The high-redshift Universe and the role of galaxies and AGN to cosmic reionization

Lecture 3

- Observational evidence of feedback at high redshift
- Early large scale structures: galaxy overdensities

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AGN-driven outflows

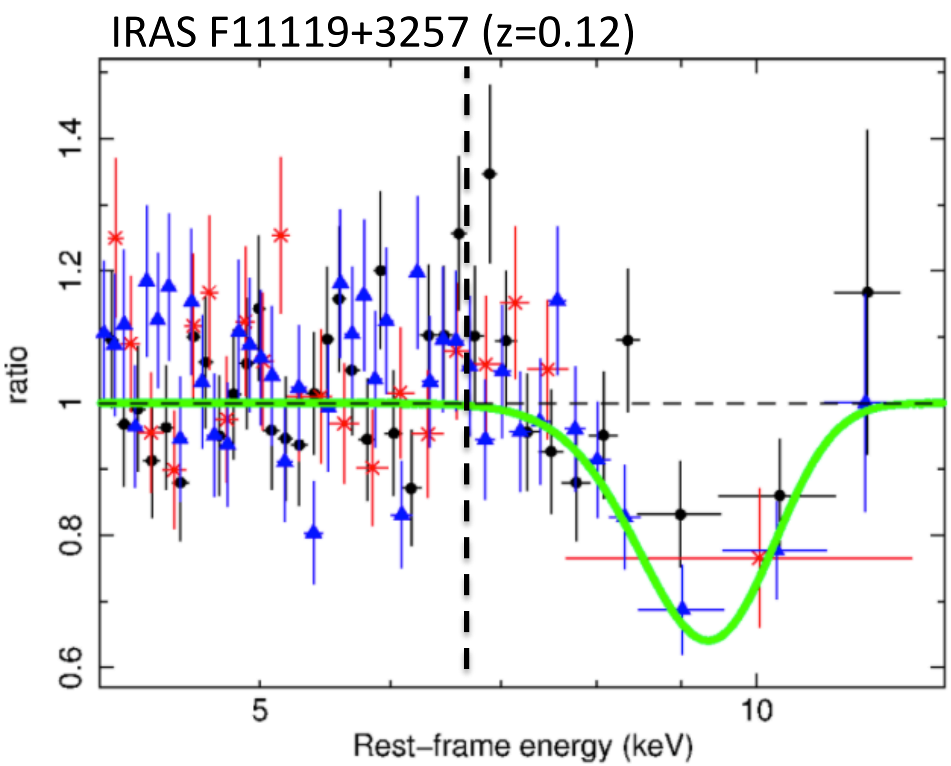
AGN-driven gas outflows extremely common
➔ interplay/feedback with ISM and IGM

How strong is this feedback?

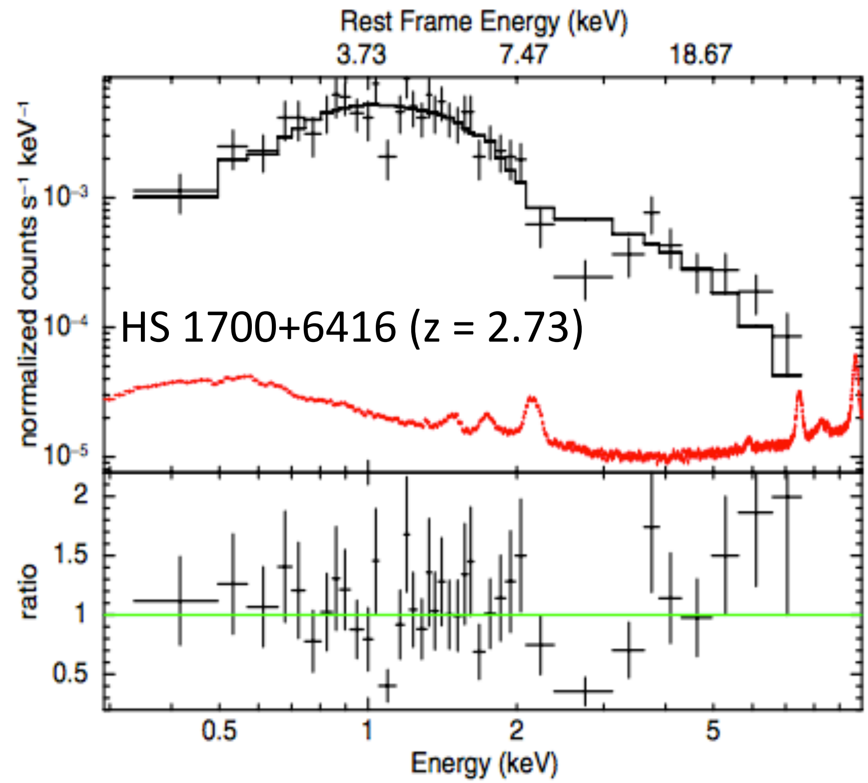
~1-30 kpc scales
Does it heat/expel the ISM halting star formation? (hence preventing the assembly of too big galaxies) . Does it alter the global structure of the host?

~30-1000 kpc scales
Does it affect the environment around QSOs (e.g. by heating the IGM)?

Outflows in AGN (highly ionized gas)



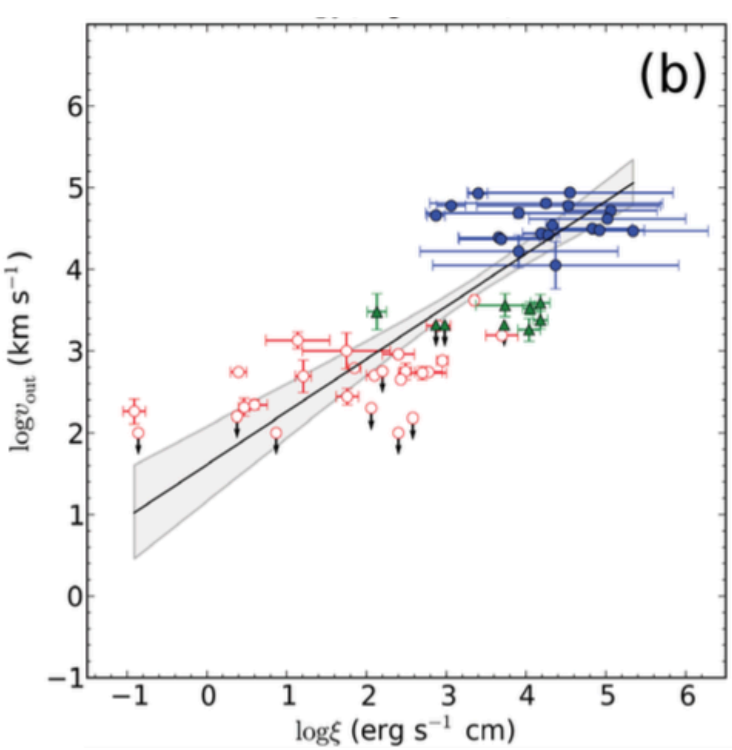
blueshifted FeXXV line at 0.3c

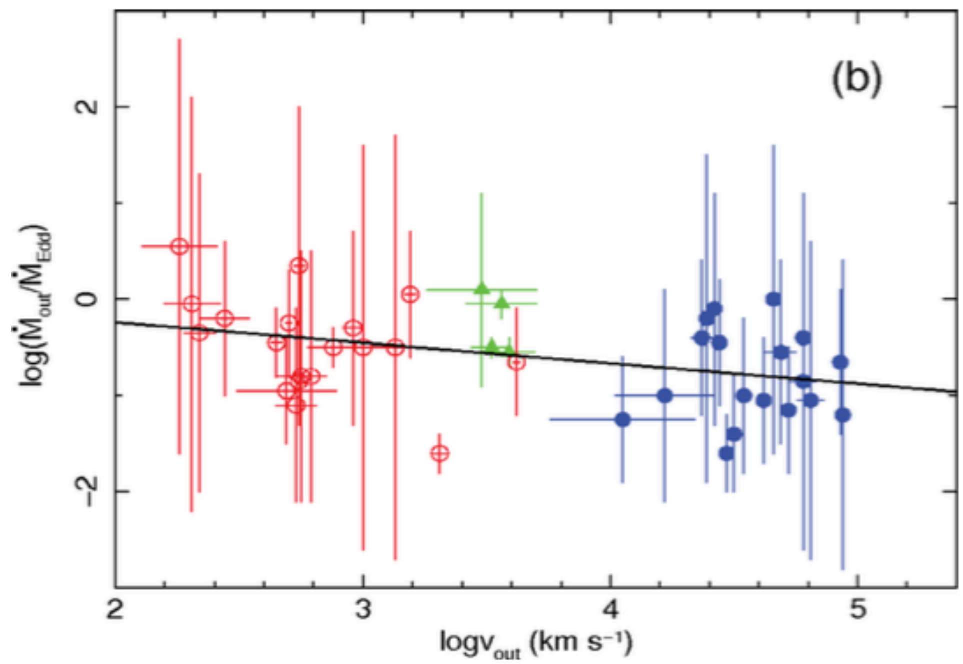


Lanzuisi et al. 2012

Tombesi et al. 2015, Nature

Outflows in AGN (highly ionized gas)



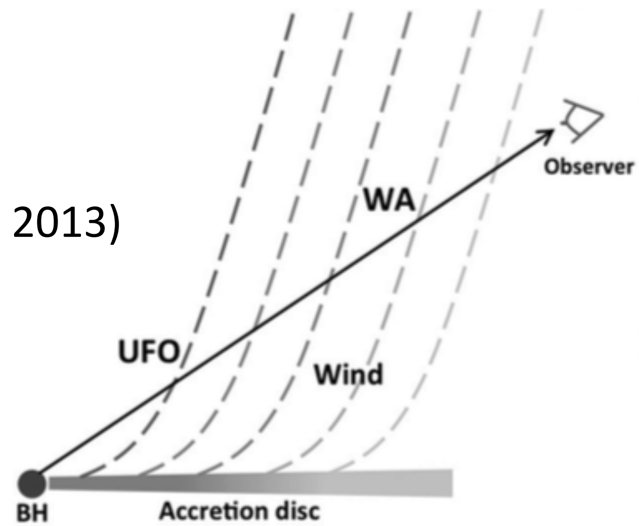


$dM_{out}/dt \sim 1\ M_{sun}/yr$

v_{out} up to ~0.3c for Ultra Fast Outflows (UFOs, Cappi et al. 2013)

UFOs: r ~ $1000r_g$ (~0.1 pc)

X-ray outflows present in >50% of local AGN



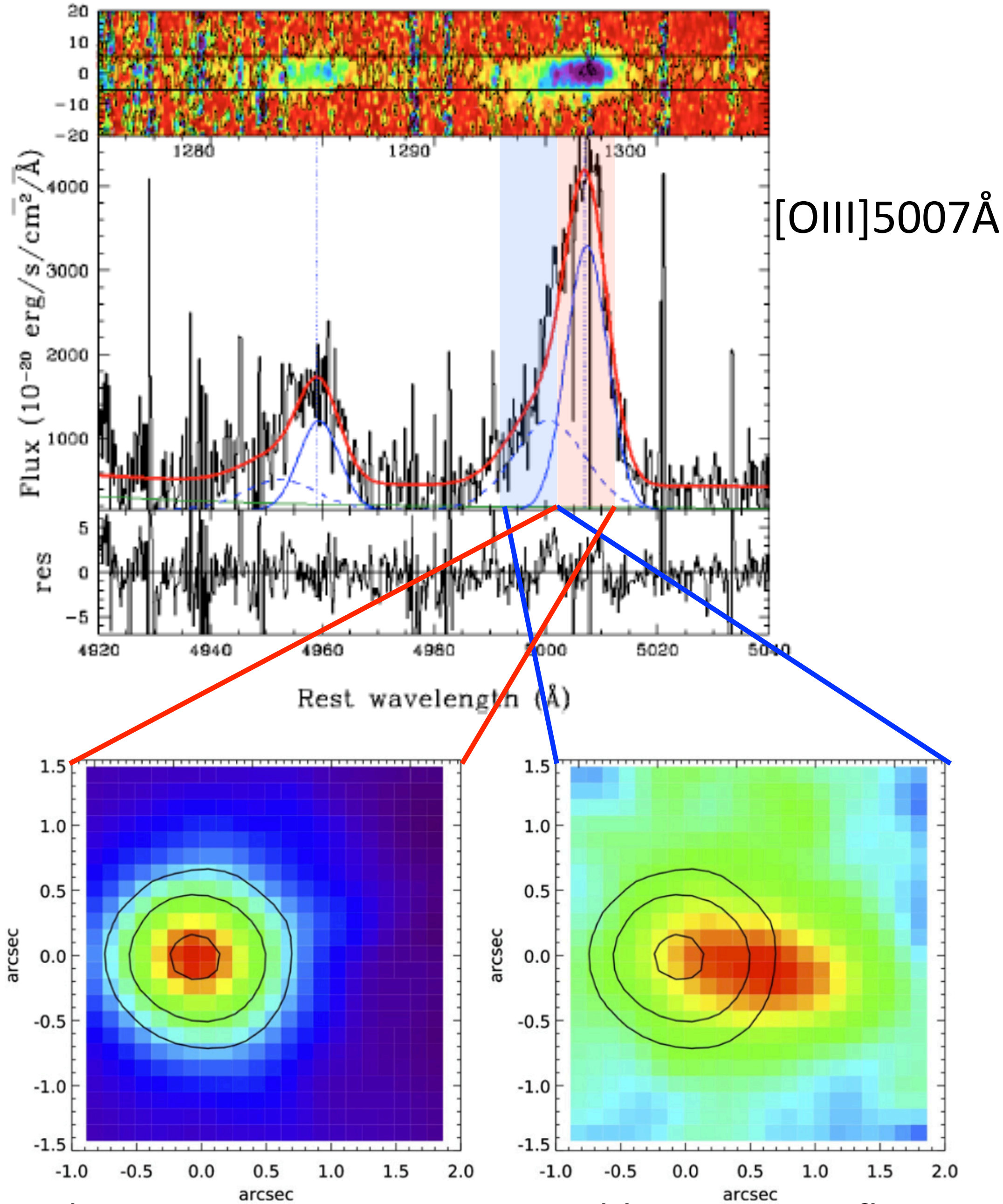
Tombesi et al. 2013

Outflows in AGN (ionized gas)

XID2028 @ z=1.59

v_{out}~ 1000 km/s
r_{out}~a few kpc scales
dM_{out}/dt~ 10-100 M_{sun}/yr

Brusa et al. 2014
Cresci et al. 2015
Perna et al. 2015

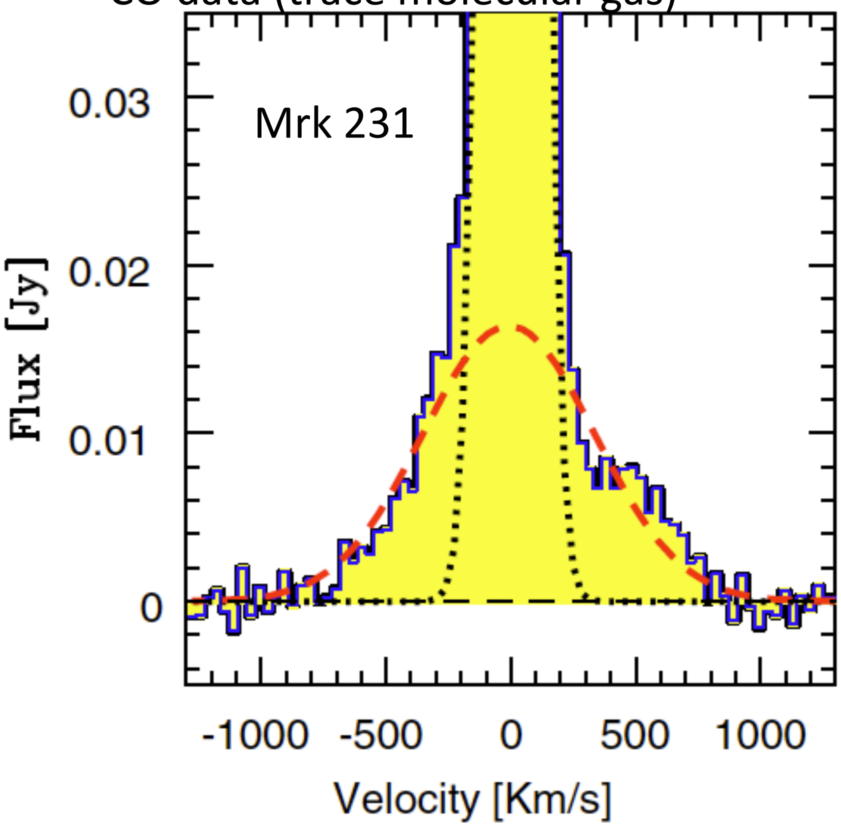


line core, rest

blue wing, outflow

Outflows in AGN (atomic and molecular gas)

CO data (trace molecular gas)

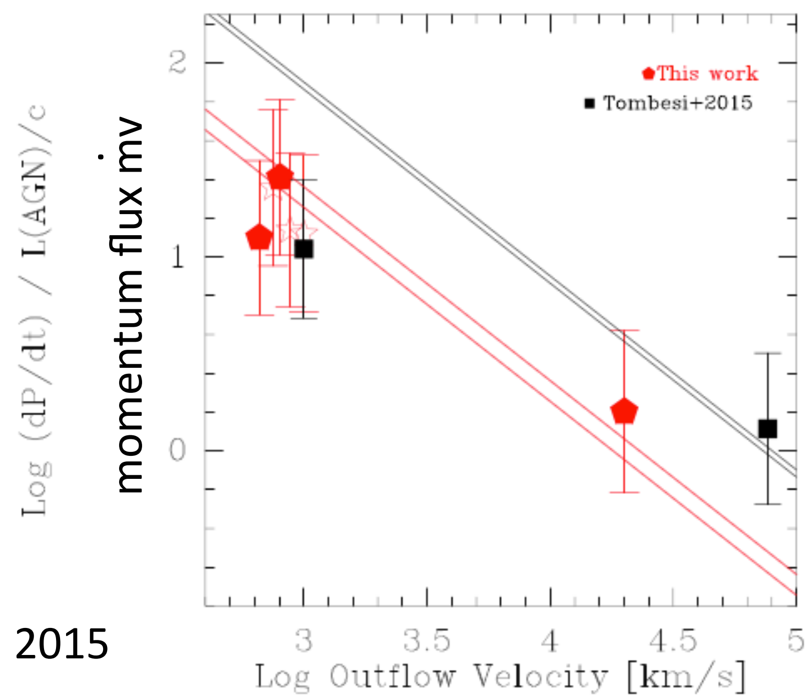


$FWHM_{broad}$~1000 km/s

Feruglio et al. 2010

Molecular outflows are the most massive
Outflow rates $\dot{m}_{out}$ > $10^{2\text{-}3}$ M_{sun}/yr ($\dot{m}_{out}$>~ SFR)
$M_{gas} = 10^{9\text{-}10}\, M_{sun}$
Gas depleted, i.e. SF shut in $t = M_{gas}/\dot{m}_{out} = 10^{6\text{-}8}$ yr

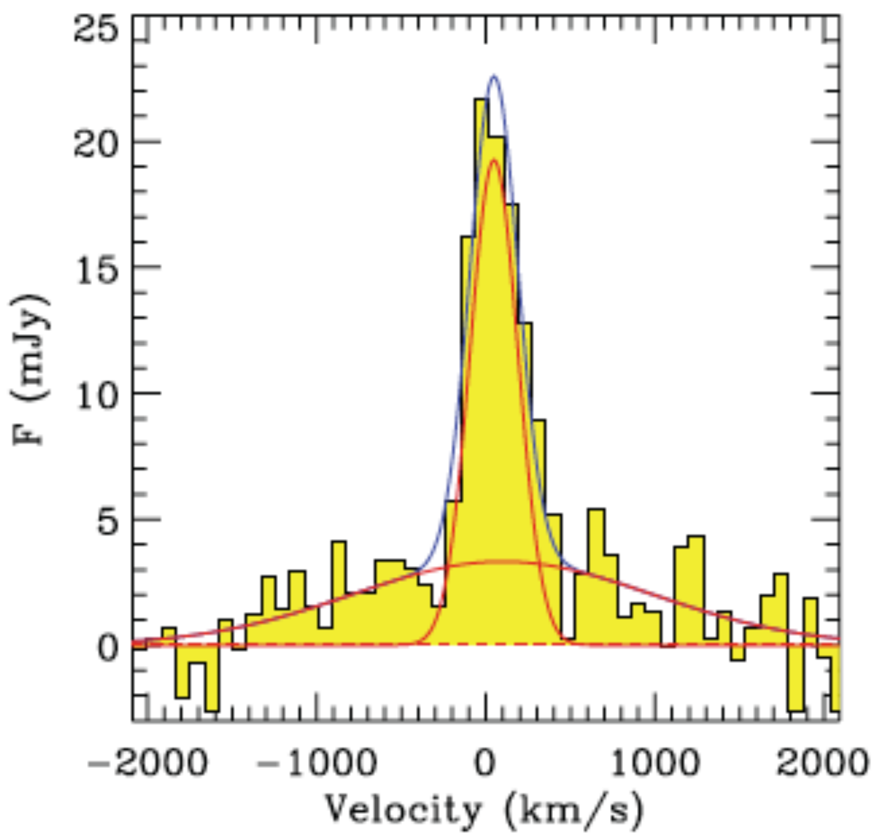
energy conserving: L_{kin}(UFO) ~ $L_{kin}(H_2)$



Feruglio et al. 2015

Outflows from SDSSJ1148 at z=6.42

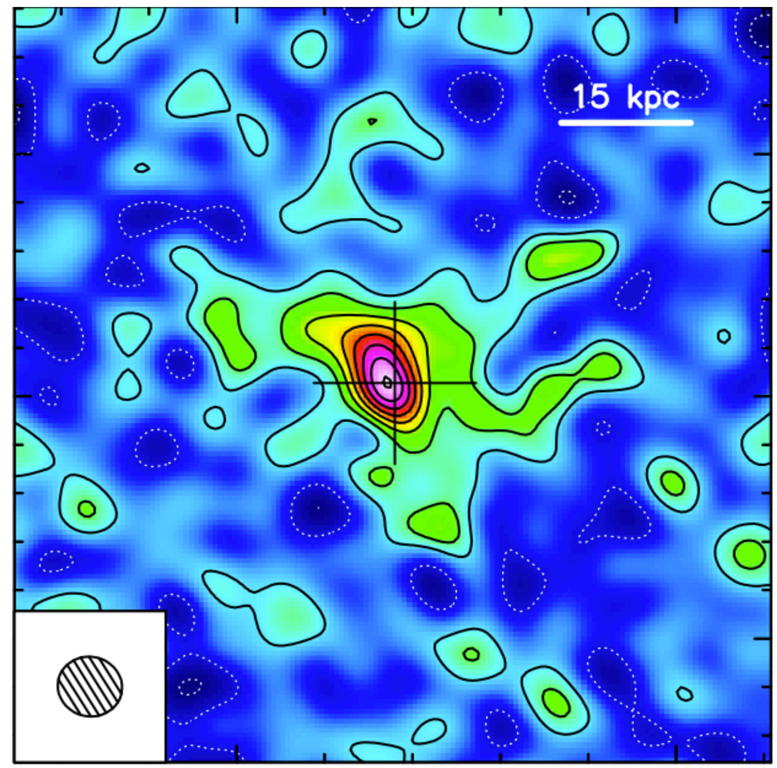
[CII]157μm (HI tracer)



$FWHM_{broad}$~1500 km/s

Maiolino et al. 2012

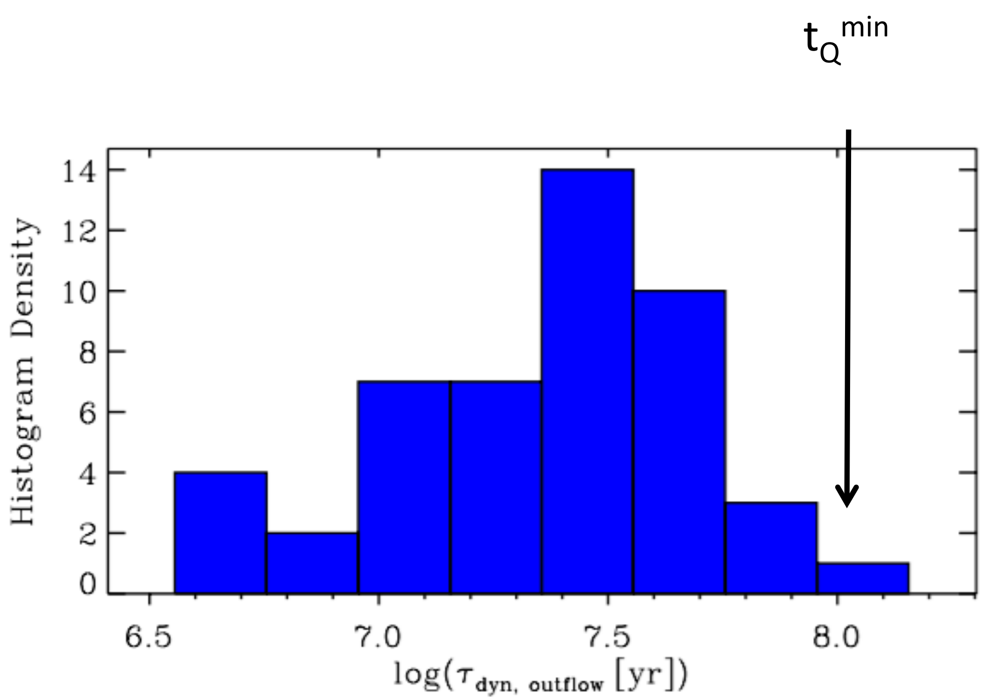
[CII] extended to 30 kpc



dM_{out}/dt >1400 M_{sun}/yr
v~1400 km/s
d > 1 Mpc in 10^9 yr

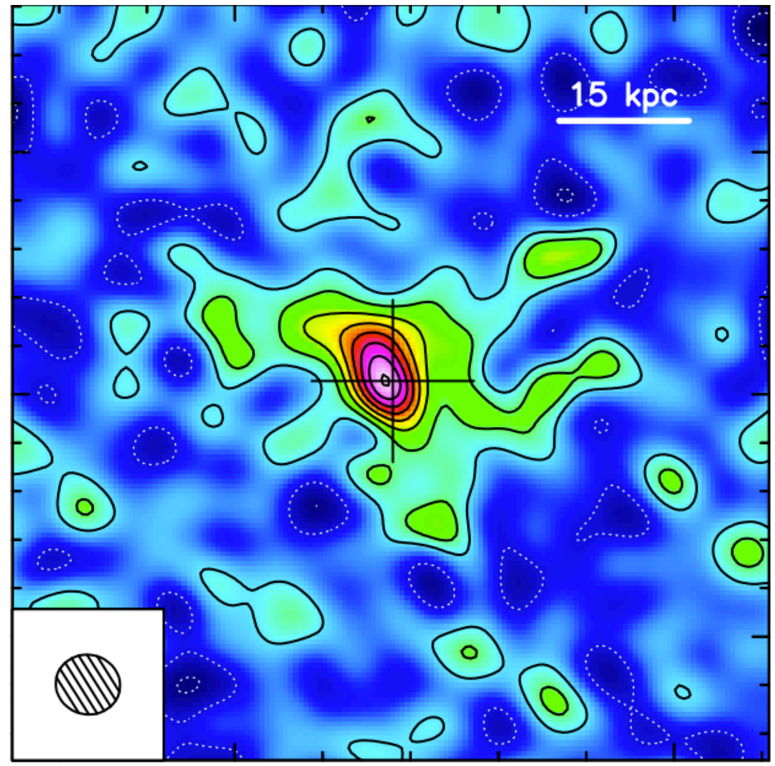
Cicone et al. 2015

Outflows from SDSSJ1148 at z=6.42



$\rightarrow$ QSO lifetime > 10^8 yr

[CII] extended to 30 kpc

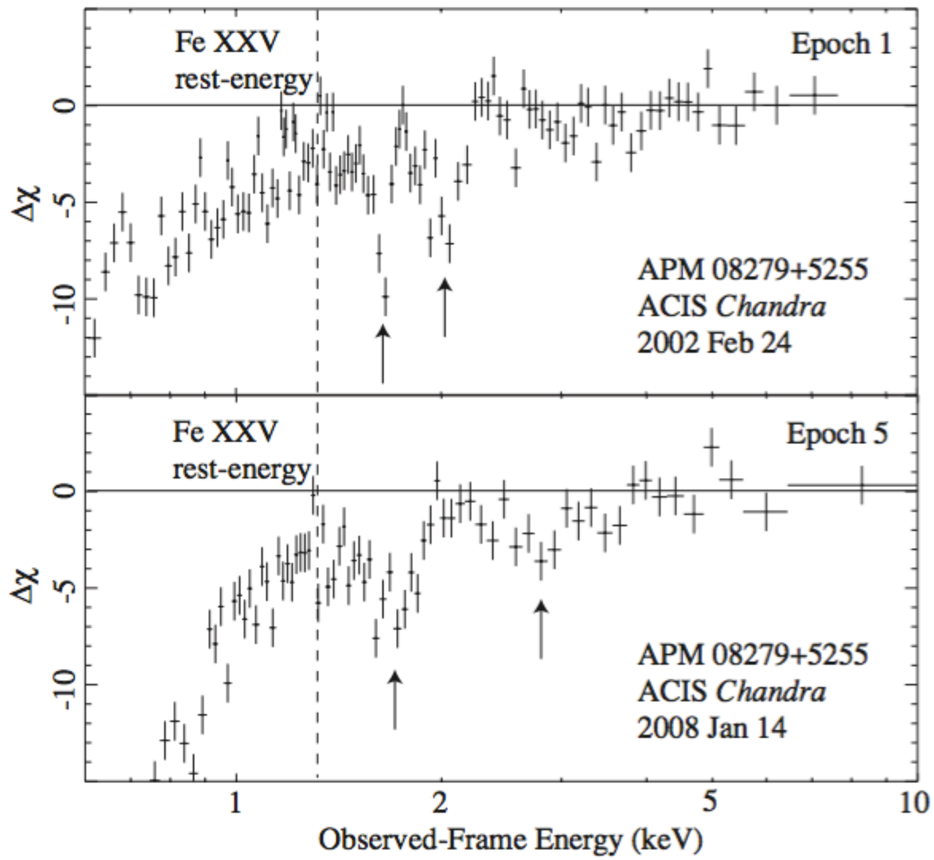


dM_{out}/dt >1400 M_{sun}/yr
v~1400 km/s
d > 1 Mpc in 10^9 yr

Cicone et al. 2015

UFOs in a high-z QSO

ultra-fast outflows
in a z=3.91, lensed QSO



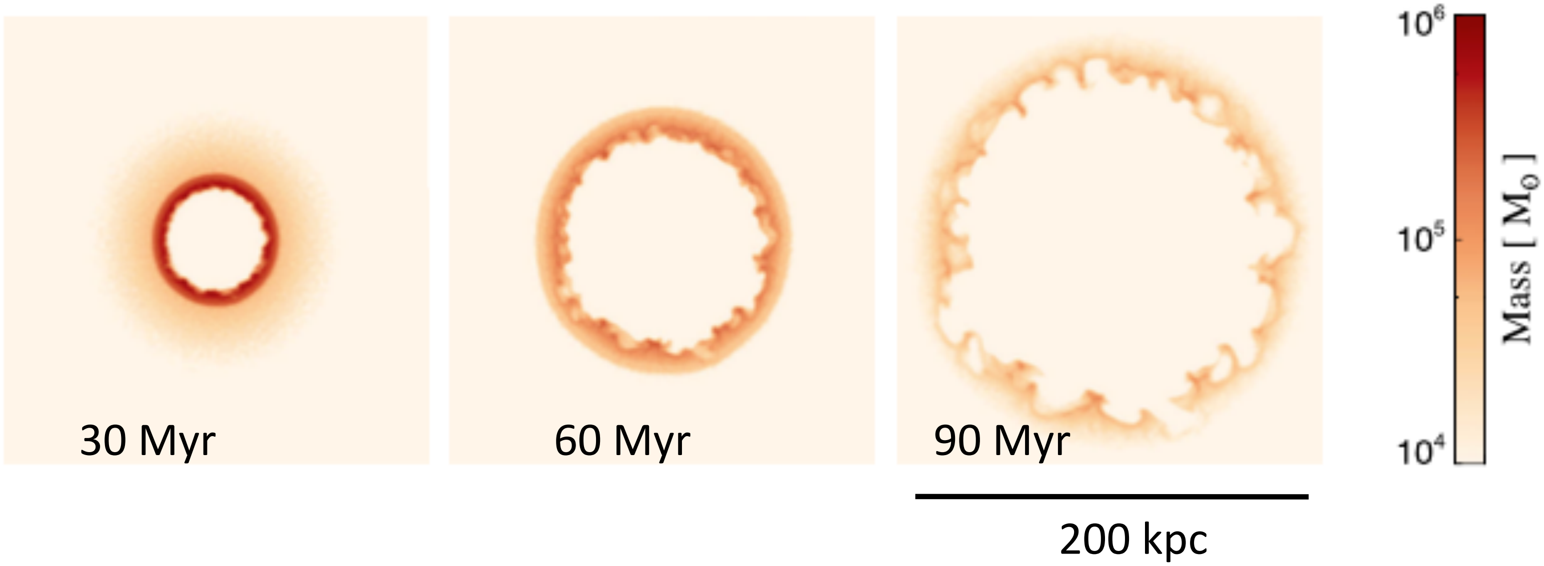
only this case known at z>3:

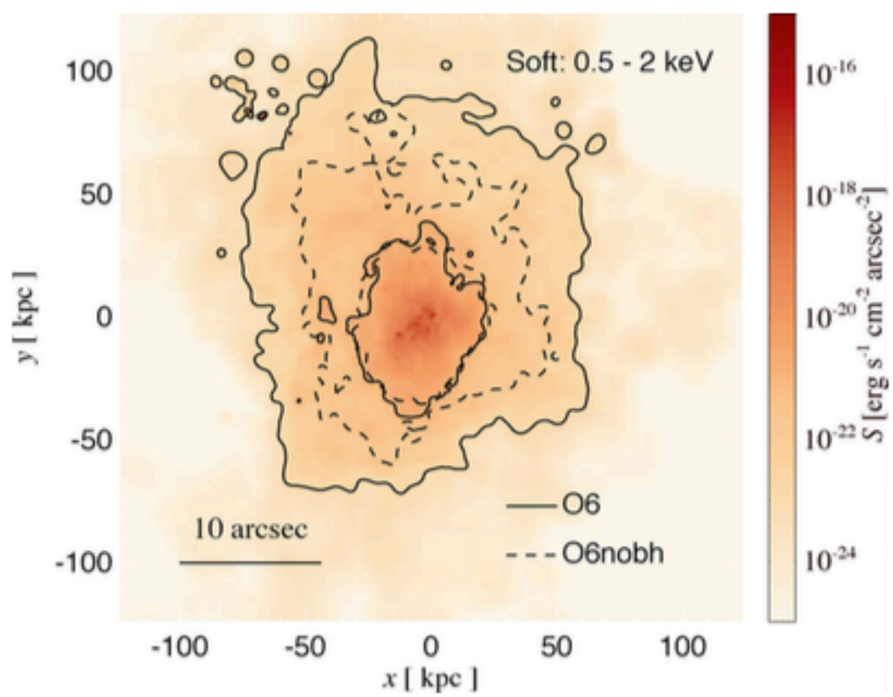
but difficult to observe:
need photon statistics and
lensing is effective but rare
➔UFOs likely abundant even
in high-z sources

v_{out} up to ~0.7c
from variability: r_{out}~$10R_g$

Chartas et al. 2009

Large-scale (0.1-1 Mpc) feedback





Costa et al. 2014 a,b

hot gas (T~10^{8-9} K) bubbles
gas heating up to a few x 100 kpc scales

effects on the environment?

Large-scale (0.1-1 Mpc) feedback

stacked thermal SZ signal from >26000 QSOs in the SDSS at z=0.1-3.0

5σ detection ➔ thermal energy injected by QSO winds (E_{tot})

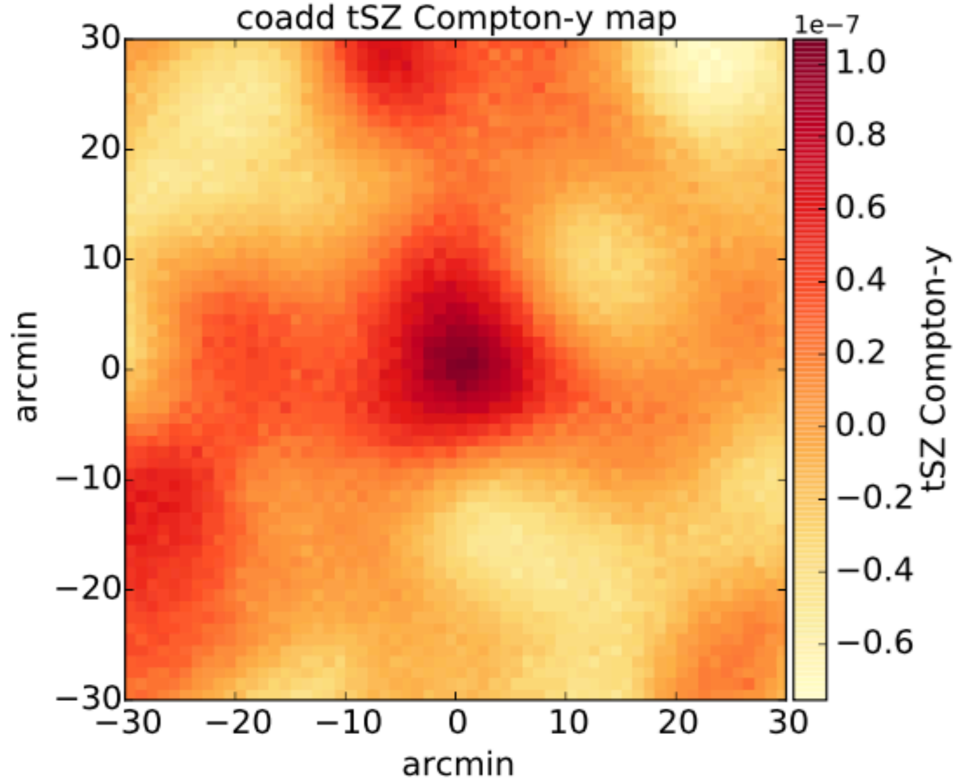
$$y(\hat{\mathbf{n}}) = \int n_e \sigma_T \frac{k_B T_e}{m_e c^2}\, \mathrm{d}l$$

$$Y(z) = D_A^2(z) \int y(\hat{\mathbf{n}})\, \mathrm{d}\Omega$$

$$E_e = \frac{3}{2} Y(z) m_e c^2 / \sigma_T$$

$$E_{tot} = (1 + \frac{1}{\mu_e}) E_e$$

FWHM ~ 10' (5 Mpc at z=1.5) signal unresolved



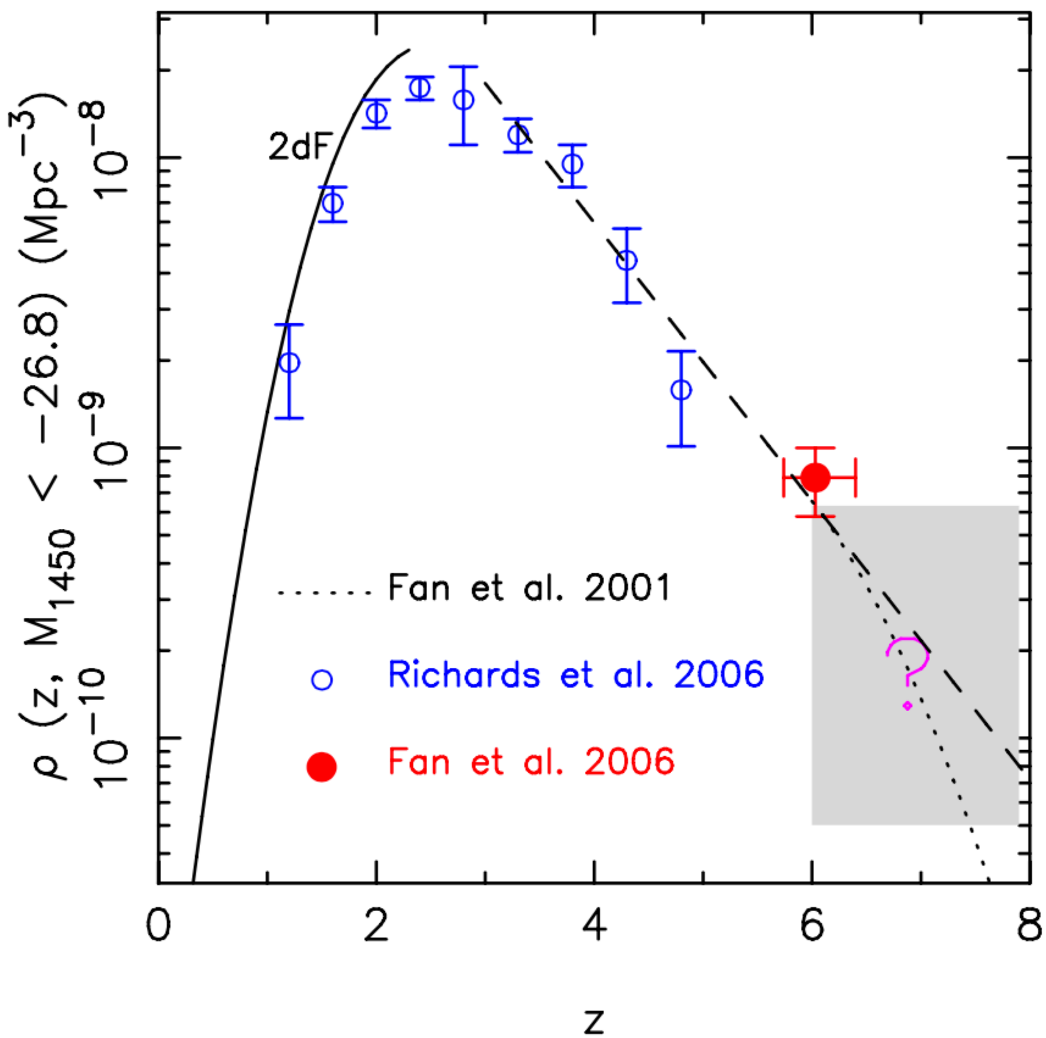
E_{tot} ~ 0.06-1 x 10^{62} erg per QSO

Ruan et al. (2015)

see also Crichton et al. 2015

The environment of early SMBHs

Early QSOs are rare



$M_{1450} < -27.8$

i.e.

$L_{bol} > 7.5 \times 10^{13}\ L_{sun}$

$M_{BH} > 2 \times 10^{9}\ \lambda_{Edd}^{-1}\ M_{sun}$

for duty cycle δ=1

1 SMBH/Gpc^3,

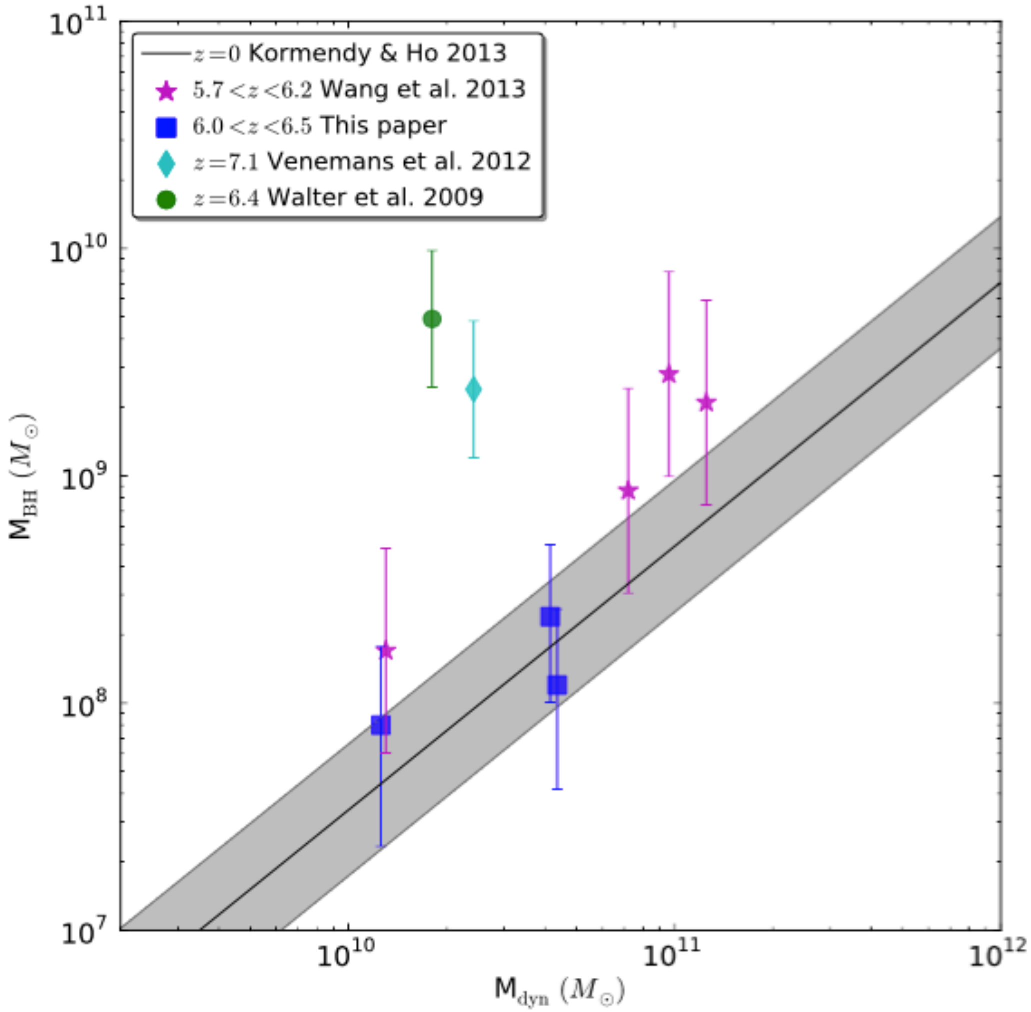
like $10^{13}\ M_{sun}$ DM halos

(for δ=0.03, i.e. 30 SMBHs/Gpc^3,

$M_{DMH} \sim 4 \times 10^{12}\ M_{sun}$)

Fan 2012

Early QSOs are massive systems

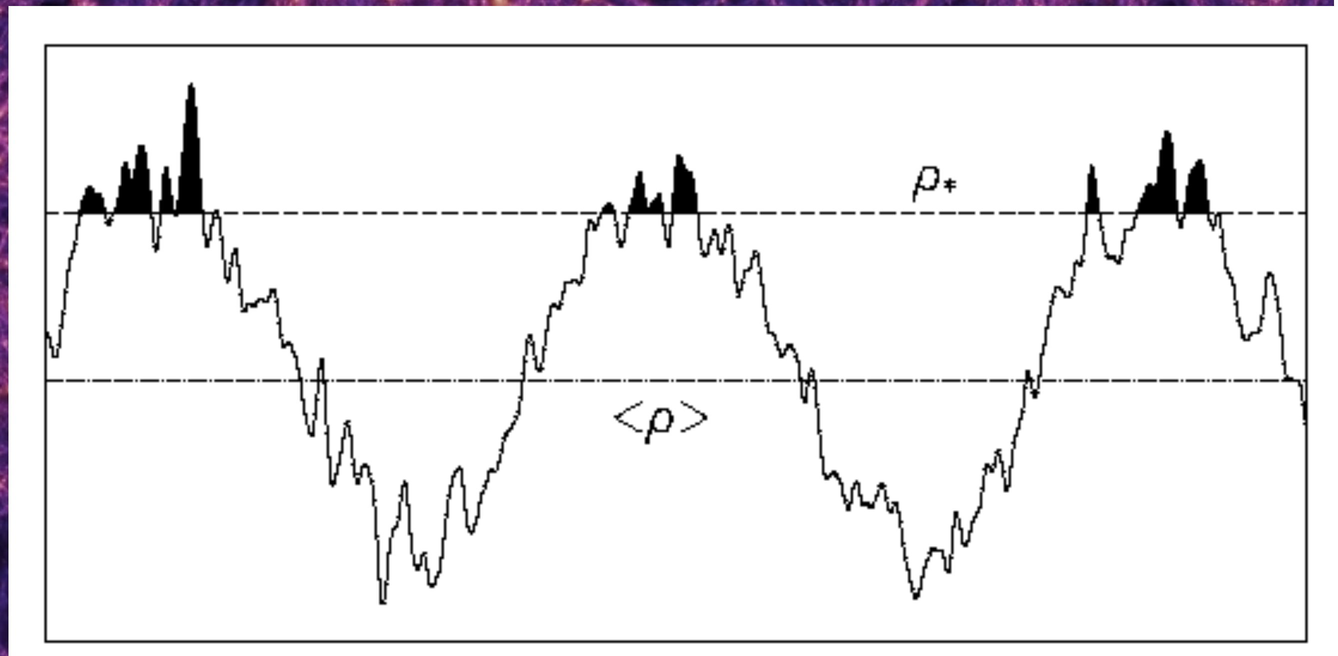


Willott et al. 2015

M_{BH} = 10^9 M_{sun} → M_* ~ 10^{11} M_{sun} → $M_{halo} > 10^{12}$ M_{sun}

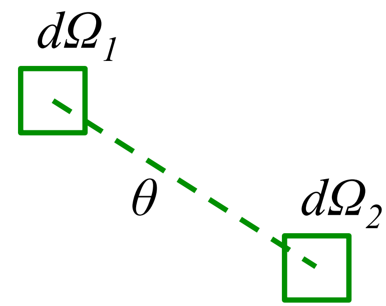
SMBHs powering z~6 QSOs are rare and big

If early SMBHs form in massive halos they should be highly clustered



Djorgovski 2005

Correlation function



angular correlation function w(θ)

$$dP = n^2[1 + w(\theta)]d\Omega_1 d\Omega_2$$

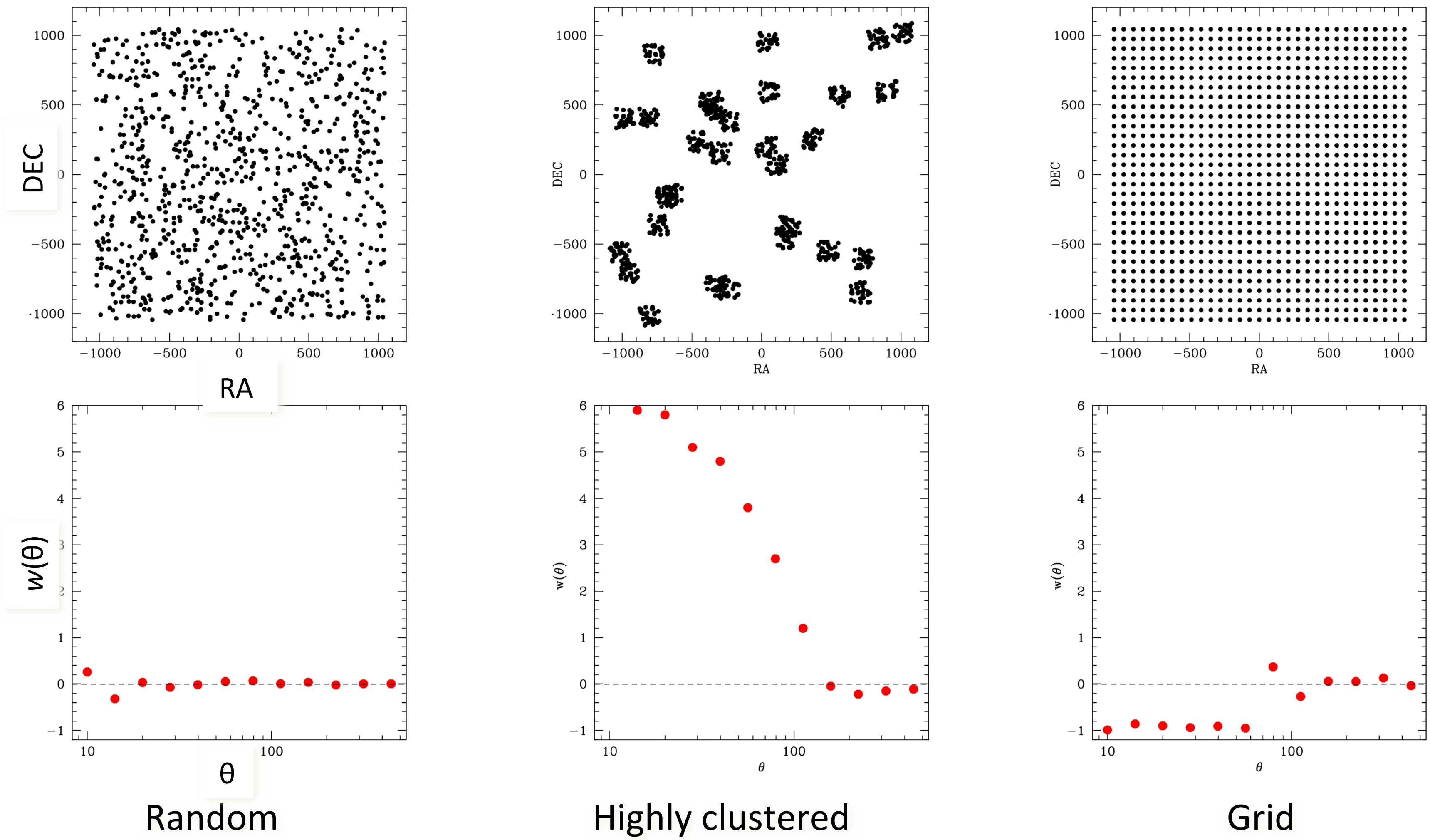
excess probability over random of finding one galaxy within the solid angle $d\Omega_1$ and another galaxy within $d\Omega_2$ separated by an angle θ

Spatial correlation function ξ(r)

$$dP = n^2[1 + \xi(r)]dV_1 dV_2$$

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

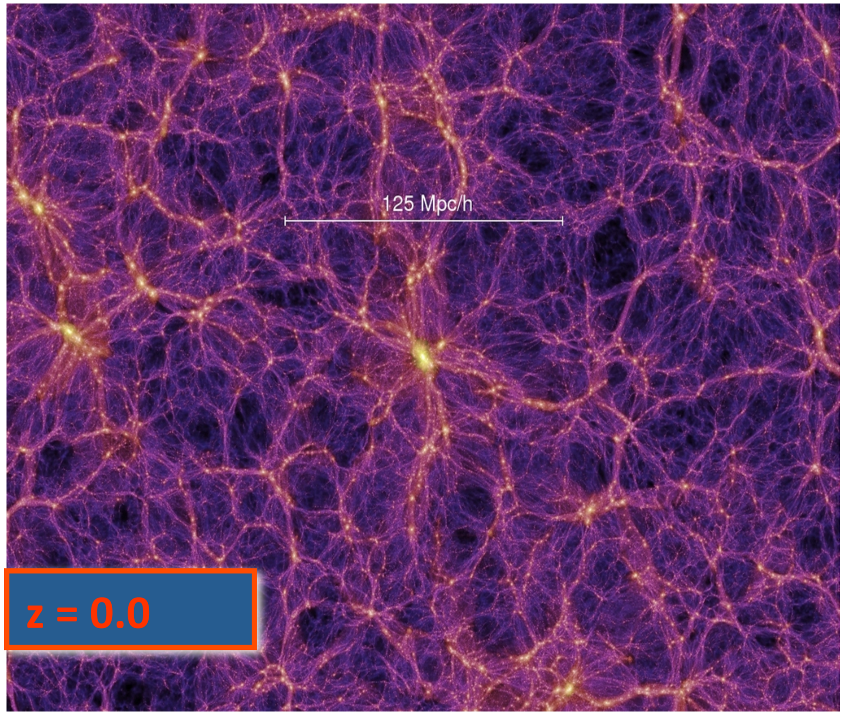
Some examples $dP = n^2[1 + w(\theta)]d\Omega_1 d\Omega_2$



Galaxy (or AGN) bias b

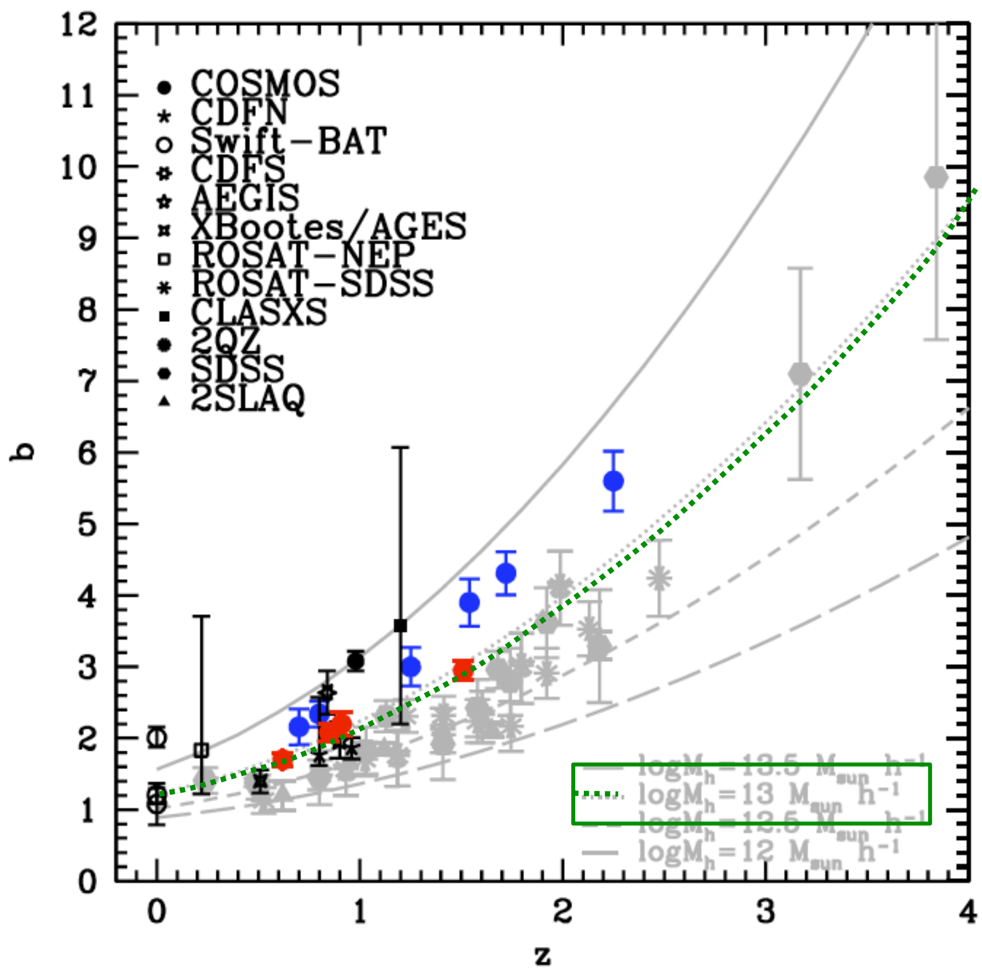
$$b^2(r, z, M) = \xi_g(r, z, M)/\xi_m(r, z)$$

ξ_g= galaxy (or AGN) corr. function ξ_m= dark matter corr. function



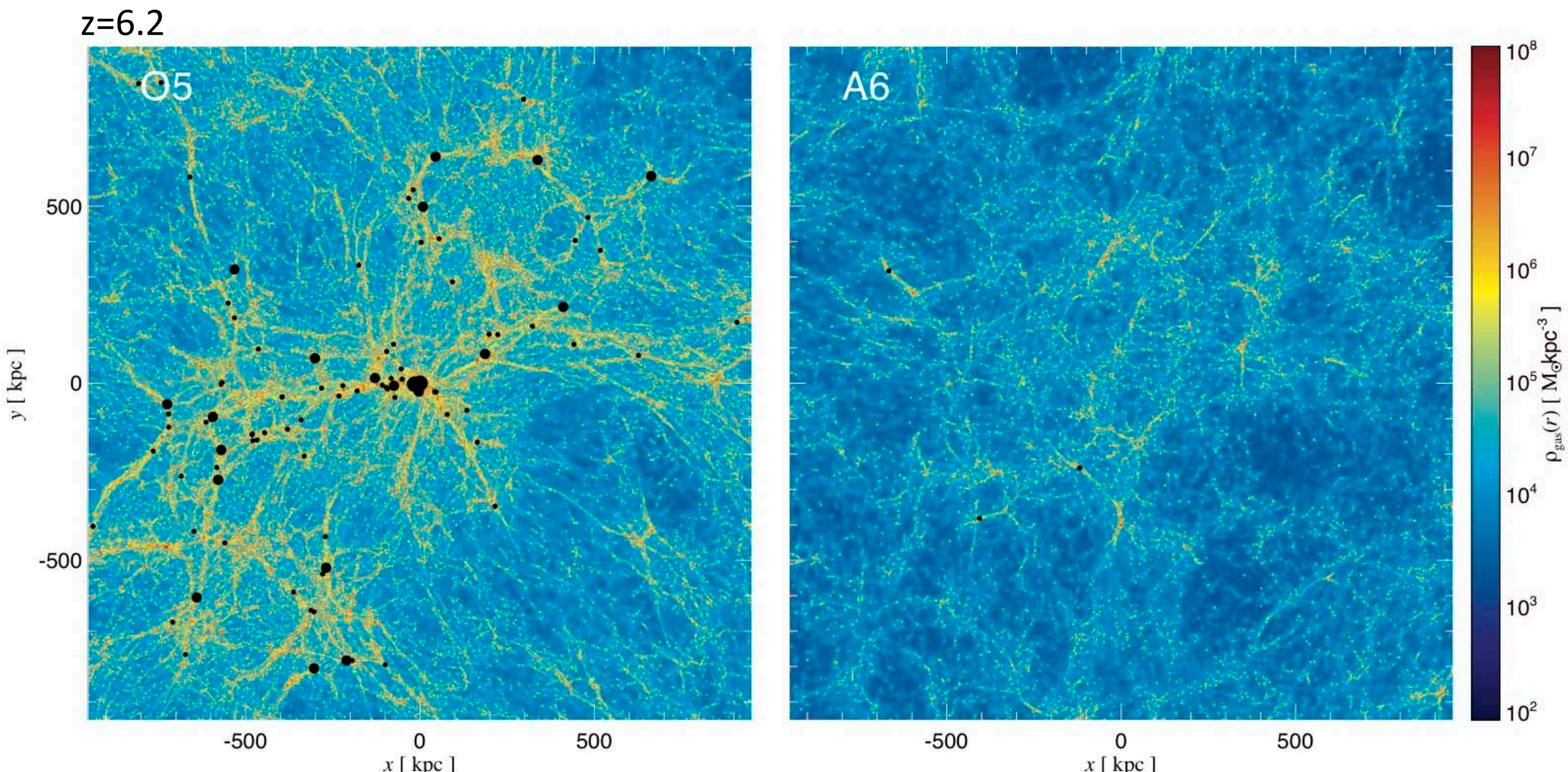
Extrapolating from z<4 suggests that early QSOs are likely highly biased and live in

halos with $M_{DMH} \sim 10^{13}\ M_{sun}$



Adapted from Cappelluti et al. 2012

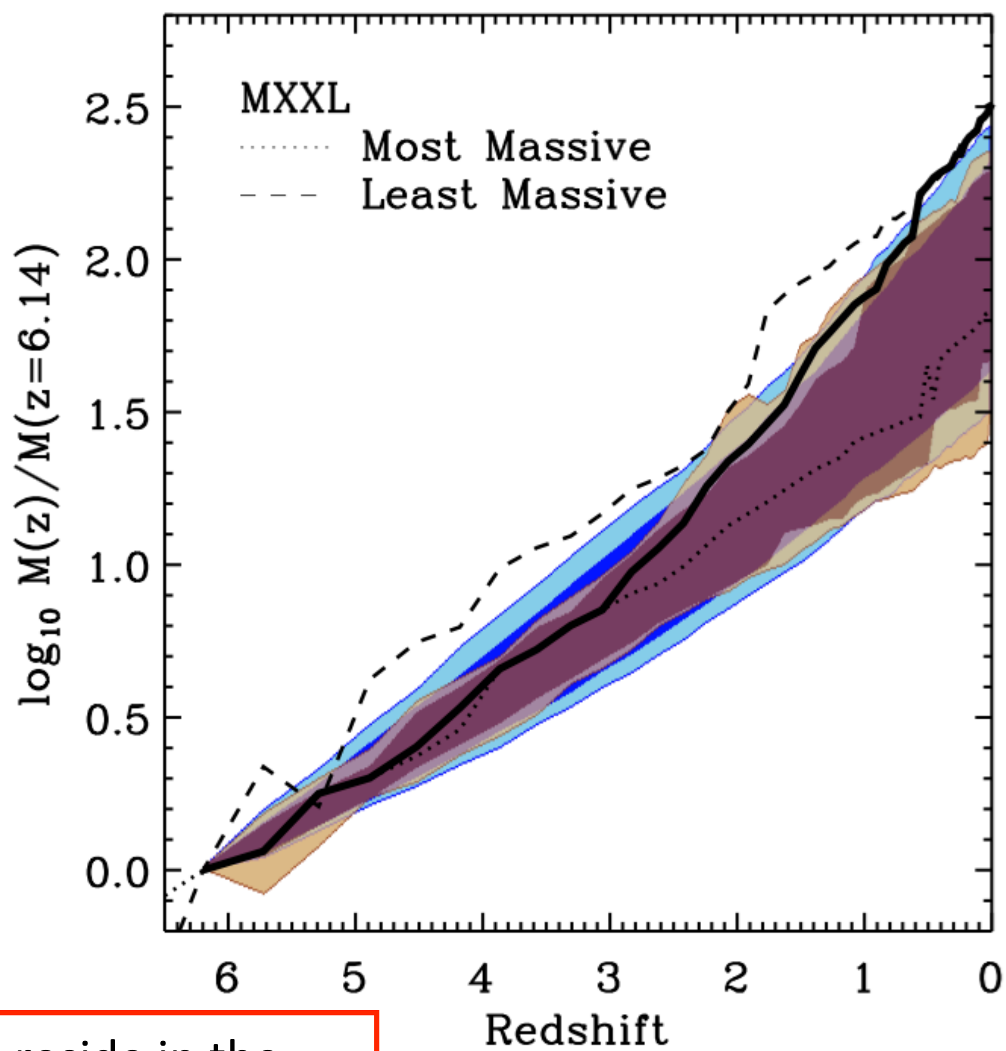
Simulations of early BH formation



Costa et al. 2014

According to (most) simulations, early SMBHs can only form in overdense environments

The fate of the most massive halos at z=6



broad range in mass of the descendants

average growth by two dex from z=6 to z=0
$10^{13}\ M_{sun} \rightarrow 10^{15}\ M_{sun}$
i.e. massive galaxy clusters

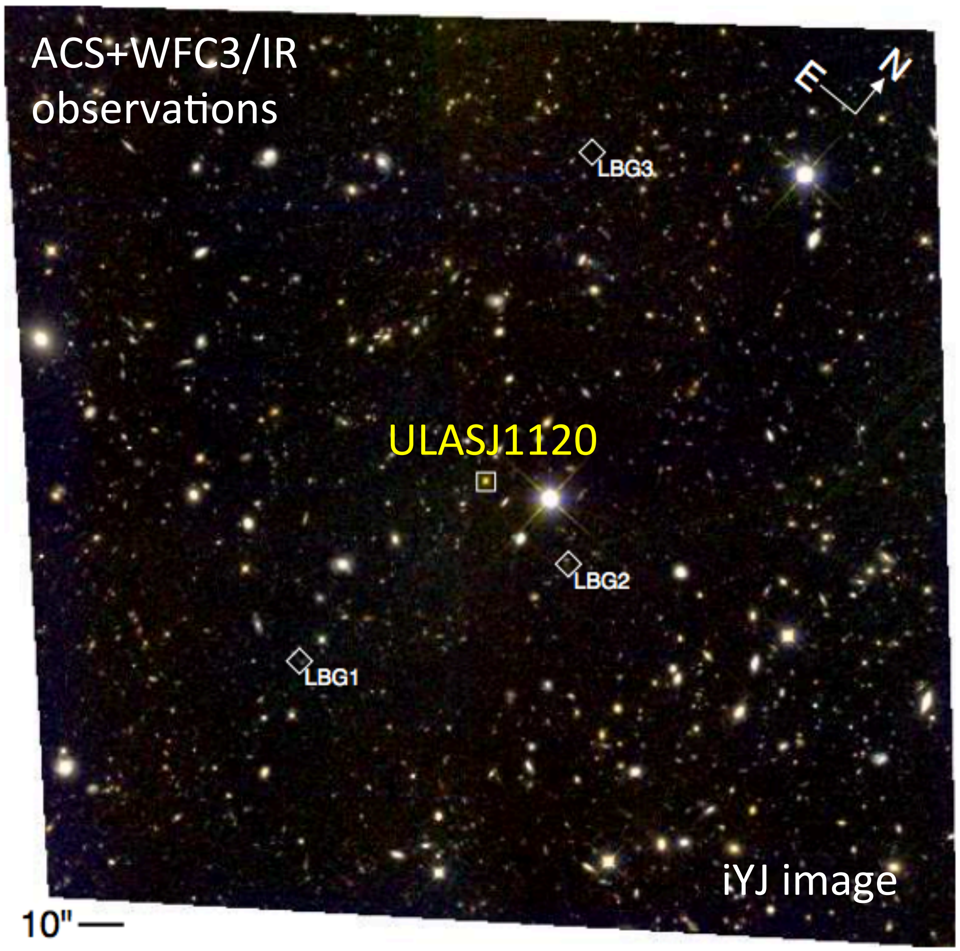
If early SMBHs reside in the most massive halos search for galaxy overdensities

Angulo et al. 2012

Galaxy overdensities around high-z QSOs

Search mostly based on small FoV instruments and inconclusive
e.g. ACS/HST = 3x3 arcmin^2 = 1x1 Mpc^2 at z=6.
(Stiavelli+05, Kim+09, Husband+13, Banados+13, Simpson+14)

1 physical Mpc

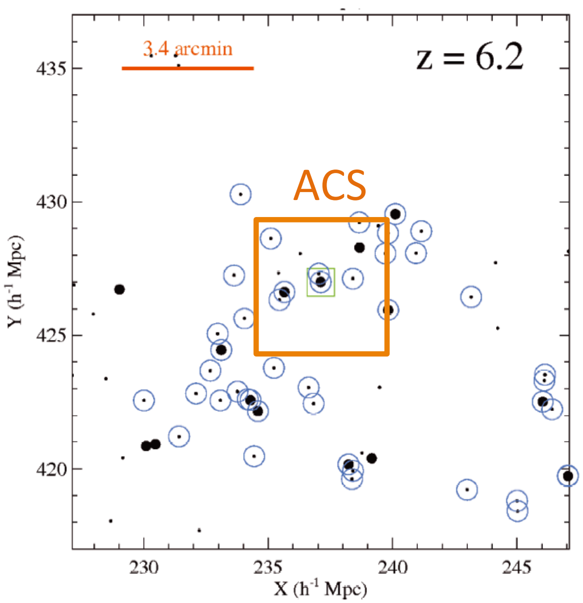


density of LBGs
similar to that in blank sky fields

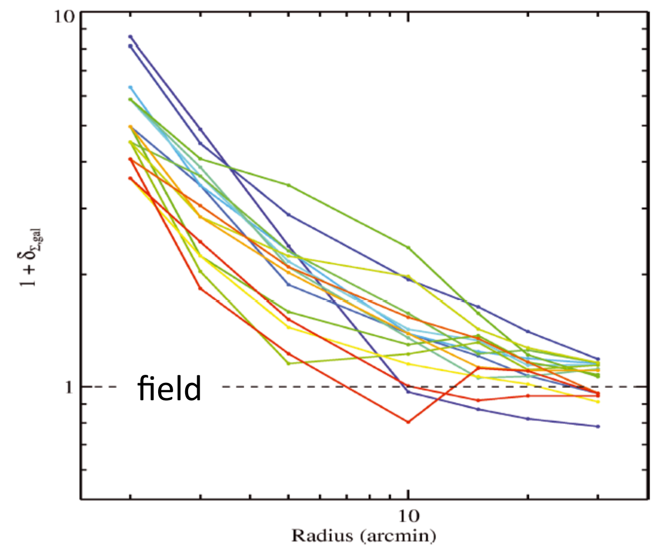
Simpson et al. 2014

Galaxy overdensities around high-z QSOs

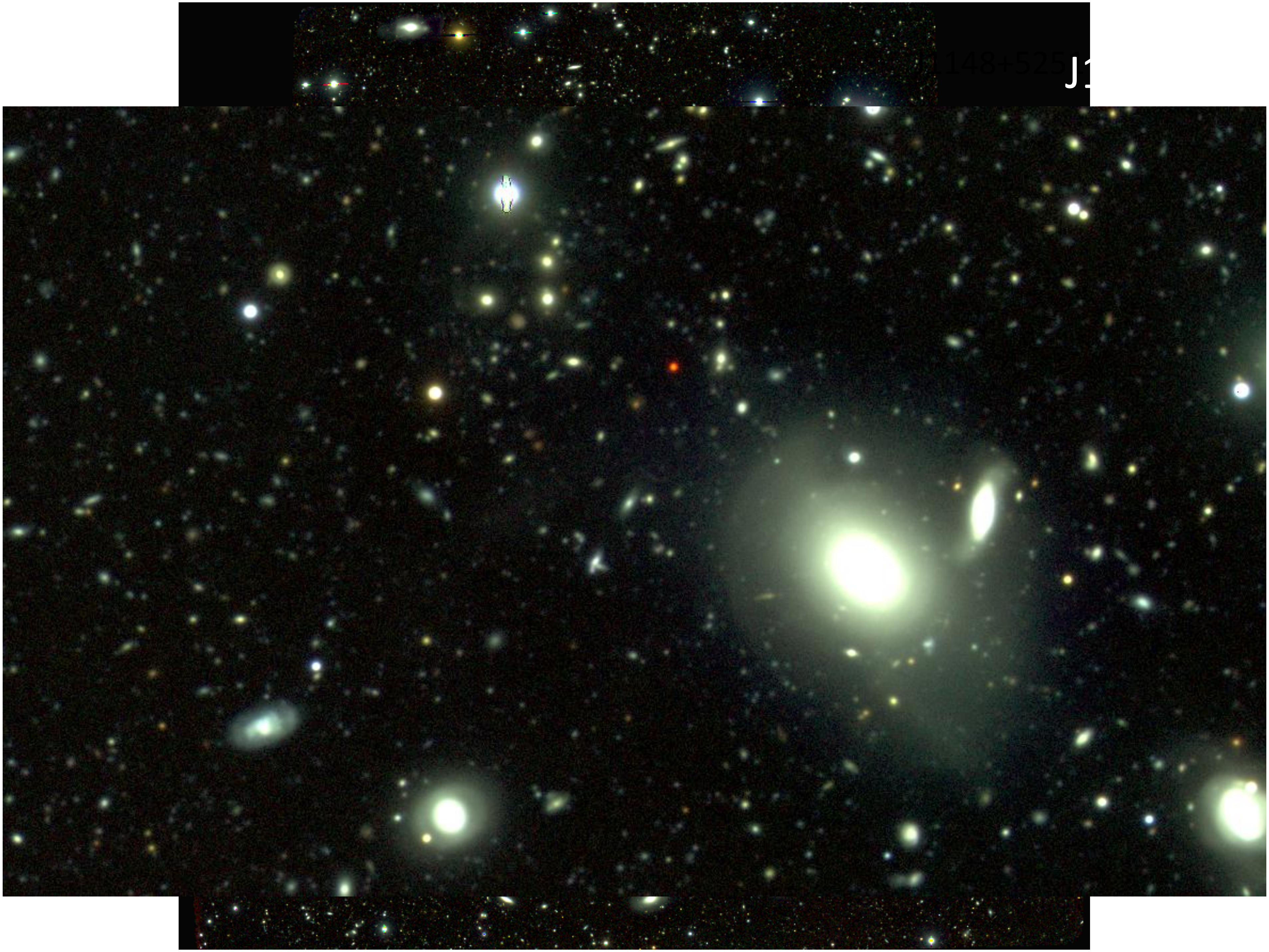
Overdensities might extend up to 30arcmin, i.e 10 phys. Mpc (Overzier+09). Feedback may limit galaxy formation in the QSO vicinity (e.g. Stroemgren radius ~ 2-4 Mpc)

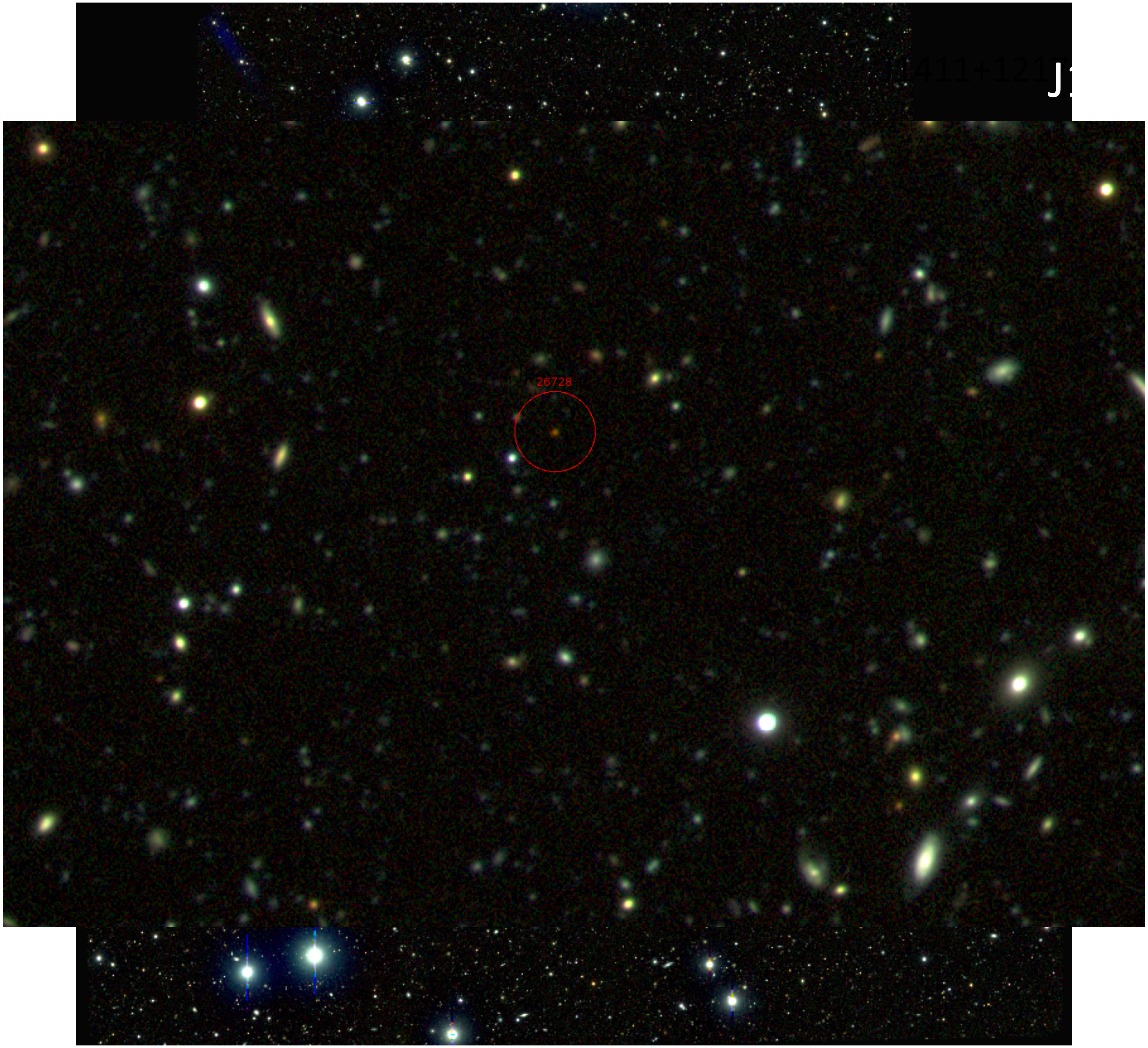


LSSs around protoclusters (Overzier+09)

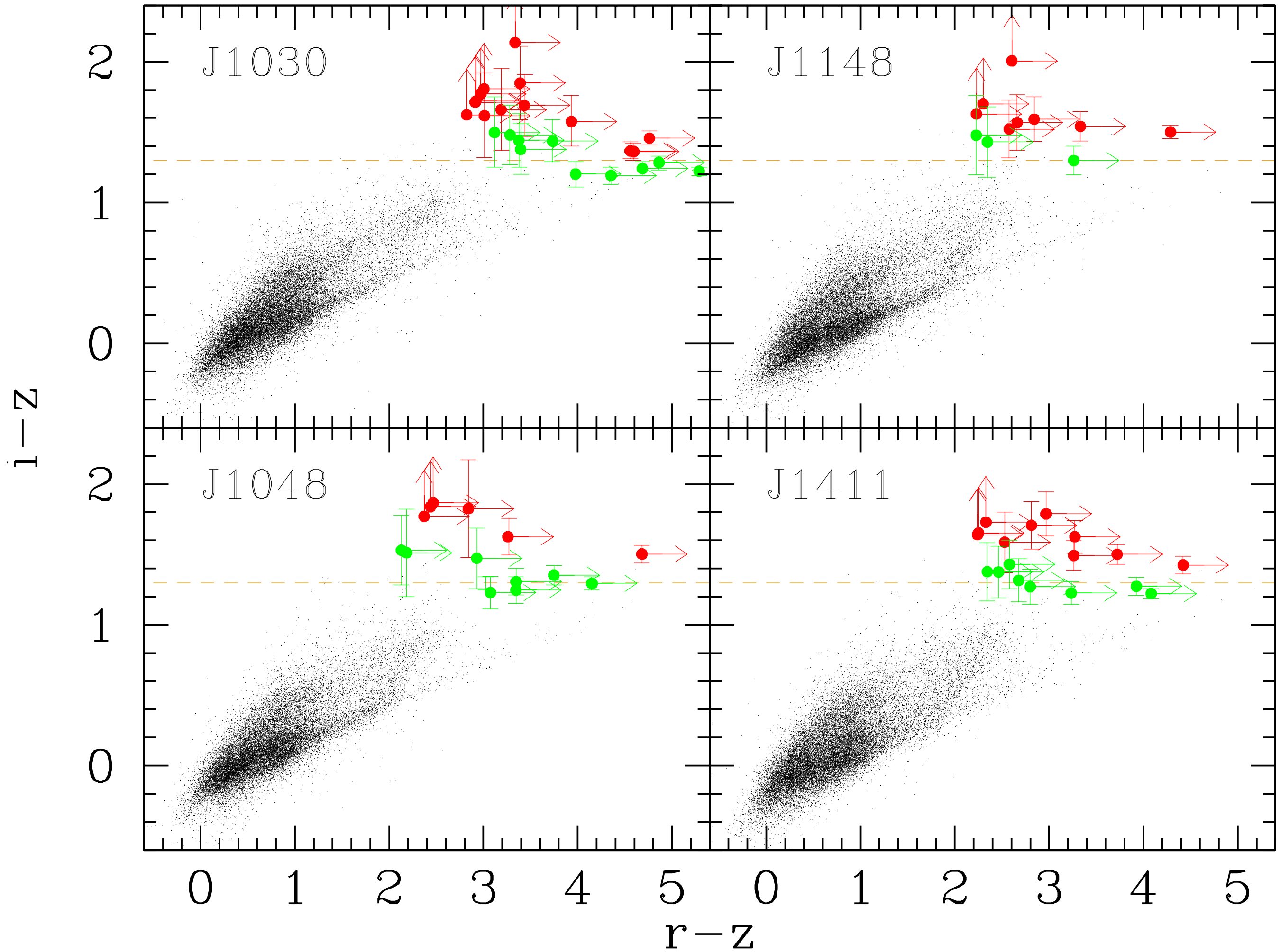


use LBC@LBT: FoV ~ 25'x25' → 8x8 physical Mpc^2 at z=6




26728

i-band dropout selection



Dropouts:

$z_{AUTO} < 25$
$r_{ape} > 27.2$

Primary
$(i\text{-}z) - \sigma_{(i\text{-}z)} > 1.3$

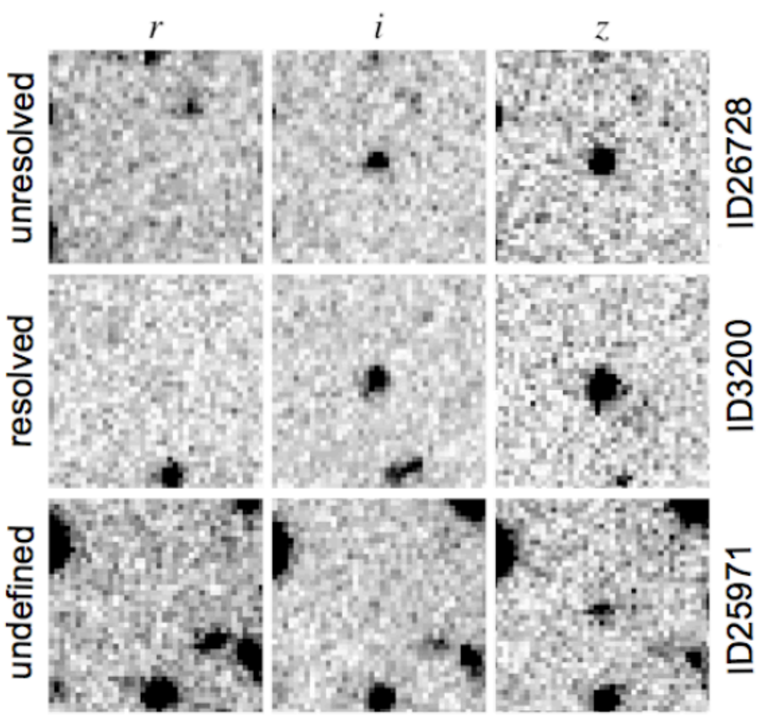
Secondary
$1.1 < (i\text{-}z) - \sigma_{(i\text{-}z)} < 1.3$

Comparison
$i\text{-}z > 1.4$

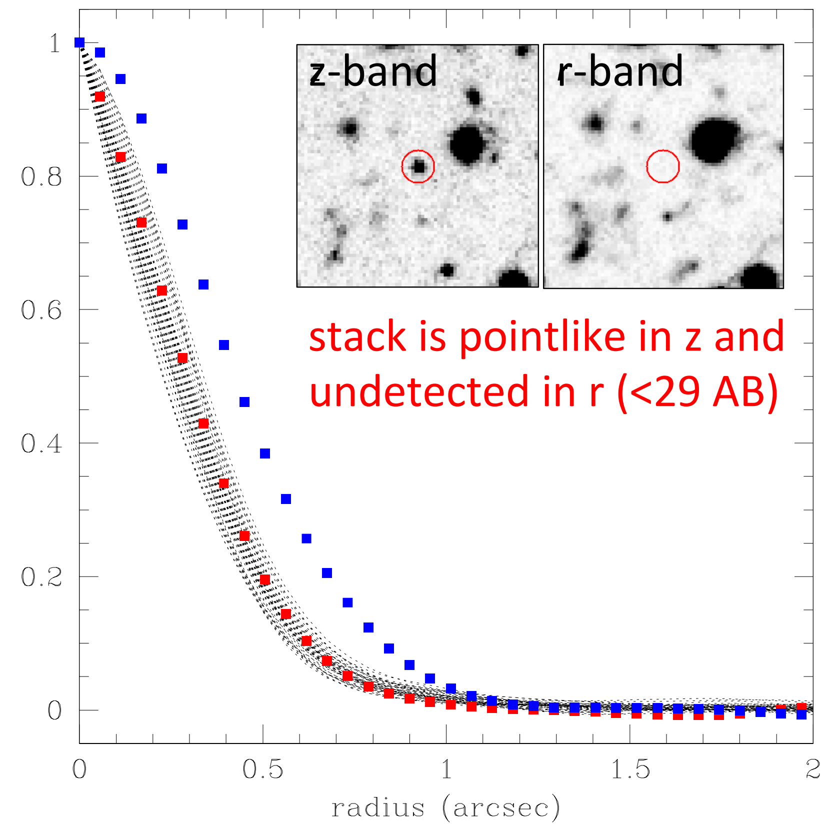
spurious candidates removed after visual inspecion

Dropout summary table

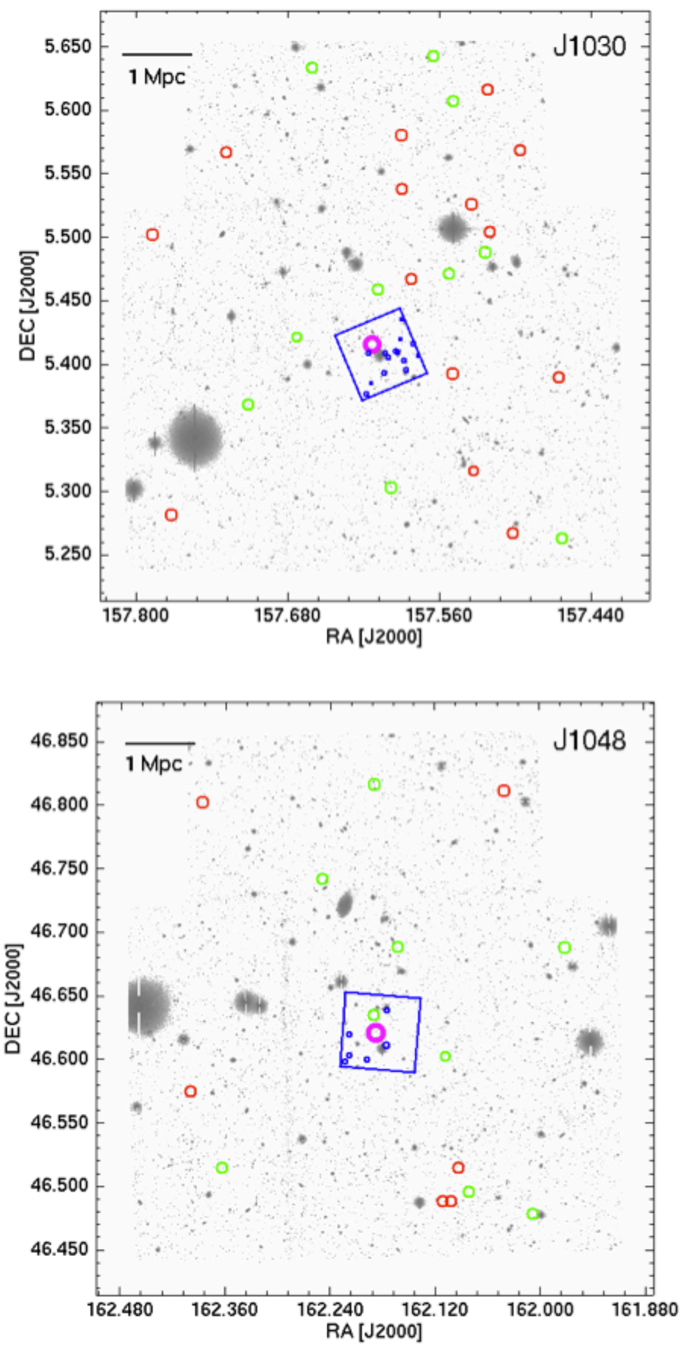
Field	Primary	Secondary
J1030	14	10
J1148	8	3
J1048	6	9
J1411	11	8



Stack of dropouts in J1030



comparison sample: same color and mag range (but detected in r band)



Primary cand.

Secondary cand.

HST/ACS

QSO

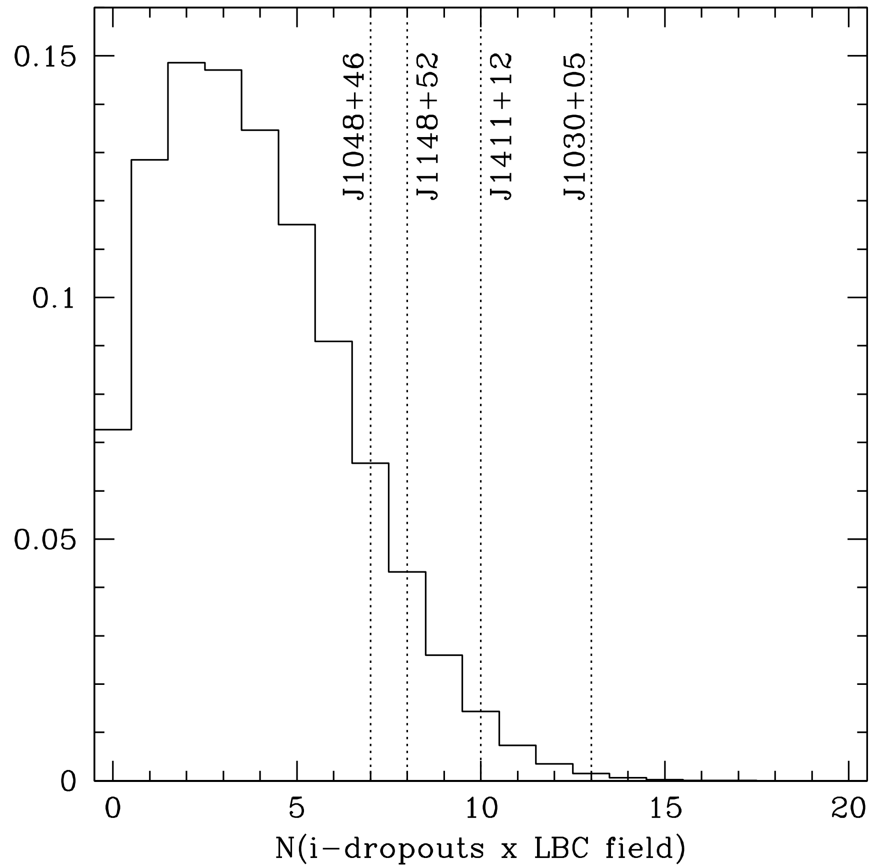
Significant overdensities

Asymmetric distribution in most fields in agreement with simulations

Dropout overdensities

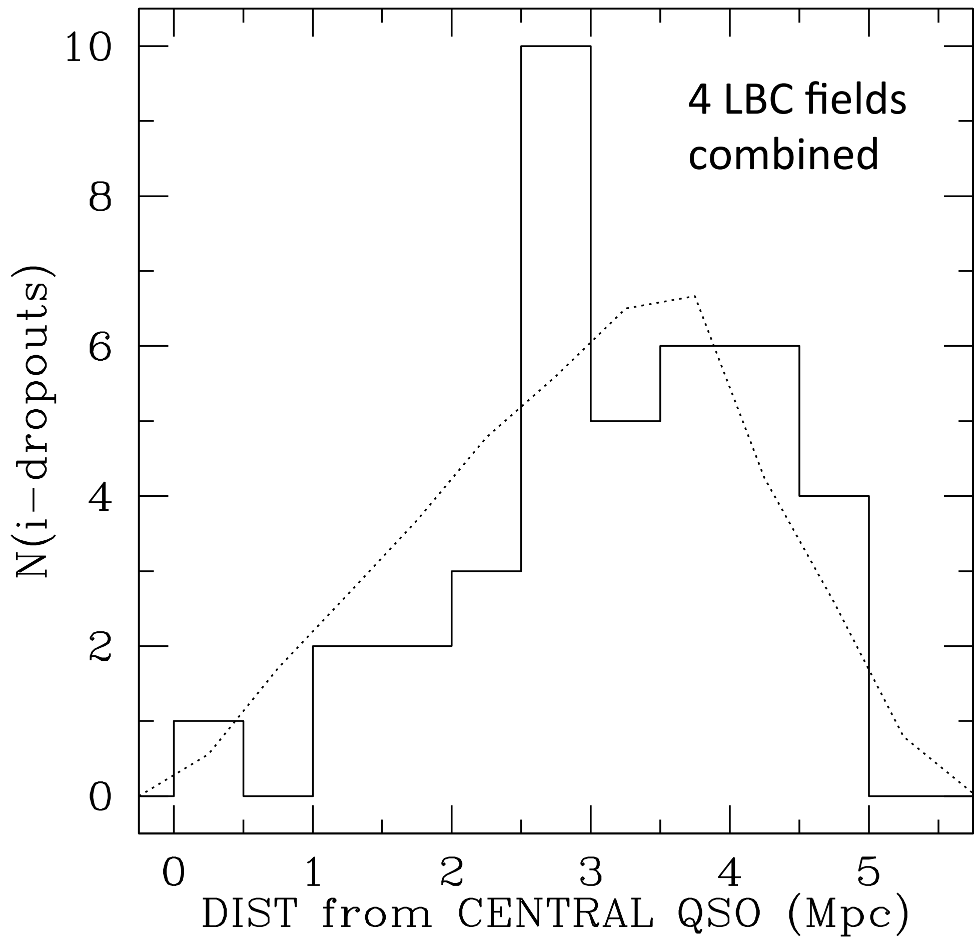
SXDS dropouts visually inspected
and corrected for incompleteness

Field	i-drop-obs.	i-drop corr.	δ	σ_δ
J1030	16	13	2.0	3.3
J1148	10	8	0.9	1.9
J1048	9	7	0.6	1.7
J1411	12	10	1.3	2.5
SXDS		4.3		

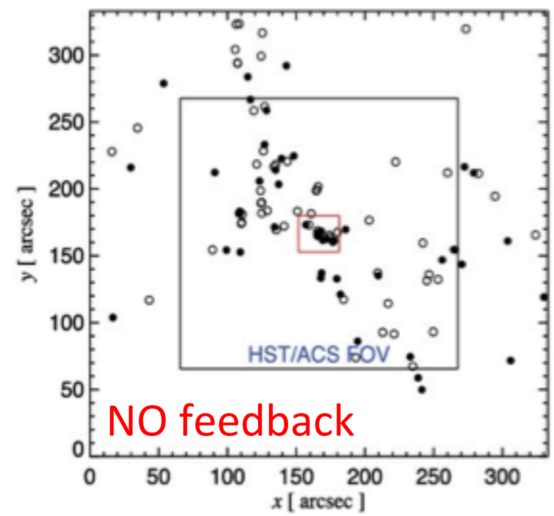


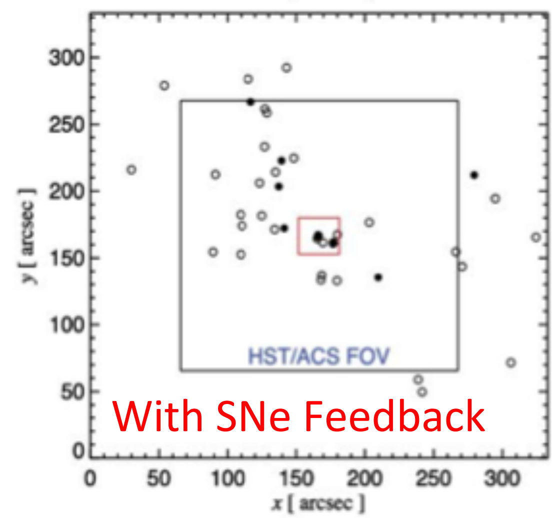
The estimated significances account for cosmic variance and photometric errors.
Combined significance: 3.7σ

Radial distribution of dropouts



Simulation by Costa+14



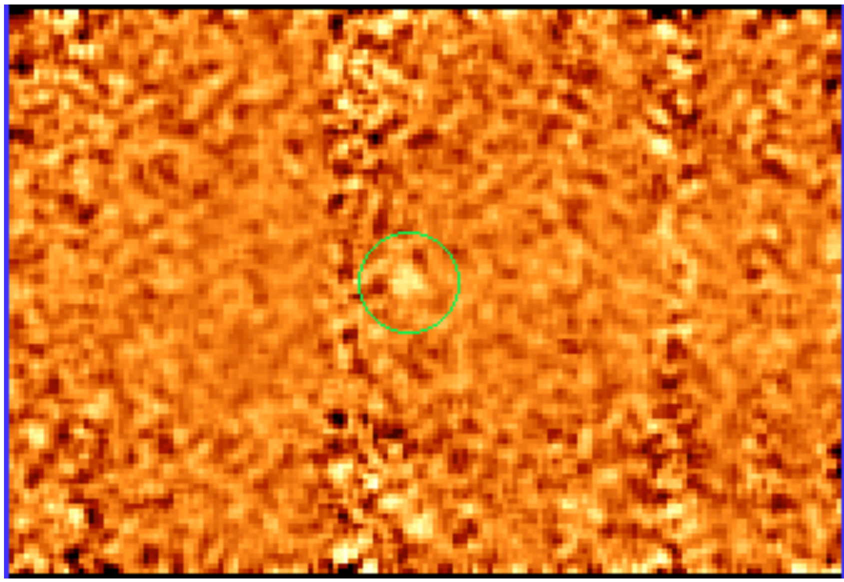


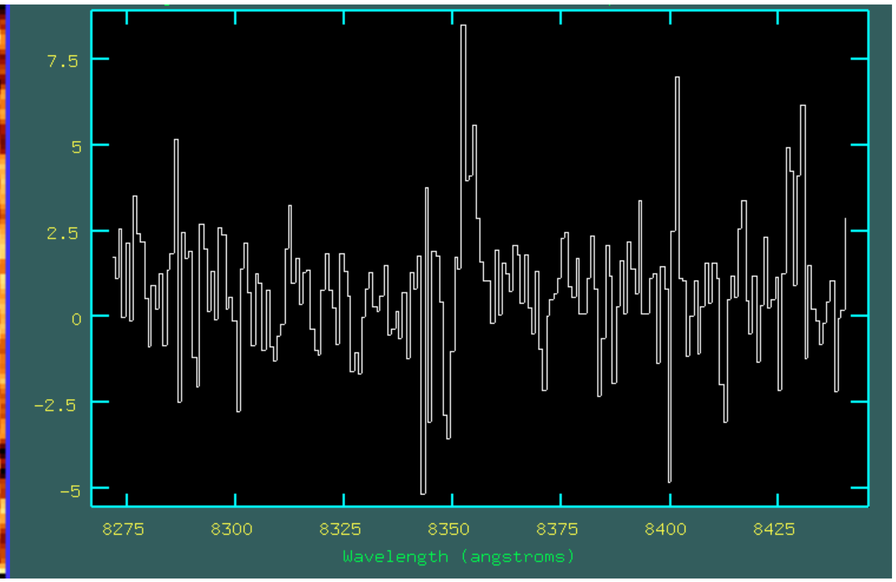
2.4σ evidence for dropout deficit at d<2.5 Mpc
(see also Utsumi+10): QSO (+ SF) feedback effects?

Optical spectroscopy

SDSS J1048 field (z=6.20)

#4811: primary dropout at z=5.9





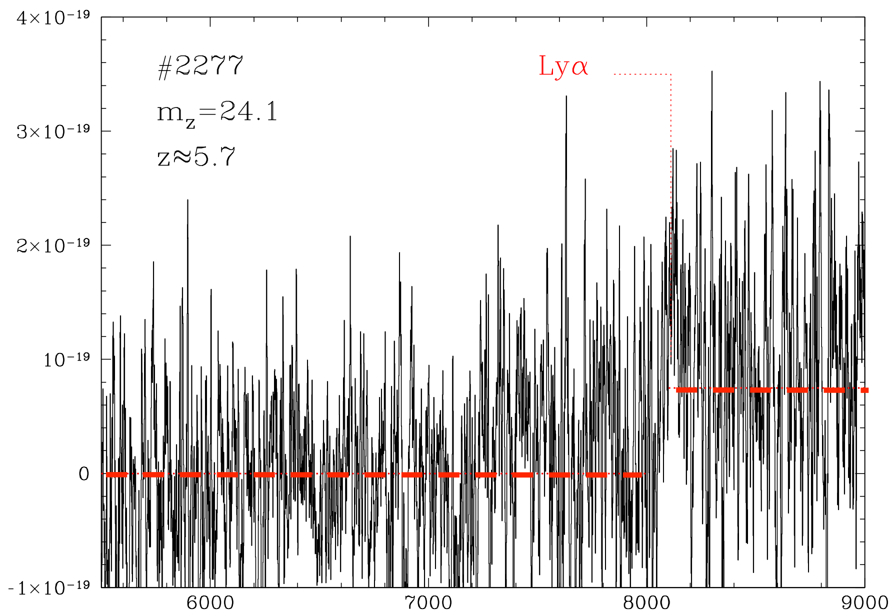
~5σ emission line, Lya at z=5.9

Δz=0.3 ➔ Δr=18 physical Mpc

Optical spectroscopy

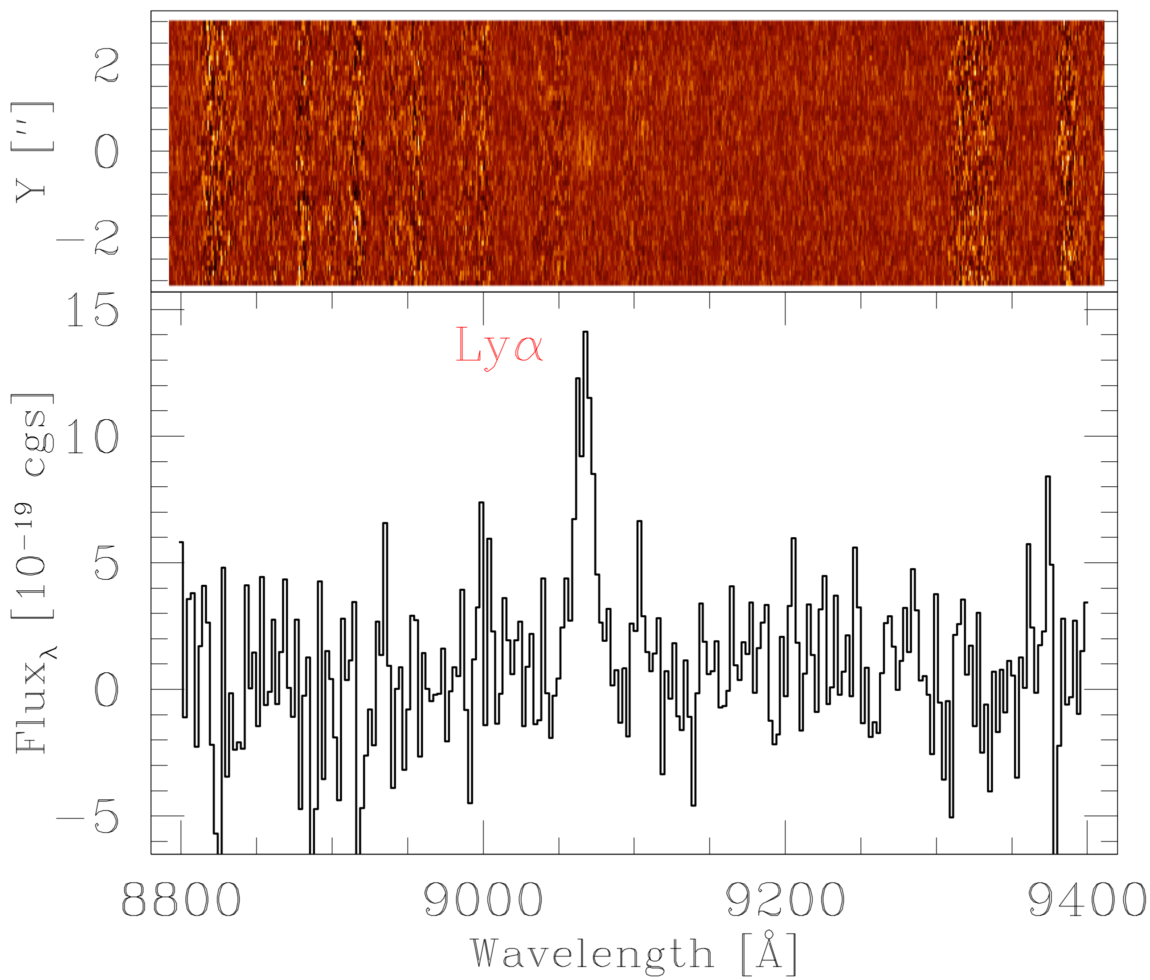
SDSS J1048 field (z=6.20)

#2277: secondary dropout at z=5.7



Optical spectroscopy

SDSS J1148 field (z=6.42)



z=6.456

separation of ~ 4 Mpc from QSO if confirmed