Production and escape of ionizing radiation in metal-poor star-forming galaxies

Adele Plat (University of Arizona) with Daniel Stark, Peter Senchyna,
Michael Topping, Mengtao Tang & Stephane Charlot

Escape of Lyman radiation from galactic labyrinths 2023, OAC, Crete

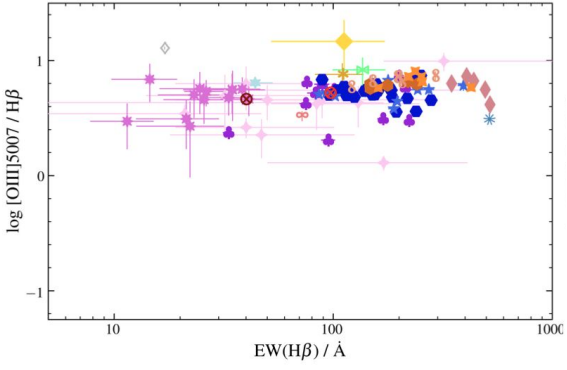
❀ How can we trace the sources of reionization through the spectral analysis of primeval galaxies?

Expected properties of primeval galaxies :
young
low mass
low metallicity
compact
blue UV slope

analogues

Investigation of optical/ultraviolet emission-line diagnostics :
Observations of metal-poor star-forming galaxies at various redshifts + LyC emitters

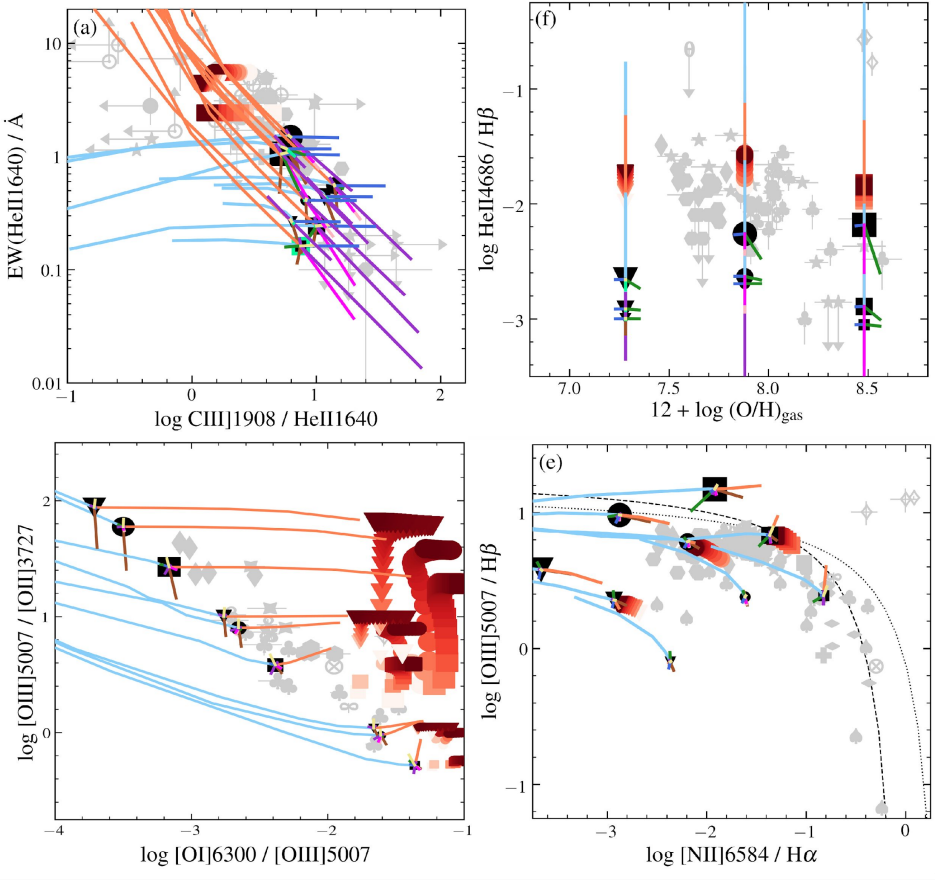
- Berg+16, 19
- Senchyna+17, 19
- Berg+18
- Stark+14
- Nanayakkara+19
- Vanzella+17
- Fosbury+03
- Erb+10
- Amorin+17
- Nakajima+18
- Schmidt+17
- Stark+15
- Laporte+17
- Giavalisco+96
- Lopez-Sanchez+10
- Steidel+16
- Schenker+13
- Leitherer+11
- Christensen+12
- Holden+16
- Leitet+11
- Izotov+17
- Chisholm+17 (Tol-0440-381)
- Izotov+16(a, b)
- Izotov+18(a, b)
- Nanayakkara+19
- Chisholm+17 (Tol-1247-232)
- Jaskot & Oey13
- Chisholm+17 (J0921+4509)
- Nakajima+16
- Vanzella+16
- De Barros+16

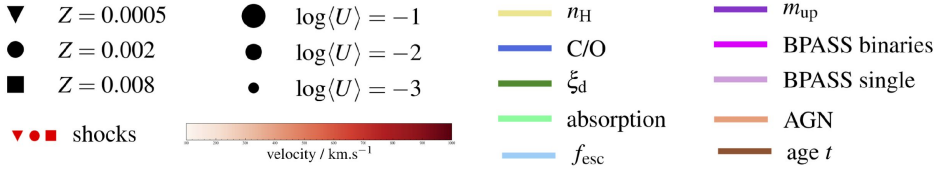


→ LyC leakers overlap with extreme star-forming galaxies

Emission-line models including :

- HII region (updated Gutkin+16) & leakage of ionizing radiation
- AGN narrow-line region (updated Feltre+16)
- Radiative shocks (Alarie & Morisset 2019)





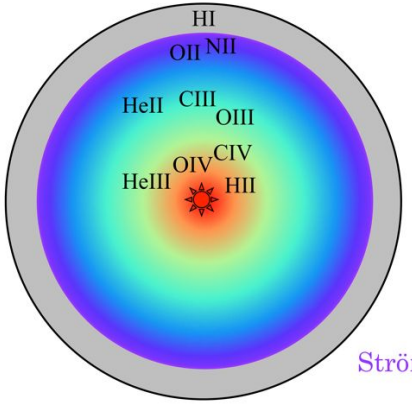
❀ A shock or AGN component helps reproducing the emission lines of metal-poor star-forming galaxies

❀ Need a hard ionizing radiation in LyC leakers ?
(see also Stasinska+15, Ramambason+20)

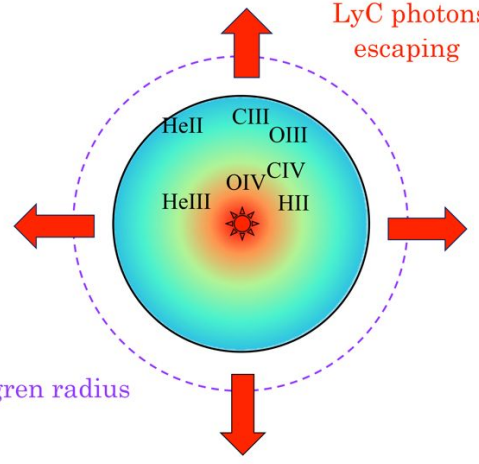
Plat+19

❀ O32 as a diagnostic for fesc ?

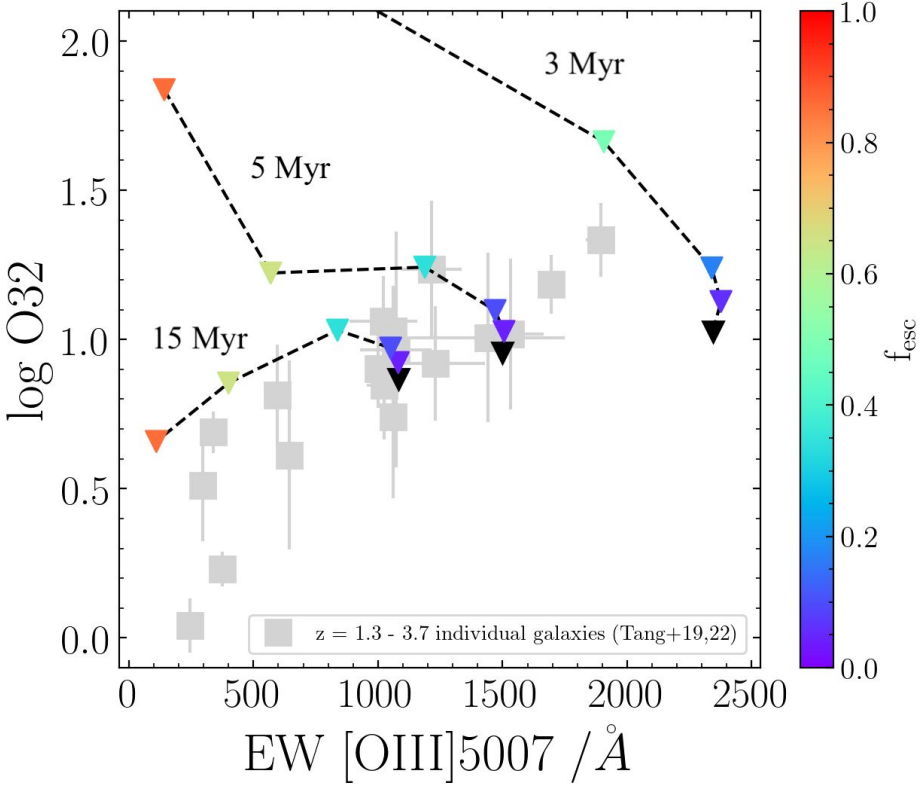
Correlation with fesc (e.g., Faisst+16, Izotov+18, Nakajima+20, Flury+22)



Ionization-bounded model
optically thick to LyC photons



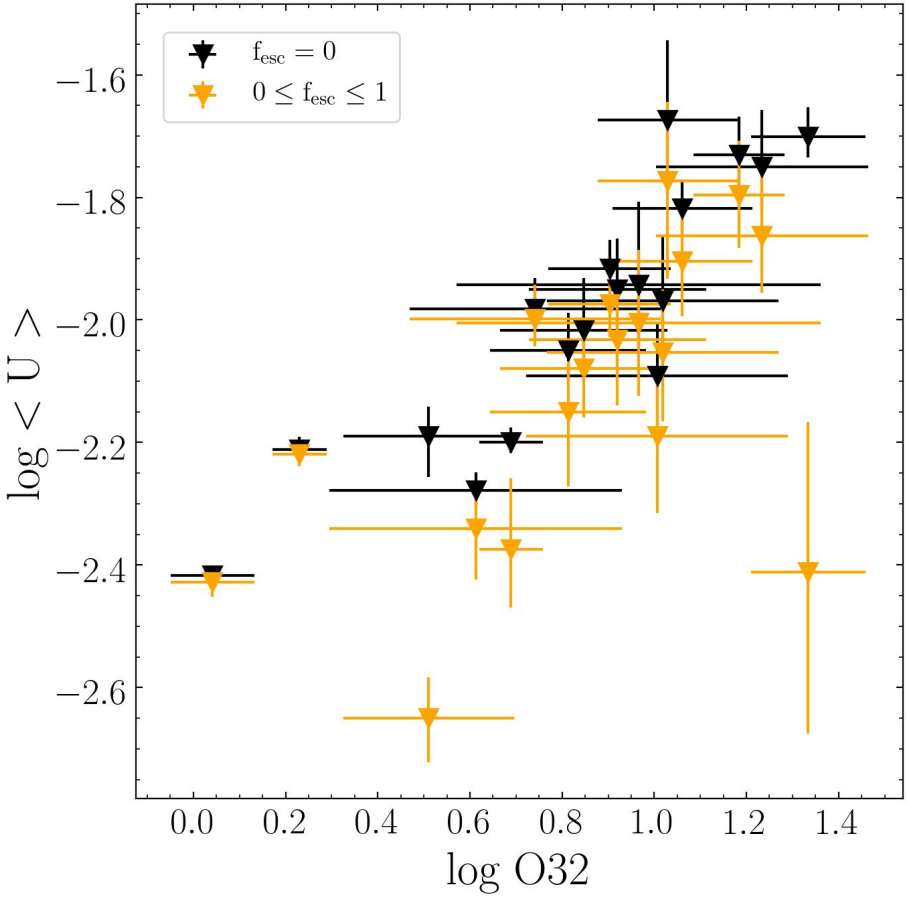
Density-bounded model
optically thin to LyC photons



O32 increases with fesc in density-bounded HII regions (e.g., Giammanco+05, Pellegrini+12, etc)

→ but degeneracy of the signatures of fesc with age, ionization parameter, metallicity … (e.g. Jaskot & Oey 2013, Nakajima & Ouchi 2014, Stasinska+15, Izotov+17, etc)

❀ What causes high O32 ?



Emission-line + photometry fit of z~2 EELGs (Tang+19,22) using BEAGLE (Chevallard & Charlot 2016)

Median parameters :
10 Myr constant SFR
Z=0.002 ($12+\log(O/H)_{gas}=7.9$)
Log<U>=-2

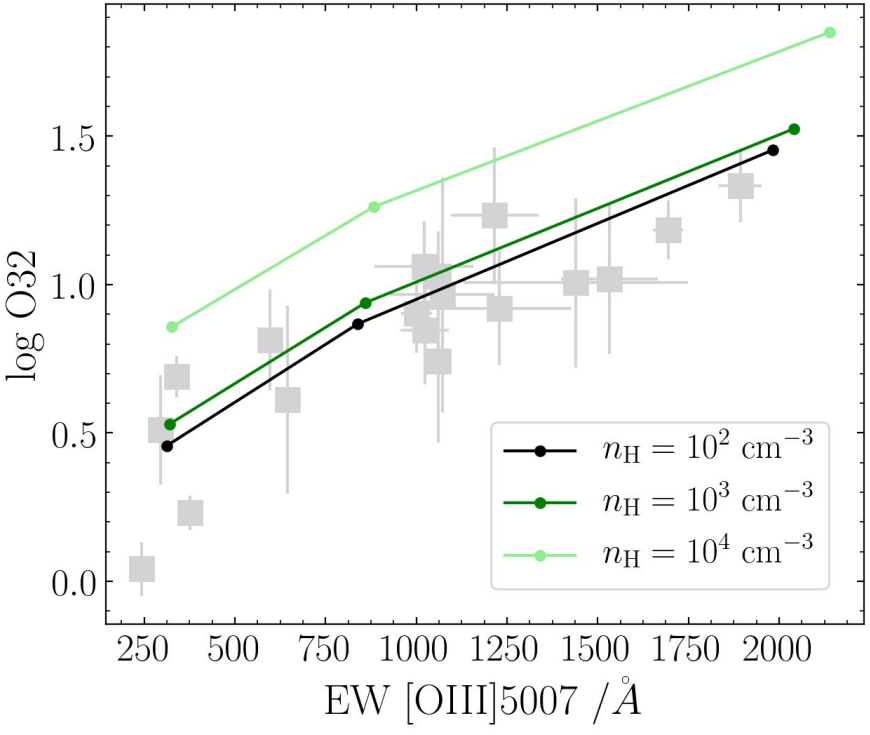
→ sources with high O32 tend to have higher ionization parameter

❀ Impact of hydrogen density

Correlation between electron density and O32 observed at low and high redshift (e.g. Shirazi+14, Stasinska+15, Reddy+23)

$$\langle U \rangle = \frac{3\alpha_B^{2/3}}{4c} \left[\frac{3Q_{\rm H}\epsilon^2 n_{\rm H}}{4\pi} \right]^{1/3}$$

→ <U> increases with n_H



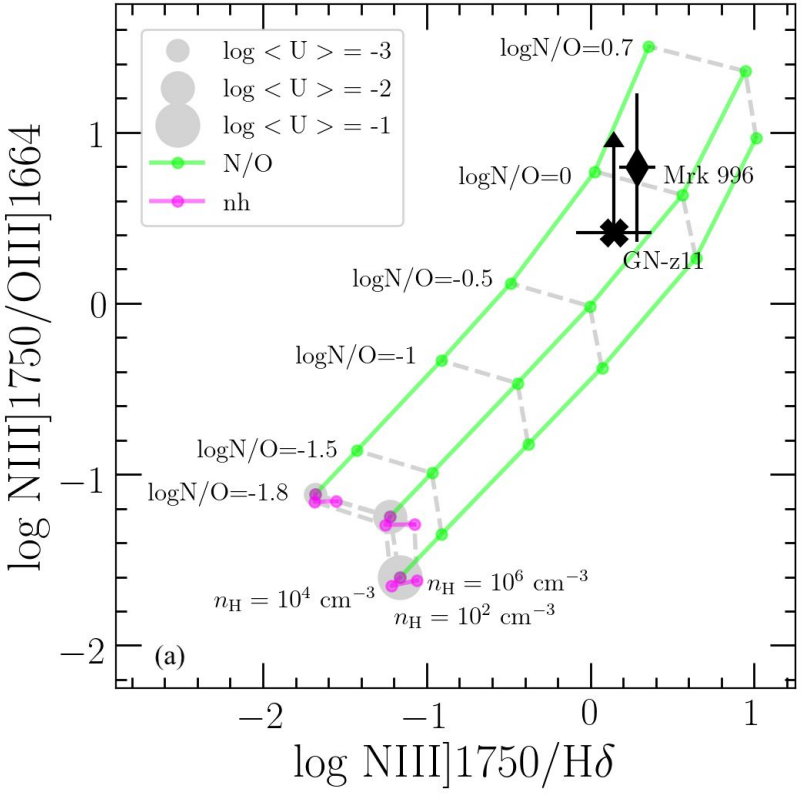
+ collisional de-excitation of [OII] at $n_H > 10^4$ cm^{-3}

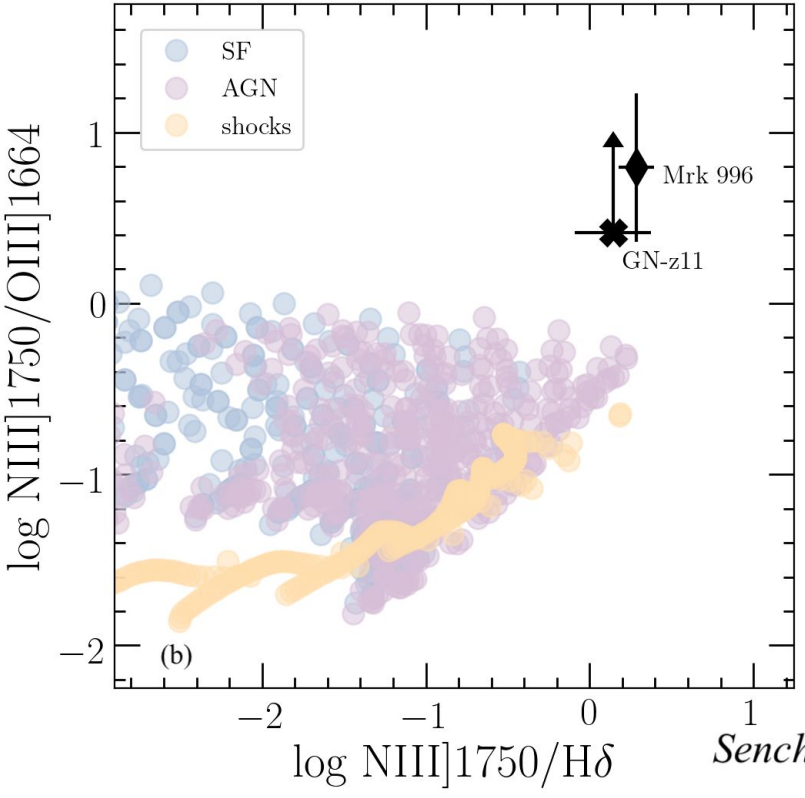
Characterization of ionizing source and escape of ionizing radiation at high redshift

→ 3 examples

❀ GN-z11 (Bunker+23) :
z=10.6 galaxy with high hydrogen density, strong NIV] and NIII] emission

→ see Peter Senchyna's talk





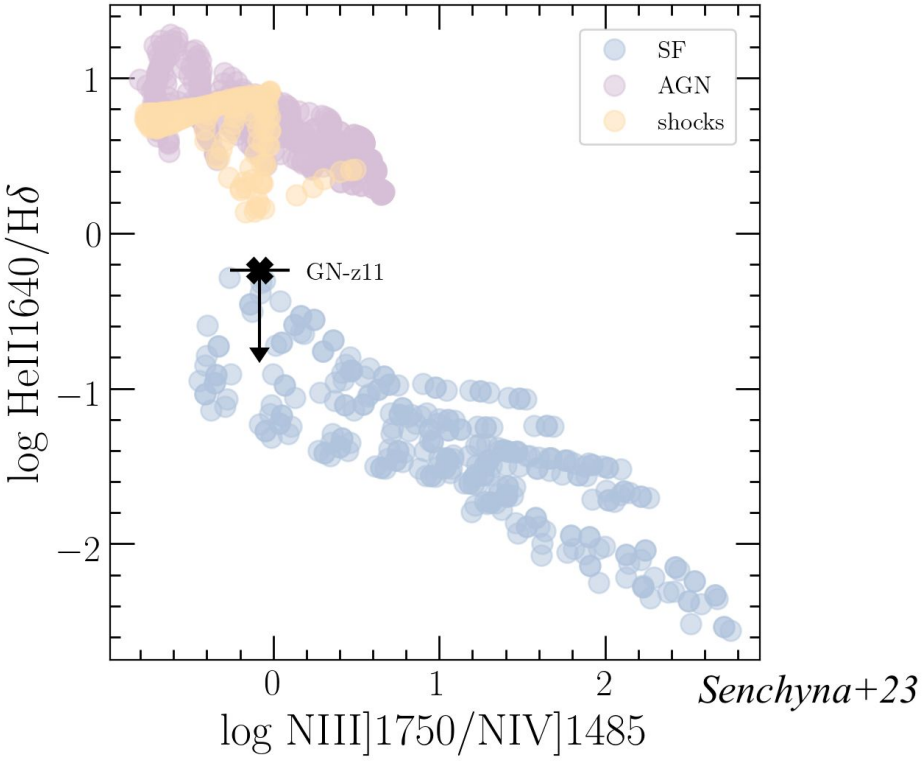
Senchyna+23

$\log(N/O)_{gas}$ = -0.25
$12+\log(O/H)_{gas}$ = 7.71

$\log\langle U\rangle$ = -1.63
age = 4 Myr

See also Cameron+23, Charbonnel+23

❀ GN-z11 : what can we say about the ionizing source ?

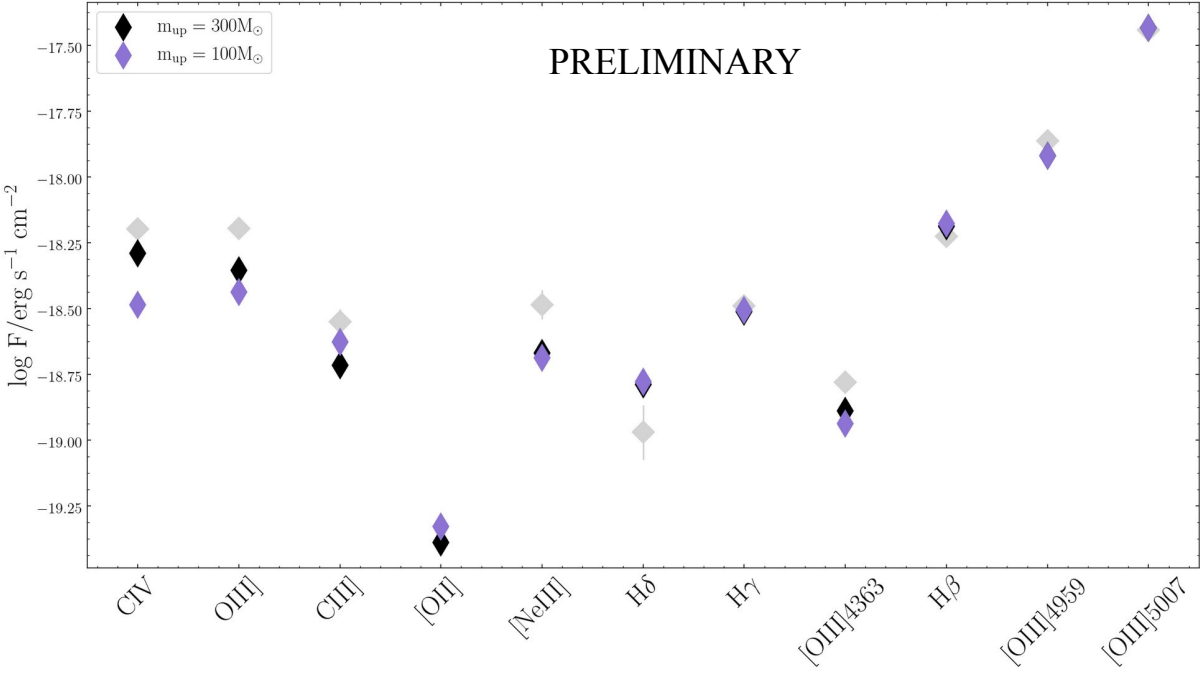


NIV]/NIII] compatible with emission from SF with low metallicity and high ionization parameter.

❀ a1703 (Stark+15)

z = 7.04

strong CIV and NIV] emission, O32 > 100 → SF with high ionization parameter ?

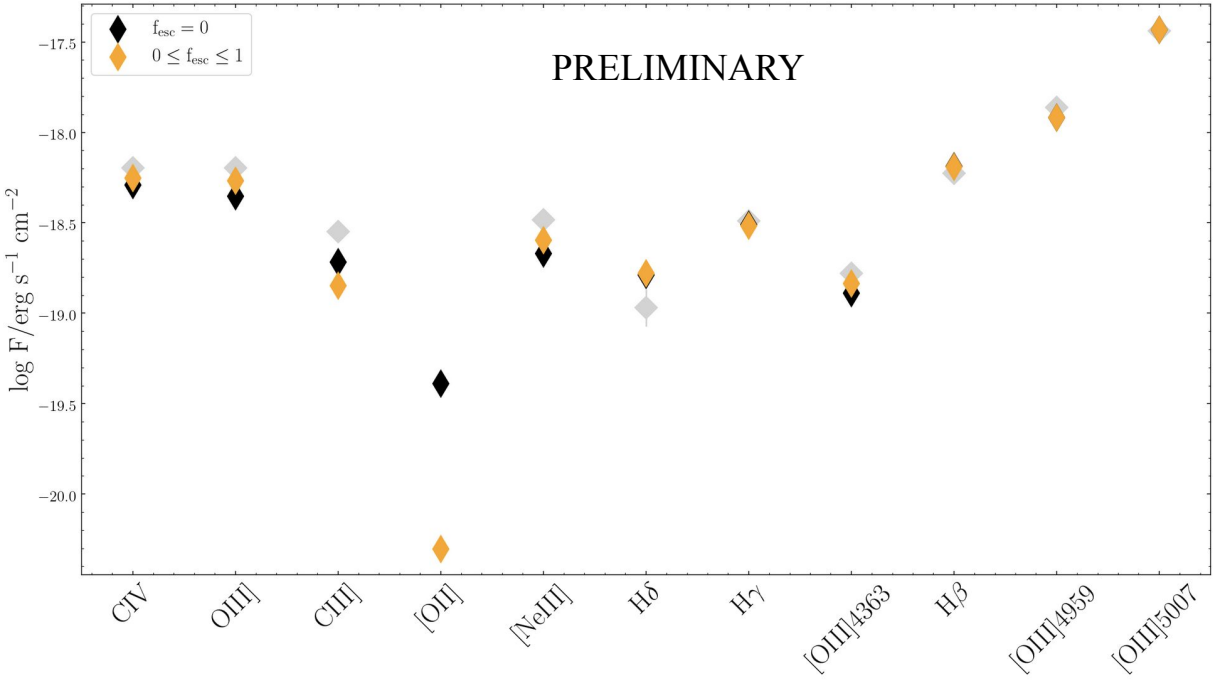


Topping in prep

$12+\log(O/H)_{gas} = 7.49$ $\log\langle U\rangle = -1.02$

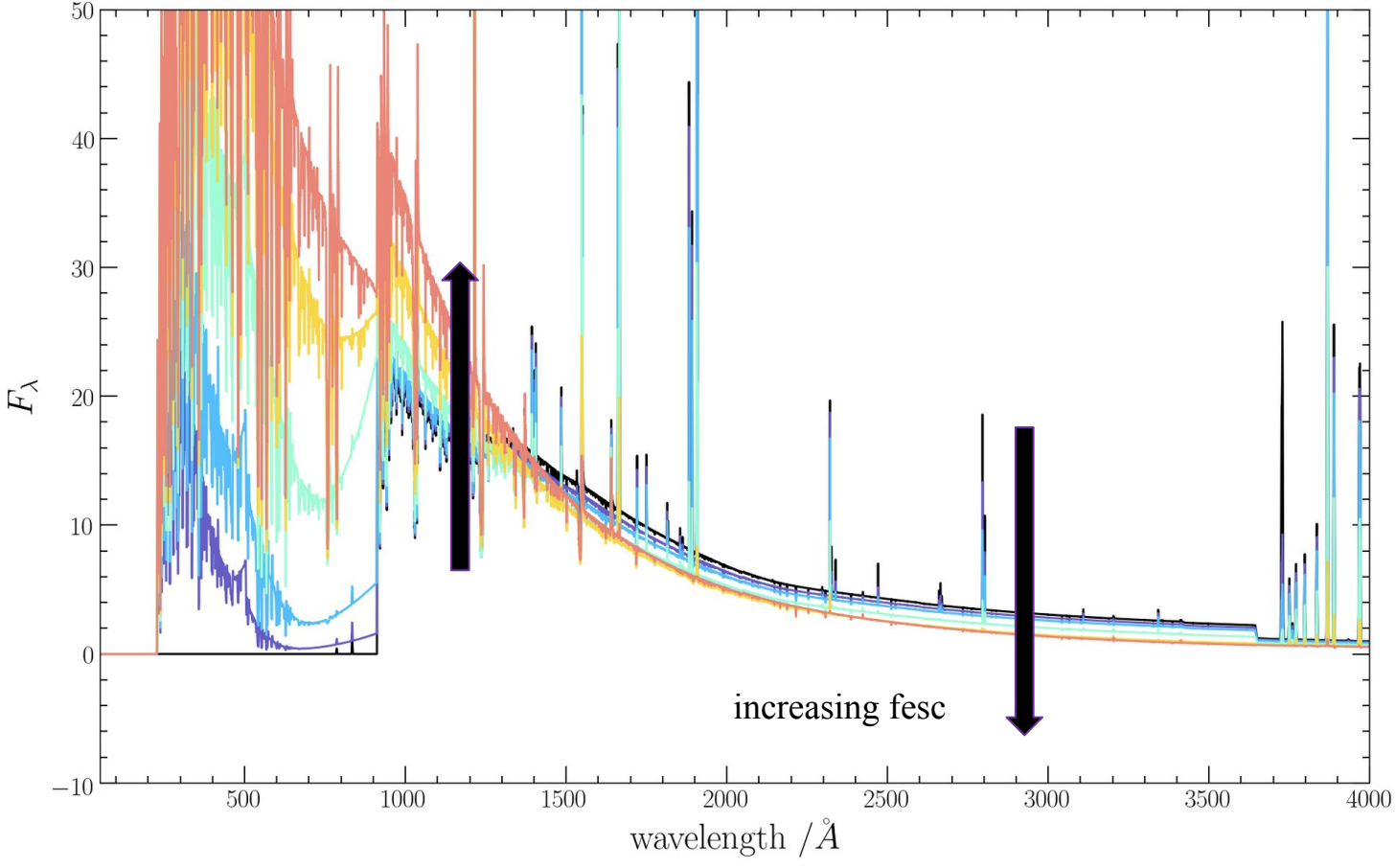
age = 1 Myr $\log M_*/M_\odot = 6.9$

❀ density-bounded (fesc) ?

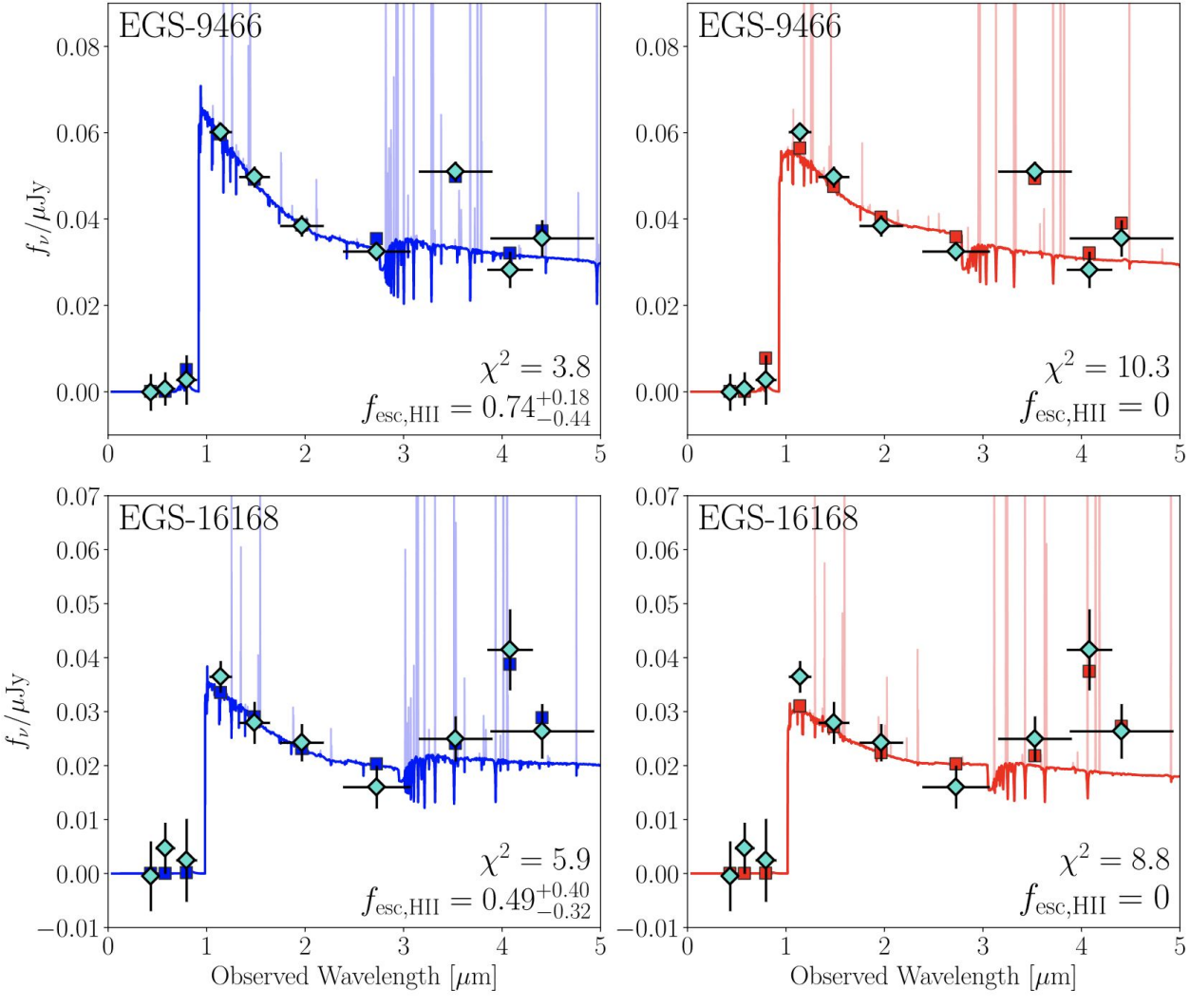


Topping in prep

❀ Blue UV slope : another indicator of fesc (e.g. Zackrisson+13,17)



❀ Blue UV slope at high redshift



CEERS data
(Finkelstein+17)

z = 7-11

Two galaxies with extremely blue UV slope $\beta = -2.9$ and $\beta = -3.1$

EW([OIII]+Hβ) = 440 and 410 Å

→ infered fesc = 0.74 and 0.49

Topping+22

❀ Summary

❀ Presence of a very hard ionizing radiation in metal-poor star-forming galaxies and some LyC leakers.

❀ High O32 is linked to high ionization parameter and probably high hydrogen density
→ more sources with high hydrogen density at high redshift ?

❀ Difficult to infer an escape fraction of LyC photons from emission lines fitting.

❀ Some galaxies with very blue UV slopes at high redshift → LyC leakers ?