Stacking analysis of quasar host galaxies at \( z > 1 \) with Subaru HSC

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Introduction

- Is star-forming activity really suppressed by AGN feedback?
- Is AGN feedback real?

=>$\Rightarrow$To investigate properties of quasar host galaxies is necessary.
Black-hole and their hosts were evolving most rapidly at the epoch $1 < z < 3$.

To investigate high-$z$ host galaxies leads to an understanding of how AGN has influenced their hosts.

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Kormendy & Ho +13
Problems

Purpose

- To investigate high-z (z >1) host galaxies
- Explore how AGN has influenced their hosts

- The light from the center of the quasar outshines the faint light from the galaxy.

⇒ Decompose quasars and hosts

- It is difficult to observe individual host galaxies at high redshifts.

Stack

Investigate the average host galaxies.

Resolution

Subaru Telescope HSC
Data & Sample selection

Data

- SDSS DR 7 quasar catalog
- Subaru Telescope HSC SSP survey 5 band \((g, r, i, z, y)\) imaging data

Sample selection

HSC S17A wide catalog
\[(\text{About 300 } \text{deg}^2)\]
\(\times\)
SDSS DR7 quasar catalog
\[(\text{About 10,000 } \text{deg}^2)\]

\(\Rightarrow 1''\) matched \(z > 1\) quasars \(3,457\) objects
**Analysis**

**Decompose quasars and hosts**

=> We assume quasar as a point source, subtract quasar component using PSF model.
Analysis

**Decompose quasars and hosts**

=>$ We assume quasar as a point source, subtract quasar component using PSF model.

\[
\text{Host flux} = \text{Total flux} - A \times \text{PSF}
\]

\[
A = \frac{\text{Count of object image}}{\text{Count of PSF image}} \quad \text{(at the central 1 pixel)}
\]
Analysis

Decompose quasars and hosts

=> We assume quasar as a point source, subtract quasar component using PSF model.

\[
\text{Host flux} = \text{Total flux} - A \times \text{PSF}
\]

=> We divide the sample into \(1 < z < 2\), \(2 < z < 3\) and \(3 < z < 4\) ranges and stack images in each band.
Analysis

Decompose quasars and hosts

$1 < z < 2$ : Stacked images of 2451 objects

A ring appears by PSF subtraction

$=>$ It is necessary to consider the uncertainty of PSF
Consider the uncertainty of PSF model

\[
\text{Host flux} = \text{Total flux} - A \times \text{PSF} - (\text{star} - A' \times \text{PSF})
\]
Analysis

**Consider the uncertainty of PSF model**

\[
\text{Host flux} = \text{Total flux} - A \times \text{PSF} - (\text{star} - A' \times \text{PSF})
\]

- We checked the residual of the star image minus the PSF model.
- We created flux controlled star sample for each redshift range and each band sample.
Analysis

Consider the uncertainty of PSF model

Host flux = Total flux - A × PSF - (star - A’ × PSF)
Analysis

Consider the uncertainty of PSF model

\[
\text{Host flux} = \text{Total flux} - A \times \text{PSF} - (\text{star} - A' \times \text{PSF})
\]
Analysis

$1 < z < 2$ (2451 objects)
Analysis

$1 < z < 2$ (2451 objects)

$2 < z < 3$ (814 objects)

$3 < z < 4$ (210 objects)
Analysis

SED fitting of the host galaxies

- Observed flux
- Model flux

1 < z < 2
2 < z < 3
3 < z < 4
**Results**

*Contour: non AGN galaxy at z > 1 from HSC Mizuki photoz catalog*
Results

color - magnitude diagram (CMD)

*Contour : non AGN galaxy at z > 1 from HSC Mizuki photoz catalog
Results

color - magnitude diagram (CMD)

Contour: non AGN galaxy at $z > 1$
from HSC Mizuki photoz catalog
Results

color - magnitude diagram (CMD)

*Contour : non AGN galaxy at z > 1 from HSC Mizuki photoz catalog
Quasar host galaxies at $1 < z < 2 \rightarrow \text{green valley}$
Quasar host galaxies at $2 < z < 4 \rightarrow \text{blue cloud}$

*Contour: non AGN galaxy at $z > 1$
from HSC Mizuki photoz catalog
Results

Luminosity matched sample

*Contour: non AGN galaxy at z > 1 from HSC Mizuki photoz catalog
Results

Luminosity matched sample

- **z < 1**
- **1 < z < 2**
- **2 < z < 3**
- **3 < z < 4**
- luminosity matched

- red sequence
- green valley
- blue cloud

*Contour: non AGN galaxy at z > 1 from HSC Mizuki photoz catalog*
Classification on CMD does not depend on luminosity.

*Contour: non AGN galaxy at $z > 1$ from HSC Mizuki photoz catalog
Results

High BH mass sample and low BH mass sample

*Contour: non AGN galaxy at $z > 1$
from HSC Mizuki photoz catalog
Results

High BH mass sample and low BH mass sample

Contour: non AGN galaxy at $z > 1$

$1 < z < 2$

$2 < z < 3$

$3 < z < 4$

$\log M_{BH}/M_{\odot} > 9$

$\log M_{BH}/M_{\odot} < 9$

VS NBH

S NBH

red sequence

blue cloud

green valley

*Contour: non AGN galaxy at $z > 1$

from HSC Mizuki photoz catalog
No significant change in the host classification on the CMD.

*Contour: non AGN galaxy at z > 1 from HSC Mizuki photoz catalog*
**Discussion**

**1 < z < 2**
- Quasar host galaxies are located in the green valley.

⇒ Consistent with the scenario that AGN in star-forming galaxies ignites and suppress star-forming activity.

**blue cloud** → **green valley** → **red sequence**

AGN ignite
⇒ Star-forming activity is suppressed by AGN feedback

**z > 2**
- Quasar host galaxies are located in the blue cloud.

⇒ The relationship (AGN feedback?) between quasar host galaxy and AGN may be different at higher redshifts.

(e.g. Star formation may be too active to be suppressed by AGN outflow?)
Summary

✓ We created images of average quasar host galaxies at $z > 1$ by using the 5 bands imaging data of HSC.

1 < $z < 2$ : Stacked images of 2451 objects

✓ We performed SED fitting of the stacked host galaxies and created color-magnitude diagram.

✓ We found quasar host galaxies at $z > 1$ are located in the blue cloud to the green valley.
Analysis

Consider the uncertainty of PSF model

Ideal way

Quasar images - Perfect PSF model at each position

- It is difficult to measure PSF around a quasar on its own.

This work

Quasar images - A × PSF model - (Star images - A' × PSF model)

- We use PSF model of HSC database
  - We assumed uncertainty isn’t depend on the position.

Uncertainty averaged by position
Results

color - magnitude diagram

- $1 < z < 2$
- $2 < z < 3$
- $3 < z < 4$
- $z < 1$

$3FTVMUT$
Results

color - magnitude diagram

- red sequence
- green valley
- blue cloud

- $z < 1$
- $1 < z < 2$
- $2 < z < 3$
- $3 < z < 4$
Appendix

Individual quasar host galaxies

1 < z < 2

2 < z < 3

3 < z < 4