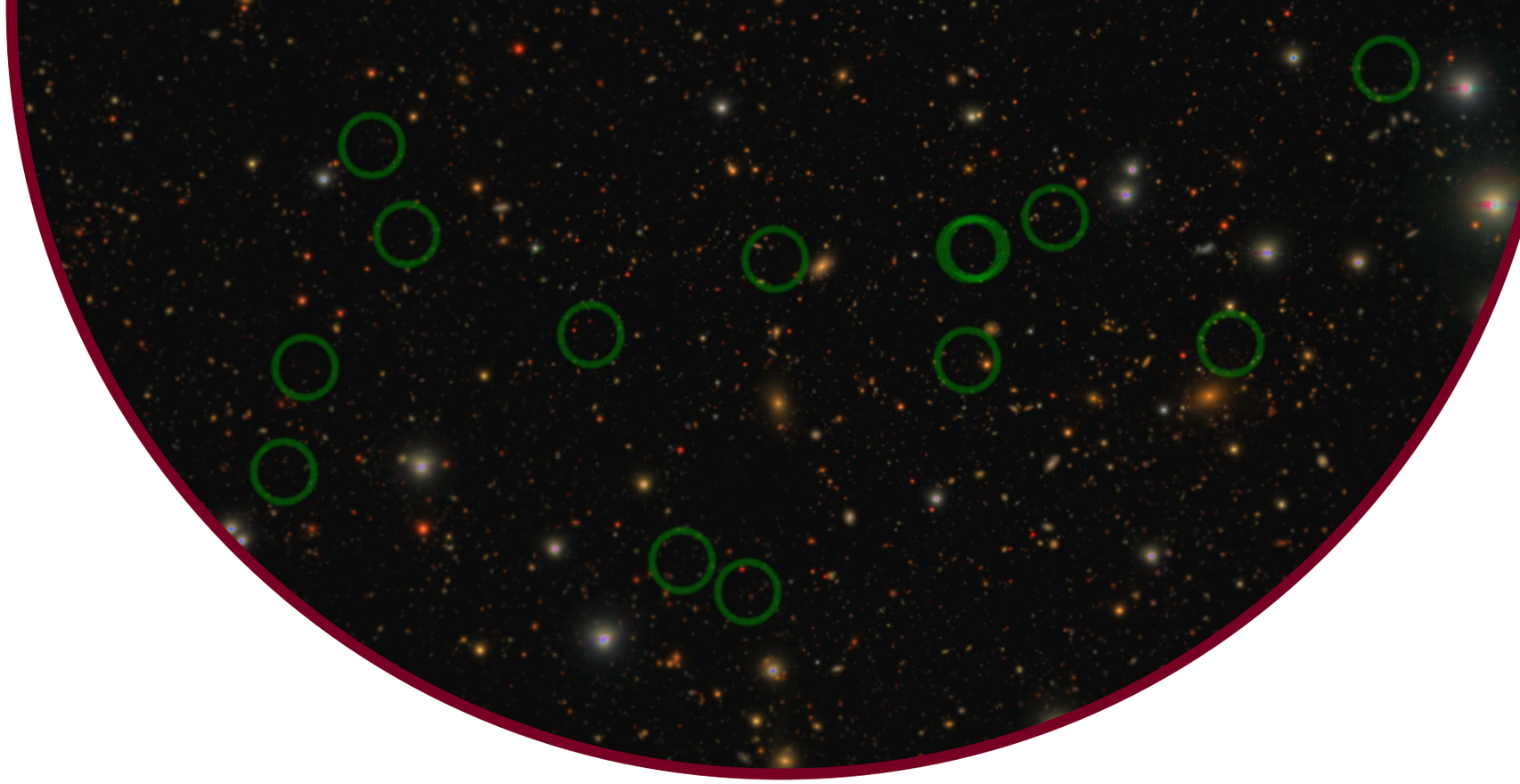


Discovery of a protocluster of massive quiescent galaxies at z=2.77

… and a previous COSMOS2020 quiescent galaxy study

Kei Ito (JSPS Fellow PD/U. Tokyo)

Collaborators: Masayuki Tanaka (NAOJ), Francesco Valentino (ESO), Sune Toft, Gabriel Brammer, Katriona Gould (DAWN), Olivier Ilbert (LAM), Nobunari Kashikawa (UTokyo), Mariko Kubo (Tohoku), Yongming Liang (ICRR), Henry J. McCracken (IAP), and John R. Weaver (UM amherst), et al.

Ito et al. 2023, ApJL in press (arXiv:2301.08845), Ito et al. 2022, ApJ, 929, 53

Formation of Quiescent Galaxies

Elliptical galaxies are likely to be quenched at early times of the Universe.

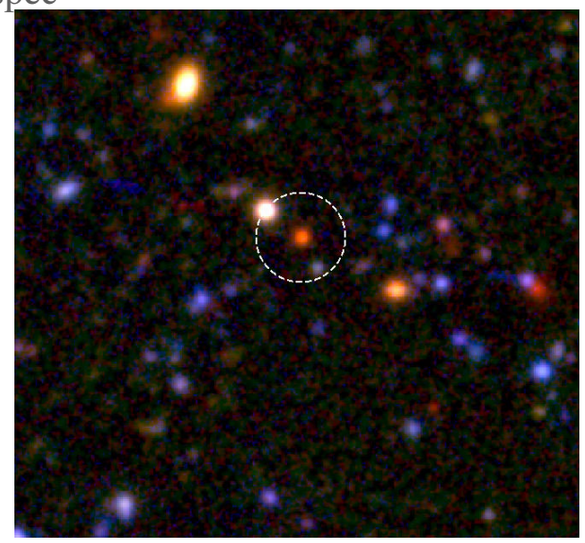
- How are they like in the early universe, including their living environment?
- How they stop star-formation ?

(NAOJ)

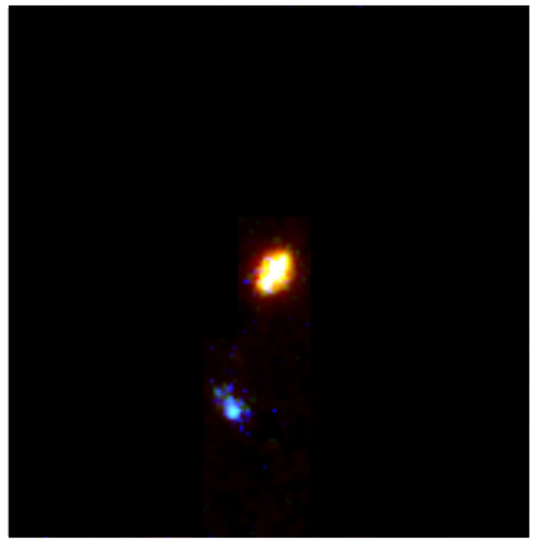
Quiescent galaxies at high redshift

- Galaxies can be quenched even at high redshift
- Spectroscopically, they are confirmed at **z~4** (e.g., Tanaka+19, Carnall+23)
- A recent JWST study shows z>4 candidates (Carnall+22)

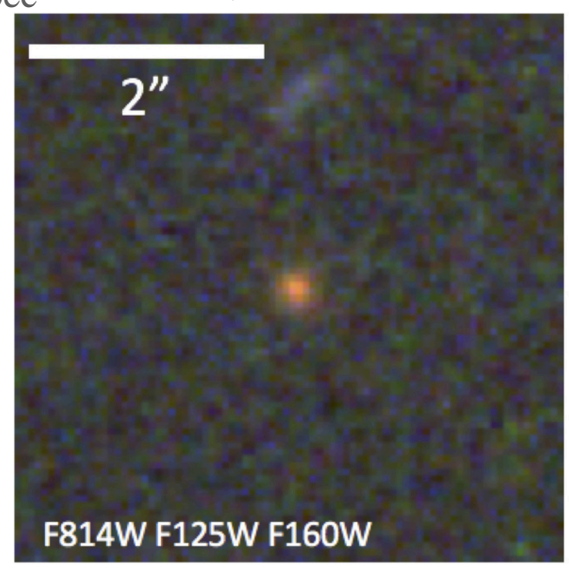
$z_{\rm spec} = 4.01$,Tanaka et al. (2019)



$z_{\rm phot} > 4$, Carnall et al. (2022)



$z_{\rm spec} = 3.717$, Glazebrook et al. (2017)



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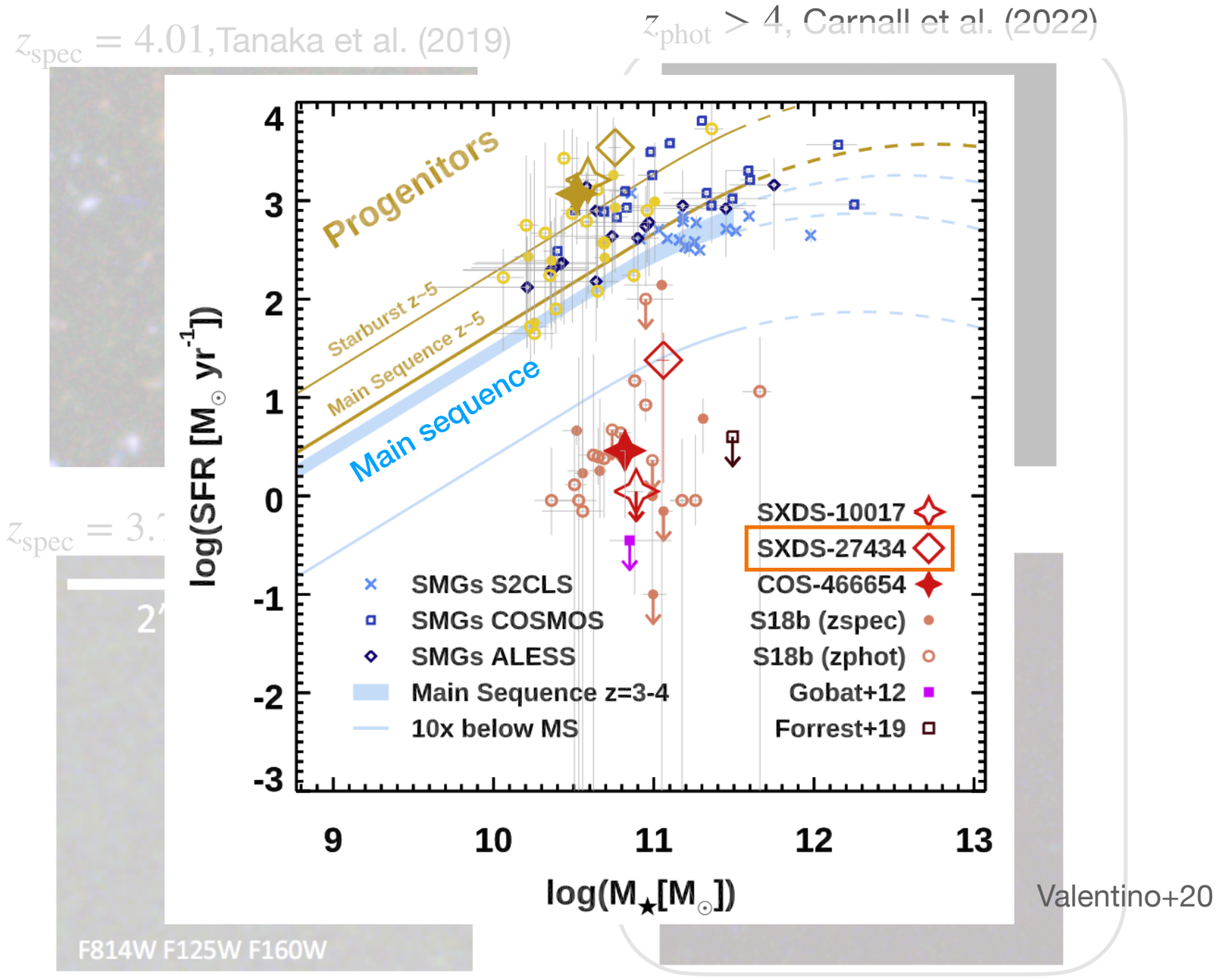
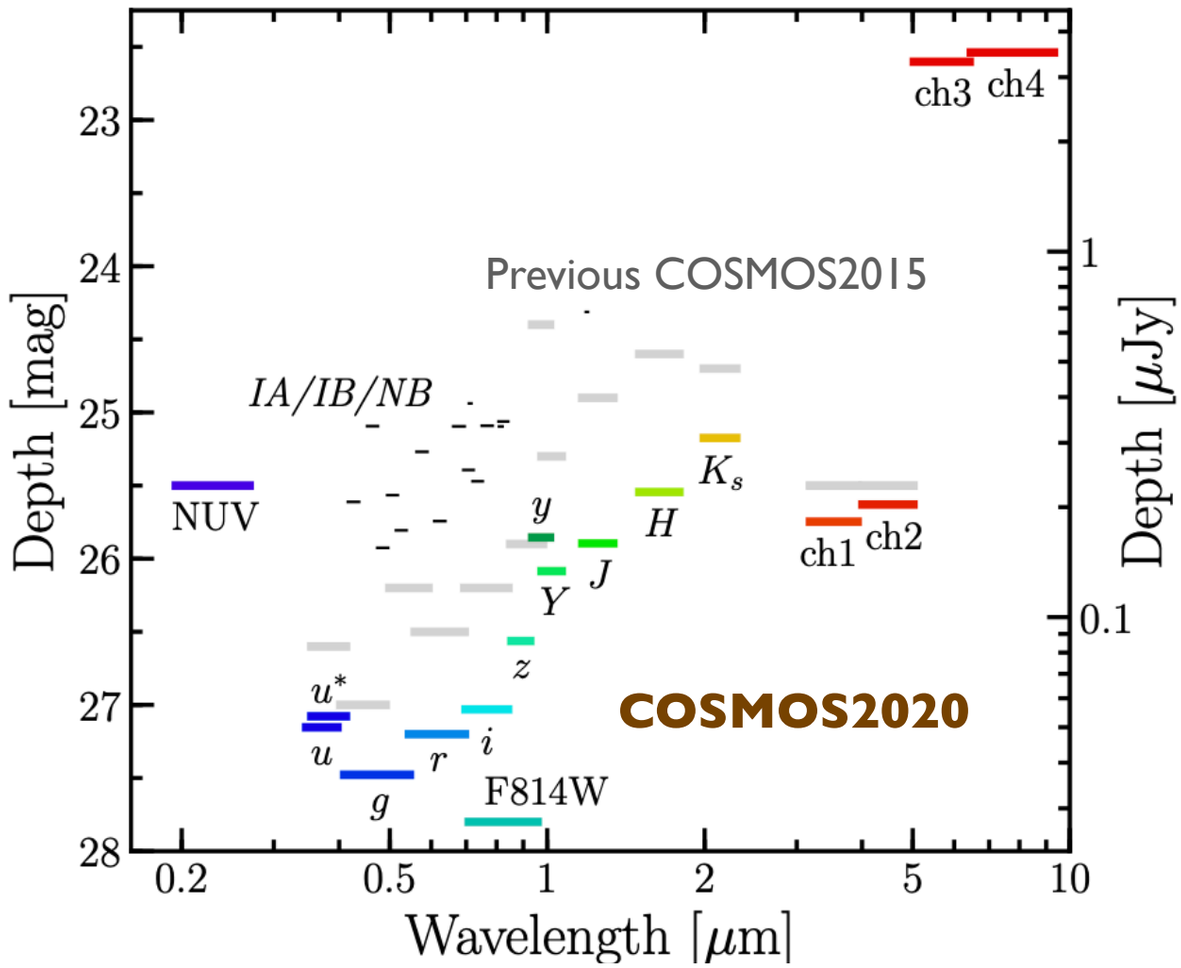


Valentino+20

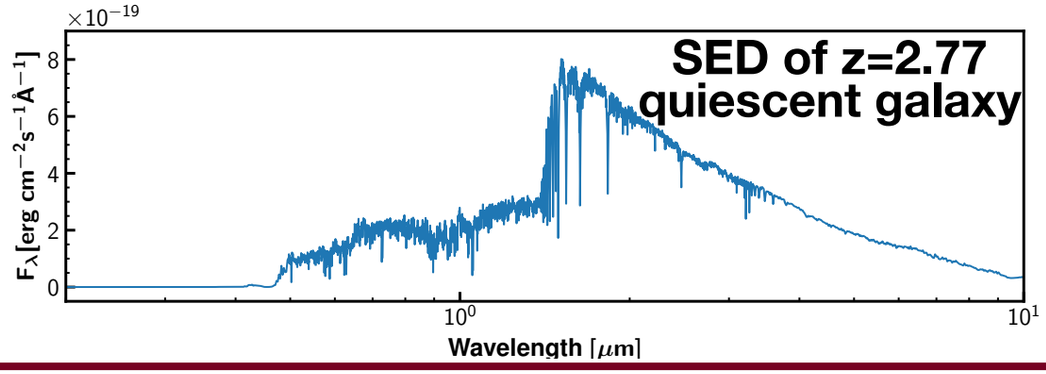
COSMOS2020

- Latest multi-photometric catalog in the COSMOS field over $\sim 2\ \mathrm{deg}^2$
- Subaru/Hyper Surpime-Cam has large contribution to the deep optical imaging

Providing large number of quiescent galaxies at high-z!



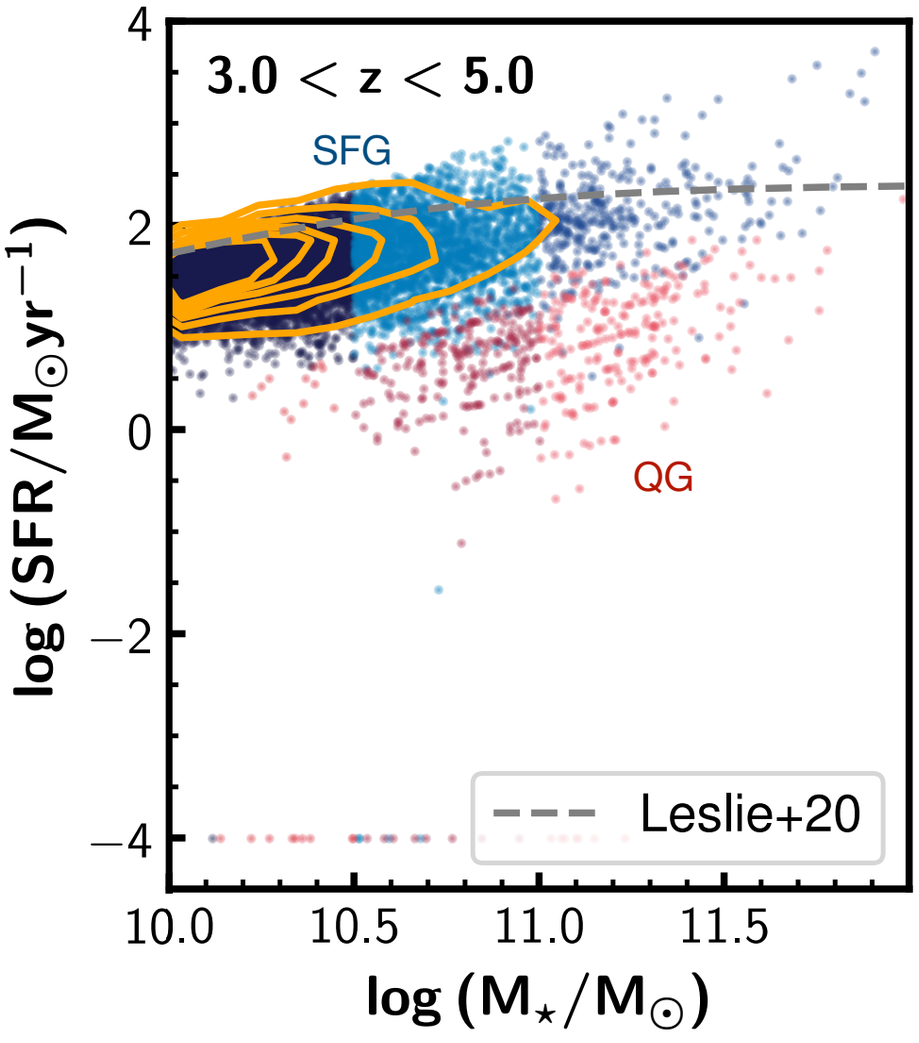
Weaver+ 2022

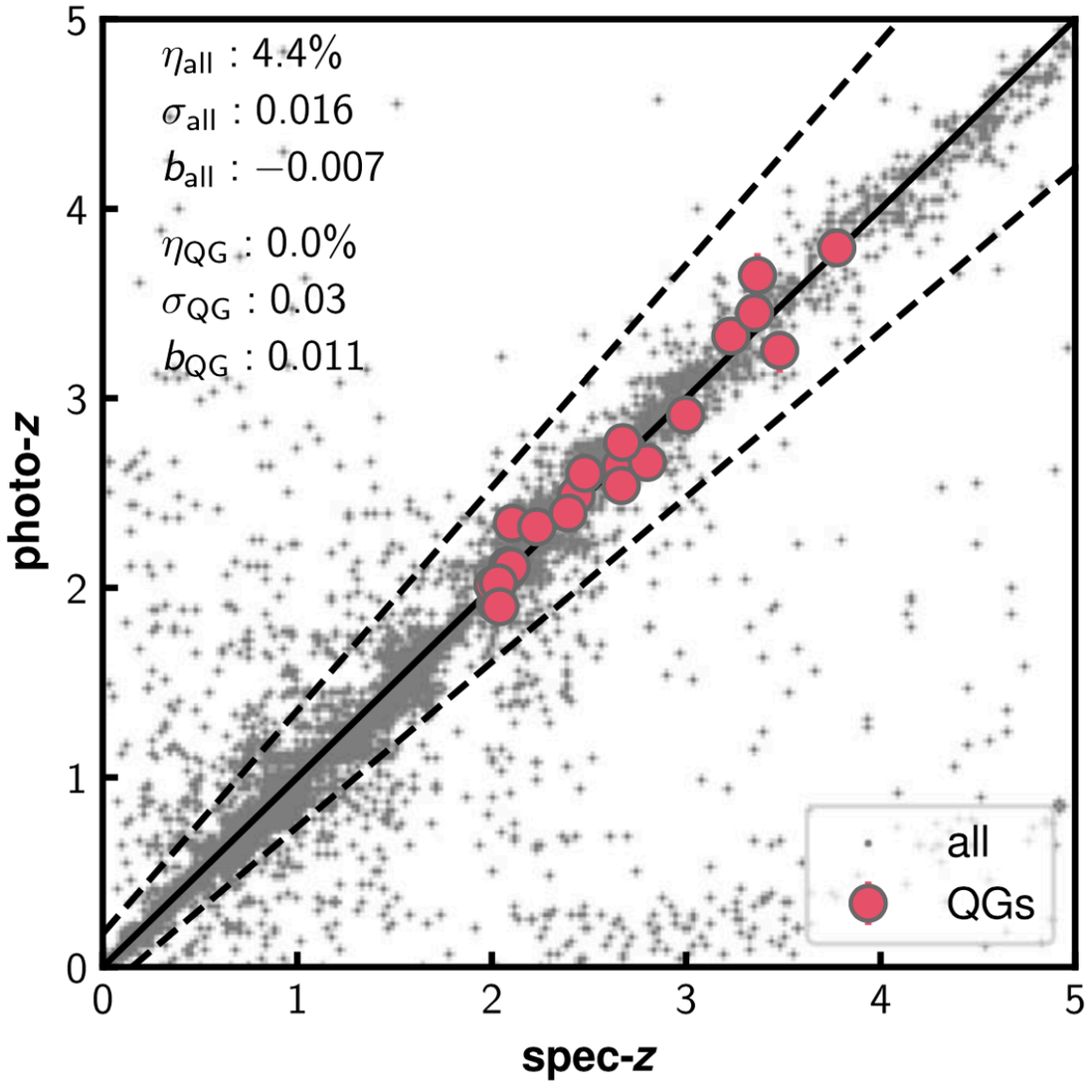


Quiescent Galaxy Sample

- **Definition of quiescent galaxies**
  - $0 < z < 5$ based on photo-z from **COSMOS2020** catalog
  - $\geq$ 1dex lower sSFR than main sequence

  →selecting quiescent galaxies based on good quality photo-z





Previous work: AGN activity of COSMOS2020 quiescent galaxies

- How is the AGN activity of quiescent galaxies at high redshift?
- Constraining X-ray and radio emission of quiescent galaxies at highest redshift
- Press-released from NAOJ, Subaru telescope, SOKENDAI, Cosmic DAWN Center on 2022 May

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Science Results

Distant Universe

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Supermassive Black Holes Inside of Dying Galaxies Detected in Early Universe

May 26, 2022
Last updated: January 19, 2023

An international team of astronomers used a database combining observations from the best telescopes in the world, including the Subaru Telescope, to detect the signal from the active supermassive black holes of dying galaxies in the early Universe. The appearance of these active supermassive black holes correlates with changes in the host galaxy, suggesting that a black hole could have far reaching effects on the evolution of its host galaxy.

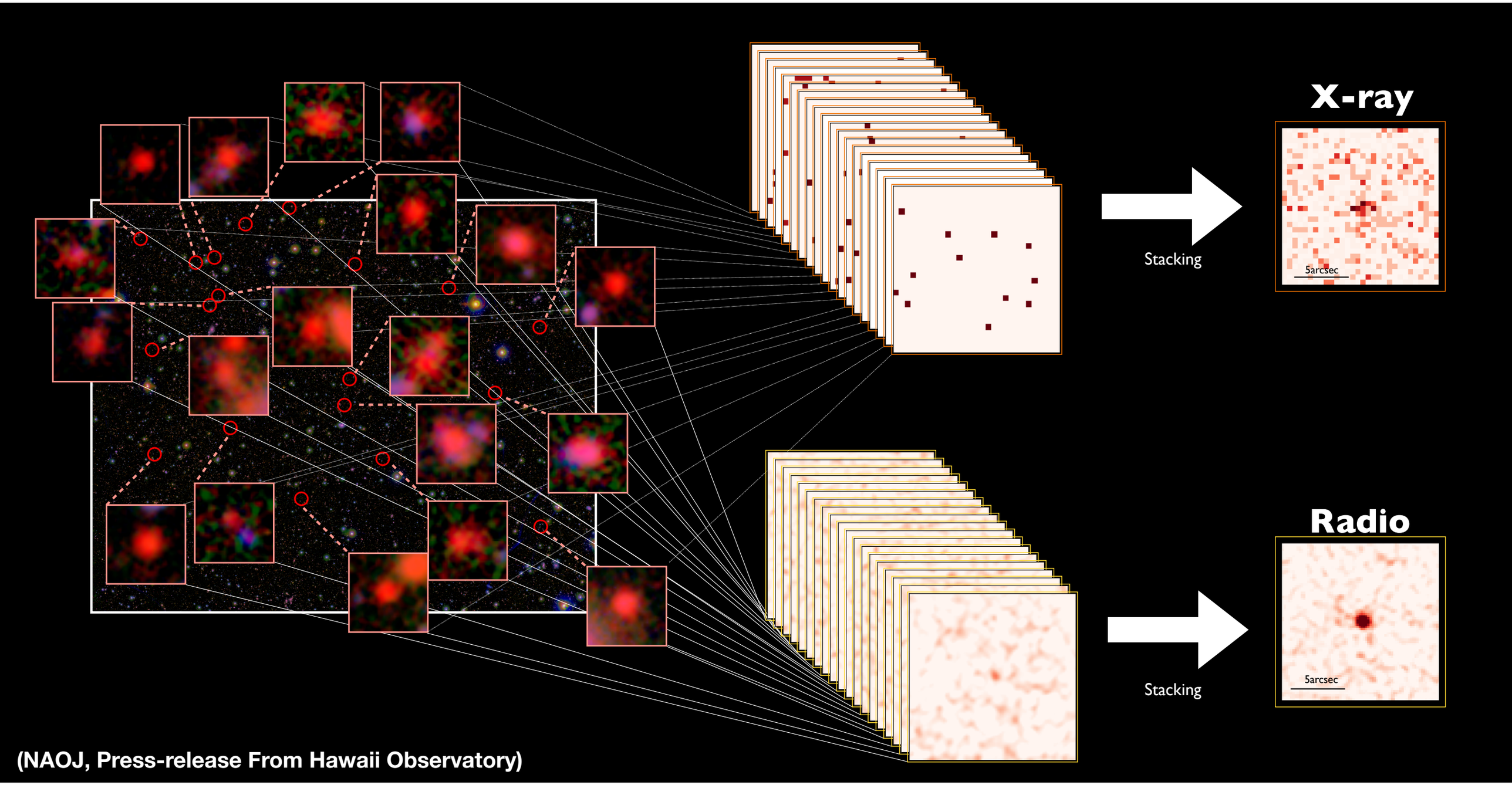
Science Results

2023 | 2022 | 2021
2020 | 2019 | 2018
2017 | 2016 | 2015
2014 | 2013 | 2012

View past Science Results

Press-release from Subaru Telescope

Previous work: AGN activity of COSMOS2020 quiescent galaxies



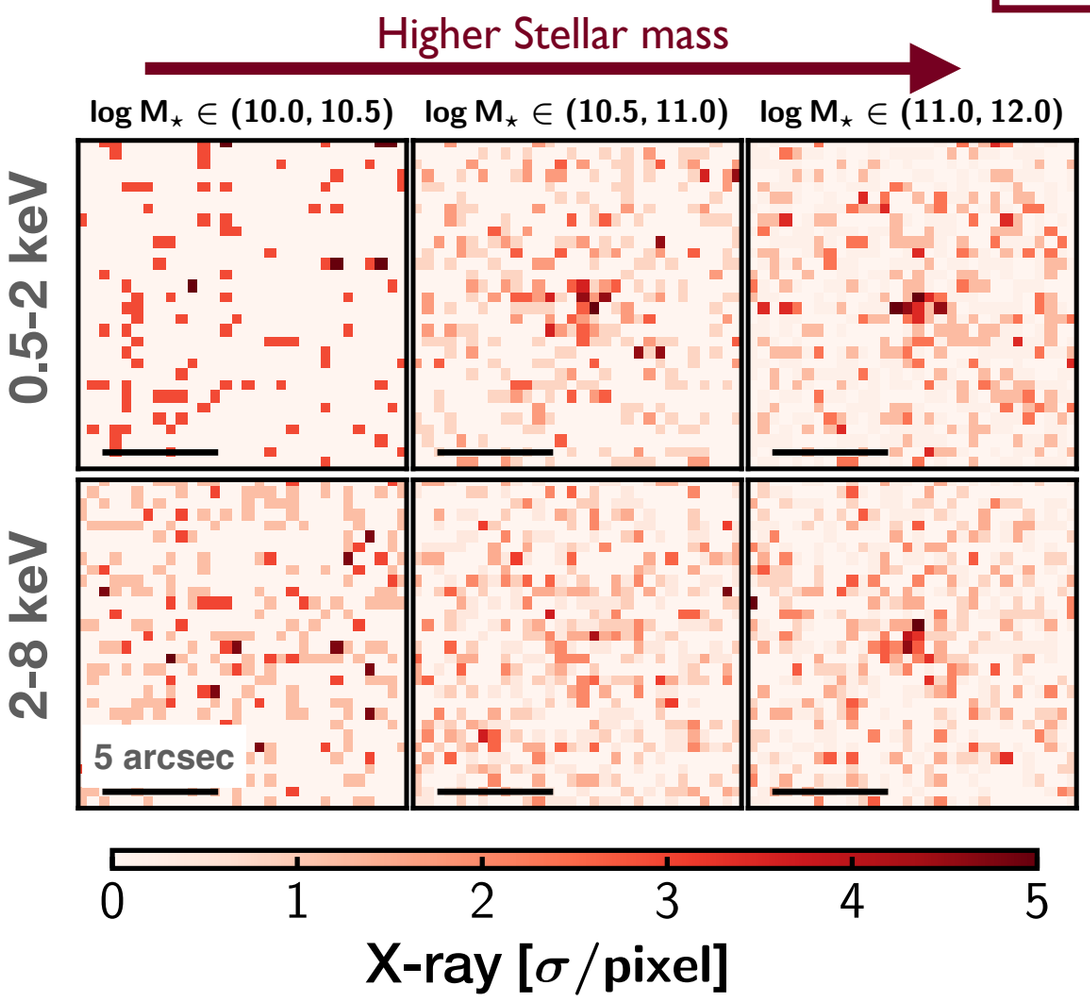
(NAOJ, Press-release From Hawaii Observatory)

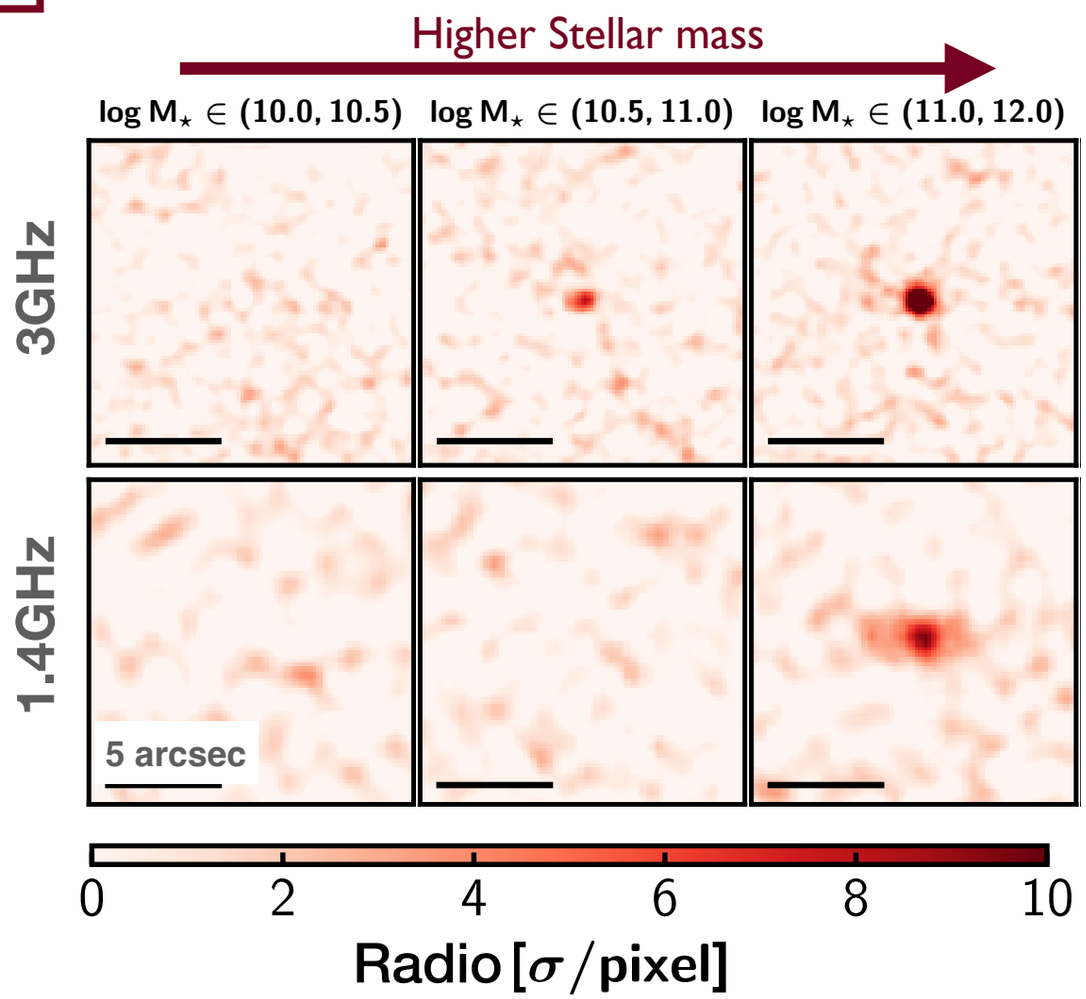
- Their X-ray and radio emission are too faint to detect individually
- Stacking multiple images to obtain the average flux of quiescent galaxies

Fully Utilizing the large sample from the wide survey area!

Stacked images of quiescent galaxies

3<z<5 QGs

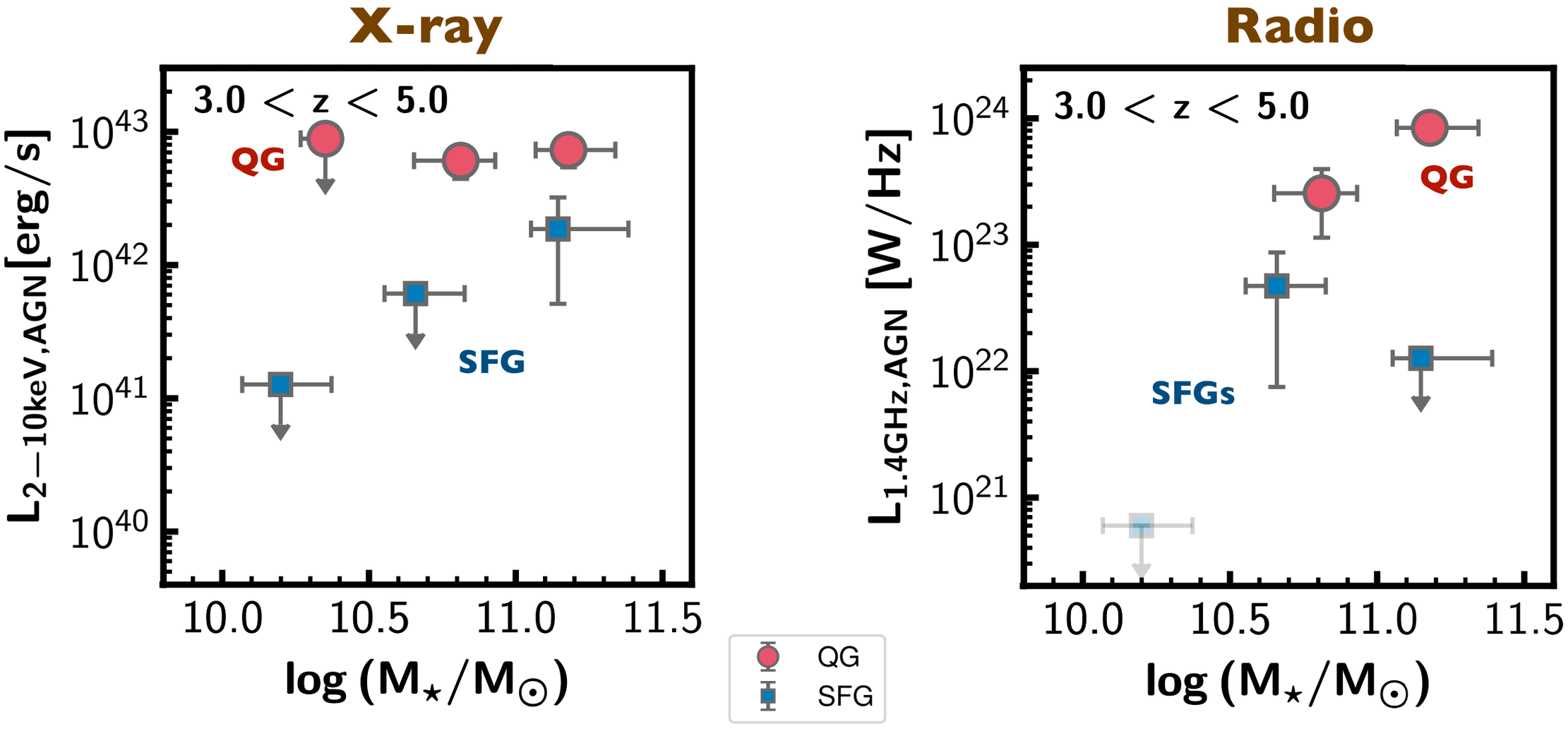




First average X-ray/radio signal detection for typical quiescent galaxies at z>2

AGN X-ray/radio luminosity of quiescent galaxies

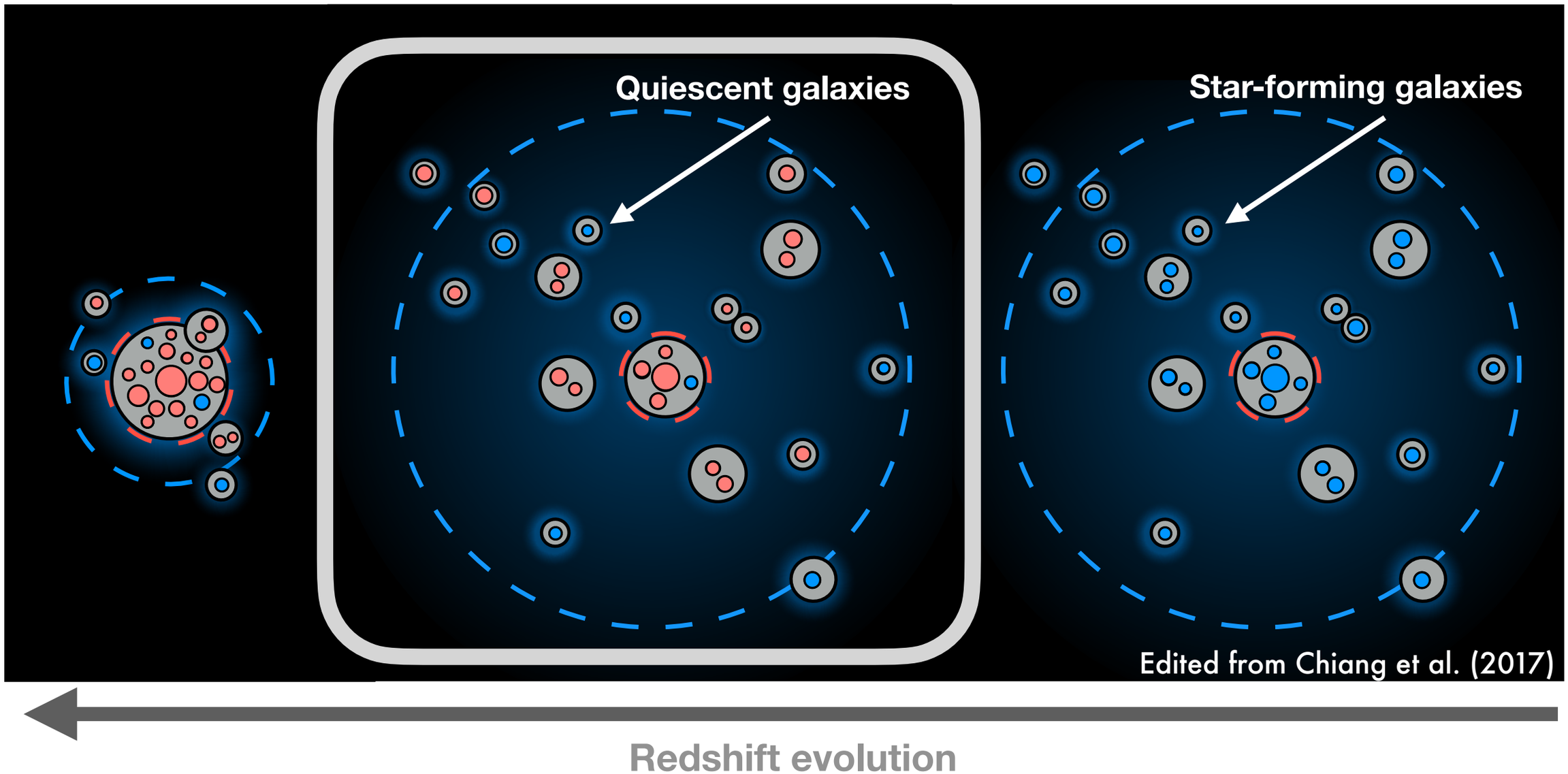
- Two sources of X-ray/radio emission: AGN and star-related one (e.g., XRB, supernova remnant)
- Quiescent galaxies have higher AGN luminosity in both X-ray and radio than star-forming
- Same trend is seen at z>1.5
  →Enhanced AGN activity in quiescent galaxies at high redshift



Large quiescent galaxy sample shows the typical AGN activity at 1-2 Gyrs from Big Bang

Current limitation of protocluster sample

- Protoclusters have been found mainly through the distribution of star-forming galaxies



Are there any protoclusters found through the distribution of quiescent galaxies?

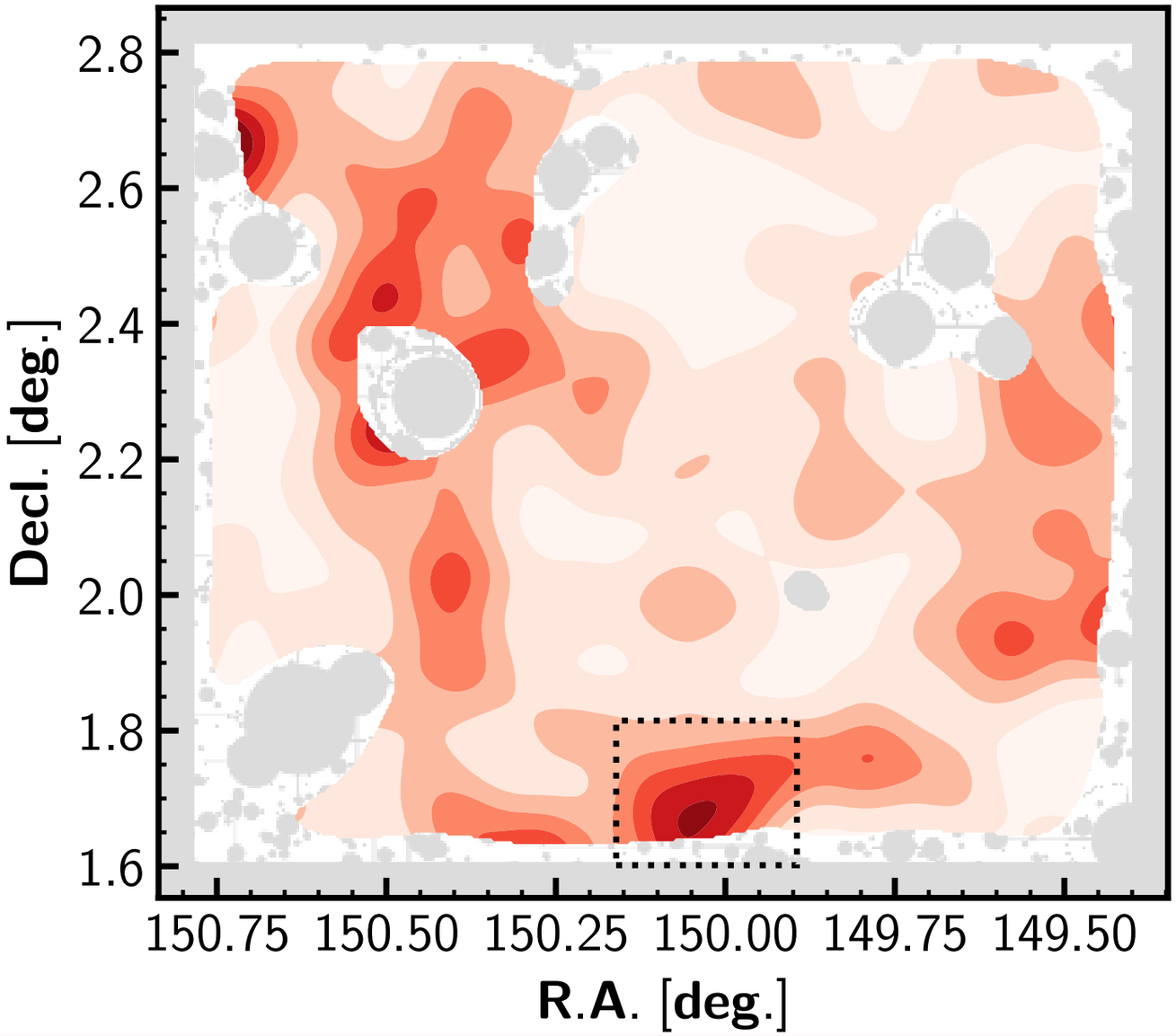
Do quiescent galaxies form overdense structures?

A significant Overdense region of quiescent galaxies

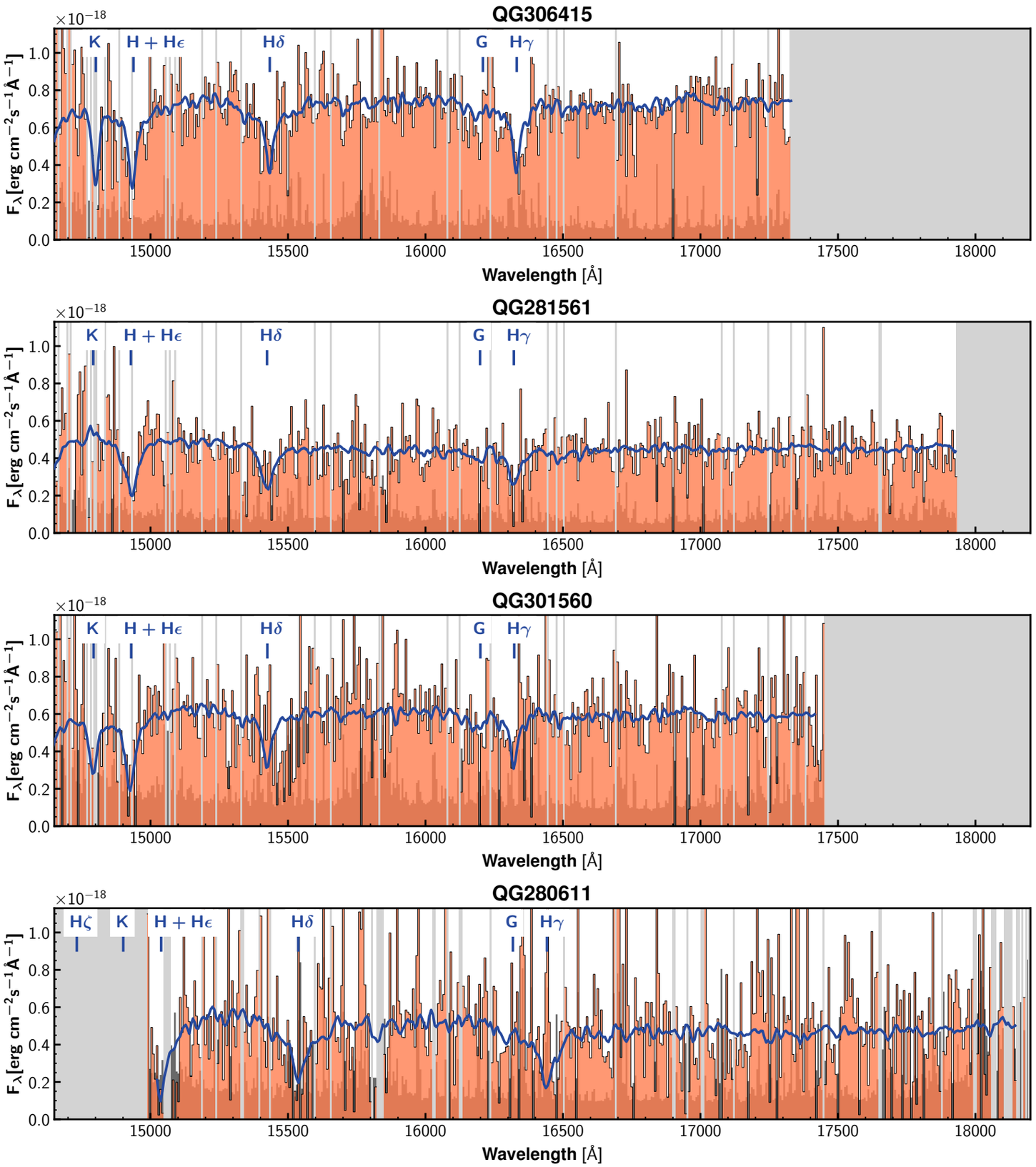
- Mapping the distribution of quiescent galaxies
- Found an overdense region with 4.2sigma significance at $2.74 < z_{\rm photo} < 2.94$
  - 14 quiescent galaxies with $\log(M_\star/M_\odot) > 10.5$ at $14' \times 8'$ ($\sim 7 \times 4$ pMpc^2)

→Is it a real structure or just due to the projection?

Density distribution of quiescent galaxies at $2.74 < z_{\rm phot} < 2.94$

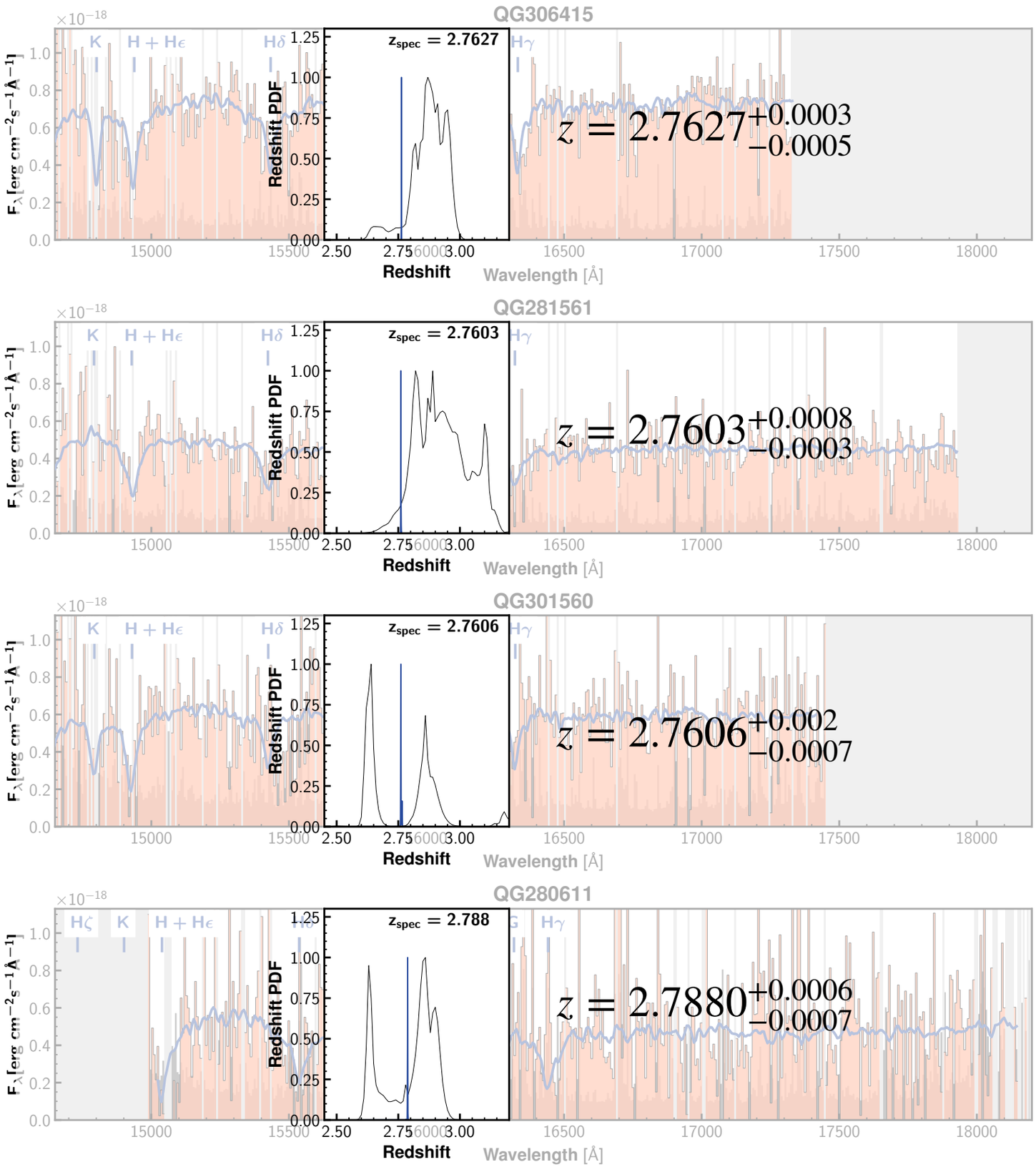


Keck/MOSFIRE follow-up spectroscopy



- MOSFIRE H-band ~3hours observation for 9 quiescent galaxies
- Subaru-Keck time exchange program (S22A-071, PI: Ito)
- Multiple Balmer absorption lines of four galaxies (Others are too faint)
- All of them are located at $z_{\rm spec} = 2.76 - 2.79$
- All of them are massive $(\log(M_\star/M_\odot) > 11)$

Keck/MOSFIRE follow-up spectroscopy



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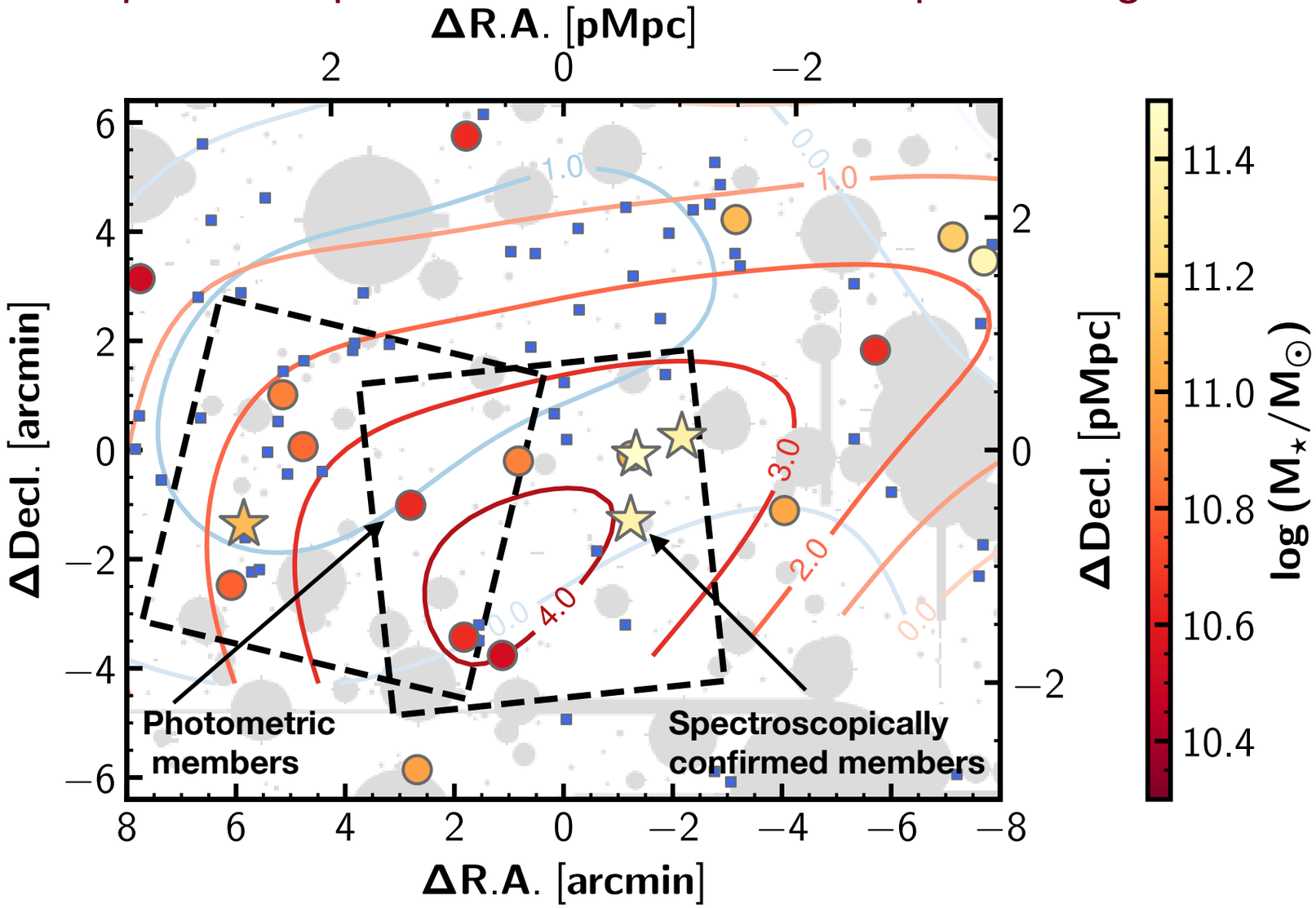
Confirmation of dense structure of quiescent galaxies

- Confirmed 4 quiescent galaxies are at $\sim 4 \times 1$ pMpc^2
  + 3 of them are at $\sim 1 \times 1$ pMpc^2 and have the same redshift ($z = 2.760 - 2.763$)
  →This field is >68 times denser in quiescent galaxies
- Star-forming galaxies are not concentrated ($0\sigma - 1\sigma$ overdensity)
  →Quiescent fraction is 3 times higher than the average

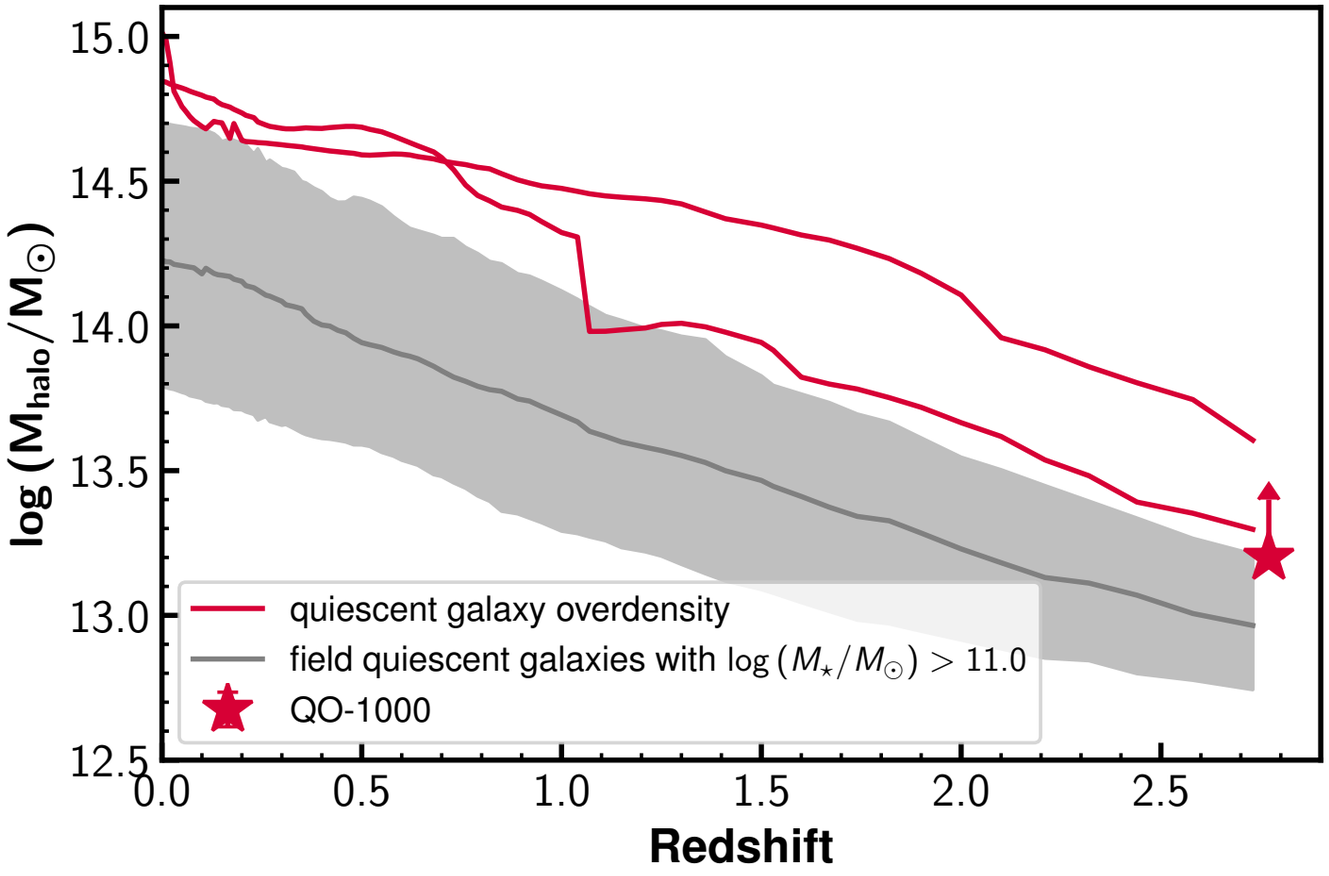
This QO-1000 is a spectroscopic overdense structure of quiescent galaxies at $z_{\rm spec} = 2.77$



Halo mass constraint of QO-1000

- Observational halo mass constraint of QO-1000
  - Converting the stellar mass of the most massive member to the halo mass
  - $\log(M_\star/M_\odot) = 11.5 \rightarrow \log(M_{\rm halo}/M_\odot) > 13.2$ (stellar to halo mass ratio of Shuntov+22)
- Comparison with Illustris TNG-300 simulation
  - Exploring the similar structure of QO-1000 in terms of number and distribution of quiescent galaxies
  - Found 2 similar structures, and **all of them will evolve to Coma-like clusters**

QO-1000 is likely a massive mature protocluster



Summary

- Exploring the massive quiescent galaxies at high redshift in the COSMOS with the support of Subaru

- AGN activity of quiescent galaxies through X-ray and radio stacking analysis (Ito et al. 2022, ApJ, 929, 53)
  - Stacking analysis detected X-ray and radio signal of quiescent galaxies at z>3
  - This strong emission implies the existence of AGN inside of them
  - The AGN activity of quiescent galaxies is higher than that of star-forming galaxies

- Discovery of a protocluster of quiescent galaxies at z= 2.77 (Ito et al. 2023, ApJL in press, arXiv: 2301.08845)
  - 4.2 sigma overdensity from photometric quiescent galaxies
  - Keck/MOSFIRE confirmed four of quiescent galaxies at z=2.76-2.79
  - This structure is likely a mature protocluster of plenty quiescent galaxies
  - Detailed investigations of members galaxies are ongoing (Star formation history, dynamical properties, morphology, Ito et al. in prep.)