A new wide exploration of radio galaxies at z~2 with the gzK selection

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Abstract

Systematic investigations of high-redshift radio galaxies (HzRGs) are useful to constrain the nature of the stellar population of their hosts. However, statistically-large samples of HzRGs, particularly at z~2, have not been constructed so far, due to their rarity and technical limitations. To address these challenges, we employed the gzK selection method that identifies both star-forming and passive galaxies in the cosmic noon. This approach enables us to carry out a comprehensive study of HzRGs at z~2. We identified a total of 88 star-forming RGs (sgzK-RGs) and 18 passive RGs (pgzK-RGs) by cross-matching optical data from Subaru/HSC, near-infrared data from VISTA VIKING, and radio data from VLA FIRST, utilizing the gzK selection criteria. Various physical properties were characterized through spectral energy distribution (SED) fitting. Interestingly, our pgzK-RGs exhibit a deviation of ~1 dex below the main sequence of star-forming galaxies, which is similar to the behavior observed in low-z RGs. This suggests that the gzK selection method can uncover a new population of RGs in the high-redshift previously unexplored.

Introduction

Radio Galaxy (RG)

- ▶Passive galaxies dominate at low-z.[1],[2]
- ▶Radio jets affect the star formation in their host.

∗Is radio-mode AGN feedback “positive” or “negative”?

⇨ **Explosions of HzRGs are the key to constraining the nature of the stellar population.**

Unfortunately…
HzRGs are rare objects.

Previous method to select HzRGs

- ▶Ultra Steep Spectra method[4]
  - ⚠Existence of non-USS RGs
- ▶Lyman break method[1]
  - ⚠Difficult to select z~2 objects

⇨ **Problem**
No statistical studies of RGs, especially at z~2.

Our Method：**gzK selection**[5]
A color selection to select galaxies at z~2 with g-z and z-Ks colors.

We can select **star-forming** and **passive** galaxies at z~2 !!

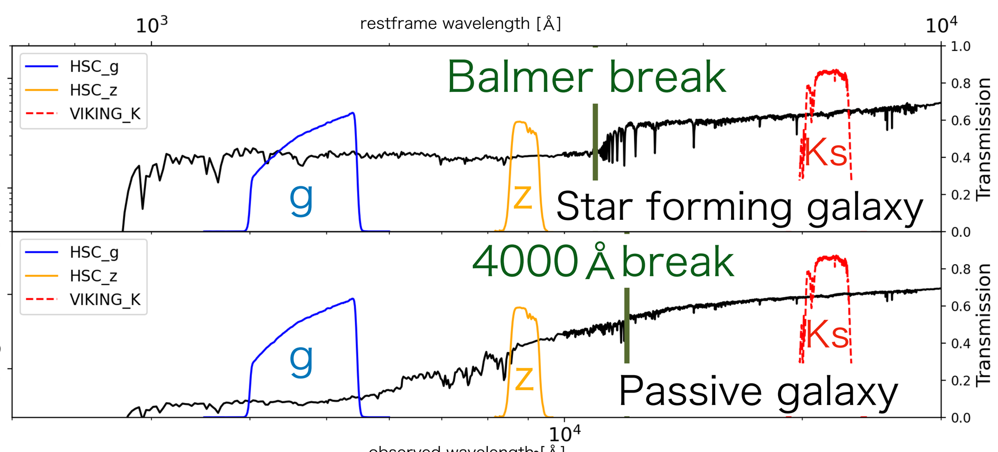

Fig. 1. Total transmission curves of gzK and galaxies model at z~2

Goals of this study

- ▶ **A new wide explosion of HzRGs regardless of population** with **gzK selection**
- ▶ **Constraining physical properties of HzRGs** in our sample

Data

Optical data：HSC-Subaru Strategic Program (HSC-SSP) S21A Wide
Near-infrared data：VISTA Kilo-degree Infrared Galaxy Survey (VIKING)
Radio data：FIRST (1.4 GHz)
(mid-infrared data (for SED fitting)：unWISE (3.4 μm, 4.6 μm))

Table 1. The limiting magnitudes (5σ, AB magnitude)

	g	r	i	z	y	Z	Y	J	H	Ks	3.4μm	4.6μm
limiting mag	26.5	26.5	26.2	25.2	24.4	22.7	22.0	21.8	21.1	21.2	20.6	20.1
Survey	HSC-SSP					VIKING					unWISE	

Sample selection

HSC - VIKING (optical-infrared sourses)
↓
gzK galaxies (@ z ~ 2)
↓ Matching radio data
gzK - FIRST (tentative candidates)
↓ SED fitting (§3) / Rejecting QSOs by removing point sources
gzK - RG (Radio galaxy candidates)

gzK criterion (model：BC03 [6])

$gzK_s = (z-K_s)_{AB} - 1.32(g-z)_{AB}$

Star-forming galaxies：$gzK_s > 0.0$
Passive galaxies：$gzK_s < 0.0$ and $(z-K_s)_{AB} > 2.7$

Radio galaxy candidates (gzK-RG)
Star-forming RG (sgzK-RG) 88 objects
Passive RG (pgzK-RG) 18 objects

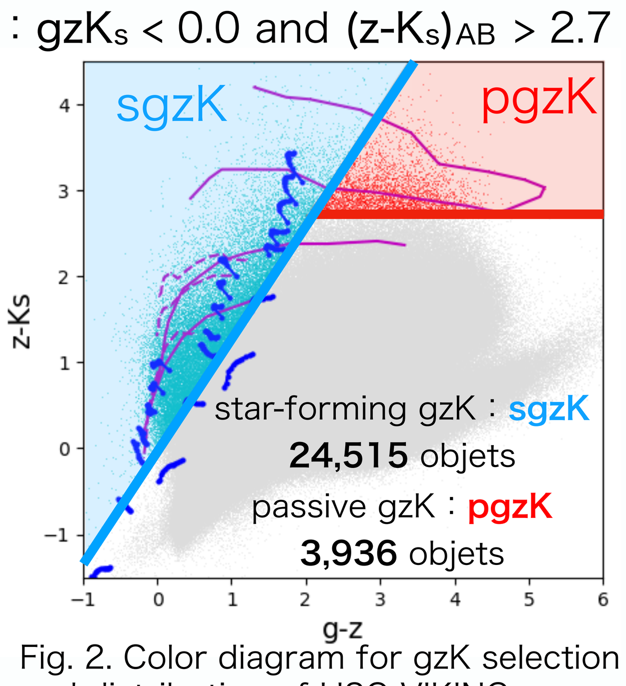

Fig. 2. Color diagram for gzK selection and distribution of HSC-VIKING
(The solid and dashed magenta lines：ssp model of τ=0.3, 1 Gyr. The blue doted lines：Constant star-formation model. All models are plotted for the range 1.4 < z < 2.5.)

Analysis

SED fitting
code：CIGALE (Code Investigating GALaxy Emission [7])
aim：to estimate physical properties of our sample
：to select reliable objets for their redshift

Method
① Fitting with 0.0 < z < 4.0 (Δz=0.1)
② Select objects at 1.4 < z_{best} < 2.5 (63% of gzK - FIRST)
③ Fitting with 1.4 < z < 2.5 (Δz=0.1)

Table 2. parameters for SED fitting

model：sfhdelayed
τ_{main} (Myr)：100.0 —10000.0
age_{main} (Myr)：100.0 —10000.0

SSP
model：BC +03
IMF：Chabrier +03
Metallicity：0.02

Dust attenuation
model：Calzetti +00
$E(B-V)_{line}$：0.001—2.0

redshift：0.0 - 4.0
Δz：0.1

Nebular emission
logU：-4.0, -2.0
f_{esc}：0
f_{dust}：0
Lines width (km/s)：300

Results & Discussion

Result of HzRGs candidates selection

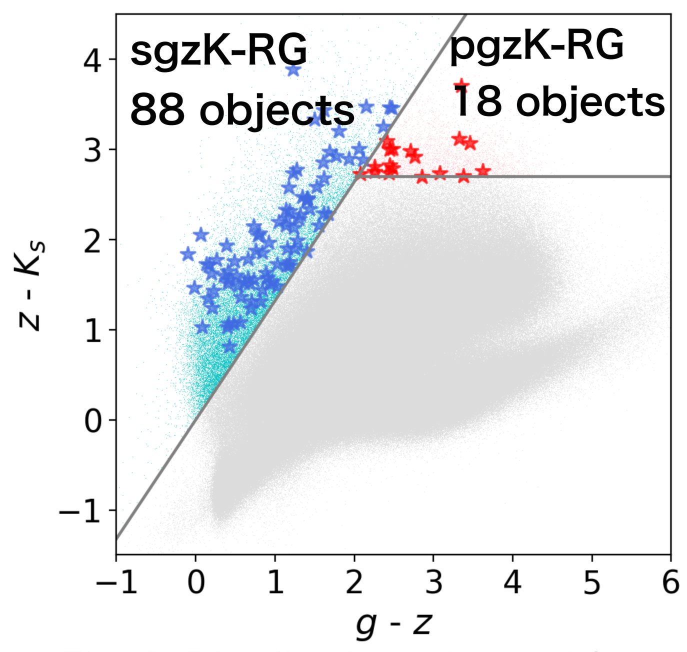

Fig. 3. Distribution of gzK-RGs

p：p-value of the KS test

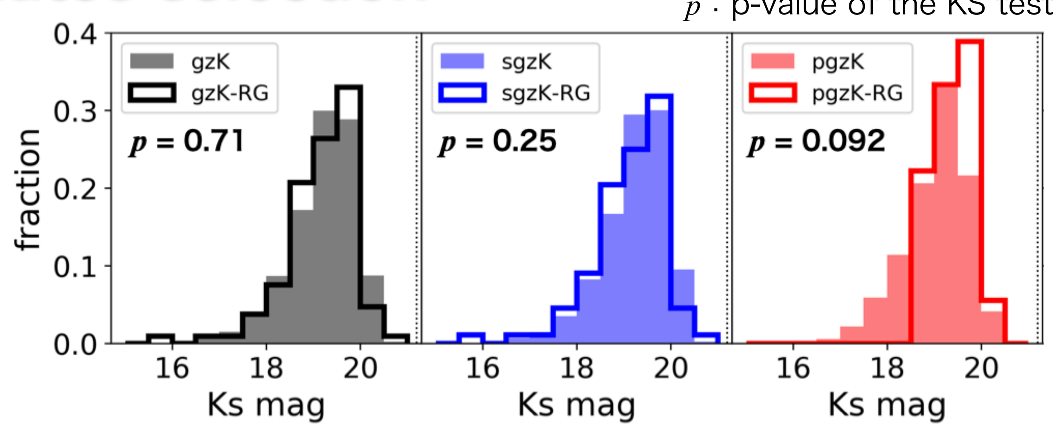

Fig. 4. Distribution of Ks magnitude

▶There is not a significant difference between gzK and gzK-RG in the distribution of Ks band magnitude.
NOTE：We can only see the distribution of bright galaxies in Ks band.

▶For both of sgzK and pgzK galaxy samples, ~0.5% of them are HzRGs.
⇨ **The number of RGs to galaxies at z~2 appears to be independent of the population, when focusing only on Ks-bright galaxies.**

Estimating physical properties with SED fitting

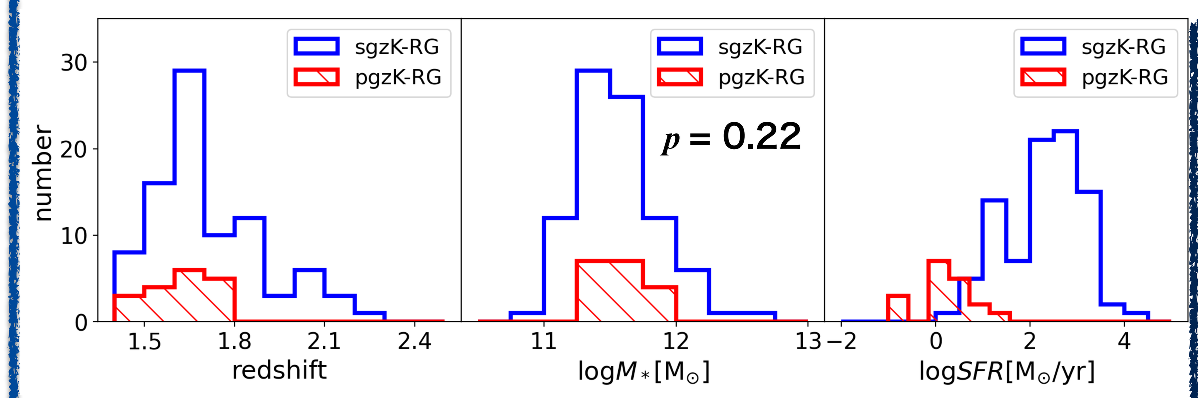

Fig. 5. Distribution of redshift, stellar mass and star-formation rate of sgzK-RG and pgzK-RG

- ▶Redshift of gzK-RGs shows a peak at z~1.6.
- ▶The majority has **stellar mass (M_*) of over $10^{11} M_\odot$.**
- ▶No significant difference in their M_*.

Redshift and M_* relation

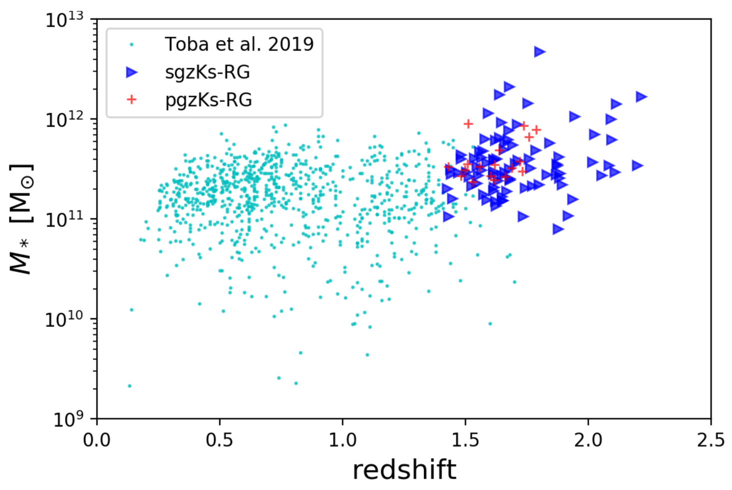

Fig. 6. Relation between redshift and stellar mass of RGs from low-z to z~2

Table 3. Stellar mass of RGs (median)

redshift	0.0 < z < 1.7 [8]	1.4 < z < 2.5 gzK-RG
$\log (M_*/M_\odot)$	**11.08**	**11.56**

▶The fraction of objects with $M_* > 10^{11.5} M_*$ is higher in the gzK-RG sample than in low-z RG sample.
▶The fraction of objects with $M_* < 10^{11} M_*$ is lower in the gzK-RG sample than in low-z RG sample.
→ low-mass RGs were not selected because we can not see dim galaxies in Ks band.

→ **gzK-RG** is more **massive** than low-z RGs

Redshift and specific star formation rate (sSFR)

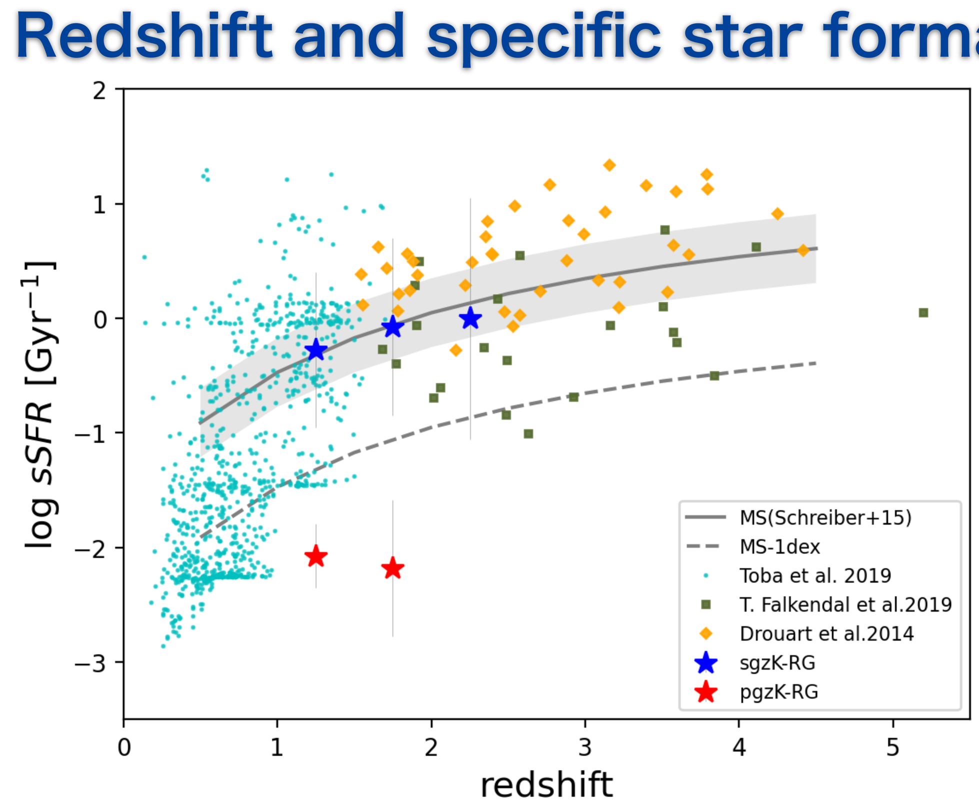

Fig. 7. Relation between redshift and specific star formation rate of RGs from z~0 to z~5. Stars show the median of gzK-RG. The solid gray line shows the main sequence of star-forming galaxies (MS), gray shaded region shows the MS with 0.3 dex scatter, and the dashed gray line shows 1 dex below MS.

sgzK-RG (z~2★)
▶Consistent with MS at z~2.
▶Consistent with sSFR evolution of HzRGs in previous studies.

pgzK-RG (z~2★)
▶**Located more than 1 dex below.**
▶**Consistent with low-z RGs.**

Previous studies
Toba+19[8]
- ▶ z < 0.8：Passive RGs are dominant
- ▶ 0.8 < z < 1.1：Consist both populations.
- ▶ 1.1 < z：star-forming RGs is dominant

Drouart+14[11] & Falkendal+19[9],[10]
- ▶ 1 < z < 5.2：star-forming RGs are dominant

The result suggests that RGs that have ceased star formation similar to low-z RGs already exist at z~2.

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