Combining MUSE, HST and JWST data to better understand the connection between Lyα and LyC emission

Josephine Kerutt

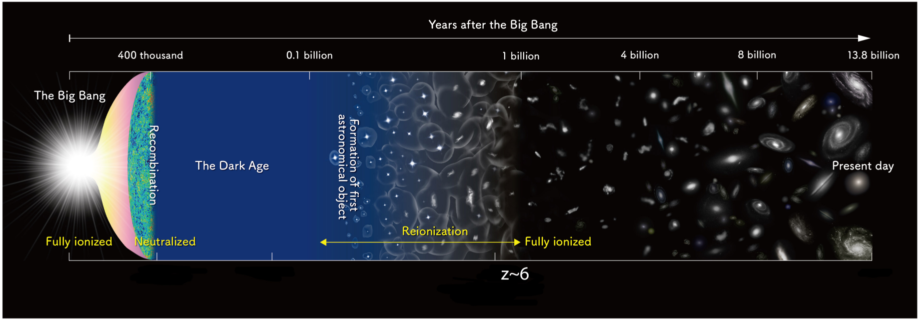
... with P. Oesch, L. Wisotzki, A. Verhamme, E. C. Herenz, H. Kusakabe, J. Matthee, V. Mauerhofer, R. Naidu, J. Schaye, C. Simmonds, T. Urrutia, and E. Vitte, ...

- How was the universe (re)ionised?
- Can we use Lyα to infer LyC escape fractions?
- Comparison between low- and high-redshift LyC leakers
- Morphological connection between LyC and Lyα

April 19$^{\mathrm{th}}$ 2023

How was the universe (re)ionised?

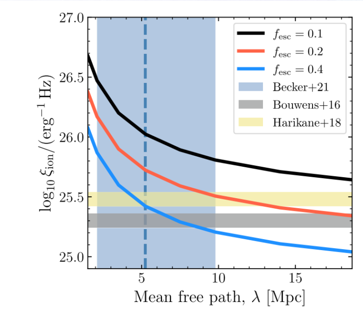
- epoch of reionisation: from neutral to ionised IGM, formation of first stars and galaxies
- source of ionising radiation not clear (AGN or star-forming galaxies)
- best candidates: massive stars in star-forming regions of galaxies



Source: NOAJ

How was the universe (re)ionised?

Recently Becker et al. 2021 showed: mean free path smaller than expected → higher escape fraction needed ~ 20% (Davies et al., 2021)

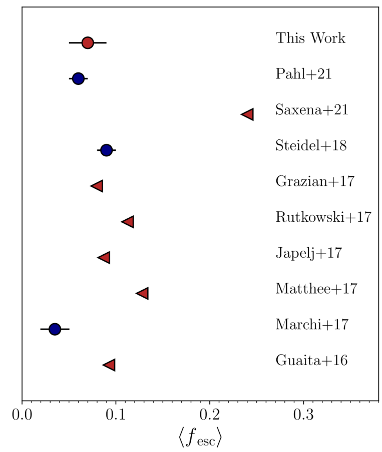


Davies et al. (2021)

Observing LyC at EoR not possible

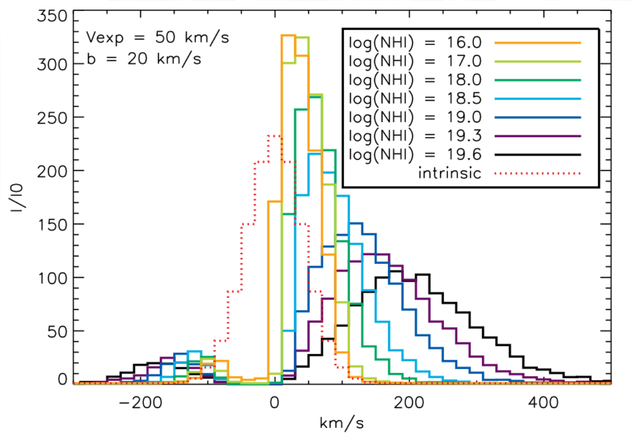
→ we need indirect tracers such as Lyα

→ calibrated at lower redshifts



Begley et al. (2022)

Can we use Lyα to infer LyC escape fractions?



Verhamme et al. (2015)

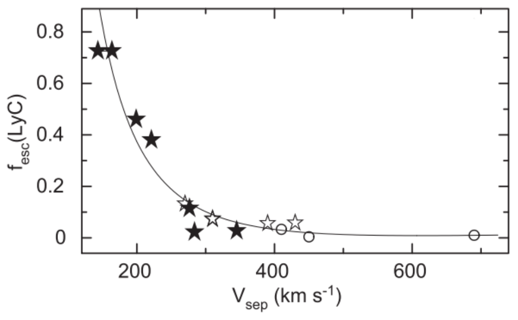
Star-forming galaxies emitting LyC emission (probably) ionised the universe.

Theory: Neutral hydrogen column density influences the escape of LyC photons, but also the shape of the Lyα line.

higher neutral hydrogen column density
→ larger peak separation

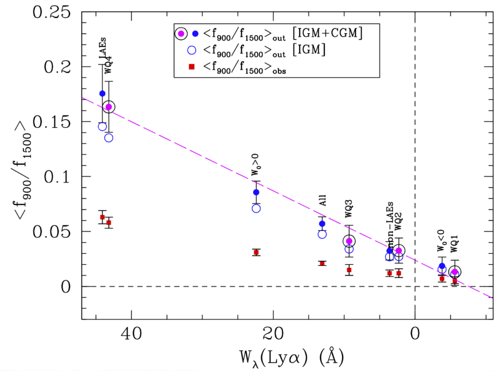
Can we use Lyα to infer LyC escape fractions?

Indeed, LyC emission and Lyα seem to be correlated (at lower redshifts)



Izotov et al. (2018)

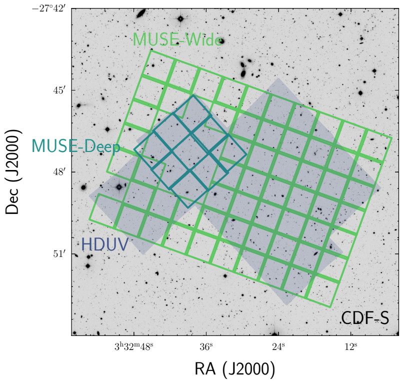
Can we find the same trends at $z \sim 3-4$?

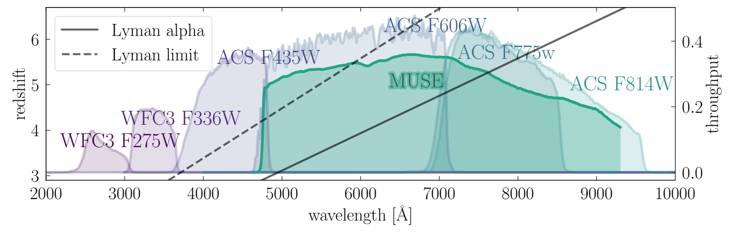


Steidel et al. (2018)

Data: MUSE and HDUV

footprints of MUSE-Wide, MUSE-Deep, and HDUV

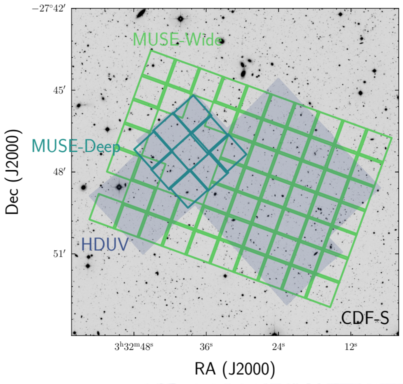




- using WFC3 F336W from HDUV (Oesch et al., 2018) to look for LyC
- based on LAEs from MUSE (Kerutt et al., 2022)

Data: MUSE and HDUV

footprints of MUSE-Wide, MUSE-Deep, and HDUV

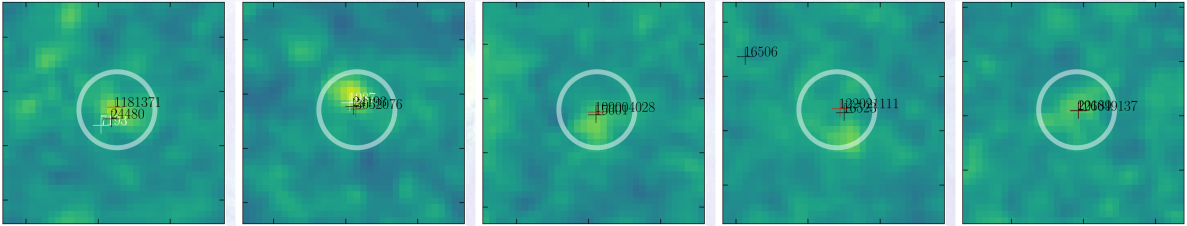


Similar work in these fields e.g.:

- Bian & Fan (2020) find no individual candidates but $f_{\rm esc} < 14 - 32\%$ from stacking
- Rivera-Thorsen et al. (2022) find 6 new LyC leakers with $f_{\rm esc} = 36 - 100\%$ (with bottom-up search)
- Saxena et al. (2022) find 11 new LyC leakers with $f_{\rm esc} = 7 - 52\%$

We find 12 LyC leaker candidates

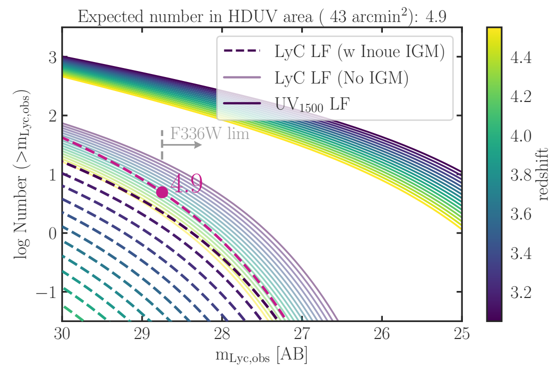
Among those 5 highly-likely (gold) and 7 potential (silver) candidates.
One gold candidate already in Saxena et al. (2022); Rivera-Thorsen et al. (2022).



avoiding interlopers:

- rgb images to see if colours match
- no additional lines in the MUSE spectrum
- reliable (confidence > 1) redshift identification
- overlap of LyC and UV emission
- lower flux in WFC3 F275W and detected in the UV

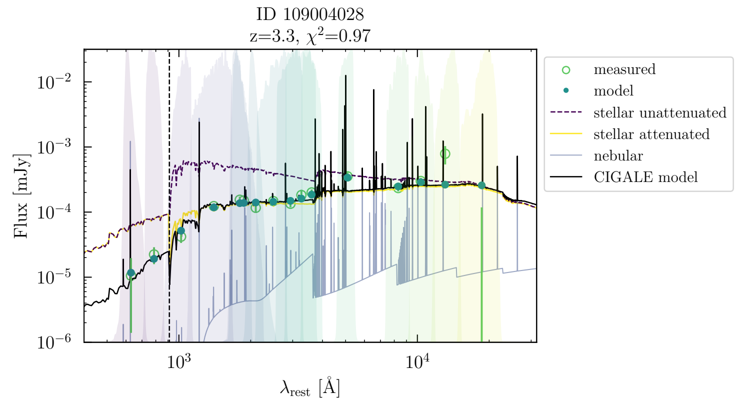
Inferring average f_{esc} from number of LyC leaker



- Assuming UV LF from Bouwens et al. (2021)
- intrinsic ratio of UV continuum to LyC luminosities of $L_{\mathrm{UV}}/L_{\mathrm{LyC}} = 3$
- using IGM transmission from Inoue et al. (2014)
- depth and size of HDUV

→ To get ∼ 5 LyC leaker candidates the underlying average escape fraction should be ≈ 12%

SED fitting

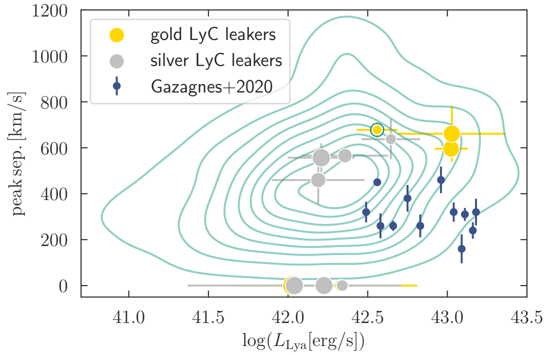


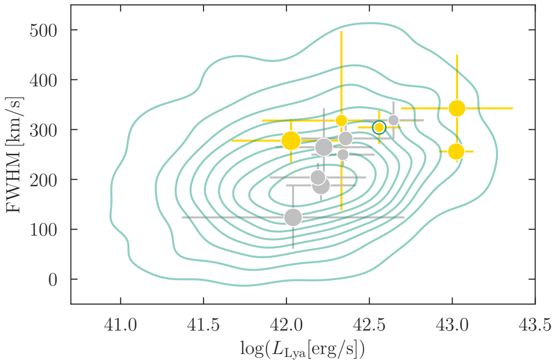
Using CIGALE (Burgarella et al., 2005; Noll et al., 2009; Boquien et al., 2019) to fit SEDs and get LyC escape fractions

- assuming no dust attenuation of LyC emission
- using 5% highest IGM transmission lines from Inoue et al. (2014)
- fixing redshift

→ we find $f_{\rm esc}$ between $\sim 20\%$ and $\sim 90\%$

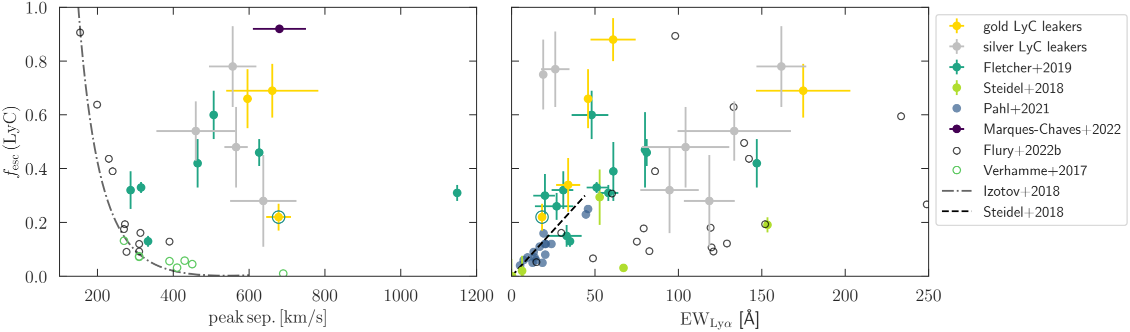
Lyα properties of our LyC leaker candidates





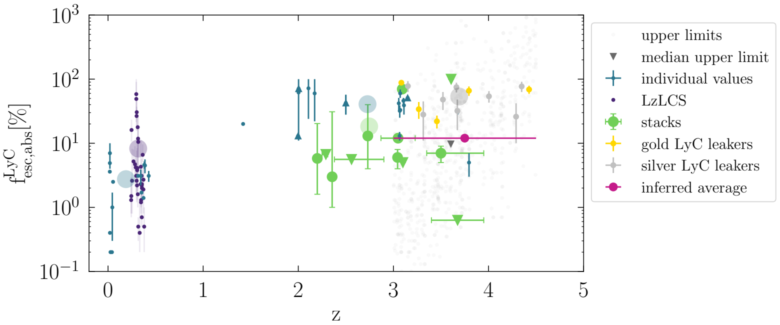
- on average higher peak sep. and FWHM then median of parent sample
- higher peak sep. than low-z LyC leakers of Gazagnes et al. (2020)

Comparing f_{esc} and Lyα properties



- from low-redshift LyC leakers: correlation between f_{esc} and peak separation
- here: surprisingly high peak separations
- Lyα EW seems to work slightly better, but not ideal either
- high Lyα EW has high f_{esc}, but low Lyα EW can have high f_{esc} as well

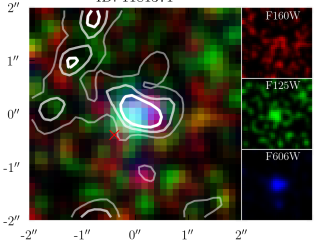
Comparison to other studies



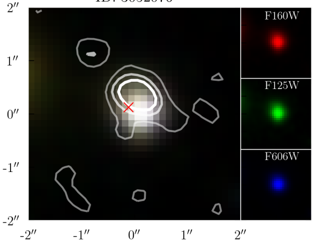
- different methods give different results for $f_{\rm esc}$
- depends on assumptions on IGM transmission, intrinsic UV to LyC ratio, dust attenuation of LyC
- most important: depends on selection biases

Explanations for the discrepancy between Lyα and LyC

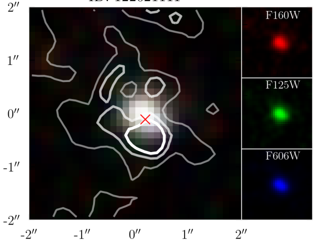
ID: 1181371



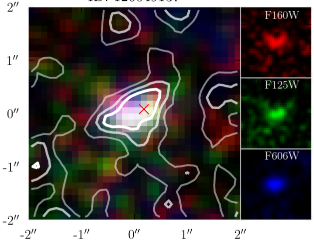
ID: 3052076



ID: 122021111

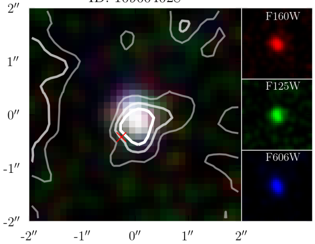


ID: 126049137



Lyα and LyC might not originate from the same place in the galaxy

ID: 109004028

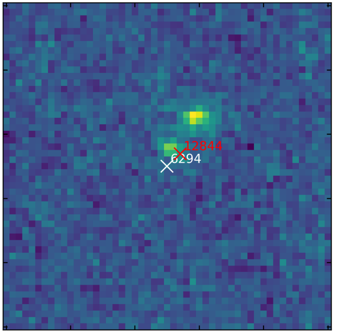


Explanations for the discrepancy between Lyα and LyC

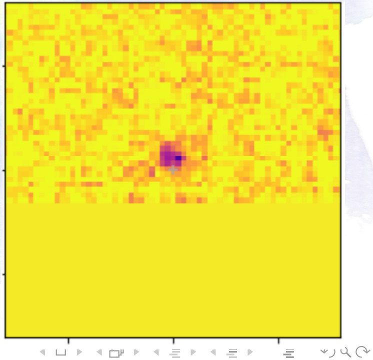
- using JWST to determine physical connection
- next project: Hα maps from FRESCO (Oesch et al. 2023)
- redshift range for Hα in FRESCO: $z = 4.82 - 6.74$
- starting with the MXDF, sample of 55 LAEs

MUSE Lyα narrowband

HST ACS F814W



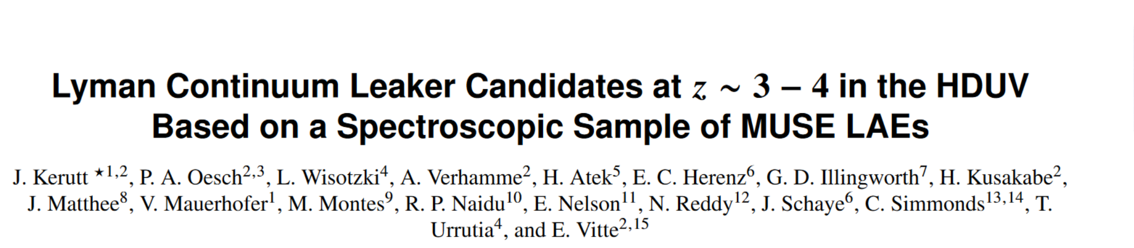
Hα from JWST



Summary... Thanks for your attention!

- we find 5 gold and 7 silver LyC leaker candidates
- f_{esc} ranges from $\sim 20\%$ to $\sim 90\%$
- we can not confirm the correlations between Lyα and LyC f_{esc} found at lower redshifts
- possible explanation: large uncertainties in f_{esc} measurements or different origins of LyC and Lyα in the galaxies

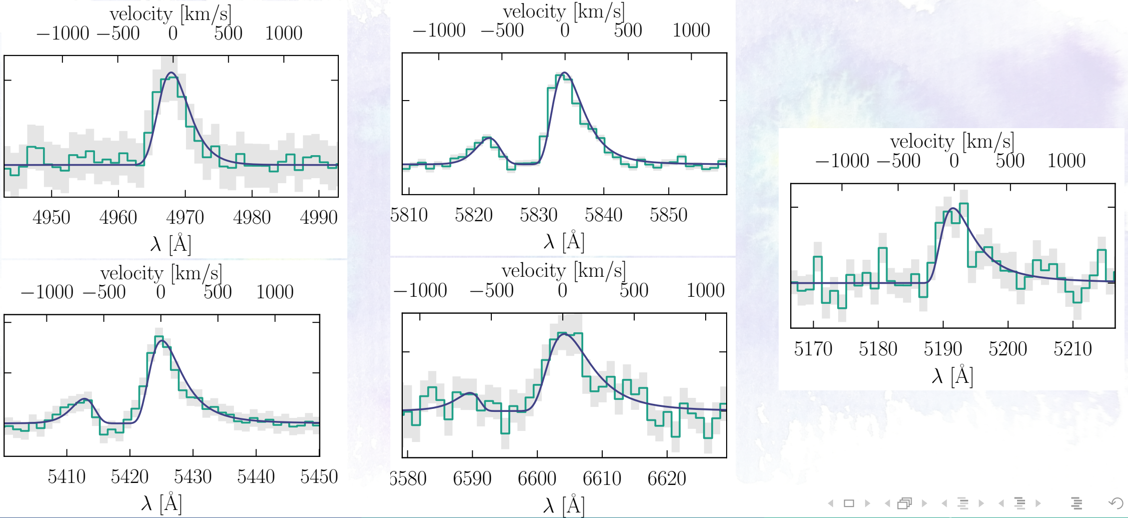
Look out for Kerutt et al. submitted...



Lyman Continuum Leaker Candidates at $z \sim 3-4$ in the HDUV Based on a Spectroscopic Sample of MUSE LAEs

J. Kerutt ★[1,2], P. A. Oesch[2,3], L. Wisotzki[4], A. Verhamme[2], H. Atek[5], E. C. Herenz[6], G. D. Illingworth[7], H. Kusakabe[2], J. Matthee[8], V. Mauerhofer[1], M. Montes[9], R. P. Naidu[10], E. Nelson[11], N. Reddy[12], J. Schaye[6], C. Simmonds[13,14], T. Urrutia[4], and E. Vitte[2,15]

Lyα properties of our LyC leaker candidates



References

Begley, R., Cullen, F., McLure, R. J., et al. 2022, Monthly Notices of the RAS, 513, 3510

Bian, F. & Fan, X. 2020, Monthly Notices of the RAS, 493, L65

Boquien, M., Burgarella, D., Roehlly, Y., et al. 2019, Astronomy and Astrophysics, 622, A103

Bouwens, R. J., Oesch, P. A., Stefanon, M., et al. 2021, Astronomical Journal, 162, 47

Burgarella, D., Buat, V., & Iglesias-Páramo, J. 2005, Monthly Notices of the RAS, 360, 1413

Davies, F. B., Bosman, S. E. I., Furlanetto, S. R., Becker, G. D., & D'Aloisio, A. 2021, Astrophysical Journal, Letters, 918, L35

Gazagnes, S., Chisholm, J., Schaerer, D., Verhamme, A., & Izotov, Y. 2020, Astronomy and Astrophysics, 639, A85

Inoue, A. K., Shimizu, I., Iwata, I., & Tanaka, M. 2014, Monthly Notices of the RAS, 442, 1805

Izotov, Y. I., Schaerer, D., Worseck, G., et al. 2018, Monthly Notices of the RAS, 474, 4514

Kerutt, J., Wisotzki, L., Verhamme, A., et al. 2022, Astronomy and Astrophysics, 659, A183

Noll, S., Burgarella, D., Giovannoli, E., et al. 2009, Astronomy and Astrophysics, 507, 1793

Oesch, P. A., Brammer, G., Naidu, R. P., et al. 2023, arXiv e-prints, arXiv:2304.02026

Oesch, P. A., Montes, M., Reddy, N., et al. 2018, Astrophysical Journal, Supplement, 237, 12

Rivera-Thorsen, T. E., Hayes, M., & Melinder, J. 2022, arXiv e-prints, arXiv:2206.10799

Saxena, A., Pentericci, L., Ellis, R. S., et al. 2022, Monthly Notices of the RAS, 511, 120