

Challenge to the Most Distant Evolved Galaxies: Hint on Star-Formation Activity during the First 500 Million Years of the Cosmic History

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TCHoU2023前期



About myself

Birthplace: Abiko, Chiba

2006-2015 Tohoku Univ. (B.Sci, PhD)

2012-2014 Harvard-Smithsonian CfA
(during PhD course)

2015-2018 Osaka-Sangyo Univ. (posdoc)

2018-2021 UTokyo, ICRR (ICRR Fellow)

2021-2023 NAOJ, Subaru (posdoc)

2023- U.Tsukuba, (posdoc)

Research Topic: Obs of high- z galaxies
Multi-wavelength study
Proto-clusters, Inter-galactic Medium



東京大学
THE UNIVERSITY OF TOKYO



筑波大学
University of Tsukuba

Ultimage Goal

Understanding of the first galaxy formation process

Immediate Goal

Observationally reveal how active star-formation was in earlier era

Approaches

1. Direct obs (w/ high sensitivity instruments)
2. Archaeological method (w/ "fossil record")

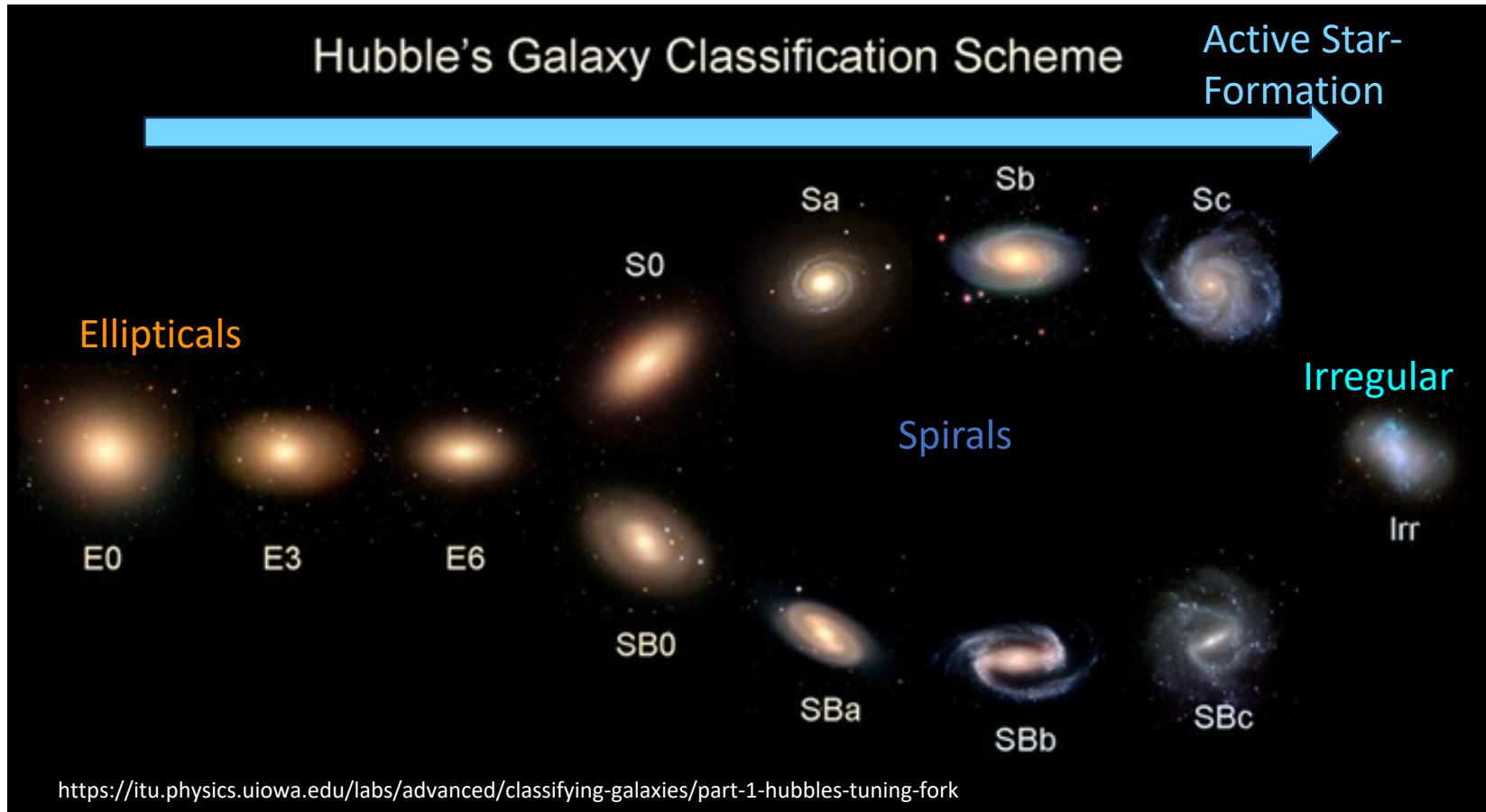
2023/6/27



TCHoU2023前期

宇宙史研究センターウェブサイトより

Passive and Star-Forming Galaxies



Passive Galaxy

- No (little) Star Formation
- Red color (old cool stars)
- Passively evolving(受動的進化)
- Settled morphology
- Featureless in spectra

Star-Forming Galaxy (SFG)

- Active Star Formation
- Blue color (young hot stars)
- Easy to observe
- Turbulent morphology

Star-Formation

Makes the galaxy easily observed, but
Drowns out the past info,,,

Key Spectral Feature of Passive Galaxies

Balmer Break

Origin: Hydrogen Balmer Break of A-type stars.

This feature becomes prominent at age = 200Myr ~ 1Gyr.

Lifetime of O,B stars

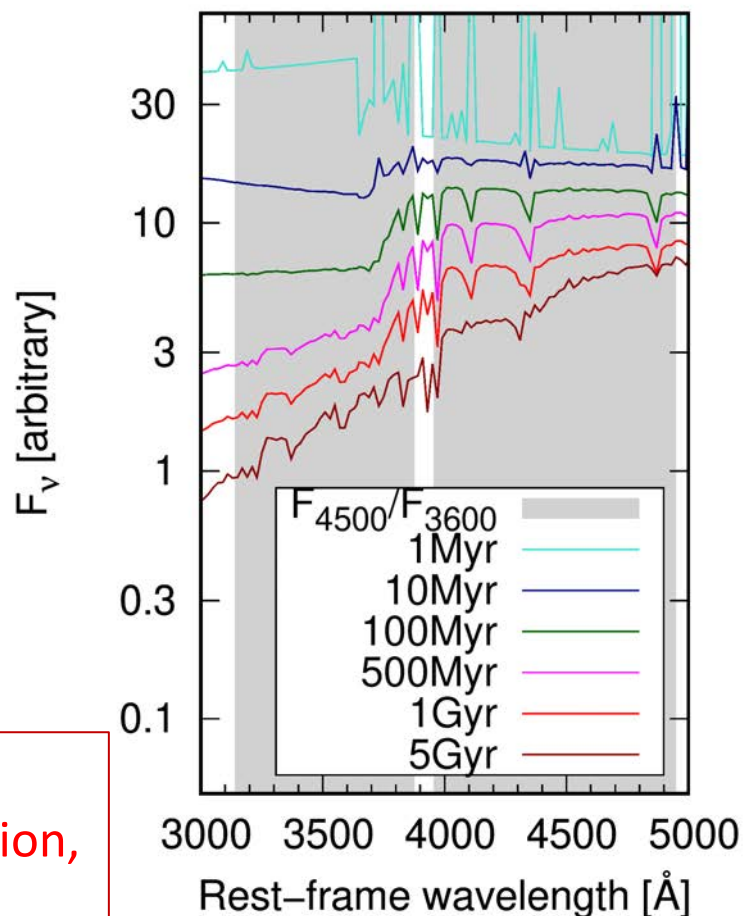
4000Å Break

Origin: Metal absorptions of G-type or cooler stars.

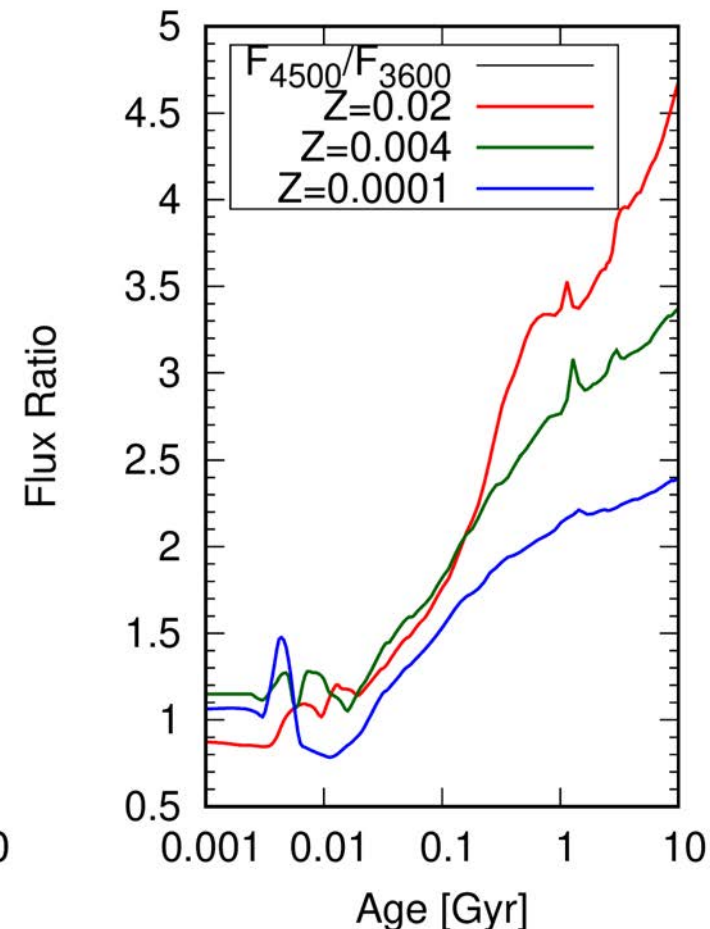
This feature becomes prominent at age > 1Gyr.

Balmer Break strength indicates
how long the galaxy is stopping Star-Formation,
(and metallicity).

BURST model spectra with $Z=0.004$

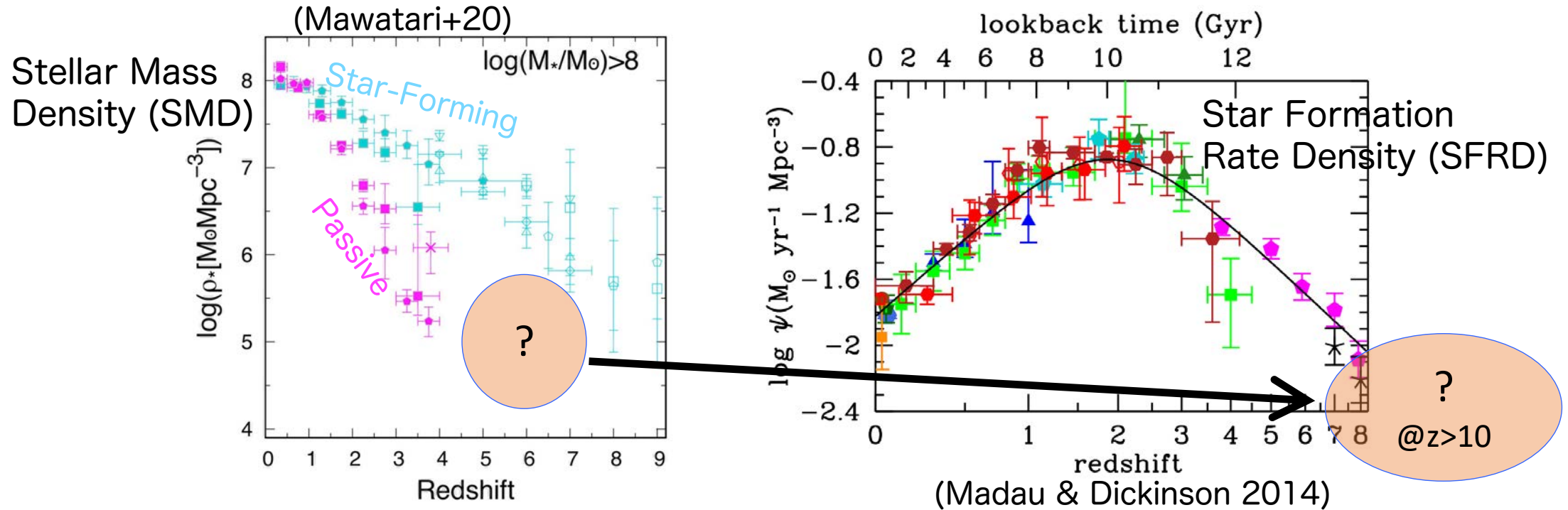


BURST models



Balmer Break Galaxy (BBG) = Passive galaxy

Potential Power of High-z Passive Galaxies



Passive galaxies at $z>5$ can open a new window on star-formation at $z>10$

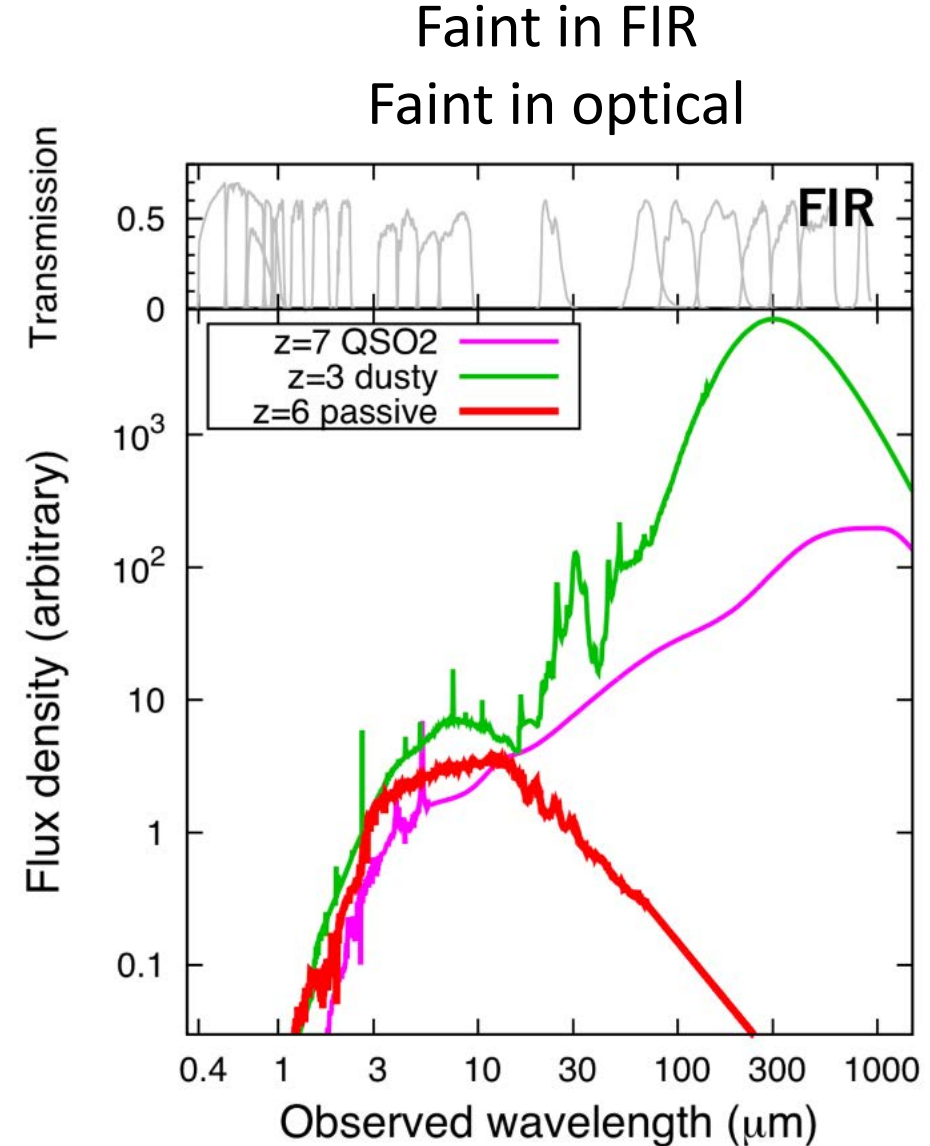
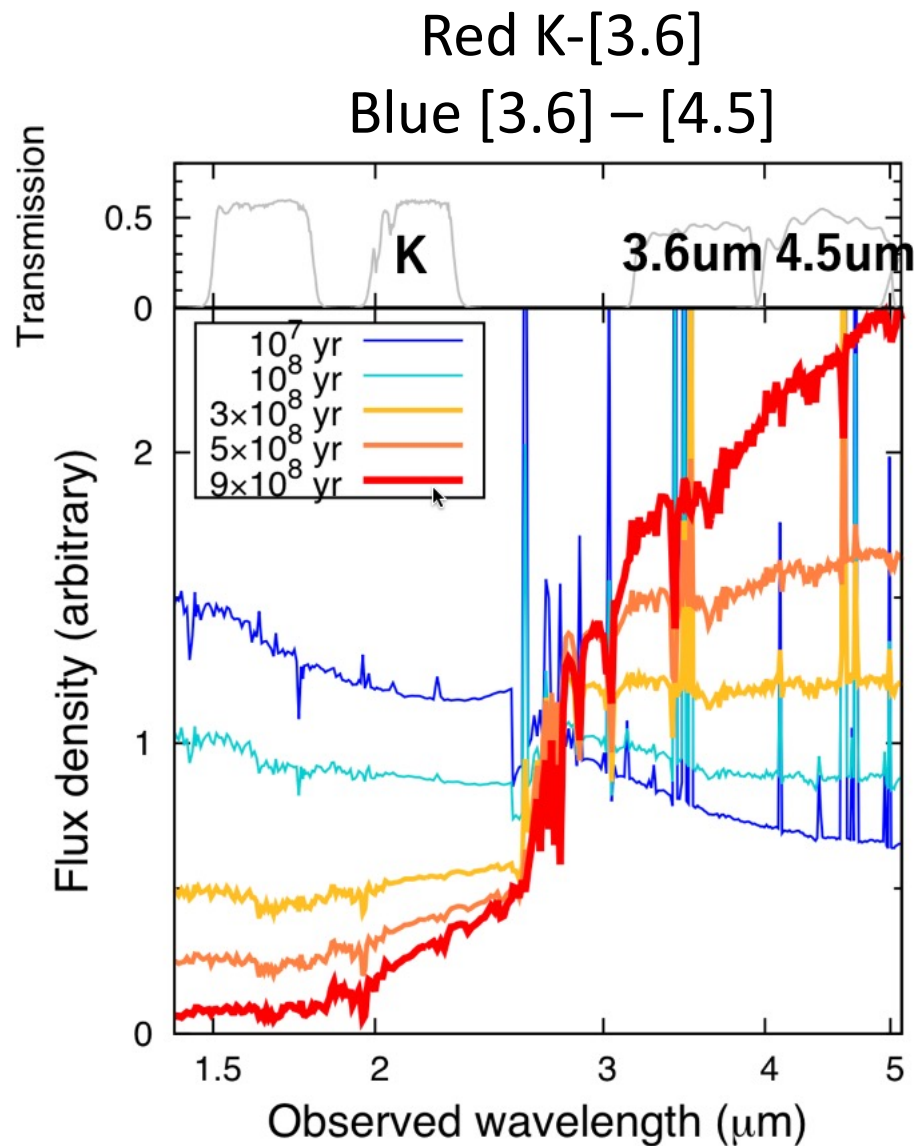
”Passive galaxy” in this work:

Galaxy with strong Balmer-break (Balmer-break galaxy; BBG) experiencing $> 200\text{Myr}$ after stopping star-formation

Our Previous Works

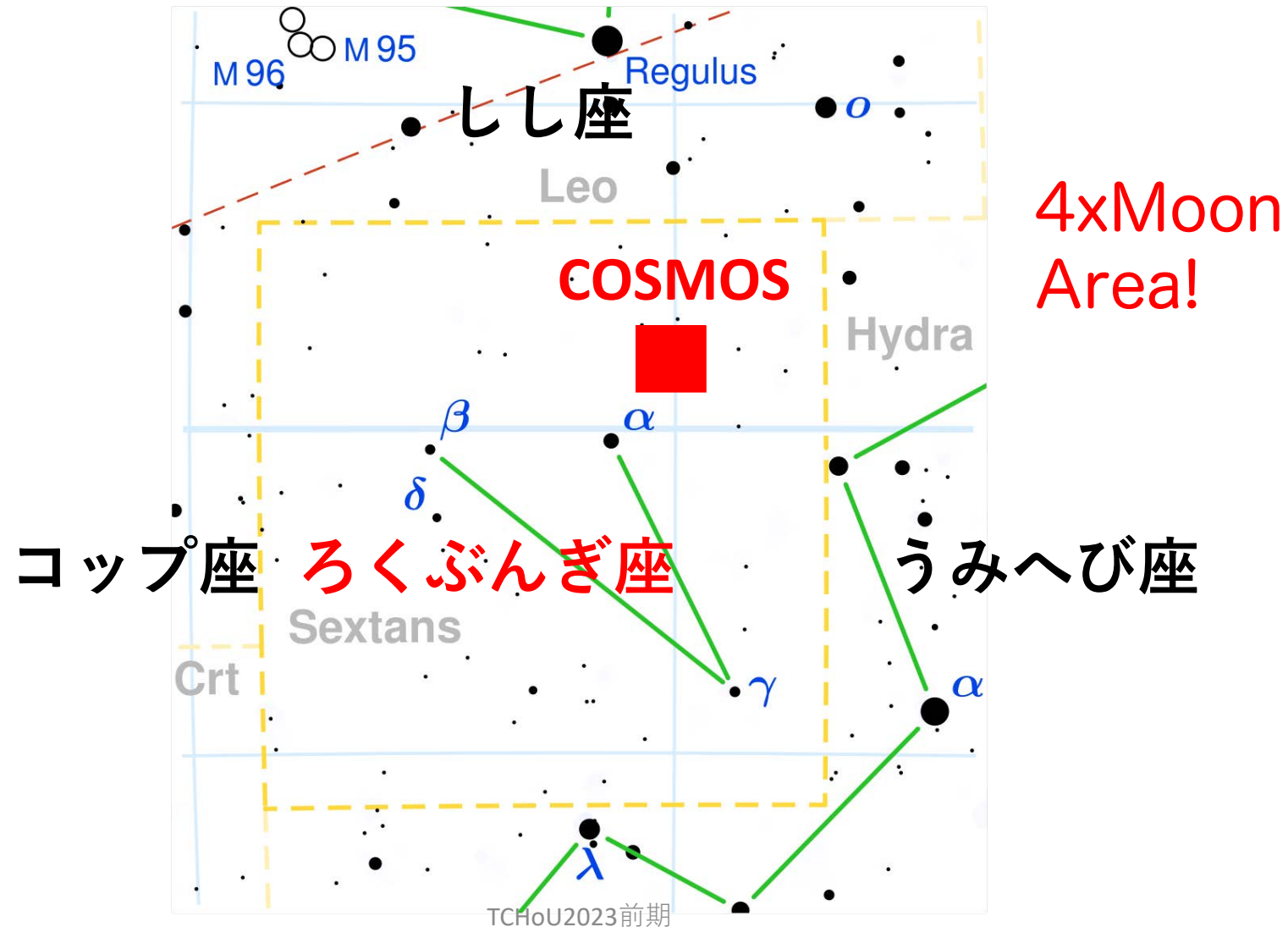
- Mawatari et al. 2016, PASJ, 68, 46
- Mawatari et al. 2020, ApJ, 889, 137
- Wide-area photometric search for $z \sim 6$ Balmer Break Galaxies
 - First Step is always photometric obs!
 - Difficulty in spectroscopy: faintness, rarity of the targets

Colors of $z \sim 6$ BBG (Mawatari+16,20)



COSMOS Field

RA = 10^h 00^m 28.6^s Dec = +02° 12' 21.0"



Rich observations in COSMOS Field



Atacama Large Millimeter/submillimeter Array: アタカマ大型ミリ波サブミリ波干渉計

- The largest Radio telescope at Chile, altitude 5000m.
- International collaboration of America, Euro, Japan+Taiwan+Korea
- Our own observations
- Cycle5 #2017.1.01259.S (PI: K. Mawatari)
- Wavelength $\sim 1\text{mm}$
- 40min exposure per target

Credit: Clem & Adri Bacri-Normier (wingsforscience.com)/ESO

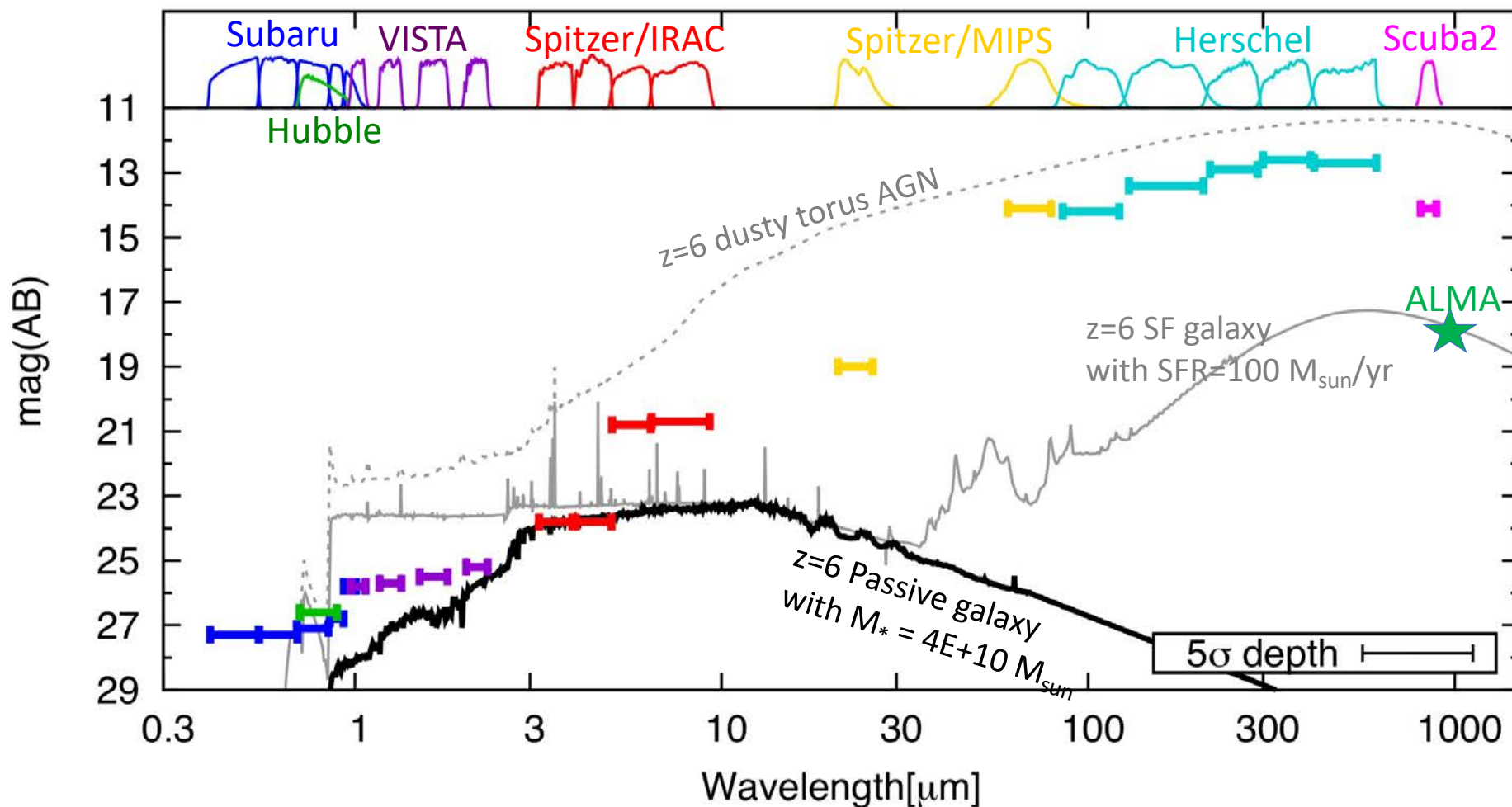
Data (Mawatari+20)

All imaging data available in COSMOS

UVISTA UD stripes 1~3 (Area = 0.5deg²)

K~25 & [3.6]~24 depth

⇔ z~6 passive galaxy down
to $M_* \sim 4 \times 10^{10} M_{\text{sun}}$.



$z \sim 6$ BBG search in COSMOS (Mawatari+20)

- Isolated objects in the Spitzer/IRAC image

$N \sim 37000$

- NIR Color selection

$$K - [3.6] > 1.75$$

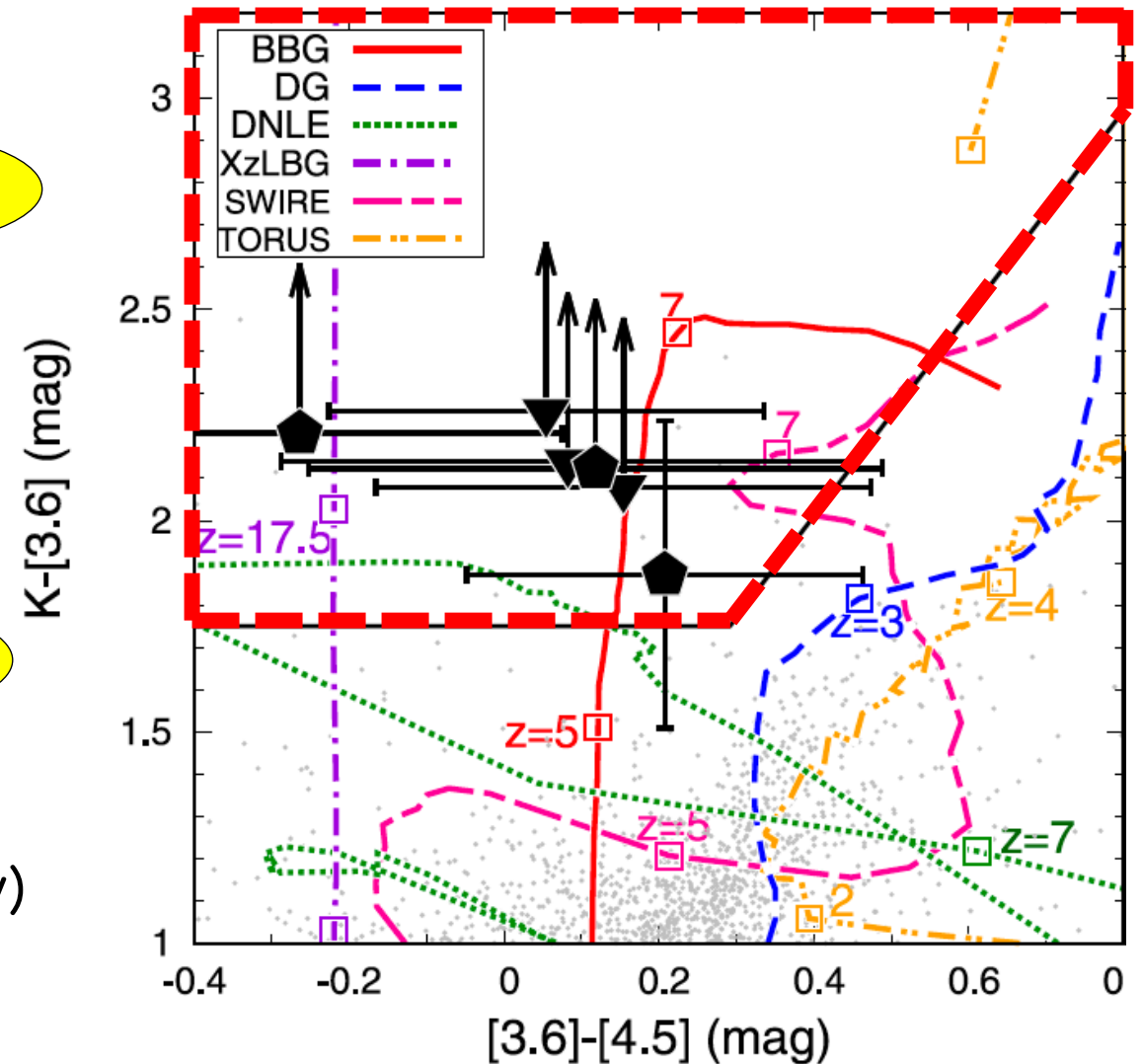
$$K - [3.6] > 2.4([3.6] - [4.5]) + 1.05$$

- Non-detection in optical, MIR($\lambda > 10\mu\text{m}$), FIR, radio, and X-ray to remove strong line emitters, extremely dusty galaxies, and AGNs.

$N = 6$

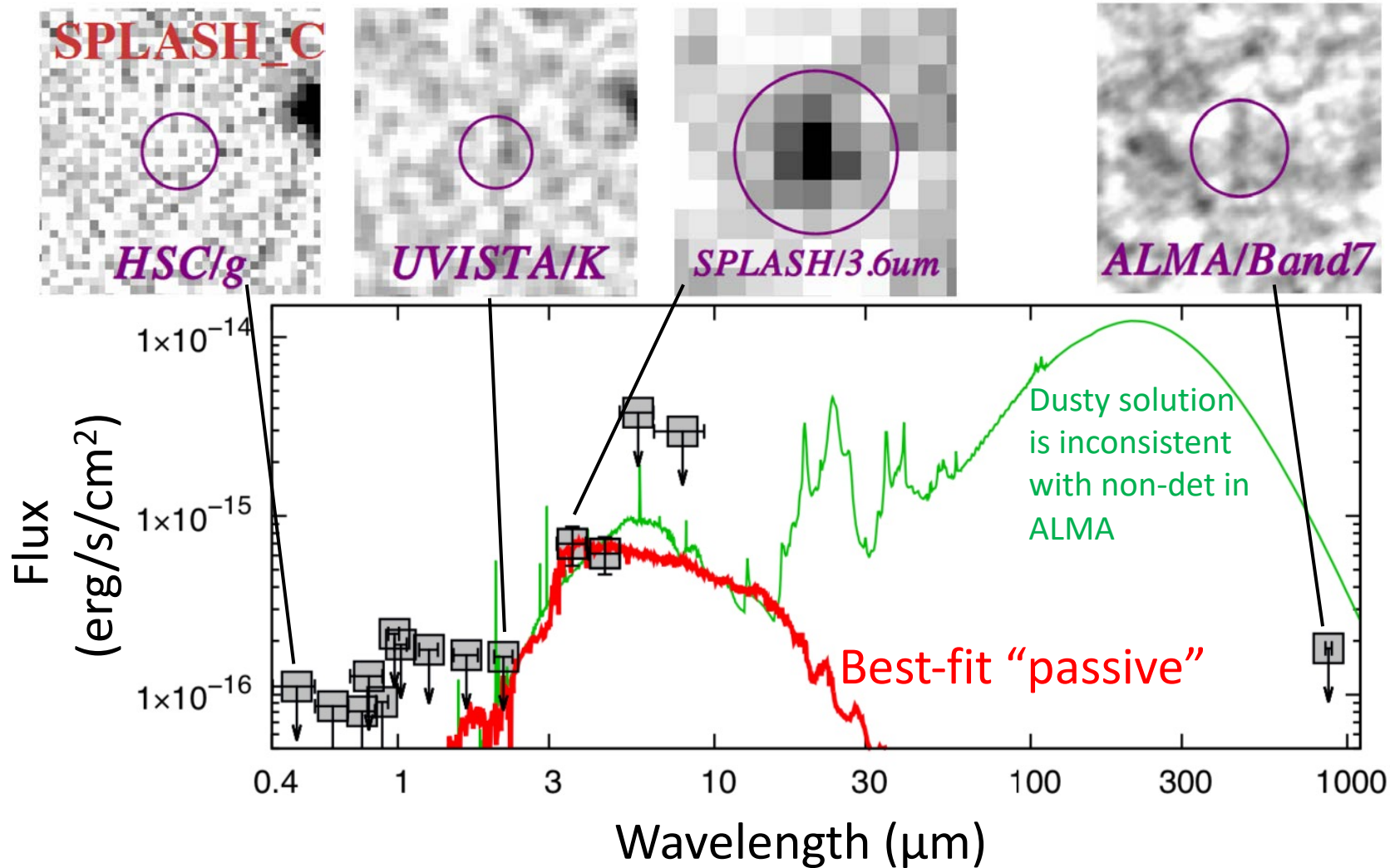
- Non-detection in ALMA Band7 ($1\sigma \sim 30\mu\text{Jy}$)

$N = 3$



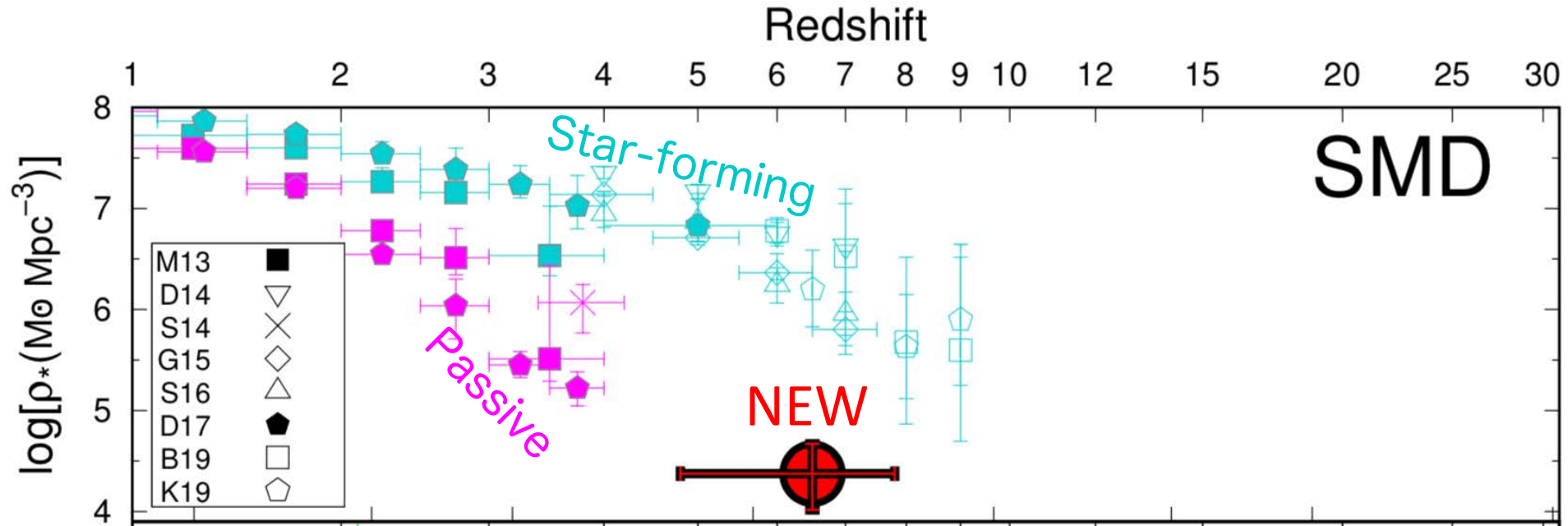
$z \sim 6$ BBG search in COSMOS (Mawatari+20)

- Photometric selection of **3 Balmer Break Galaxies at $5 < z < 8$** in COSMOS
- SED analysis suggests that they are **at $z \sim 6$ (age of Univ ~ 1 Gyr), stellar age > 0.5 Gyr, and passive phase (no SF, no Dust).**



$z \sim 6$ BBG search in COSMOS (Mawatari+20)

Stellar Mass Density



SMD of the BBGs at $z \sim 6$ is consistent with the measurements for lower- z passive galaxies.

z~6 BBG search in COSMOS (Mawatari+20)

Progenitors of z~6 BBGs

●Def. of the progenitors

: age = τ_{SFH}



Progenitors' z and SFR are sensitive to SFH shape...

●SFRD of the progenitors

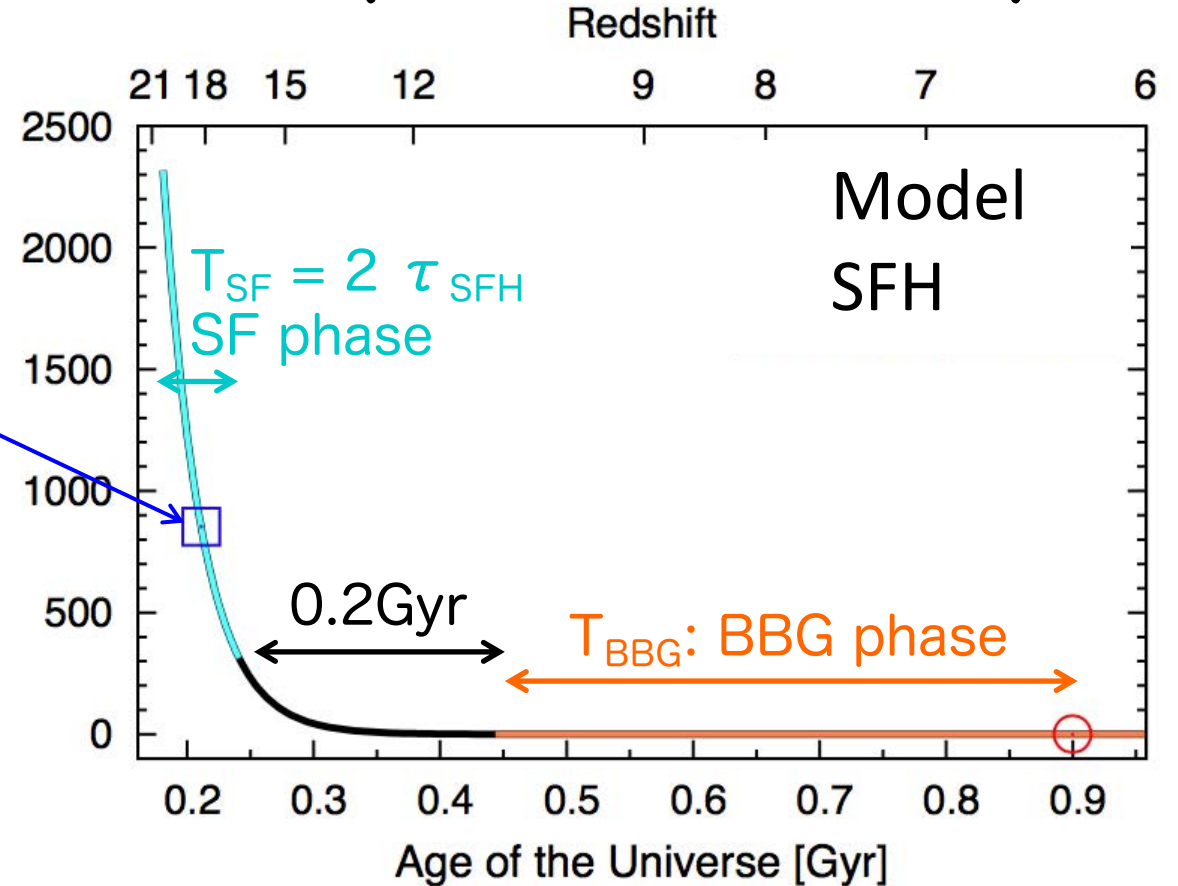
$$\rho_{\text{SFR}} \approx \sum_{i=1}^3 \frac{M_{*,i}^{\text{BBG}}}{T_{\text{SF},i}} \times \frac{1}{V_{\text{eff}}} \times \frac{T_{\text{SF},i}}{T_{\text{BBG},i}}$$

$$\approx \frac{\rho_*^{\text{BBG}}}{\langle T_{\text{BBG}} \rangle}$$

Fraction of observable timescale



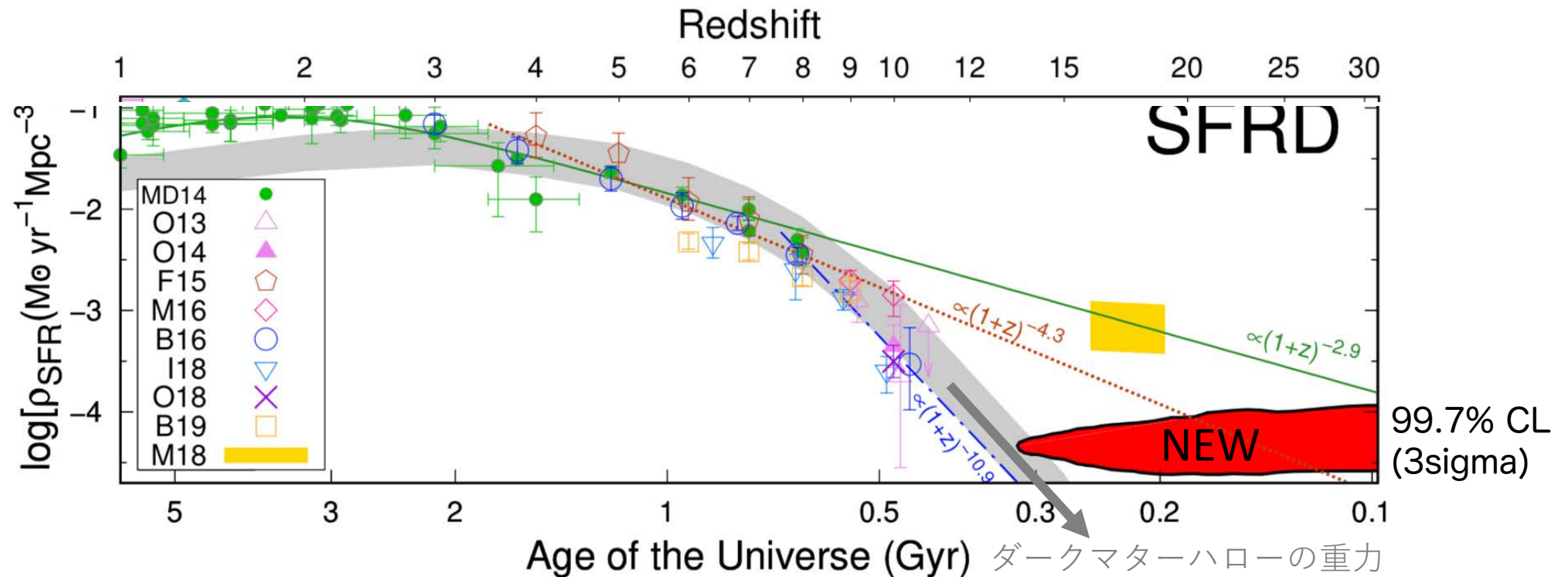
Progenitors' SFRD is less sensitive to SFH assumption!



$z \sim 6$ BBG search in COSMOS (Mawatari+20)

Star Formation Rate Density at $z \sim 20$

- ✓ $2.4\text{E-}5 < \text{SFRD}/(\text{Msun}/\text{yr}/\text{Mpc}^3) < 1.2\text{E-}4$ at $z > 14$ (99.7% confidence level)
- ✓ Our result supports smooth evolution (Finkelstein+15, Kikuchi+19) more than rapidly declining evolution (Oesch+14,18, Harikane+18).
- ✓ Relatively high SFRD indicates higher SF efficiency at $z > 10$.



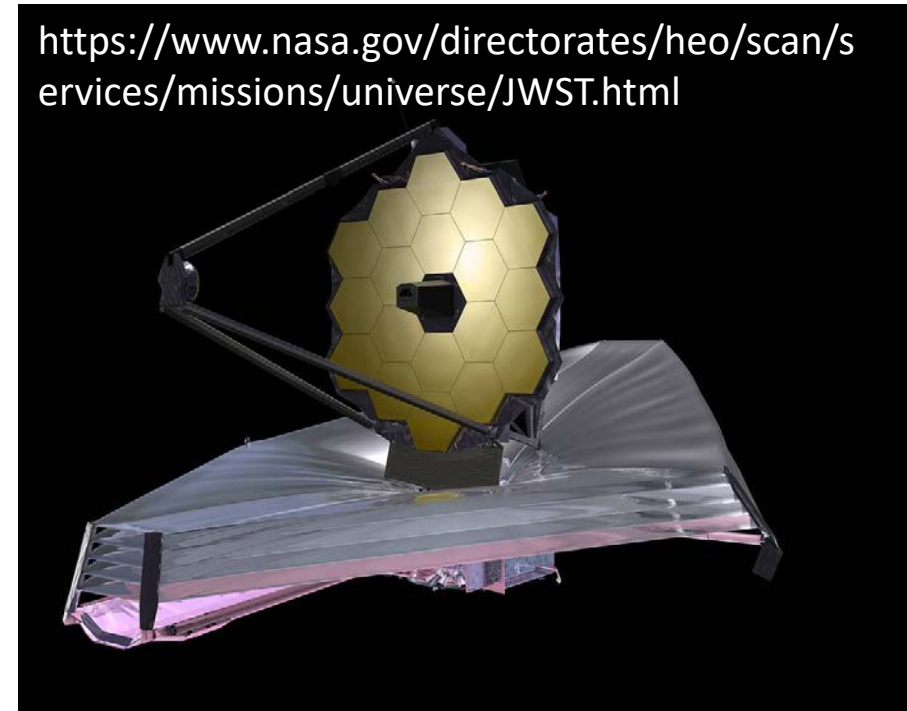
Summary of our previous works

- Identification of passive galaxy "candidates" at $z \sim 6$
- They give interesting constraint on SFRD at $z > 10$
- Many technical concerns,,,
 - Based on many non-detections
 - Photometric id of the Balmer breaks
 - Combination of different instruments

=> Need of Spectroscopic confirmation

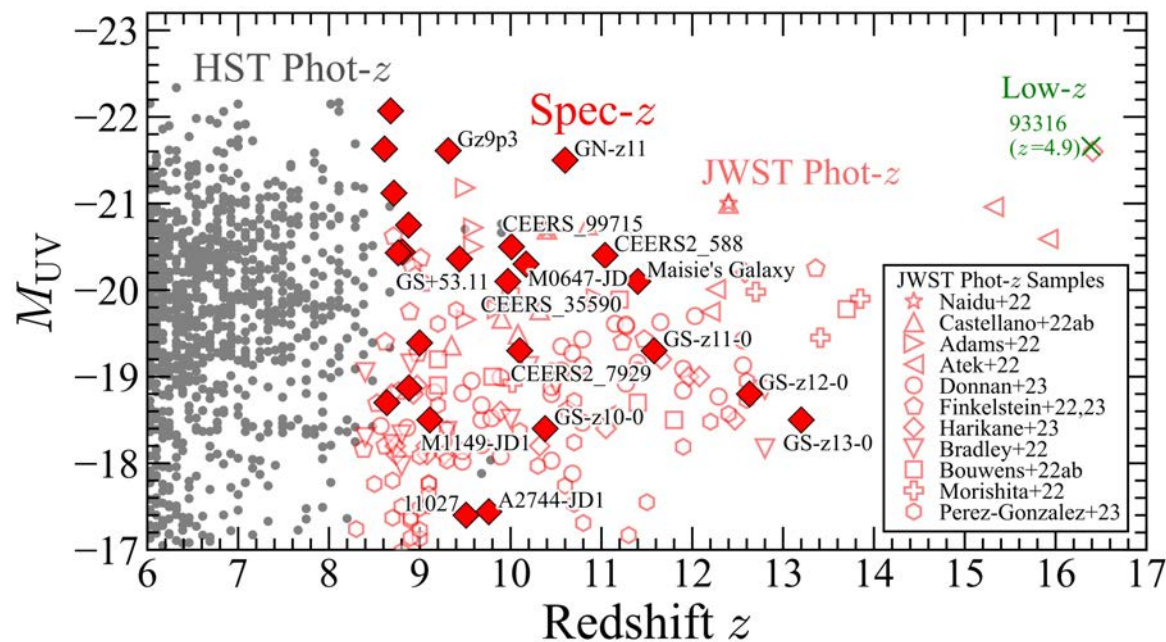
Now, it's a new (JWST) age!

James Webb Space Telescope, launched in 2021 Dec

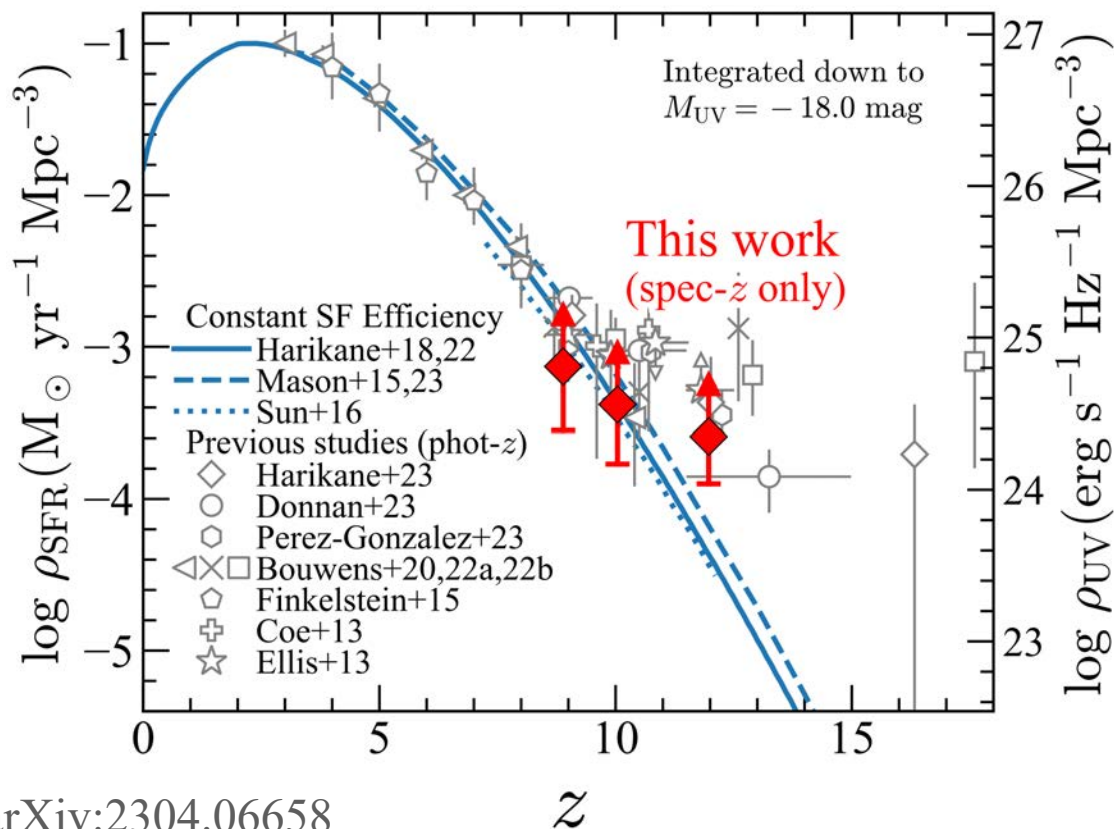


Recent JWST results

- Direct observations of $z > 10$ star-forming galaxies



Harikane+23, arXiv:2304.06658

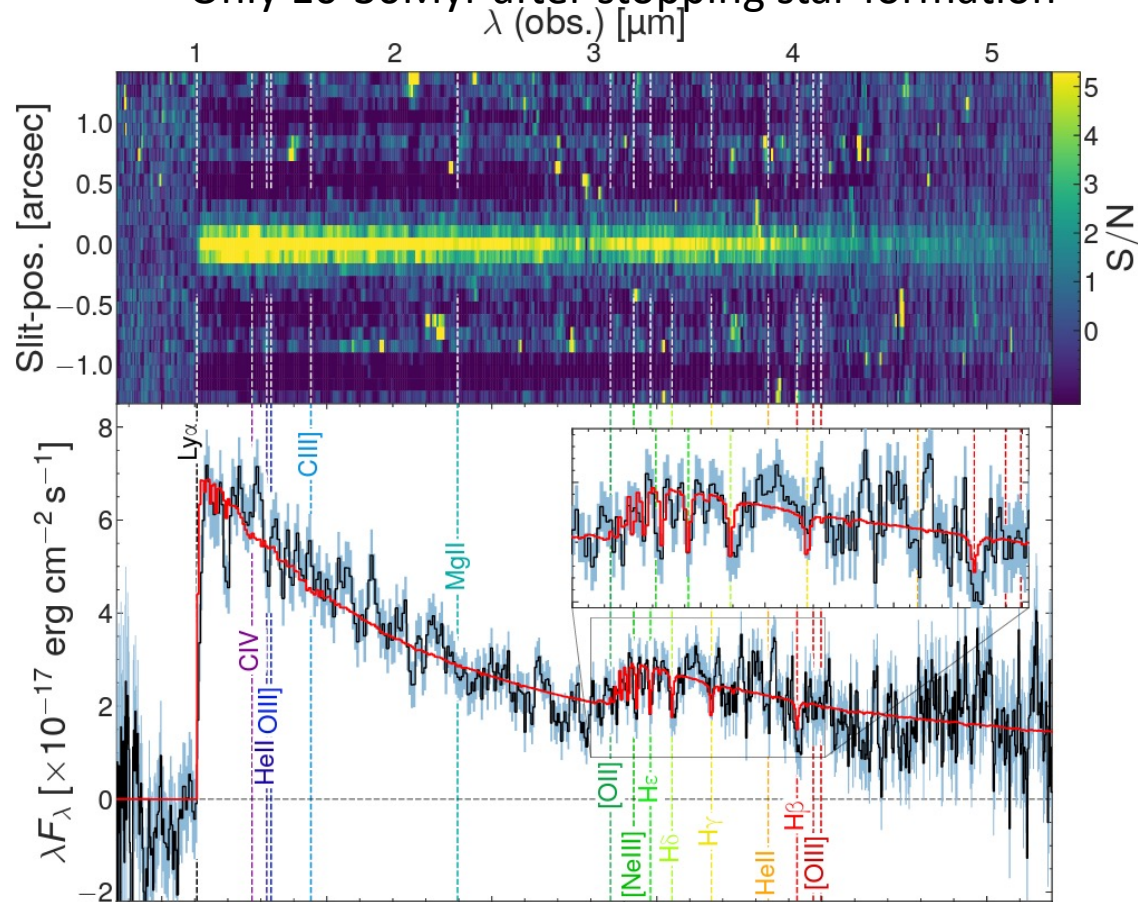


Recent JWST results

- Spectroscopy of Passive Galaxies (up to $z=7.3!$?)

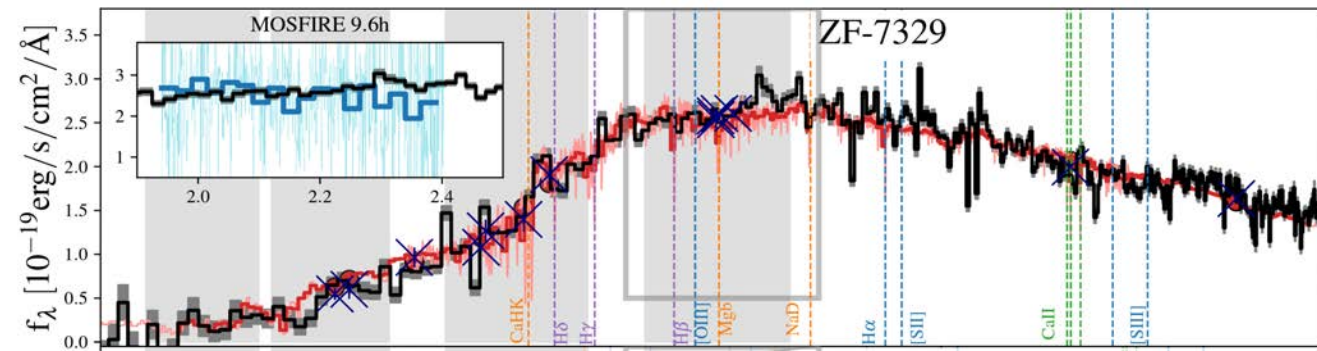
$z=7.3$ quiescent galaxy (Looser+23, arXiv:2302.14155)

Only 10-30Myr after stopping star-formation



$z=3.2$ quiescent galaxy (Nanayakkara+22, arXiv:2212.11638)

Only 10-30Myr after stopping star-formation



The area JWST observed is NOT enough.
Wider-area imaging survey for the candidates
is needed!

Our Challenges in Univ. of Tsukuba

- RIOJA project (Hashimoto et al. 2023, arXiv:2305.04741)
 - JWST spec of ALMA $6 < z < 9$ galaxies
 - $z=7.88$ overdensity region
 - Accelerated galaxy evolution
 - Dust production, quenching

