Evidence for a patchy end to Reionization from JWST

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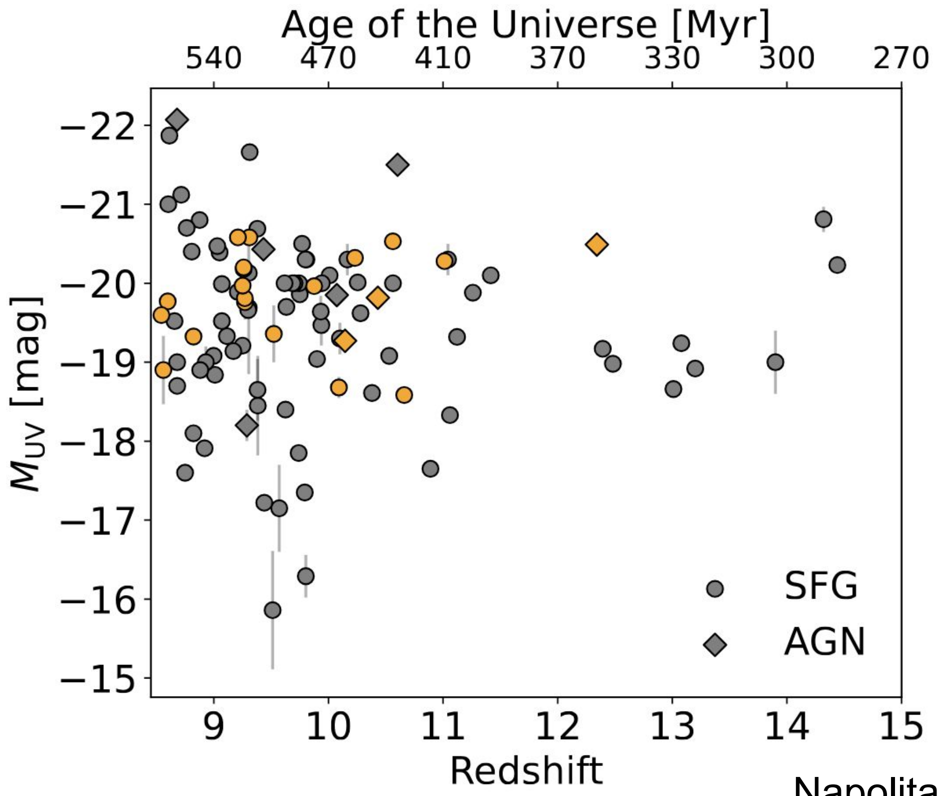
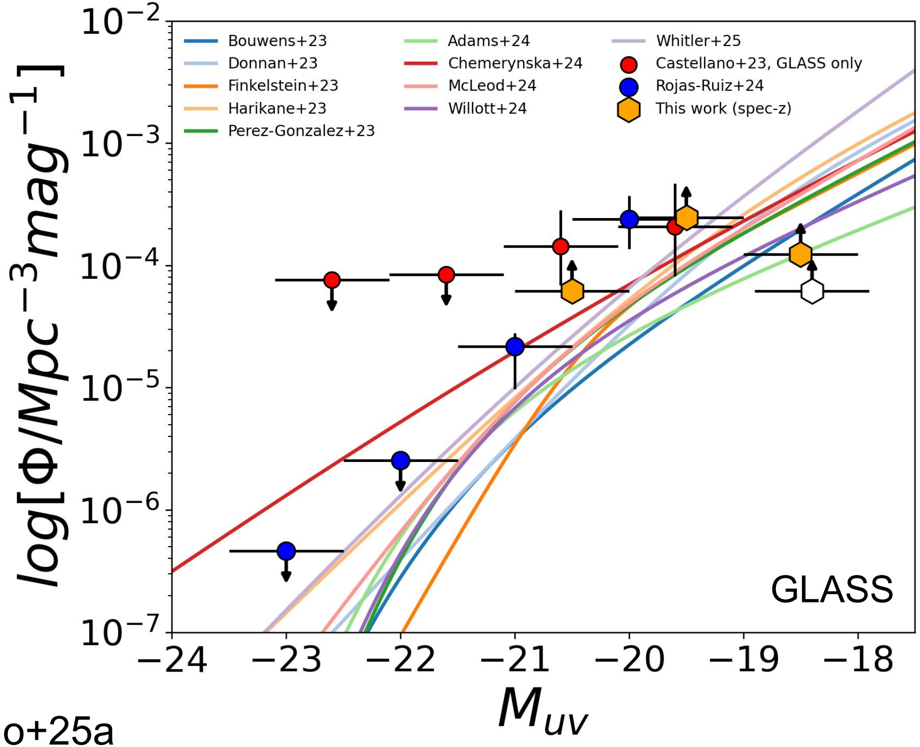
RECAP
erc synergy grant

A census of galaxies as Cosmic Time progresses

Pre-JWST only four galaxies at z > 8.5 were known (see Zitrin+15, Oesch+16, Hashimoto+18, Larson+22)

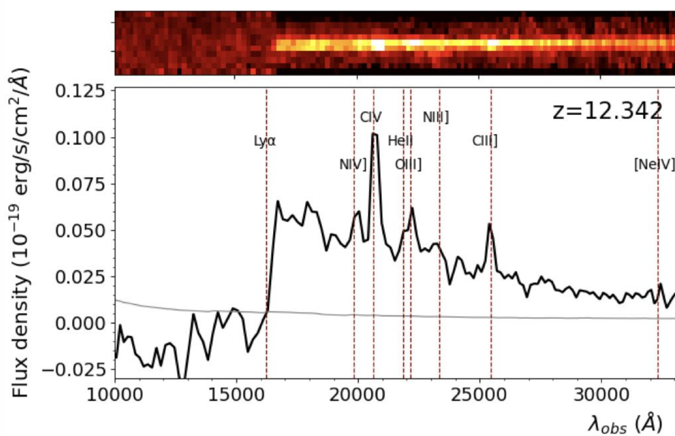


UV LF at 9.5 ≤ z ≤ 11



Napolitano+25a

Two extreme high-z UV AGN:



GHZ2 at z = 12.342

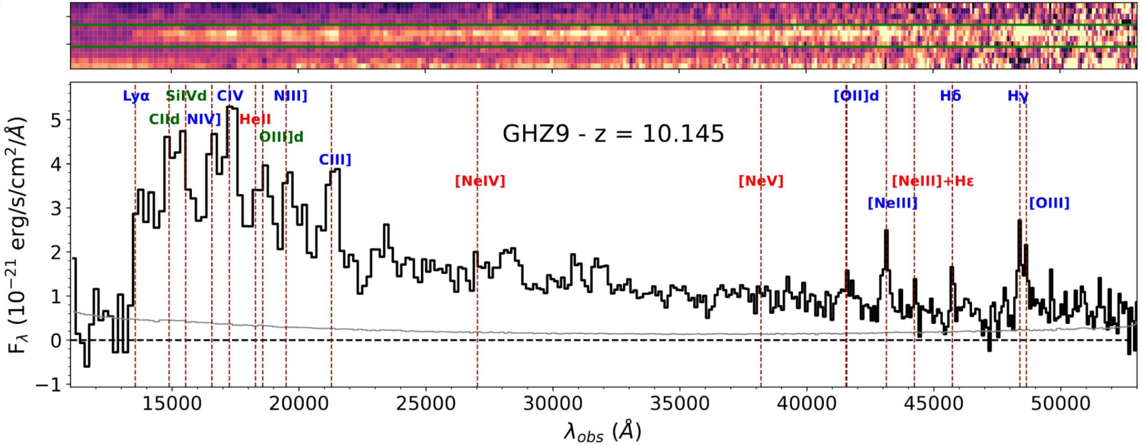
Muv = -20.5, β = -2.4

Castellano, Napolitano et al. 2024, 25;

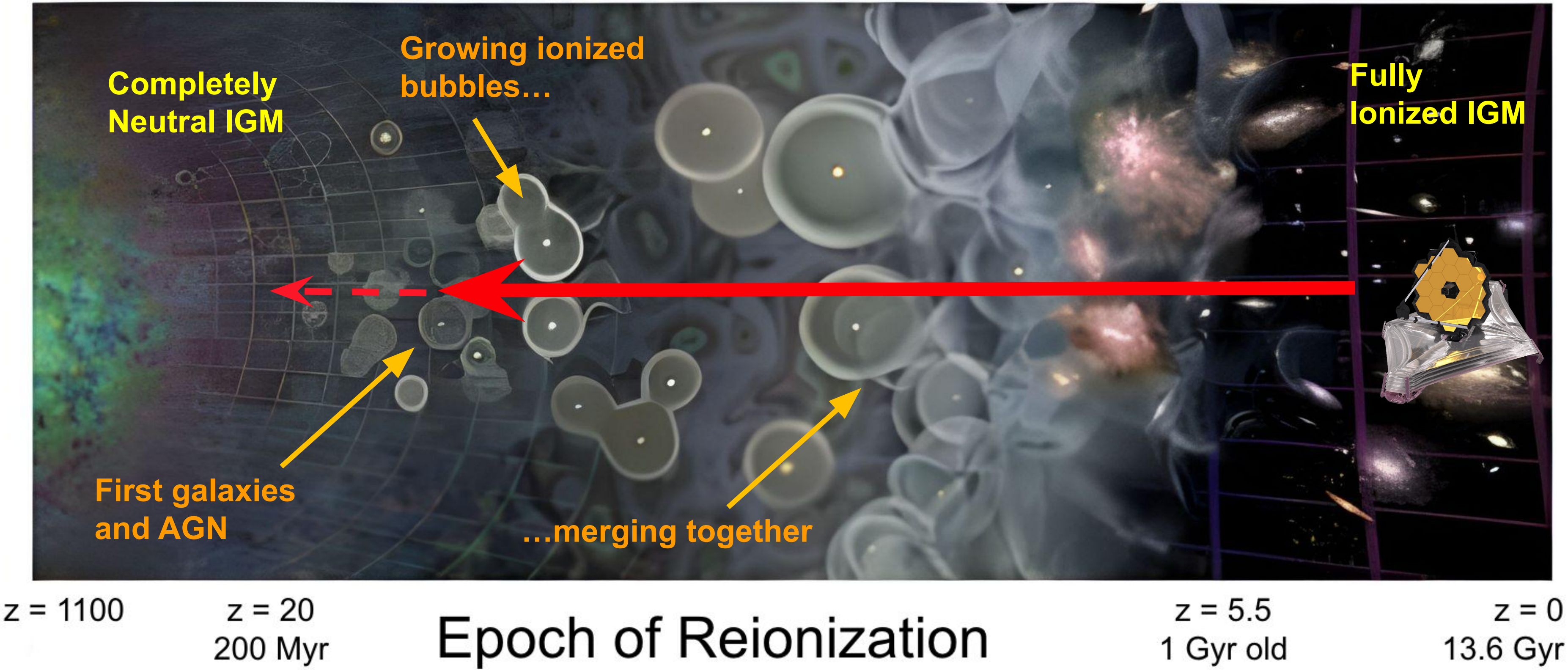
GHZ9 at z = 10.145

Muv = -19.3, β = -1.10

Napolitano+25b

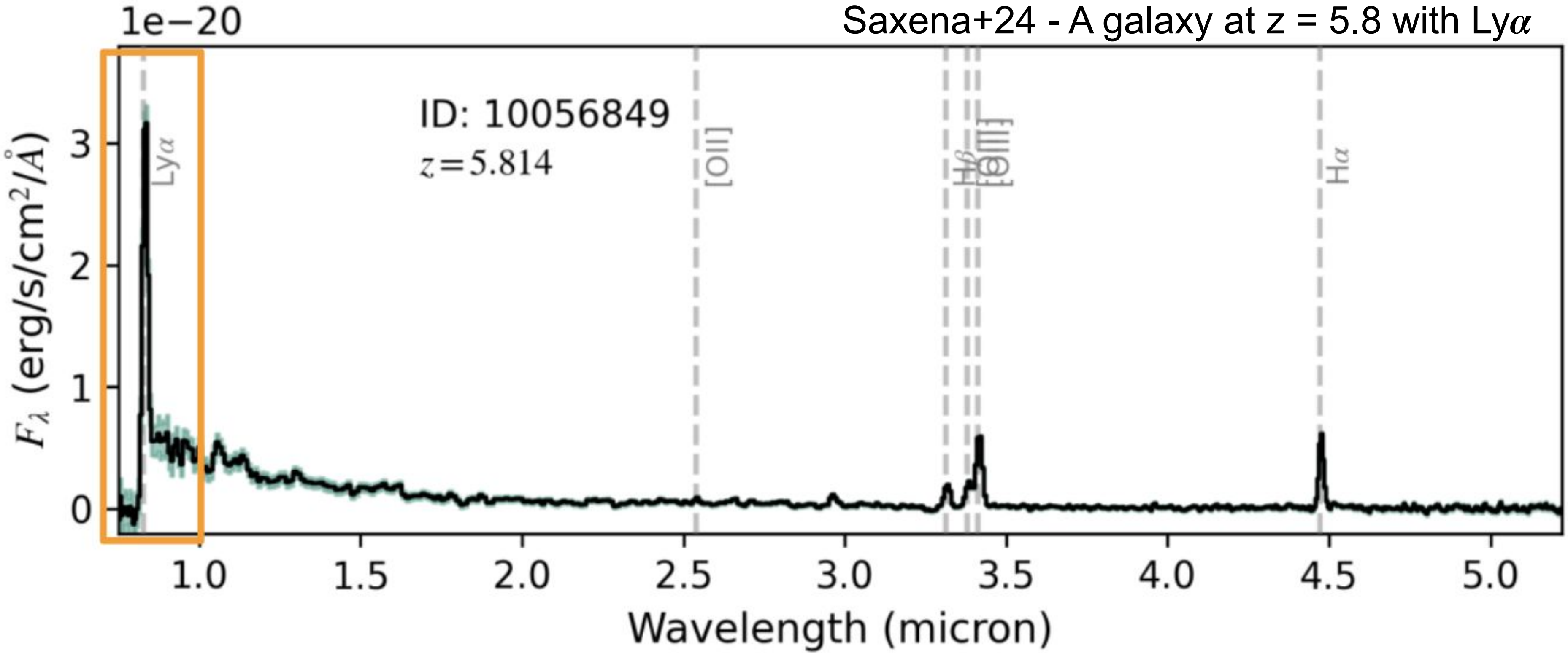


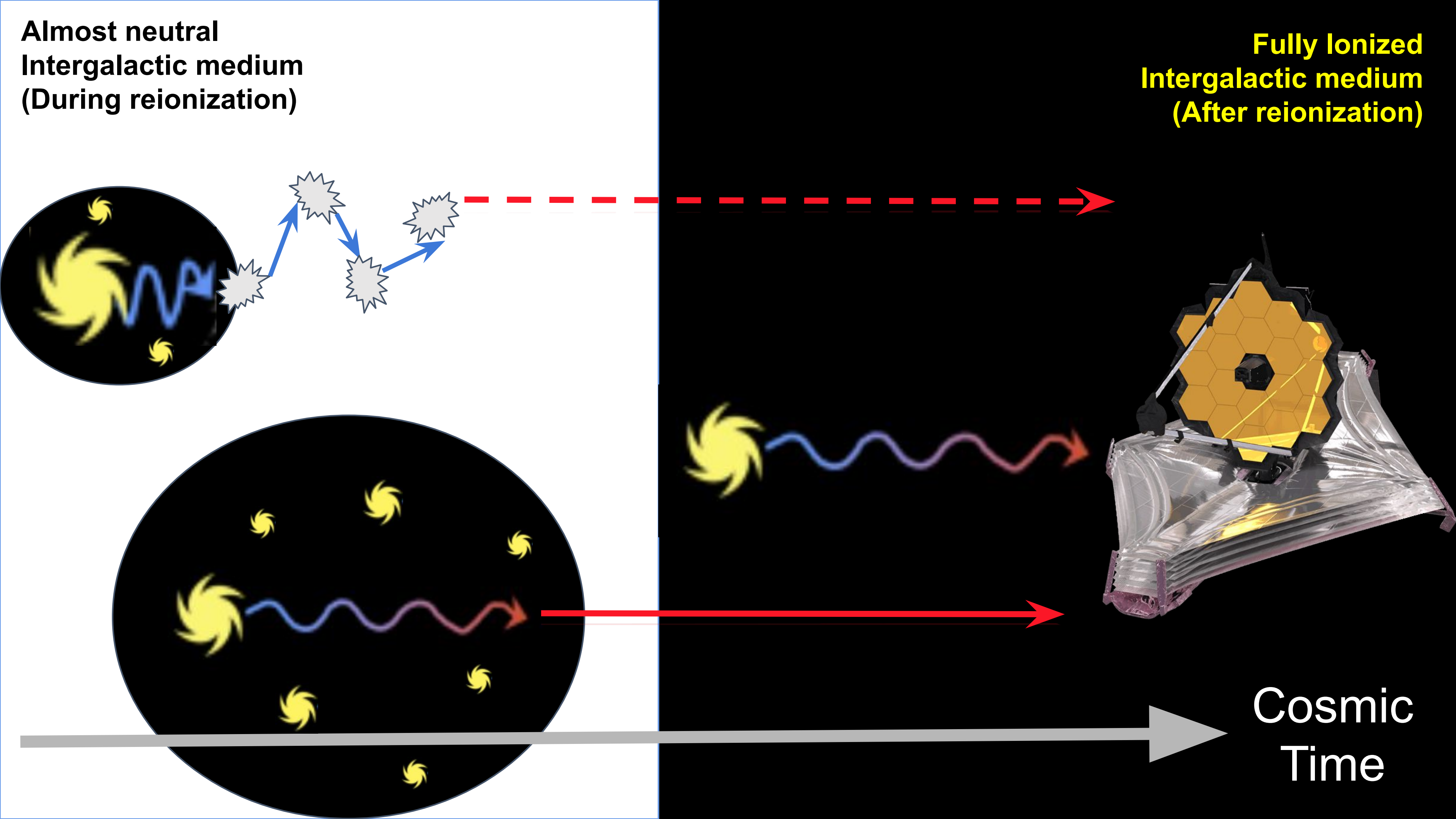
The Epoch of Reionization



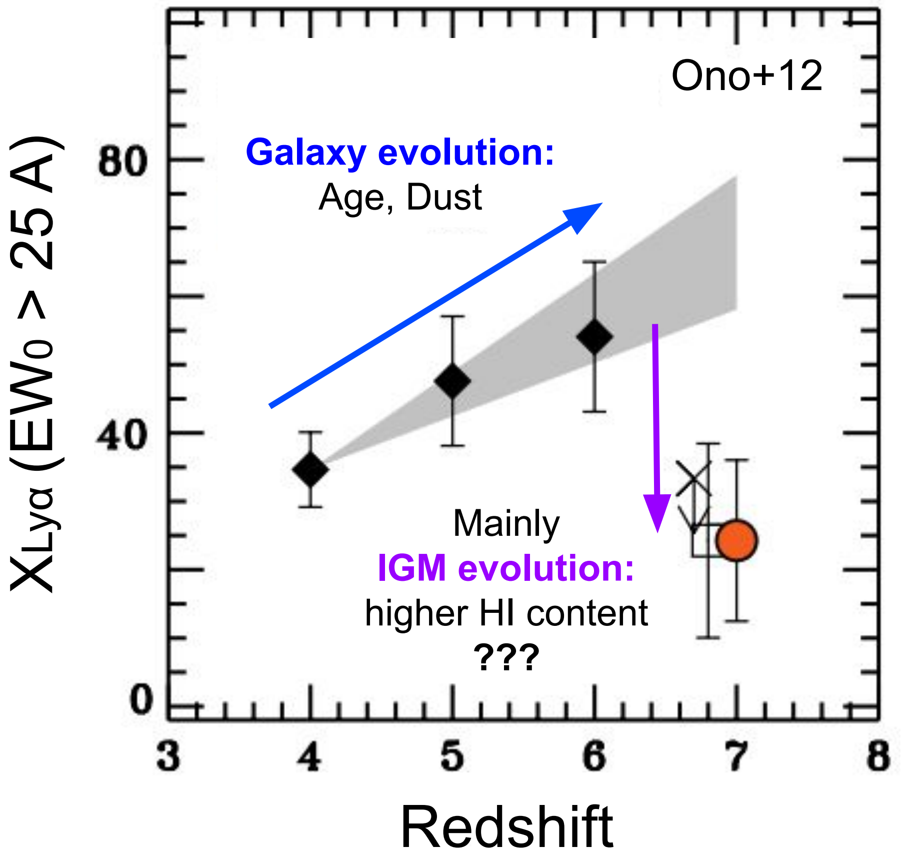
The IGM time evolution and topology probed by Lyα emission

Saxena+24 - A galaxy at z = 5.8 with Lyα




Almost neutral
Intergalactic medium
(During reionization)
Fully Ionized
Intergalactic medium
(After reionization)
Cosmic
Time

The time evolution of Lyα emission (before JWST)



The fraction of Lyα emitters (LAEs) over the total number of star forming galaxies

($X_{Ly\alpha} = N_{LAEs} / N_{SFGs}$)

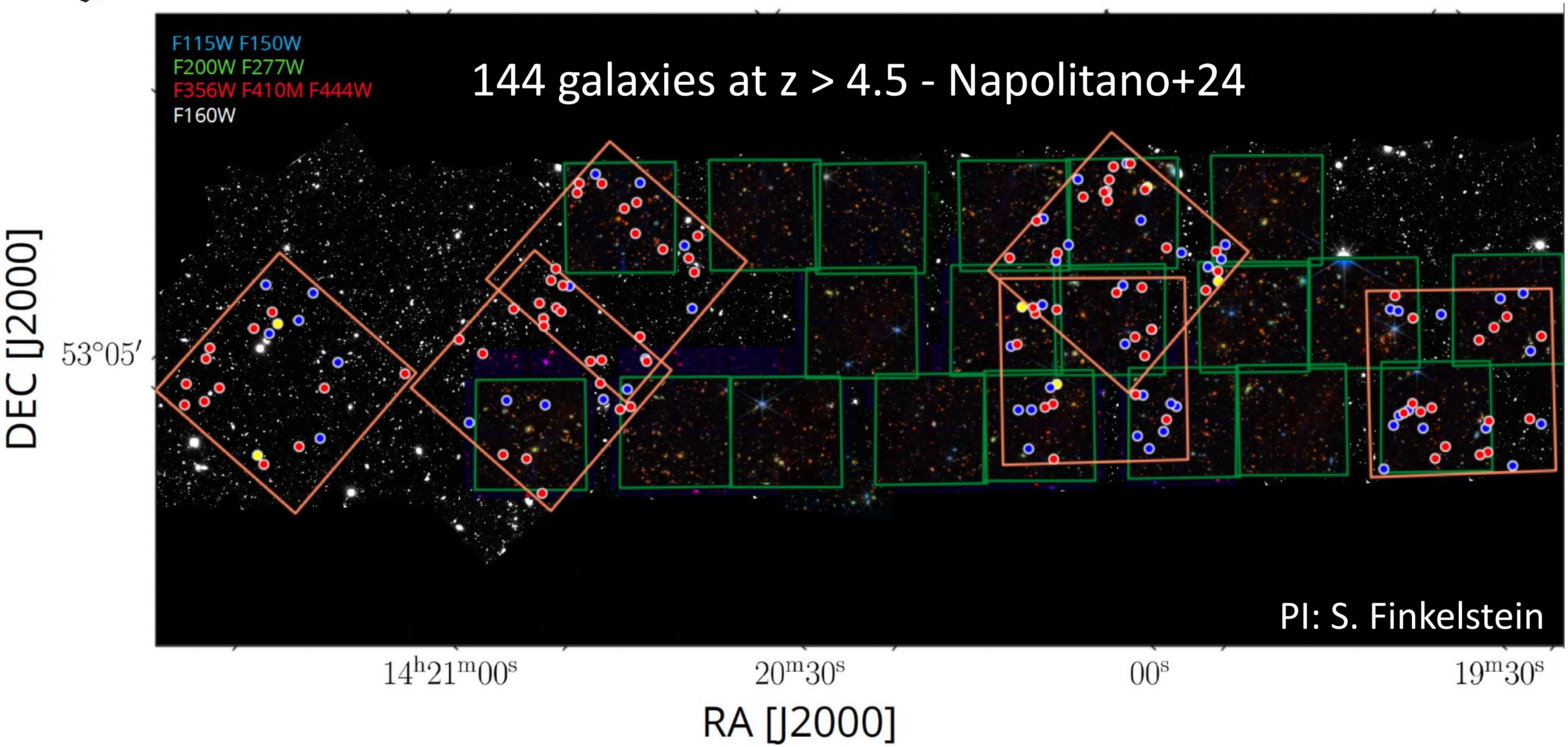
mostly depends on:

Galaxy evolution at z < 6

IGM evolution at z > 6

See also Stark+11, Tilvi+14, DeBarros+17, Pentercci+18, Mason+19

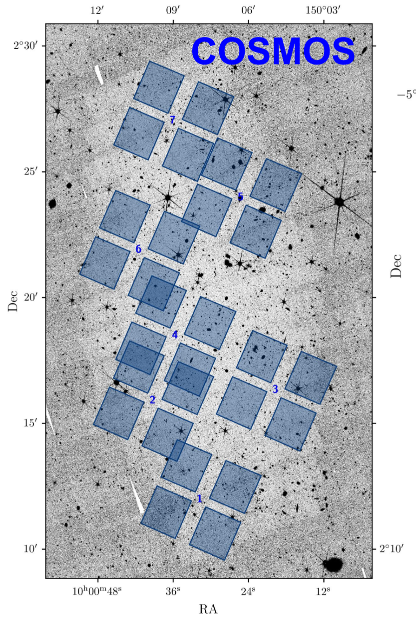
The CEERS NIRSpec PRISM sample

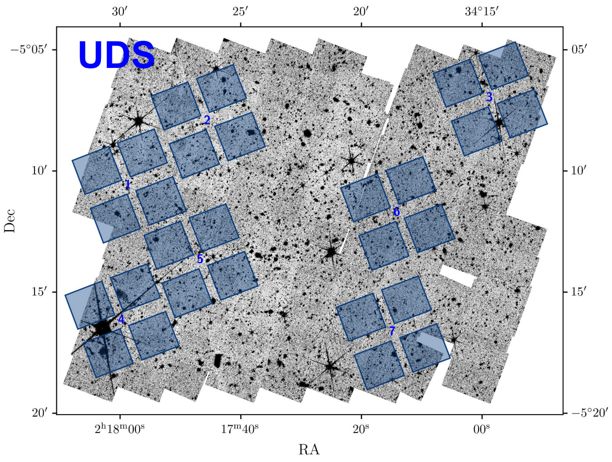


The CAPERS survey (GO-6368, PI: M. Dickinson)

Napolitano+25c (This work):
651 galaxies at 4.5 < z < 11

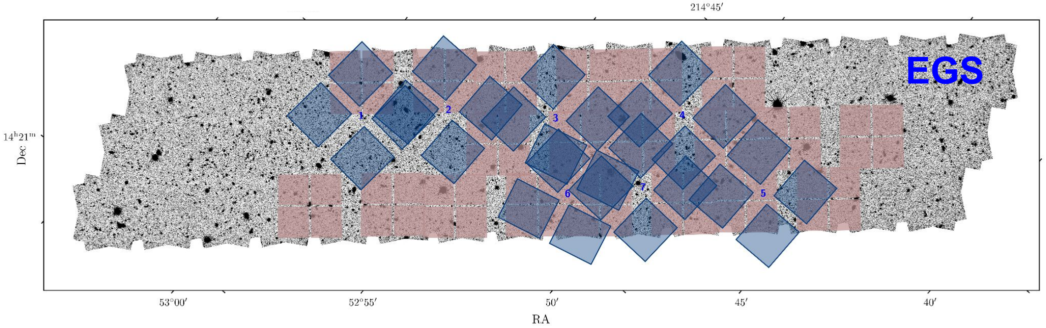
from the CAPERS-UDS field
and DAWN JWST Archive
(v3, Heintz+24, de Graaff+25)

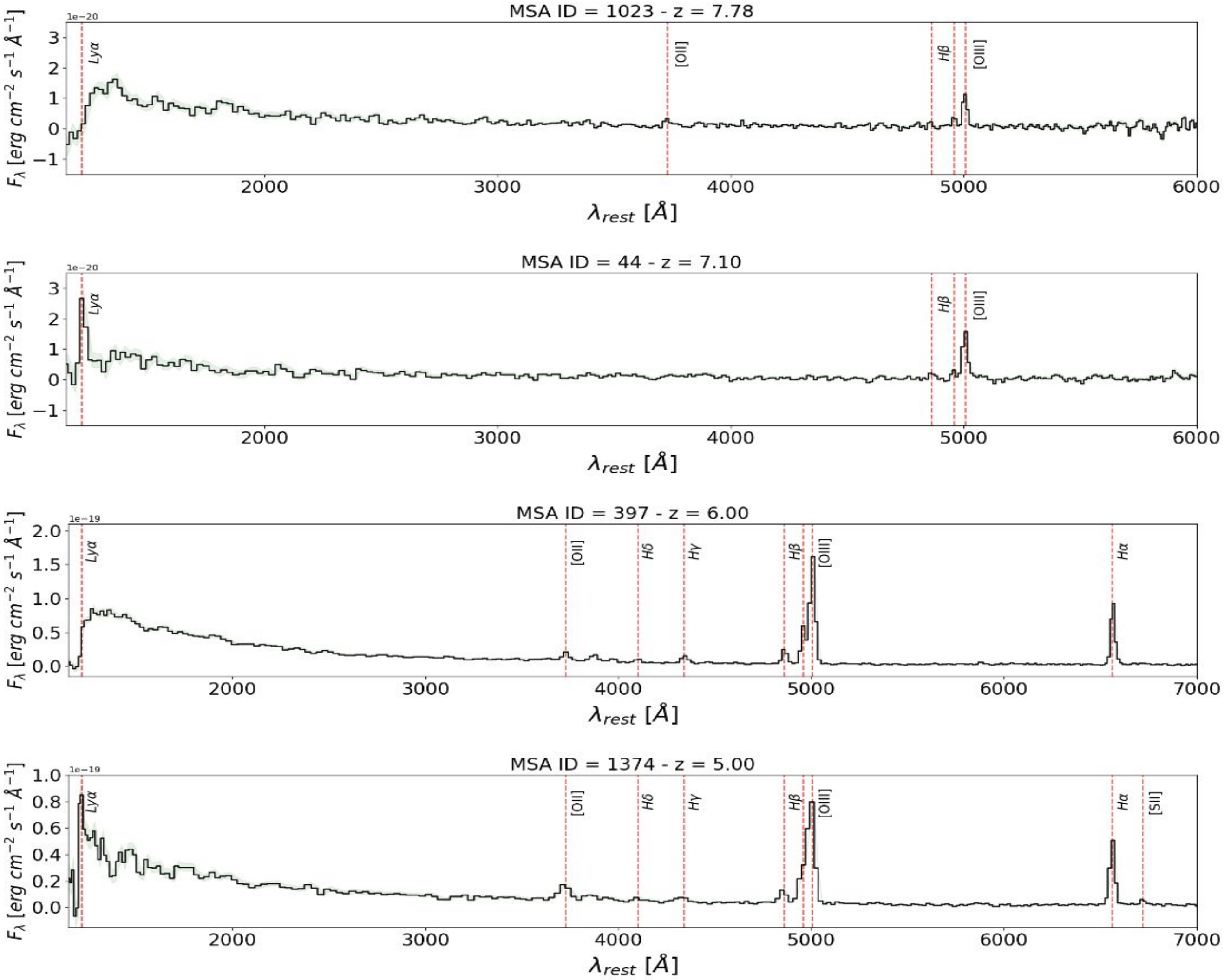




~4.5 hr per
pointing

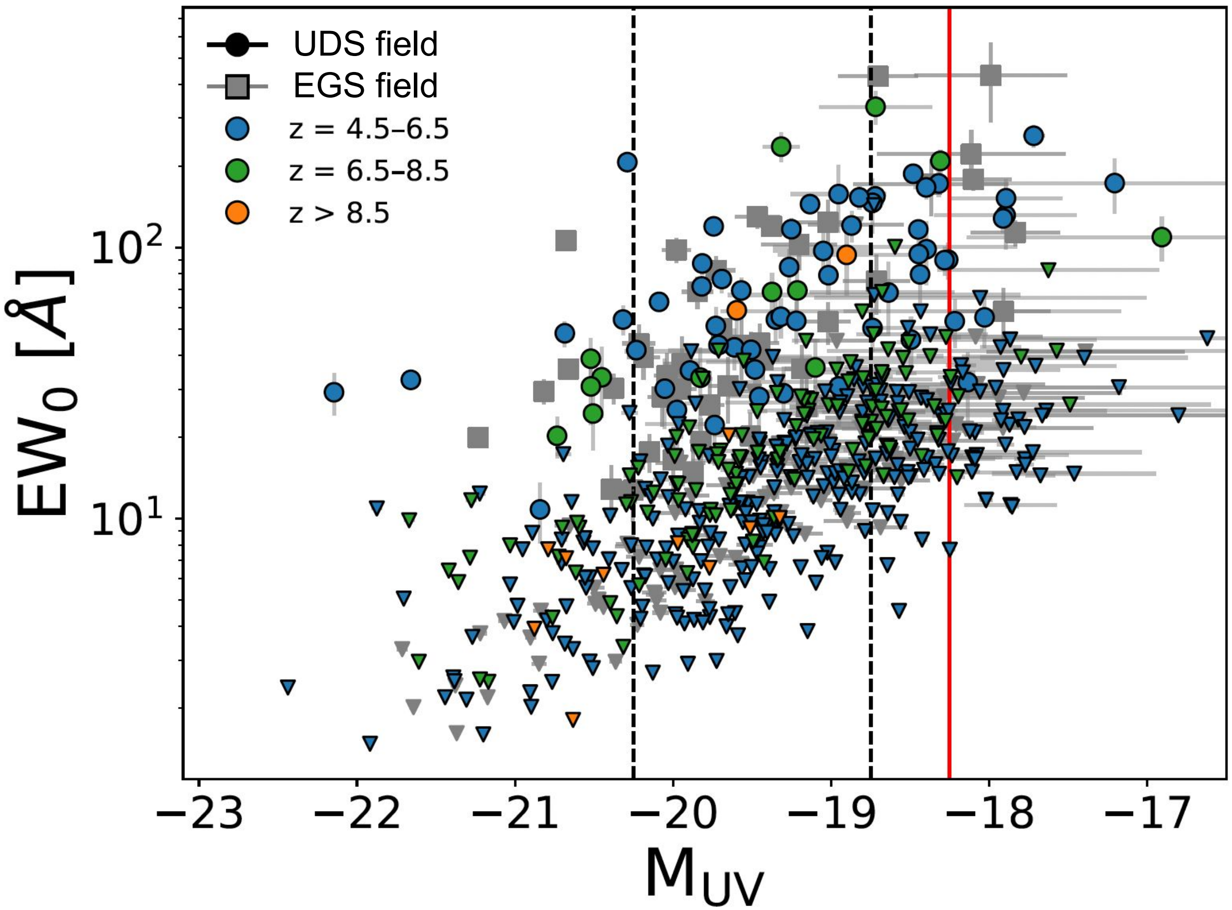
Courtesy:
Mark Dickinson





- Spectroscopic redshift from optical lines, i.e. Hα, [OIII] λ5007,λ4959, Hβ, and [OII]λλ3727
- Spectro-photometric corrections from available photometry from Merlin+24
- Stellar Masses from SED fitting
- Muv and UV slope β from the continuum

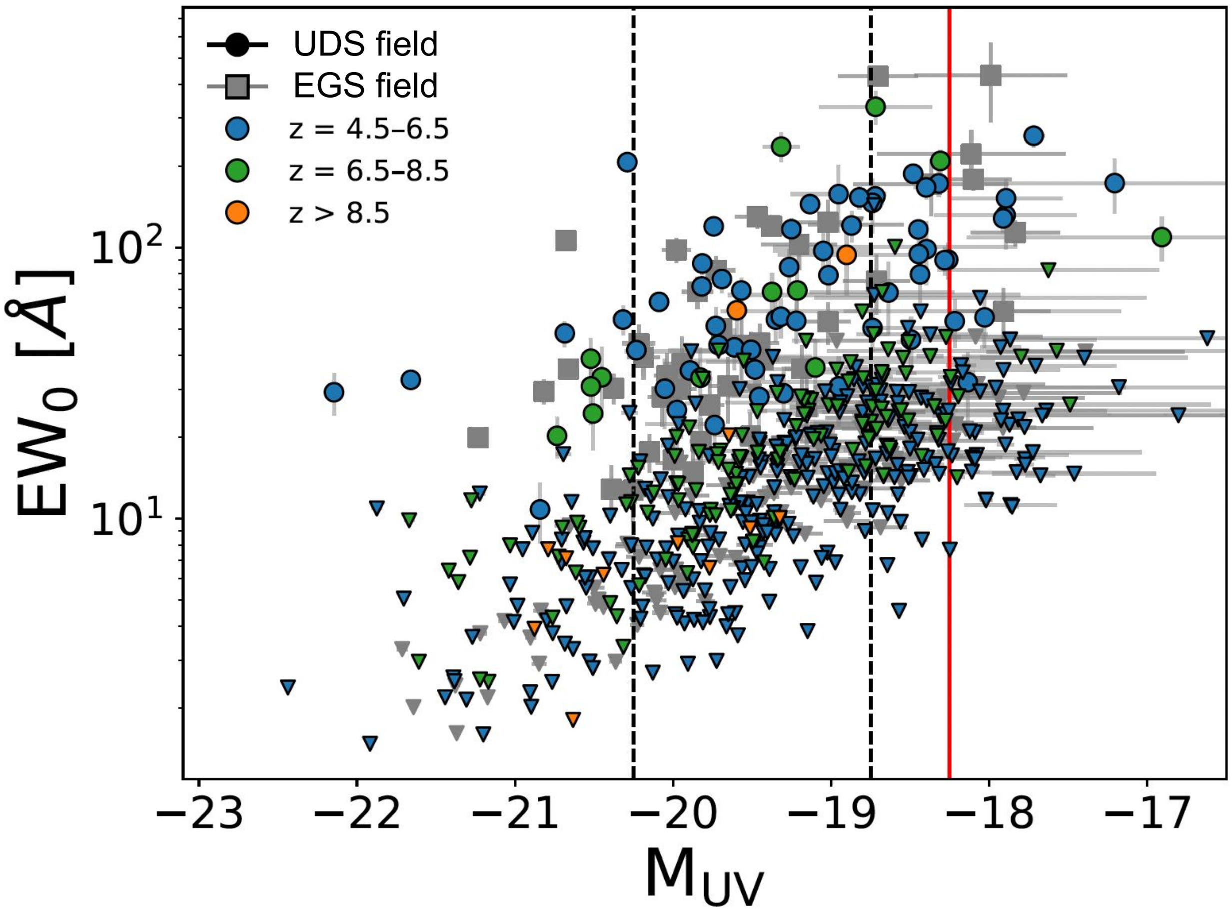
Lya EW0 and Muv relation



73 Lya emitting galaxies with S/N > 3 in the UDS field

See also, e.g. Nakane+24, Napolitano+24, Jones+25

Lya EW0 and Muv relation



The fraction of Lyα emitters (LAEs) over the total number of star forming galaxies

($X_{Ly\alpha}$ = N_{LAEs} / N_{SFGs})

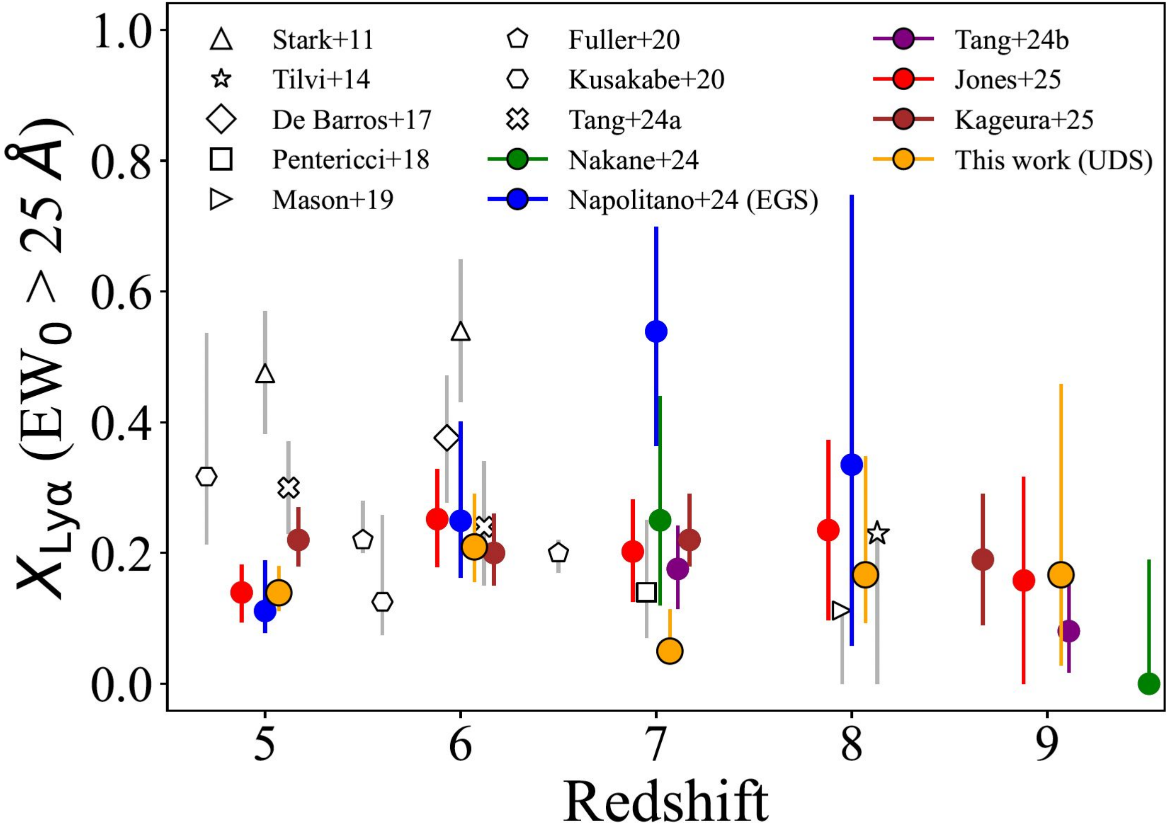
Adopted cut:

$-20.25 < M_{UV} < -18.75$

AGN excluded

$EW_{0,lim} < 25$ Å

Evolution of Lya visibility across different line of sights



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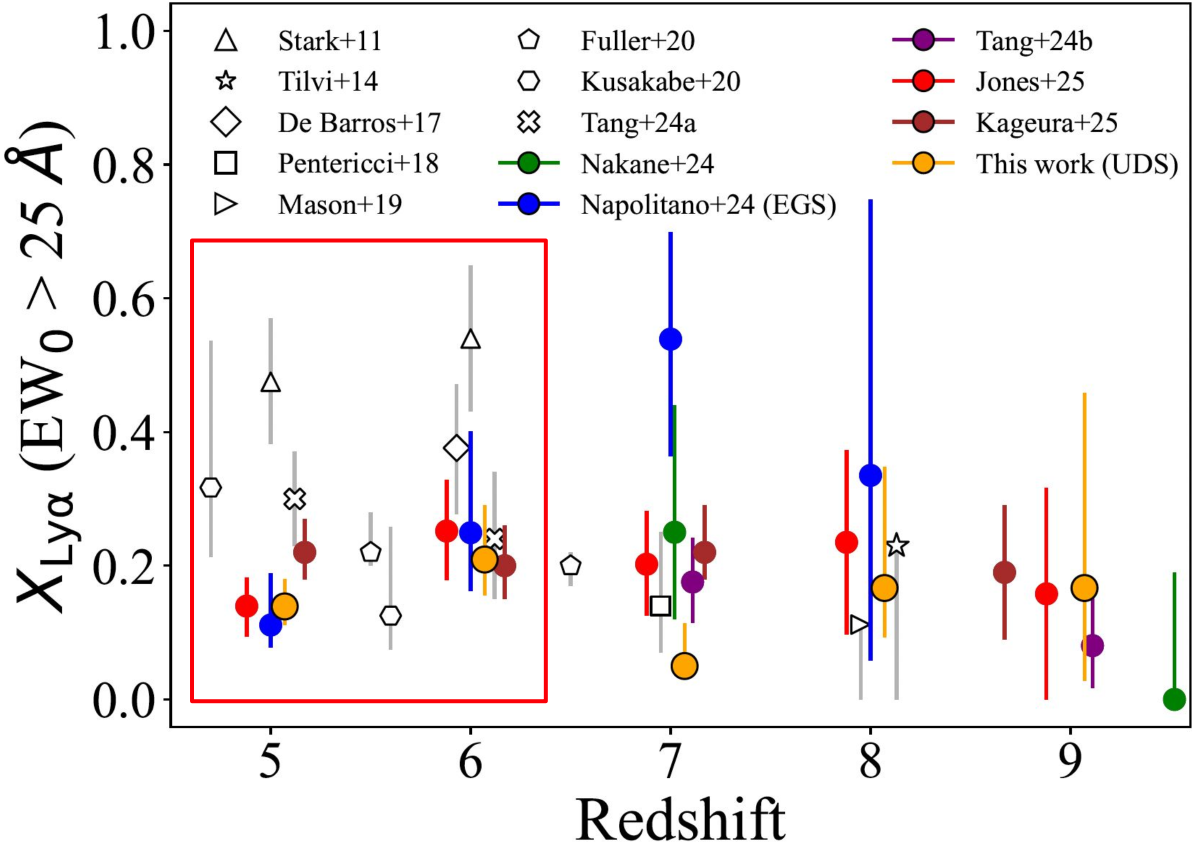
Napolitano+25c (This work)

EGS field

UDS field

GOODS-S/N fields

The evolution of Lyα visibility
…how to tackle possible systematics



In the post Reionization Universe at z < 6

we find a discrepancy between the JWST and ground-based results!

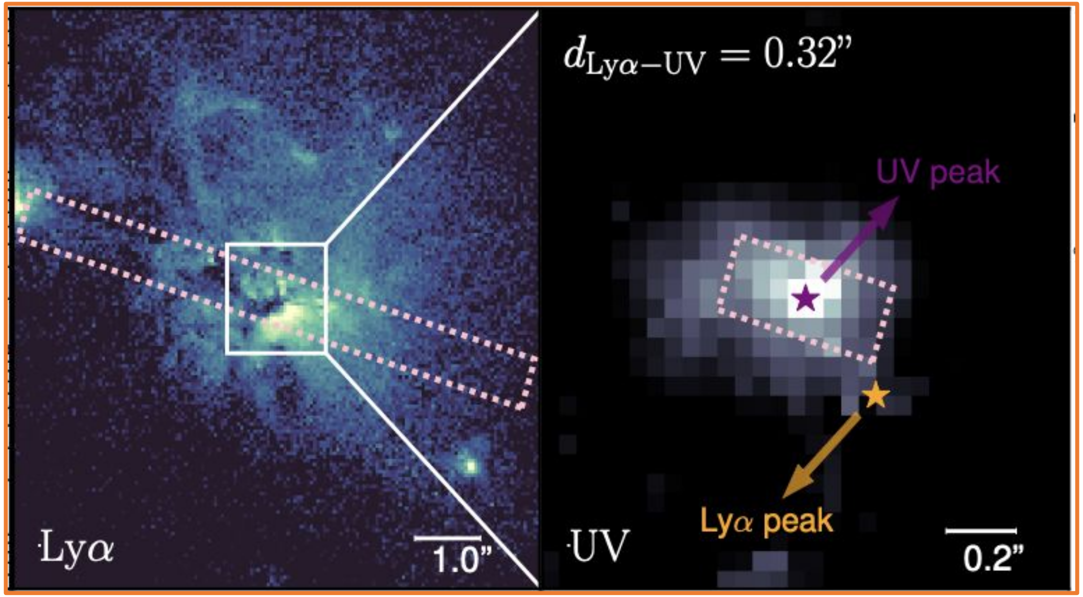
Napolitano+25c (This work)

…see also Nakane+24, Napolitano+24, Jones+25, Tang+24a,b, Kageura+25

We explored this effect using the SPICE simulation

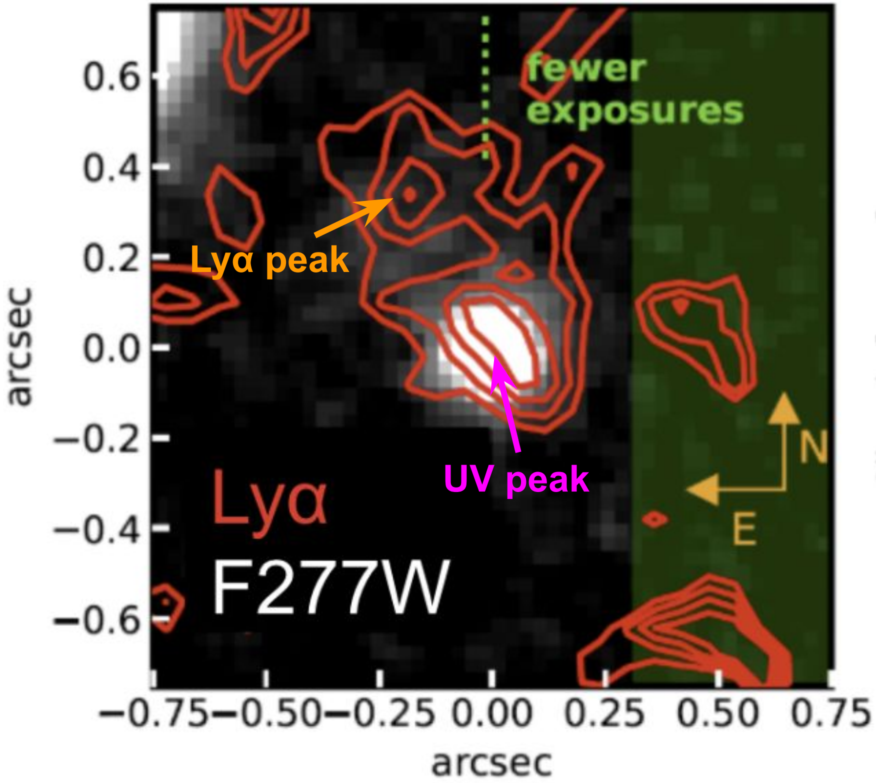
Ground-based
~ 1 × 10 arcsec²

JWST NIRSpec
~ 0.2 × 0.5 arcsec²

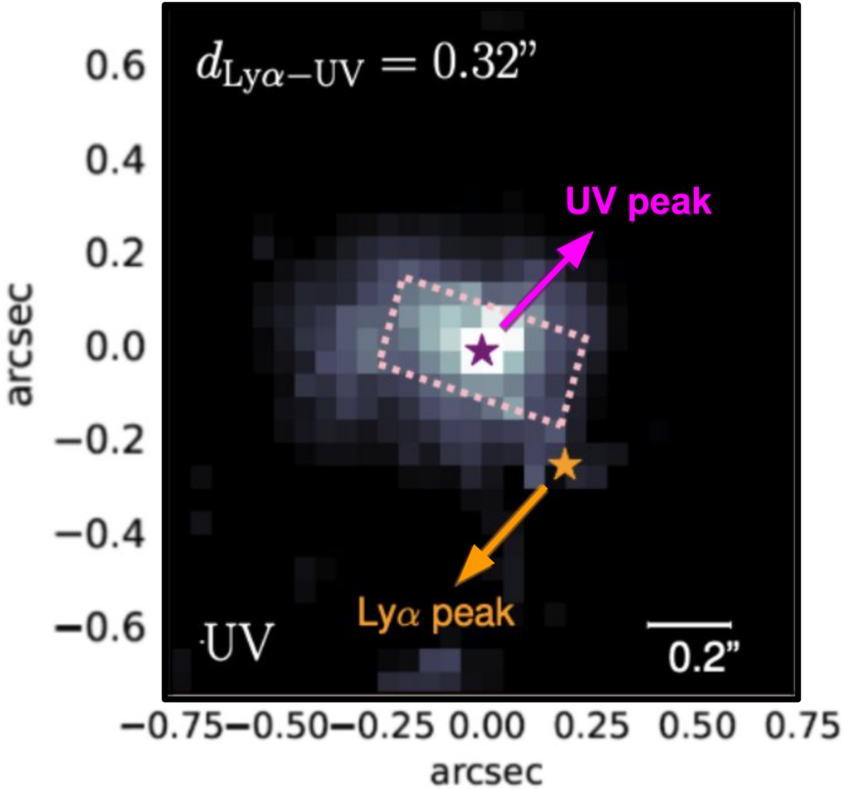


Result: 26-37% of total Lyα flux is lost due to slit losses
Bhagwat+25

Lyα spatial offset measured from IFU JWST observations

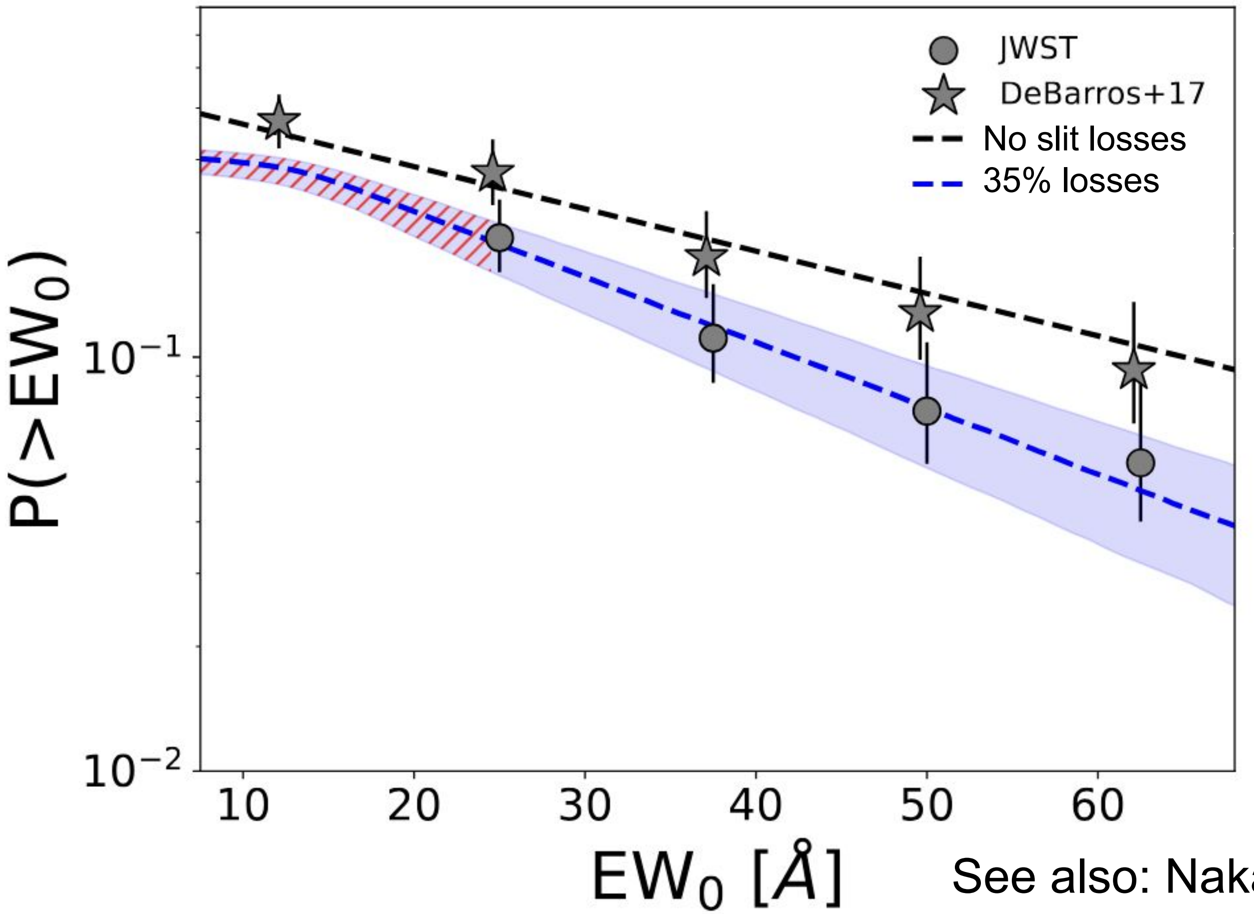


NIRSpec IFU of GN-z11: 0.4'' Lyα offset (Scholtz+24)



SPICE simulation (Bhagwat+25)

JWST Lyα slit losses measured from MOS observations

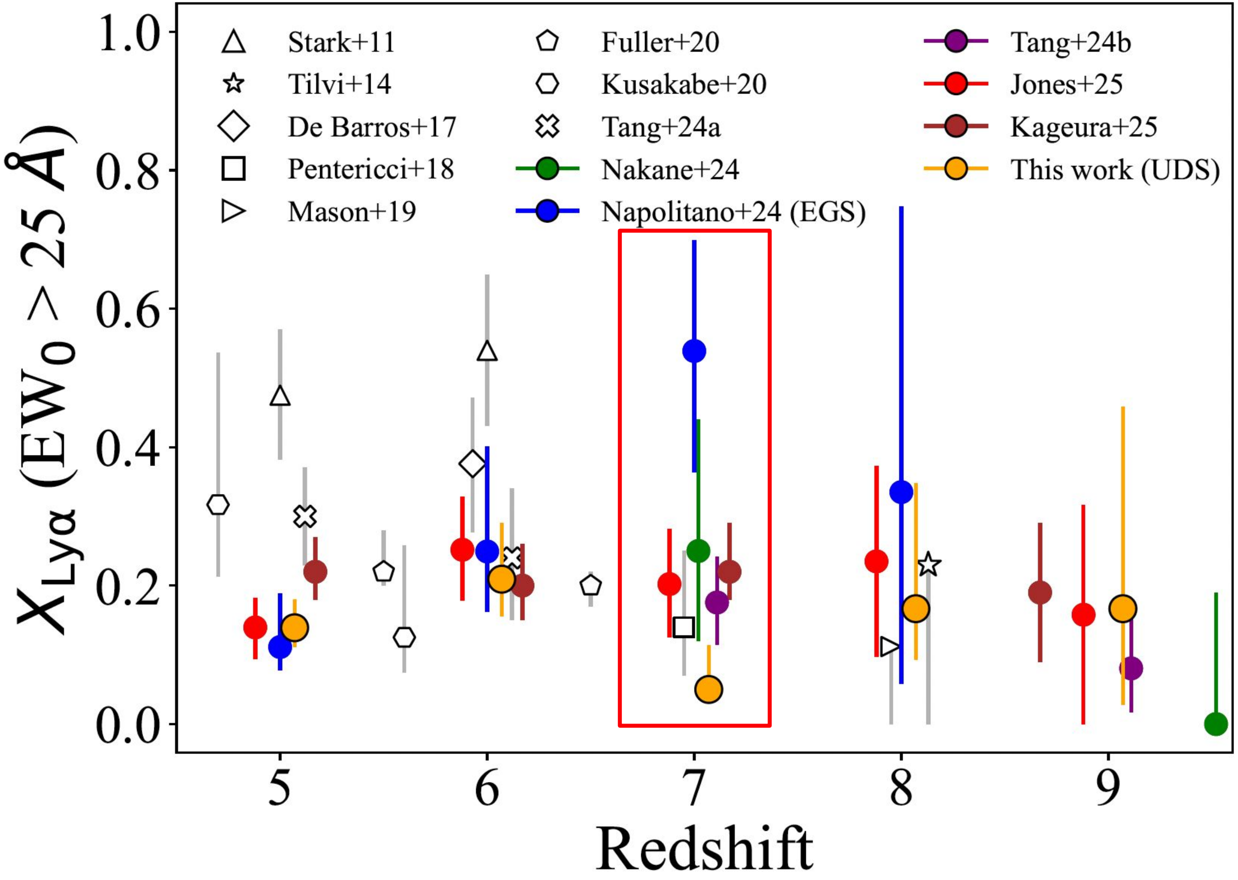


JWST and ground-based (DeBarros+17) star-forming galaxies **matched in physical properties**, differ in their Lyα EW_0 CDFs.

Result: (35 ±10)% of total Lyα flux is lost Napolitano+25c

See also: Nakane+24, Ning+24, Tang+24

Evolution of Lya visibility across different line of sights



The fraction of Lyα emitters (LAEs) over the total number of star forming galaxies

($X_{Ly\alpha} = N_{LAEs} / N_{SFGs}$)

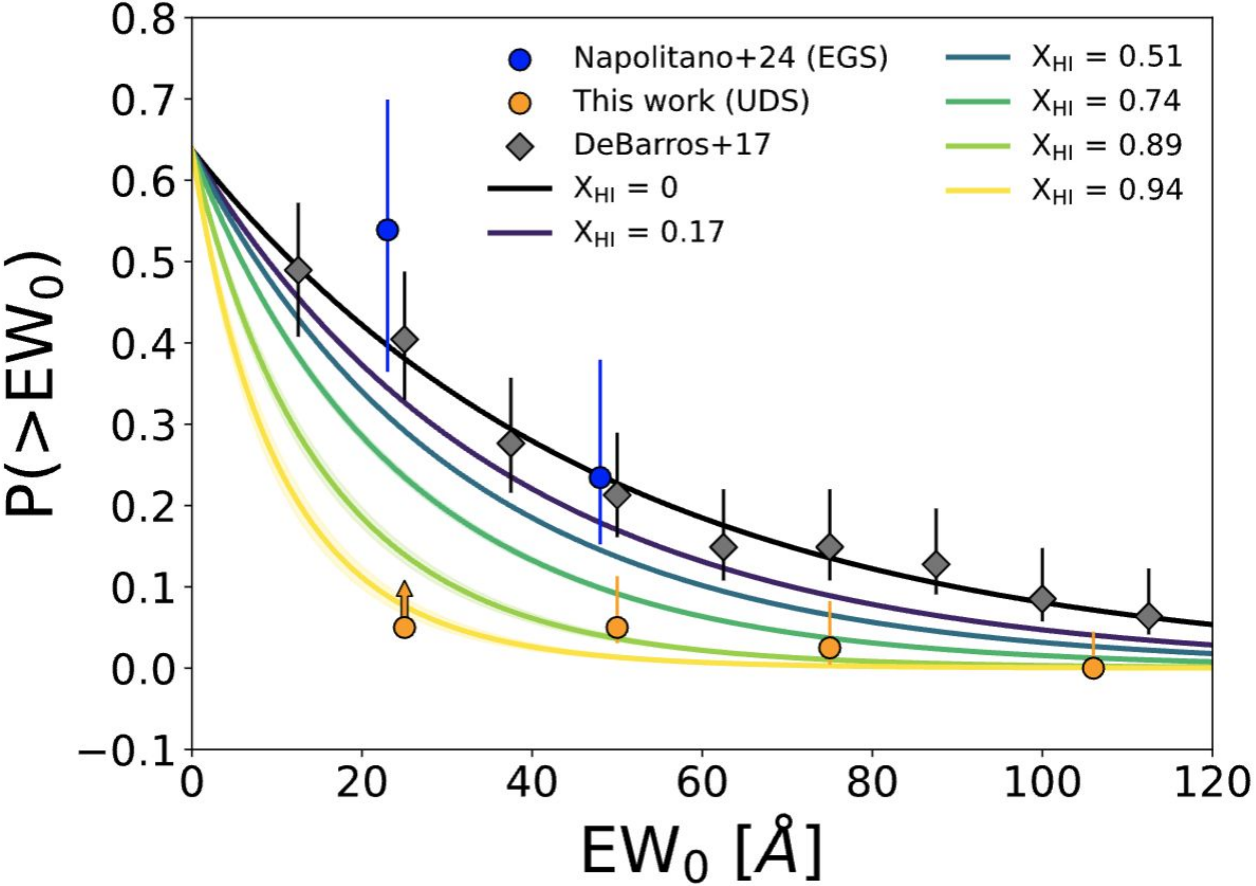
EGS field

UDS field

GOODS-S/N fields

2.7σ discrepancy between the EGS and UDS results at z = 7

The neutral hydrogen fraction at z = 7



At z = 7 there is huge field-to-field variation:

This a proof of a spatially inhomogeneous Cosmic Reionization

Models: Dijkstra+11

Characterization of the ionized bubbles

$$\frac{d}{dt}R^3 = 3H(z)R^3 + \frac{3 f_{\rm esc}\dot{N}_{\rm ion}}{4\pi\langle n_{\rm H}(z)\rangle} - C_{\rm HII}\langle n_{\rm H}(z)\rangle\alpha_B R^3$$

Cen & Haiman (2000)

The radius of the ionized bubble is

$$R_{ion}(t) \propto \left(\frac{\dot{N}_{ion} f_{esc} t}{H_0 \Omega_b (1+z)^3}\right)^{1/3}$$

Shapiro & Giroux 1987

Matthee+18, Larson+22, Saxena+23

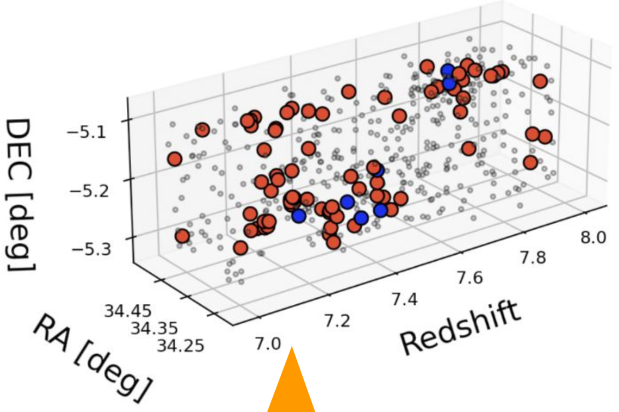
The ionizing photon rate is

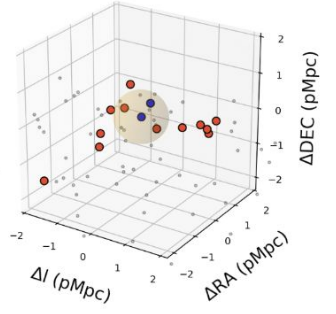
$$\dot{N}_{ion} = \frac{3.3 \times 10^{54}}{\alpha} 10^{-0.4(M_{UV}+20)} \left(\frac{912}{1500}\right)^{\beta+2} \mathrm{s}^{-1}$$

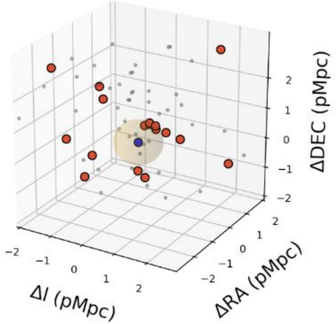
Mason&Gronke 2020

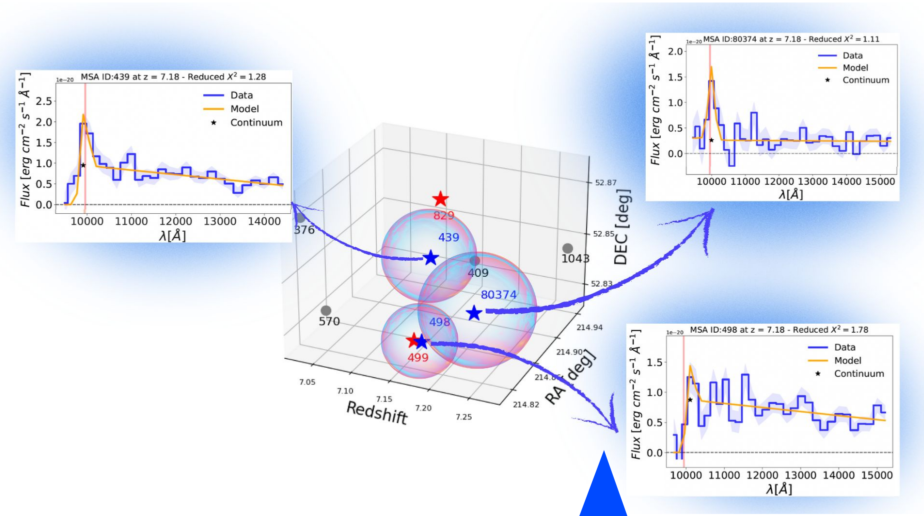
Ionized bubbles identification from the JWST

Area ~ 100 arcmin^2









Napolitano+25c

Napolitano+24

UDS field
z_{spec} ~ 7.29 and 7.77
3 Lyα emitting galaxies
within 0.5 - 0.6 pMpc

We found four new confirmed ionized bubbles

…see also Chen+24,+25, Tilvi+20, Leonova+22, Larson+22, Jung+22

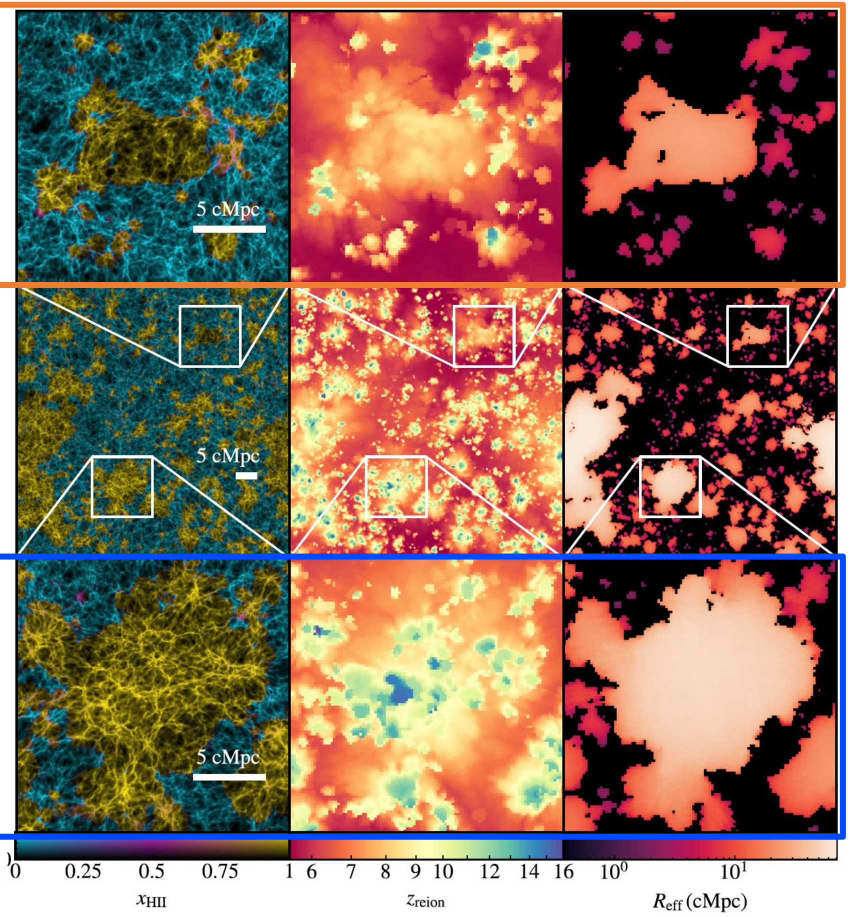
EGS field
z_{spec} ~ 7.18 and 7.48
3 Lyα emitting galaxies
within 1.2 - 2.5 pMpc

Ionized bubble statistics: a direct comparison to simulations

UDS-like, small bubbles, highly neutral

Full simulation cube

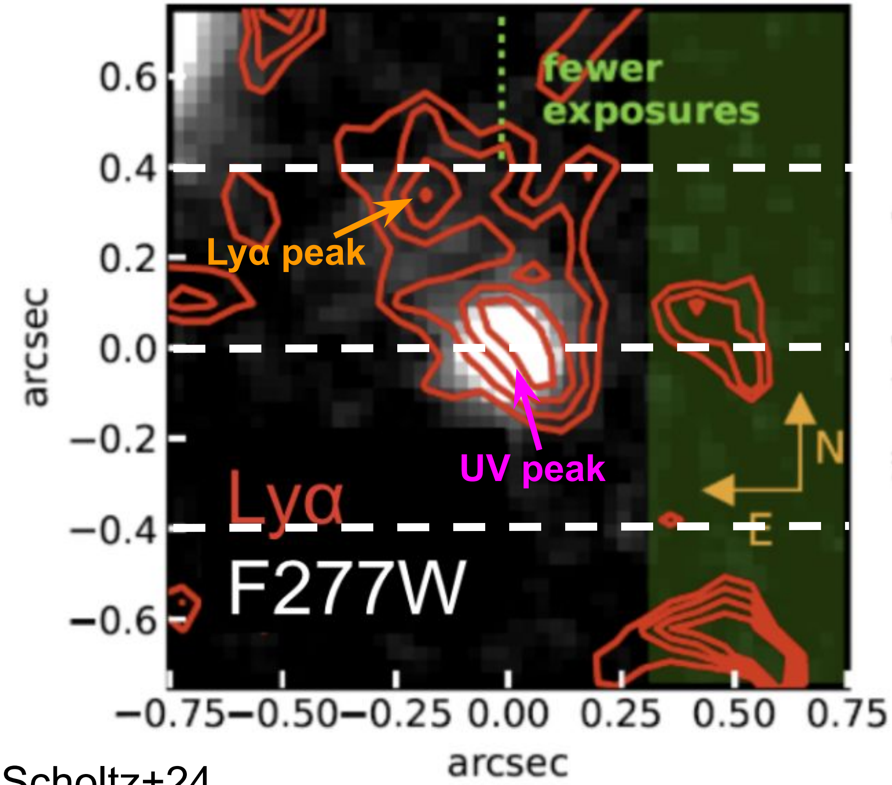
EGS-like, large bubbles, highly ionized

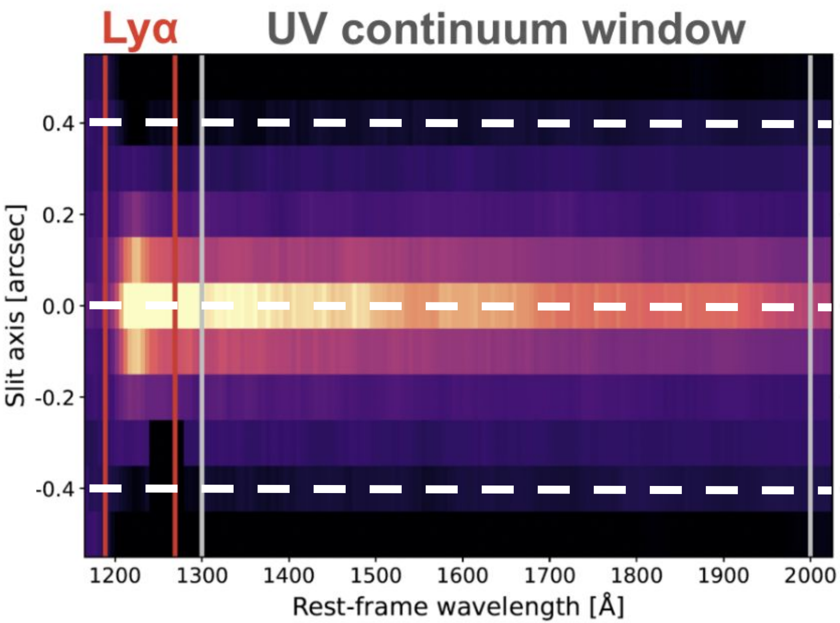


Neyer+24,25

What's next?

IFU spectra of LAEs are needed for further progress.





Scholtz+24

Summary

- In the context of Cosmic Reionization Lyα is one of our best probes to trace the evolution of the neutral hydrogen fraction.

- Models and observations both suggest a significant JWST NIRSpec MOS Lyα slit loss (~35%).

- Observations suggest a spatially inhomogeneous end of cosmic reionization characterized by ionized bubbles.

- IFU spectra are needed for further progress.

Feel free to reach out: lorenzo.napolitano@inaf.it

Thank you!