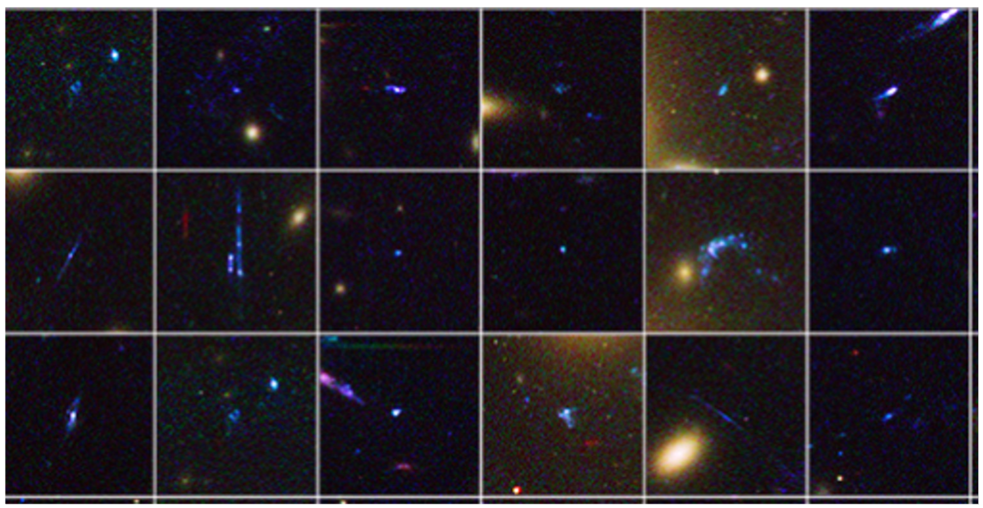
A Roman WFI Grism Census of Ionizing Efficiency and Bursty Star Formation Across Cosmic Noon

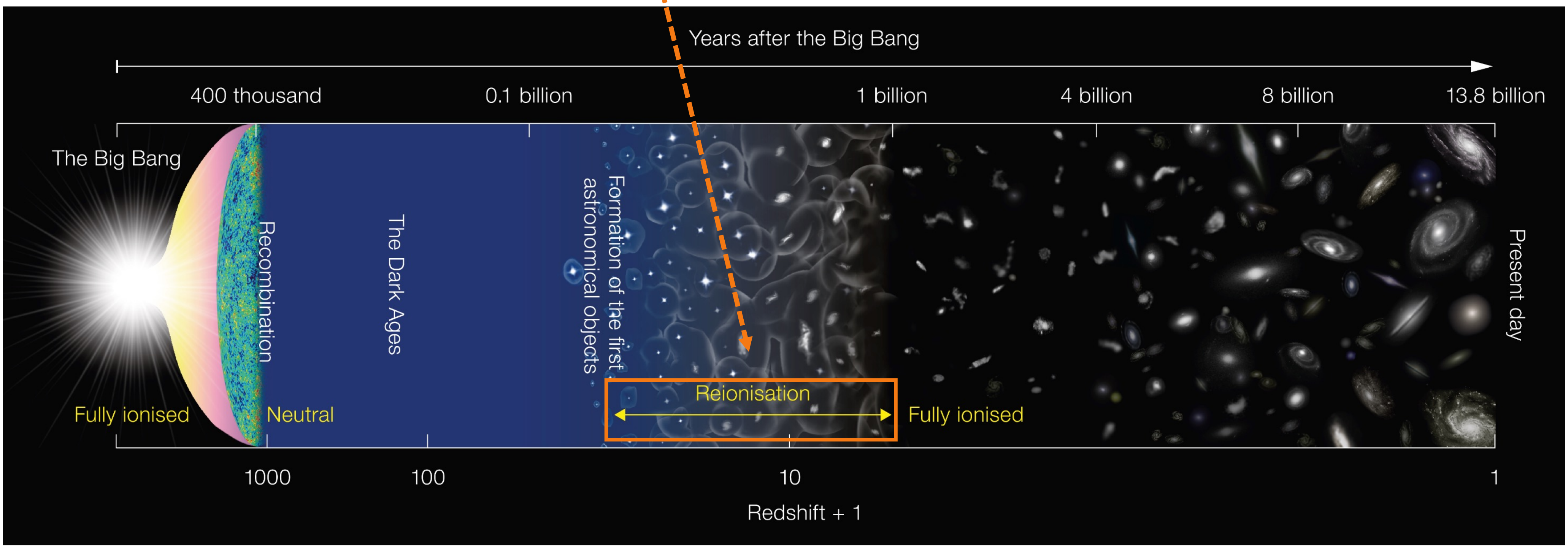
Keunho J. Kim (Caltech/IPAC)



Collaborators:
Anahita Alavi, Peter Watson, James Colbert, Vihang Mehta, Takahiro Morishita, Brian Siana, Zahra Sattari, and Harry Teplitz, and Xin Wang

The Universe was reionized by the first generation of stars and galaxies.

However, the reionization process remains elusive.



Credit: ESO

How do galaxies ionize IGM not only during reionization, but also afterward?

$\boldsymbol{\Gamma}_{\text{ion}}$ (density of ionizing UV radiation) =

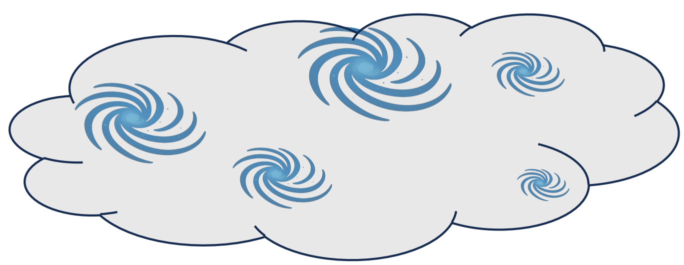
$\boldsymbol{\rho}_{\text{UV}}$ (galaxy UV luminosity density)

$\times$

$\boldsymbol{\varepsilon}_{\text{ion}}$ (ionization photon efficiency)

x f_{esc} (escape fraction)

($\dot{N}_{\text{ion}}$: Ionizing photon emissivity)



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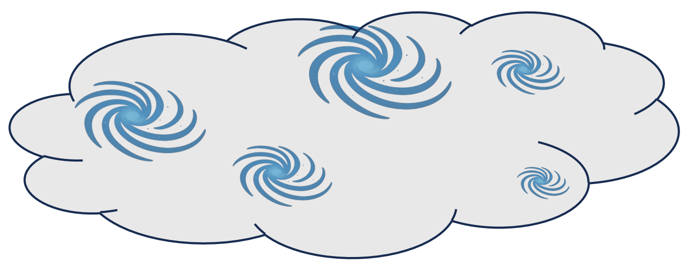
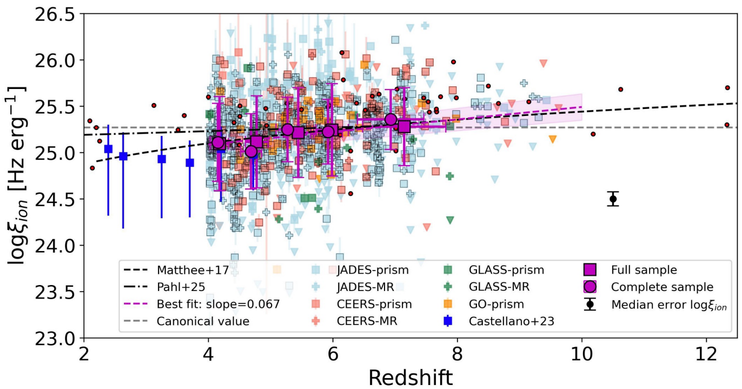
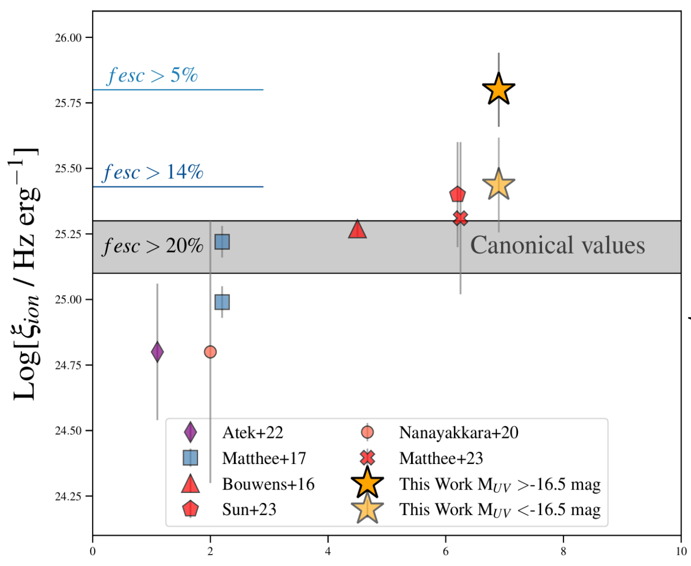


Motivation

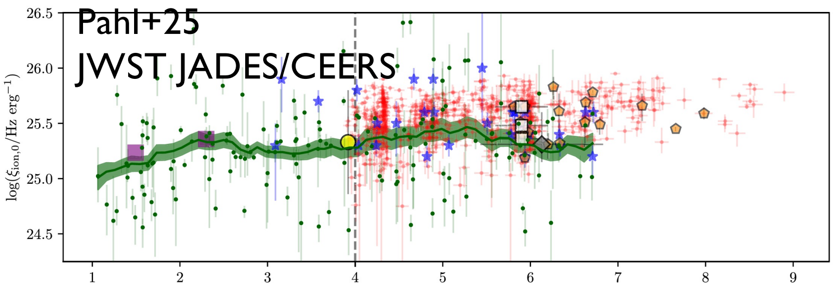


Begley+25
JWST PRIMER/JADES

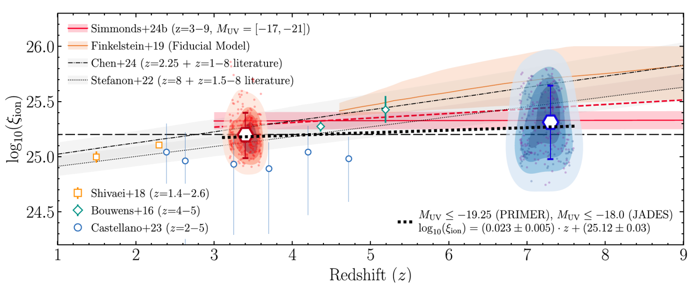


Is ξ_{ion} Changing with Redshift and/or Other Galaxy Properties?

Pahl+25
JWST JADES/CEERS



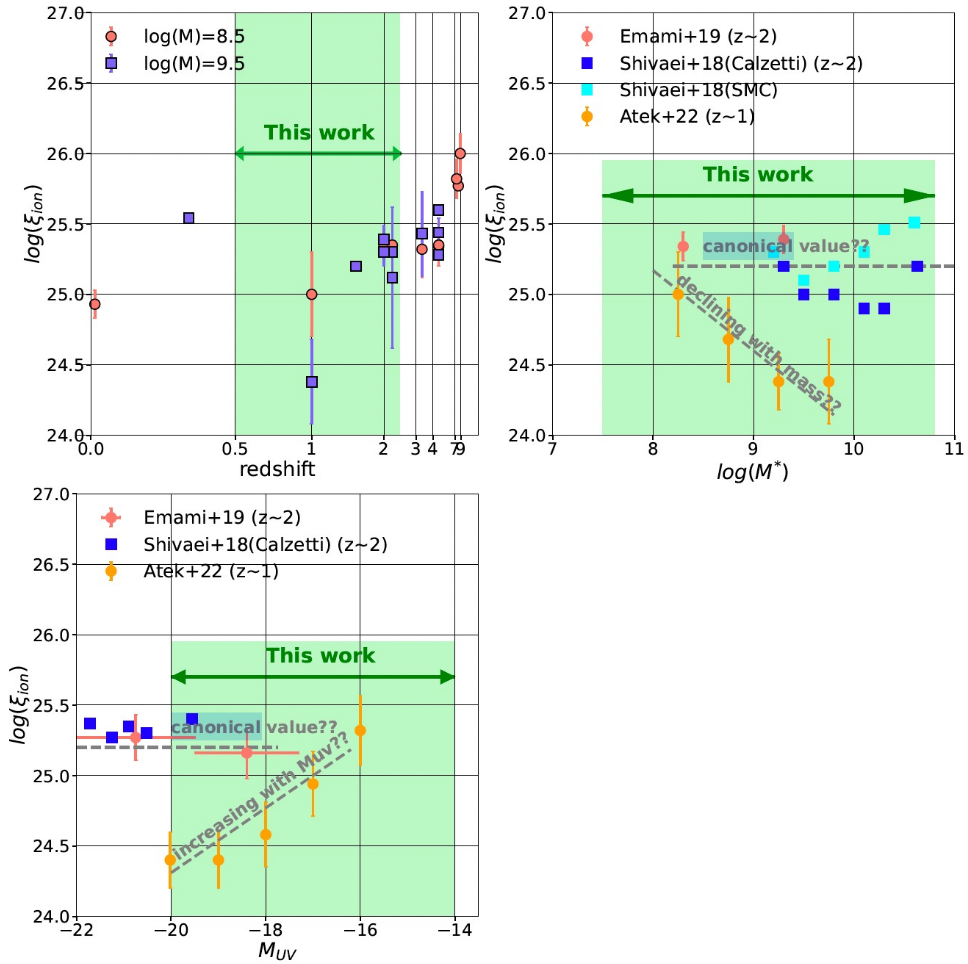
Atek+24
JWST/A2744



Llerena+25
JWST spectroscopic surveys

See also, Bouwens+16; Lam19

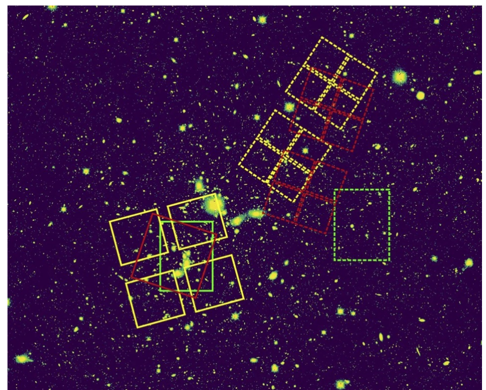
Zoom into Cosmic Noon



James Webb Space Telescope　Cycle 3 AR Proposal　**6319**

Measuring ionizing photon production efficiency and characterizing the bursty star formation history of dwarf galaxies at 0.5 < z < 2.4

GLASS/NIRISS footprint



PI: Anahita Alavi

An archival proposal to use the GLASS-JWST ERS:

- NIRISS grism
- two orthogonal grisms, 3 filters
- These grism spectra will probe the Hα emission line at 0.5 < z < 2.3
- **Project is in progress: we have identified 147 lensed galaxies at 0.5 < z < 2.3, all with robust detections in both Hα and UV continuum (SNR > 3 for each).**

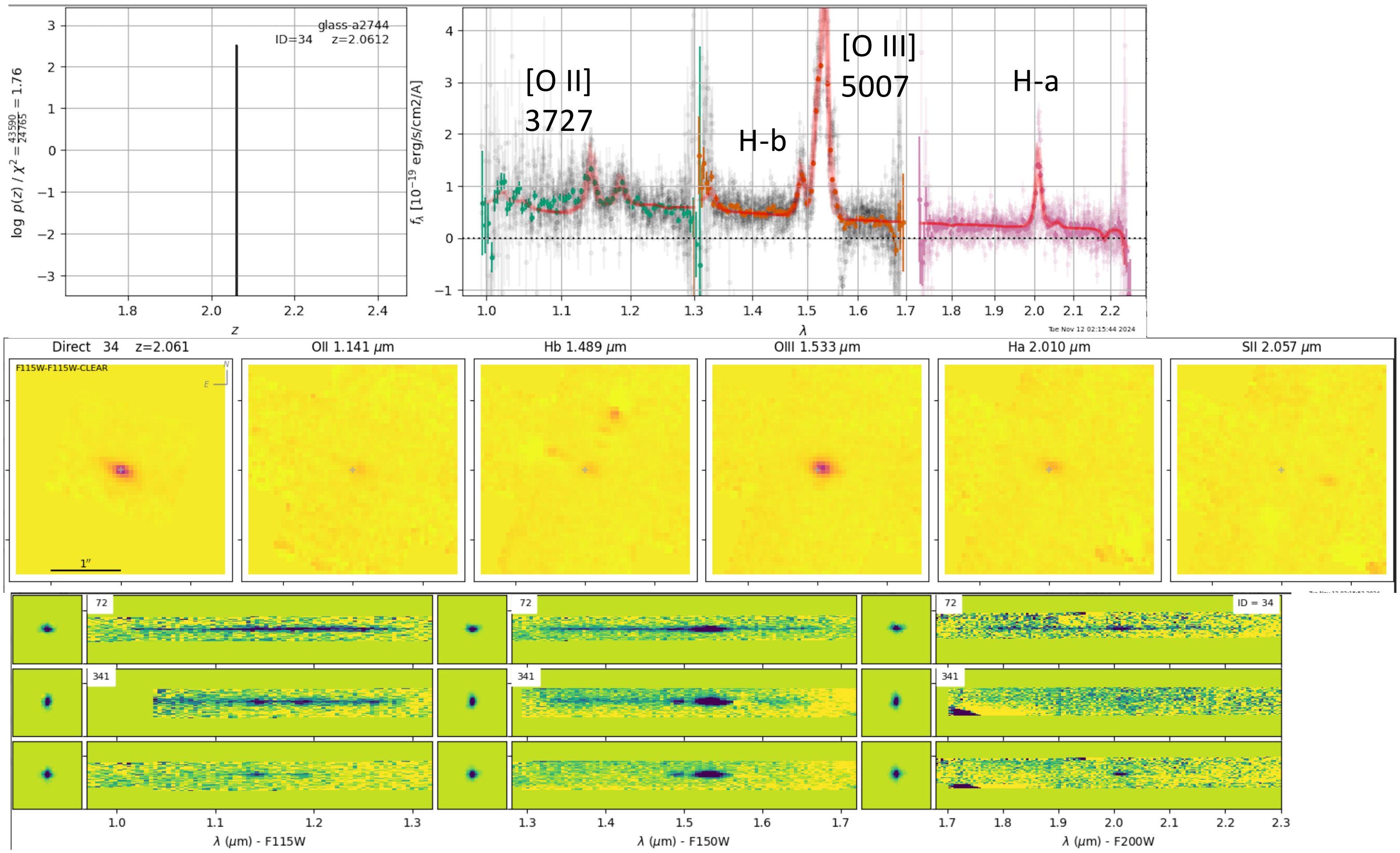
Analysis

- **The NIRISS** grism catalog with secure redshift confirmed with visual inspection (Watson et al. 2025)
- **Dust exinction correction** for both H-a and UV-continuum based on the Balmer decrement and UV-contninuum slope following the extinction laws/cuvers commonly employed (i.e., Cardelli+89; Gordon+03)
- **Correcting for [NII] contamination** from H-a flux using the factor provided by Faisst+18
- Assuming the case B recombination,

$$L(H\alpha)\ [erg\ s^{-1}] = 1.36 \times (1 - f_{esc})\ 10^{-12}\ \dot{N}_{\rm ion}\ [s^{-1}]$$

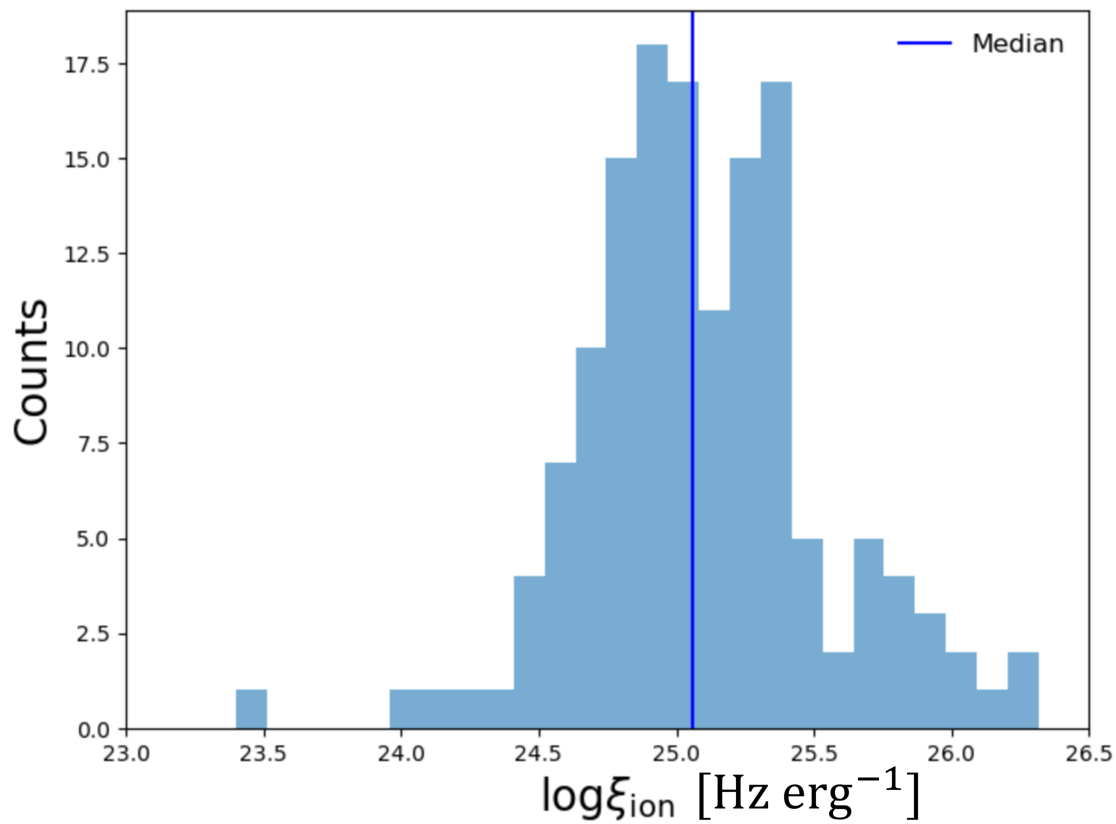
$$\xi_{\rm ion} = \frac{\dot{N}_{\rm ion}}{L_{UV}}\ [erg^{-1}\ Hz]$$

Example Grism; a galaxy at z=2.06



ξ_{ion} distribution

- Median $\log(\xi_{ion})$ of ~ 25.06 ± 0.6, broadly consistent with other studies at similar redshift Emami+20;Atek+22;Pahl+25



Kim+26b, in prep.

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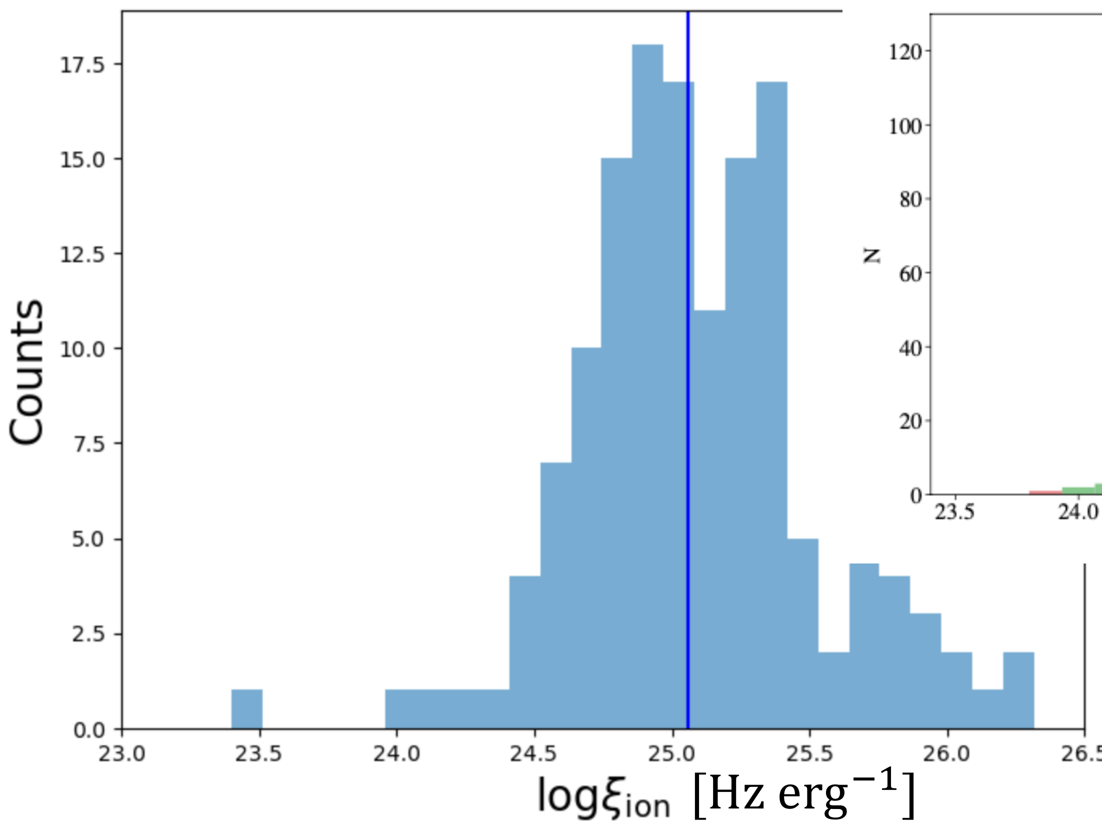
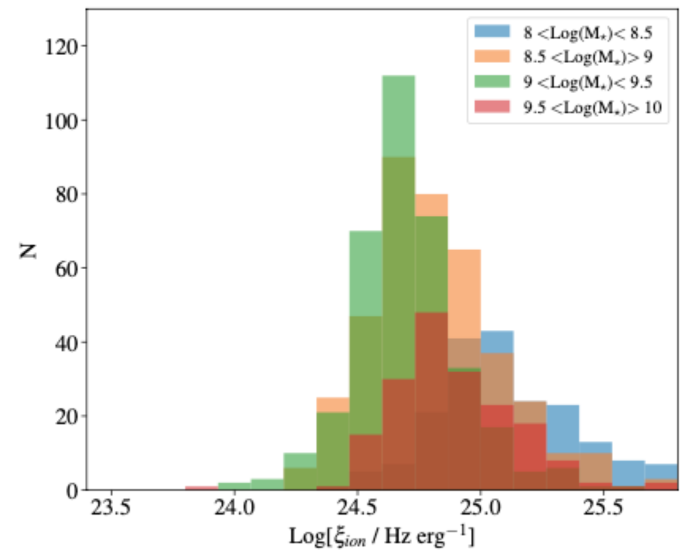
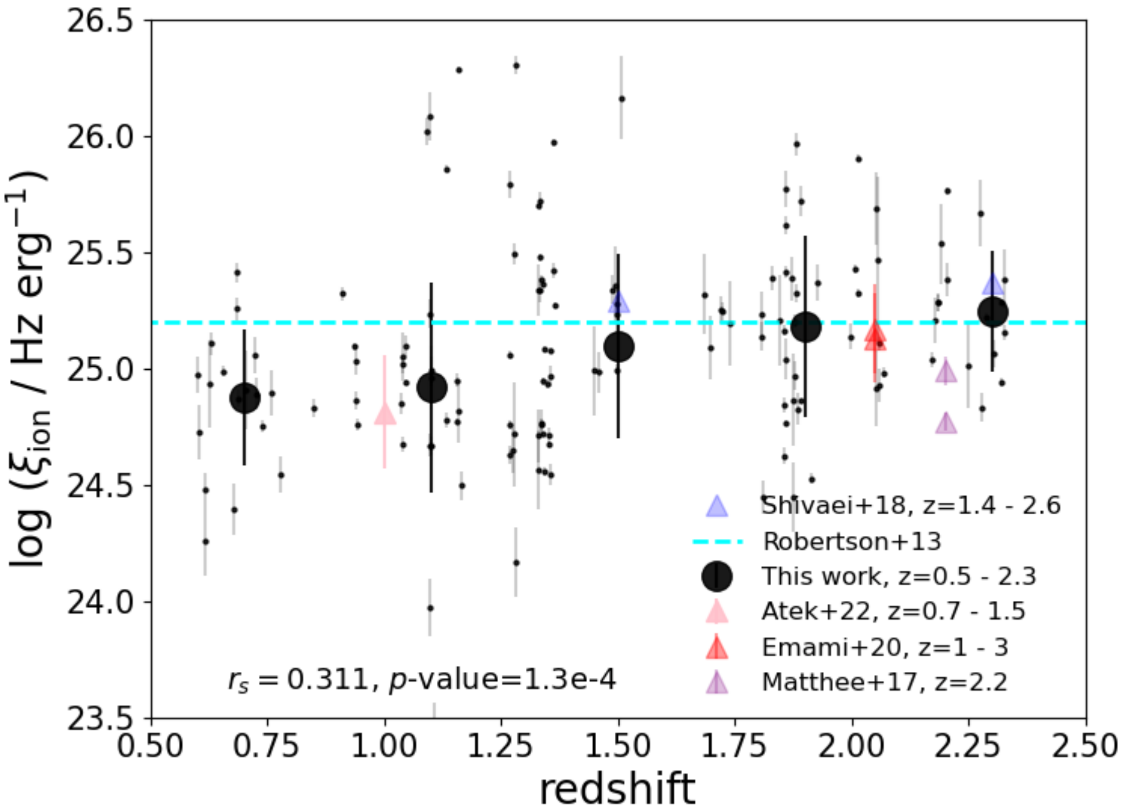




ξ_{ion} for galaxies at 0.7 < z < 1.5 (Atek+22)

Kim+26b, in prep.

ξ_{ion} vs. redshift



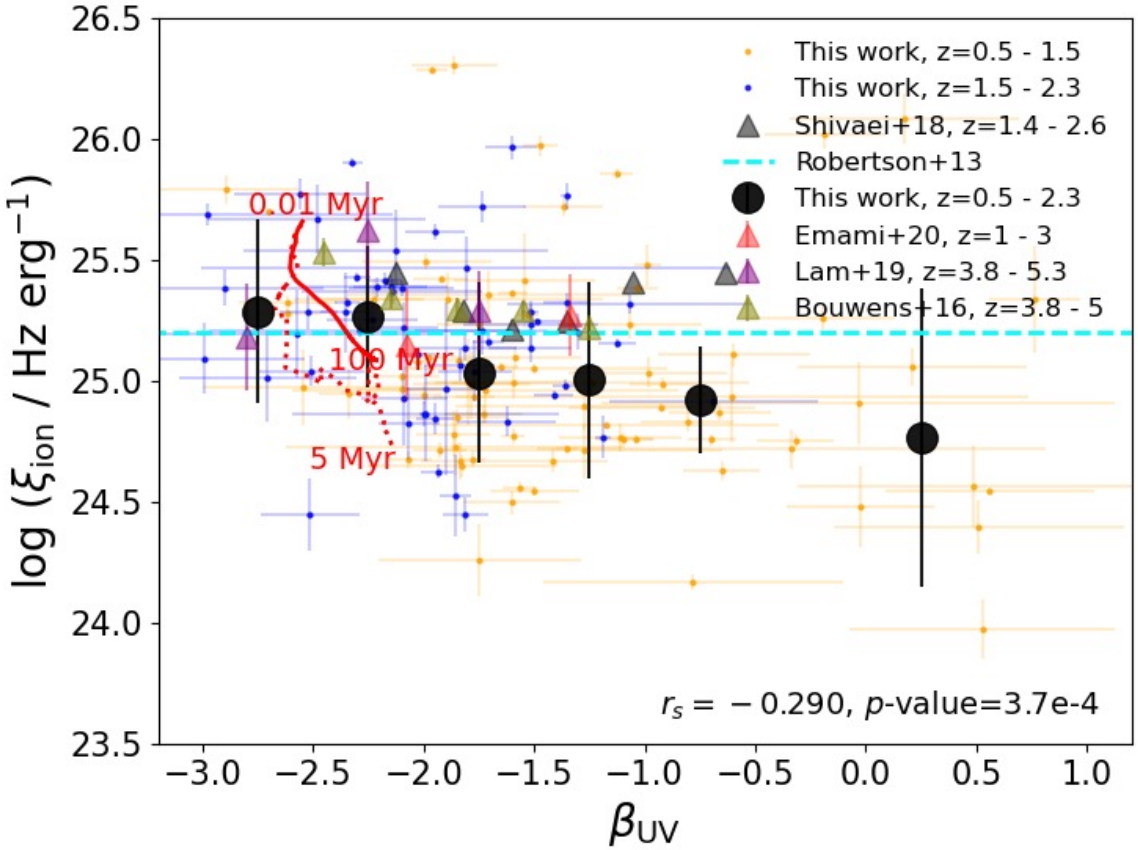
- At 0.5 < z < 2.3, ξ_{ion} and redshift shows a weak to moderate correlation, but with very high statistical significance (p-value = 1.3e-4).

- This result extends the analysis of redshift evolution down to low redshift (z = 0.5).

c.f., Matthee+17; Shivaei+18; Emami+20;Atek+22;Pahl+25; Llerena+25, and references therein for a wide range of redshift (0.5 < z < 7).

Kim+26b, in prep.

ξ_{ion} vs. UV-continuum slope β

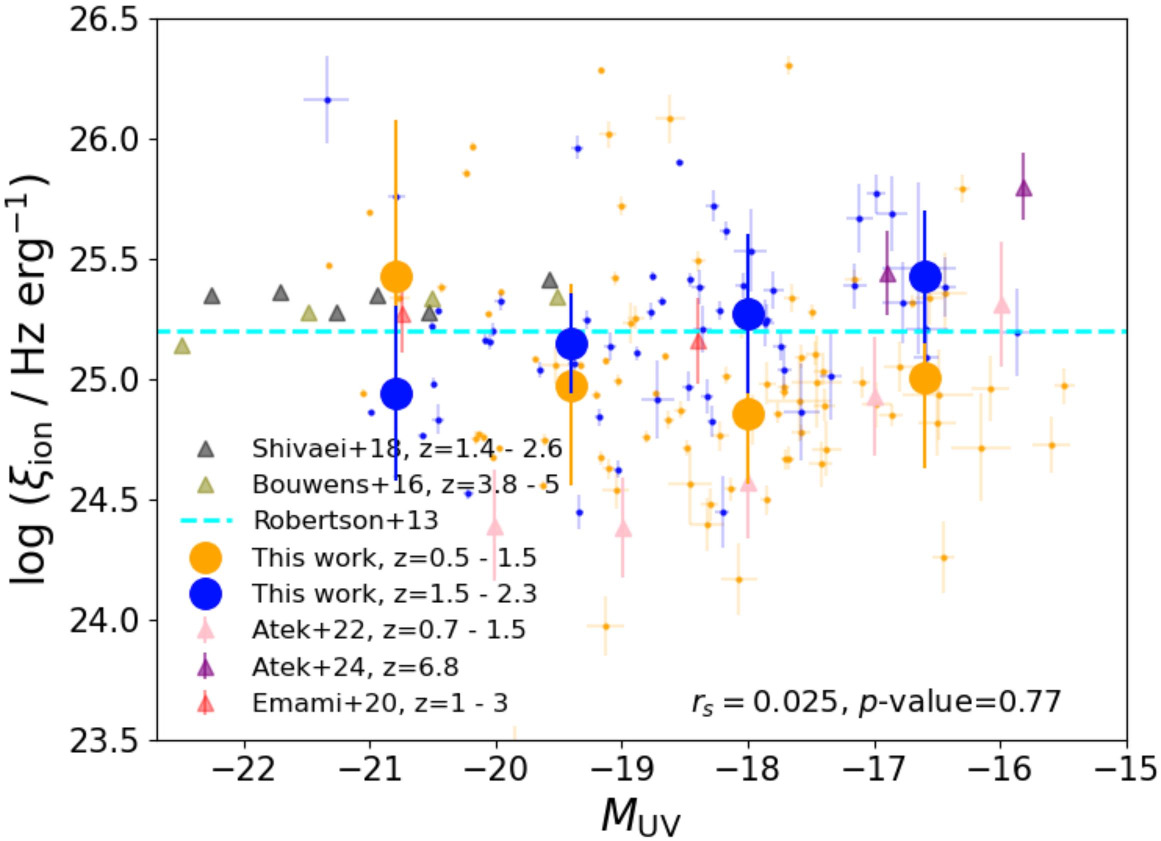


Kim+26b, in prep.

- Both ξ_{ion} and UV slope is sensitive to starburst age (that is, burstiness), such that **younger starbursts** tend to exhibit **higher** ξ_{ion} and **bluer UV slope** (e.g., Schaerer 03).
- Starburst models (red curves) from Schaerer02.
- ξ_{ion} and UV slope shows a weak to moderate correlation, but with very high significance (p-value = 3.7e-4, ~4σ)

c.f., Bouwens+16; Izotov+17; Shivaei+18; Lam+19; Emami+20; Pahl+25 for relations between ξ_{ion} and β over a wide range of redshift (0 < z < 6)

ξ_{ion} vs. UV luminosity



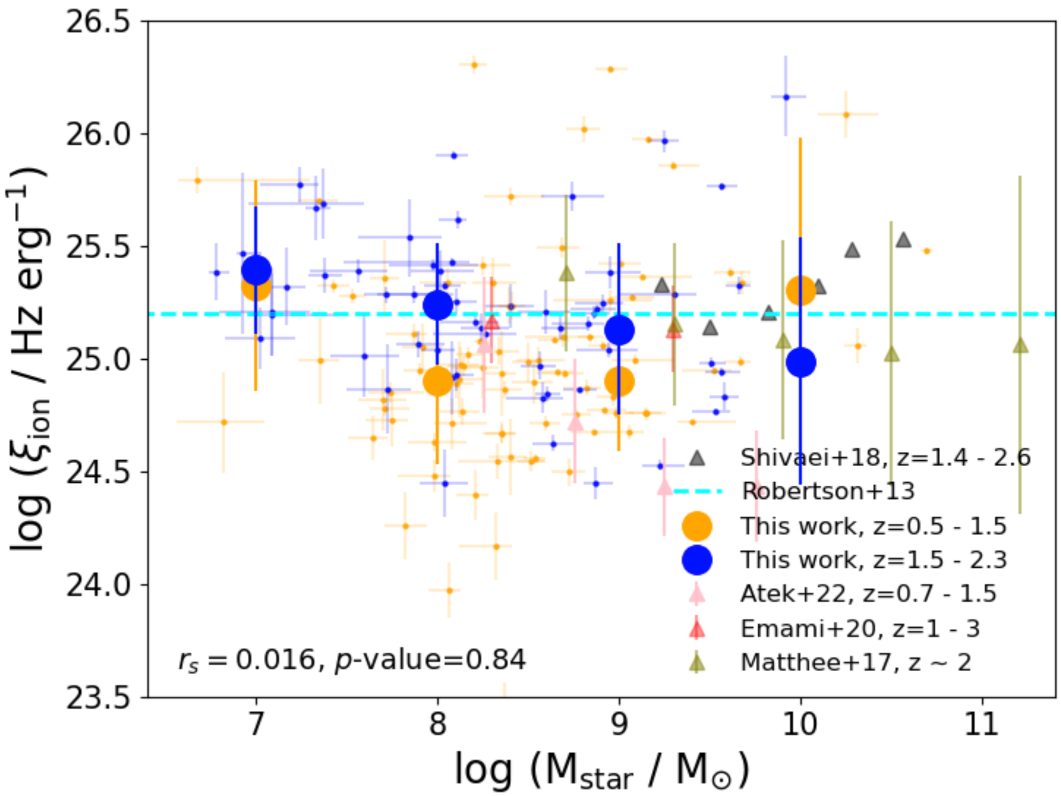
Kim+26b, in prep.

- The relationship between ξ_{ion} and $M_{\rm UV}$ has been widely studied to determine whether dwarf galaxies are efficient producers of ionizing photons (e.g., Atek+24) or whether there is no significant depdence (e.g., Lam+19).

- In our galaxy sample, the low-z (0.5 < z < 1.5) subsample does not show an increasing trend of ξ_{ion} with increasing $M_{\rm UV}$ (**orange circles**). In contrast, **the high-z (1.5 < z < 2.3) subsample shows an increasing trend of ξ_{ion} with increasing M_{UV}** (**blue circles**).

c.f., Bouwens+16; Izotov+17; Shivaei+18; Lam+19; Emami+20; Atek+22, 24 Pahl+25 for relations between ξ_{ion} and $M_{\rm UV}$ over a wide range of redshift (0 < z < 7)

ξ_{ion} vs. Stellar mass



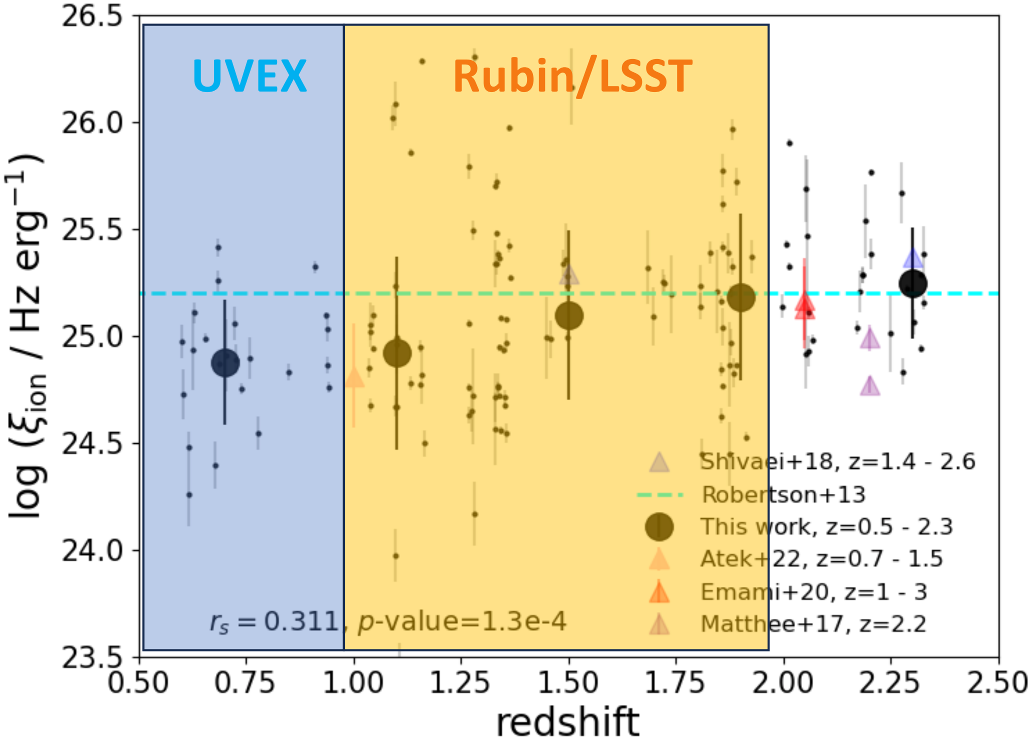
Kim+26b, in prep.

-The trend of $\xi_{\rm ion}$with $M_{\rm star}$ is qualitatively consistent with that observed for UV luminosity. Specifically, the high-redshift ($1.5 < z < 2.3$) subsample (**blue circles**) exhibits **increasing $\xi_{\rm ion}$toward lower stellar masses**, analogous to the increase in $\xi_{\rm ion}$toward fainter $M_{\rm UV}$.

- Stellar mass obtained from the UNCOVER-MeGaScience catalog (Wang+24).

c.f., Bouwens+16; Izotov+17; Shivaei+18; Lam+19; Emami+20; Atek+22, 24 Pahl+25; Llerena+25 for relations between ξ_{ion} and $M_{\rm star}$ over a wide range of redshift (0 < z < 7)

Demographics of Ionizing Efficiency and Bursty Star Formation Across Cosmic Noon (0.5 < z < 1.9) with Roman (+UVEX + Rubin/LSST)



* **Roman grism spectroscopy (HLWAS Medium Tier)**
- Emission-line flux limit: 1.5x10^{-16} erg cm^{-2} s^{-1} (5σ)
- Corresponds to Hα-derived SFR = 1–20 $M_{\odot}\ yr^{-1}$ at 0.5 < z < 1.9 (Kennicutt & Evans 2012)
- Using the SF main sequence (e.g., Speagle et al. 2014), this corresponds to log($M_{\rm star}$/ $M_{\odot}$) ≈ 8.9–10, probing the *sub-M galaxy population** (e.g., Tomczak et al. 2014; Weaver et al. 2022)

* **Rest-frame (~1500 Å) UV luminosity**
- 0.55 < z < 0.9: UVEX Near-UV imaging to 25.8 mag (planned launch in 2030)
- 0.9 < z < 1.9: Rubin/LSST 2-year g-band imaging to 26.0 mag

* **Unique science enabled by the wide survey area**
- Measuring ξ_ion and bursty star formation for large samples
- Investigating their dependence on:

Environment: from cosmic voids to galaxy clusters
Morphology: Diffuse, compact, clumpy galaxies

References: Roman HLWAS; UVEX; Rubin/LSST

Demographics of Ionizing Efficiency and Bursty Star Formation Across Cosmic Noon (0.5 < z < 1.9) with Roman (+UVEX + Rubin/LSST)

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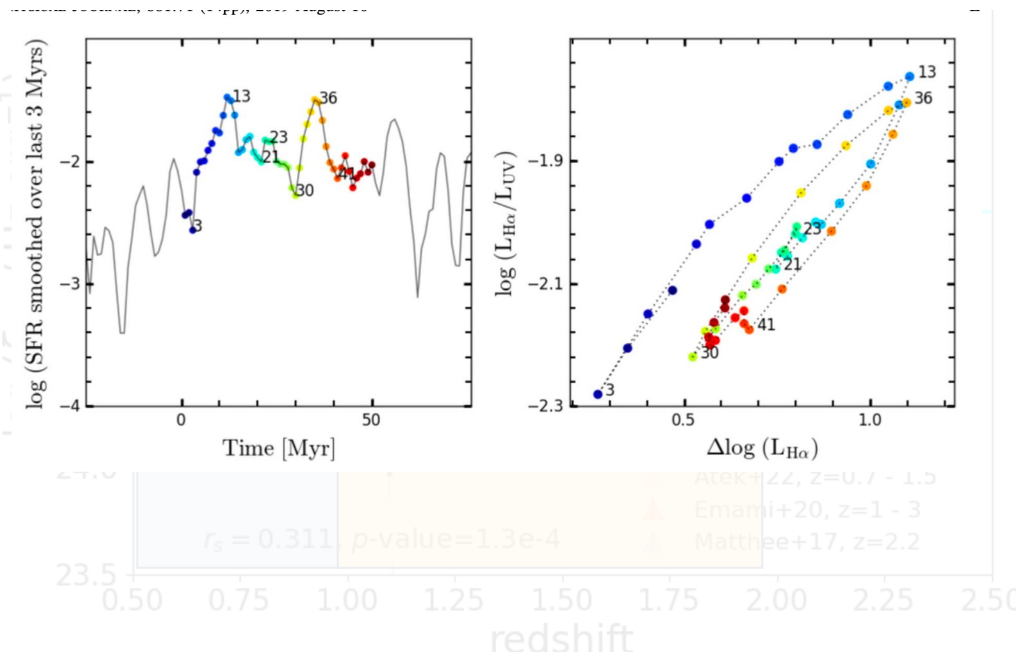
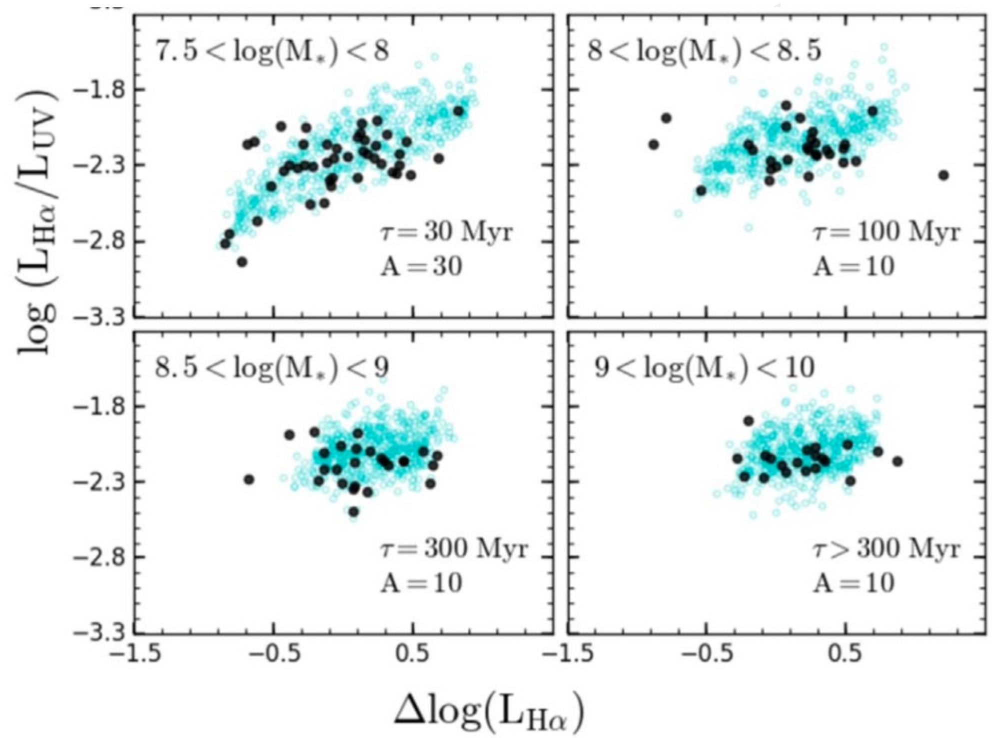
Bursty star formation histories traced by Hα and UV-continuum





Emami+19 (see also Weisz+12; El-Badry et al. (2018); Hopkins et al. (2018)

References: Roman HLWAS; UVEX; Rubin/LSST

Summary & Conclusions

- We have been measuring the ionizing photon production efficiency (ξ_{ion}) of dwarf galaxies to estimate their contribution to the ionizing photon budget.

- By leveraging gravitational lensing, we extend previous ξ_{ion} measurements to include very faint galaxies (M_UV ~ -15). Moreover, JWST's Grism spectroscopy allows for unbiased sample selection.

- *ξ_{ion} distribution*: Measurements of ξ_{ion} of the entire sample (with grism visual inspection) show **the median log(ξ_{ion}) of 25.06 ± 0.6, broadly consistent with the literature**.

- *ξ_{ion} and redshift*: There is a **weak to moderate positive correlation, with high statistical significance**, between ξ_{ion} and redshift in our sample at 0.5 < z < 2.3 —indicating that galaxies at higher redshifts tend to exhibit higher ξ_{ion}.

- *ξ_{ion} and UV slope*: We also find a **weak to moderate negative correlation**, **again with high significance,** between ξ_{ion} and UV slope. Galaxies with higher ξ_{ion} tend to show bluer UV slope , which may suggest that **starburst age (burstiness)** plays a key role in shaping both ξ_{ion} and the UV-continuum slope.

- *ξ_{ion} and UV luminosity and stellar mass*: the low-z (0.5 < z < 1.5) subsample **does not show an increasing trend of ξ_{ion} with increasing M_{UV} (decreasing M_{star})**. In contrast, the high-z (1.5 < z < 2.3) subsample **shows an increasing trend of ξ_{ion} with increasing M_{UV} (decreasing M_{star}).**