2022.12.15 IPMU Postdoc Colloquium

Galaxy quenching in the distant Universe revealed with multi-wavelength observation

Tomoko Suzuki (Kavli IPMU)

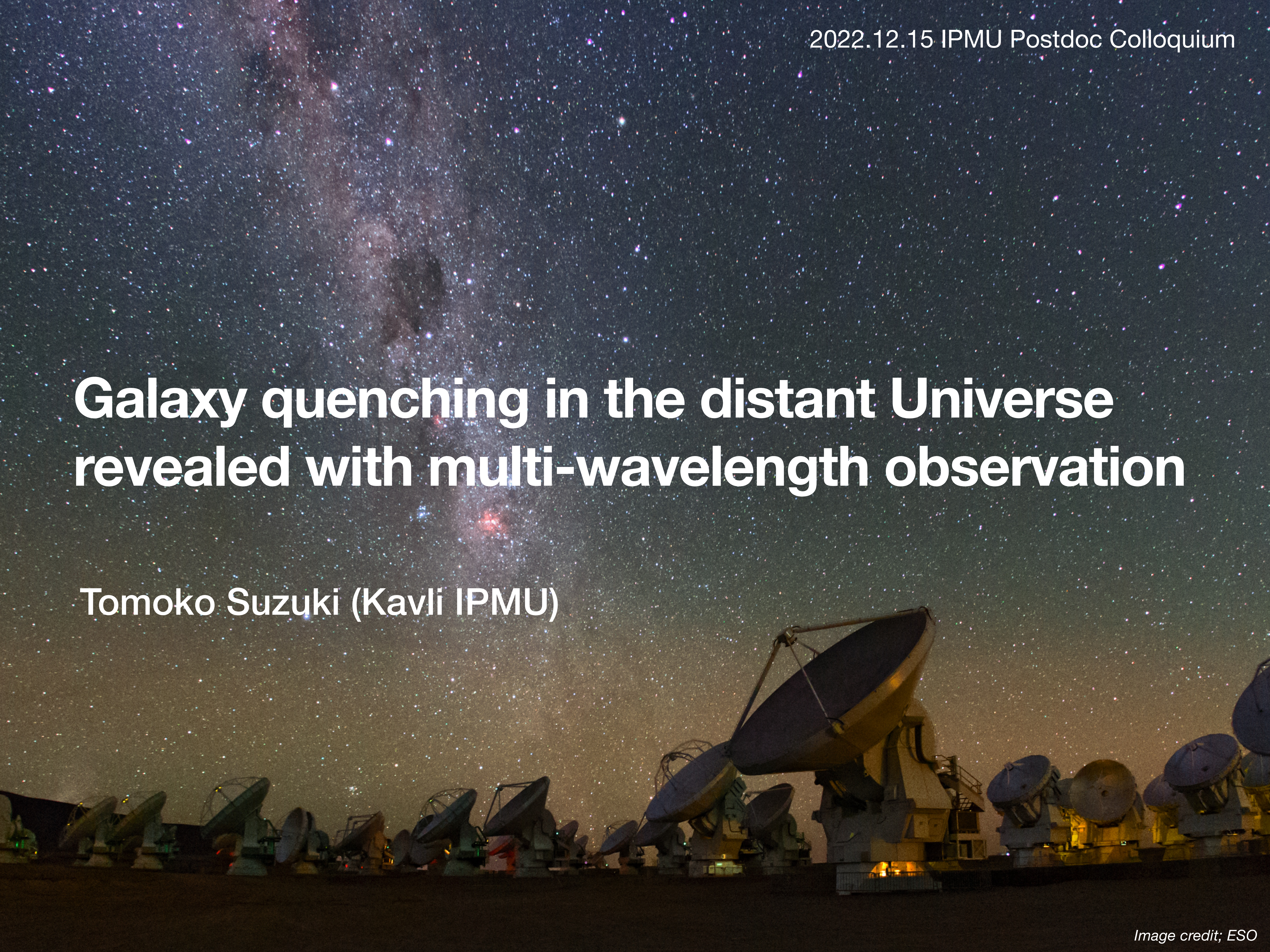
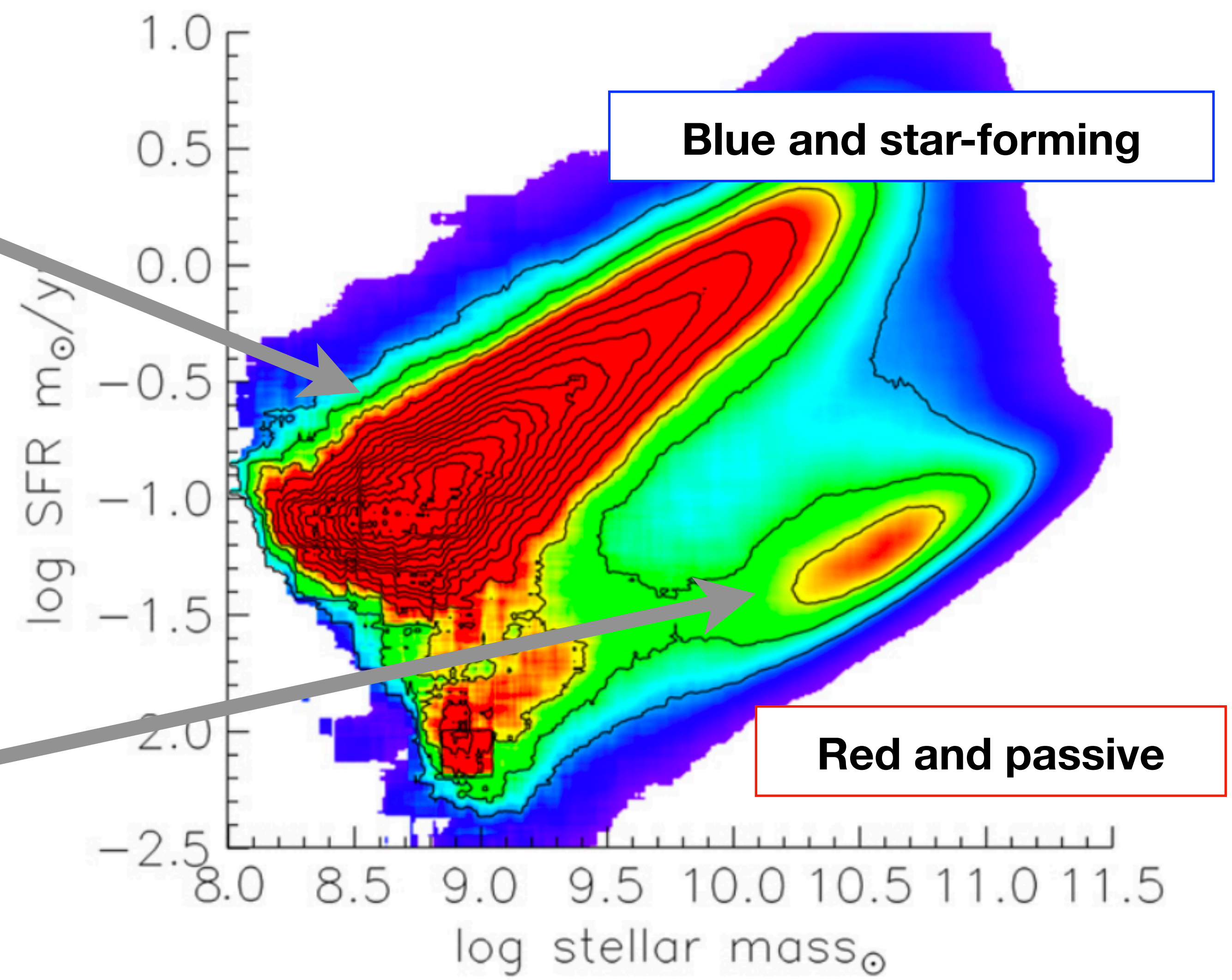


Image credit; ESO

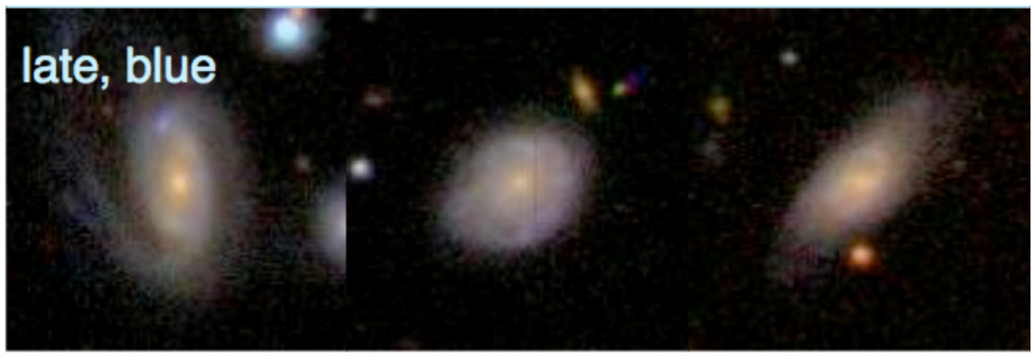
Bimodality of galaxies in the Universe

Schawinski et al. (2014)

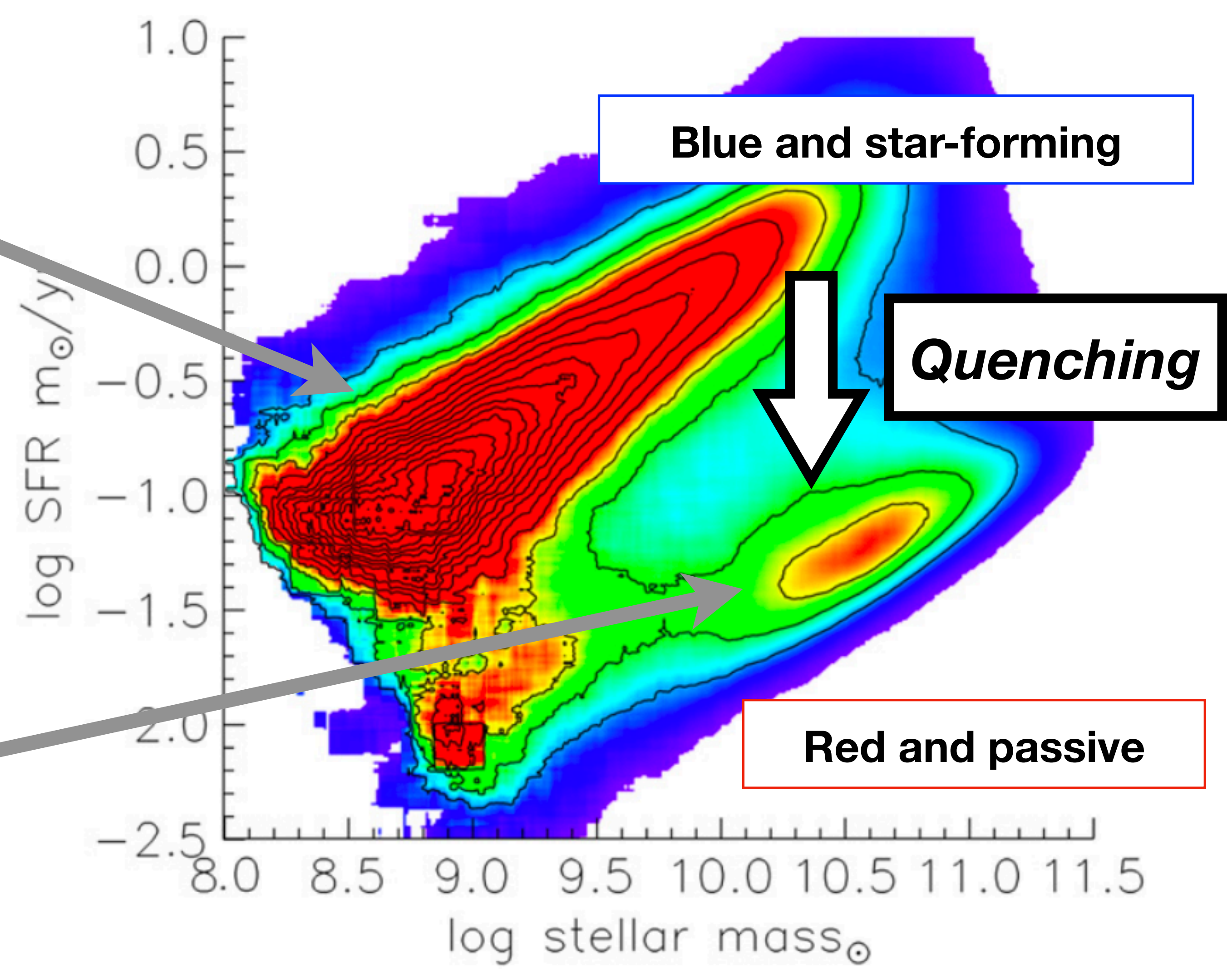


z = 0, Renzini & Peng (2015)

What’s driving galaxy quenching?



Schawinski et al. (2014)



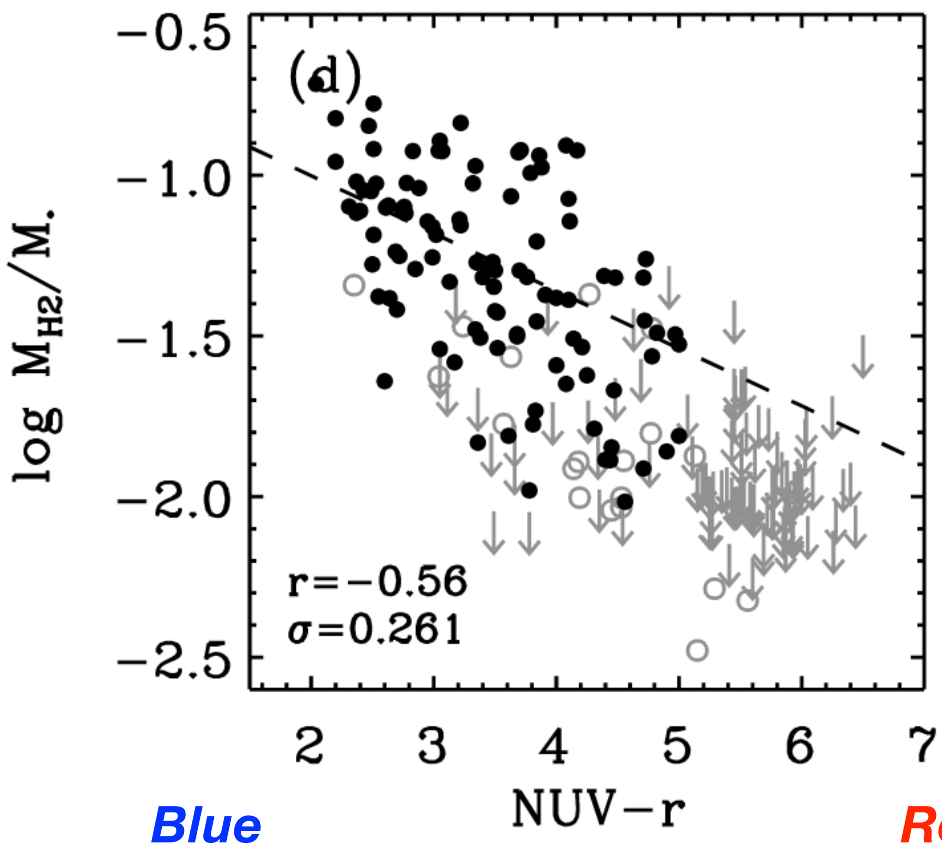
z = 0, Renzini & Peng (2015)

- **What is the main driver of galaxy quenching?**

- **How it changes across cosmic time?**

Molecular gas: fuel of star-formation

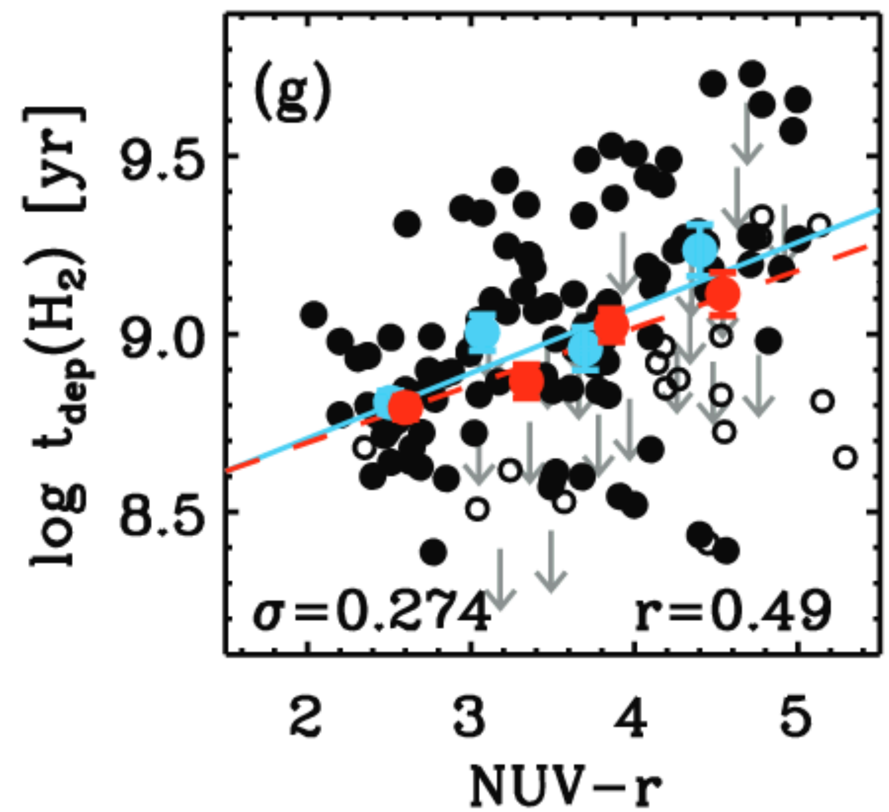
Gas mass fraction
= M_{H2}/M_{star} or $M_{H2}/(M_{star}+M_{H2})$



Blue
(young, star-forming)

Red
(old, passive)

Gas depletion timescale = **M_{H2}/SFR**
(Star-formation efficiency)



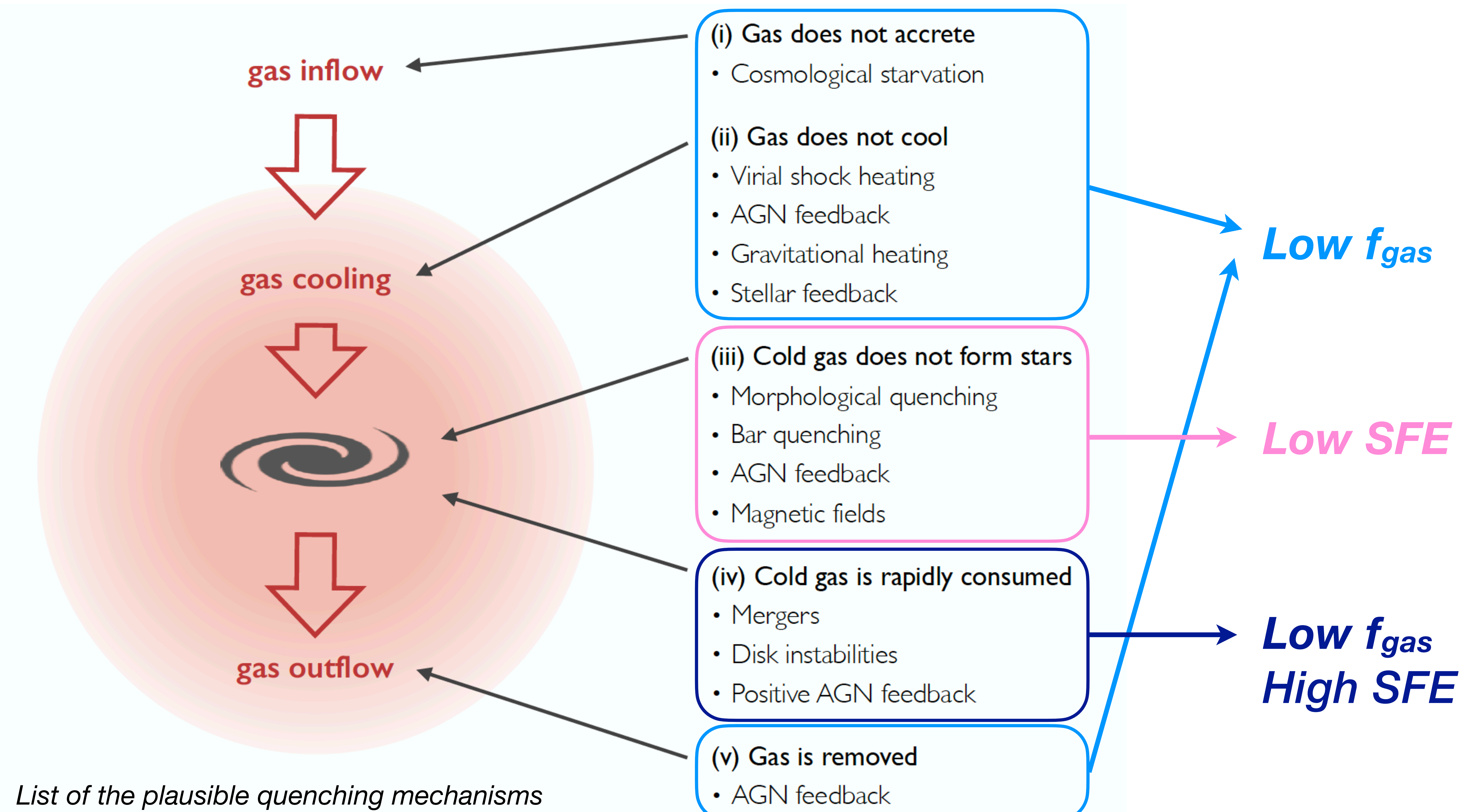
Local galaxies (Saintonge+11ab)

Galaxies with red colors

- gas-poor (no fuel of star-formation)
- cannot convert gas into stars efficiently

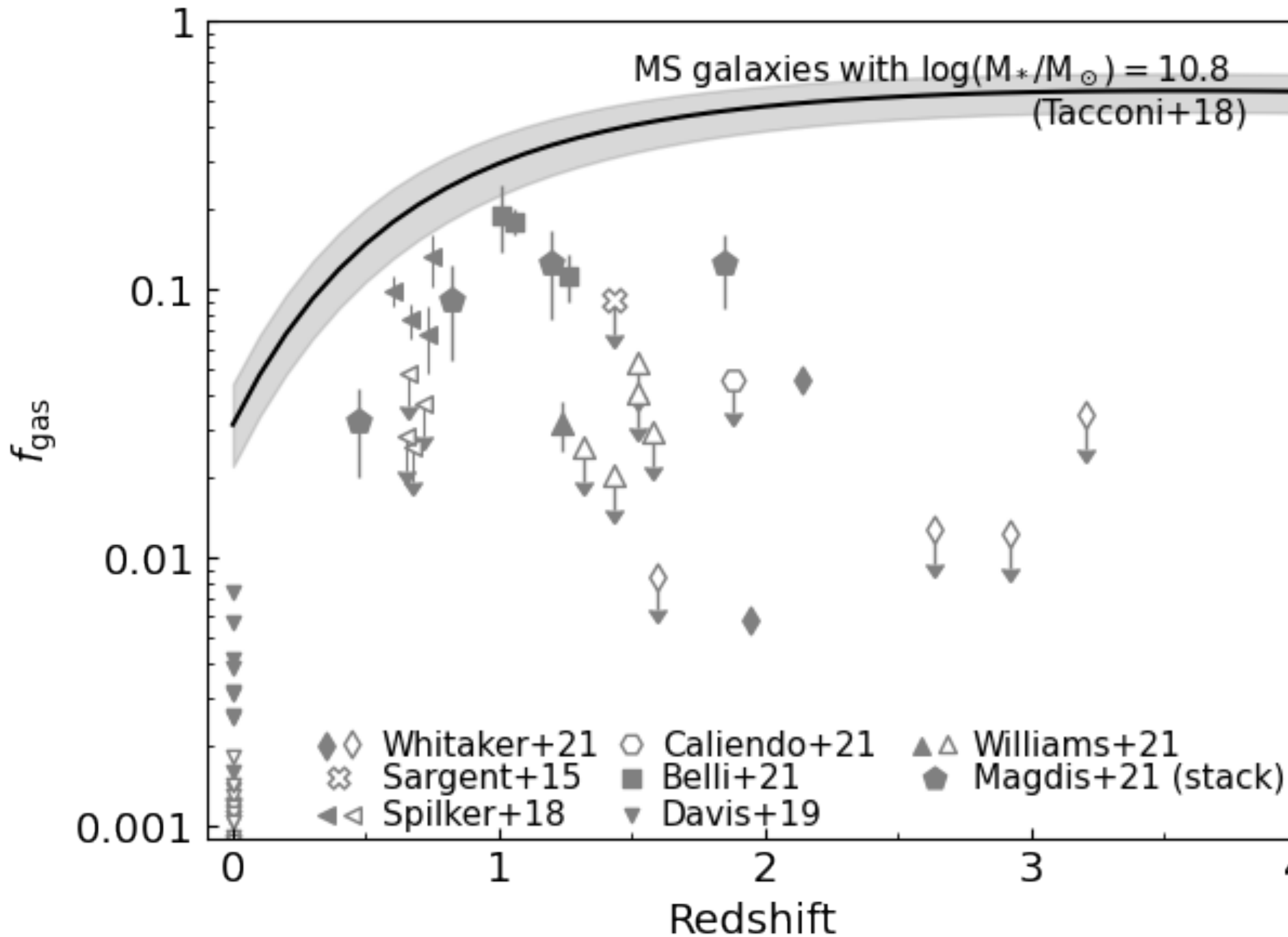
Gas properties and quenching processes

Gas fraction and depletion timescale (star-formation efficiency)
= Key quantities to distinguish the quenching mechanisms



List of the plausible quenching mechanisms from Man & Belli (2018)

Gas content in quiescent galaxies at high redshift



- **Low gas fraction (< 0.1) and short depletion timescale (< 1 Gyr)**

  (Sargent+15; Spilker+18; Caliendo+21; Whitaker+21…)

- Longer depletion timescale of QGs at z ~ 1.8 (**~ 2-3 Gyr**; Gobat+18)

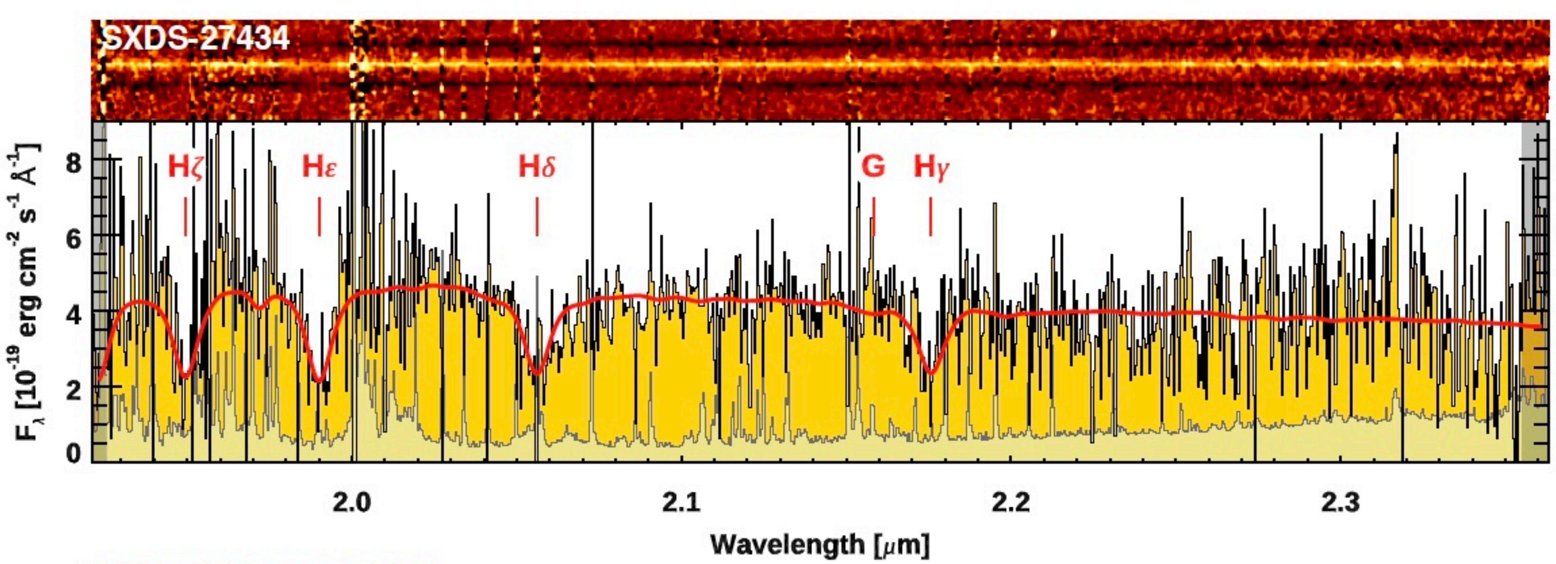
Quiescent galaxy search at z > 3

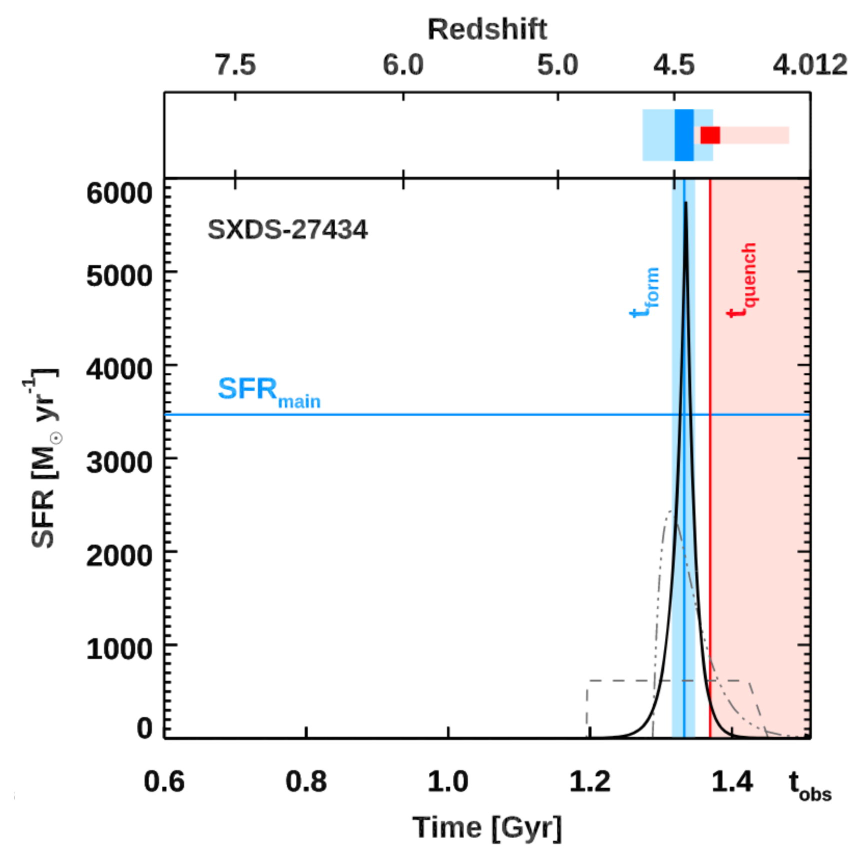
- Getting closer to the epoch of quenching of massive galaxies

- The number of spectroscopically confirmed quiescent galaxies is increasing at z > 3

  : Glazebrook+17; Schreiber+18b; Tanaka+19; Valentino+20; Kubo+21…

z = 4.01 (Tanaka+19; Valentino+20)





Quiescent galaxies at z = 3.5 - 4 from ZFOURGE

- ZFOURGE: deep NIR survey with medium-band filters in J and H-band (Straatman+14)

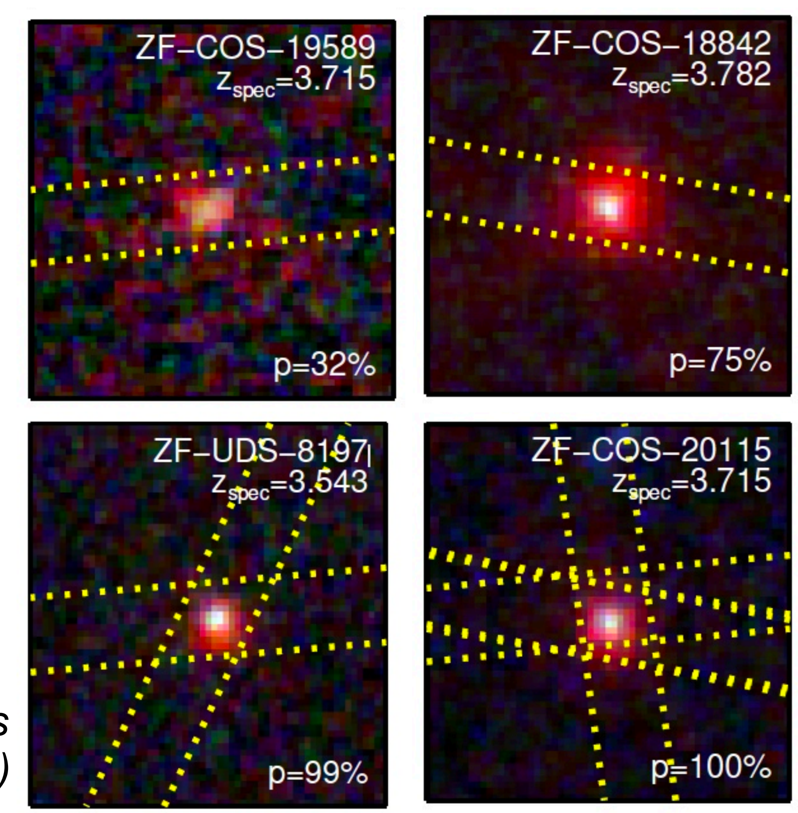
  —> accurate photometric redshifts and accurate classification of quiescent and star-forming galaxies based on colors (e.g., Spitler+14)

- Spectroscopic confirmation of quiescent galaxy candidates at z > 3 (Glazebrook+17; Schreiber+18)

  —> **4 quiescent galaxies at z = 3.5 - 4.0**

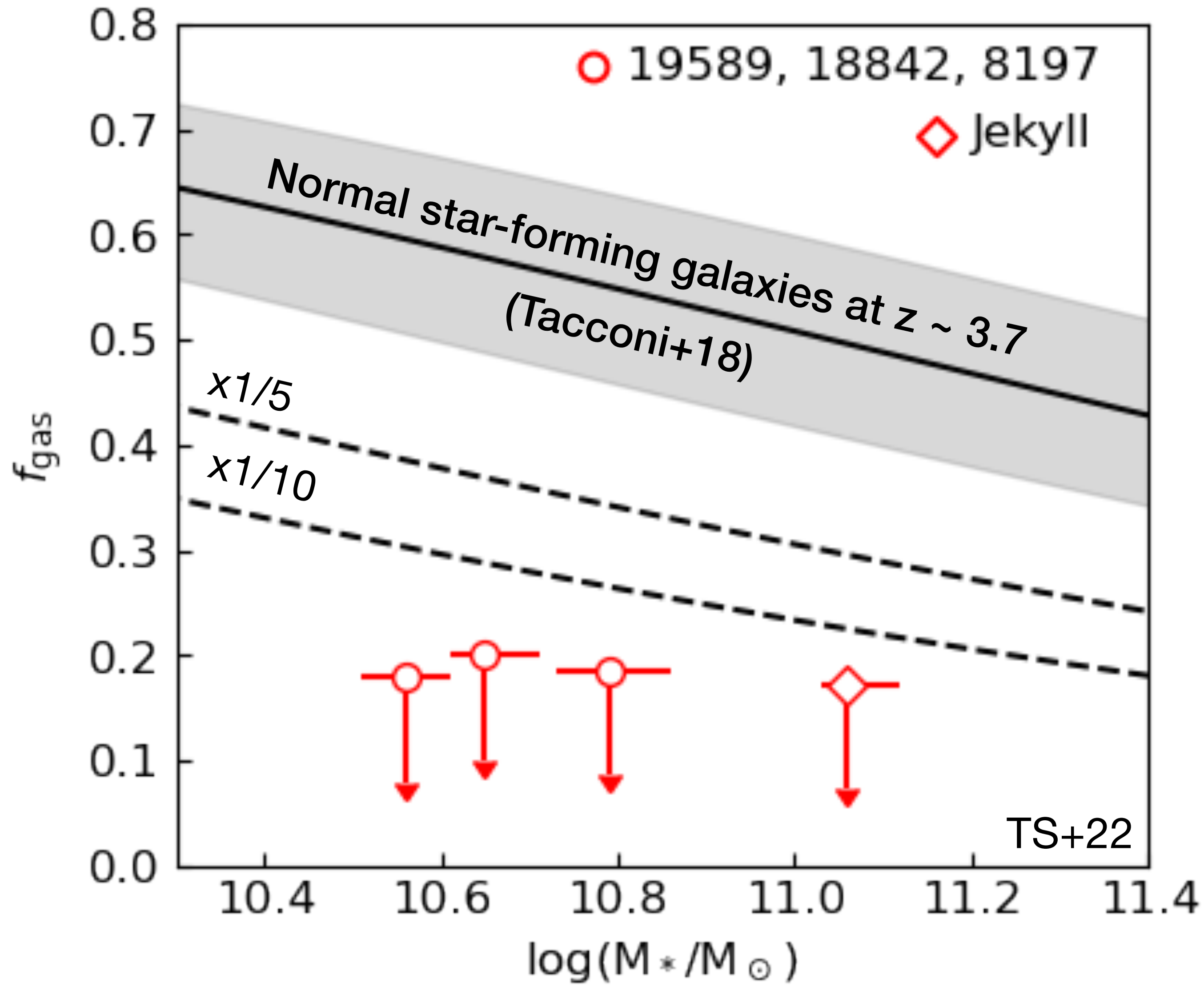
- **Sub-mm follow-up observation with ALMA (TS+22)**

  —> Atomic carbon line ([CI])



HST image of the four QGs (Schreiber+18b)

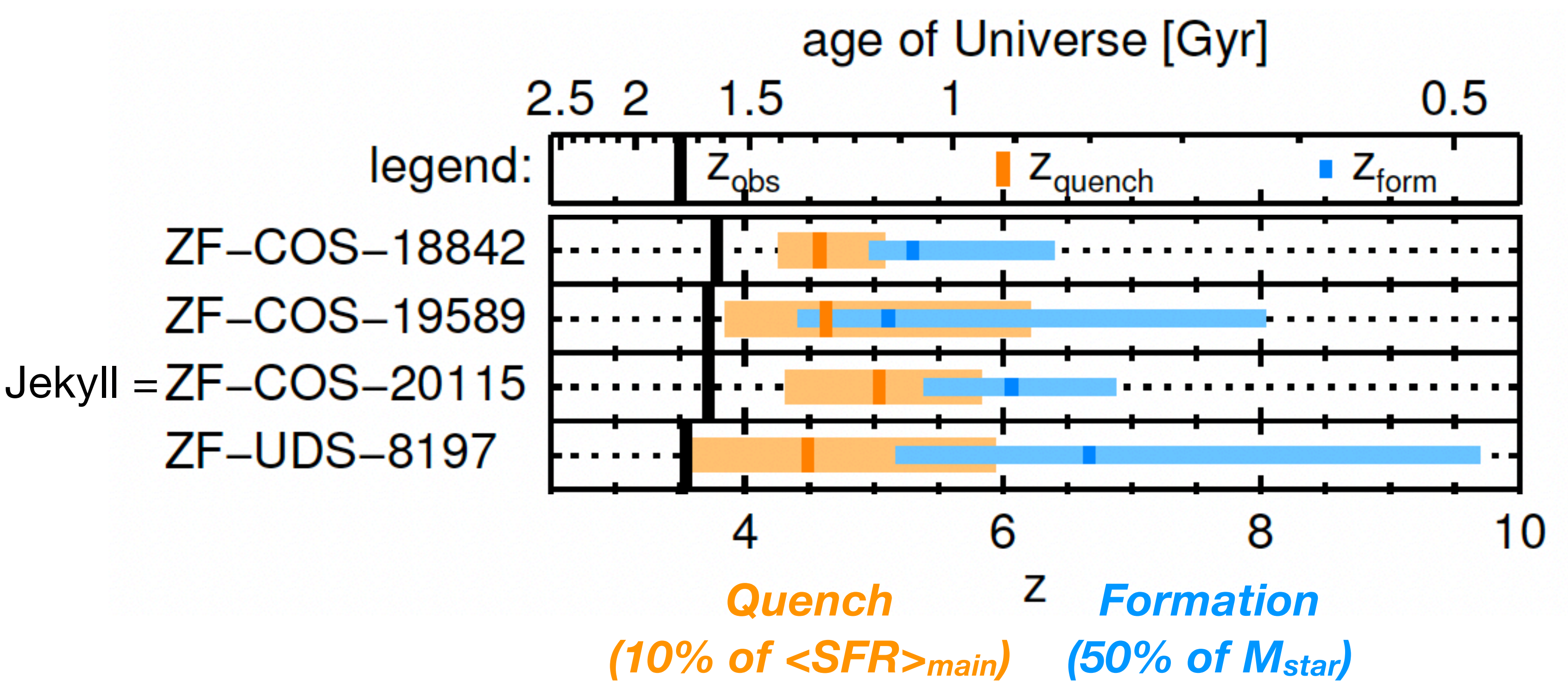
Gas content in quiescent galaxies at z ~ 3.7

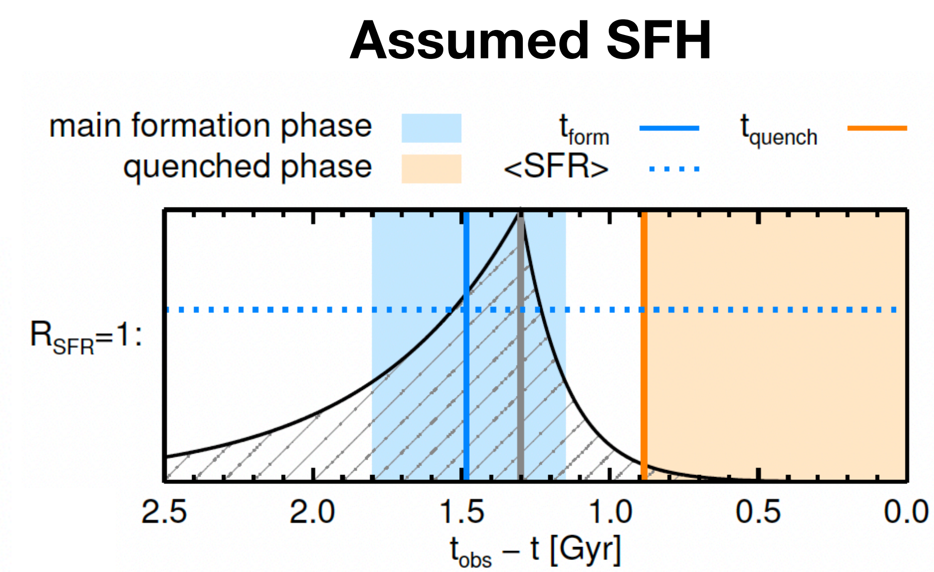


- **f_{gas} < 20 %** (< 3 times lower than star-forming galaxies at a given M_{star})

- No reasonable constraint on gas depletion timescale

Reconstructed star-formation history





Schreiber+18

- SED fitting using NIR spectra + broad-band photometry (Schreiber+18)
- *z_{form} - z_{quench}* = a proxy of the timescale of quenching

: **The targets quenched in 0.2-0.5 Gyr since their formation epoch**

—> Need to consume/expel the molecular gas quickly

Reconstructed star-formation history

age of Universe [Gyr]

Assumed SFH

Jekyl

Massive galaxies at z > 3.5 stop their star-formation by consuming/expelling the molecular gas rather than by reducing star-formation efficiency

(e.g., Sargent+15; Williams+20; Caliendo+20; Whitaker+21 for z ~ 1-3)

- SED fitting using NIR spectra + broad-band photometry (Schreiber+18)
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QGs in a semi-analytical model

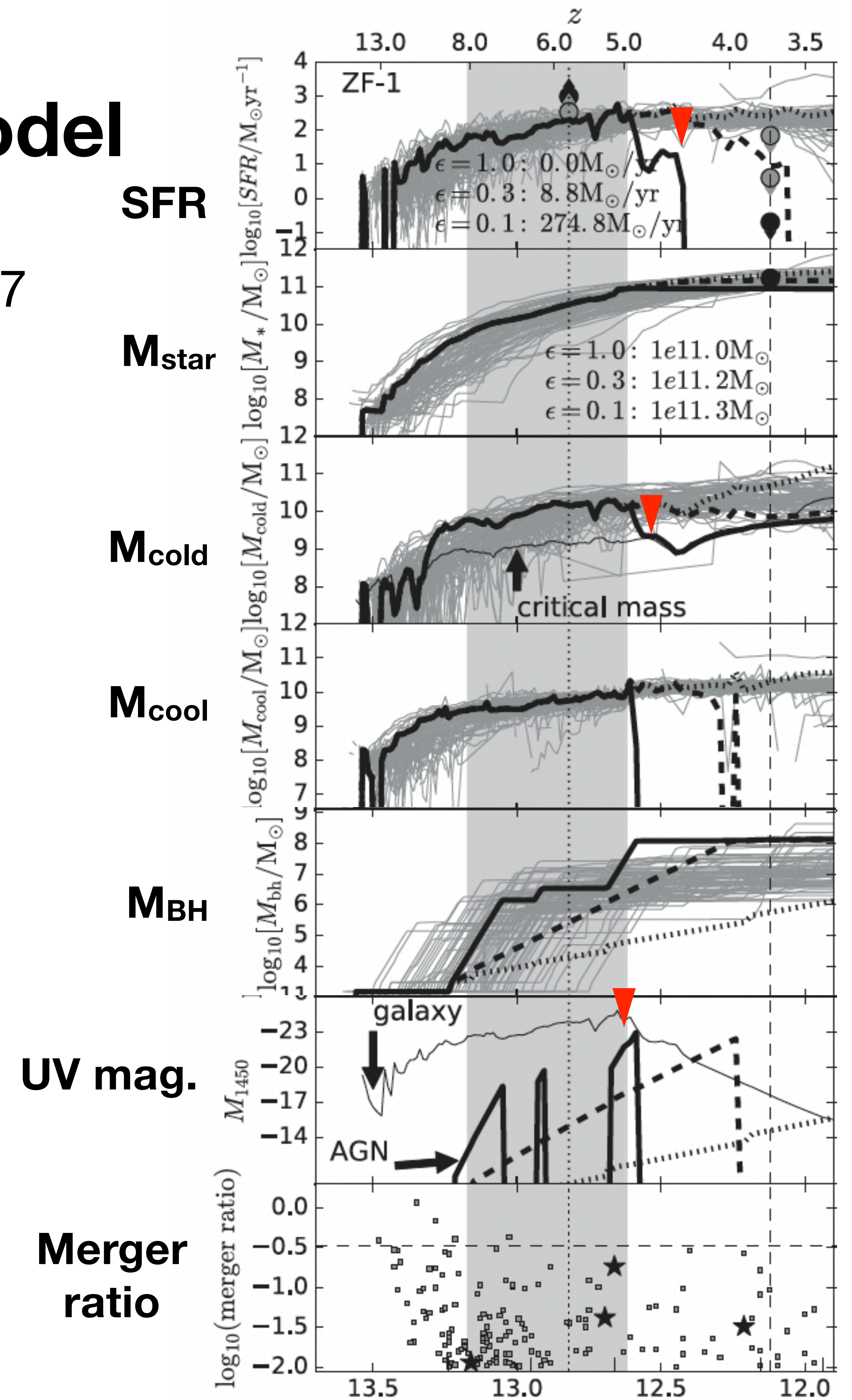
Three massive quiescent galaxies at z ~ 3.7 in a semi-analytical model, MERAXES (Qin+17ab)

- Suppression of gas cooling in ISM by the AGN activity at z ~ 5

- Quench at z ~ 4.0-4.5 by consuming the remaining cold gas in 0.1-0.3 Gyr

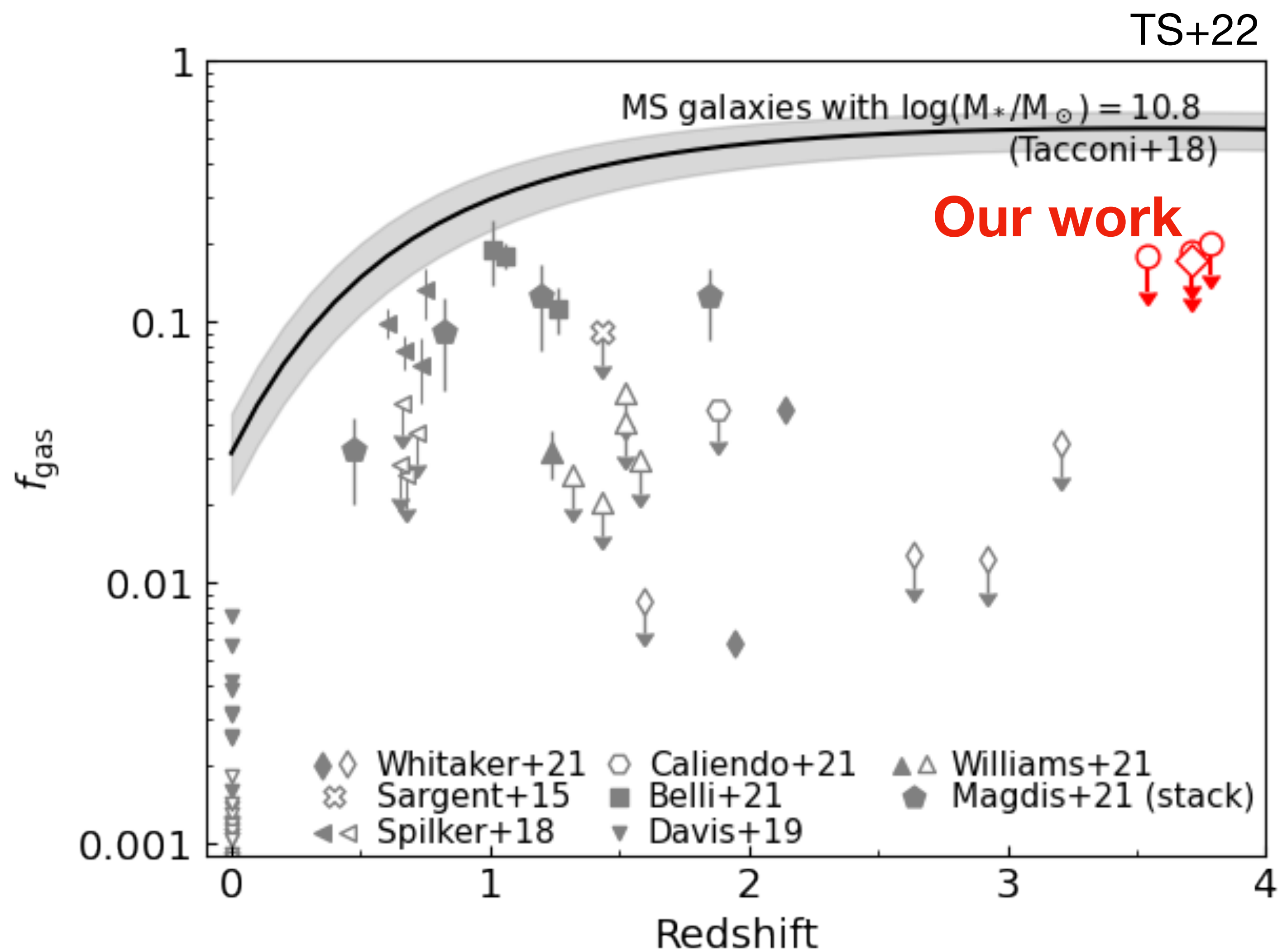
- f_{gas} ~ 0.05 at z ~ 3.7

AGN feedback may play a role on quenching at z > 3.5



Qin et al. (2017a)

What's next?



1. **Small number of quiescent galaxies with the rest-frame optical spectra** (and gas mass information) **at z > 0.5**

2. **Quiescent galaxy search at z > 4**

1. Construct a larger sample of QGs

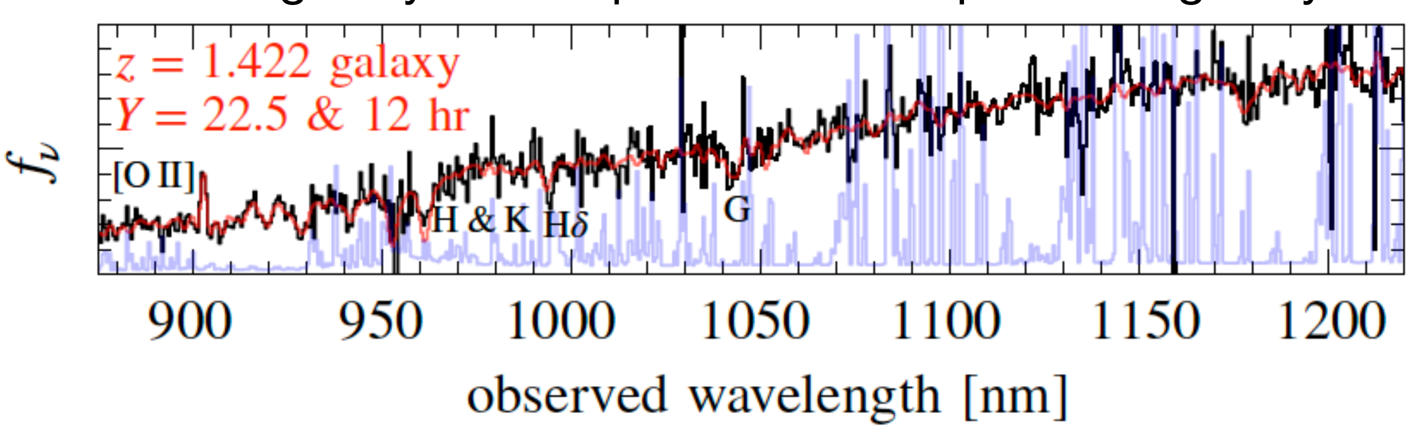
Subaru/Prime Focus Spectrograph (PFS)

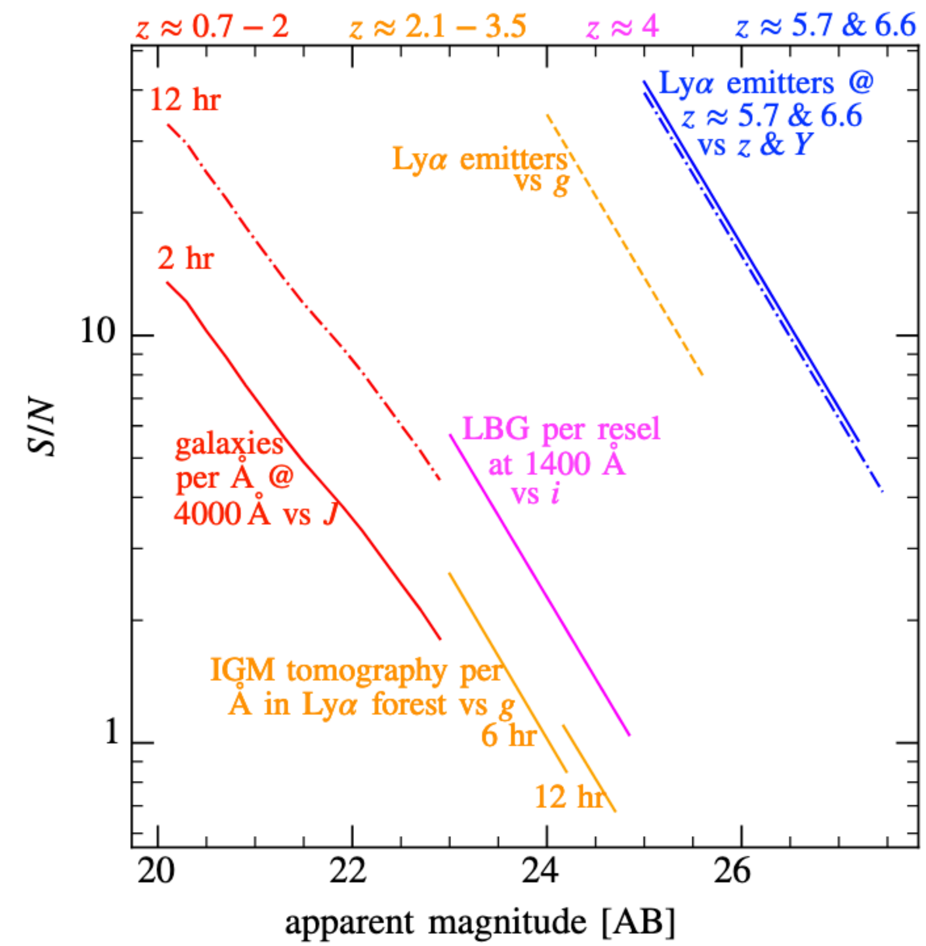
- Optical-NIR spectrograph with wide field-of-view and high multiplicity
- **Wavelength coverage up to 1.2 μm**

PFS-SSP Galaxy Evolution Survey (Greene+22)

- **Low-z "Deep" sample (12 hours)**
  —> 14,000 galaxies at z ~ 0.7-2.0 in total

PFS galaxy mock spectrum for a quiescent galaxy



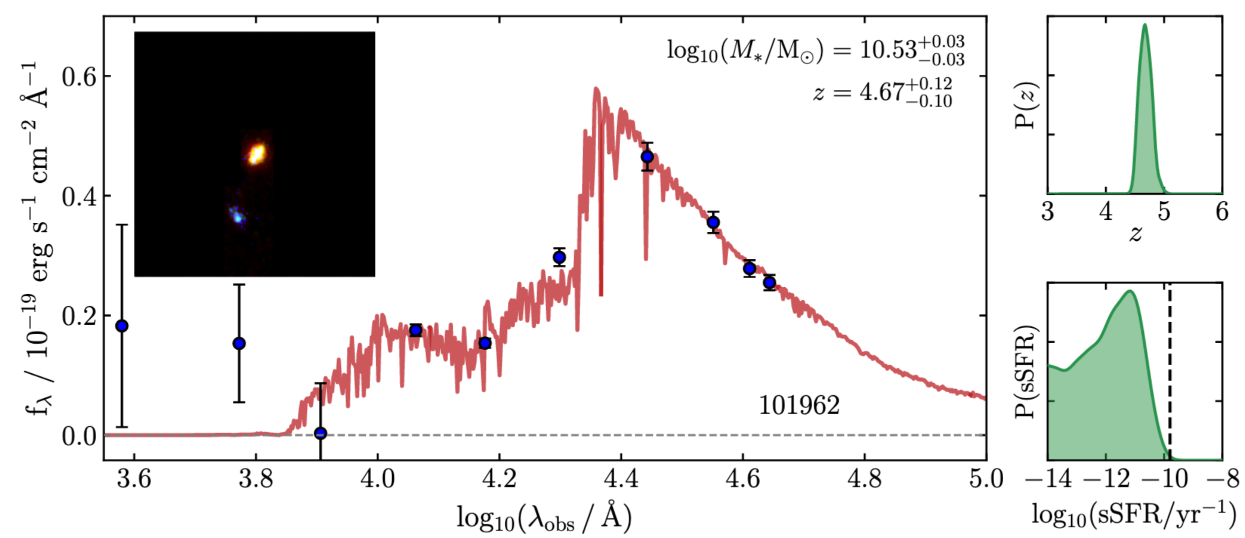


Greene+22 (arXiv: 2206.14908)

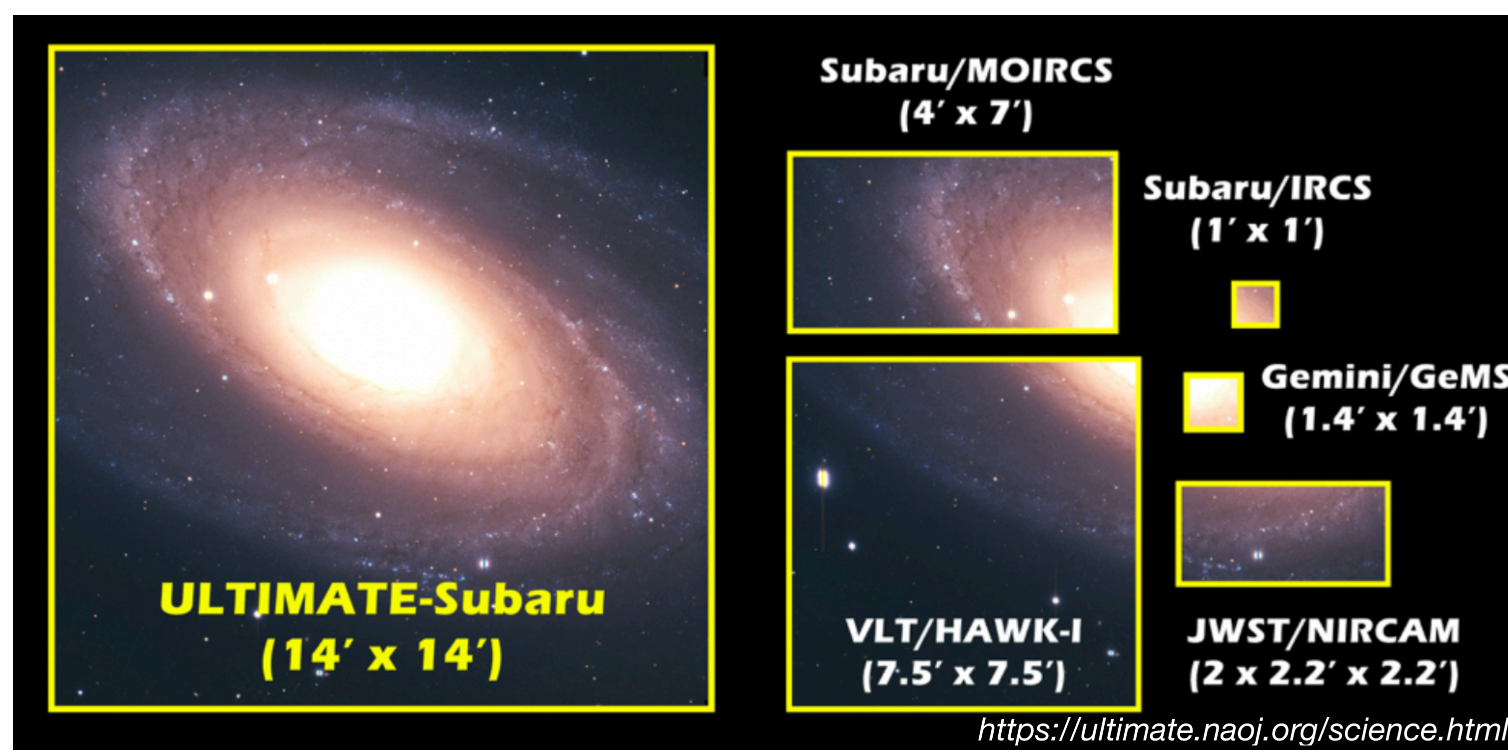
2. Go to higher redshift

- **JWST**
  : **Wavelength coverage up to 5 μm** + high sensitivity

Carnall+22



- **ULTIMATE-Subaru**
  : **Wide-field NIR imager**
  (14 arcmin x 14 arcmin)
  + Adaptive Optics
  (0.2 arcsec resolution)
  + MB filters at K-band



Take away points

- Spectroscopic observation to reconstruct star-formation history and sub-mm observation to trace molecular gas are crucial to study physical mechanisms driving galaxy quenching

- The obtained star-formation histories and gas mass fractions suggest that **the quenching of massive galaxies at $z > 3.5$ happens by losing gas in a short timescale of several 100 Myrs**

- Subaru/PFS will allow us to investigate the star-formation history of a statistical number of quiescent galaxies at $z = 0.7 - 2.0$ for the first time