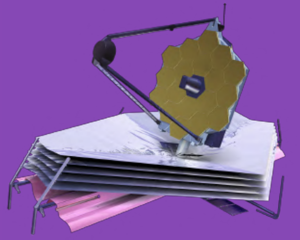


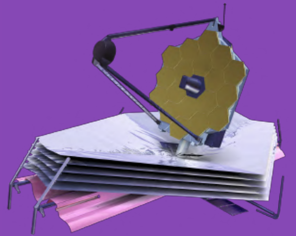
Unveiling the ionising properties of galaxies at the Epoch of Reionisation with NIRCam

(Simmonds+2023(30 LAEs), 2024a(677 ELGs), 2024c(~15K, all types))

Charlotte Simmonds, Sandro Tacchella, David Puskas,
William Baker, William McClymont, **Amanda Stoffers,**
Natalia Villanueva, Callum Witten **+JADES**

JWST ADVANCED DEEP EXTRAGALACTIC SURVEY

Kavli Institute for Cosmology Cambridge



TLDR:

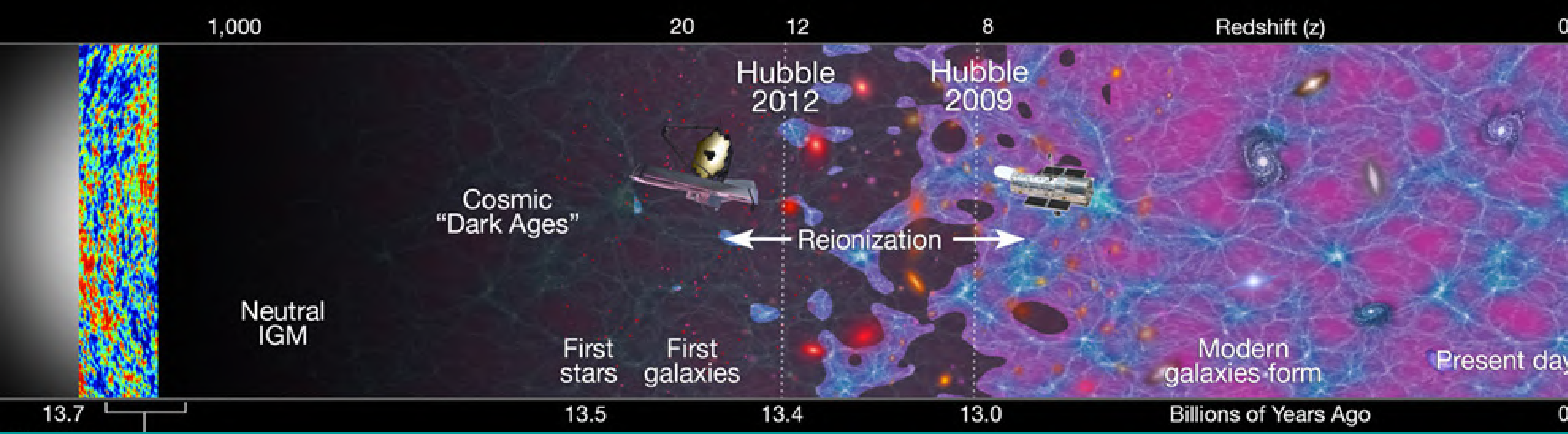
Galaxies <u>can</u> produce enough ionising photons to ionise the Universe

(without breaking physics)

I hope you like LOTR!-

JWST ADVANCED DEEP EXTRAGALACTIC SURVEY

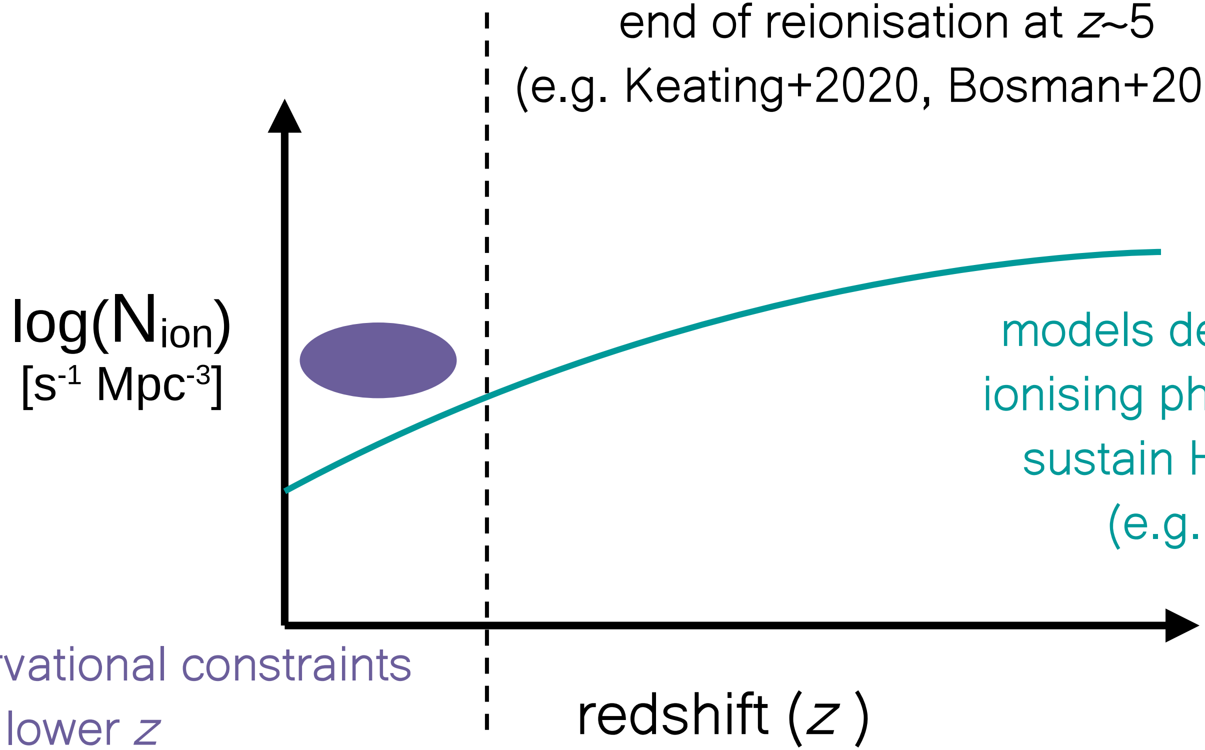
JADES



Motivation: EoR

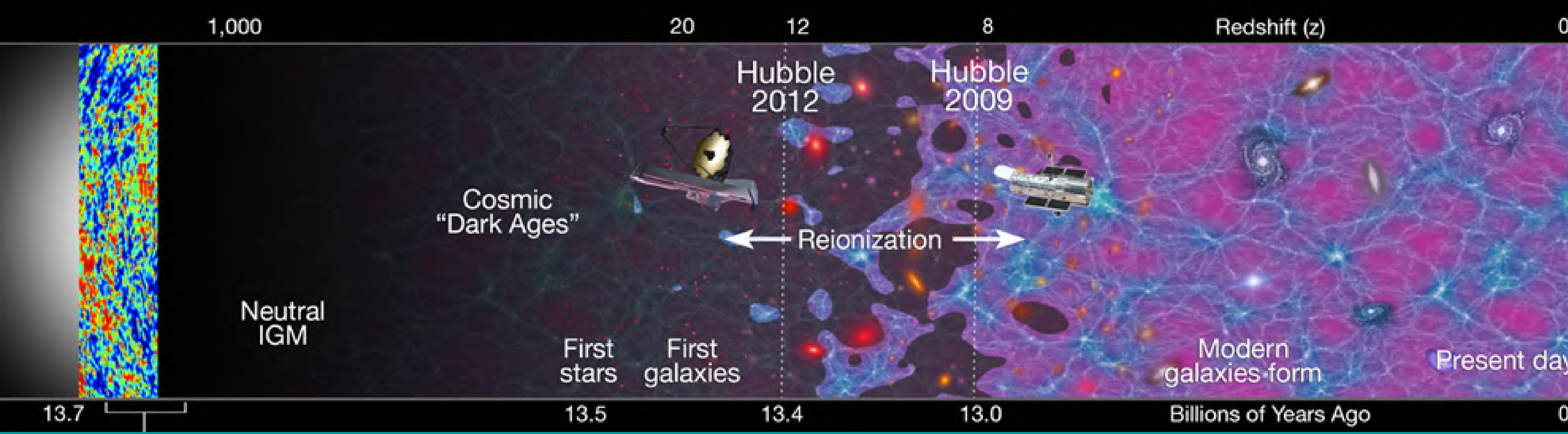
How can we study EoR?
Cosmic ioinising budget, N_{ion}

end of reionisation at z~5
(e.g. Keating+2020, Bosman+2022)



models describing how much ionising photons are needed to sustain H-ionisation in IGM
(e.g. Madau+1999)

+ strong observational constraints at lower z
(e.g. Becker & Bolton 2013, Davies+2024)

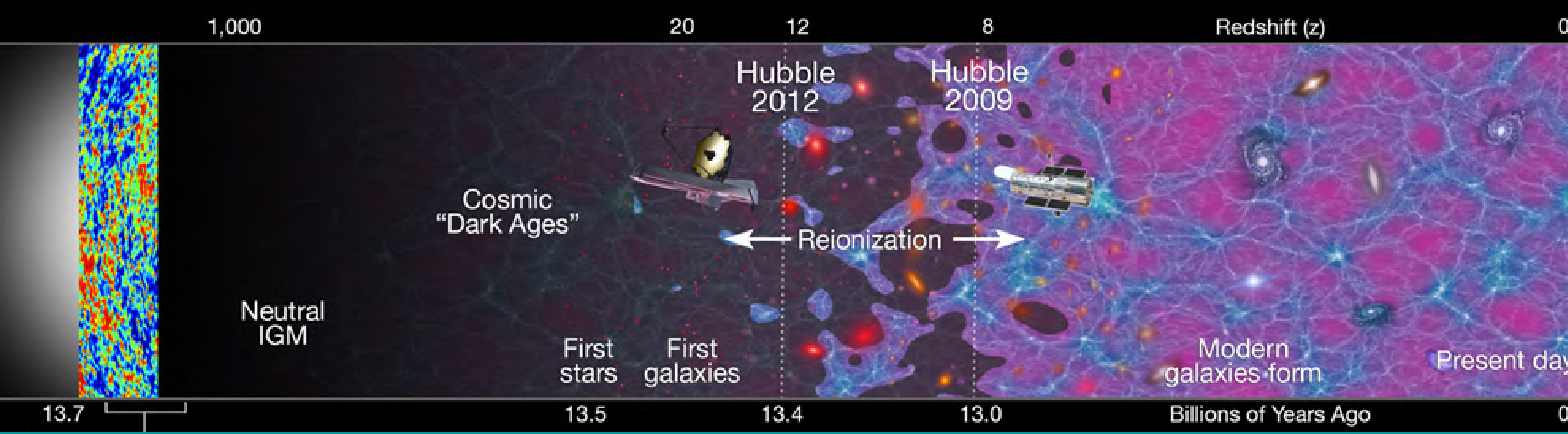


Motivation: EoR – 3 main ingredients

$$\dot{N}_{\rm ion}(z) = f_{\rm esc} \times \xi_{\rm ion}(z) \times \rho_{\rm UV}(z)$$

→ Ionising photon flux per Mpc^3, as a function of redshift

N_{ion}: cosmic ionising budget



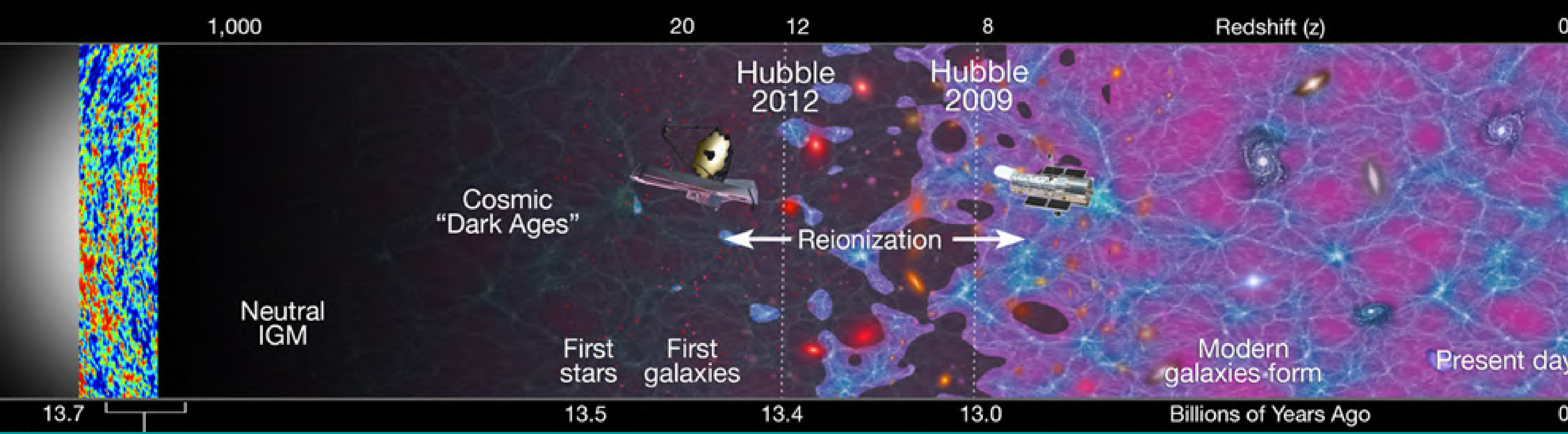
Motivation: EoR – 3 main ingredients

LyC escape fraction

$$\dot{N}_{\rm ion}(z) = f_{\rm esc} \times \xi_{\rm ion}(z) \times \rho_{\rm UV}(z)$$

Ionising photon flux per Mpc^3, as a function of redshift

N_{ion}: cosmic ionising budget



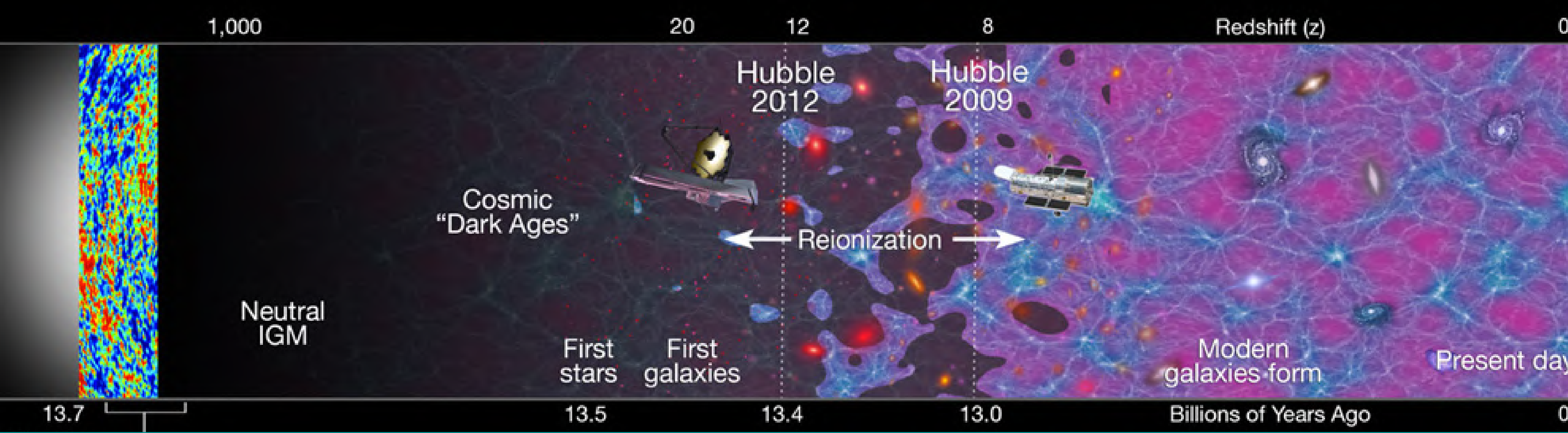
Motivation: EoR – 3 main ingredients

UV luminosity function

$$\dot{N}_{ion}(z) = f_{esc} \times \xi_{ion}(z) \times \rho_{UV}(z)$$

Ionising photon flux per Mpc^3, as a function of redshift

N_{ion}: cosmic ionising budget



Motivation: EoR – 3 main ingredients

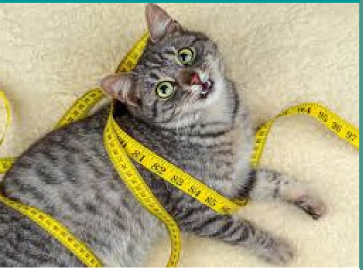
Ionising photon production efficiency

$$\dot{N}_{\rm ion}(z) = f_{\rm esc} \times \xi_{\rm ion}(z) \times \rho_{\rm UV}(z)$$

Ionising photon flux per Mpc^3, as a function of redshift

N_{ion}: cosmic ionising budget

Methods for estimating ξion



ξion = production rate of LyC photons per unit UV continuum luminosity. Usually measured through Hα and [OIII] emission

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

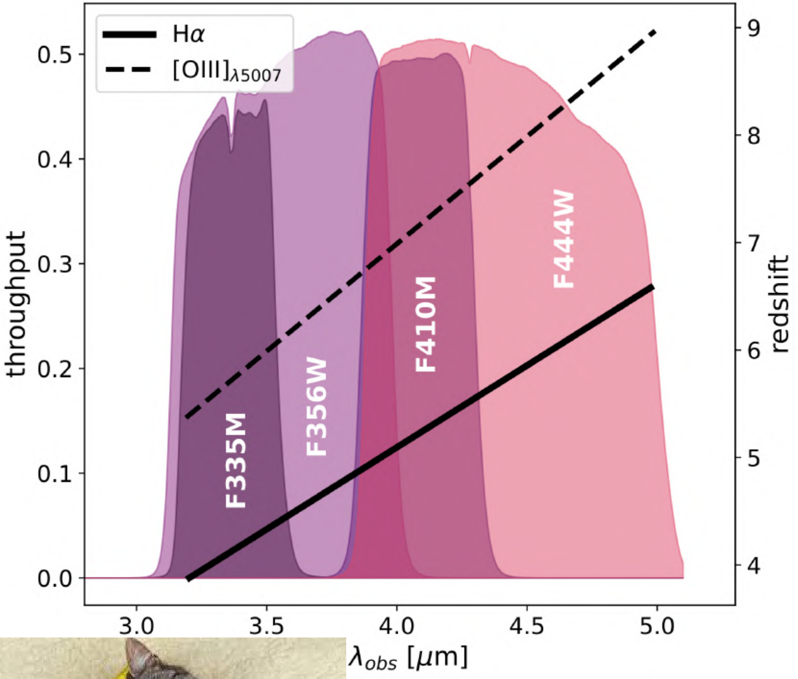
ionising photons produced

monochromatic UV luminosity

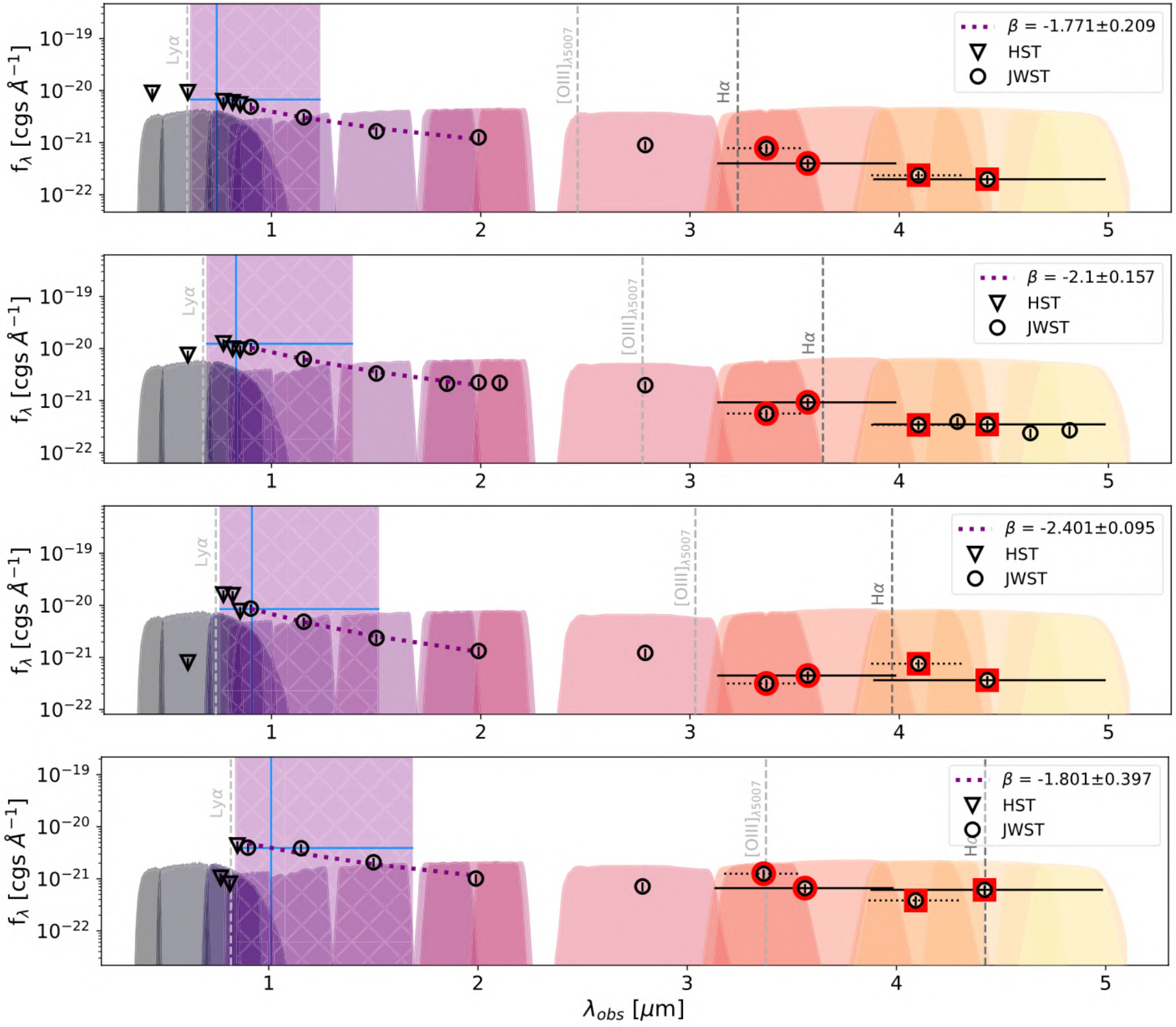
Assuming $f_{esc} = 0$

$$\xi_{\rm ion,0} = \xi_{\rm ion} \times (1 - {\rm f_{esc}}).$$

Simmonds+2024a; ELGs



F335M/F356W   F410M/F444W



Methods for estimating ξion

1. For LAEs, we estimated Hα with JEMS photometry (had Lyα from MUSE)

(30 gals, Simmonds+2023)

2. For ELGs, we estimated Hα and [OIII] with NIRCam photometry* + Prospector**

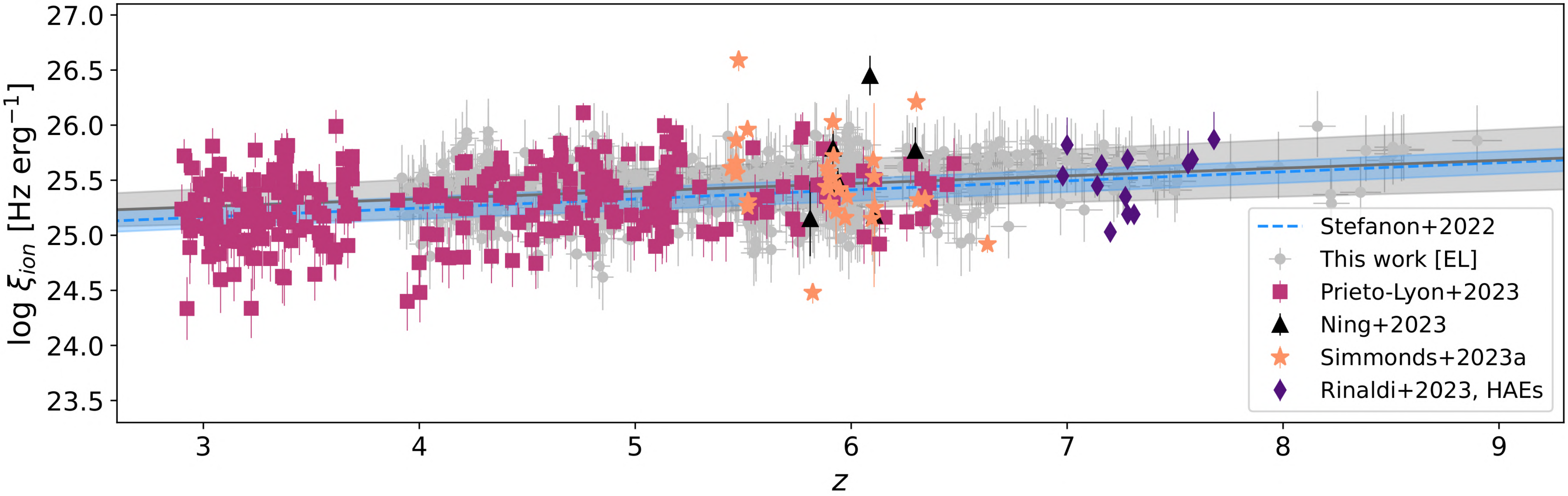
(good agreement between Prospector-inferred fluxes and observed ones)

(677 gals, Simmonds+2024a)

* Rieke+2023

** Johnson+2019,2021

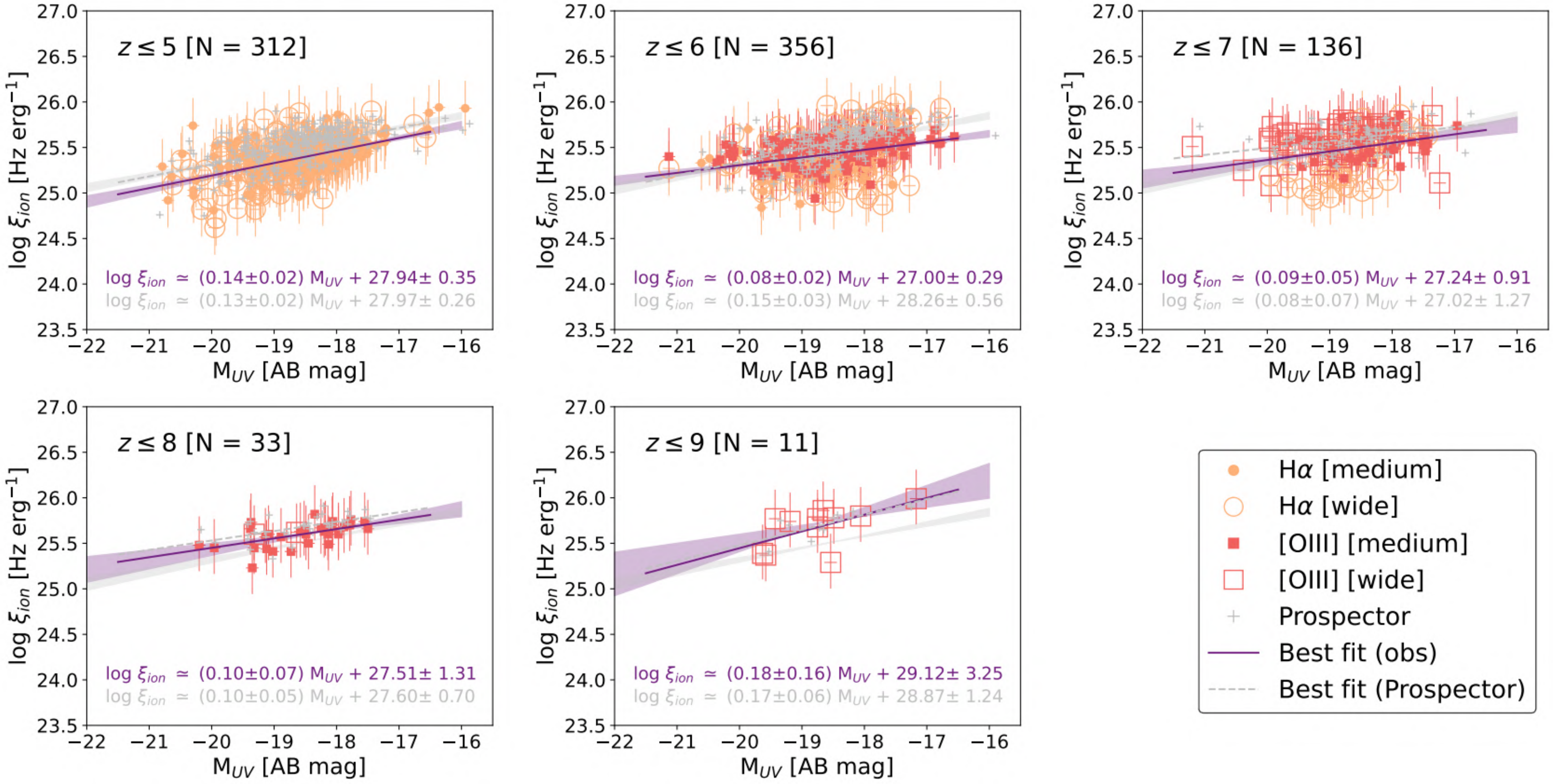
ξ_{ion} evolution with redshift (20 LAEs + 677 ELGs + literature)



We find a slight increase of ξ_{ion} with z, in agreement with previous studies

ξion as a function of MUV, in redshift bins:

Fainter ELGs are significantly more efficient in producing ionising photons



Conclusions (so far)

In Simmonds+2024a, we found low-mass UV-faint galaxies **with bursty SFHs** are more efficient in producing ionising radiation

→ most likely are the main drivers of reionisation!

However... some things to keep in mind

This sample is population limited

(because we impose strong emission line detections, ELGs)

However, this is a special population

(most likely representative of the culprits responsible for the reionisation of the Universe)

We find the ionising photon production efficiency increases with redshift...

CRISIS?!

(e.g. Munoz+2024)

$$\dot{N}_{\rm ion}(z) = {\rm f}_{\rm esc} \times \xi_{\rm ion}(z) \times \rho_{\rm UV}(z)$$

Methods for estimating ξion

1. For LAEs, we estimated Hα with JEMS photometry (had Lyα from MUSE)
(30 gals, Simmonds+2023)

2. For ELGs, we estimated Hα and [OIII] with NIRCam photometry + Prospector
(good agreement between Prospector-inferred fluxes and observed ones)
(677 gals, Simmonds+2024a)

3. For potentially all types of galaxies (90% complete in stellar mass), we use Prospector and full JADES+HST photometry set
(~15K gals, Simmonds+2024c)

Methods for estimating ξion

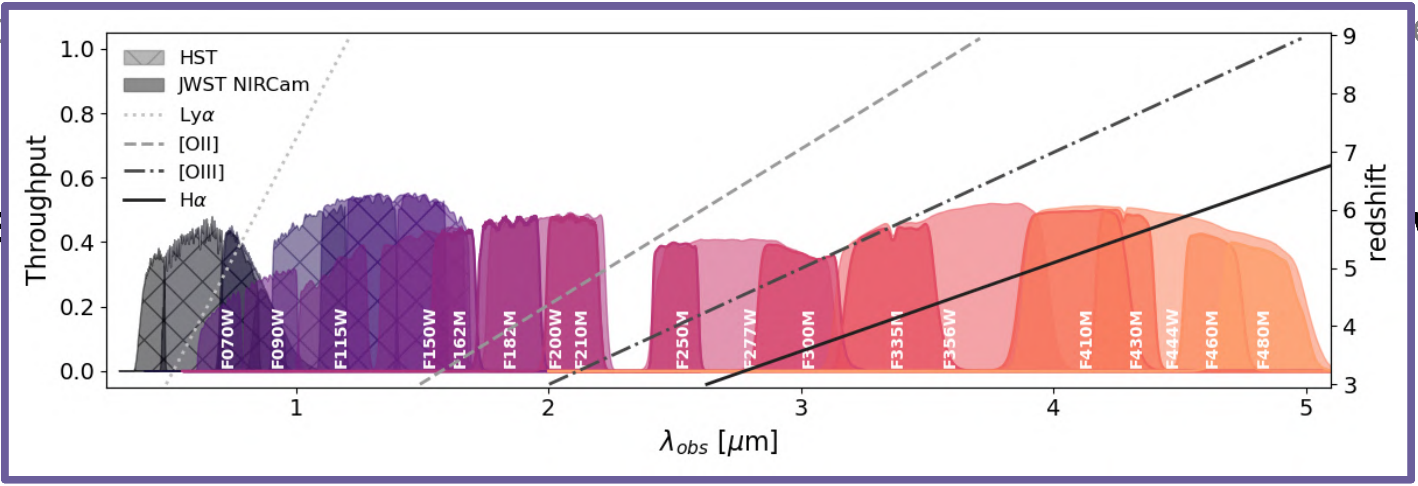
1. For LAEs, we estimated Hα with JEMS photometry (had Lyα from MUSE)

(30 gals, Simmonds+2023)

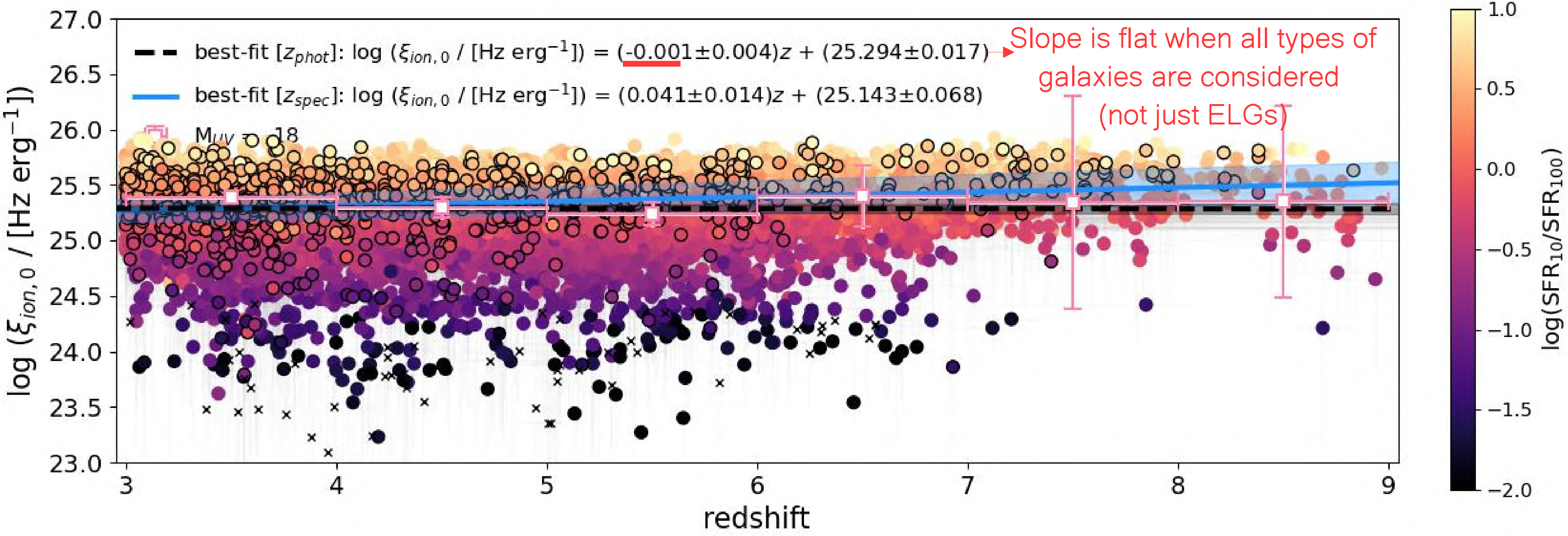
2. For ELGs, we estimated Hα and [OIII] with NIRCam photometry + Prospector

(goo … es)

3. For pote … we use



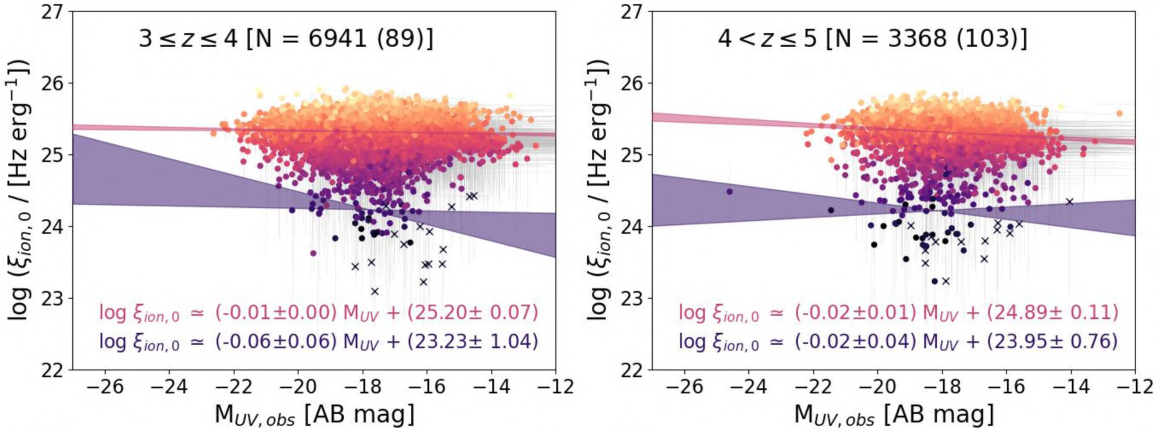
Updated evolution of ξ_{ion} with redshift - burstiness



Circles with (without) edges = z_{spec} (z_{phot}) sample

The z_{spec} sample shows an evolution with redshift consistent with previous studies, because it is also biased towards emission line galaxies

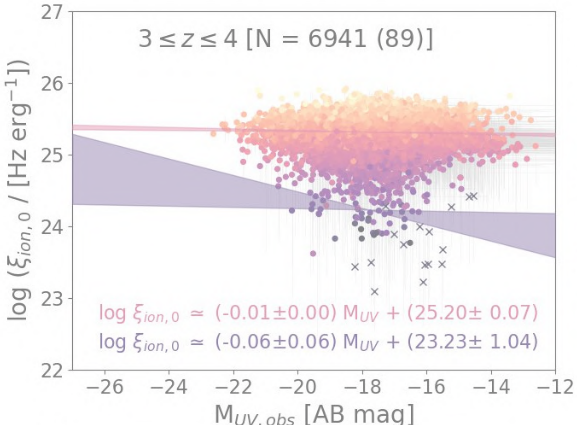
Updated evolution of ξ_{ion} with M_{UV} per redshift bin:
Unveiling a secondary population with log(SFR10/SFR100)<-1

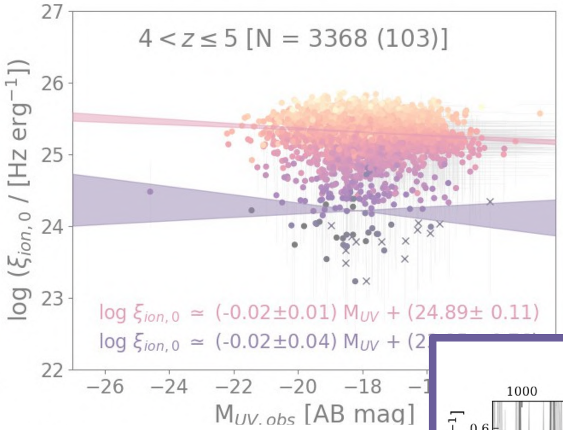


→ SF (97%)

→ MQ (3%)

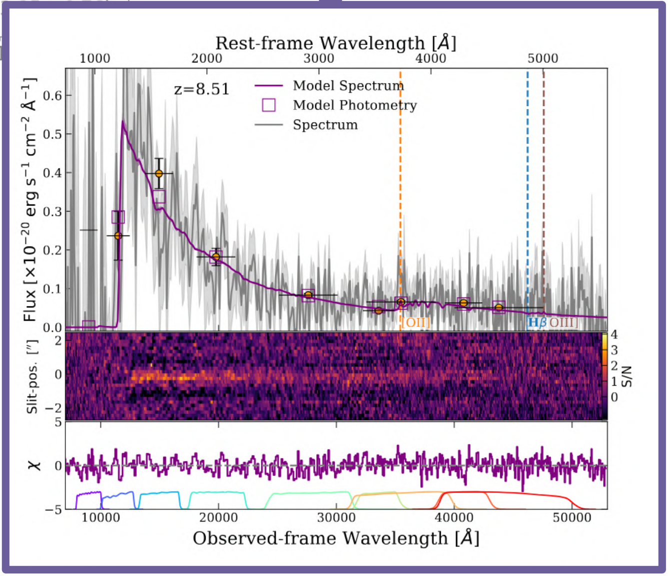
Updated evolution of ξ_{ion} with M_{UV} per redshift bin:
Unveiling a secondary population with log(SFR10/SFR100)<-1





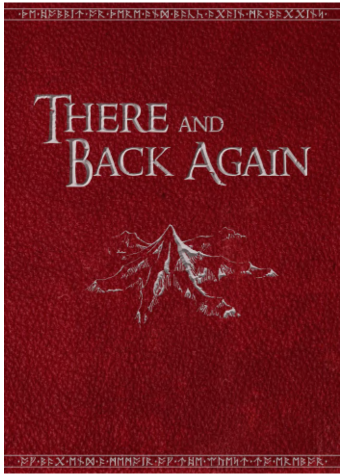
→SF (97%)

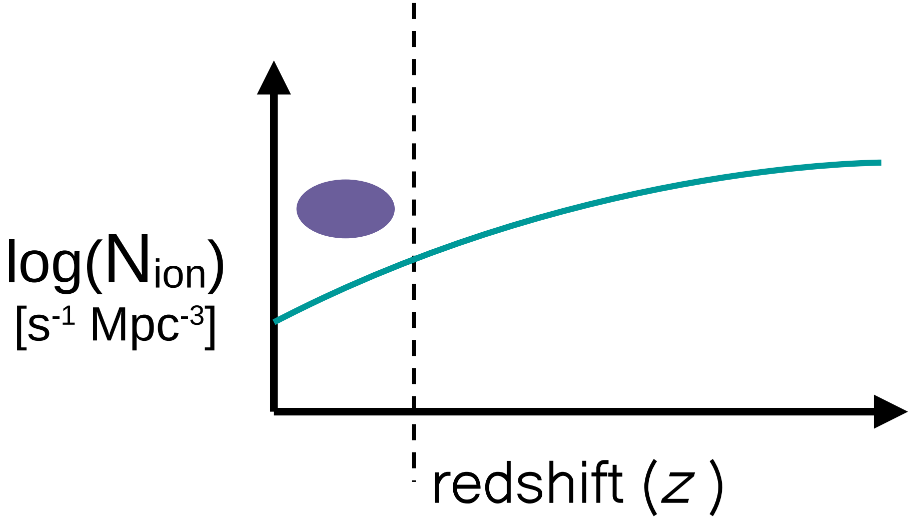
→MQ (3%)



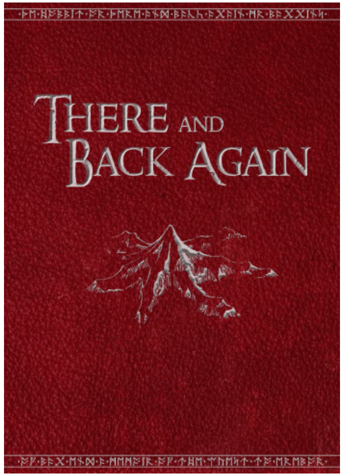
Mini-quenched galaxies are just the other side of the coin regarding bursty SF

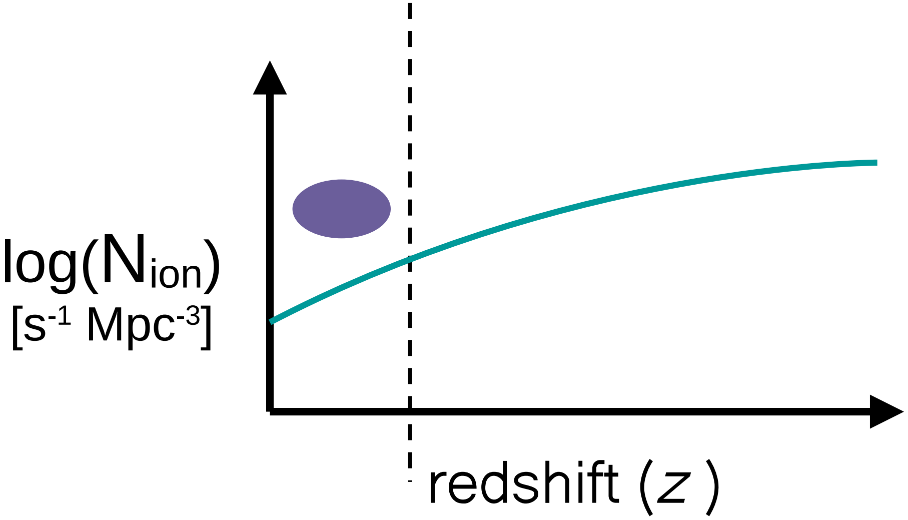
Example of MQ galaxy at z=8.5 (Baker+2025)





EoR revisited: – 3 main ingredients





EoR revisited: – 3 main ingredients

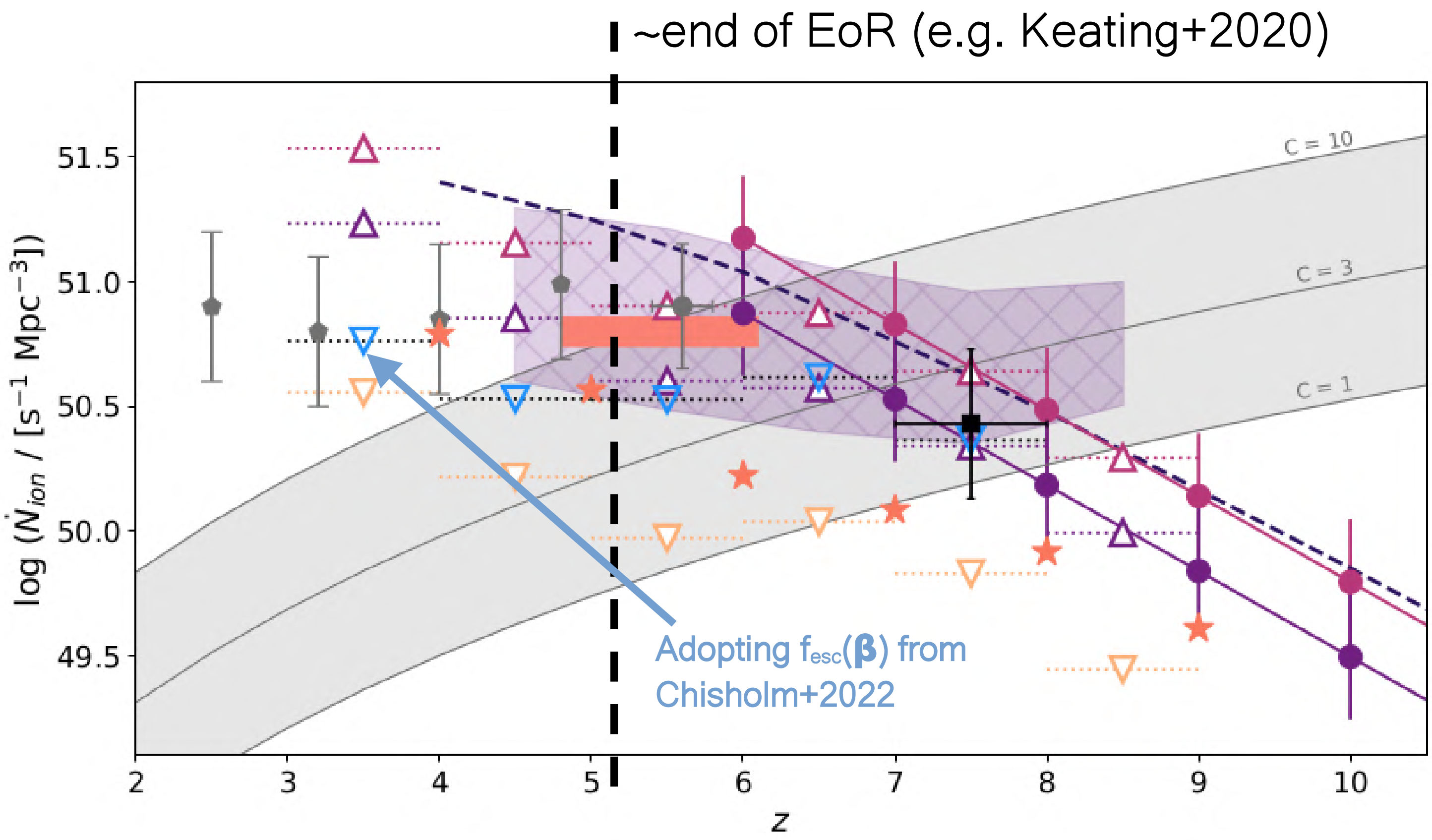
basically flat!

$$\dot{N}_{ion}(z) = f_{esc} \times \xi_{ion}(z) \times \rho_{UV}(z)$$

10,20% fixed,
+Chisholm+2022

Bouwens+2021
(and basically flat ξ_{ion}-M_{UV} relations)

Broader context: cosmic ionising photon budget (N_{ion})



For every clumping factor and redshift bin, **the fainter and lower mass galaxies dominate!**

Grey curves, Madau+1999 = N_{ion} required to maintain H-ionisation in IGM

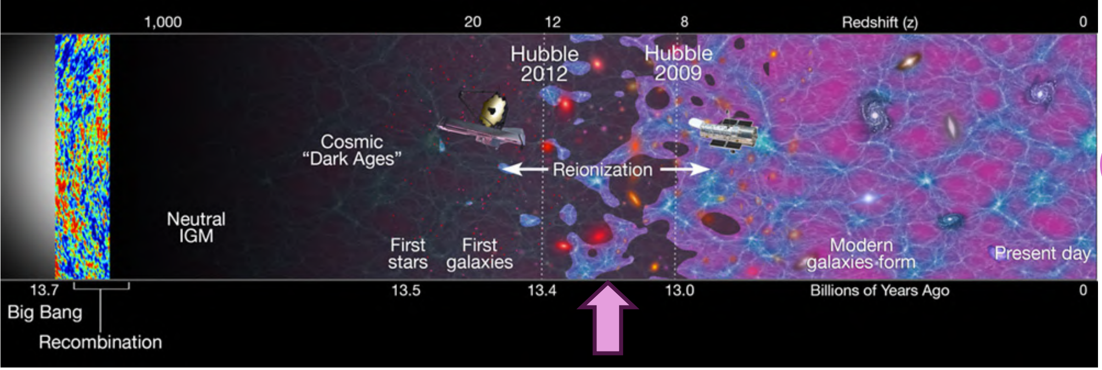
Clumping factors (C=1 → uniform IGM, C>1 → more recombinations, so more ionising photons needed)

Broader context: cosmic ionising photon production

Faint low-mass galaxies have enhanced ξion due to the **burstiness** of their SFHs and are likely key to reionisation.

By studying a 90% stellar-mass complete sample of ~15K galaxies, we find that galaxies can reionise the Universe by *z*~5 without creating an overestimation of ionising photons (also see Cain+2025)

But what about AGN?



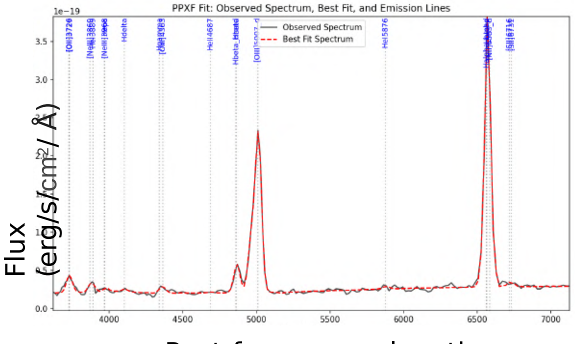
What are the sources responsible for Reionization?

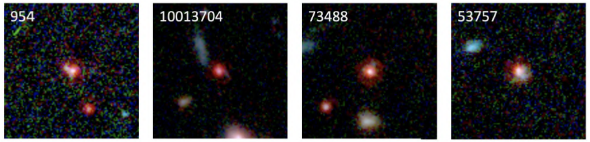
Master thesis: "Insights into Early Black Hole Accretion During the Reionization Epoch from Emission Lines of JWST-Discovered AGNs"

Supervisor: Prof. Piero Madau *Co-supervisor*: Prof. Roberto Maiolino

Research Interests:

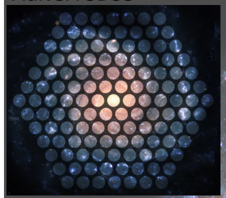
- Epoch of Reionization and early Universe
- Spectroscopic and photometric analysis of high-redshift galaxies
- AGNs at high redshift
- SED fitting
- Photoionization modeling
- Multiwavelength data analysis from deep fields and large surveys (JWST, HST, SDSS, etc.)





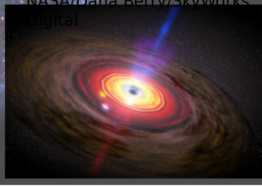
Maiolino et al 2024

MaNGA SDSS



Greta Zucchi

MSc student – PhD candidate (Unimib, Italy)

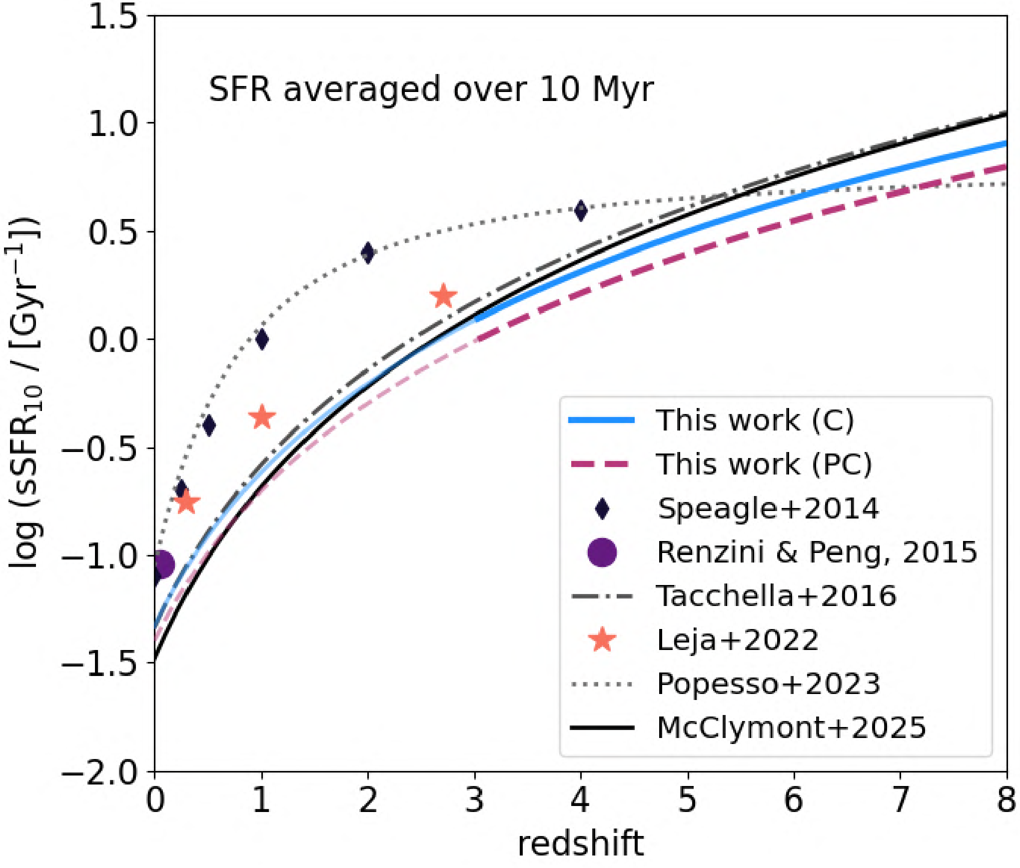


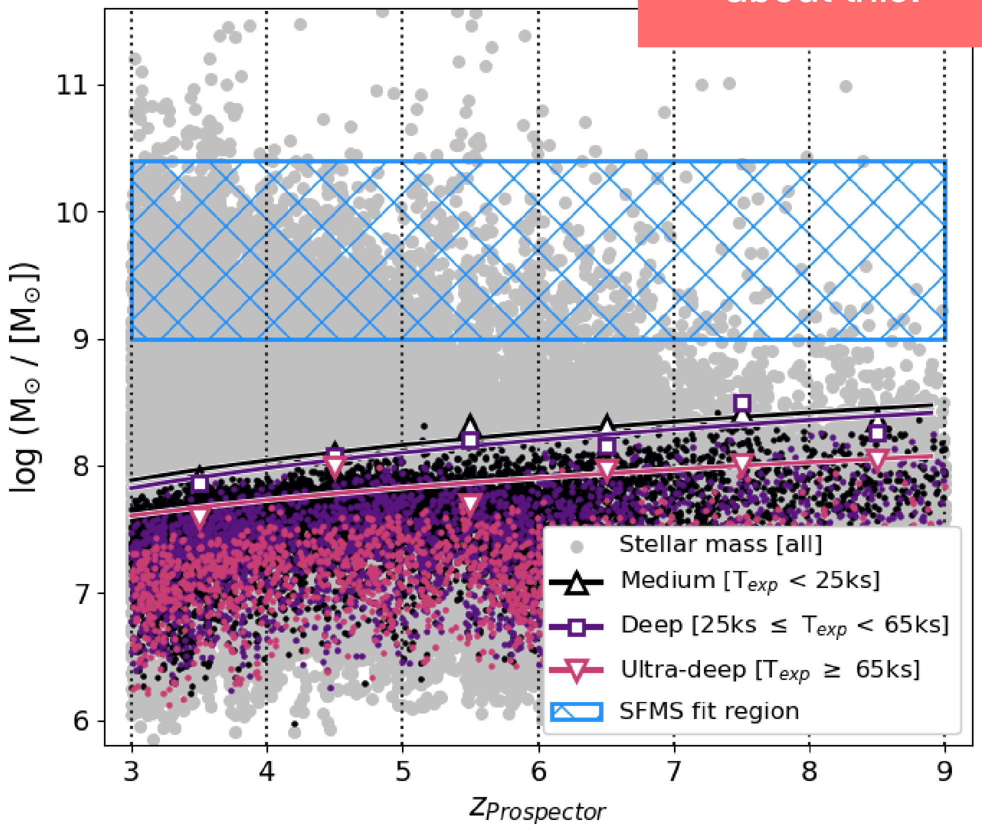
NASA/Dana Berry/SkyWorks Digital

Contacts: gretazucchi15@gmail.com ,g.zucchi5@campus.unimib.it

And speaking of bursty SFHs…. (Simmonds+in prep)

Please talk to me about this!





Conclusions

We find that **low-mass faint galaxies are more efficient in producing ionising radiation,** this is driven by the burstiness of their SFHs. These kind of galaxies are likely responsible for reionising the Universe.

Galaxies produce enough ionising radiation to ionise the Universe by z~5

→ And galaxies SFHs are bursty!

THANK YOU!

Caveats/limitations

- **AGN contribution** cannot be disentangled from photometry alone, so we cannot be sure our sample does not contain them. AGN have been observed at high-z and might be important to reionisation (e.g. Joudzbalis+2023, Maiolino+2023, Madau+2024). Underestimating AGN contribution can lead to higher derived stellar masses (Buchner+2024)

- We adopted a **Chabrier IMF,** using the MILES stellar library - we might be missing extreme objects that would not be fit with our assumptions (e.g. top heavy IMF, Cameron+2023a)

- **Photometric redshifts** have been proven to be overall good for the GOODS-S NIRCam sample (Hainline+2023, Rieke+2023), but not perfect