Environment around quasars at $z \sim 3$ revealed with the Subaru HSC and CFHT survey data

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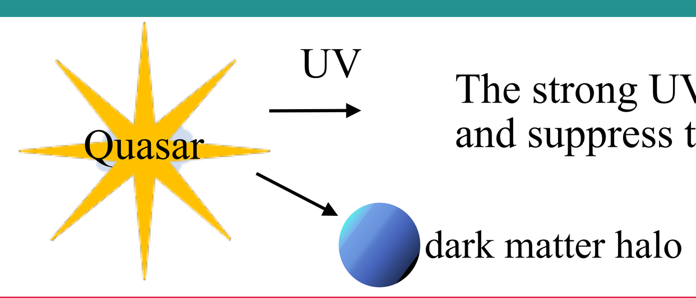
We statistically investigate the relationship between the spatial distribution of u-dropout galaxies over 20 deg^2 obtained by the combining the Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP) and the Canada-France-Hawaii Telescope (CFHT) Large Area U-band Deep Survey (CLAUDS), and the positions of 67 quasars obtained by Sloan Digital Sky Survey (SDSS). We measured the density of u-dropout galaxies in the vicinity of the quasars and investigated correlations of their overdensity with the UV luminosity and black hole mass of the quasars. As a result, we found that none of the quasars hosting the most massive BHs reside in the most overdense regions, and that none of the quasars with the largest proximity zones reside in the most overdense regions. These findings may indicate that the quasars radiation suppresses galaxy formation in their vicinity.

Introduction



The strong UV radiation from quasars may ionize halo gas around quasars and suppress the star formation of galaxies.

In order to understand galaxy formation/evolution, we need to observationally characterize where/how quasars appear in the large scale structure of galaxies.

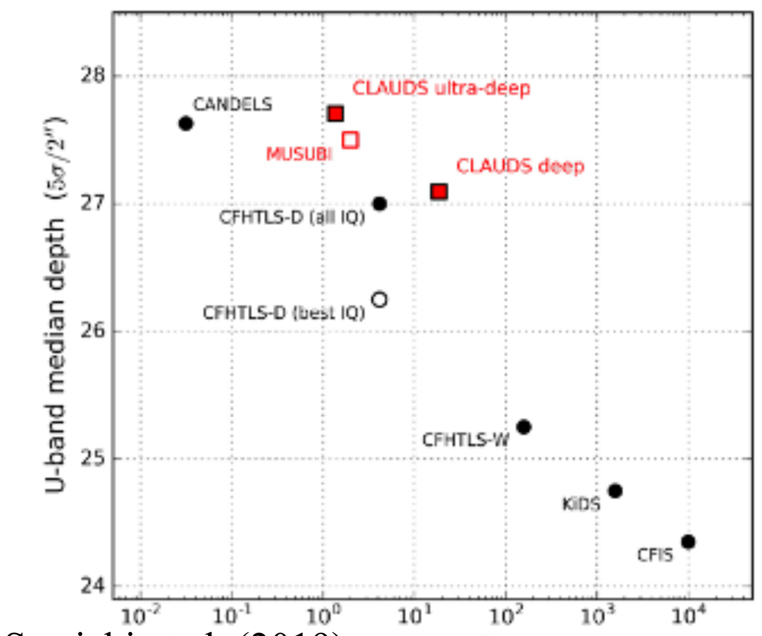
low-z (z<3)	Most quasar halo masses are ~ $10^{11.5-12}\ h^{-1}\ M_\odot$ (e.g. Ross et al. 2009)
z~3	Shen et al. (2007) found quasar halo masses 0.60-0.72 $\times 10^{12}\ h^{-1}\ M_\odot$ Eftekharzadeh et al. (2015) found quasar halo masses 2-3 $\times 10^{12}\ h^{-1}\ M_\odot$ → Controversial results, but the reason of this discrepancy remains unclear.

Several studies characterize the density around quasars at $z \sim 3$ by searching for galaxies clustered around them.

- Falder et al. (2010) investigated 11 quasar environments with stacking analysis, and showed that the galaxy density around the quasars is above the local background.
- Fossati et al. (2021) investigated 27 quasar environments, and found that the quasars reside in overdense regions of LAEs. (However, this may be due to the fluorescence caused by the quasar radiation.)

The two studies have limited spatial coverage around quasars (~ 10^2 kpc) and number of samples.
→ We need coverage up to ~1 Mpc around quasars to evaluate the effect of UV radiation and 50 samples at least for statistical analysis.

HSC-SSP+CLAUDS provides an unprecedentedly deep and large sample of u-dropout galaxies.
We can investigate the environment around quasars at $z \sim 3$.



Sawicki et al. (2019)

overdensities including protoclusters of u-dropout galaxies (HSC-SSP + CLAUDS)
+
spectroscopic quasars (SDSS)
↓
Statistical investigation of the cross-correlation between quasars and overdensities.

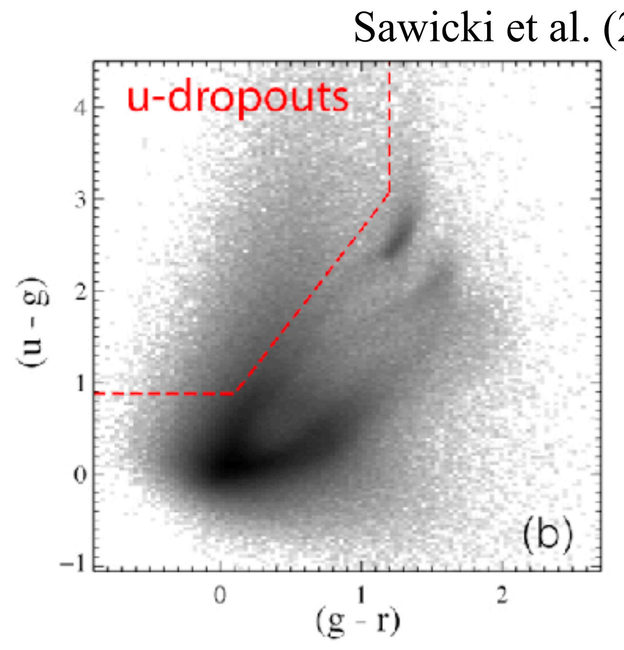
Data & Sample selection

Data HSC-SSP, CLAUDS S16A imaging data
SDSS DR16 QSO catalog

Selection

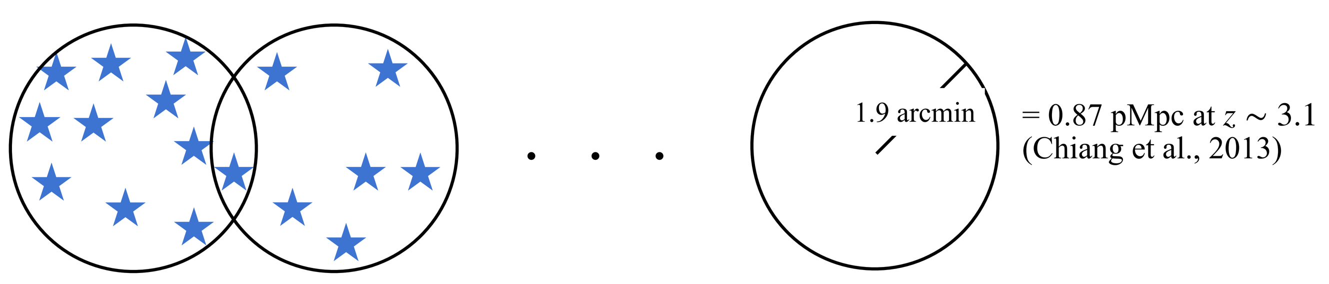
protoclusters (Toshikawa et al. in prep.):

u-dropout selection
$$\begin{cases} u-g > 0.88, \\ g-r < 1.2, \\ u-g > 1.88(g-r)+0.68 \end{cases}$$



Sawicki et al. (2019)

Count up the number of u-dropout galaxies in the aperture



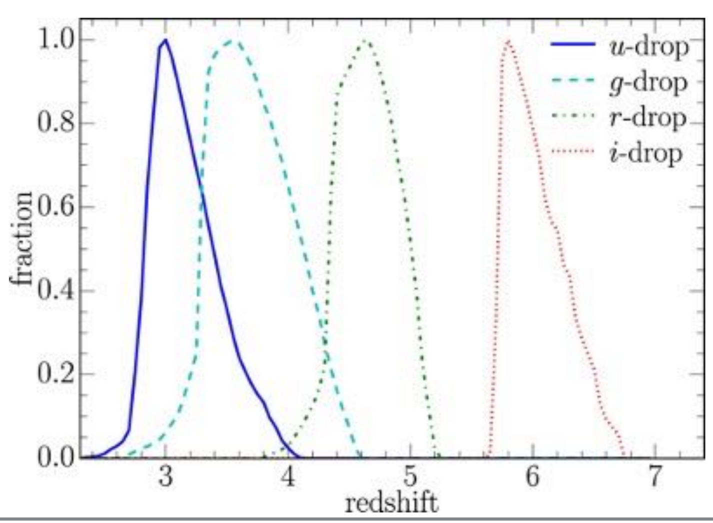
overdensity significance $\sigma = \dfrac{N-\bar{N}}{\sigma_N}$

N: number of galaxy in the aperture
$\bar{N}$: average of N
σ_N: standard deviation of N

Defined > 4σ region as a protocluster candidate
↓
25 protocluster candidates

quasars:

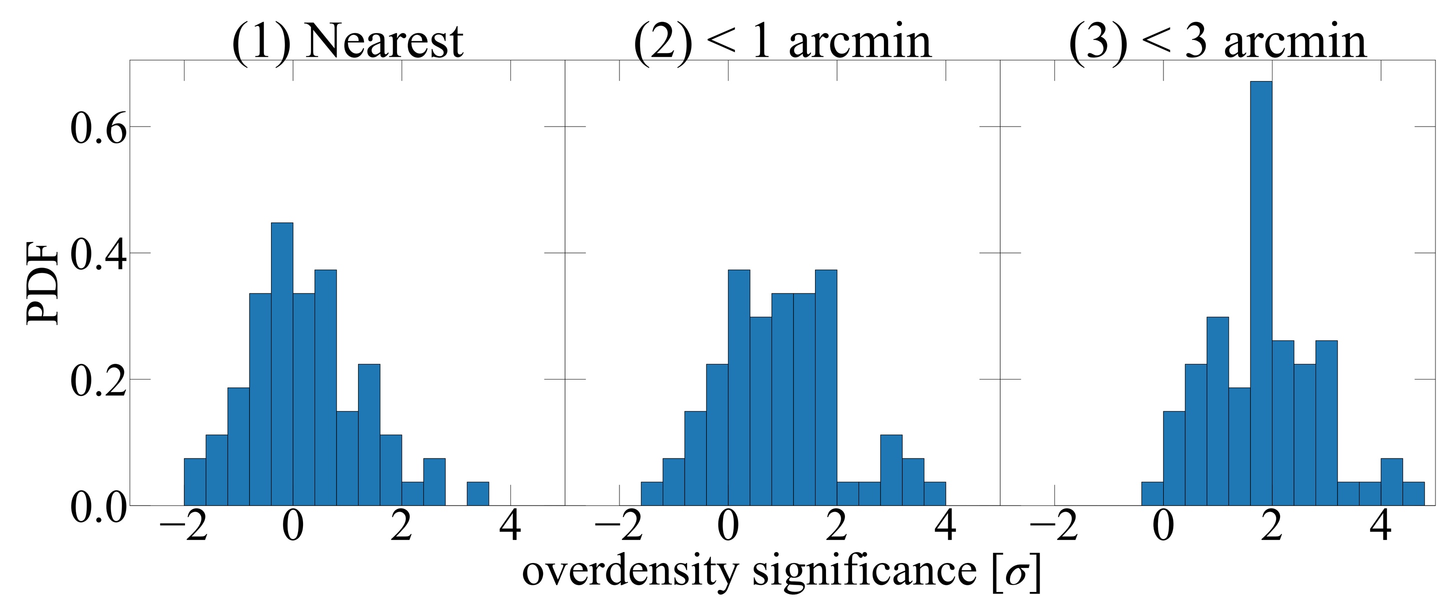
$2.8 < z_{spec} < 3.4$
where the u-dropout galaxy selection fraction > 0.5
↓
67 quasars



Toshikawa et al. (2016)

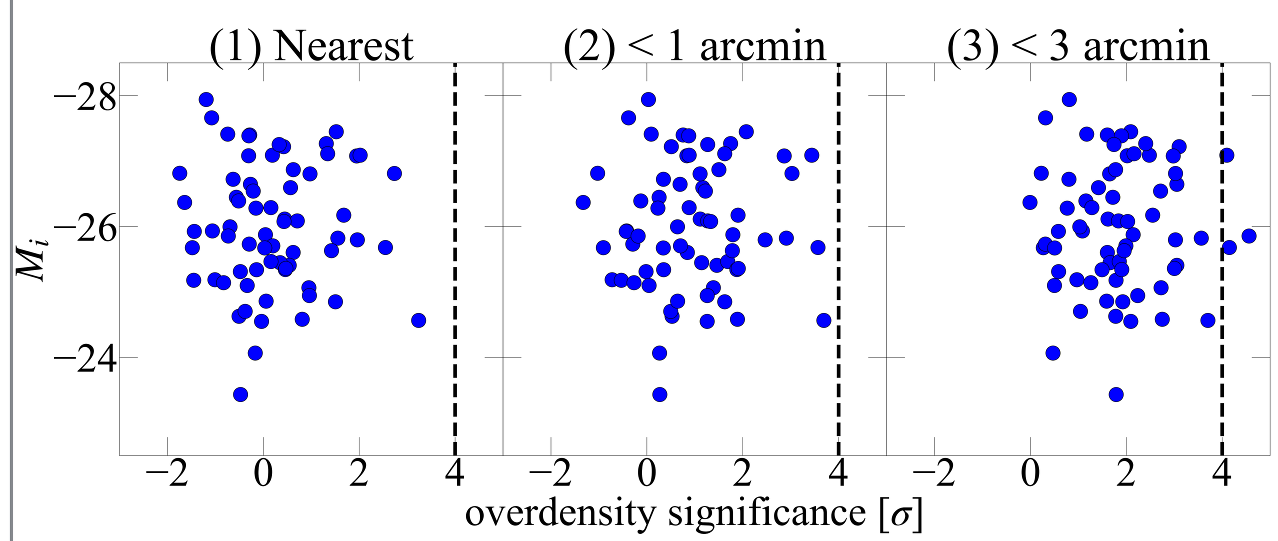
Results & Discussion

We measure the overdensity significances at the quasar positions (Nearest), the maximvum overdensity significances within 1 and 3 arcmin of quasars (< 1 arcmin and < 3 arcmin). The typical protocluster radius r_{pc} with the mass $\gtrsim 10^{14}\ M_\odot$ is 1.9 arcmin $\lesssim r_{pc} \lesssim$ 3.0 arcmin (= 1.4 pMpc).



We investigate correlation between the properties (UV luminosity and BH mass) of the quasars and the overdensity significance.

We use the quasar i-band absolute magnitude to represent their rest-UV luminosity.



Spearman's rank correlation test

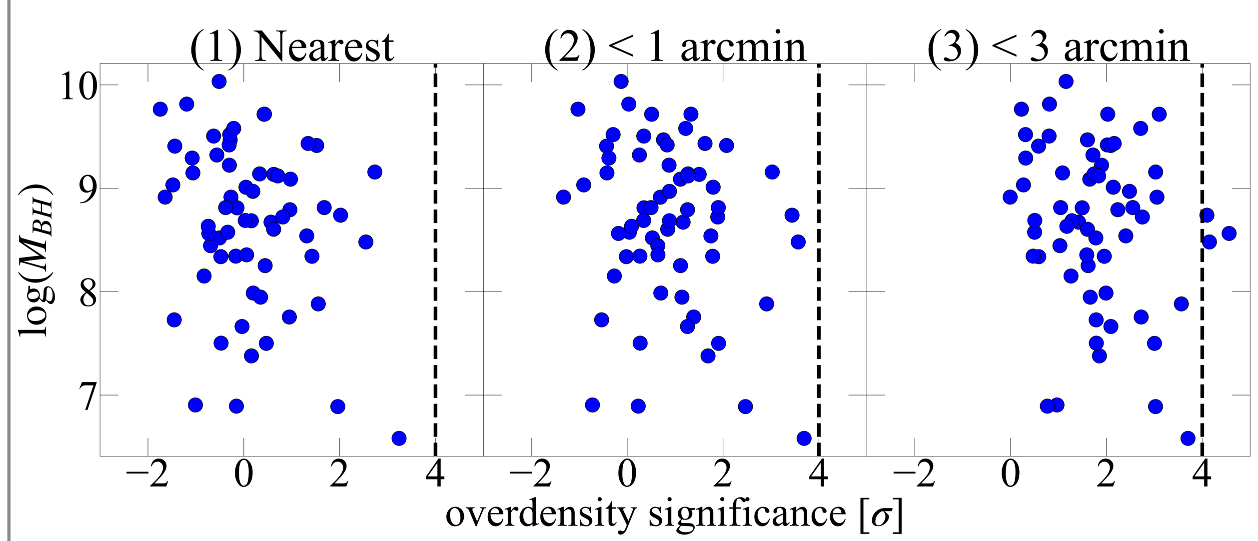
	Nearest	< 1 arcmin	< 3 arcmin
ρ*	0.0103	−0.0232	−0.0134
p-value	0.934	0.852	0.914

Insignificant correlation between the quasar UV luminosities and the overdensity significances.

The BH masses were take from Rakshit et al. (2020) for the SDSS DR14 quasars and from our own measurements for the DR16 quasars. The BH mass estimator is as follow

$$\log\left(\frac{M_{BH}}{M_\odot}\right) = A + B\log\left(\frac{\lambda L}{10^{44}\ \mathrm{erg\ s^{-1}}}\right) + C\log\left(\frac{\Delta V}{\mathrm{km\ s^{-1}}}\right)$$

A = 0.660, B = 0.53, C = 2 (Rakshit et al. 2020)
ΔV : the FWHM of emission line of C IV
λL : the monochromatic continuum luminosity at 1350 Å

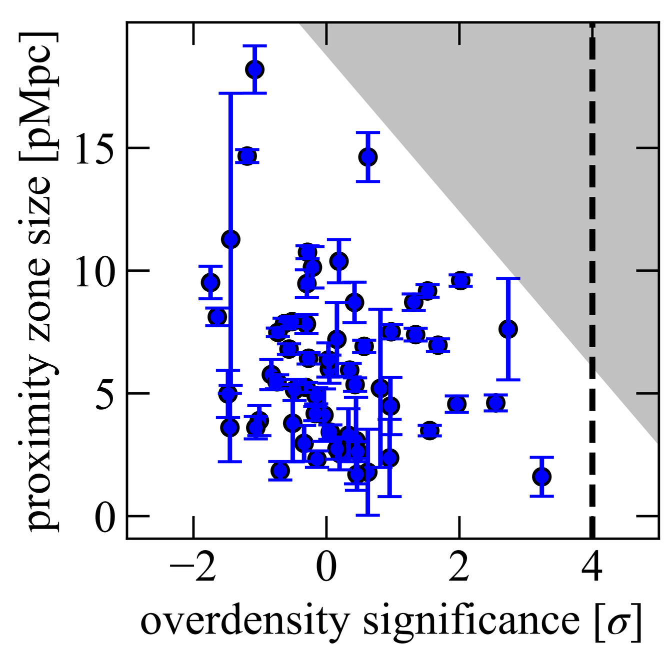


Spearman's rank correlation test

	Nearest	< 1 arcmin	< 3 arcmin
ρ*	−0.206	−0.180	−0.172
p-value	0.106	0.158	0.177

Quasars with the most massive BHs may avoid the most overdense regions (but overall no correlation was found between the BH masses and the overdensity significances).

The fact that the most massive BHs tend to avoid the most overdense regions may indicate that galaxy formation was delayed due to the quasar feedback in the past.
We measured the proximity zone size of the quasars to test this hypothesis.



proximity zone radius: $R_{pz} = \dfrac{d}{1+z}\left(\dfrac{9.5\times10^{8}}{\alpha+2.75}\dfrac{f_{\nu L}}{\Gamma_{bkg}}\right)^{\frac{1}{2}}$ (Calverley et al. 2011)

$f_{\nu L}$: the flux at Lyman limit
d : the luminosity distance to the quasar
z : the quasar redshift
α : the index of power-law fit of the flux ($f_\nu \propto \nu^{-\alpha}$)
$\Gamma_{bkg} = 0.792 \times 10^{-12}\ \mathrm{s^{-1}}$ (the average of background radiation intensity at z = 2.83 - 3.42 Haardt & Madau (2012))

Spearman's rank correlation test
$\rho^* = -0.166$, p-value = 0.198

Quasars with the largest proximity zones are not found in the most overdense regions (but overall no correlation was found between the proximity zone sizes and the overdensity significances).

→ The present results are be consistent with the scenario that massive BHs have grown with accompanying strong UV radiation, which suppresses galaxy formation in their vicinity.

References

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