Quasar Clustering, the Quasar Luminosity Function, and the HSC

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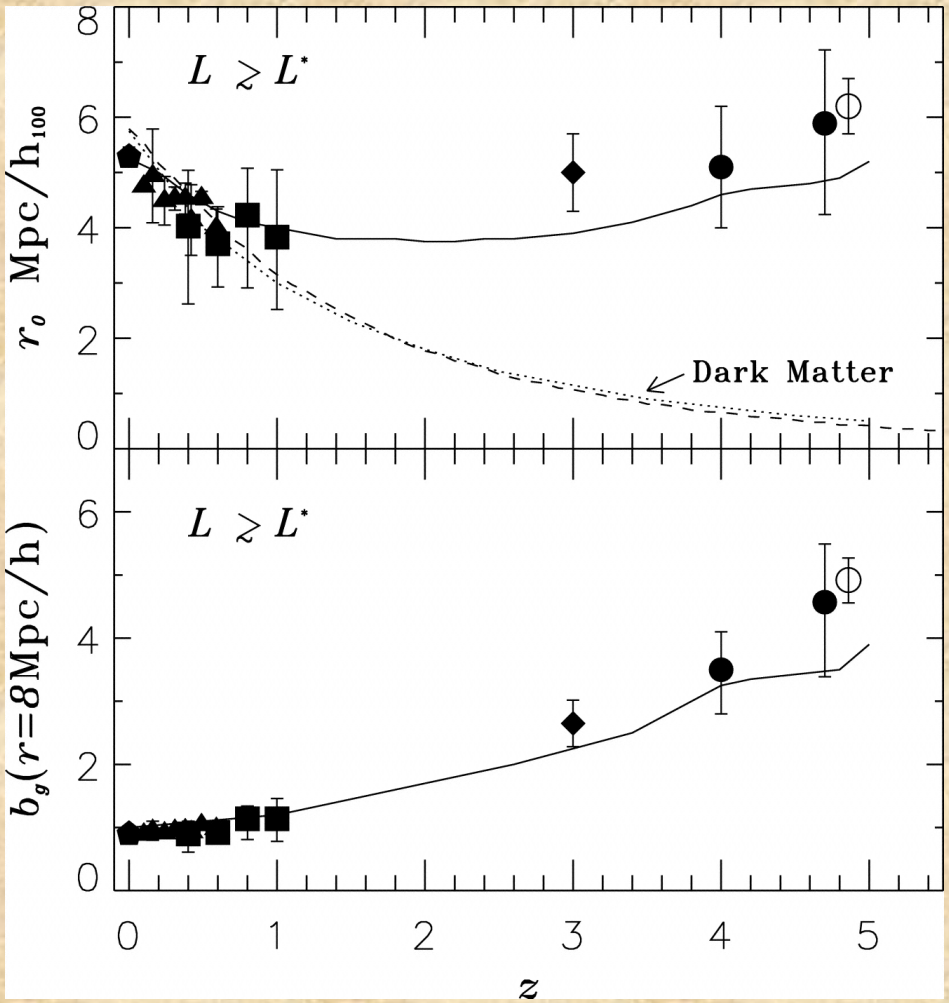
- Given that all galaxies with bulges contain supermassive black holes, they must have gone through a quasar phase; rapid growth at high Eddington rate.
- What is the trigger of that quasar phase? What is the galaxy doing when the quasar is growing?
- Clues from quasar host galaxy studies, and measuring the luminosity function and clustering of quasars as a function of redshift.

Ingredients in a quasar evolution model

- What is relationship between galaxy stellar mass, dark matter halo mass, and black hole mass as a function of time?
- Is black hole feeding driven by galaxy major mergers? Minor mergers?
- What is the resulting Eddington ratio distribution as a function of time?
- How does all this tie to star formation? Dust obscuration?

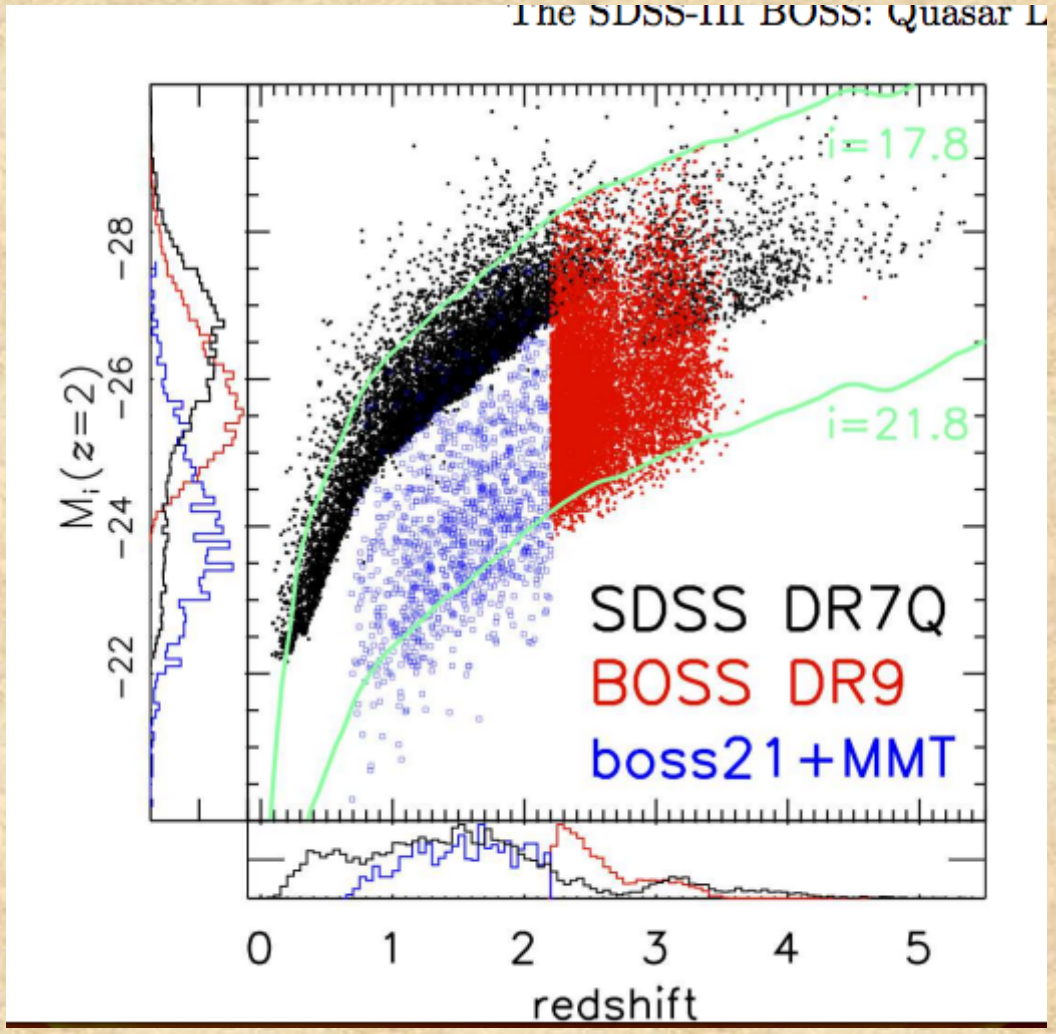
The relationship between galaxies/quasars and dark matter: "bias"



Correlation length, inferred galaxy bias as a function of redshift, from angular clustering of galaxies by Ouchi et al. 2004

Dark matter halos of a given *mass* are ever rarer at higher redshift

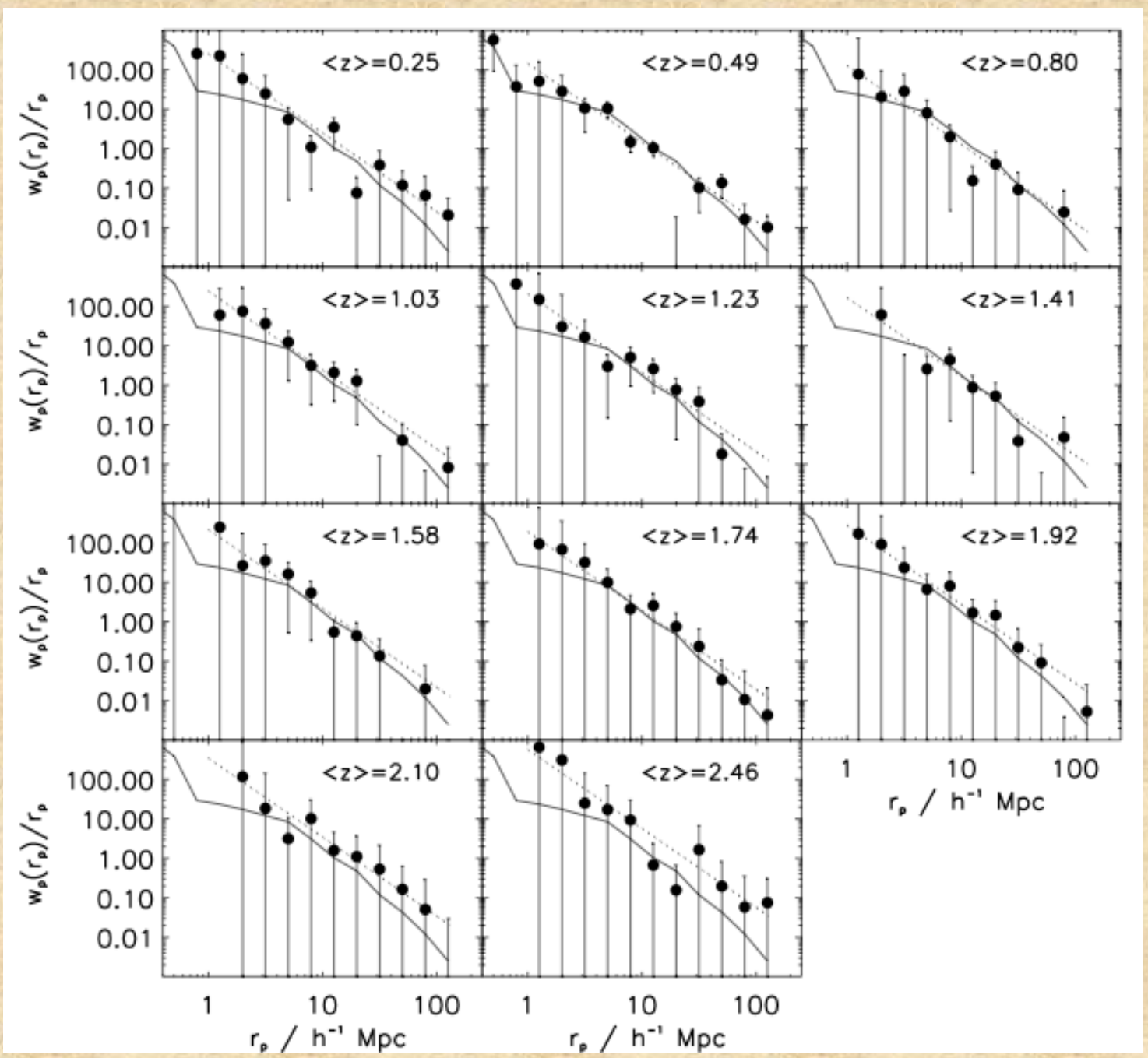
- At visible wavelengths, SDSS has made the most comprehensive catalogs of quasars.



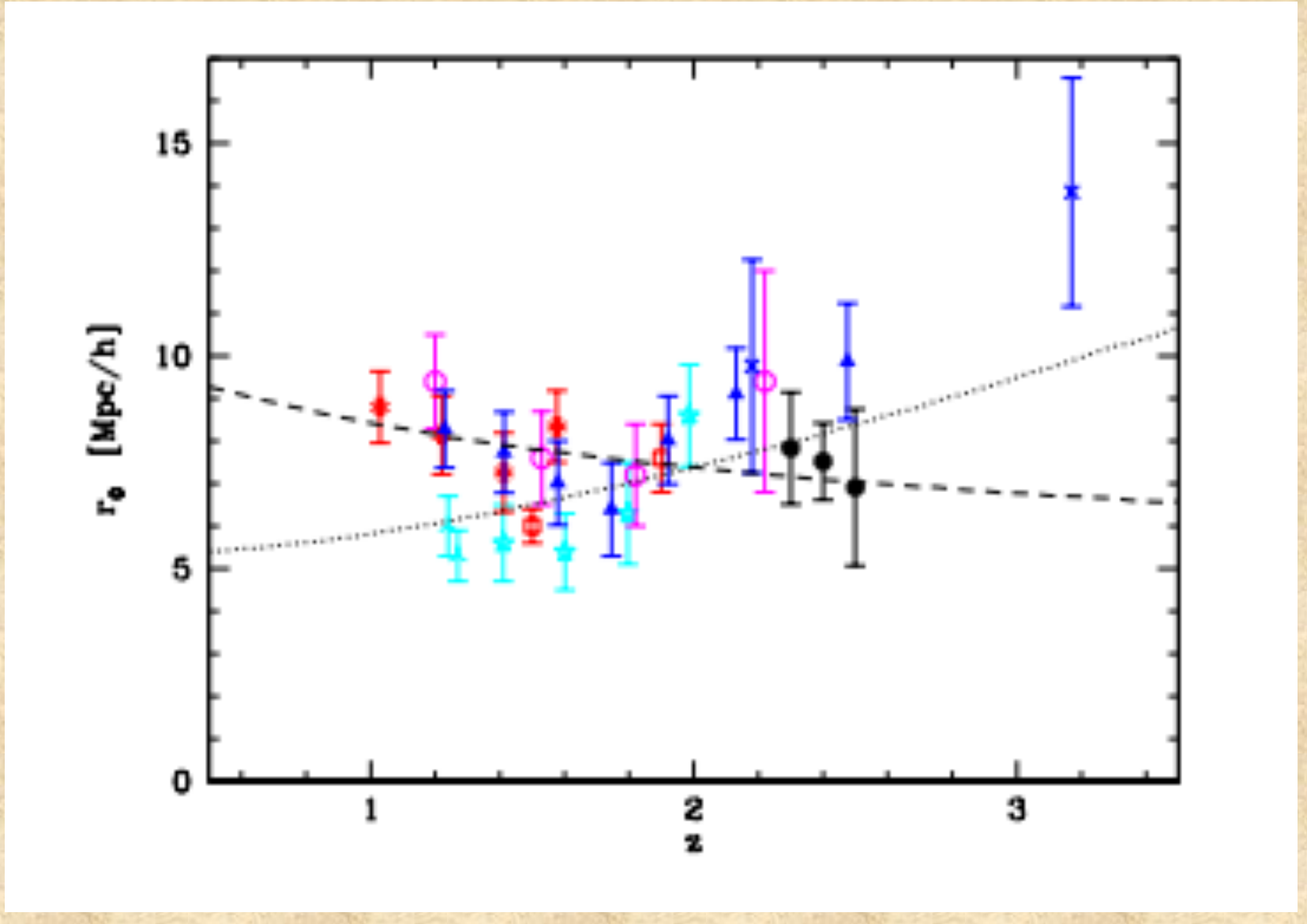
Ross et al. 2012b: the distribution in redshift and luminosity of quasars from SDSS I/II/III. Now over 200,000 quasars in all.

SDSS DR5 quasar sample, a complete sample of ~30,000 objects. Projected correlation function in redshift slices.

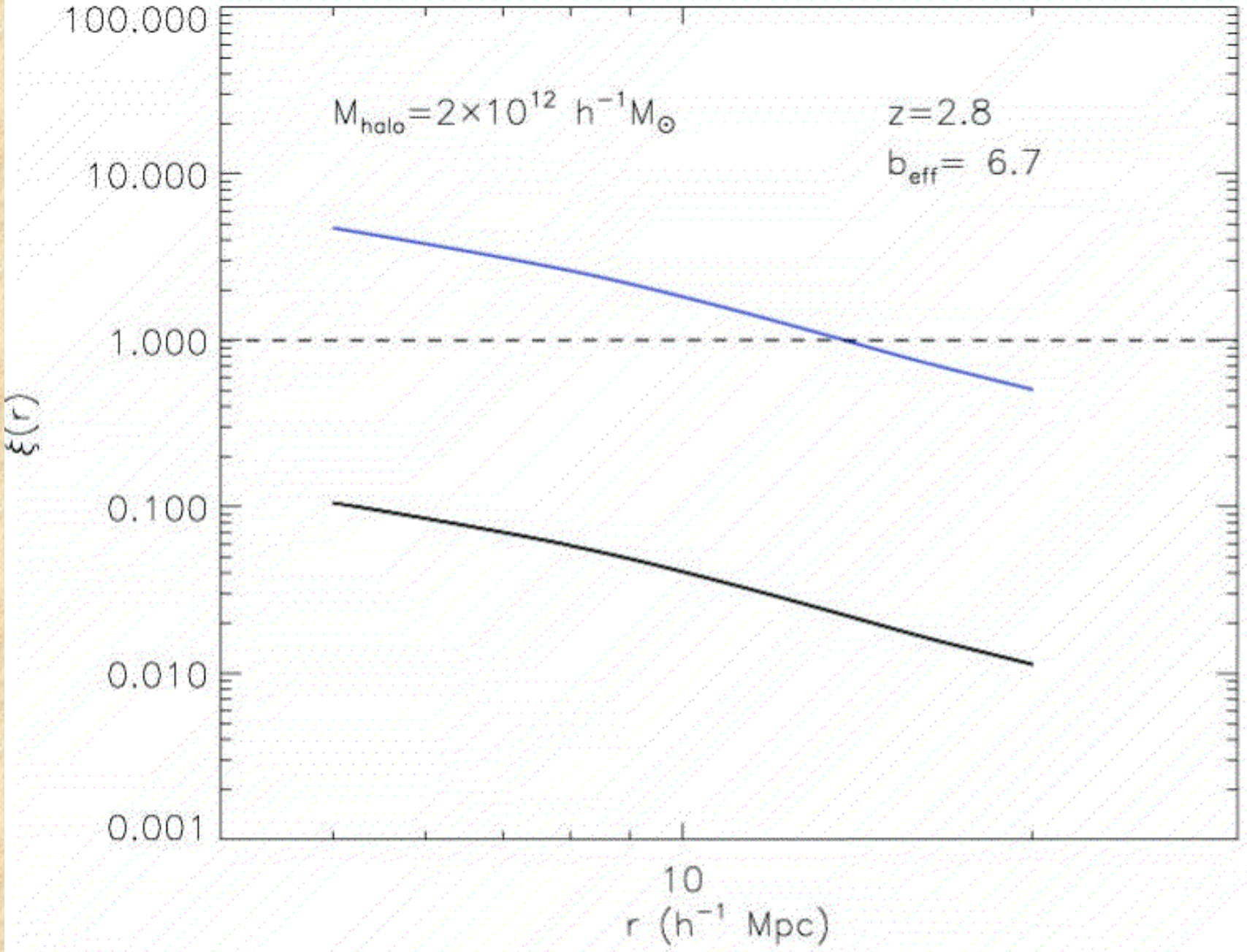
The clustering length changes very little with redshift.



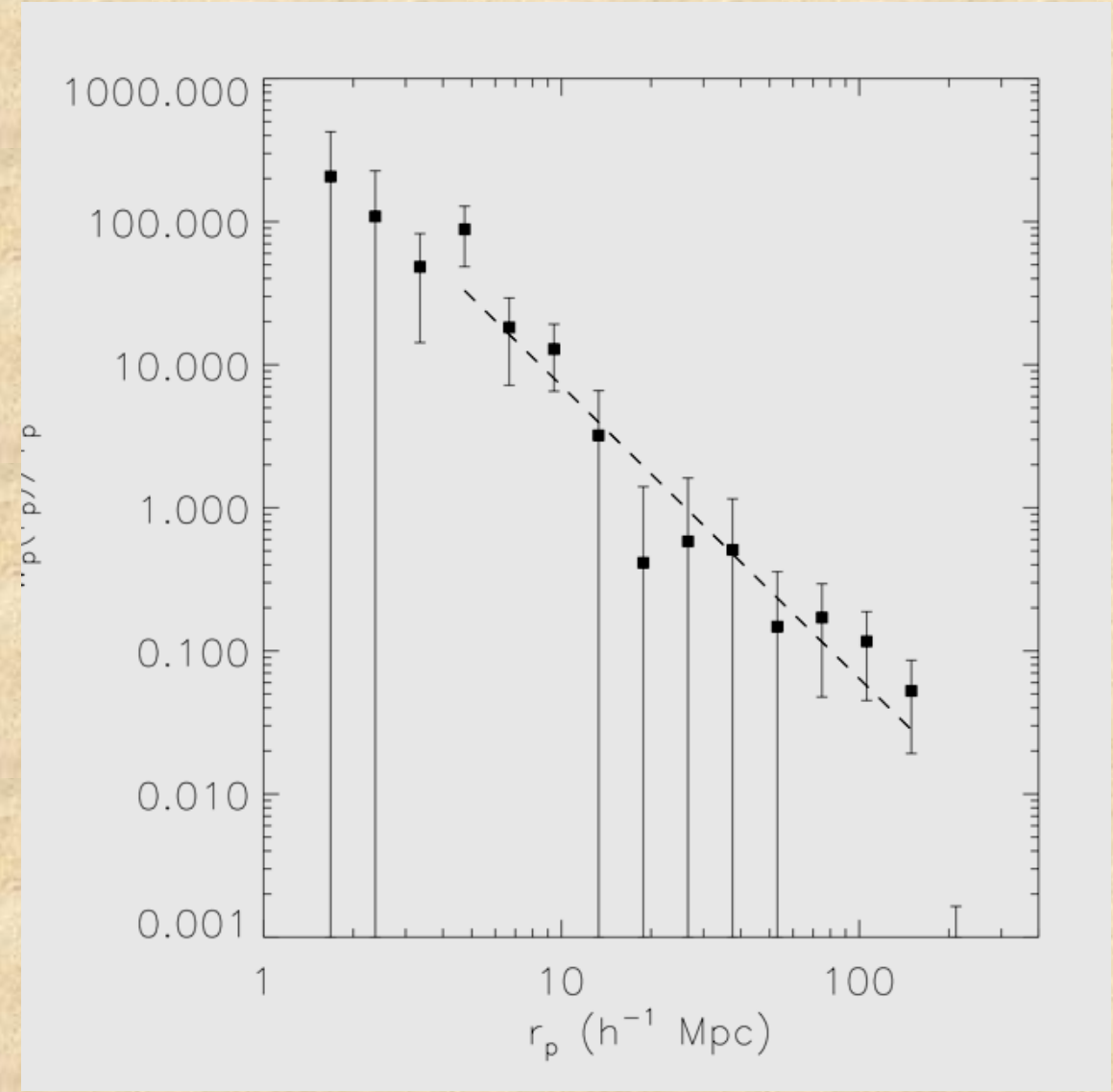
Ross et al. 2009



Measurements of quasar cluster correlation length as a function of redshift from various sources. White et al. 2012


100.000
10.000
1.000
0.100
0.010
0.001
$M_{halo}=2\times10^{12}\ h^{-1}M_\odot$
z=2.8
$b_{eff}=6.7$
$\xi(r)$
10
r (h^{-1} Mpc)

Measured correlation function for 2.9 < z < 5 quasar sample



Projected correlation function

Projected distance on the sky

Equivalent to

$\xi(r) = (r/r_0)^{-\gamma}$

r_0=15.2±2.7 Mpc/h

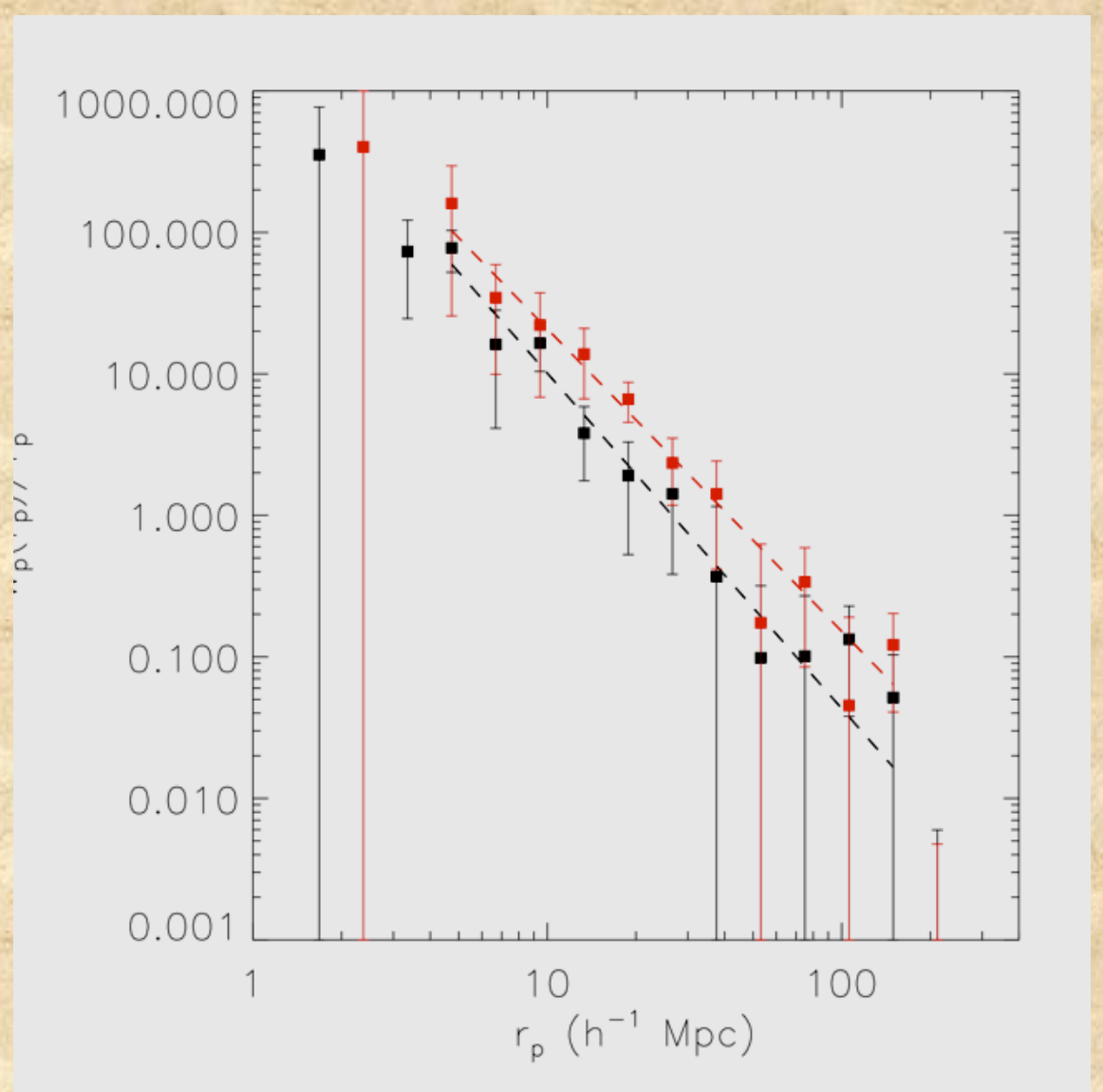
γ= 2.0±0.3

A bias of 10!

At these redshifts, ordinary galaxies have r_0~5 Mpc/h

Shen et al. 2007

So the clustering was larger in the past



For $2.9 < z < 3.5$:

r_0=16.9±1.7 Mpc/h

***b*~10**

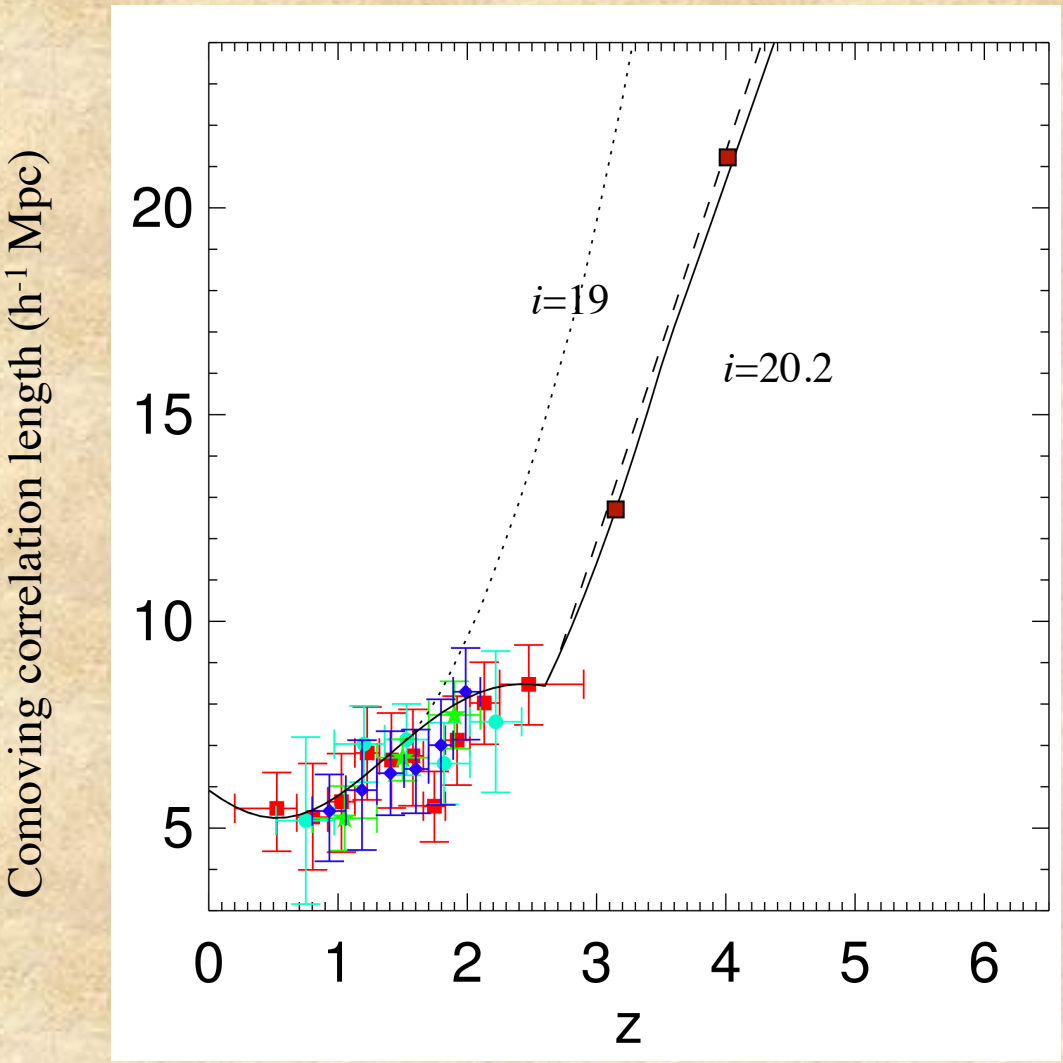
For $z > 3.5$:

r_0=24.3±2.4 Mpc/h

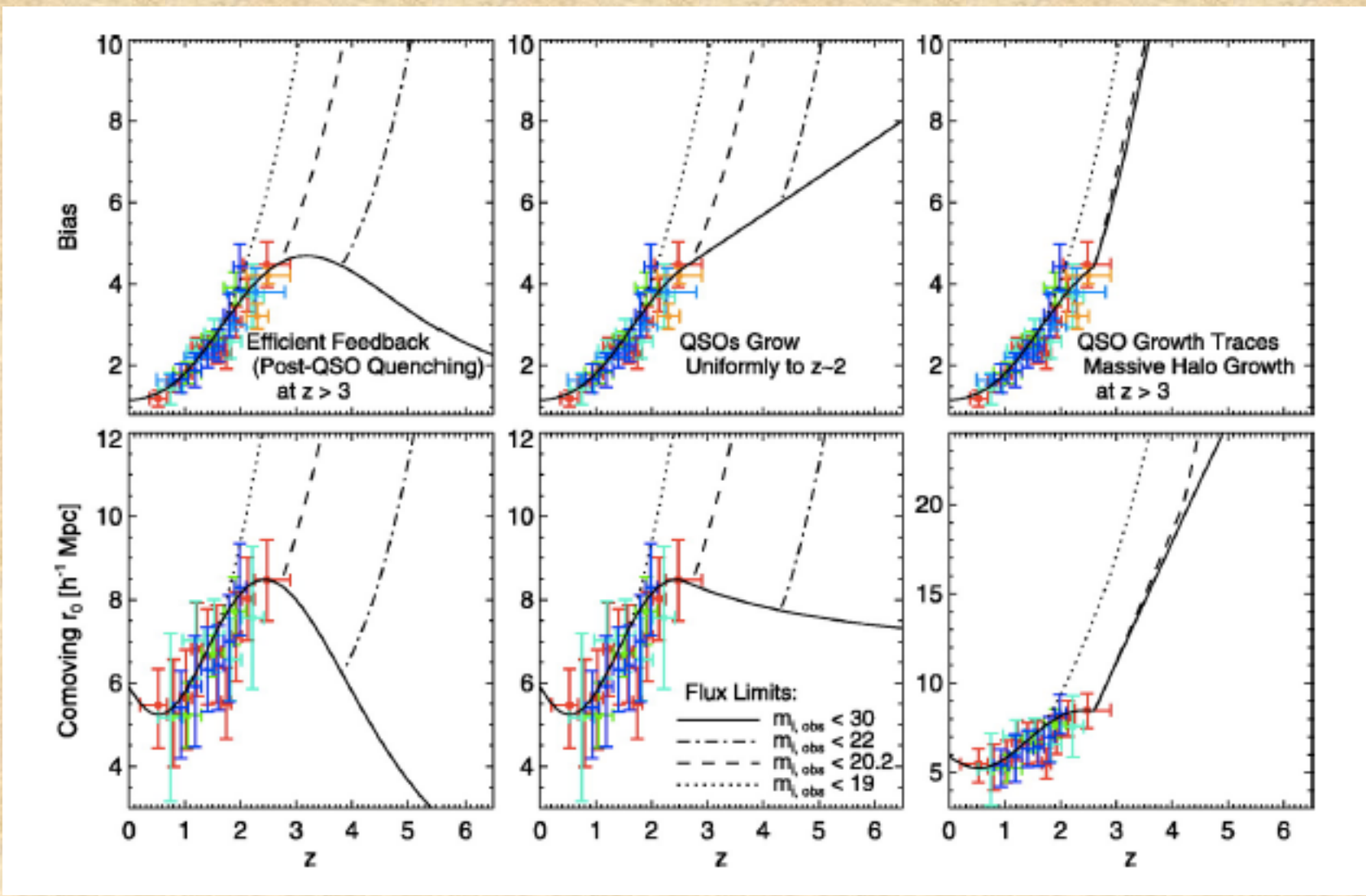
***b*~15**

Luminosity Dependence of Quasar Clustering

- At $z < 3$ (after the peak in quasar growth), objects of a given luminosity have a range of Eddington ratios (and therefore black hole masses). Black hole mass is also not correlated strongly with dark matter halo mass. Thus the clustering strength does not depend on luminosity.
- At higher redshifts, quasars are undergoing dramatic growth, and tend to be at Eddington ratio ~ 1. We expect a strong dependence on luminosity.
- SDSS has measured clustering of high-luminosity quasars at high redshift. HSC will be able to push to lower luminosities, and measure cross-correlation with galaxies.

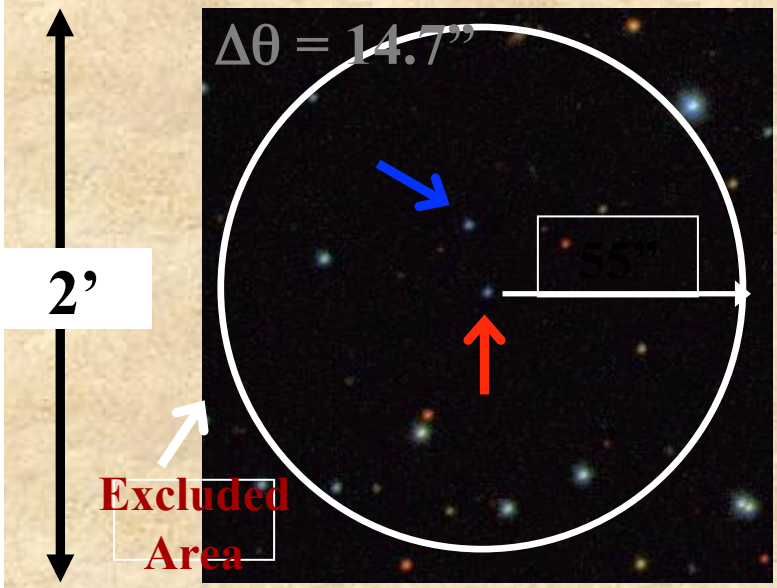


Hopkins et al. 2007: Predicted correlation length with redshift; details depend on magnitude limit and model for feedback. Probing to fainter magnitudes at high redshift is important!

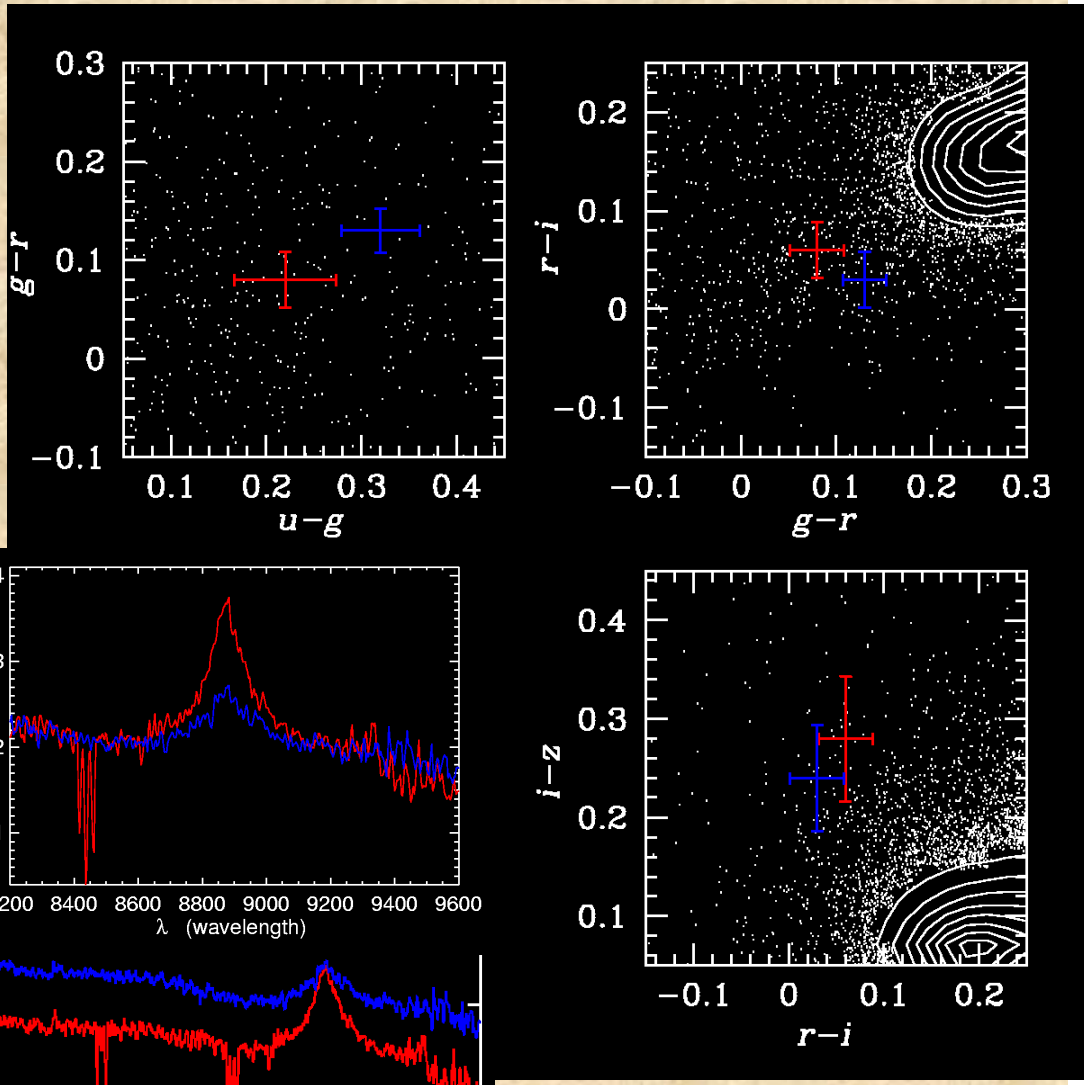


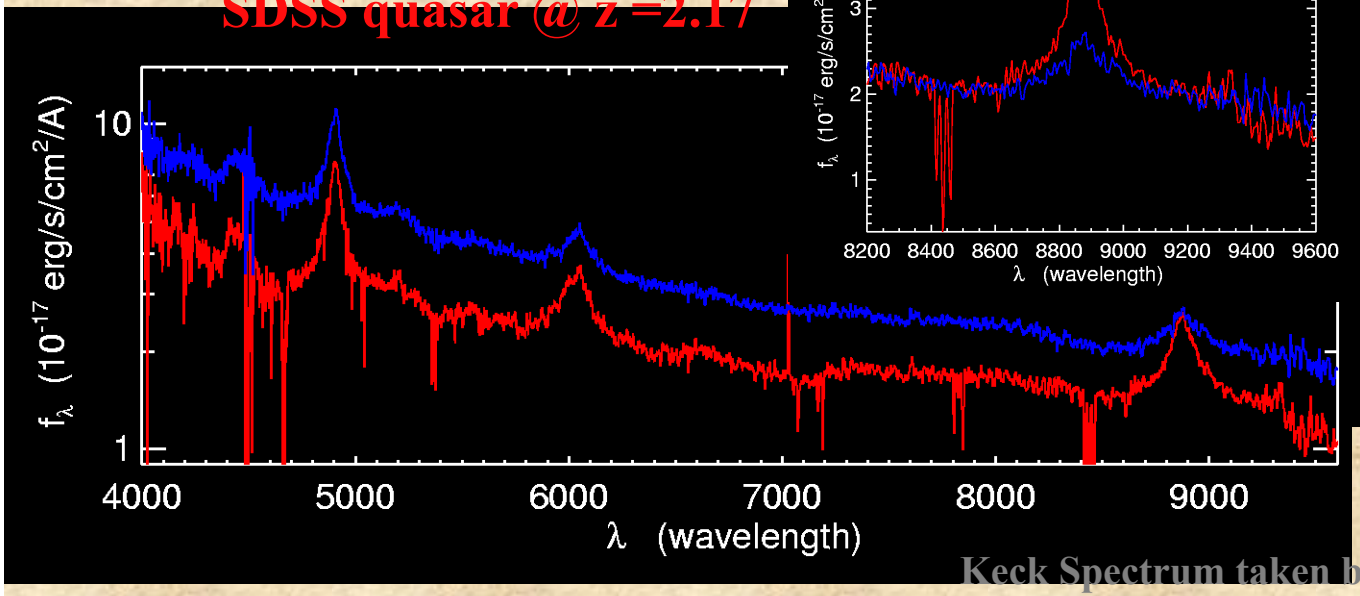
Hopkins et al. 2007: the dependence of quasar clustering as a function of redshift and apparent magnitude, for different models of quasar growth.

Finding Quasar Pairs (Hennawi et al. 2006)



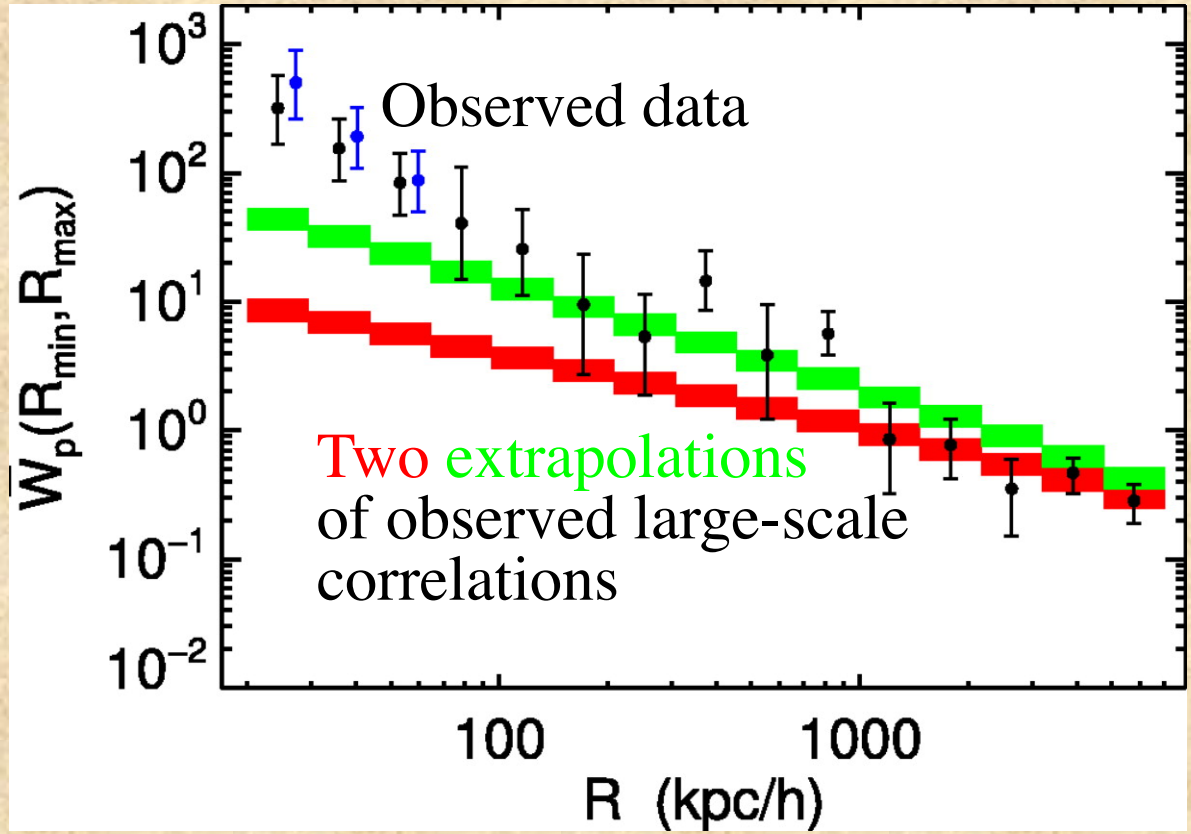
SDSS quasar @ z =2.17





Keck Spectrum taken by Bob Becker & Michael Gregg

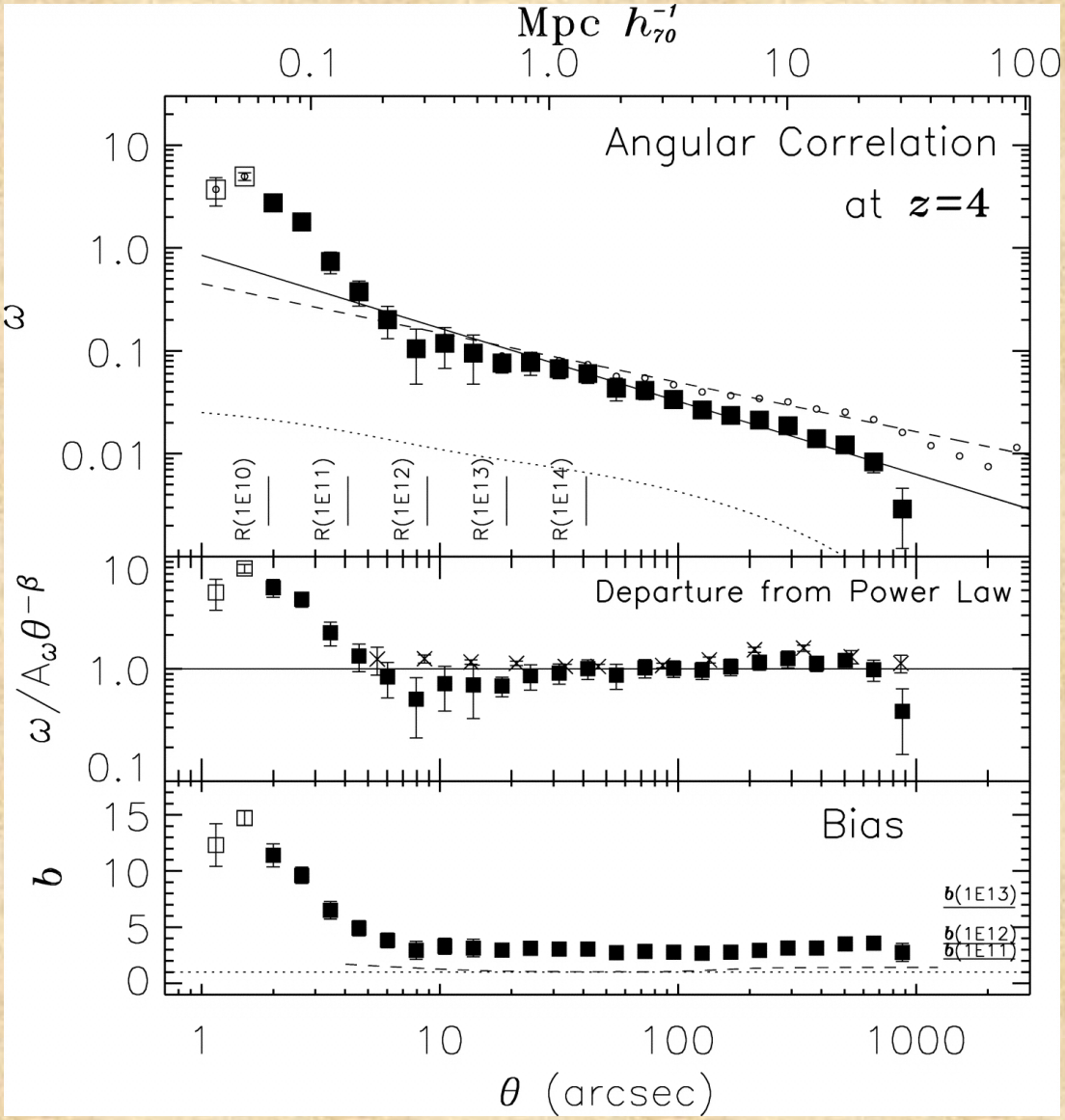
The correlation function shows a substantial excess over the power-law form, especially below 100 kpc.



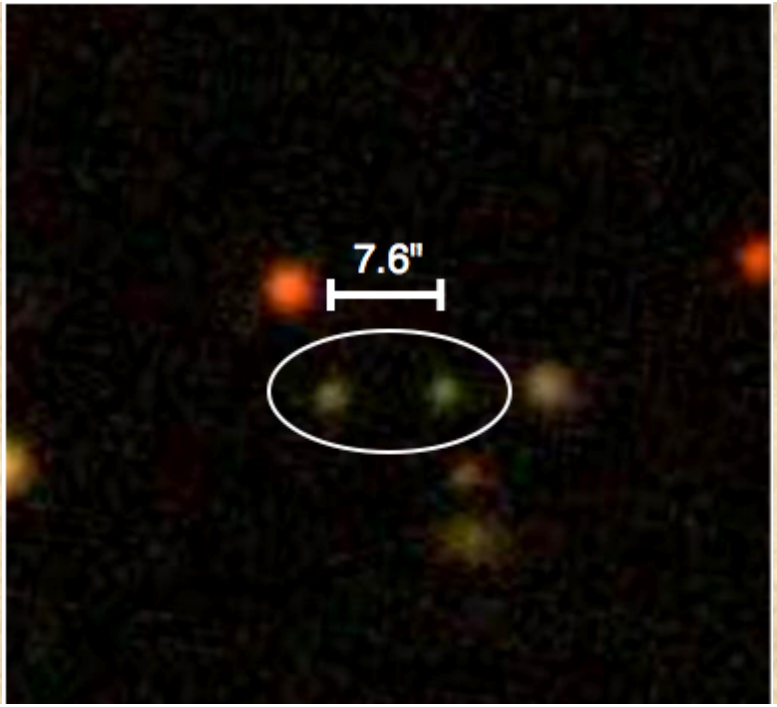
Hennawi et al. 2006

What about higher redshifts?

Ouchi et al. 2005:
Angular clustering of z~4 ***galaxies*** shows a dramatic excess at small scales, much more so than at low redshift.

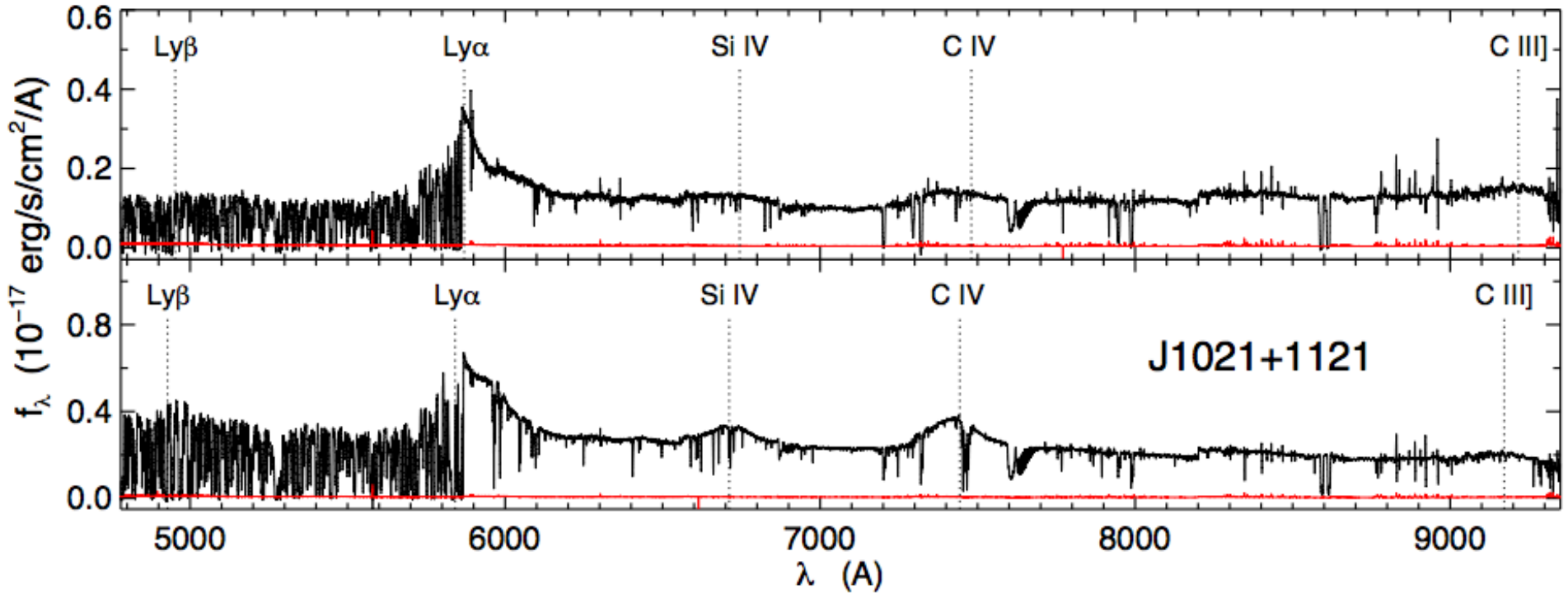


We have now have 27 pairs at z>2.9



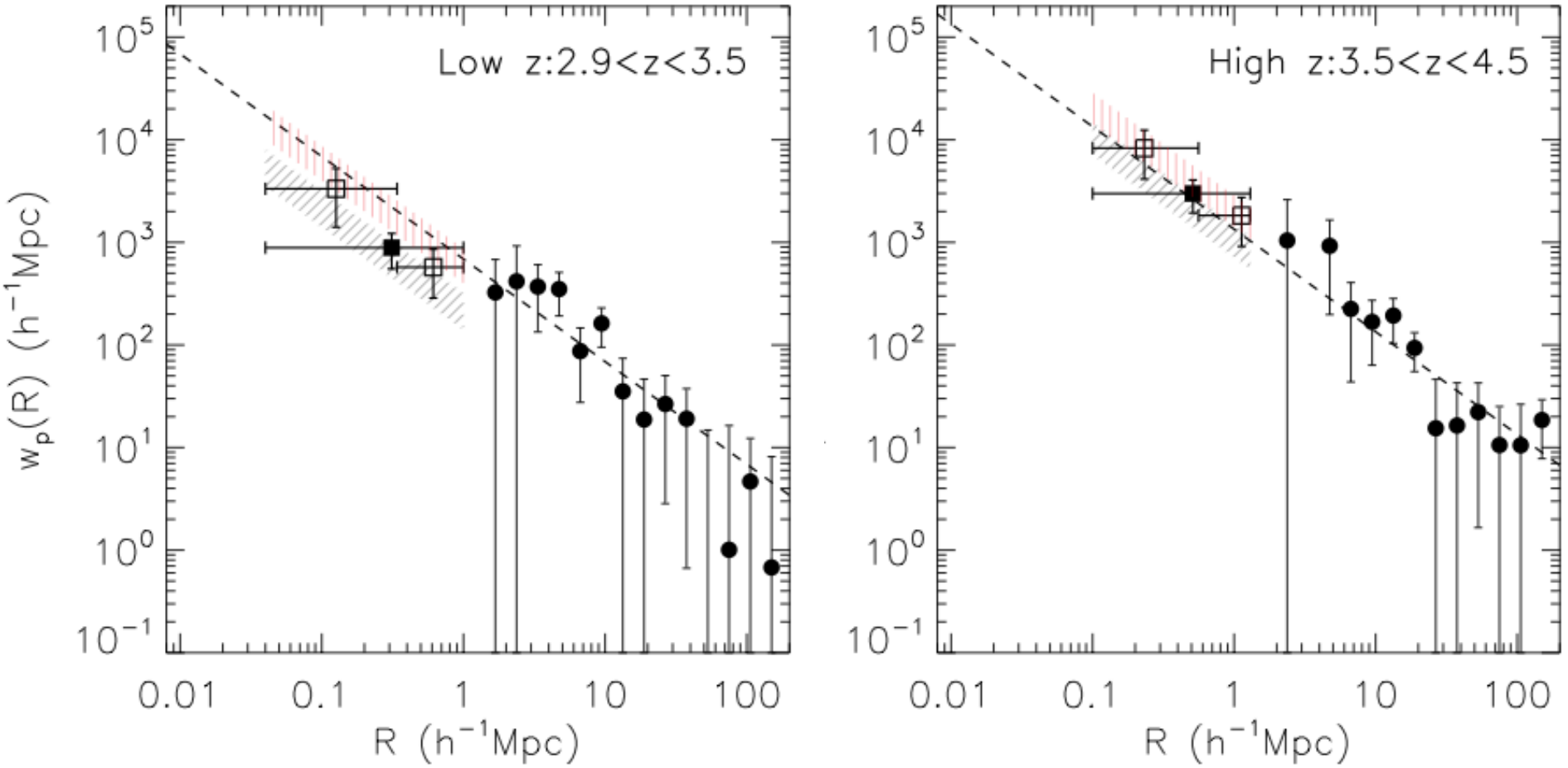
Pair at z=3.8, separated by 40 kpc

Hennawi et al. 2010



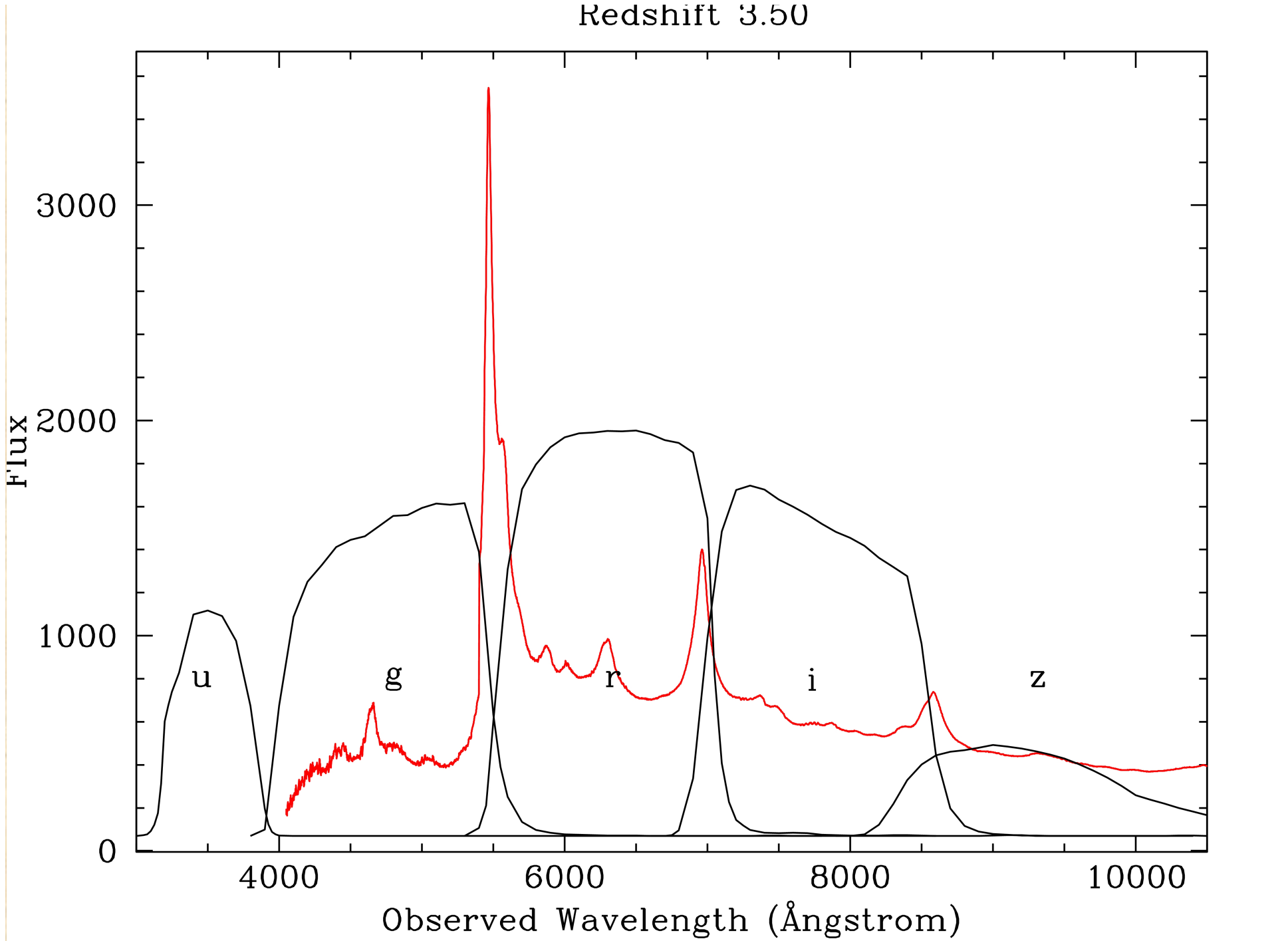
Inferred $\xi(r)$ on small scales in two redshift bins. Completeness correction is quite uncertain.

Shen et al. 2010; see also Kayo&Oguri 2012

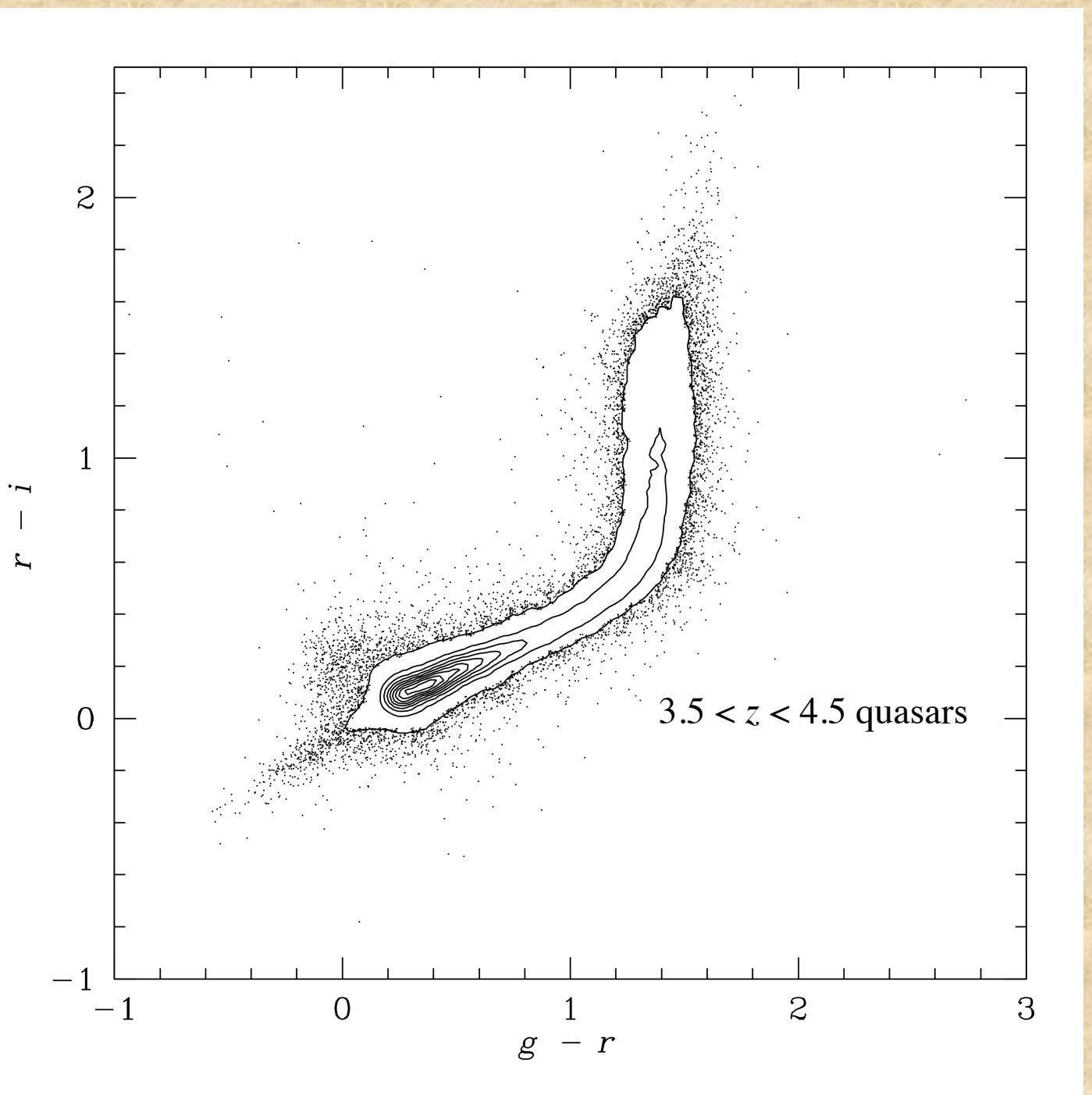


What can we do with HSC?

- We will be restricted to angular clustering. But selection of $z > 3.5$ quasars from broad-band colors and variability is fairly straightforward, and the photo-zs should be good (strong breaks at Lyα and the Lyman limit, *but see Masayuki's talk yesterday*).
- We predict 10,000 quasars with z>3.7 in the HSC Wide Survey. and 2000 in the Deep Survey.

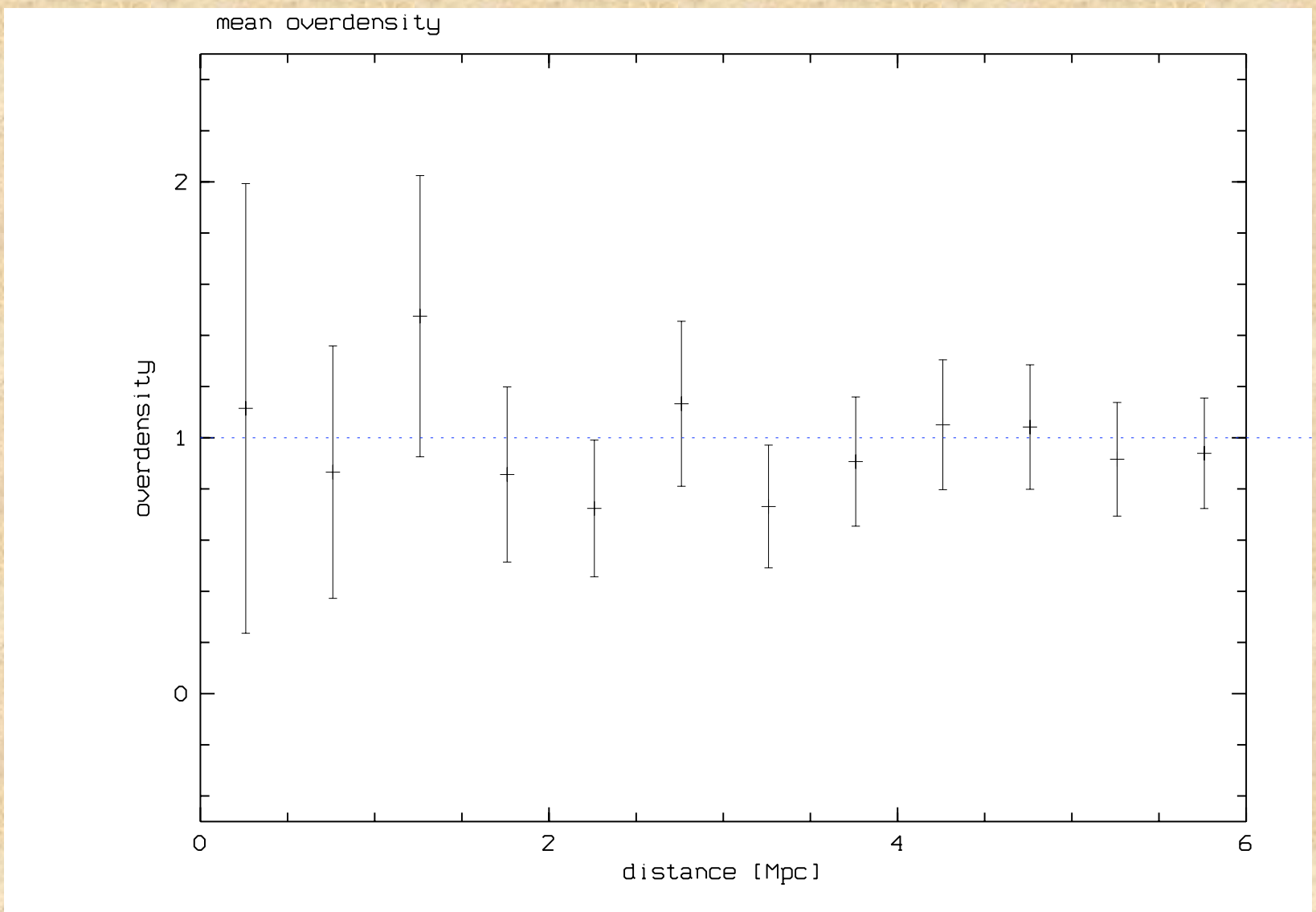

Redshift 3.50
Flux
3000
2000
1000
0
u
g
r
i
z
4000
6000
8000
10000
Observed Wavelength (Ångstrom)

At $z > 3.5$, quasars drop out of the *u*-band. The Lyα forest moves into the *g* band, and quasars become red in *g-r.*



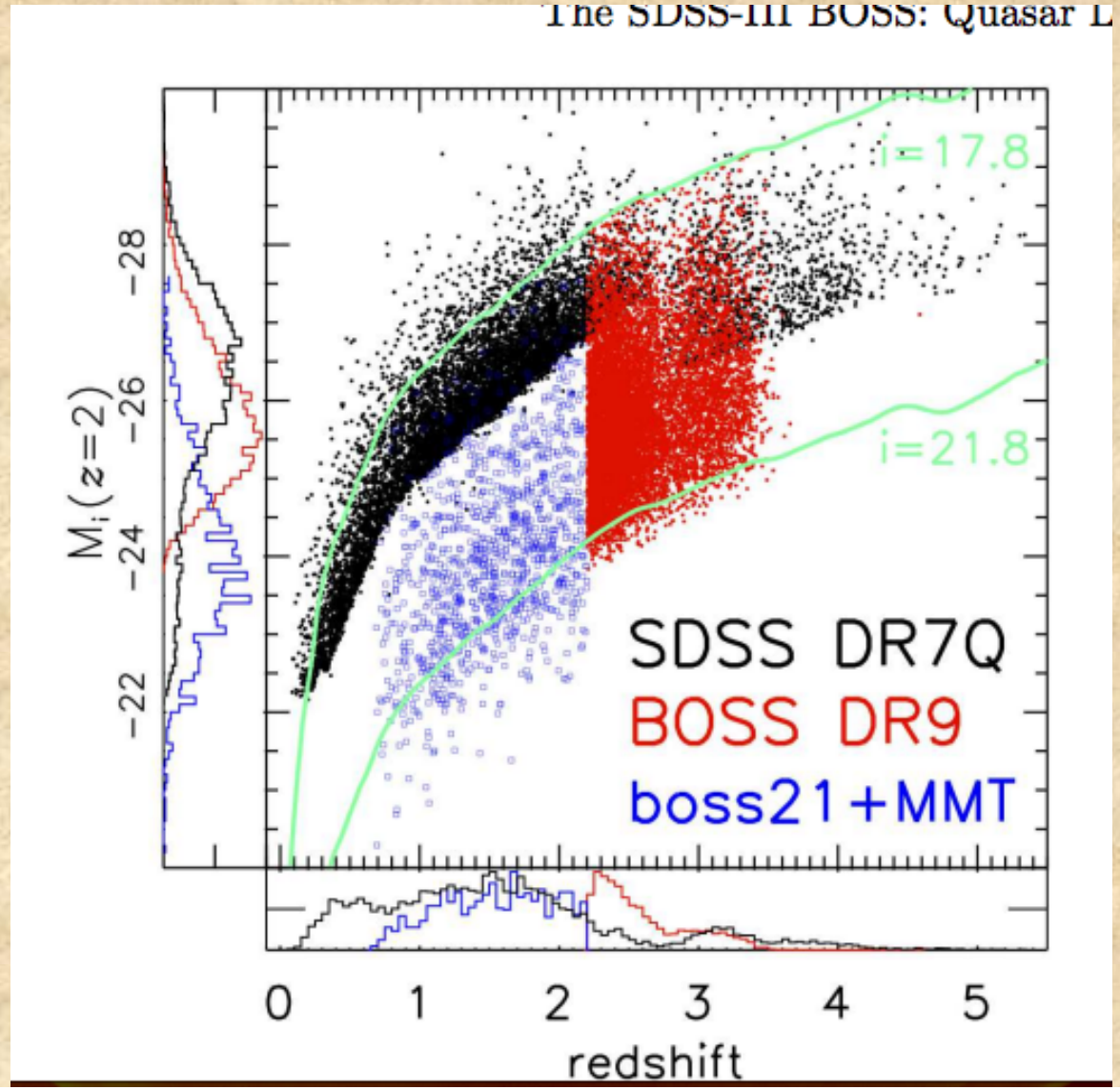
The Clustering Environments of High-Redshift Quasars

- At low redshifts ($z < 1$), quasars do not seem to live in rich environments. But they are in highly biased halos at $z>3$; are they associated with overdensities of galaxies? How about pairs of quasars? HSC Deep will be well-suited to address this question. There will be ~500 $z>2.2$ BOSS quasars in the HSC Deep fields.



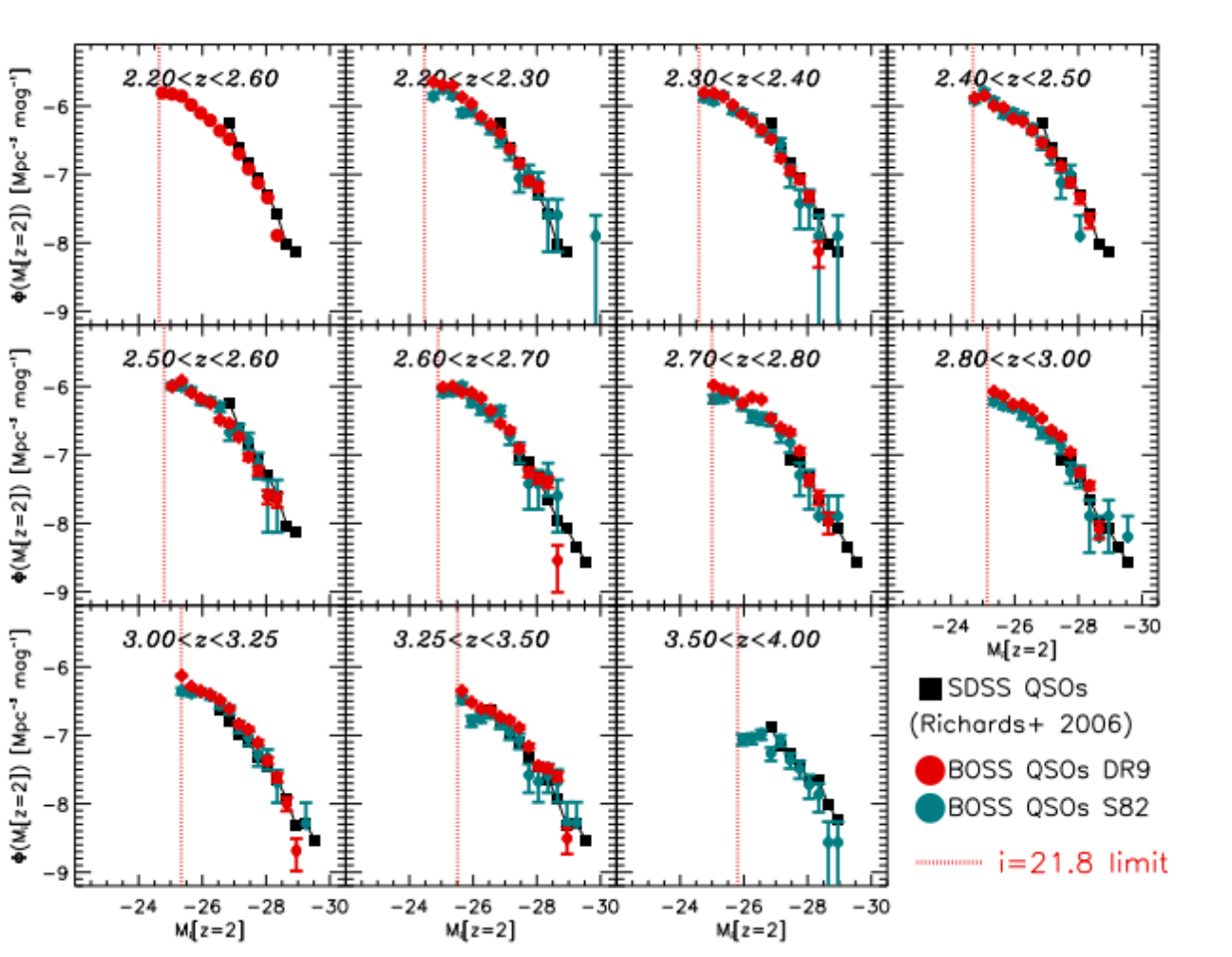
Fried et al, in preparation: Overdensity of galaxies around 6 z~3.8 quasars from deep VLT imaging. No overdensity seen! HSC will be able to do this analysis with much larger sample.

The Luminosity Function of SDSS quasars



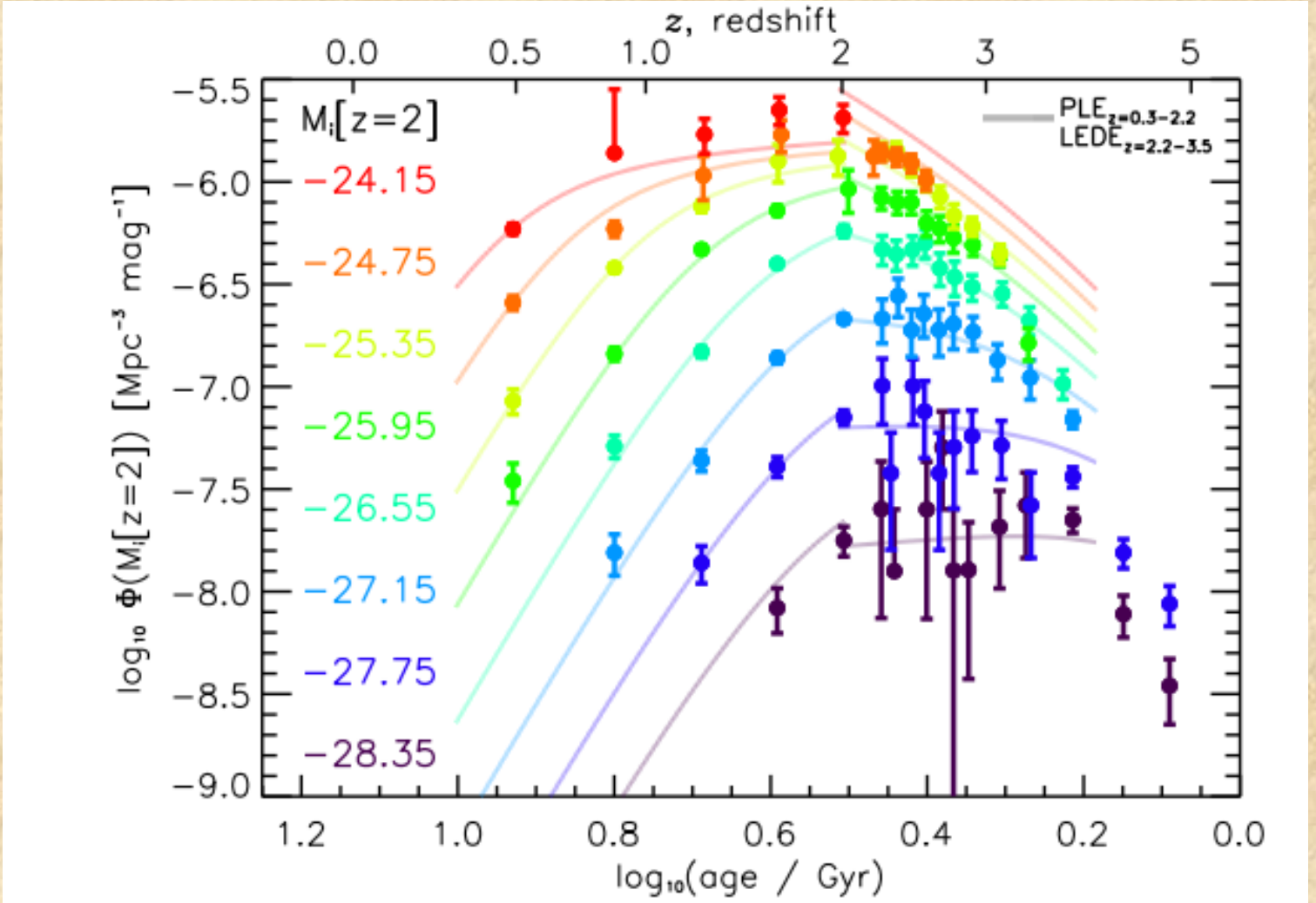
Ross et al. 2012

The luminosity function from this sample goes deep enough to see the break in the power law to z~3.5

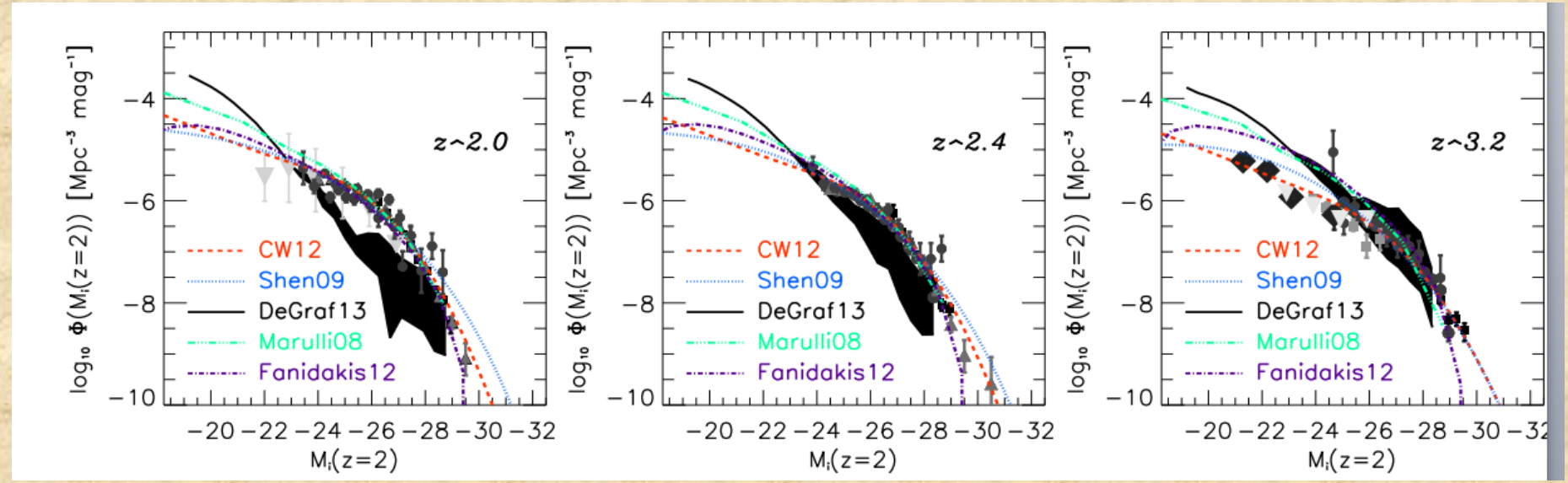


Ross et al. 2012; each panel is a different redshift range.

Cosmic downsizing: space density of lower-luminosity quasars peaks at lower redshifts

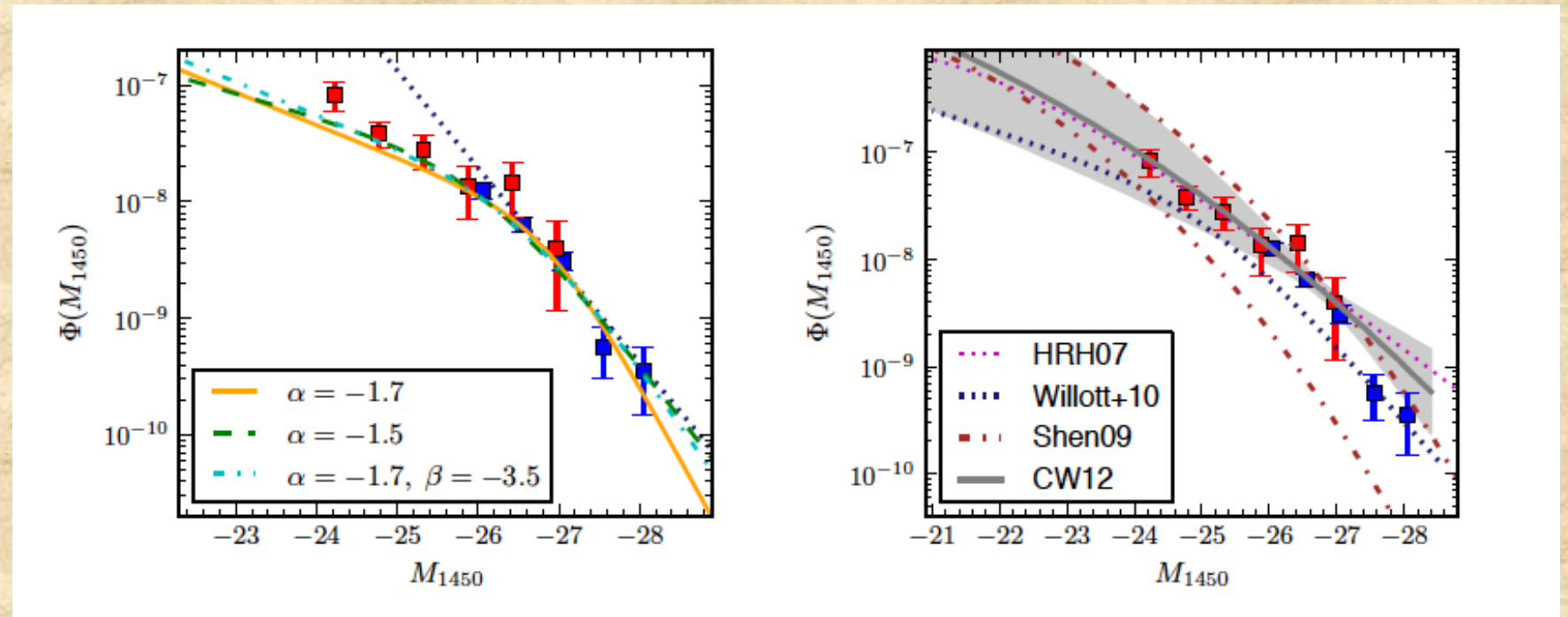


See also Ikeda et al. 2011



Ross et al. 2012: Observed LF in redshift bins, with various phenomenological and semi-analytic quasar models superposed.

A Separate Survey on Stripe 82 focussed on z~5 quasars



McGreer et al. 2012: 73 quasars with $4.7 < z < 5.1$.

Questions Ahead

- How will contamination from non-quasars and photo-z errors affect our estimation of angular clustering? Galaxy-quasar cross-correlations? Luminosity Function?
- Need more sophisticated theoretical predictions for clustering of galaxies around quasars at high z.
- First-year science: first measurement of galaxy population around high-z quasars.