The Prevalence of Bursty Star Formation in Low-Mass Galaxies at $z = 1$–7 from Hα-to-UV Diagnostics

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Introduction

- most galaxies follow a linear relationship, SFMS
  - increased scatter of SFMS suggests more bursty SFHs
- galaxies at earlier epochs(z>9) exhibit more bursty SF
  - one of the possible key of the over abundance of UV-bright galaxies at z>10
- compare time-sensitive tracers of SF to probe burstiness
  - hydrogen recombination lines (e.g. Hα, Hβ) and the UV continuum
    →detect recent variations in SFR over 10 Myr $\lesssim t \lesssim$ 100 Myr

Data and Analysis

- spectroscopy
  - JWST/NIRSpec data from CEERS (234) and RUBIES (866)

  →remove AGN and sources sources at $z \geq 7$

  →restrict to galaxies with S/N≥ 3 for both Hα and Hβ emission lines
  - assume Calzetti dust law (2001) and case B recombination
- photometry: crossmatch with spectroscopic sample
  - JWST /NIRCam imaging from the CEERS/EGS and PRIMER/UDS

  →SED fitting (BAGPIPES)

  →select S/N≥ 3 for the dust-corrected UV luminosities

  →346 galaxies at $0.8 \leq z < 7$, $7.0 \leq \log(M_*/M_\odot) \leq 10.9$
- limiting stellar mass: $\log(M_{\mathrm{lim,i}}) = \log(M_{*,i}) + 0.4(m_i - m_{\mathrm{lim}})$
  - $M_{*,i}$: stellar mass of galaxy, m_i: apparent magnitude, m_{lim}: limiting magnitude of survey
  - evaluate $M_{\mathrm{lim,i}}$ for the faintest 30% of galaxies and take the 90th percentile as threshold
    - exclude galaxies below the thresholds from SFMS fitting
- limiting SFR values
  - Hα-based: the sensitivity of the NIRSpec G395M grating with 5σ detection threshold
  - UV-continuum-based: 3σ limiting SFR(UV) of maximum of the 16th percentile rest-frame M_{UV}

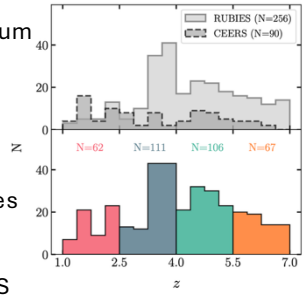

Figure 1. Spectroscopic redshift distribution of our sample split by survey (top) and by redshift bin (bottom). The

Table 5. Fractional Shift in Galaxies Around the Hα-to-UV Ratio Equilibrium Range Between $1 \lesssim z \lesssim 2.5$ and $5.5 < z < 7$

Stellar Mass	$\Delta f_{\mathrm{above}}$	Δf_{eq}	$\Delta f_{\mathrm{below}}$
$7 < \log(M_*/M\odot) < 8.5$	$-0.13^{+0.15}_{-0.10}$	$0.07^{+0.14}_{-0.12}$	$0.11^{+0.10}_{-0.08}$
$8.5 \leq \log(M_*/M\odot) < 10.9$	$-0.18^{+0.12}_{-0.16}$	$0.15^{+0.16}_{-0.14}$	$0.02^{+0.16}_{-0.12}$

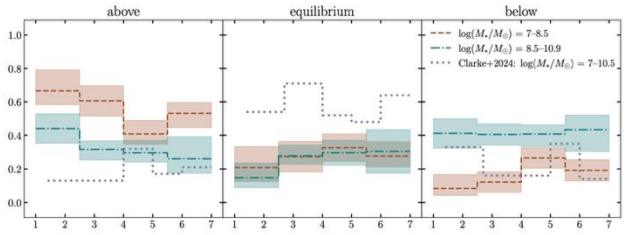

Figure 5. The fraction of galaxies whose Hα-to-UV ratios are consistent (middle panel) and inconsistent (outer panels) with a constant SFH computed by V. Mehta et al. (2023) shown as a function of redshift. For each stellar mass and redshift bin, we

Summary

- examine the SFMS
  - difference between the Hα- and UV-continuum-based SFMS isn't statistically significant
  - Hα-based SFMS relations are flatter than the best-fit relations and literature relations
- examine the dust-corrected Hα-to-UV ratio
  - evidence for bursty star formation in 73^{+4}_{-4}% of galaxies
  - lower-mass galaxies are more likely to be observed in a recent (≲100 Myr) SF burst than higher-mass galaxies
  - no evolution in the relative fraction of galaxies above, below, or within the equilibrium range over z=1–7
- upcoming JWST surveys and robust analyses would probe SFH of galaxies in early Universe

Results and Discussion

SFMS

- dust-corrected Hα- and UV-continuum-based SFRs
- scatter difference: $\langle\sigma_{\mathrm{H}\alpha}\rangle - \langle\sigma_{\mathrm{UV}}\rangle = 0.01 \pm 0.4$dex

  ⇨don't detect short-timescale (~10 Myr) SFR variability
- mass-incomplete subsamples exhibit flatter Hα-based SFMS
  - especially at high-z ($z \gtrsim 5.5$)
    - sensitivity limits in the NIRSpec observations→bias against low-SFR galaxies
    - increased SF variability in low-mass galaxies at early times→enhance the number of galaxies observed during a burst phase

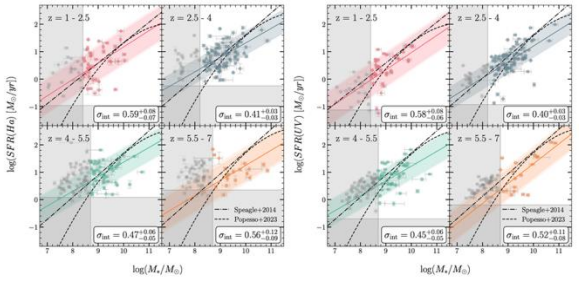

Figure 2. Hα- (left) and UV-continuum-based (right) SFRs vs. stellar masses for our galaxy sample binned by redshift.

Hα-to-UV luminosity ratio

- compare with an equilibrium range ($\log(L_{\mathrm{H}\alpha}/L_{\mathrm{UV}}) = [-1.93, -1.78]$) (Mehta et al. 2023)
  - predicted by stellar population synthesis models with a constant SFH (~100 Myr)
- Hα-to-UV ratio as a function of stellar mass and redshift (Figure4)
  - $\langle\sigma_{\mathrm{low-mass}}\rangle - \langle\sigma_{\mathrm{high-mass}}\rangle = -0.04 \pm 0.04$dex
    - no significant difference between low-mass and high-mass galaxies
  - across all redshifts, low-mass galaxies exhibit higher Hα-to-UV ratios
    - consistent with more bursty star formation

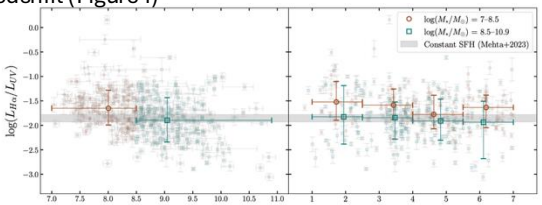

Figure 4. Left panel: The Hα-to-UV ratio vs. stellar mass for our galaxy sample binned by stellar mass. The large points represent the median values in each stellar mass bin. The vertical error bars denote the 16th and 84th percentiles of each bin and the horizontal error bars denote the stellar mass range of each bin. The horizontal gray hatched region shows the equilibrium range of the Hα-to-UV ratio calculated by V. Mehta et al. (2023). Right panel: The Hα-to-UV ratio vs. redshift for our galaxy sample binned by stellar mass. The large points represent the median values in each stellar mass and redshift bin. The vertical

f_{above}(lie above the Hα-to-UV ratio equilibrium range), f_{below}(lie below) and f_{eq}(lie within)

- 73^{+4}_{-4}% of the sample have Hα-to-UV ratios that lie either above or below the equilibrium range
  - inconsistent with a constant SFH over ~100 Myr
  - Clarke et al. 2024: 48–71% of 146 galaxies at z~1.4–7 deviate from a constant SFH
  - Asada et al. 2024: 60% of 125 galaxies at z~4.7–6.5 deviate from a constant SFH
- across all redshifts, low-mass galaxies exhibit higher $f_{\mathrm{above}}(0.53^{+0.05}_{-0.05})$ and lower $f_{\mathrm{below}}(0.18^{+0.04}_{-0.03})$

  ↔for high-mass galaxies, lower $f_{\mathrm{above}}(0.33^{+0.04}_{-0.04})$ and higher $f_{\mathrm{below}}(0.41^{+0.04}_{-0.04})$
- high-z ($5.5 \leq z < 7$), low mass, UV-faint galaxies have higher $f_{\mathrm{above}}(0.53^{+0.06}_{-0.09})$ and lower $f_{\mathrm{below}}(0.19^{+0.06}_{-0.06})$

  ⇨substantial portion of low-mass, UV-faint galaxies are observed during burst phases

  ↔some studies predict a higher prevalence of temporarily quiescent systems in this regime

the duty cycle of star formation evolves (Figure5)

- high-mass galaxies maintain low duty cycle ($f_{\mathrm{below}} > f_{\mathrm{above}}$) across all redshifts except $1 \leq z < 2.5$
- low-mass galaxies exhibit high duty cycle ($f_{\mathrm{above}} > f_{\mathrm{below}}$) at all redshifts
  - broadly consistent with recent work (e.g. Cole et al. 2025)
- redshift-binned difference in the fractional values between z = 1–2.5 and z = 5.5–7 (Table5)
  - no evolution in the duty cycle over $1 \lesssim z < 7$

  ⇨the relative balance between bursty and steady SF remains roughly constant over z=1–7