# AGN Activity of Massive Quiescent Galaxies to z~5 Revealed by X-ray and Radio Stacking

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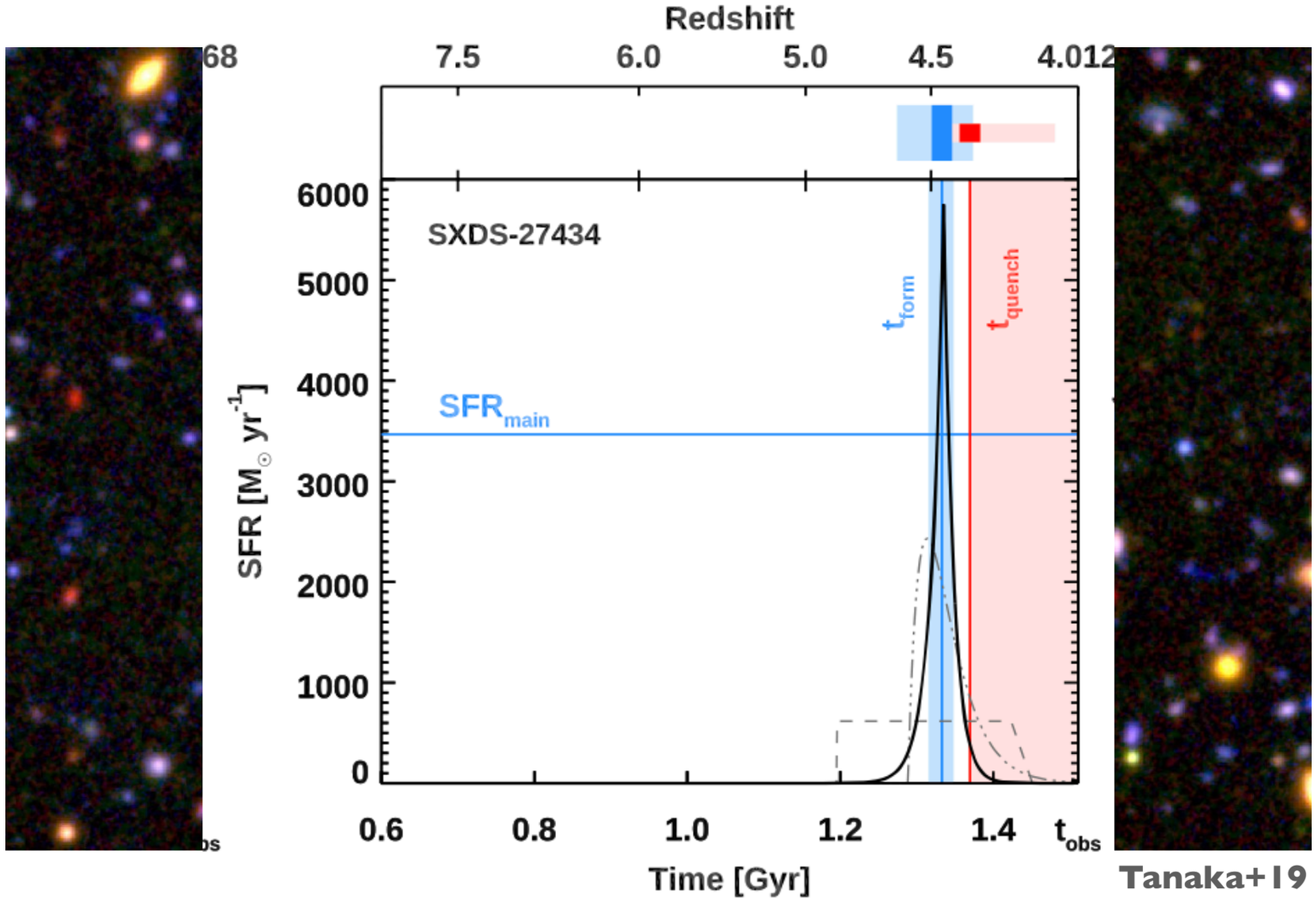
**Ito et al. (2021b), ApJ, submitted**

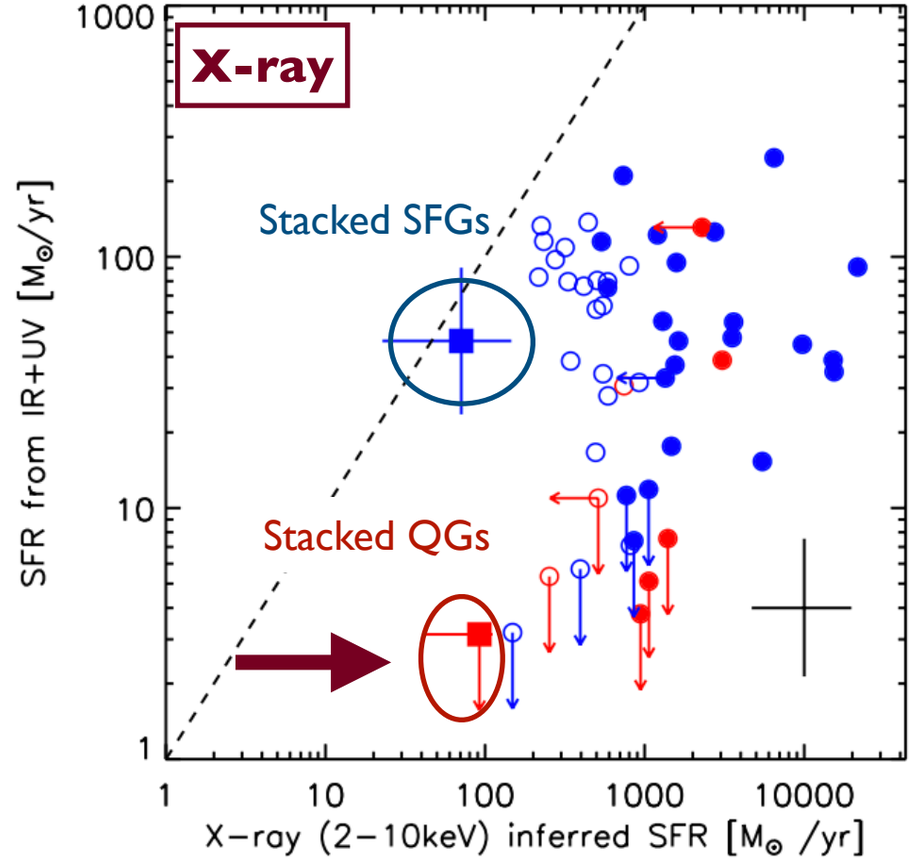
# Massive Quiescent Galaxies at high redshift

- Star formation of massive elliptical galaxies is suppressed (quenching)
- Quiescent galaxies (QGs) are now spec-z confirmed up to z~4
- They have intense star formation and suddenly quench at z>4.
  →What is the mechanism for quenching?

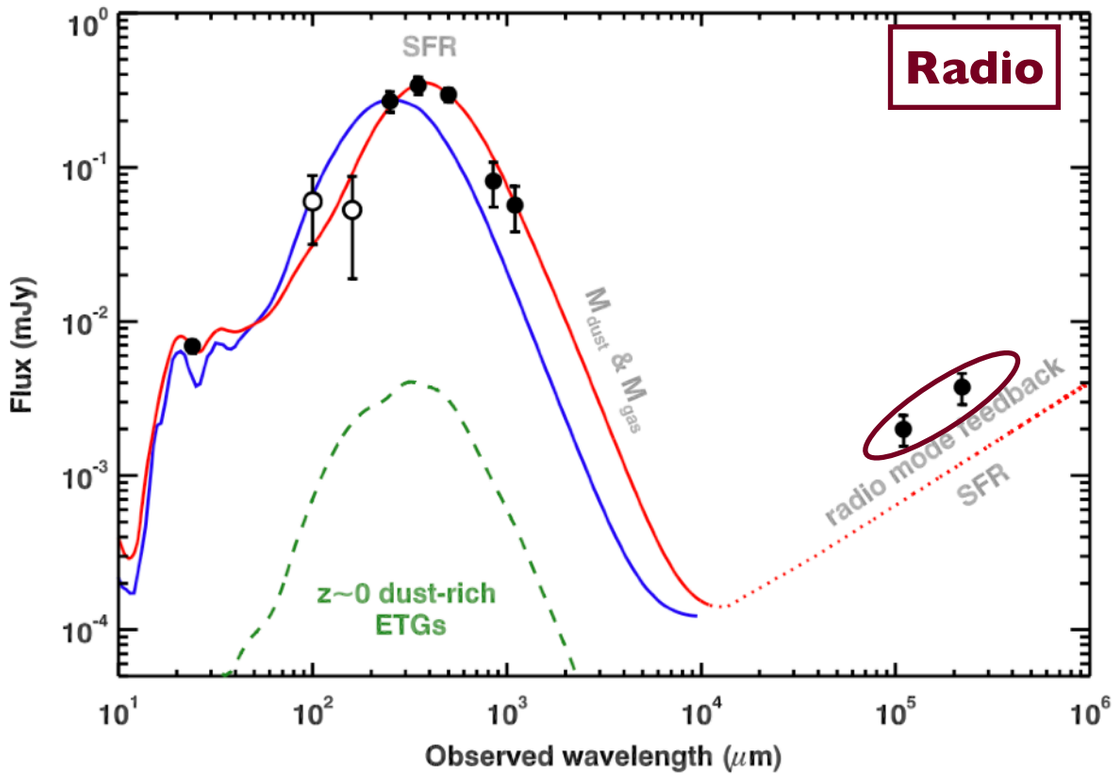


# High-z QGs and AGNs

- AGN feedback is one of preferable quenching process
- Several observational studies connecting high-z QGs and AGNs
  - Stacking analysis revealed enhanced X-ray/radio luminosity at z~2
    → Indicating the existence of AGNs?
  - Several reports of X-ray luminous QGs at z~3-4



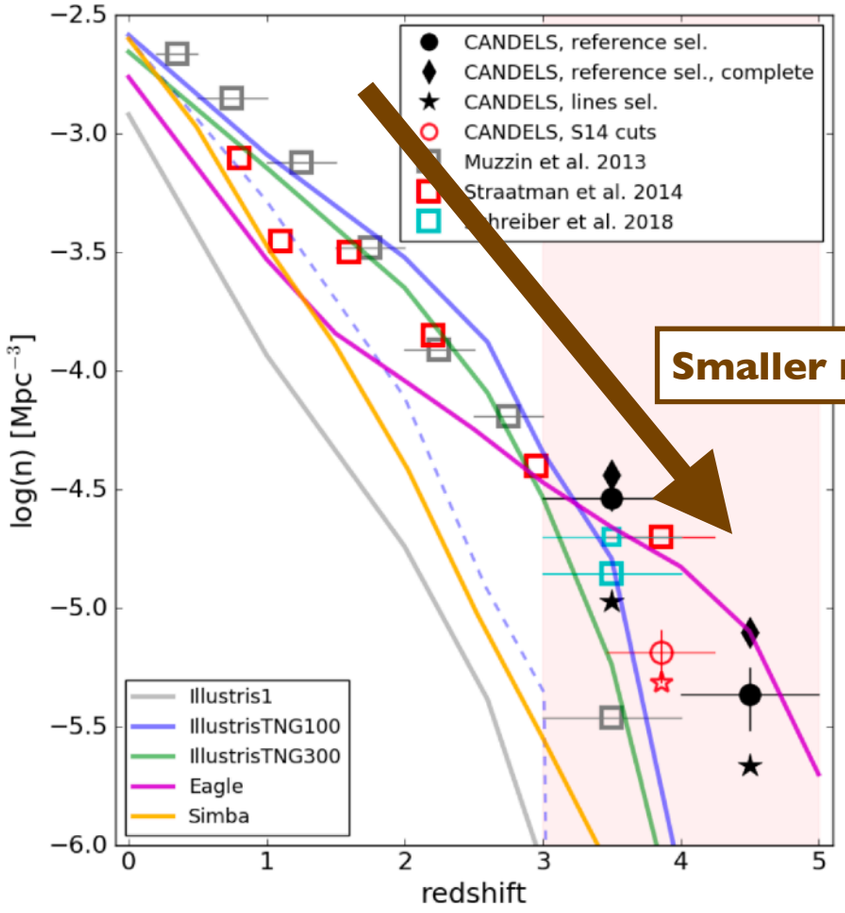

Olsen+13




Gobat+18

# Current problems and this work

- Current Problems for this topic
  - Average picture of z>2 QG is not well understood
    →Is high X-ray/radio luminosity seen even at z>2?
  - We have to compare QGs' AGN luminosity to SFGs
    →Is QGs' AGN more active than those of SFGs?
- What we need is
  - more QG sample at high redshift (i.e., wider field)
  - wide X-ray/radio survey

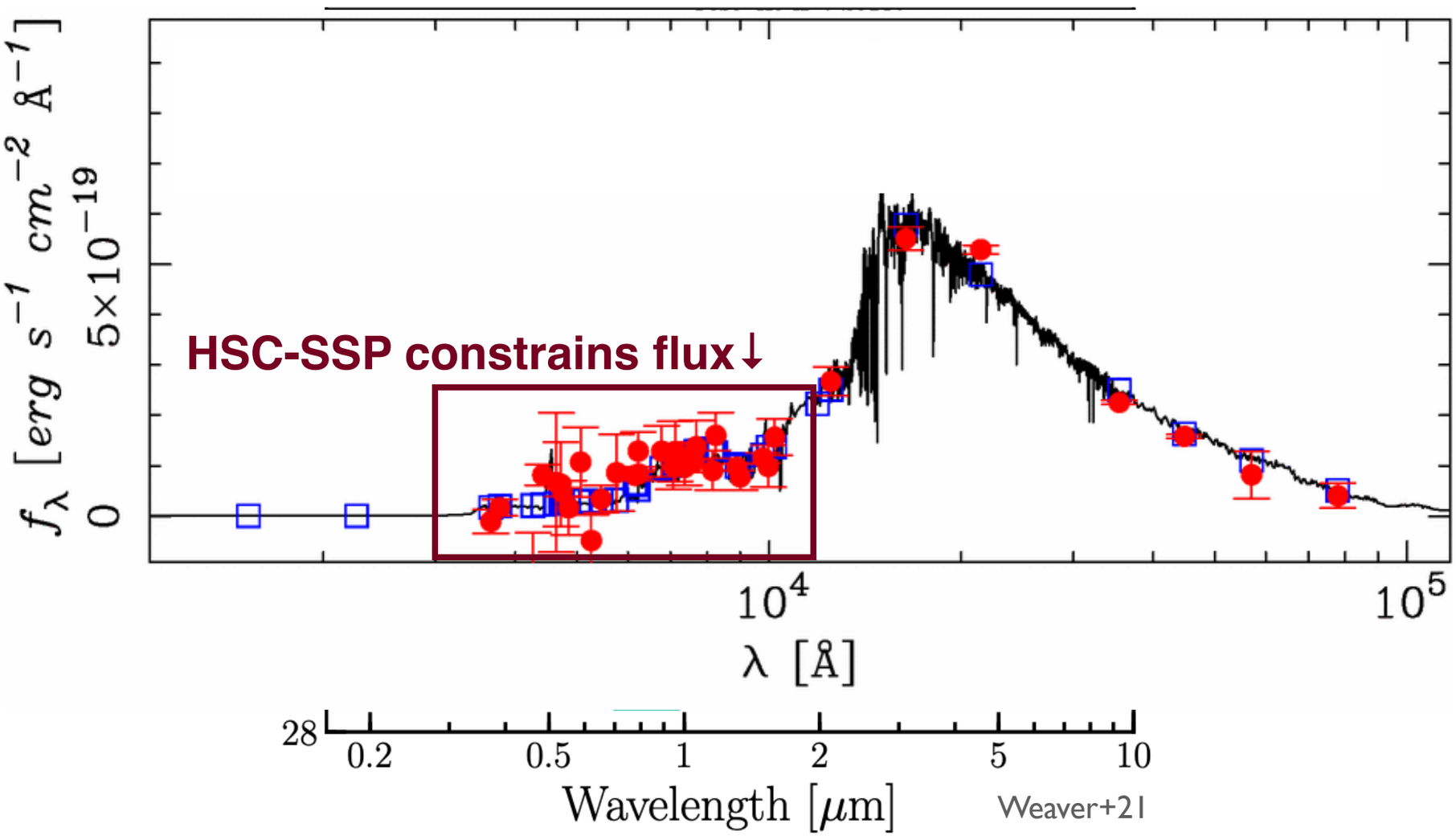



**Smaller number density towards higher-z**

**Merlin+19**

# COSMOS2020

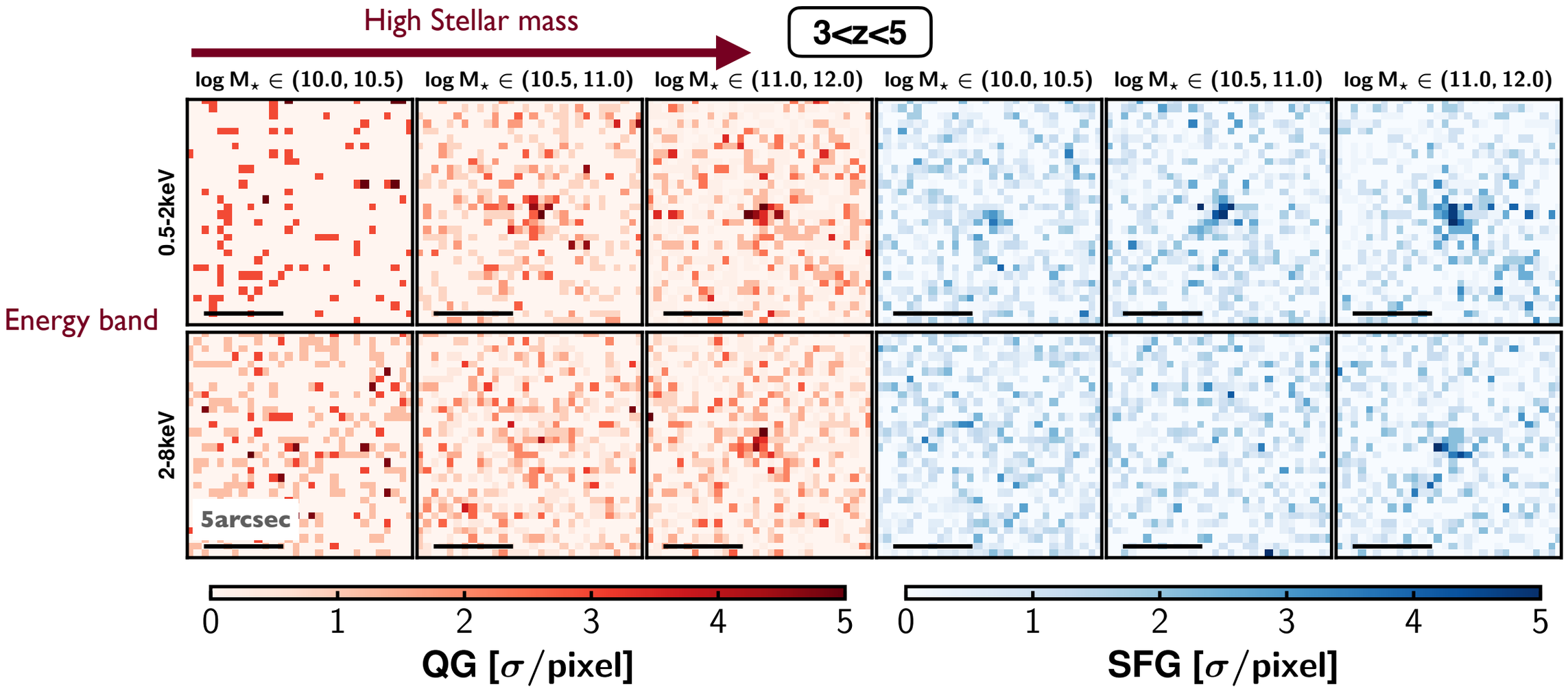
- COSMOS2020: Latest catalog in the COSMOS field (**~2deg²**)
  - Including the latest survey (CLAUDS, **HSC-SSP**, SPLASH, etc…)
- Quiescent Galaxies: sSFR is 1dex lower than main sequence
- Individually X-ray detected sources are excluded
  ←Not to affect the entire properties




Weaver+21

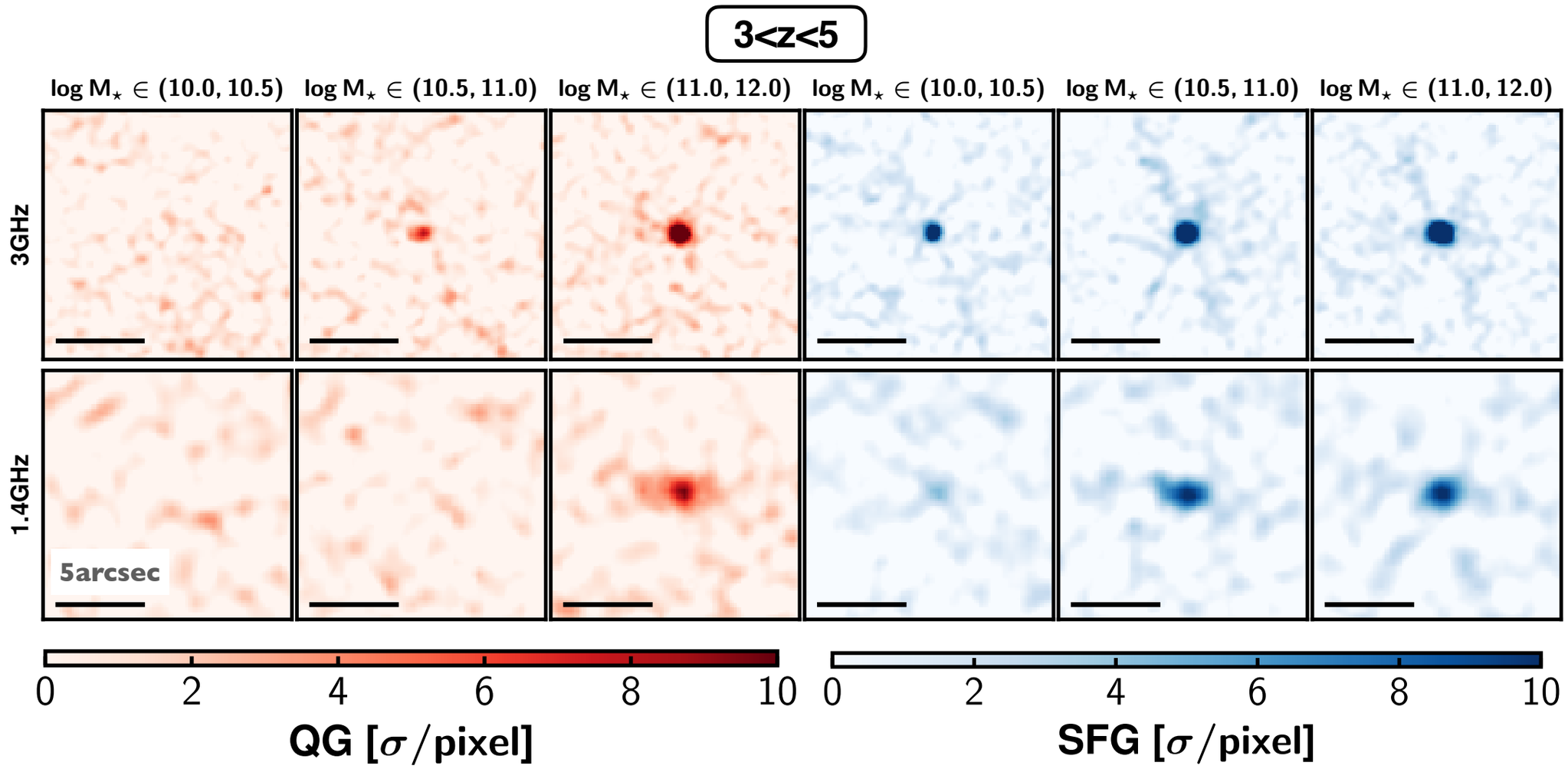
# X-ray stacking analysis

- Stacking the Chandra COSMOS Legacy survey images (Civano+16)
- Significant emission is detected at any redshift in more than one band
  →This work derives average emission of QGs at z>3 for the first time



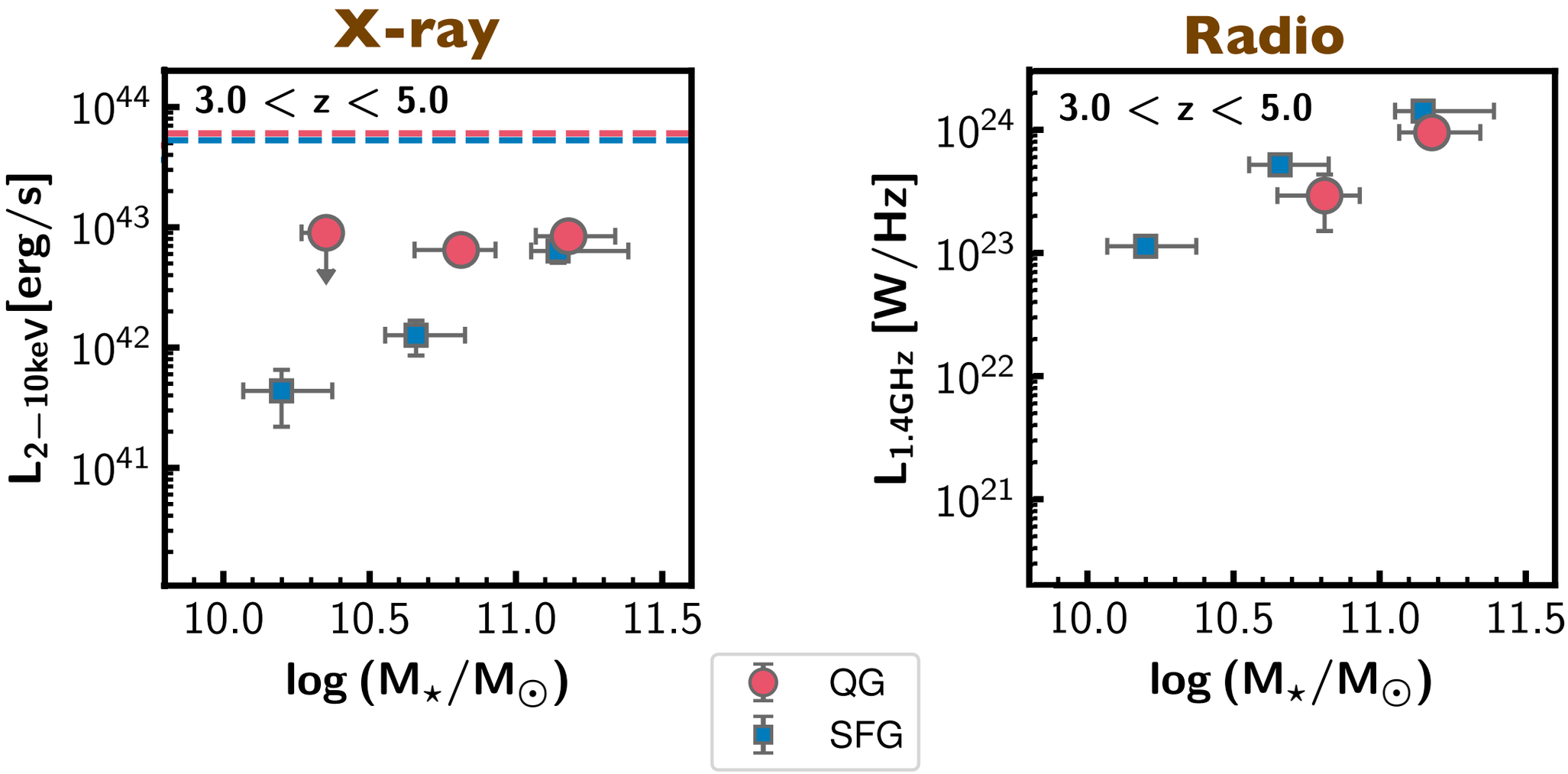
# Radio stacking analysis

- VLA-COSMOS survey: covering the entire COSMOS field by VLA 1.4GHz (Schinnerer et al. 2007), 3GHz (Smolčić et al. 2017)
- Conducting stacking by the similar method as in X-ray
  →Signal is detected up to z~3-5 (especially at 3GHz) for the first time



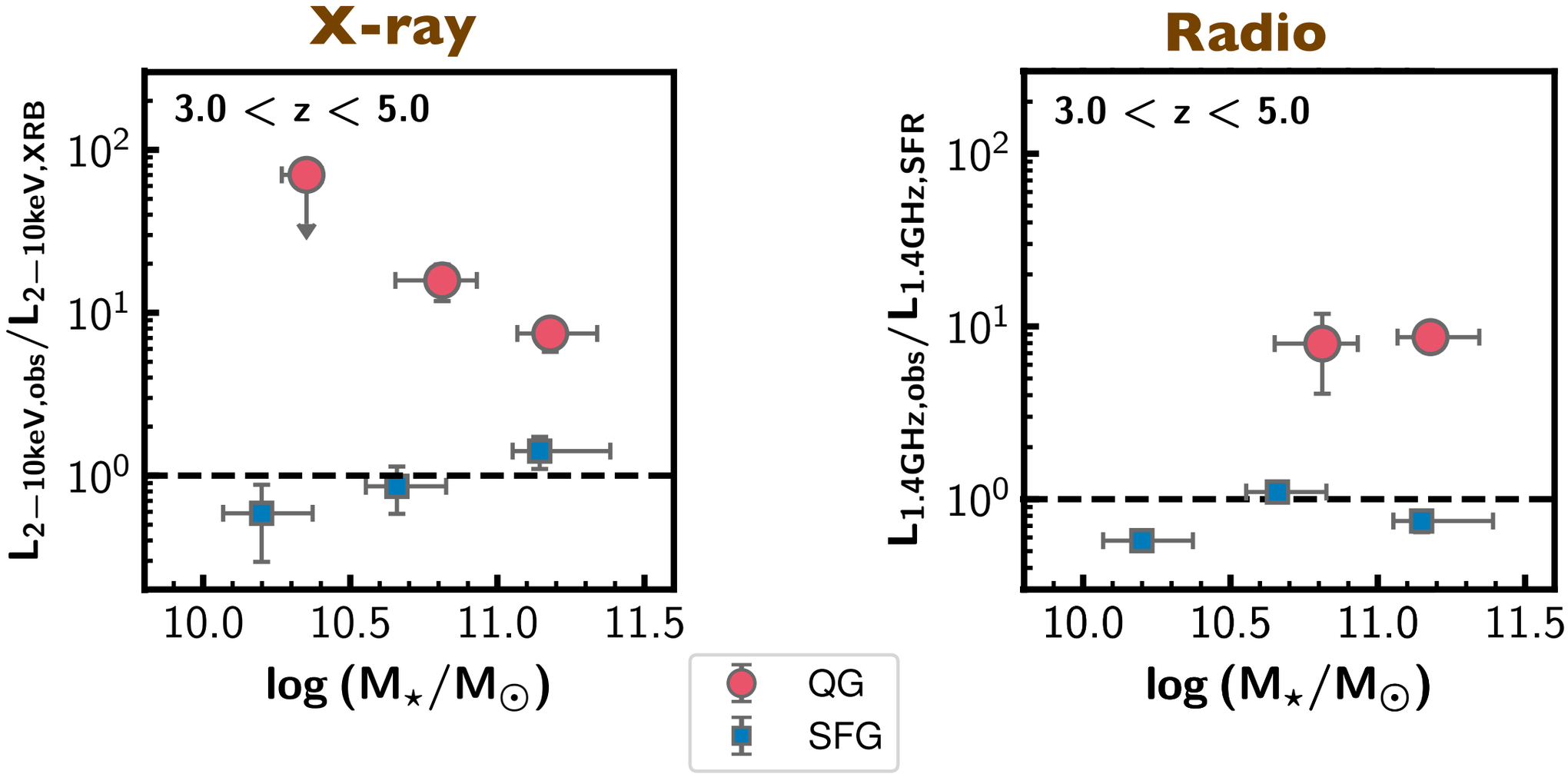
# X-ray/radio Luminosity of QGs

- Intrinsic rest 2-10keV and 1.4GHz luminosity is derived.
- Not only AGNs, but also X-ray binaries/SFR can contribute luminosity
  →What is the origin of the luminosity?



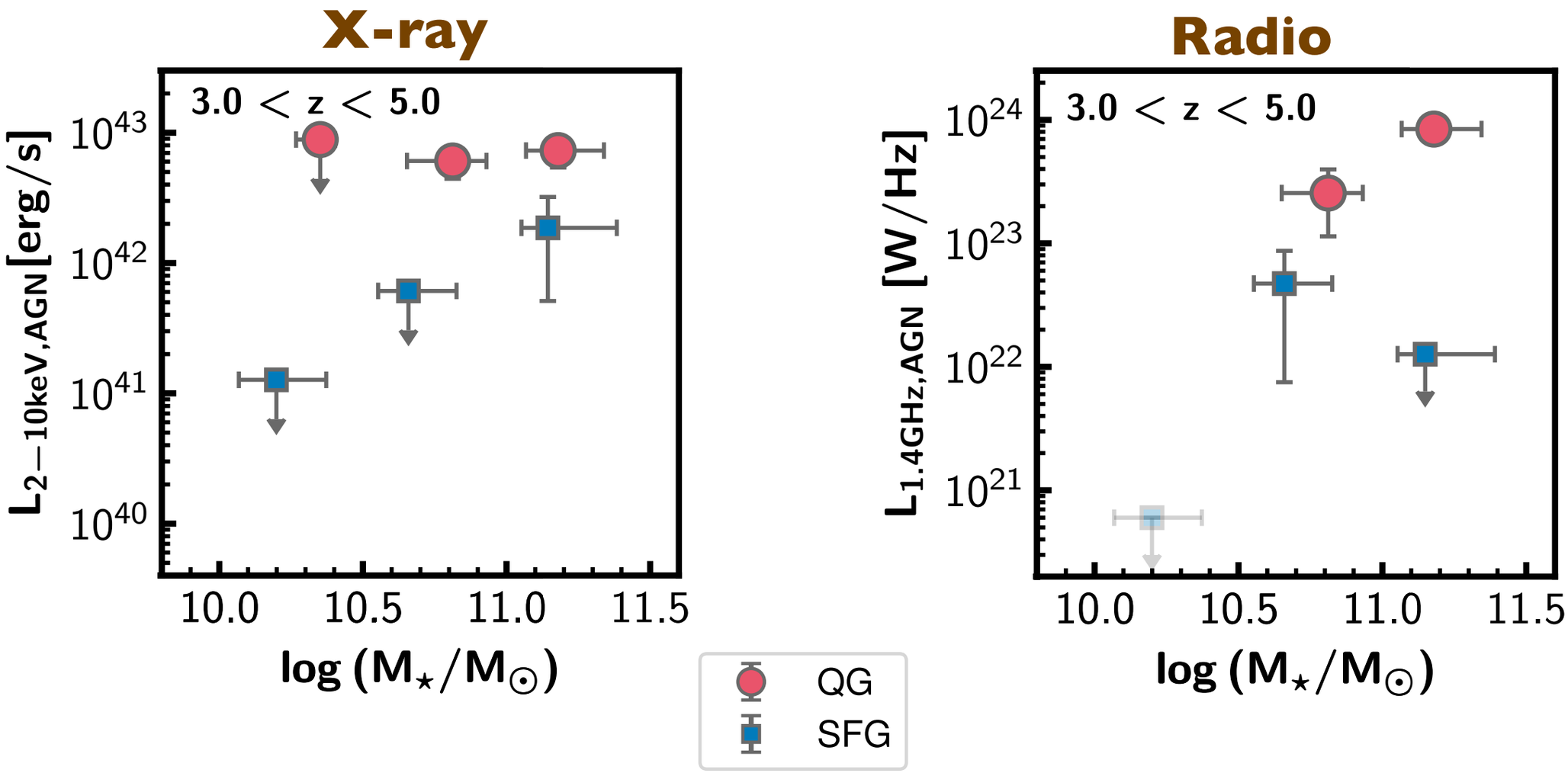
# XRB/SFR related luminosity

- Estimating XRB/SFR luminosity from SED-fitting stellar mass and SFR
  - XRB luminosity in X-ray: Lehmer+16
  - SFR-related luminosity in radio: Delvecchio+20
- QG's luminosity can not be explained by XRB/SFR luminosity
  →QGs have AGNs as a additional source



# AGN X-ray/radio luminosity of QGs

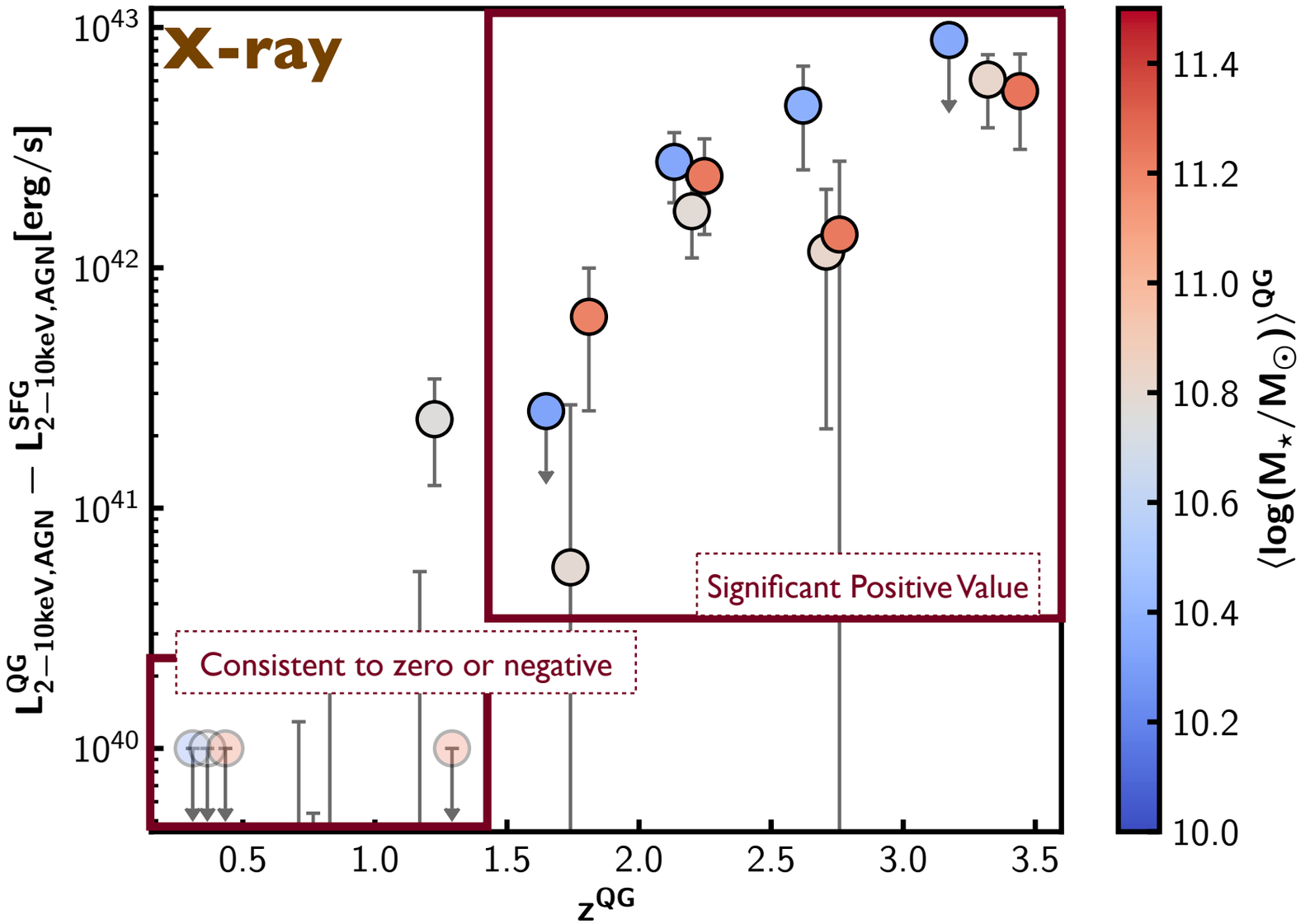
- AGN X-ray/radio luminosity is estimated as the excess of the observed luminosity to the expected XRB/SFR luminosity.
- QGs have higher AGN luminosity than SFGs
  →AGNs are more active in QGs than in SFGs



# X-ray AGN luminosity

- QGs have systematically higher AGN luminosity than SFGs at z>1.5.
- There is no significant difference at z<1.5.
  →Quenching at high redshift is related to the AGN activity?

**AGN luminosity difference between SFG and QG**



# Radio AGN luminosity

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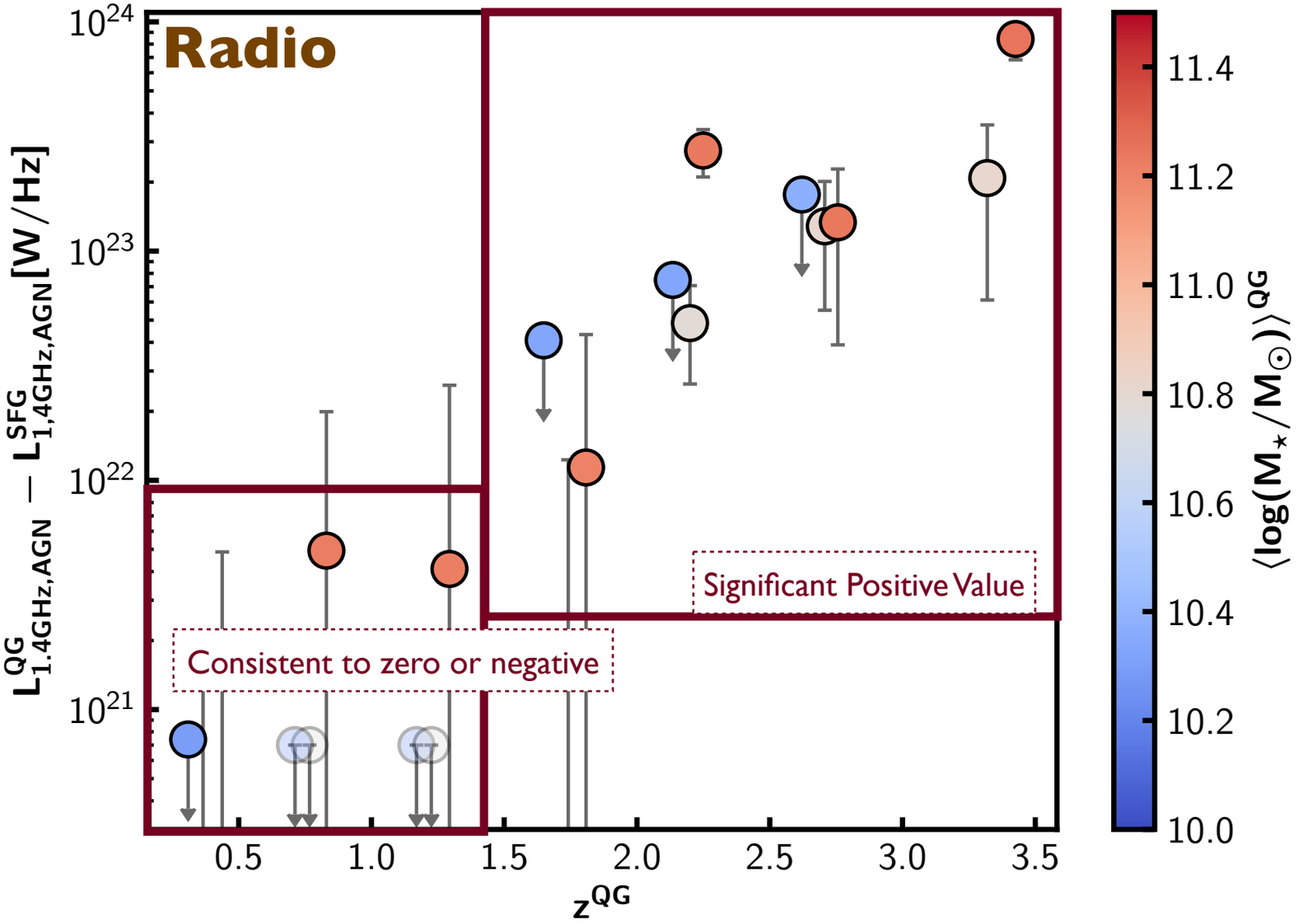
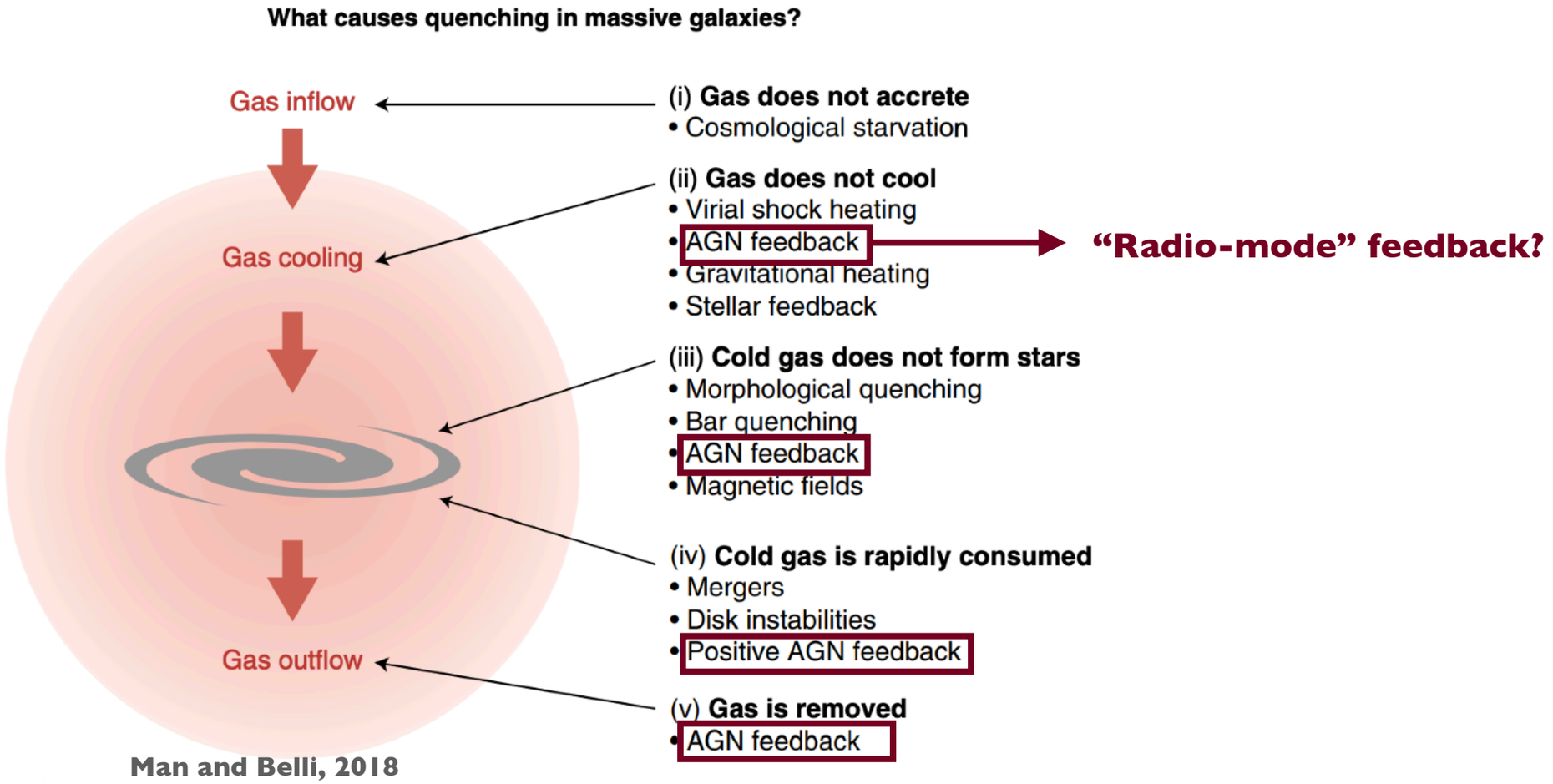


# Quenching and AGNs

- Observed X-ray/radio luminosity is higher than star-related luminosity
  →QGs posses low-luminosity AGNs up to z~5 in general
- X-ray/radio AGN luminosity is higher in QGs at z>1.5.
  →"Radio-mode feedback" is occurring? (∵ low-luminosity $L_{\rm X} \sim 10^{42}{\rm erg/s}$)
- Insignificant luminosity difference at z<1.5
  →Different quenching mechanism gets dominant?
  e.g., environmental quenching at z<2 (Kawinwanichakij+17)



# Summary

- We conducted X-ray/radio stacking for quiescent galaxies at z<5
- Latest QG catalog from COSMOS2020 provide plenty QG sample.
- In particular, HSC-SSP make significant contribution for optical flux.
- Most distant (z~3-5) X-ray/radio QG emission is detected.
- X-ray/radio luminosity is higher than expected from SFR/stellar mass.
- QG's AGN luminosity is higher than SFG at z>1.5

Quenching at high-z (z>1.5) is closely related to AGNs
→Radio-mode feedback is important?