The z~4 radio galaxy survey with HSC-SSP and FIRST

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Abstract

Using the *g*-dropout galaxy catalog selected from the Hyper Suprime-Cam - Subaru Strategic Program (HSC-SSP) and Very Large Array - Faint Images of the Radio Sky at Twenty-Centimeters (VLA FIRST) catalog, we find 145 HzRG candidates at z~4. We examine the *K*-*z* relation by performing a stacking analysis of VIKING *Ks* band images of HzRG candidates. We confirm that *z*~4 HzRGs are on the known *K*-*z* relation. The SED fitting analysis shows that the *z* ~ 4 HzRG candidates are very massive, reaching up to 10^{11} solar mass. Our findings suggest that HSC-selected HzRGs are consistent with the picture of general RGs studied so far.

1. Introduction

Radio galaxy (RG) is a kind of active galactic nuclei with a strong radio emission.Their host galaxies are massive elliptical galaxies in general.The Correlation between BH mass and bulge mass was discovered(Fig. 1), so a co-evolution scenariofor supermassive black holes and host galaxies was considered.In the scenario, RGs are thought to be in the final stage. Therefore, in order to understand the total picture of the galaxy evolution, it is an interesting and powerful approach to investigate high-*z* RGs (HzRGs).

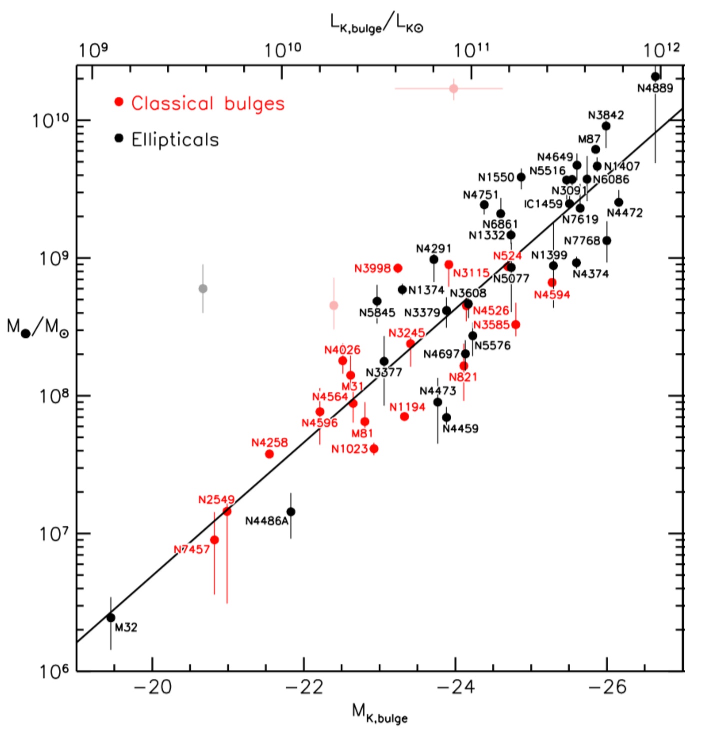

Fig.1: Correlation between BH mass and bulge mass (Kormendy & Ho ,2013)

Problem

HzRGs found by past studies are only a few at z > 3, since the field of size of past deep surveys for HzRGs are too small to find objects with a very low surface density, such as HzRGs.

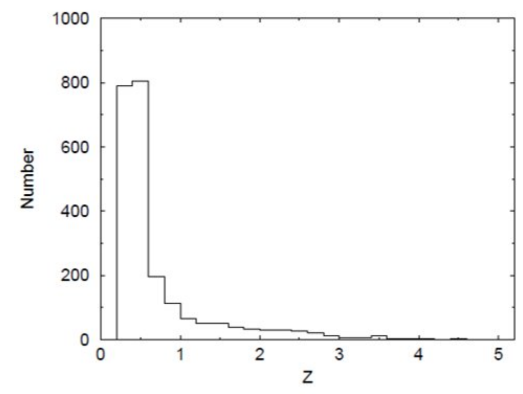

Fig.2: Number of the known radio galaxies (Khabibullina & Verkhodanova ,2009)

We further explore HzRG candidates to study the statistical understanding of its properties using the deep and wide data from HSC-SSP and VLA FIRST surveys.

2. Sample selection

Data

- *g*-dropout (z ~ 4) galaxies from the HSC SSP S19A wide (Aihara et al. 2018)
- radio catalog: FIRST (Helfand et al. 2015)

Selection

HSC S19A wide *g*-dropout galaxies (2,553,430 objects) × FIRST clean sample (720,712 objects)

- 1 arcsec matching
- *i*<22: to remove low-z galaxies and/or high-z QSO

HzRG candidates
144 objects

3. Methods and results

To investigate the nature of HzRGs, we performe a multi-wavelength data analysis using VIKING near-infrared wide-area imaging survey (Edge et al. 2013) and un-WISE mid-infrared all-sky imaging survey (Schlafly et al. 2019).

K-*z* relation

We investigate the empirical *K* - *z* relation which is the empirical relation between the *K*-band magnitudes and redshifts of radio galaxies.

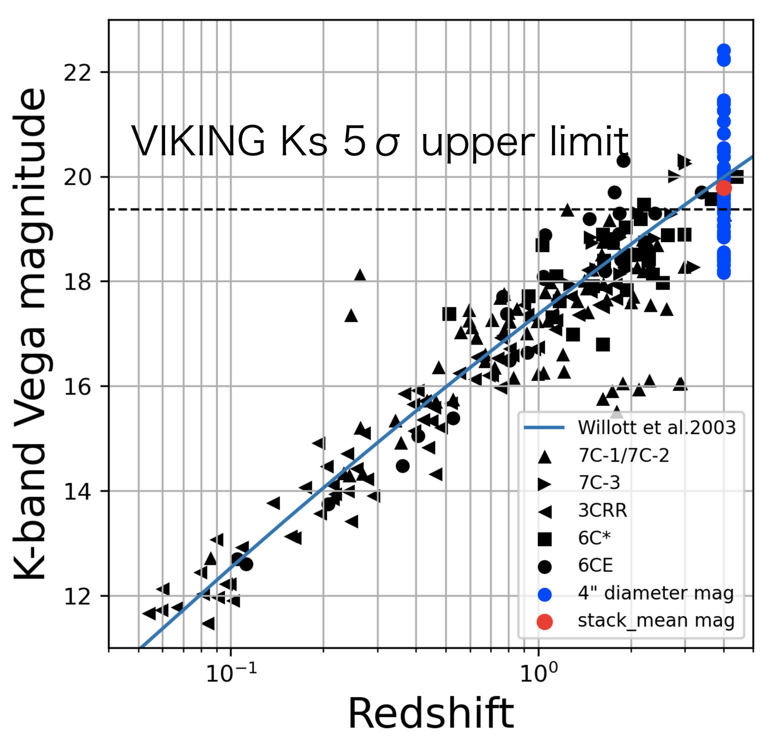

Fig.3: *K*-*z* relation: The black dots show the known radio galaxies. The light blue line is the known *K* - *z* relation (Willott et al. 2003). The blue points show the *z* ~ 4 radio galaxy candidates from this study. The red points show the average K-band magnitudes from the stacking analysis.

The average magnitude in the Ks band obtained by the stacking analysis of HzRG candidates is 19.8 Vega Mag.

→Our HzRG candidates are considered to be consistent with the known *K*-*z* relation extrapolated at *z* ~ 4.

SED fitting

We performe a SED analysis of 34 HzRG candidates detected with VIKING and unWISE using XCIGALE (Yang et al. 2020).

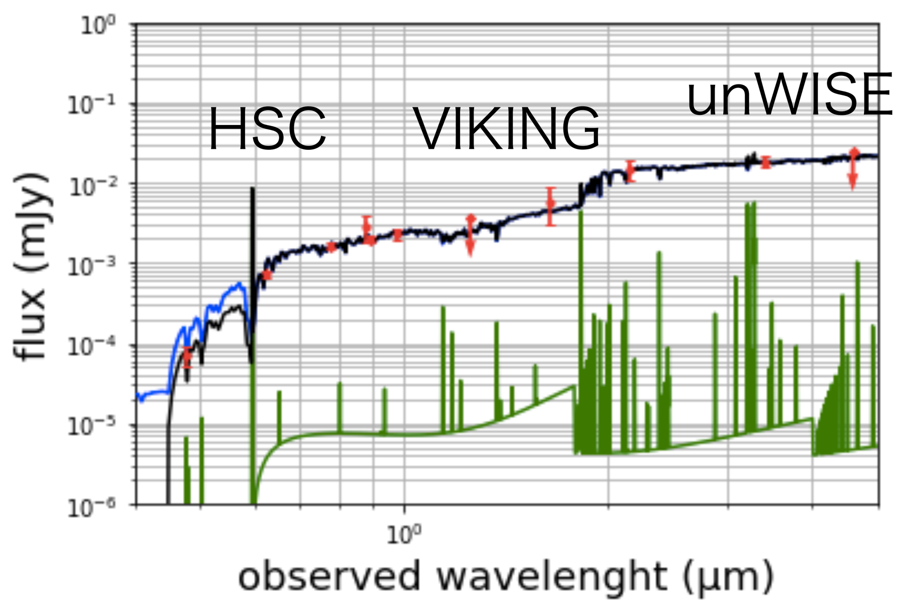

Fig.4: An example of the SED fit. The best-fit z_ph is 3.9. The red dots and black line show the observed data and the best-fit model, respectively. The blue line shows Stellar component, the green line shows Nebular emission.

SFH	
Model	sfhdelatedbq
τ_{main} (Myr)	1,10,100,200,300,400,500, 600,700,800,900,1000,1100, 1200,1300,1400,1500,1600, 1700,1800,1900,2000
age_{main} (Myr)	500,600,700,800,900,1000, 1500,2000,3000,4000,5000
age_{bq} (Myr)	1,10,100,200,300,400,500
r_{sfr} (Myr)	0.5,0.1,0.01,0.001
SSP	
Model	Bruzual and Charlot (2003)
IMF	Chabrier (2003)
Metallicity	0.02
Nebular emission	
$\log U$	$-0.2, -0.4$
f_{esc}	0
f_{dust}	0
Lines width (km/s)	300
Dust attenuation	
Model	dustatt modified starburst
$E(B-V)_{\text{lines}}$	0.001,0.01,0.1,0.15,0.2,0.25, 0.3,0.35,0.4,0.45,0.5,0.55,0.6, 0.8,1.0,1.3,1.6,2.0
Redshift	
redshift range	0.1 ~ 5.0
Δredshift	0.1

Table.1: X-CIGALE SED fitting parameter

In Fig. 5, there are sources at z_photo~2 in addition to the target z_photo~4 sources.

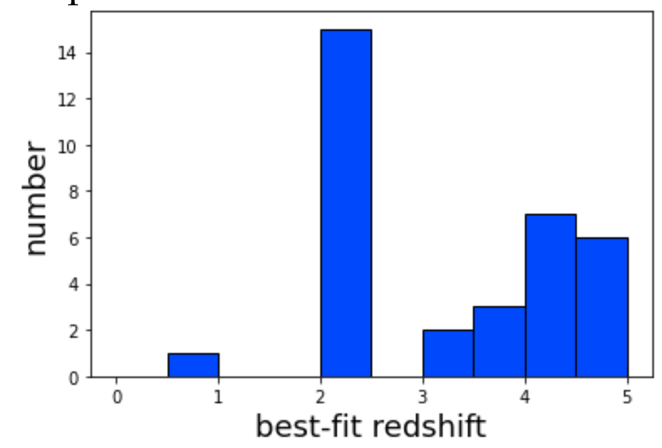

Fig.5: The photo-z distribution of the 34 HzRG candidates obtained from the SED fitting.

In Table. 2, there are the best-fit parameter of 6 reliable HzRG selected in 34 HzRG candidates.

id	best-redshift	stellar mass	stellar mass_err	E(B-V)	E(B-V)_err
14	4.6	3.154e+11	1.062e+11	0.302	0.238
20	3.9	2.777e+11	9.103e+10	0.284	0.206
33	4.2	9.751e+11	8.706e+10	0.010	0.041
39	4.5	9.055e+11	1.008e+11	0.019	0.048
41	4.4	4.498e+11	8.369e+10	0.116	0.143
58	3.7	5.424e+11	1.479e+11	0.593	0.315

Table.2: Best-fit parameters for visually-confirmed 6 reliable HzRGs

The average stellar mass of HzRG (z~4) is 5.8×10^{11} $M_\odot$.

⇒ It is comparable to HzRGs that have been studied in previous studies.

4. Discussion

Rest-frame *UVJ* color diagram to study the trend of star formation activity of HzRG.

↓

One of the HzRG candidates is classified as a quiescent galaxy, and the other radio galaxies also show near quiescent colors. (Fig.6)

In Fig. 6, we also show the g-dropout galaxies that are detected in unWISE for comparison.
The results suggest that not only radio galaxies but also massive galaxies at z~4 are dominated by Quiescent galaxies.

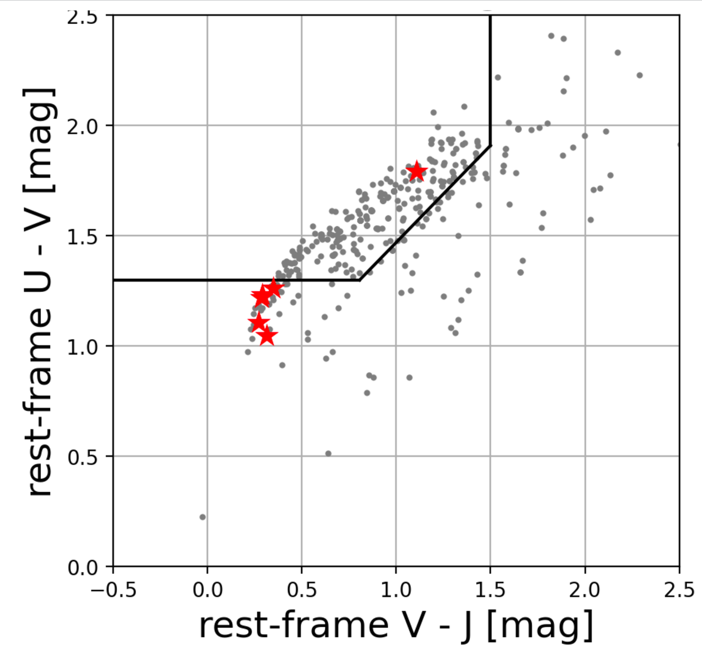

Fig.6: rest-frame *UVJ* diagram。 The red star show 6 reliable HzRGs.The gray points with are some 400 objects with g-dropout + unWISE detecte. The black line is a criteria of quiescent galaxies (Muzzin et al. 2013).

Star formation activity from SED fit

Fig. 7 shows the SFHs of the six reliable HzRG candidates. Here, we simply added the SFHs for each lookback time.
The radio galaxies at z~4 had a star formation history with starburst started at z~6 and quenched at z~5 in general.

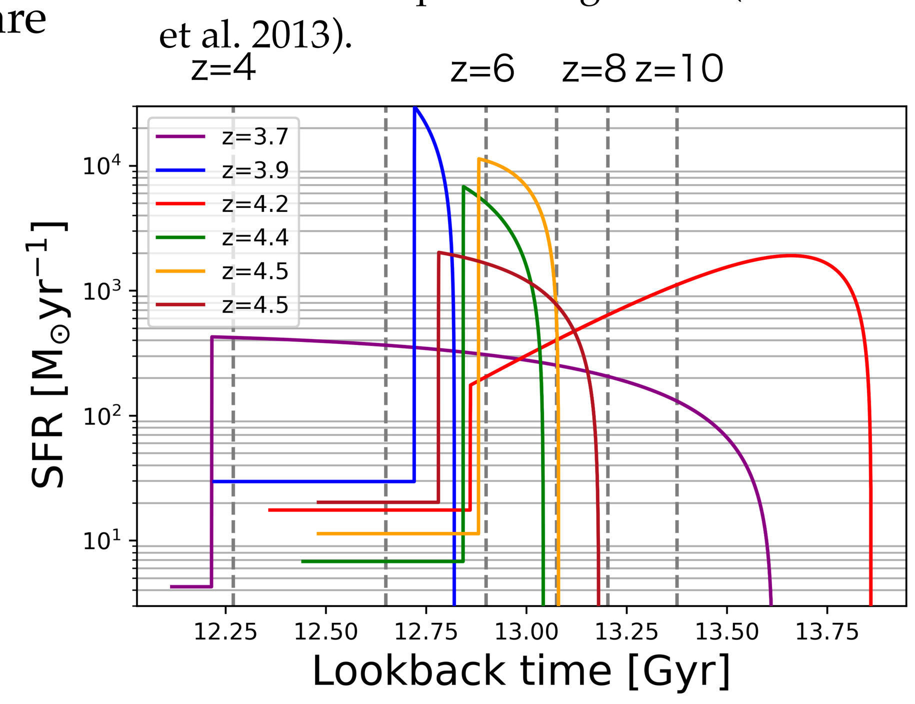

Fig.7: SFH summation of HzRG6 objects

5. Summary

- 145 HzRG candidates are selected by matching the g-dropout galaxies selected from HSC-SSP Wide with FIRST radio source catalog in about 500 deg^2.
- The HzRG candidates show properties consistent with the known K-z relation.
- The stellar population of the z ~ 4 HzRG candidates is consistent to passively evolving galaxies with a past active star formation at z~6.

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