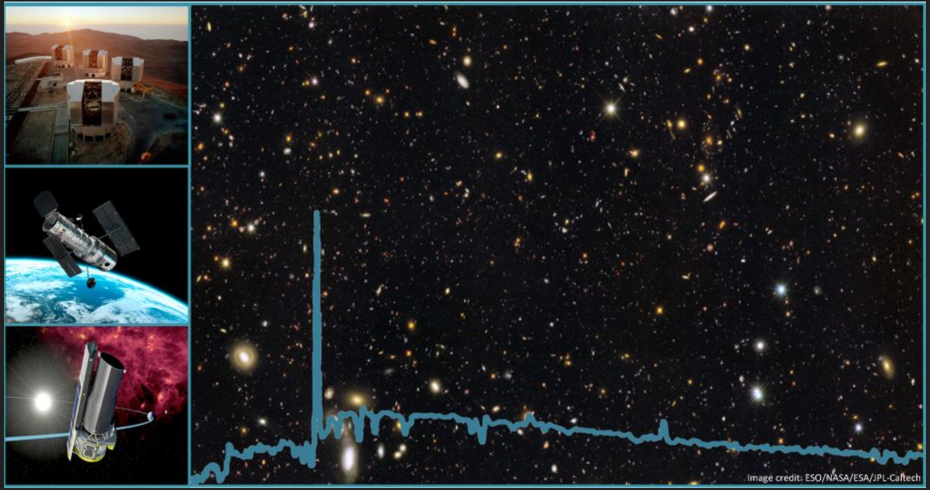
The VANDELS survey

The ionizing properties of star-forming galaxies at $3 < z < 5$

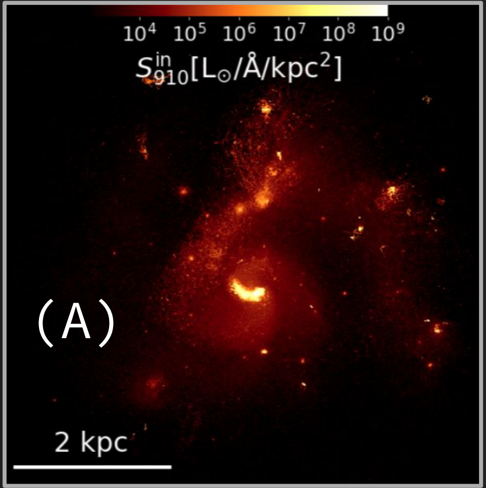
Alberto Saldana-Lopez, Daniel Schaerer (University of Geneva - Switzerland)

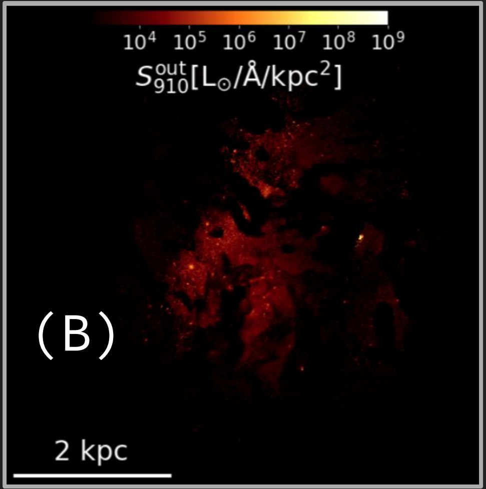
http://vandels.inaf.it/



alberto.saldanalopez@unige.ch

A tribute to Olivier Le Fèvre - July 2022





How to reionize the Universe?

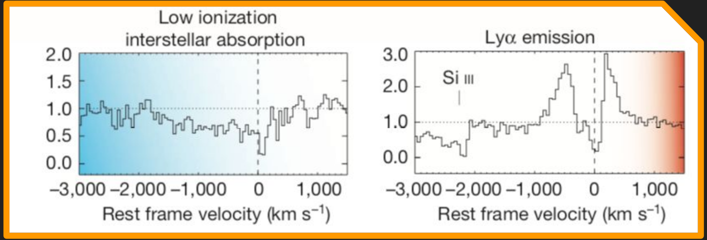
ionization rate of the Universe

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

the fraction of escaping ionizing photons

ionizing photons produced per UV luminosity

the UV luminosity per Universe volume

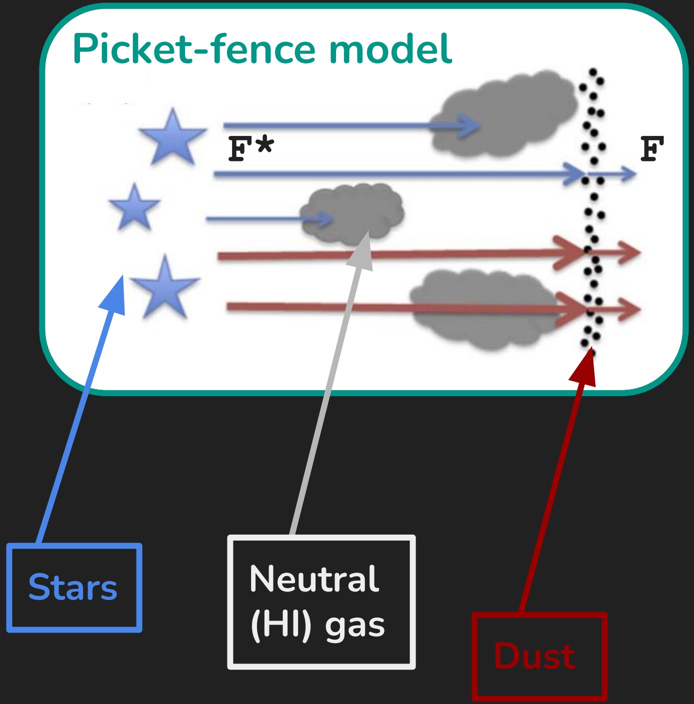


fesc = escaping (B) / produced photons (A)

Mauerhofer 2021

"How to… model a clumpy and dusty ISM"

- "Picket-fence" model (optically thick HI GAS distributed in clumps) + foreground and homogenous screen of DUST



if lines are saturated

$$F_\lambda = F_\lambda^\star \times 10^{-0.4 k_\lambda E_{\mathrm{B-V}}} \times \left(C_f \exp(-\tau_\lambda) + (1 - C_f)\right),$$

$$f_{\mathrm{esc}}^{\mathrm{abs,pred}} = 10^{-0.4 k_{912} E_{\mathrm{B-V}}} \times (1 - C_f),$$

Dust attenuation — Residual flux

Cf: covering fraction
(fraction of sight lines covered by optically thick HI gas)

Heckman 2001, Vasei 2016, Reddy 2016, Gazagnes 2018, Steidel 2018, Chisholm 2018, Gazagnes 2020

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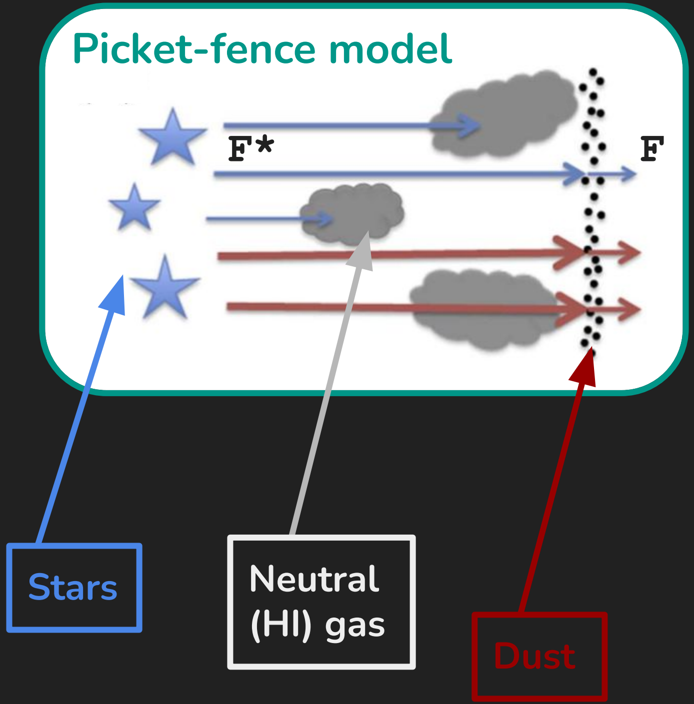

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WARNING!
Nature is not so simple, see Mauerhofer et al. 2021 for cosmological zoom-in simulations (RAMSES)

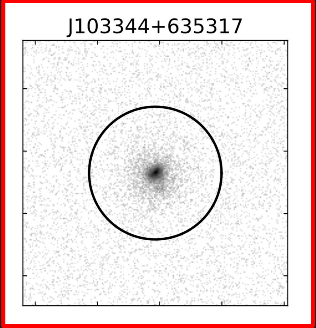
- Predicting fesc for **low-z** galaxies **(z = 0.3)**

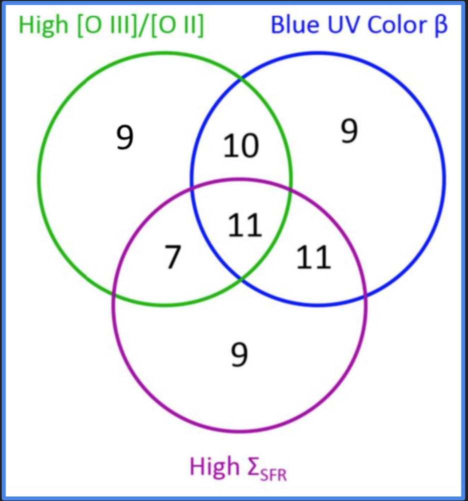
The Low-Redshift Lyman Continuum Survey (LzLCS)

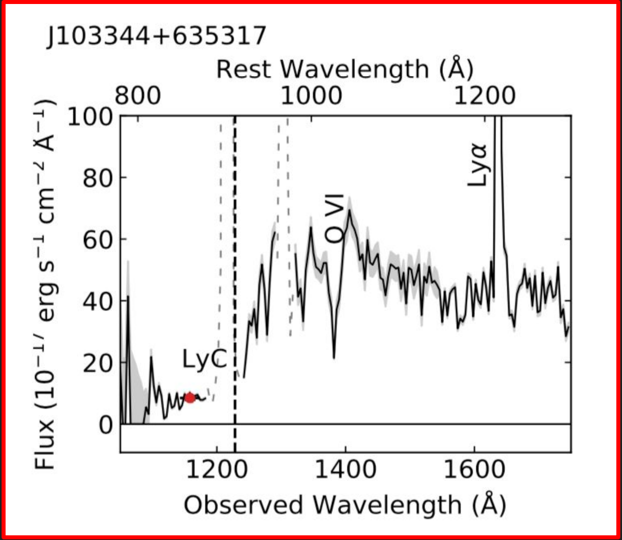
- **HST large program** (GO15626, PI A. Jaskot),
- **66 new + 23 archival galaxies at z~0.3** observed in the **far-UV (+LyC)** with HST/**COS/G140L**...

89 LyC observations at low-z
50 confirmed LyC emitters

Flury 2021a, arXiv: 2201.11716
Flury 2021b, arXiv: 2203.15649

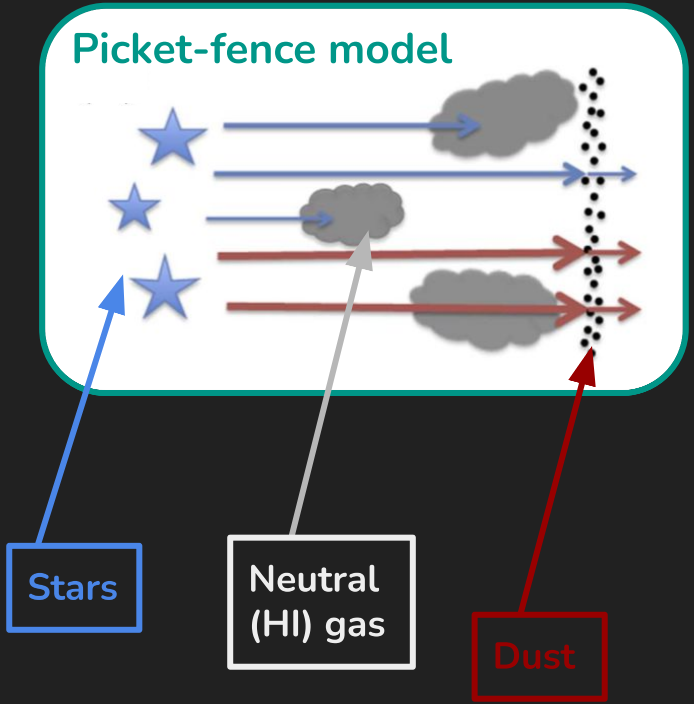


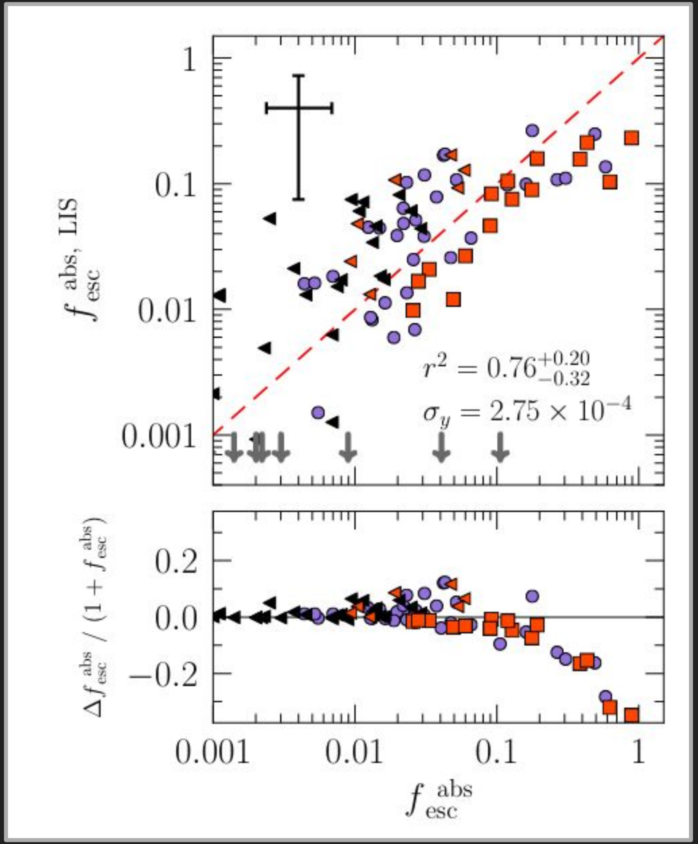




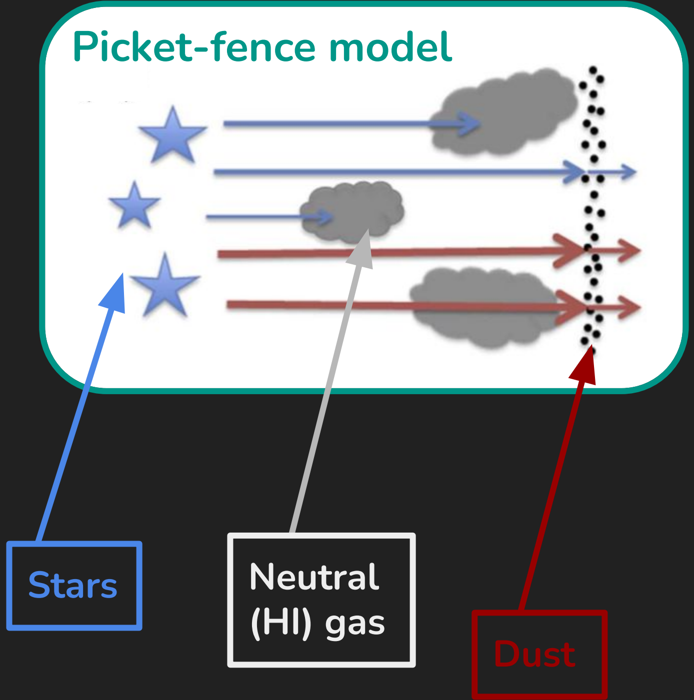
- Predicting fesc for **low-z** galaxies **(z = 0.3)**

Saldana-Lopez et al. 2022 (arXiv:2201.11800)

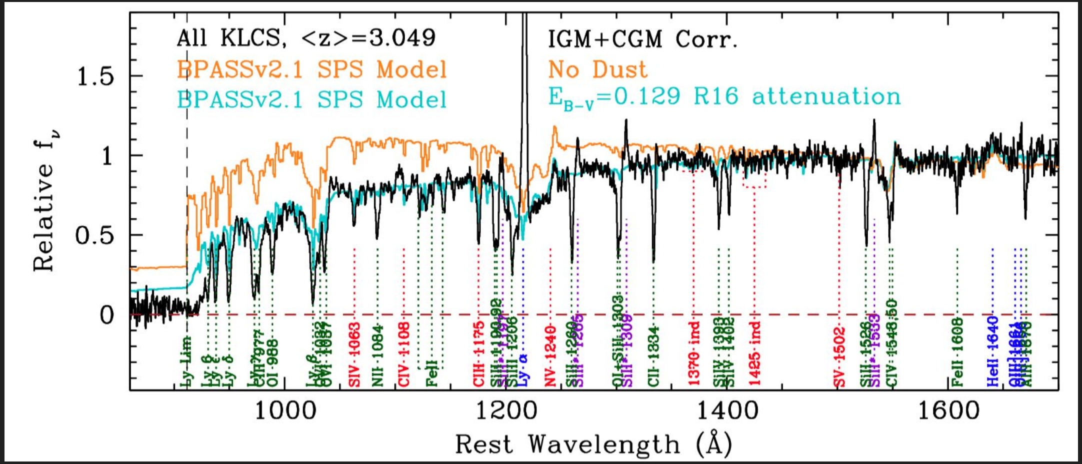


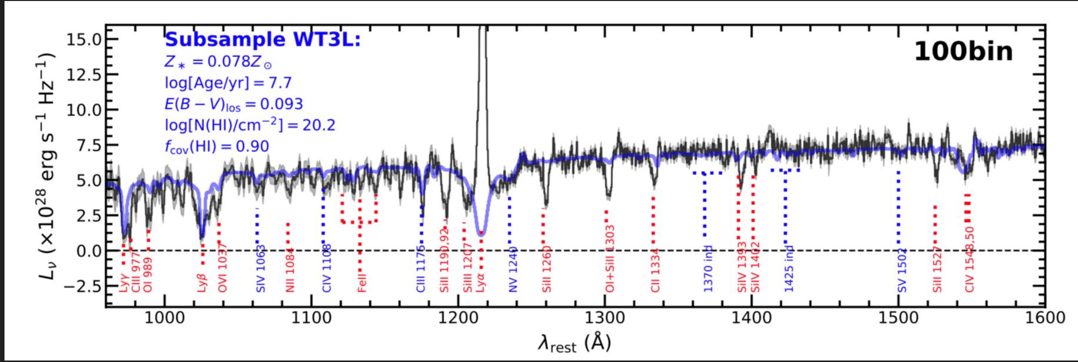


- Predicting fesc for **high-z** galaxies **(z = 2-3)**



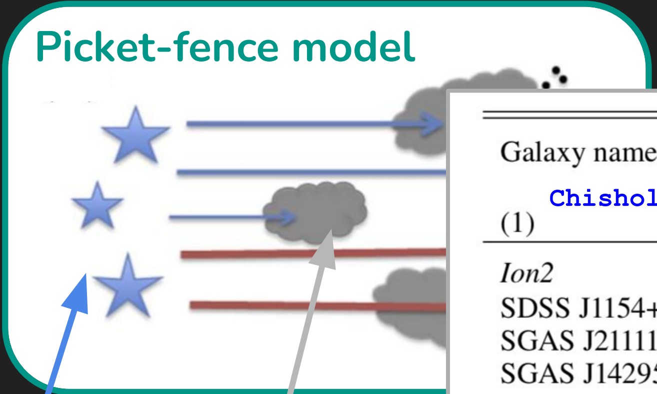
Steidel et al. 2018



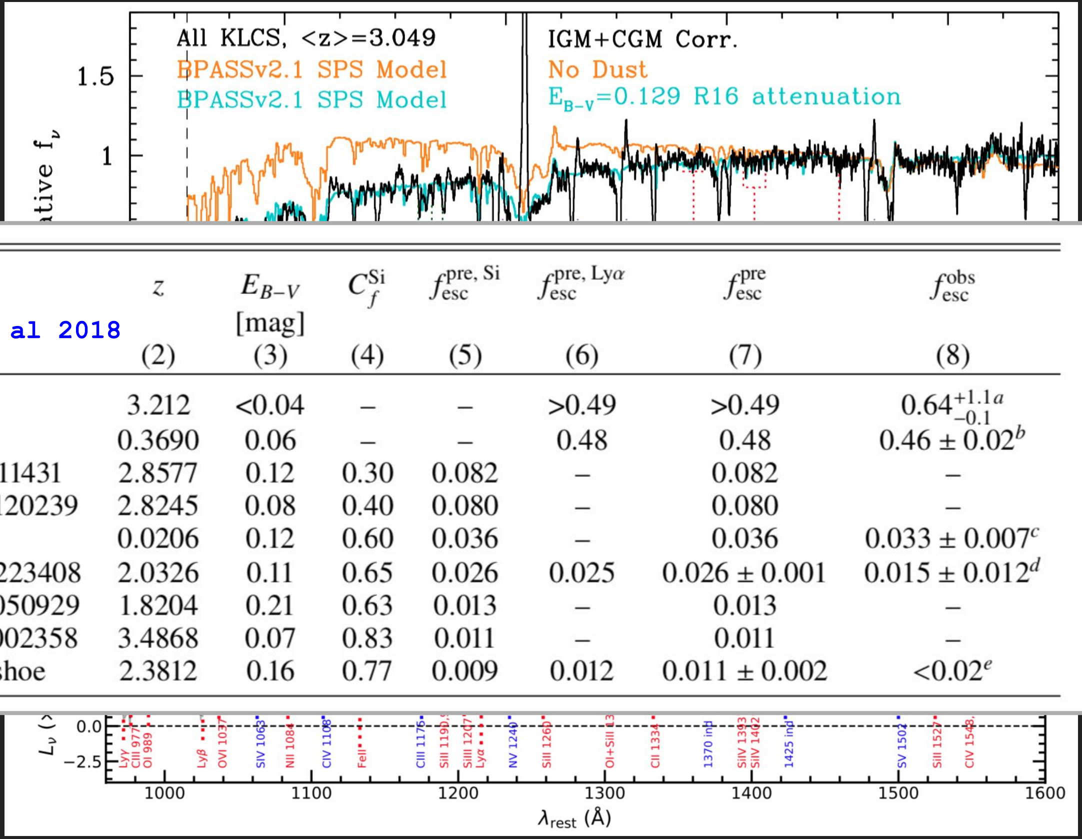


Reddy et al. 2021

- Predicting fesc for **high-z** galaxies **(z = 2-3)**



Steidel et al. 2018



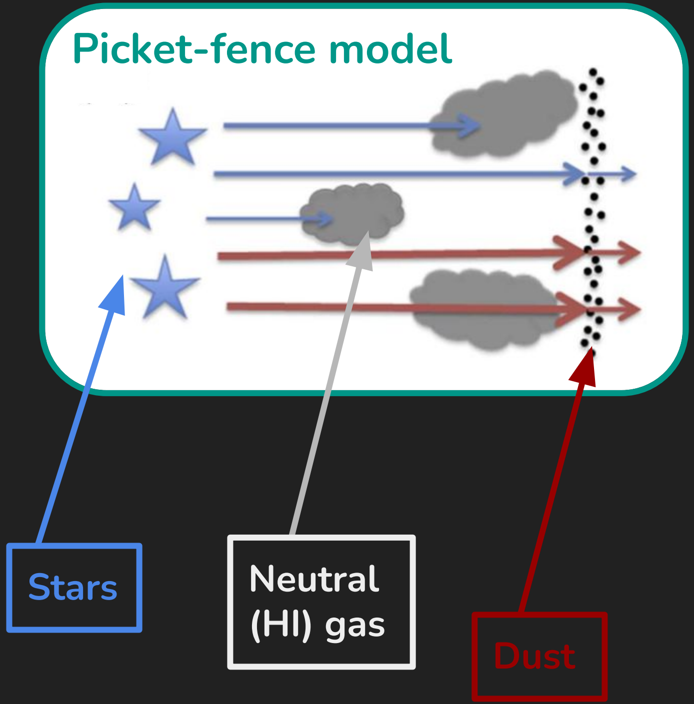
Chisholm et al 2018

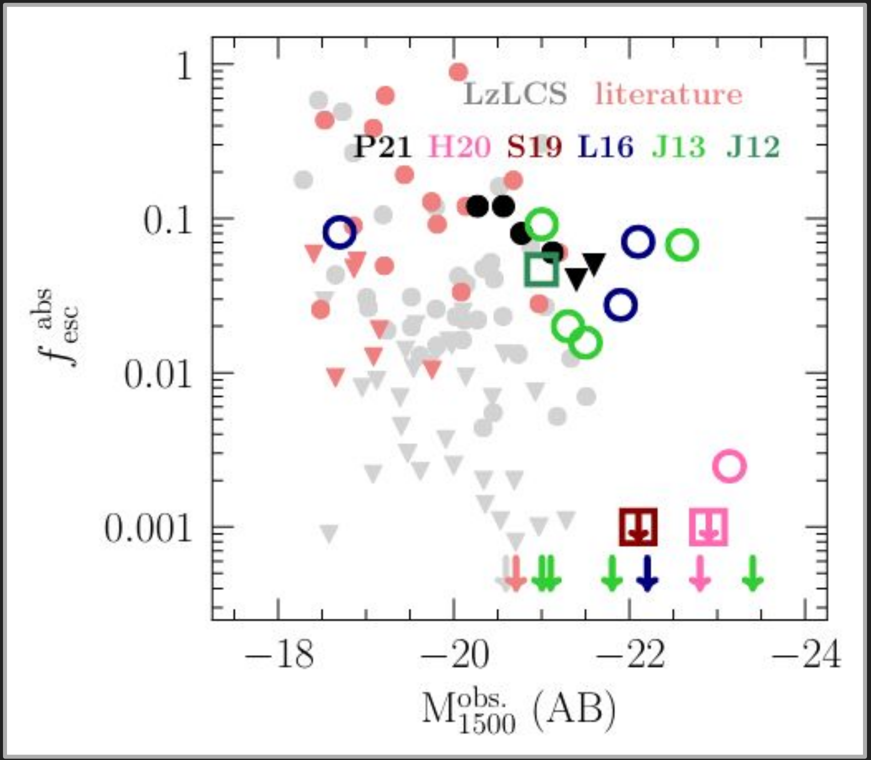
Galaxy name (1)	z (2)	E_{B-V} [mag] (3)	C_f^{Si} (4)	$f_{esc}^{pre, Si}$ (5)	$f_{esc}^{pre, Ly\alpha}$ (6)	f_{esc}^{pre} (7)	f_{esc}^{obs} (8)
Ion2	3.212	<0.04	–	–	>0.49	>0.49	$0.64^{+1.1}_{-0.1}$ [a]
SDSS J1154+2443	0.3690	0.06	–	–	0.48	0.48	0.46 ± 0.02[b]
SGAS J211118.9−011431	2.8577	0.12	0.30	0.082	–	0.082	–
SGAS J142954.9−120239	2.8245	0.08	0.40	0.080	–	0.080	–
Haro 11	0.0206	0.12	0.60	0.036	–	0.036	0.033 ± 0.007[c]
SGAS J090003.3+223408	2.0326	0.11	0.65	0.026	0.025	0.026 ± 0.001	0.015 ± 0.012[d]
SGAS J095738.7+050929	1.8204	0.21	0.63	0.013	–	0.013	–
SGAS J145836.1−002358	3.4868	0.07	0.83	0.011	–	0.011	–
The Cosmic Horseshoe	2.3812	0.16	0.77	0.009	0.012	0.011 ± 0.002	<0.02[e]

Reddy et al. 2021

- Predicting fesc for **high-z** galaxies **(z = 4-6)**

Saldana-Lopez et al. 2022 (arXiv:2201.11800)

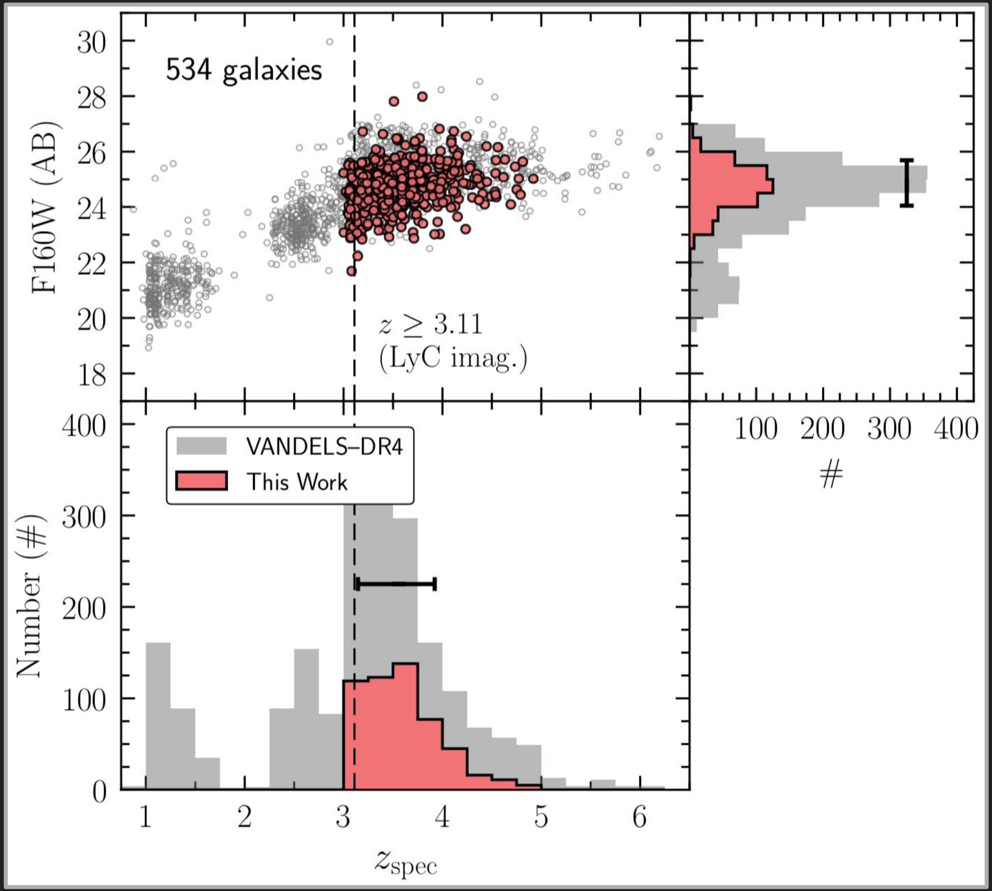




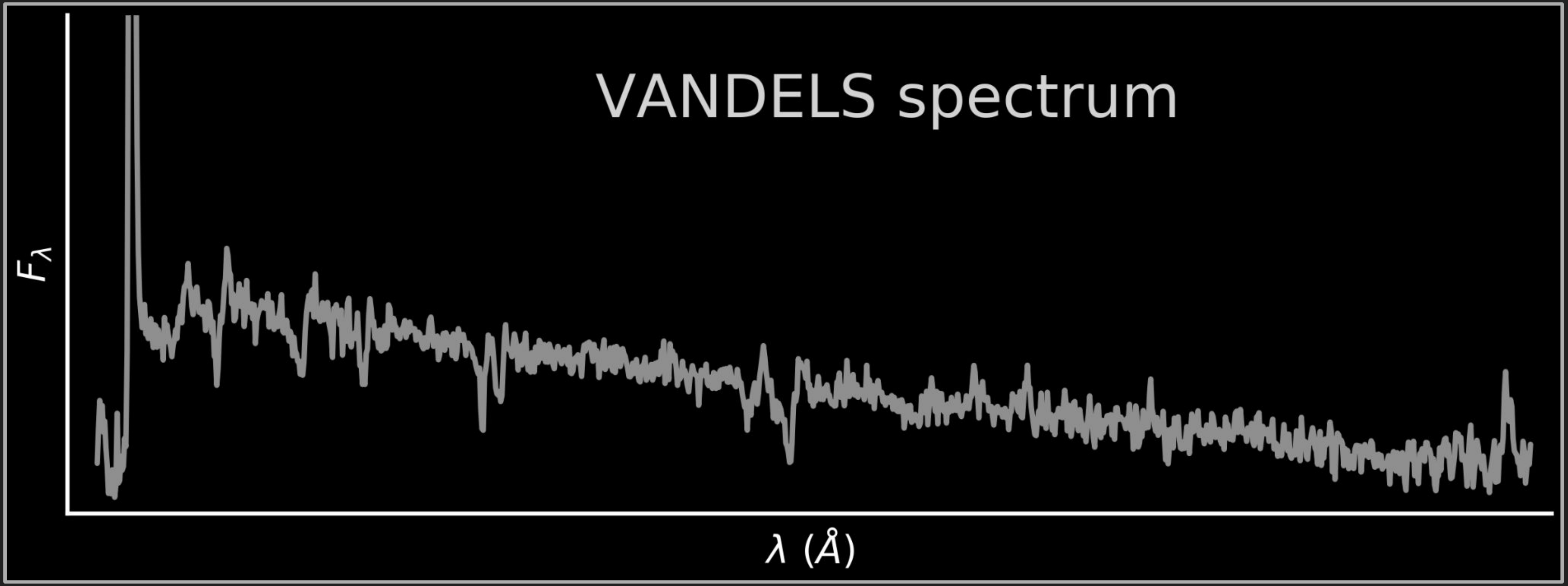
The VANDELS survey:

R~600 VIMOS spectra
2100 galaxies
20 to 80 hours exp.
~500 galaxies (DR4)
selected by S/N
at 3 < z < 5

Saldana-Lopez et al., in prep.



SED fitting with **FiCUS** (**FItting the stellar Continuum of Uv Spectra**):
Saldana-Lopez 2022 (arXiv: 2201.11800)
Chisholm et al. 2019



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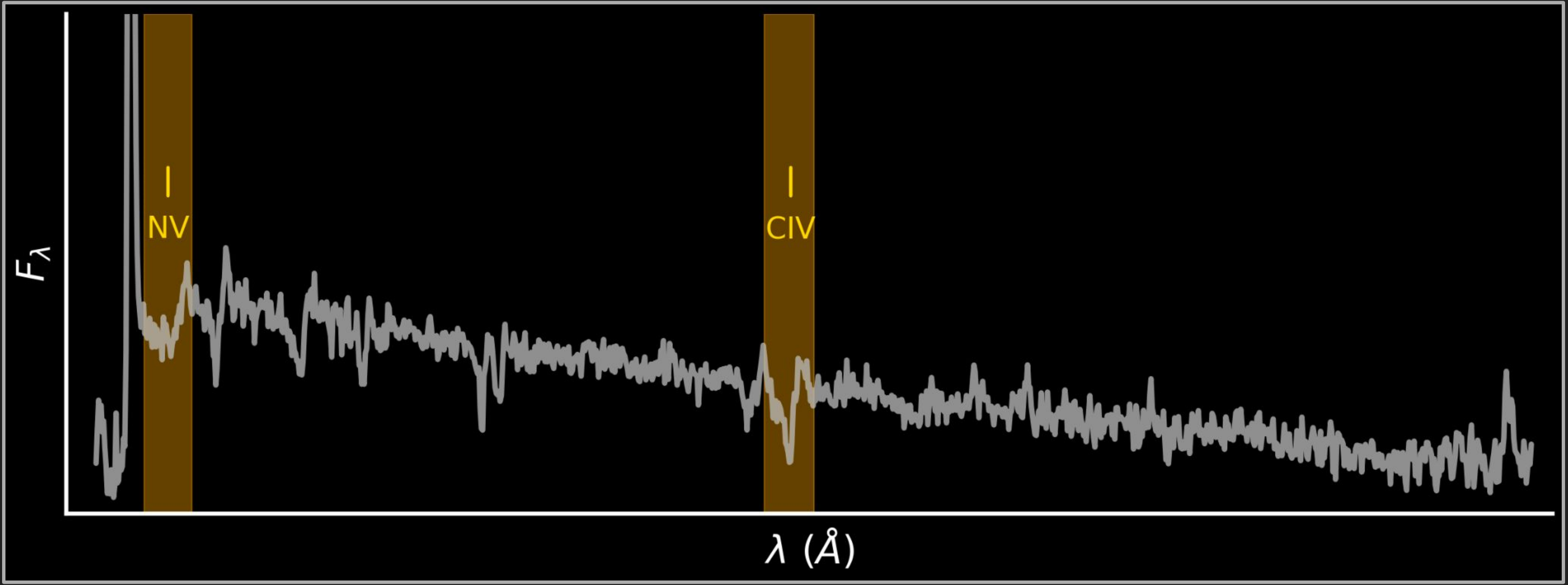
Chisholm et al. 2019



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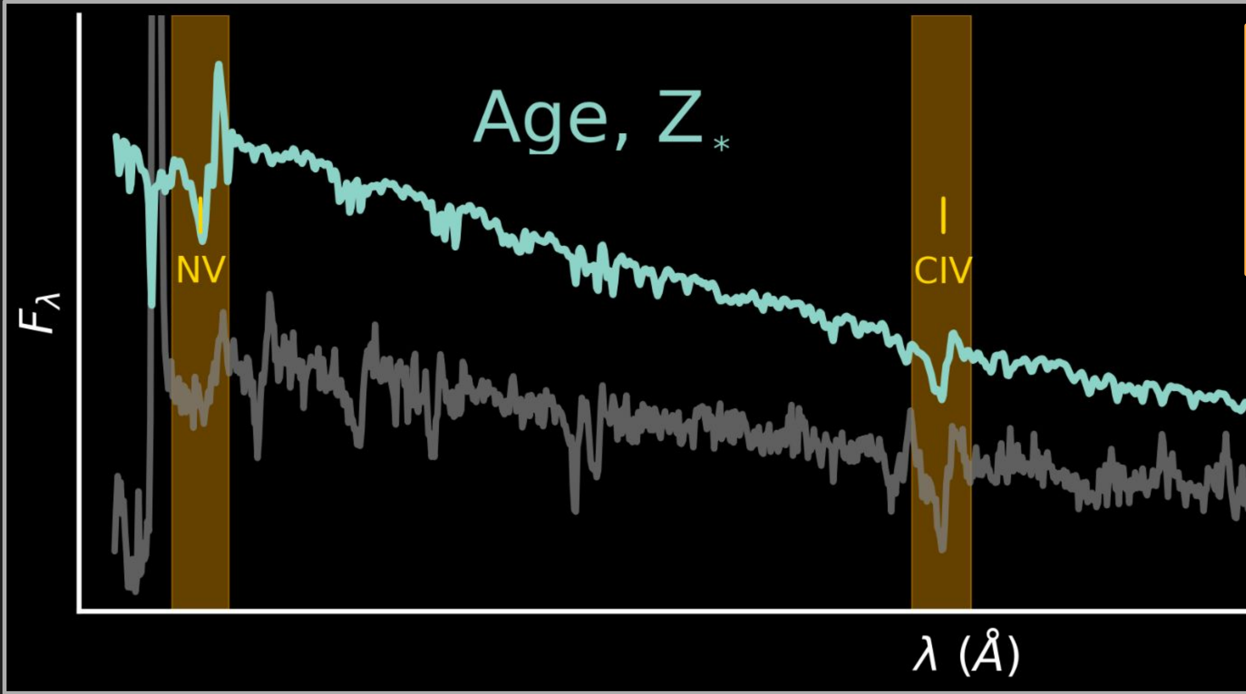


$$F^\star(\lambda) = 10^{-0.4k(\lambda)E_{\mathrm{B-V}}} \sum_{i,j} X_i F^{S99}_{i,j}$$

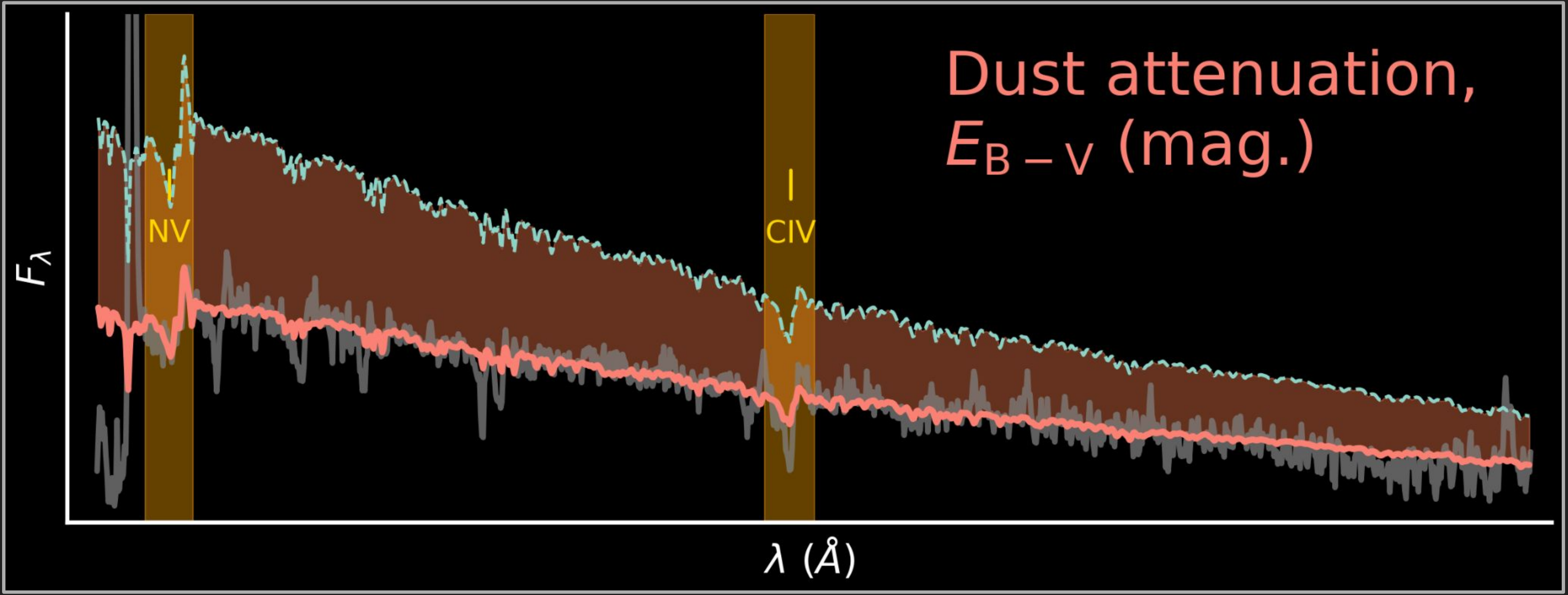
$$i \equiv 1, 2, 3, 4, 5, 8, 10, 15, 20, 40\ Myr$$

$$j \equiv 0.05, 0.2, 0.4, 1\ Z_\odot$$

SED fitting with **FiCUS**:

Saldana-Lopez 2022 (arXiv: 2201.11800)

Chisholm et al. 2019



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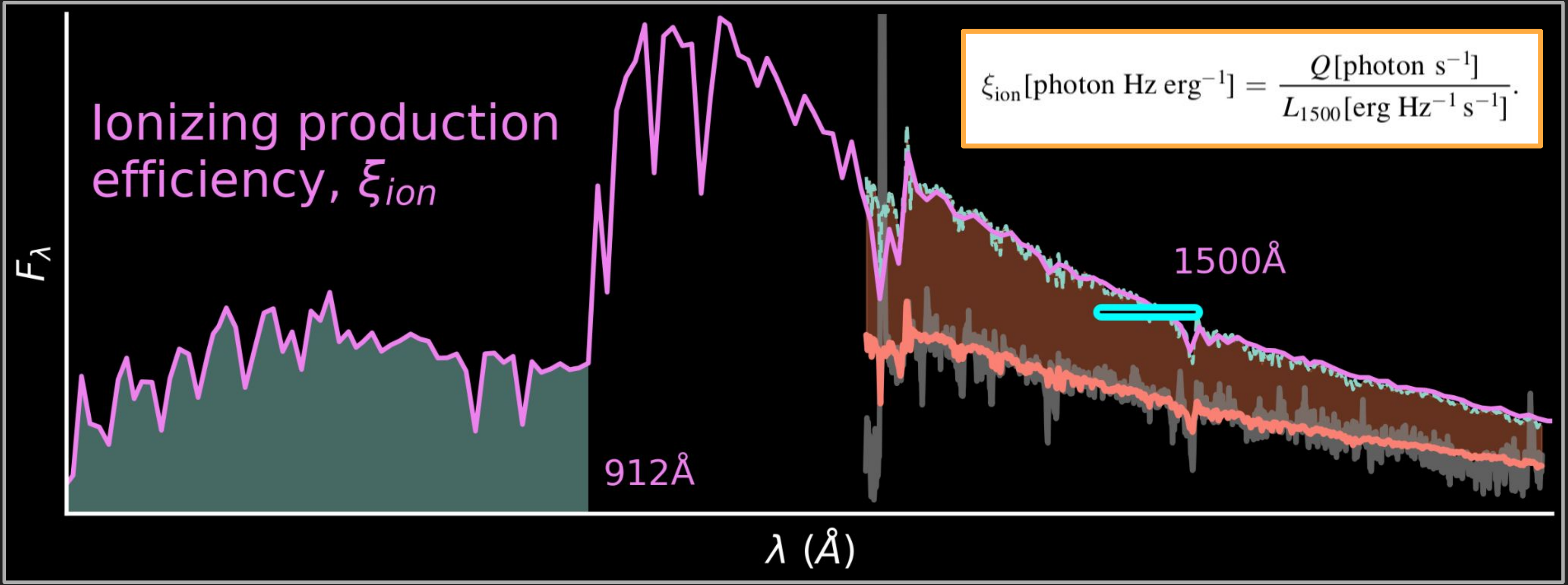


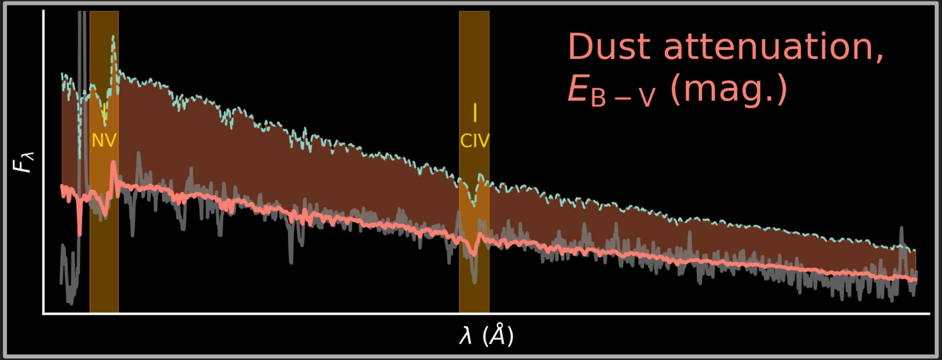
Computing **escape fractions:**

Saldana-Lopez 2022 (arXiv: 2201.11800)

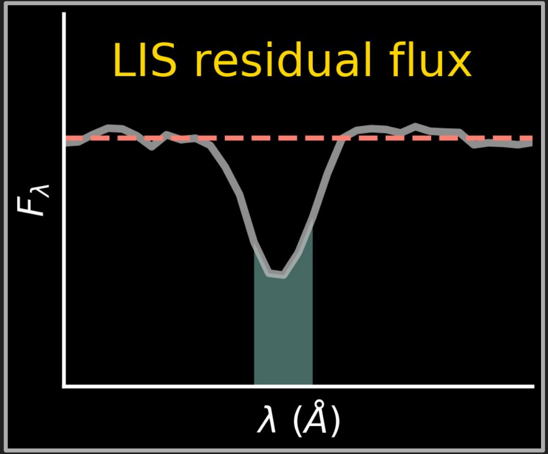
$$f_{\rm esc}^{\rm abs,pred} = 10^{-0.4 k_{912} E_{\rm B-V}} \times (1 - C_f),$$

Dust attenuation

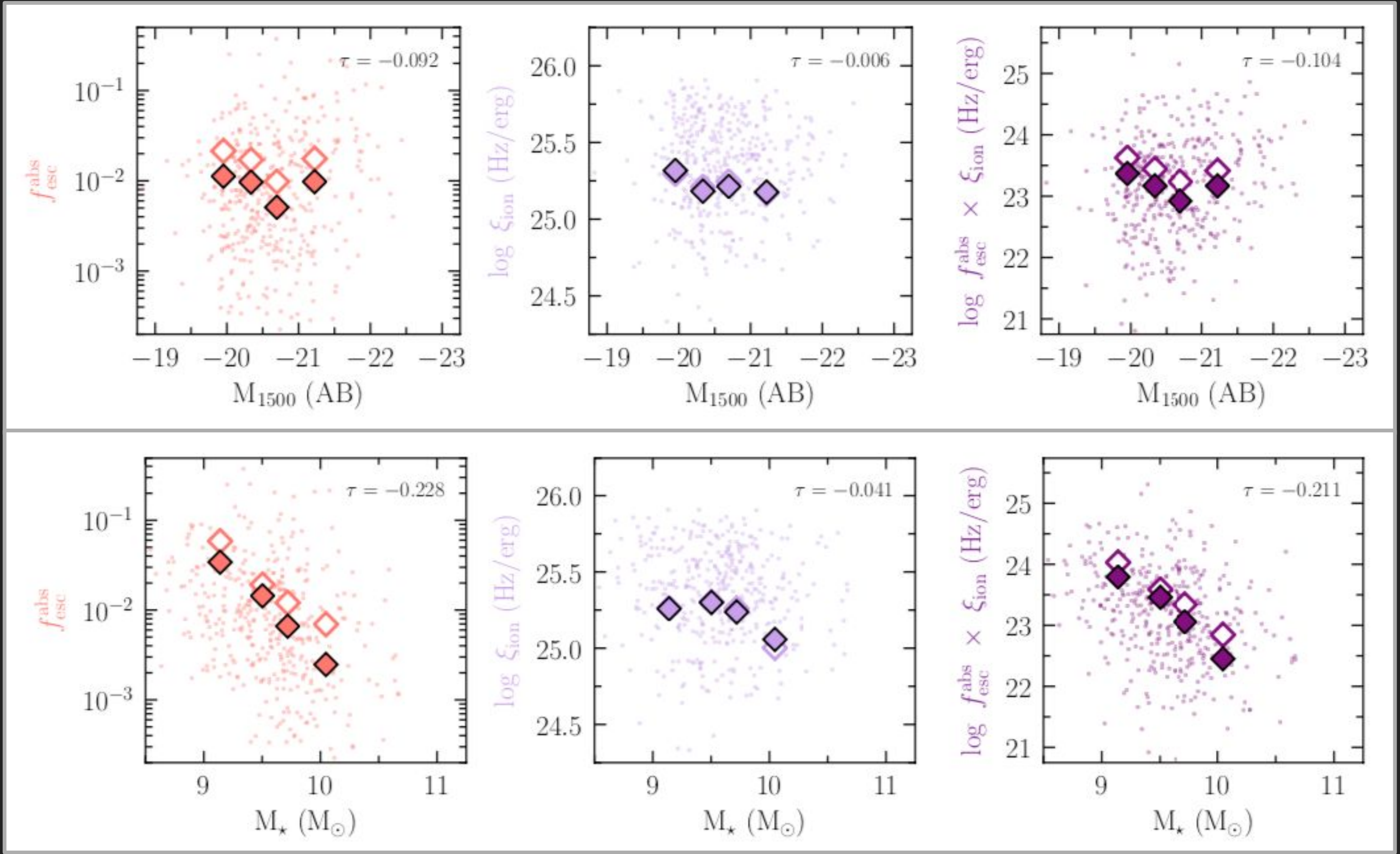
Residual flux



X



Ionizing escape fraction and production efficiency with **galaxy properties**



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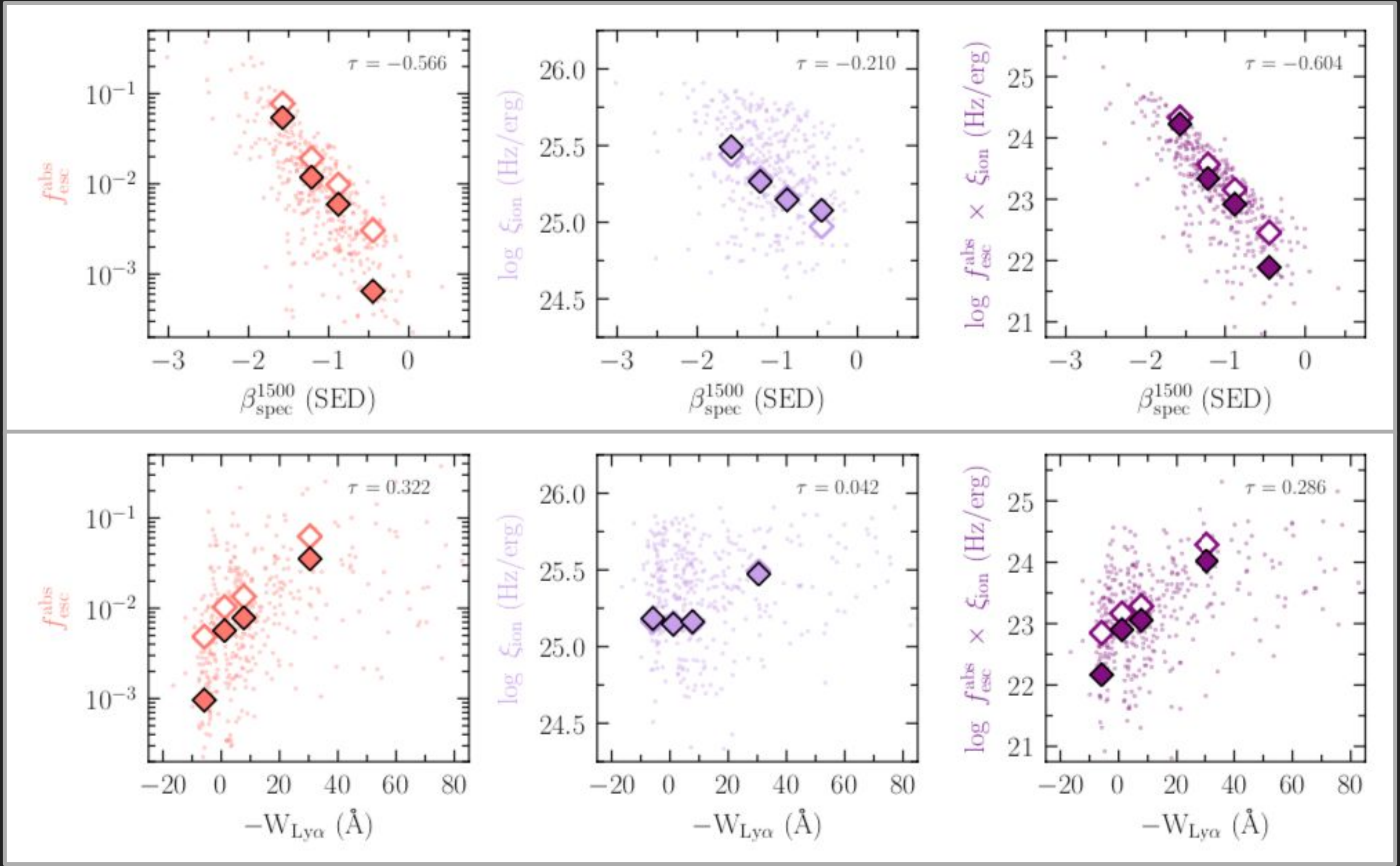
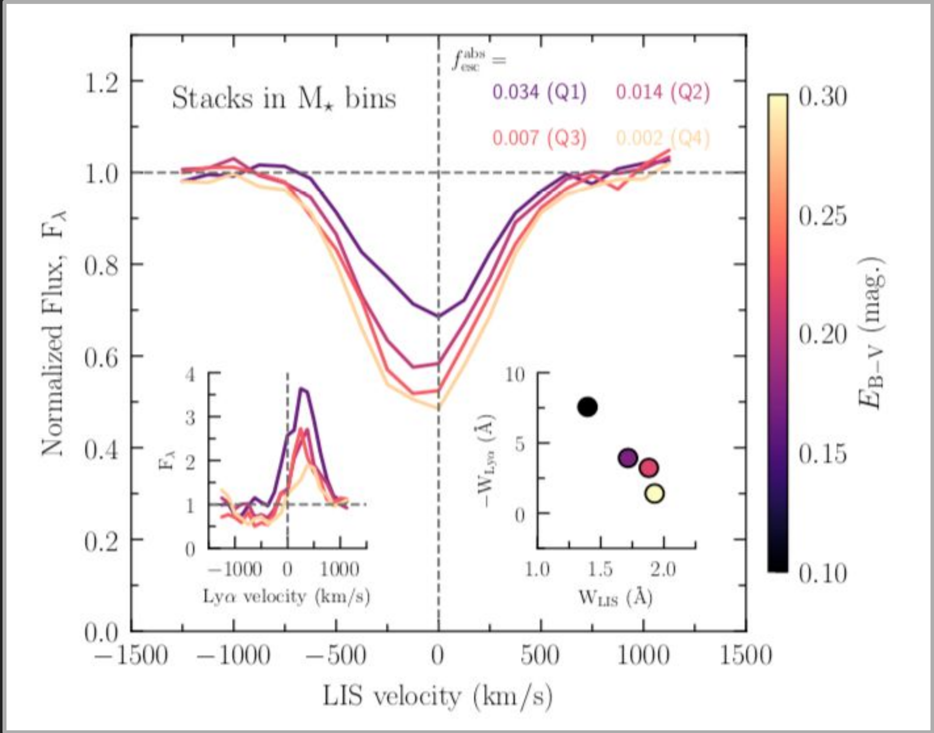
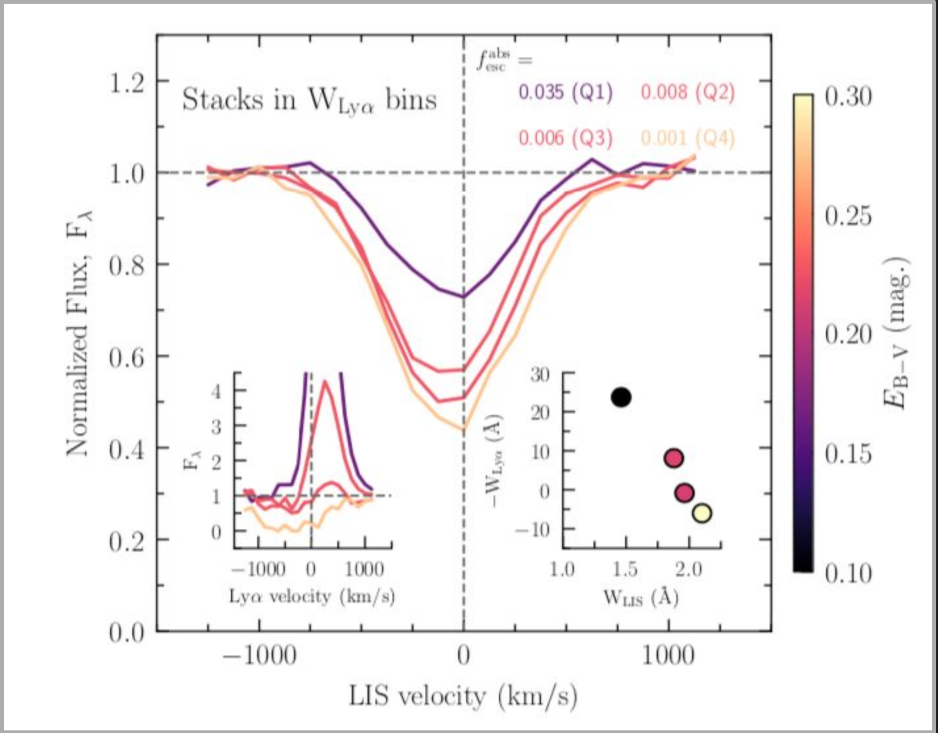
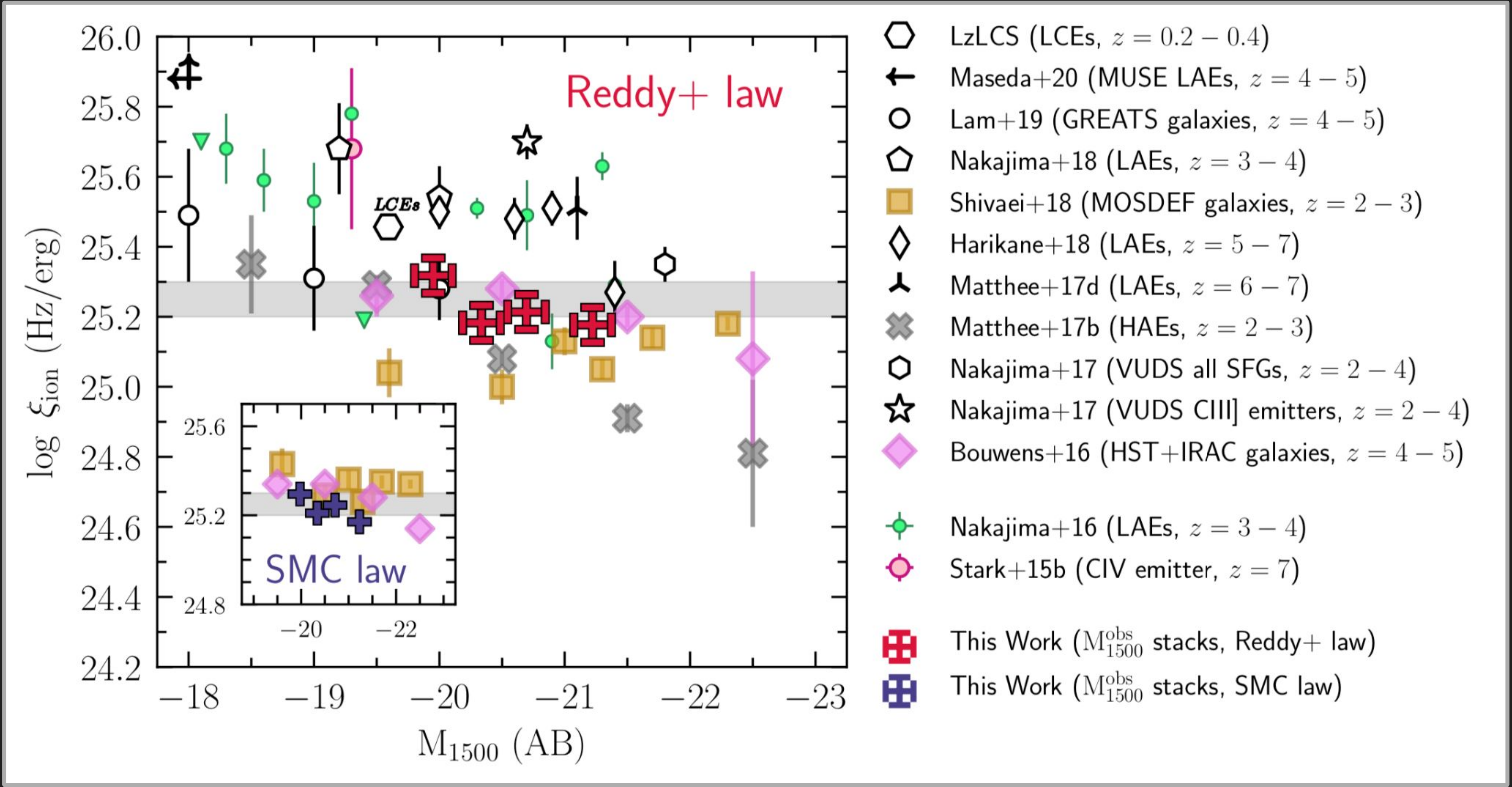


Absorption lines, LyA, dust-attenuation and **escape fraction** connection





The ionizing photon production efficiency



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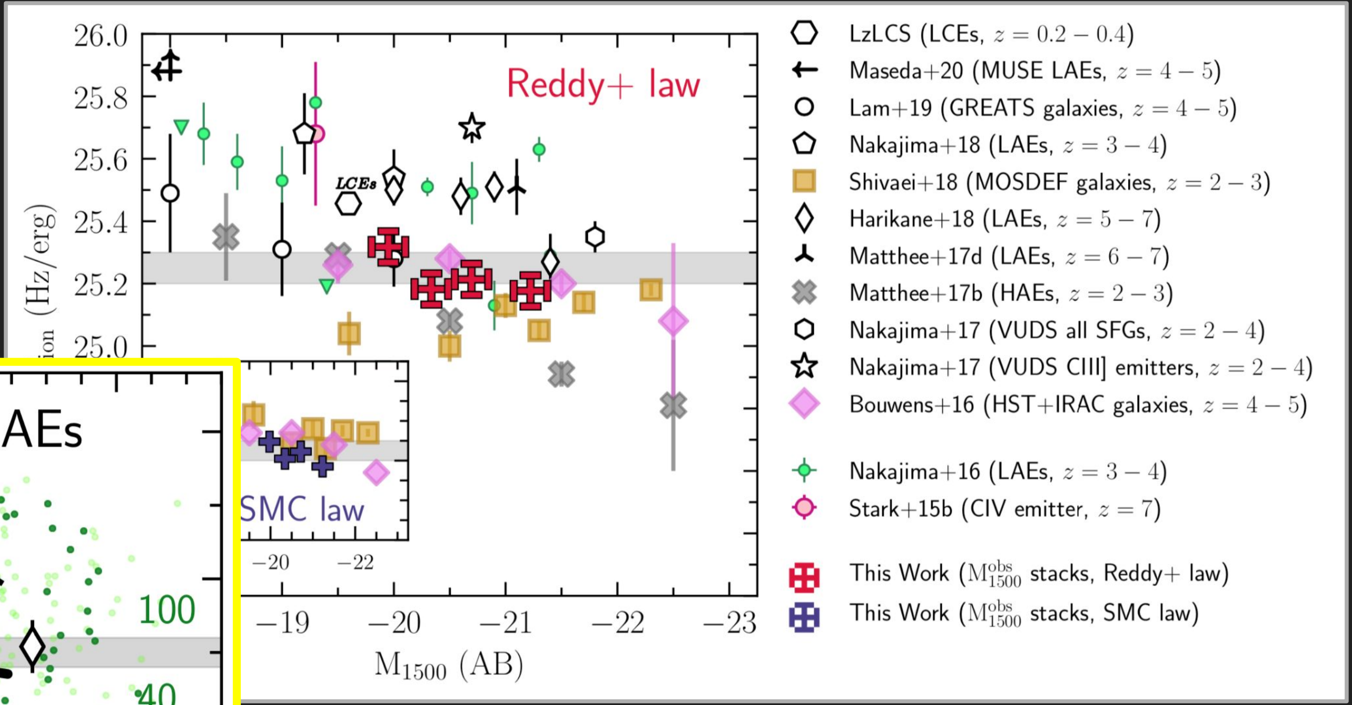
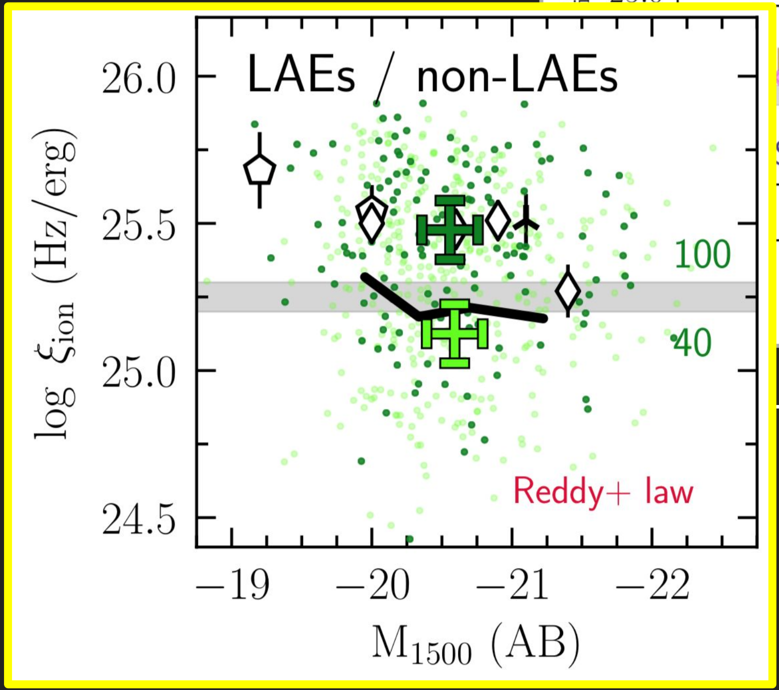
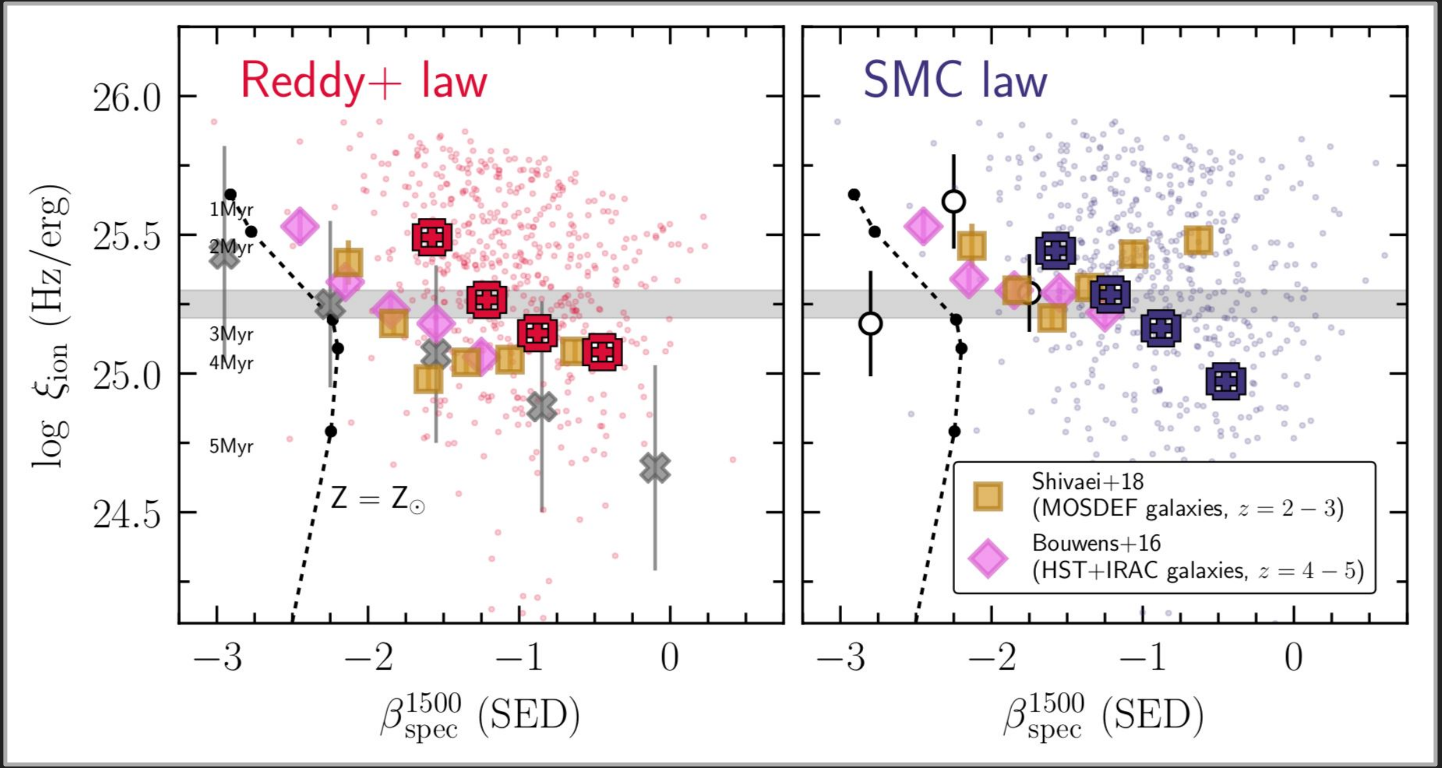




- LyA emitters have systematically higher production efficiencies

The ionizing photon production efficiency



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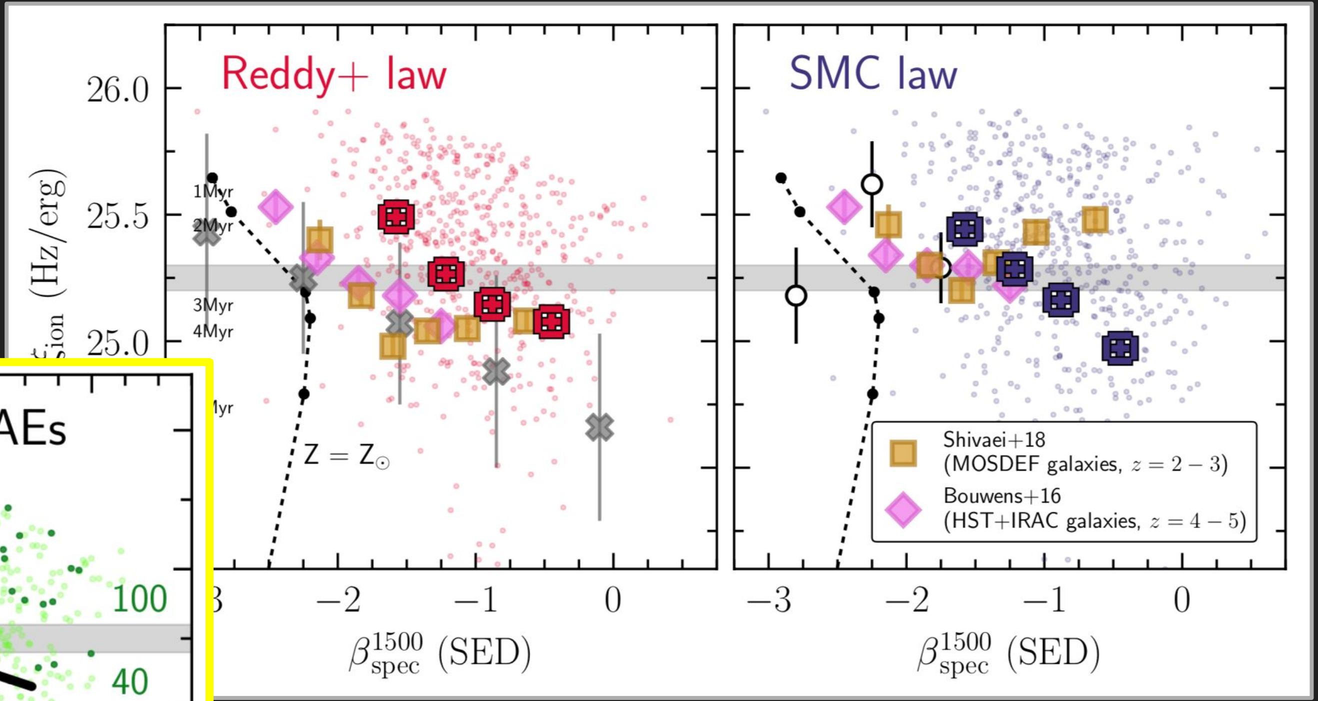
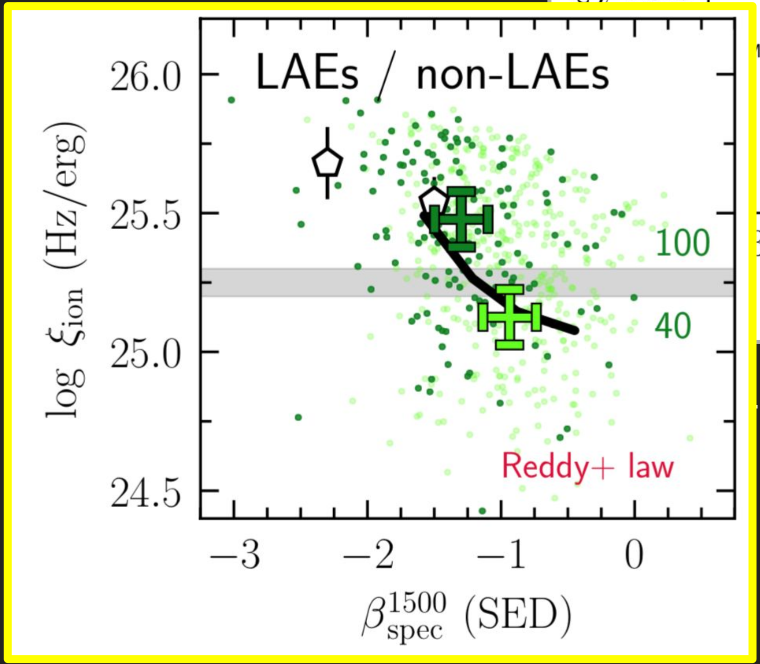
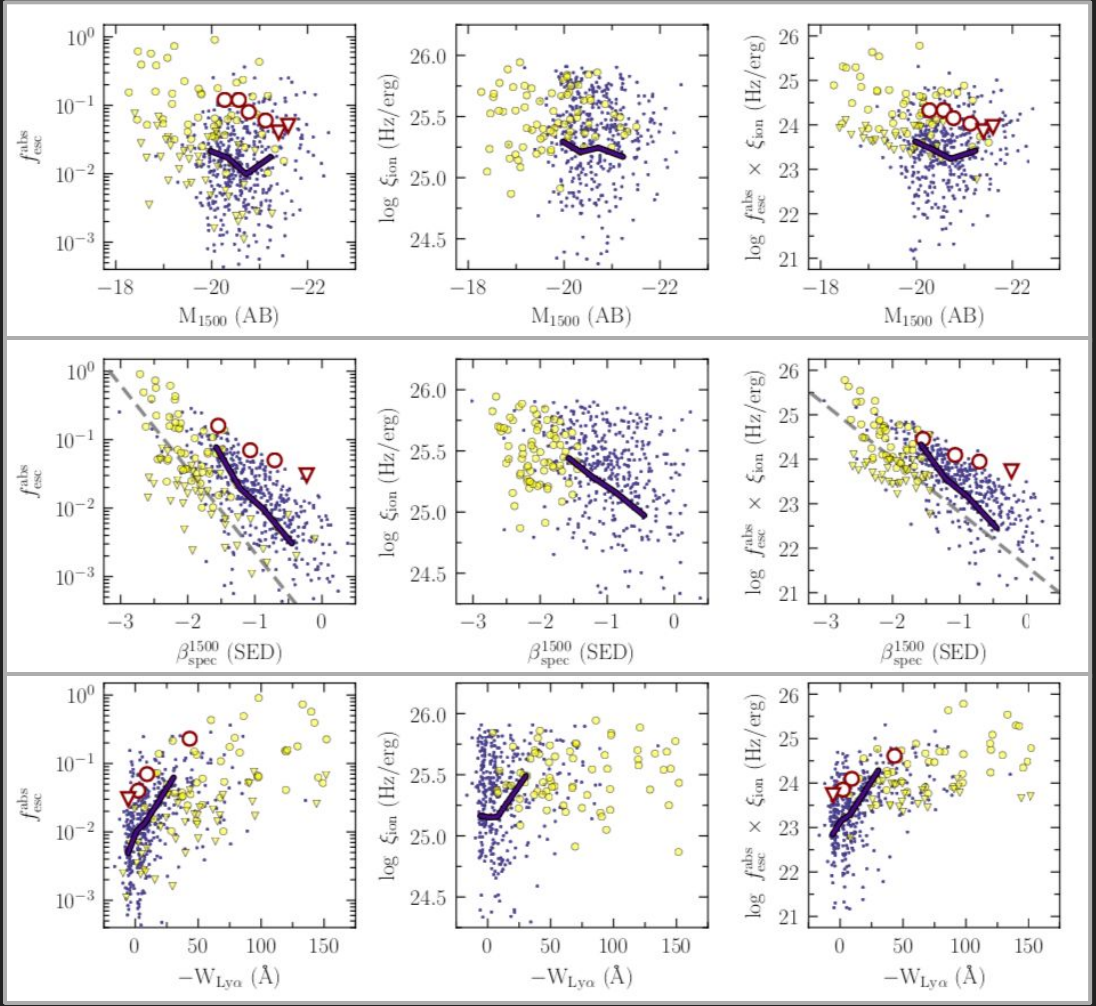




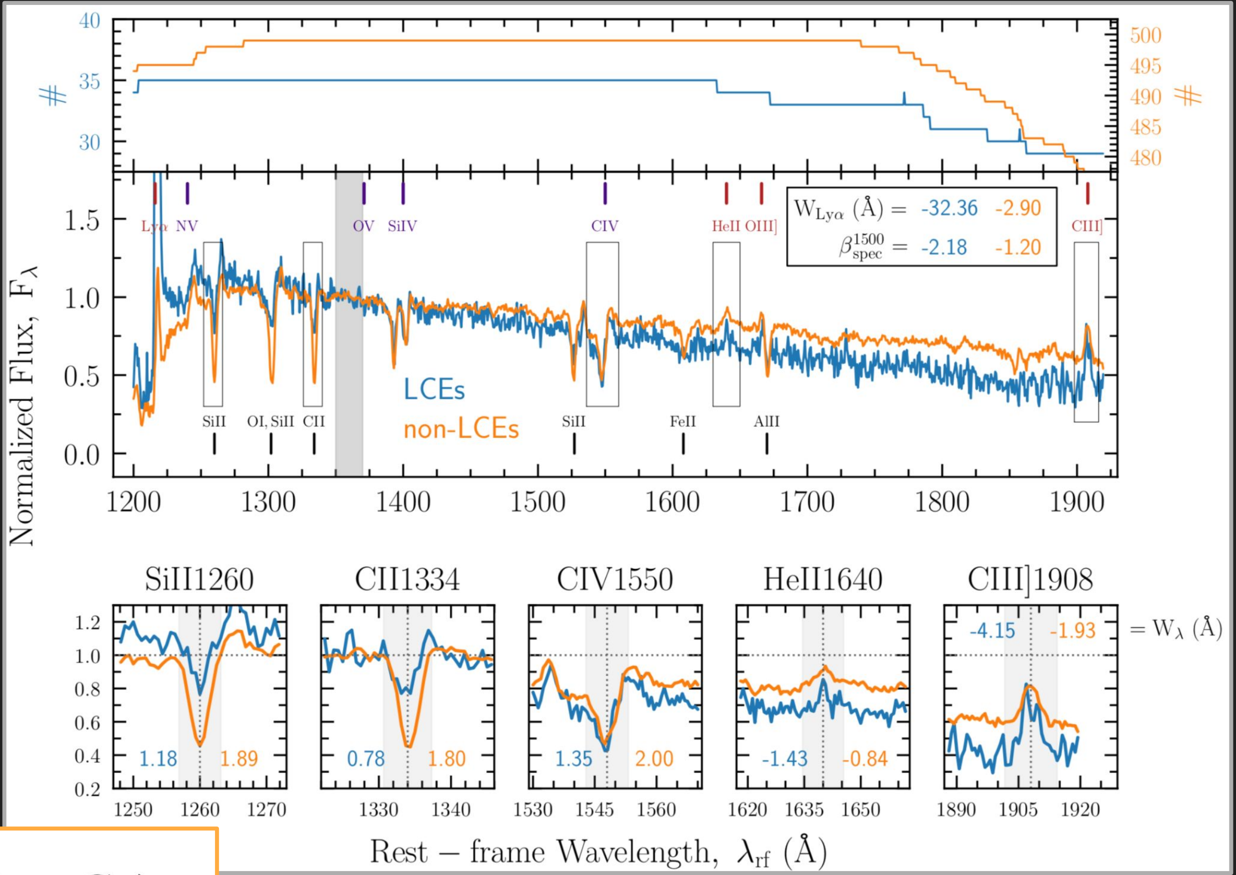
LyA emitters have systematically higher production efficiencies



> Comparison with **low-z (LzLCS)** and **high-z (KLCS)** studies

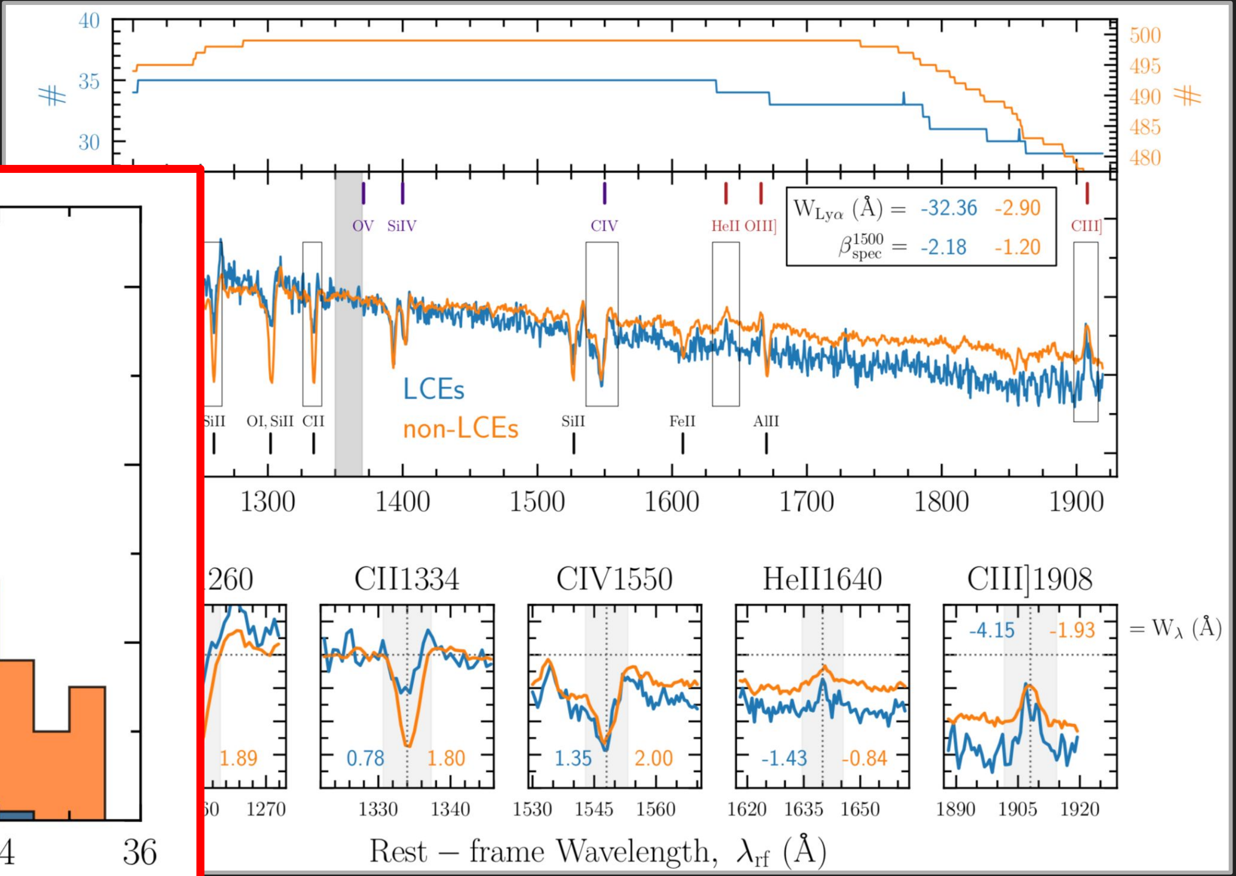
LCE (candidates) in VANDELS

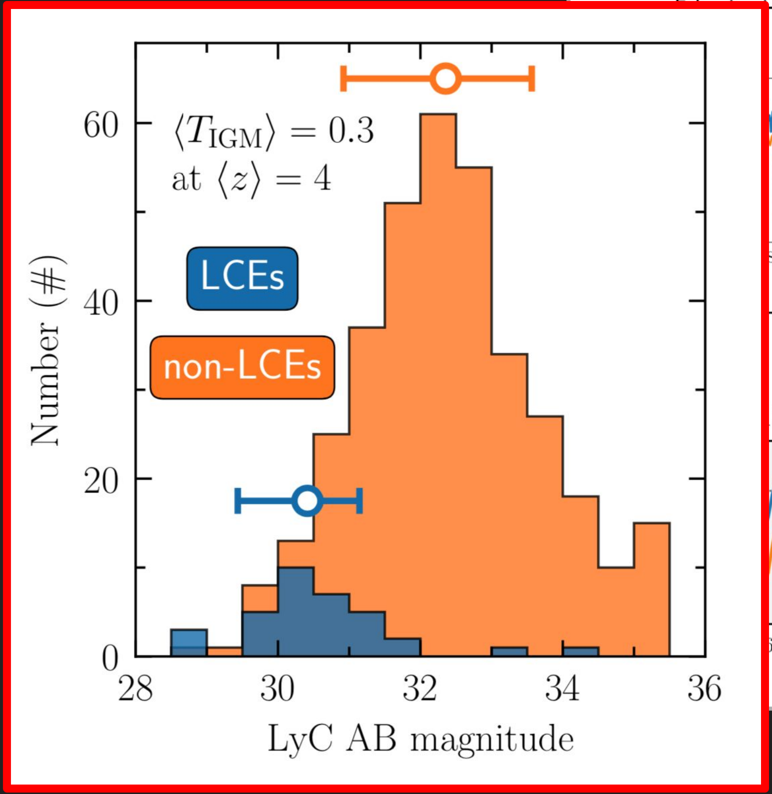
- **Stronger LyA**
- Bluer slopes
- Weaker LIS lines
- **Stronger nebular lines**



$$f_{esc}^{abs,pred} = 10^{-0.4 k_{912} E_{B-V}} \times (1 - C_f),$$

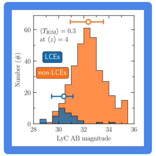
LCE (candidates) in VANDELS





VANDELS

A deep VIMOS survey of the CANDELS UDS and CDFS fields



Summary and conclusions

- The **escape fraction** of high-z galaxies may strongly **evolve with galaxy Mass, SFR and UV slope.**
- LyA emitters and potential LCEs have higher ionizing efficiencies than the average population.
- **Potential LCEs at high-z** share properties with confirmed low-z emitters: **strong LyA and nebular lines,** blue slopes and weaker absorption lines.
- This work provide an alternative method to predict the escape fraction and ionizing efficiency at high-z and at the EoR.