Reionization's labyrinth:

how to escape following the indirect indicators' thread

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Collaborators: *A. Calabrò, L. Napolitano, M. Castellano, P. Santini et al.*

The archetype of a Lyman Continuum Leaker

- **Faint, low mass galaxies** are thought to be responsible for cosmic reionization.
- From empirical data and models, to explain the reionization, a Lyman continuum (LyC) escape fraction of ~10-20% is needed

The LyC flux can be measured via photometry or spectroscopy at $\lambda < 912$ Å.

→ **impossible** to detect at $z > 4$ due to IGM opacity, that increases with redshift

→ **difficult** to detect at low z, galaxies in the local universe contain lots of H, so LyC flux is absorbed locally

The archetype of a Lyman Continuum Leaker

- **Faint, low mass galaxies** are thought to be responsible for cosmic reionization.
- From ... data and ... ape ... p

The ... meas... y or spectrosc... 912 Å.

We want to find analogs for cosmic reionizers (the **LyC leakers**) at low and intermediate z to study a possible link between LyC flux and promising indirect indicators of this emission!

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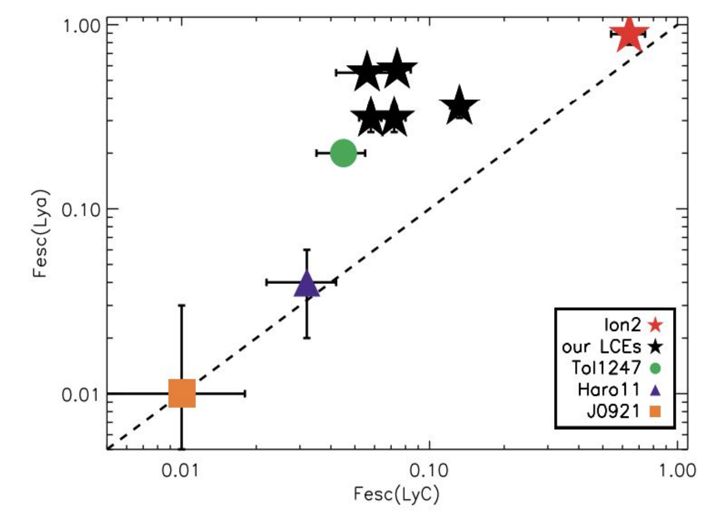
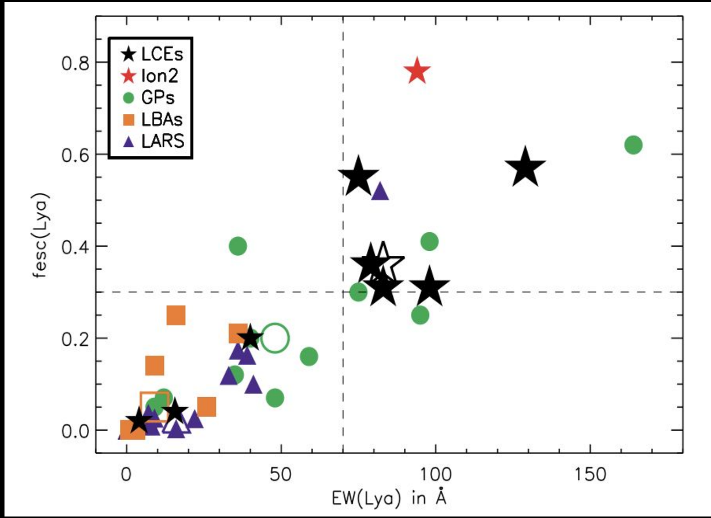
Indirect indicators of LyC escape - Lyα

Lyα and high ionization emission lines seem to be related to the escape of LyC photons at all redshifts.

At low-to intermediate redshift Ly***α*** is the best indirect indicator of LyC emission (e.g. Verhamme+17, Marchi+18)





Verhamme+17

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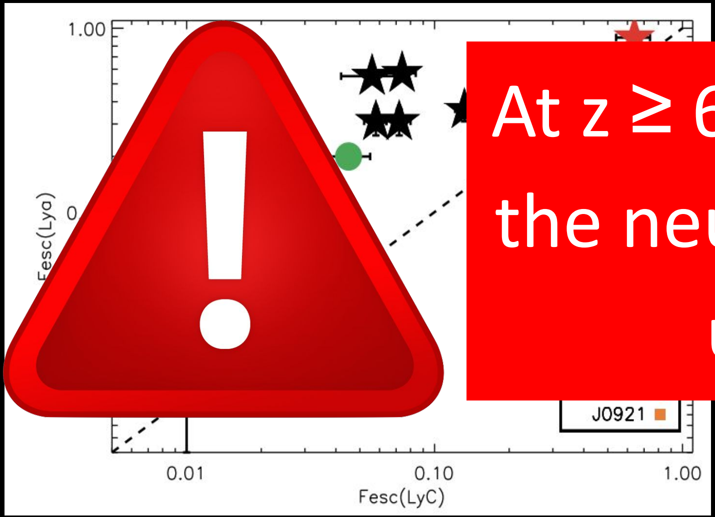

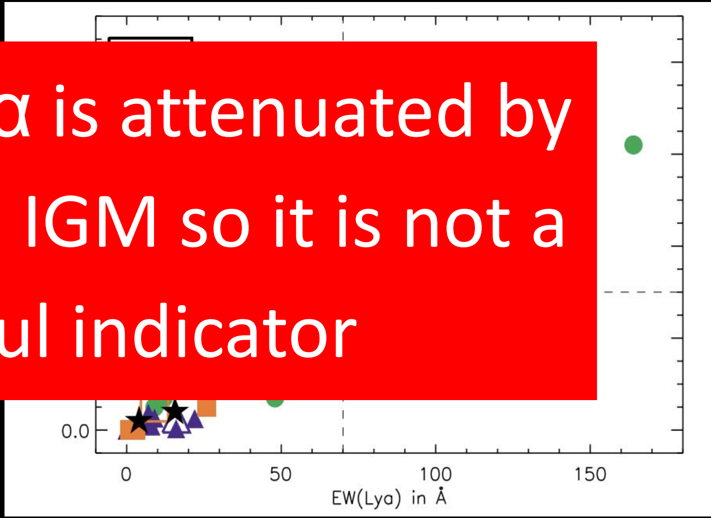

At $z \geq 6$, Lyα is attenuated by the neutral IGM so it is not a useful indicator

Verhamme+17

Indirect indicators of LyC escape - rest-frame UV lines

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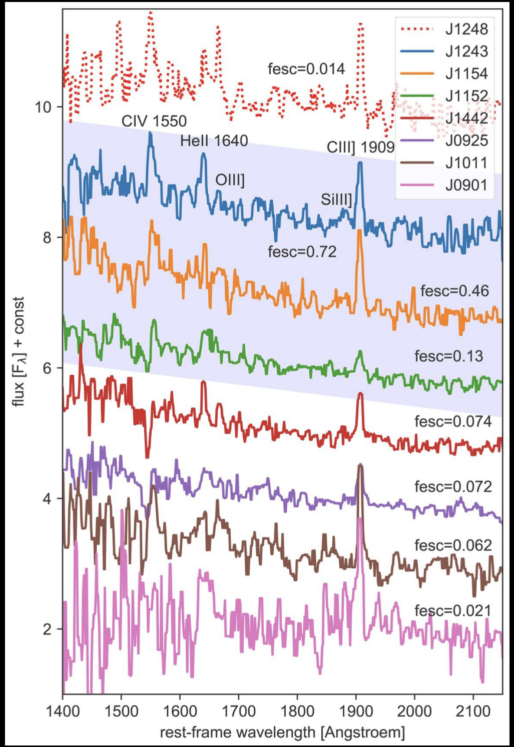
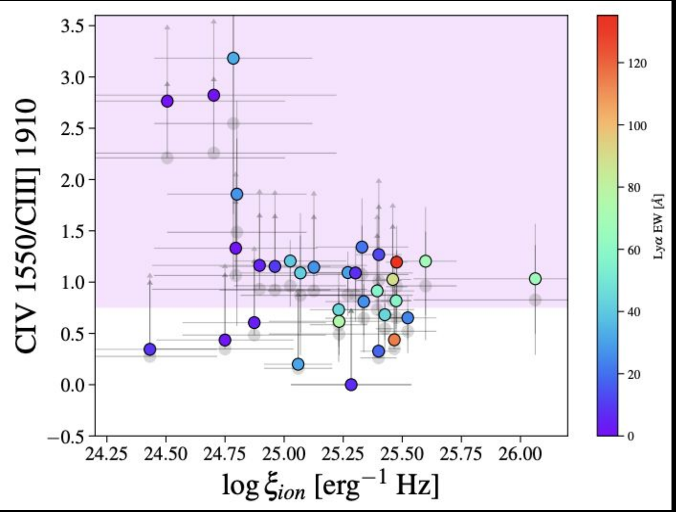
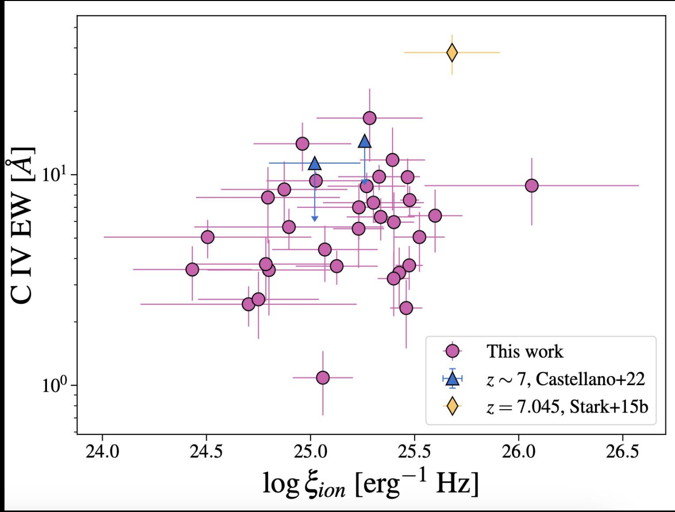
Schaerer+22



Nebular CIV is detected in most low-z confirmed LyC leakers. We have analysed the rare nebular CIV emitters @z=3 and they share many properties of the high leakers (Saxena+22, Mascia+23a). **However, these lines are faint.**

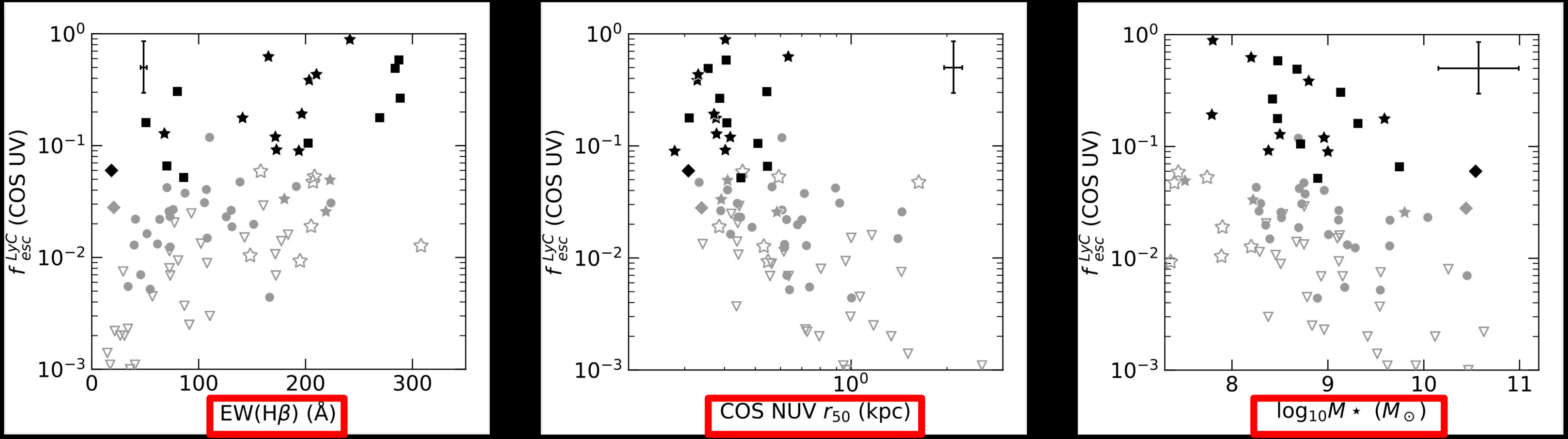




Mascia+23a

Indirect indicators of LyC escape

The most systematic and complete study of low redshift LyC leaking galaxies and indirect diagnostics comes from the **Low-Redshift Lyman Continuum Survey** (PI A. Jaskot)



Flury+22

See S. Flury's talk tomorrow!

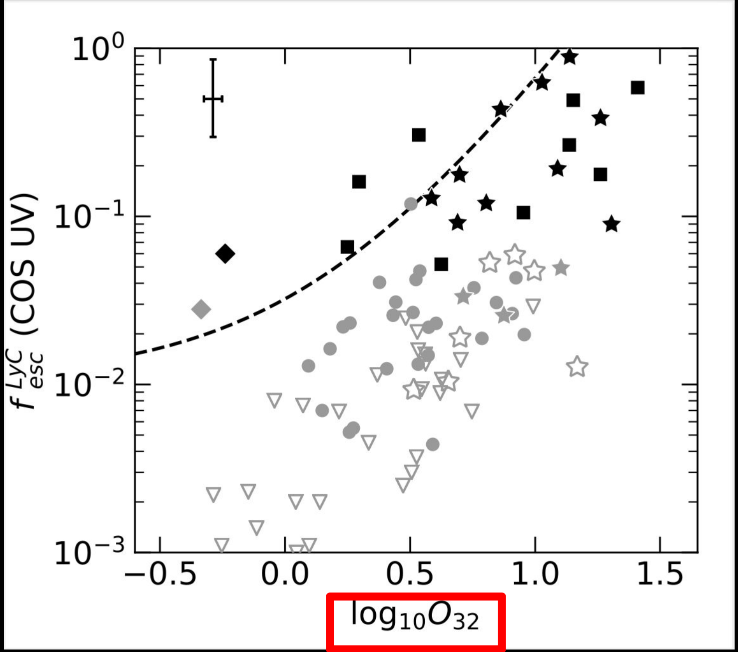
Indirect indicators of LyC escape - rest-frame optical lines

LyC leakers should have a high **[O III] λλ4959,5007/[O II] λ3727**.

[OIII]/[OII] ratio changes with:

1. **spectral shape of ionizing source** → no AGN contamination
2. **gas temperature**
3. **metallicity**
4. ionization parameter
5. gas density

Necessary but not sufficient condition to define a LyC leaker!

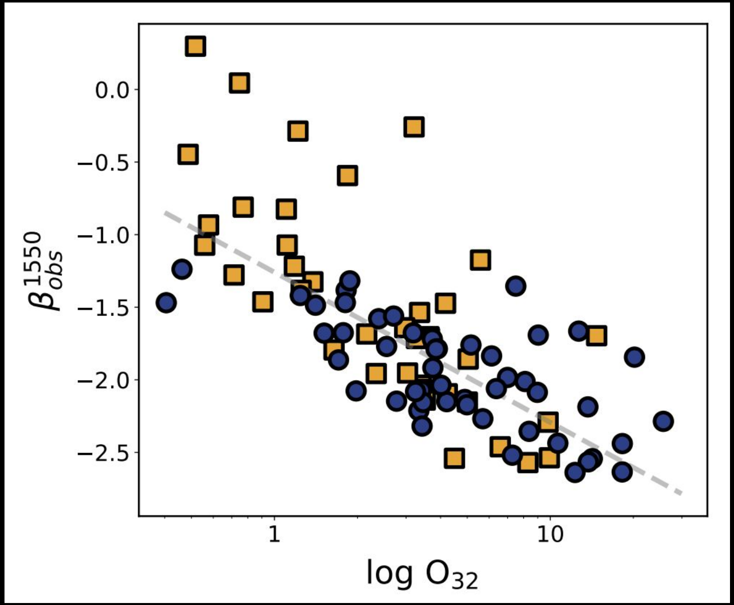


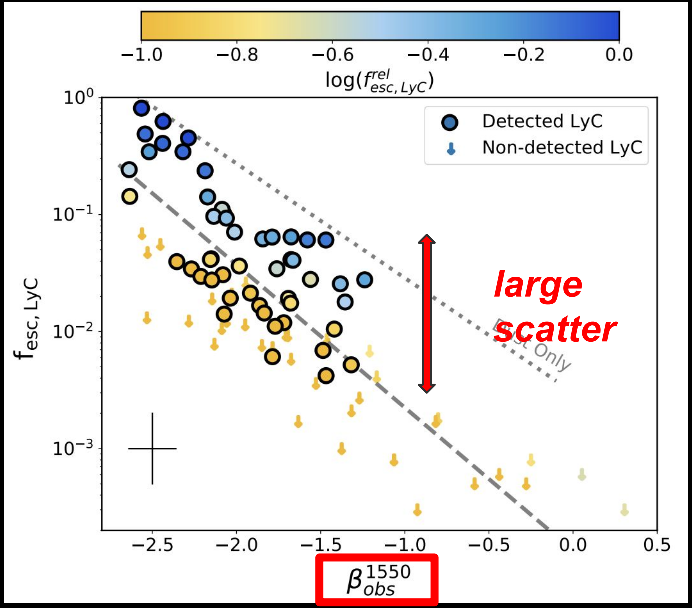
Flury+22

Indirect indicators of LyC escape - UV-β slopes

= the slope between rest-frame 1300 Å and 1800 Å.

It is easily measurable in high z galaxies.





Chisholm+22

Predicting f_{esc} of EoR galaxies

From the 18 spectroscopic and physical properties of the 88 local LCEs analysed by Flury+22 (+ Izotov+16a,b, +18a,b, +21; Wang+19), we calibrate an empirical relation with the f_{esc} values using the most correlated ones.

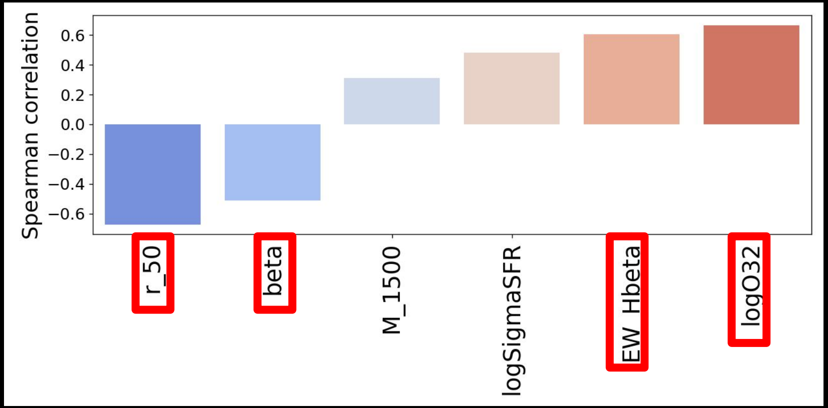
$$\log_{10}(f_{esc}) = A + B\log_{10}(O32) + Cr_e + D\beta$$

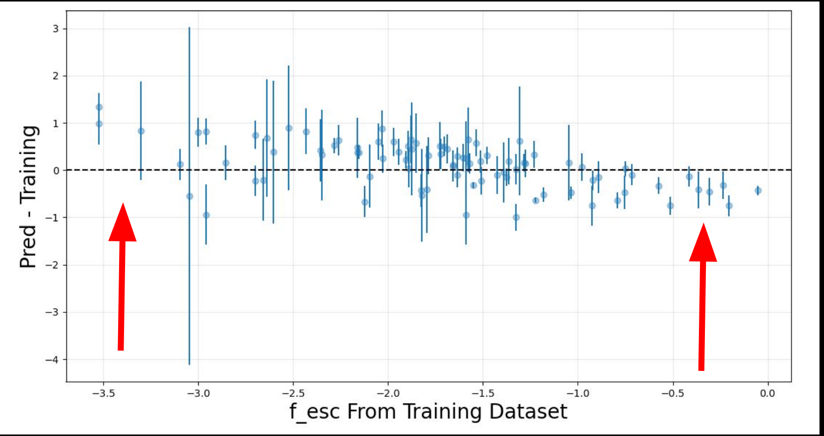
A = −1.92 [−2.51, −1.71]

B = 0.48 [0.38, 0.69]

C = −0.96 [−1.20, −0.62]

D = −0.41 [−0.58, −0.31]





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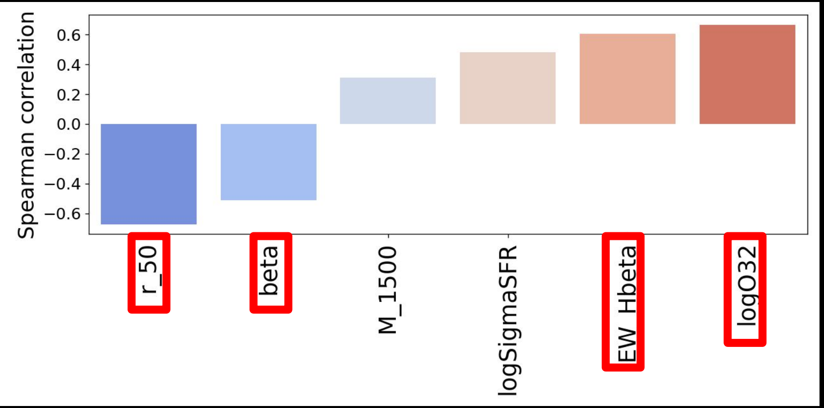
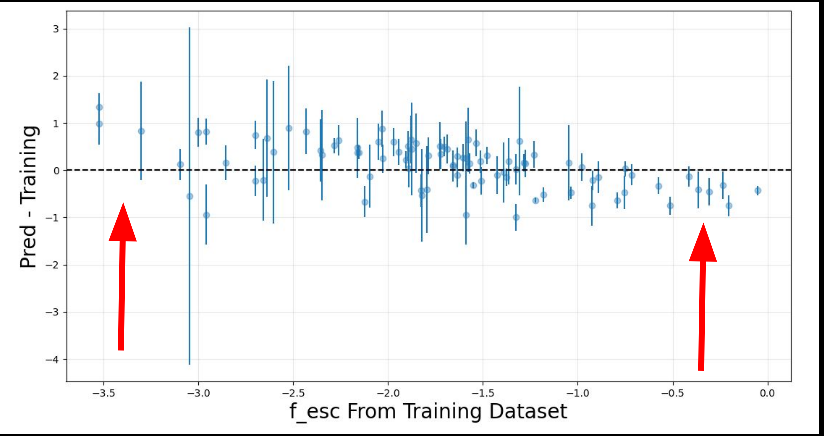
$$\log_{10}(f_{esc}) = A + B\,EW(H\beta) + Cr_e + D\beta$$

A = −1.92 [−2.46, −1.75]   B = 0.0026 [0.0019, 0.0035]

C = −0.94 [−1.14, −0.67]   D = −0.42 [−0.59, −0.33]





We can measure many of these indirect indicators in high redshift galaxies and thus predict their f_{esc} values with JWST

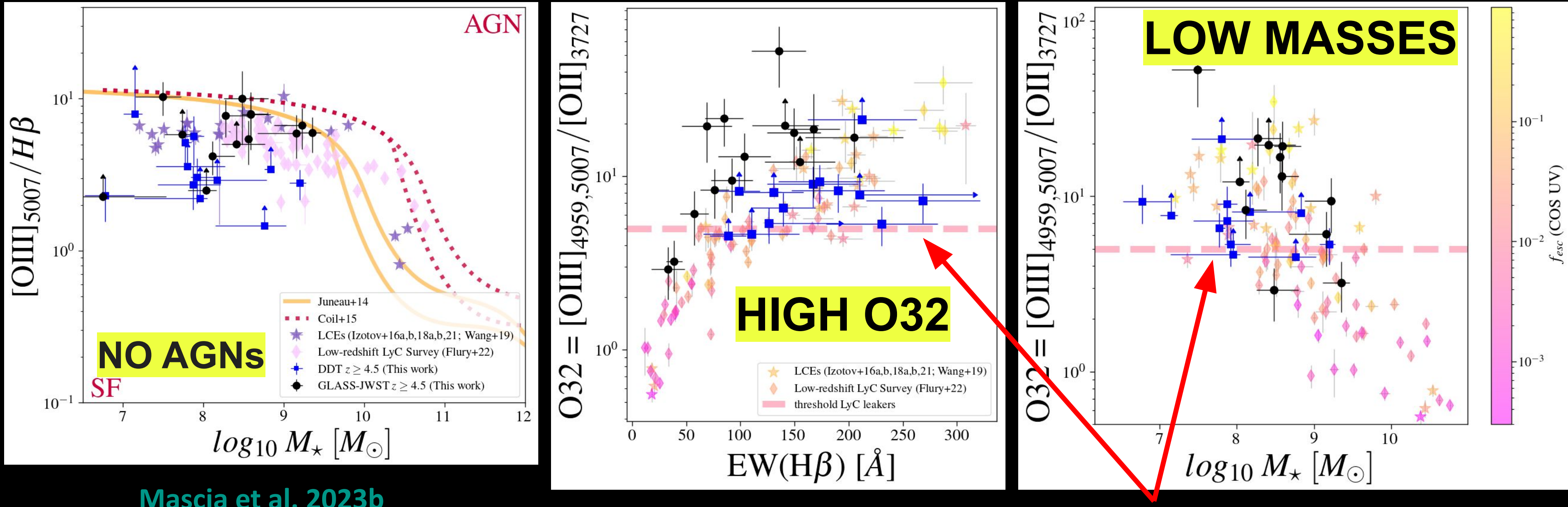
↓

Indirect LyC diagnostics at the EoR

Indirect LyC diagnostics at the end of reionization

29 GALAXIES AT 4.5 < z < 8

from the **GLASS-JWST Early Release Science Program** (PI Treu) and the **JWST DDT program** (PI. W. Chen), both on the A2744 cluster field.



Mascia et al. 2023b

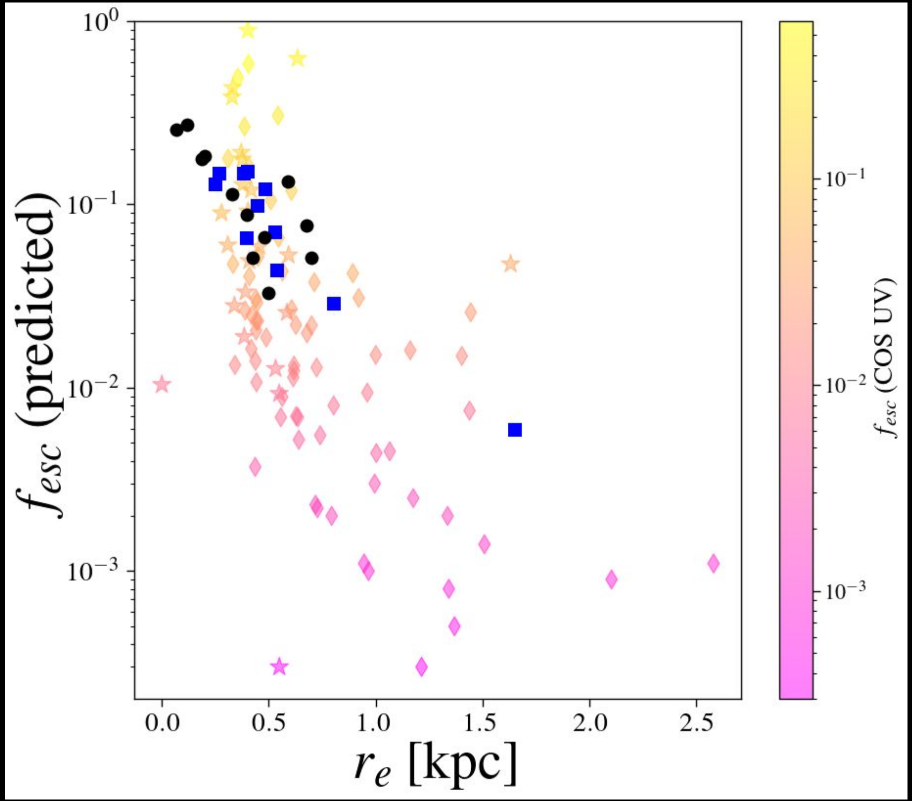
O32 = 5: threshold for LCEs (Flury+22)

f_{esc} of EoR galaxies

We apply the relation to our high-z galaxies.

Most of our galaxies have predicted f_{esc} > 0.05, i.e. they would be considered leakers.

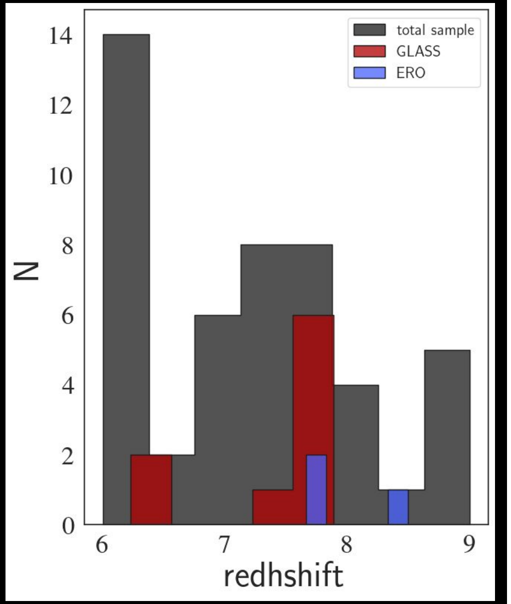
The average f_{esc} is 0.12 with the bluest, and most compact sources having f_{esc} as large as 0.2−0.4.

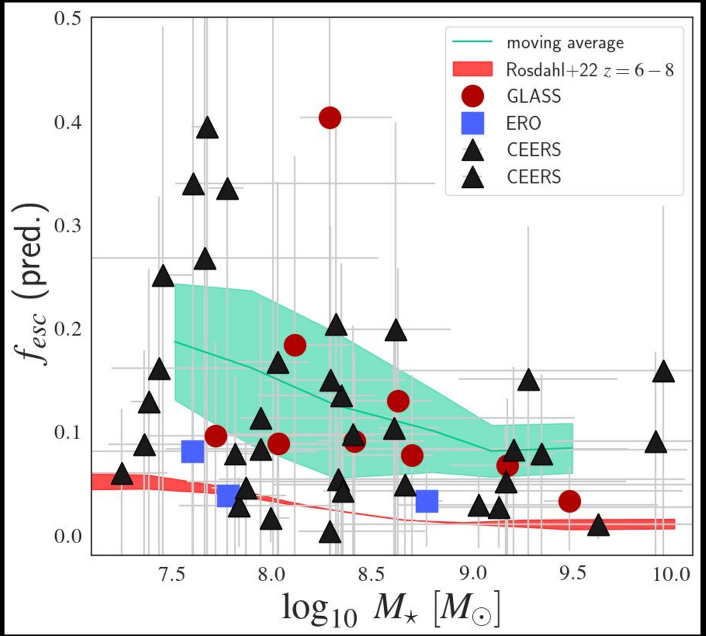


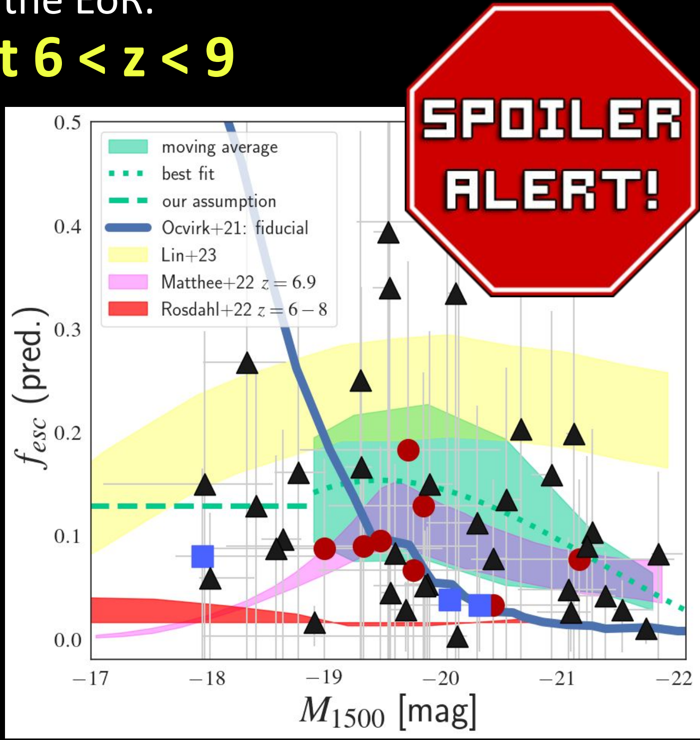
Which galaxies contributed more @EoR?

We select sources from **CEERS - Early Release Science Program** (PID 1345, PI Finkelstein) plus GLASS and ERO, to create a large sample of high-z galaxies at the EoR.

TOTAL SAMPLE: 48 sources at 6 < z < 9







Mascia et al. in prep.

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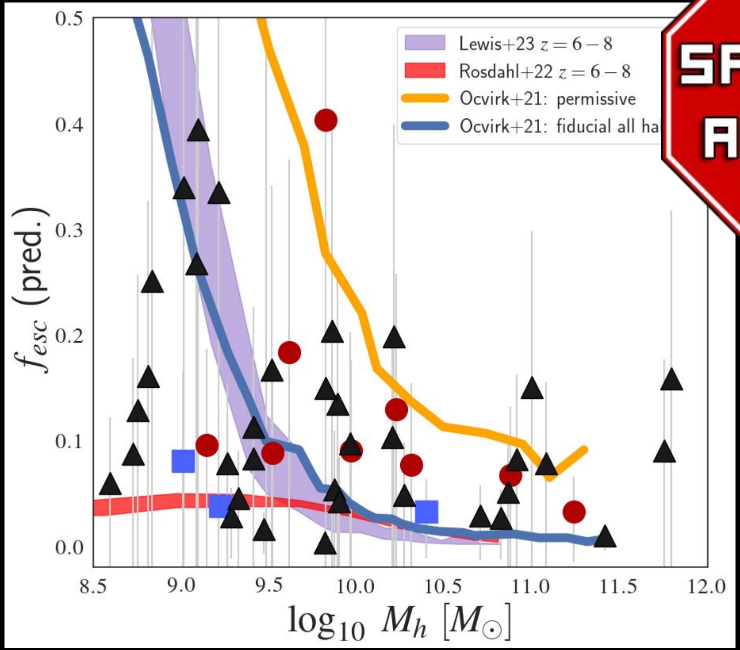
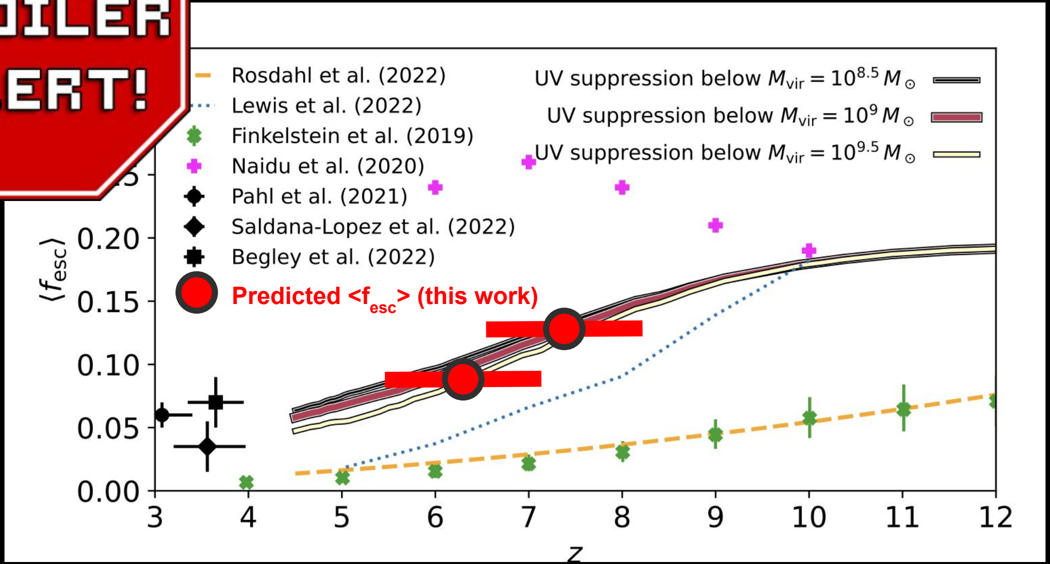


Prediction from radiation-hydrodynamical simulations by Ocvirk+21, Lewis+23, Rosdahl+22



DELPHI semi-analytical galaxy formation model from Trebitsch+22

Mascia et al. in prep.

Take-home message

1) We derived accurate relations to infer the escape fraction of EoR galaxies from measurable spectroscopic/physical properties, calibrating on a large sample of low-z leakers

2) We characterize **29** gravitationally lensed $4.5 \leq z \leq 8$ galaxies in the Abell 2744 cluster which are on average, low mass galaxies (average stellar mass of ~$10^{8.1}$ $M_\odot$), compact sources (r_e ~ 0.2-0.5 kpc) and show strong optical emission lines ([OIII], Hβ, Hα)

   → Assuming that the mechanism that drive the escape of LyC photons are the same as at low redshift, we use our calibrated relation to predict an **escape fraction of ~ 0.1**.

3) We are now studying a much larger sample of EoR galaxies with the aim of evaluating the dependance of f_{esc} on M_{UV} and mass

Thank you!