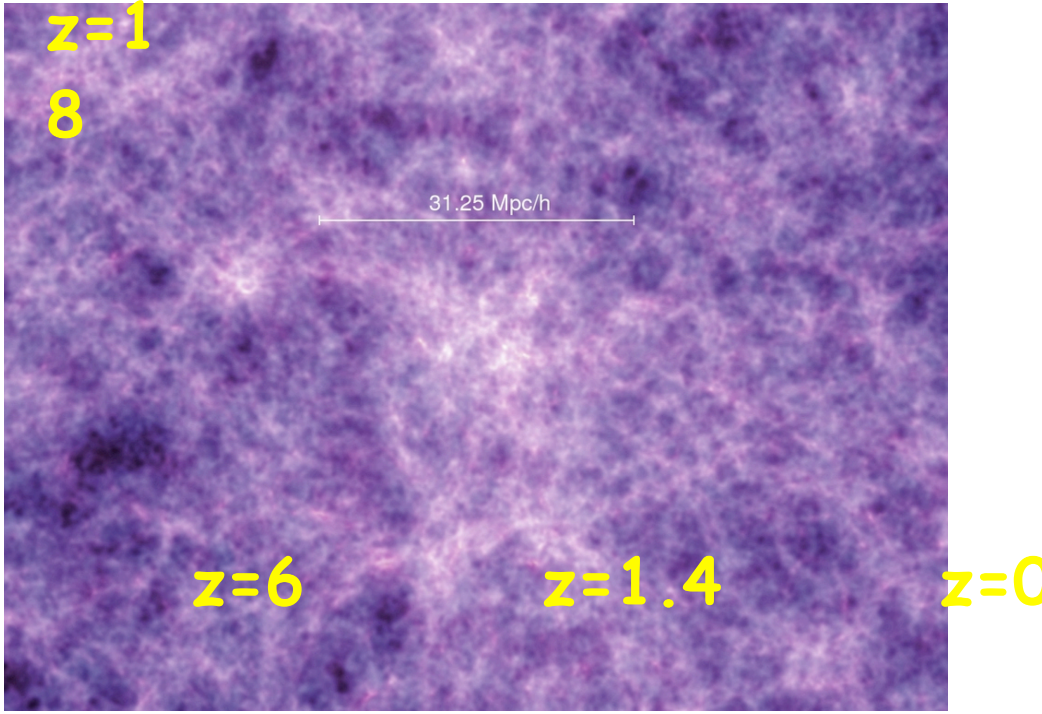
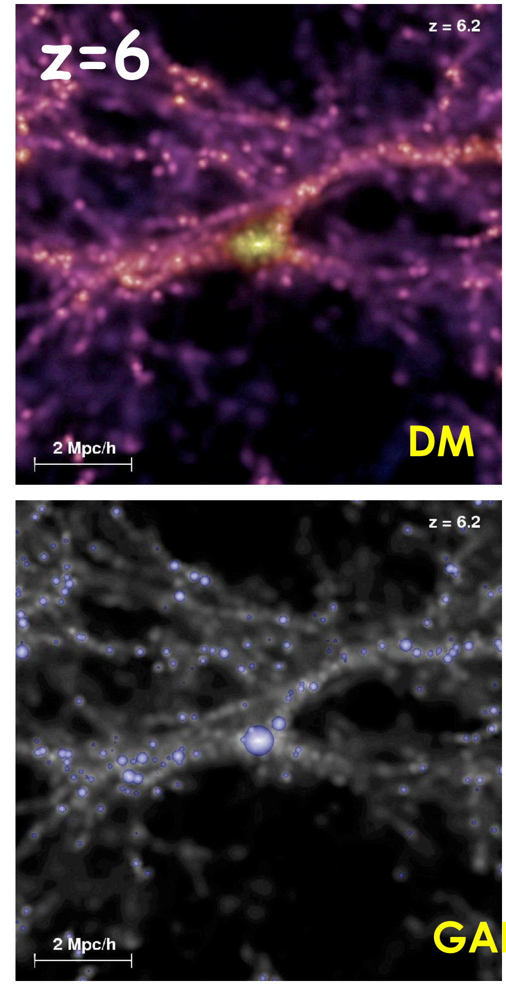
The environment of radio galaxies and quasars:
a new perspective using the Millennium Simulations





Roderik Overzier
JHU/MPA
Seeon, June 8 2007

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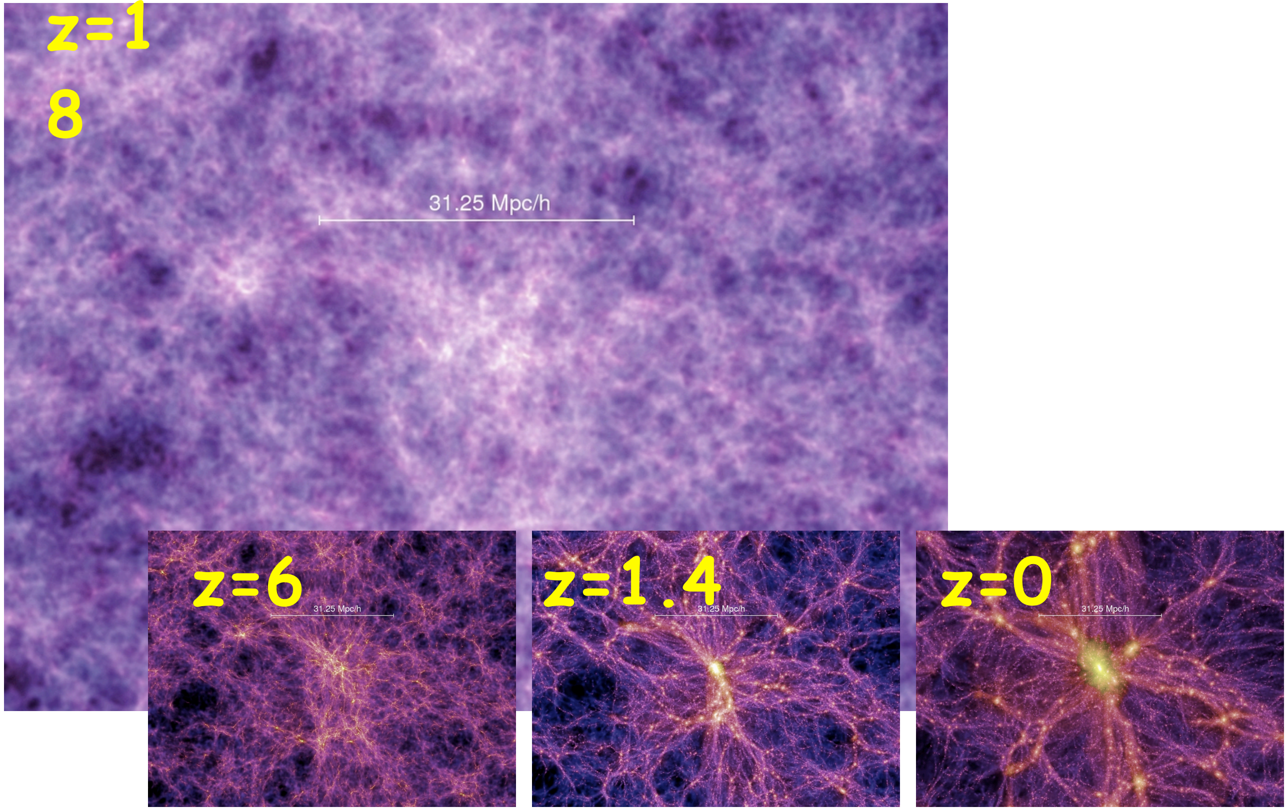

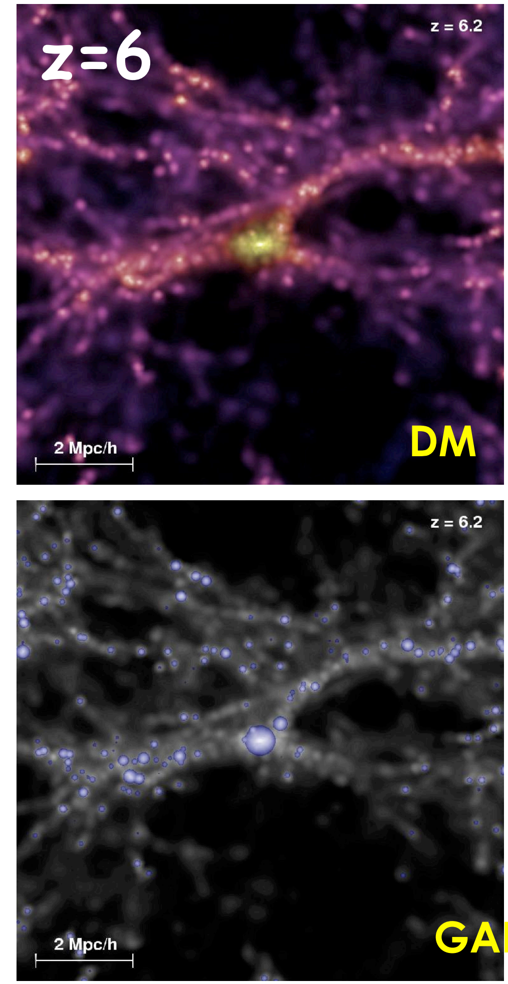

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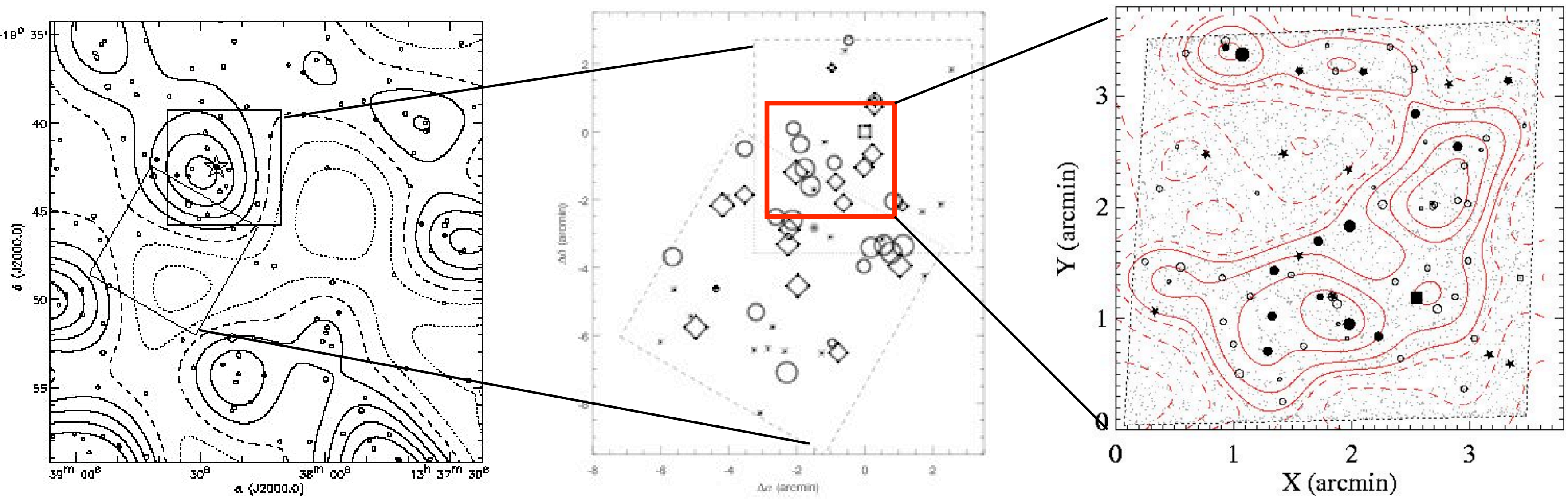
Q1: What are the richest structures present at $z>2$?

Q2: Is this the typical environment of $z>2$ radio galaxies and $z=6$ quasars?

Q3: Can we find/detect these structures?

Motivation 1 The environment of high redshift radio galaxies

TNJ1338 : "Protocluster" of Lyman break galaxies, Lya emitters and a luminous radio galaxy at z=4.1(?)



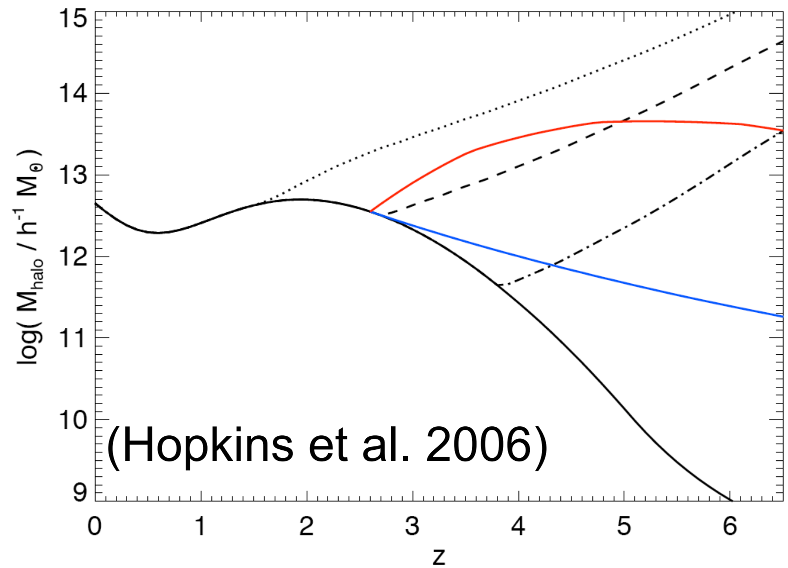
Subaru 30'x30' **VLT 2x7'x7'** **ACS 3.4'x3.4'**

Miley et al. (2004) Overzier et al. (2006) Intema et al. (2006) Venemans et al. (2002)

- How representative of HzRGs in general ?
- How representative of forming clusters in general?
- Relation to non-RG protoclusters?
- Derived cluster evolution relies on several critical assumptions that are not directly measurable (needed: bias, volume, mass overdensity, cluster mass, virialization redshift, etc.)

Motivation 2 Luminous Quasars at z~6

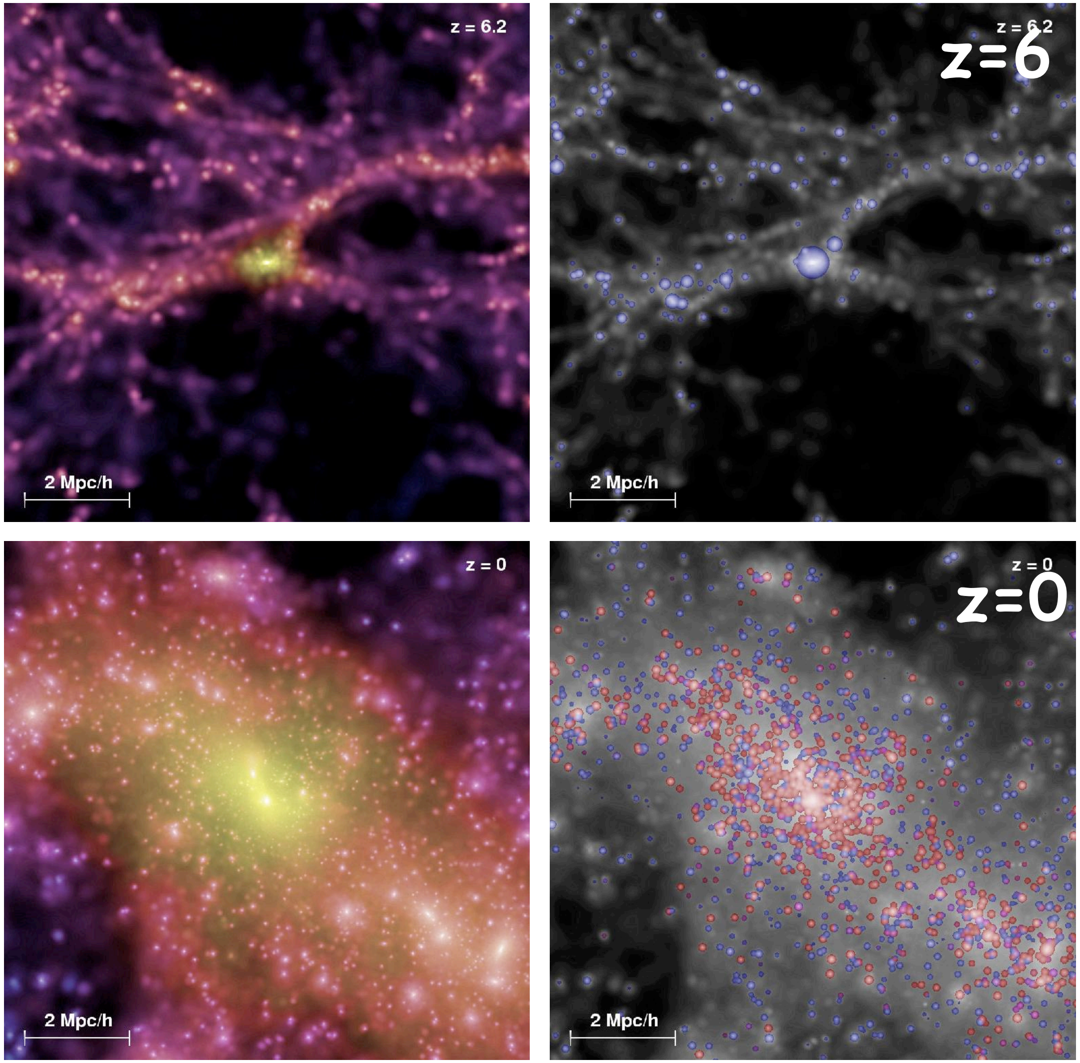
- SDSS found ~20 QSOs at z>5.7 (Fan et al. 2006)
- Near end reionization epoch
- Black hole masses of ~10^9 M_o
- Spectral properties similar to luminous quasars at low redshift
- Metallicity implies rapid formation of a massive host galaxy
- Rarest objects in early Universe (~1 Gpc^{-3})



How can we estimate the quasar host halo mass and its z=0 descendant?

- Stellar mass: quasar host galaxy unaccessible
- Clustering: not feasible with ~20 objects

"The Fate of the First Quasars"



- **z=6:**
Stellar mass = $6.8\times10^{10}\ h^{-1}M_\odot$, the largest in the entire simulation at z = 6.2

- **z=0:**
The centre of the ninth most massive cluster, $M = 1.46\times10^{15}\ h^{-1}M_\odot$

- **The quasar progenitor can be traced back to z=17**

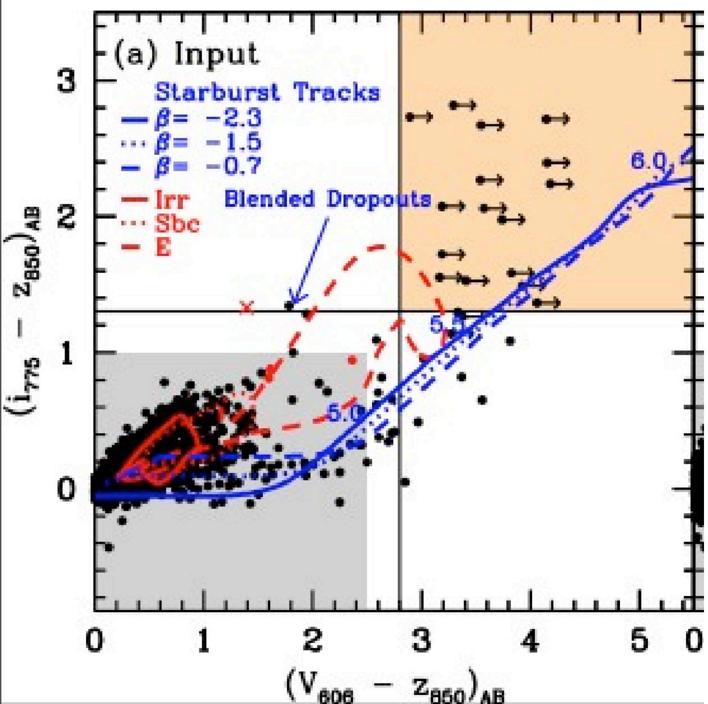
Millennium Run (V. Springel et al. 2005)

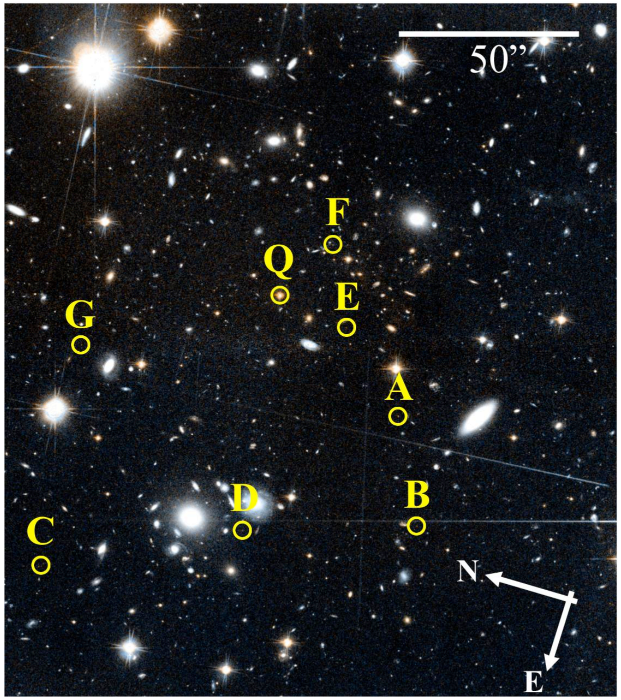
Large-scale structure at z=6 - II

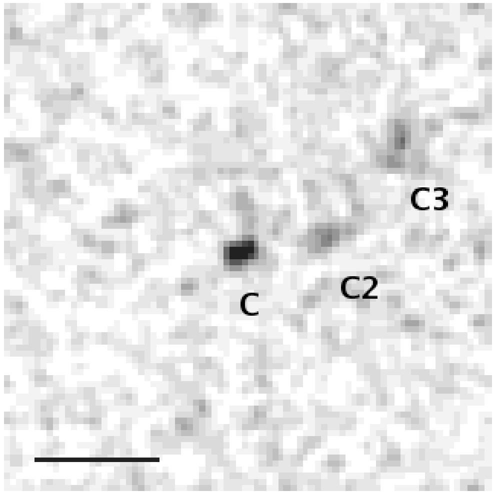
Clustering of i-dropouts near QSO SDSS J0836+0054 at z=5.8

(Zheng & ACS Team 2005)

At Mpc scale…







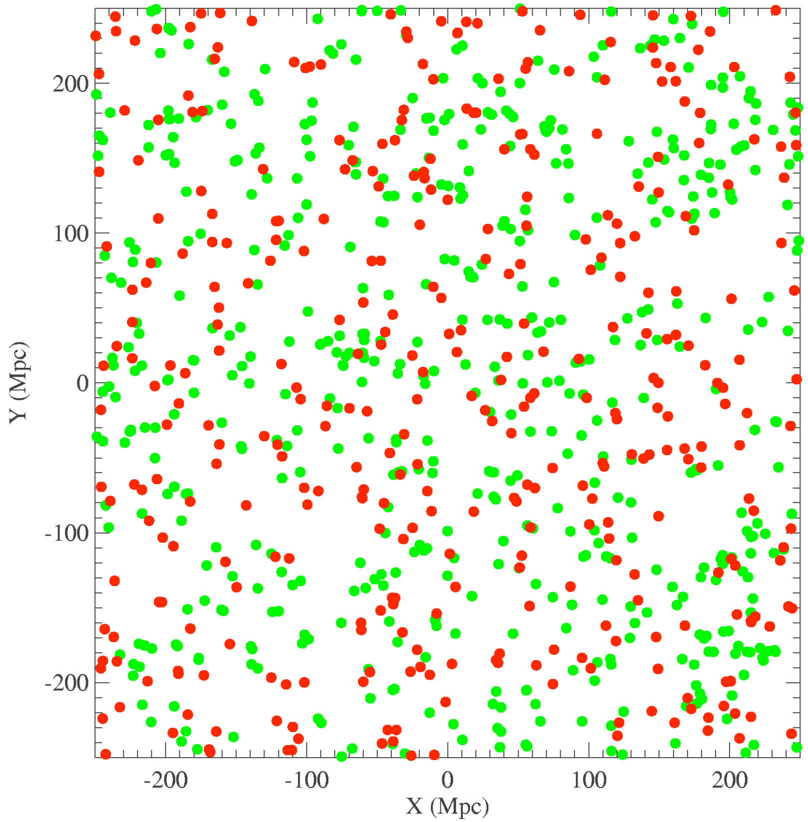
…and at kpc scale.

Similar excess found near RQ QSO SDSS J1030+0524 at z=6.3 (Stiavelli et al. 2004, Willott et al. 2005)

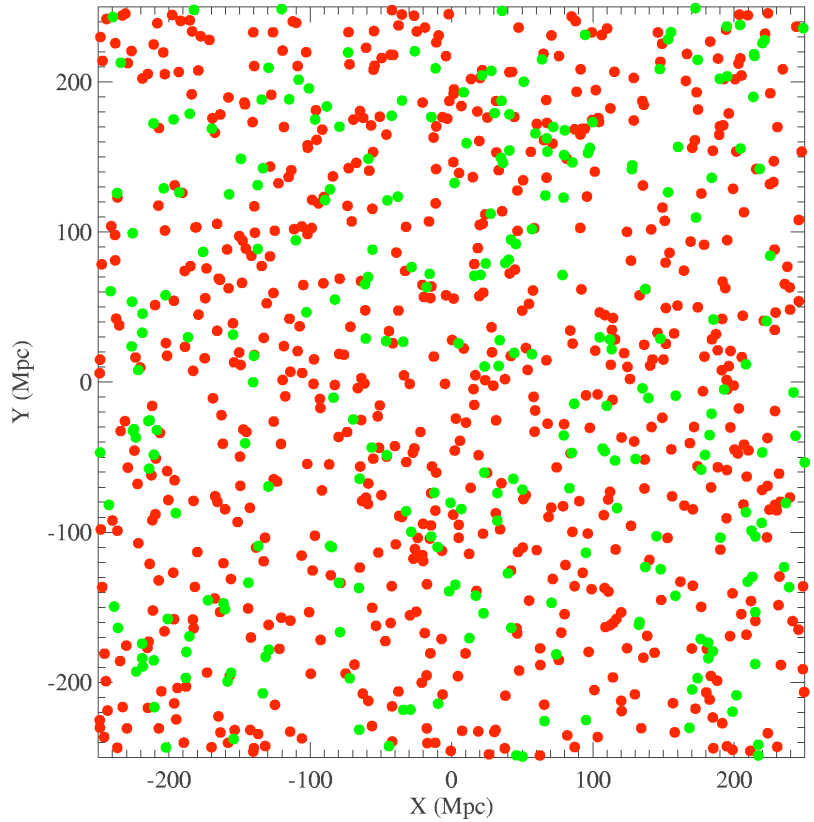
Q: Is clustering near luminous z > 5.5 quasars common?

What is the fate of the most massive halos vs. galaxies at z=6?

Top 1000 most massive z=6 halos



Top 1000 most massive z=6 galaxies

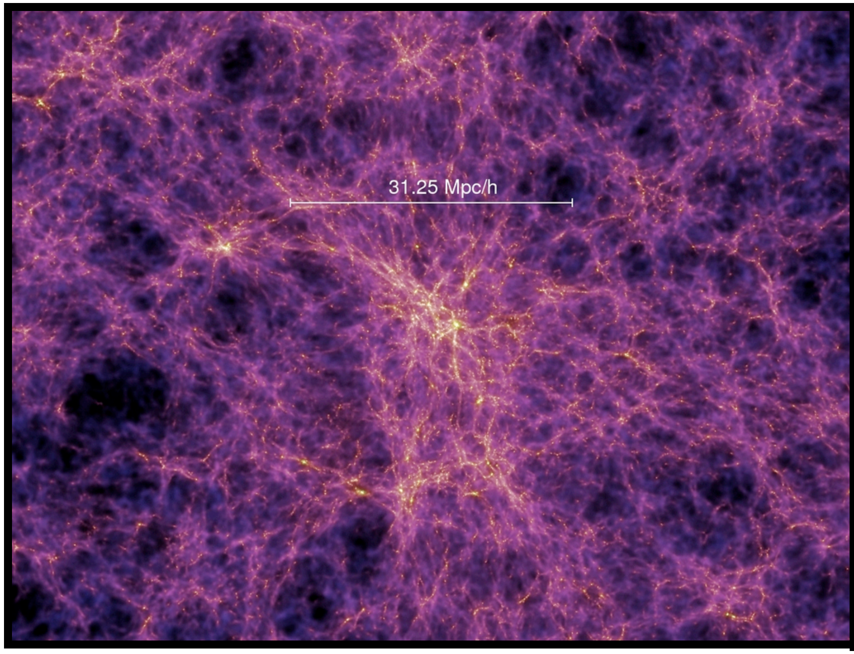


Green points: end up in $M \geq 10^{14}\ M_o$ clusters at z=0

Red points: end up in $M < 10^{14}\ M_o$ systems at z=0

~68% for halos vs. ~27% for galaxies

Fake observations of *real* simulations



Millennium Run Simulations (Springel et al. 2004)

- 10^{10} dark matter particles in a 500^3 h^{-3} Mpc^3
- 64 `snapshots' between z=127 and z=0
- Semi-analytical post-processing ("galaxy building" includes gas cooling, SF, superwind+AGN feedback, chemical enrichment)

z=0:

2832 $M \geq 10^{14}$ M_o clusters

21 $M \geq 10^{15}$ M_o clusters

Goal: model the observed properties of `quasar-like' fields at z=6/protoclusters using mock pencil beam surveys

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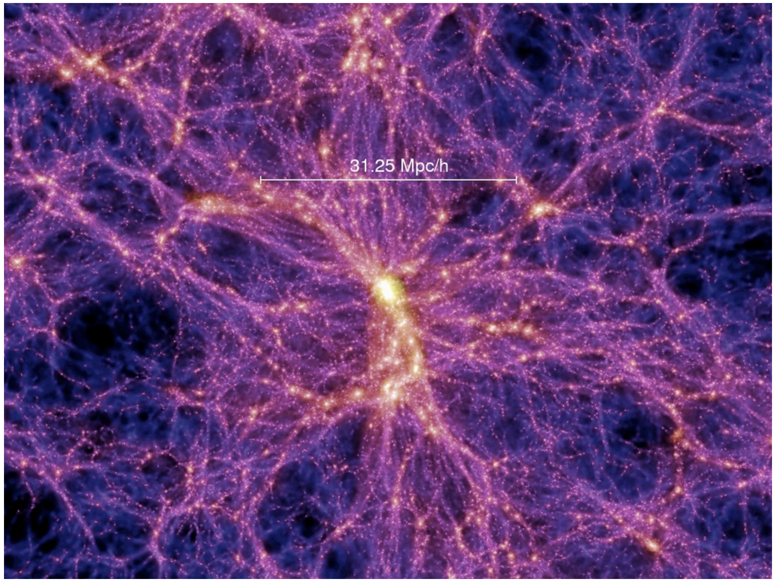
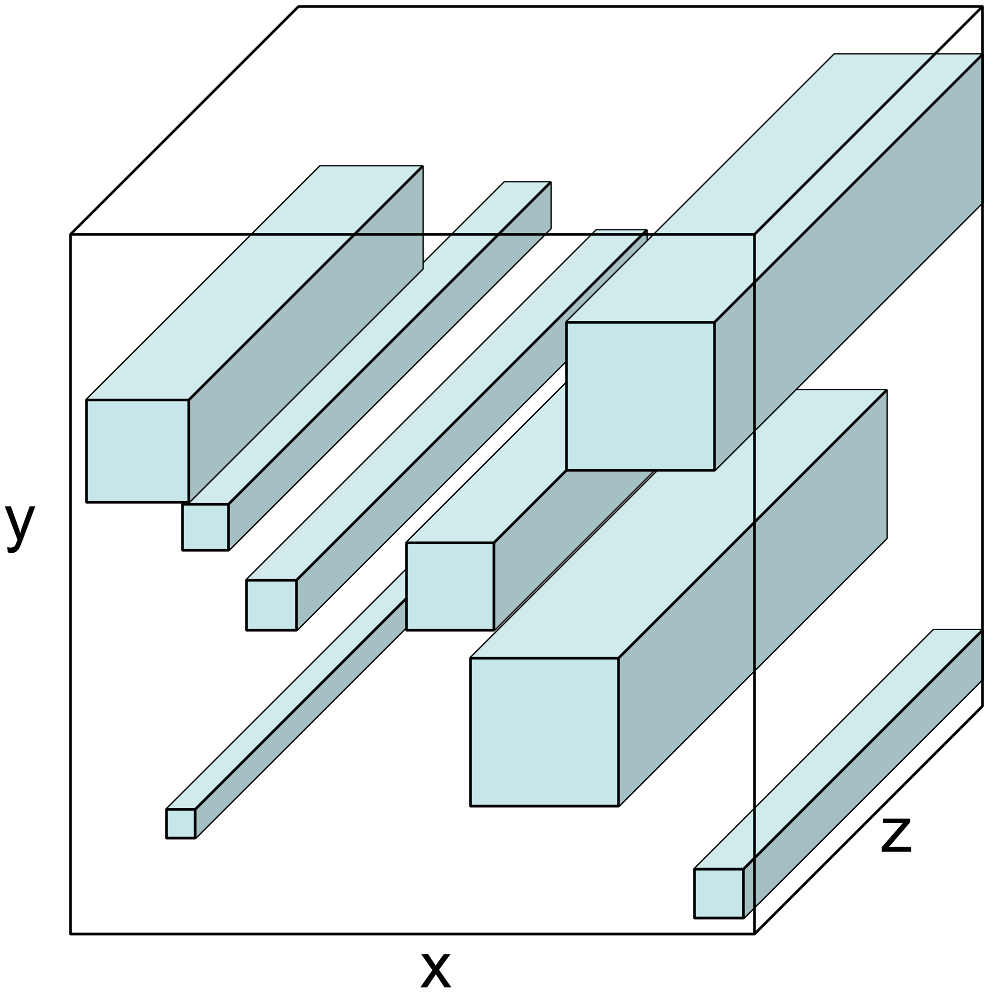


Goal: model the observed properties of `quasar-like' fields at z=6/protoclusters using mock pencil beam surveys

Construction of mock pencil beams based on the Millennium

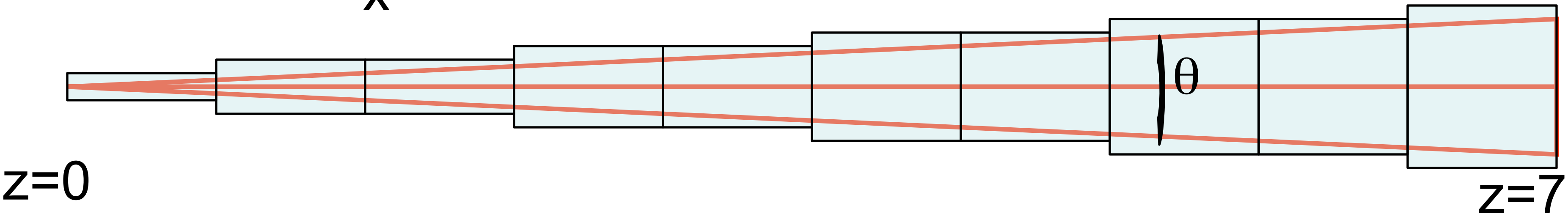


Millennium Simulations have *limited volume* ($500^3\ h^{-3}\ Mpc^3$)

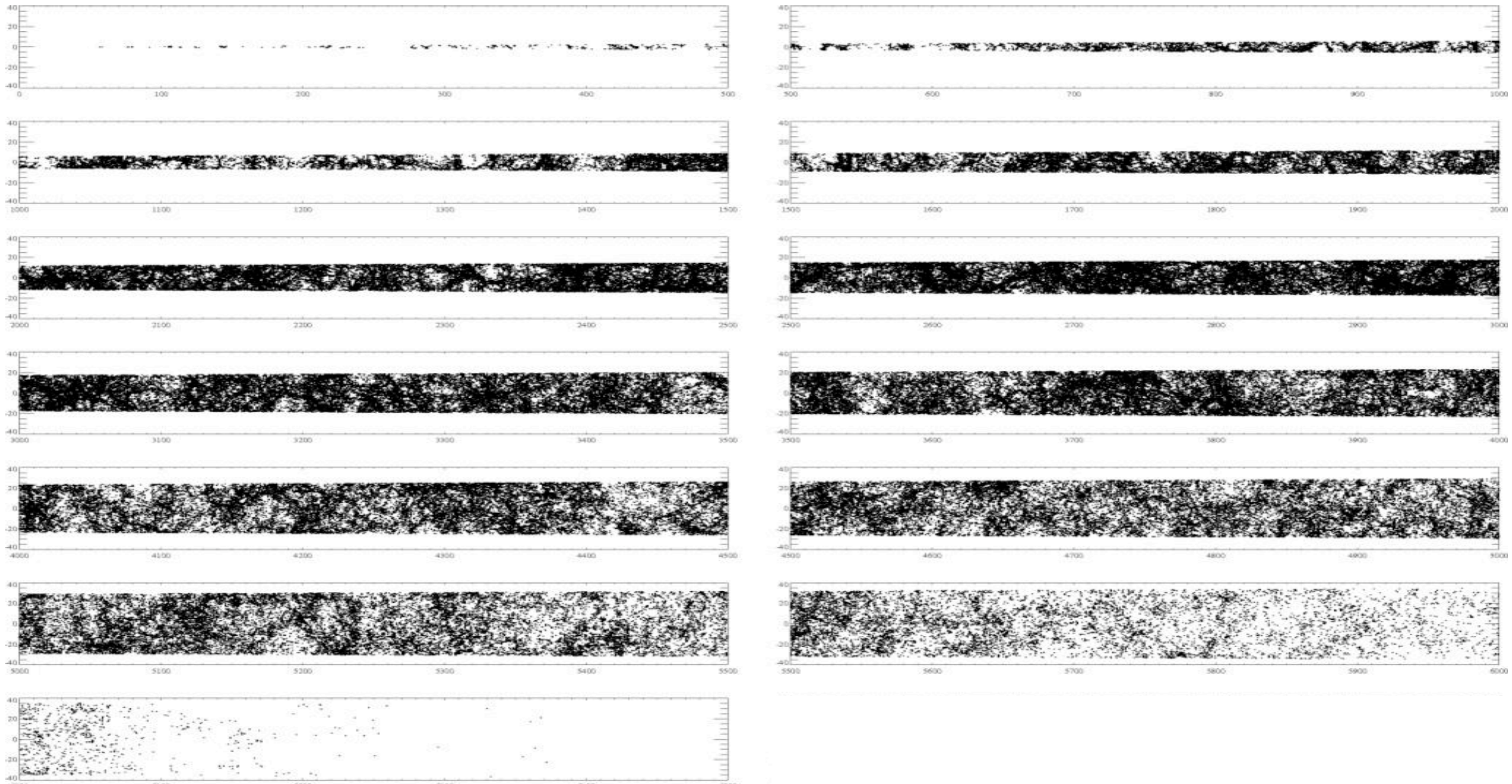
But we want to get out to distances of $D_{co,z=7}$ = 9000 Mpc (z~7) while L_{box}=500 h^{-1} Mpc (z~0.17)

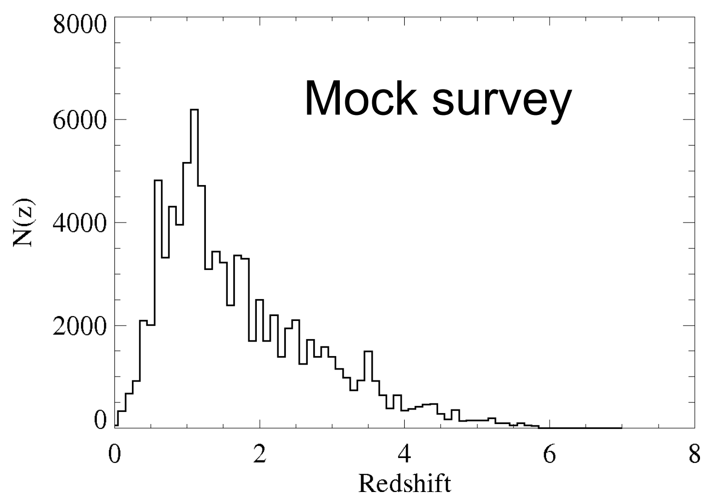
Use box replication method to create arbitrary volumes

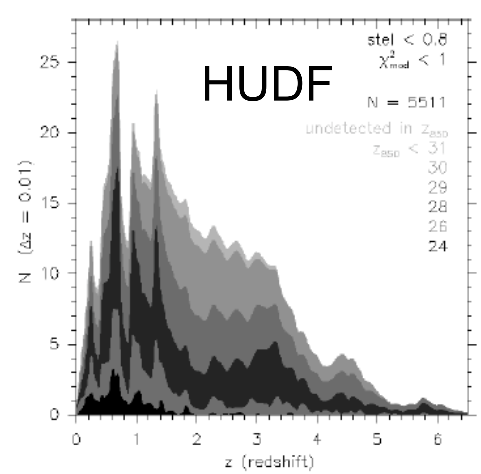
(Blaizot et al. 2003,Kitzbichler & White 2006)



Mock pencil beam (20'x20')







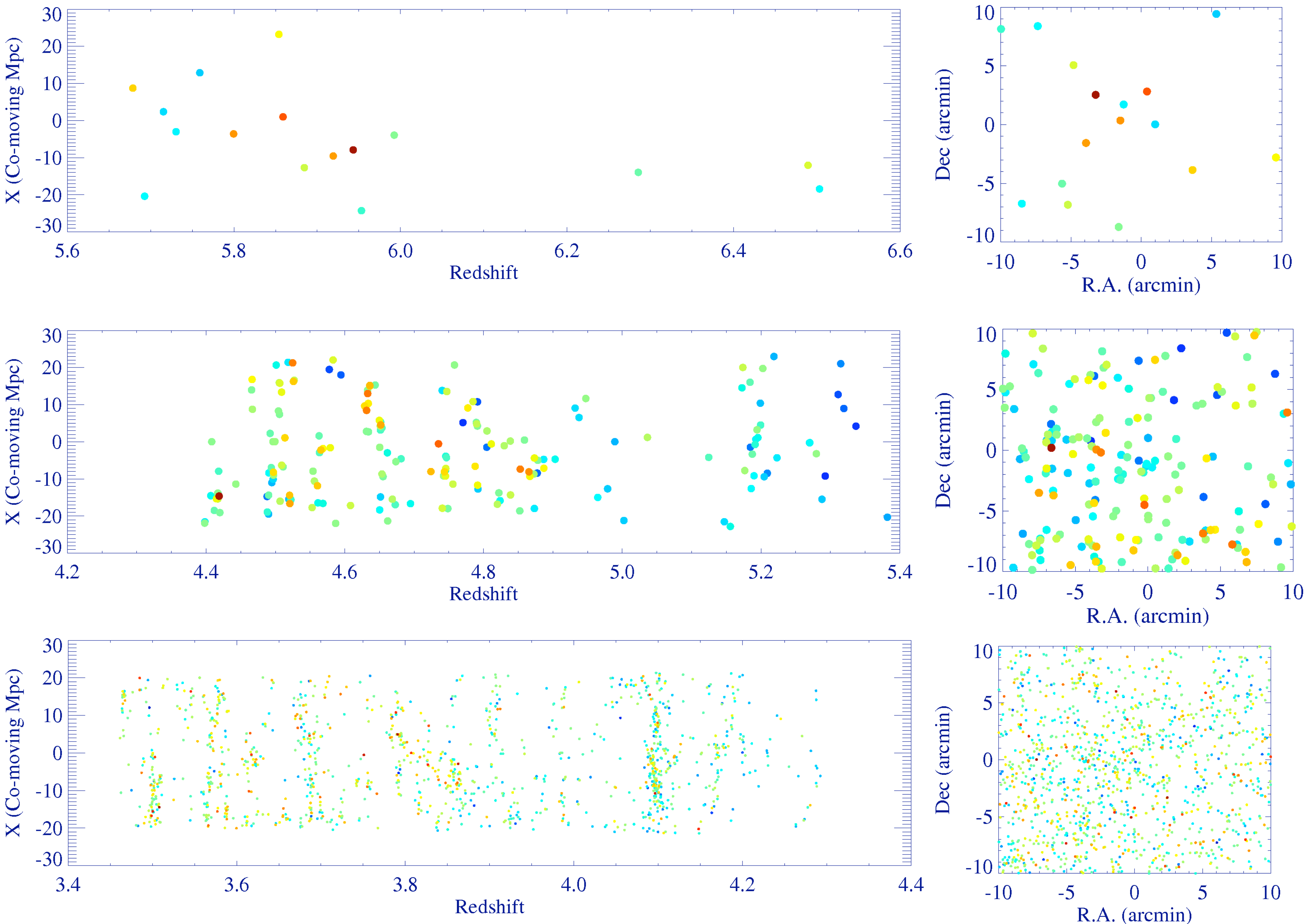
- Good match with total number counts (about factor 2)
- General match with observed redshift distributions N(m,z)

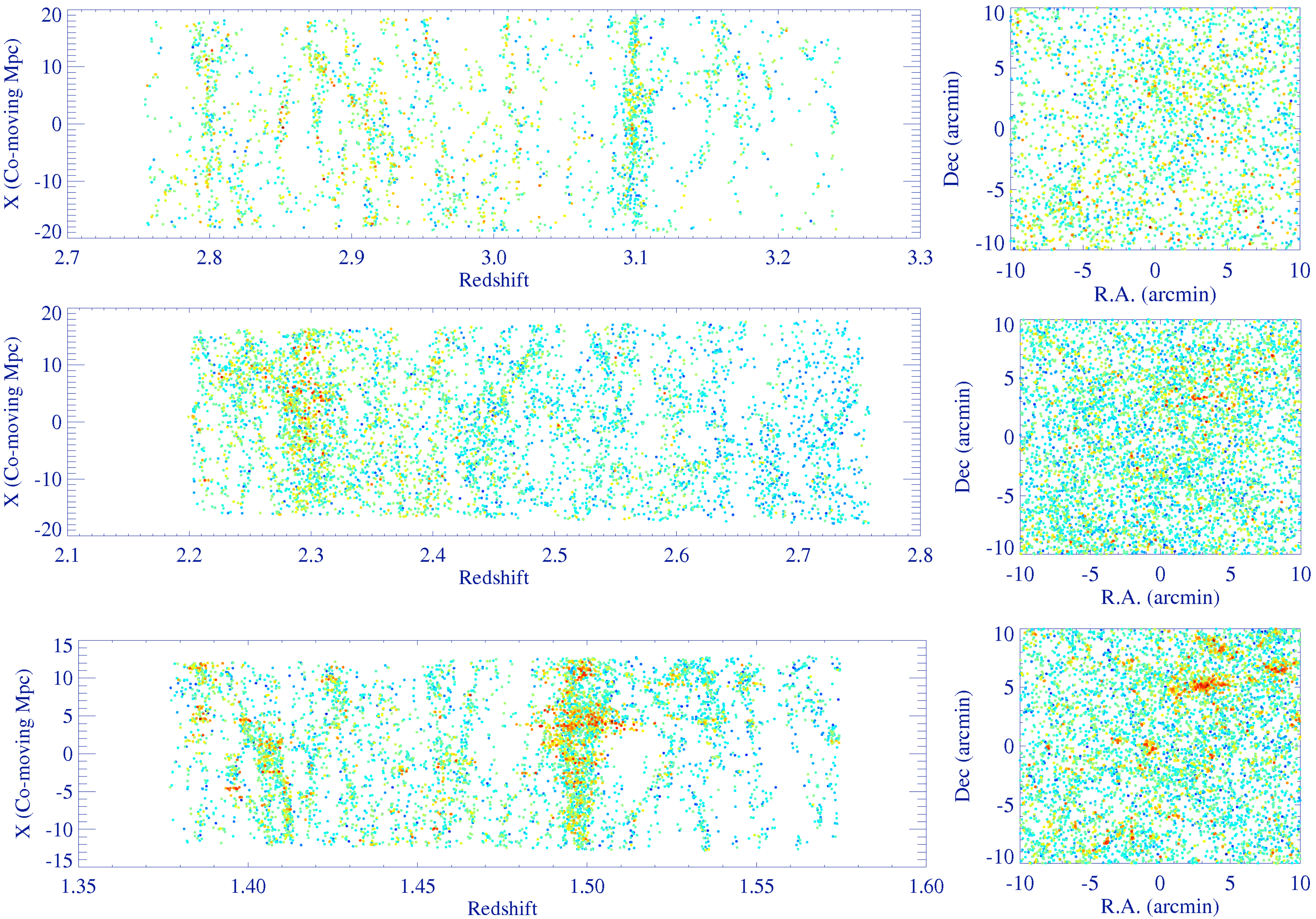
To study the observable characteristics of proto-clusters at different redshifts, we extracted:

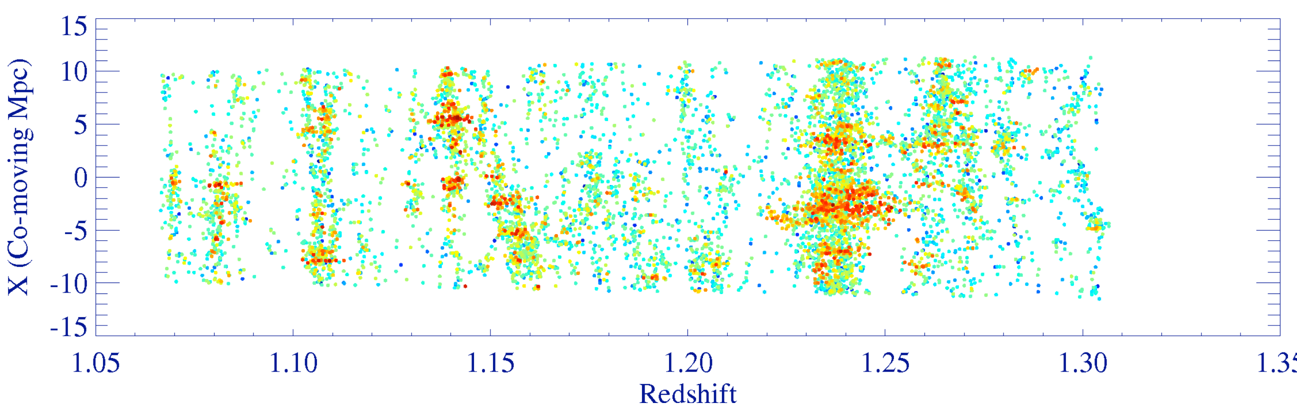
- 10 random mock lightcones of 20’x20’ or ~1 square degree in total to z=7 (GOODS survey: 320 sq. arcmin)
- Lightcones oriented at the progenitors of clusters with masses at z=0 in the range 10^{14}-10^{15} M_o
- Observe the proto-clusters at a set of redshifts:

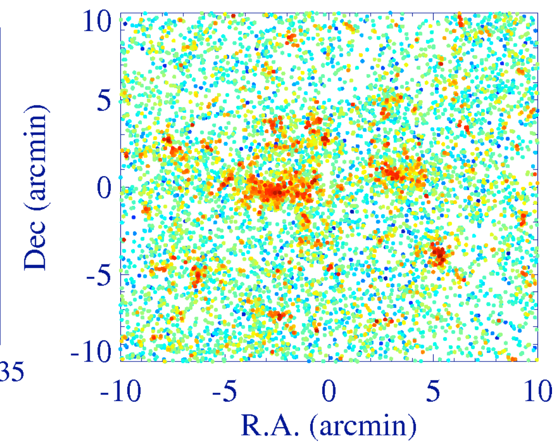
  z = [1.24, 1.5, 2.0, 2.3, 3.1, 4.1, 5.2, 5.9]
- Filters currently used u’g’r’i’z’JHK_S (and UGVR by interpolation)

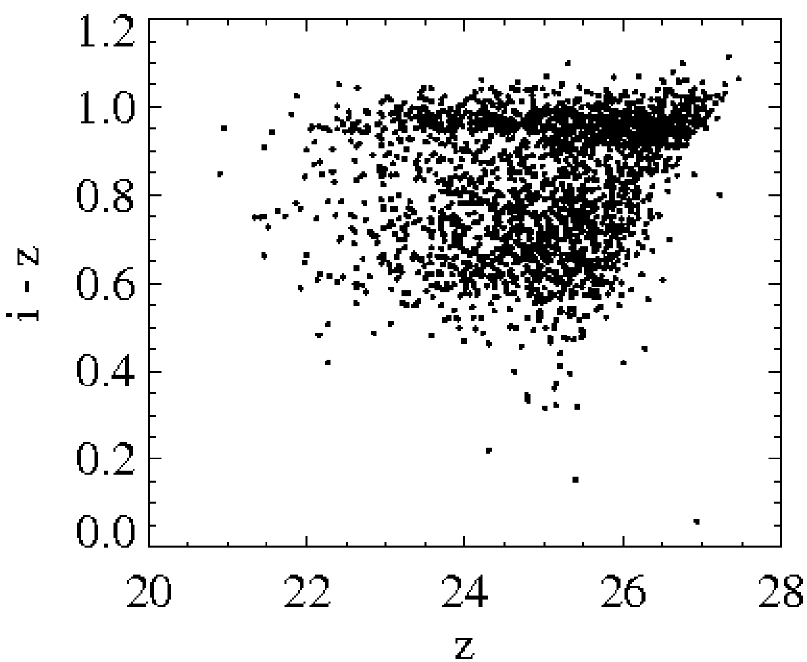
Assembly history of a $M(z=0)=10^{15}\ M_o$ cluster

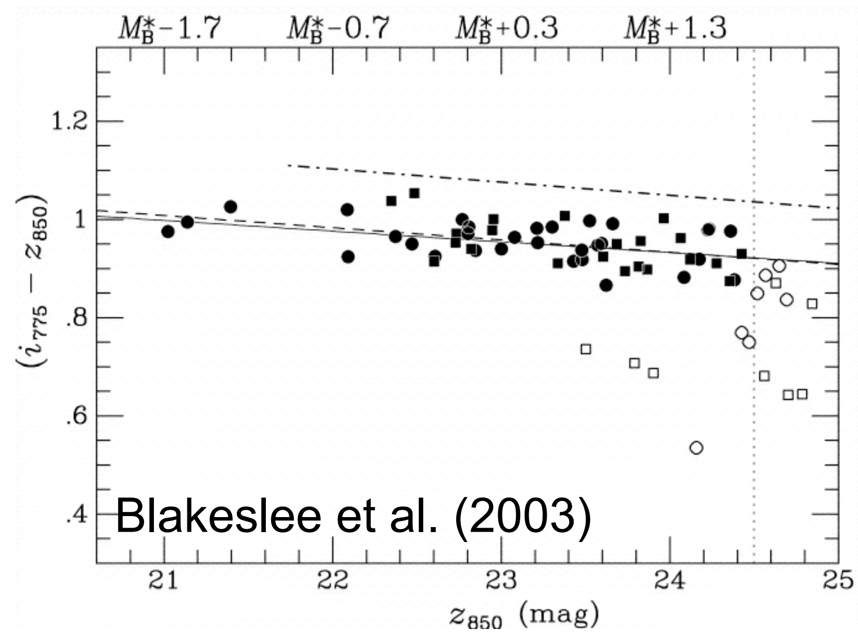



X (Co-moving Mpc)
Redshift
Dec (arcmin)
R.A. (arcmin)
X (Co-moving Mpc)
Redshift
Dec (arcmin)
R.A. (arcmin)
X (Co-moving Mpc)
Redshift
Dec (arcmin)
R.A. (arcmin)

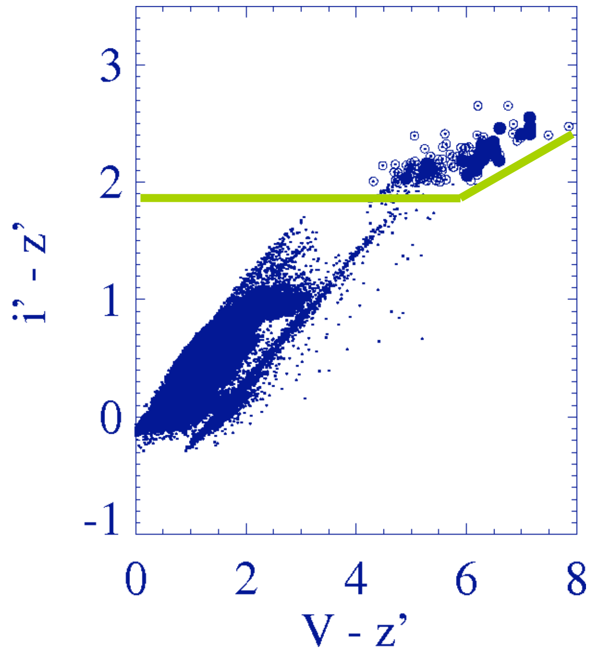

X (Co-moving Mpc)
15
10
5
0
-5
-10
-15
1.05
1.10
1.15
1.20
1.25
1.30
1.35
Redshift

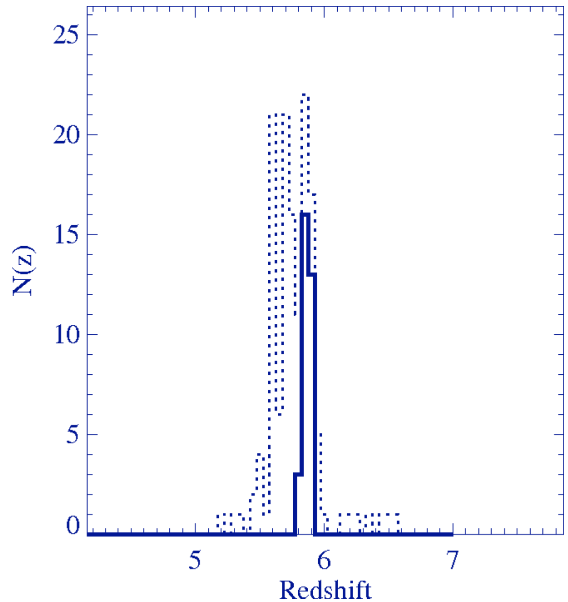

Dec (arcmin)
10
5
0
-5
-10
-10
-5
0
5
10
R.A. (arcmin)

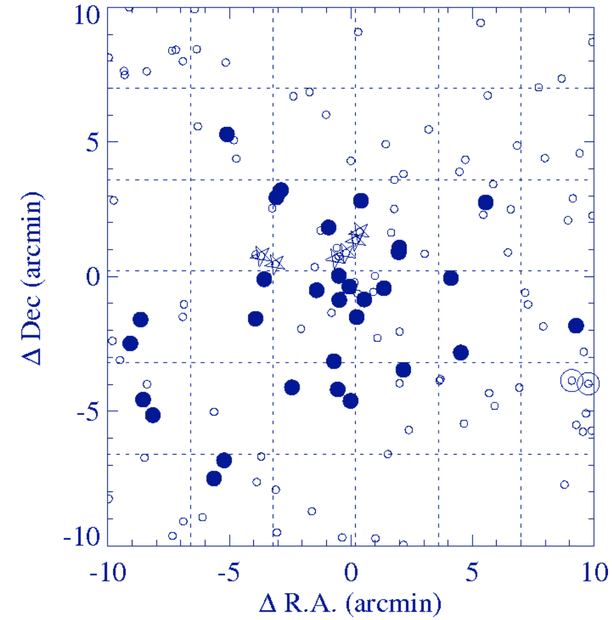

i - z
1.2
1.0
0.8
0.6
0.4
0.2
0.0
20
22
24
26
28
z

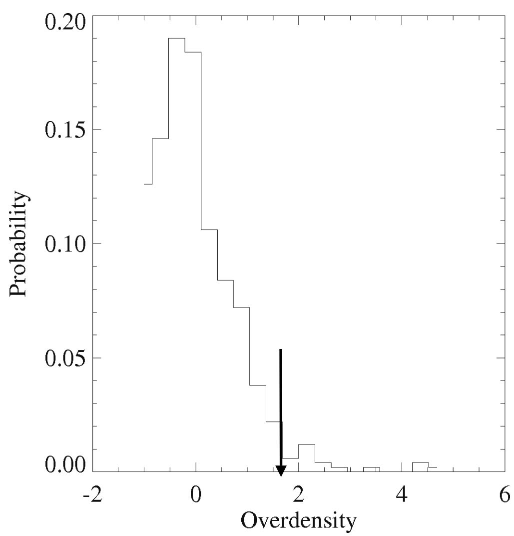

$M_B^*-1.7$
$M_B^*-0.7$
$M_B^*+0.3$
$M_B^*+1.3$
$(i_{775} - z_{850})$
1.2
1
.8
.6
.4
21
22
23
24
25
z_{850} (mag)
Blakeslee et al. (2003)

Protocluster galaxies at z~5.9 with i-dropout selection



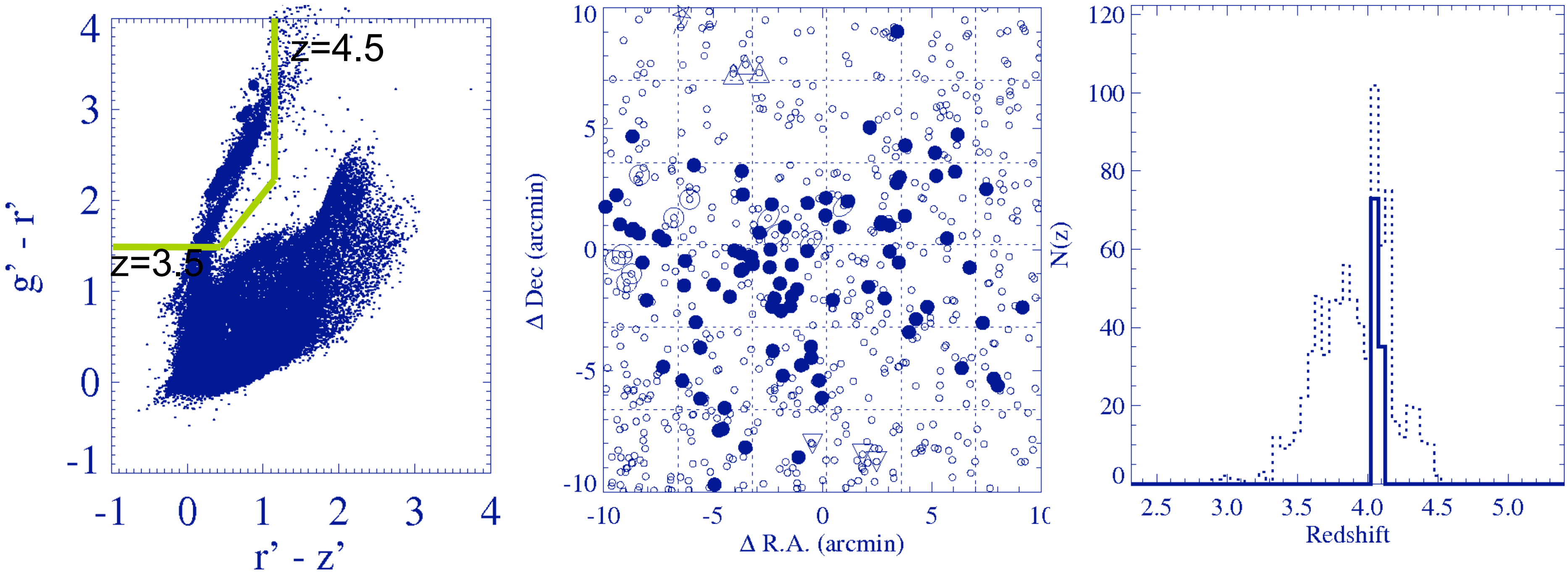




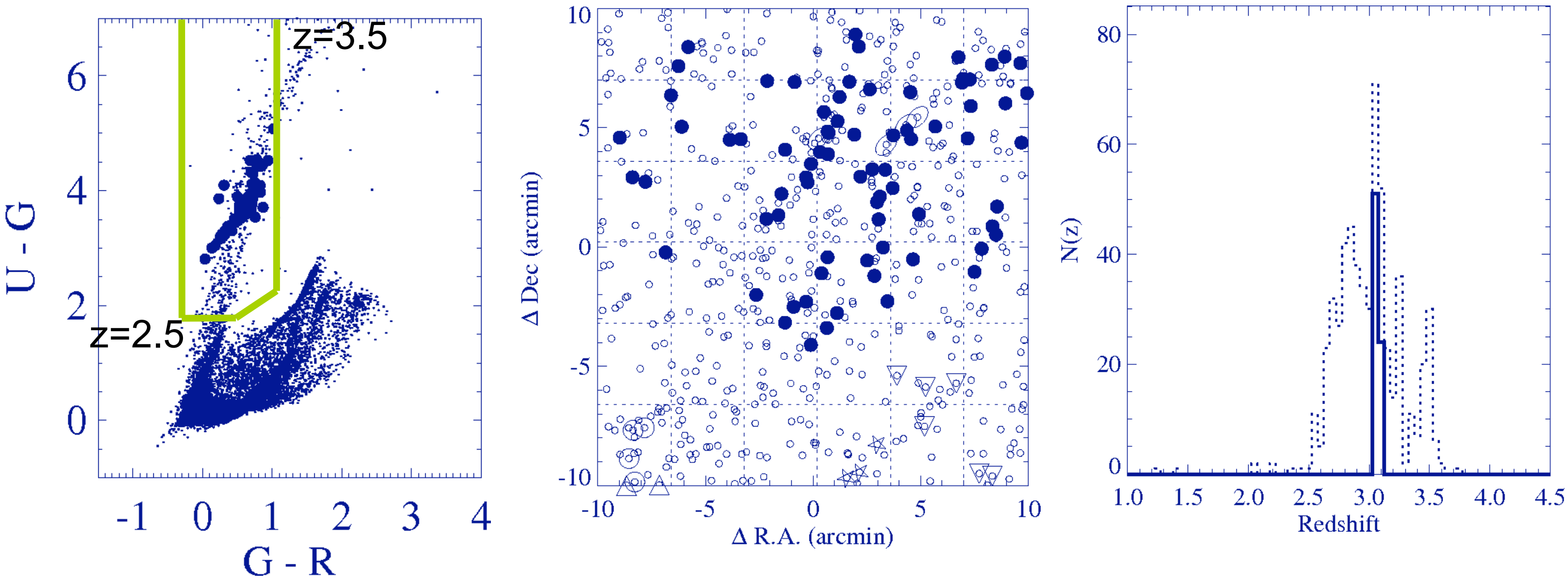


- Probability of finding such a structure (z < 27 mag) by chance is ~3%
- But you would have to show that its at the right redshift!

Protocluster galaxies at z~4.1 with g-dropout selection



Protocluster galaxies at z~3.1 with U-dropout selection



CDM: BCG assembly at z>2 likely far from complete:

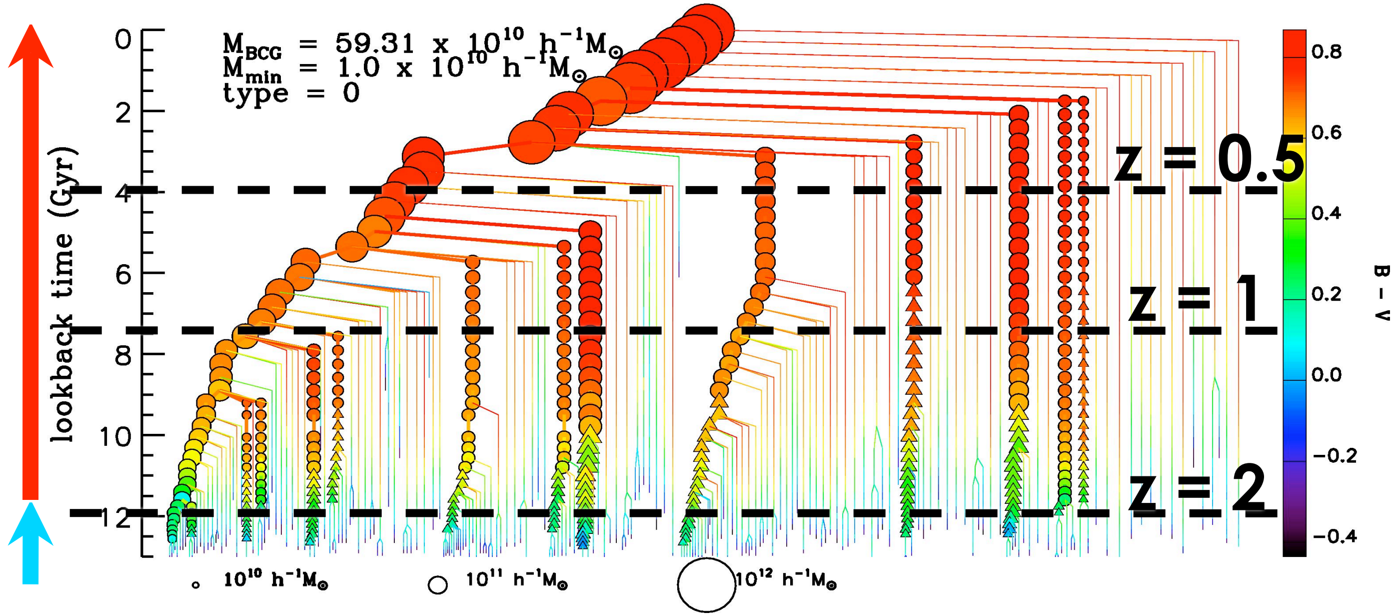
No SF

Merger

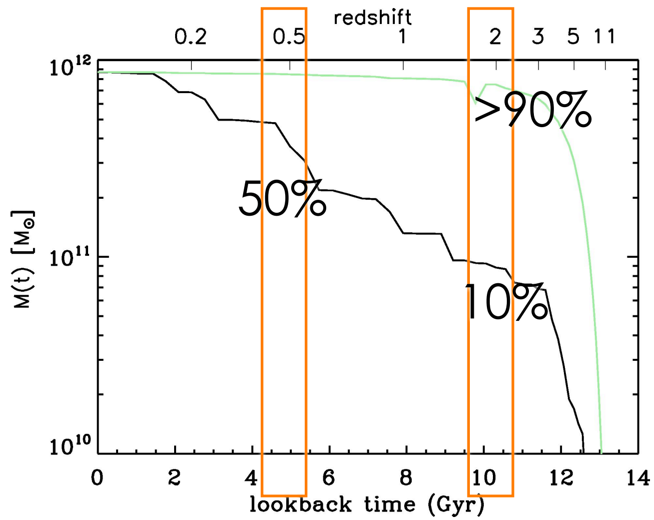
accretion

quenching

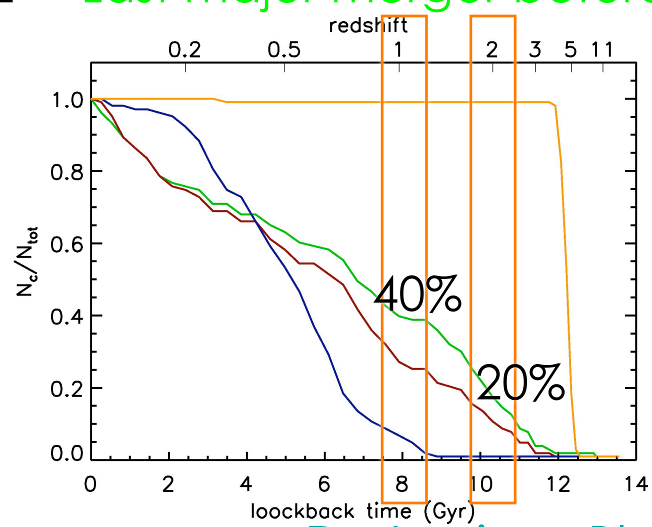
SF



Mass assembled/formed at z



Last major merger before z



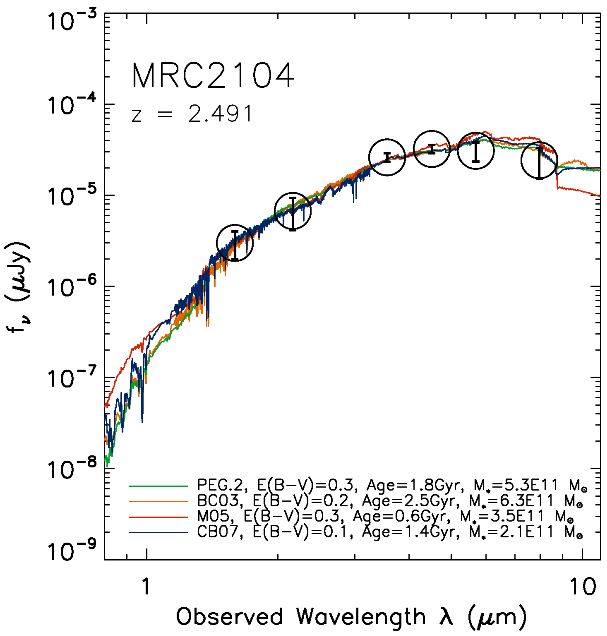
De Lucia & Blaizot (2006)

Are mass estimates of (certain) HzRGs too high?

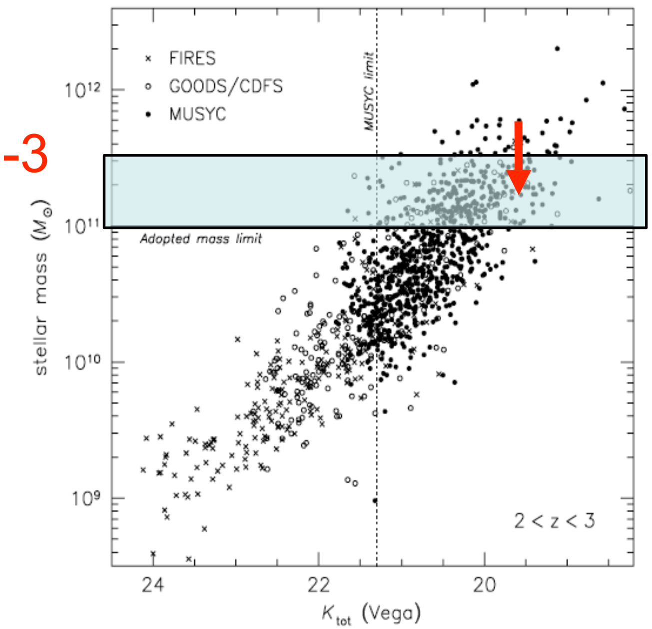
1) Millennium simulations contain 3000 clusters, ~20 superclusters
However, none of these contain a 10^{12} M_o galaxy at z>2

2) The number density of radio galaxies is $\sim10^{-(5\text{-}6)}$ Mpc^{-3}, indicative of fairly normal clusters

Perhaps `solved' in the near future by better SED libraries?



M_* reduces by factor ~2-3



Van Dokkum et al. (2006)

See talk by Alessandro (Rettura et al., in prep.)

Conclusions

Machinery is in place to construct fake protocluster surveys from real simulations

- useful for testing evolutionary scenarios of hi-z RGs/QSOs
- useful for predictions given observational constraints
- useful for choosing best observing strategy
- future surveys (JWST/Herschel/LOFAR/SZ/…)