Galaxy assembly in the first billion years: Mini-quenching, lulling galaxies, and more evidence for bursty SFHs driven by intense feedback

Tobias Looser

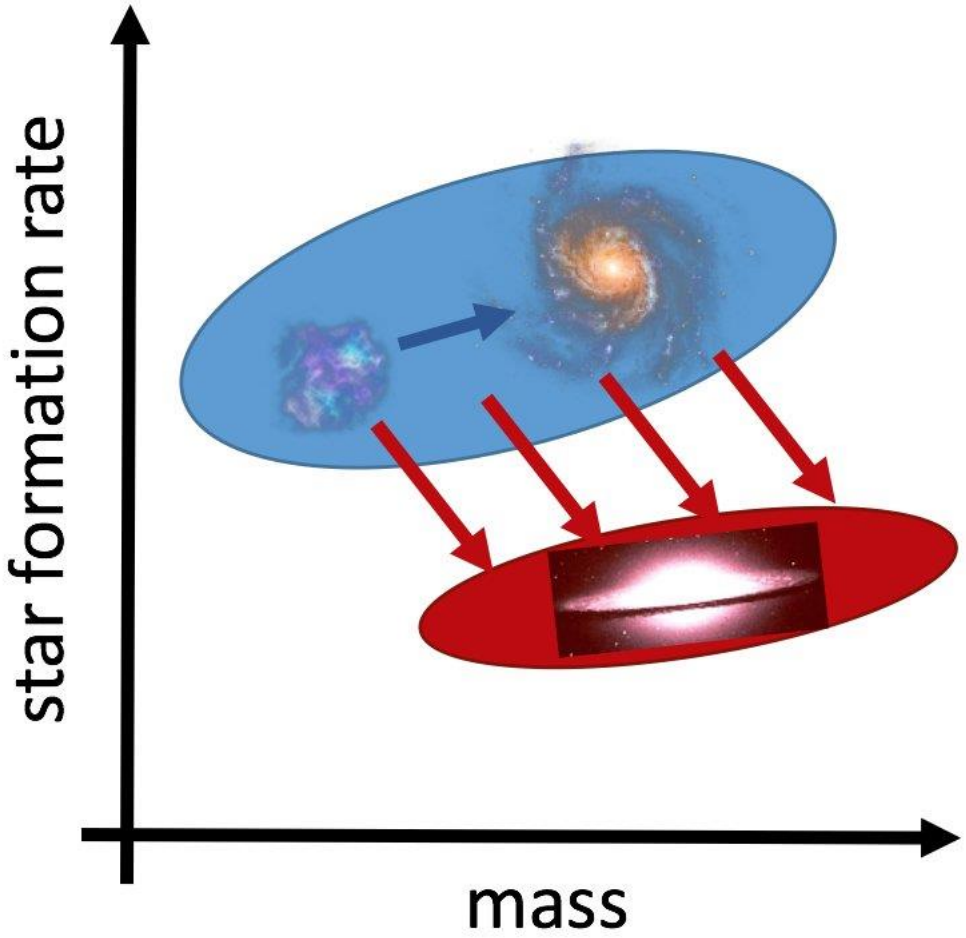
Swiss National Science Foundation Mobility Fellow

18th Potsdam Thinkshop, July 14-18, 2025

CENTER FOR ASTROPHYSICS HARVARD & SMITHSONIAN

Swiss National Science Foundation

Low-redshift galaxies are known to broadly follow a bimodal distribution: Star-forming and quenched galaxies



Credits: Guido Roberts-Borsani

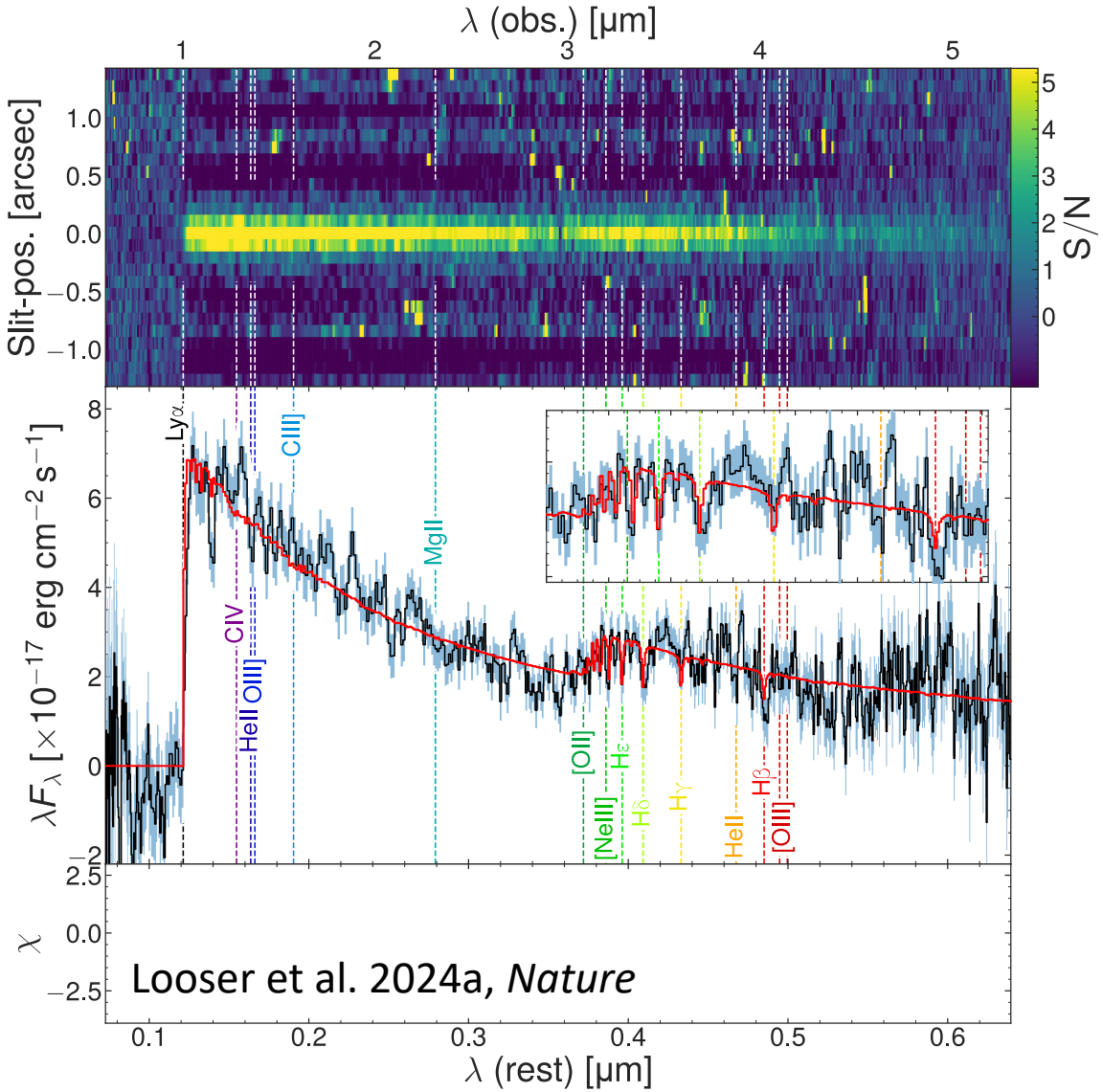
- These two populations are connected by galaxies in relatively slow transition
- Early quiescent galaxies have been identified out to z<5 pre-JWST, and out to redshift z=7.3 with JWST (Weibel+2024)
- Most of them have been found to be massive ($M_\star > 10^{10}\ M_\odot$) and relatively old

Discovery of a (mini-)quenched galaxy at z=7.3

- NIRSpec R100/prism spectrum, *28h exposure*
- UV-bright, pre-selected as HST Lyman-break galaxy → Expected to be star forming
- Balmer break → evolved stellar populations

- No nebular emission lines: SFR < 0.1 $M_\odot$/yr
- The galaxy is low-mass: $M_\star = 4–6\times10^8\ M_\odot$

→ **This is low-mass, quenched galaxy, 700 Myr after the Big Bang**



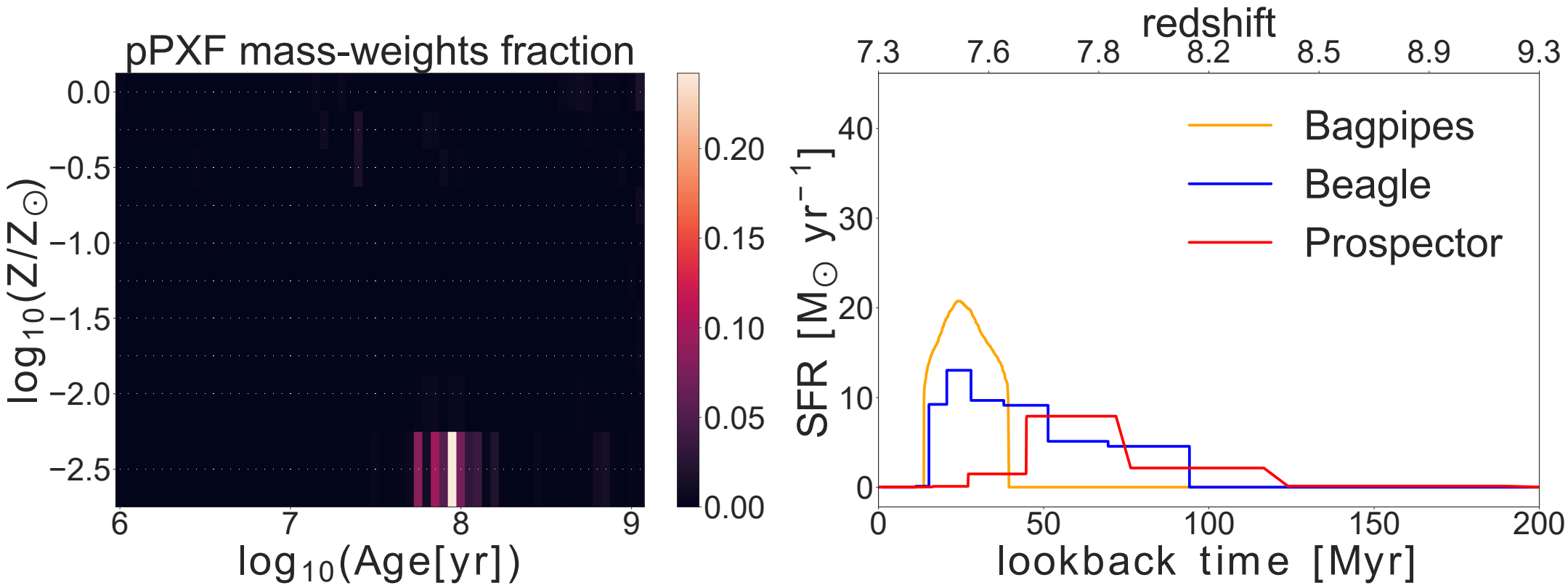
(Mini-)quenched galaxy

$\stackrel{\text{def}}{=}$

Galaxy with no or negligible star formation activity at the epoch of observation

Quiescence can be temporary or permanent

Spectral fitting codes agree that the galaxy quenched recently (10-40 Myr) and rapidly, following a short starburst episode

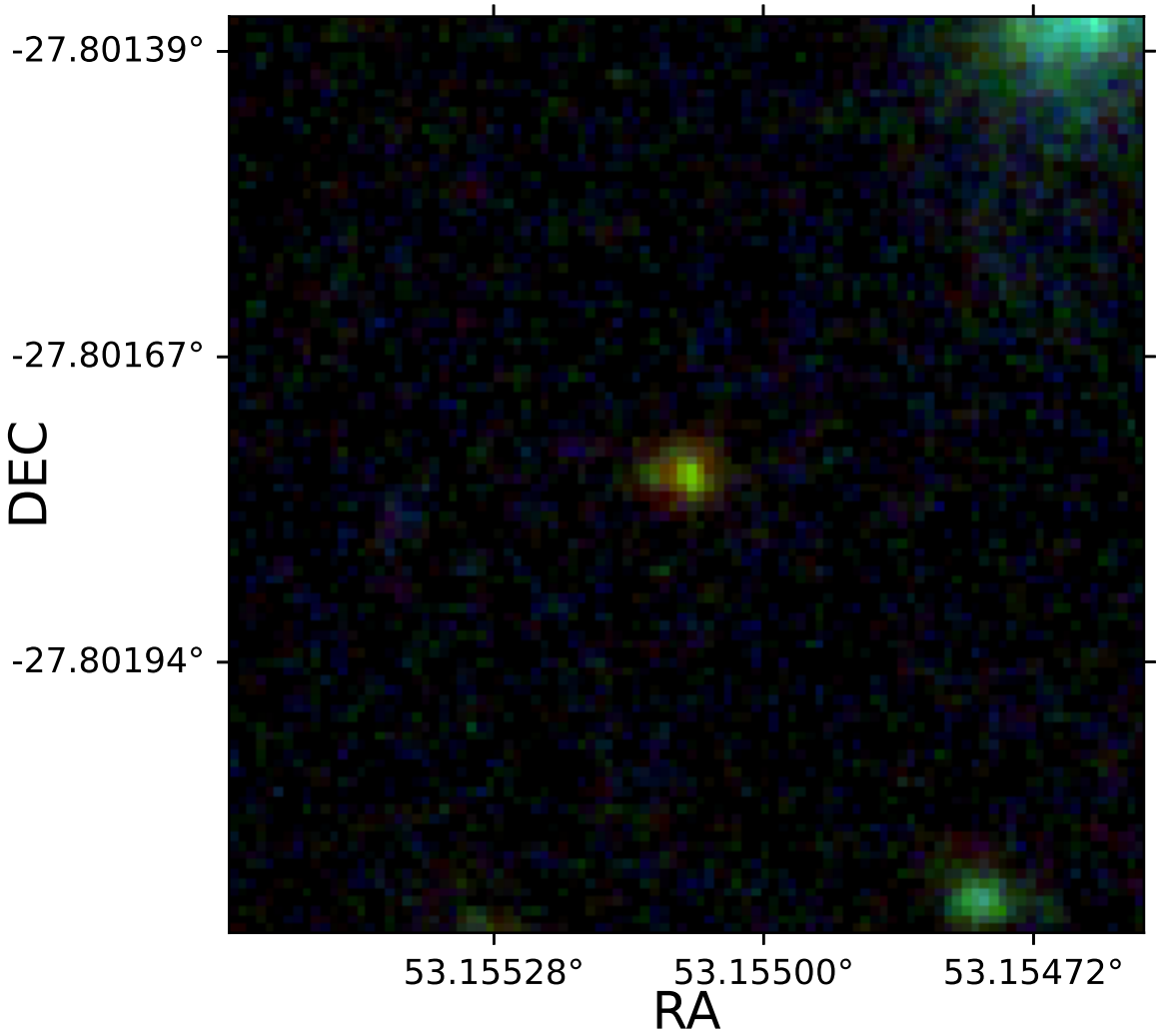


Which physical mechanisms halted star formation?

A. UV background?

Invoked by EoR simulations for quenched dwarfs with
$M_\star \approx 10^5 - 10^7\ M_\odot$
(maximally $< 10^8\ M_\odot$)

→ Disfavored for this galaxy

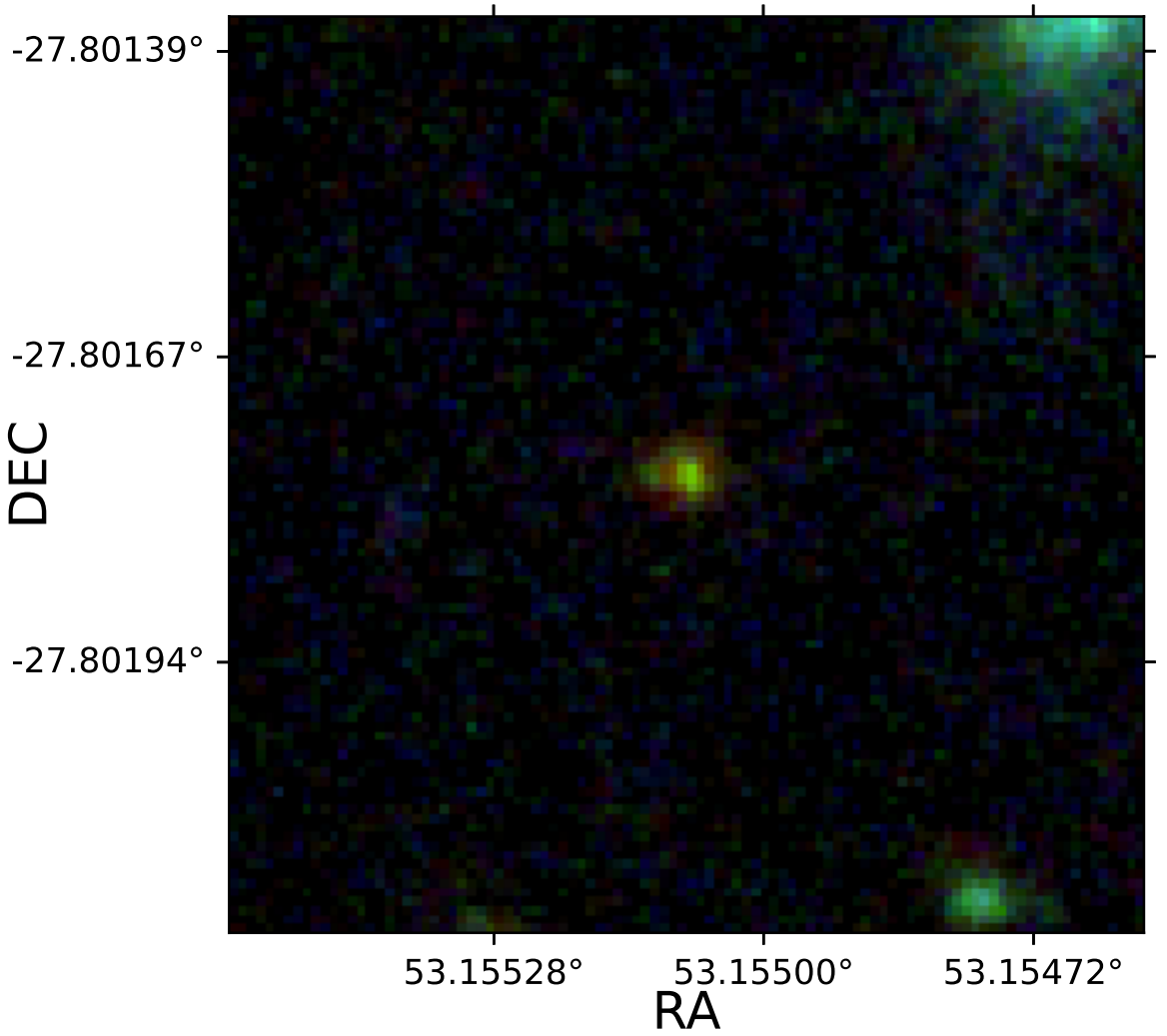


Which physical mechanisms halted star formation?

B. Environment?

- Some simulations show supressed SFR in over-densities during the EoR
- However, no (massive) galaxy nearby

→ Disfavored for this galaxy



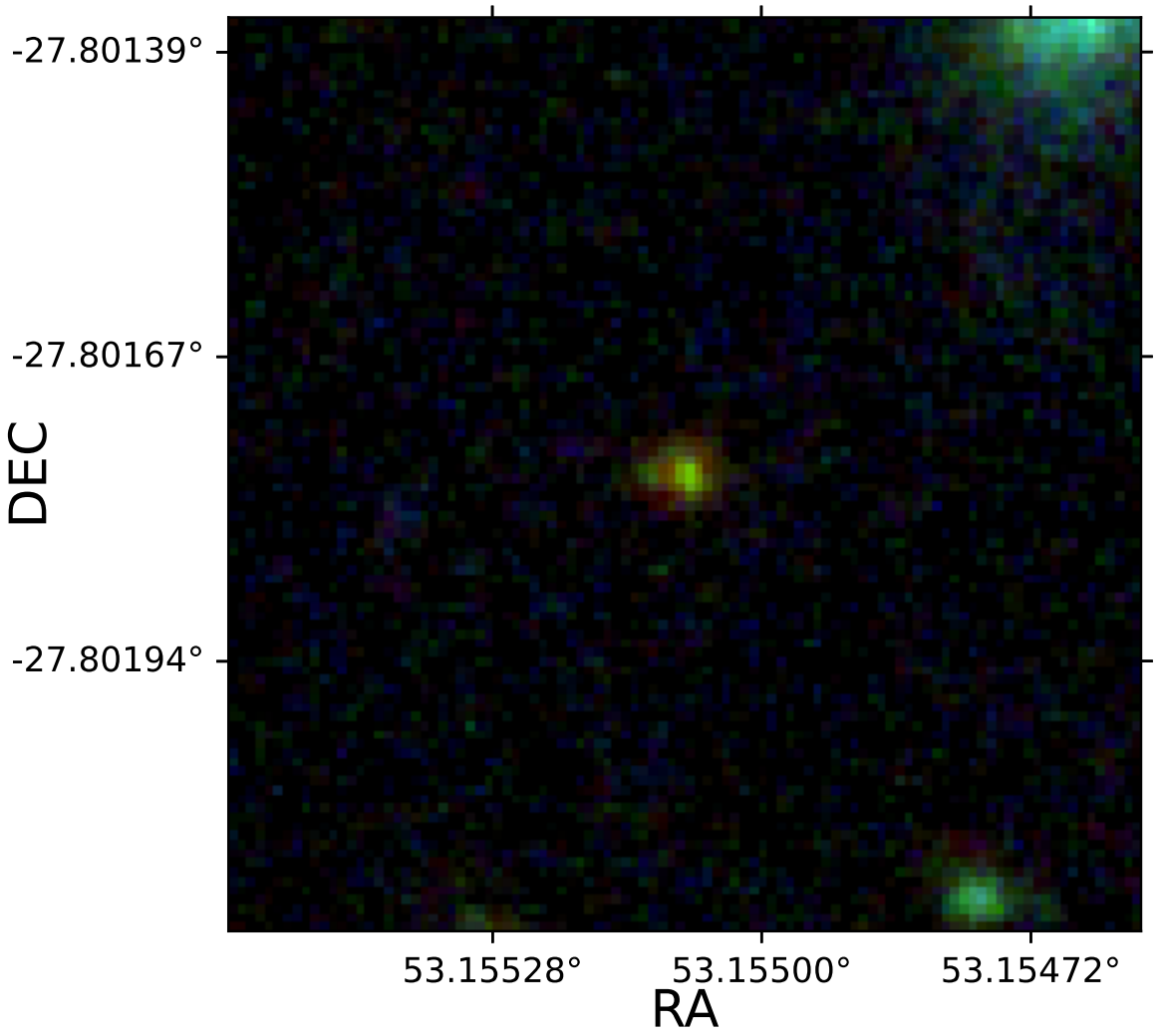
Which physical mechanisms halted star formation?

C. Internal feedback?

Short duration of SFH & rapid quenching rather suggest a starburst episode followed by quenching by internal feedback:

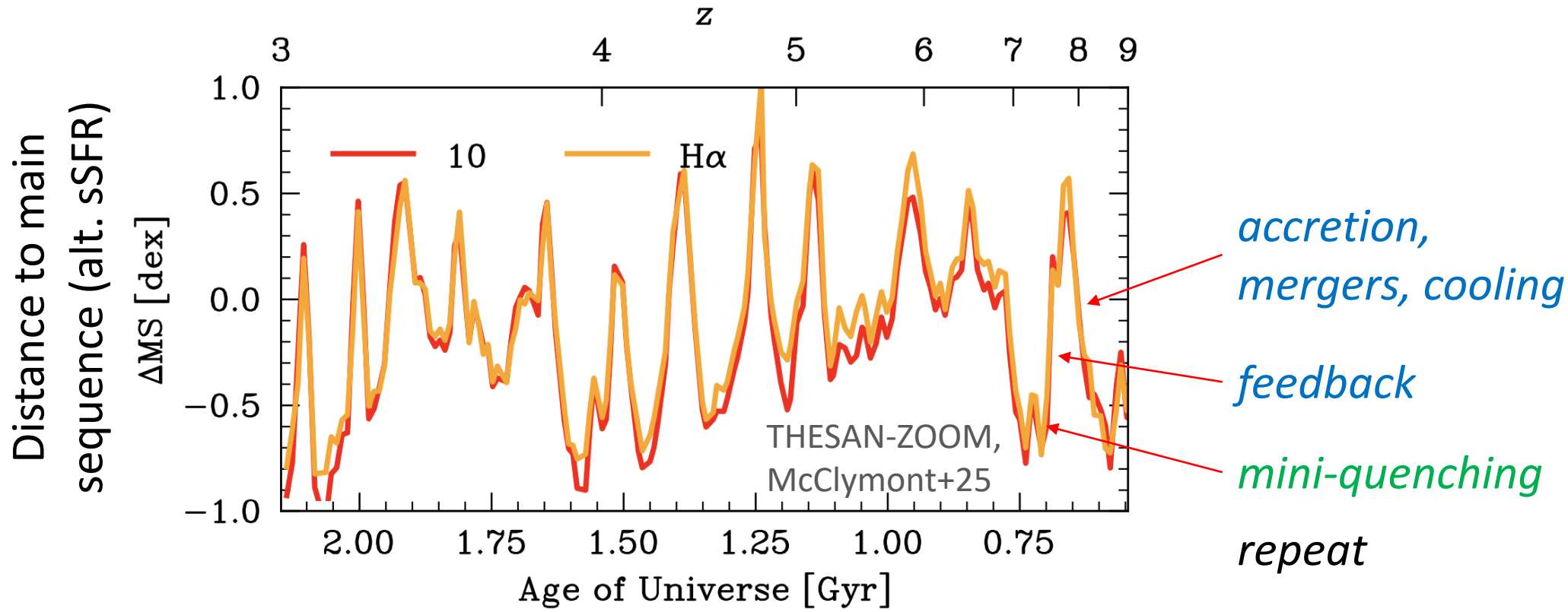
- Star-formation feedback (radiation-driven outflows, e.g. Gelli+2023, Ferrara+2023)
- AGN feedback - see e.g. strong AGN-driven outflow in GN-z11

→ Ejecting the ISM



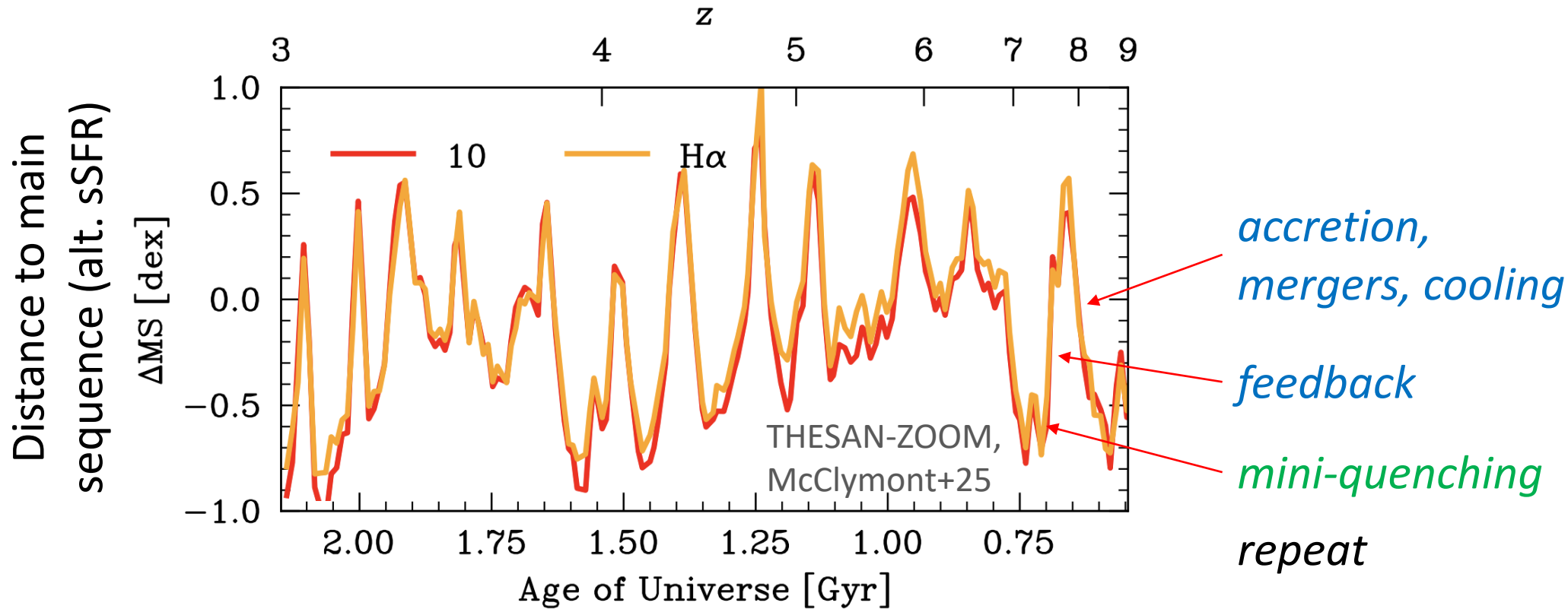
Is the galaxy only temporarily quiescent, i.e. a natural evolutionary stage of bursty star formation?

Simulations predict bursty SFHs and quiescent phases through feedback and variable gas accretion in the early Universe



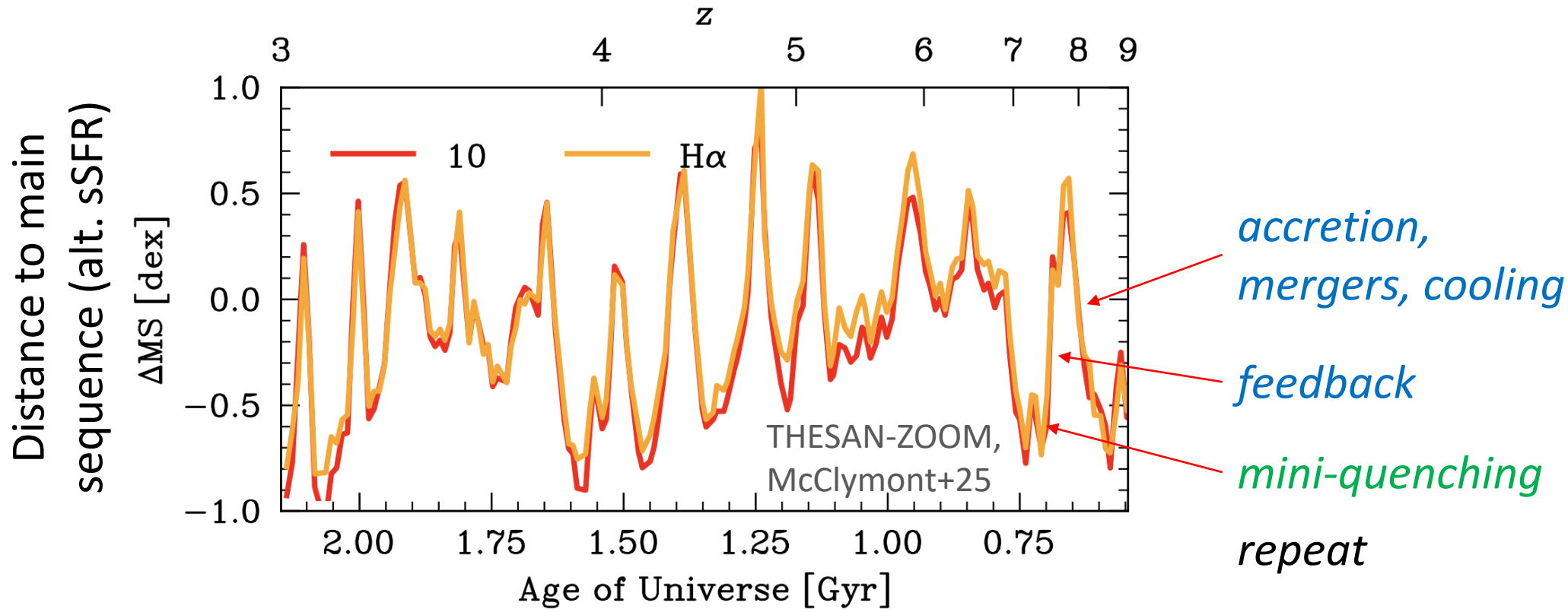
See also Ceverino+2018, Ma+2018, Gelli+2023,25, Dome+2023,2024, Pallottini+2023, Katz+22,24, Choustikov+23, Dayal+13, Kim+2015, Faucher-Giguère 2018, Barrow+20, Furlanetto+22, Wilkins+22, Narayanan+24, …

Simulations predict bursty SFHs and quiescent phases through feedback and variable gas accretion in the early Universe



- Interestingly, the mass of this galaxy, $M_\star = 10^{8.6} – 10^{8.8}\,M_\odot$ lies in the upper / beyond the mass range for which bursty SFHs are typically invoked
- But arguably we caught the galaxy in such a mini-quenched phase

Simulations predict bursty SFHs and quiescent phases through feedback and variable gas accretion in the early Universe

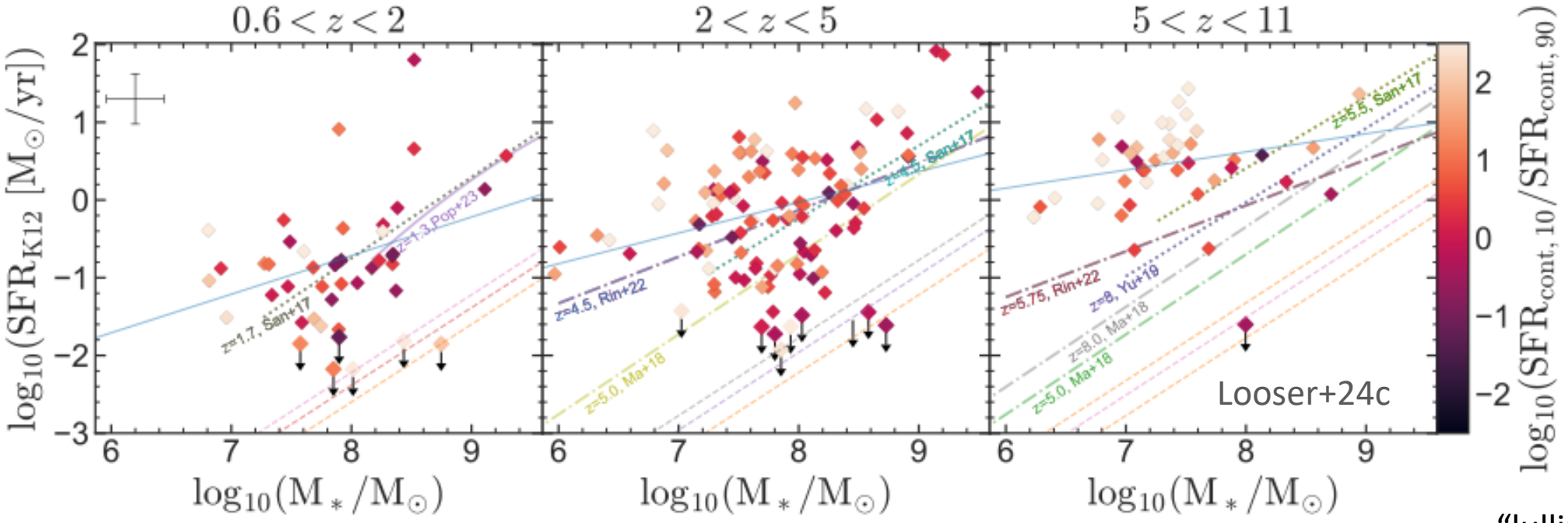


Many simulations focussing on low-mass bursty SFHs don't include AGN feedback

- However, see e.g., Koudmani+2019,21,22,23 on AGNs in dwarf galaxies
- Or Lovell+2022 z>5, AGN mini-quenched galaxies in FLARES ($M_\star > 10^9\ M_\odot$)

Observational evidence for bursty SFHs from the stellar continuum

From nebular emission lines

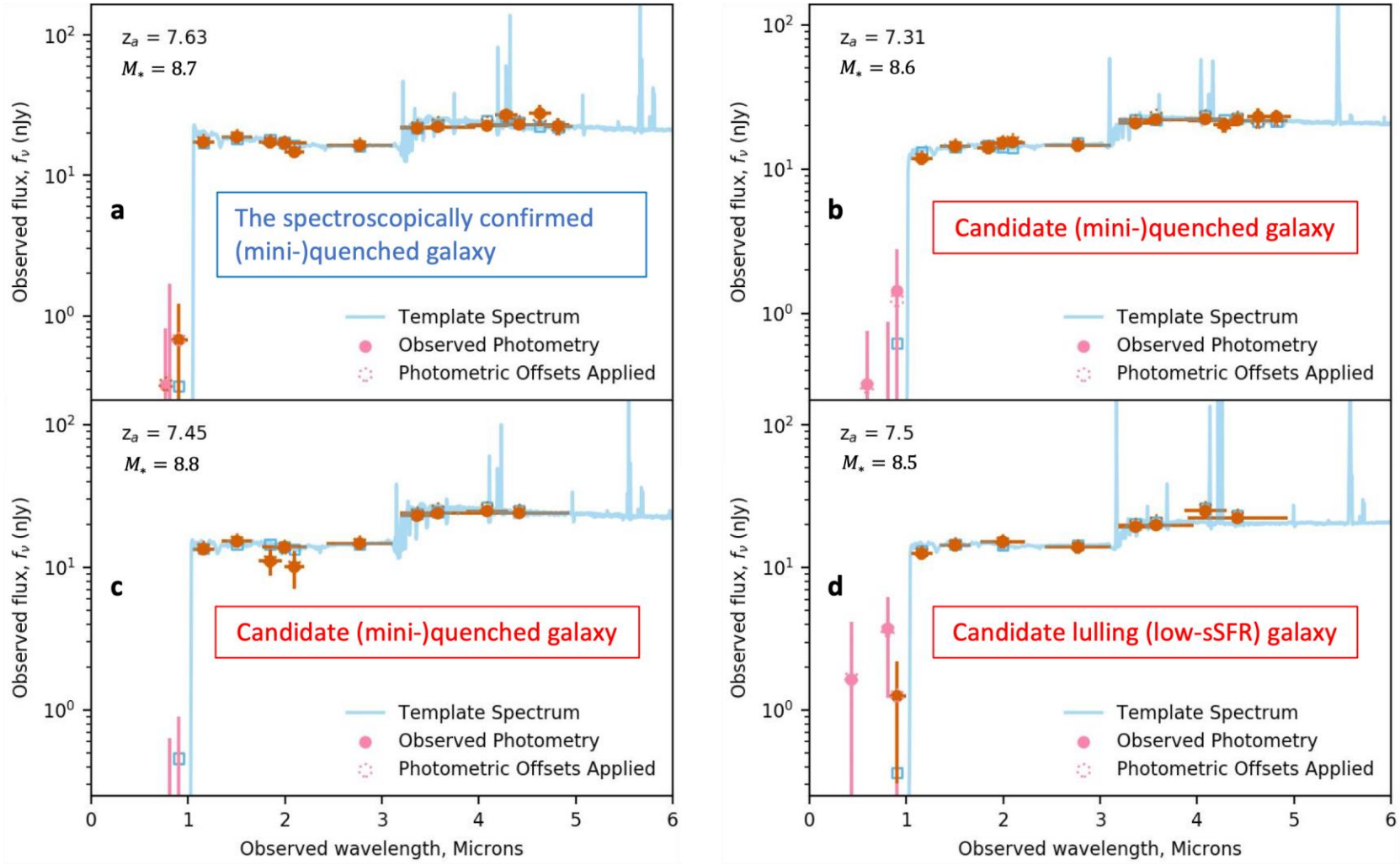


"burst"

"lulling" & (mini-)quenched

- Above "MS": galaxies are star-bursting according to continuum
- Below "MS": galaxies are lulling according to continuum
- High-redshift and low-mass galaxies preferentially observed in bursts
- If SFHs are extremely bursty, where are the "lulling" & mini-quenched galaxies? Fainter → Observation bias (Sun+24)

OASIS: 74h Cycle 3 program OASIS, targeting candidate low-mass mini-quenched and lulling galaxies

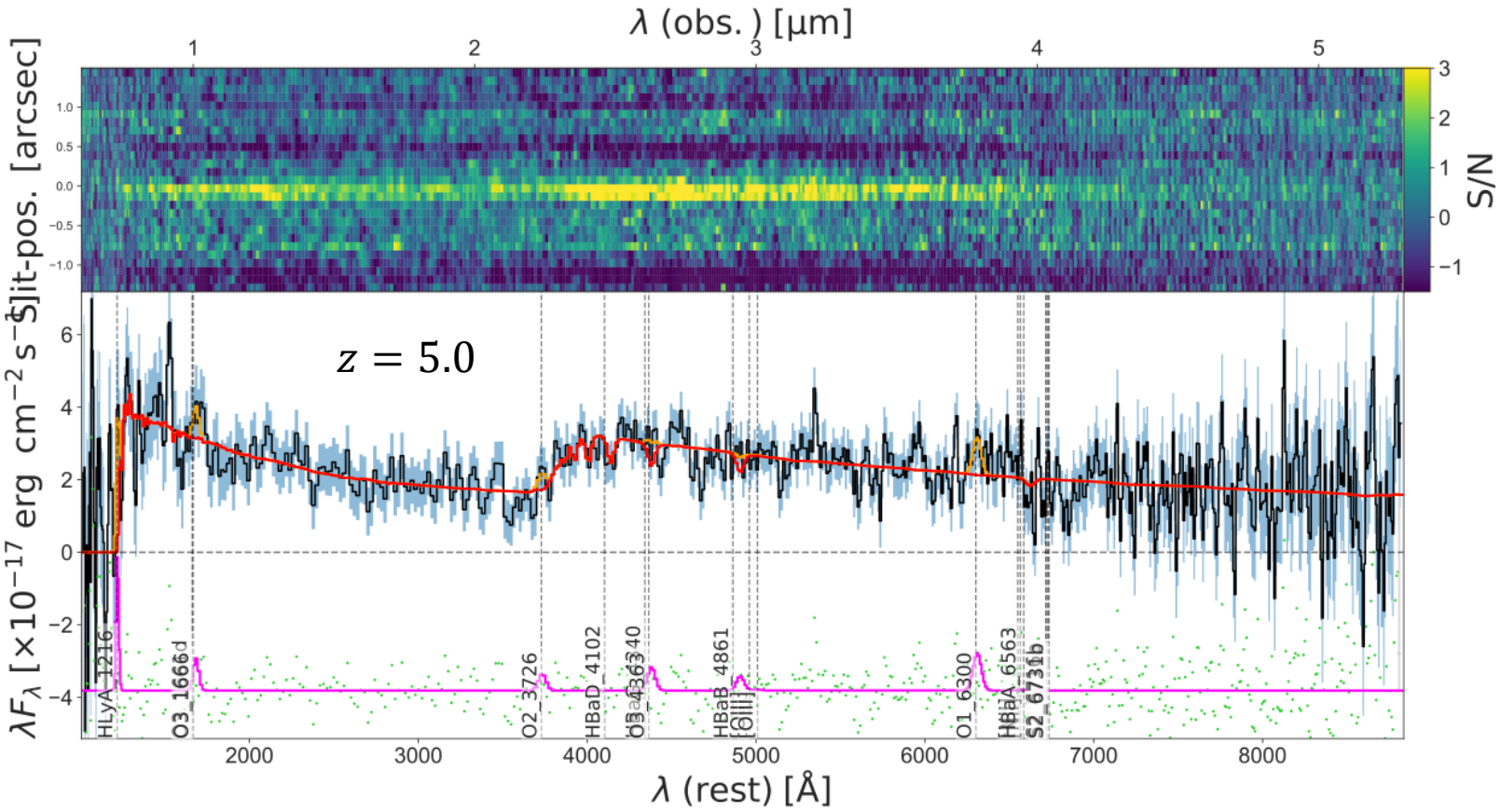


PI: T. Looser
Co-PI: F. D'Eugenio

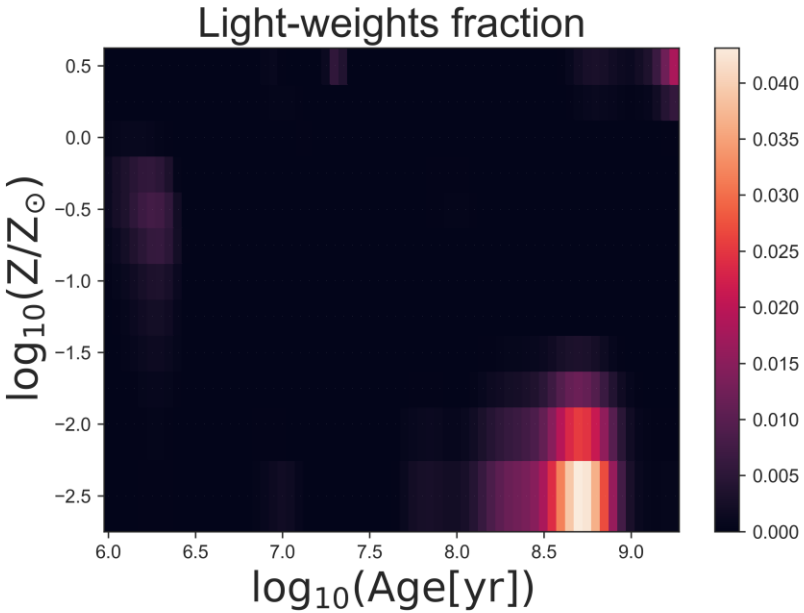
Going deep, to study SFHs

See also Trussler+2024

OASIS: An older mini-quenched galaxy



Work in progress

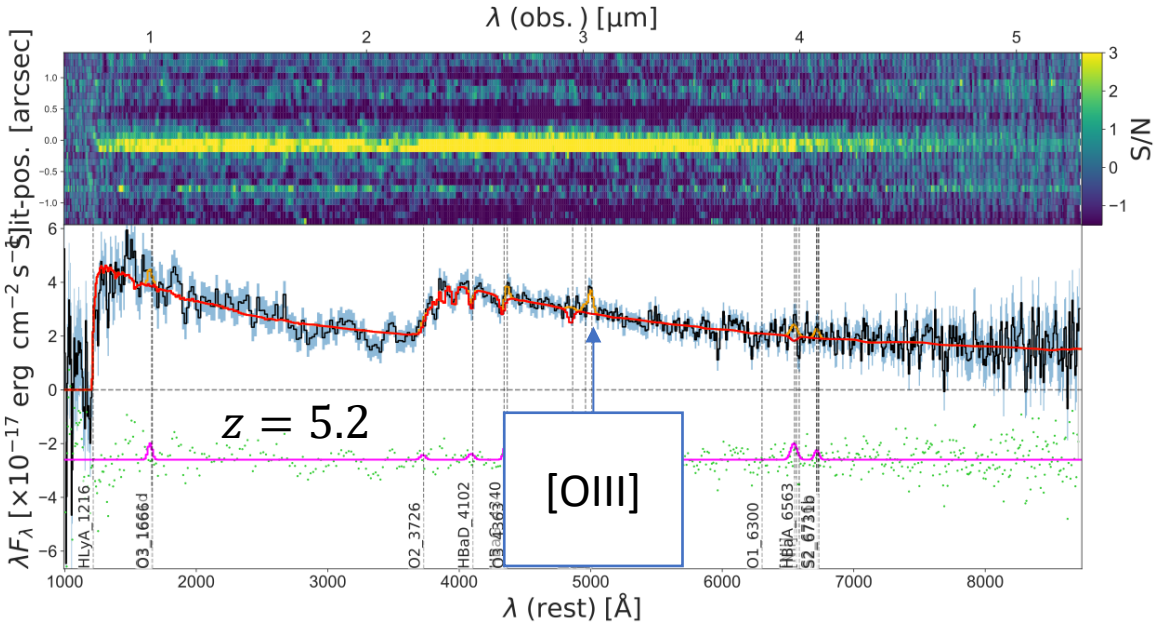


- Deeper Balmer break, flatter UV-slope than the z=7.3 system
- More evolved, stellar populations > 100 Myr
- Galaxies can stay mini-quenched for longer than we thought?

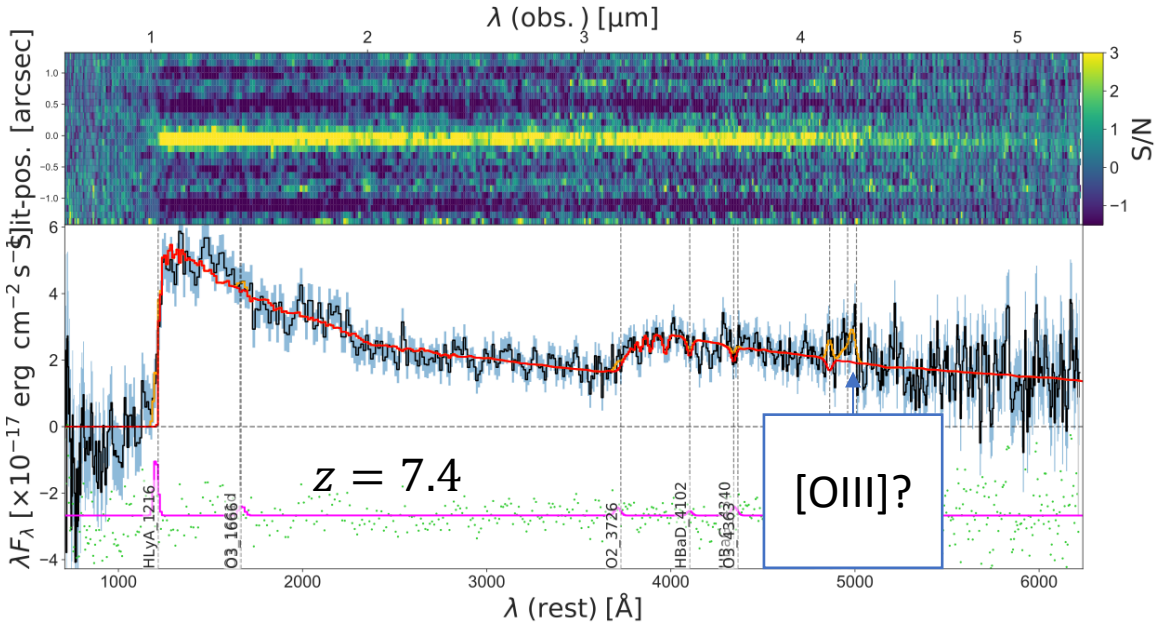
And more similar systems. See also Baker+2025, Covelo-Paz+2025

OASIS: Lulling galaxies

Work in progress



See also Strait+2024

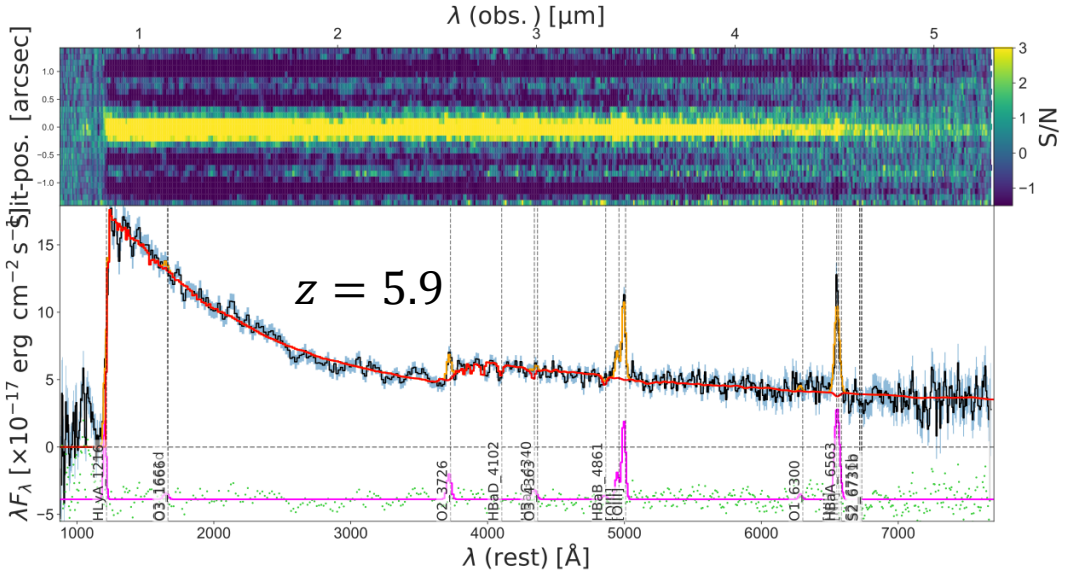


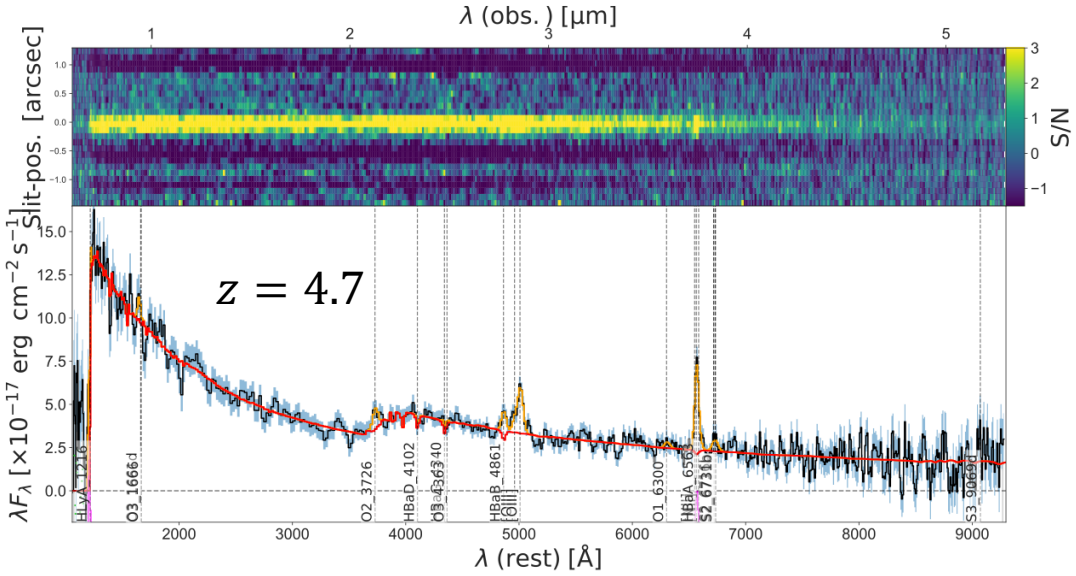
See also Strait+2023, Covelo-Paz+2025

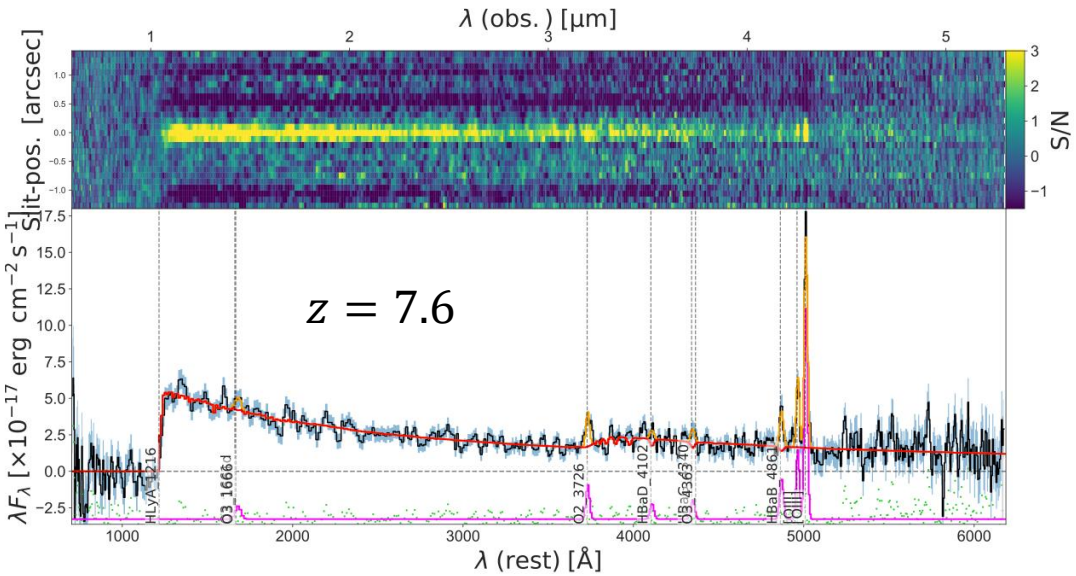
- Deeper Balmer breaks and flatter UV-slope than the z=7.3 system
- But weak [OIII] emission -> ISM present

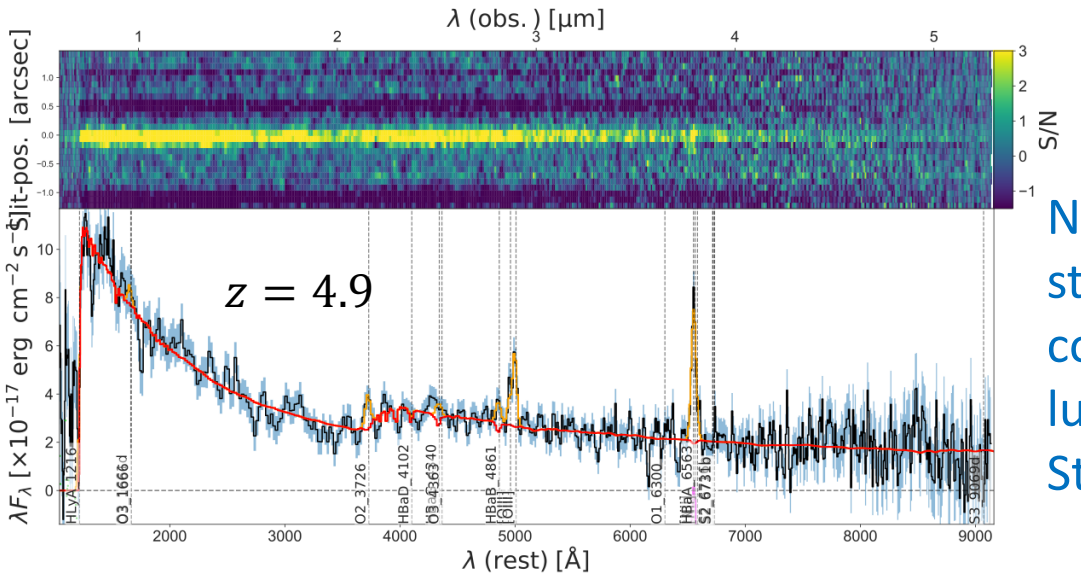
OASIS: Large variety of nebular emission EWs, UV slopes and Balmer break strengths, supporting bursty SFHs

Work in progress









Now we can study ISM conditions in lulling galaxies. Stay tuned

The discovery of a (mini-)quenched galaxy at z=7.3 and the additional JWST-results by JADES & OASIS:

- Confirm that star formation histories are bursty at early times and in low-mass galaxies
- Exhibit a large variety in physical properties of mini-quenched & lulling galaxies. What are their SFHs and duty cycles? How does this all fit together with the general galaxy population? How bursty is star formation at high-z?
- Usher in the era in which we can directly constrain theoretical models of feedback processes which regulate and quench star formation during the fist billion years after the Big Bang

Additional slides

Key physical properties of the (mini-)quenched galaxy at z=7.3

Key inferred properties	PPXF	BAGPIPES	BEAGLE	PROSPECTOR
$\log_{10}(M_\star/M_\odot)$	-	8.6 ± 0.1	$8.8^{+0.1}_{-0.2}$	$8.7^{+0.1}_{-0.1}$
$\log_{10}(\mathrm{SFR}\ [M_\odot/\mathrm{yr}])$	-	< -1.3	$-2.5^{+1.0}_{-1.0}$	$-2.6^{+1.5}_{-2.7}$
$\log_{10}(\mathrm{Z}/\mathrm{Z}_\odot)$	< -2.0	-0.7 ± 0.1	$-1.9^{+0.4}_{-0.2}$	$-1.7^{+0.2}_{-0.2}$
$\mathrm{t_{quench}}$ [Myr]	~ 20	~ 10	16^{+7}_{-4}	38^{+9}_{-10}
$\mathrm{t_{form}}$[Myr]	~ 100	40 ± 10	93^{+69}_{-47}	116^{+85}_{-45}
$\mathrm{A_V}$ [mag]	0.4 ± 0.1	$0.32^{+0.25}_{-0.17}$	$0.51^{+0.03}_{-0.04}$	$0.1^{+0.1}_{-0.0}$

Could there be alternative interpretations to quenched?

A. Star-forming, extreme Lyman-continuum (LyC) leaker. $f_{esc} > 0.9$ could strongly suppress nebular emission?

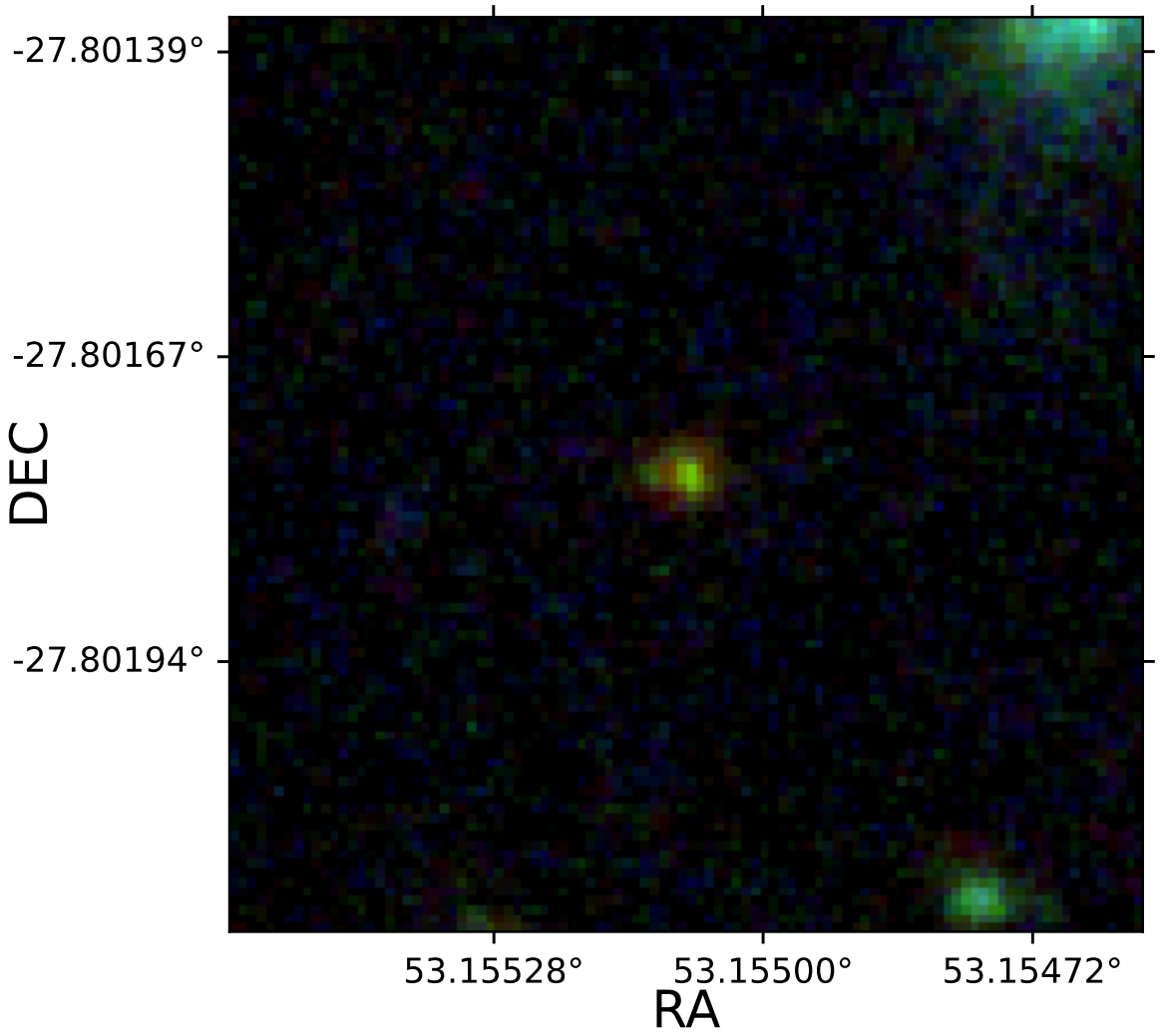
   Scenario disfavoured:

   - Balmer break
   - Hδ absorption
   - Blue, but not extreme UV slope
   - Full spectral fitting code Beagle prefers quiescent solution over high f_{esc}
   - Fitting with decoupled emission lines: Stellar populations > 10 Myr

B. Locally completely obscured star formation?

   Scenario disfavoured: Galaxy not detected in deep ALMA observations (however, not very constraining)

JADES/DEEP NIRCam 444W-F200W-F090W rgb Image

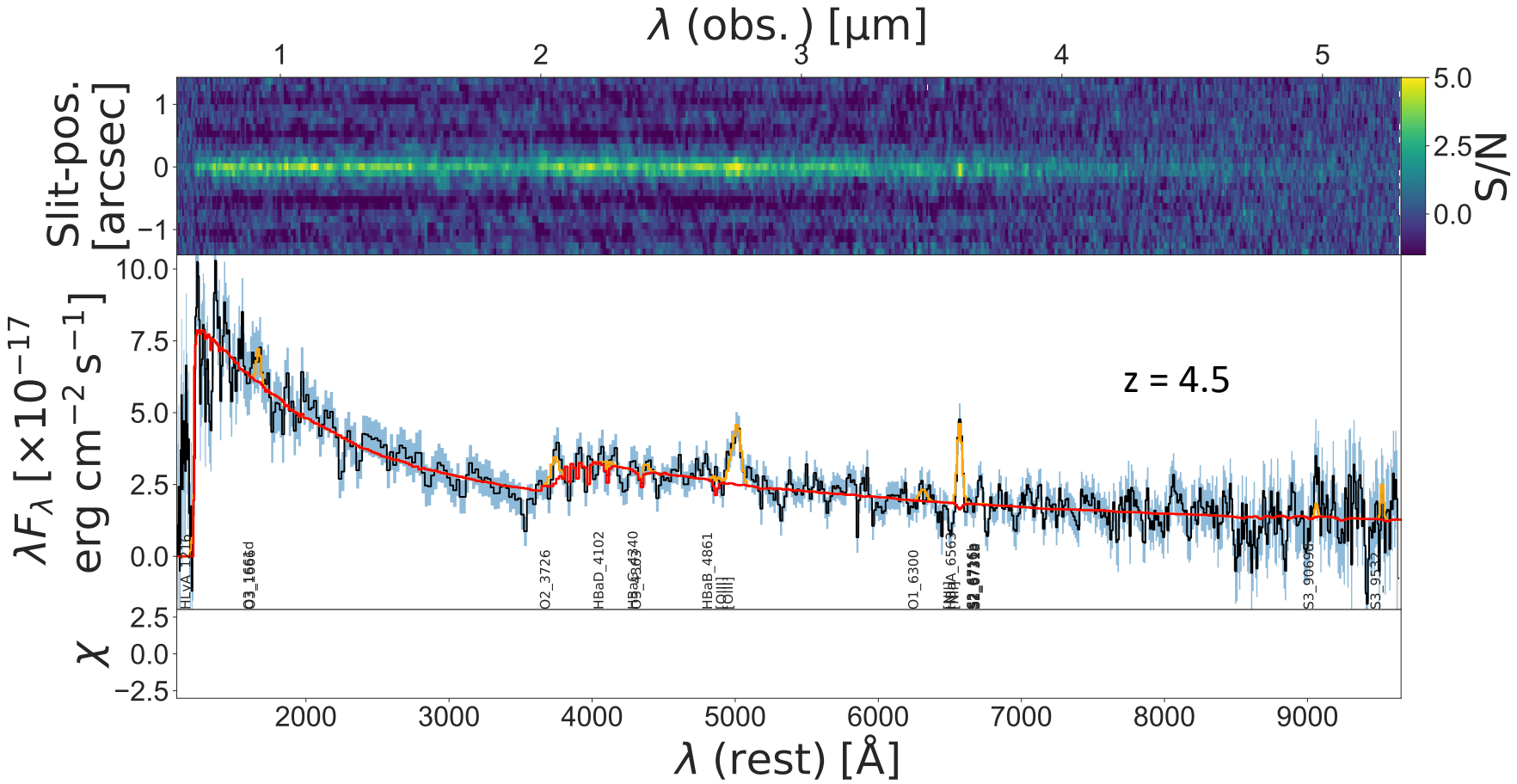


- Compact: half-light radius R_e = 0.2 kpc
- Fainter source 0.13 arcsec to the East
- Clump? Companion? Low-redshift interloper in the slit, driving results?
- Photometry from JADES+JEMS
- Decomposition with Forcepho: Redshift consistent with main target

→ Bluer
→ If anything, biasing our analysis to star-forming solution

Secondary source too close to be deblended

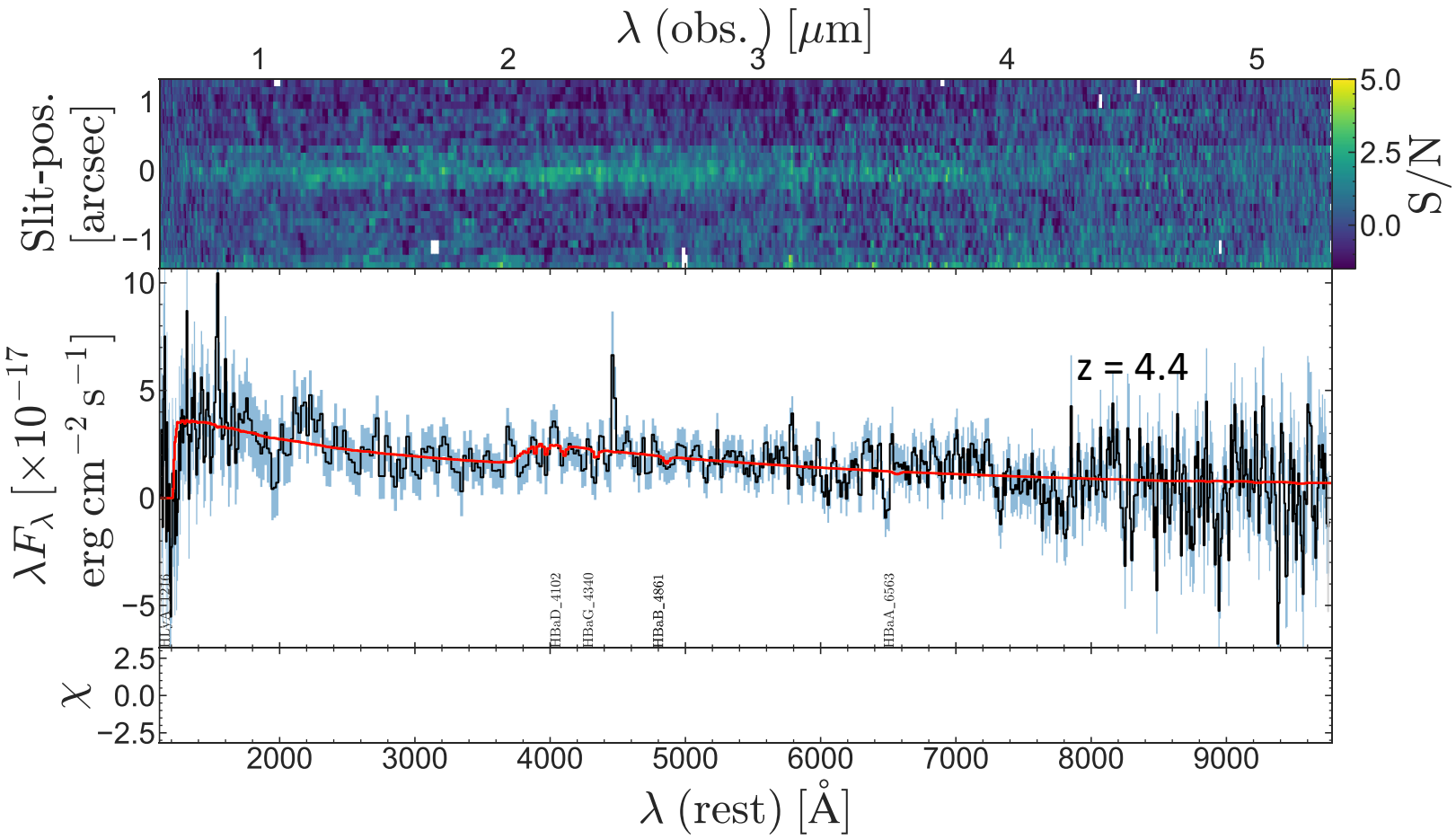
Observational evidence for bursty SFHs: Example of a galaxy observed in a “lull” phase



“Lull” phase confirmed by continuum

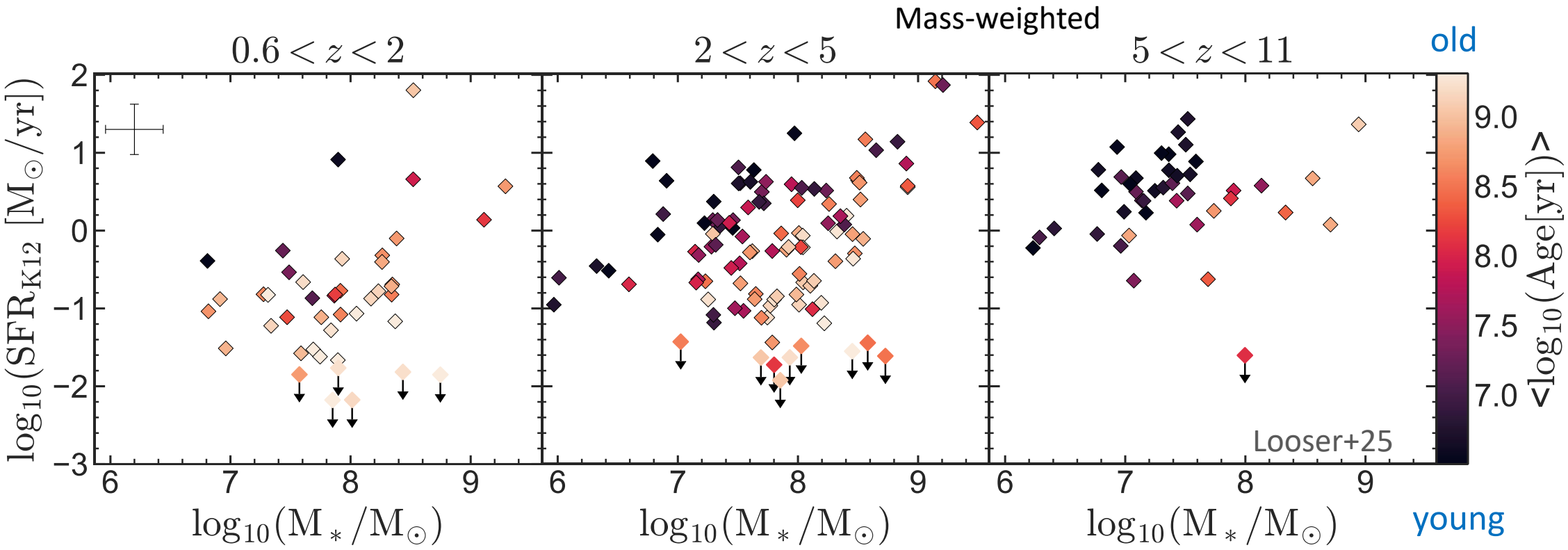
See also Strait+2023, more similar systems in JADES

Observational evidence for bursty SFHs: Example of another galaxy observed in a (mini-)quenched phase



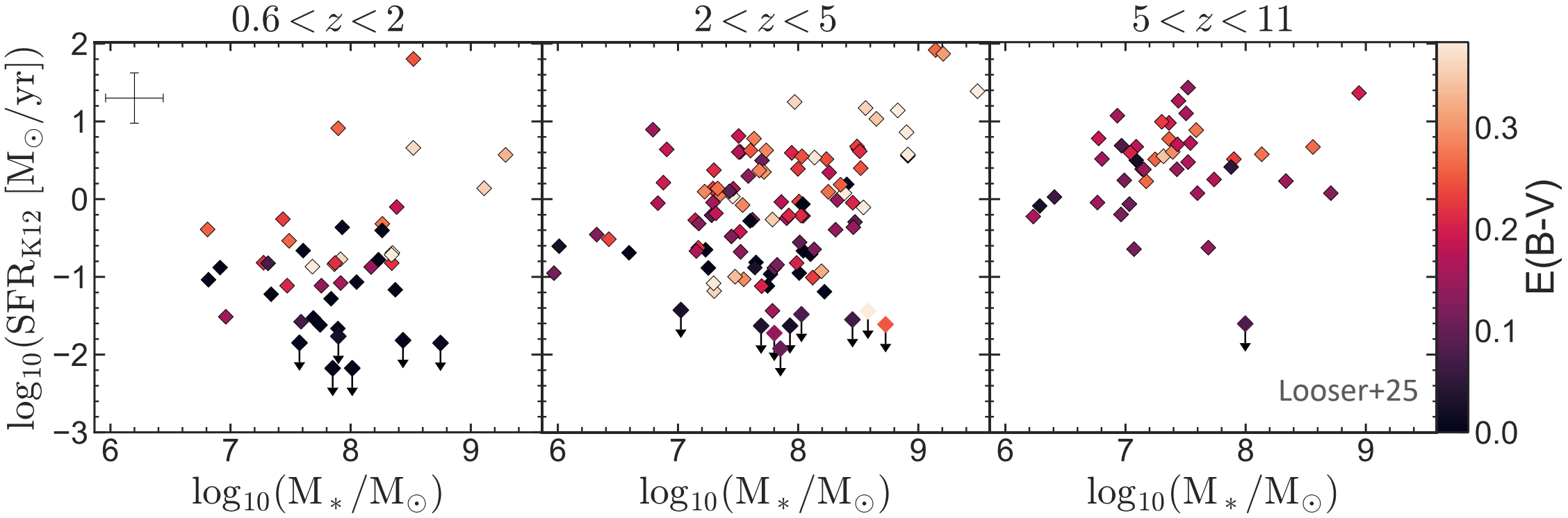
More similar systems in JADES

Evidence for longer time-scale physics shaping SFHs: Stellar ages



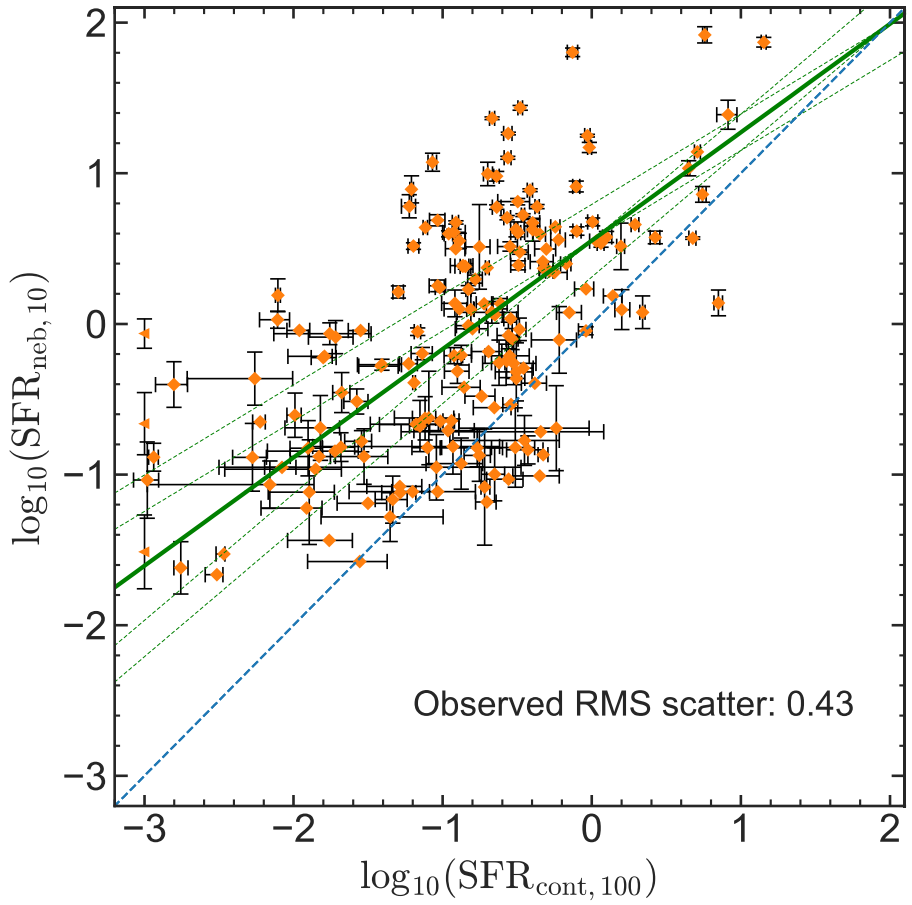
- The galaxies are younger with increasing redshift and decreasing mass
- But also strong trend with distance from the MS

Interesting trends in dust reddening of the stellar continuum

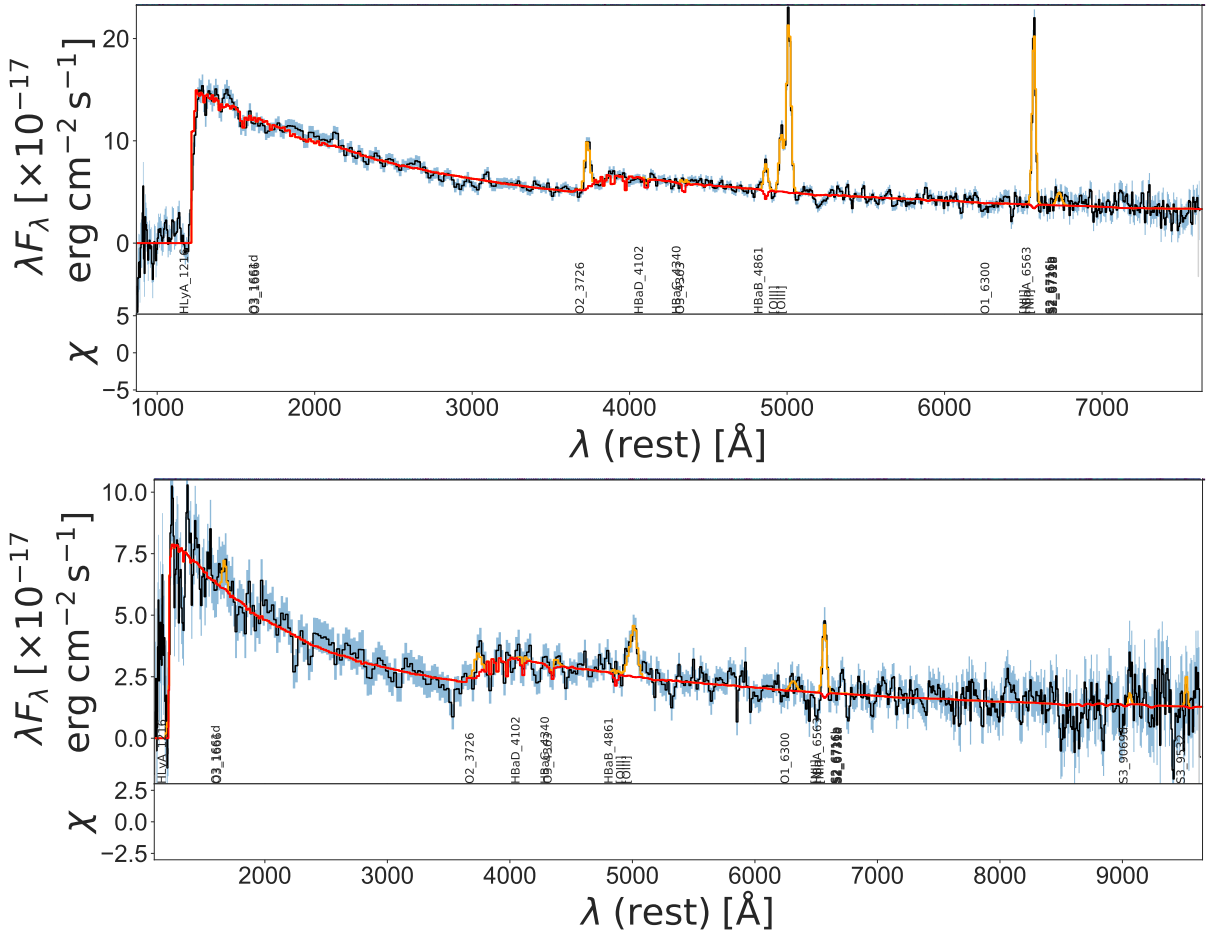


- Most high-redshift galaxies show evidence for some dust
- The amount of dust increases with stellar mass
- Galaxies below the MS tend to have less dust

SFR measured from stellar continuum on 10/100 Myr timescales with non-parametric full spectral fitting (pPXF)



From young stellar populations (<100 Myr)



How much of the scatter and offset is physical?

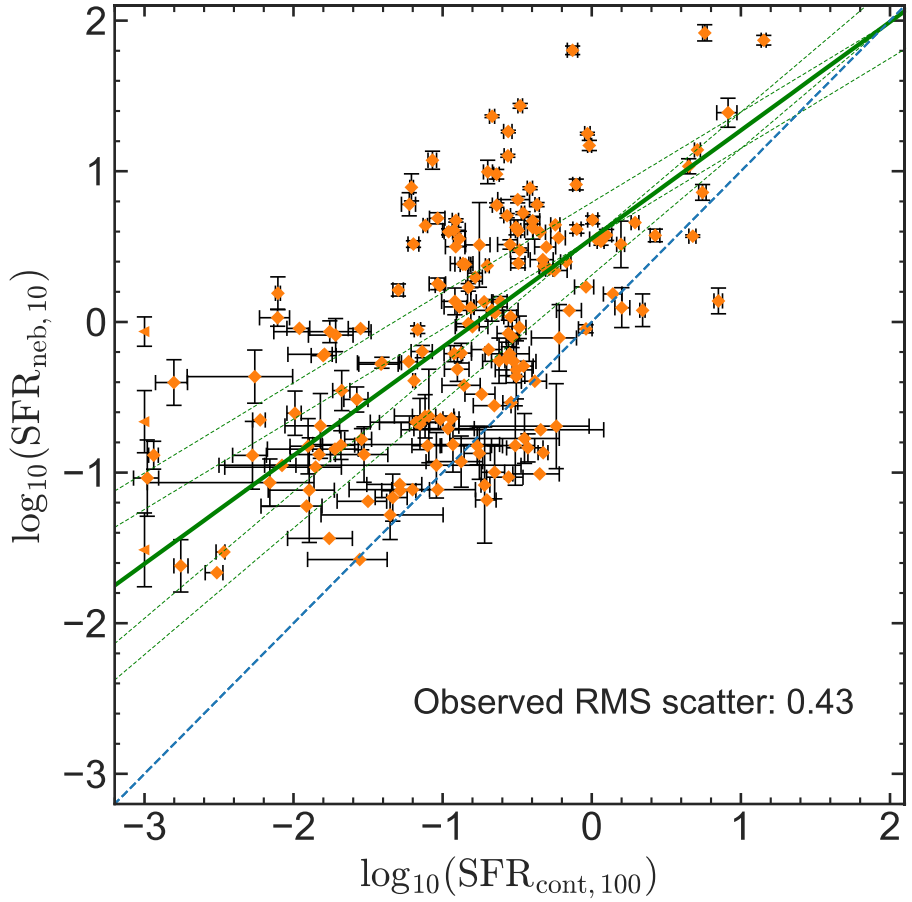
Observability and selection bias

Looser et al. 2023b

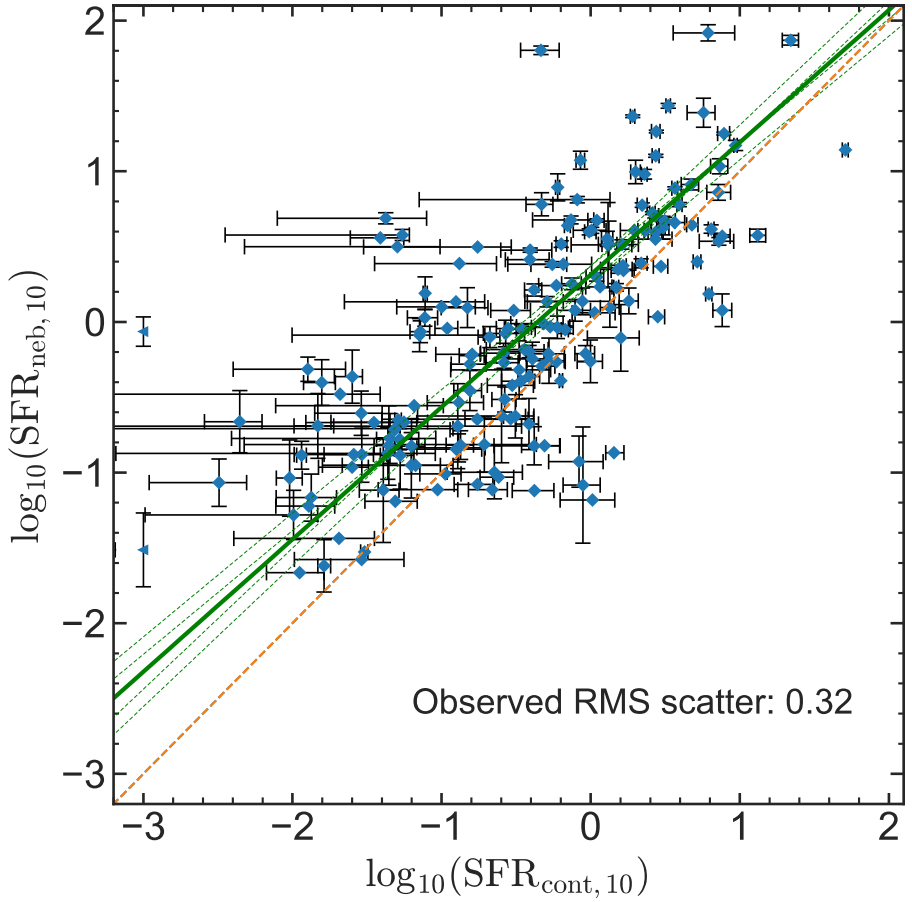
What can the stellar continuum tell us about star formation?

SFR measured from stellar continuum on 100/10 Myr timescales

From nebular emission lines



From young stellar populations (<100 Myr)

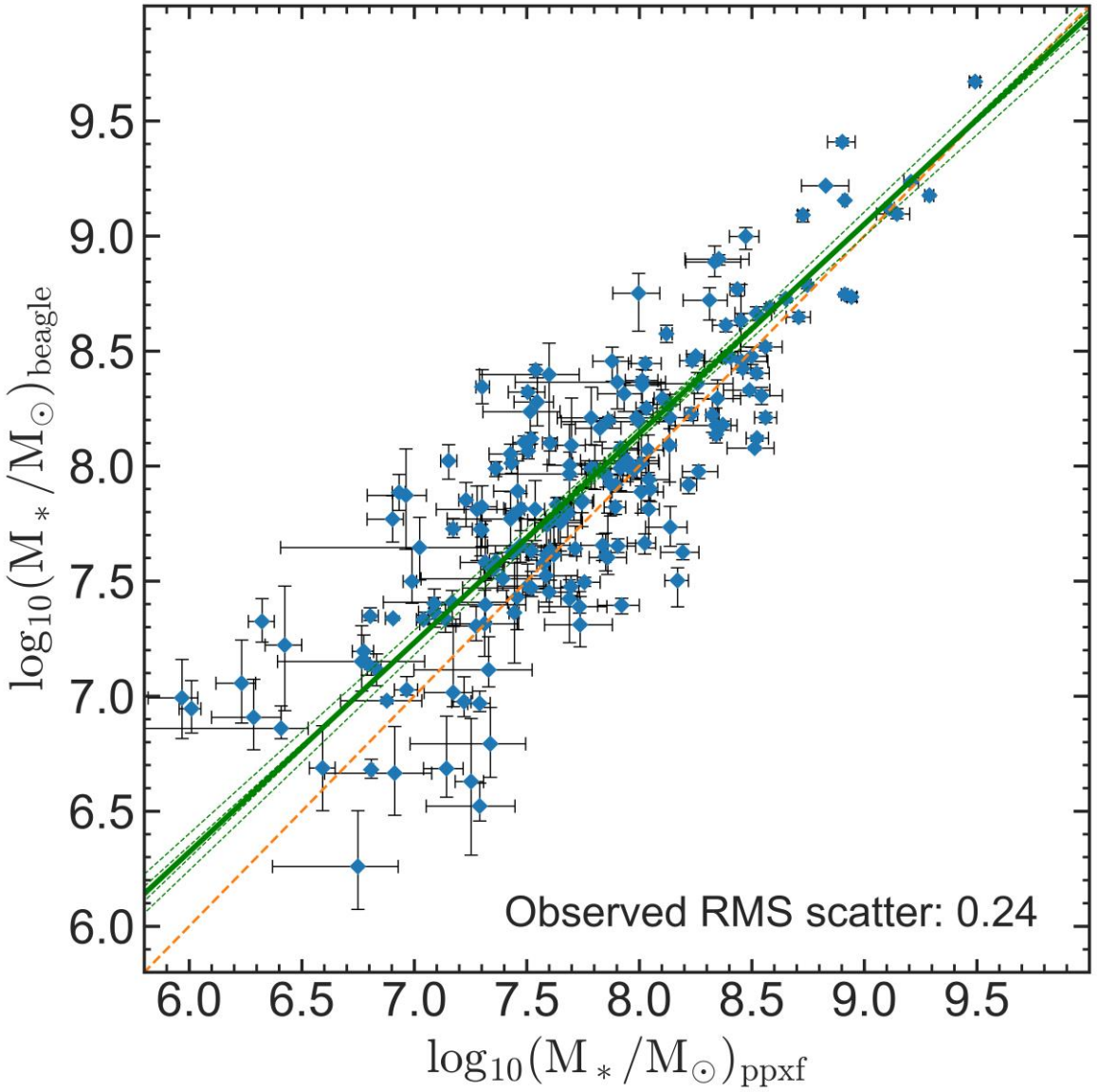


From young stellar populations (<10 Myr)

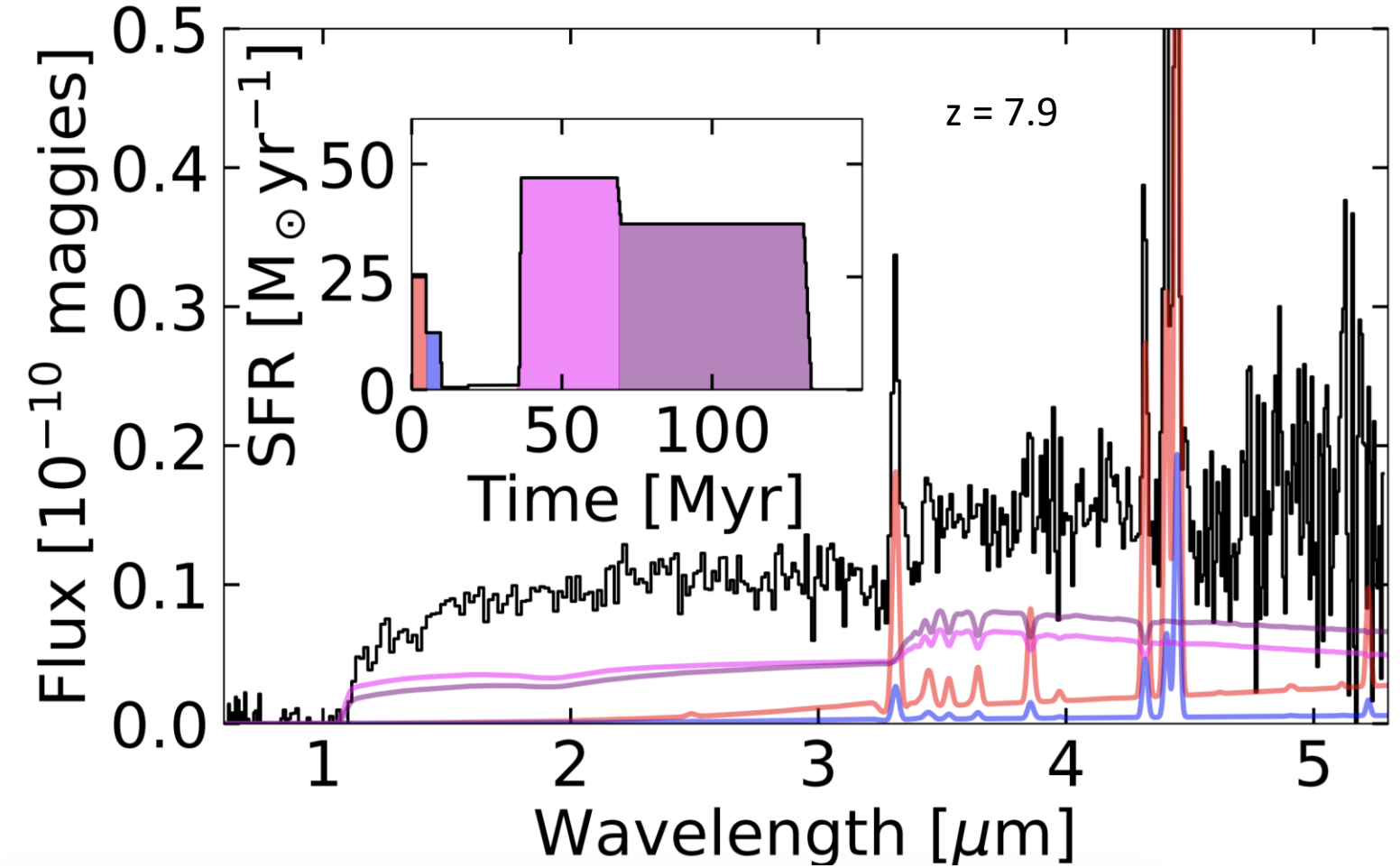
Looser et al. 2023b

How much physics is left in this plot in terms of differential dust attenuation, f_esc & neb. continuum?

Stellar mass: pPXF vs BEAGLE

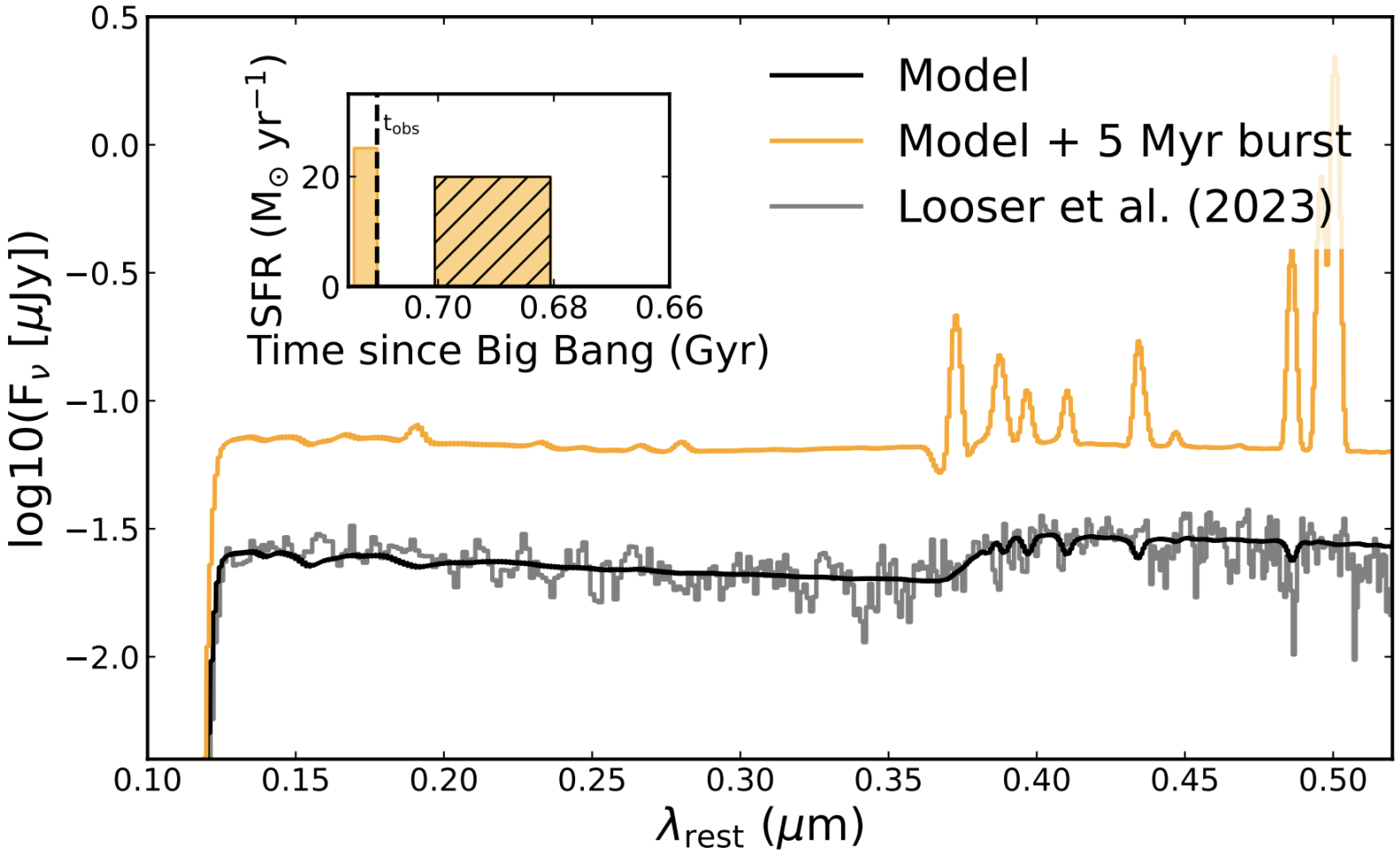


Observational evidence for bursty SFHs: A rejuvenating galaxy



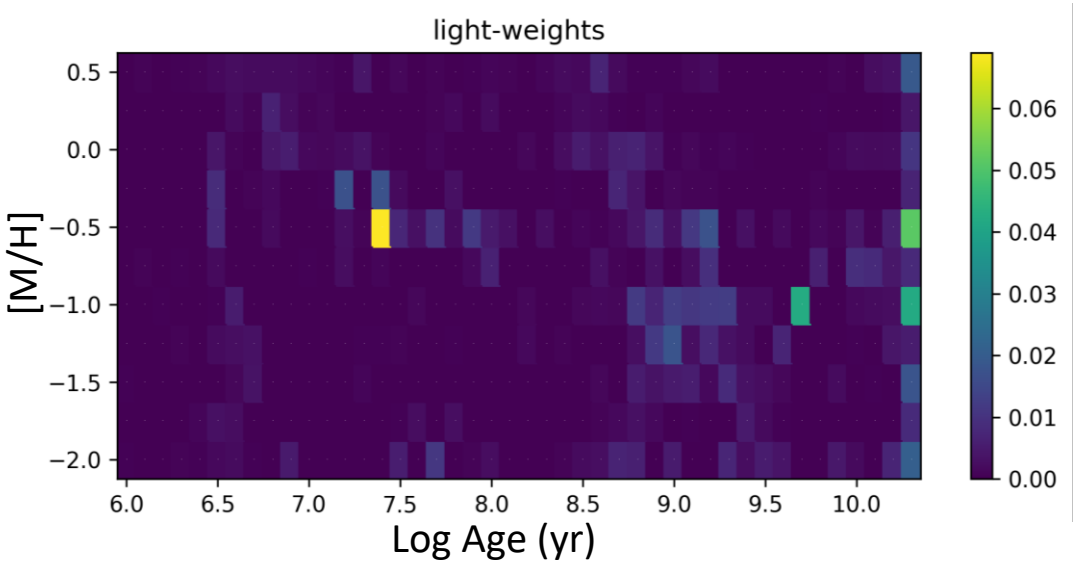
Witten+2024 (incl. TJL)

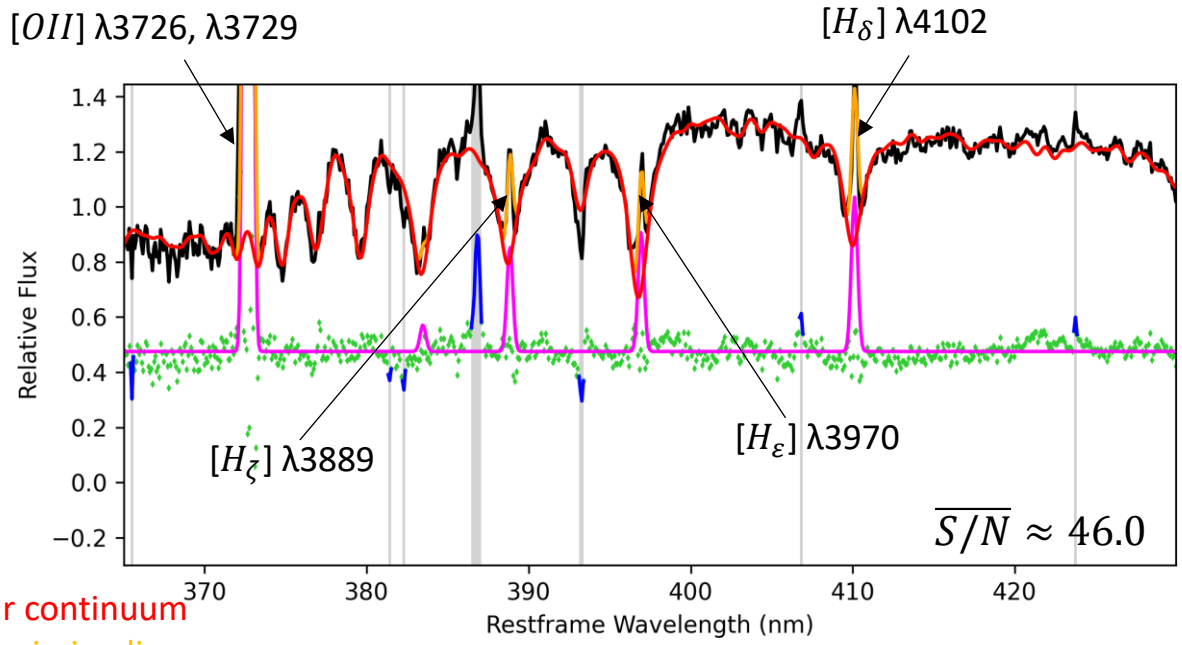
Outshining makes it difficult to detect mini-quenched phases in SFHs, even only shortly after rejuvenation



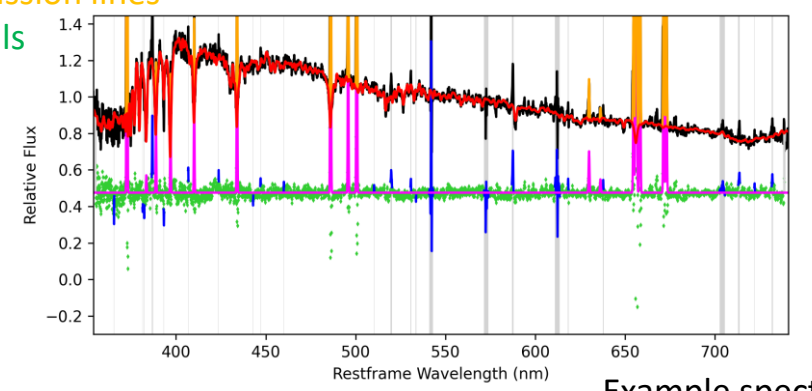
Witten+2024 (incl. TJL)

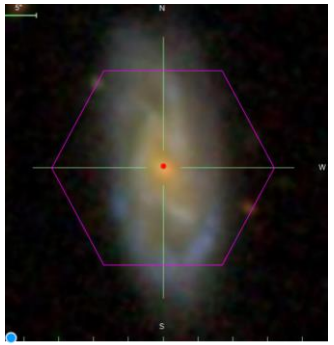
Reconstructing Star Formation Histories and stellar Metallicities of individual galaxies with pPXF





Stellar continuum
Gas emission lines
Residuals
Masked





Example spectrum: SDSS MaNGA