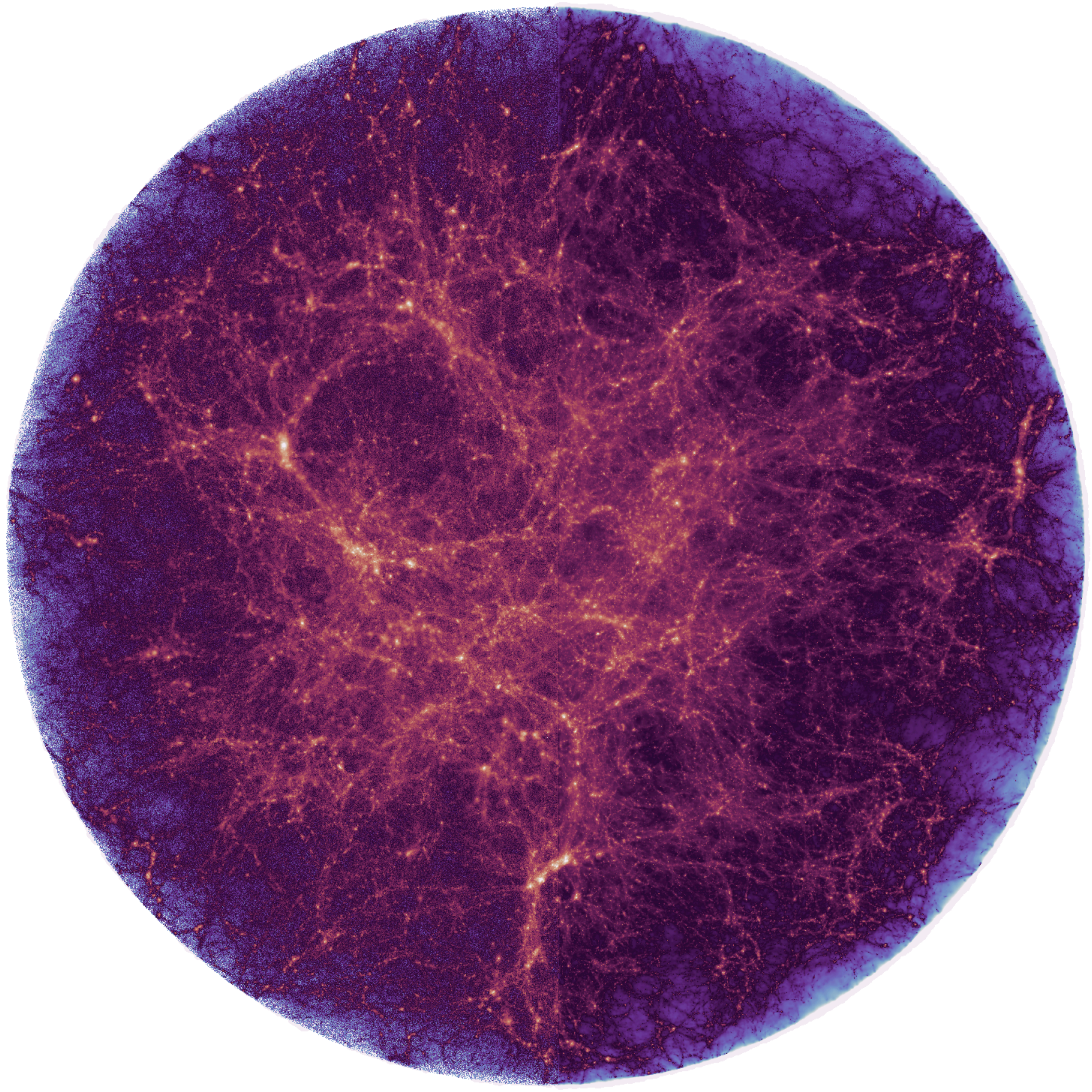
Ionising Properties of Galaxies in the EoR

FLARES: First Light And Reionisation Epoch Simulations



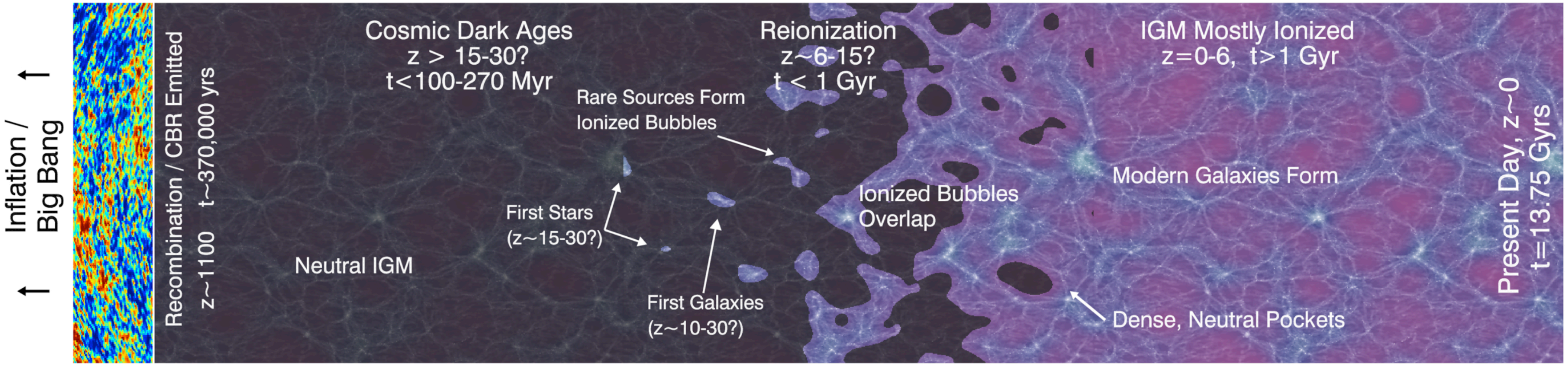
Louise Seeyave, 18 April 2023
Supervisors: Stephen Wilkins, Peter Thomas
University of Sussex

UNIVERSITY OF SUSSEX

Outline

1. Introduction: $\dot{N}_{\rm ion,intr}$ and $\xi_{\rm ion}$
2. Theory
3. Simulations and observations
4. FLARE simulations
5. Ionising properties of galaxies in FLARES
6. Conclusion

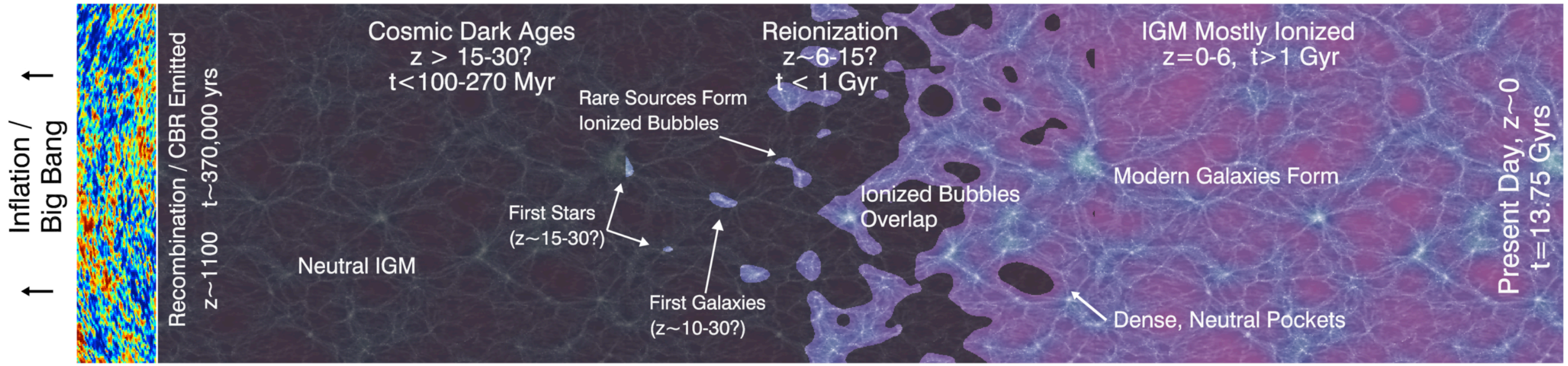
Sources of reionisation



Credit: Robertson et al. 2010, Nature

Sources of reionisation

Stars and AGN in high-redshift galaxies



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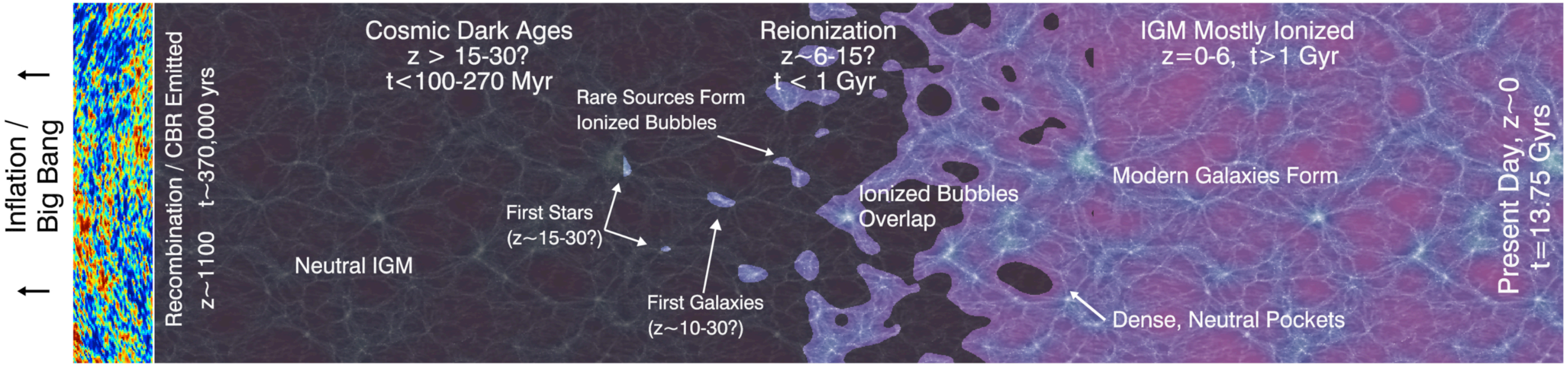
Sources of reionisation

Stars and AGN in high-redshift galaxies

- To what extent do each contribute?



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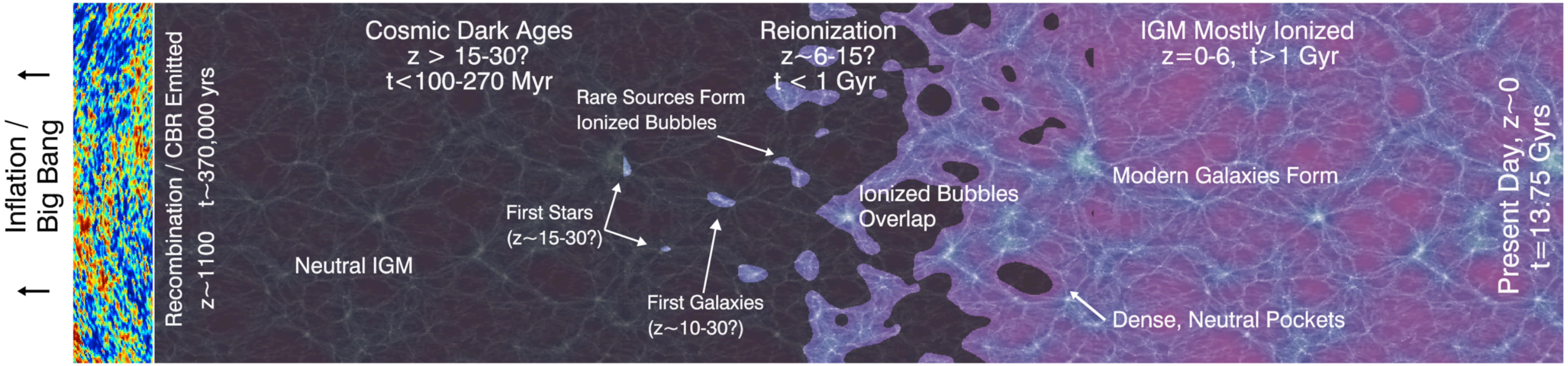

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Sources of reionisation

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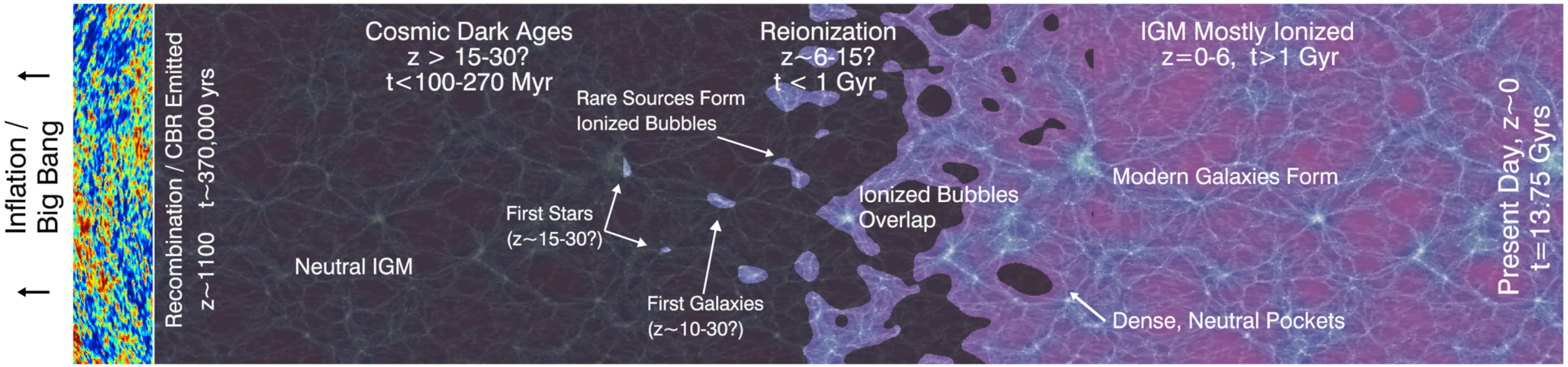
- How much ionising radiation escapes into the IGM?



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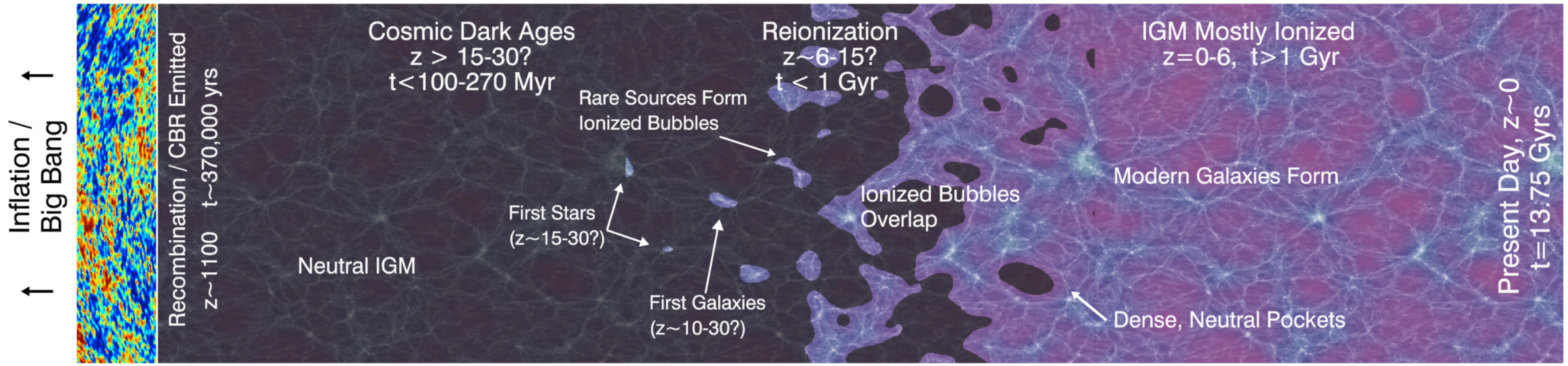

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Ionising properties of a source

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$$\dot{N}_{\rm ion,esc} = f_{\rm esc} \times \dot{N}_{\rm ion,intr}$$

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Intrinsic far-UV luminosity

Ionising properties of a source

Intrinsic ionising emissivity: $\dot{N}_{\rm ion,intr}$

Specific ionising emissivity: $\dot{N}_{\rm ion,intr}/M_*$

Ionising photon production efficiency: $\xi_{\rm ion} = \dfrac{\dot{N}_{\rm ion,intr}}{L_{\rm UV}}$

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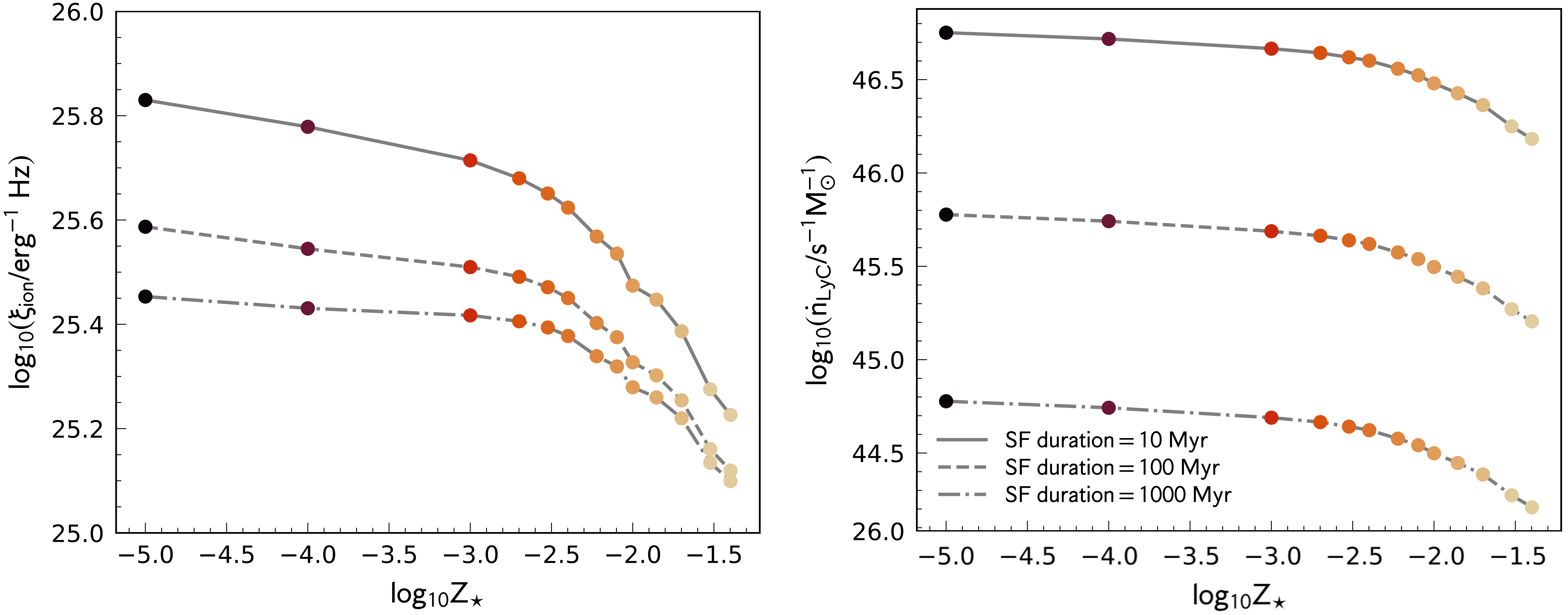
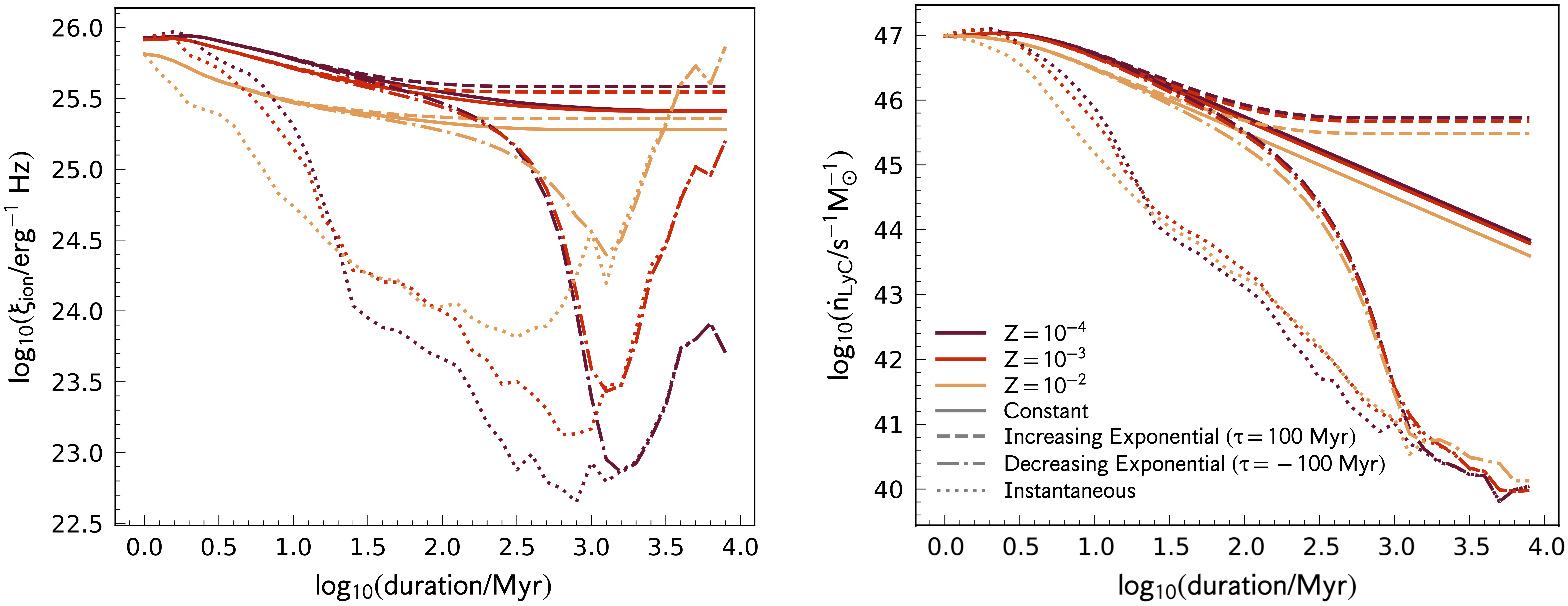
SFH and Z

SF duration: galaxy has experienced x Myr of continuous star formation



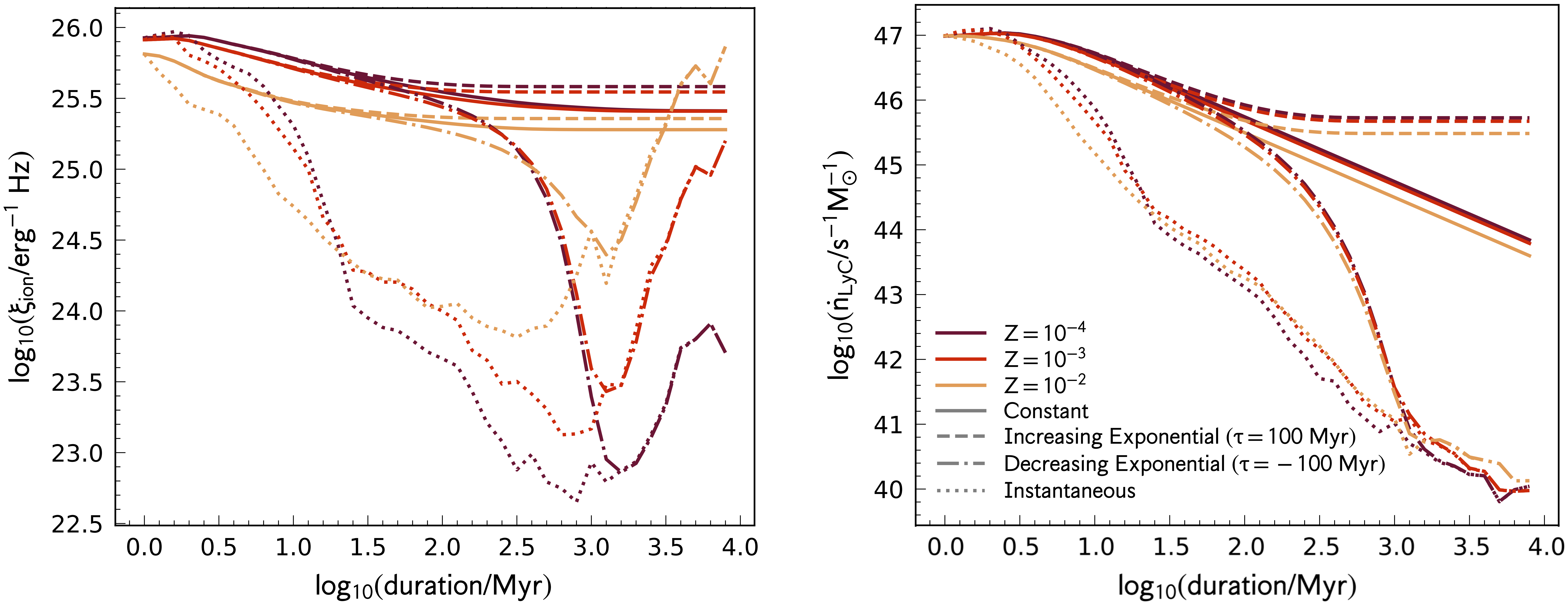
SFH and Z



26.0
25.5
25.0
24.5
24.0
23.5
23.0
22.5
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
$\log_{10}(\xi_{ion}/erg^{-1}\ Hz)$
$\log_{10}(duration/Myr)$
47
46
45
44
43
42
41
40
$\log_{10}(\dot{n}_{LyC}/s^{-1}M_{\odot}^{-1})$
$Z = 10^{-4}$
$Z = 10^{-3}$
$Z = 10^{-2}$
Constant
Increasing Exponential ($\tau = 100$ Myr)
Decreasing Exponential ($\tau = -100$ Myr)
Instantaneous

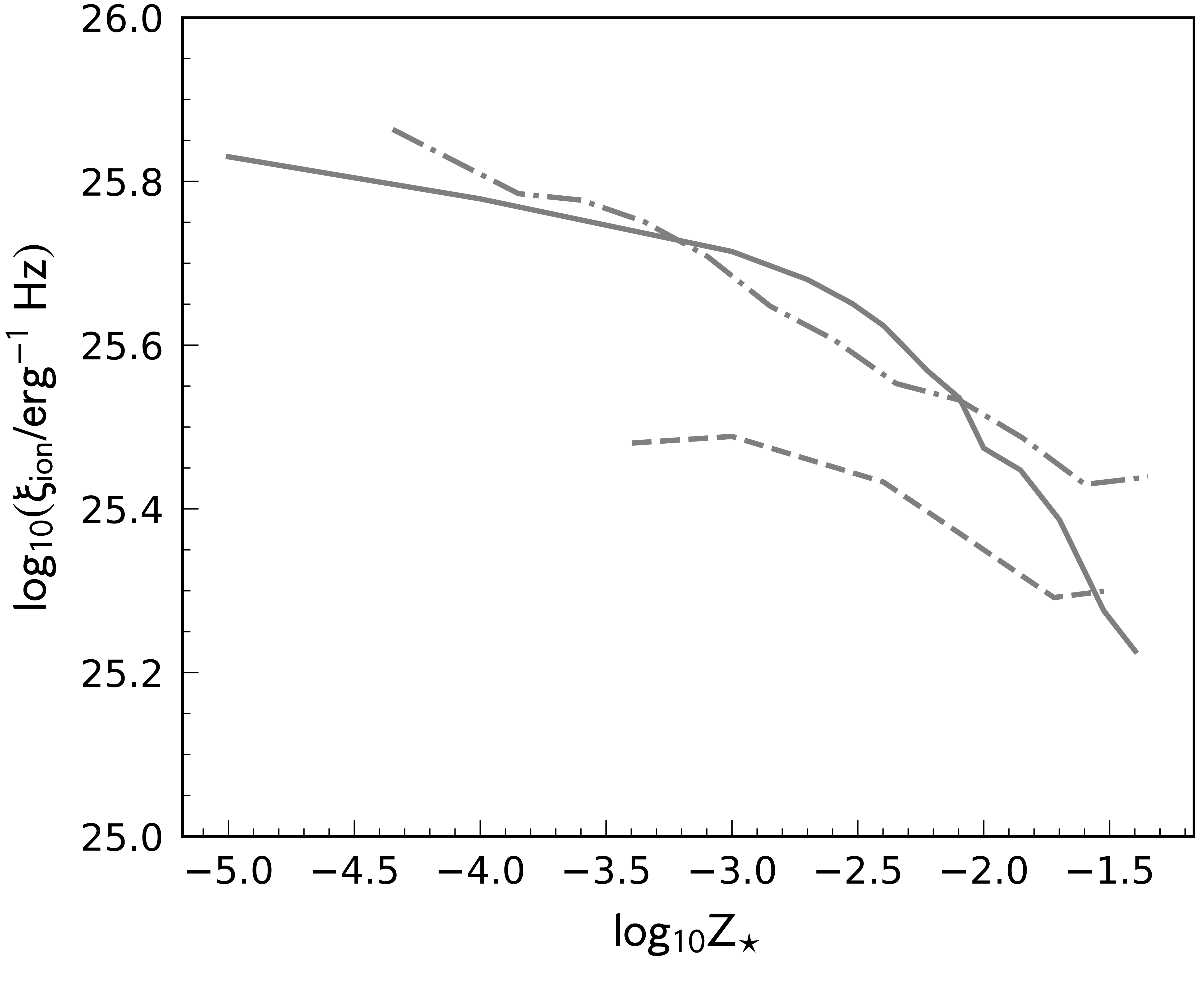
SFH and Z

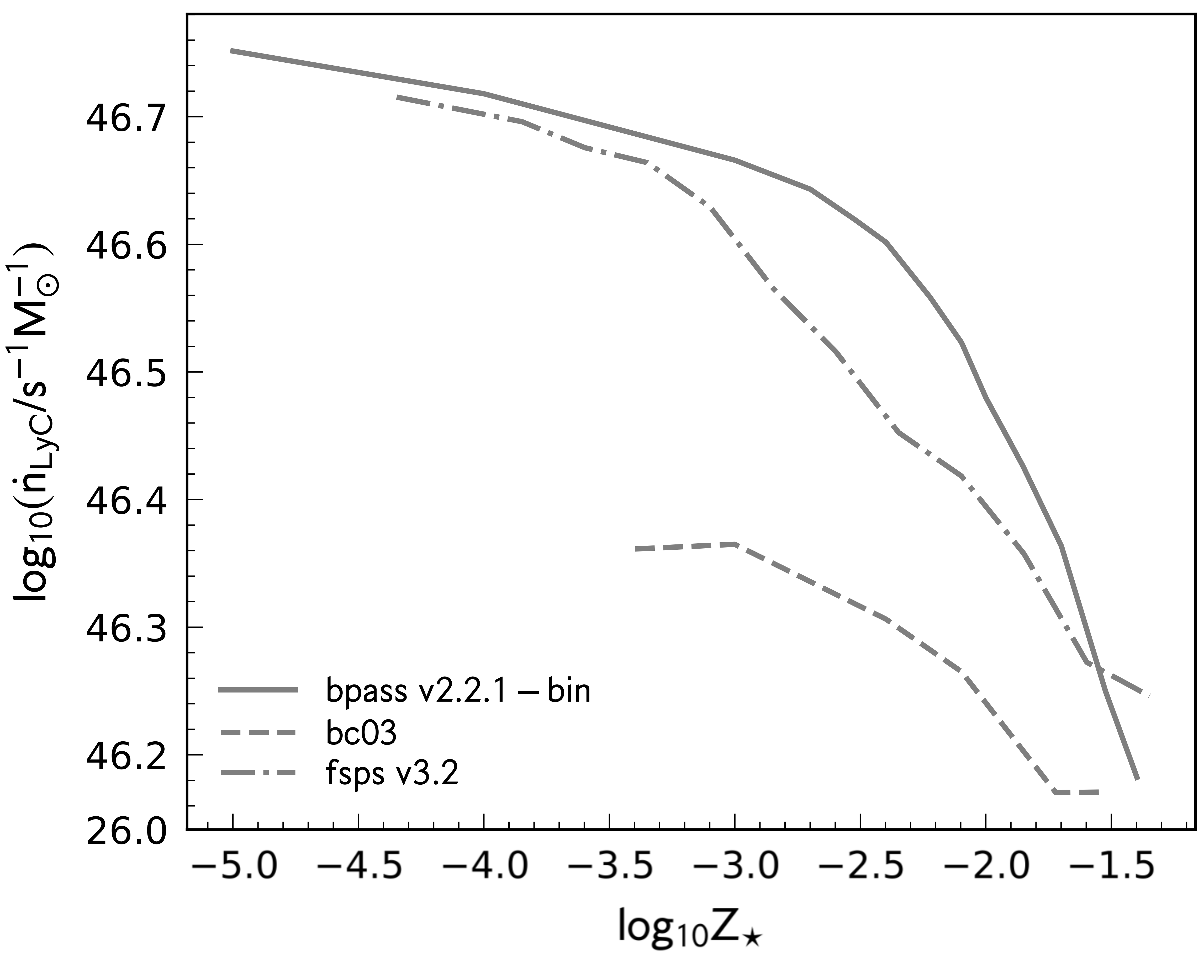
SPS model: binary v2.2.1 BPASS (Stanway & Eldridge 2018)



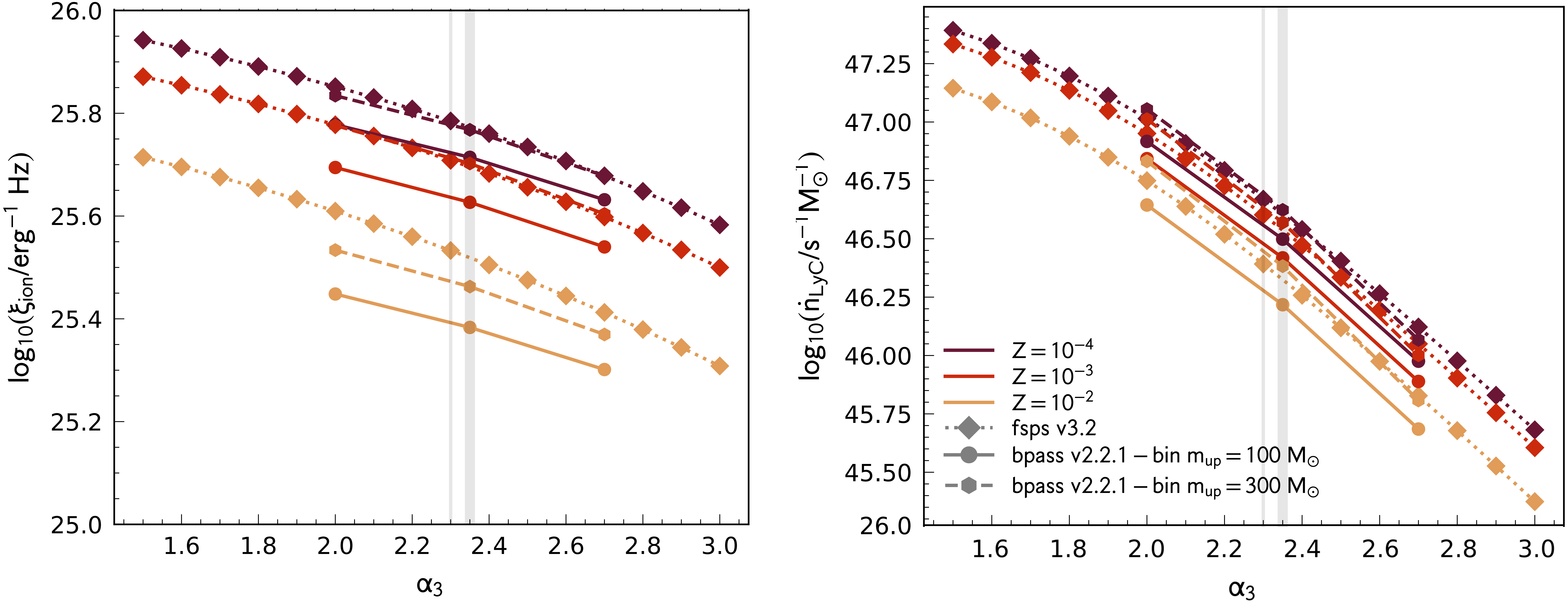
SPS model

- BPASS v2.2.1 — binary (Stanway & Eldridge 2018)
- BC03 (Bruzual & Charlot 2003)
- FSPS v3.2 (Conroy & Gunn 2010)





IMF



26.0
25.8
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$\log_{10}(\xi_{ion}/erg^{-1}\ Hz)$
1.6
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3.0
α_3
47.25
47.00
46.75
46.50
46.25
46.00
45.75
45.50
26.0
$\log_{10}(\dot{n}_{LyC}/s^{-1}M_\odot^{-1})$
$Z = 10^{-4}$
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fsps v3.2
bpass v2.2.1 – bin $m_{up} = 100\ M_\odot$
bpass v2.2.1 – bin $m_{up} = 300\ M_\odot$

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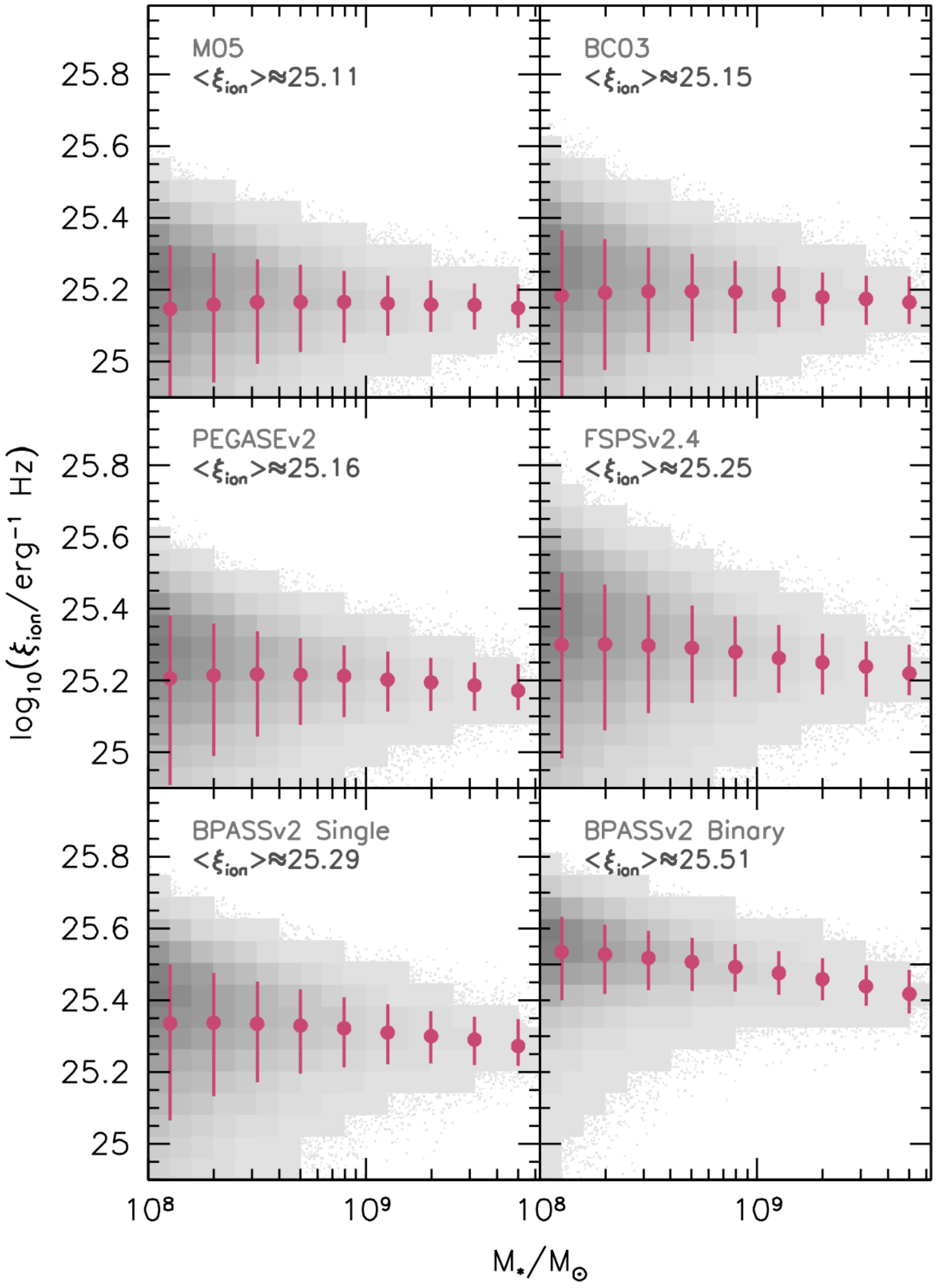
Observing $\xi_{\rm ion}$

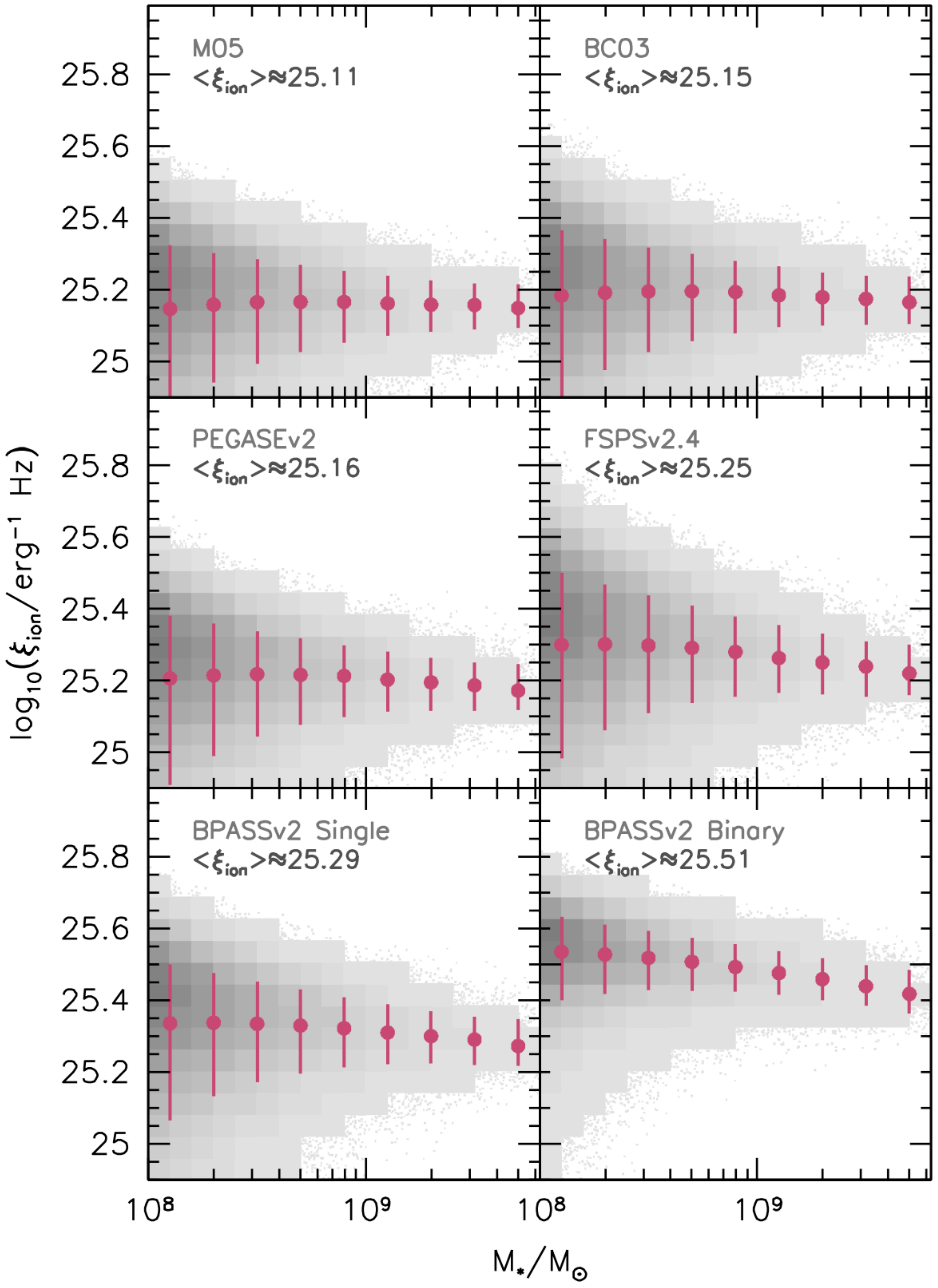
- Estimate $\dot{N}_{\rm ion,intr}$ from Balmer recombination lines (using spectroscopy or estimated from colours)
  - Hα — e.g. Bouwens et al. 2016, Harikane et al. 2018, Stefanon et al. 2022
  - Hβ — e.g. Matthee et al. 2022, Fujimoto et al. 2023
- SED fitting
  - E.g. Castellano et al. 2022, Endsley et al. 2022, Tang et al. 2023

Simulating $\xi_{\rm ion}$



Simulating $\xi_{\rm ion}$

Bluetides — Wilkins et al. 2016



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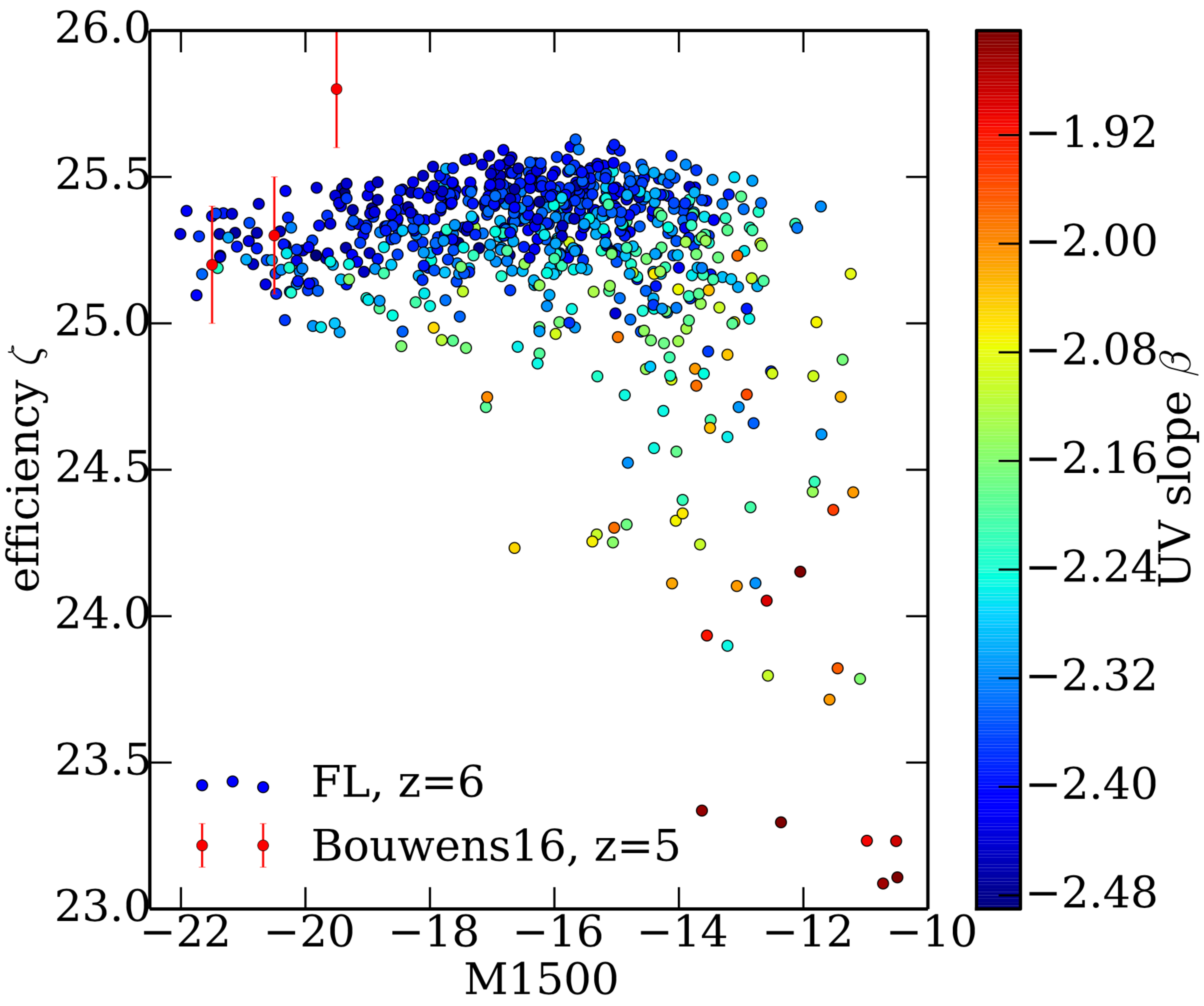

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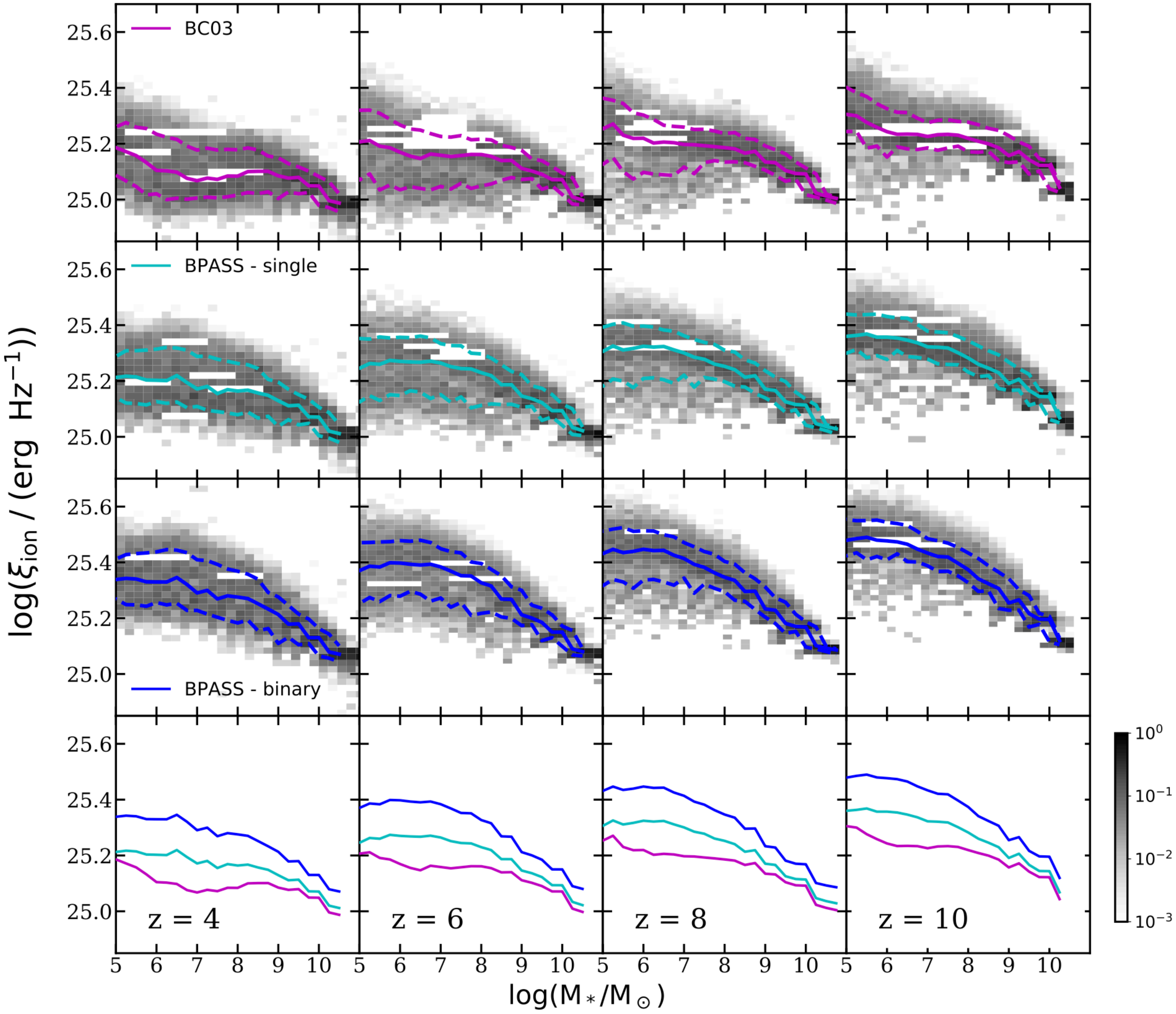
FirstLight — Ceverino et al. 2018

SC SAM — Yung et al. 2020



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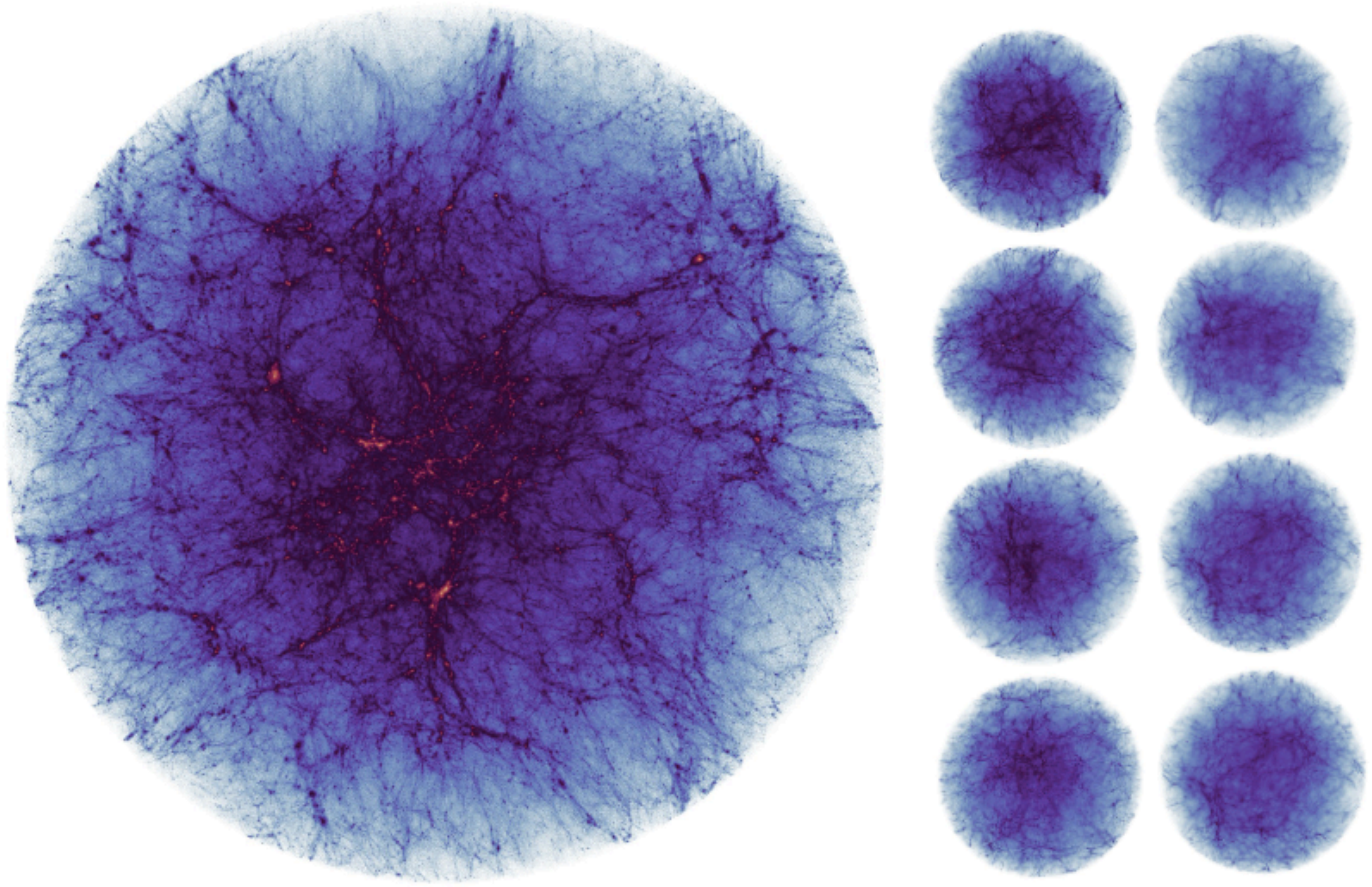
FLARES

Hydrodynamic zoom simulations in the EoR (z>5)



Lovell et al. 2021

FLARES

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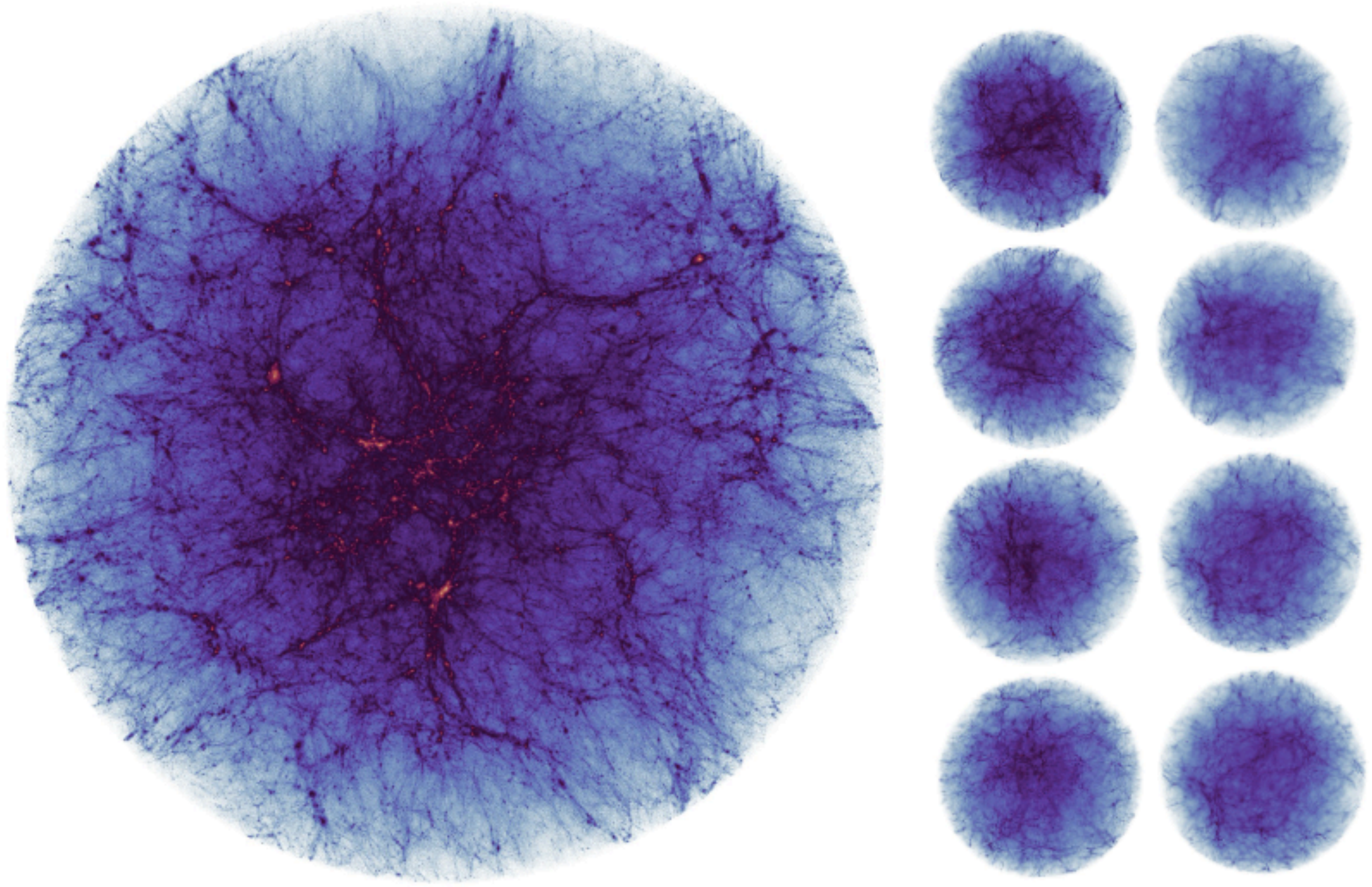
- 40 spherical regions (radius 14 h^{-1}Mpc) selected from a large $(3.2\text{cGpc})^3$ dark matter-only parent box



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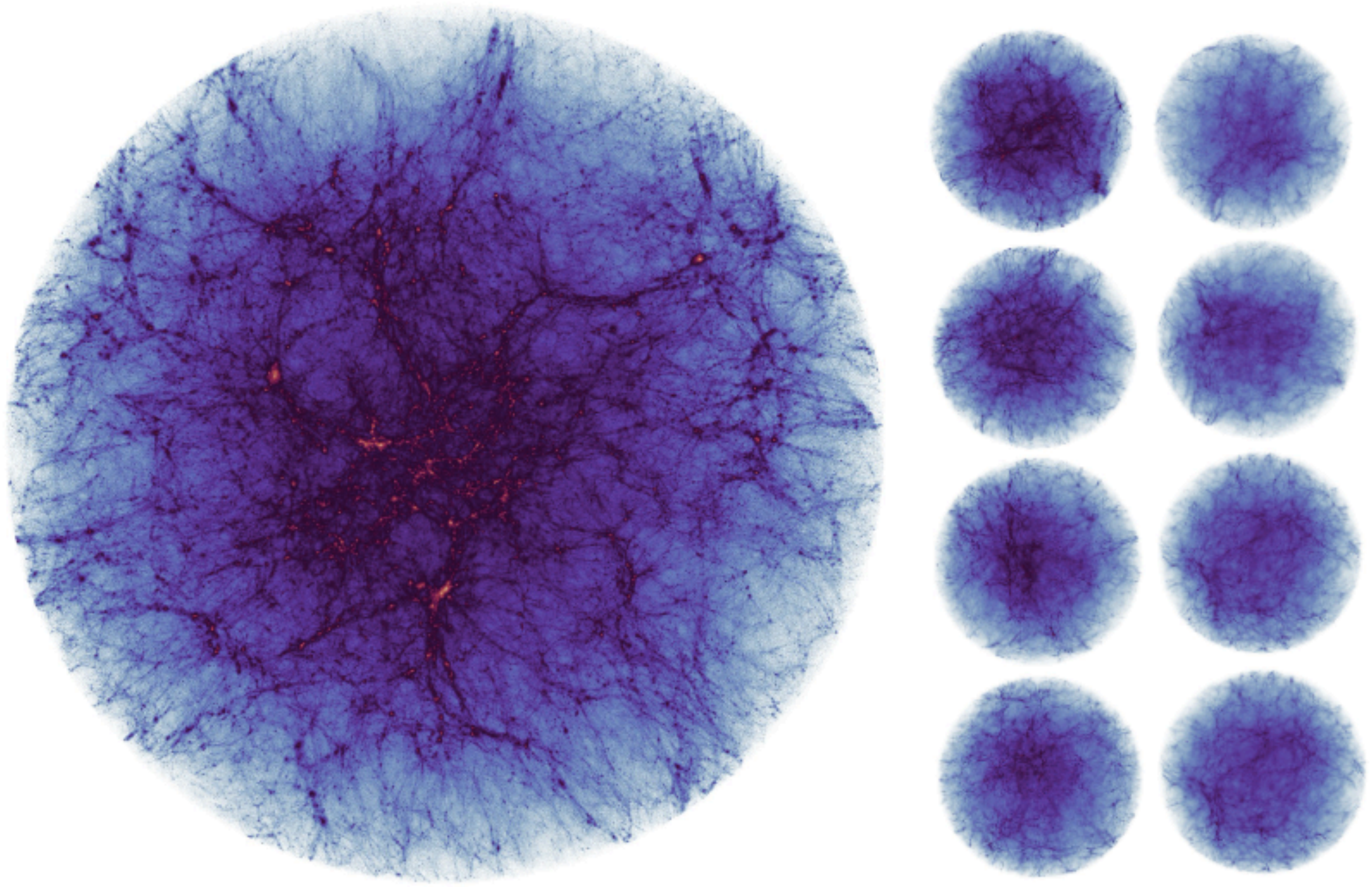

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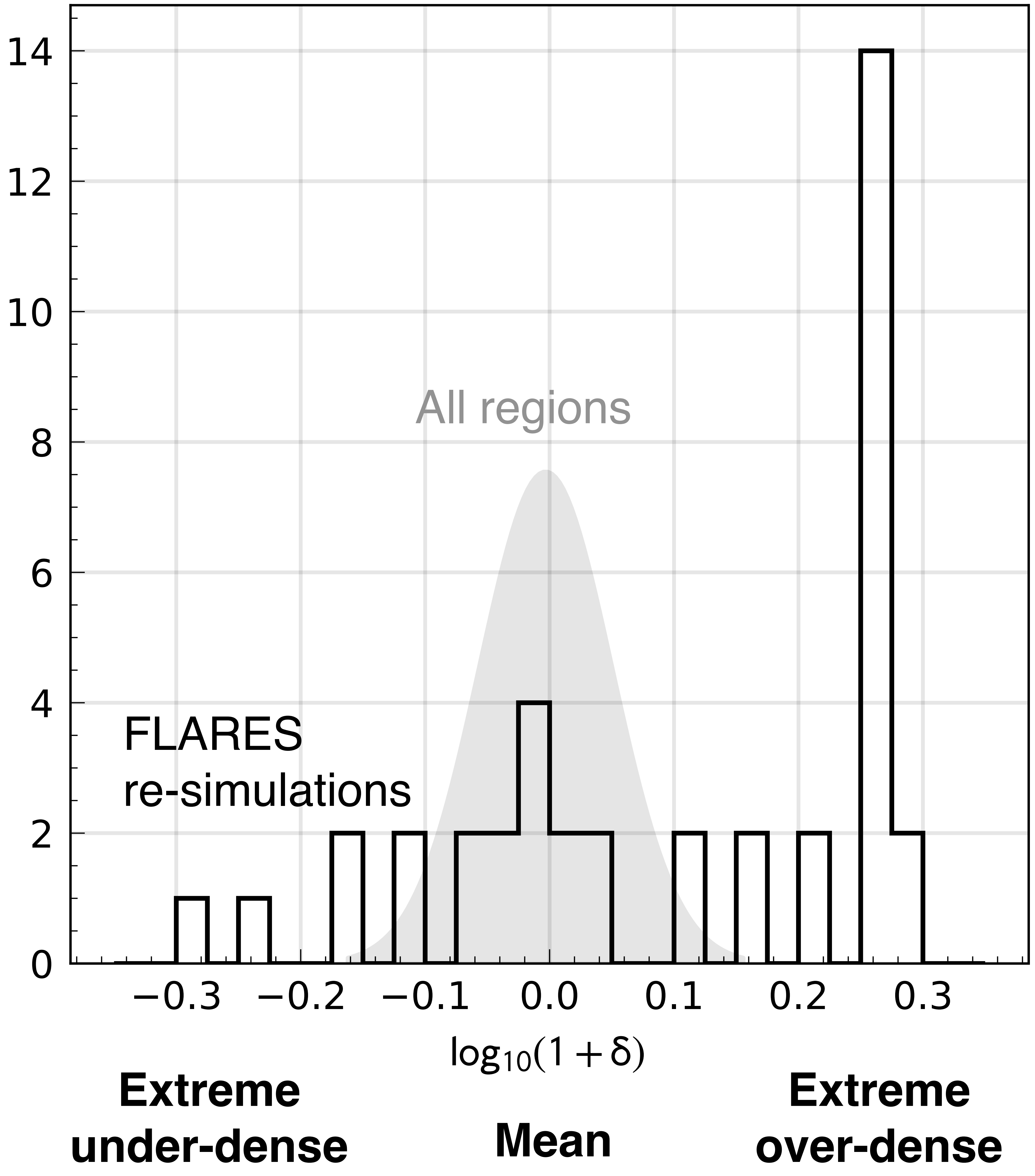

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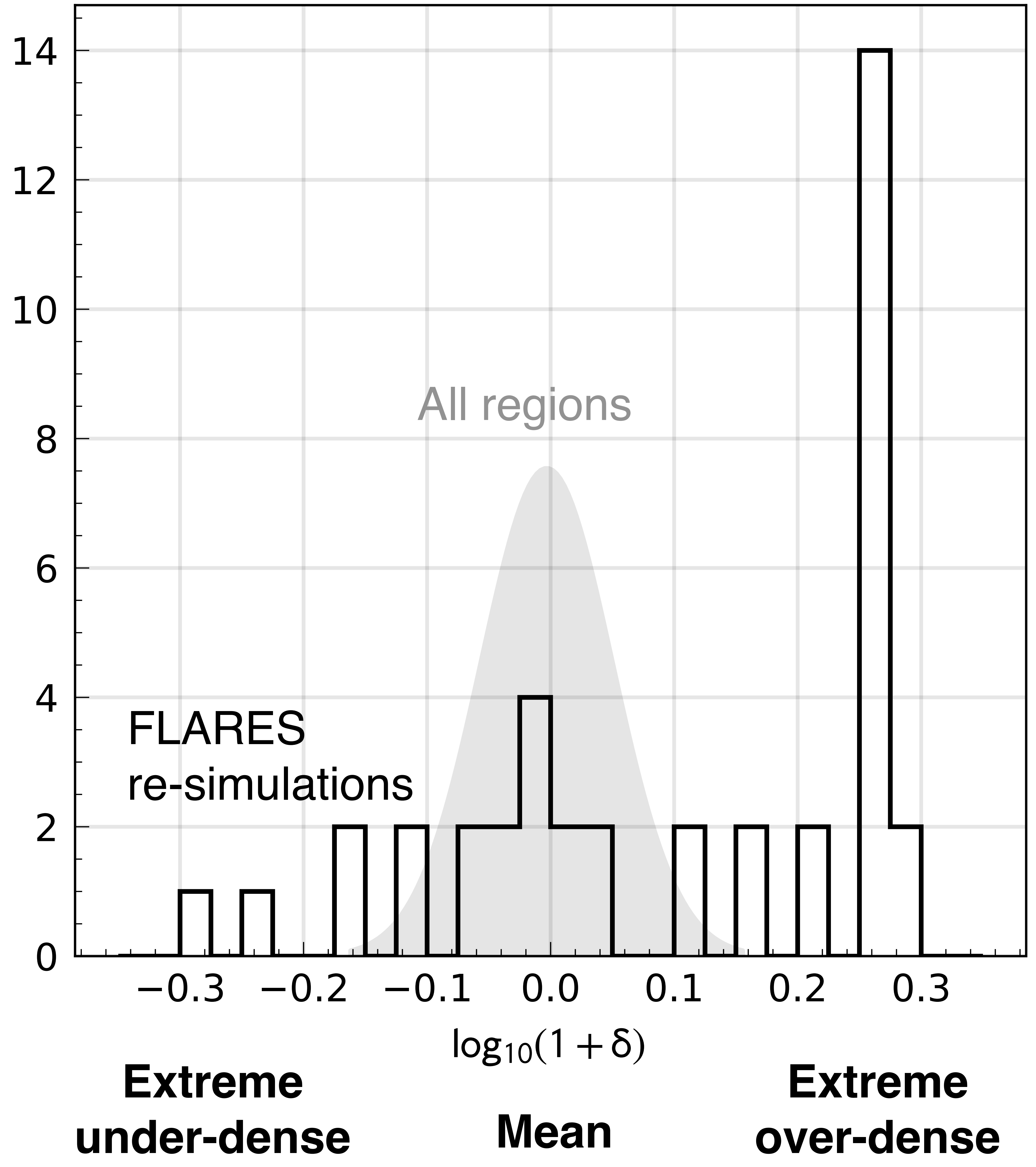
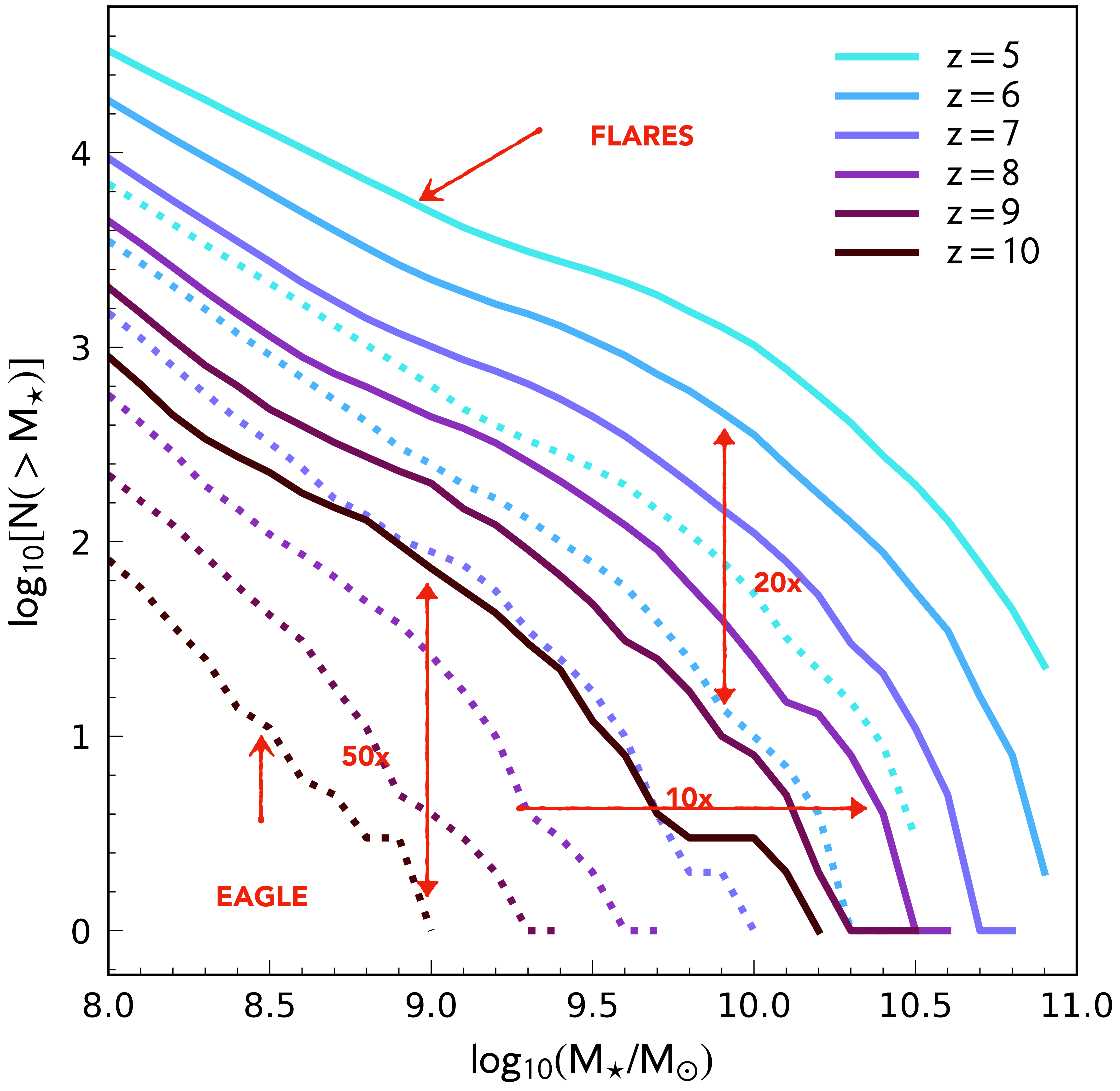
- Statistical weighting scheme recovers the distribution of overdensities in the parent box



FLARES

Hydrodynamic zoom simulations in the EoR (z>5)

CUMULATIVE # OF GALAXIES



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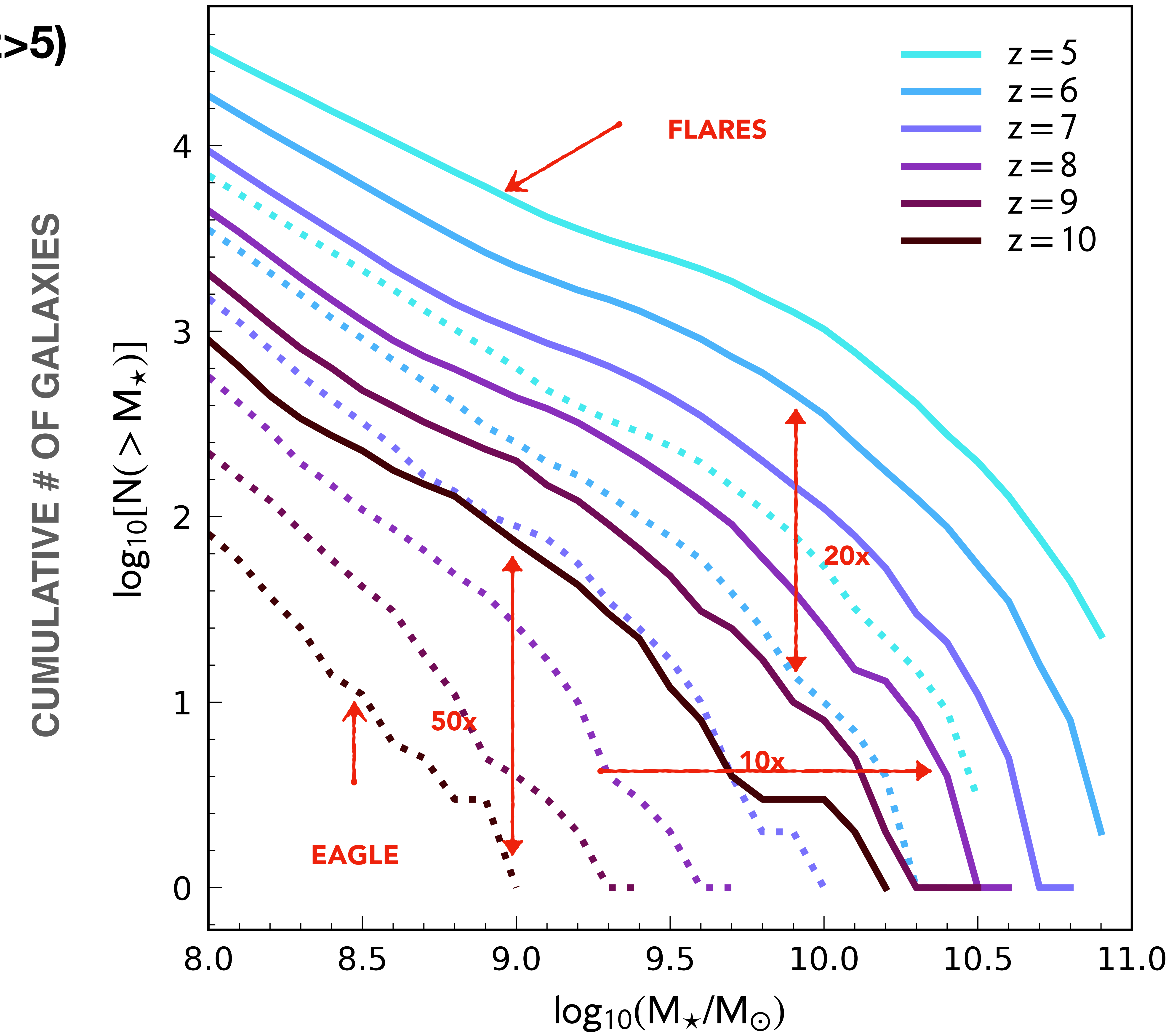
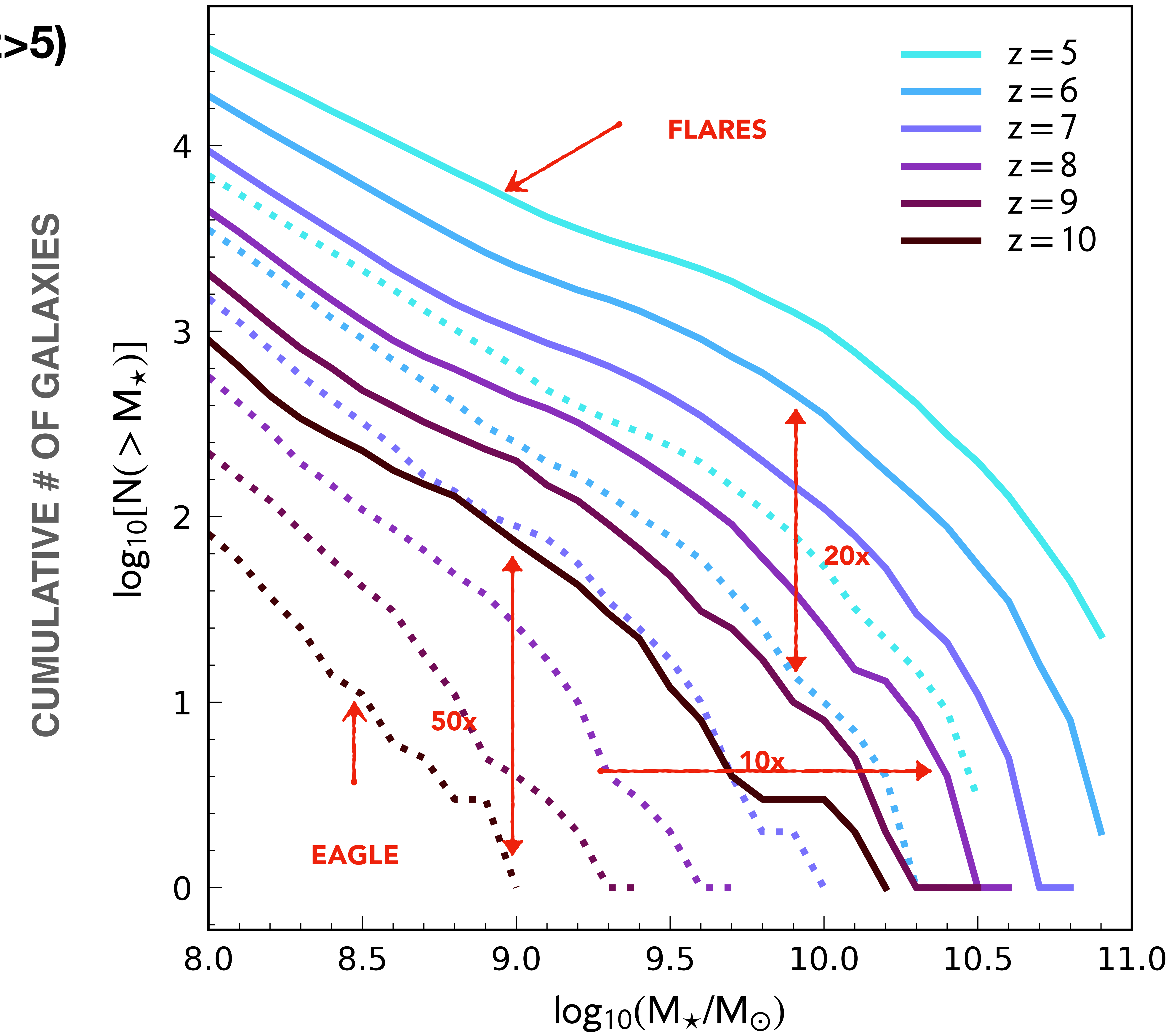


FLARES

Hydrodynamic zoom simulations in the EoR (z>5)

Able to efficiently simulate many massive galaxies, which are more accessible to observations.



Forward-modelling

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Vijayan et al. 2021:

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1. Associate each stellar particle with a stellar SED based on its age and metallicity
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   - Gas spectrum from Cloudy photoionisation code, assume $f_{\rm esc} = 0$
3. Add dust (two components):
   - Contribution of dust in the diffuse ISM
   - For young (<10 Myr) stellar particles, include birth cloud dust extinction

Ionising properties of a source

Intrinsic ionising emissivity: $\dot{N}_{\rm ion,intr}$

Specific ionising emissivity: $\dot{N}_{\rm ion,intr}/M_*$

Ionising photon production efficiency: $\xi_{\rm ion} = \dfrac{\dot{N}_{\rm ion,intr}}{L_{\rm UV}}$

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Note: $\dot{N}_{\rm ion,intr}$ and $L_{\rm UV}$ are obtained from pure stellar SEDs

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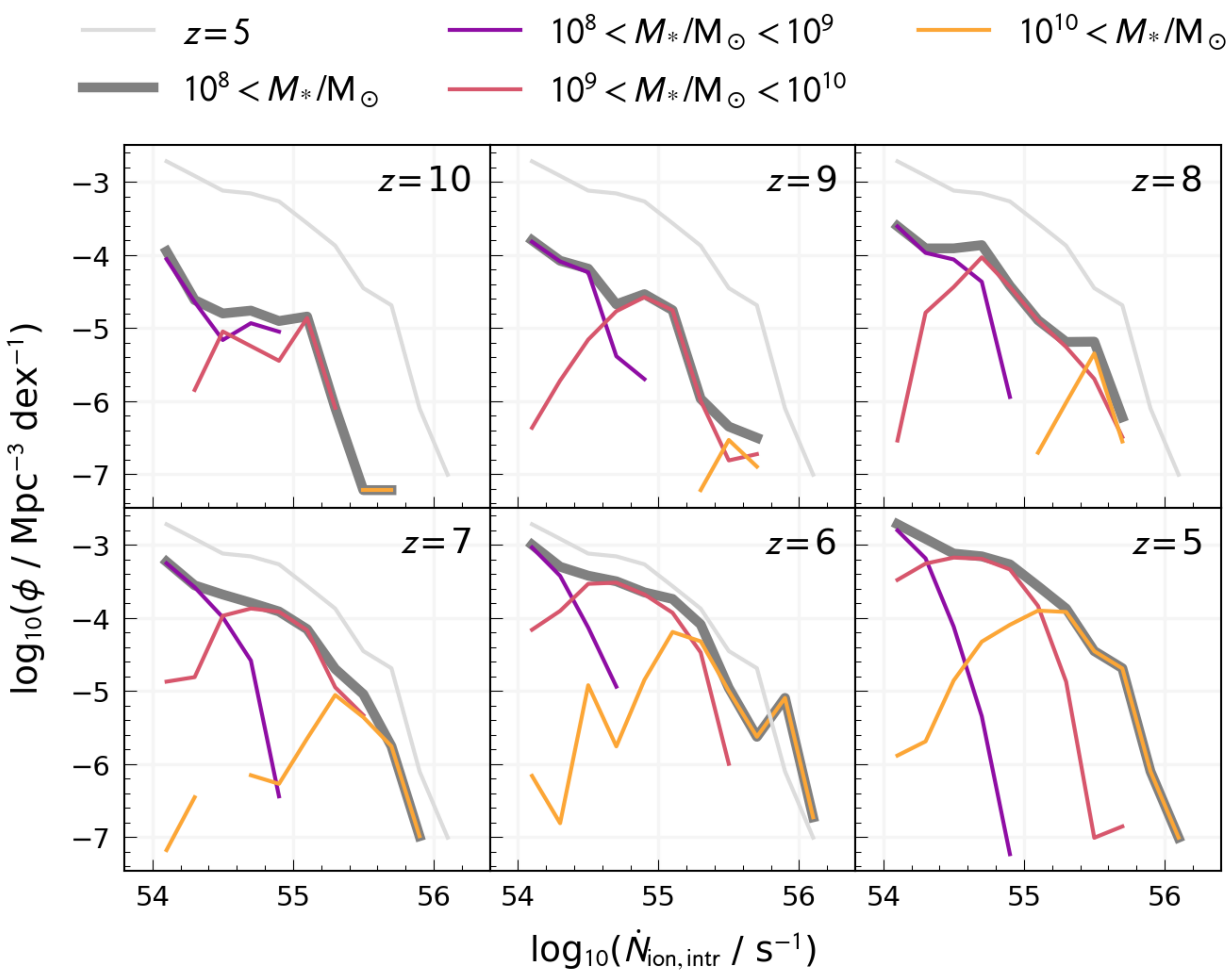
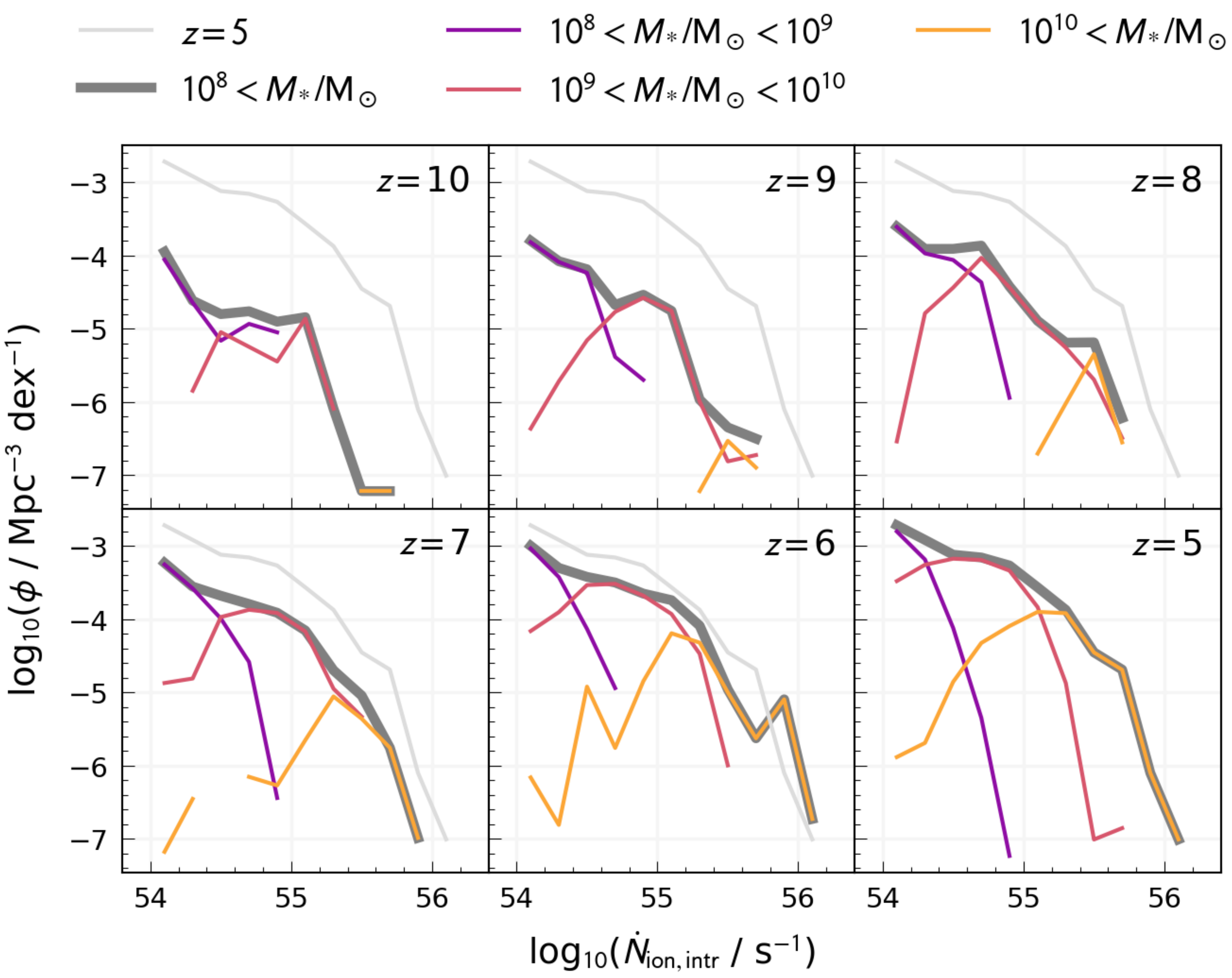
Intrinsic LyC luminosity function



Intrinsic LyC luminosity function

*Stars only, no AGN



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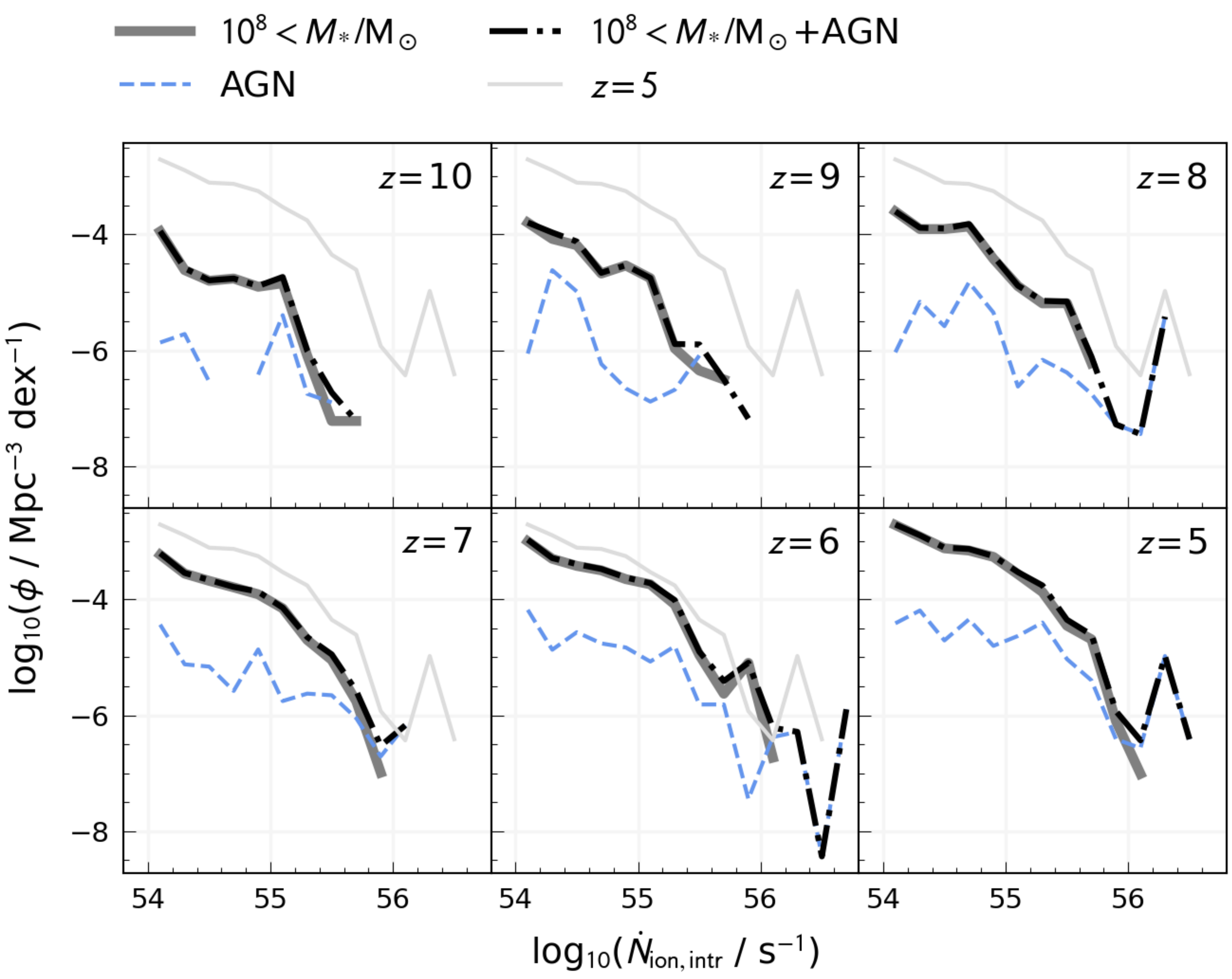
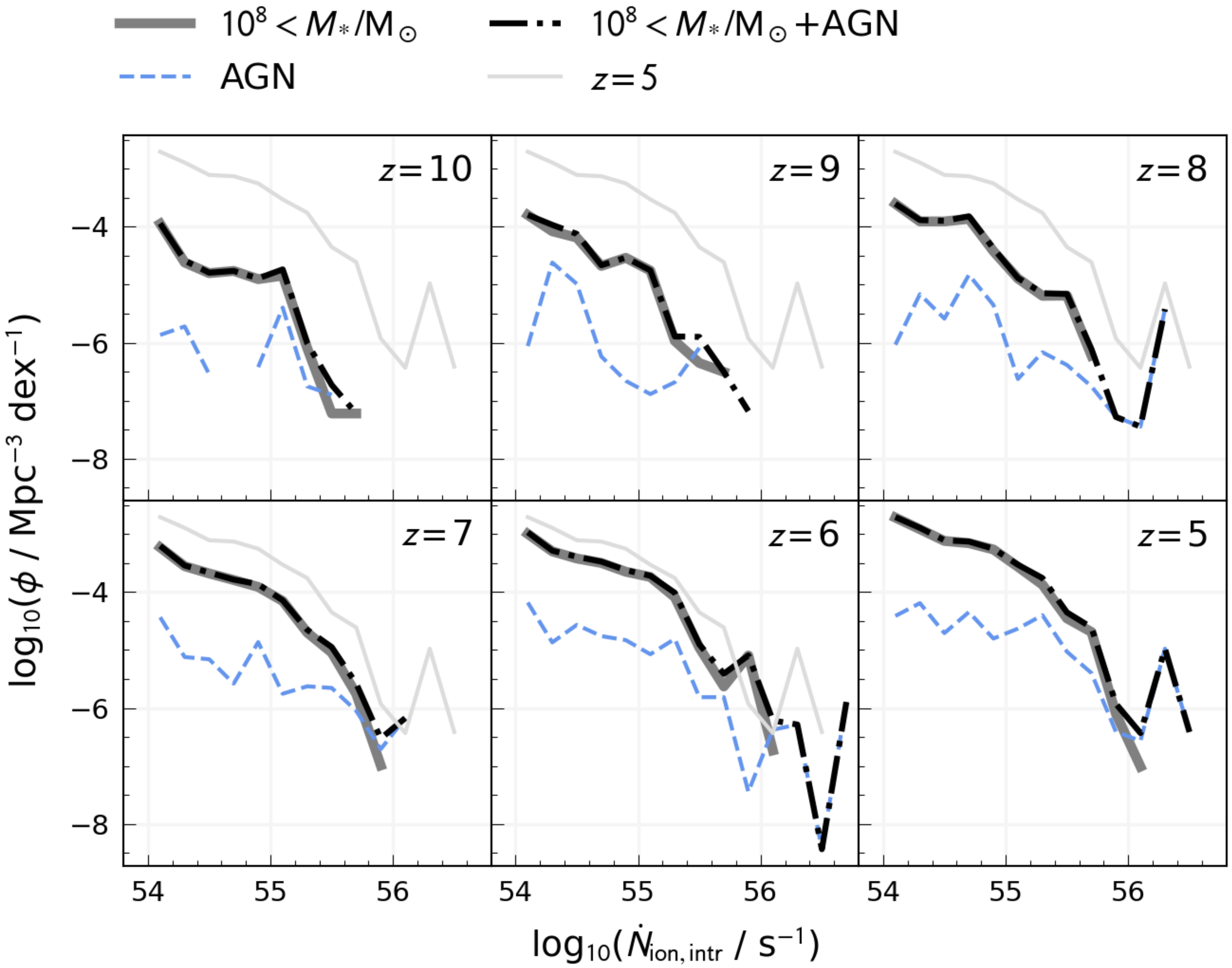
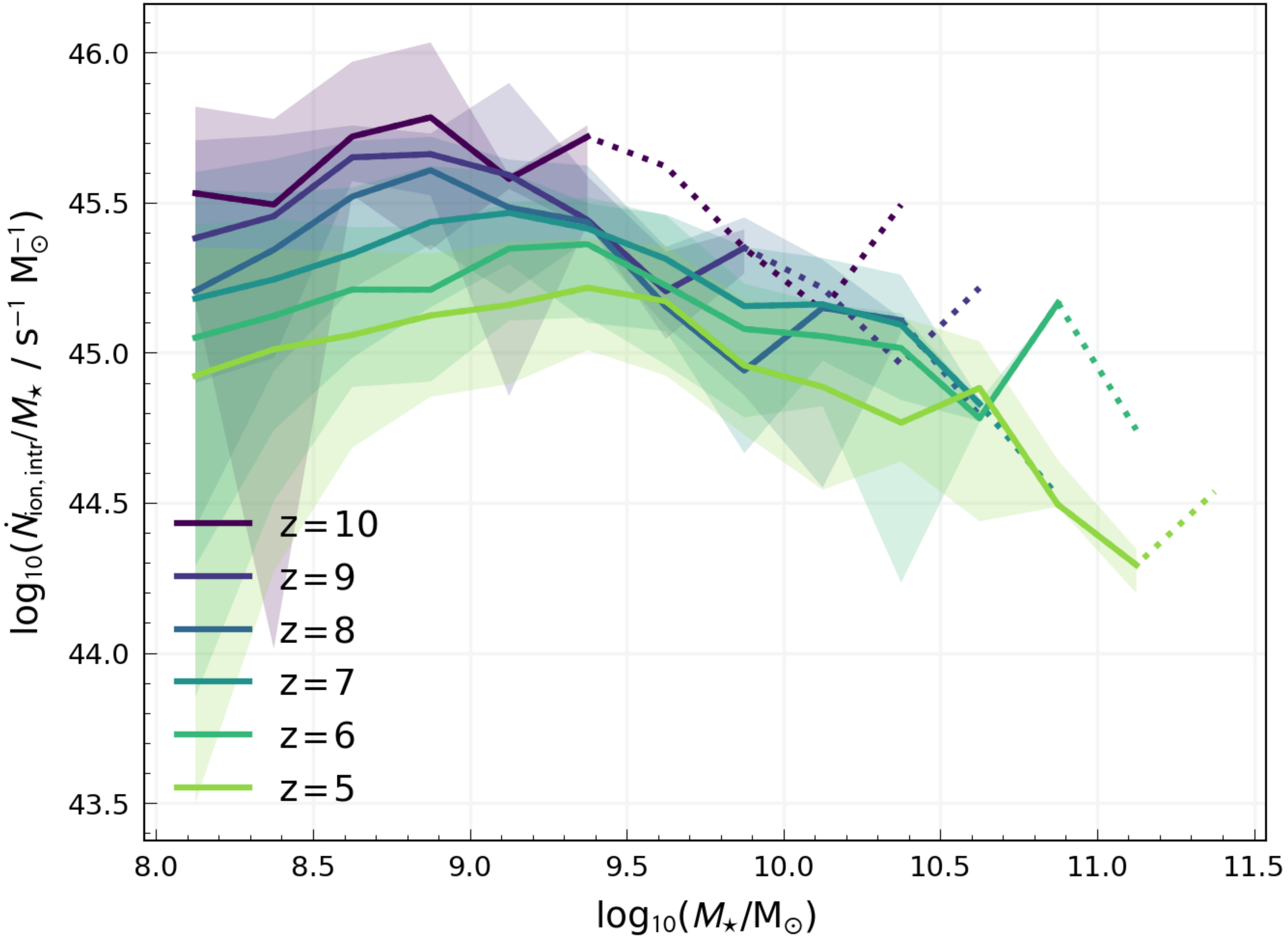


Intrinsic LyC luminosity function

(Now including AGN)

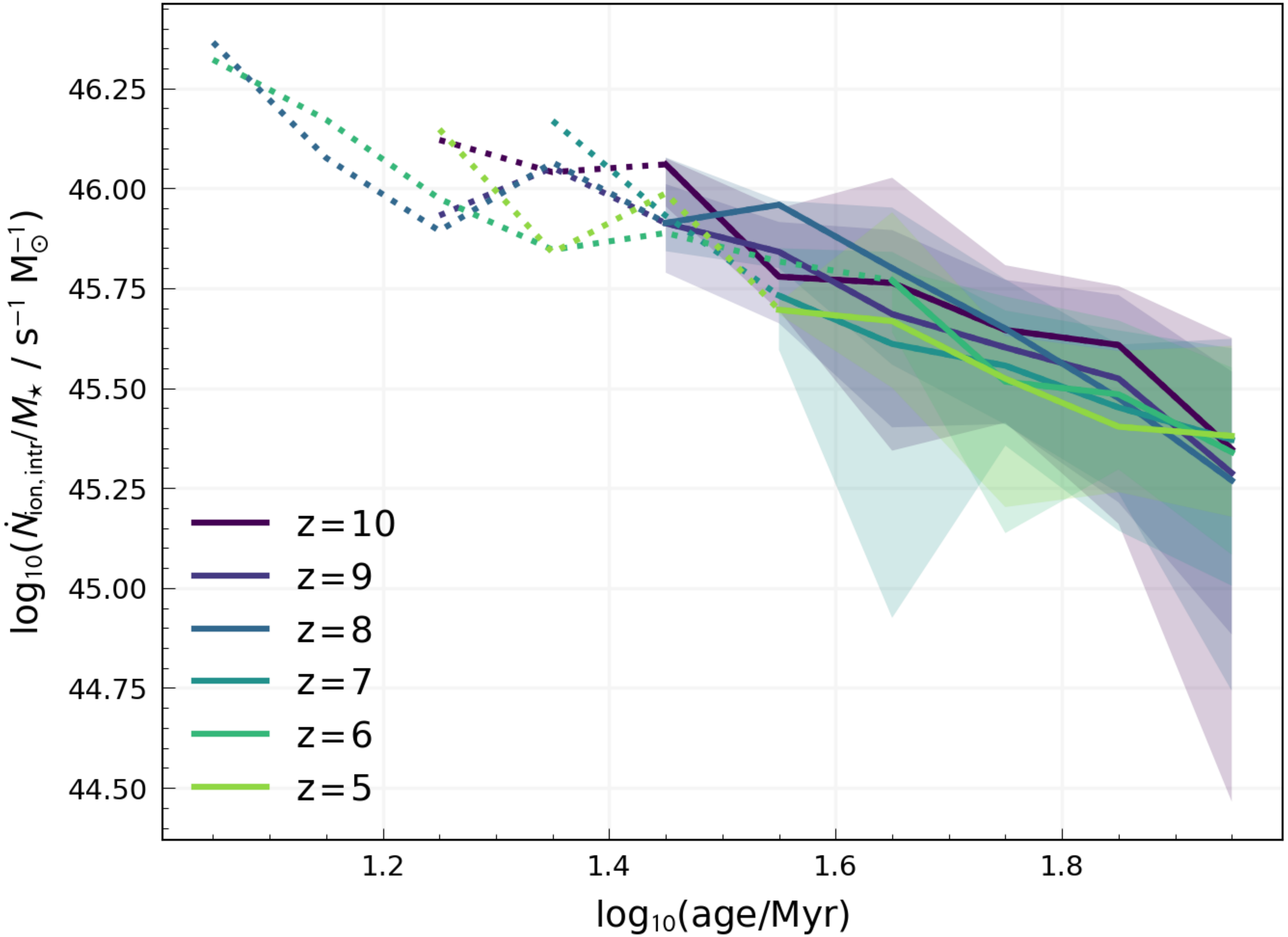


Specific emissivity & stellar mass



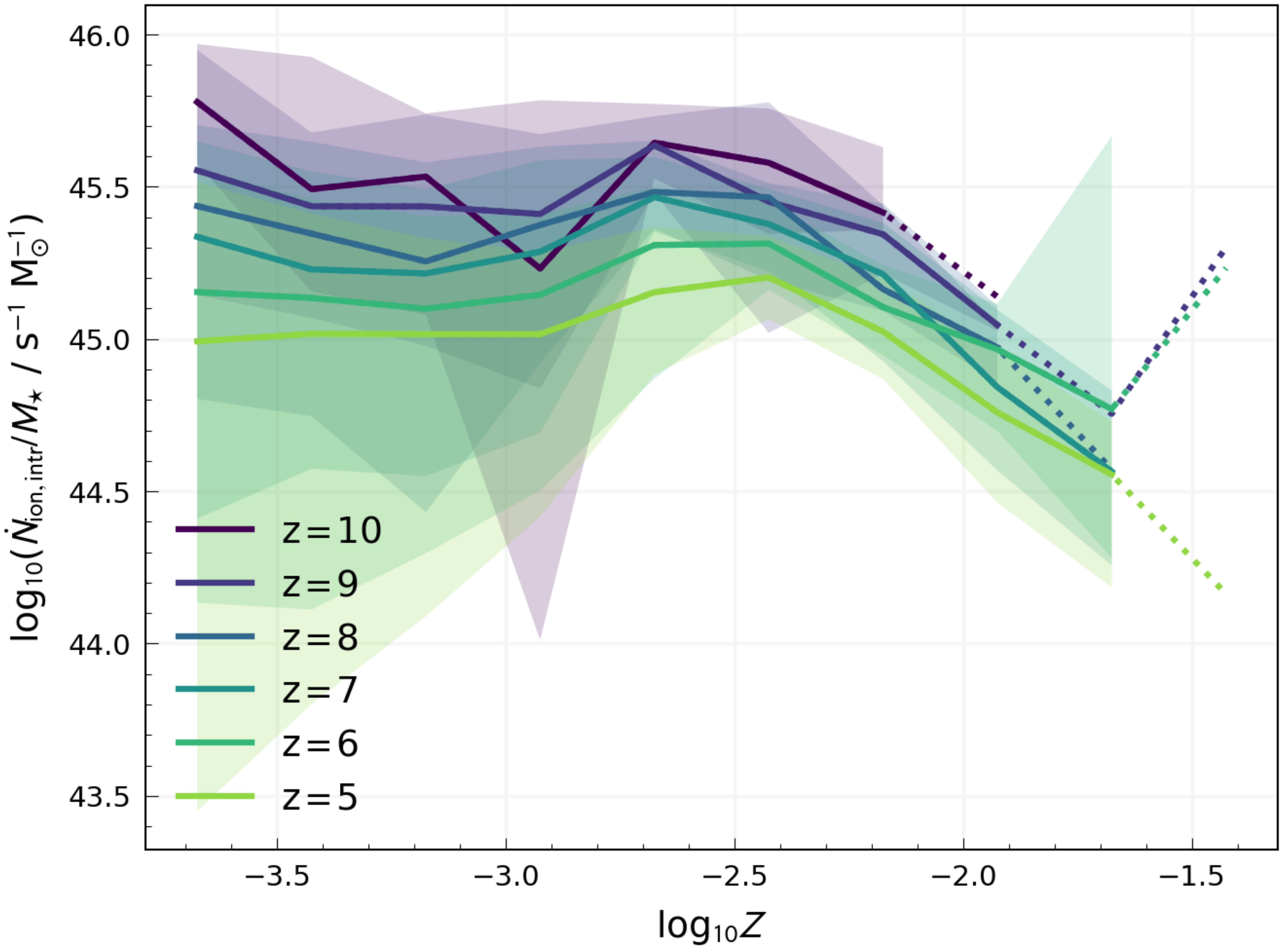
Specific emissivity & age

age: initial mass-weighted median stellar age

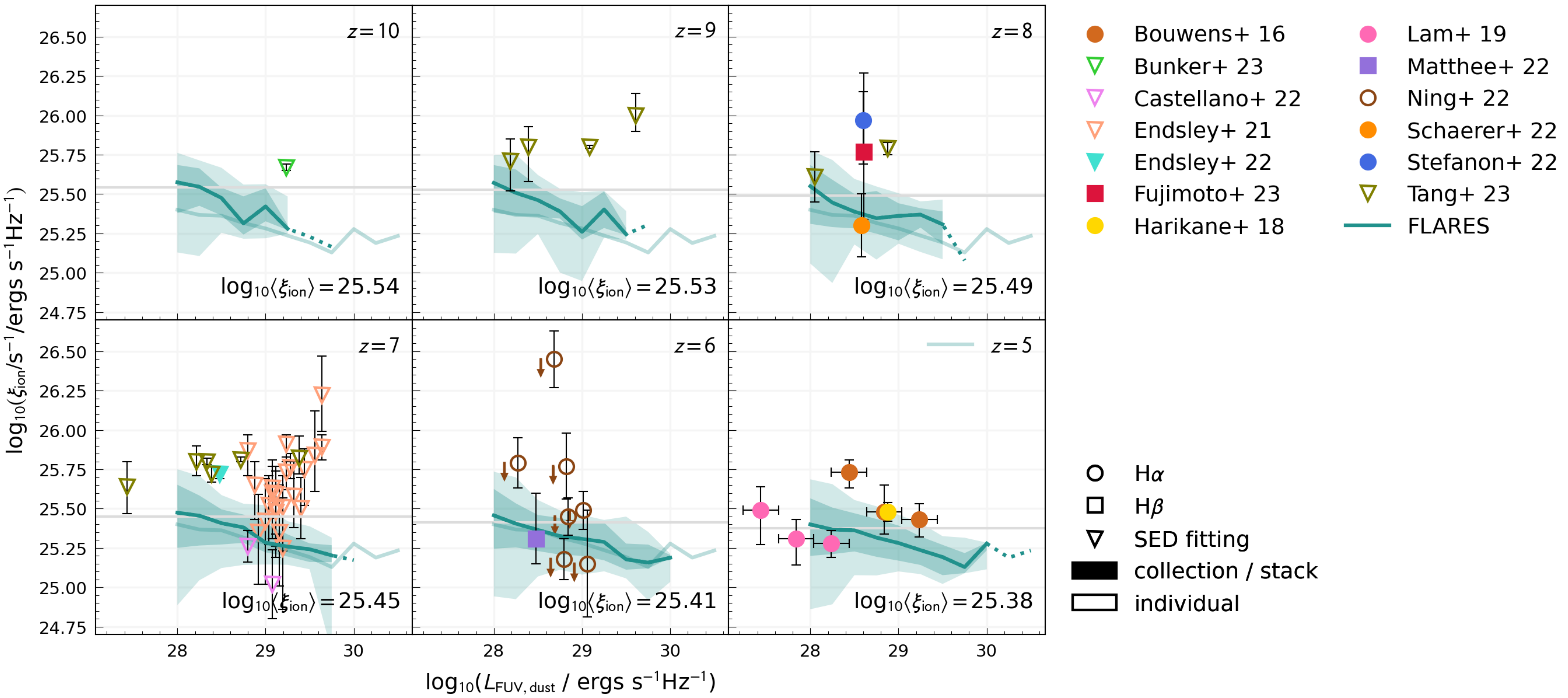


Specific emissivity & Z

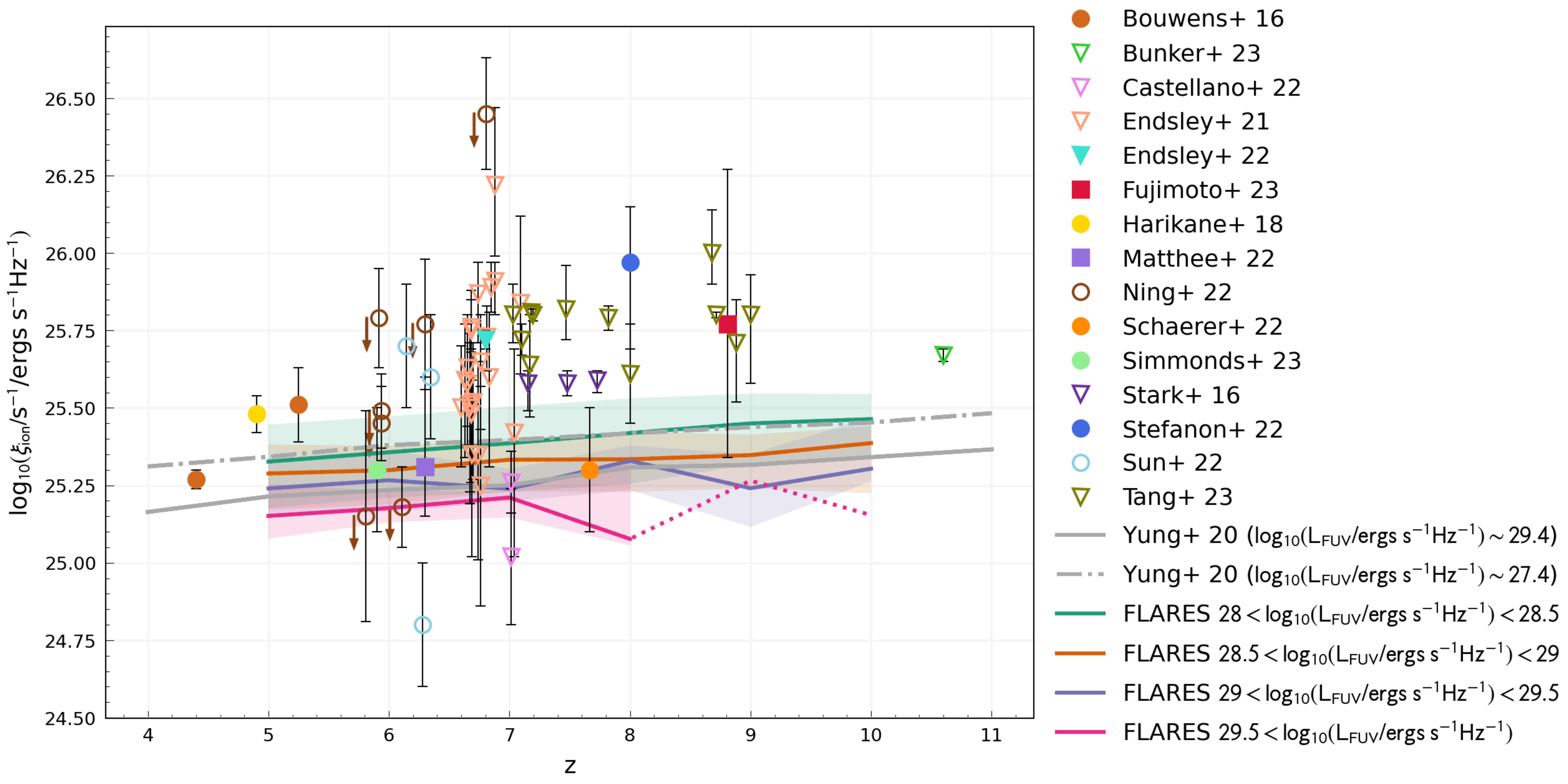
Z: initial mass-weighted median stellar metallicity



Production efficiency & L_{UV}



Production efficiency & z



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FLARES Papers

I. Environmental dependence of high-redshift galaxy evolution - **Lovell+2021**

II. The Photometric Properties of High-Redshift Galaxies - **Vijayan+2021**

III. The Properties of Massive Dusty Galaxies at Cosmic Dawn - **Vijayan+2022**

IV. The Size Evolution of Galaxies at $z \geq 5$ - **Roper+2022**

V. The Redshift Frontier - **Wilkins+2022**

VI. The Colour Evolution of Galaxies z=5-15 - **Wilkins+2022**

VII. Star Formation and Metal Enrichment Histories - **Wilkins+2022**

VIII. The Emergence of Passive Galaxies in the Early Universe - **Lovell+2022**

IX. The Physical Mechanisms Driving Compact Galaxy Formation and Evolution - **Roper+2022**

X. Environmental Galaxy Bias and Survey Variance at High Redshift - **Thomas+2022**

XI. [OIII] emitting galaxies at $5>z>10$ - **Wilkins+2022**

XII. The Lyman-Continuum Emission of High-Redshift Galaxies **- Seeyave+in-prep**

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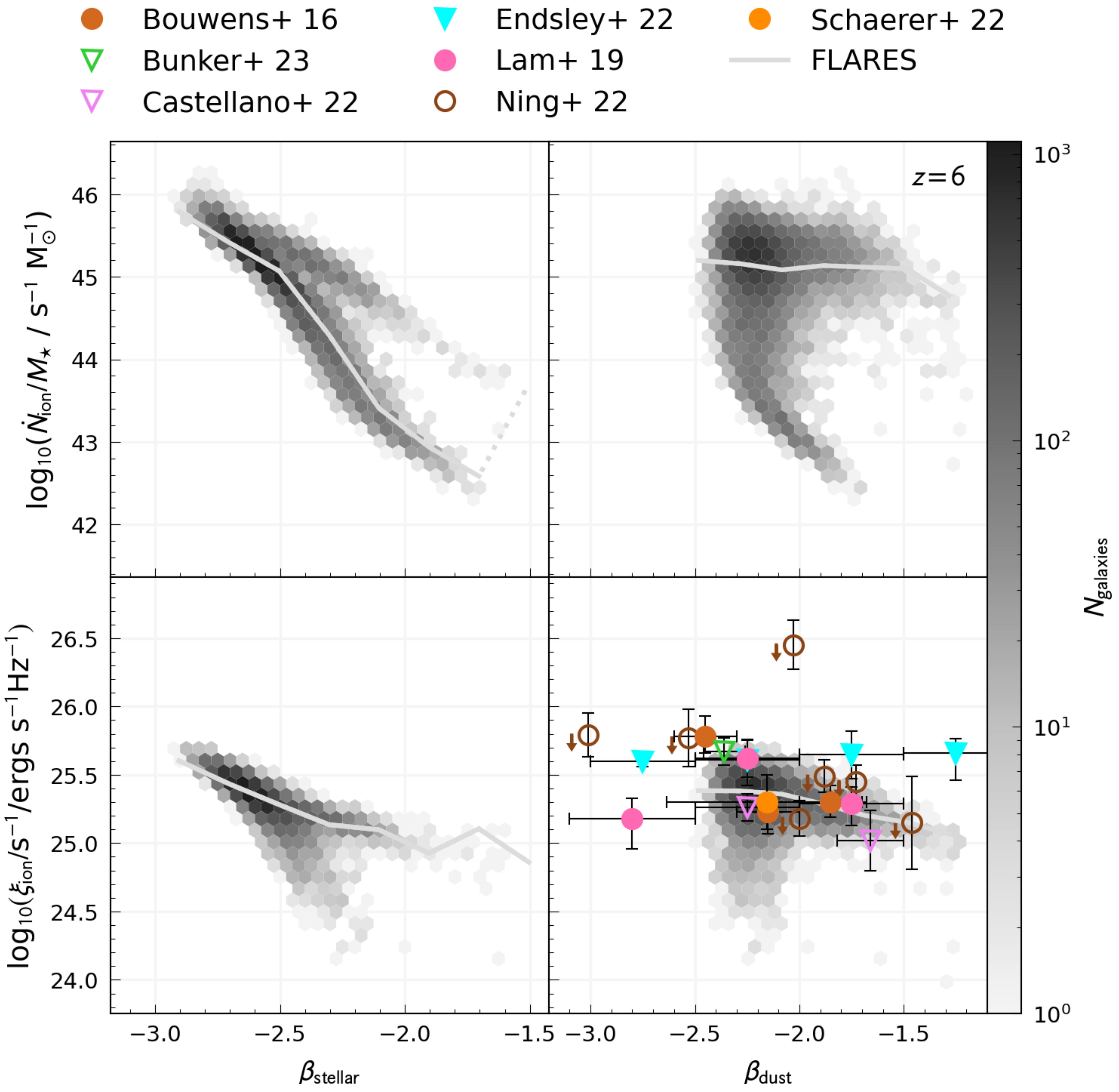
Conclusion

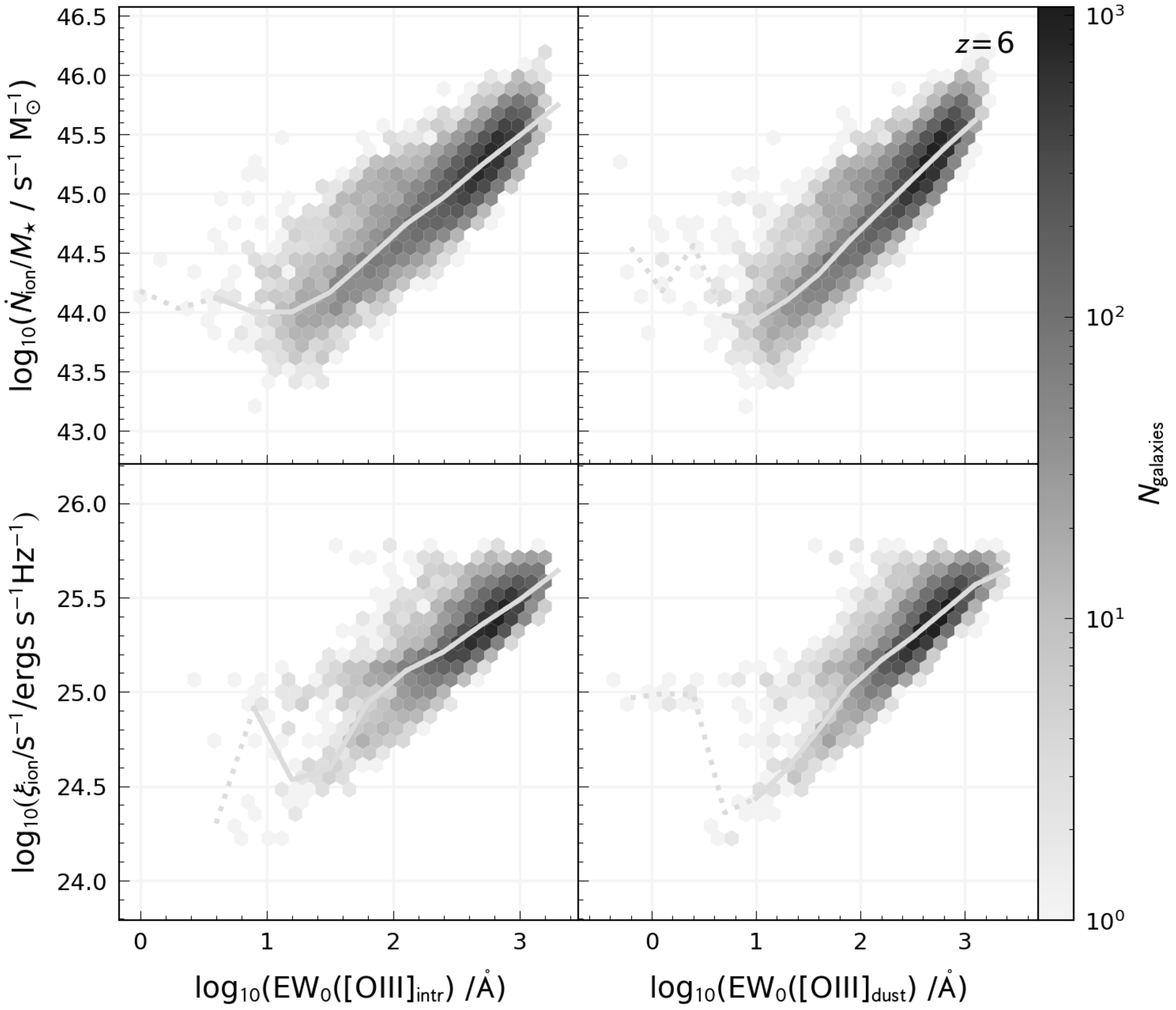
- Of the galaxy sample considered in FLARES, stellar emission from the lower-mass ($M_* \approx 10^8 - 10^9\ \mathrm{M}_\odot$) population produces the most ionising radiation.
- AGN contribute a smaller fraction but extend the LyC luminosity function to higher values.
- The specific emissivity of galaxies decreases with increasing age and metallicity ($Z = 10^{-2.5}$ onwards).
- Production efficiency increases with decreasing far-UV luminosity and evolves weakly with redshift.
- FLARES does not predict the high values of ionising photon production efficiency that have recently been measured.

Production efficiency & β

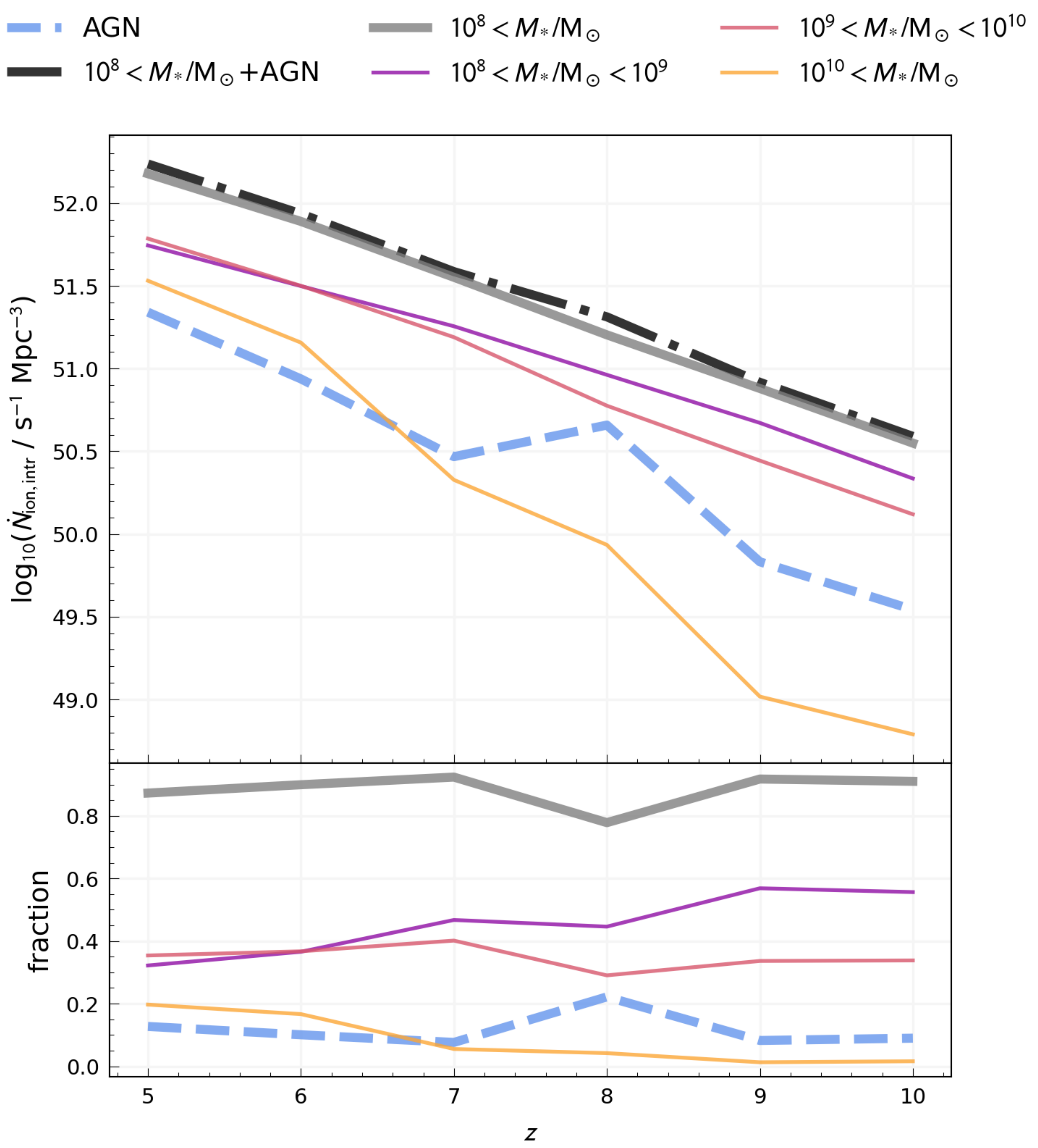


Production efficiency & [OIII] EW

[OIII] EW: combined equivalent widths of the [OIII] doublet ([OIII]$\lambda\lambda 4960, 5008\text{Å}$)

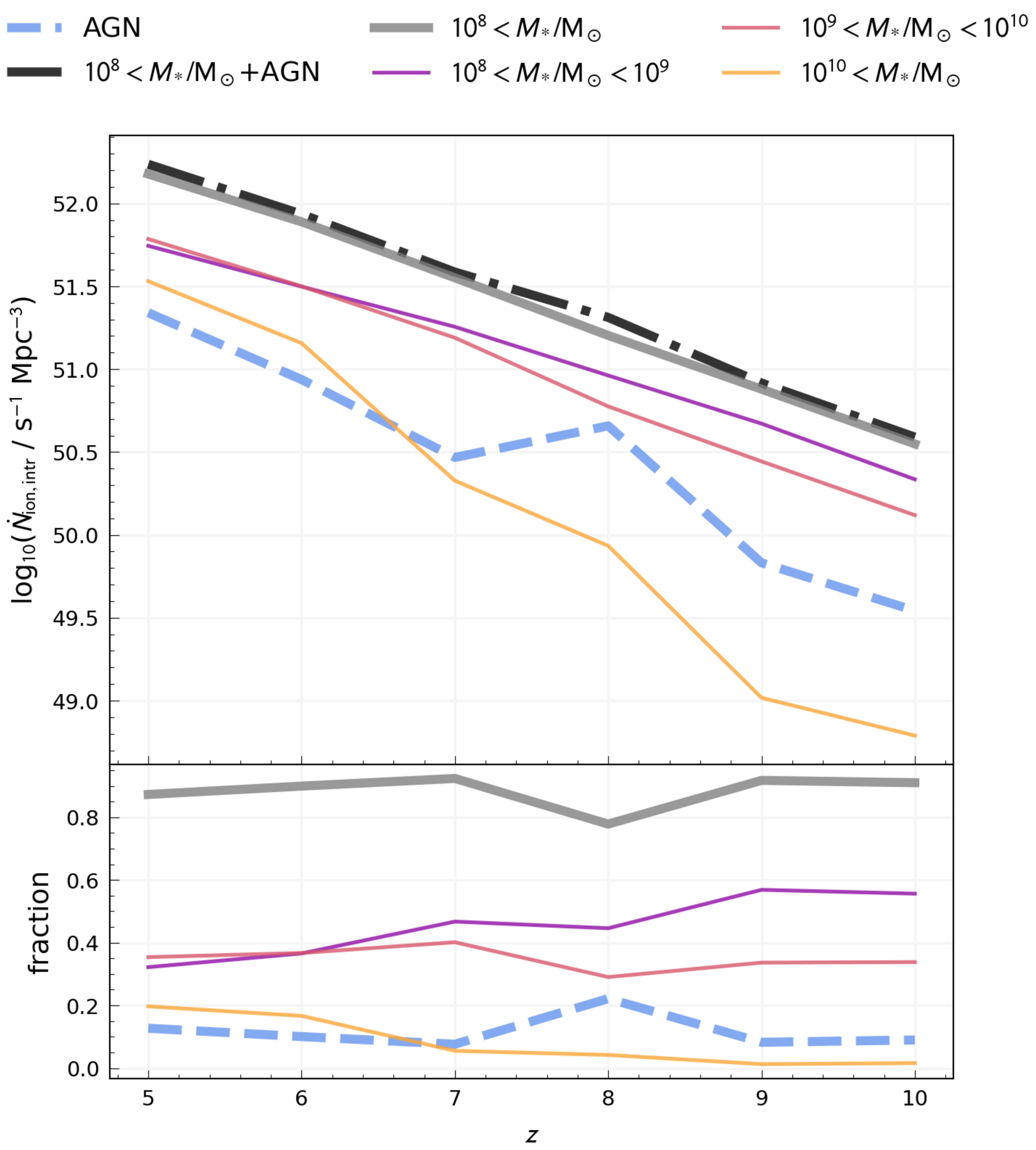


Total intrinsic emissivity: Stars vs. AGN



Total intrinsic emissivity: Stars vs. AGN

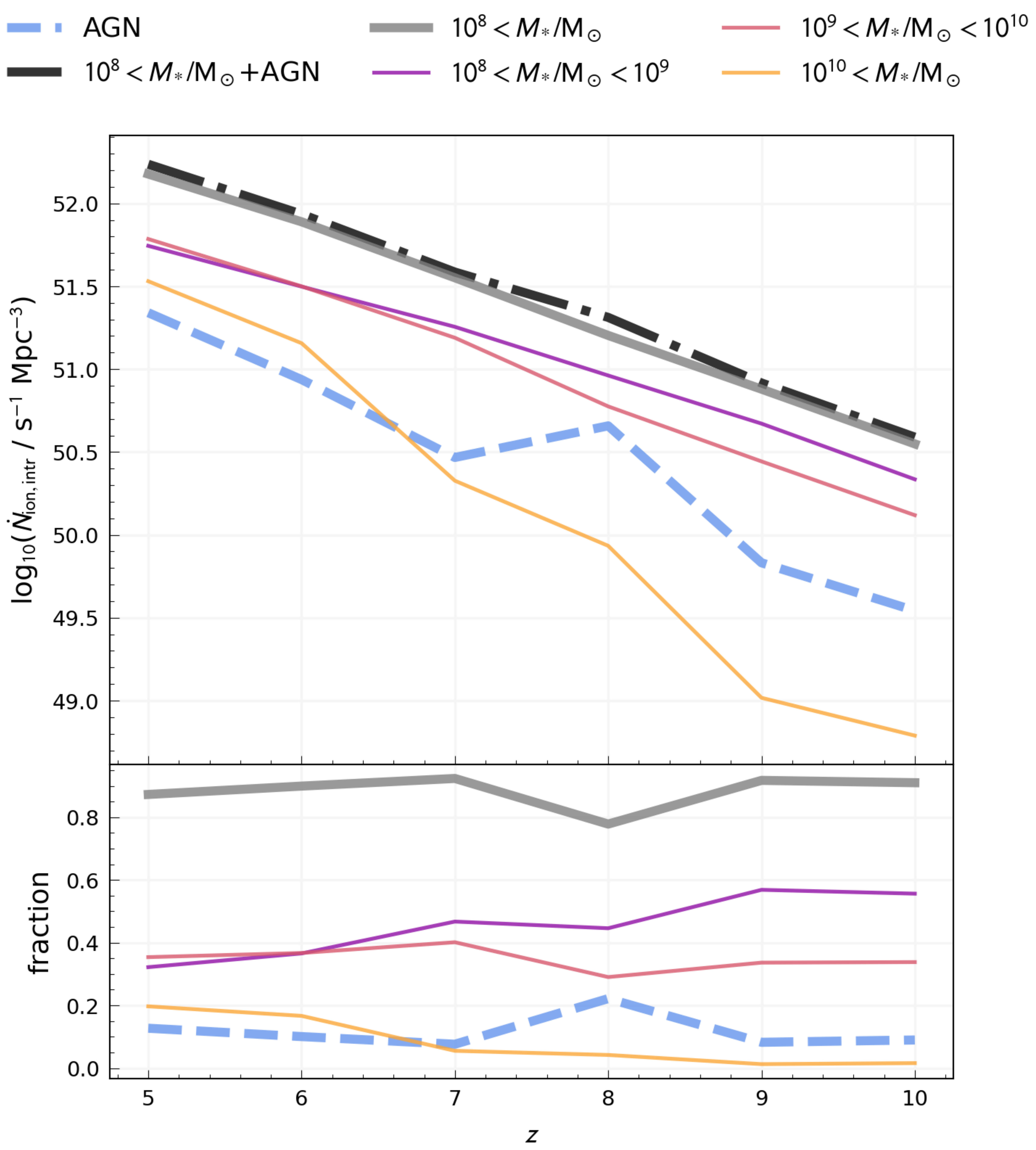
Lower-mass galaxies ($M_* = 10^8 - 10^9$ M$_\odot$) are the main source of ionising photons



Total intrinsic emissivity: Stars vs. AGN

Lower-mass galaxies ($M_* = 10^8 - 10^9$ M$_\odot$) are the main source of ionising photons

*Require $f_{\rm esc}$ to comment on contribution to reionisation!



$\xi_{\mathrm{ion,H}\alpha}$