Identifying evolving massive structures at z~5 with Lyman Break Galaxies

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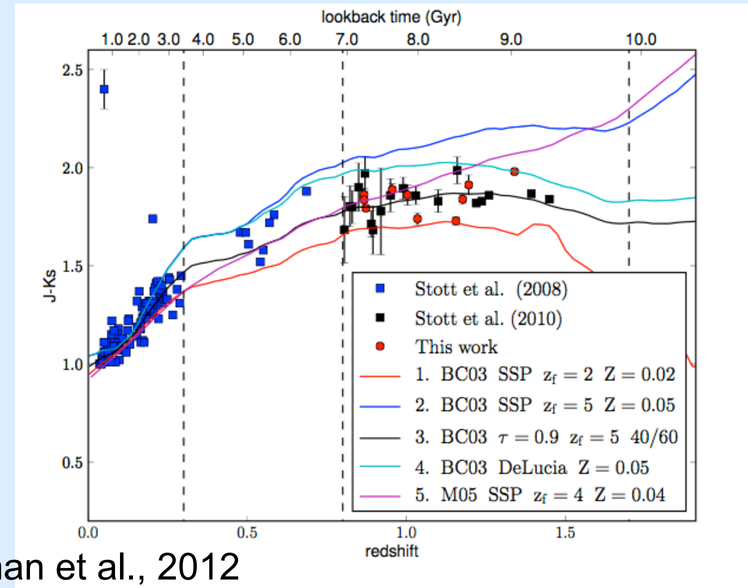
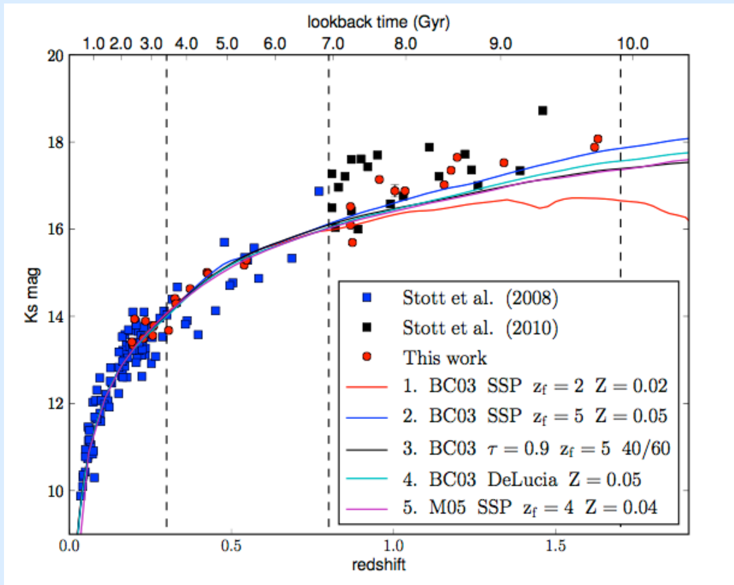
Infant groups and clusters?

- What is the best way of observationally identifying galaxy groups and clusters undergoing their earliest evolutionary stages?
- We know from observations of clusters out to z<1.5 that a significant fraction of their galaxy populations appeared to have formed their stars at z~3 or above, particularly the most massive galaxies.





Lidman et al., 2012

Infant groups and clusters?

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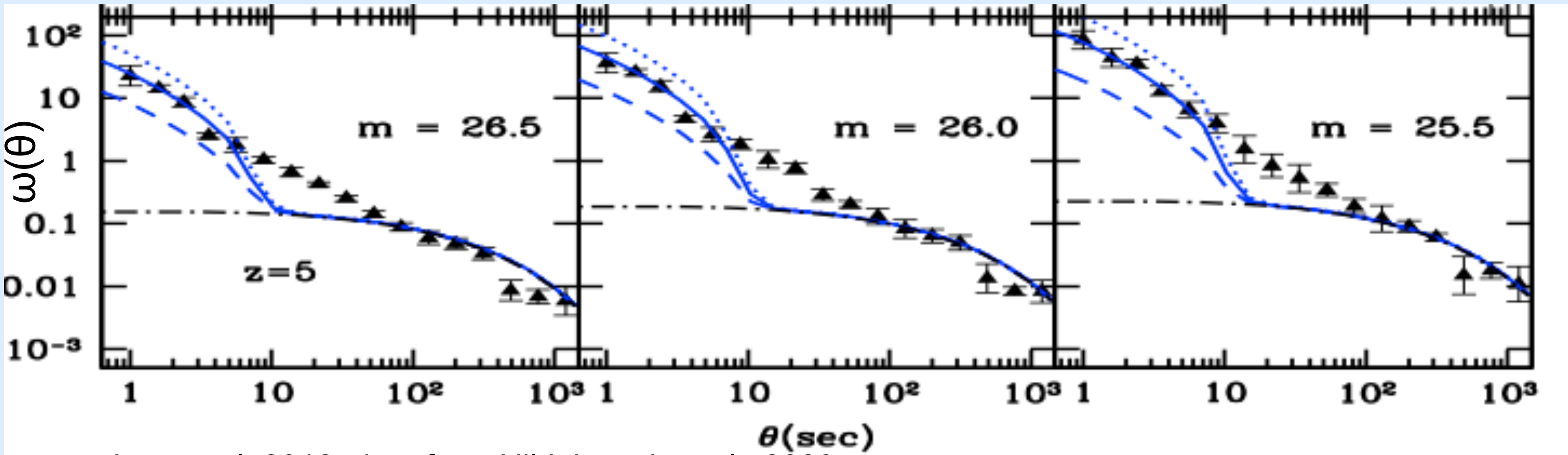
- To identify early clustering at high redshift, we need a tracer population with a high enough surface/volume density that they can be seen to cluster on Mpc scales and they must in some way be a "typical" population at this redshift.
- Currently, the best such population for this are Lyman break galaxies (LBGs).
- At z~5 LBGs are $M_*=10^9-10^{10}M_\odot$ galaxies with SFRs of ~10-few tens Msun/year. Little dust obscuration ($0<Av<0.3$) & sub-solar ($Z\sim0.1-0.3Z_\odot$) metallicity .
- To depths of IAB~26 they have a surface density of 1 per few arcmin^2 (depends whether spectroscopically confirmed or not) and volume density of ~3×10^{-4}Mpc^{-3}

LBGs as tracers of structure

- LBGs can be used to trace structures via photometry of through spectroscopy.
- With photometry the LBGs have been used to probe galaxy bias and hosting halo mass/halo occupation number through a comparison of the angular correlation functions of the observed LBGs and catalogues of simulated DM halos.



Jose et al. 2012, data from Hildebrandt et al., 2009

LBGs as tracers of structure

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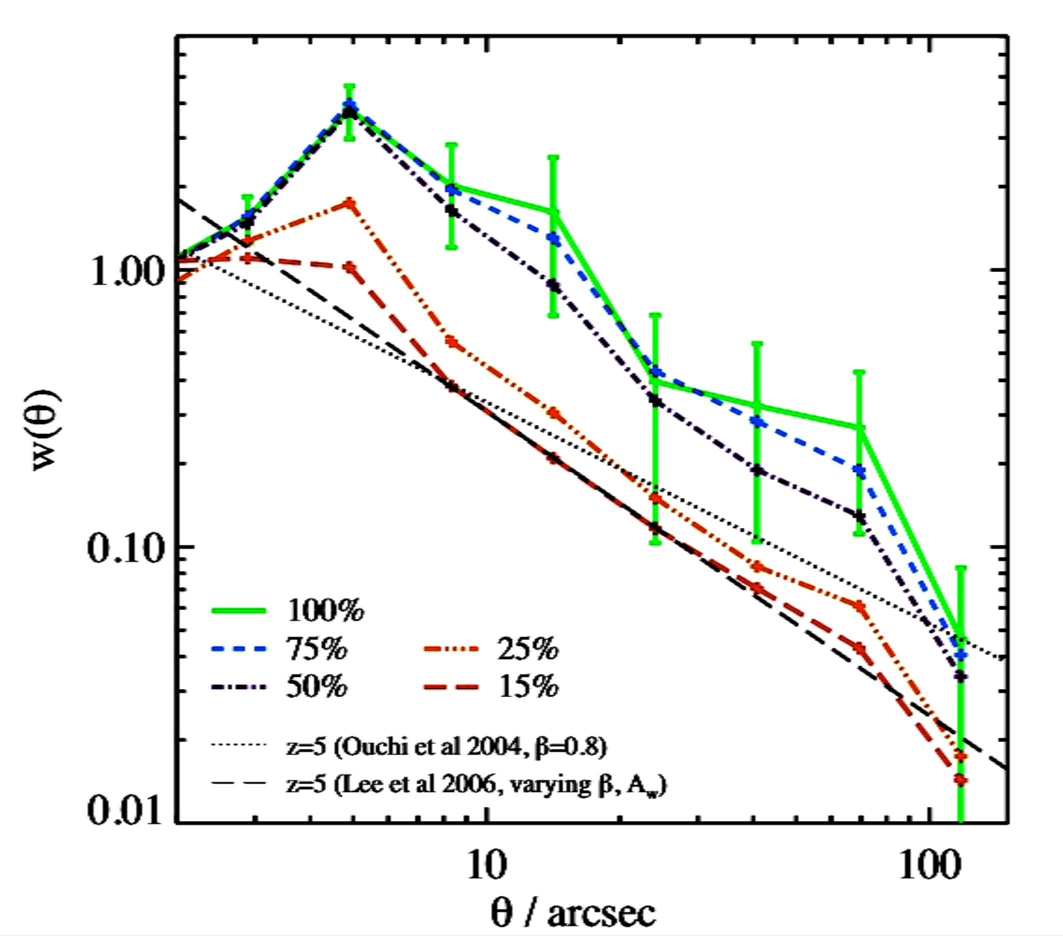
- Care must be taken when interpreting photometric data. Samples can be (are!) contaminated by interlopers that are themselves strongly clustered eg at z~5 contaminants include ERO-like intermediate redshift spheroids. Models used might fit well, but might be too simplistic (eg assumption on what parameters are important).



Stanway et al 2008

LBGs as tracers of structure

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- With spectroscopy individual structures can be isolated and identified. At these redshifts, sample sizes and volumes probed will be considerably smaller than with photometry: spectroscopy samples typically cover few hundred arcmin^2, photometric samples can cover degree scales.

The ESO Remote Galaxy Survey

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We carried out ERGS as an ESO LP in 2006-2010. A FORS2 spectroscopic survey for LBGs spread over multiple fields. We added in other fields from an earlier survey with the same selection function.

Together we observed 14 fields, each of ~45 arcmin^2.
We have confirmed over 90 z~5 and above galaxies selected to have $I_{AB}<26.3$ from data sets with 3σ point-source limits of
V=28.1, R=28.1, I=27.2, z= 26.0 J=24.6, K=23.8, all AB

Four fields are contiguous on sky, rest scattered over sky to defeat cosmic variance.

The ESO Remote Galaxy Survey

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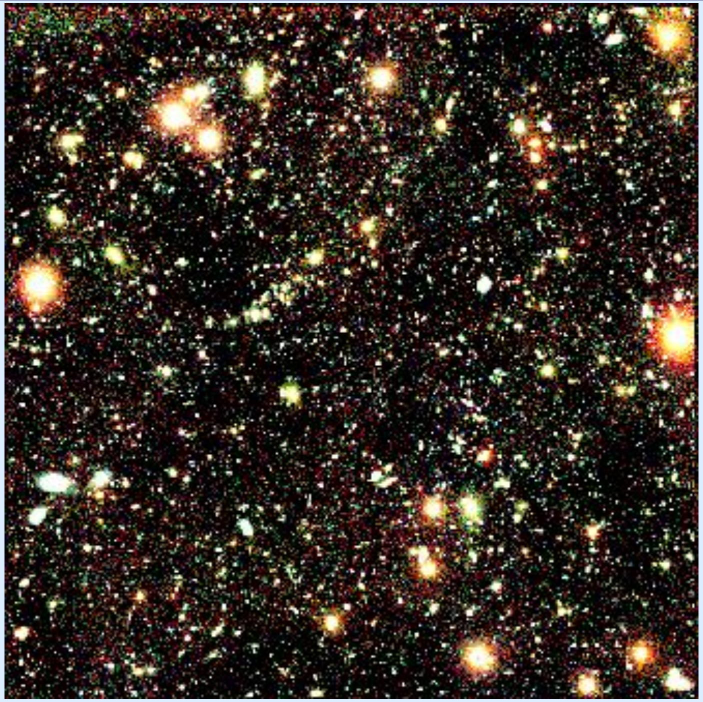


- Better than 80% spectroscopic completeness for dropout candidates (i.e. 80% of best candidates end up on mask).

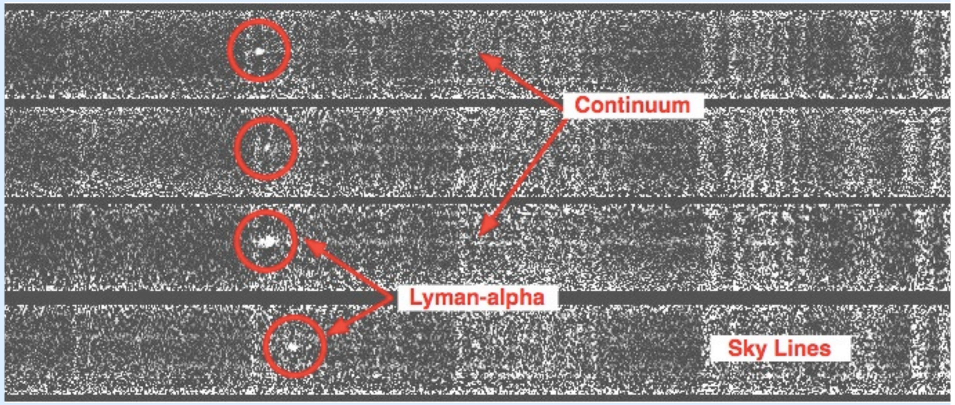
- Reasonable S/N on continuum

- In the 10 widely-scattered fields: 72 confirmed redshifts at 4.4<z<6.4 including at z<5.6:

  - 38 Lyman-α emission lines

  - 32 redshifts determined from breaks

  Not biassed towards/against either type of source.



3D clustering: tracing z~5 structure

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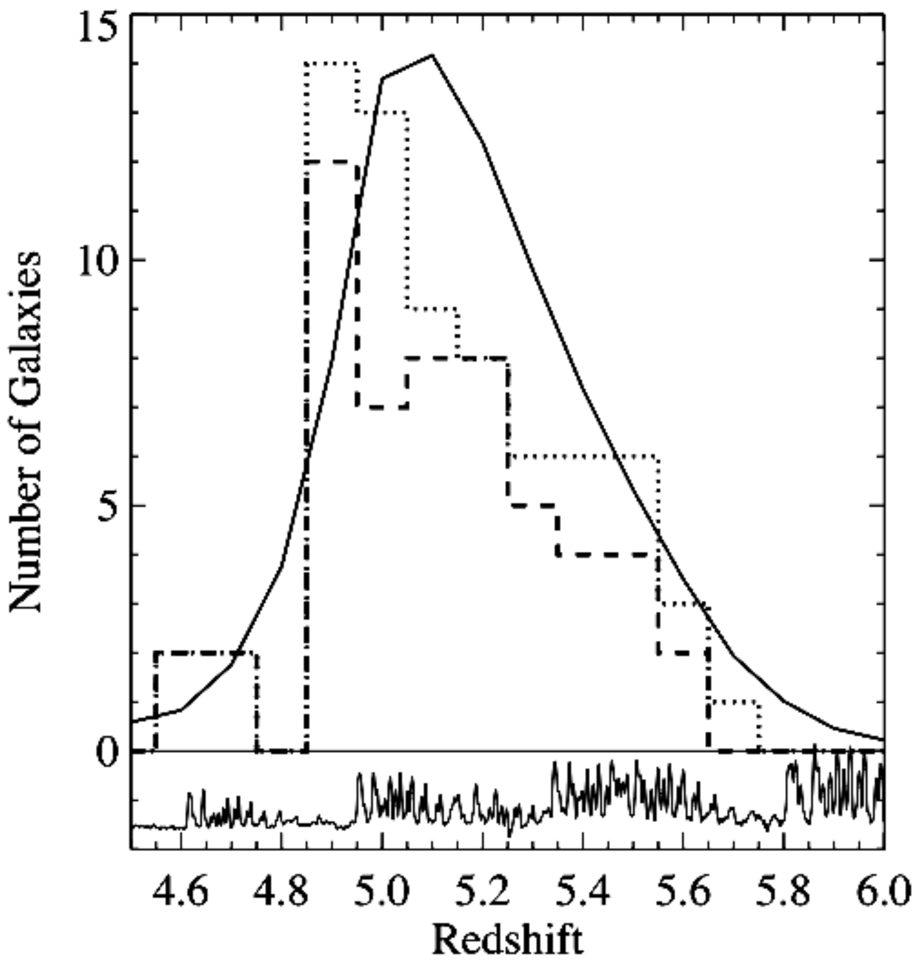
Results of imaging and spectroscopy published in Lehnert & Bremer 2003, Douglas et al 2008, 2009, 2010).



- •Typical fields have 1 source per 6-8 sq arcmin with spectroscopically-confirmed redshift between 4.6<z<5.6
- •Typical fields have 0 or 1 source in each of the Δz=0.1 redshift bins between 4.6<z<5.6
- •Most fields show no clustering of sources spatially or in redshift.
- •Overall redshift distribution is as expected from modelling of the selection function.

3D clustering: tracing z~5 structure

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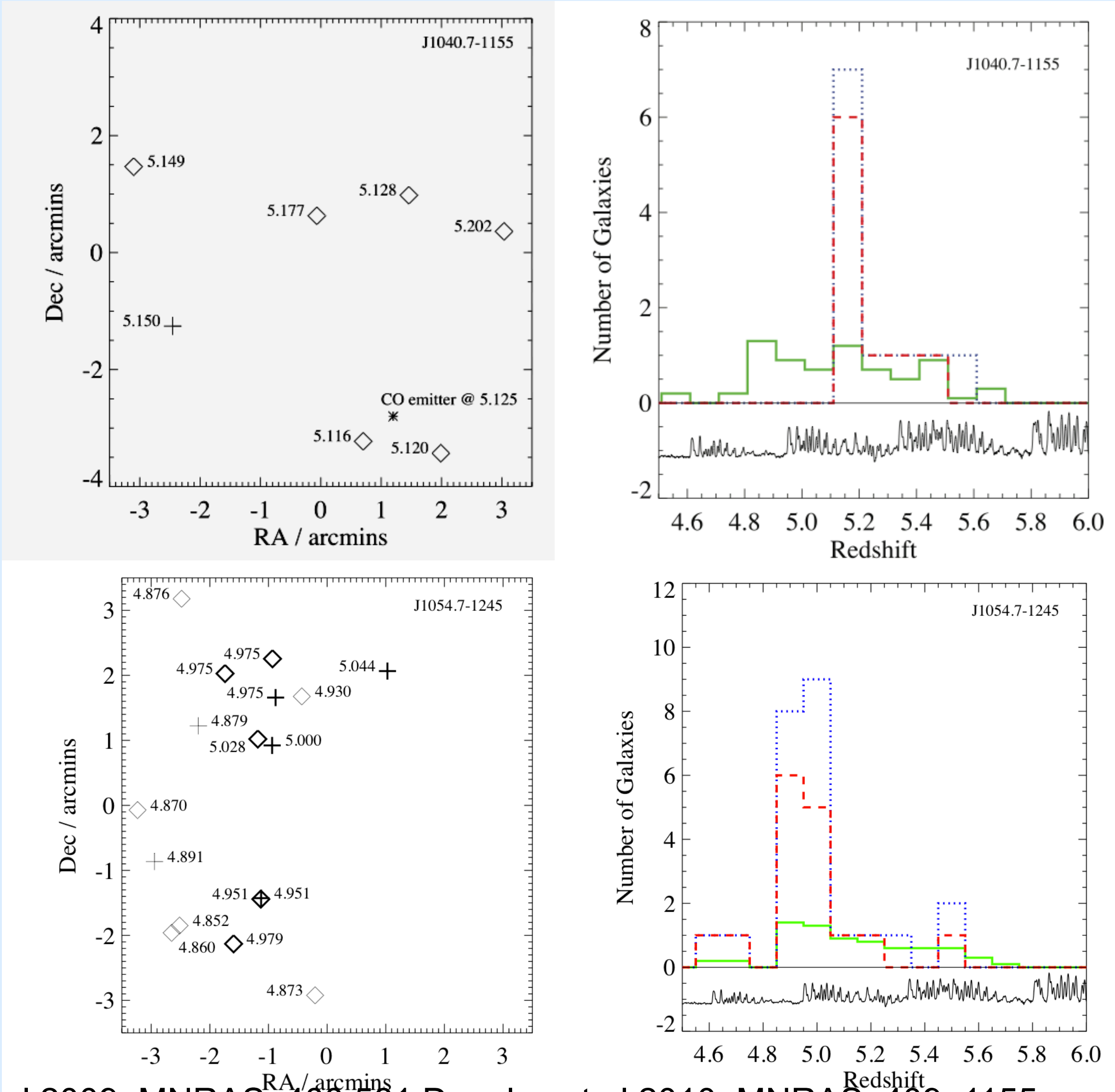
- However, two of the fields show clear spikes in their redshift distribution
- One field has seven objects in one Δz=0.1 redshift bin (8 proper Mpc, 50 comoving Mpc).
- Another has 17 in two such bins (almost all objects encompassed by a range in redshift of Δz=0.15).
- Spatial scale of field is about 4x4 proper Mpc^2, 27x27 comoving Mpc^2.



Douglas et al 2009, MNRAS, 400,561;Douglas et al 2010, MNRAS, 409, 1155

3D clustering: tracing z~5 structure

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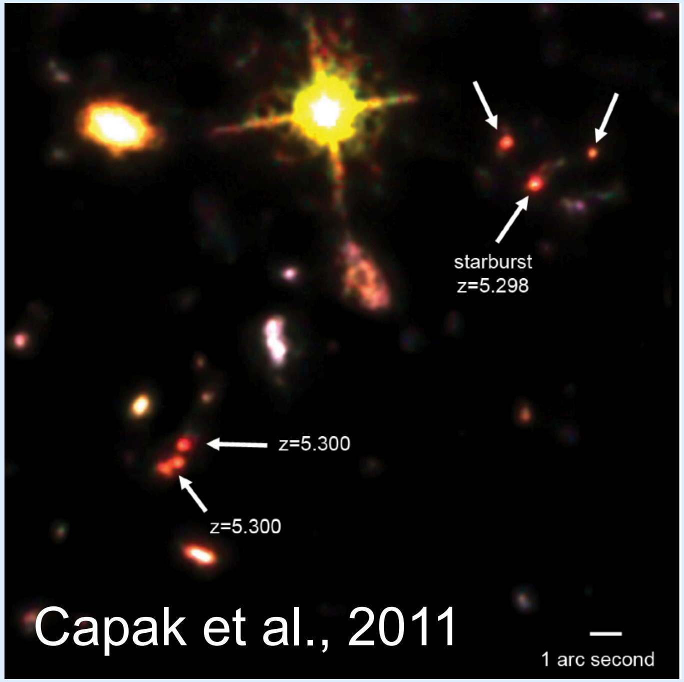
- These may be the first steps in cluster formation, but could more likely be (collapsing?) sheets or filaments at z~5. Either way, they are significant structures forming at a look-back time of 12 Gyr.
- The structures must contain other objects, not just the unobscured star-formers represented by the LBGs (can't be a case of the LBGs being visible in a redshift spike because they somehow "triggered/switched on" each other:- They are too far apart for that).
  - Searched for other galaxies in the field using mm imaging and spectroscopy (ATCA, APEX), to look for obscured star forming galaxies sharing same structures. (Davies et al, 2010, MNRAS, 408, L31;2012, MNRAS, 425, 153; Stanway et al., 2008,ApJ,687, L1; 2010, MNRAS, 407, L94). i.e looking for similar configuration to that observed by Capak et al., 2011

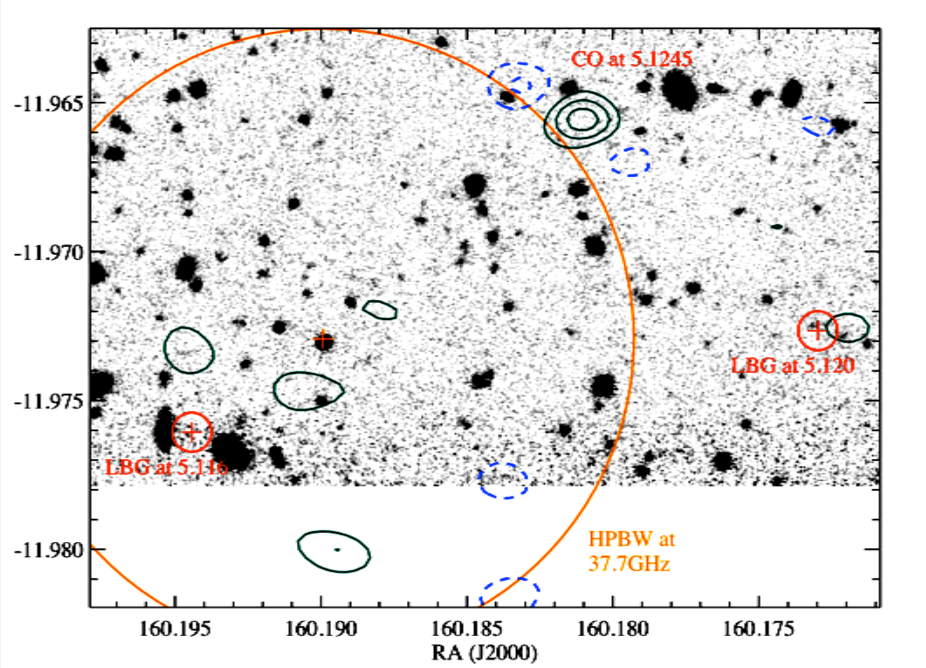


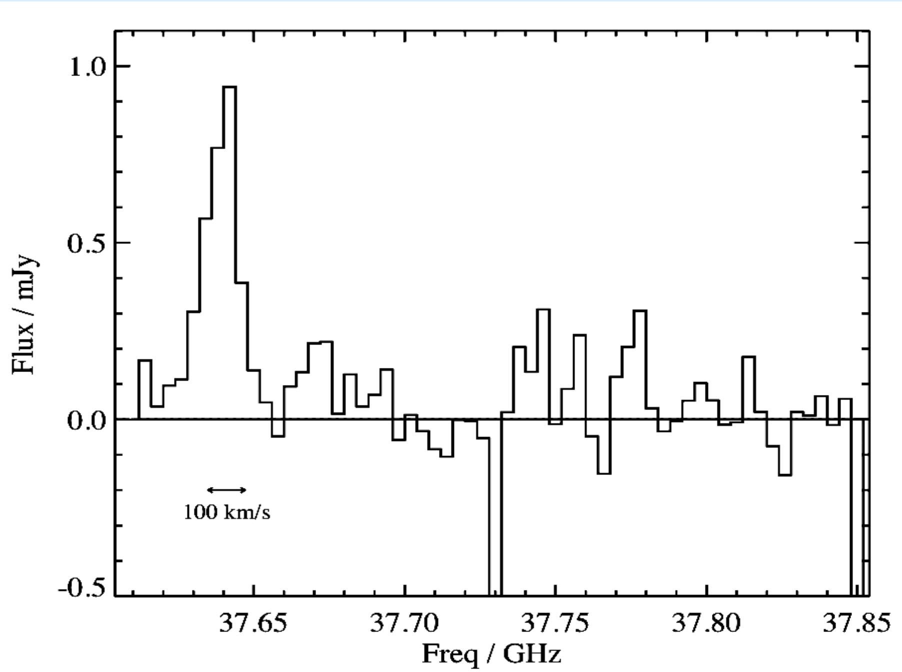
Capak et al., 2011

Other sources in the structures

- Apart from one possible weak CO emitter, no detections of any source in line or continuum, nor of the LBGs. So no SMGs with SFR>~200$M_{\odot}yr^{-1}$
- Line emission from one optically-faint source at 37.64GHz
- Likely CO(2-1) at z=5.1245±0.0001 => M_{H2}~$2x10^{10}$ $M_{\odot}$
- Reobserved at the NRAO Green Bank Telescope in May 2009
- Line emission redetected at 3σ

(Stanway et al 2008, ApJ, 687)





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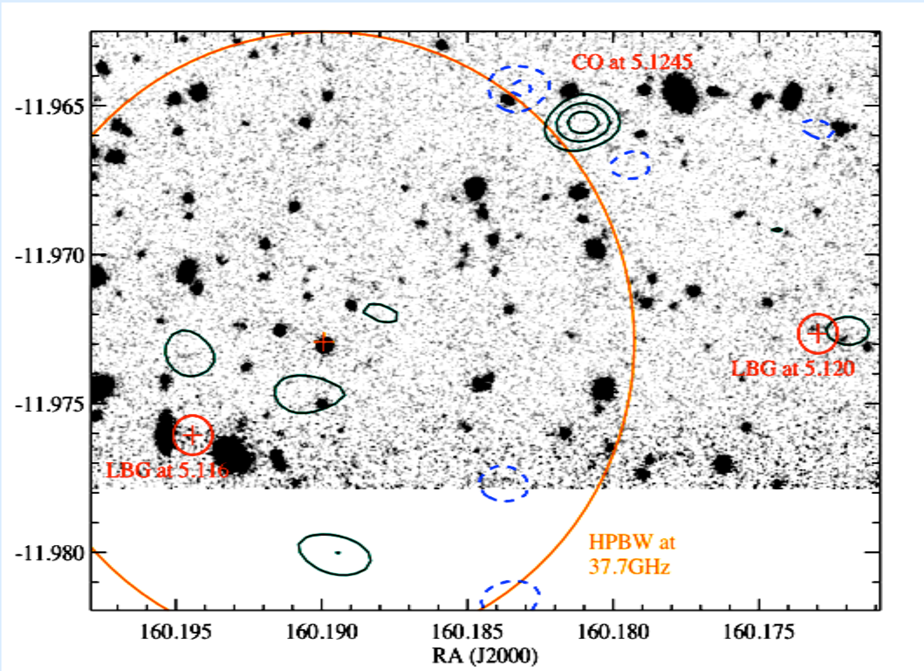
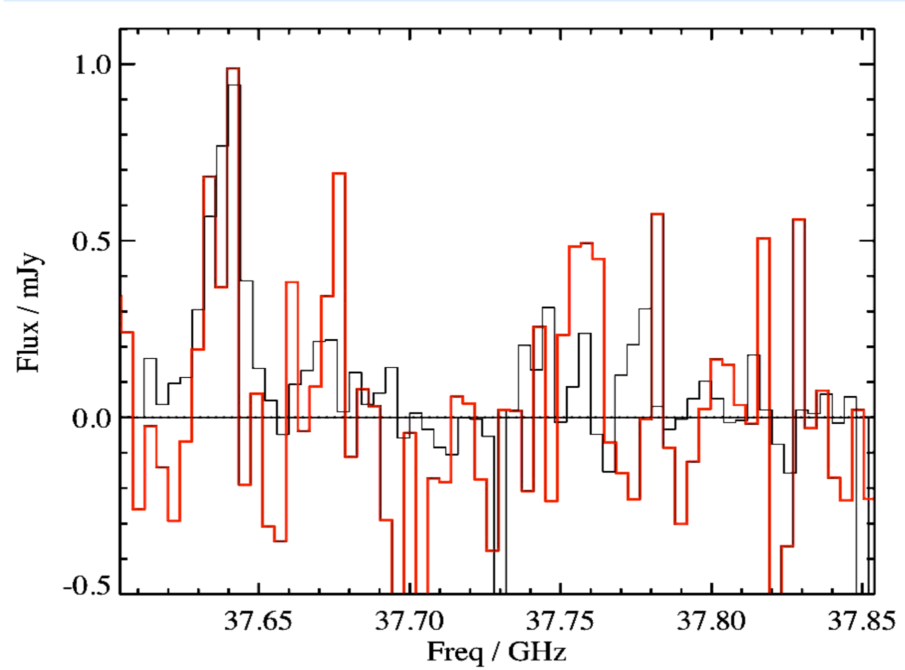
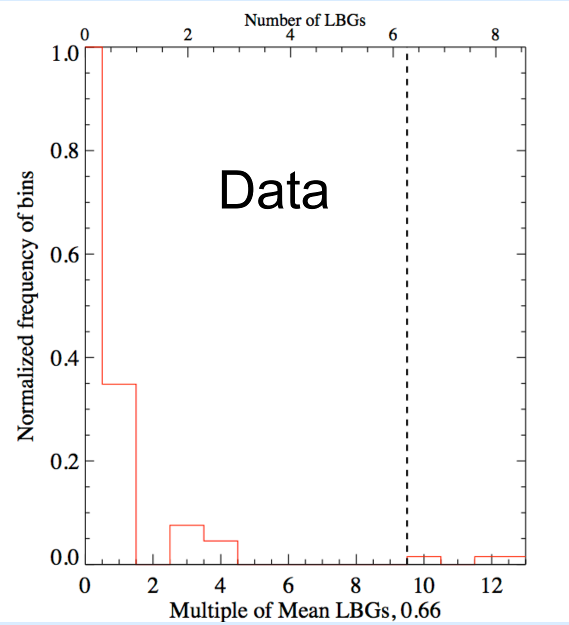
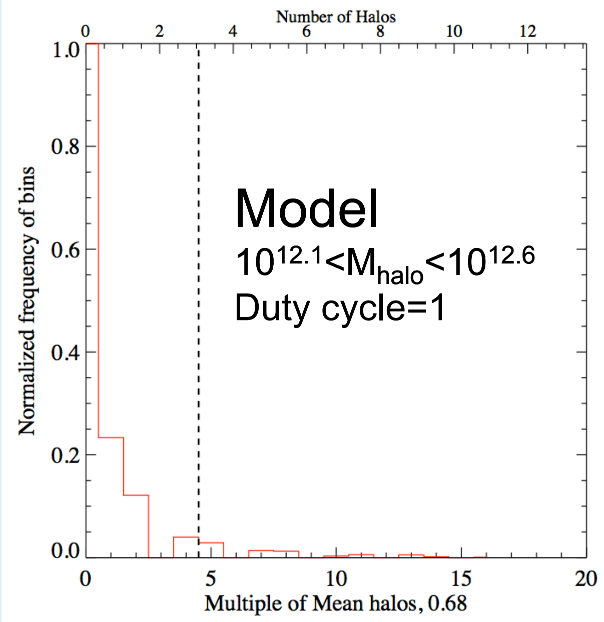
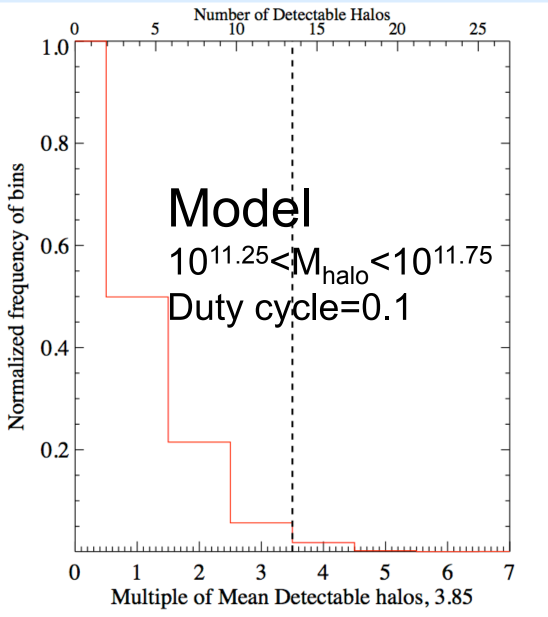




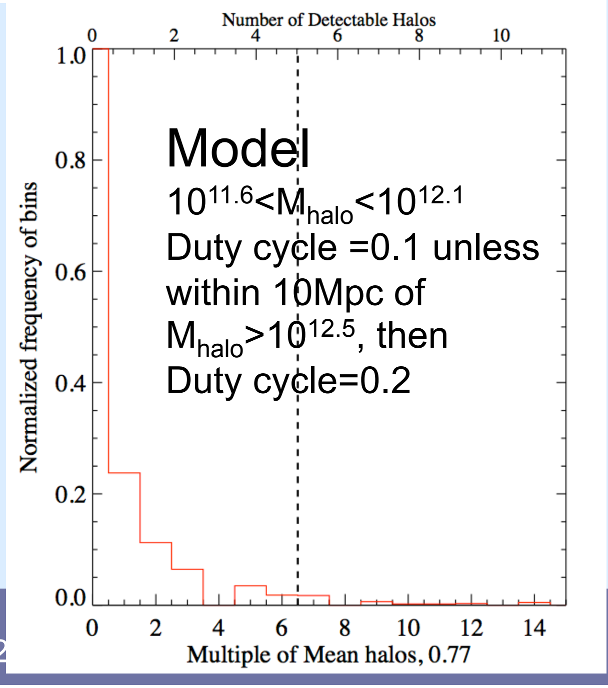
Clustering statistics







Compare stats from observations to those of simulations to work out what kind of DM halo hosts z~5 LBGs.
Compare the distribution of redshift bin occupation in our survey to that of Millennium simulation halos via selection fn.



Simple comparison of simulations and data does not work, either statistics disagree or duty cycle is unfeasibly high. More complicated models, eg using conditional probability for a halo to host an LBG can be made to work

Clustering around z~5 quasars

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•Powerful (SDSS) quasars contain SMBHs of $\sim 10^8$-$10^9 M_\odot$ and are likely to be found in massive galaxies (for z~5). Expectation is that they are found in significant/strongest overdensities at these redshifts (and in the more massive halos) in order to explain build-up of mass in a short period of time. Naïvely expect that QSOs trace peaks in the density distribution.

•We may therefore expect to see clustering of other galaxies around them at the same redshift.

•Several previous attempts at identifying clusters/clustering around z=5-6 QSOs using LBGs, mainly photometric attempts and often heroically trying for the highest redshifts (z>6). Mixed/contradictory/ambiguous results, possibly because the techniques used are not optimum.

Clustering around z~5 quasars

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- We chose 3 z~5 SDSS QSOs essentially at random from those available in 2008 & observed their fields in same way as for our earlier ERGS survey (**to provide baseline**).

- Fields of J0338+0021 (z=5.027), J1204-0021 (z=5.086) and J2130+0026(z=4.951) observed in similar manner to ERGS.

- QSOs have z_{AB}~18.5-20.3, M~ -28.1-29.5

- J0338+0021 has a fainter QSO (z_{AB}~20.8) at similar redshift 2.5 arcmin away (Djorgovski et al., 2003):- Not selected for this reason, could be true of other QSOs, depends on exact brightness of any companion or if field has had previous follow-up observations.

Clustering around z~5 quasars

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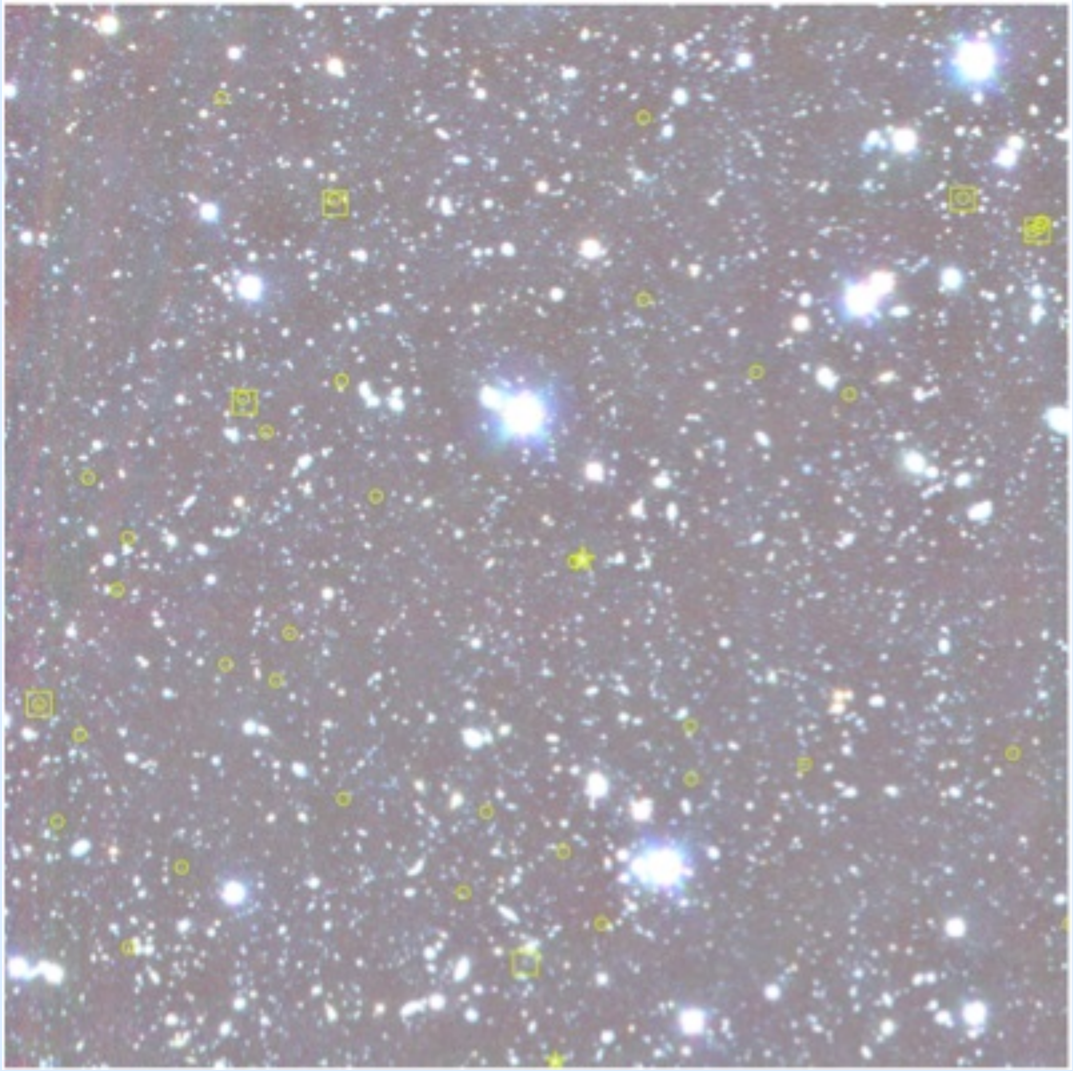
•Imaging indicated no clear overdensity of photometrically-selected LBG (R-band drop outs) around QSOs. Range in numbers of good z~5 LBG candidates in these fields similar to typical ERGS fields, though J0338+0021 is quite rich). Would not say there was convincing evidence of clustering in all cases based on photometry alone.

•However, spectroscopy probes any structure with more sensitivity……



Clustering around z~5 quasars

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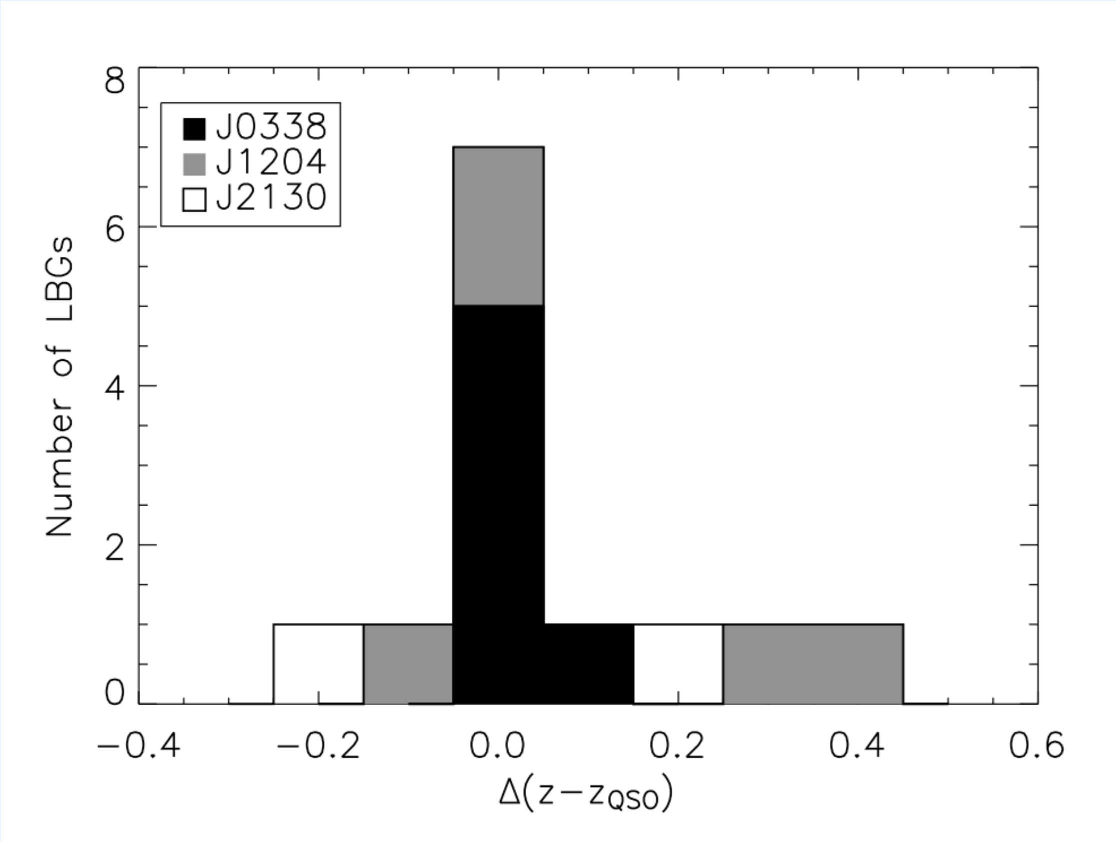

•LBGs **<u>DO</u>** cluster around z~5 QSOs, but not necessarily all and the clustering is usually not as strong as can be seen in the field. Proto-clusters?
•Assuming clustered LBGs trace overdensities, z~5 QSOs do not trace strongest overdensities
•Spectroscopy is vital to uncover this, photometric selection is insufficient.

Conclusions

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•Spectroscopic surveys of z~5 LBGs in the general field can clearly identify (forming) structures in 3-D.

•So far such work is on small fields and areas, potential to explore larger areas and volumes in the future (ideally $>10^7$ Mpc^3).

•2-D approaches probably too simplistic to explore clustering of these galaxies. Probably not a simple case of galaxies uniformly tracing a restricted range of halo mass.

•Do SDSS-luminosity z~5 QSOs show evidence for being found in the most overdense regions at these redshifts?

•Imaging/photometry shows no clear excess of LBGs around them.

•Spectroscopy shows a range of LBG clustering around QSOs , and certainly no more significant than what you can find in the “field”.

•So, is there a better signpost for the most overdense regions?