Subaru Users Meeting FY2023

A massive quiescent galaxy in a group environment at $z = 4.53$

Kakimoto et al. 2024, ApJ in press (arXiv:2308.15011)

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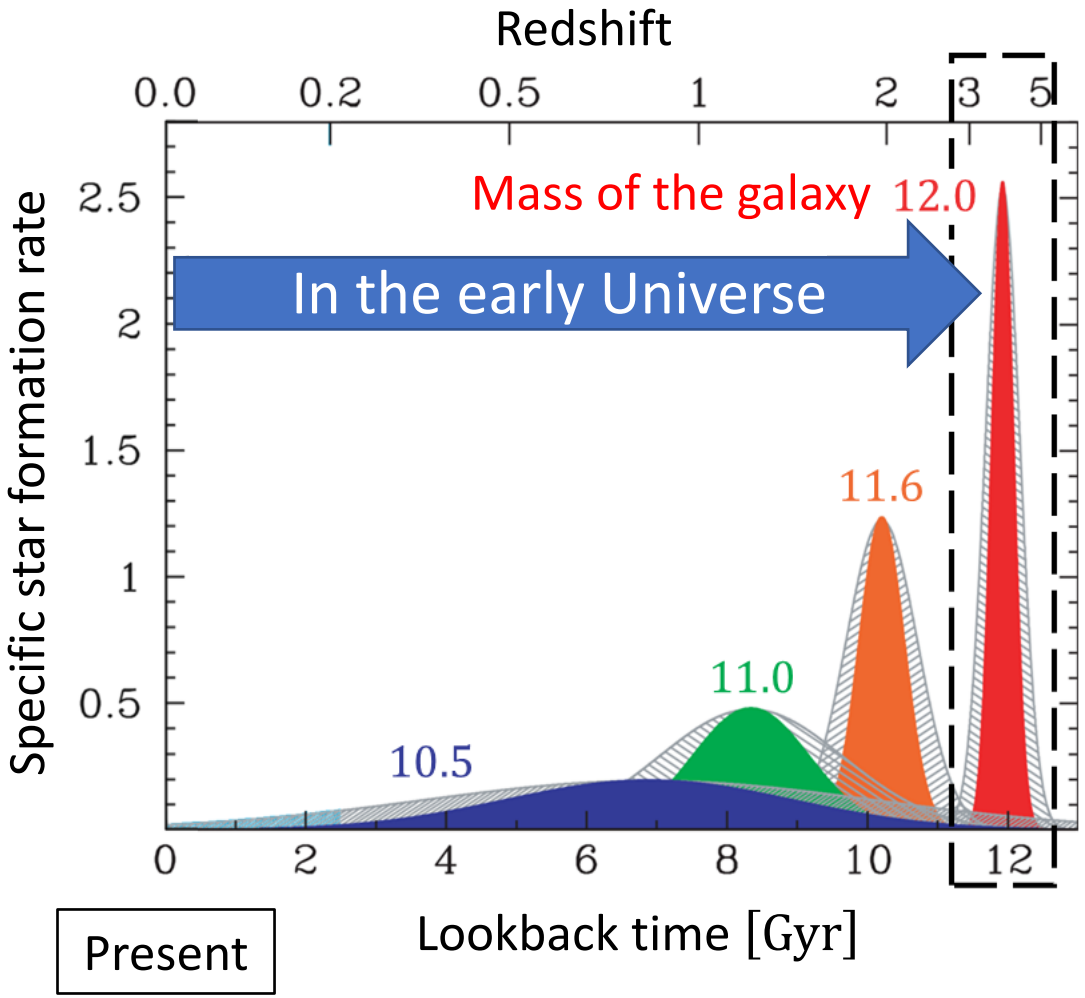
Masato Onodera (NAOJ), Rhythm Shimakawa (Waseda University) et al.

2024/1/25

Abstract

1. A massive quiescent galaxy at $z = 4.53$
    1. Confirmed at the second highest redshift
    2. Inferred star formation history shows this galaxy experienced starburst at $z_{\rm phot} \sim 5$ following a rapid quenching phase.
2. A massive galaxy group candidate at $z = 4.5$ (5 massive galaxies)
    1. First discovery of the galaxy group with a quiescent galaxy
    2. This over-density significance is the largest in the COSMOS field at $4.4 < z_{\rm phot} < 4.7$.
    3. The Inferred halo mass from the central quiescent galaxy is $\sim 10^{12.3}\ M_{\odot}$, and 3 SFGs are located $\lesssim R_{\rm vir}\ (70\ {\rm kpc})$.

1.1 Star formation history of Local Ellipticals



Star formation histories of massive elliptical galaxies in the local Universe. (Thomas et al. 2010)

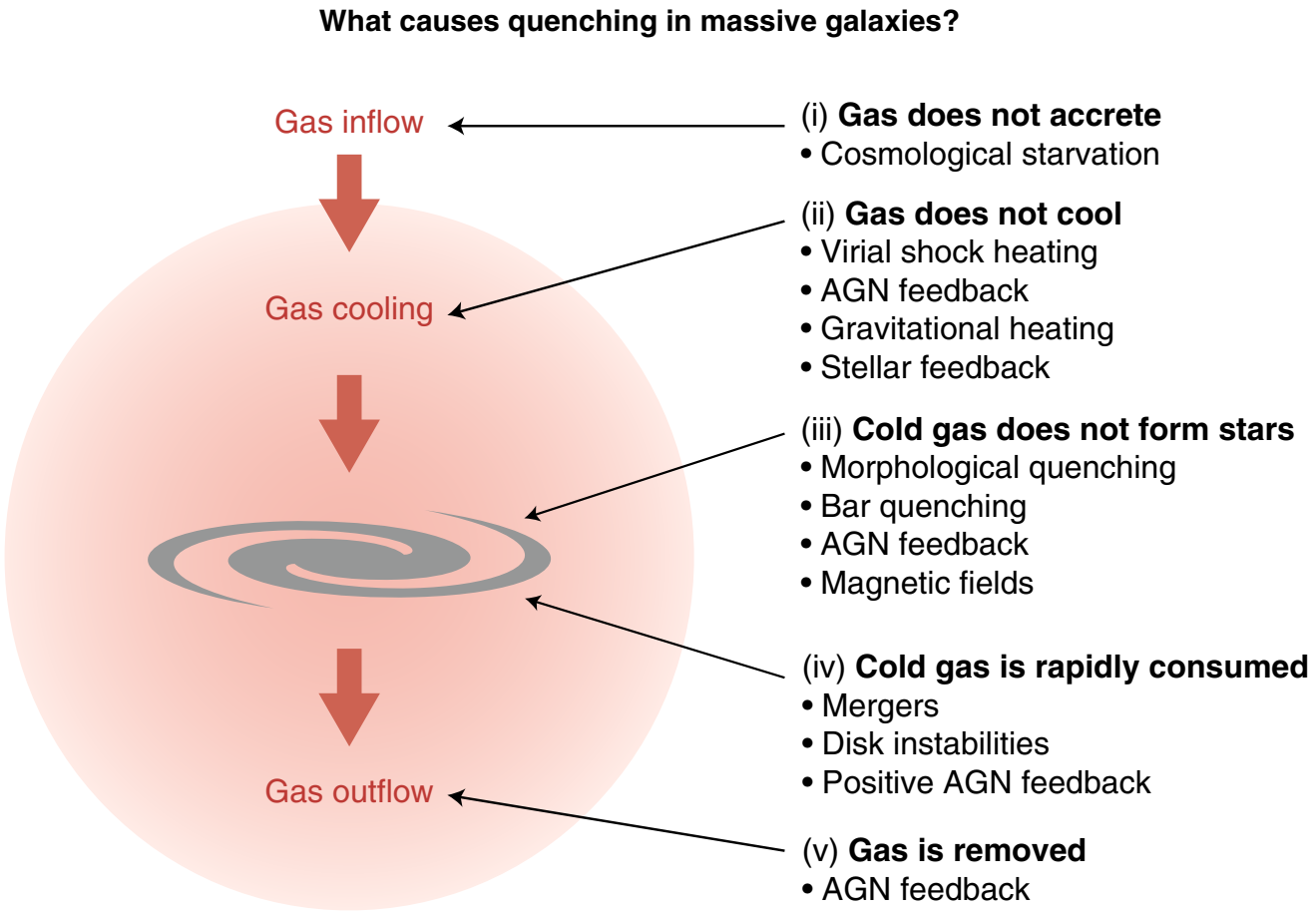
Open Question

- What are the physical drivers of starburst and subsequent quenching?

- Many studies have been carried out to search for the progenitors of the local ellipticals.
- Method: Directly observe the quenching phase of the galaxy.

1.2 Possible quenching mechanism

- Man & Belli 2018



- Mass quenching
  - AGN feedback
  - Stellar feedback
- Environmental quenching
  - Strangulation (starvation)
  - Mergers
  - Galaxy harassment
  - Ram-pressure stripping

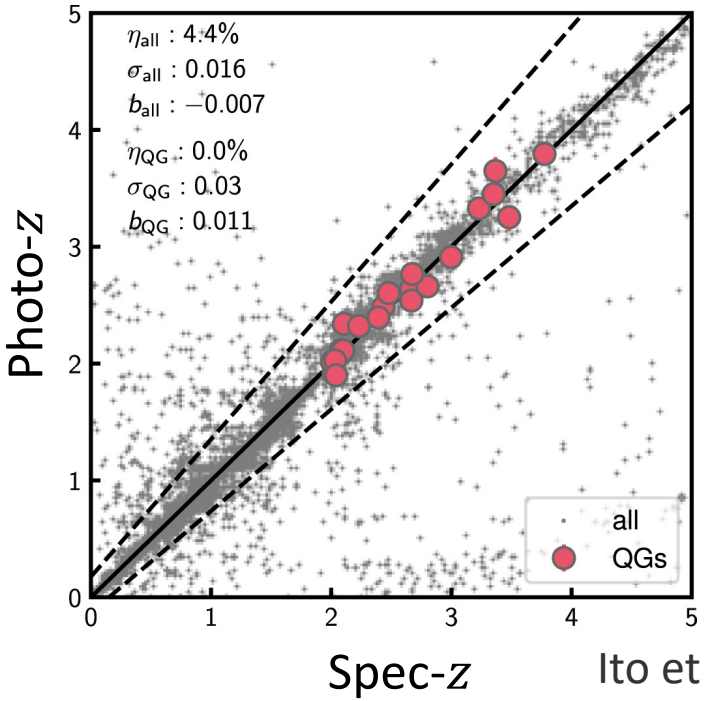
- Which is a main driver of massive galaxy quenching at high redshift?

2.1 Target Selection

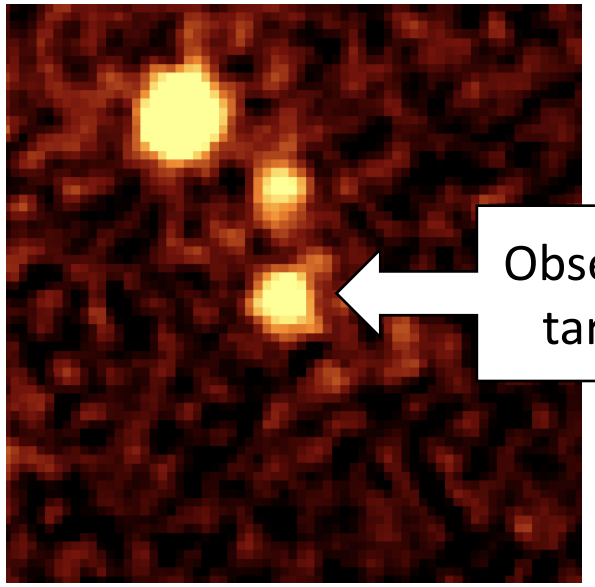
COSMOS field

- The main data sets cover a wide area ($\approx 2\ \mathrm{deg}^2$).
- This field has been observed from X-rays to radio wavelengths.

  → High-precision photometric redshifts can be obtained.



Ito et al. 2022



VISTA K_s-band image

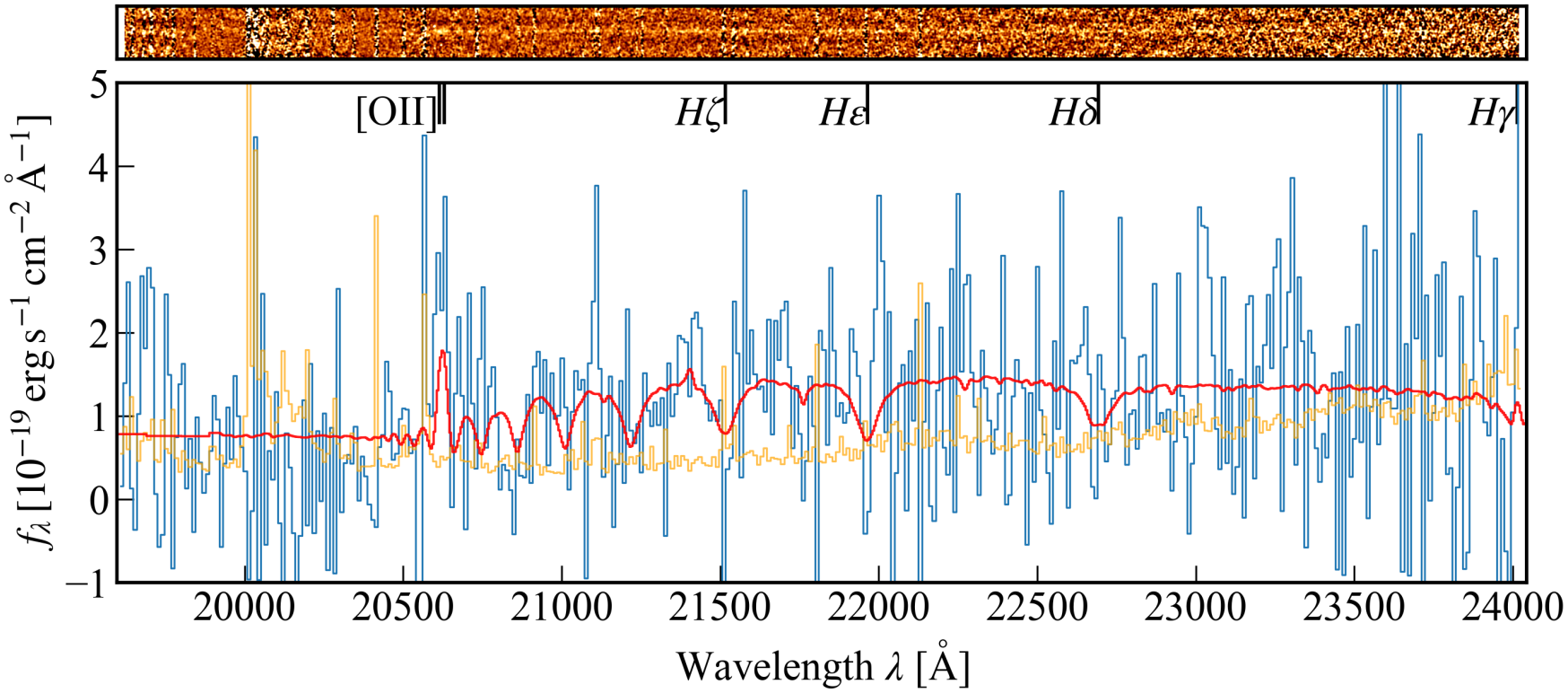
A massive galaxy candidate with a strong Balmer break at $z_{\mathrm{phot}} \sim 4.7$. (Weaver et al. 2022)

2.2 Target Spectrum

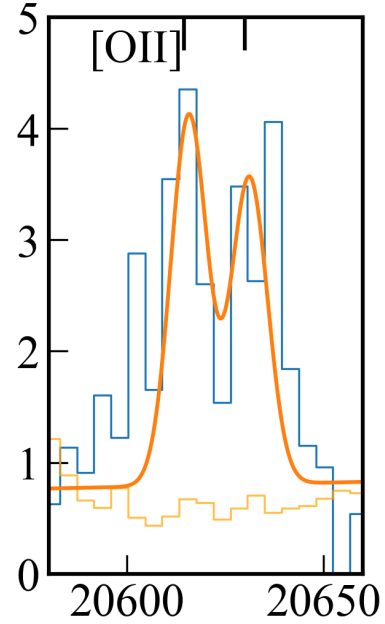
Spectrum

Error

Model Spectrum



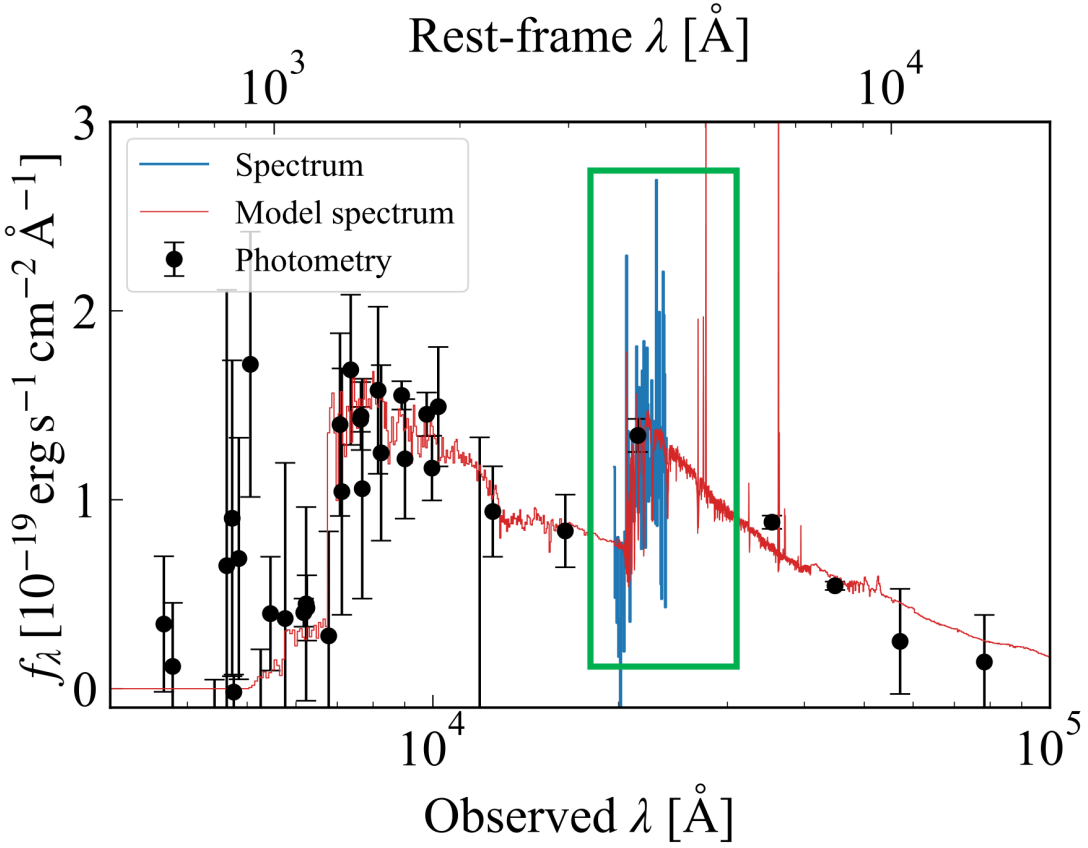
Keck/MOSFIRE K-band spectrum



Blow-up of [OII]

◆ The presence of faint [OII] lines allows the measurement of the secure spectroscopic redshift. $z_{\rm spec} = 4.5313 \pm 0.0005$

2.3 Performing SED fitting (Prospector)



Rest-frame UV to NIR SED &
model spectrum from prospector.

Fitting code: Prospector [Johnson et al. 2021]

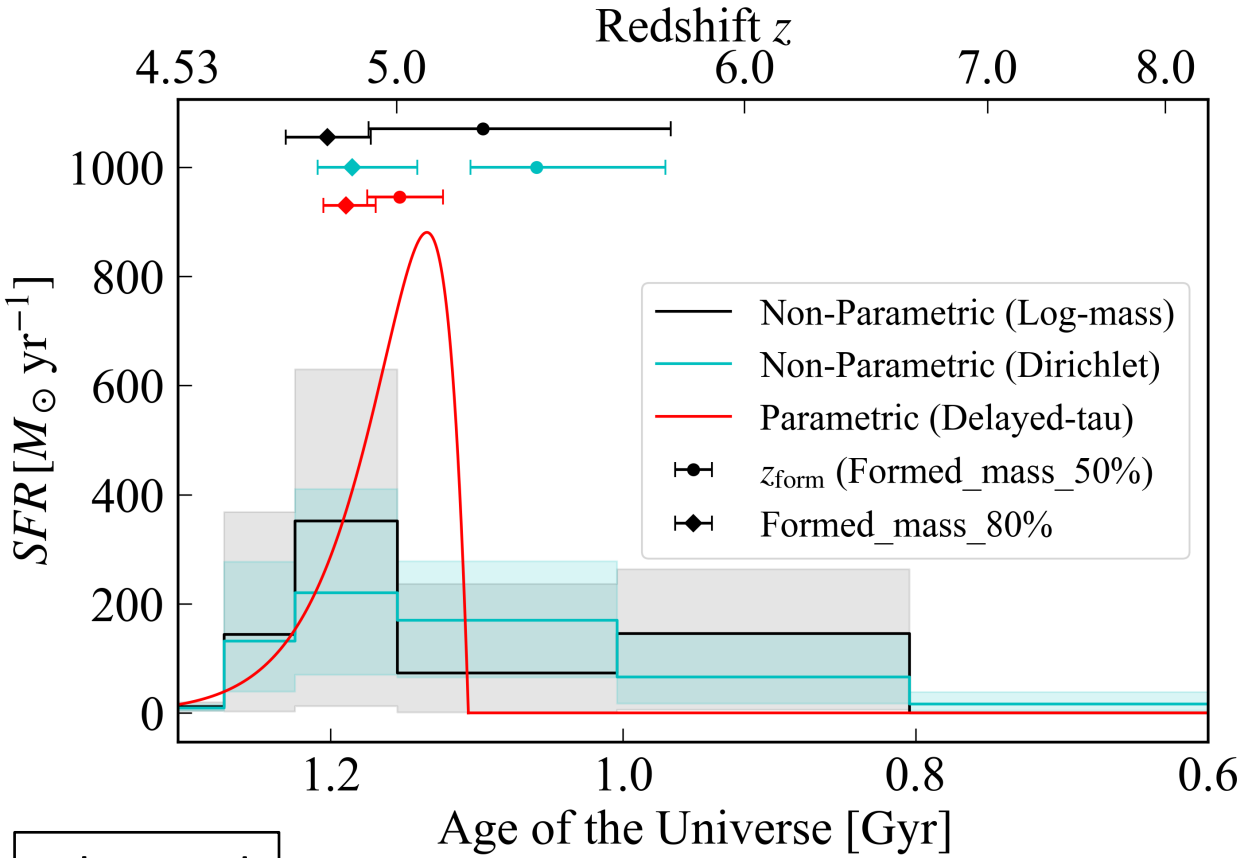
Assumption:

- Chabrier (2003) IMF
- Solar metallicity
- Delayed tau-model ($SFR(t) \propto te^{-t/\tau}$)
  Non-parametric SFH
- $z_{\mathrm{spec}} = 4.53$

Model Spectrum Features

- Strong Balmer break
  → Being quenched phase

2.4 Estimated star formation history



Observed

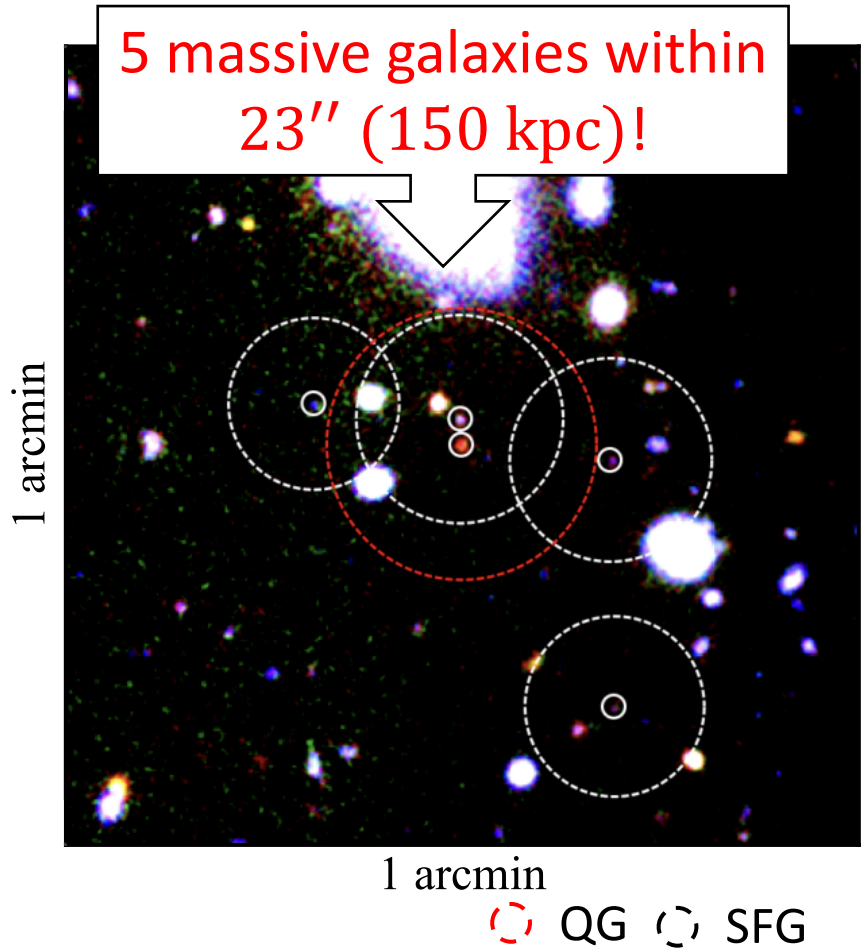
Inferred star formation history of the quiescent galaxy.

Physical properties

- Large stellar mass $\sim 10^{10.8}\,M_\odot$
- Young stellar age $\sim 200\,\mathrm{Myr}$
- This galaxy experienced starburst at $z \sim 5$ and then rapidly quenched.

- One of the progenitors of massive ellipticals in the local Universe.
- Spectroscopically confirmed at the second highest redshift

2.5 Surrounding environment



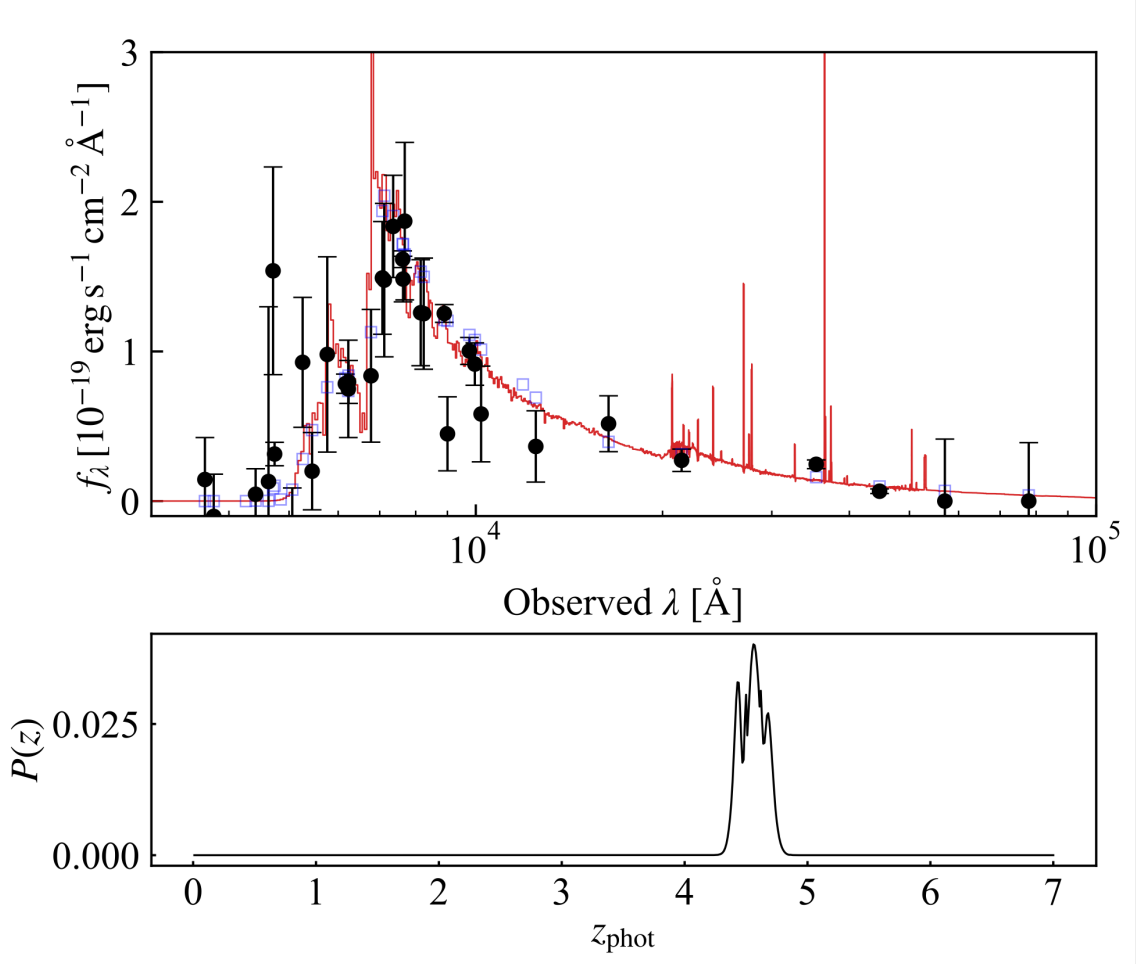
RGB image (Red: VISTA/Ks-band, Green: VISTA/H-band, Blue: HSC/i-band)

Located in the galaxy group?

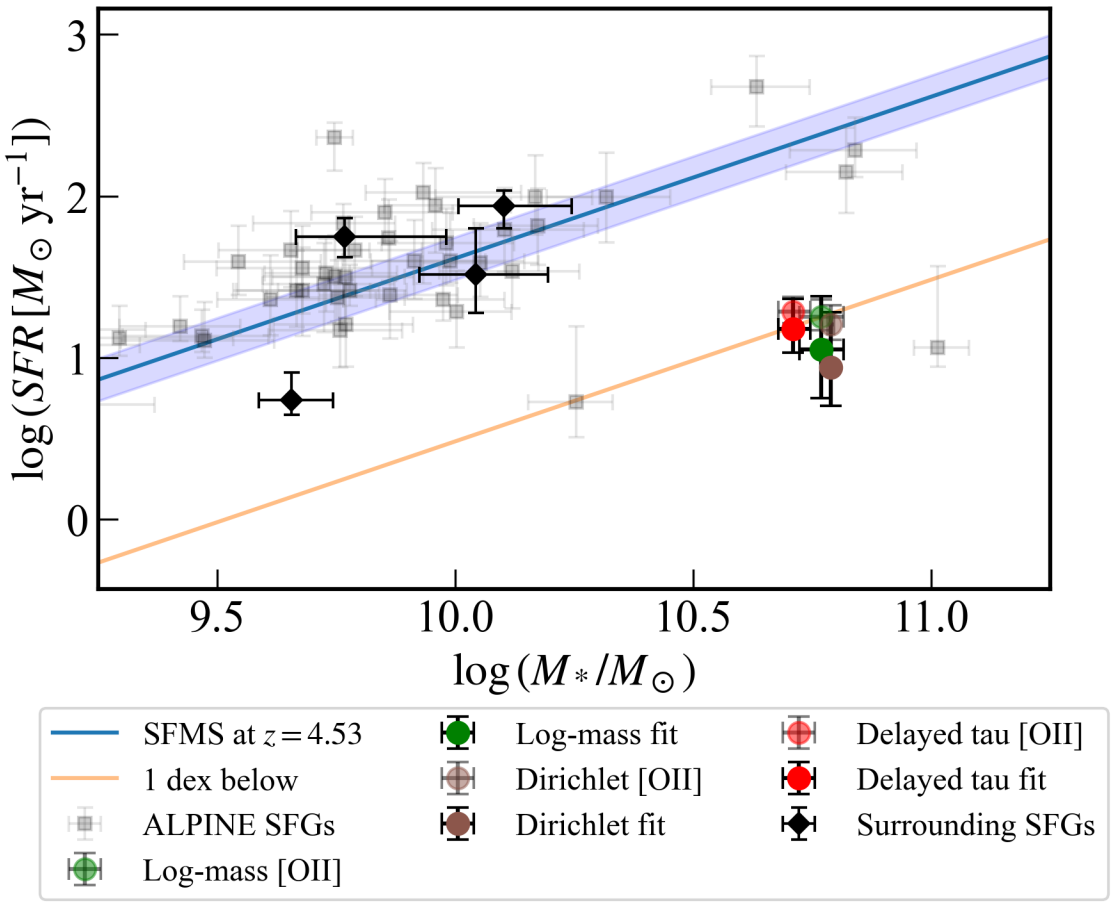
- 4 massive star-forming galaxies within $23''(150\ \mathrm{kpc})$ from the quiescent galaxy.
- The companion galaxy is located at $\sim 13\ \mathrm{kpc}$ from the QG.

- Over-density significance ($4.4 < z_{\mathrm{phot}} < 4.7$)
  - 12σ in the kernel density estimation method. $r = 30''(200\ \mathrm{kpc})$ → The densest region!
  - 2.2σ at $r = 2.5'(1\ \mathrm{Mpc})$ → Significantly compact!

2.6 Physical properties of the members



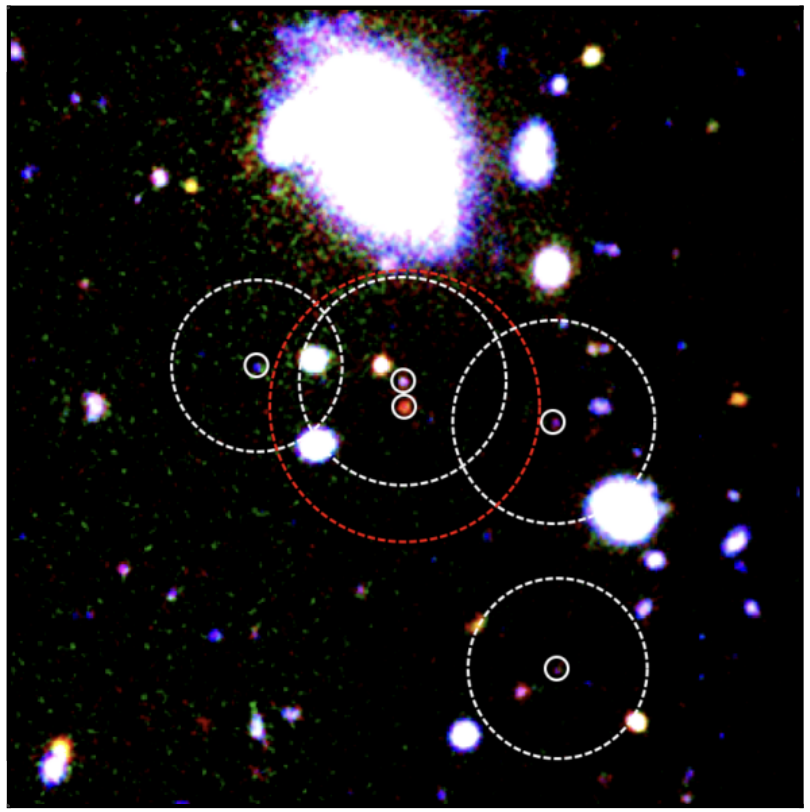
Rest-frame UV to NIR SED of the member galaxy



Relation between stellar mass and star formation rate.

All members are normal star-forming galaxies except the central quiescent galaxy.

2.7 Group characteristics



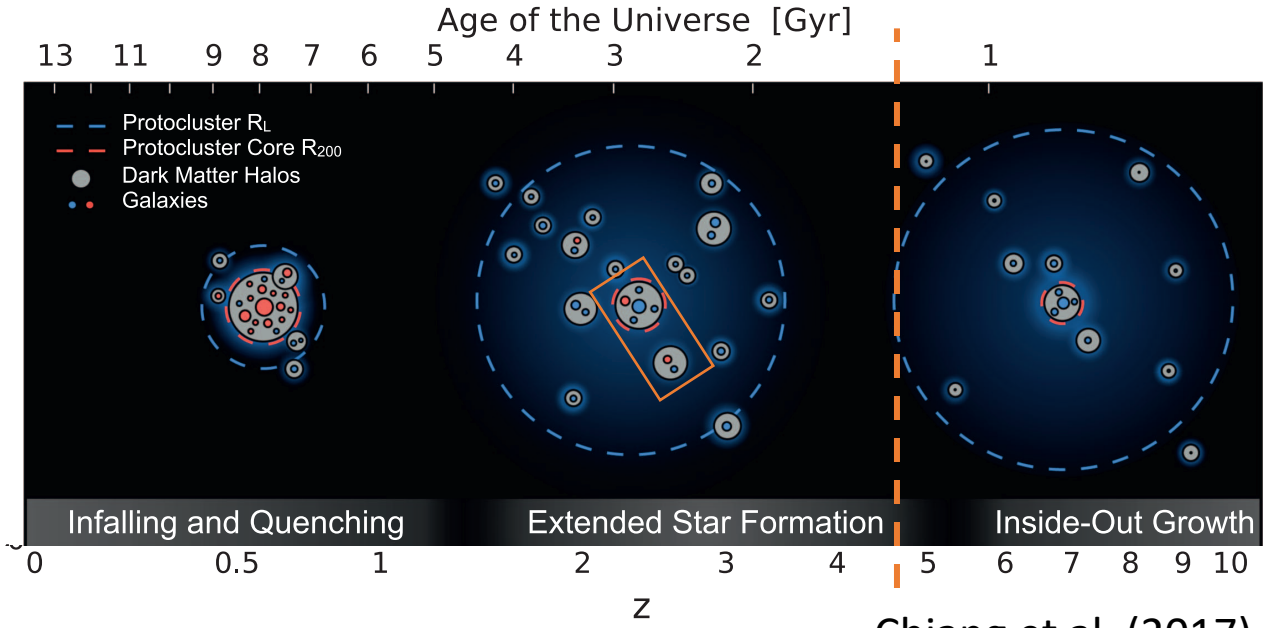
RGB image (Red: VISTA/Ks-band, Green: VISTA/H-band, Blue: HSC/i-band)

Located in the galaxy group?

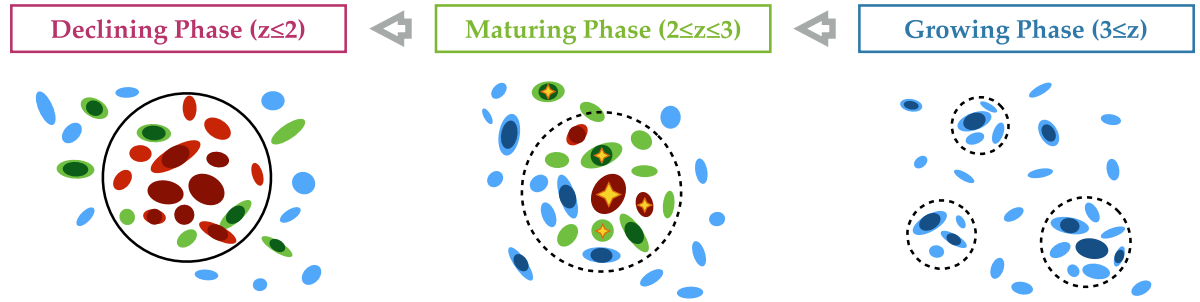
- QG's halo-mass is $\sim 10^{12.3}\ M_{\odot}$ from stellar-to-halo mass relation (Shuntov+ 22).
- 3 SFGs are possibly located within or on the virial radius (~ 70 kpc) of the QG.

- These galaxies are likely to form a group.
- This is the first time to focus on the environment for quenching at $z > 4$.
- Environmental effects (interactions or mergers) may cause the galaxy to quench or starburst.

2.8 Formation scenario



Chiang et al. (2017)



	Declining Phase	Maturing Phase	Growing Phase
Galaxies	Starvation / Environmental quenching	Energetic AGN feedback	Massive galaxy formation
Halo Gas	Cold gas depletion / Superheated plasma	Pre-heating / Core collapse	Cold gas stream in hot gas

Shimakawa et al. (2018)

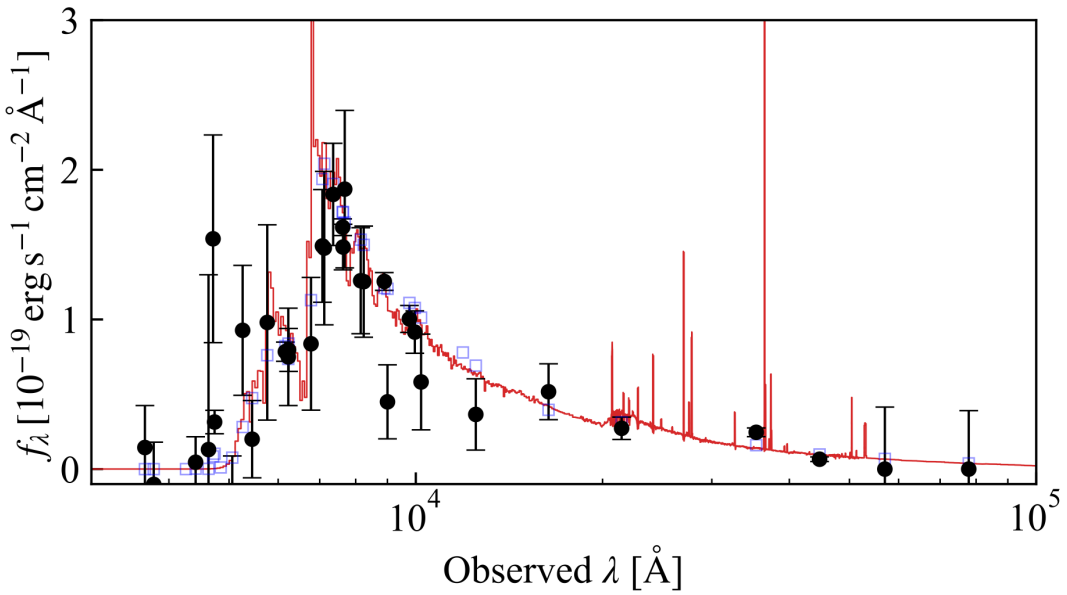
Simulation: Cores would be the first regions to show evidence of galaxy quenching.

Minor mergers and galaxy interactions increase star formation efficiency and AGN activity.

The **core-scale quenching** has already occurred at $z > 4$ by gas consumption due to the starburst and/or AGN feedback.

2.9 Future prospects

- Spectroscopic follow-up of the galaxy group (S24A)



Model SED of one of the star-forming members in a group.

◆ FOCAS multi-object spectrograph on the Subaru telescope
We plan to observe the Lyman alpha emission and/or break.

◆ Confirm the redshift and physical properties of the target.

→ First step to confirm the extreme overdense environment for quenching

3. Summary

◆ We confirm a massive quiescent galaxy at $z = 4.53$ using Keck/MOSFIRE spectrograph.

Unique properties

◆ Spectroscopically confirmed at the second highest redshift

◆ This galaxy is in the small over-density region (galaxy group?).

→ Environmental effects (mergers and/or interactions) may play a role to the galaxy quench.

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