Are Luminous Quasars at z ~ 4 Tracers of the Most Massive Dark Matter Halos?

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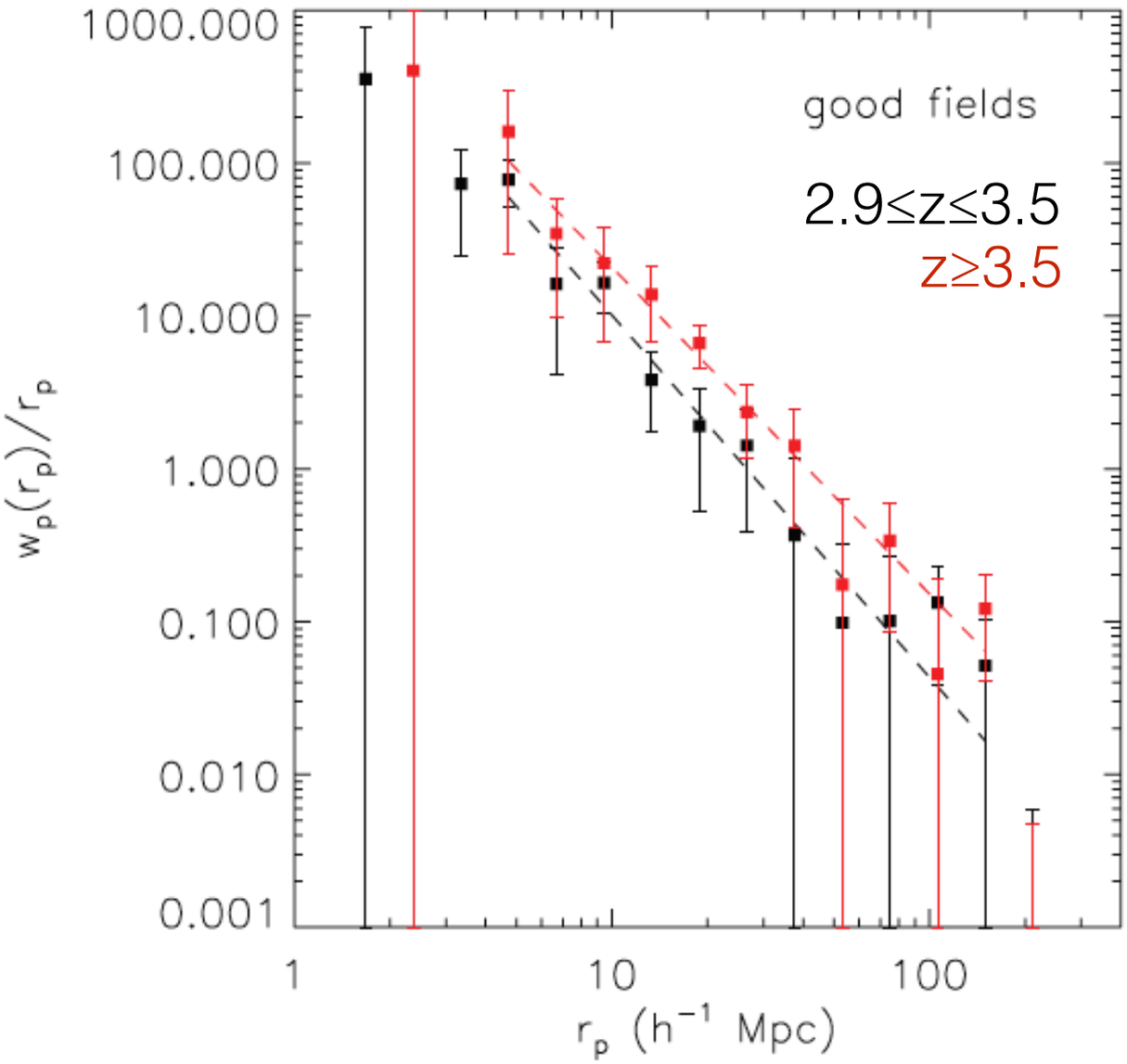
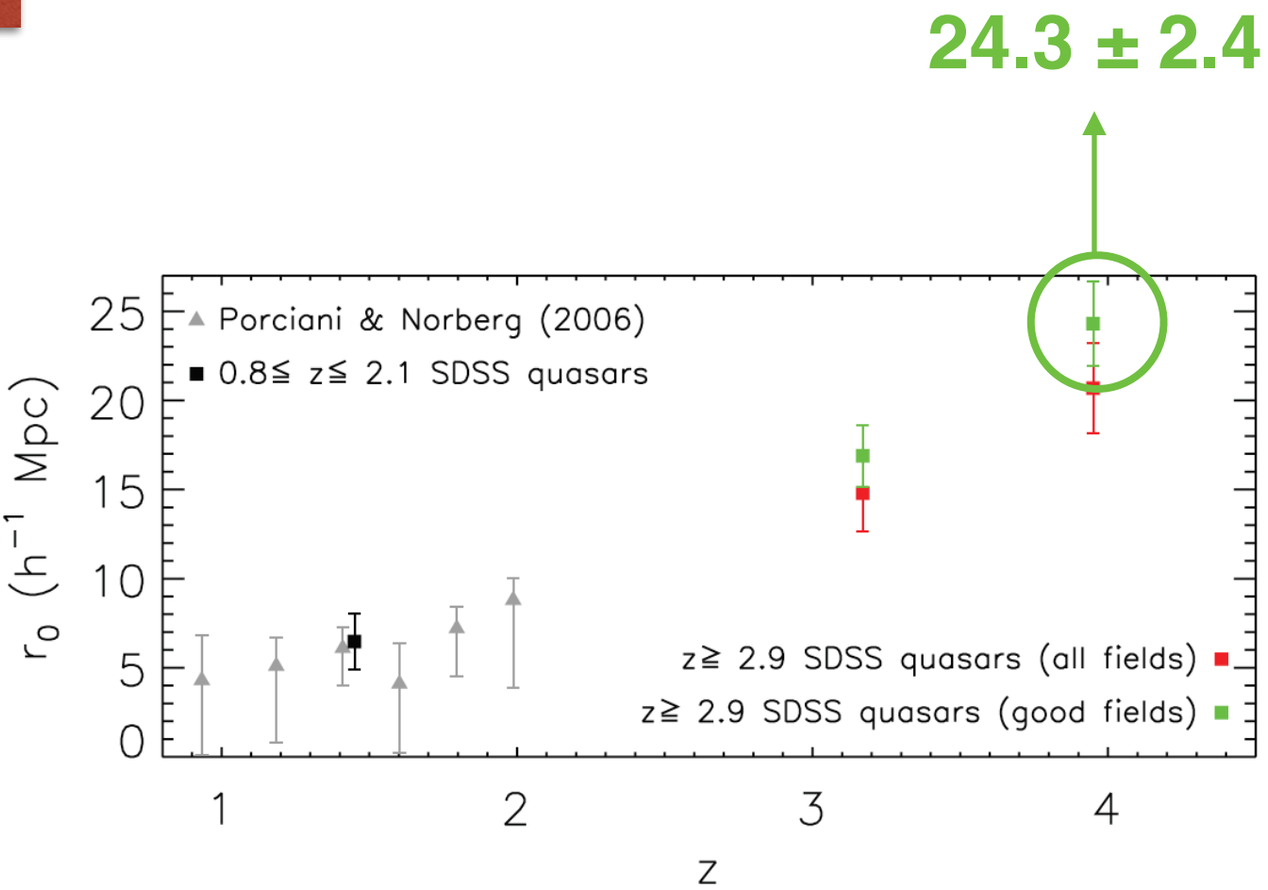
Clustering Measurements of AGN
Garching, July 17, 2014

Why do we use QSOs at z~4 as high density tracers?

Extremely Strong QSO Clustering





$M_{halo} \gtrsim 6 \times 10^{12}\, h^{-1} M_{\odot}$

Shen et al. (2007)

We expect a large Galaxy-QSO cross-correlation!!!

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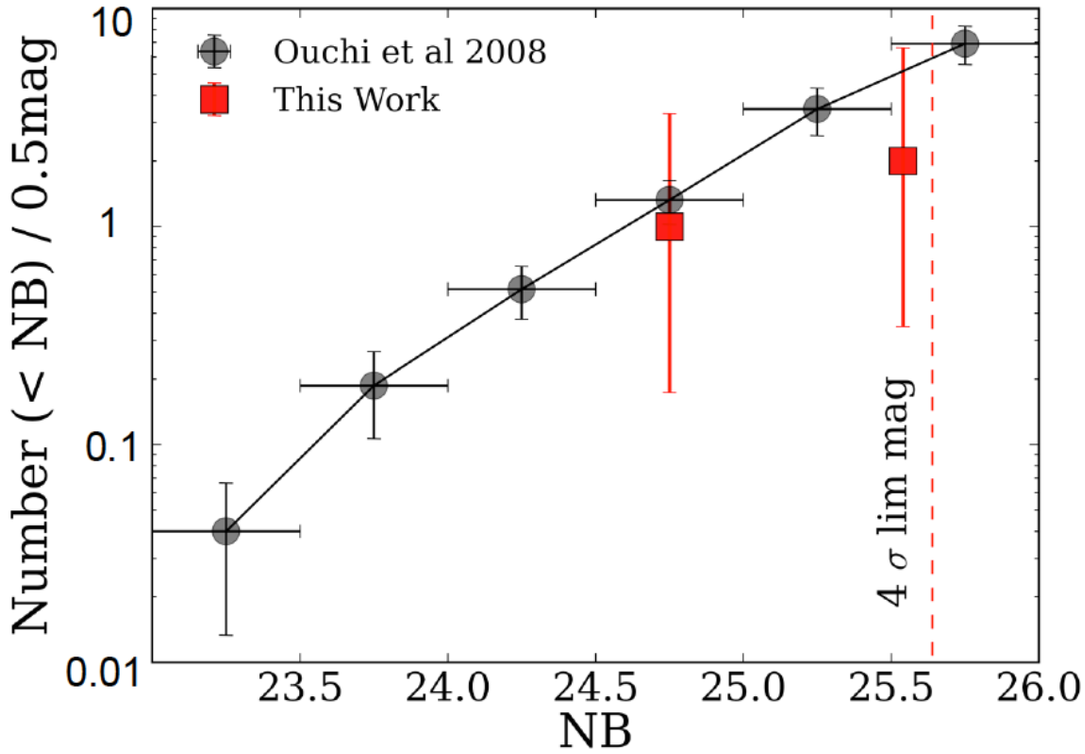
QSO environments at the highest redshifts

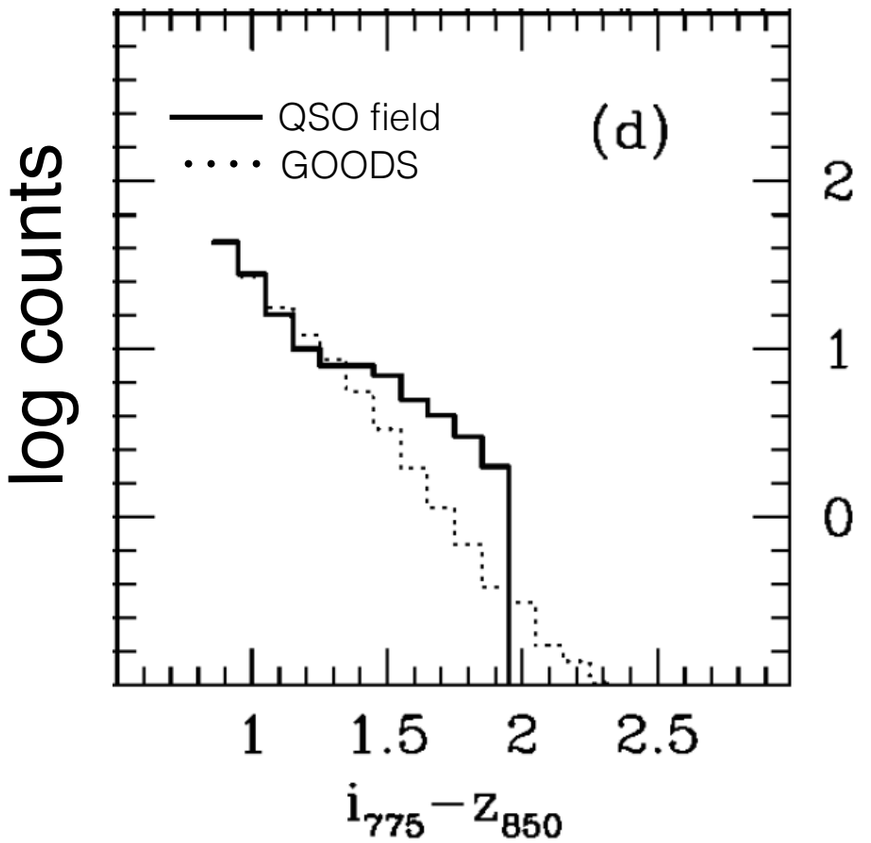
Diverse results for galaxy search around z ~ 6 QSOs

No Overdensity



Bañados et al. (2013)

Overdensity



Stiavelli et al. (2005)

Others examples

- Willot et al. (2005)
- Kim et al. (2009)
- Simpson et al. (2014)

- Zheng et al. (2006)
- Kim et al. (2009)
- Utsumi et al. (2010)
- Morselli et al. (2014)

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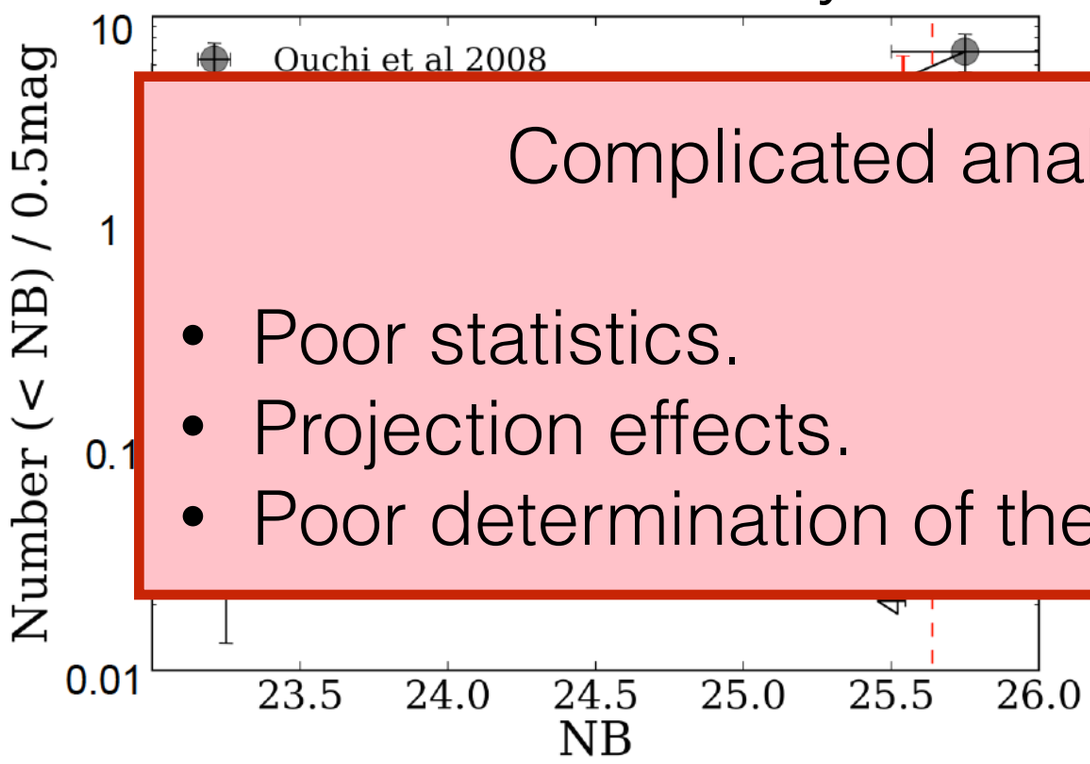

Bañados et al. (2013)

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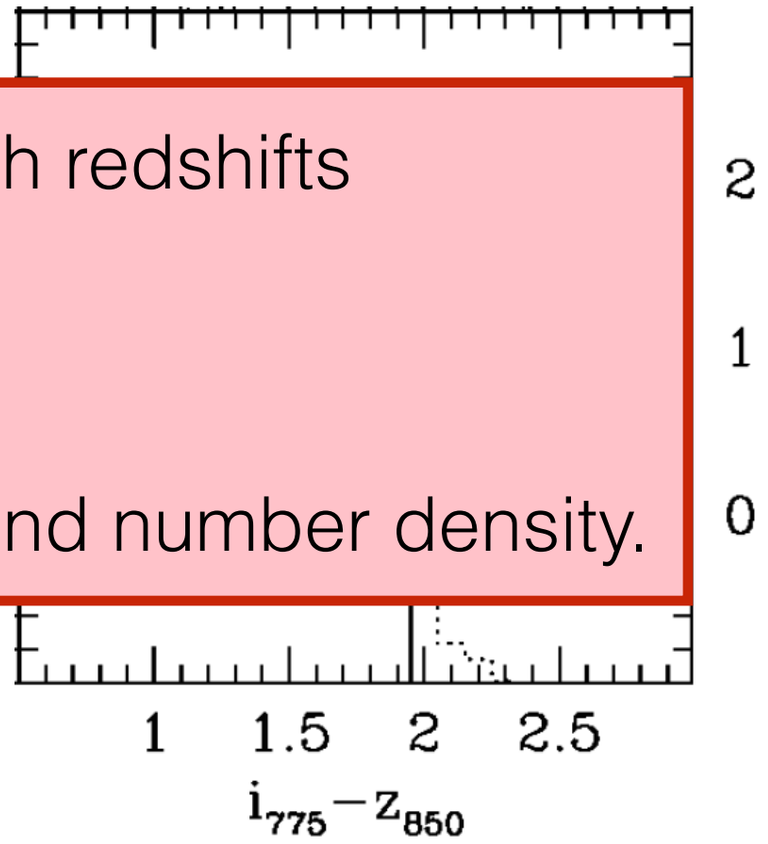

Stiavelli et al. (2005)

Complicated analysis at high redshifts

- Poor statistics.
- Projection effects.
- Poor determination of the background number density.

Others examples

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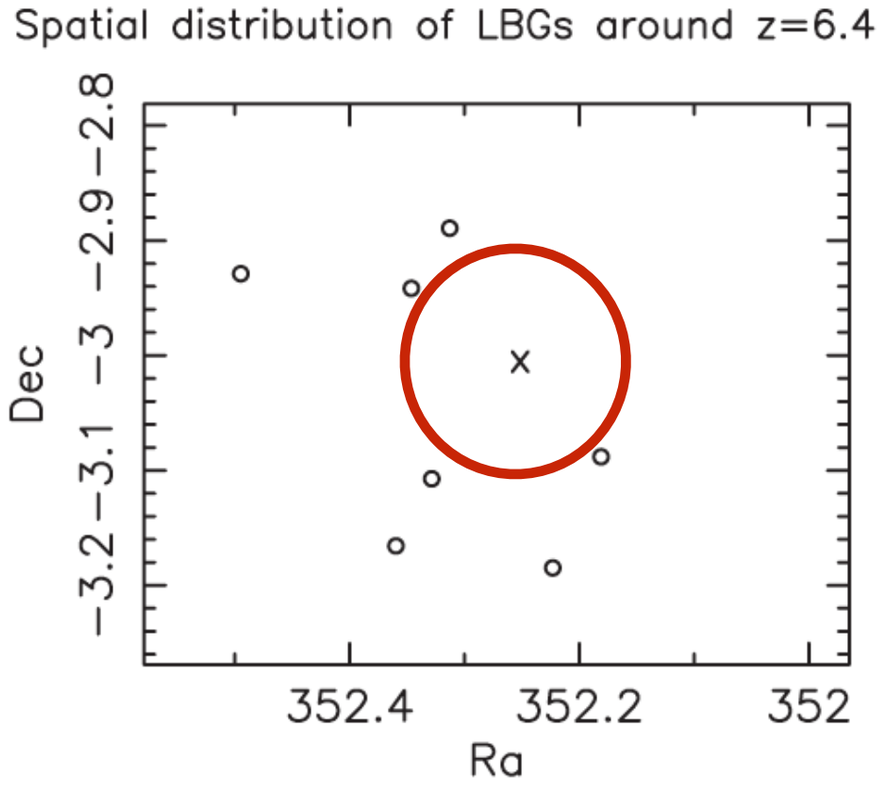
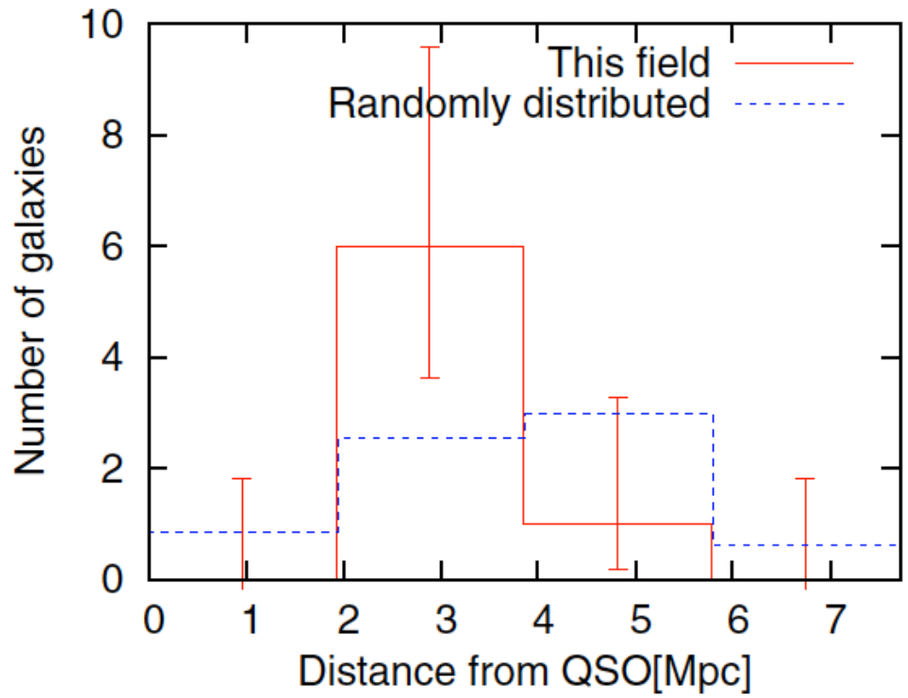
What do we expect from the study of QSO environments at z~4?

- Test the M_{BH} - M_{halo} relation of nearby galaxies at higher redshifts.
  Find the progenitors of the most massive clusters at z = 0.

- The first measurement of QSO-galaxy clustering at z ~ 4.

- Extra physics related
  Strong ionizing radiation from the quasar could prevent star formation.





Utsumi et al. (2010)

Custom Narrow band filters imaging on the most massive BHs

- VLT/FORS
- 6 SDSS quasar fields

  $z = 3.78 \pm 0.04$

  $M_{BH} > 10^9 M_\odot$

- Custom set of filters

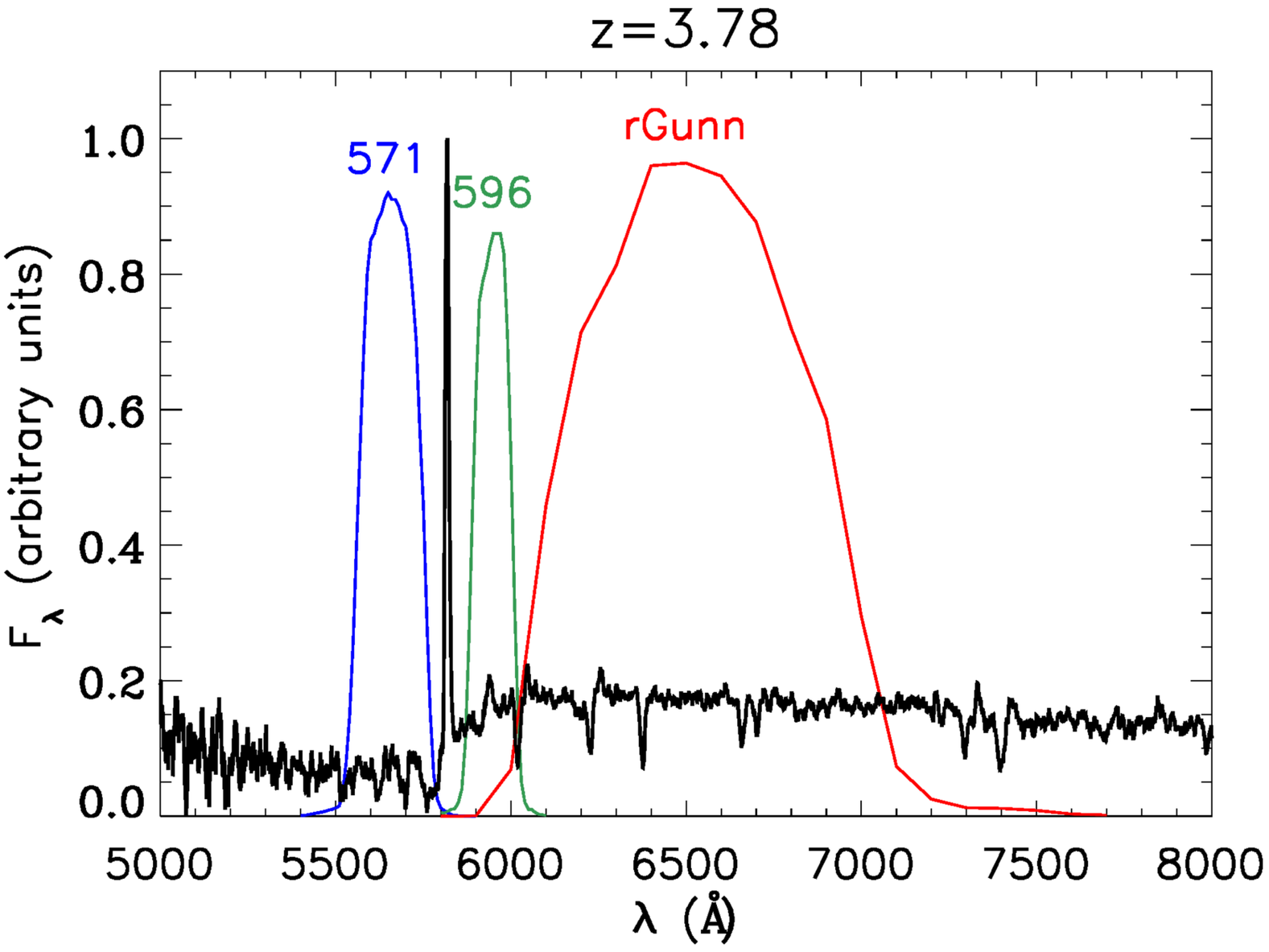
$$\mathrm{NB}_{571} : \lambda_{eff} = 5657\mathring{A}$$
$$\mathrm{FWHM} = 187\mathring{A}$$

$$\mathrm{NB}_{596} : \lambda_{eff} = 5947\mathring{A}$$
$$\mathrm{FWHM} = 116\mathring{A}$$

- Broad-band filter

$$\mathrm{r}_{Gunn} : \lambda_{eff} = 6490\mathring{A}$$

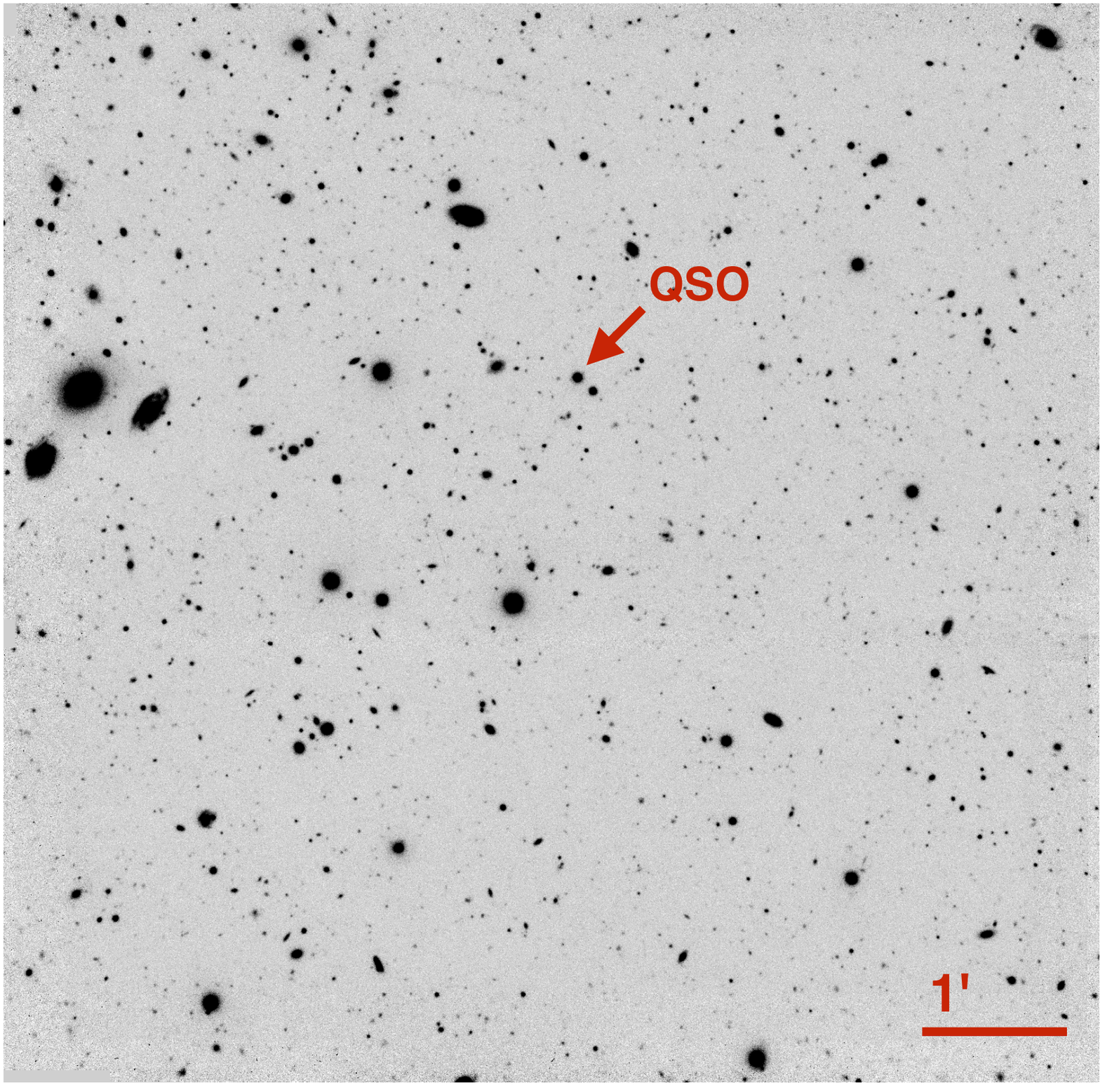
(Composite Spectra from Jones et al. 2012)



Narrow band filter: Δz ~ 0.1

Custom Narrow band filters imaging on the most massive BHs

FoV = 6.8' × 6.8'
= 3 × 3 Mpc^2
= 14.5 × 14.5 $cMpc^2$



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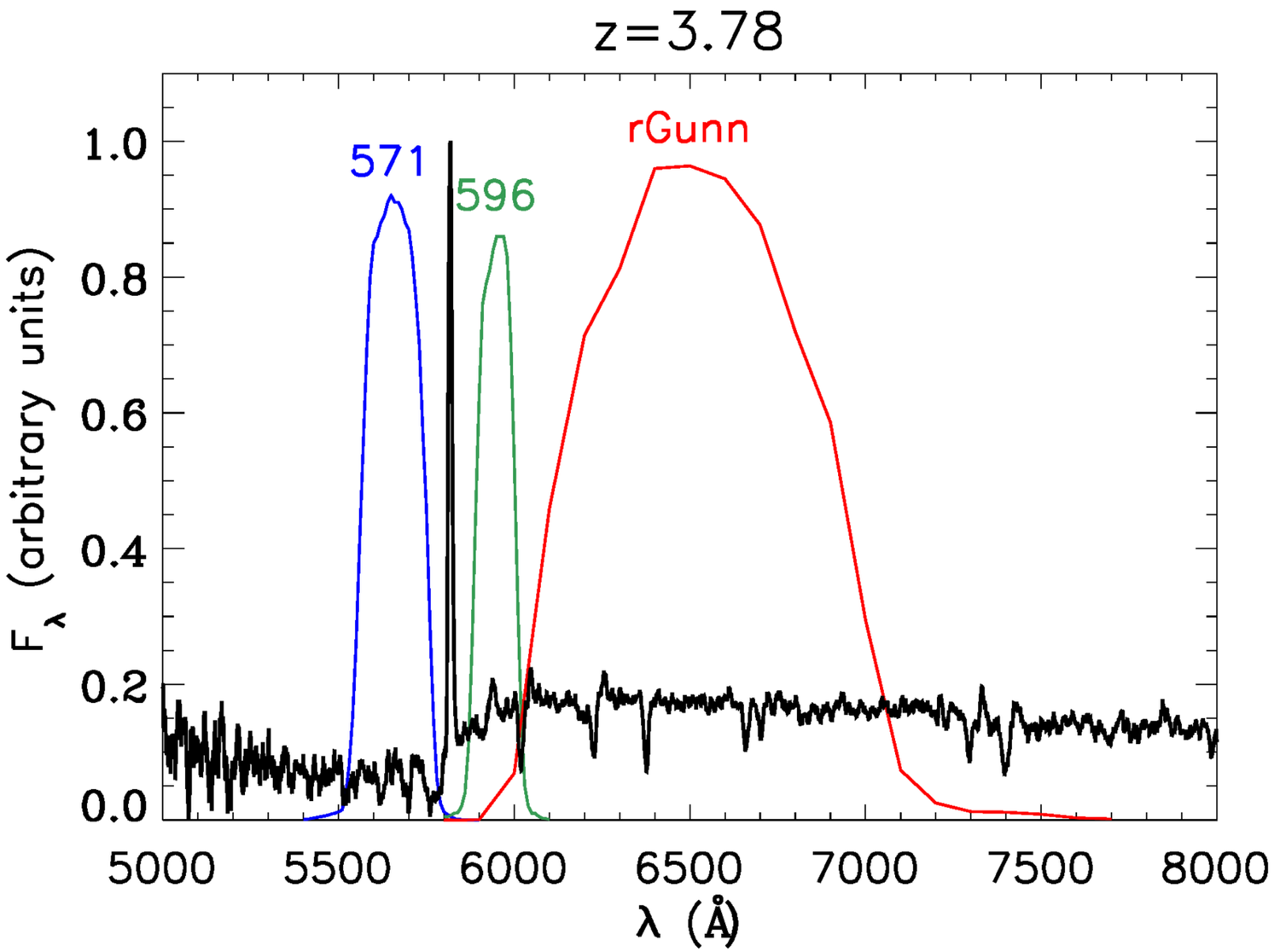
LBG selection on Custom Narrow band filters

- Detection on r_{Gunn} band
- S/N > 4 in r_{Gunn} and NB_{596}
- color-color cuts



LBG selection on Custom Narrow band filters

- Detection on r_{Gunn} band
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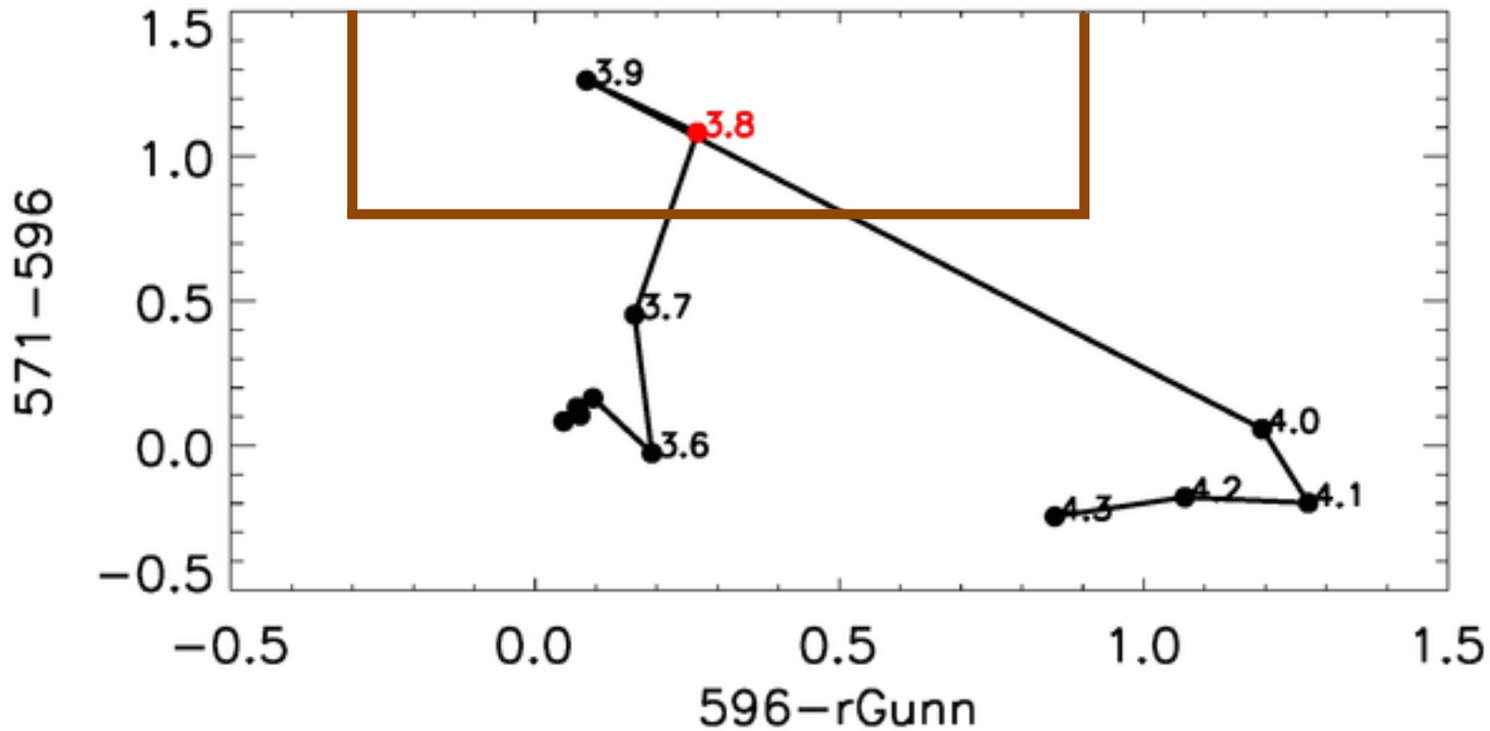
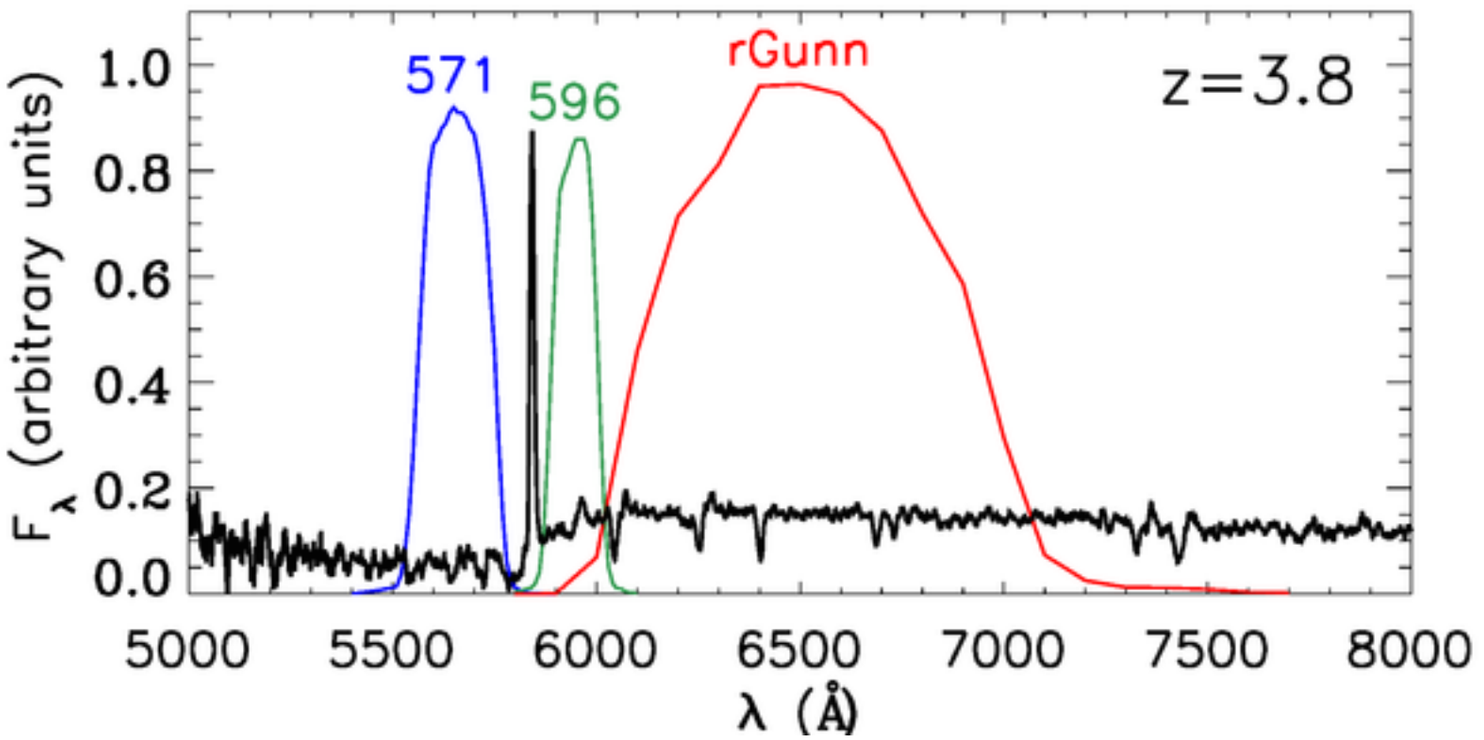
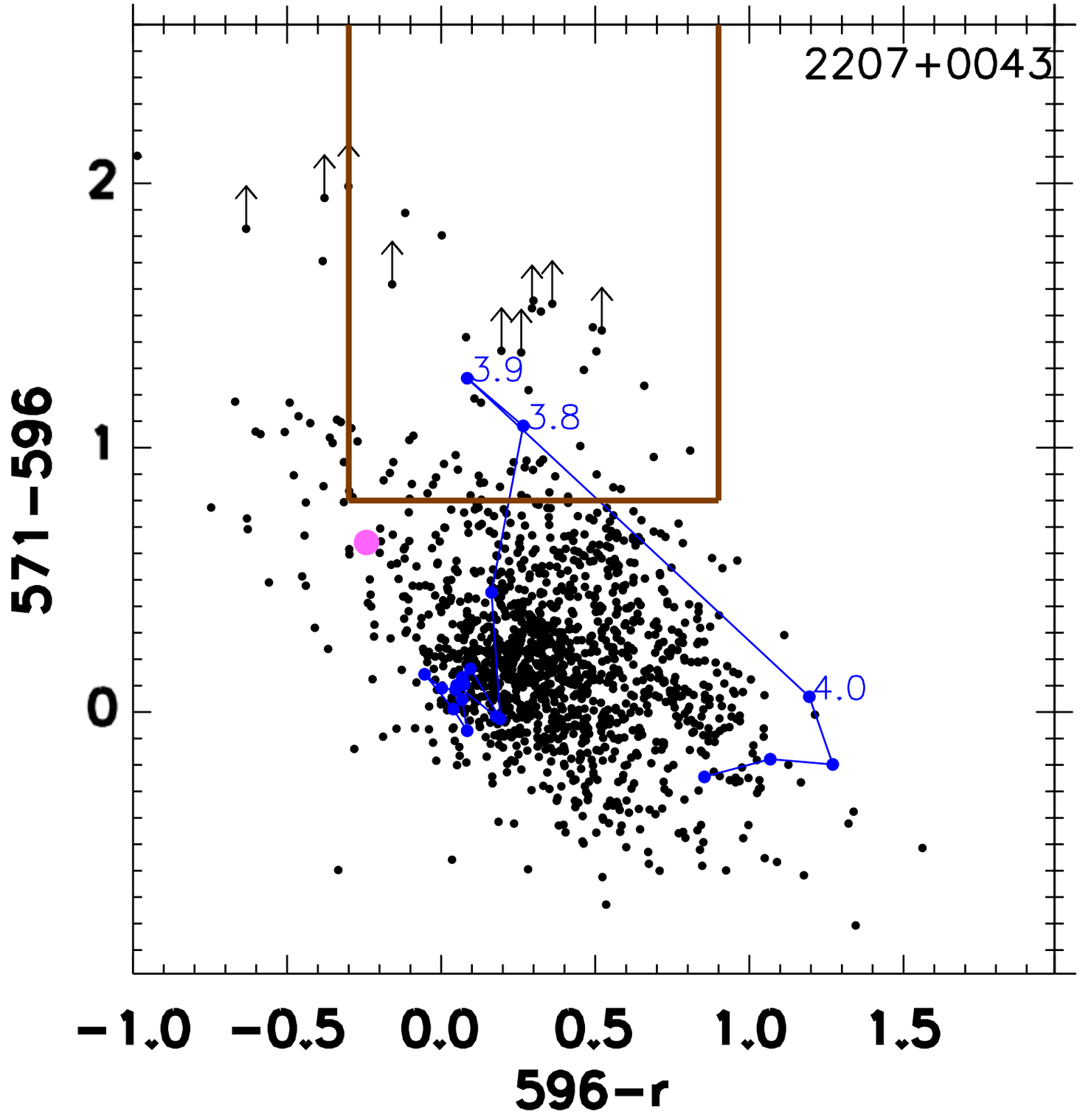
LBG Evolutionary Track

- Selection Region





Color-Color Diagrams for LBG Selection



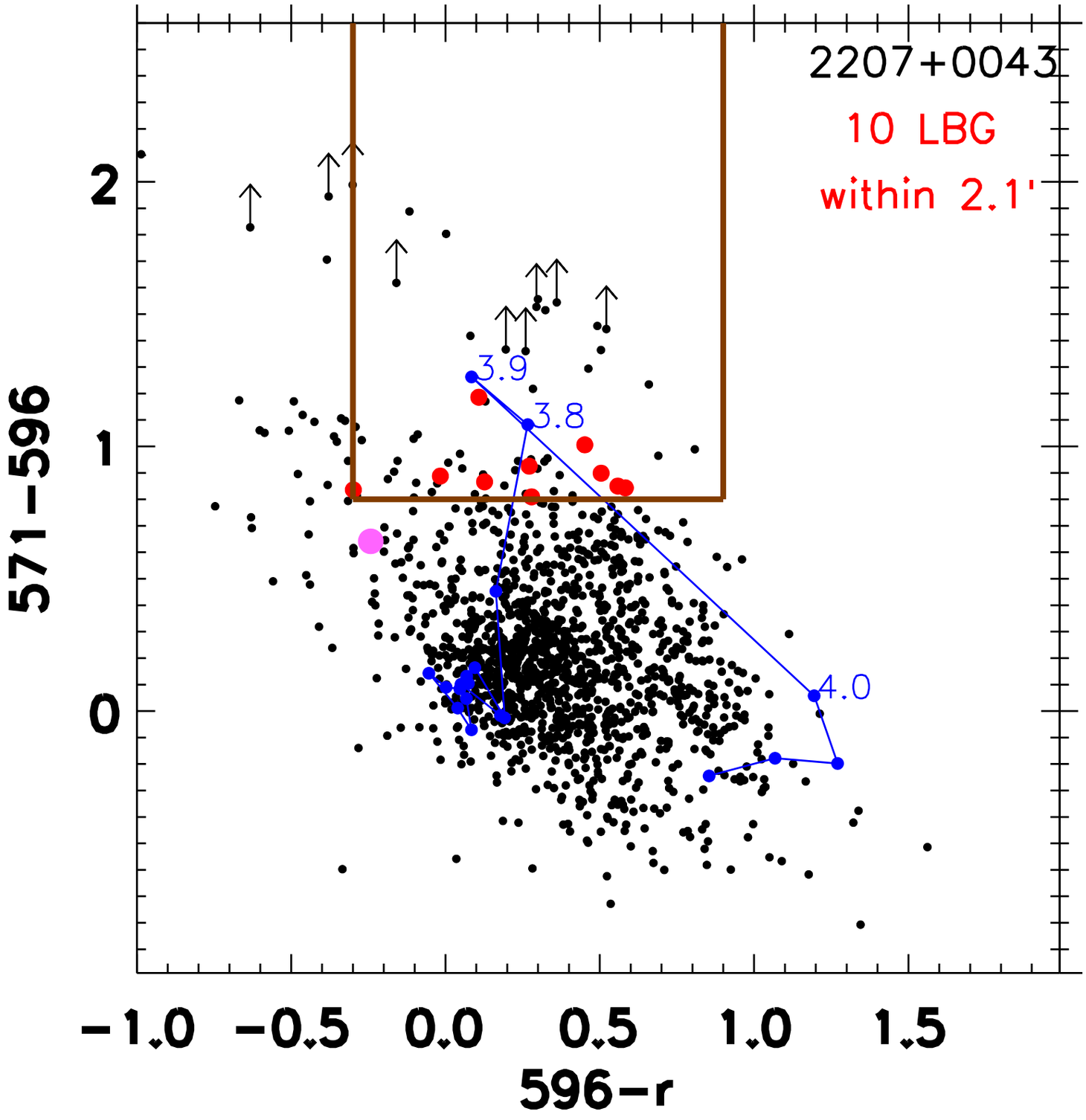
Limit magnitudes (4σ, 2")

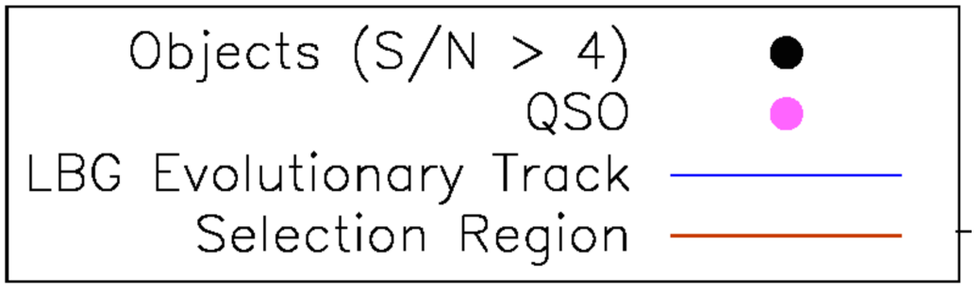
NB_{571} = 25.9

NB_{596} = 25.4

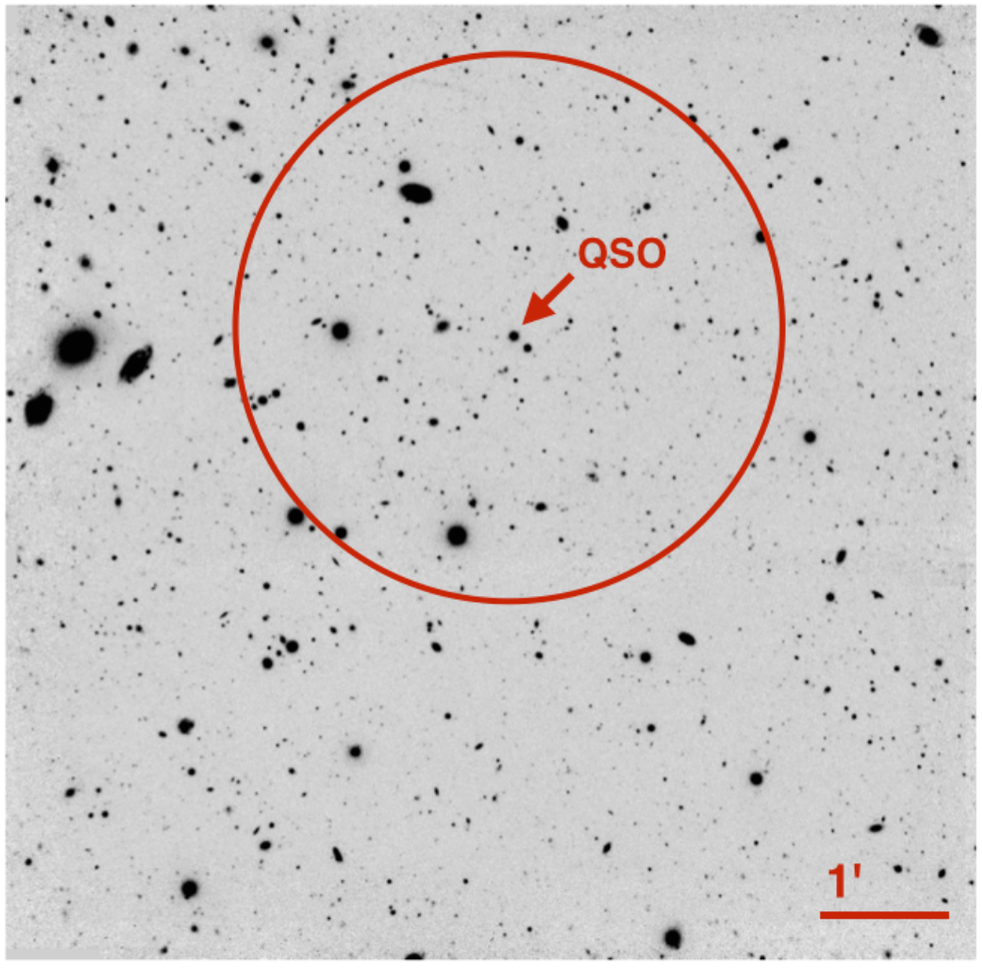
r_{Gunn} = 25.6

Color-Color Diagrams for LBG Selection





Selection within **2.1'**



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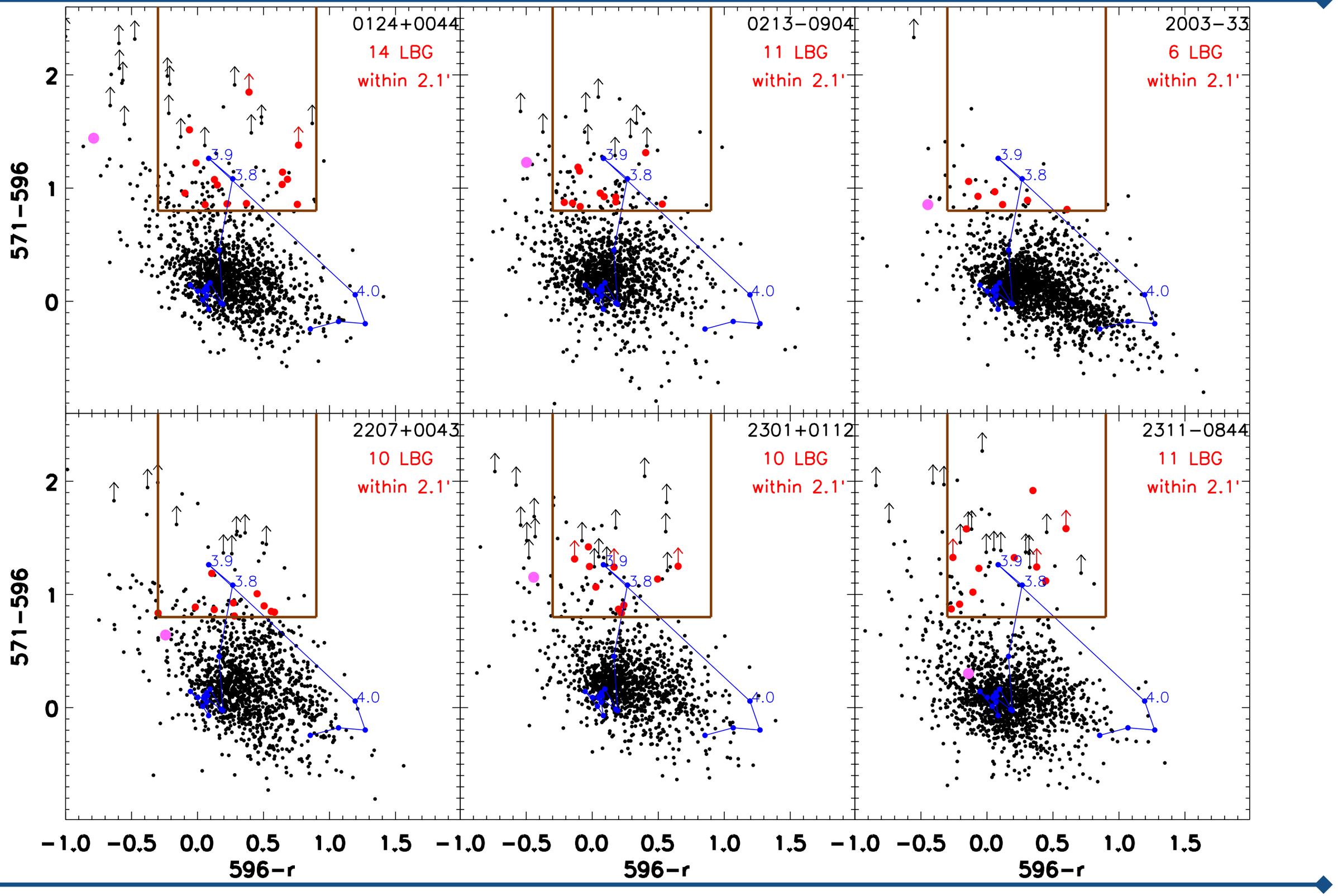
Color-Color Diagrams for LBG Selection



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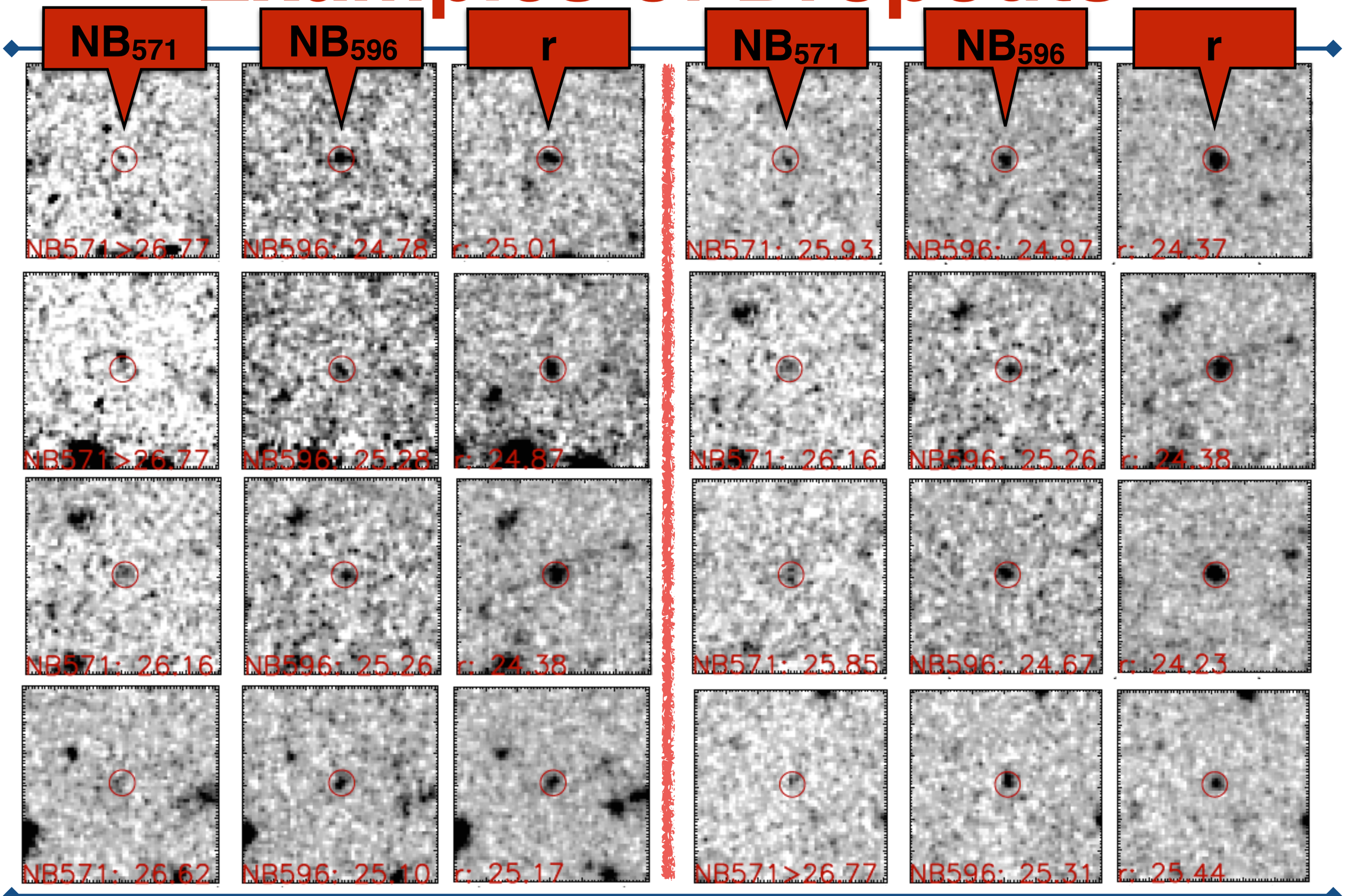
Examples of Dropouts



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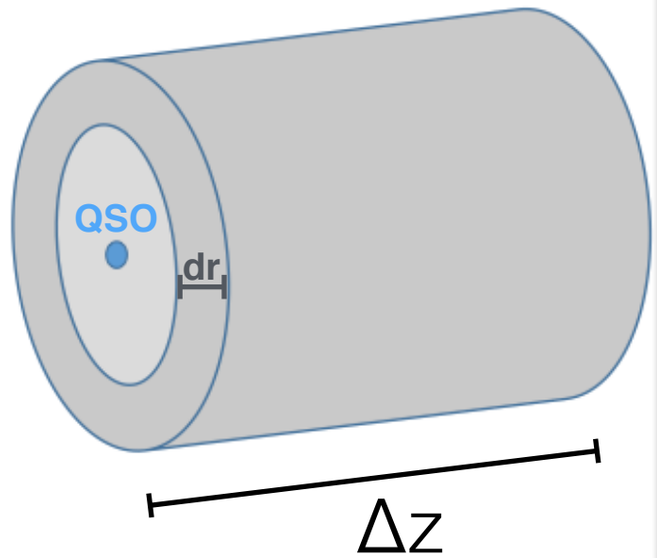
Expected Clustering Signal

Number of LBGs $$N_g(r) = \int n_g[1 + \xi_{gq}(r)]dV$$

Luminosity function of LBG at z~4

Ouchi et al. (2004)

Cylinder volume



Power law correlation function

$$\xi_{gq}(r) = \left(\frac{r}{r_0^{gq}}\right)^{-\gamma}$$

Assumption: linear bias

$$\delta_g = b_g\delta \qquad \delta_q = b_q\delta \quad \rightarrow \quad r_0^{gq} = \sqrt{r_0^g r_0^q}$$

$r_0^g = 4{,}1 \pm 0{,}2$ Ouchi et al. (2004)

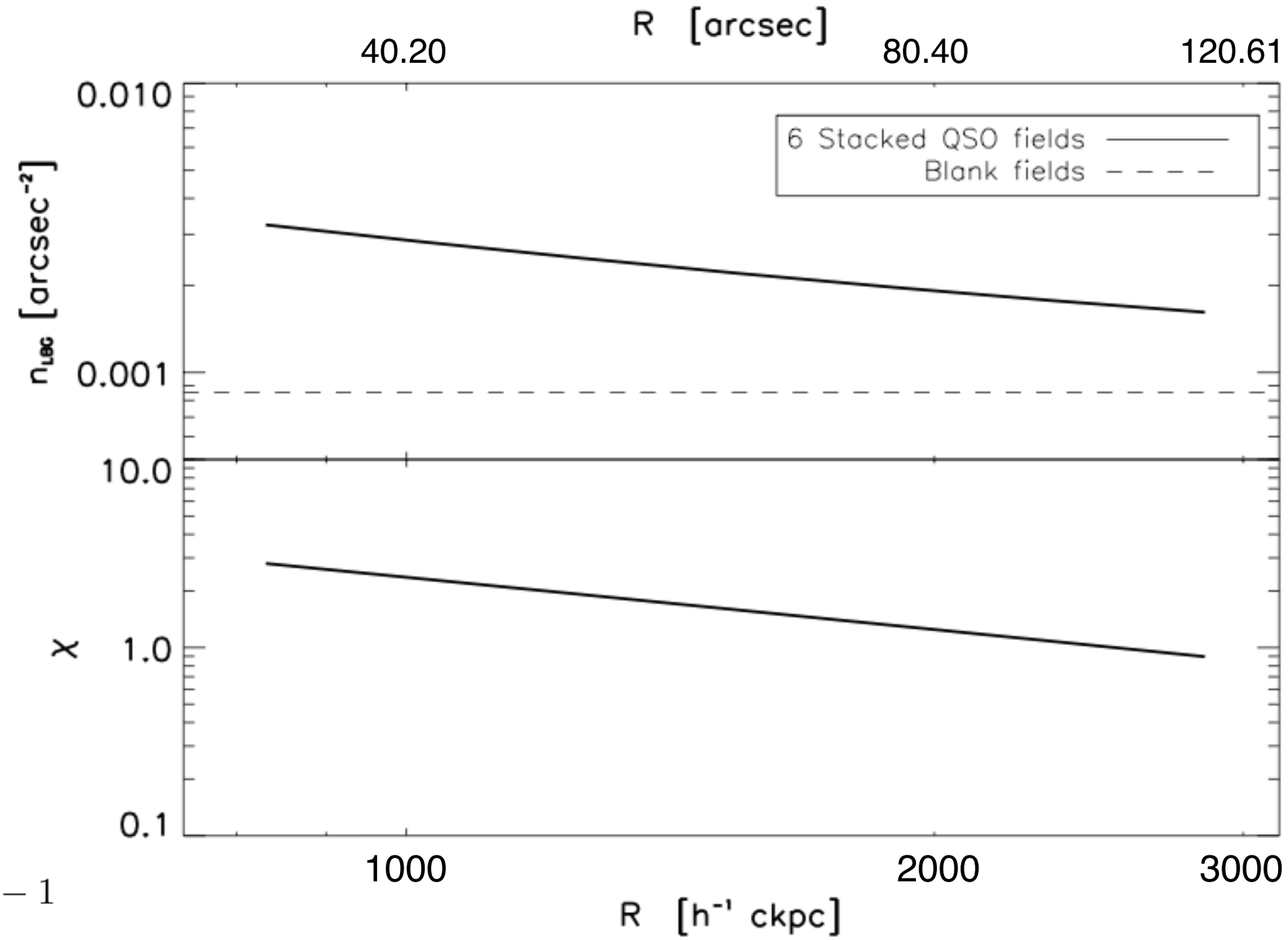
$r_0^q = 24{,}3 \pm 2{,}4$ Shen et al. (2007)

$\gamma = 2{,}0$

Estimator: $\chi = \frac{1}{\Delta V}\int \xi_{gq}(r)dV \quad \rightarrow \quad \chi = \frac{N_g}{n_g \Delta V} - 1$

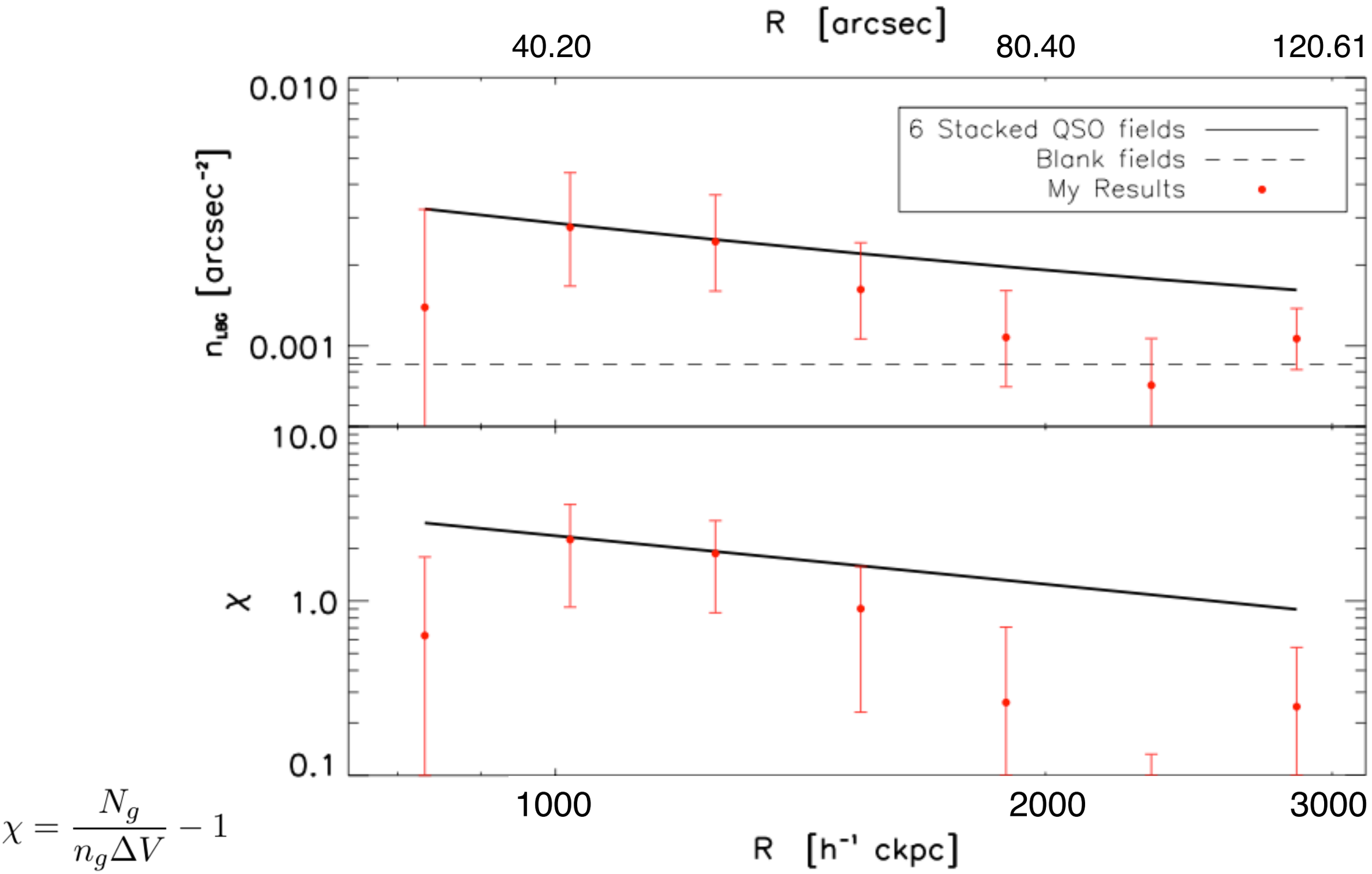
(Volume average correlation function)

Expected Clustering Signal



$$\chi = \frac{N_g}{n_g \Delta V} - 1$$

Preliminar evidence for galaxy overdensity around z~4 QSOs



$$\chi = \frac{N_g}{n_g \Delta V} - 1$$

Future Work

- Model redshift selection function imposed by our filters (in progress).

- Implement Landy-Szalay type estimator for the correlation function to extend clustering analysis to (~3-4 Mpc).

- First measurement of QSO-LBG cross-correlation function (r_0, $\boldsymbol{\gamma}$).

- Time on VLT/FORS2 (30h) to study QSO-LAE cross-corrleation as additional check on results.

- Conduct similar analysis on a sample of 8 binary QSOs at z ~ 4. Do binary environments trace proto-clusters?

Summary

- Survey for galaxies around z = 3.8 QSOs with the most massive SMBHs ($M_{BH} > 10^9 M_\odot$).

- Novel narrow band filter technique used to obtain more precise redshifts ($\Delta z \sim 0.1$).

- Preliminar evidence for galaxy overdensity around z~4 QSOs, in rough accord with expectations from QSO-LBG auto-correlation.

- More results are coming.

- I am open to suggestions and comments.

Thank you!