Environment of SDSS quasars explored with Subaru HSC narrow-band emitters

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Major mergers of gas-rich galaxies have been proposed as a possible triggering mechanism for quasar activity (e.g., Hopkins et al. 2008), implying that the surrounding environment may be closely linked to the physical processes that regulate galaxy interactions and gas inflows onto the central supermassive black hole. However, this connection remains controversial, as previous studies have reported diverse quasar environments. Characterizing quasar environments is therefore essential for understanding the physical mechanisms that trigger quasar activity. Here, we investigate quasar environments using narrow-band (NB) selected emission-line galaxies. Most NB-selected emission-line galaxies are expected to be gas-rich star-forming galaxies, and their redshifts can be accurately estimated from the NB selection. They are therefore useful tracers for studying gas-rich environments around quasars. We present a statistical study of the local density environments around 104 SDSS quasars in the Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP) Deep fields. The quasars were selected from the SDSS DR16 quasar catalog, and their environments were traced using NB-selected emission-line galaxies from Hayashi et al. (2020). We also constructed a comparison galaxy sample whose stellar masses and redshifts were matched to those of the quasars, and measured the local number density of emission-line galaxies around both samples. The local number density of NB-selected emission-line galaxies around quasars appears, on average, to be lower than that around the comparison galaxies by 26.6 ± 24.9% within 0–500 pkpc and by 17.3 ± 17.2% within 500–1000 pkpc. However, these differences are not statistically significant. Our results therefore suggest that quasar activity is not preferentially associated with an enhanced number density of surrounding gas-rich galaxies.

Introduction

The major-merger scenario has been proposed as one of the mechanisms of the quasar triggering (e.g., Hopkins et al. 2008).
→ Is quasar activity related to environment?
Previous studies were limited by survey depth or sample size, and therefore quasar environments remain controversial at low-z (e.g., Serber+06; Zhang+13; Stott+20; Karhunen+14; Bettoni+15; Wethers+23; Shibata+25) and high-z (Kashikawa+07; Utsumi+10; Pudoka+24; Goto+17; Uchiyama+18; Suzuki+24).

So, in our previous study, we statistically investigated quasar environments at (z<1.0) using the deep, wide-area HSC-SSP S20A Wide data (Shibata et al. 2025).

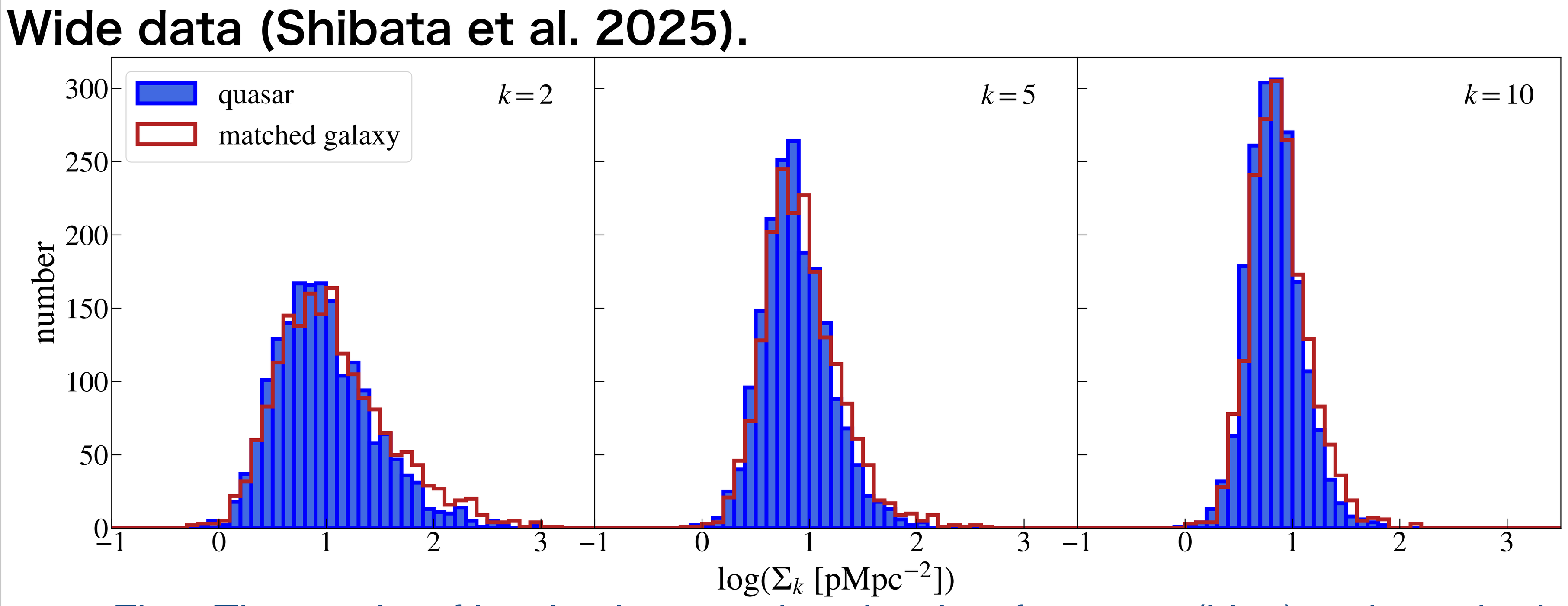

Fig.1 The results of local galaxy number density of quasars (blue) and matched galaxies (red) using Mizuki photo-z galaxies.

We found that quasars do not live in the overdense regions (compared to matched galaxies).

Shibata+25 did not focus on gas-rich galaxies. Since gas-rich galaxies are essentially star-forming galaxies, we newly focus on emission-line galaxies (ELGs), which exhibit star-formation-related emission, to investigate the gas-rich environment of quasars.

Sample selection & Analysis

Emission-line galaxies

・HSC PDR2 NB emitter catalog (Hayashi et al. 2018, 2020)
This catalog contains Ha, [O III], and [O II] emitters using NB816 (z=0.2, 0.6, 1.2) and NB921 (z=0.4, 0.8, 1.5).

・Depth-homogenized cuts
NB cmodel mag ≤ 23.5 mag & NB line flux $\geq 4\times10^{-17}$ erg s^{-1} cm^{-2}
After some quality cuts → 38714 ELGs

Quasars

・SDSS DR16 quasar catalog (Lyke et al. 2020; Wu et al. 2022)
Quasars are selected in the same redshift ranges as the ELGs.
For each quasar, we search for matched-galaxy candidates with $\Delta\log(M_\star)\leq 0.3$ dex. Quasars without such candidates are removed.
→ 104 quasars

the stellar mass of quasar host galaxies $M_\star$ estimated from M_{BH} (Marconi & Hunt 2003)

$$M_\star = \frac{M_{BH}}{1.75\times10^{-3}}$$

Matched galaxies

For each quasar, we select one ELG as a matched galaxy, matching both redshift and stellar mass to those of the quasar host.
→ 104 matched galaxies

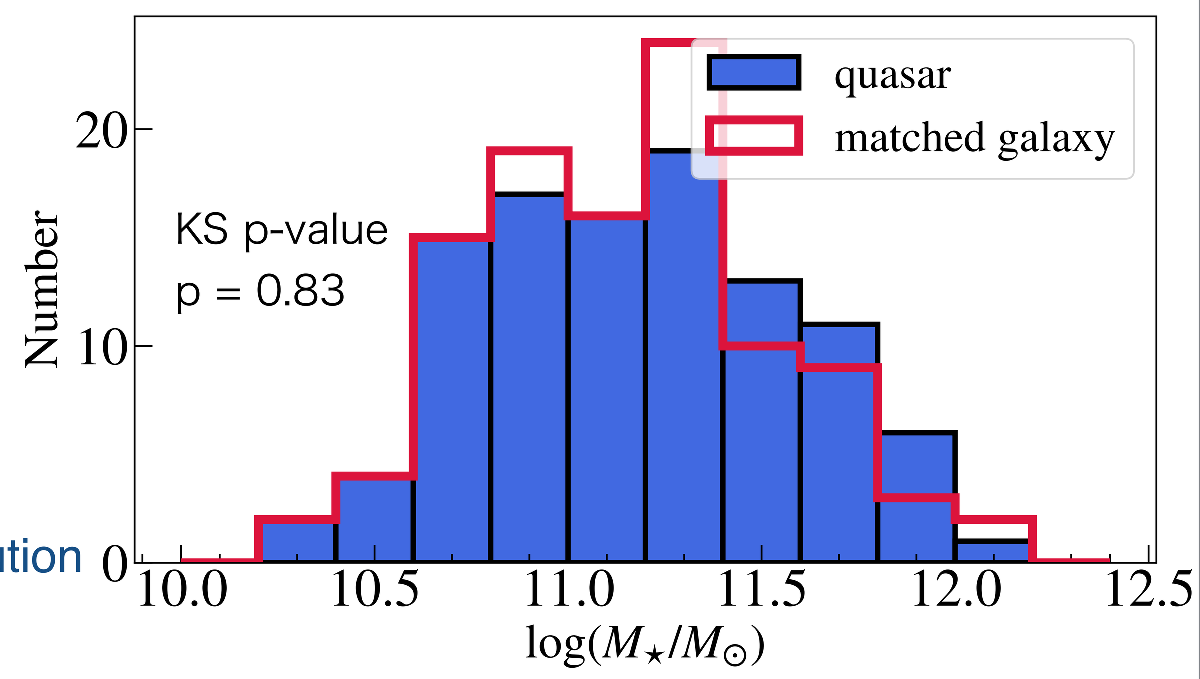

Fig.2 The stellar mass distribution of quasar sample (blue) and matched galaxy sample (red).

ELG number densities are measured in concentric annuli with a width of 500 pkpc around quasars and matched galaxies, using random points to estimate the effective survey area.

$$\Sigma_{r_1,r_2} \equiv \frac{N_{ELG}}{\pi(r_2^2-r_1^2)\,C_{r_1,r_2}}\ \mathrm{pkpc}^{-2}$$

r_1, r_2 : inner/outer radii of each 500 pkpc annulus
N_{ELG} : number of ELGs in the same redshift range
C_{r_1,r_2} : fraction of the unmasked area within the $\pi(r_2^2-r_1^2)$

For each radial bin, mean densities are calculated using only individual measurements with ($C_{r_1,r_2}\geq 0.5$).

Results & Discussion

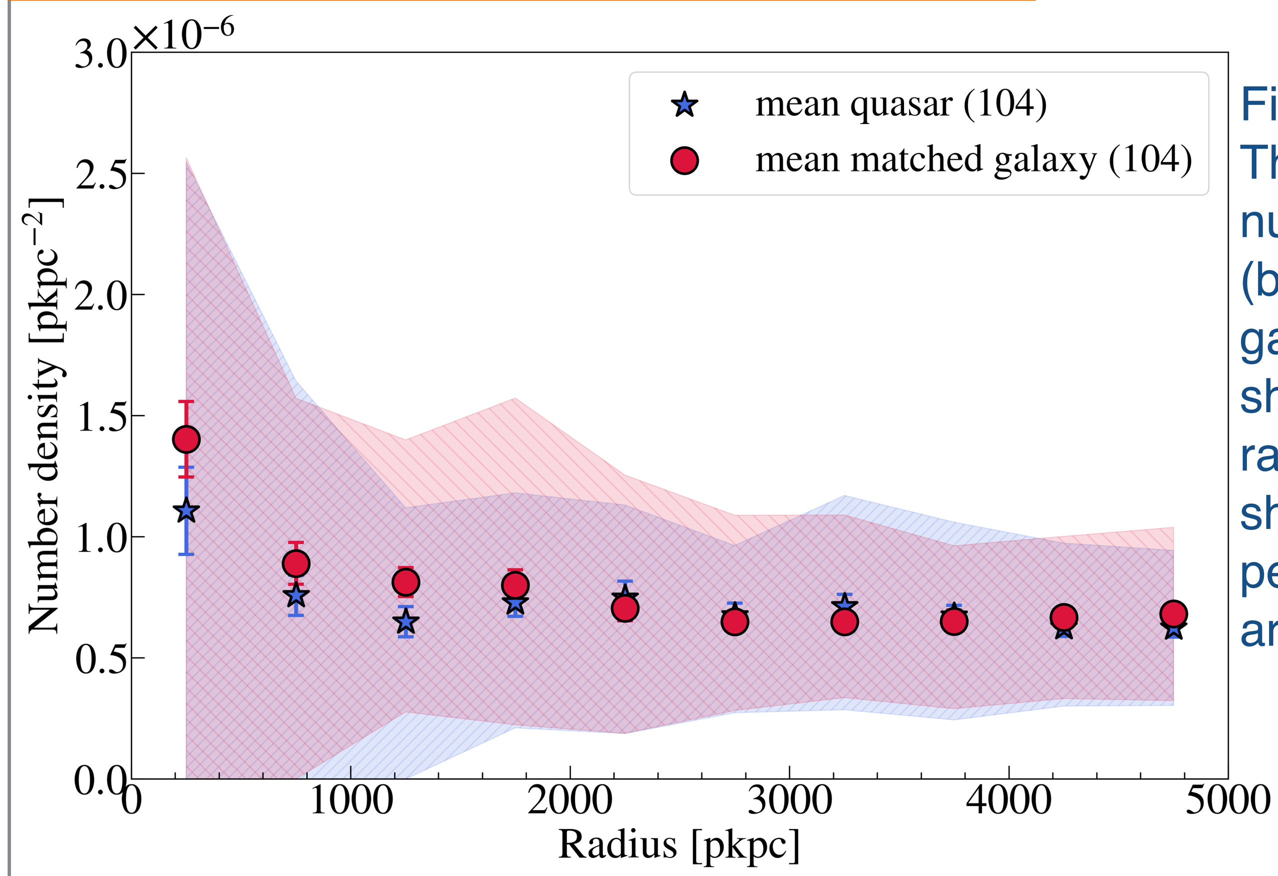

Fig.3 The results of local galaxy number density of quasars (blue) and matched galaxies (red). Markers show averages in each radial bin, shaded regions show the 16th–84th percentiles, and error bars are standard errors.

NB-selected ELG number densities around quasars are **lower on average** than those around matched galaxies by 26.6 ± 24.9%, 17.3 ± 17.2%, and 25.3 ± 15.2% in the 0–500, 500–1000, and 1000–1500 pkpc bins, respectively.
However, these average differences are **not significant given their uncertainties**, and KS tests on the individual density distributions also show **no >3σ significant differences** (p = 0.075, 0.46, and 0.068).

To examine the mass-ratio dependence, we divide ELG companions into major (>1/4), minor (1/10–1/4), and mini (<1/10) companions according to their stellar-mass ratios to the quasar host or matched galaxy.

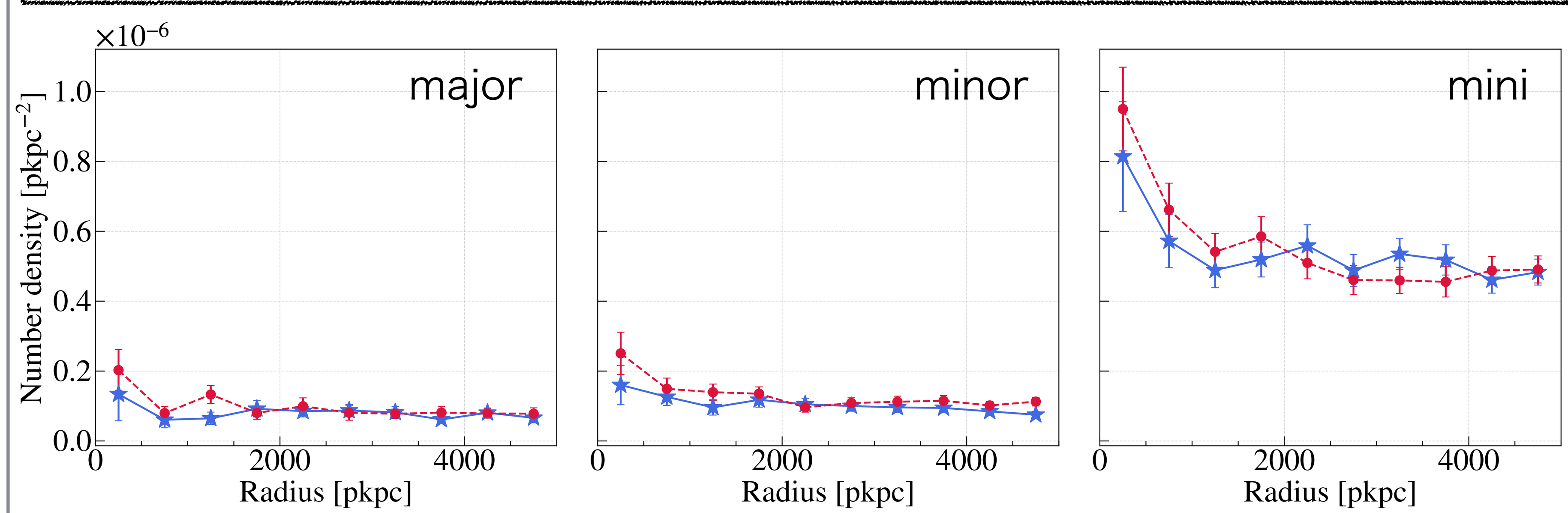

Fig.4: Number densities of ELGs around quasars (blue) and matched galaxies (red), separated into major, minor, and mini companions.

We find **no clear mass-ratio dependence** in the ELG density difference between quasars and matched galaxies. In the inner 1.5 pMpc, quasars show slightly lower ELG number densities in all major, minor, and mini classes, but the differences are not statistically significant.

Summary

- We investigate gas-rich environments around 104 SDSS quasars using HSC NB-selected ELGs.
- ELG number densities around quasars tend to be lower on average than those around redshift- and stellar-mass-matched galaxies in the inner 1.5 pMpc, but the differences are not statistically significant.
- When companion ELGs are divided into major, minor, and mini classes, we find no clear mass-ratio dependence.
- This average trend is consistent with Shibata et al. (2025): quasars do not show enhanced environments compared with matched galaxies, even when gas-rich ELGs are used as tracers. This may suggest that some quasars are triggered without requiring galaxy-rich environments.

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