The ionizing photon production efficiency of star-forming galaxies at z~4-10

arXiv:2412.01358

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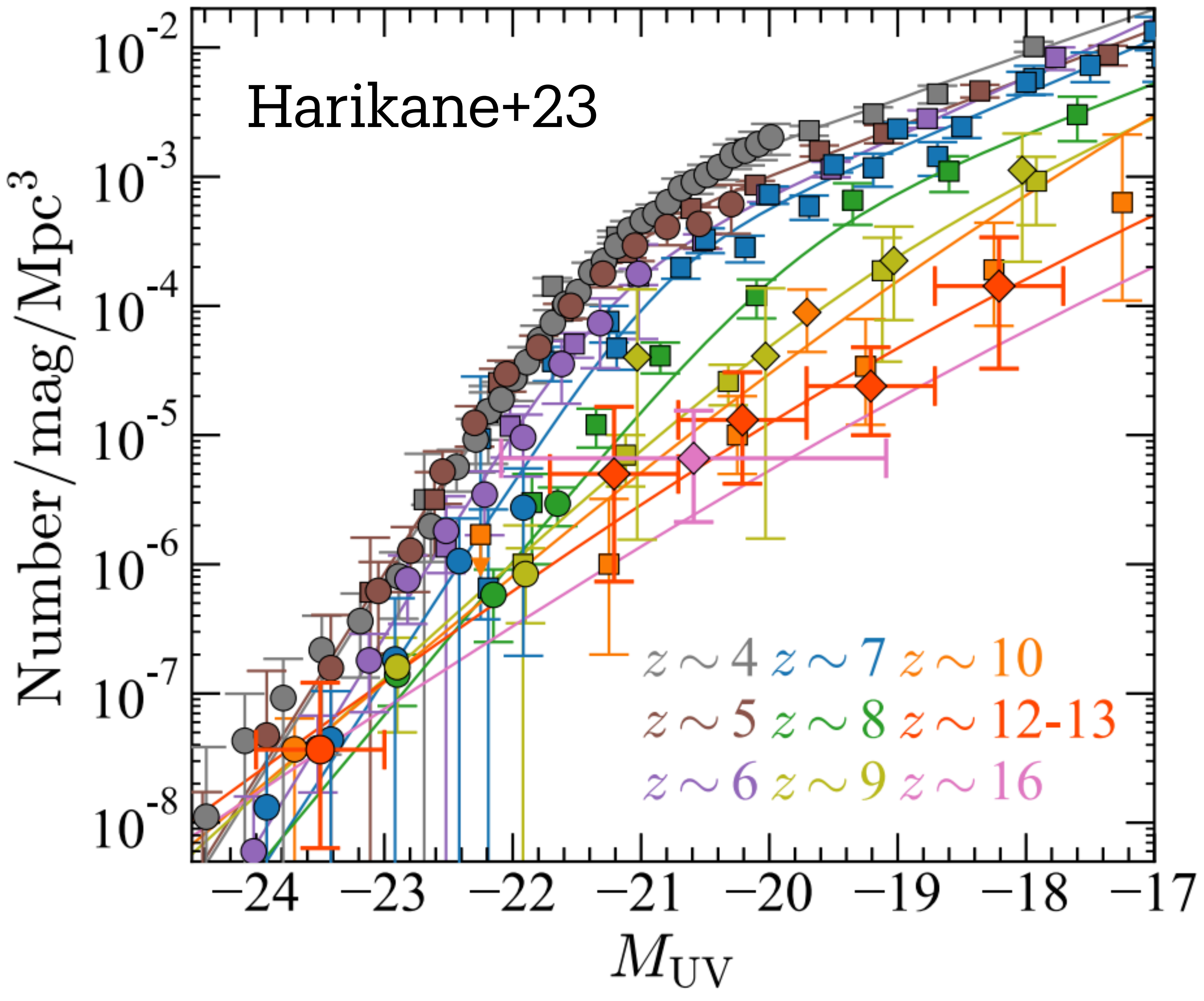
April 8th 2025
Escape of Lyman radiation from galactic labyrinths, OAC, Kolymbari, Crete

Total ionizing emissivity

Key to determine the contribution of sources during the EoR

$$\dot{n}_{ion} = \rho_{UV}\xi_{ion}f_{esc}$$

We need to know how many sources we have (UV luminosity function)



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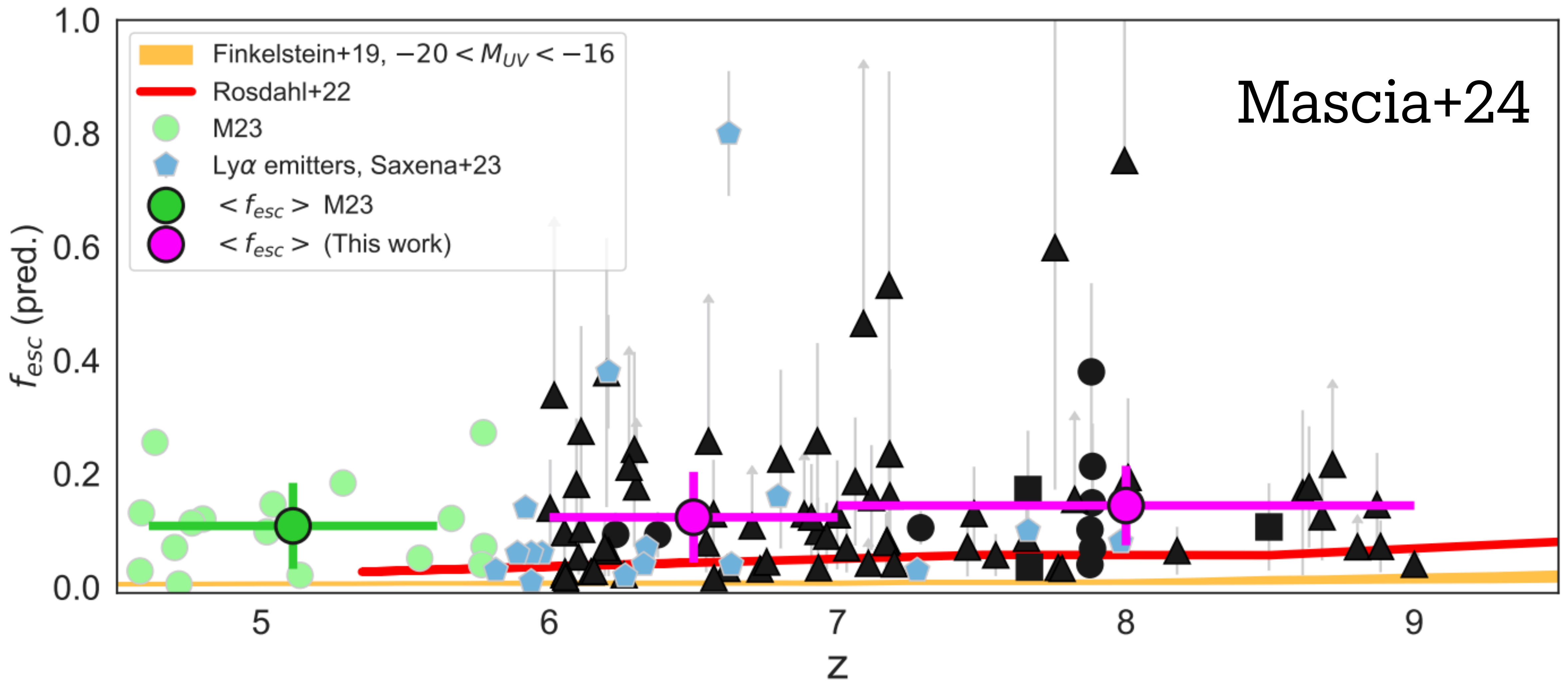

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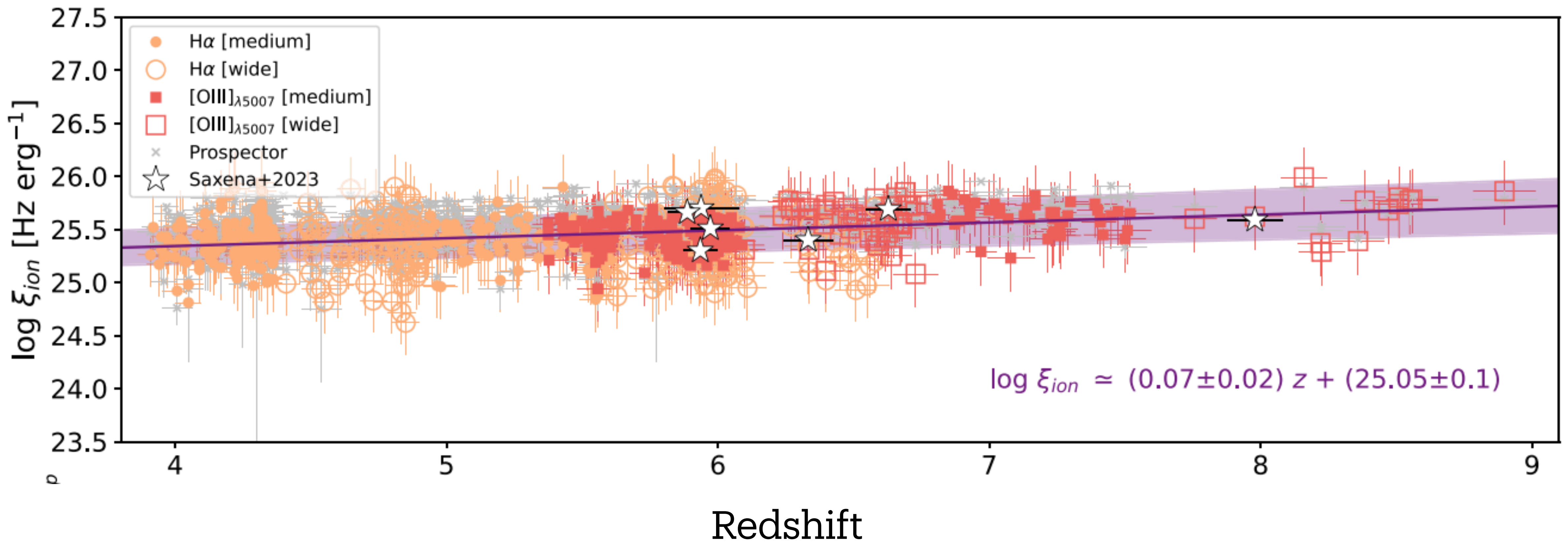
We need to measure how many LyC photons they are producing

Simmonds+24



ξion determined from Balmer lines: photometry or spectroscopy

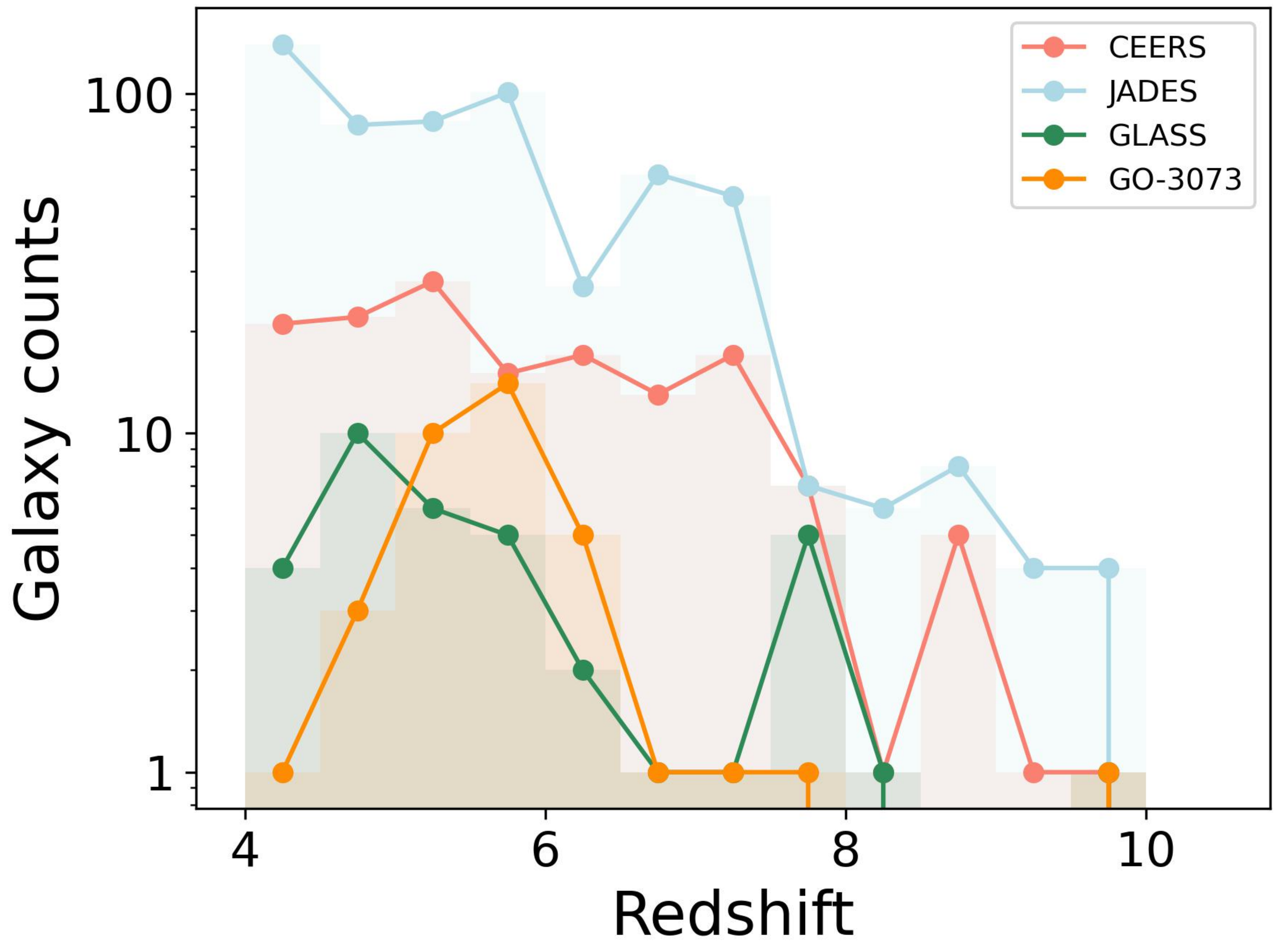
The sample

We selected at z~4-10 with NIRSpec spectra
(Prism or grating)

CEERS (Finkelstein+23): 148 galaxies
JADES (Eisenstein+23): 569 galaxies
GLASS (Treu+22): 36 galaxies
GO-3073 (PI: Castellano, M.): 37 galaxies

We removed AGN from our final sample based on the AGN sources identified in Roberts-Borsani+24 and Brooks+24: final sample of 761 galaxies

Lensing model available in Bergamini+23



The ionizing photon production efficiency

$$\xi_{ion} = \frac{N(H^0)}{L_{UV}},$$

ionizing photon rate

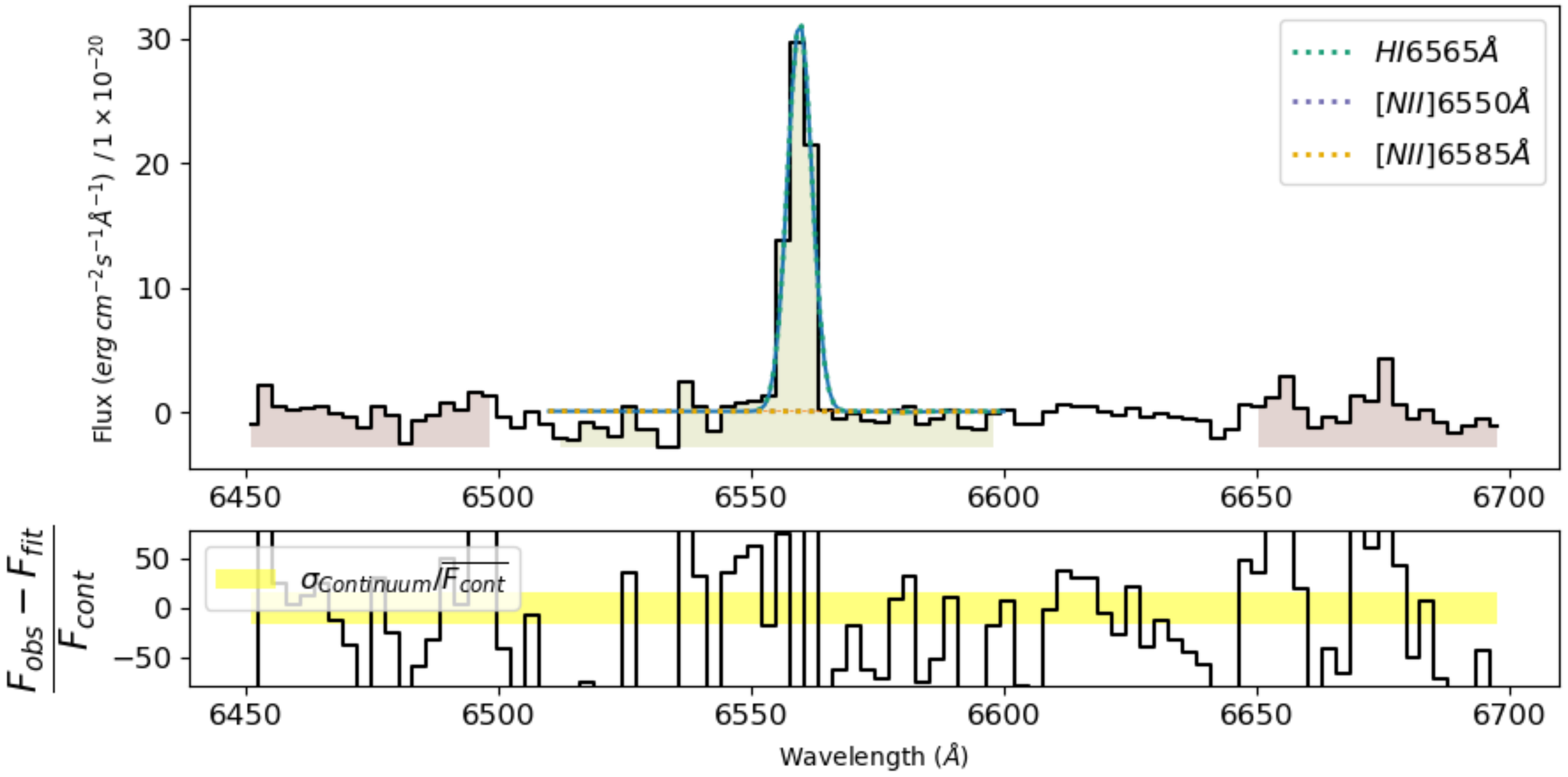
UV luminosity density at 1500Å

From Halpha or Hbeta

$$L(H\alpha)[ergs^{-1}] = 1.36 \times 10^{-12} N(H^0)[s^{-1}],$$

$$L(H\beta)[ergs^{-1}] = 4.87 \times 10^{-13} N(H^0)[s^{-1}].$$

Leitherer+95 assuming no ionizing photons escape the galaxy (fesc = 0) and case B recombination.



All LyC photons are reprocessed into the Balmer lines.

SED fitting

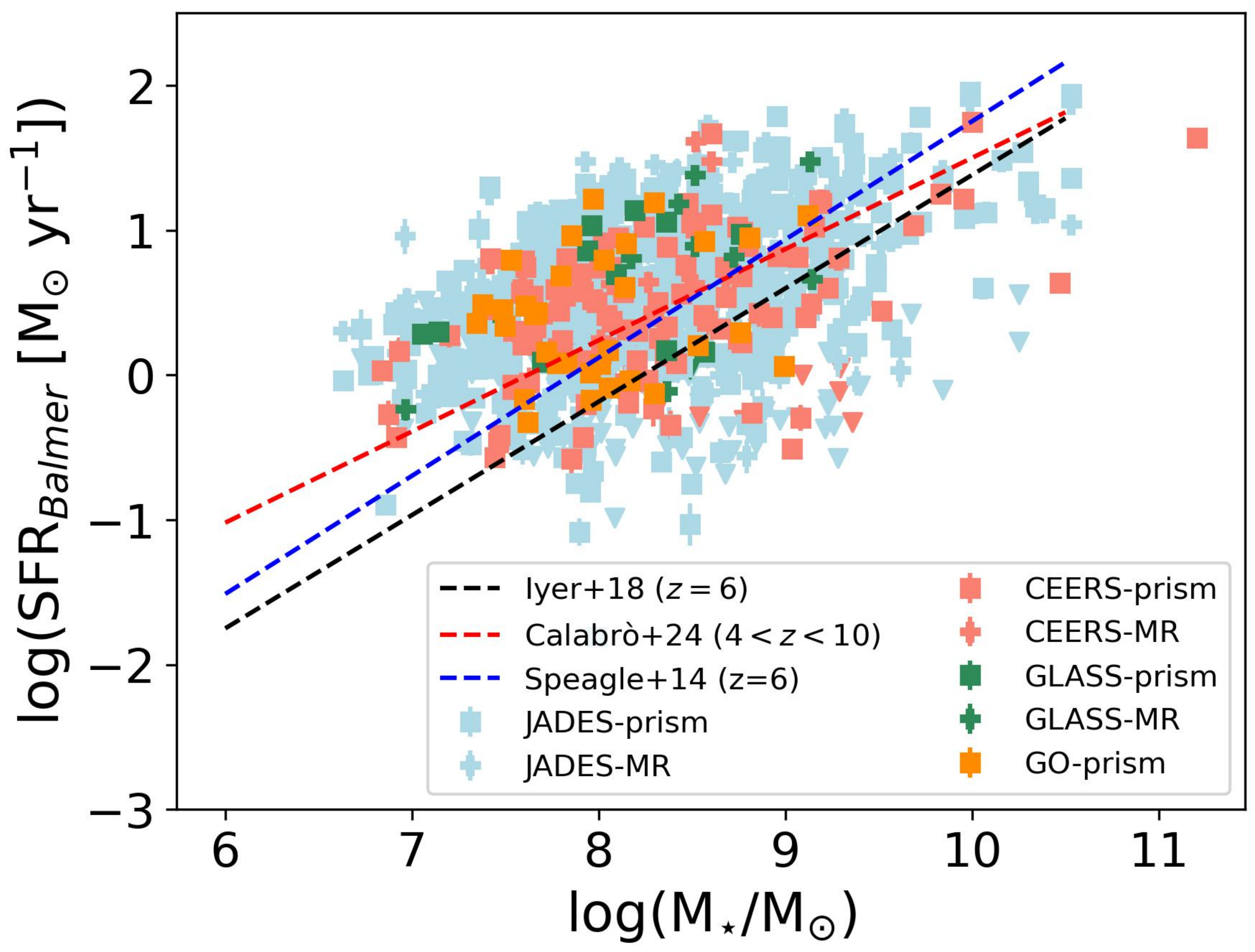
BAGPIPES (Carnall+18) to estimate the physical parameters with the Bruzual & Charlot (2003) stellar population models.

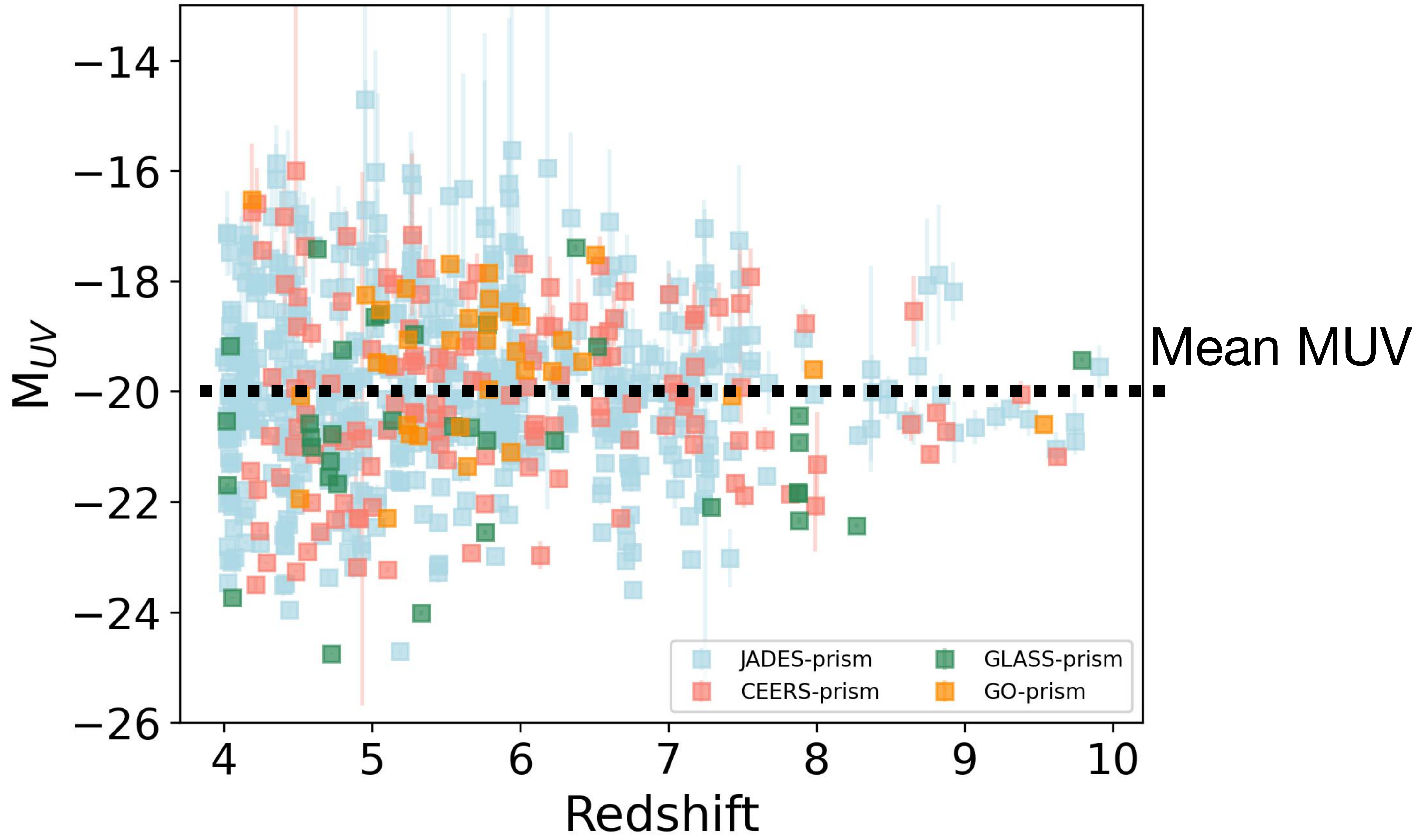
We considered a delayed exponential τ-model for the star formation history (SFH)

We determined L_UV from SED model

We used E(B-V) to dust correction assuming Calzetti+2000 attenuation curve

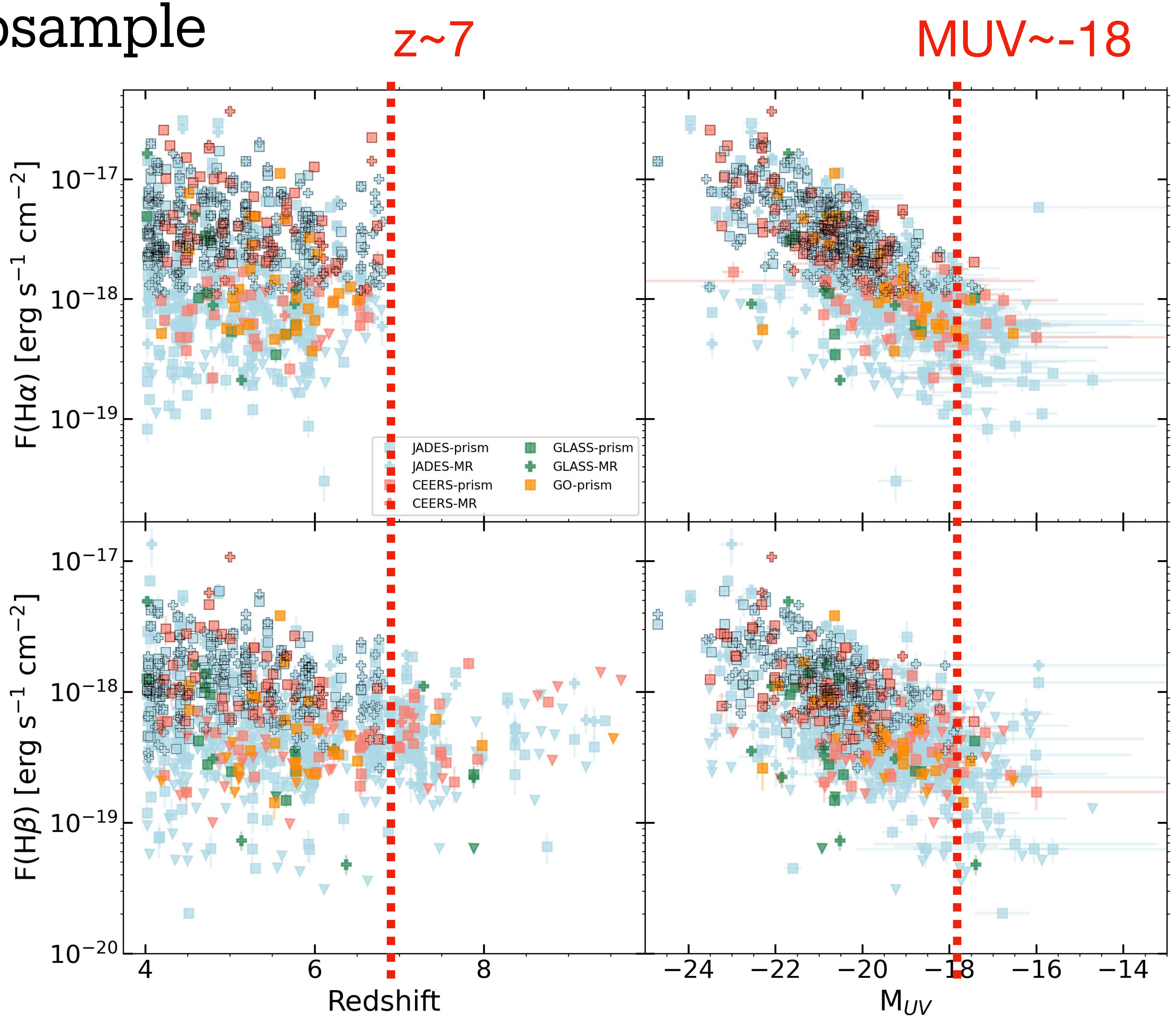
Reddy+22 calibration





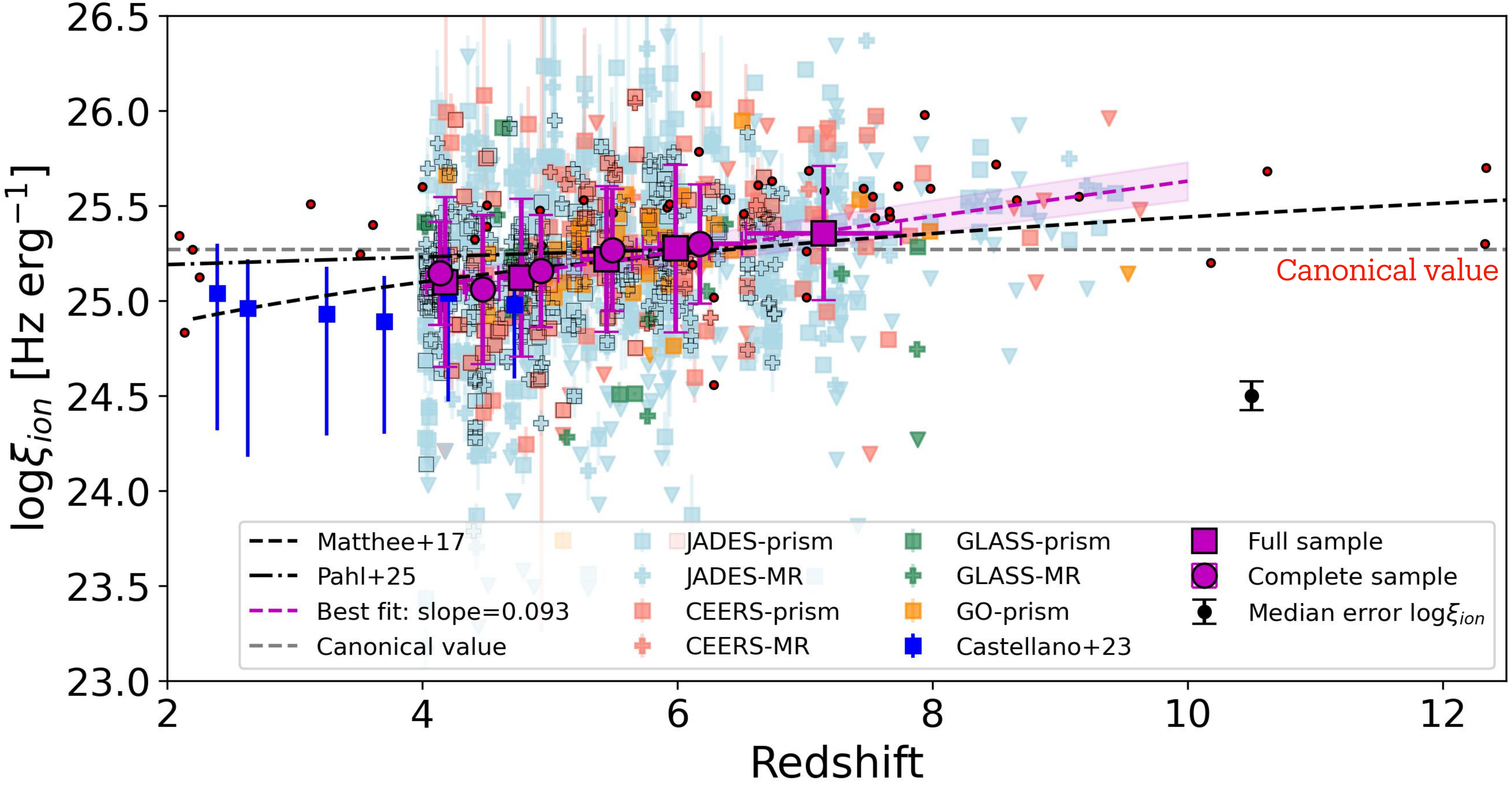
The complete subsample

Similar to the completeness of other spectroscopic samples (Dottorini+24)



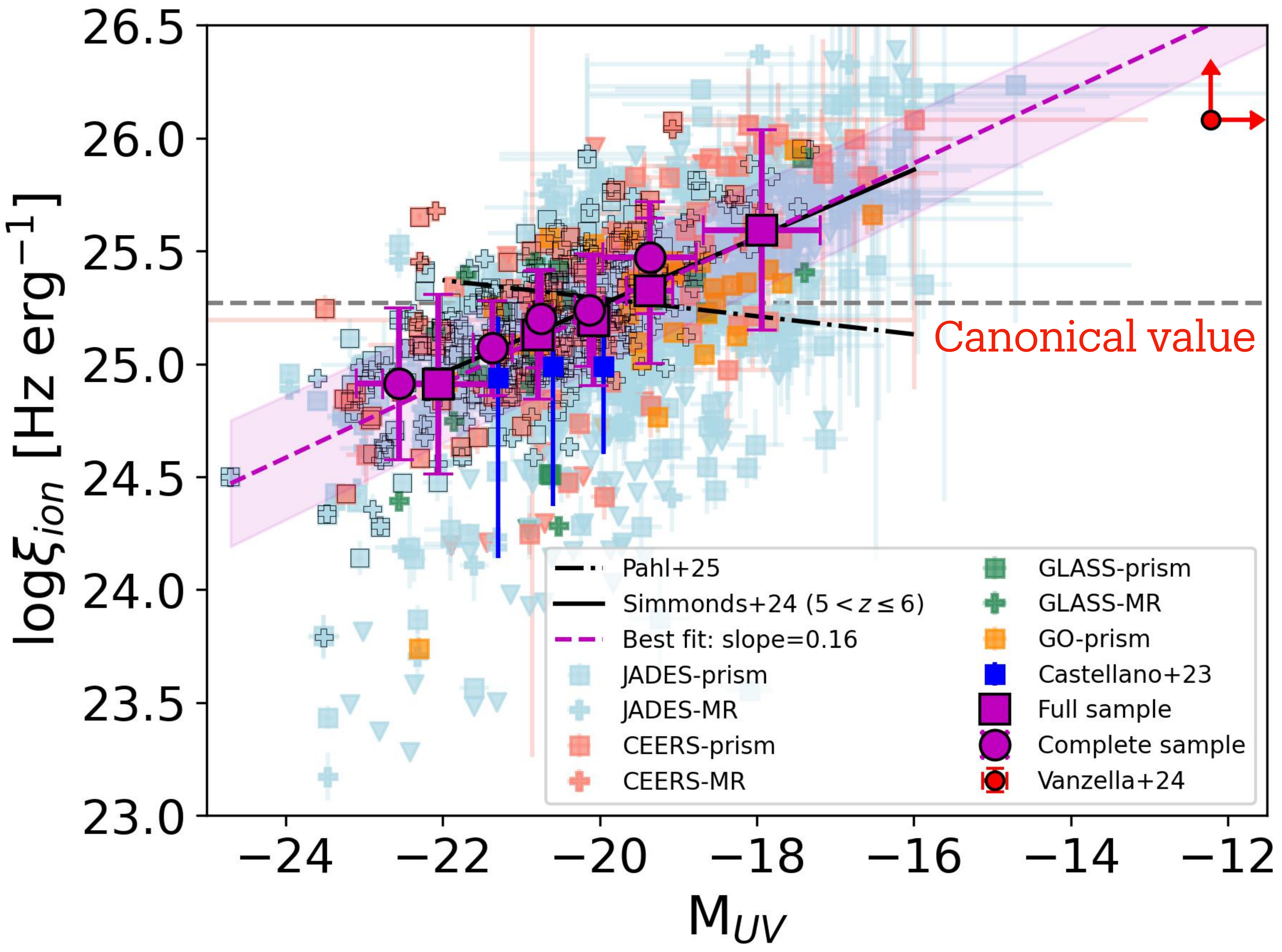
Redshift evolution

We obtained a mean value of log(ξion [Hz erg−1])=25.22 (σ = 0.42dex) for the galaxies in the full sample.



Increase of ξion with increasing redshift

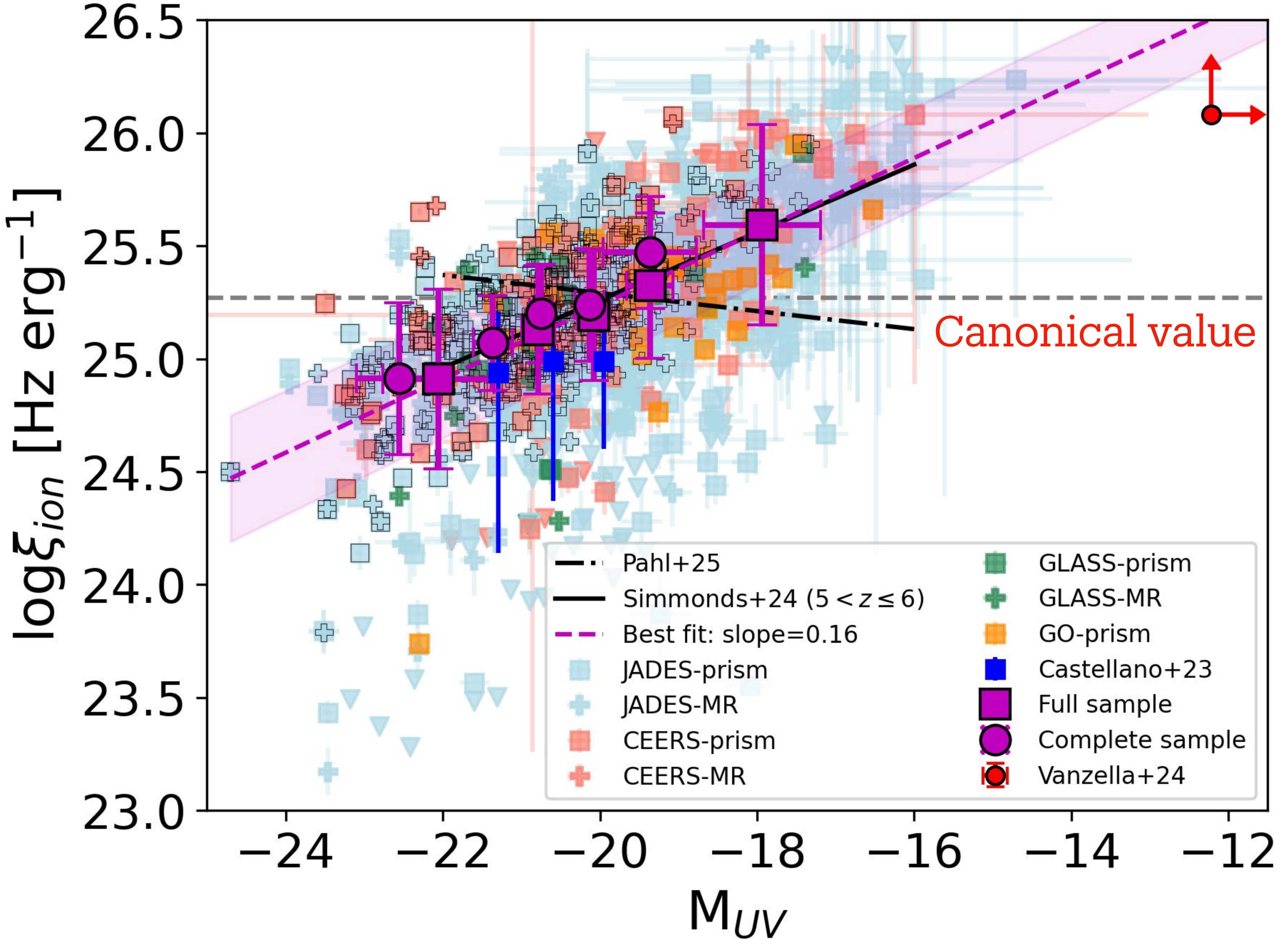
Relation with absolute UV magnitude

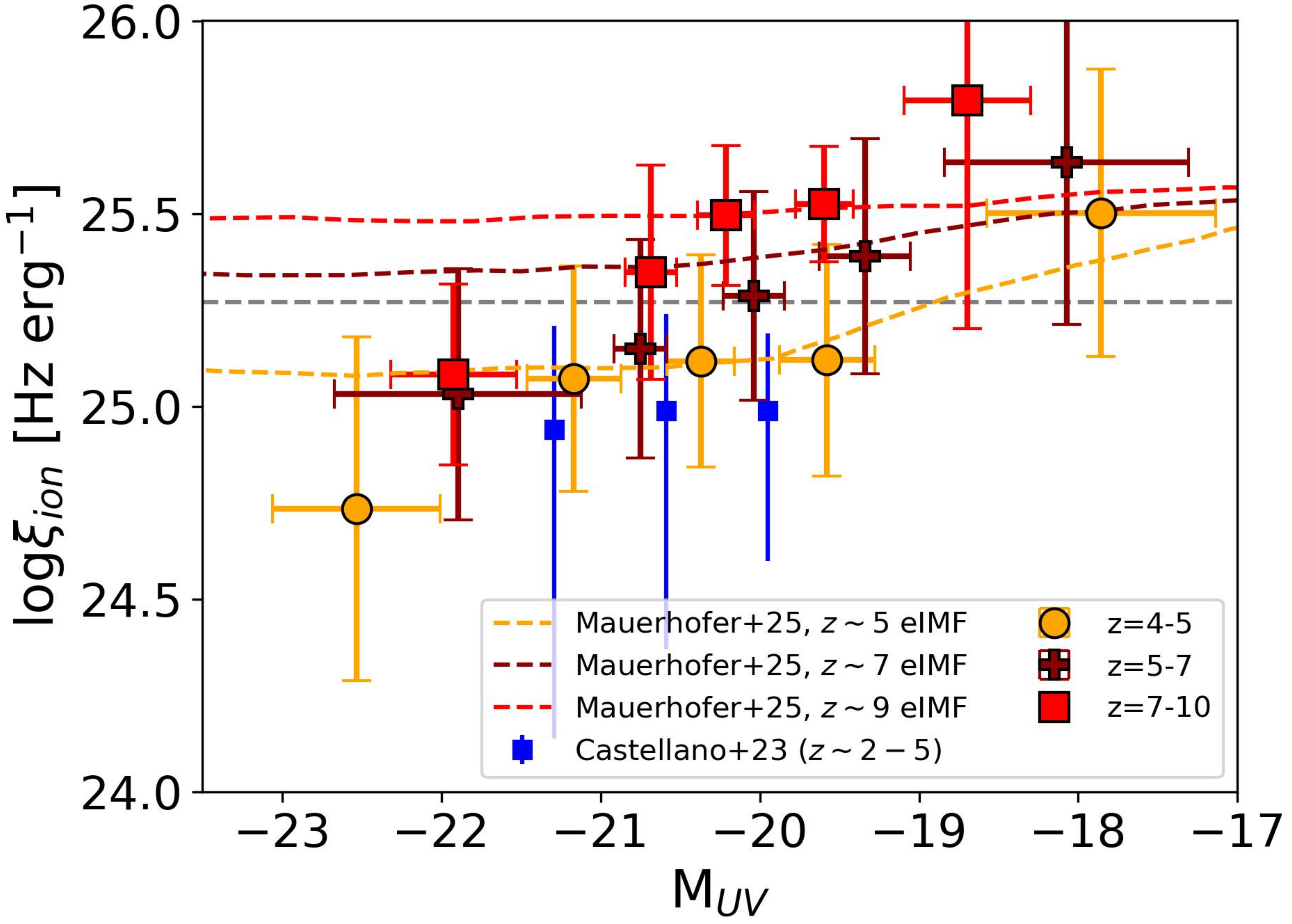


Increase of ξion with increasing Muv

Fainter >-19.3 mag are efficient producers of ionizing photons

Relation with absolute UV magnitude





Increase of ξion with increasing Muv

Fainter >-19.3 mag are efficient producers of ionizing photons

Consistent with the increase of ξion with the increase of MUV found in models at z~5-7 (Mauerhofer+25)

Models with a top-heavy IMF

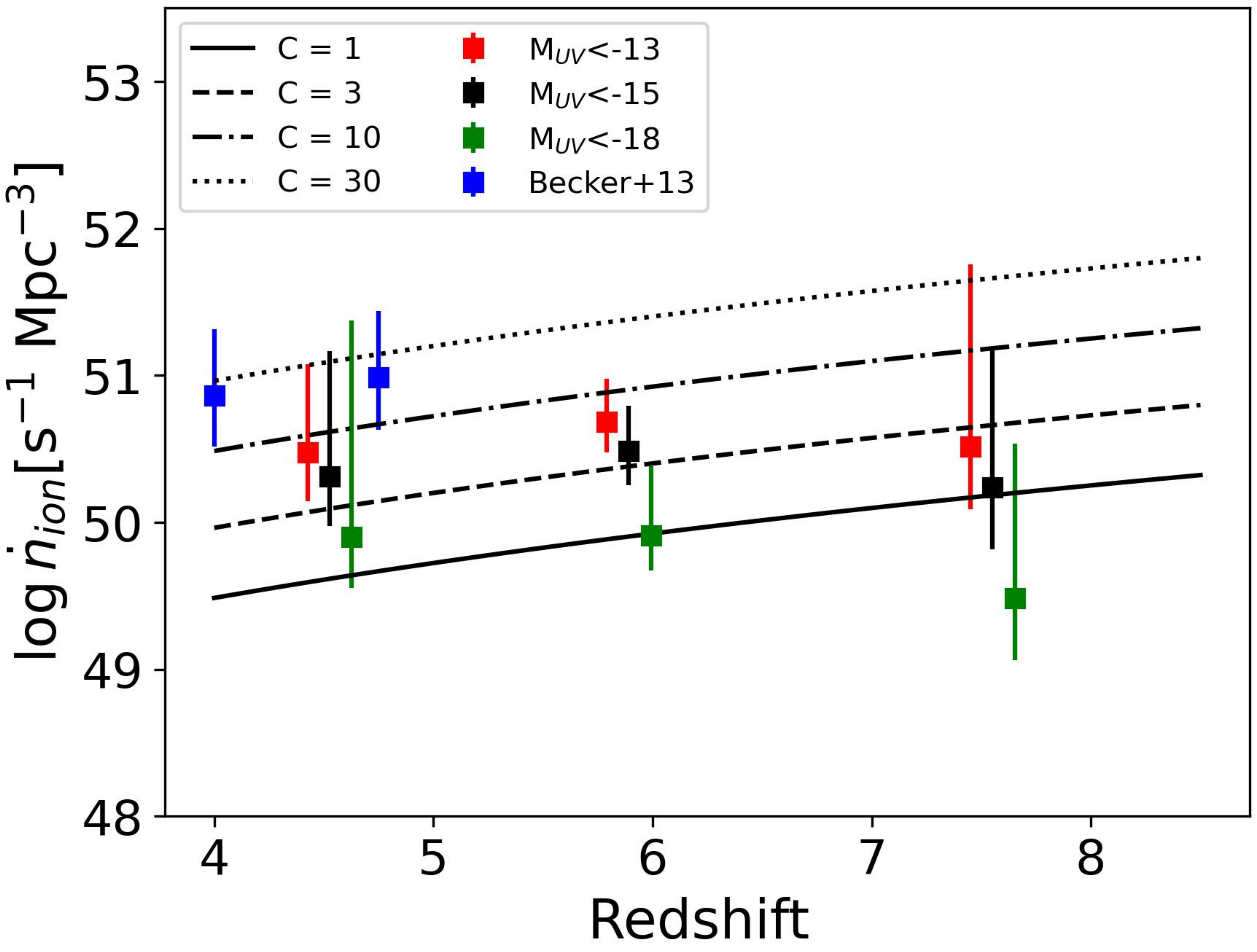
Total ionizing emissivity

UV LF (Bouwens+21)

Median fesc=0.13
(Mascia+23,Mascia+24)

Galaxies can sustain reionization provided the clumpiness factor does not exceed 10: <u>no budget crisis</u>

Consistent with low redshift constraints by the Lya forest.



Faint UV (-15 – -13) contribute ~50% at z~7-5

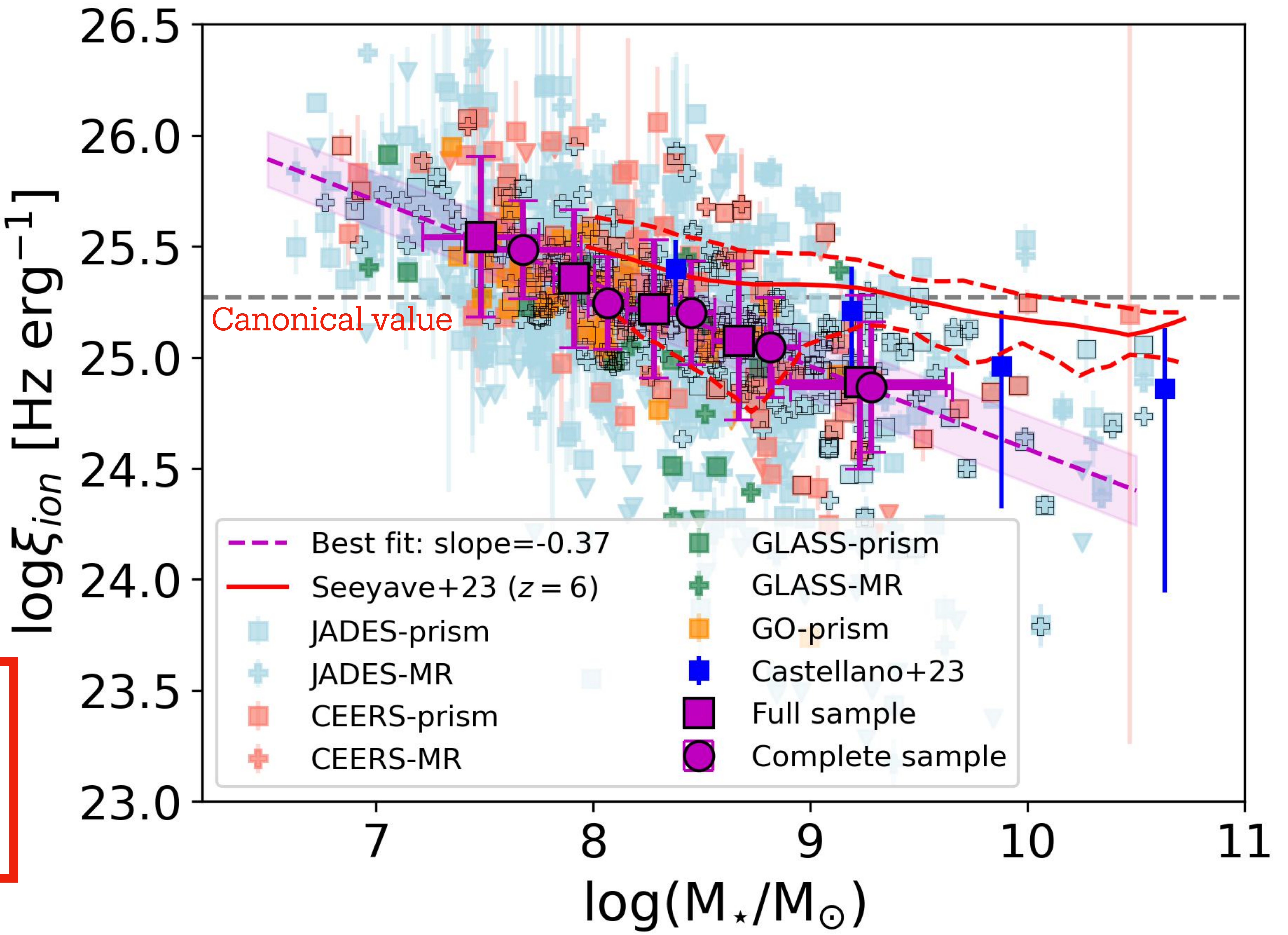
Bright UV (<-18) contribute ~9% at z~7-5

Relation with stellar mass

Decrease of ξion with increasing stellar mass

<10^8 Msun are efficient producers of ionizing photons

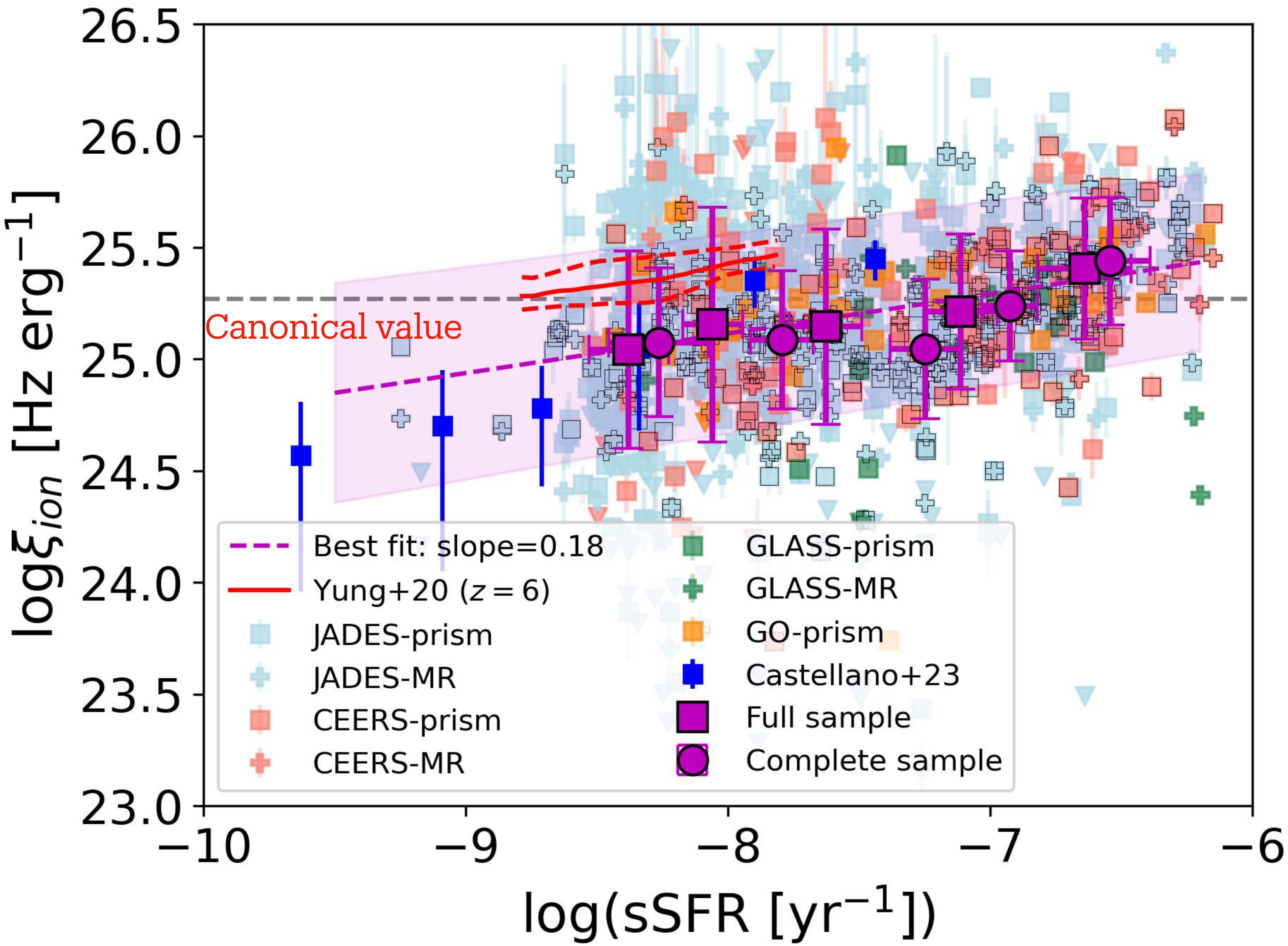
Due to the combined effects of increasing age and metallicity with increasing stellar mass, with metallicity likely playing a bigger role (Seeyave+23)



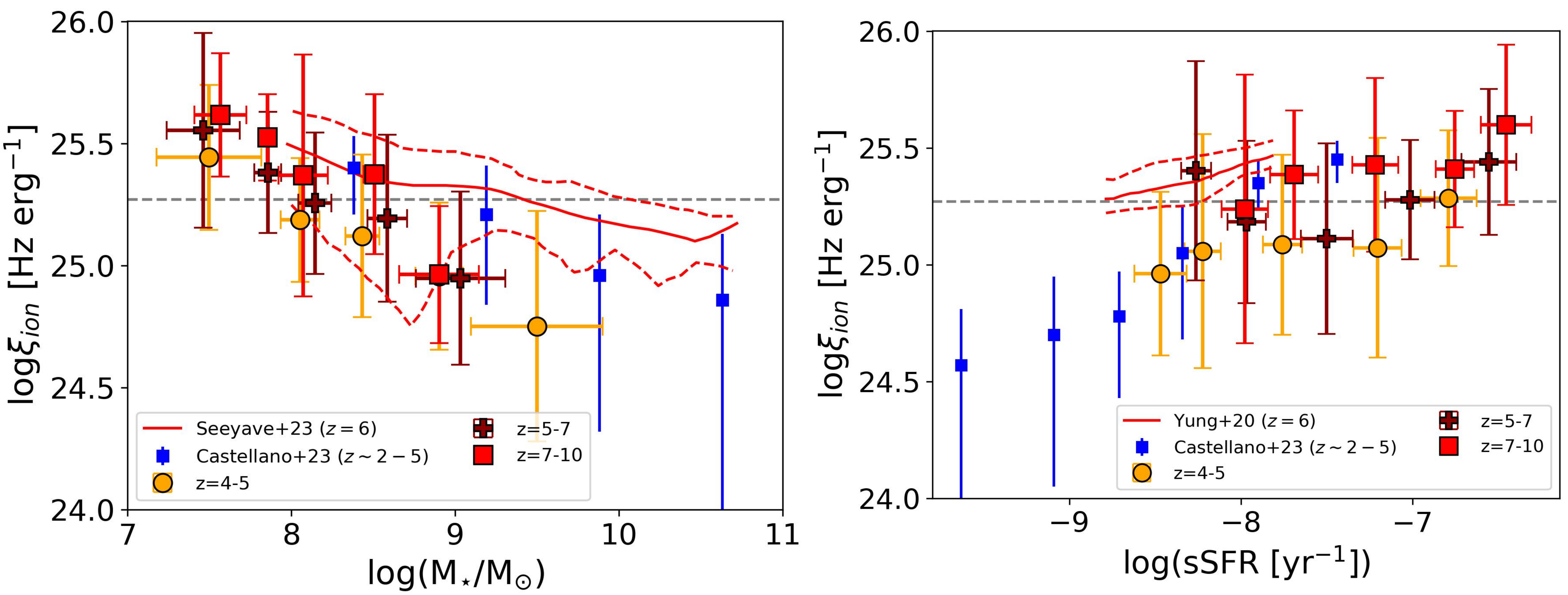
Relation with specific star formation rate

Increase of ξion with increasing sSFR

>10^-7 yr^-1 are efficient producers of ionizing photons



Redshift evolution of the relations



Same slopes at different redshifts: <u>different properties of the populations</u>

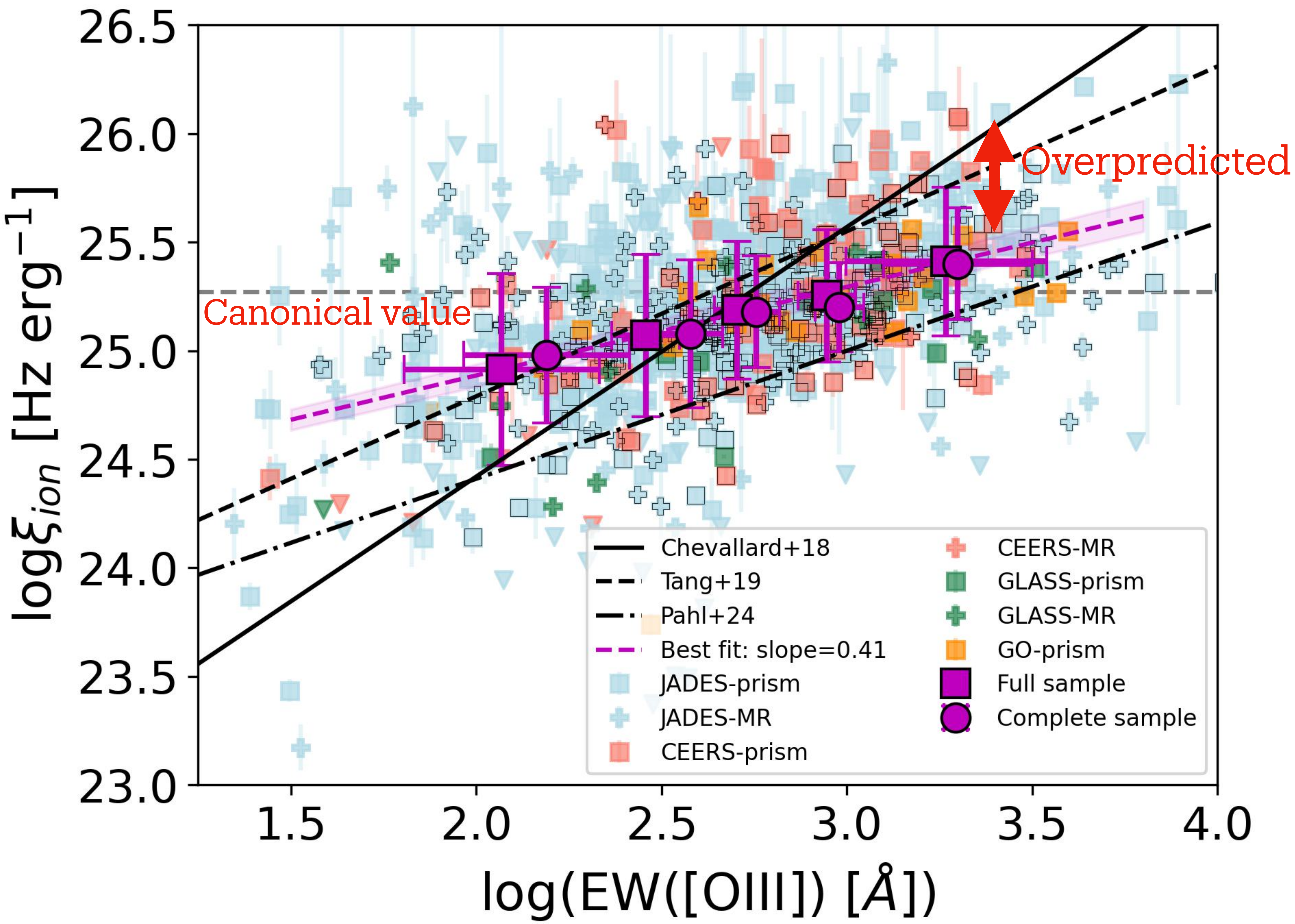
Physical conditions leading to the photon production in galaxies remain essentially the same across cosmic epochs, i.e. for the same metallicity and ages the efficiency is the same.

Relation with EW([OIII])

The EW([OIII]) has been often used as a proxy for ξion (Chavellard+18, Tang+19)

Increase of ξion with increasing EW

>880A are efficient producers of ionizing photons



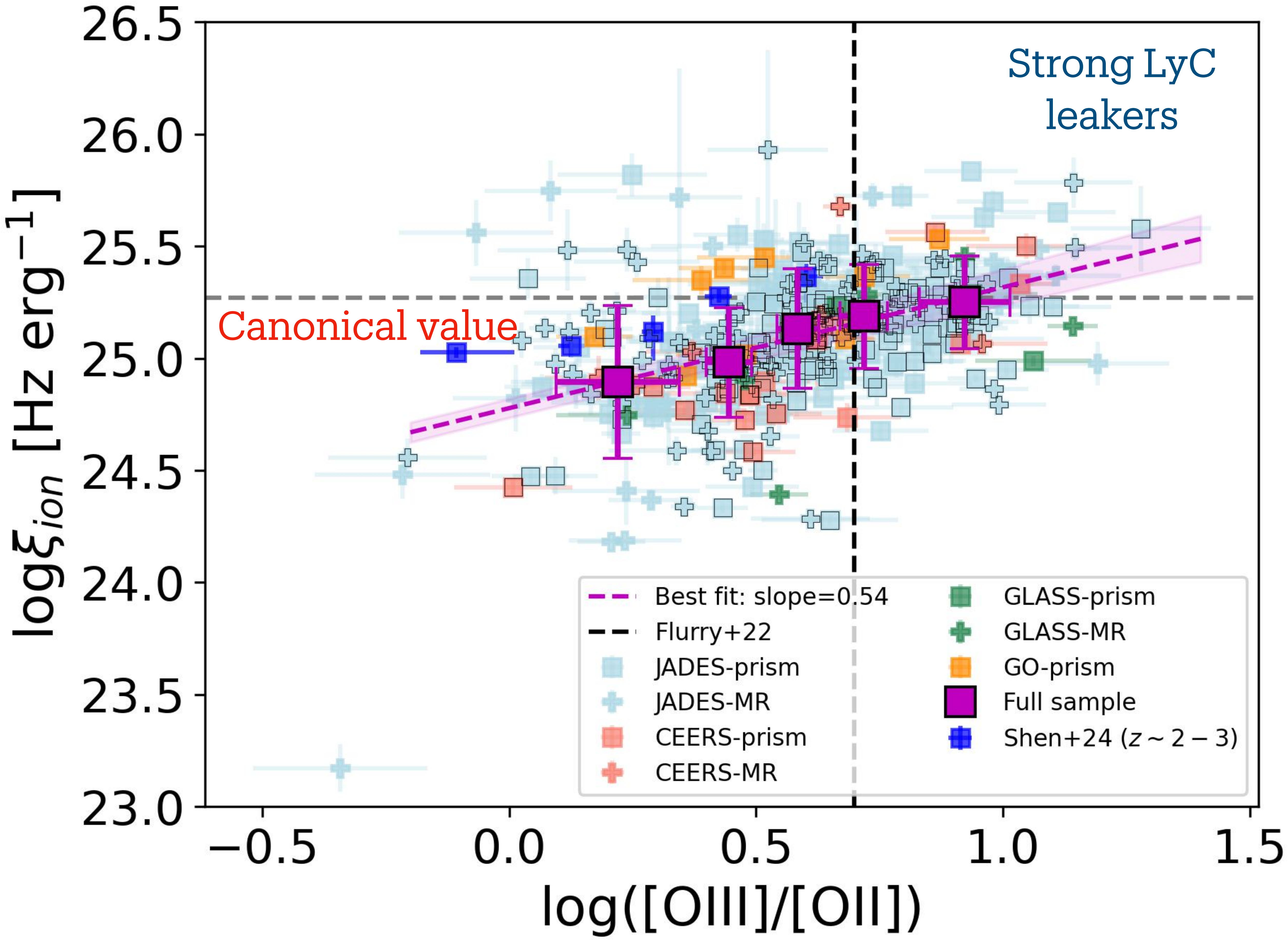
Dependency with metallicity would limit the use of [OIII] as a sole tracer of high-z efficient ionizing systems (Laseter+24)

Relation with O32=log([OIII]/[OII])

O32 has been often used as a proxy for escape of LyC photons (Flury+22)

Increase of ξion with increasing O32

>0.9 are efficient producers of ionizing photons



Galaxies with high photon production efficiency might also be those where the conditions for high leakage of such photons are found (high O32, faint UV magnitudes, and low-stellar masses)

Summary and conclusions

arXiv:2412.01358

- Evolution of the ionizing photon production efficiency of star-forming galaxies with higher values of ξ_{ion} at higher redshifts.
- Low-mass, faint UV, and with high levels of sSFRs galaxies tend to be efficient in producing ionizing photons.
- No budget-crises: Our median values for the galaxy population during the EoR are not as extreme as those found by some other authors (e.g., Maseda+20; Prieto-Lyon+23; Atek+24; Saxena+24).
- Slopes of the relations do not significantly change with redshift. Conditions for photon production do not change and redshift evolution is due to the different statistical populations.
- We find an increase of ξ_{ion} with EW(O[III]).
- Leakers could also be efficient in producing ionizing photons (high O32).

Thanks!

Extra slides

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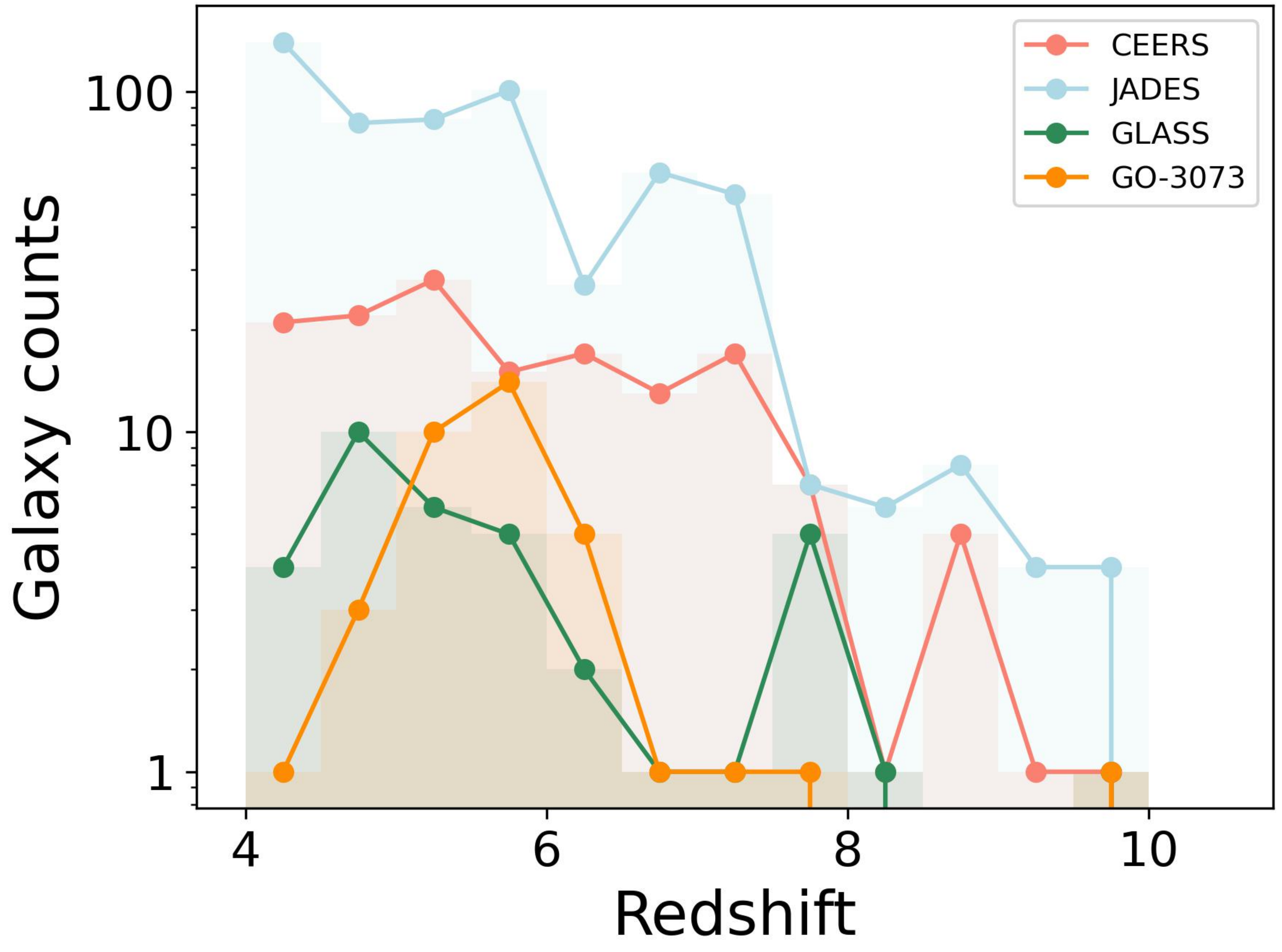
We removed AGN from our final sample based on the AGN sources identified in Roberts-Borsani+24 and Brooks+24: final sample of 731 galaxies

Lensing model available in Bergamini+23

Complete sample: 396 galaxies with F200W<29.3 mag and line fluxes>1.1-1.9 × 10−18 erg s−1 cm−2

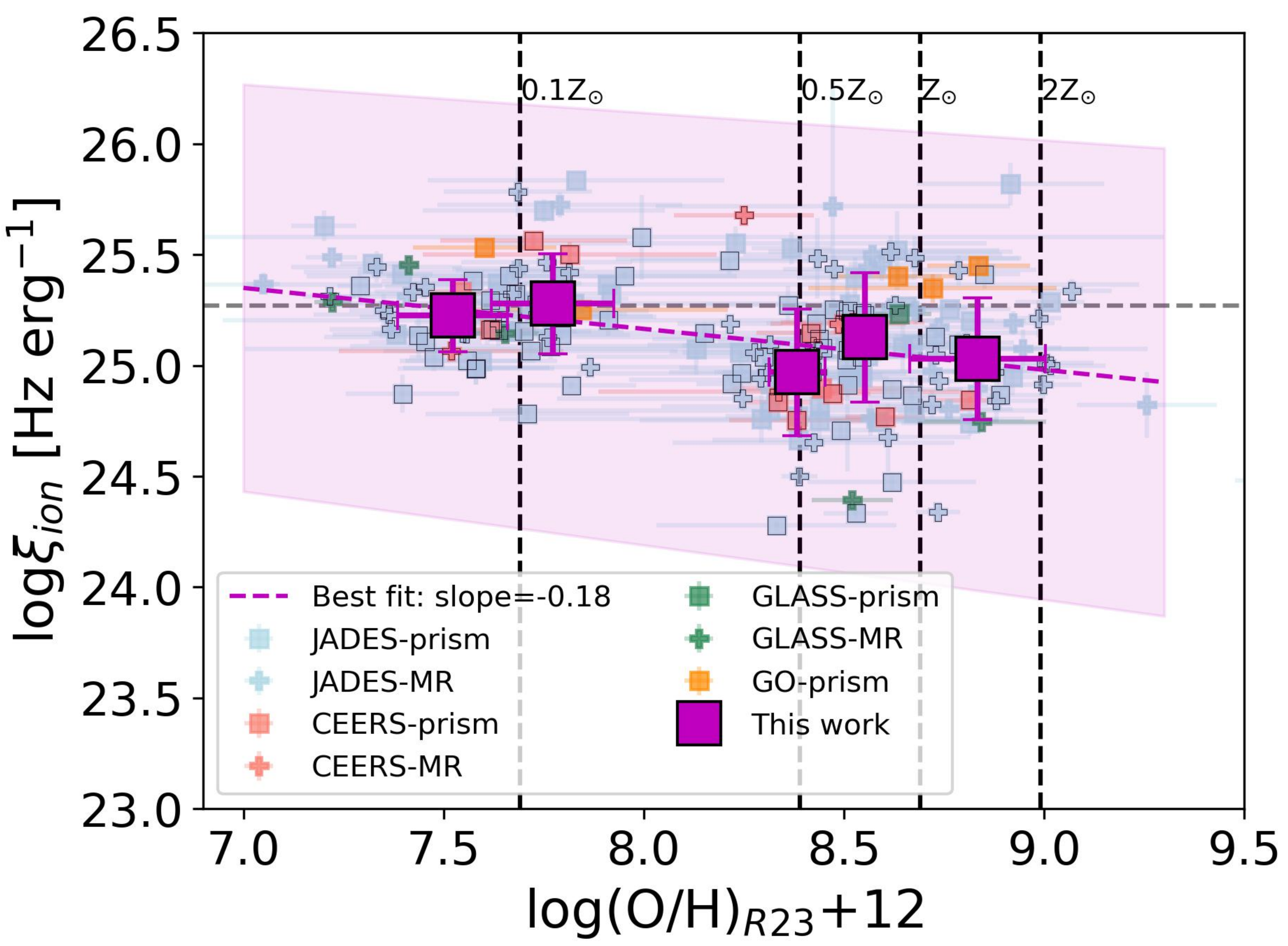


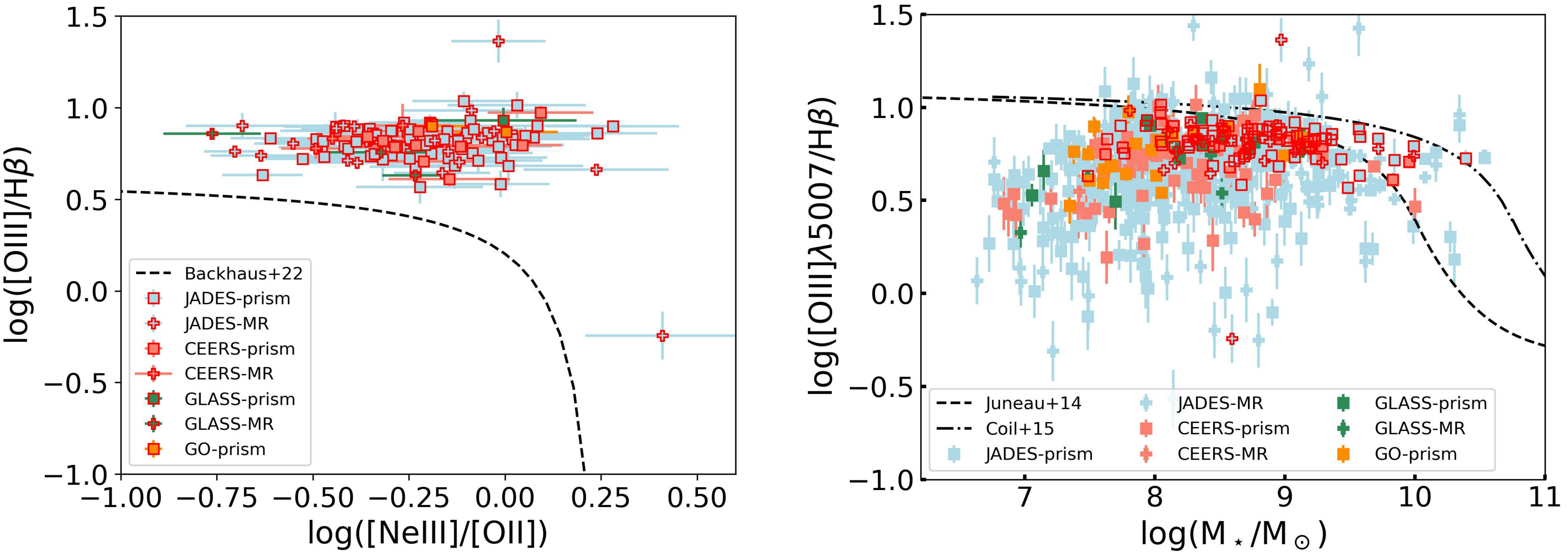
Relation with gas-phase metallicity

We estimated gas-phase metallicities from R23 and O32 calibrations (Sanders+24)

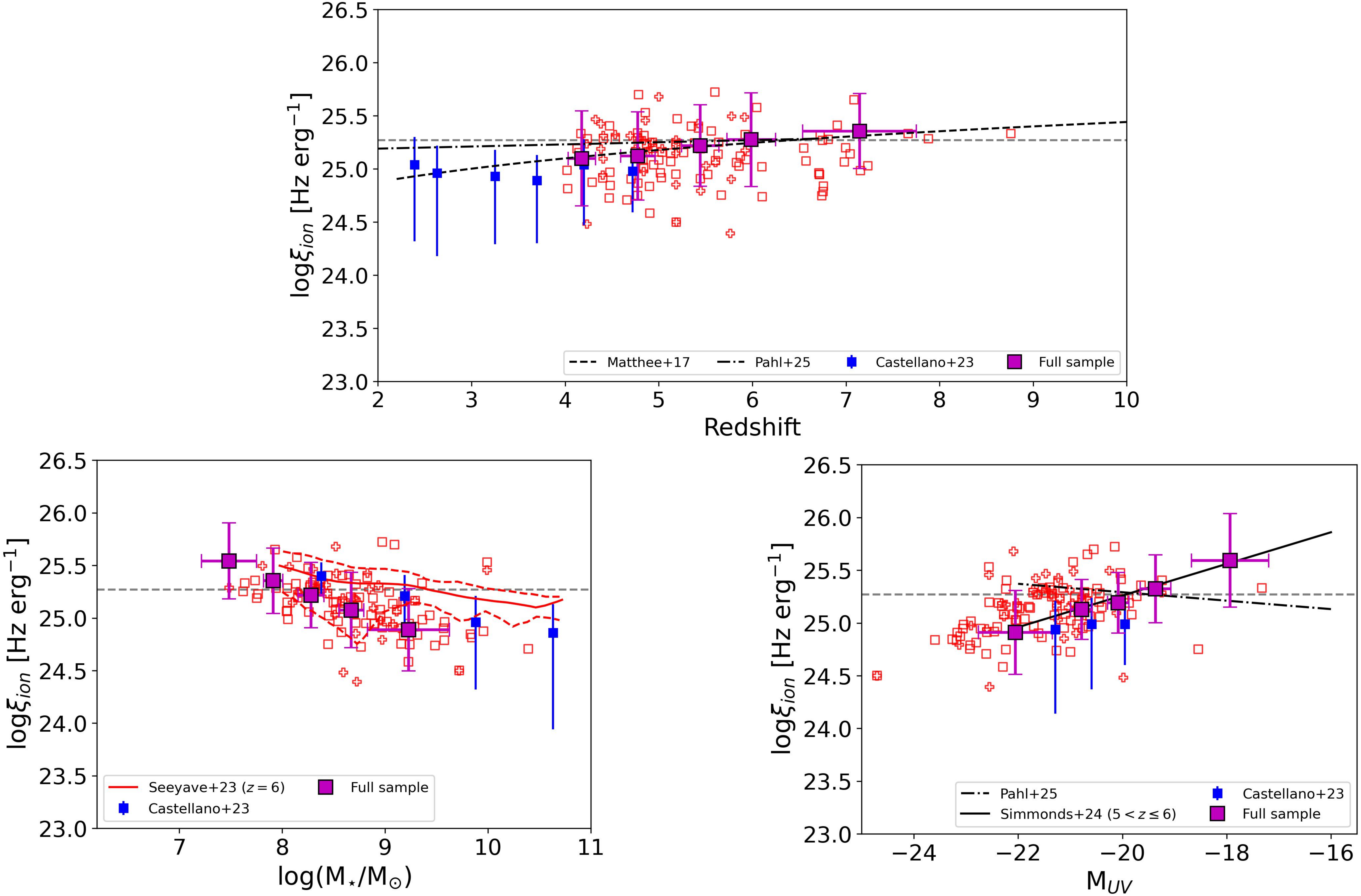
Decrease of ξion with increasing metallicity

<10%solar are efficient producers of ionizing photons

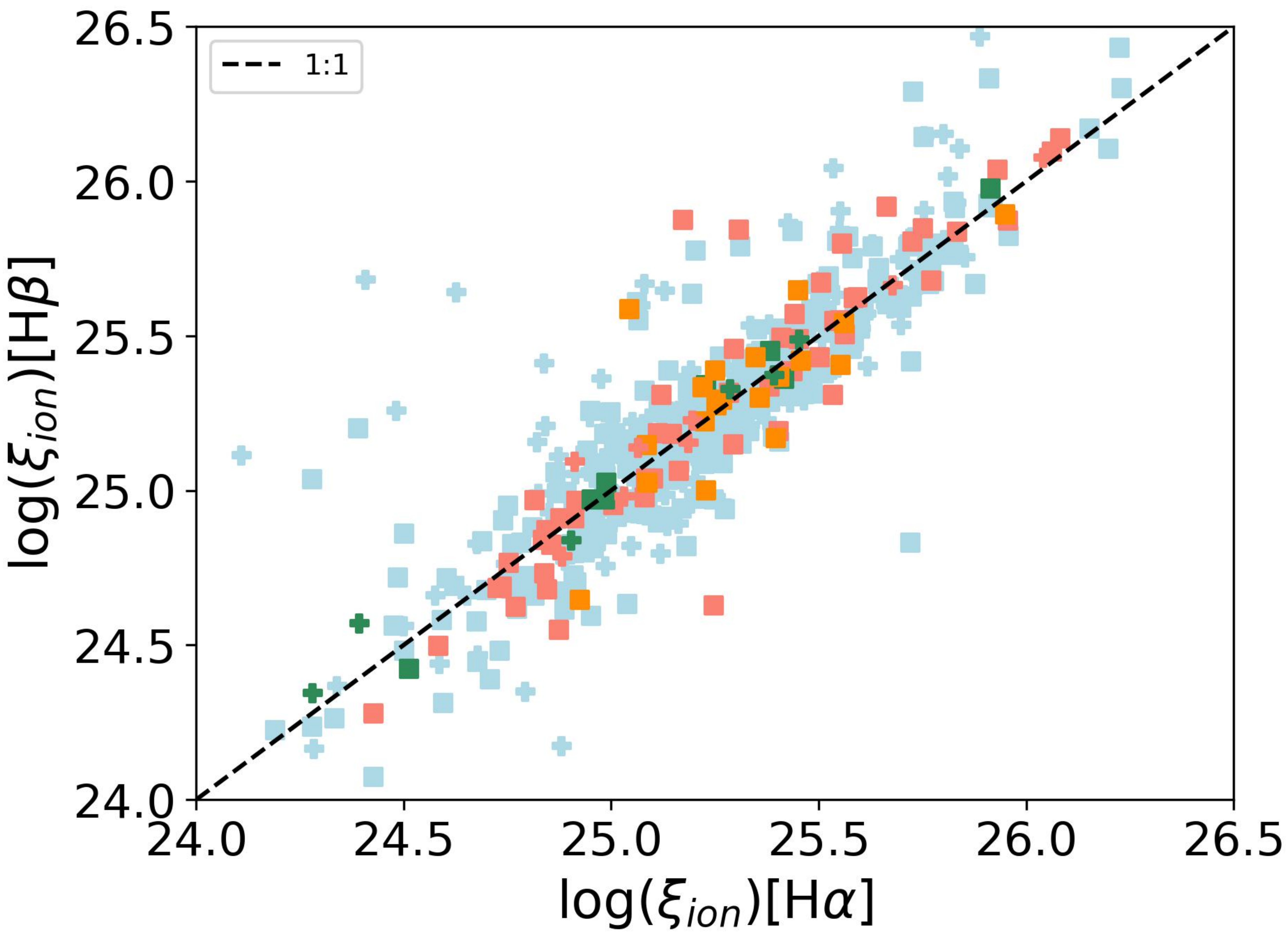




log([OIII]/Hβ)
log([NeIII]/[OII])
Backhaus+22
JADES-prism
JADES-MR
CEERS-prism
CEERS-MR
GLASS-prism
GLASS-MR
GO-prism
log([OIII]λ5007/Hβ)
log(M⋆/M⊙)
Juneau+14
Coil+15



logξ_ion [Hz erg^−1]
Redshift
Matthee+17
Pahl+25
Castellano+23
Full sample
log(M⋆/M⊙)
Seeyave+23 (z = 6)
M_UV
Simmonds+24 (5 < z ≤ 6)



1:1
log(ξ_ion)[Hβ]
log(ξ_ion)[Hα]
24.0
24.5
25.0
25.5
26.0
26.5

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