The Nature of New z~4 High-z Radio Galaxies from HSC-SSP and VLA/FIRST

Yuta Yamamoto, Tohru Nagao, Hisakazu Uchiyama (Ehime Univ.), Takuji Yamashita, Yoshiki Toba (NAOJ), Mariko Kubo (Tohoku Univ.), Akatoki Noboriguchi (Shinshu Univ.), Yoshiaki Ono, Yuichi Harikane (Tokyo Univ.), and the WERGS team

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) catalogs, we find 146 HzRG candidates at z~4. We specifically focus on 7 HzRGs with near-IR and mid-IR photometry. The SED fitting analysis for them shows that the 7 z~4 HzRG candidates are very massive, reaching up to 10^{11} solar mass. The so-called UVJ diagram and the SED-based SFHs suggest that HzRGs are characterized by a passive nature with a past burst of the star formation. These results suggest that the radio jet in HzRGs may have worked as a negative feedback to the star formation and also as a suppressor for the star formation.

This study is part of **A Wide and Deep Exploration of Radio Galaxies with Subaru HSC (WERGS) project** (Yamashita et al. 2018).

1. Introduction

The 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 scenario for supermassive black holes and host galaxies was considered. In this scenario, RGs are thought to be in the final stage of the co-evolution. Therefore, in order to understand the total picture of the galaxy evolution in the early Universe, it is an interesting and powerful approach to investigate high-*z* RGs (HzRGs).

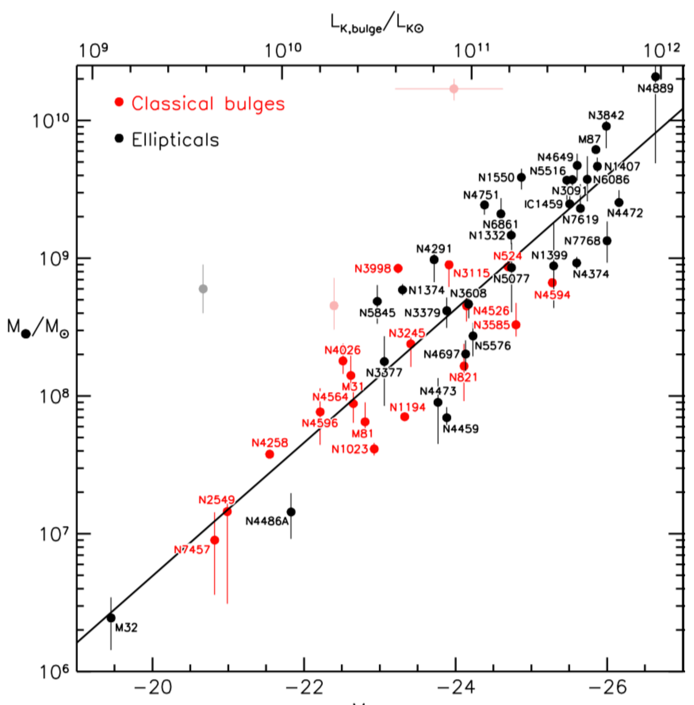

Fig.1: Correlation between BH mass and bulge mass (Kormendy & Ho 2013)

Problem

HzRGs found by past studies are only few at z > 3, since the surface density of HzRGs is too low to be systematically searched through past surveys whose area and depth were not sufficient.

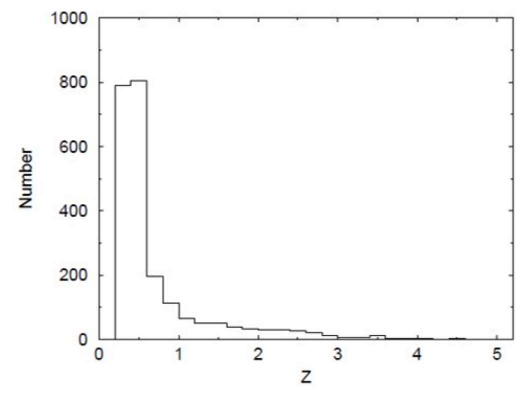

Fig.2: Number of the known radio galaxies (Khabibullina & Verkhodanova 2009)

We newly explore HzRG candidates to study their statistical properties using the deep and wide data from HSC-SSP and VLA FIRST surveys.

2. Sample selection

Data

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

Selection

HSC S19A wide *g*-dropout galaxies (2,553,410 objects) × FIRST clean sample (720,712 objects)

↓
- 1 arcsec matching
- *i*<21.5: to remove low-z galaxies and / or high-z QSO

HzRG candidates **146 objects**

↓
- Near-infrared data (VIKING, UKIDSS)
- Mid-infrared data (unWISE)

HzRG candidates (+ **VIKING**, unWISE) **21 objects** + HzRG candidates (+ **UKIDSS**, unWISE) **7 objects**

3. SED fitting of HzRG candidates

We perform a SED analysis of 28 HzRG candidates detected with VIKING, UKIDSS and unWISE using X-CIGALE (Yang et al. 2020) for a selection of reliable HzRGs.

SED fitting

Table 1 shows the parameters used for the SED fitting.

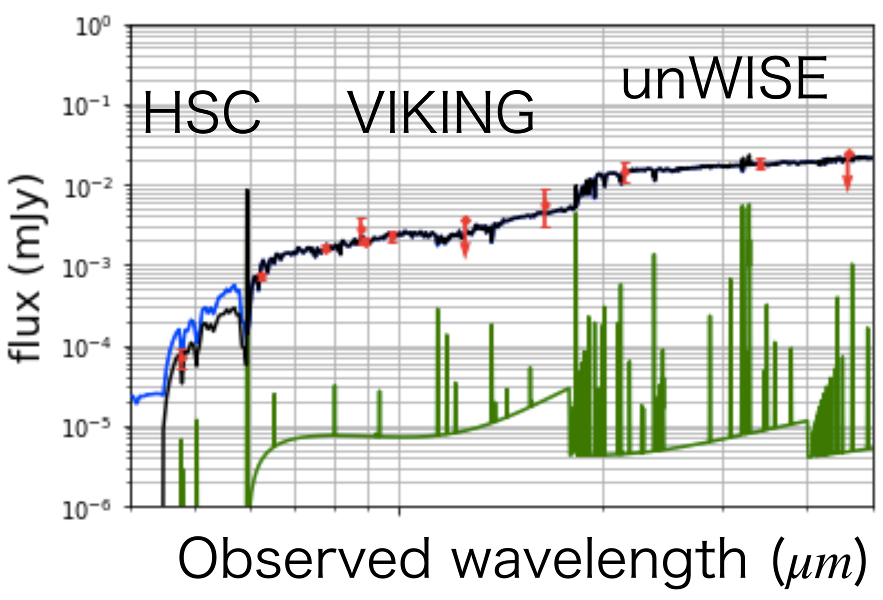

Fig.3: An example of the SED fit. The best-fit z_ph is 3.9. The red dots and black line show the observed data and the best-fit model, respectively. The blue line shows the stellar component, and the green line shows the nebular emission.

HzRG candidates (+ **VIKING**, unWISE) **21 objects** | HzRG candidates (+ **UKIDSS**, unWISE) **7 objects**

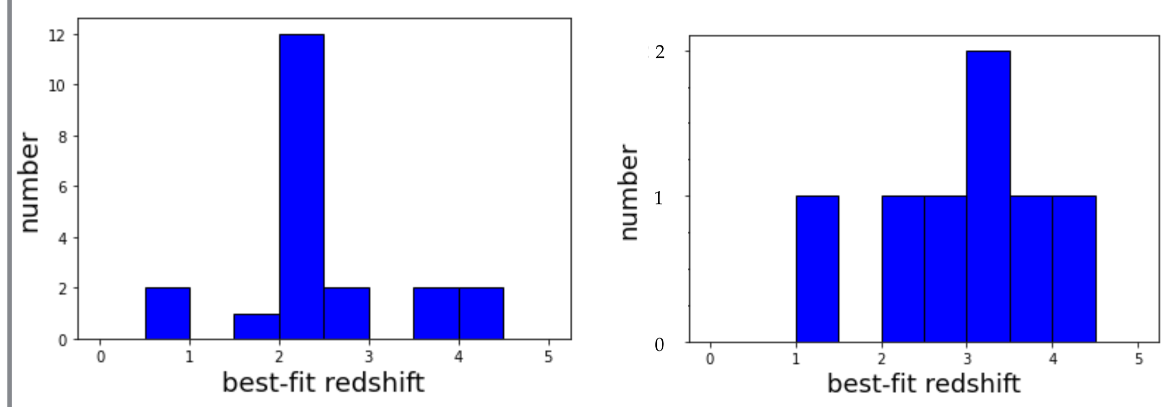

Fig.4: The photo-z distribution of the 34 HzRG candidates obtained from the SED fitting.

↓ 3.3 < photoz < 5.0

FInal HzRG candidates (+ **VIKING**, unWISE) **4 objects** + Final HzRG candidates (+ **UKIDSS**, unWISE) **3 objects**

Star-Formation History (SFH)	
Model	sfhdelayed
$\tau_{\rm main}$ (Myr)	10, 20, 50, 100, 200, 500, 1000, 2000
$\rm age_{main}$(Myr)	100, 200, 300, 400, 500, 600 700, 800, 900, 1000, 2000, 4000 8000, 13000
SSP	
Model	Bruzual and Charlot (2003)
IMF	Chabrier (2003)
Metallicity	0.02
Nebular emission	
logU	−0.2, −0.4
$f_{\rm esc}$	0
$f_{\rm dust}$	0
Lines width (km/s)	300
Dust attenuation	
Model	Calzetti et al. (2000)
$E(B-V)_{\rm lines}$	0.01, 0.1, 0.2, 0.4, 0.6, 0.8 1.0, 1.2, 1.4, 1.6, 1.8, 2.0
Redshift	
redshift range	0.1 to 5.0
Δredshift	0.1

Table.1: X-CIGALE SED fitting parameters

Finally, **7 objects** are selected as reliable HzRGs.

Table 2 shows the best-fit parameters of the 7 reliable HzRGs selected from the 34 HzRG candidates.

ID	reduced χ^2	Bayes.Redshift	Bayes.$E(B-V)_{\rm lines}$	Bayes.log($M_{\rm star}$) [$M_\odot$]
14	0.9	4.1 ± 0.3	0.6 ± 0.4	$(2.8 \pm 1.1) \times 10^{11}$
20	0.7	4.2 ± 0.3	0.5 ± 0.3	$(2.5 \pm 0.9) \times 10^{11}$
30	1.6	3.7 ± 0.3	0.7 ± 0.6	$(4.1 \pm 1.3) \times 10^{11}$
61	1.5	4.0 ± 0.3	0.5 ± 0.6	$(5.1 \pm 1.7) \times 10^{11}$
19	0.9	3.7 ± 0.3	0.5 ± 0.3	$(4.8 \pm 1.5) \times 10^{11}$
94	1.3	3.8 ± 0.3	0.1 ± 0.2	$(5.5 \pm 0.8) \times 10^{11}$
109	1.0	3.8 ± 0.3	0.6 ± 0.5	$(4.4 \pm 1.3) \times 10^{11}$

Table.2: Best-fit parameters for visually-confirmed 7 reliable HzRGs

The stellar mass of HzRGs (z~4) are very massive (average: 4.2×10^{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 star formation activity of HzRG.

↓

Fig.5 shows the UVJ color, with HzRG plotted along the single-burst color track. This shows that the star-formation history of HzRGs are single-burst-like and passively evolving.

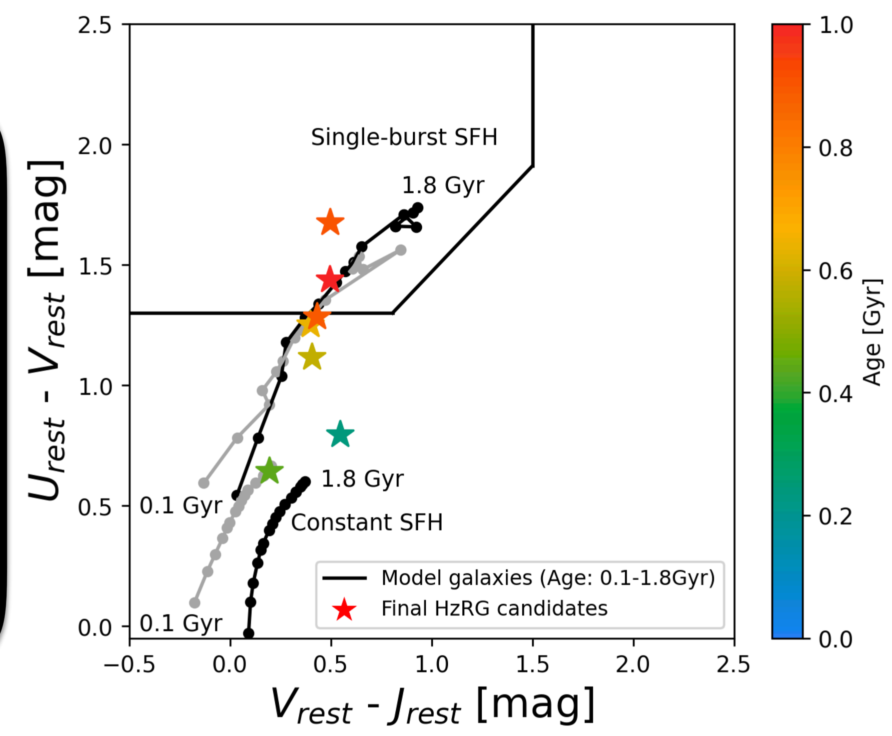

Fig.5: Rest-frame *UVJ* diagram. The stars denote the 7 reliable HzRGs. The solid black line is the quiescent galaxy boundary of (Muzzin et al. 2013). The model tracks are based on the single-burst and constant SFHs, with the metallicity of Z=0.004 (gray) and Z=0.02 (black).

Star-formation history from the SED fit

↓

Fig.6 shows that the 7 HzRG candidates had their most active star-formation phase >200 Myr ago, and their SFR sharply dropped after the peak of the star-formation.

↓

HzRGs are in the process of suppressing star-formation activity.
=>The radio jet may have worked as a negative feedback to the star formation and also as a suppressor for the star formation.

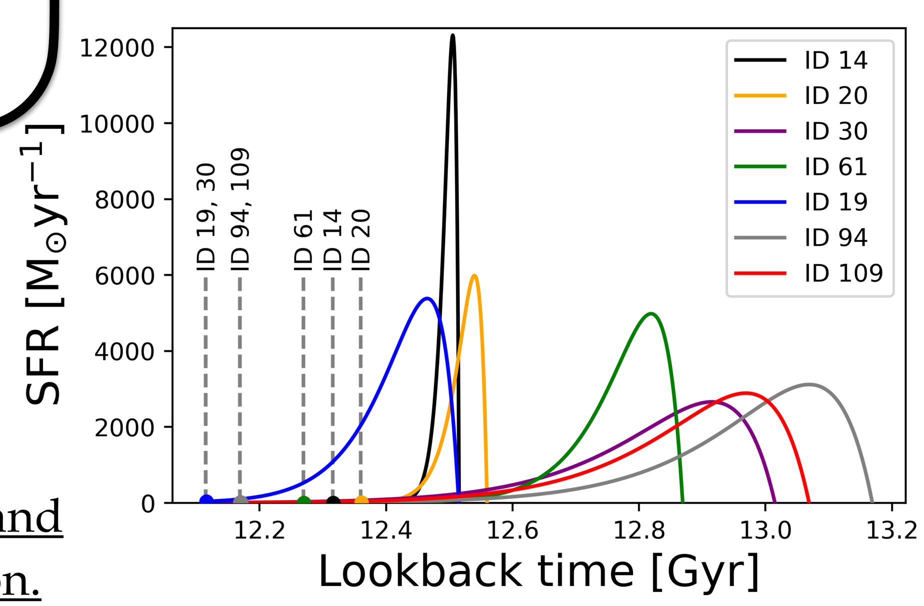

Fig.6: Estimated SFH of 7 HzRG objects

5. Summary

- 146 HzRG candidates are selected by matching the g-dropout galaxies selected from HSC-SSP Wide with FIRST radio source catalog in ~ 560 $\rm deg^2$.
- The SED analysis for 7 reliable HzRGs shows their massive nature (~$10^{11} M_\odot$).
- The stellar population of the z ~ 4 HzRG candidates is consistent to passively evolving galaxies with a past active star formation.

References

Aihara et al. 2018, PASJ, 70, S4
Chabrier, 2003, PASP, 115, 763
Edge et al. 2015, ApJ, 801, 26
Helfand et al. 2015, ApJ, 801, 26
Khabibullina & Verkhodanova, 2009, AstBu, 64 123
Calzetti et al. 2000, ApJ, 533, 682
Kormendy & Ho, 2013, ARA&A, 51, 511
Schlafly et al. 2019, ApJS, 240, 30
Bruzual & Charlot 2003, MNRAS, 344, 1000
Yang et al. 2020, MNRAS, 491, 740