Low-mass and High-sSFR Hα Emitters at z ~ 2 in the ZFOURGE–COSMOS Field

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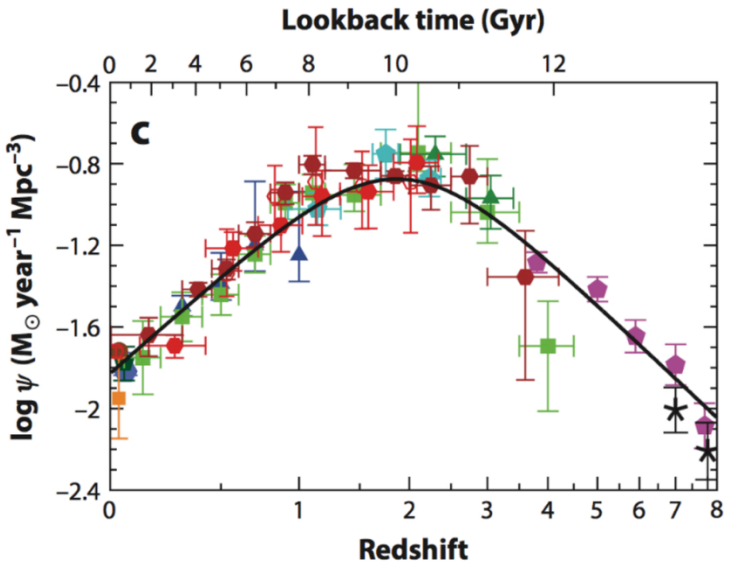
1. Introduction

Cosmic noon

: period when the star formation rate density reaches its maximum

- Redshift ~ 2
- Understand physical mechanisms :
  - gas inflow, metal accumulation

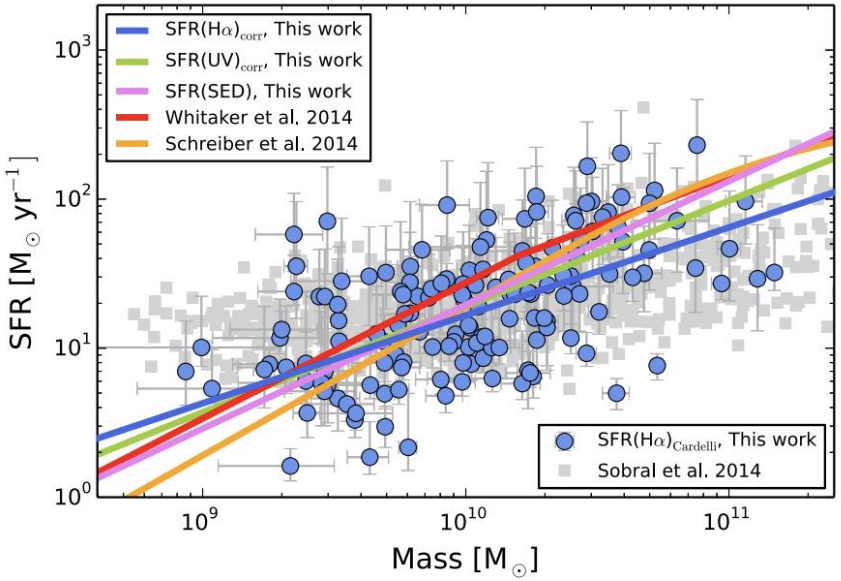


Star formation rate density history as a function of redshift (Madau & Dickinson 2014).

Star-forming main sequence (SFMS)

: correlation between the stellar mass and star formation rate

- Star formation rate ∝ Stellar mass
- Most star forming galaxies follow
- Scatter is caused by:
  - gas, environment, interaction, stellar feedback etc.
- Low mass: low-potential well → large scatter



SFR–stellar mass relations at z=2.09-2.61 (Shivaei et al. 2015)

1. Introduction

Select Hα emitter at z ~ 2

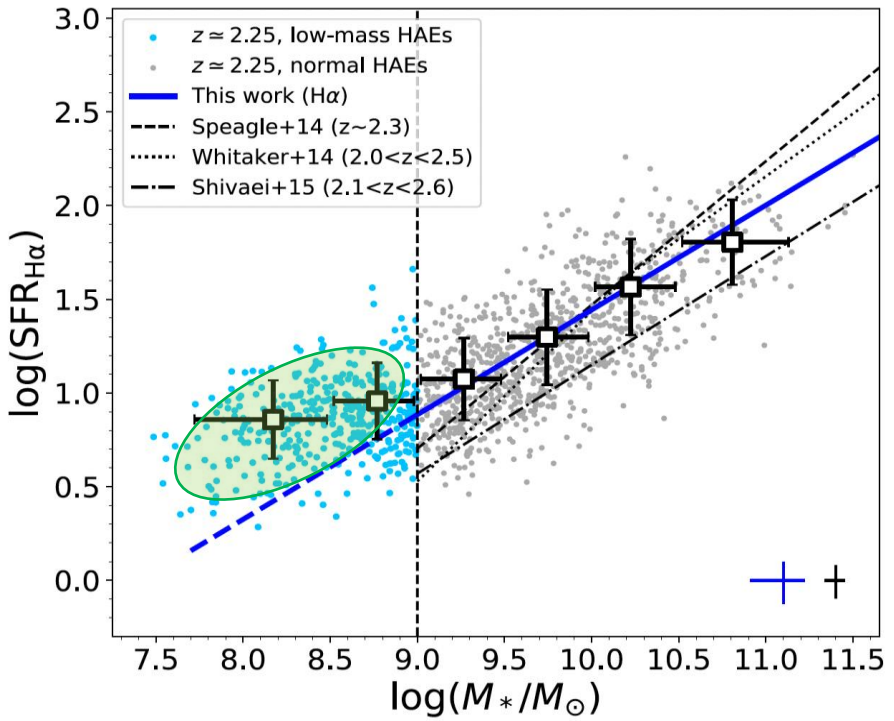
- Use Ks-band flux excess method
  - Hα emission at z~2 covered by Ks-band
- ZFOURGE-COSMOS field survey data
- Low-mass galaxies ($M_* < 10^9\ M_\odot$) :
  - its SFR > star-forming main sequence

Research goal

- Physical properties of low-mass with high sSFR galaxies

Previous studies

- 3D-HST: not detect Hα at z~2
- MOSDEF, ZFIRE, JWST: observation data exist, but not studied yet



The SFMS of 1318 HAEs at z_{med} = 2.25 in the ZFOURGE fields (Chen et al. 2024a).

2. Target selection

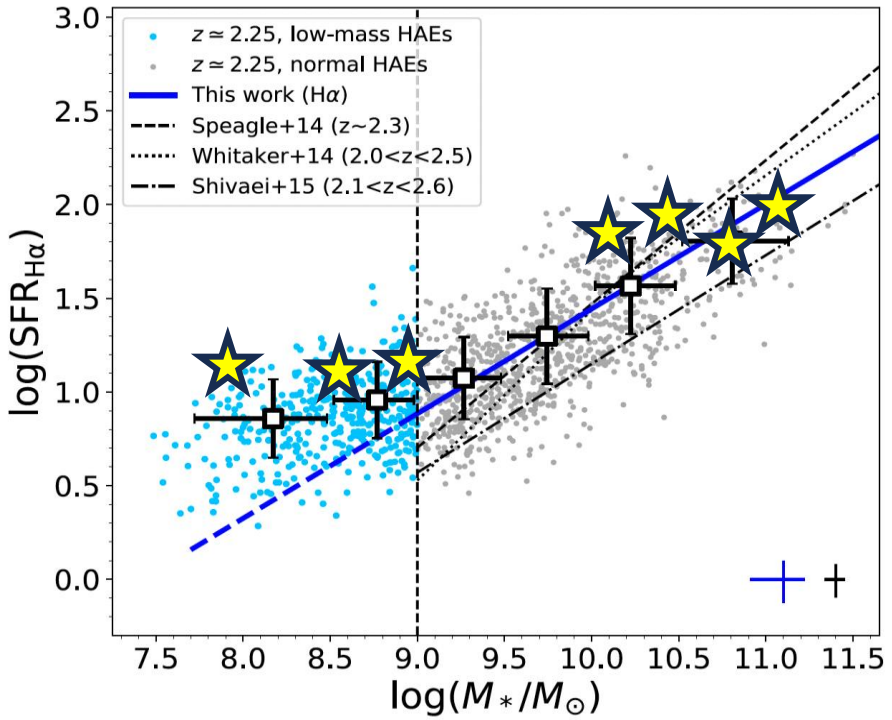
Select targets

- Find a population of low-mass with high sSFR galaxies
  - 3 targets: low mass ($M_* < 10^9\ M_\odot$) + high sSFR (3 times high SFR)
  - 4 targets: high mass ($M_* > 10^{10}\ M_\odot$) + close to SFMS

- To find physical properties, need to detect strong emission lines
  - Hα, Hβ, [O III], [O II], [N II]
    - At z= 2.0-2.5, observed wavelength: 1.1 – 2.3 μm

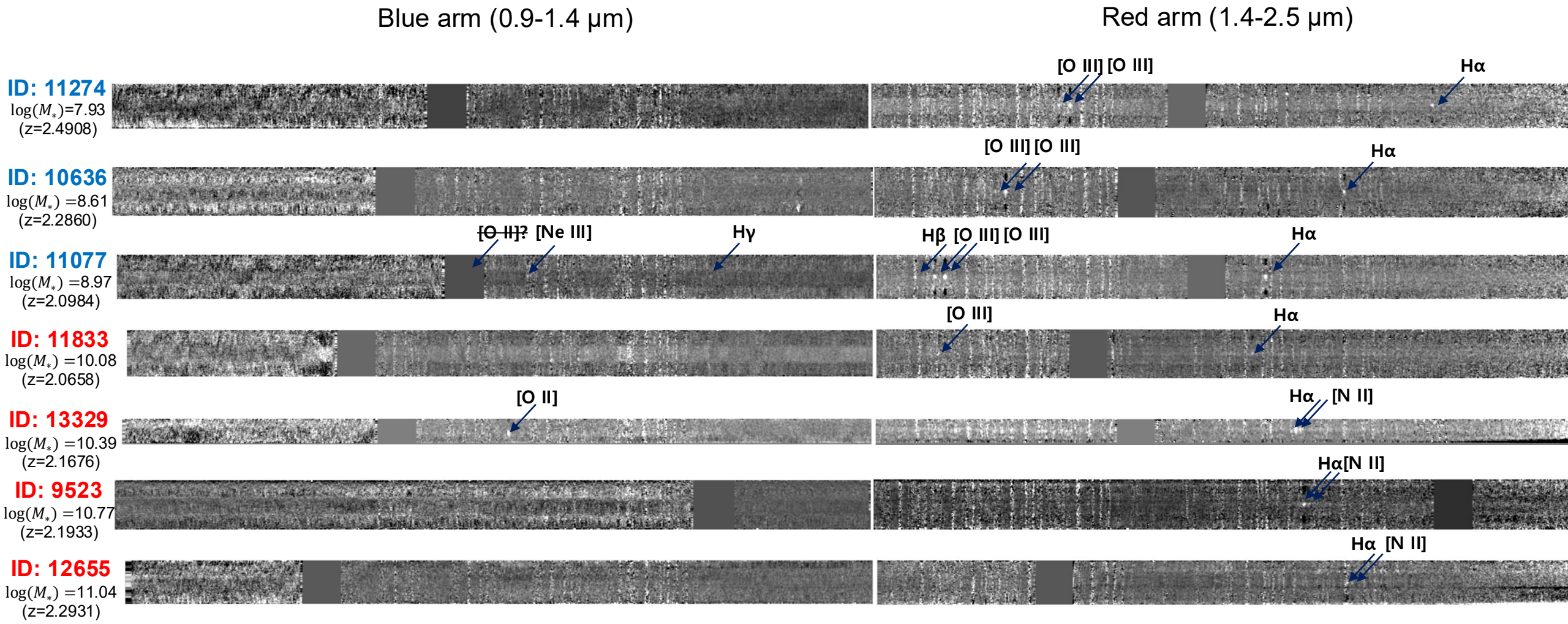
Subaru/SWIMS Observation

- Observation wavelength: 0.9 – 2.5 μm
- Spectral resolution: R ~ 1000 (0.5” slit)
- Total exposure time: ~ 250 minutes
- Observation date: 2022 February 5 - 2022 February 6 (S22A0045N)



The SFMS of 1318 HAEs at z_{med} = 2.25 in the ZFOURGE fields (Chen et al. 2024a).

3. Result: 2D Spectra



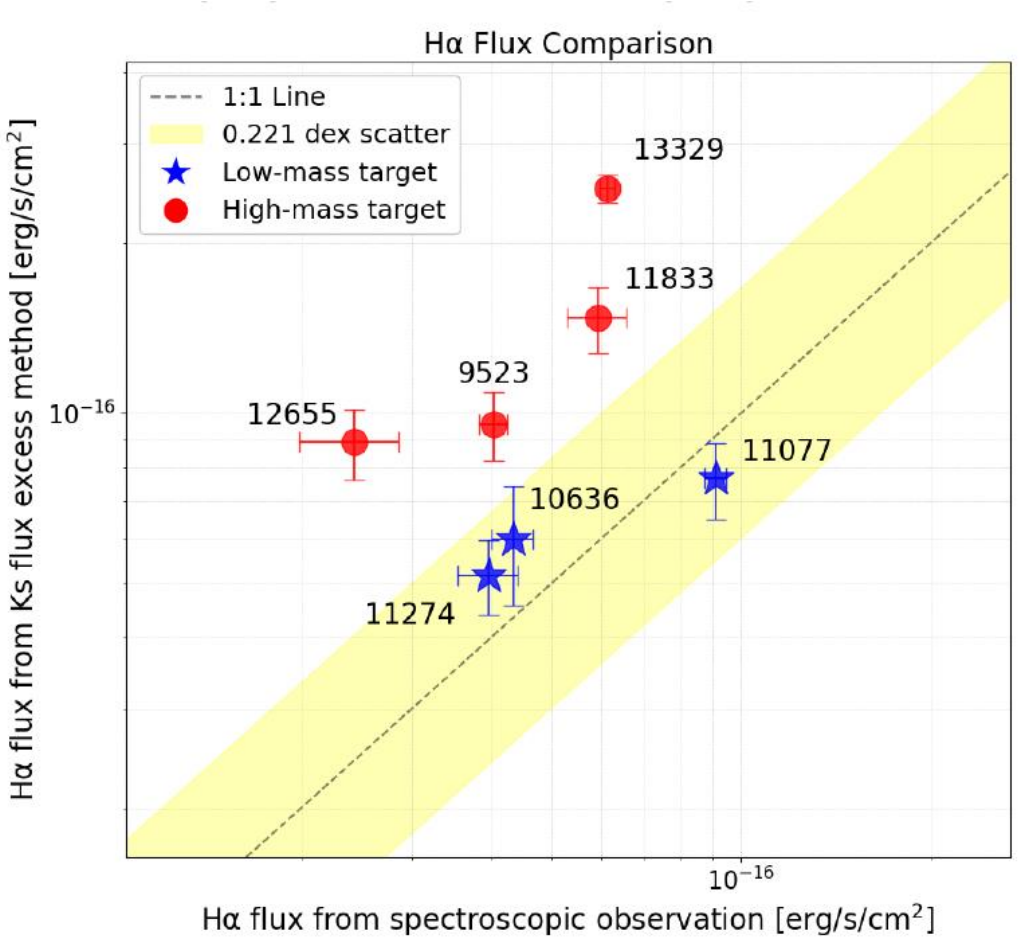
- Detect Hα emission lines in all targets
- Low-mass: [O III] 5007 > Ha, [N II] not detect
- High-mass: [O III] 5007 < Ha, 3 out of 4 detect [N II]

3. Result: star-forming distribution

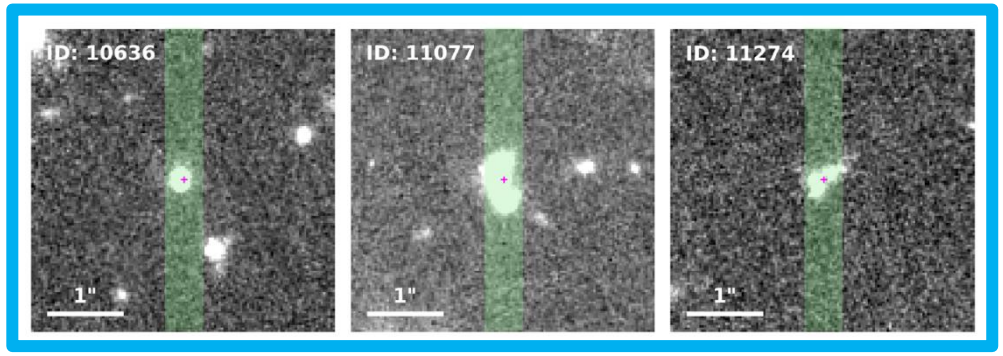
Comparison of Ks-filter excess method with spectroscopic observation

- Low-mass: near the 1:1 line (within error range)
- High-mass: far from the 1:1 line

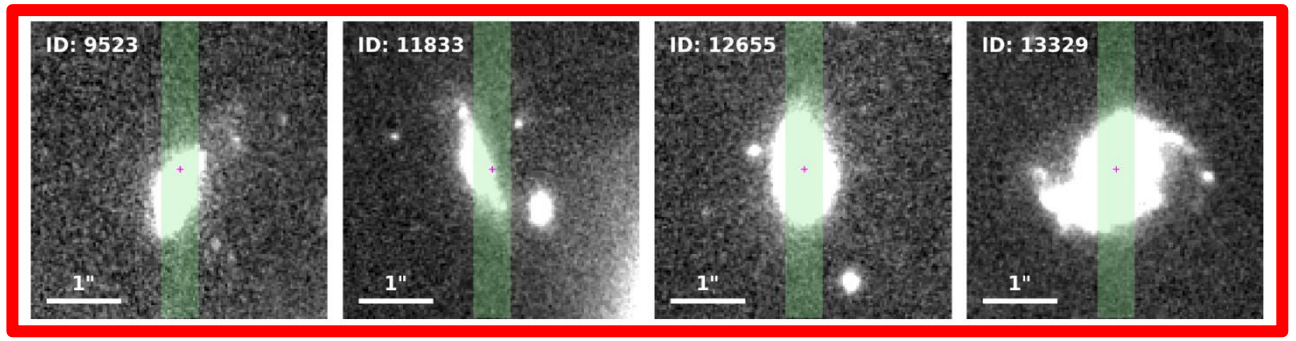
- Slit-loss effect
  - Low-mass: compact star formation distribution
    → easy to fit galaxy within slit



Low-mass



High-mass



Slit area with JWST NIRCam imaging (F200W)

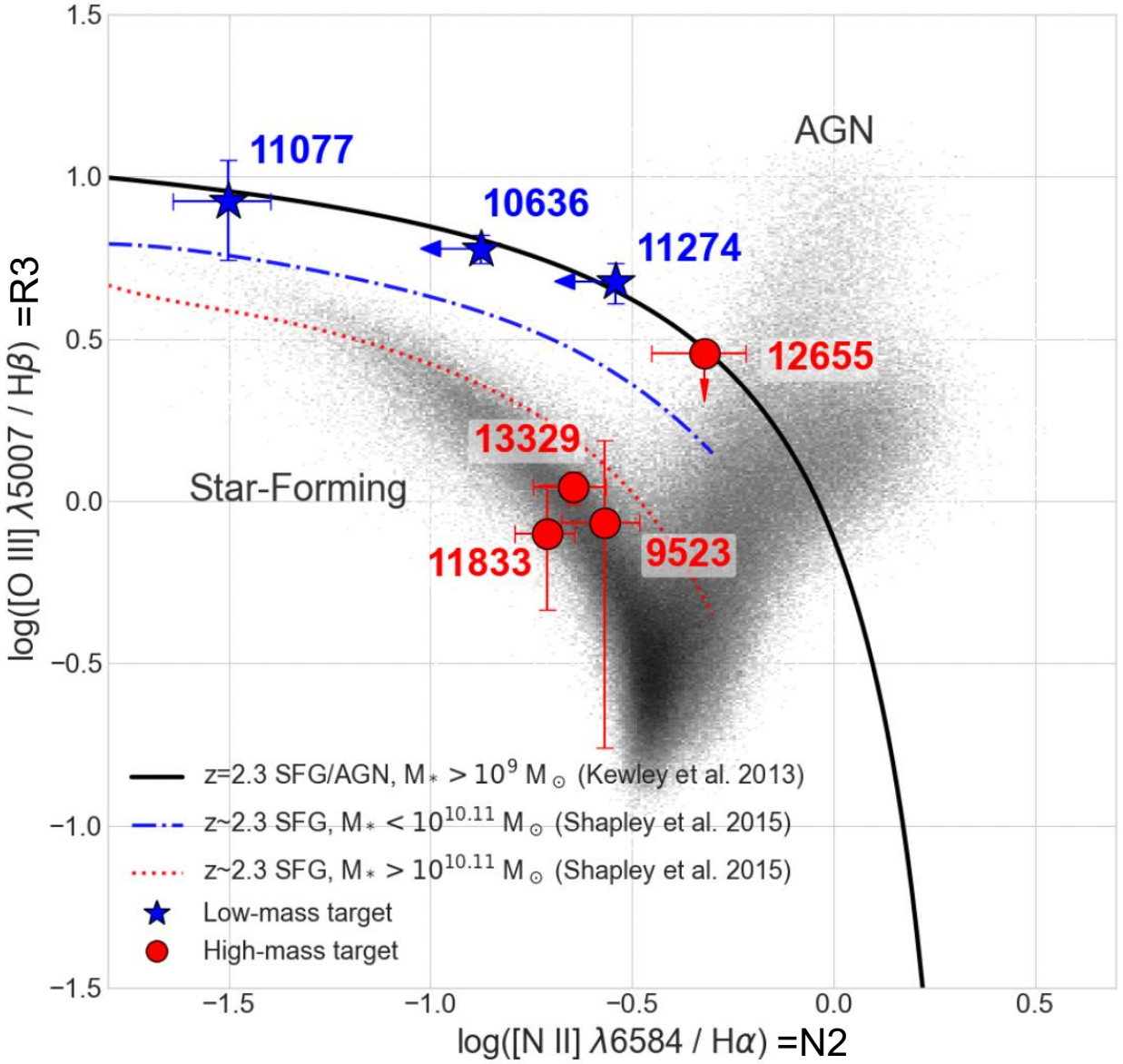
3. Result: BPT diagram

Data from other survey
- MOSDEF: 11077 (N2), 13329 (R3)
- ZFIRE: 11833 (N2)

Low-mass targets:
- high [O III]/Hb line ratio
- close to boundary between AGN and SFG

High-mass targets:
- low [O III]/Hb line ratio
- similar with local galaxies

➔ 11077, 9523: AGN candidate (Cowley et al. 2016), but optical BPT diagram cannot distinguish
- 11077 (IR)
- 9523 (X-ray & radio crossmatch)



3. Result: reionization galaxy analogues

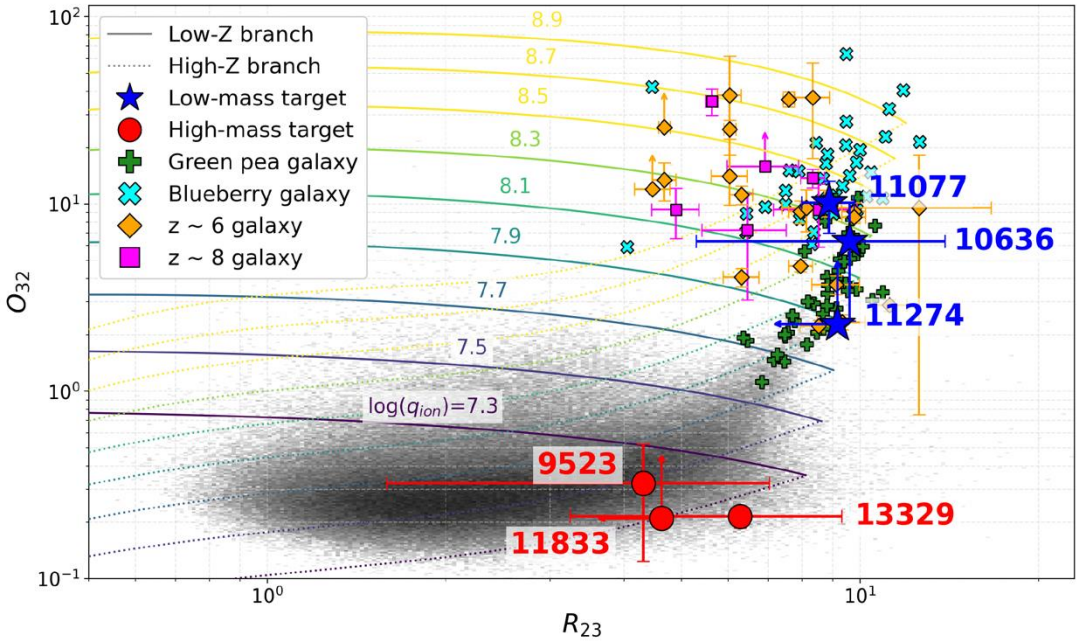
O32 vs. R23 Diagram
- metallicity + ionization information
- but R23 metallicity degeneracy exists

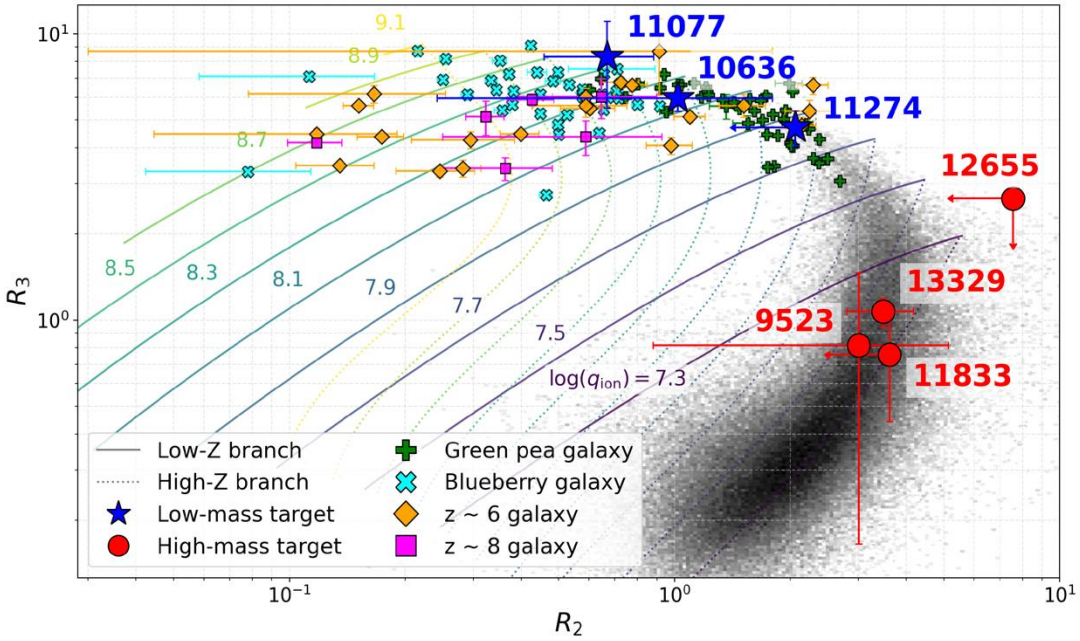
R3 vs. R2 Diagram
- separates the contributions of [O III] and [O II]

Low-mass targets:
- similar distribution to reionization epoch galaxy

➔ high-ionization parameters and low metallicity

High-mass targets:
- similar distribution to local galaxy





$$O_{32} = \frac{[\mathrm{O\,III}]\lambda 5007}{[\mathrm{O\,II}]\lambda\lambda 3726, 3729} \qquad R_{23} = \frac{[\mathrm{O\,II}]\lambda\lambda 3726, 3729 + [\mathrm{O\,III}]\lambda\lambda 4959, 5007}{\mathrm{H}\beta}$$

$$R_3 = \frac{[\mathrm{O\,III}]\lambda 5007}{\mathrm{H}\beta} \qquad R_2 = \frac{[\mathrm{O\,II}]\lambda\lambda 3726, 3729}{\mathrm{H}\beta}$$

log(q_{ion}): Nakajima & Ouchi (2014)
z>6 data: Cameron et al. (2023)

4. Discussion

Metallicity and Ionization parameter

Metallicity:
- Best-fit line: from sample that close to SFMS
- Derive using O3N2 index (Pettini & Pagel 2004)
- Low-mass targets:
  - even using upper limit, lower metallicity than high-mass galaxies

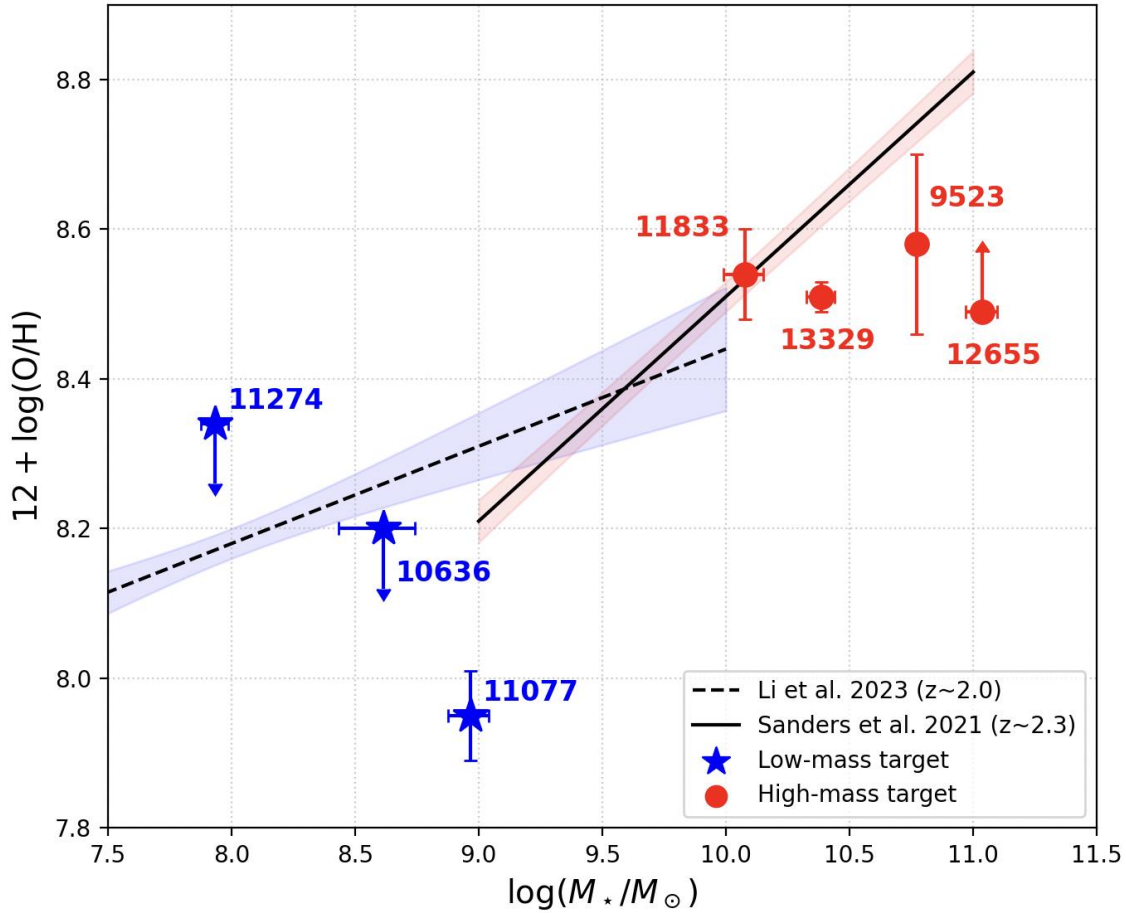
Ionization parameter:
- metallicity (O3N2) + O32 index (Kobulnicky & Kewley 2004)
- log U
  - low-mass targets: ~ -2.2
  - high-mass targets: ~ -3.2

  (local H II region: -3.2 < log U < -2.9 (Dopita et al. 2000))

  ➔ ~ 1 dex high in low-mass

  ➔ low-mass target: high ionizing photon number density

Mass-metallicity relation at z~2



$$\mathrm{O3N2} = \log\left(\frac{[\mathrm{O\,III}]\,\lambda5007/\mathrm{H}\beta}{[\mathrm{N\,II}]\,\lambda6584/\mathrm{H}\alpha}\right)$$

4. Discussion

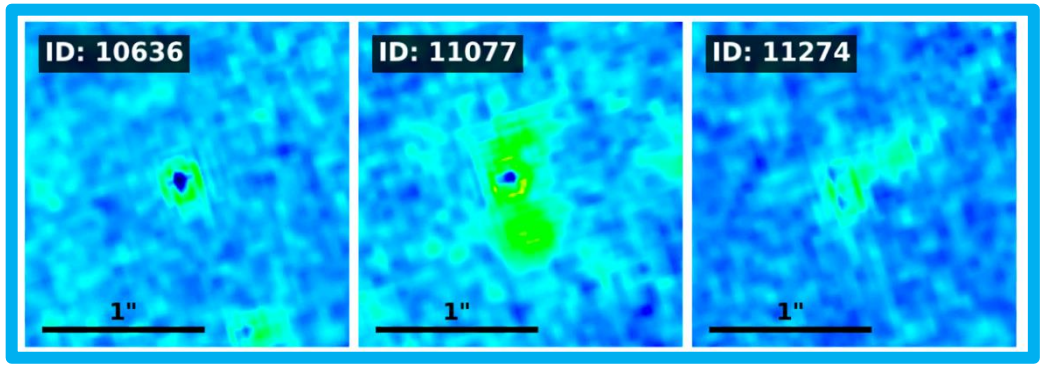
Radial color gradient
(F115W-F277W from JWST/NIRCam)

Low-mass targets
- positive gradients
- central concentration of young stellar populations

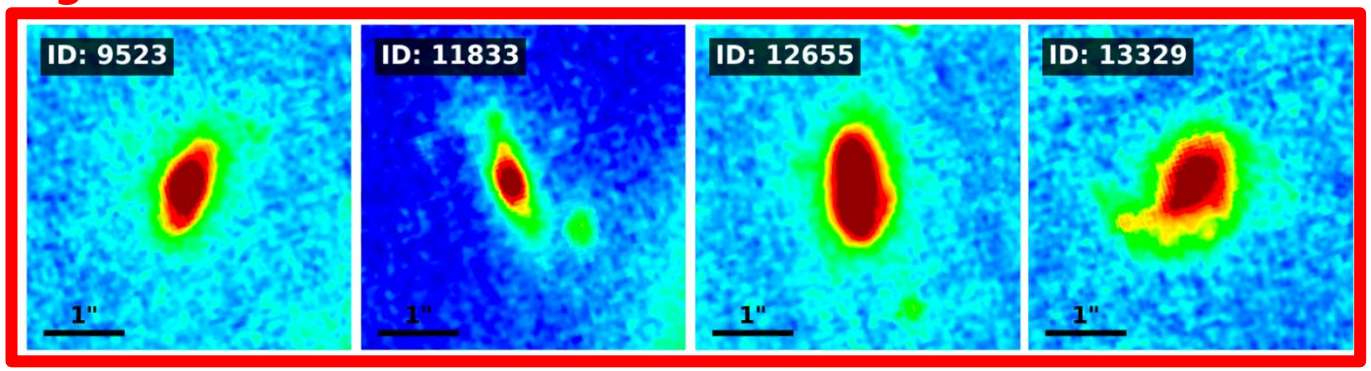
High-mass targets
- negative gradients
- consistent with an "inside-out growth" pattern

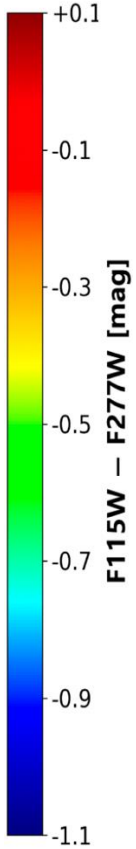
Estimate stellar age (for Low-mass targets)
center area with $Z = 0.2Z_{\odot}$ & SSP model.
- ID 10636: ~7.2 Myr
- ID 11077: ~8.7 Myr
- ID 11274: ~10.5 Myr

Low-mass



High-mass





Implication: very young ages ($\lesssim 10$ Myr) confirm
➔ recent and intense star formation episodes occurring on short timescales.

5. Summary

- Low-mass galaxies ($M_* < 10^9\ M_\odot$) at $z \sim 2$ are key to understand feedback processes and the large scatter in SFMS
- Observed three low-mass and four high-mass galaxies using Subaru/SWIMS
- Low-mass with high sSFR galaxies:
  - Strong [O III] and weak [N II] emission
  - Low metallicity and high ionization parameters (log $U = -2.2$)
  - Reionization galaxy analogues at z~2
  - Positive gradient in color map
  - Young/compact stellar population in the center