Investigating the connection between LyC and Lyα emission and other indirect indicators

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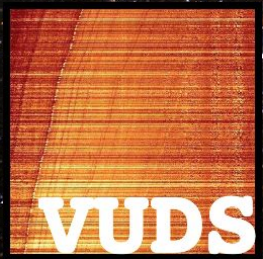
D. Schaerer, M. Castellano, B. Ribeiro and
the VUDS collaboration



Emission line galaxies with MOS: from cosmic noon to the reionization era
18-22 September 2017, Kavli institute for Cosmology, Cambridge

Background: Lyman Continuum (LyC) emission

- The LyC is the radiation at **λ≤912Å** that is able to **ionize the neutral hydrogen**
- is produced by **massive OB-type stars in young star clusters** and by active galactic nuclei (AGN).

Measuring the LyC in faint sources is important to identify the most likely sources of Reionization in the high redshift universe

To give a measurement of the amount of ionizing radiation escaping from galaxies we define the ***relative escape fraction***:

$$f_{esc}^{rel}(LyC) = \frac{L_\nu(1500)/L_\nu(895)}{f_\nu(1500)/f_\nu(895) \cdot e^{-\tau_{IGM,z}}}$$

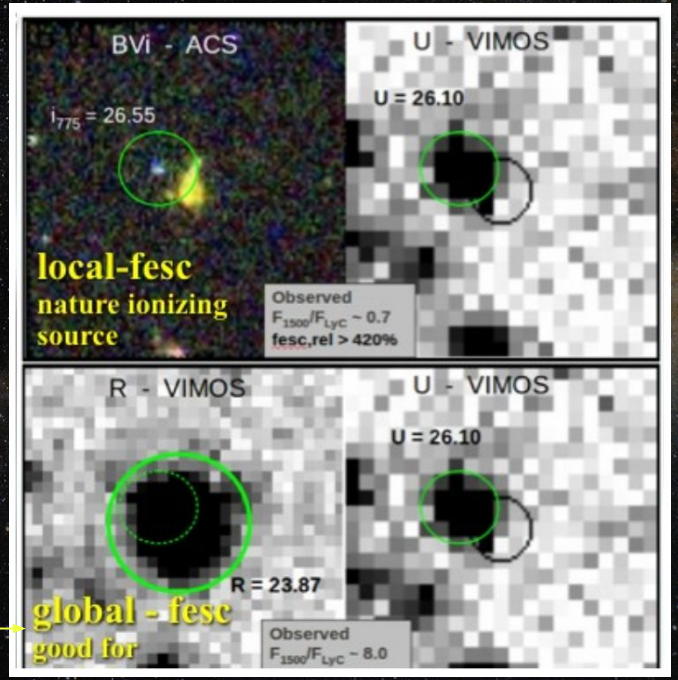
$L_\nu(1500)/L_\nu(895)$ → from models
$f_\nu(1500)/f_\nu(895)$ → from observations
$e^{-\tau IGM,z}$ → from simulations

Individual detections are rare (Izotov et al. 2016, Vanzella et al. 2016, Mostardi et al. 2015, Shapley et al. 2016)
➡ **Stacking** of large sample provides upper limits on the average escape fraction of galaxies with given properties

Background: Lyman Continuum (LyC) emission

Main problem: line of sight contamination
Lower redshift interlopers can **mimic the LyC emission** from high redshift galaxies if they are located in a line of sight very close to the targets.

It is possible to distinguish the two objects only using **HST observations**



Vanzella et al. 2012

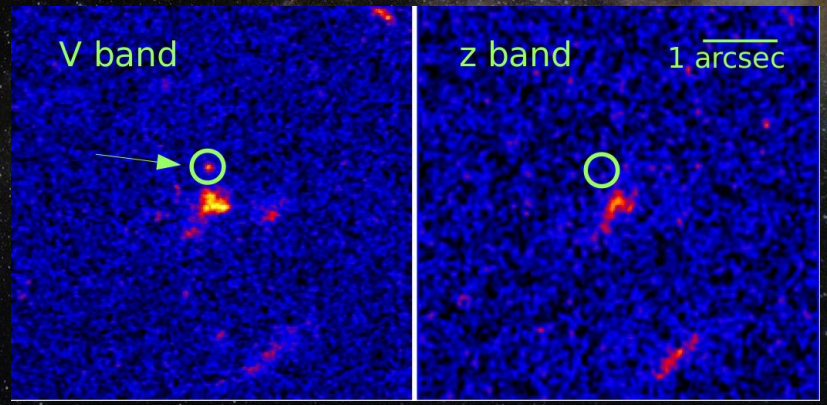
Estimation of the average escape fraction of ionizing photons of z∼4 VUDS galaxies

Sample selection

We selected 46 star-forming galaxies with accurate spectroscopic redshifts from the entire VUDS database at **3.5≤z≤ 4.5** having HST coverage in the ECDFS (CANDELS and GEMS) and COSMOS (CANDELS) fields

Cleaning procedure

- Separate isolated, single-component sources from those with multiple components with a direct inspection of the HST images
- Look at the colour images of each multi-component source excluding all the sources that show components with different colours
- Exclude objects with spectral defects in the spectral range corresponding to the LyC

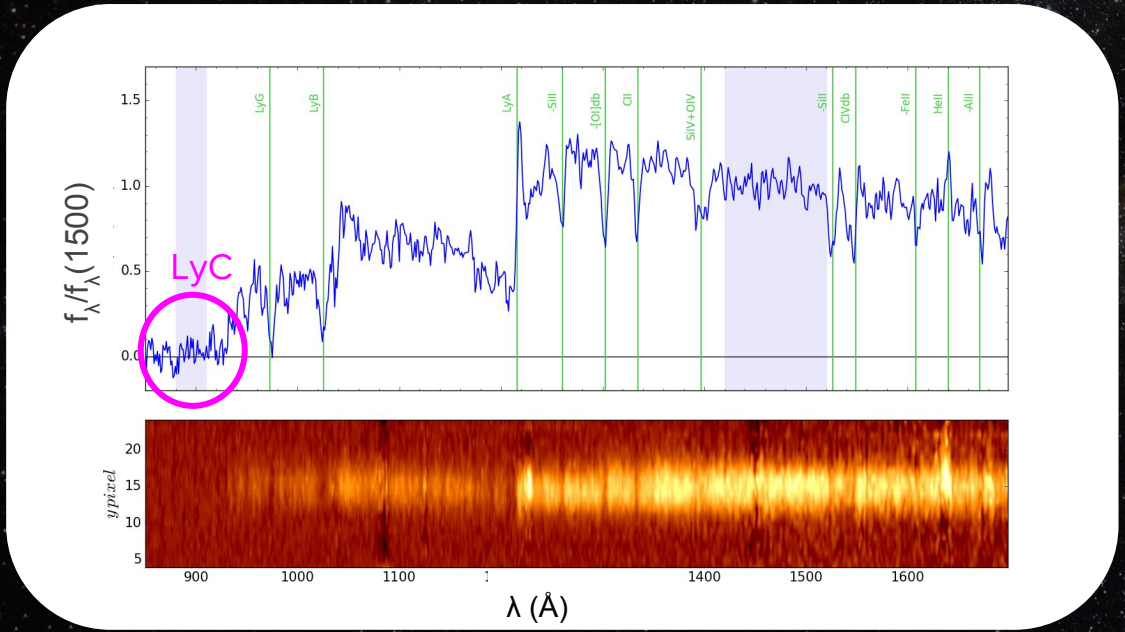


13 objects excluded

Estimation of the average escape fraction of ionizing photons of z∼4 VUDS galaxies

33 un-contaminated galaxies in the final sample at z_{median}=3.8 → No individual detection

Spectral stack



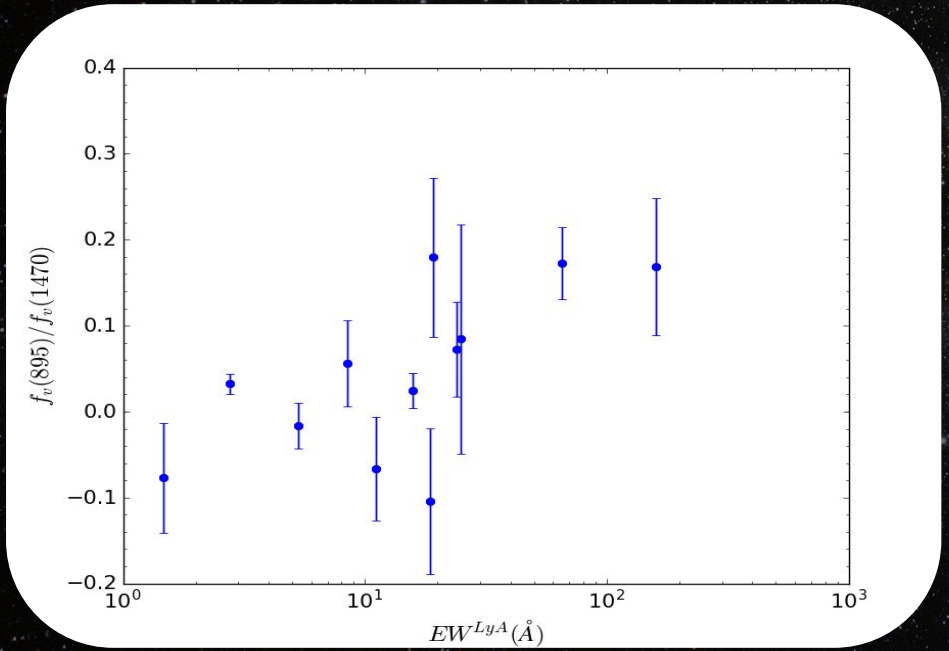
$f^{rel}_{esc} = 0.09 \pm 0.04$

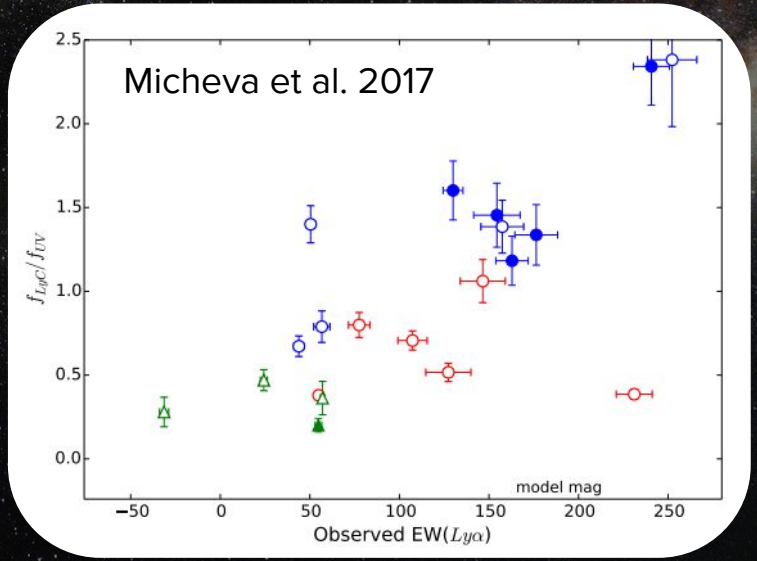
We assume $L_\nu(1500)/L_\nu(895)=3$ and we evaluate an average transmissivity using the prescription given by Inoue et al. 2014

Estimation of the average escape fraction of ionizing photons of z∼4 VUDS galaxies

We also find a tentative correlation between the limits given in the LyC flux and the EW of the Lyα emission line

These results are presented in
Marchi, F., Pentericci, L., Guaita, L., et al. 2017, A&A, 601, A73



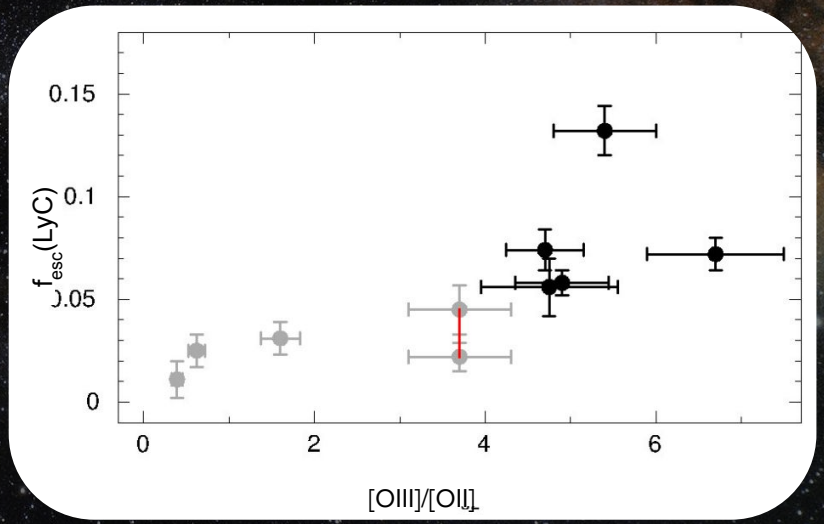


Background: indirect LyC emission indicators

Measuring the LyC flux (and the escape fraction) is only possible until z∼4.5 where the IGM still transmit (Inoue et al. 2014). There is therefore the need to look for indirect indicators of LyC radiation that can facilitate the search for LyC leakers.

Proposed indicators:

- **High Lyα EW (Dijkstra et al. 2016)**
- Double peaked Lyα profile (Verhamme et al. 2016)
- Low Lyα FWHM (Dijkstra et al. 2016)
- **Lyα close to the systemic redshift (Dijkstra et al. 2016; Verhamme et al. 2015)**
- High [OIII]/[OII] ratio (Jaskot et al. 2013; Nakajima et al. 2014; Izotov et . 2016)
- Low IS absorption lines EWs (Chisholm et. al 2017)
- **Low-mass and compact morphologies (Ouchi et al. 2009; Wise & Chen 2009; Izotov et al. 2016)**



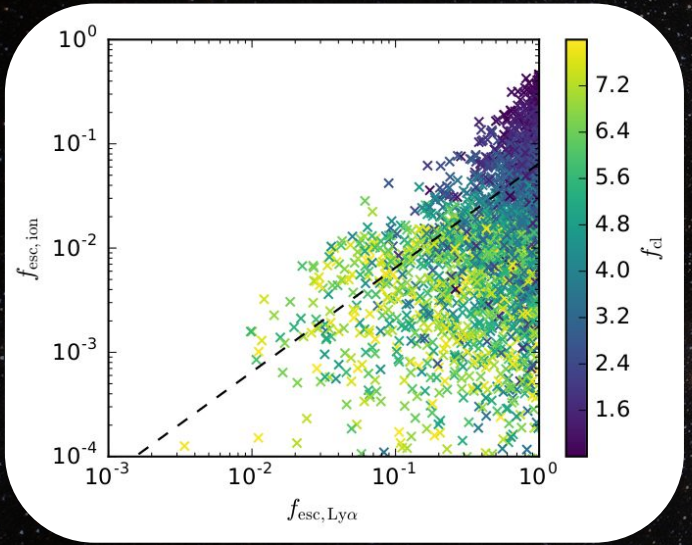
Izotov et al. 2016

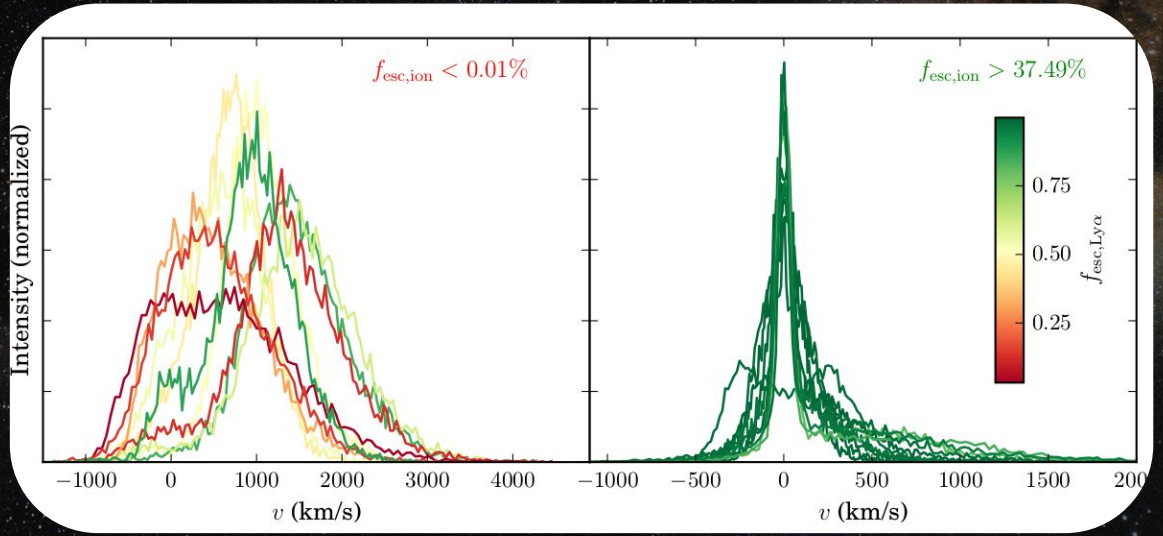
Background: indirect LyC emission indicators

Some of these indirect indicators are also supported by theoretical studies

high $f_{esc,ion}$ → high $f_{esc,LyA}$

high $f_{esc,ion}$ → Small FWHM(LyA) and low LyA velocity offset





Dijkstra et al. 2016

Investigating the connection between LyC and Lyα emissions and other indirect indicators in z∼4 VUDS galaxies

Sample selection

All VUDS galaxies with reliable spectroscopic redshift **3.5≤ z ≤ 4.3** in VVDS-2h, ECDFS and COSMOS. HST imaging not required

- **Excluded** from this sample all the galaxies with **spectral defects** or strong residuals from **sky lines** in the LyC region
- **Excluded** all the galaxies with possible **AGN** features
- **Excluded** all the clearly contaminated objects visually checking the 2D spectra and the available low-resolution images

Initial sample:
248 galaxies

Final sample:
201 galaxies

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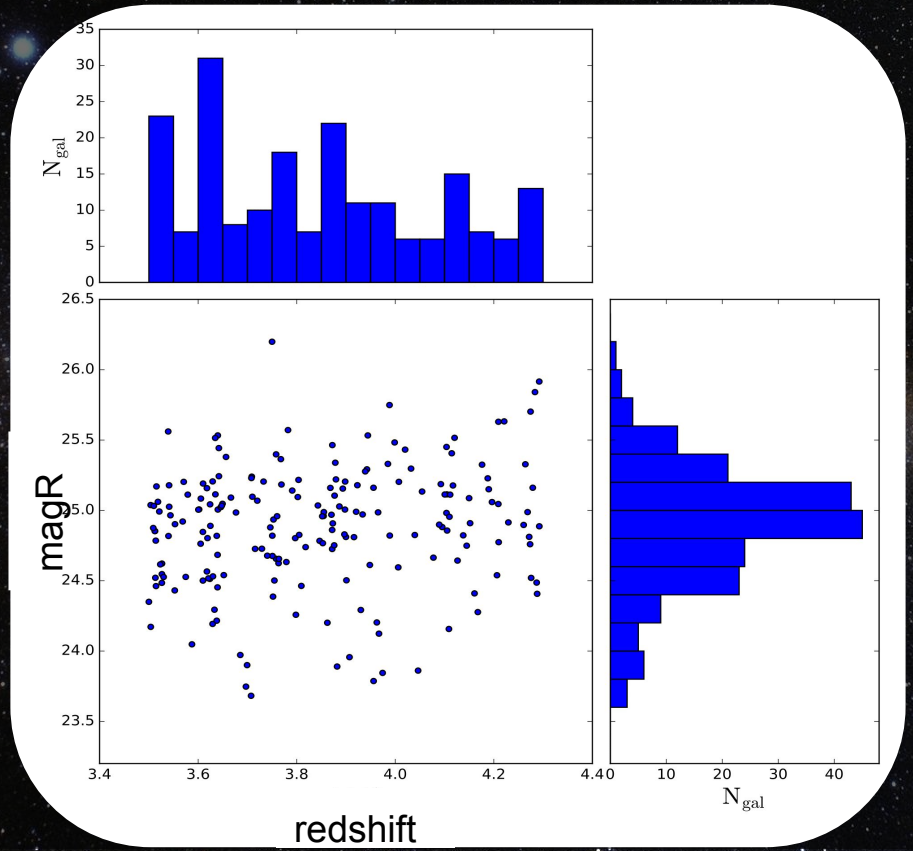
201 galaxies at
z_{median}*=3.8*
with
$magR_{median}$*=24.9*



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Indirect indicators that we can study exploiting the VUDS data:

- **EW(LyA)** → Cassata et al. 2015 for **all the galaxies in our sample** (10% of the sample has EW(LyA)>55 Å and 25% has EW(LyA)>25 Å)
- **rest-frame UV sizes** → Ribeiro et al. 2016, only for the objects in COSMOS and ECDFS (***122 sources***, I band obs-frame)
- **LyA spatial extent** → was evaluated for sources with sufficient S/N (EW>10 Å) (***76 sources***)
- **LyA velocity offset** with respect to the systemic redshift →only for the sources were the evaluation of the systemic redshift was feasible (***48 sources***)

Systemic redshift evaluation

- From **CIII** (**13** sources)
- From **LIS** (**35** sources): we evaluated the $zsys_{IS}$ only in the galaxies that showed strong SiII1260.42, CII1334.53 or SiIIλ1526.71 in absorption by fitting the lines with a gaussian and applying the formula from Steidel et al. 2010 → $\mathbf{z_{SYS}=z_{IS}+0.00299-0.00291\,(2.7-z_{IS})}$

Investigating the connection between LyC and Lyα emissions and other indirect indicators in z∼4 VUDS galaxies

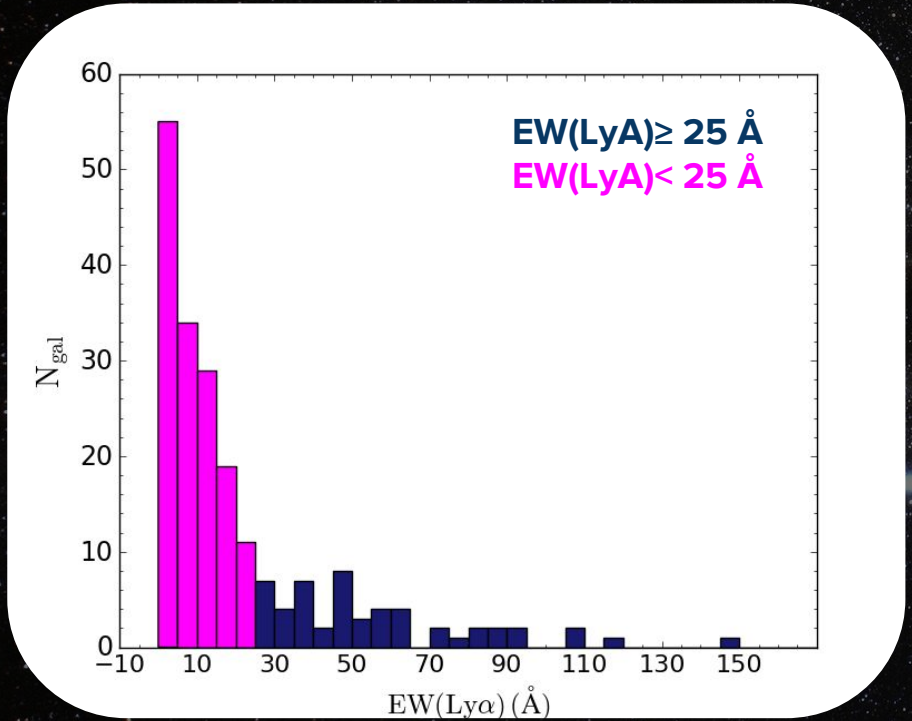
Method:

- We group the galaxies in **different sub-samples** according to the measured properties
- for each sub-sample, we produce **stacked spectra** where we directly measured the **ratio between the LyC and the UV continuum density fluxes**
- We assume to have the *same statistical contamination* from lower-z interlopers in all the sub-samples considered. We look for a **differential LyC signal** and not a true value

  ➔ We did not apply any cleaning procedure as in Guaita et al. 2016 and Marchi et al. 2017

Investigating the connection between LyC and Lyα emissions and other indirect indicators in z∼4 VUDS galaxies

Method: distributions of the parameters and definition of the sub-samples



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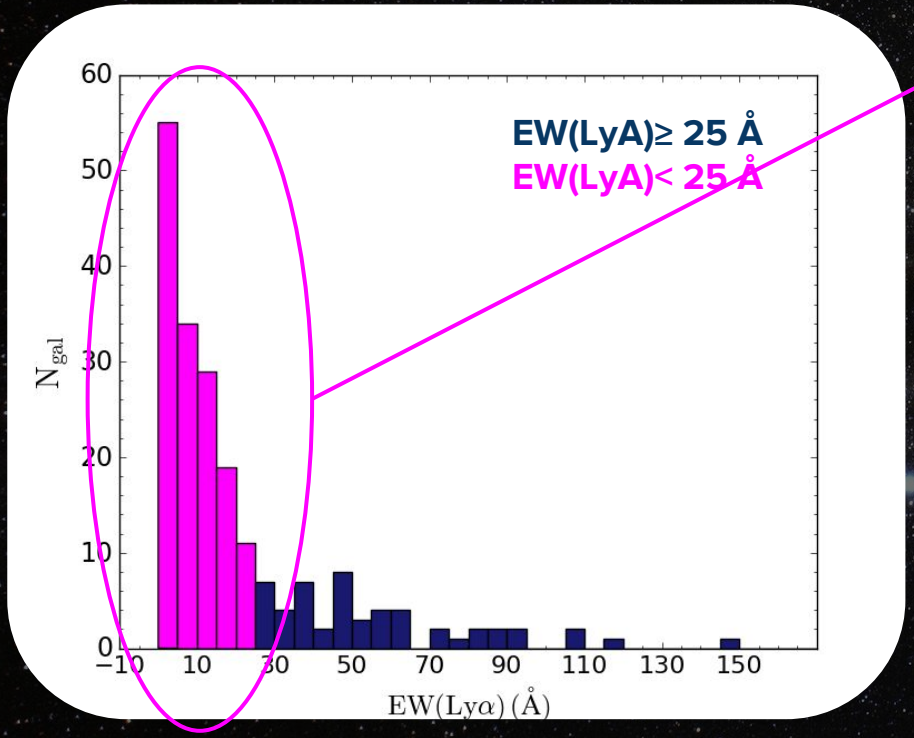

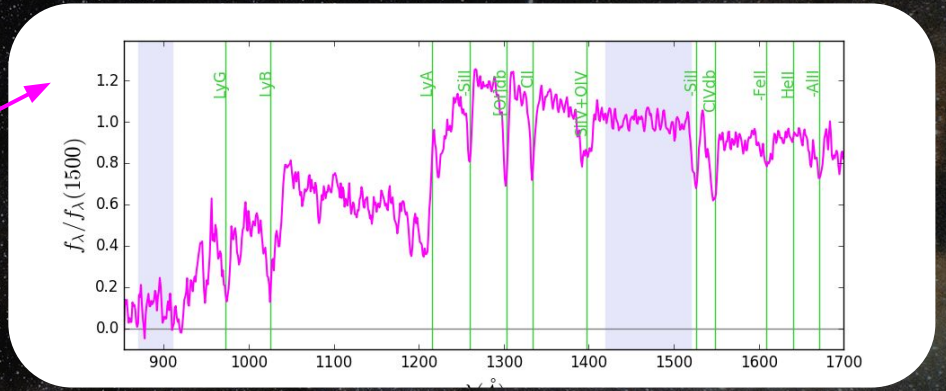

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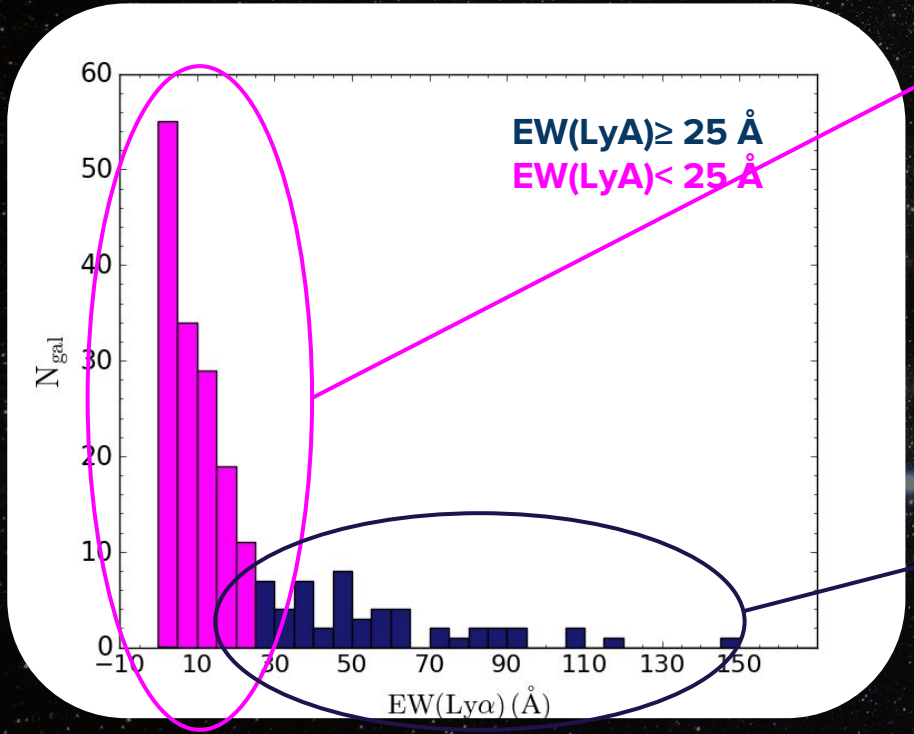

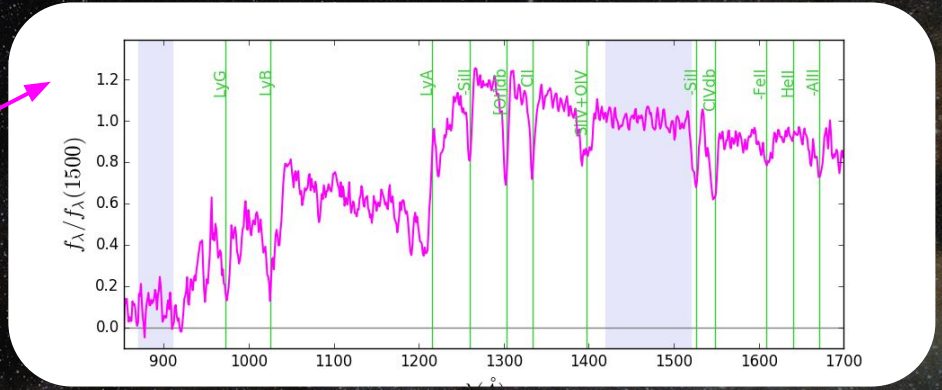

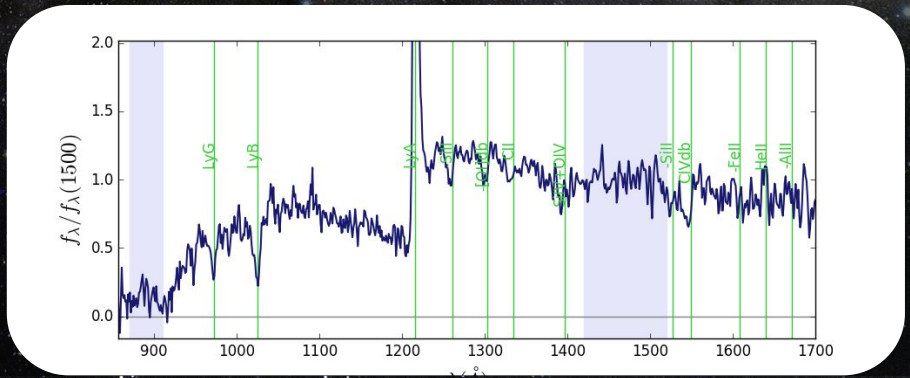

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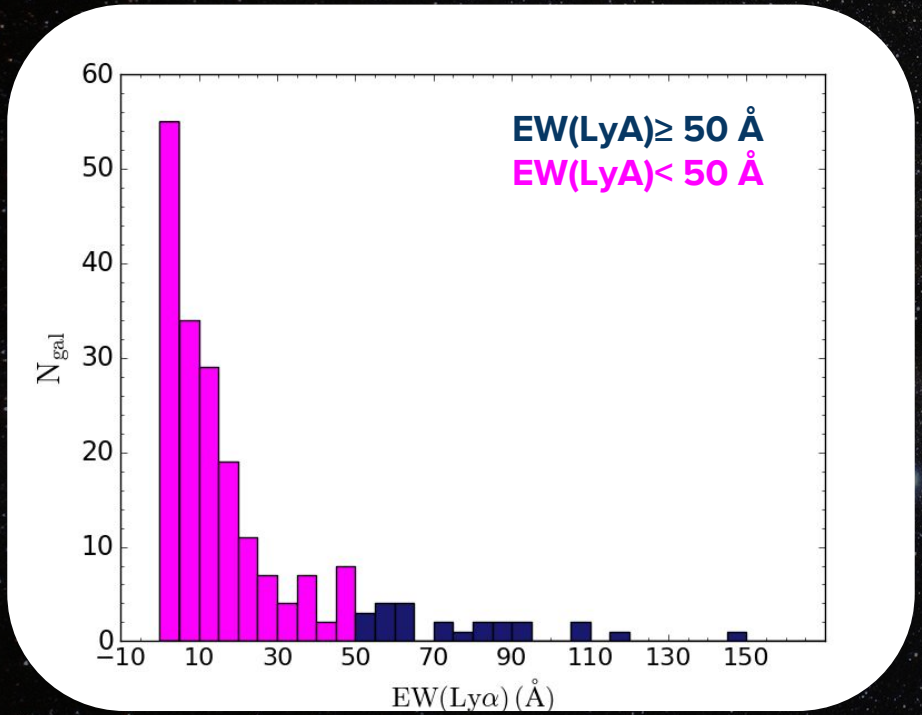

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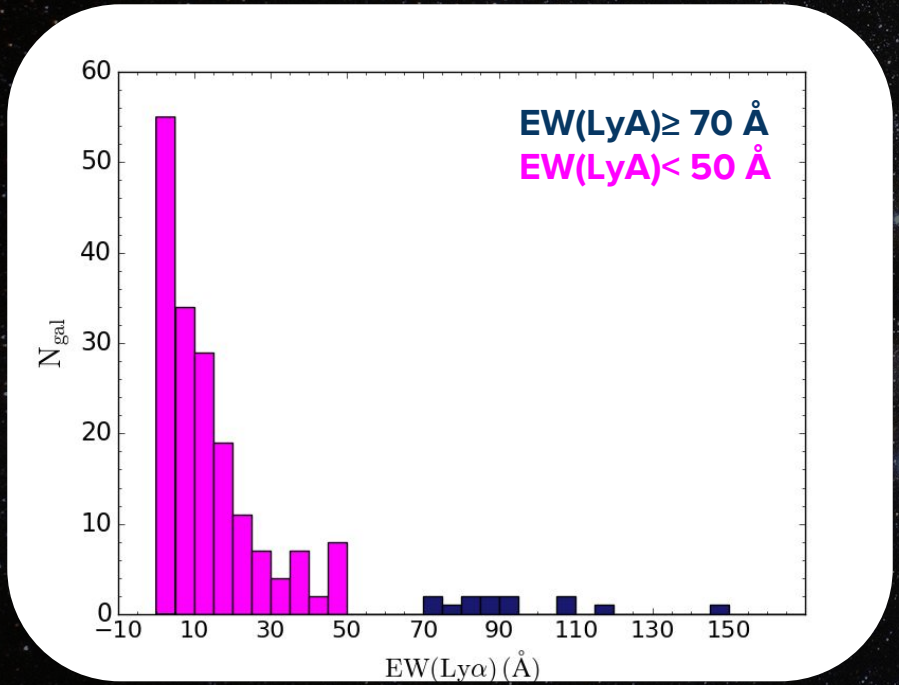

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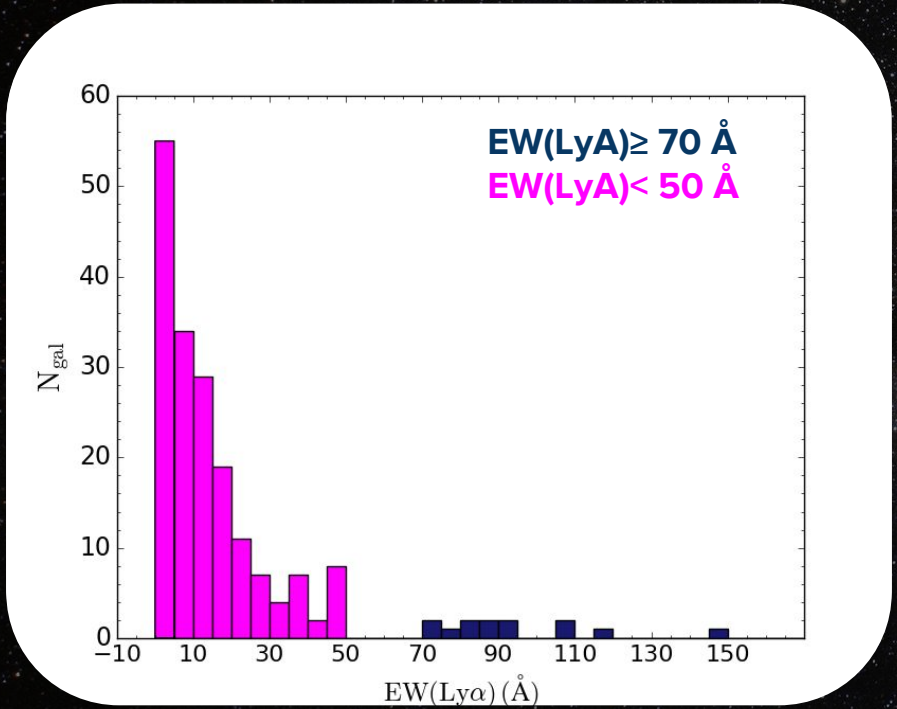

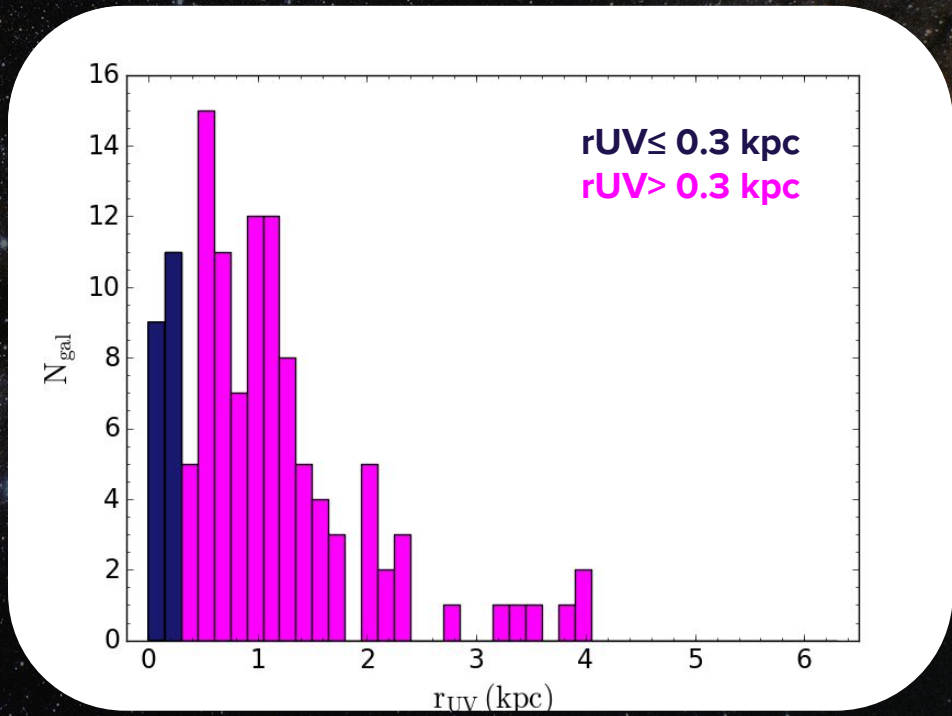

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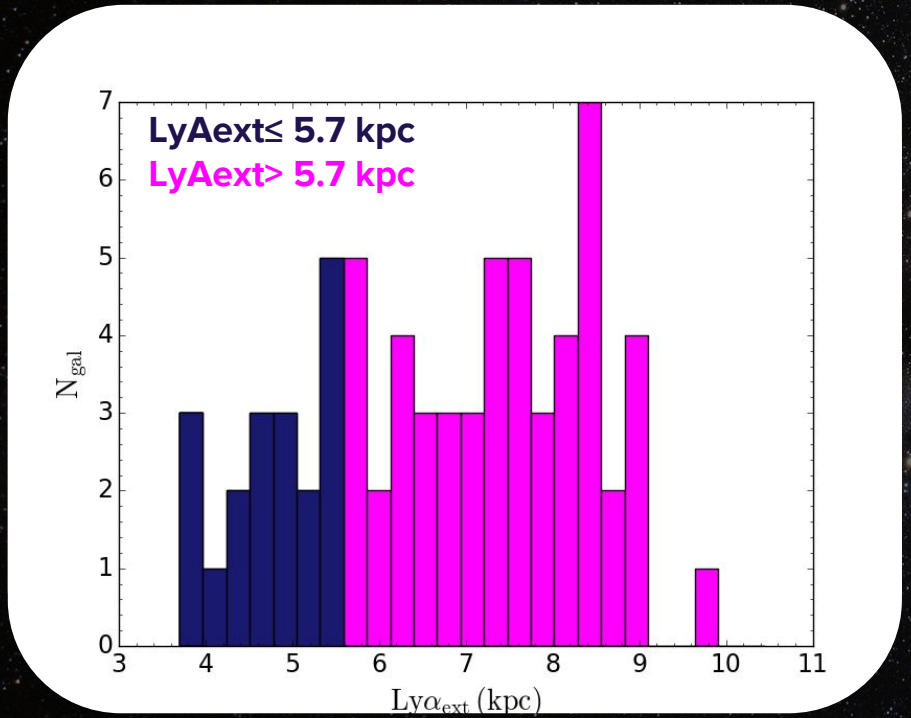
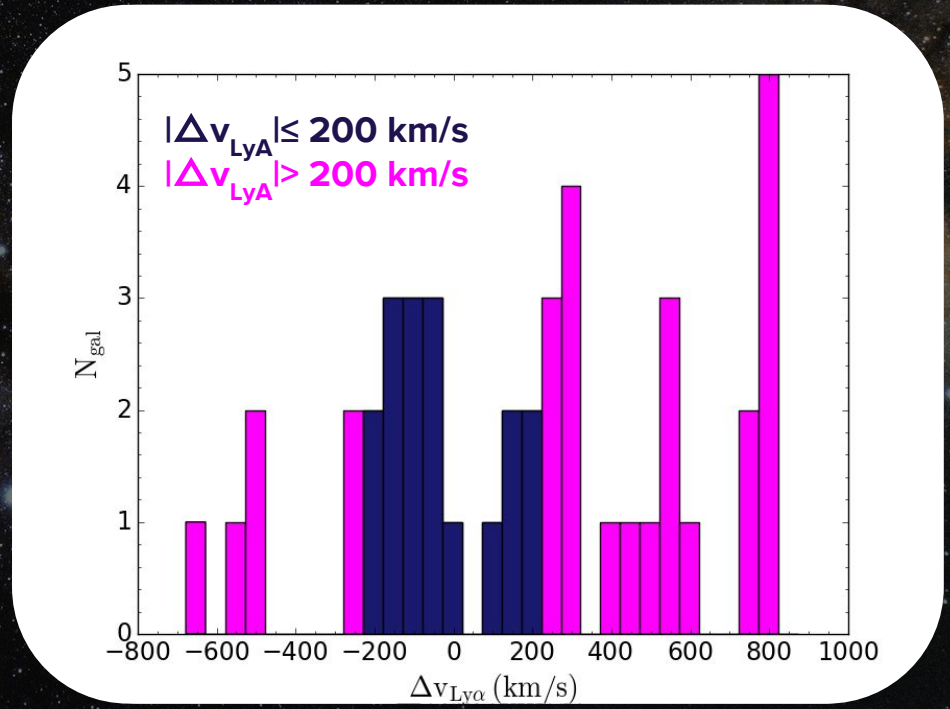
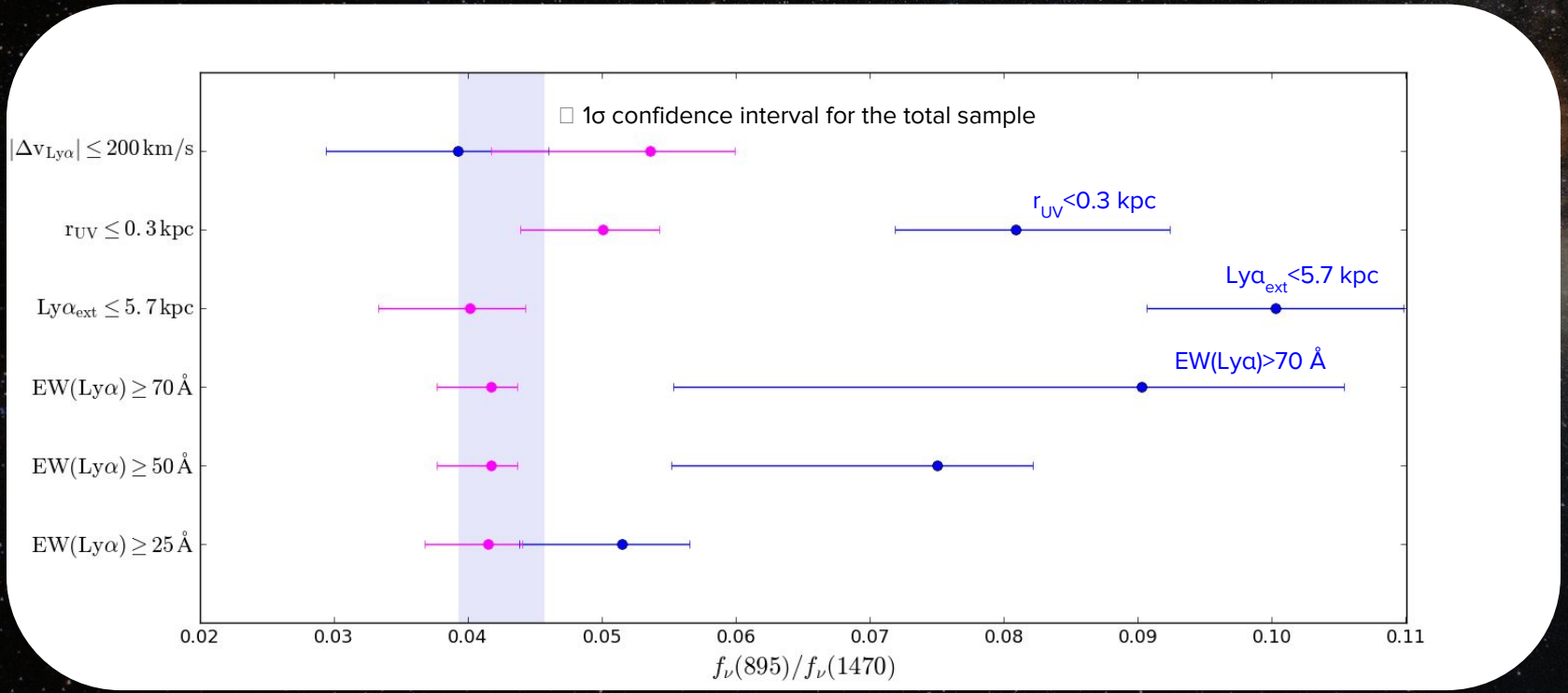




Investigating the connection between LyC and Lyα emissions and other indirect indicators in z∼4 VUDS galaxies

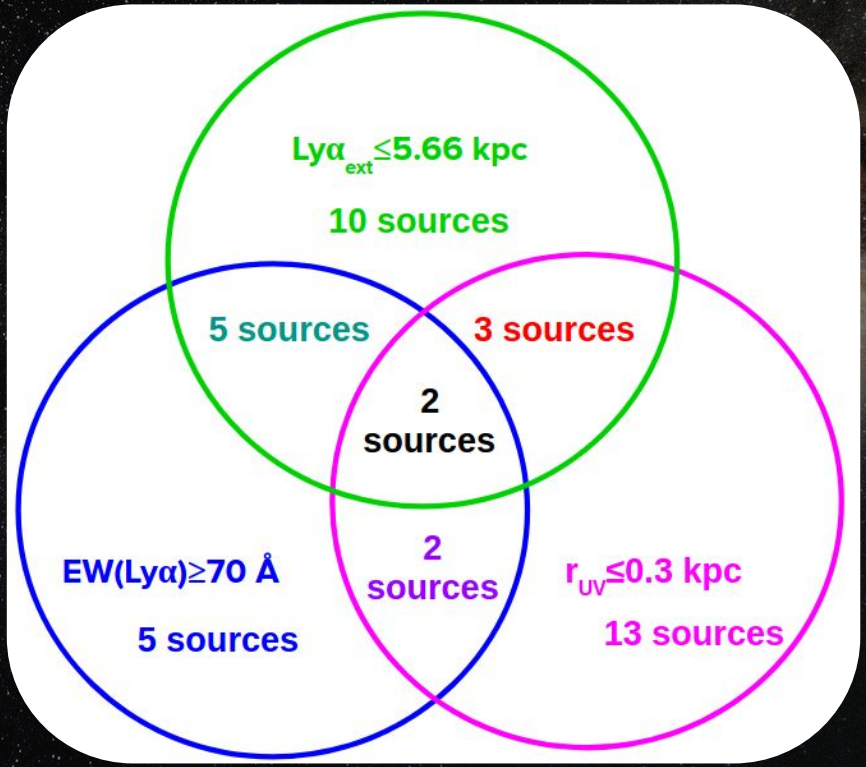
Results: stack of the sources in each sub-sample



Investigating the connection between LyC and Lyα emissions and other indirect indicators in z∼4 VUDS galaxies

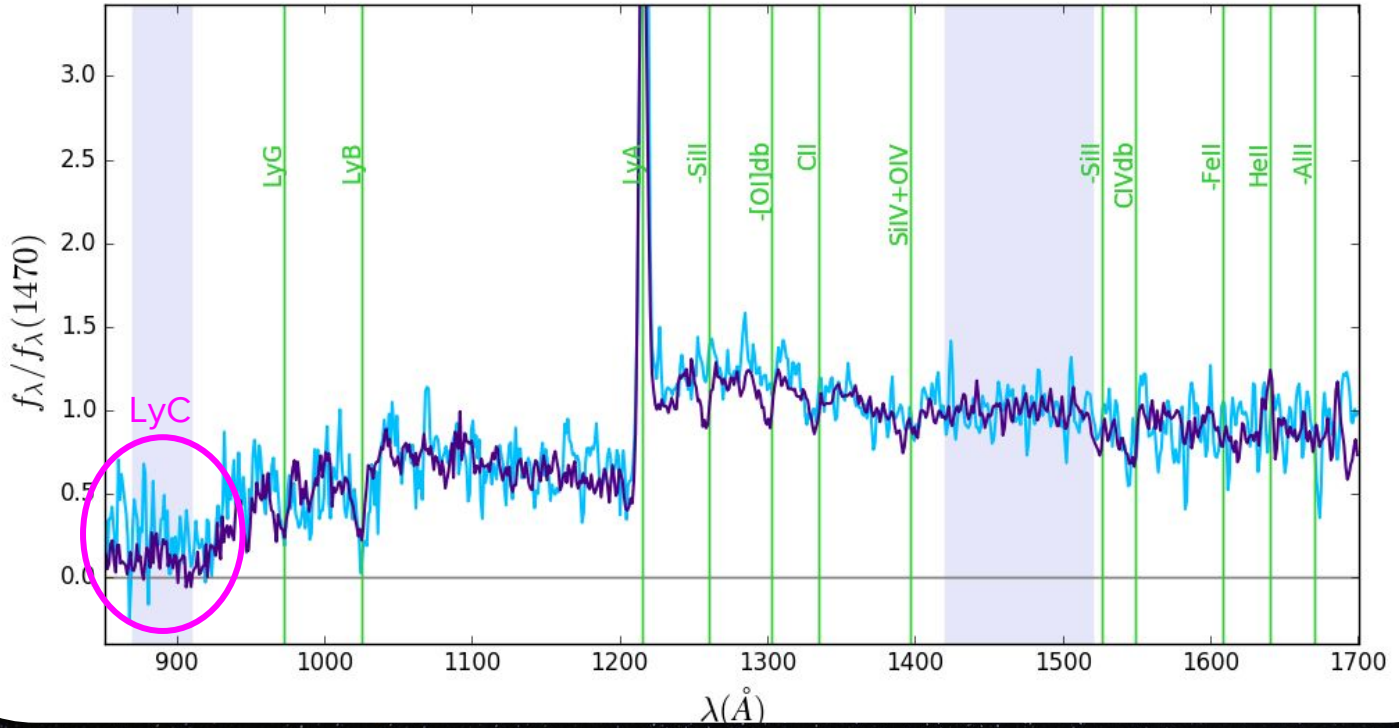
Results: most significant sub-samples

- LyA_{Ext}<5.7 kpc (20 sources)
- EW(LyA)>70 Å (14 sources)
- r_{UV}<0.2 kpc (13 sources)



Investigating the connection between LyC and Lyα emissions and other indirect indicators in z∼4 VUDS galaxies

Stacks of the sub-samples with LyA_{ext}>5.7 kpc and LyA_{ext}≤ 5.7 kpc



Investigating the connection between LyC and Lyα emissions and other indirect indicators in z∼4 VUDS galaxies

Our results indicate that UV compact, strong Lya emitting sources with a small extent of the Lya spatial profile, have likely a higher LyC escape fraction than the rest of the population of high-redshift star-forming galaxies

The results obtained for the **velocity shift of the LyA** with respect to the systemic redshift, are not in agreement with theoretical expectations (Dijkstra et al. 2016; Verhamme et al. 2015). This could be due to several reasons:

- our evaluation of the systemic redshift could be wrong, since it relies in most cases on an average relation between the systemic redshift and that obtained from the interstellar absorption lines that was tested only at lower redshift (Steidel et al. 2010)
- we know that in ~ 30% of the galaxies the Lyα emission is double peaked, but the peak separation is actually smaller than the VUDS resolution and we might be underestimating the velocity of the main (red) peak.

Investigating the connection between LyC and Lyα emissions and other indirect indicators in z∼4 VUDS galaxies

Low-redshift interlopers contamination

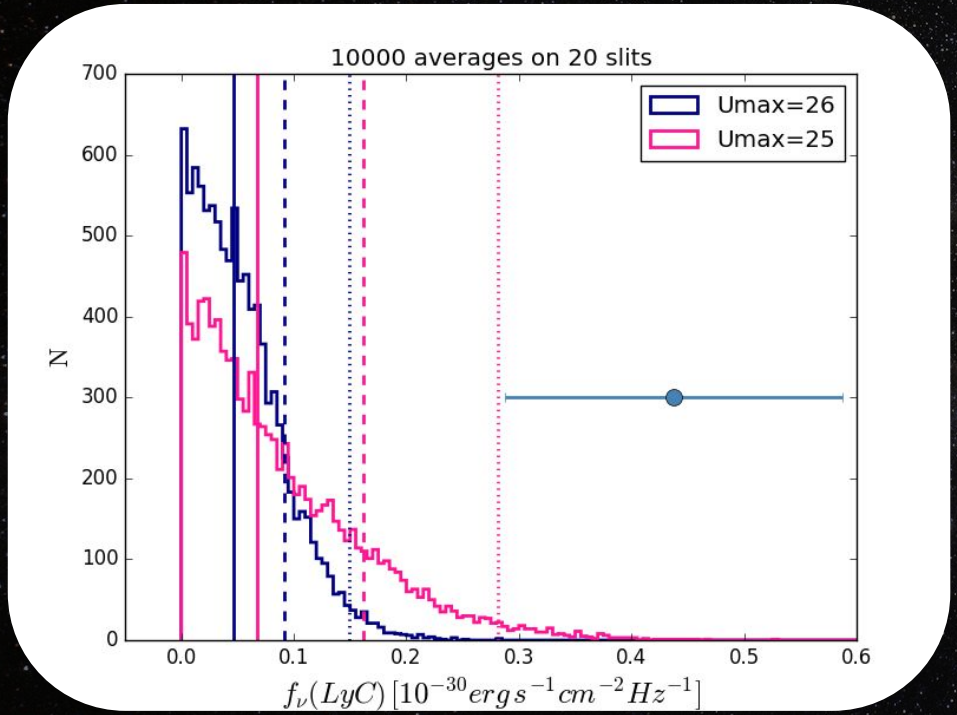
We simulated the contamination from random interlopers in each subsample (as in Vanzella et al. 2010)

Method

- Use deep U band image background cleaned of CDFS
- Place X (X=subsample size) random slits (size 1 x 2seeing arcsec) on U band image avoiding bright sources (Umax=25 or 26)
- Derive mean flux (equivalent to random contamination)
- Repeat the same procedure 10000 times
- take the median value of the distribution

Investigating the connection between LyC and Lyα emissions and other indirect indicators in z∼4 VUDS galaxies

Low-redshift interlopers contamination



- We find the same average contamination in all the sub-samples considered
- *Since the significant sub-samples are small, there is a large spread in the distribution of the simulated fluxes ➜ large uncertainty in the evaluation of the real contamination that is present in the sub-samples ➜ not possible to transform the flux density ratio in a reliable relative escape fraction*

Summary and conclusions

From a small sample of VUDS galaxies free from LoS contamination thanks to deep multi-wavelength HST imaging:

- We estimate an average relative escape fraction of **0.09±0.04**
- We find a tentative trend between the **flux density ratios** and the **Lyα EW** for the LAEs in our sample

From a large sample of VUDS galaxies:

- We find that **compact Lyα and compact UV morphologies** and **high Lyα EWs** are strongly correlated to higher relative escape fractions
- It is not possible to give reliable values of the relative escape fraction of LyC photons accounting for the contamination only through simulations