The ionizing properties of galaxies through the eyes of absorption line spectroscopy

UNIVERSITÉ DE GENÈVE

Alberto Saldana-Lopez (UniGE), Daniel Schaerer et al.

The VANDELS survey: the ionizing properties of star-forming galaxies at $3 \leq z \leq 5$ using deep rest-frame ultraviolet spectroscopy

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Just accepted!

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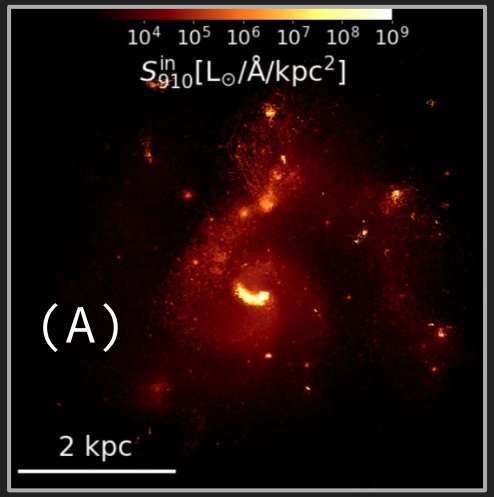
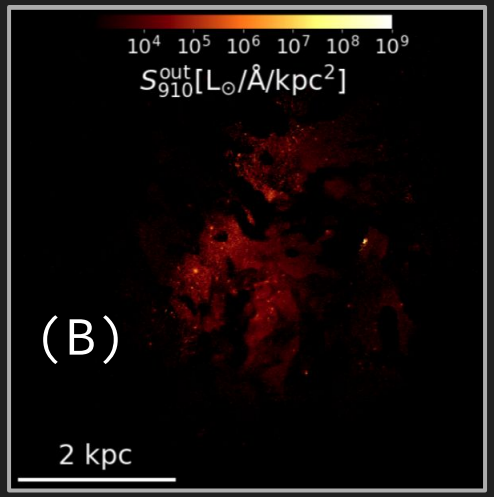




How to reionize the Universe?

ionization rate of the Universe

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

the fraction of escaping ionizing photons

ionizing photons produced per UV luminosity

the UV luminosity per Universe volume

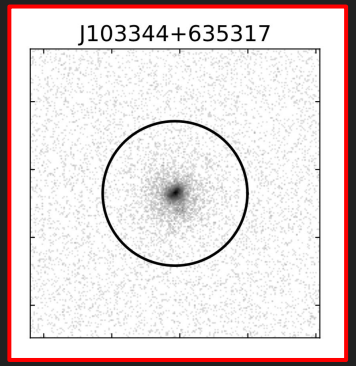
fesc = escaping (B) / produced photons (A)

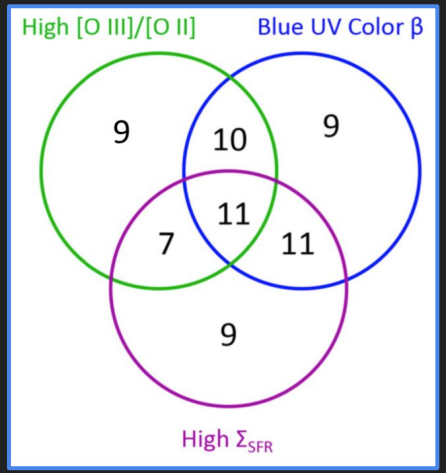
Mauerhofer 2021

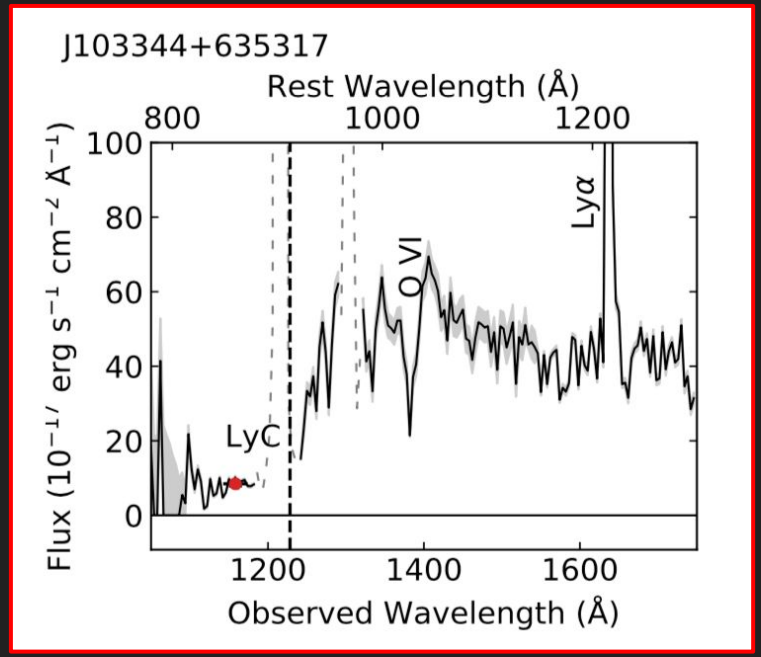
The Low-Redshift Lyman Continuum Survey (LzLCS)

- **HST large program** (PI Jaskot) > at z~0.3
  HST/**COS/G140L** covers the **far-UV + LyC**

89 LyC observations at low-z
50 confirmed LyC emitters







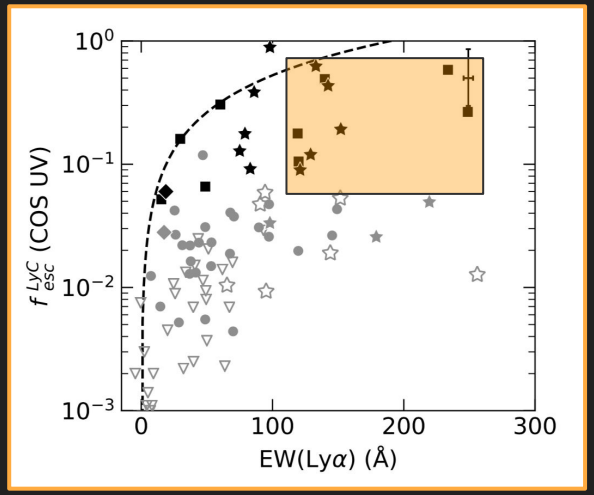
Flury 2021a, arXiv: 2201.11716
Flury 2021b, arXiv: 2203.15649

The Low-Redshift Lyman Continuum Survey (LzLCS)

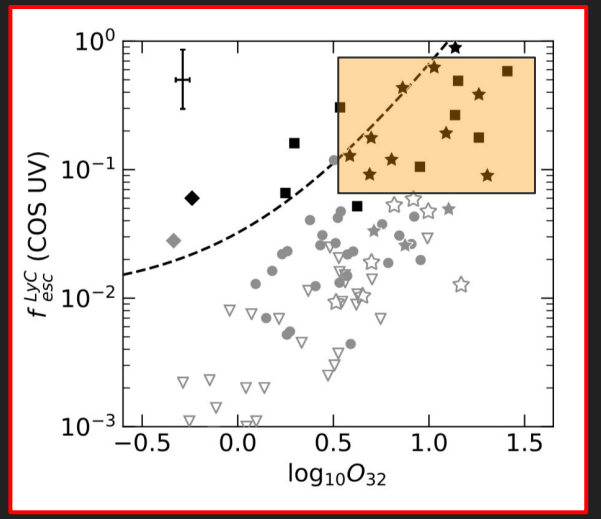
GOAL

To get the first **statistical sample** of galaxies with LyC measurements, covering a **wide range of properties** to test **LyC diagnostics**

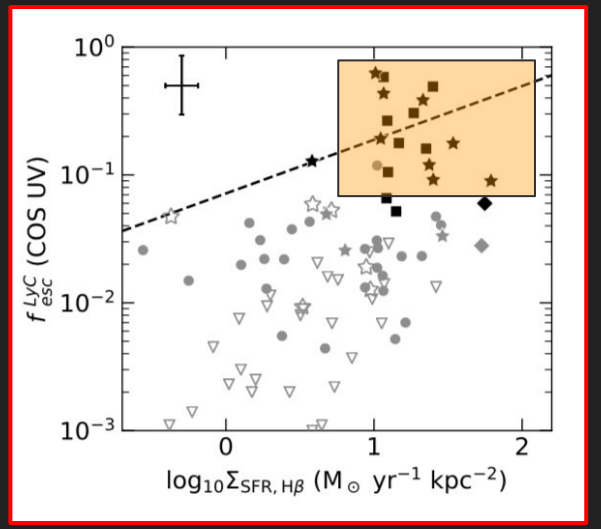
Strong Ly-alpha



High ionization



Compact star-formation



Flury 2021a, arXiv: 2201.11716
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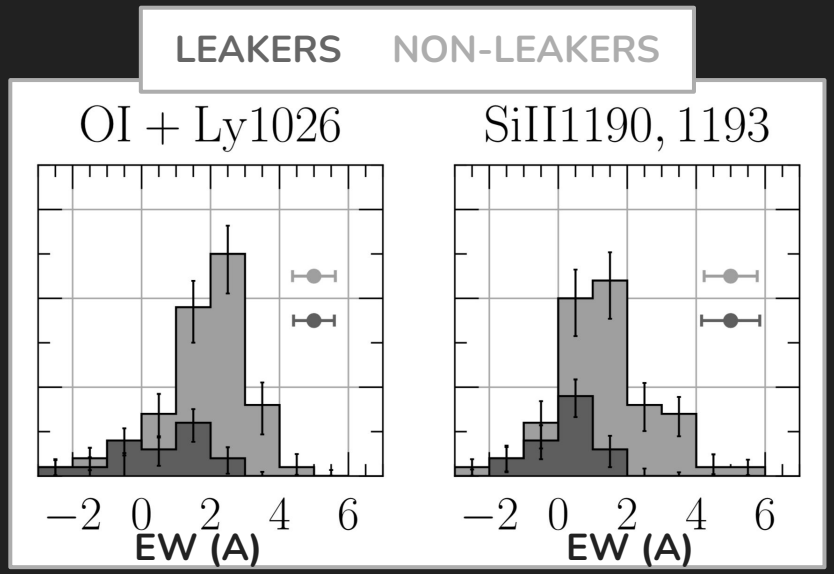
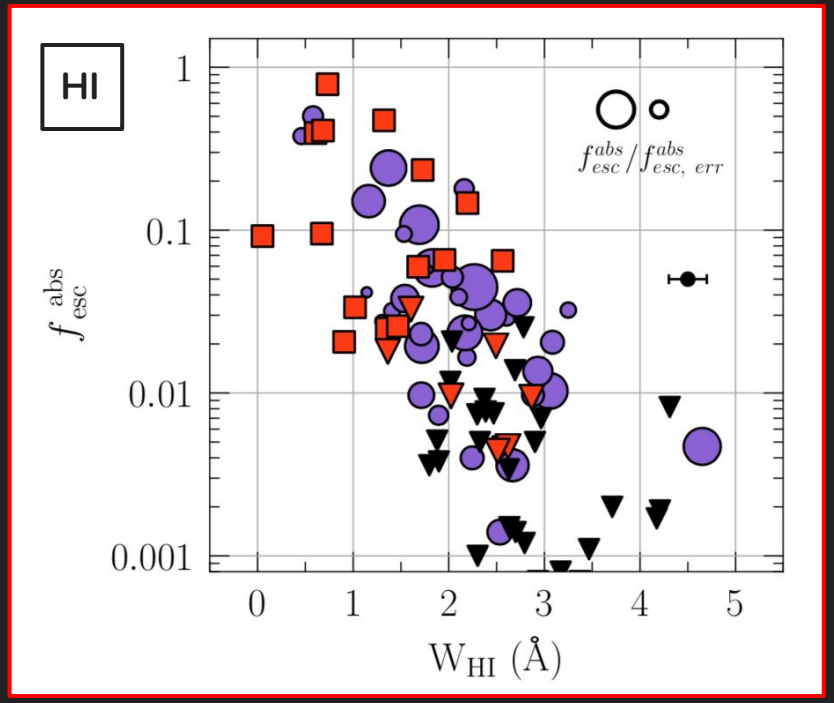
Weak absorption lines in LyC emitters

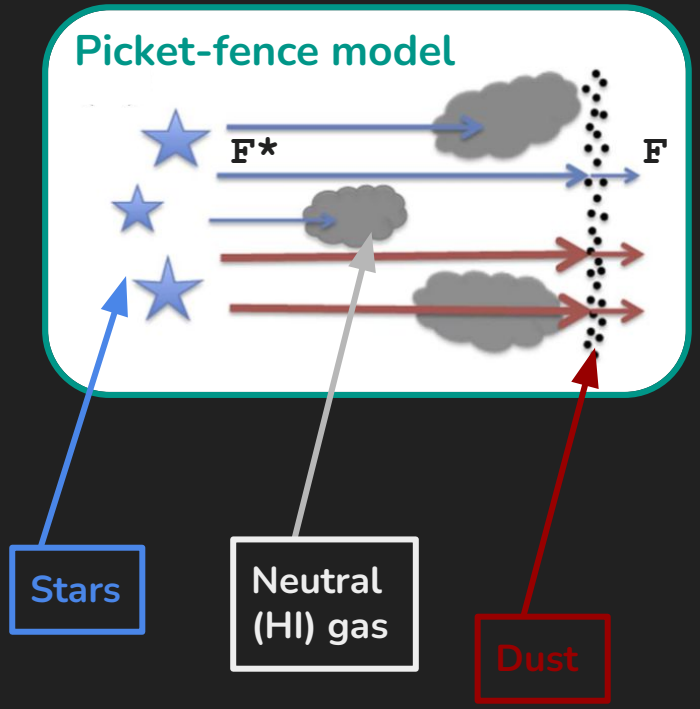
Saldana-Lopez+ 2022 (arXiv: 2201.11800)





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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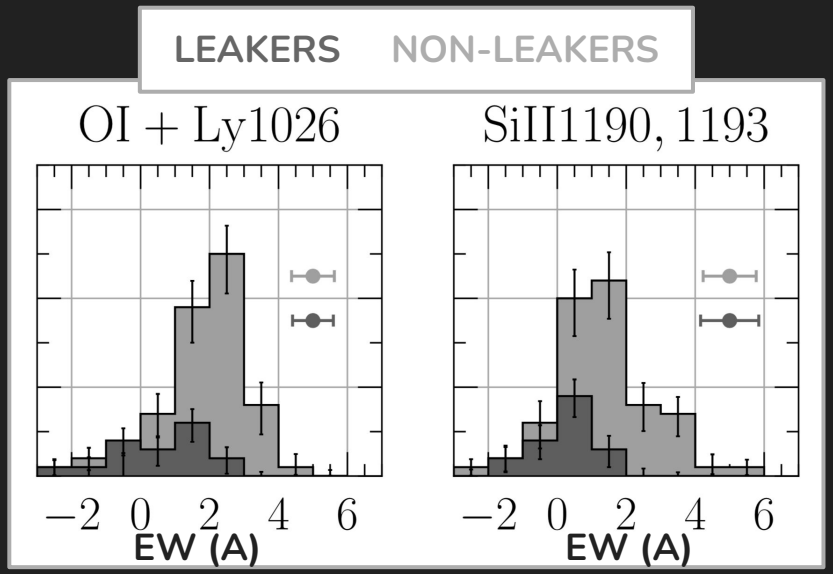
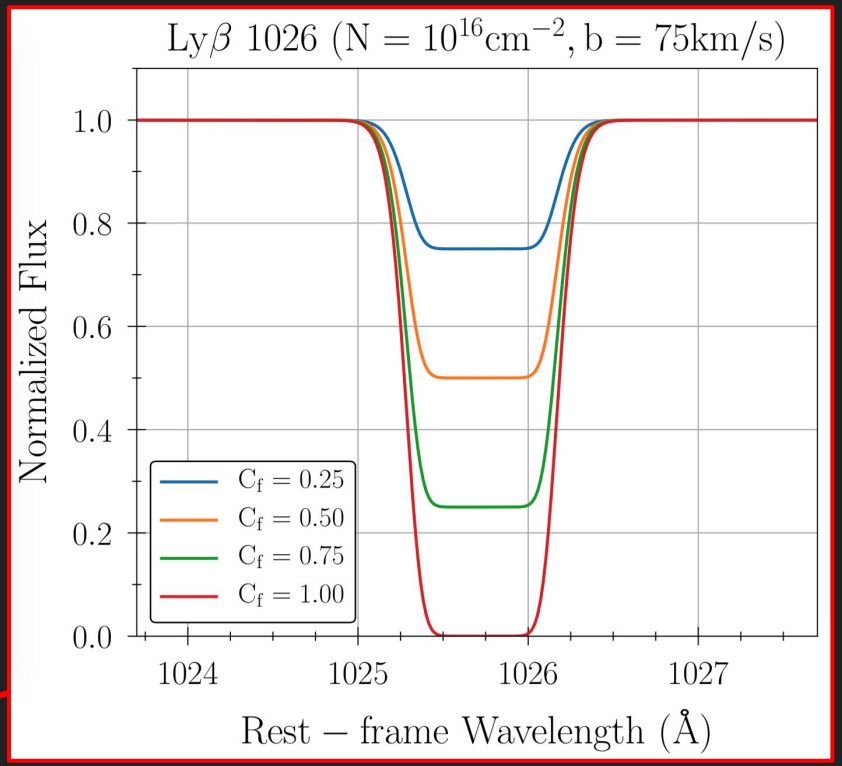
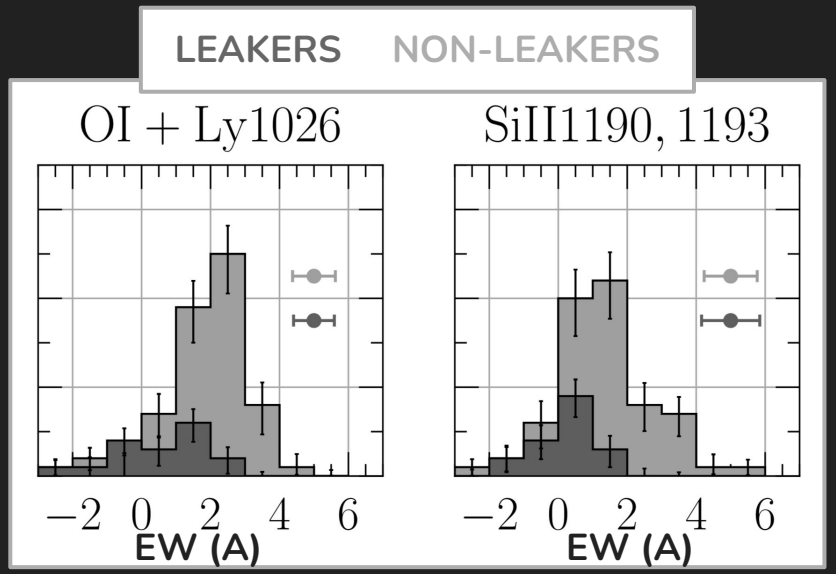


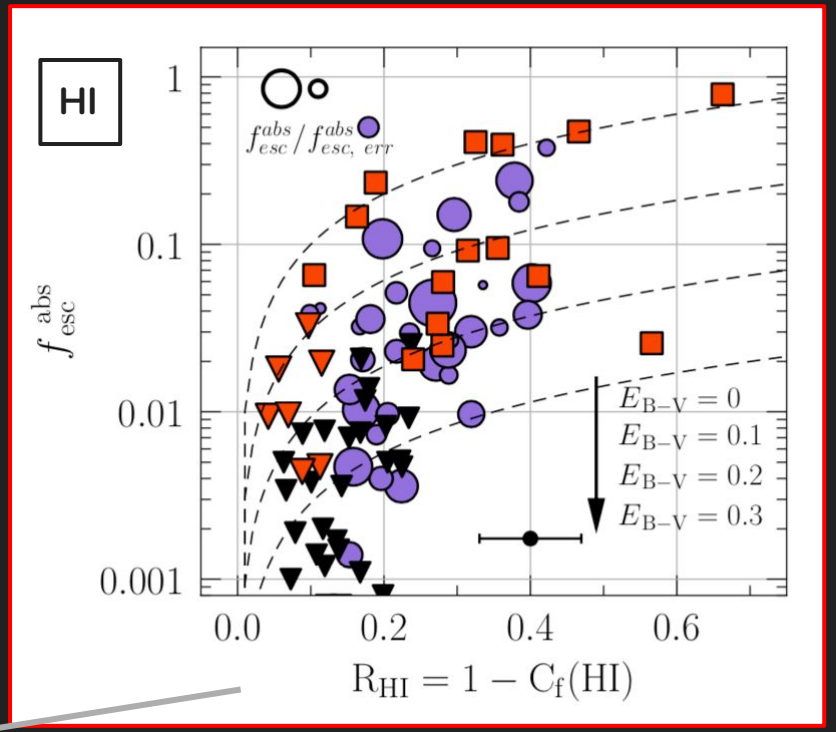


Weak absorption means small residual fluxes

Weak absorption lines in LyC emitters

Saldana-Lopez+ 2022 (arXiv: 2201.11800)





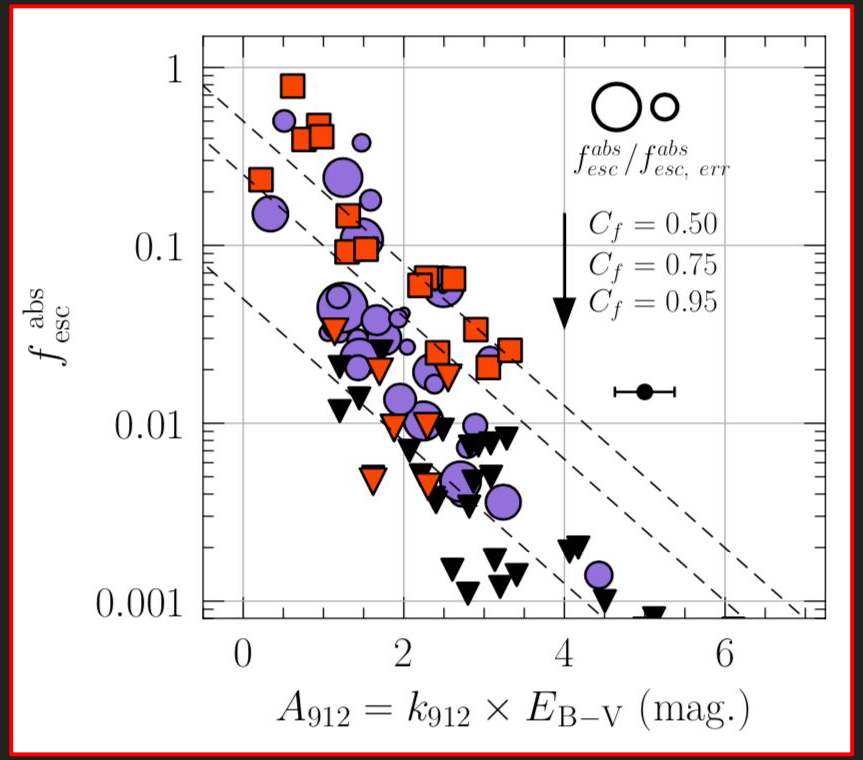
Covering fraction and residual flux are intertwined

Low dust attenuation in LyC emitters
Saldana-Lopez+ 2022 (arXiv: 2201.11800)

Both the Residual Flux of the lines and the DUST attenuation have to be taken into account to infer fesc:

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

Dust attenuation — Residual flux



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Choustikov et al. 2023

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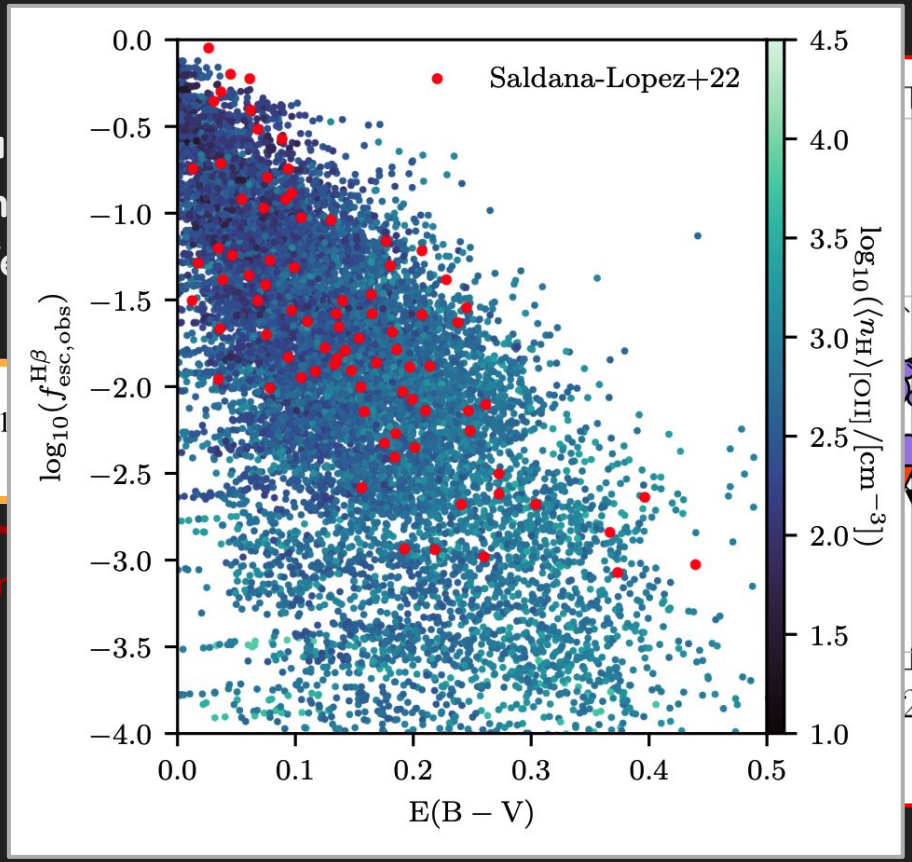
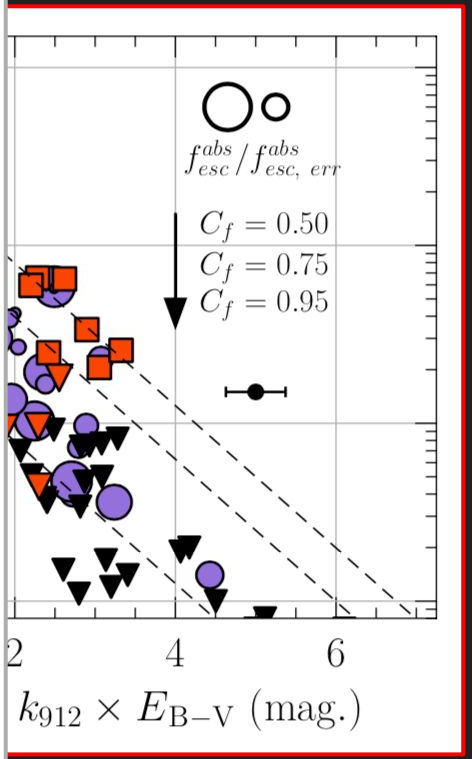
the DUST attenuation
into account to infer fe

$$f_{\rm esc}^{\rm abs,pred} = 10^{-0.4 k_{91}}$$

Dust atter

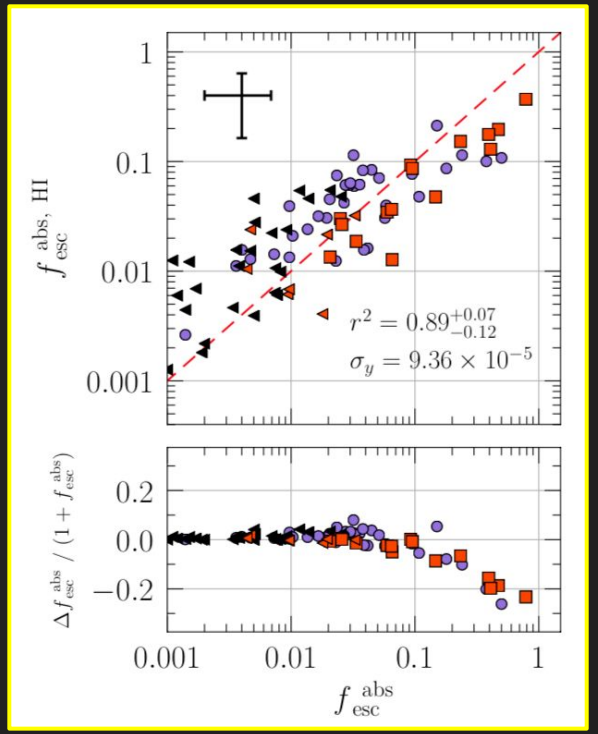




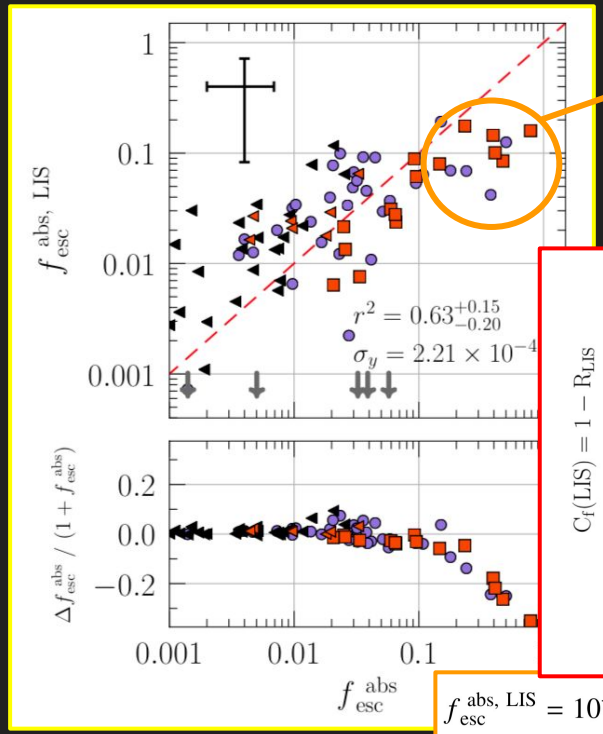
Predicting fesc with UV line diagnostics

Saldana-Lopez+ 2022 (arXiv: 2201.11800)

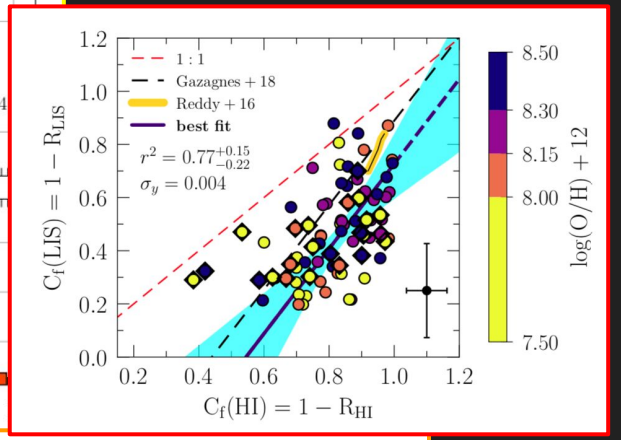
Using **HI** lines



Using **LIS** lines



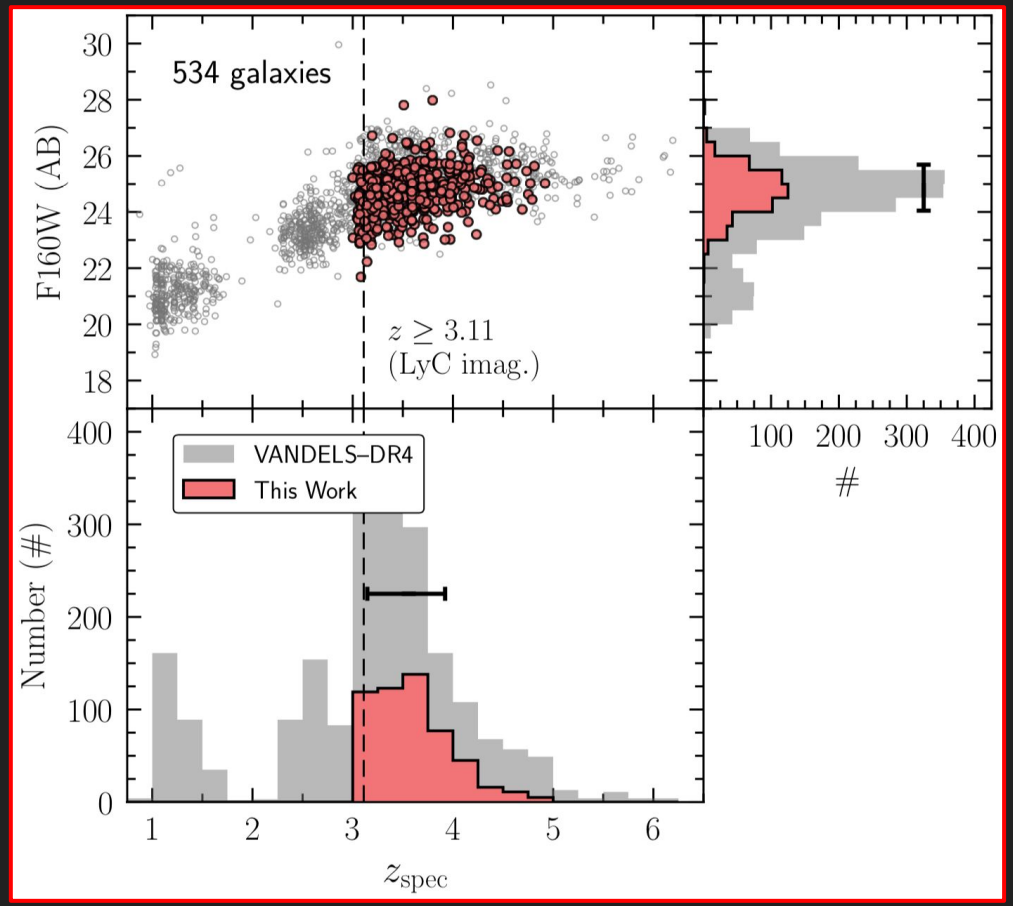
Highly ionized ISM, "picket fence" may not apply!



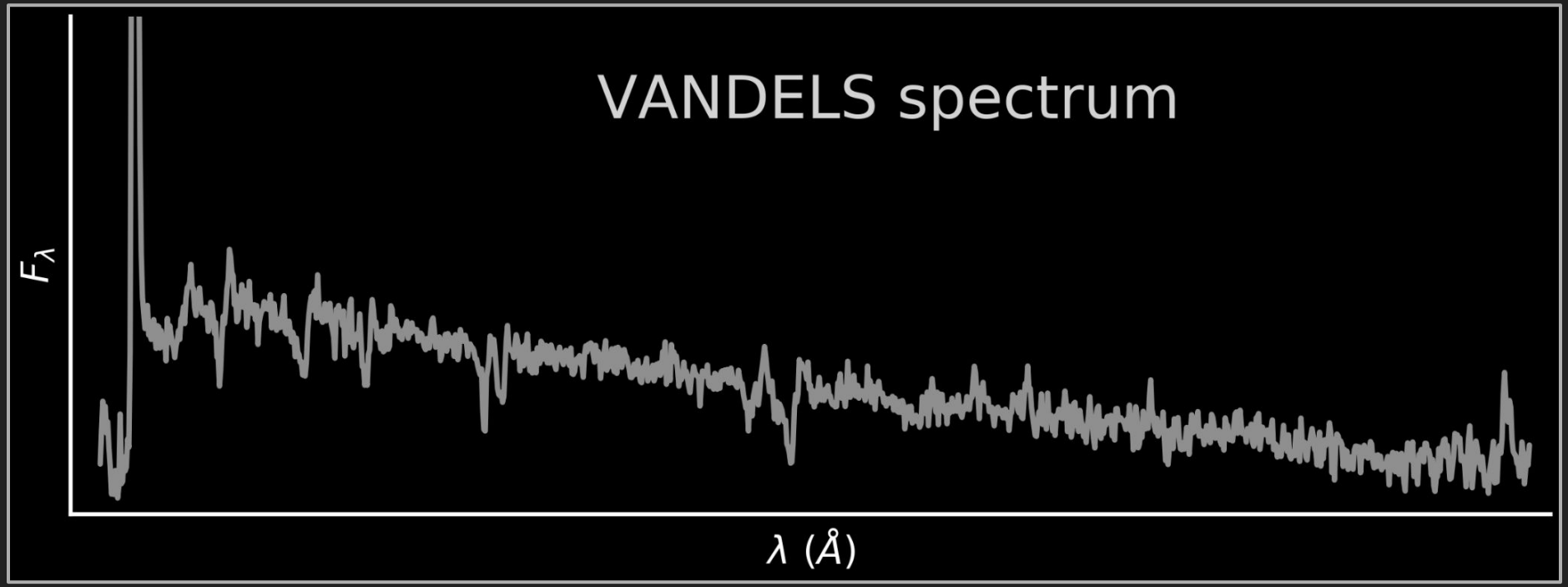
$$f_{\rm esc}^{\rm abs,\ LIS} = 10^{-0.4 k_{912} E_{\rm B-V}} \times (a \times {\rm R(LIS)} + b),$$

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



SED fitting with **FiCUS** (**FItting the stellar Continuum of Uv Spectra**):
Saldana-Lopez+ 2022 (arXiv: 2211.01351),
see also Chisholm et al. 2019



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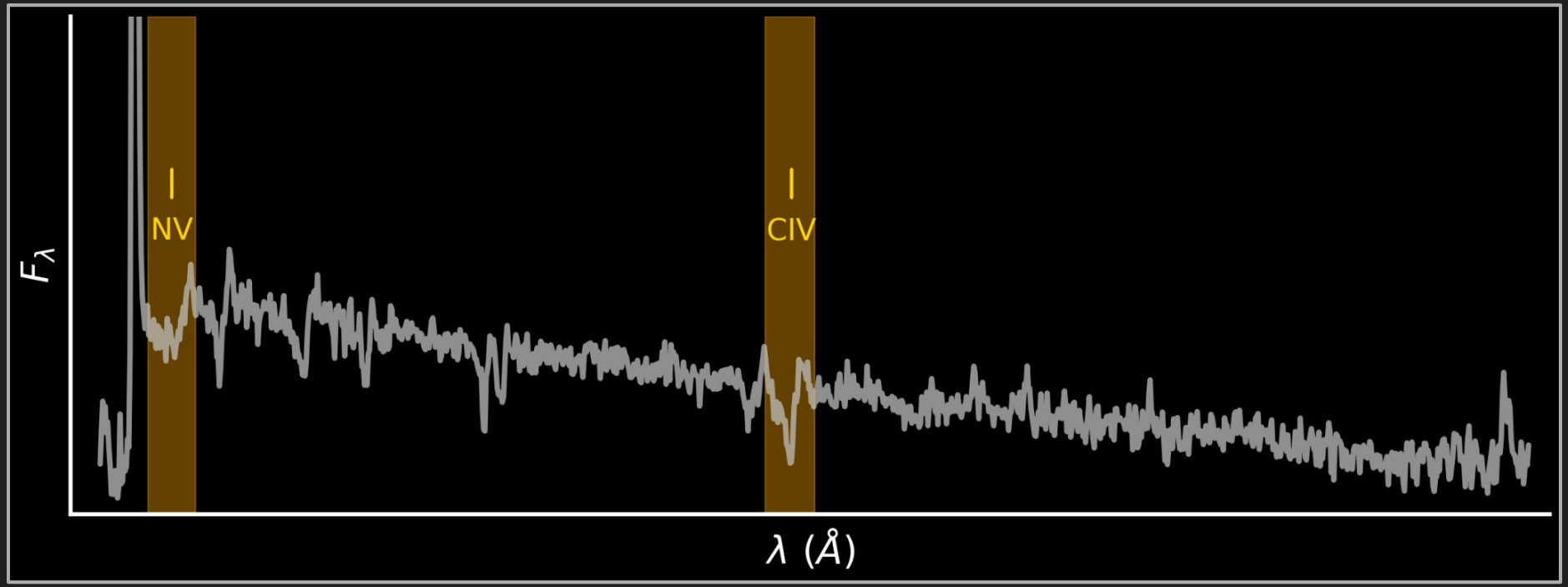

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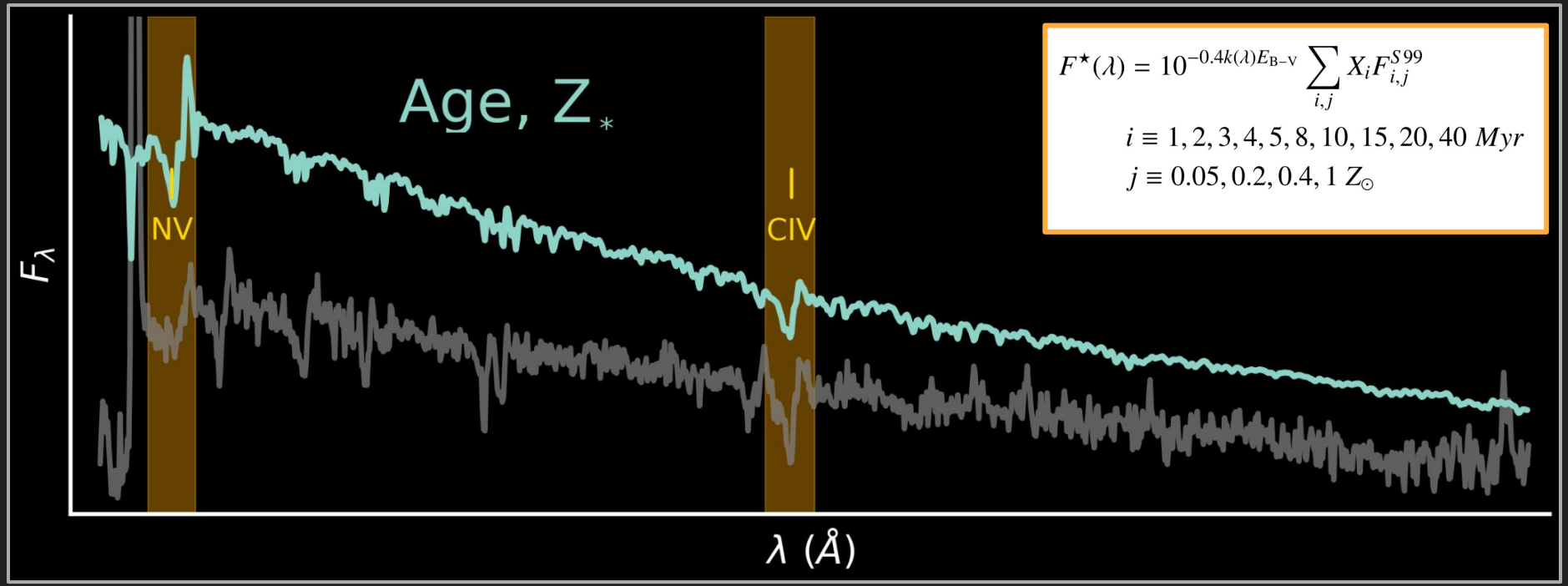

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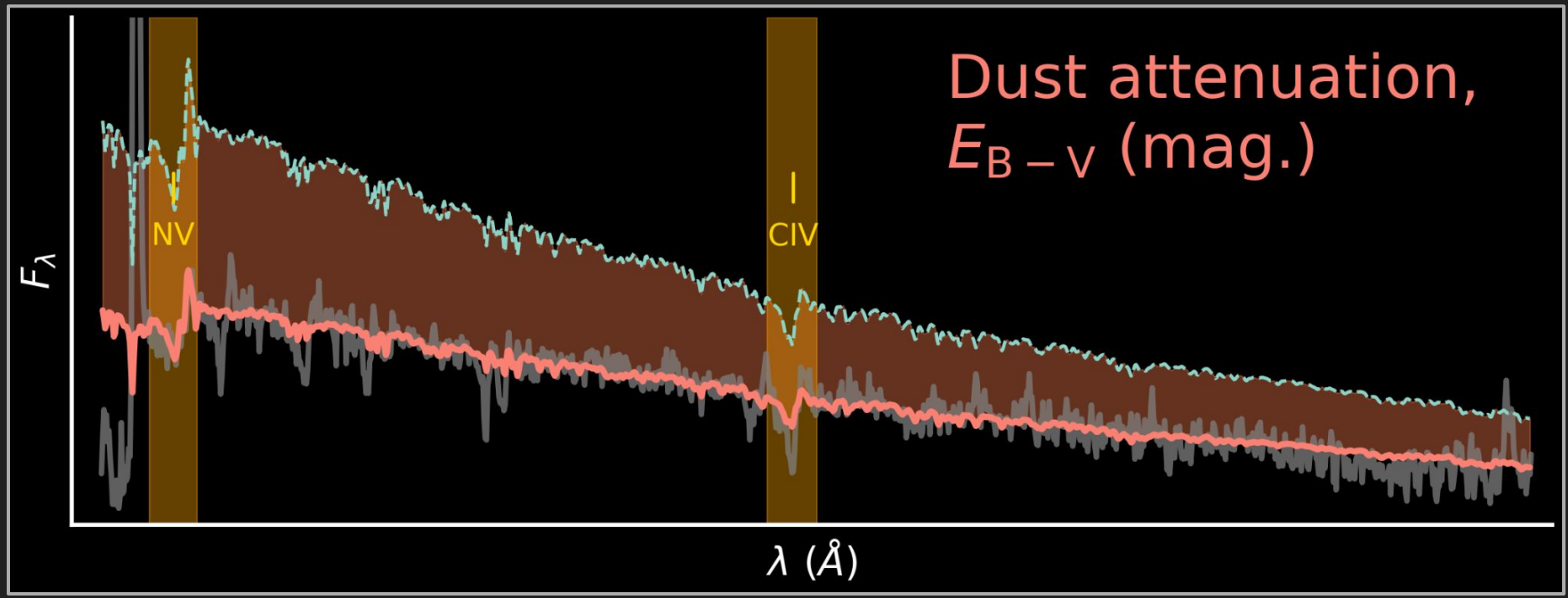
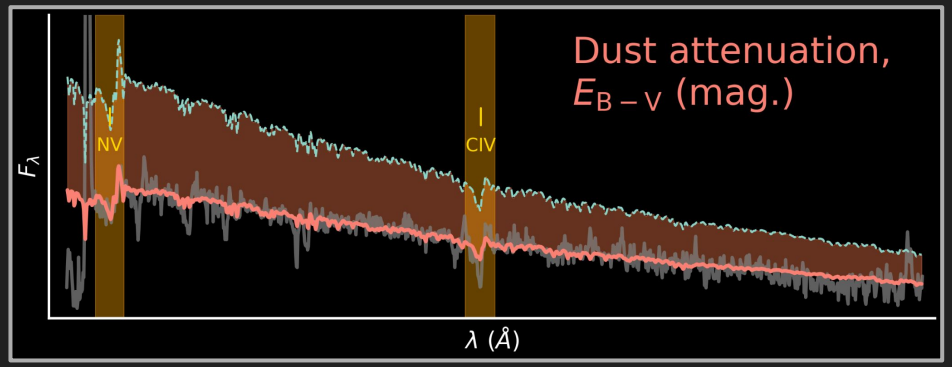


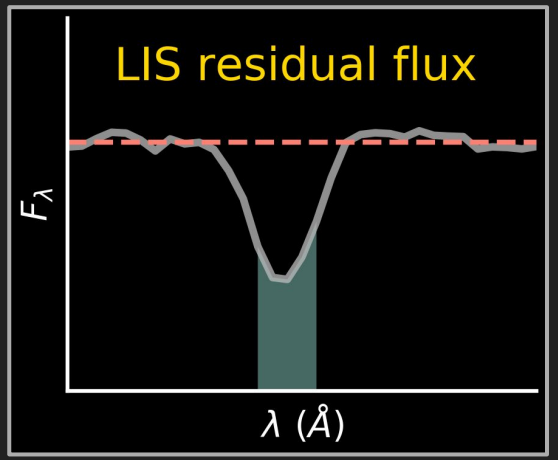
Computing **ionizing escape fractions:** Saldana-Lopez+ 2022 (arXiv: 2211.01351)

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

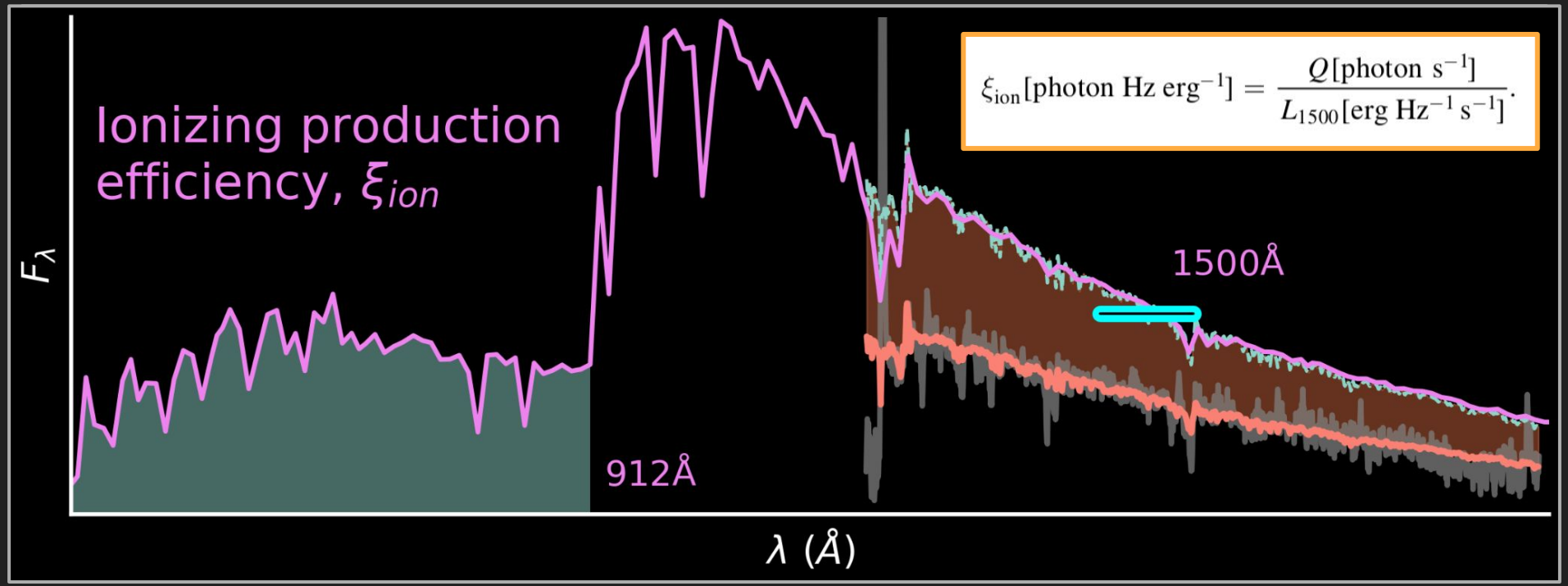
Dust attenuation — Residual flux



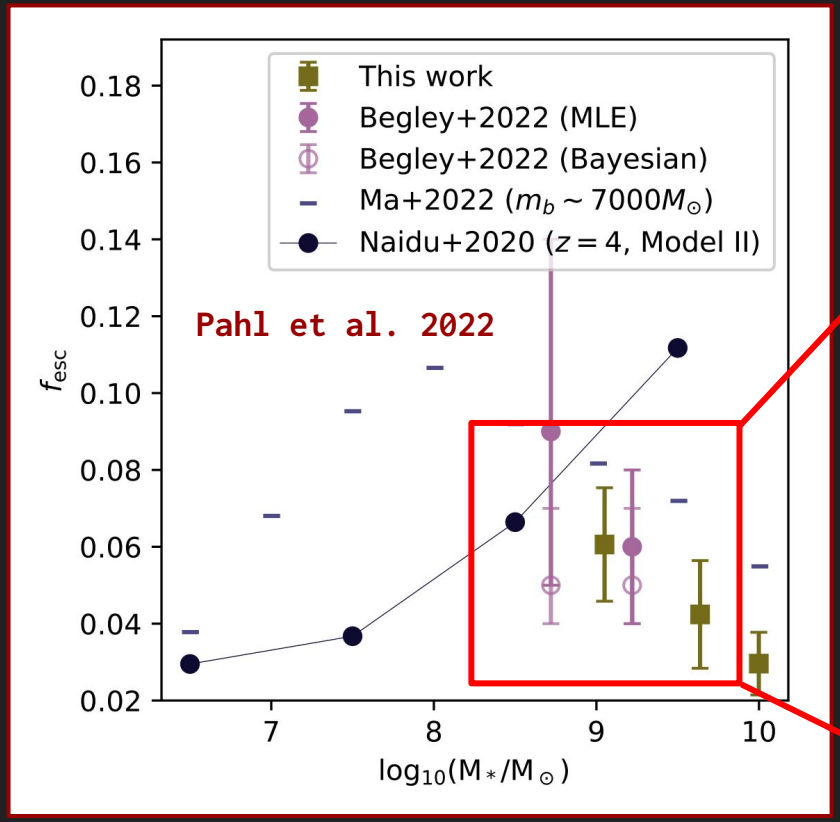
X



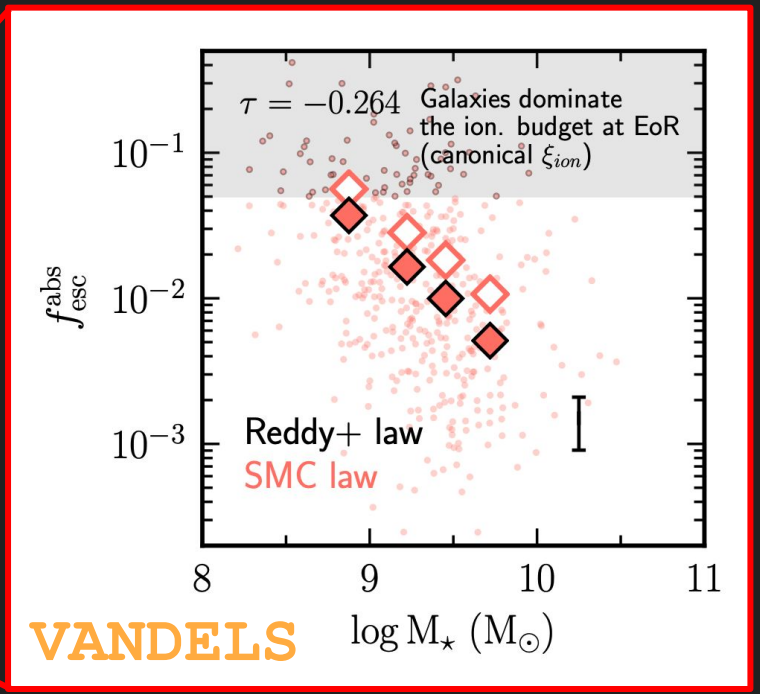
Computing **ionizing photon production efficiencies:** Saldana-Lopez+ 2022 (arXiv: 2211.01351)



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



"Lower-M* galaxies show higher fesc"



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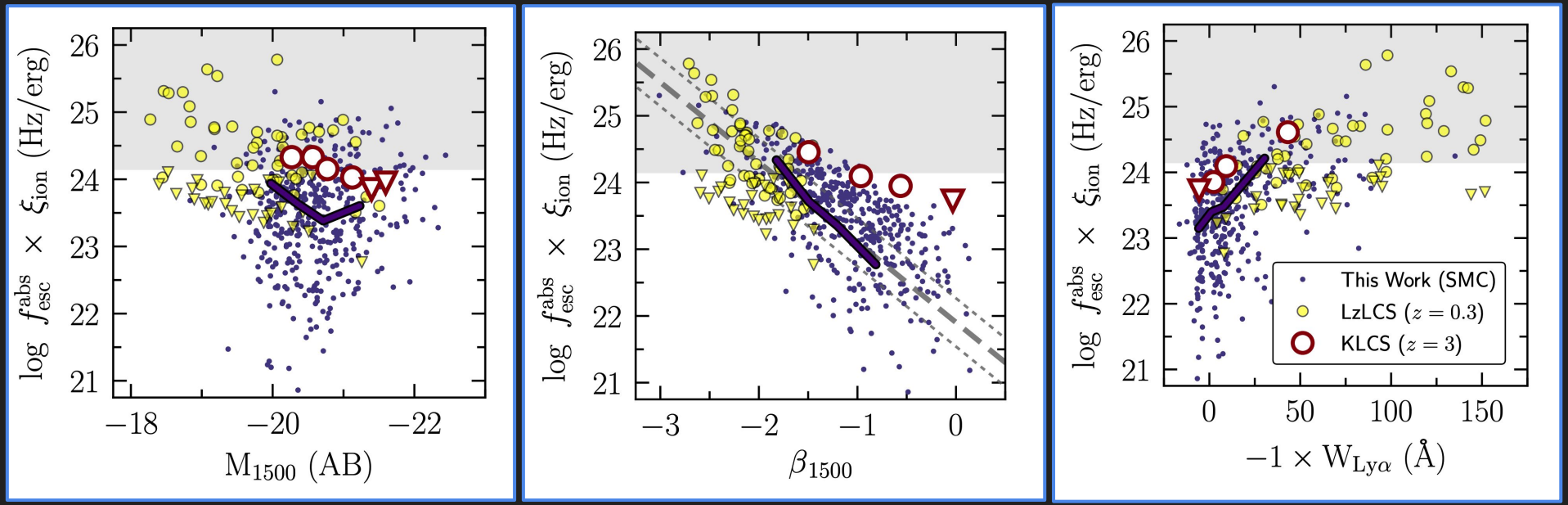
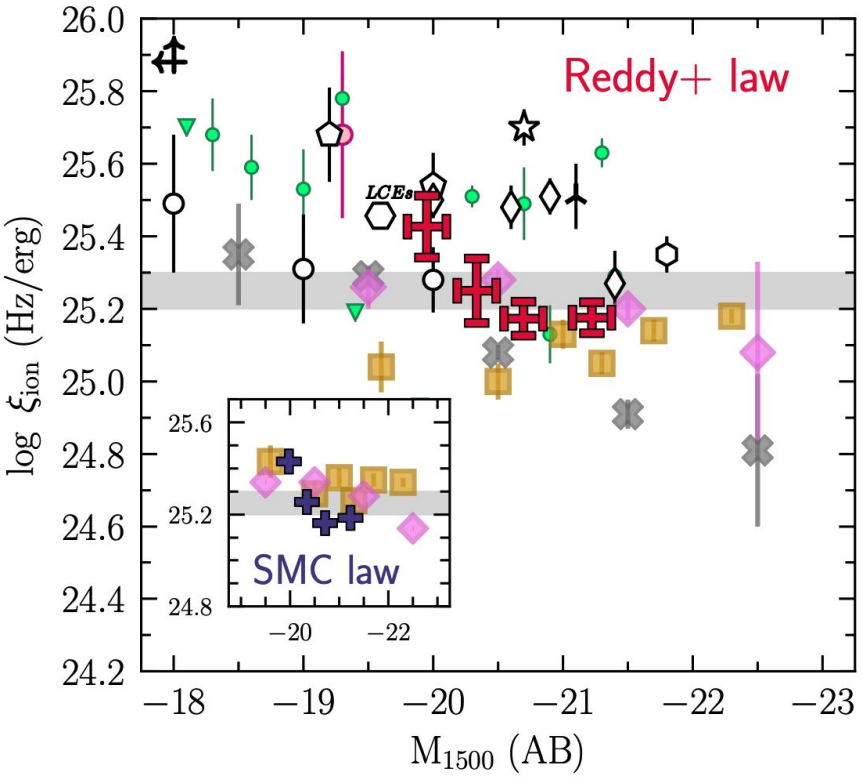
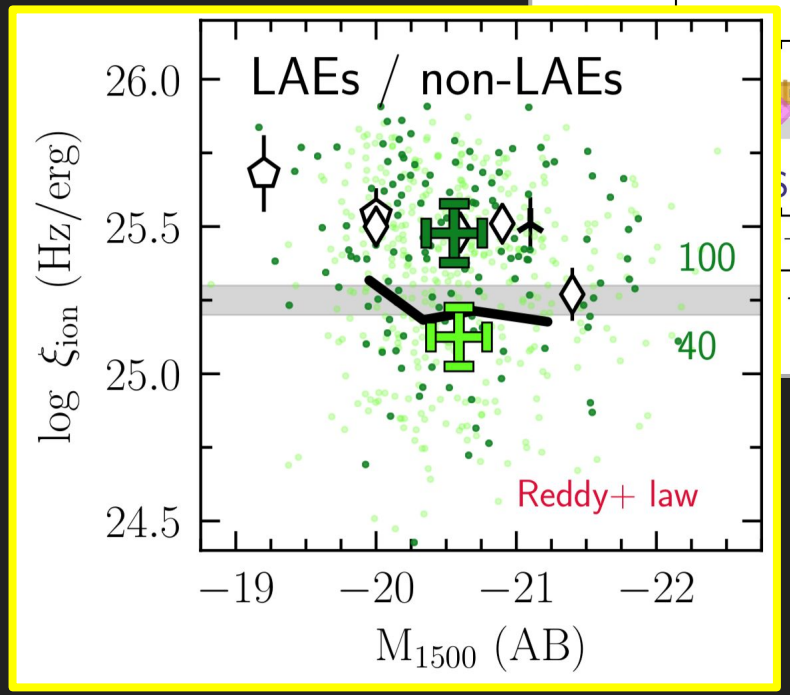


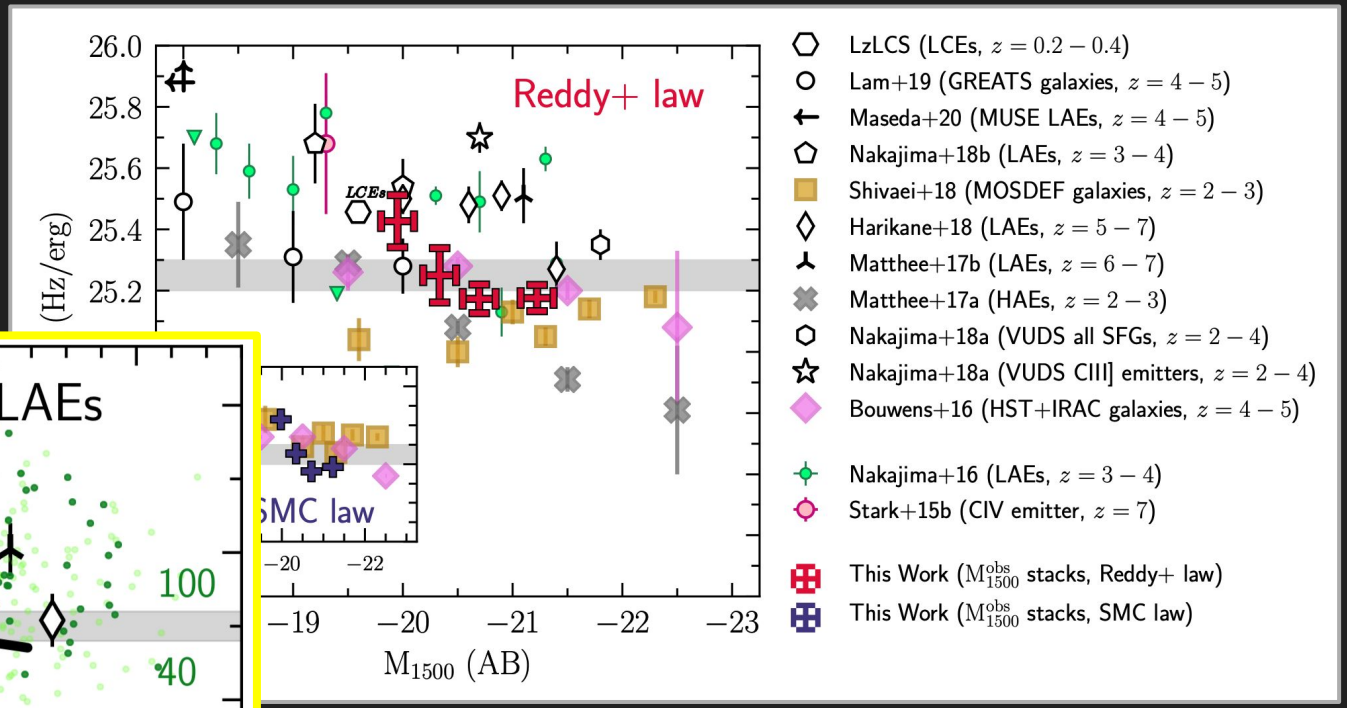
"The ionizing output of galaxies increase towards lower-UV luminosities, bluer UV-slopes and higher LyA EWs"

The ionizing photon production efficiency



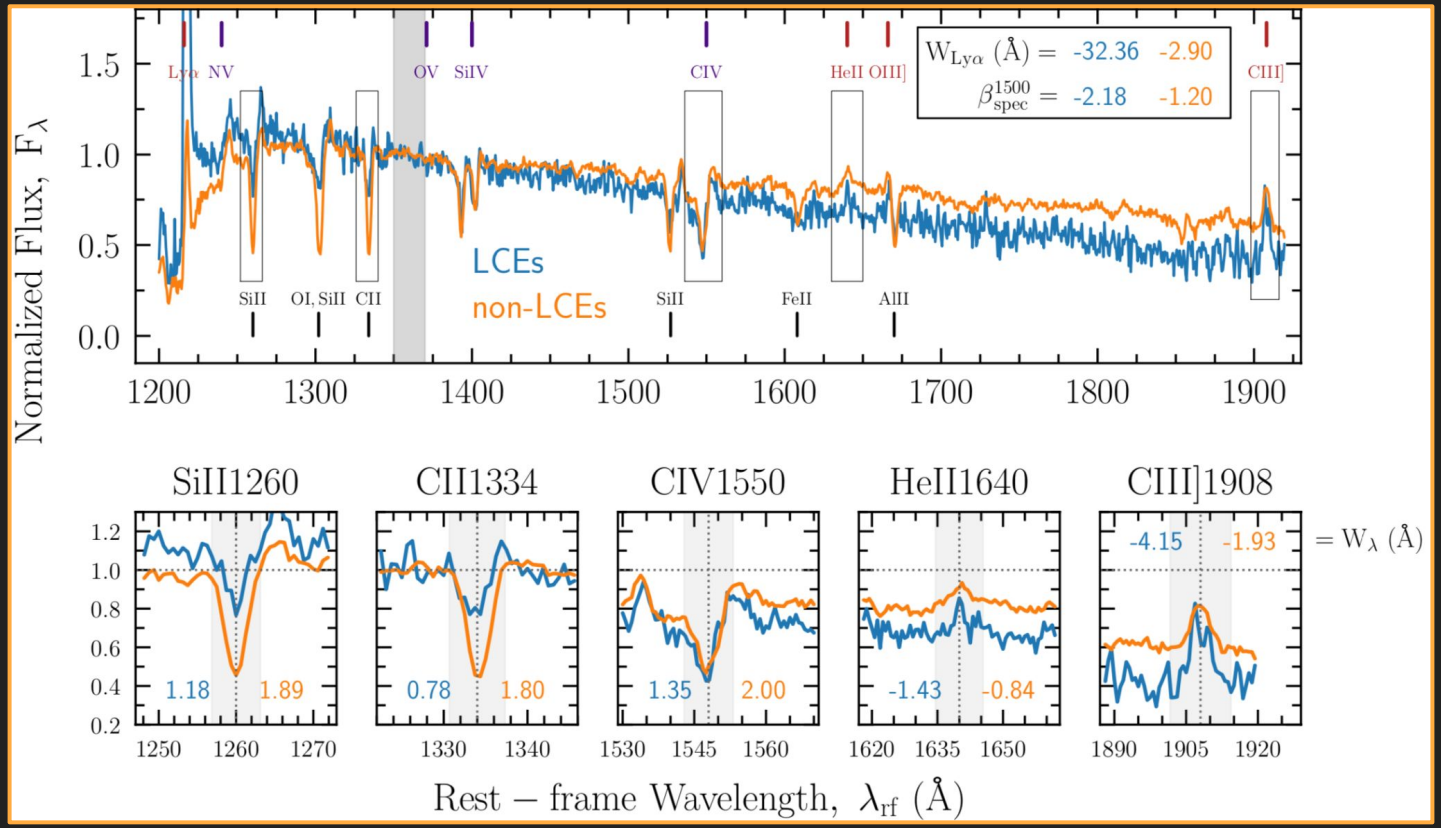
- LzLCS (LCEs, $z = 0.2 - 0.4$)
- Lam+19 (GREATS galaxies, $z = 4 - 5$)
- Maseda+20 (MUSE LAEs, $z = 4 - 5$)
- Nakajima+18b (LAEs, $z = 3 - 4$)
- Shivaei+18 (MOSDEF galaxies, $z = 2 - 3$)
- Harikane+18 (LAEs, $z = 5 - 7$)
- Matthee+17b (LAEs, $z = 6 - 7$)
- Matthee+17a (HAEs, $z = 2 - 3$)
- Nakajima+18a (VUDS all SFGs, $z = 2 - 4$)
- Nakajima+18a (VUDS CIII] emitters, $z = 2 - 4$)
- Bouwens+16 (HST+IRAC galaxies, $z = 4 - 5$)
- Nakajima+16 (LAEs, $z = 3 - 4$)
- Stark+15b (CIV emitter, $z = 7$)
- This Work ($M_{1500}^{\rm obs}$ stacks, Reddy+ law)
- This Work ($M_{1500}^{\rm obs}$ stacks, SMC law)





"LAEs and potential LCEs have higher ionizing efficiencies than the average SFG population."

Potential LCEs at high-z share properties with low-z emitters:



...strong LyA and nebular lines, blue slopes and weaker absorption lines.

"Deep, non-ionizing UV spectroscopy provides an alternative method to predict the escape fraction and ionizing efficiency of high-redshift galaxies..."

Carl Sagan
(I think, maybe, actually don't know...)