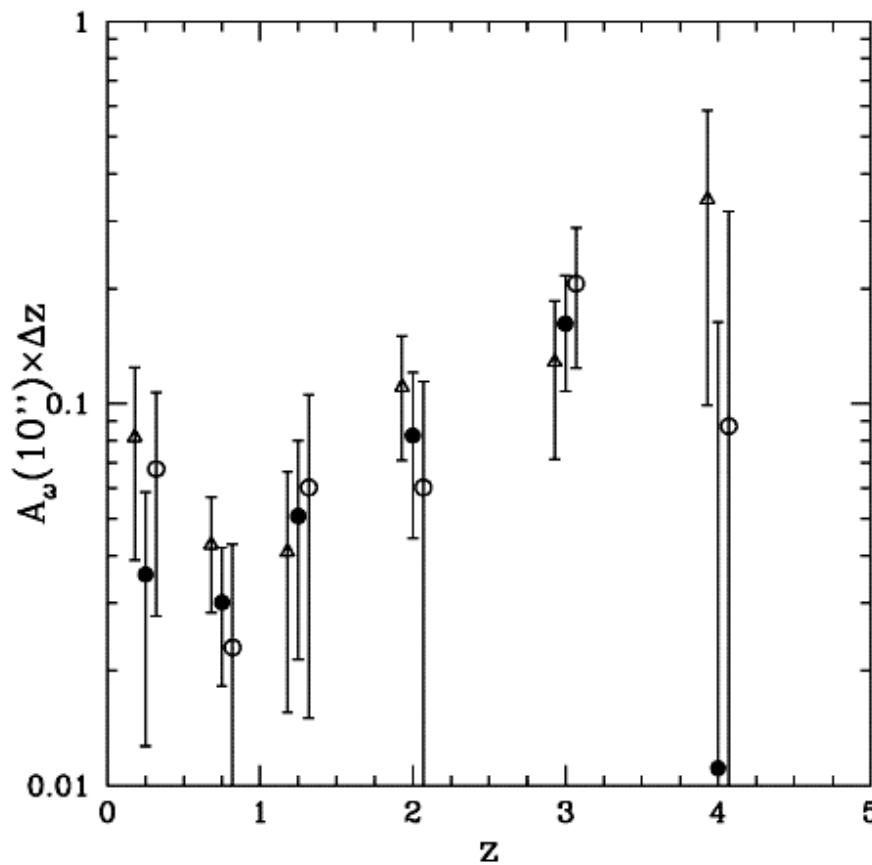
Clustering length
as a function of
redshift



(Coil et al., DEEP survey team)

Evolution of Clustering

- But at higher redshifts (and fainter/deeper galaxy samples), the trend reverses: stronger clustering at higher redshifts = earlier times!



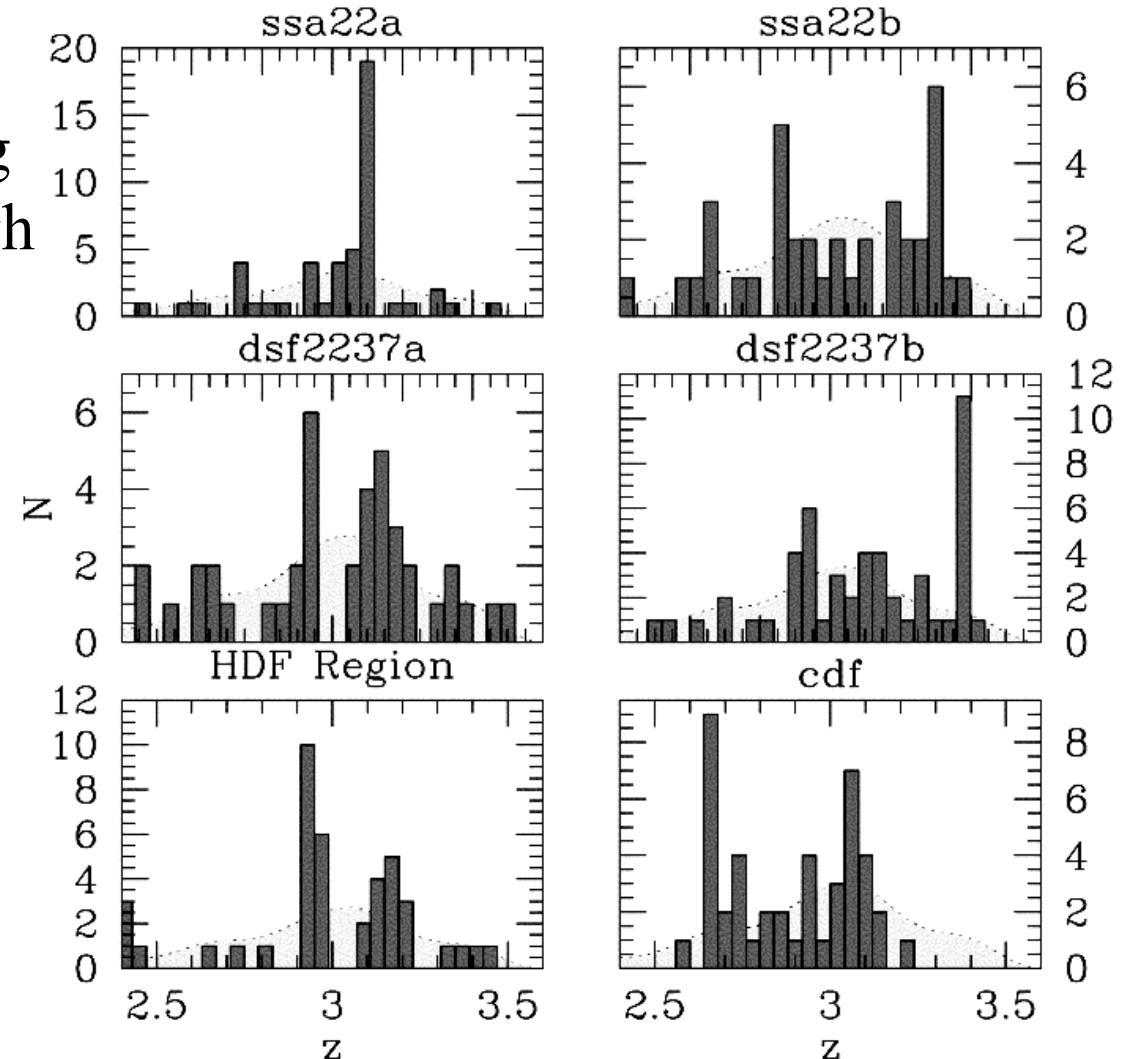
(*Hubble Deep Field data*)

Early Large-Scale Structure: Redshift Spikes in Very Deep Surveys

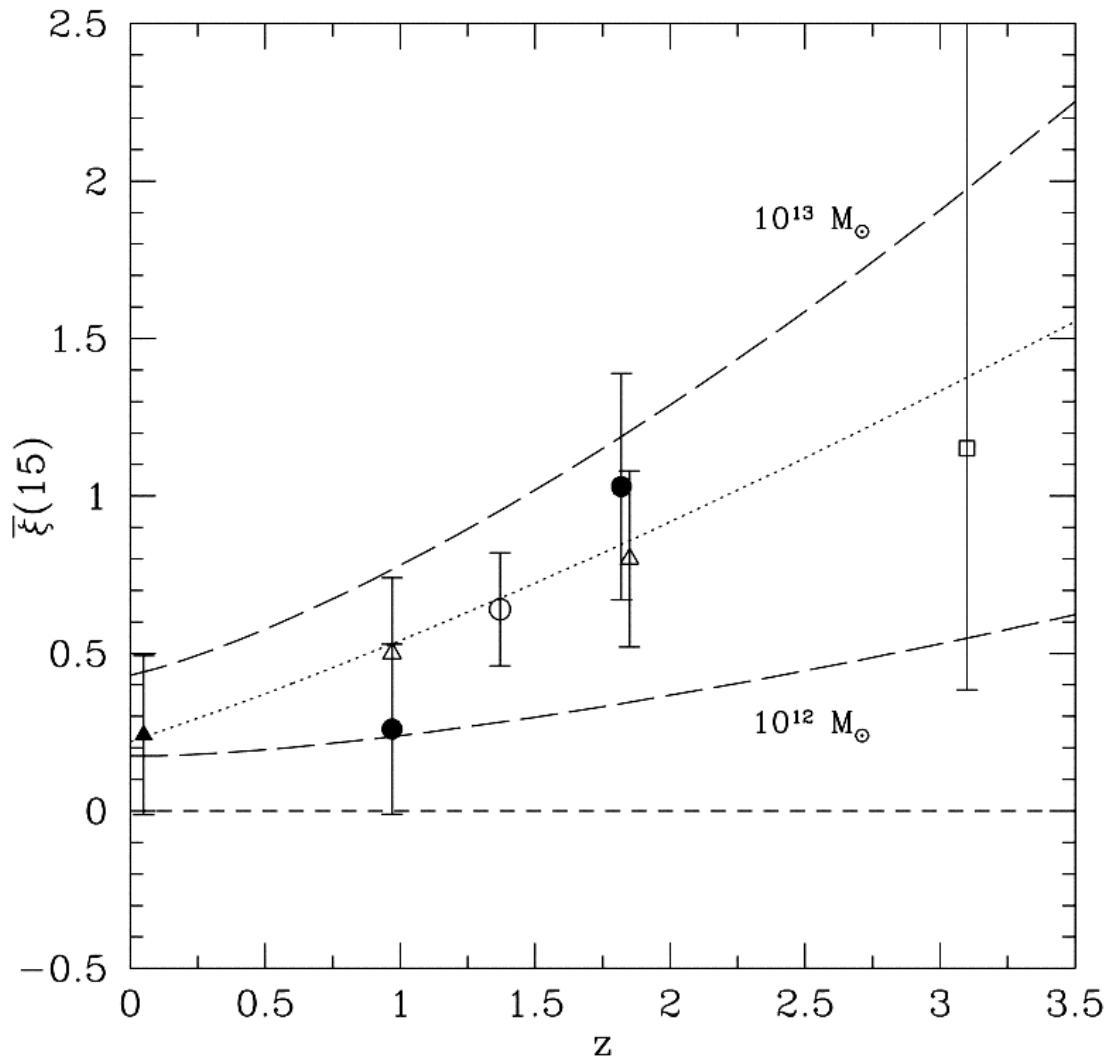
Strong clustering of young galaxies is observed at high redshifts (up to $z \sim 3 - 4$), apparently as strong as galaxies today

This is only possible if these distant galaxies are highly biased - they are high-sigma fluctuations

(*Steidel, Adelberger, et al.*)



Clustering of Quasars is Also Stronger at Higher Redshifts

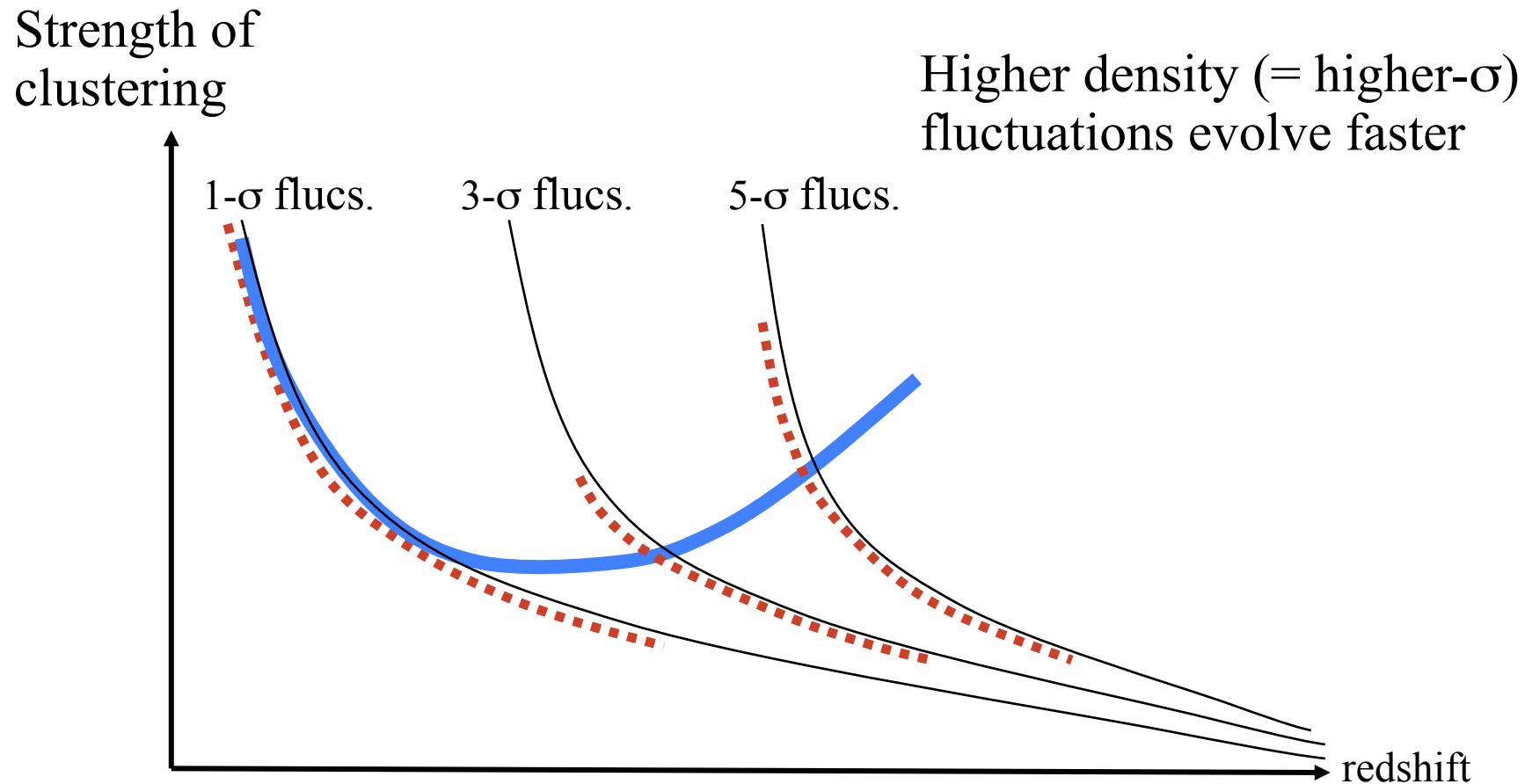


How is this possible?

Clustering is supposed to be *weaker* at higher z 's as the structure grows in time.

Evolution of bias provides the answer

Biasing and Clustering Evolution

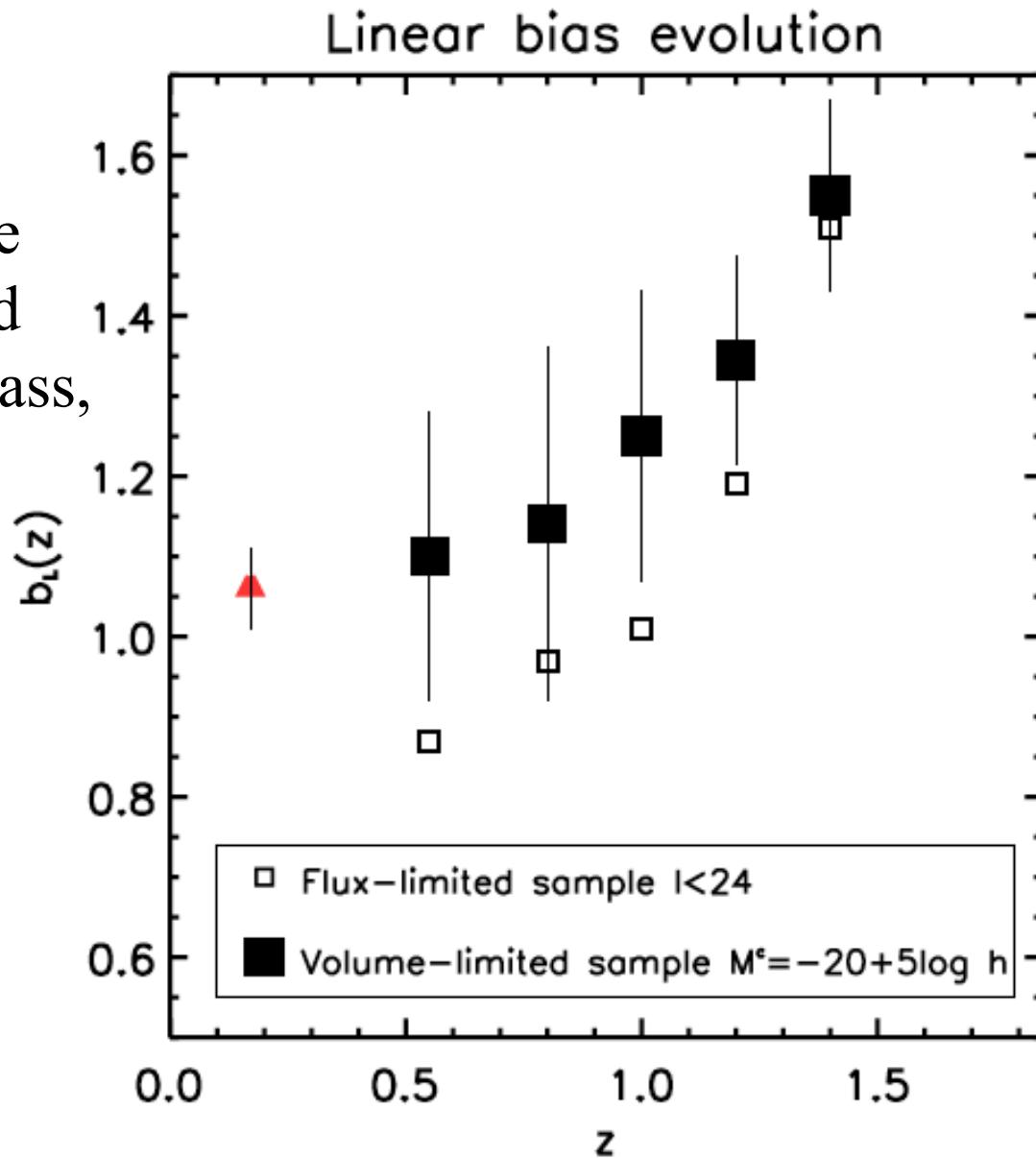


At progressively higher redshifts, we see higher density fluctuations, which are intrinsically clustered more strongly ...

Thus the net strength of clustering seems to increase at higher z's

The Evolution of Bias

At $z \sim 0$,
galaxies are
an unbiased
tracer of mass,
 $b \sim 1$



But at higher
 z 's, they are
progressively
ever more
biased

(Le Fevre et al.,
VIMOS Survey Team)

Evolution of Clustering and Biasing

- The strength of clustering (of mass) grows in time, as the gravitational infall and hierarchical assembly continue
 - However, the rate of growth and the strength of clustering at any given time depend on the mass and nature of objects studied
 - This is generally expressed as the evolution of the 2-point correlation function, $\xi(r;z) = \xi(r,0) (1+z)^{-(3+\epsilon)}$
 - Clustering/LSS is observed out to the highest redshifts ($z \sim 4 - 6$) now probed, and it is surprisingly strong
- What we really observe is *light*, which is not necessarily distributed in the same way as *mass*; this is quantified as ***bias***:

$$(\Delta\rho/\rho)_{\text{light}} = b (\Delta\rho/\rho)_{\text{mass}}, \quad \xi(r)_{\text{light}} = b^2 \xi(r)_{\text{mass}}$$

- Bias is a function of time and mass/size scale
- Galaxies (especially at high redshifts) are biased tracers of LSS, as the first objects form at the highest peaks of the density field
- Today, $b \sim 1$ at scales $>$ galaxies