The evolution of massive galaxies explored by high-z radio galaxies

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Abstract
This study aims to systematically understand the properties of high-z radio galaxies (HzRGs). By matching the g-dropout Lyman break galaxy sample from the Subaru HSC-SSP survey with the FIRST radio source catalog, we obtained 146 candidates of HzRGs at z~4.. To investigate the properties of these HzRG candidates, SED fits were performed on 28 objects detected in the VIKING, UKIDSS and unWISE infrared data. We found that 7 objects have SEDs which are consistent with the SED of HzRGs at z~4, and that these objects are massive galaxies with stellar masses as high as $10^{11} M_{\odot}$. We also investigate their star formation histories and find that they are consistent with a model of abruptly ceasing star formation.

1. Introduction

Massive galaxies tend to form their stars rapidly and quench star formation rapidly in the early Universe.

However, the physical mechanism for the suppression of star formation is not well understood.

▶ How does an active galactic nucleus affect the suppression of the star formation in the early universe?

For tackling this question, we focus on high-z radio galaxies (HzRGs).

Fig.1: Star formation history of early-type galaxies (Thomas et al. 2005)

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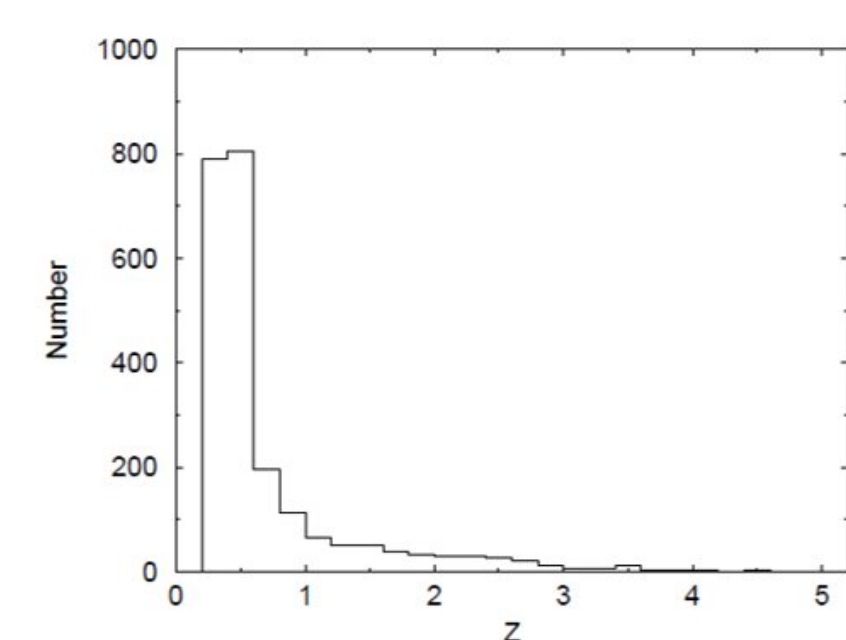
Fig.2: Number of the known radio galaxies (Khabibullina & Verkhodanova 2009)

We newly search for HzRGs 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 from the HSC SSP S19A wide (Aihara et al. 2018)
· radio source catalog: FIRST (Helfand et al. 2015)

Selection

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

•1″ matching

HzRG candidates 184 objects

•i<21.5: to remove low-z galaxies and/or high-z QSO

HzRG candidates 146 objects

Fig.3: i-band magnitudes of 184 HzRG candidates

Blue：184 HzRG candidates

Yellow：low-z galaxies and/or high-z QSO

spectroscopic observation

Observation of one spectroscopically unobserved object at i=21.08
· 1500 sec integration with Subaru-FOCAS
· The filter is Y-47/B300mm for long slit observations in the 4700-9100 Å optical band.

Result z=3.73,
Lyα FWHM = 3980 km/s ⟶ **High-z quasar**

⟶ Consistent with our assumption that objects with i<21.5 are nearby galaxies or high-z quasars

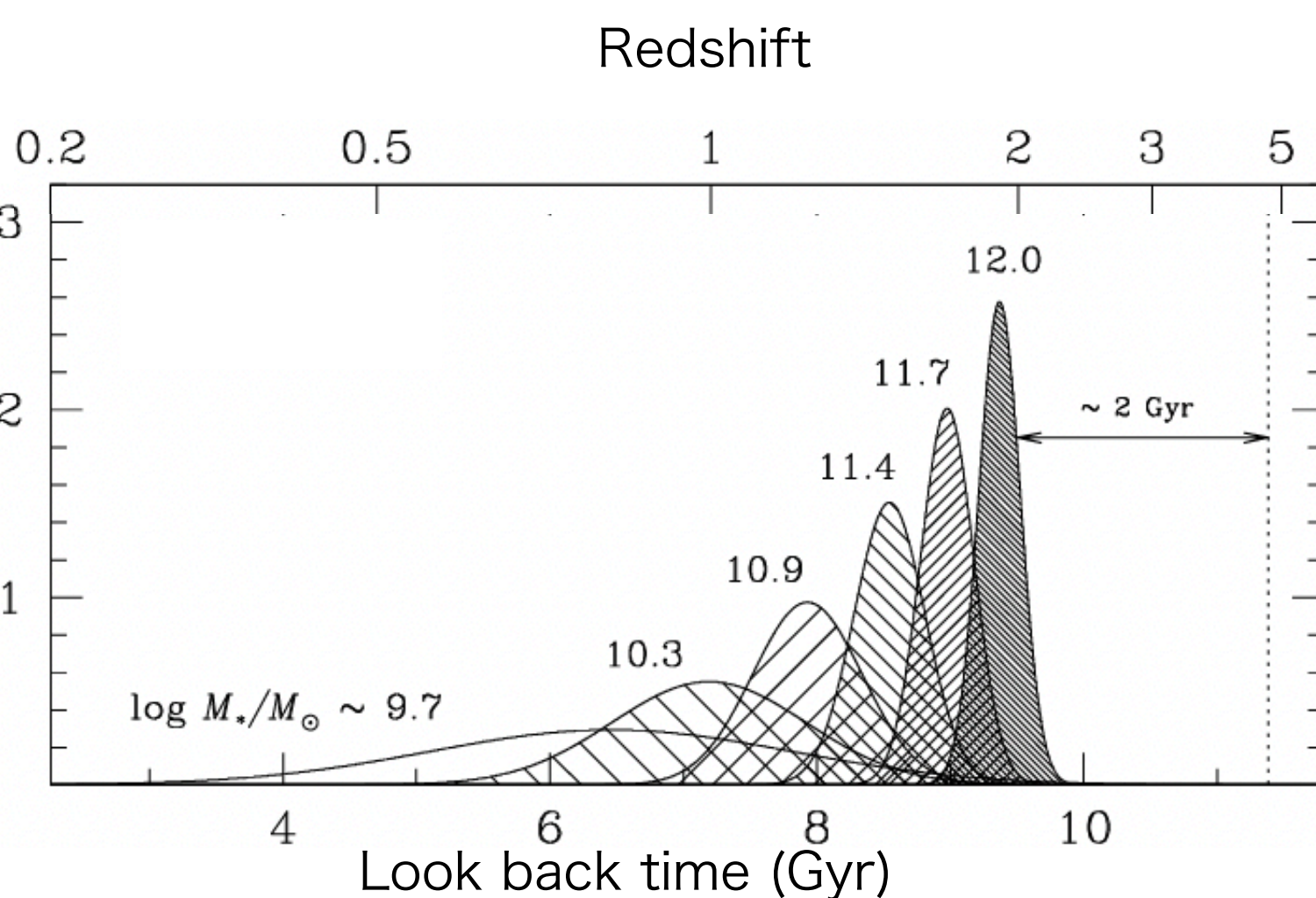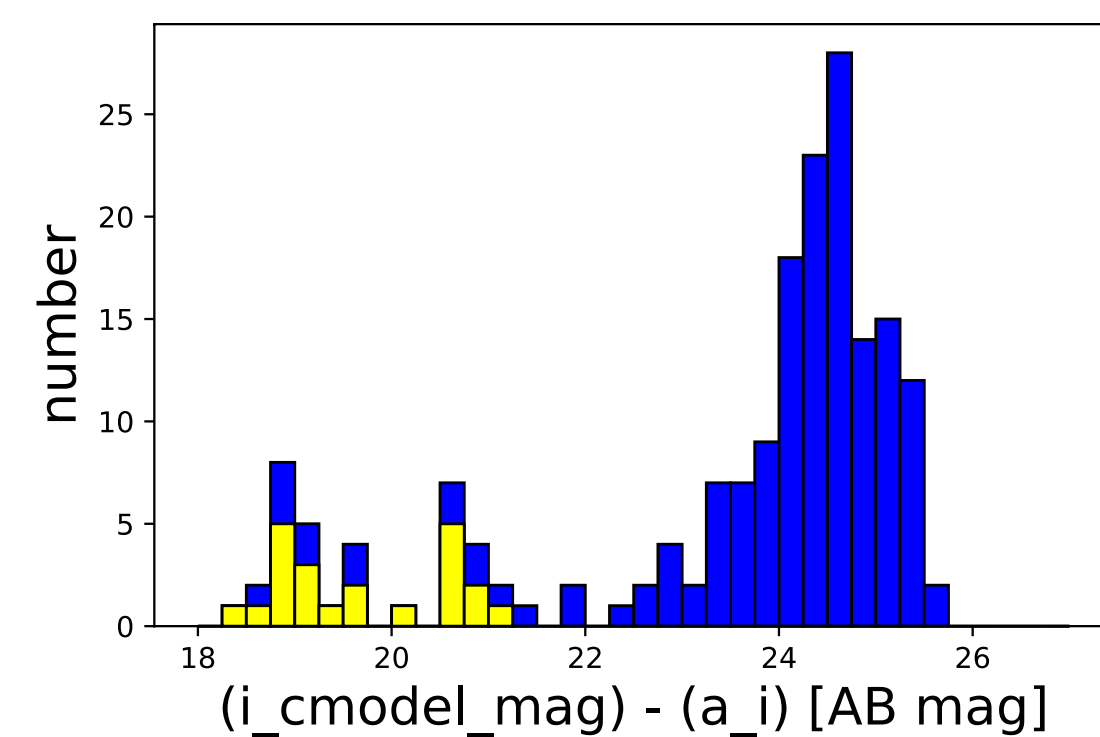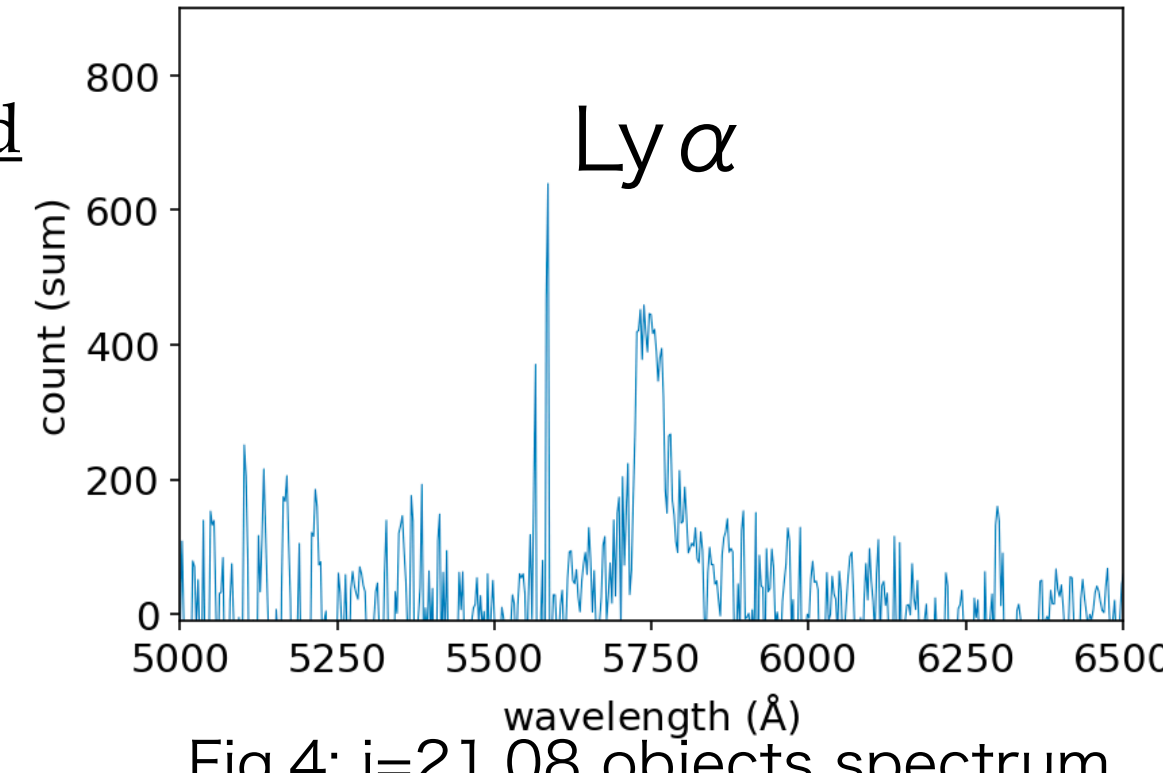Fig.4: i=21.08 objects spectrum

3. Analysis

SED fitting

We perform a SED analysis of 28 HzRG candidates detected with VIKING, UKIDSS and unWISE using X-CIGALE (Yang et al. 2020) for selecting reliable HzRGs.
We assume the "delayedsfh" model for the star-formation history.

Reference

Aihara et al. 2018, PASJ, 70S, 4
Edge et al. 2015, ApJ, 801, 26
Helfand et al. 2015, ApJ, 801, 26
Khabibullina & Verkhodanova, 2009, AstBu. 64 123

Kormendy & Ho2013, ARA&A, 51, 511 Schlafly et al. 2019, ApJS, 240, 30
Willott et al. 2003, MNRAS, 446, 599
Yang et al. 2020, MNRAS, 491, 740

HzRG candidates 146 objects

•near-IR data：VIKING, UKIDSS
•mid-IR data：unWISE

•SED fit (photo-z = 3.3 ~ 4.7)

HzRG candidates with IR-data 28 objects ⟶ **Final HzRG candidates 7 objects**

▶ 7 final z~4 HzRG candidates were selected.

Table.1: The result of the SED fit for 7 HzRGs at z~4

ID	χ^2	Redshft	E(B-V)	Stellar mass ($10^{11} M_{\odot}$)
14	0.9	4.1 ± 0.3	0.6 ± 0.4	2.8 ± 1.1
20	0.7	4.2 ± 0.3	0.5 ± 0.3	2.5 ± 0.9
30	1.6	3.7 ± 0.3	0.7 ± 0.6	4.1 ± 1.3
61	1.5	4.0 ± 0.3	0.5 ± 0.6	5.1 ± 1.7
19	0.9	3.7 ± 0.2	0.5 ± 0.3	4.8 ± 1.5
94	1.3	3.8 ± 0.2	0.1 ± 0.2	5.5 ± 0.8
109	1.0	3.8 ± 0.3	0.6 ± 0.5	4.4 ± 1.3

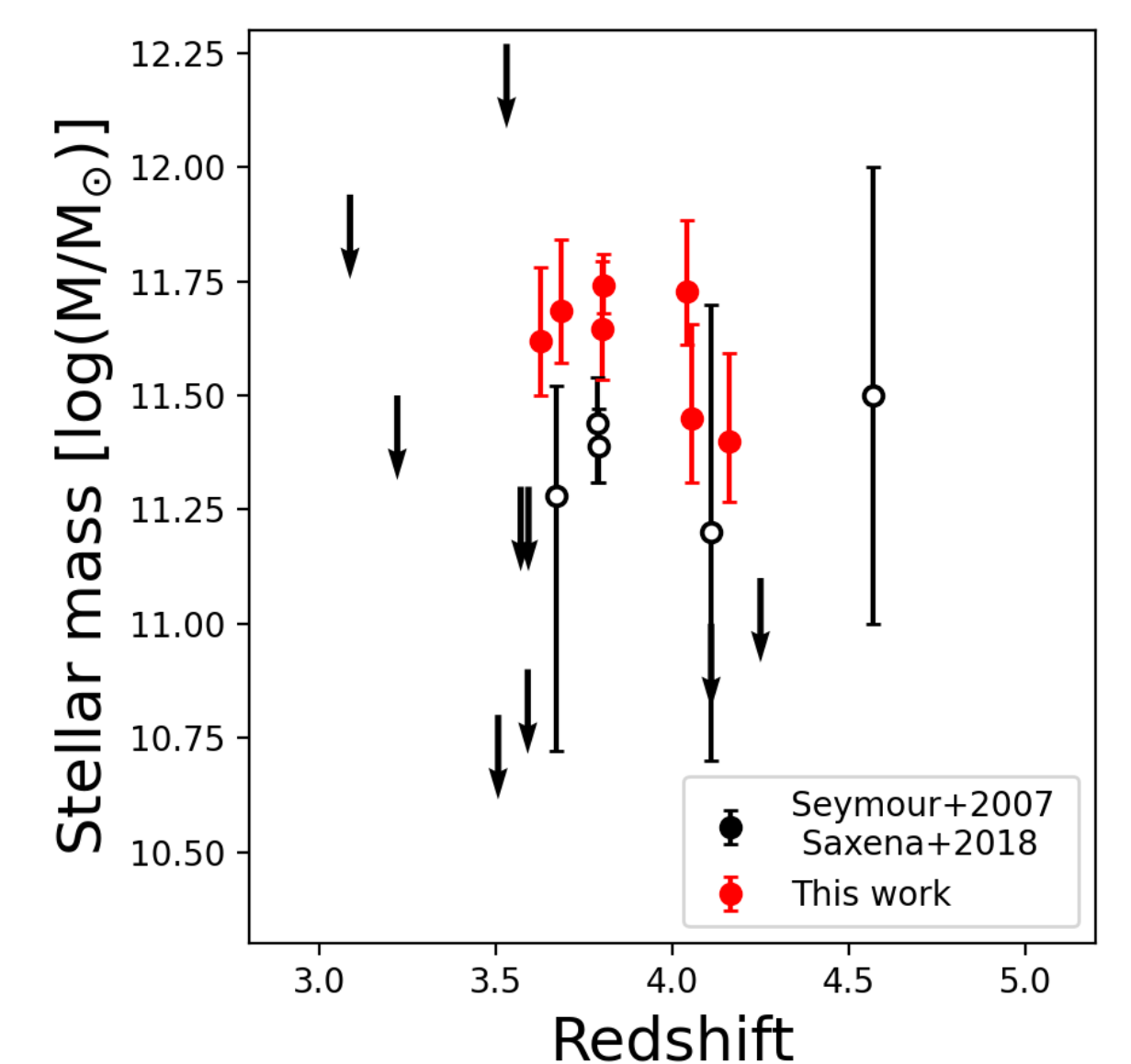The average stellar mass of 7 targets is $4.2 \times 10^{11} M_{\odot}$.

Fig.5: Comparison of stellar masses of 7 objects with those of the previously-identified HzRGs

▶ The stellar mass of the HzRGs in this work tends to be slightly heavier than the HzRGs found so far (stellar mass: $< 3.3 \times 10^{11} M_{\odot}$), but this may be due to the selection effect of this work (targeting bright sources).

4. Discussion

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

Fig. 6 shows that HzRG fits the model of Tau=0.1 Gyr (rapid suppression of the star formation)

The strongest model for rapidly quenched star formation is AGN feedback in the quasar mode (e.g., Smethurst et al. 2021).

▶ In the early universe, a quasar before HzRG ? ← This result suggests that the galaxy co-evolution scenario (e.g., Hickox et al. 2009) is the same in the early universe.
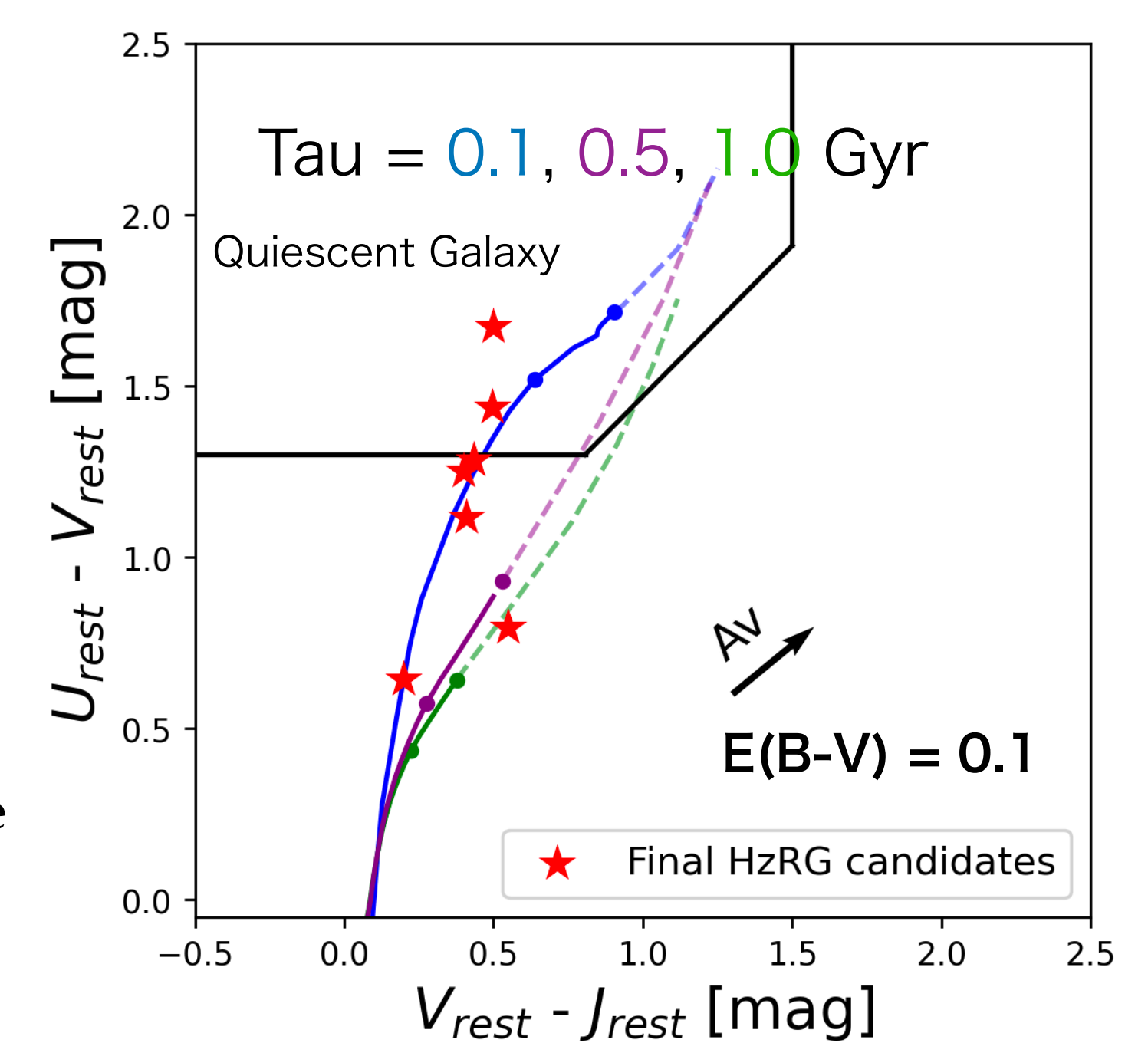
Fig.6: Rest-frame UVJ diagram. Red stars are the 7 HzRG candidates and the black line is the region of the Quiescent galaxy of Muzzin et al. 2013. The color tracks of the BC03(delayed) model are plotted at Tau=0.1, 0.5, and 1.0 Gyr.
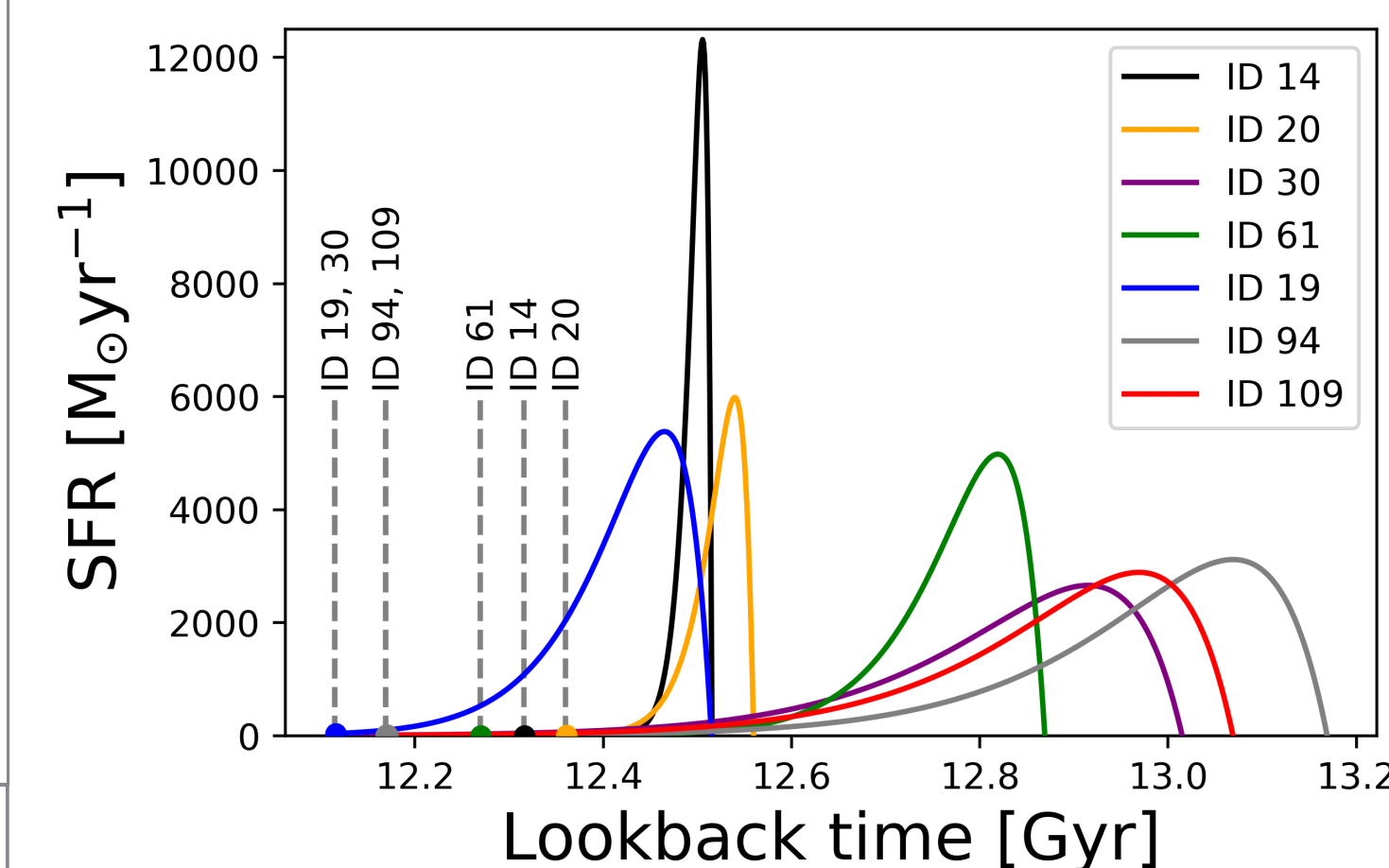
Star-formation history inferred by the SED fit

Fig. 7 shows the SFHs of 7 final HzRG candidates.

All HzRGs are rapid star formation in the past, followed by a rapid decline in star formation.

▶ Radio galaxies do not appear when star formation is active?

Fig.7: SFH of 7 final HzRG

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 deg².
· The SED analysis for 7 final HzRGs shows their massive ($4.2 \times 10^{11} M_{\odot}$).
· The star formation history based on UVJ diagrams and SED fits suggests that HzRGs were active star formers in the past, but that star formation is already suppressed at z~4.