Classifying the spectral shapes of Lyman-alpha emitting galaxies in the MUSE Extremely Deep Field

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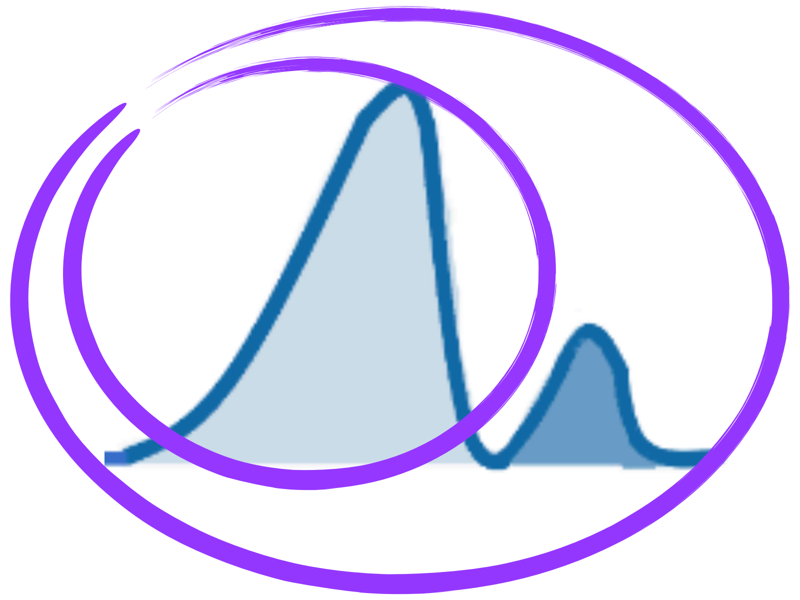
Diversity of observed Lya emission lines from Lya emitting galaxies (LAEs)

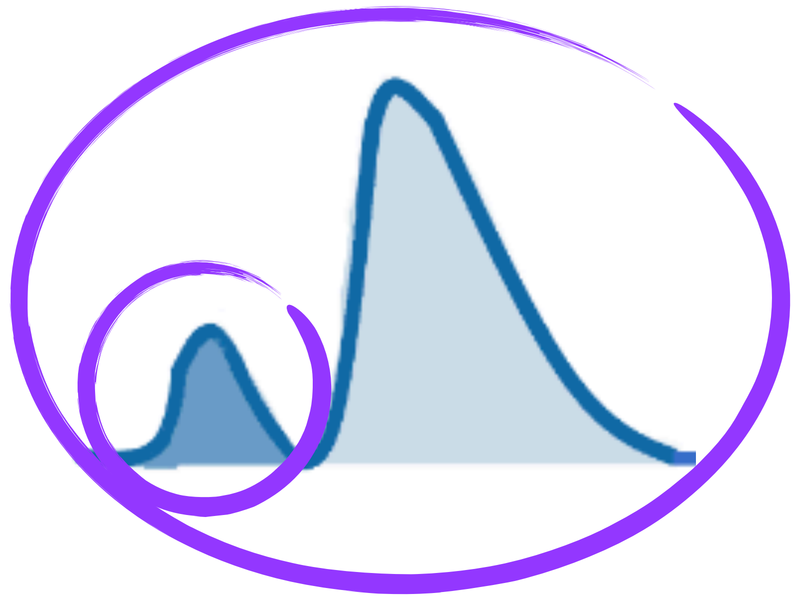
What can we learn about formation and evolution of galaxies with such peculiar LAEs?

1. Characterize **exchanges** between the **CGM** and the **galaxies** (Dijkstra+06):

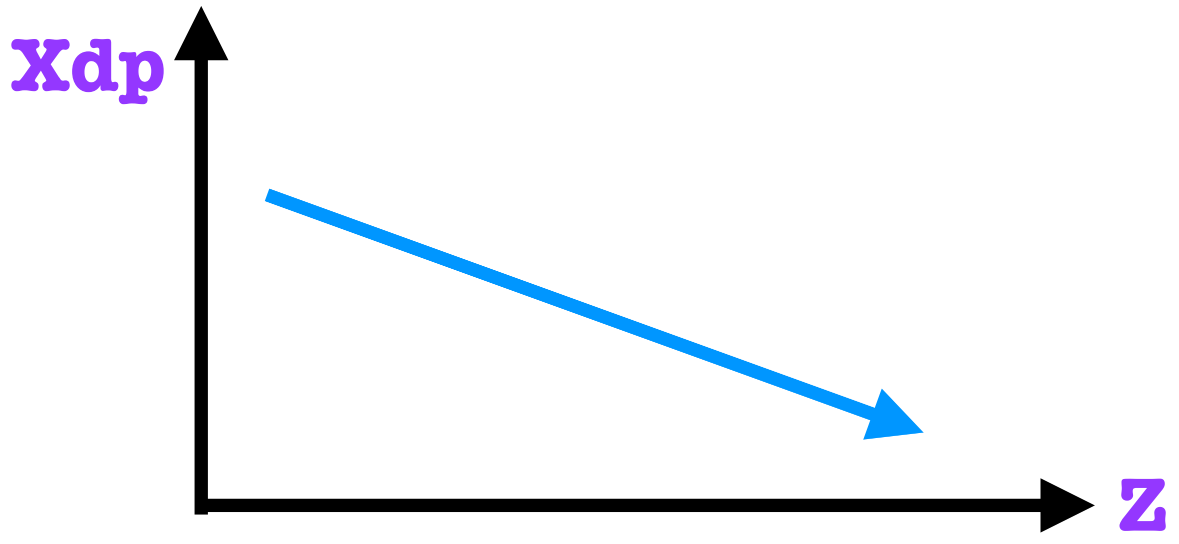
<u>Inflow</u>
Only a few ones
Furtak+22
Marques-Chaves+22



<u>Outflow</u>
Most common ones



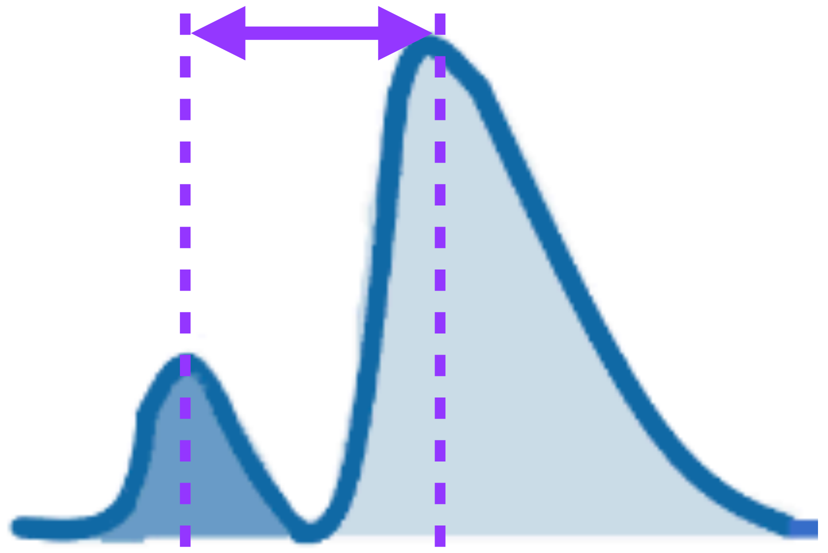
2. Study of the properties of the **IGM**:
➢Opacity
➢Ionized bubbles



Laursen+11
Hayes+21
Garel+21

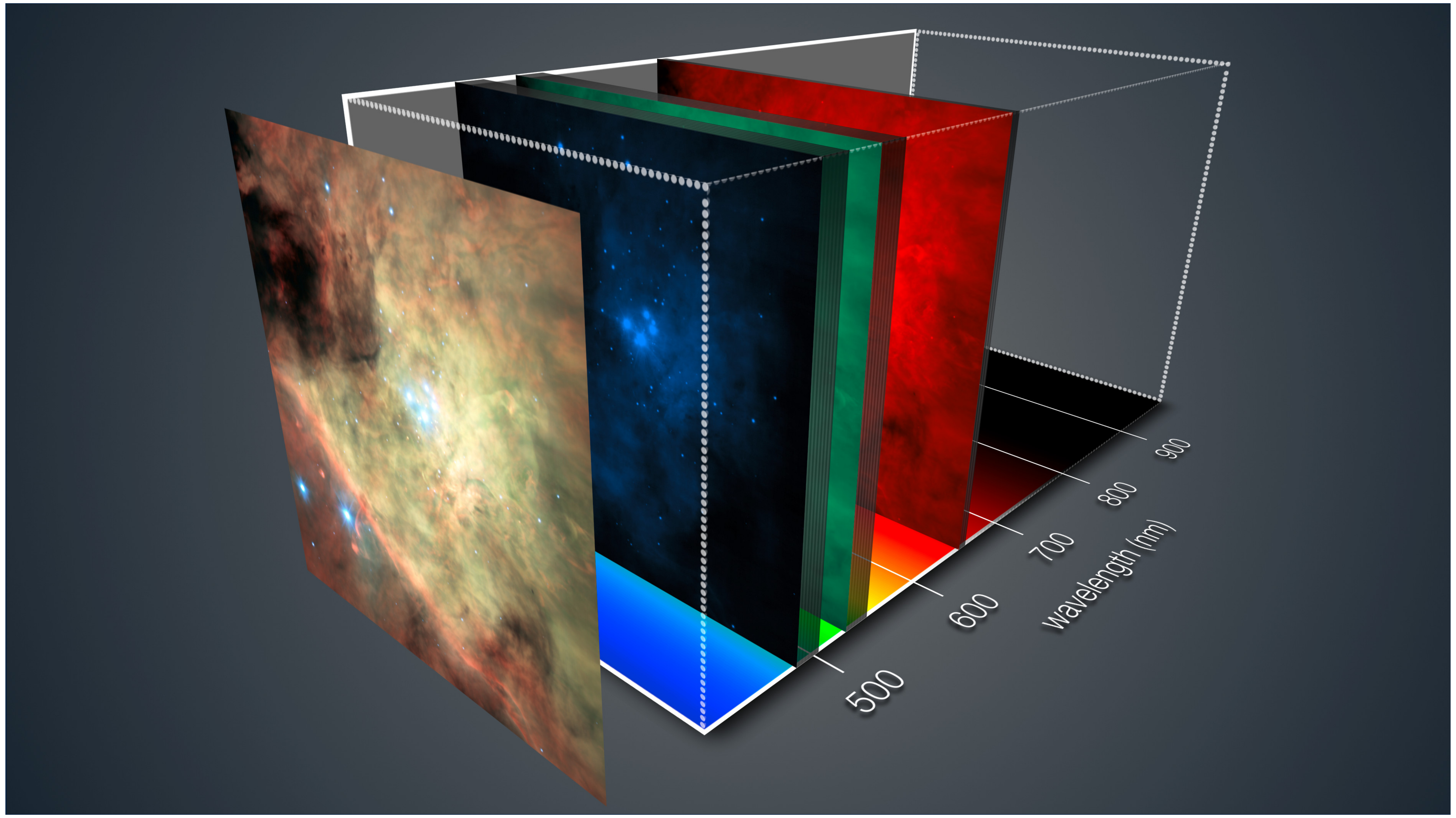
3. Determine the **column density of HI** along the line of sight to get the **escape fraction of ionizing photons**

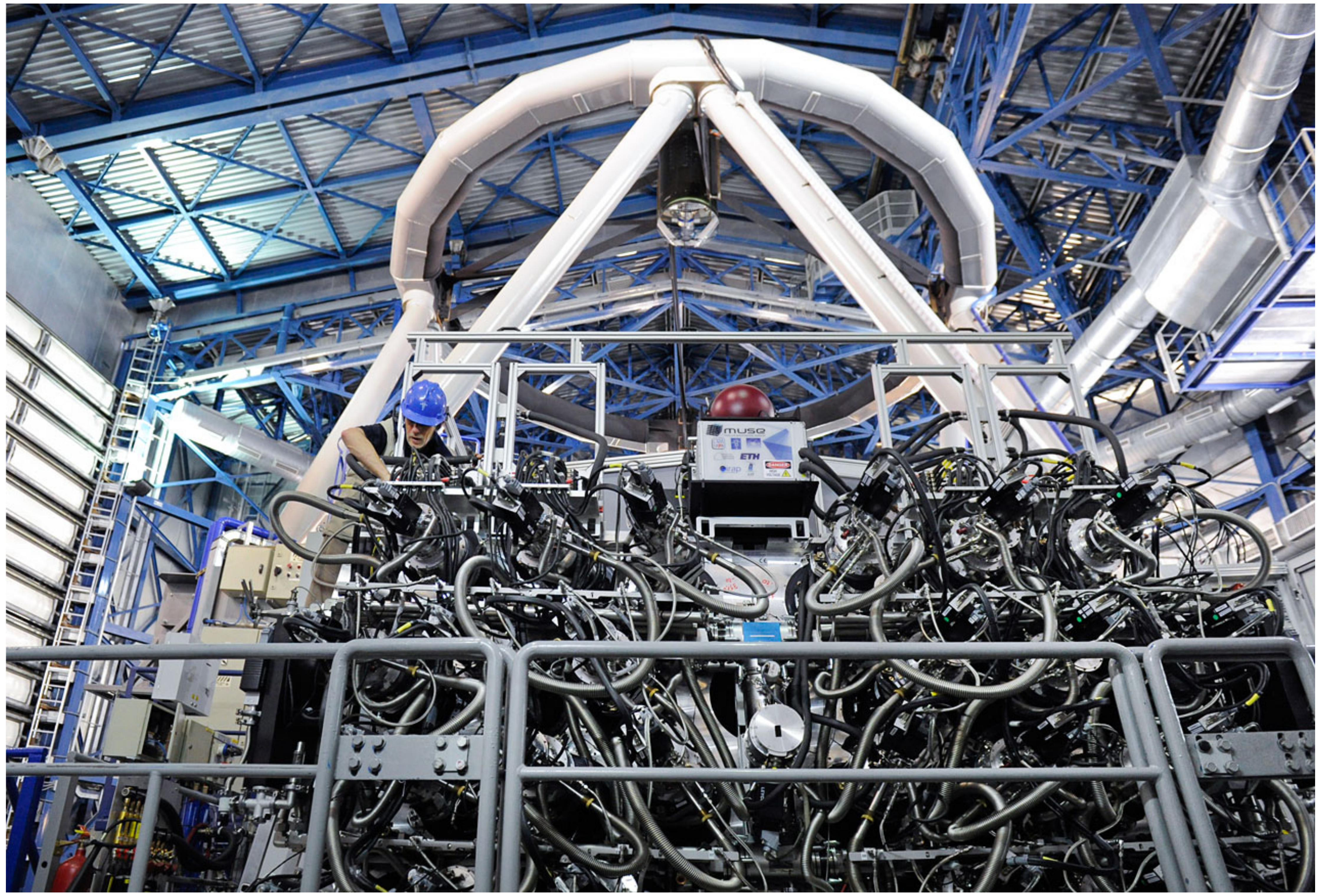
Verhamme+15+17
Izotov+21
Flury+22
Naidu+22



Multi Unit Spectroscopic Explorer (MUSE) data

Bacon+10





Credit: ESO

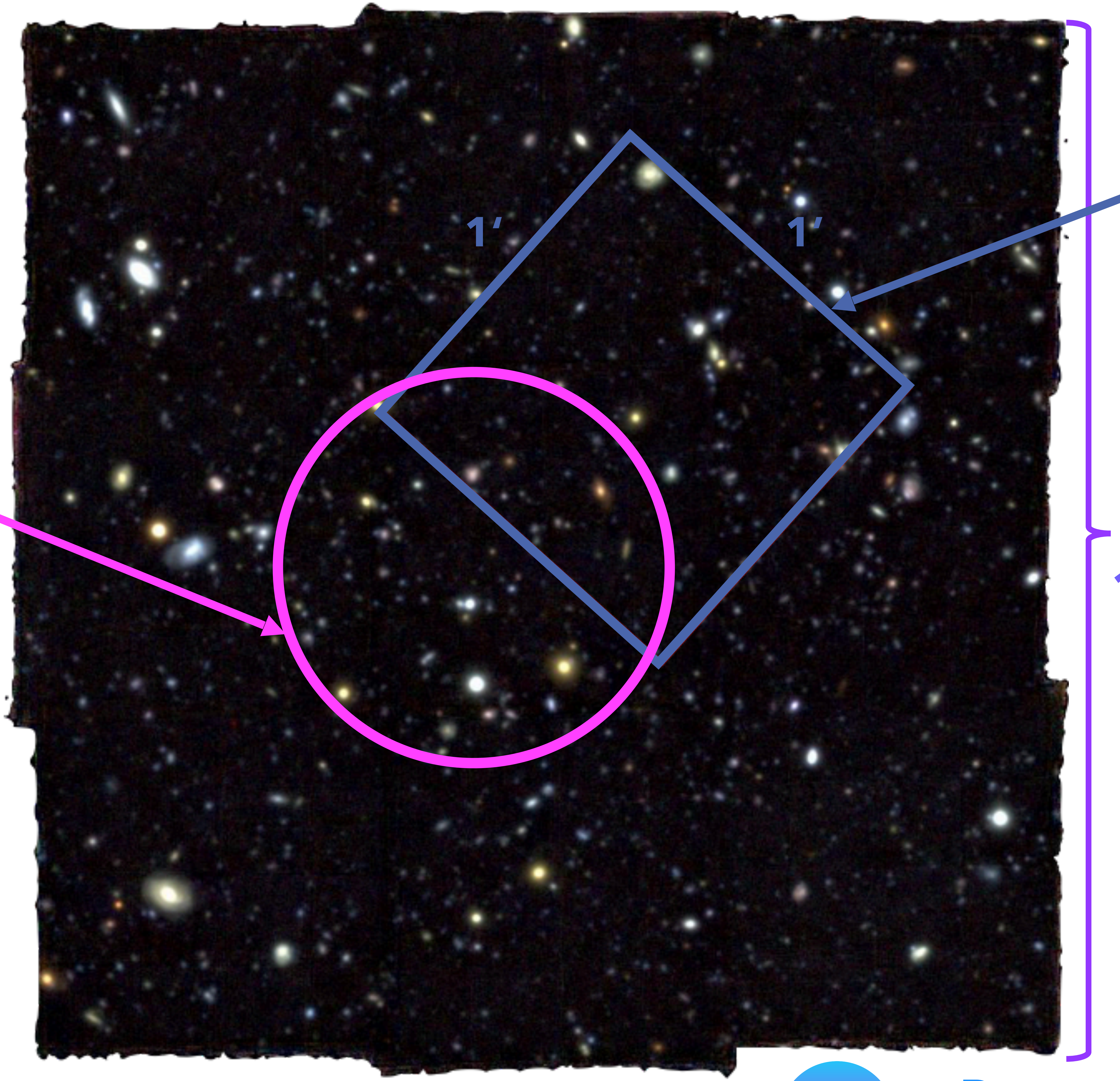
Spatial coverage of the cube: (1′×1′)

Spectral coverage: 465 nm to 930 nm

$(\Delta X, \Delta Y)$=(0.2",0.2") and $\Delta\lambda$=1.25Å

The MUSE Ultra Deep Field

Bacon+23
Bacon+17



Detection limits at 3σ:
$6.3 * 10^{-20} erg \, . \, s^{-1} \, . \, cm^2$

GTO (Guaranteed Time Observations)

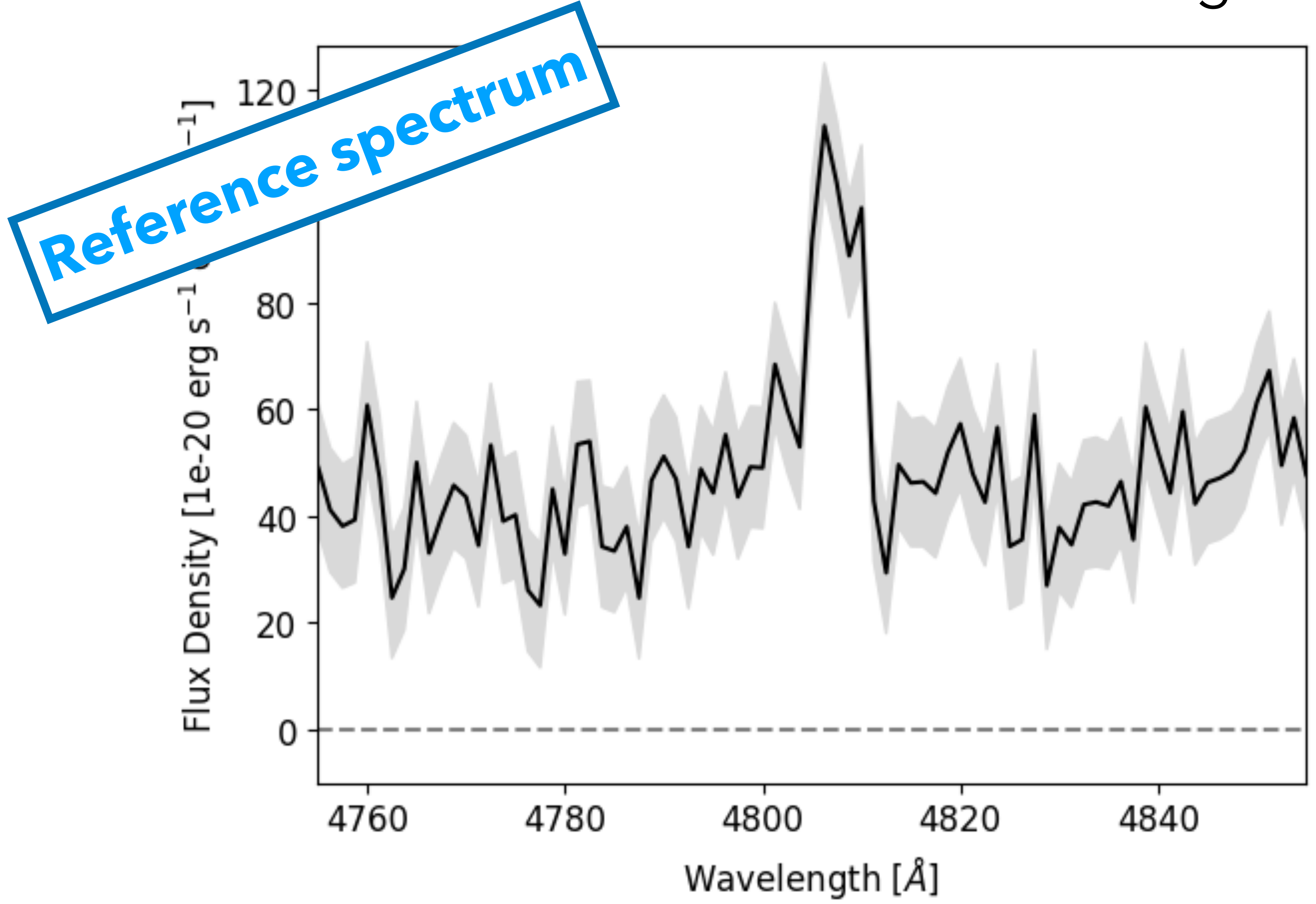
Parent sample of 504 LAEs
$2.8 < z < 6.6$

STEP 1: building rest-frame Lya spectra

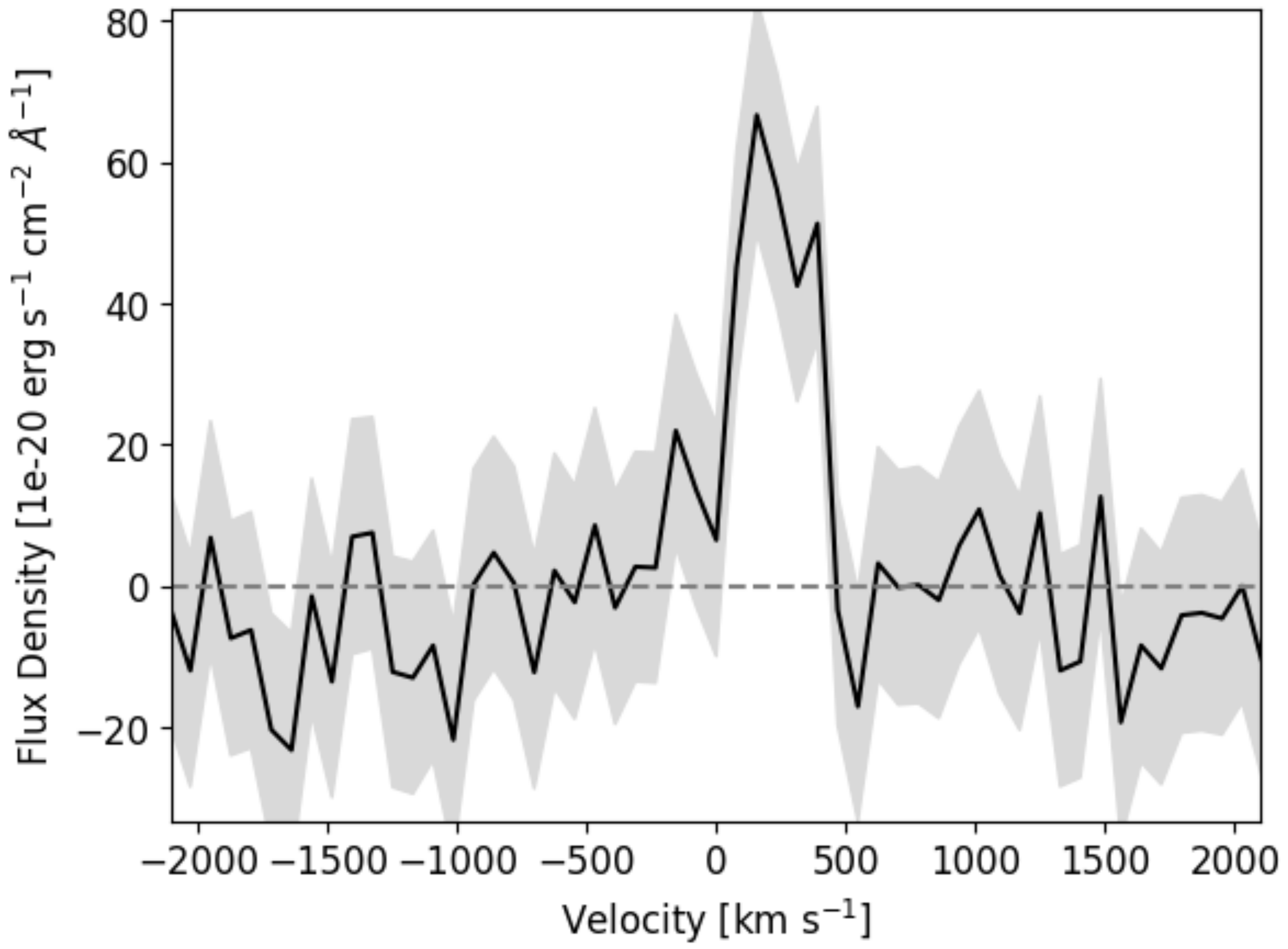
STEP 2: signal detection of the Lya line

STEP 3: classification

Continuum + observed wavelength



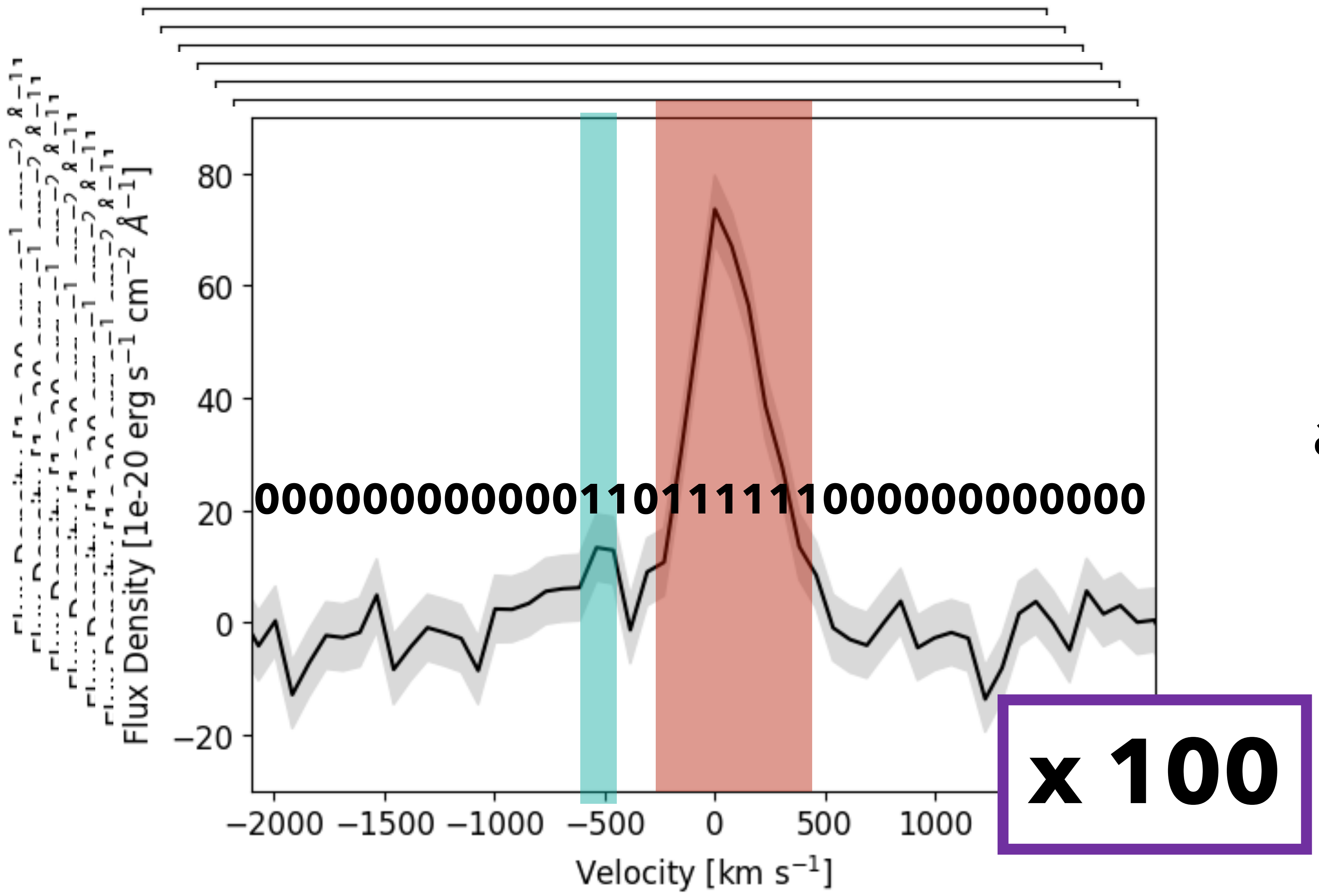
Continuum subtracted + rest-frame velocity



STEP 1: building rest-frame Lya spectra

STEP 2: signal detection of the Lya line

STEP 3: classification



Each pixel is assigned a random value following a gaussian distribution of its variance value

Derivation of the SNR spectrum of each perturbed spectrum

Each SNR perturbed spectrum is analyzed:

- **determination an area of signal if, for at least 2 adjacent pixels, SNR >= 1**
- the pixels in the area(s) of signal are assigned a value of 1, otherwise 0

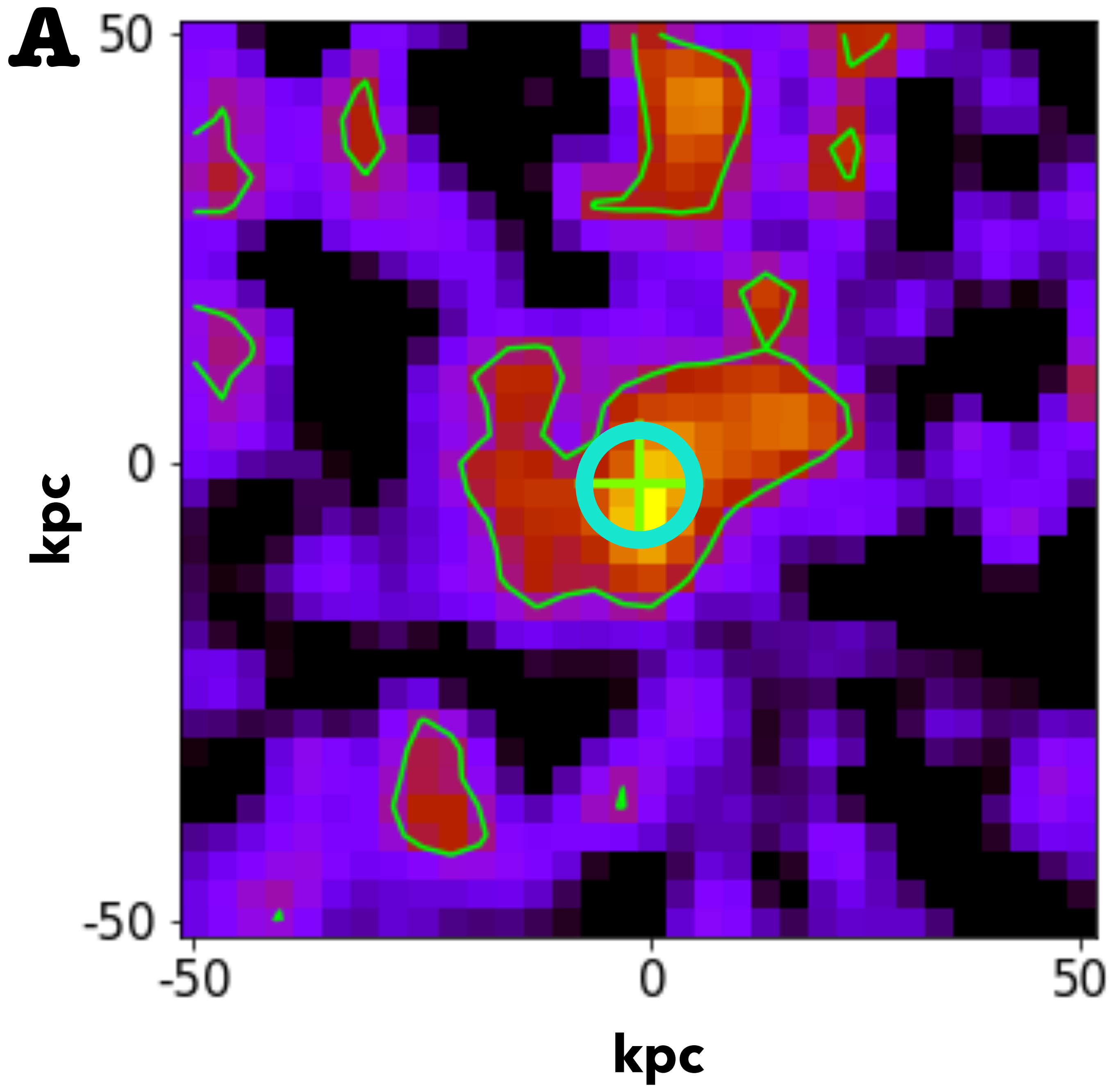
STEP 1: building rest-frame Lya spectra

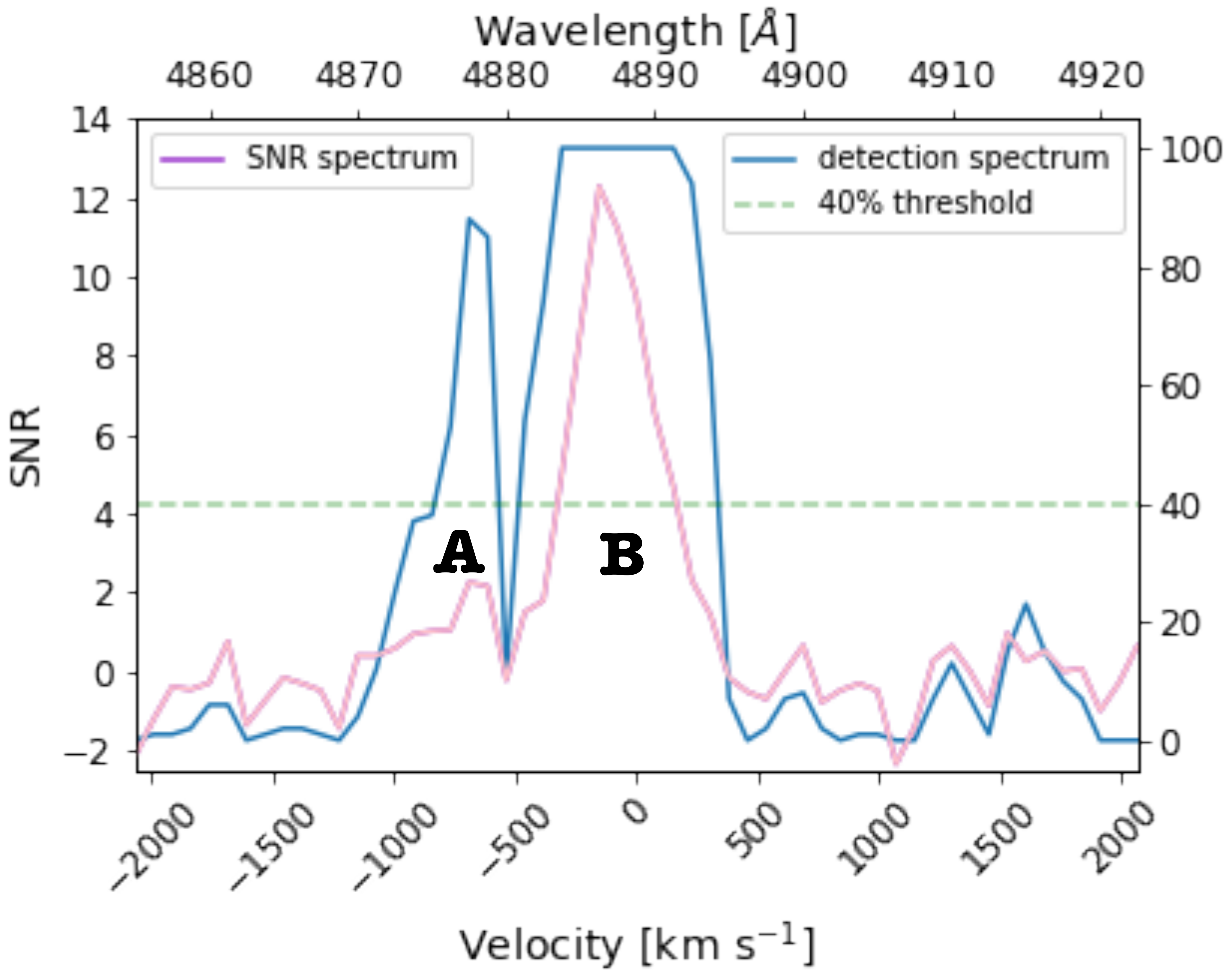
STEP 2: signal detection of the Lya line

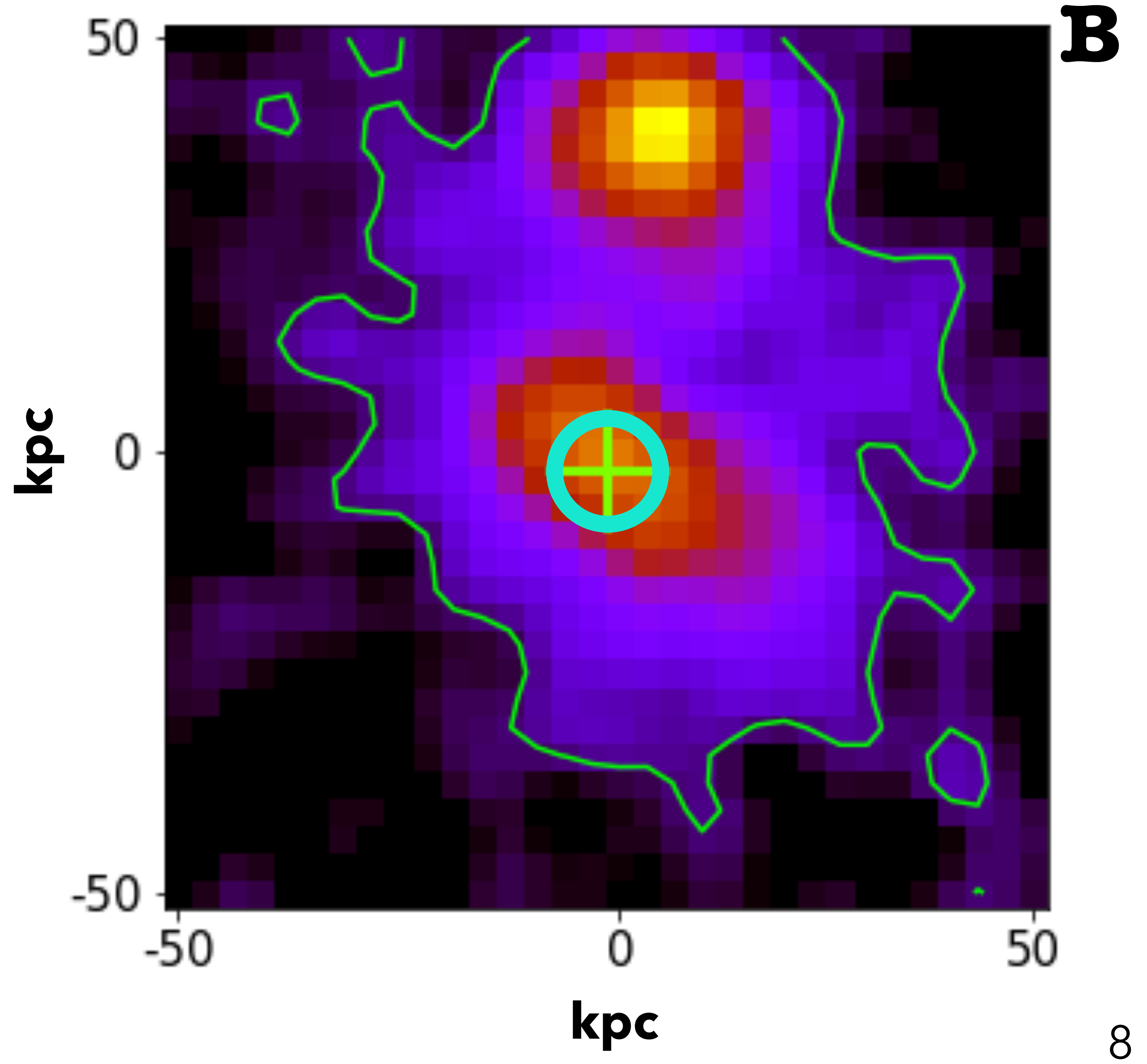
STEP 3: classification

Detection spectrum:

- sum of the values for each pixel
- if the detection spectrum reaches 100, it means the pixel has been considered in an area of signal of each of the 100 perturbed spectra



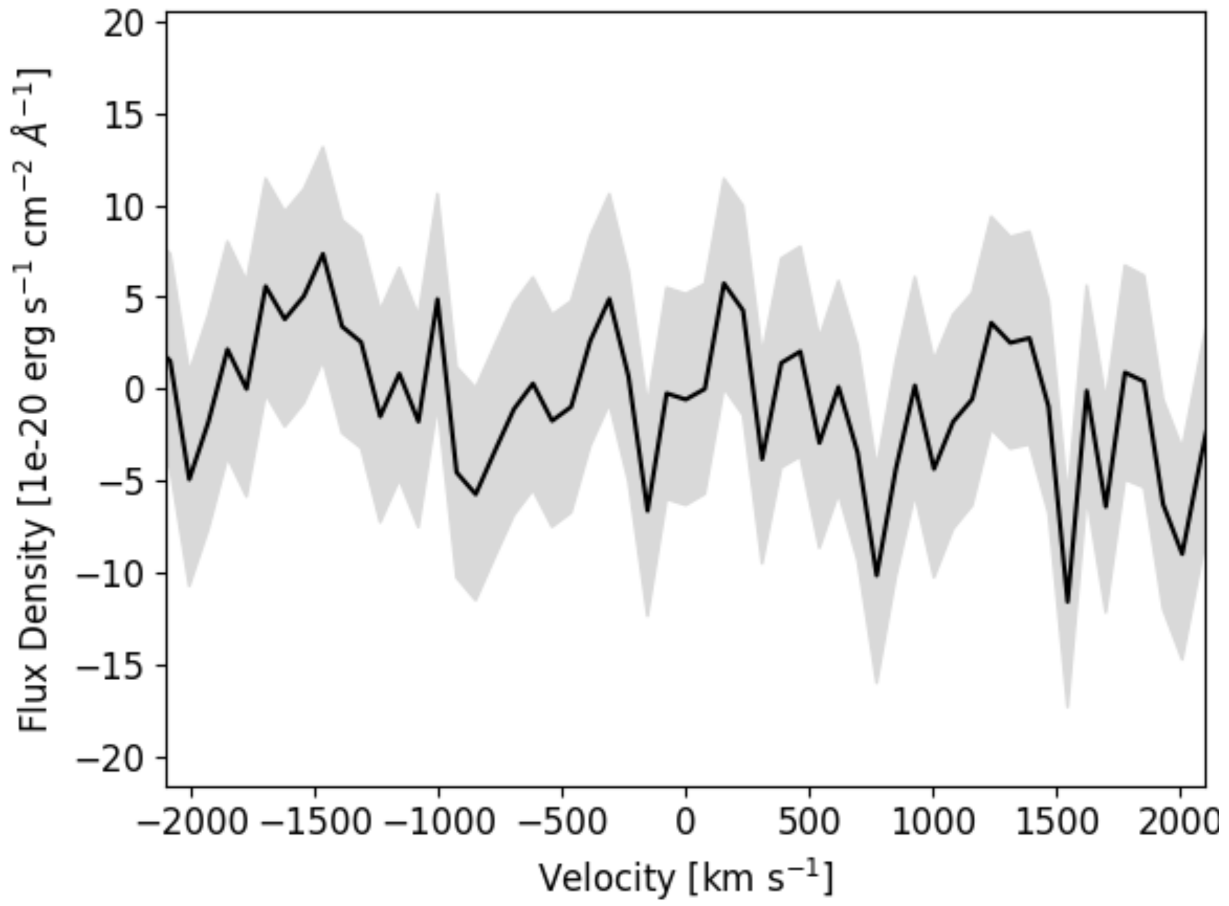


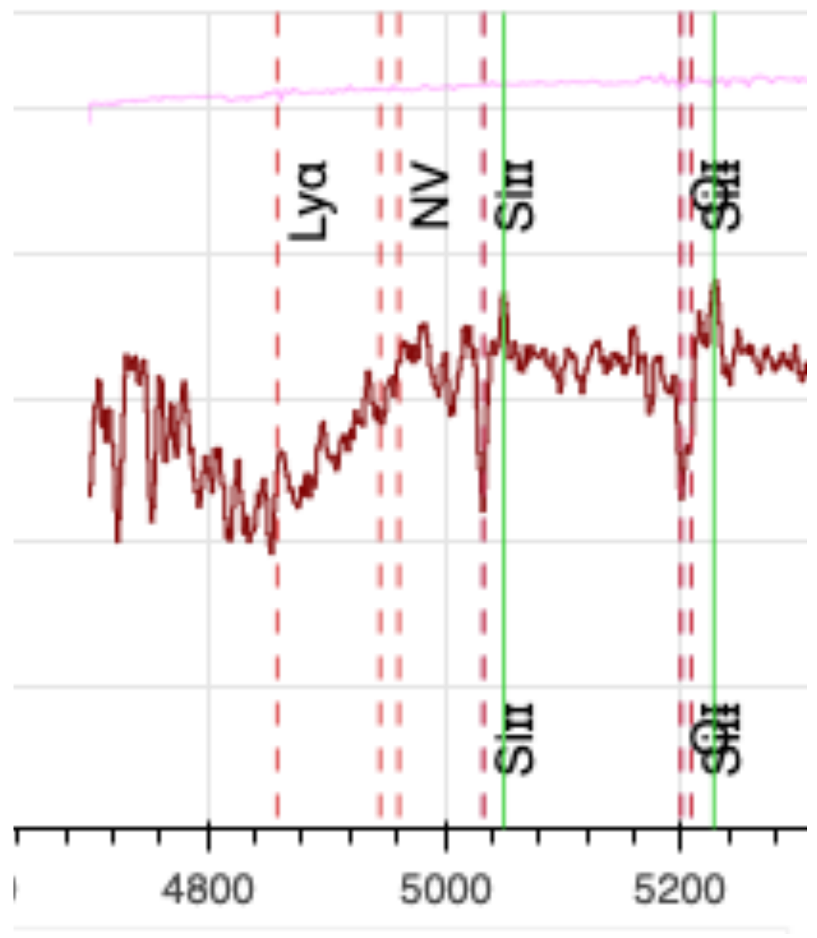


1 arcsec diameter aperture $SNR \geq 5$

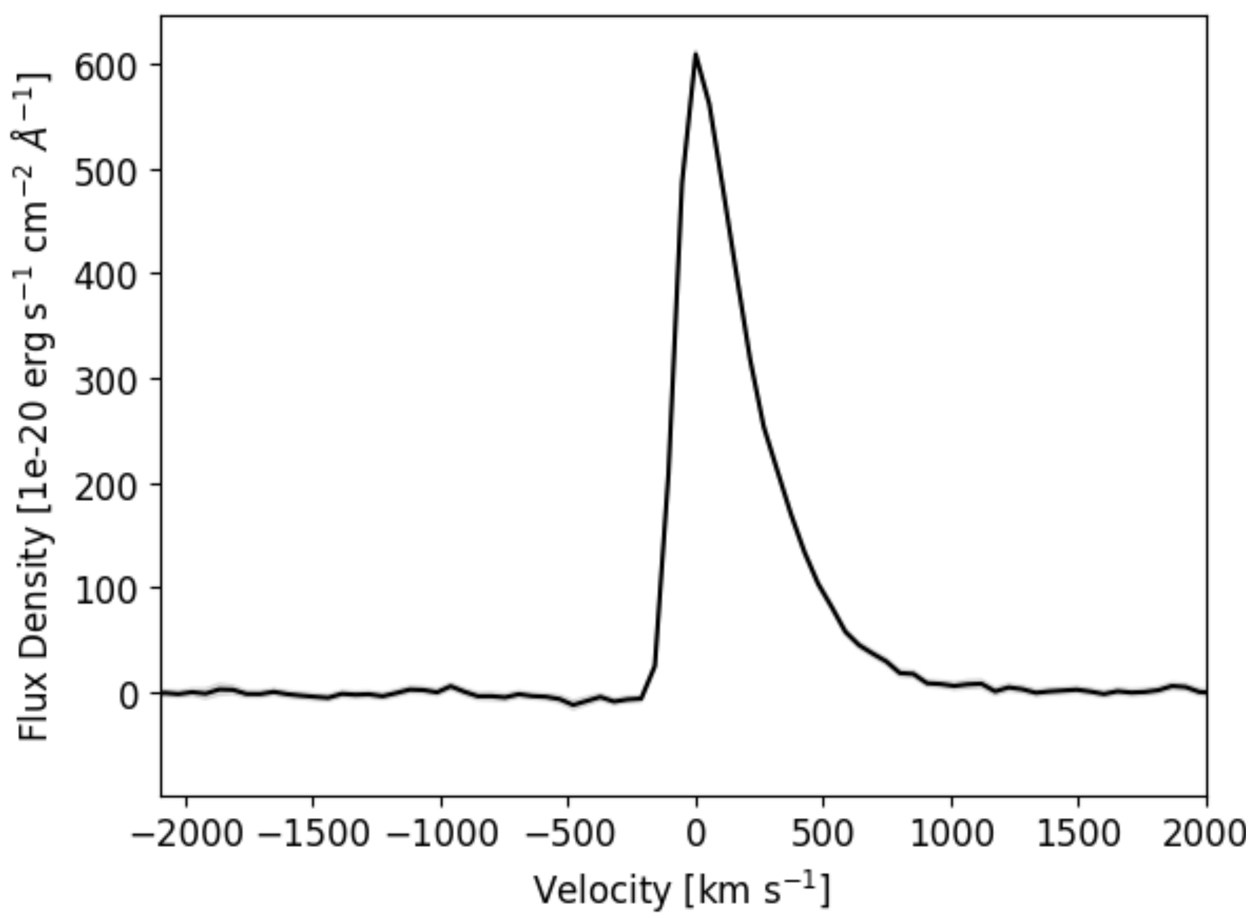
Classification distribution

No-peak
11/504
3%

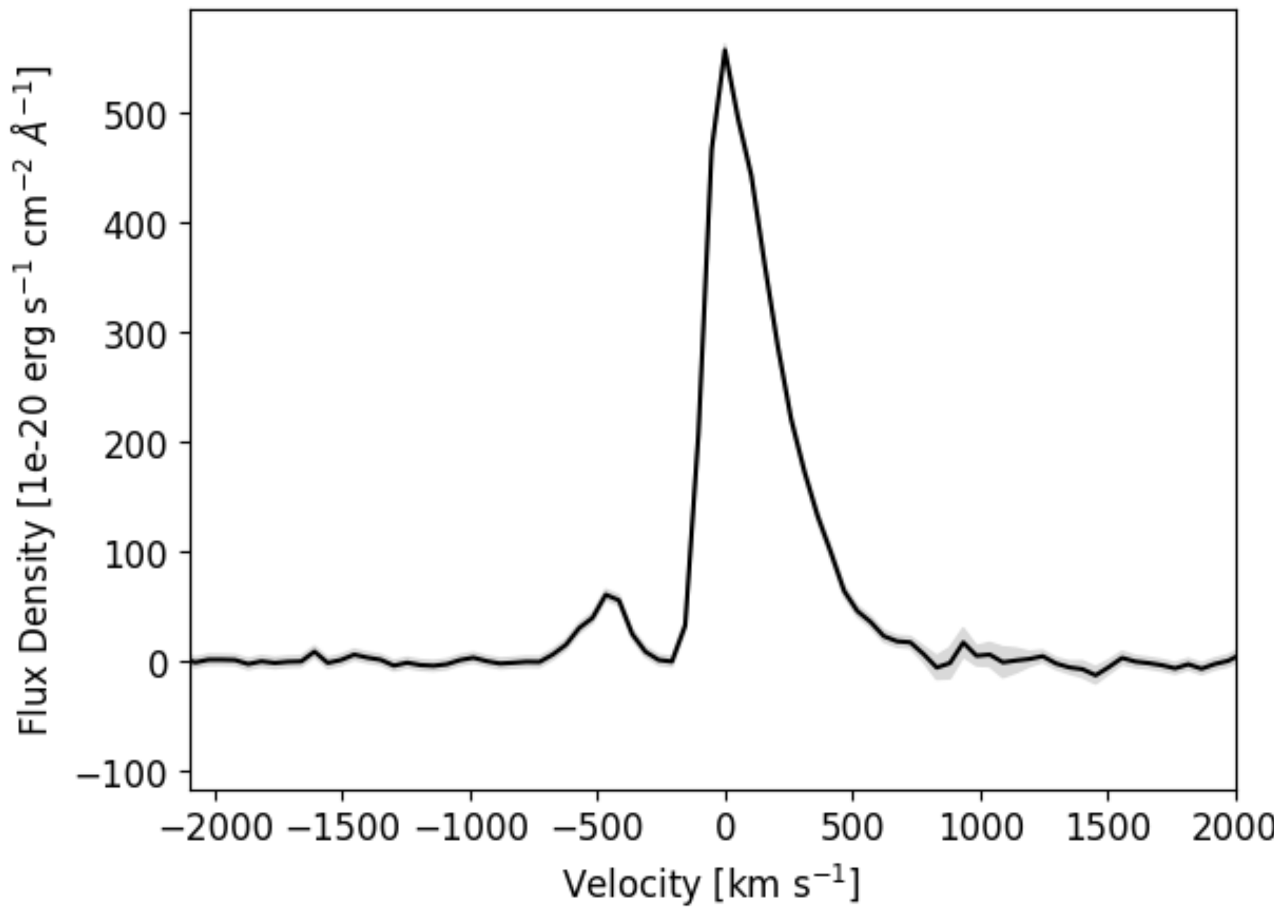


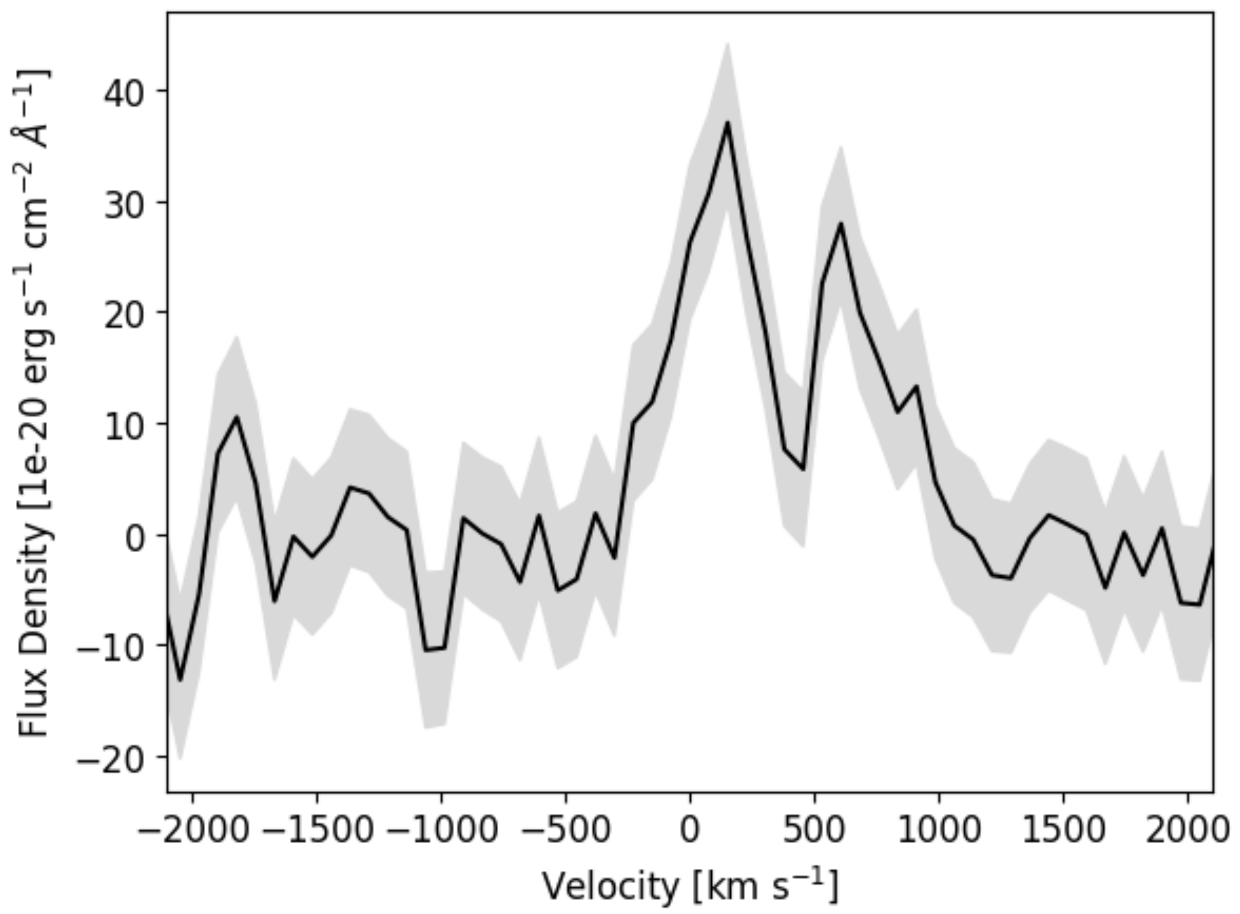


Single-peak
213/504
42%

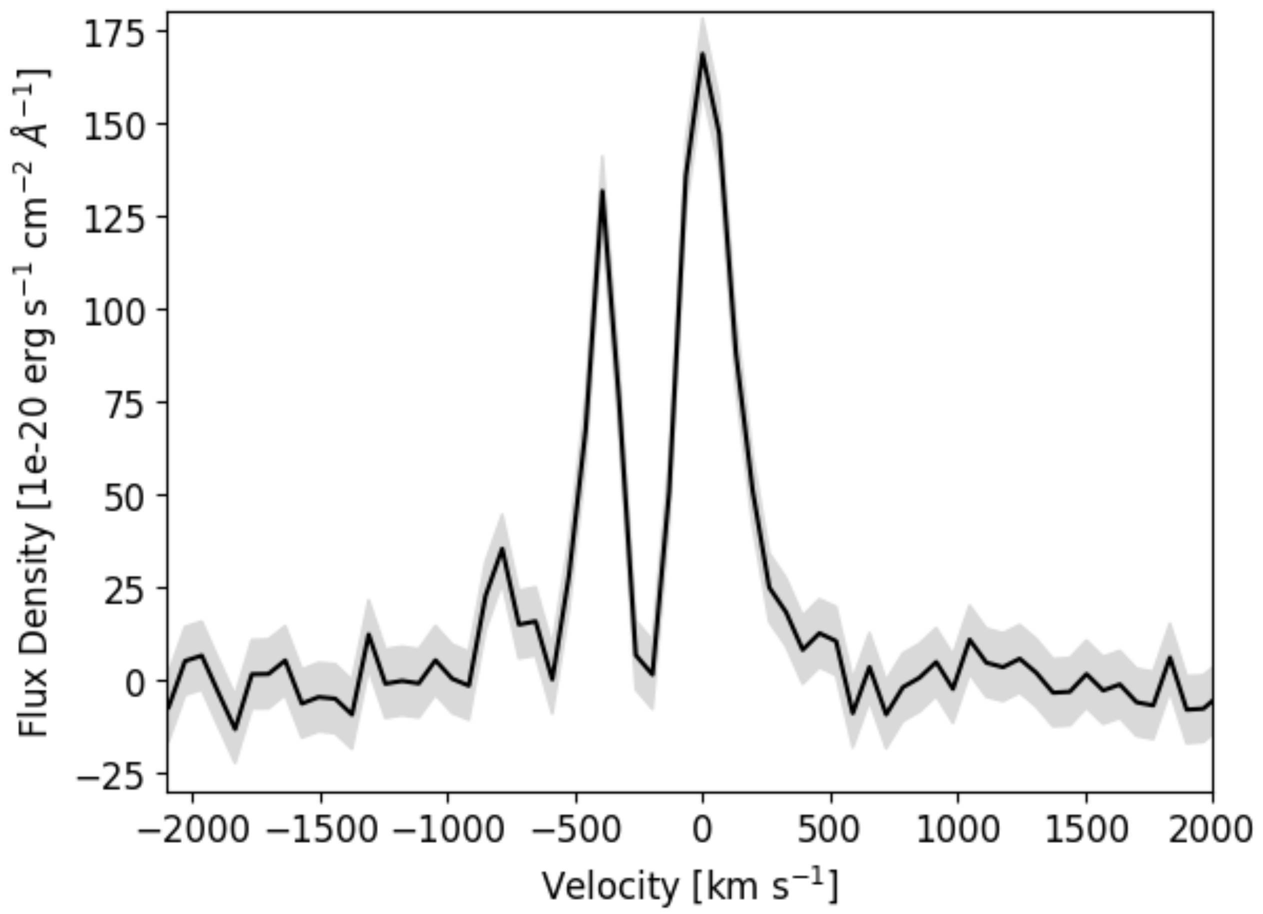


Double-peak
251/504
50%



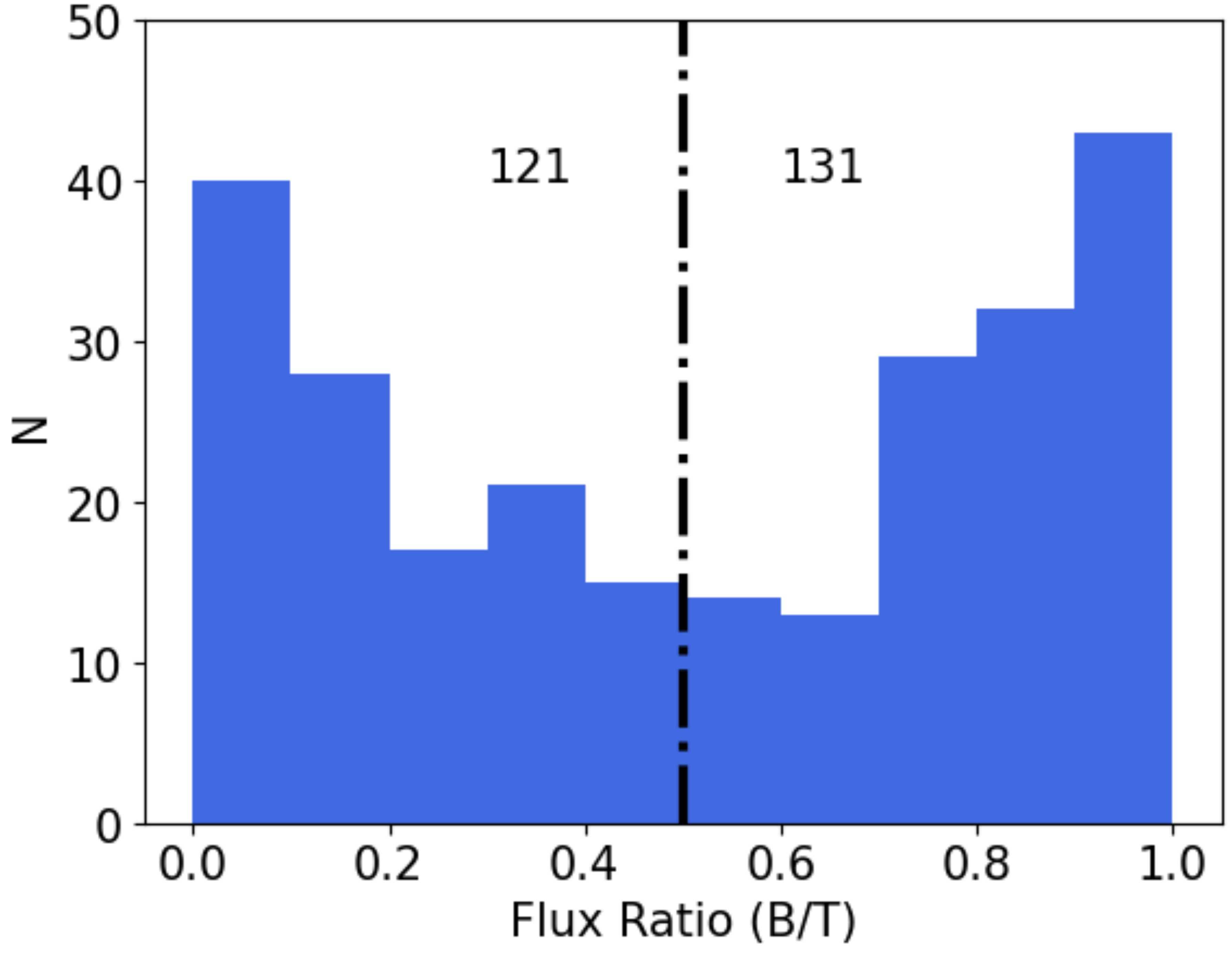


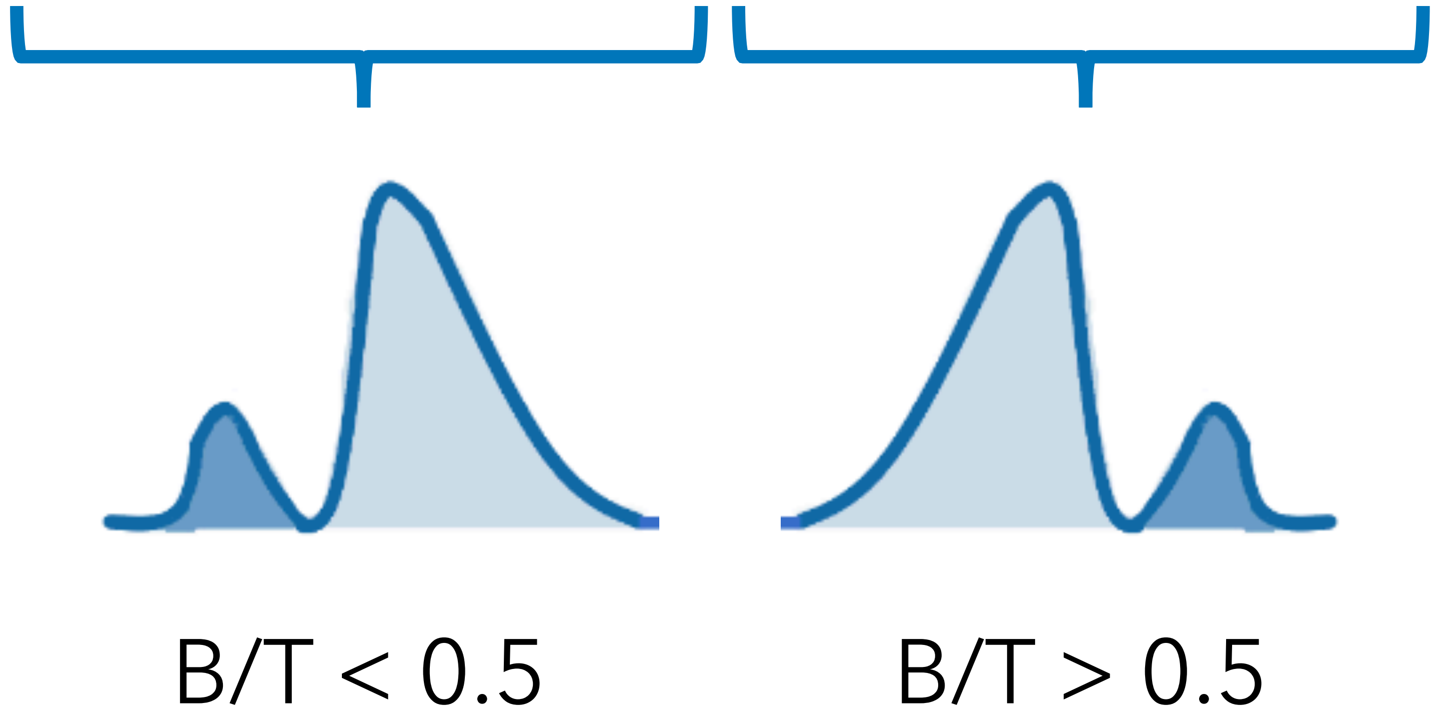
Triple-peak
24/504
5%



Gas kinematics in the ISM/CGM of galaxies

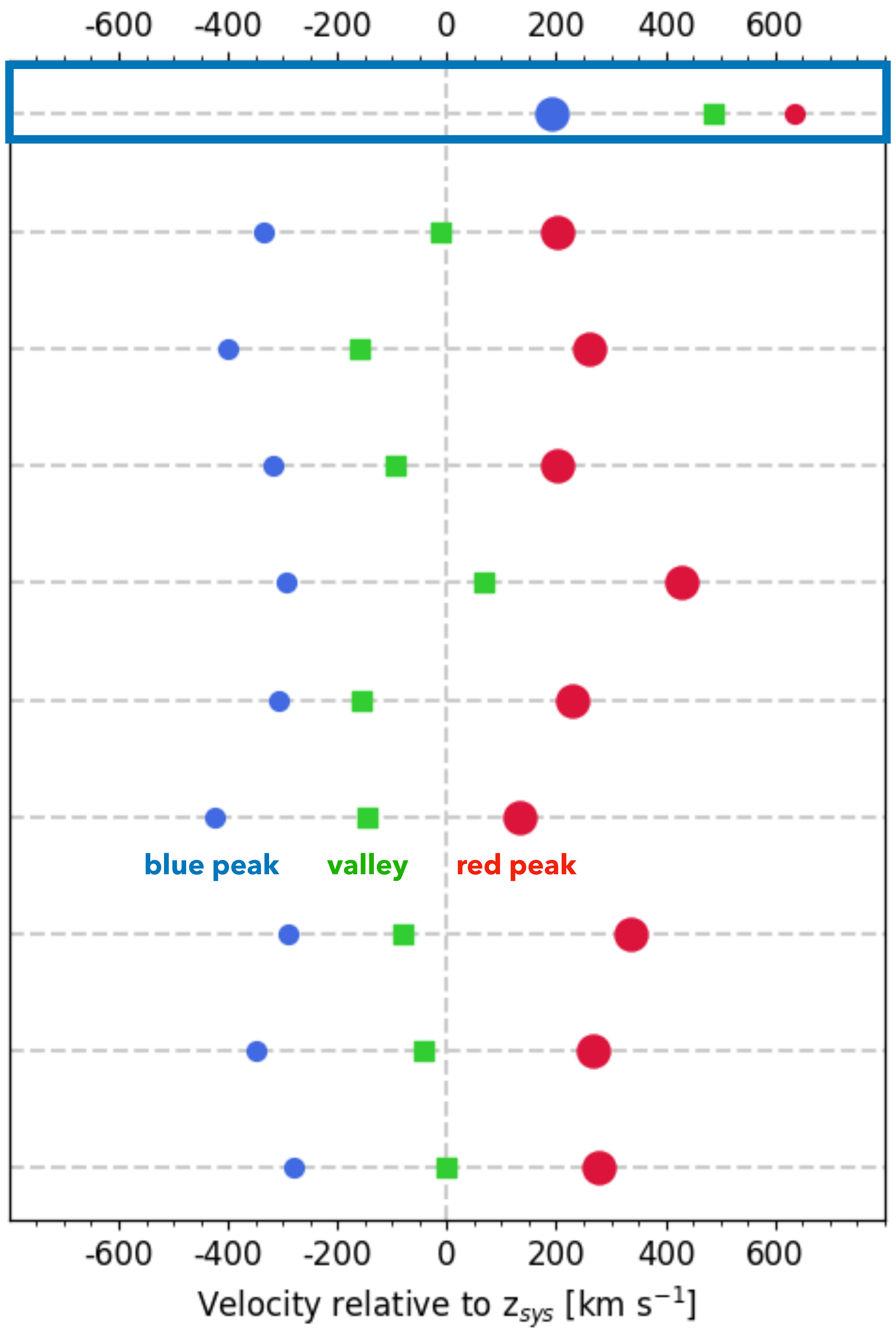
Vitte et al. in prep





52% of the double-peaks have a **blue peak stronger than the red one.**
It may indicate signatures of **inflows.**

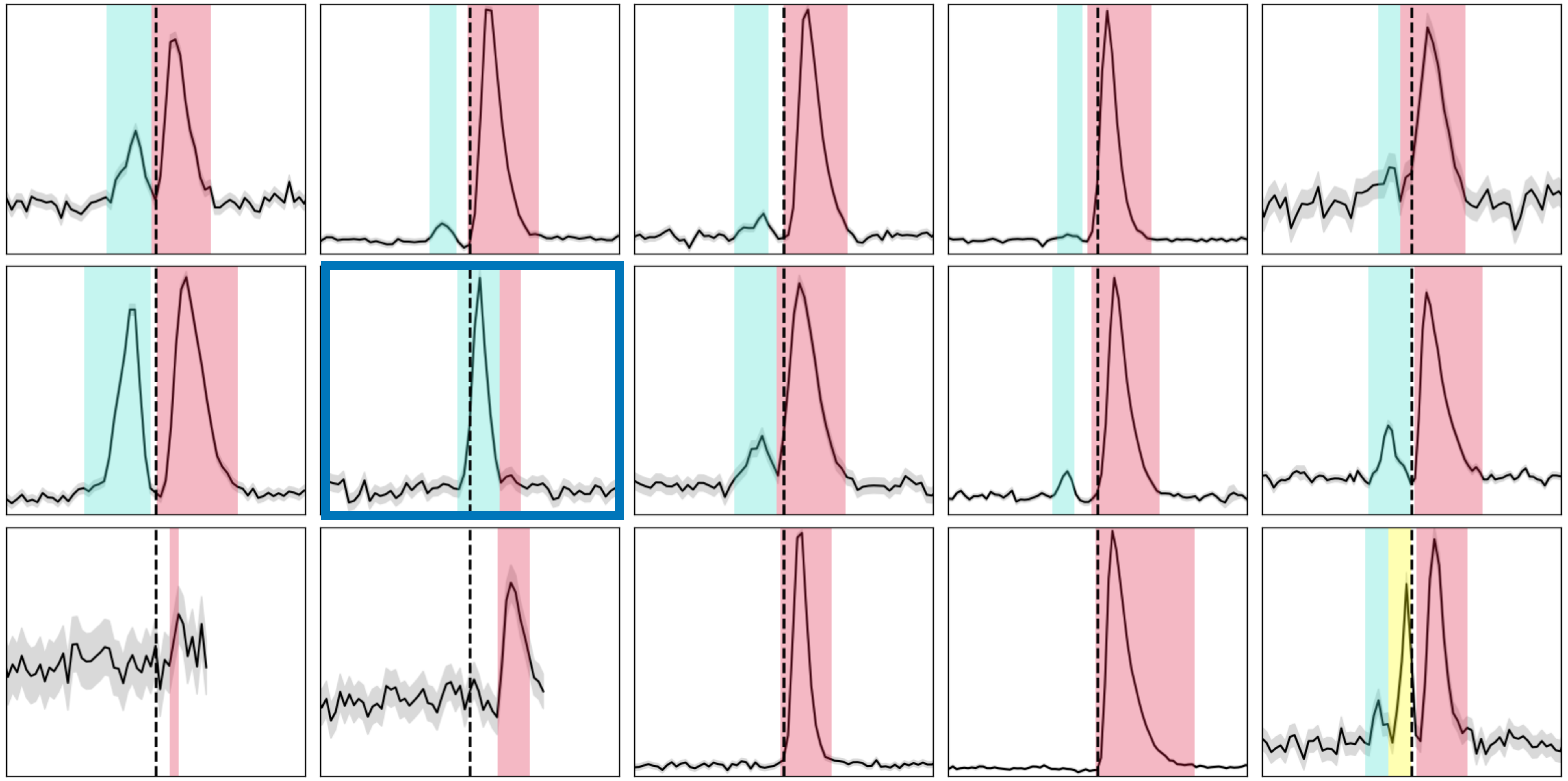
Warning! Lack of systemic redshifts



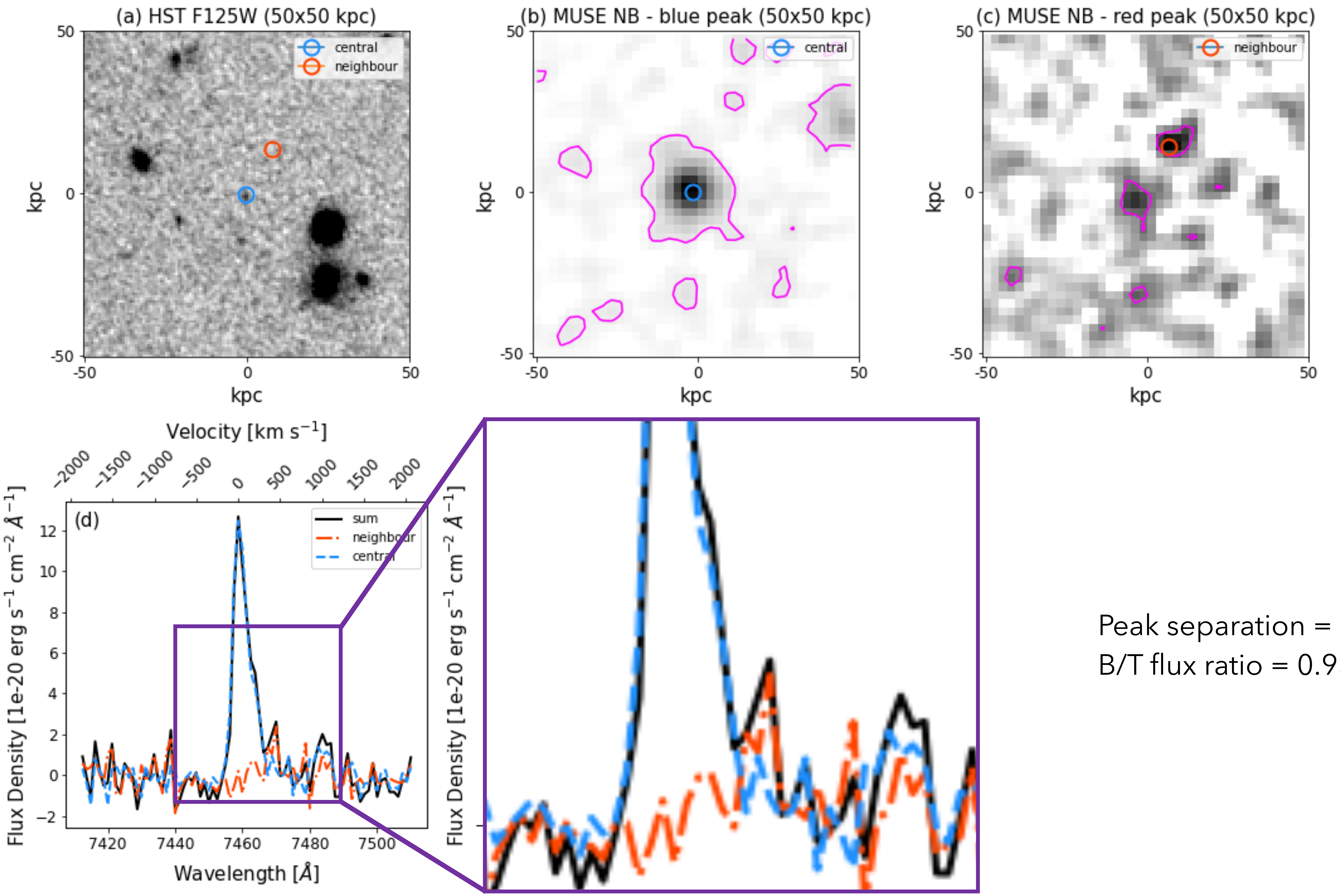
Only 15 LAEs have the systemic redshift from nebular lines in the MUSE spectra

The systemic redshift is needed to confirm the nature of the double-peaked Lya lines we observe:

- coming from radiative transfer?
- two red peaks or two blue peaks?
- satellite?



Satellite contamination



Peak separation = 401 km/s
B/T flux ratio = 0.95

Universal fraction of double-peaks

Fraction of double-peaked LAEs of 49% (106/217)

With:

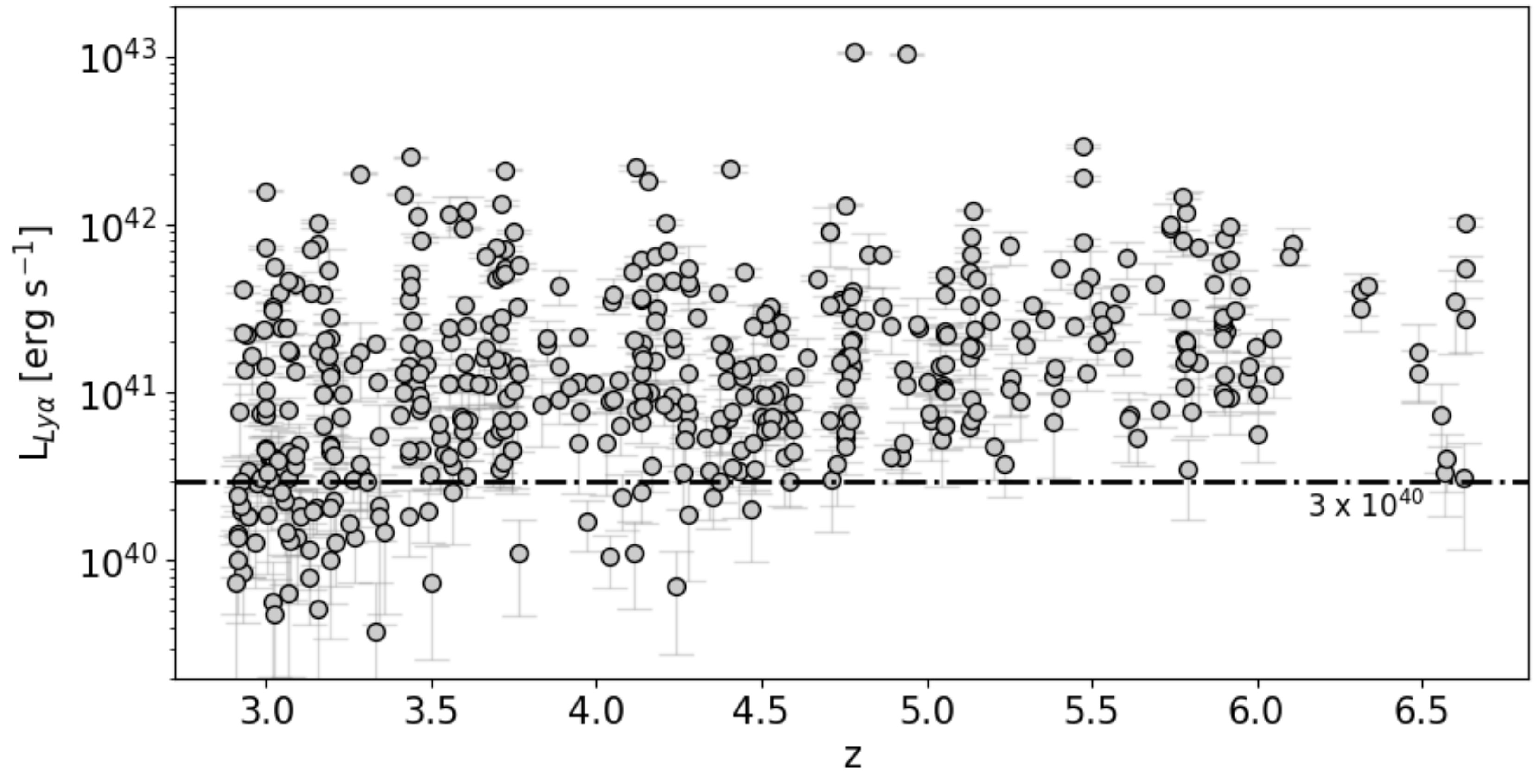
$$L_{Ly\alpha}\,[erg/s] \geq 3 \times 10^{40}$$

Peak sep $\geq 150\,km\,s^{-1}$

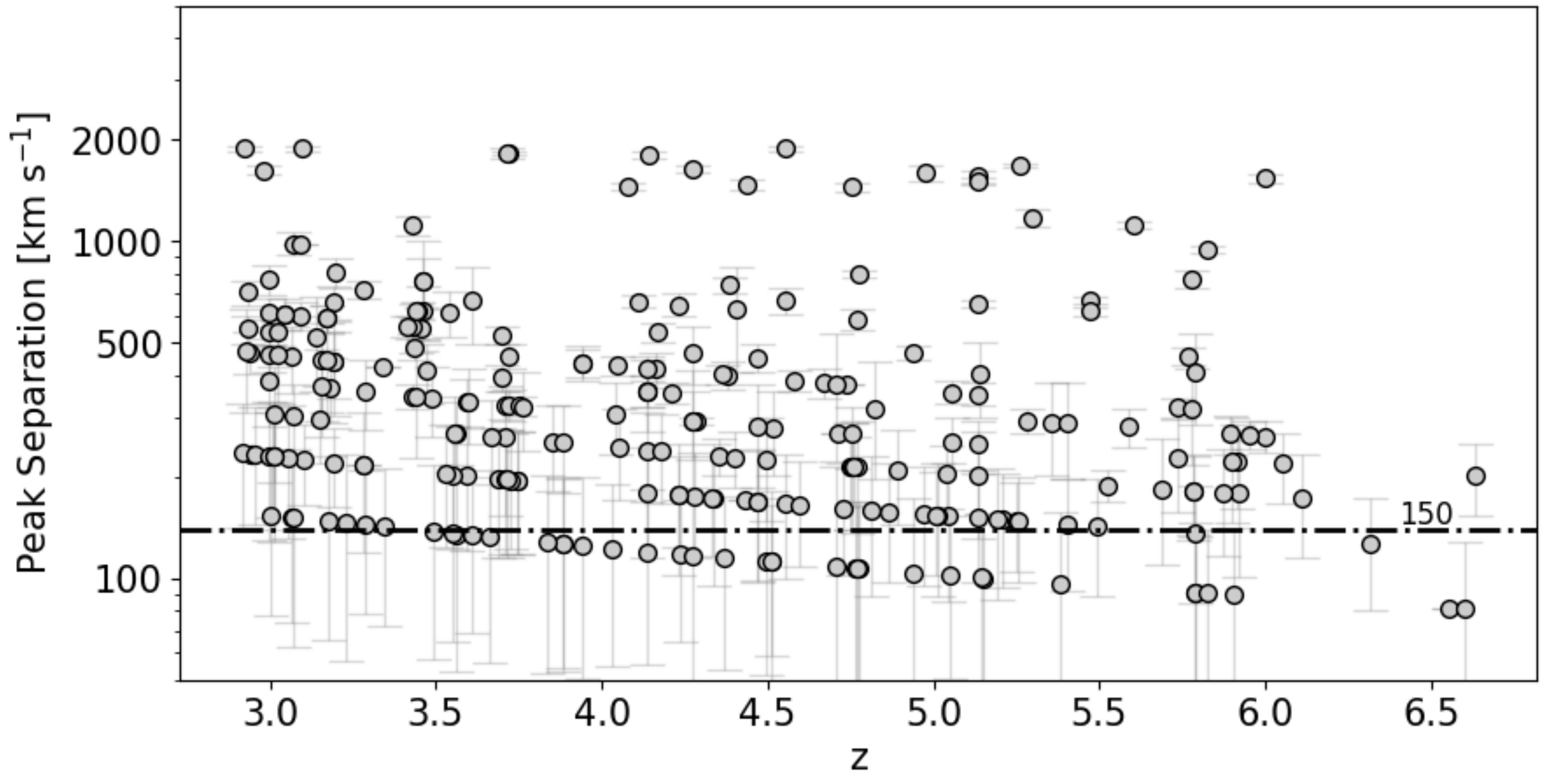
$SNR \geq 7$ equivalent to $1/7 \leq B/T \leq 1 - 1/7$

Complete parent sample

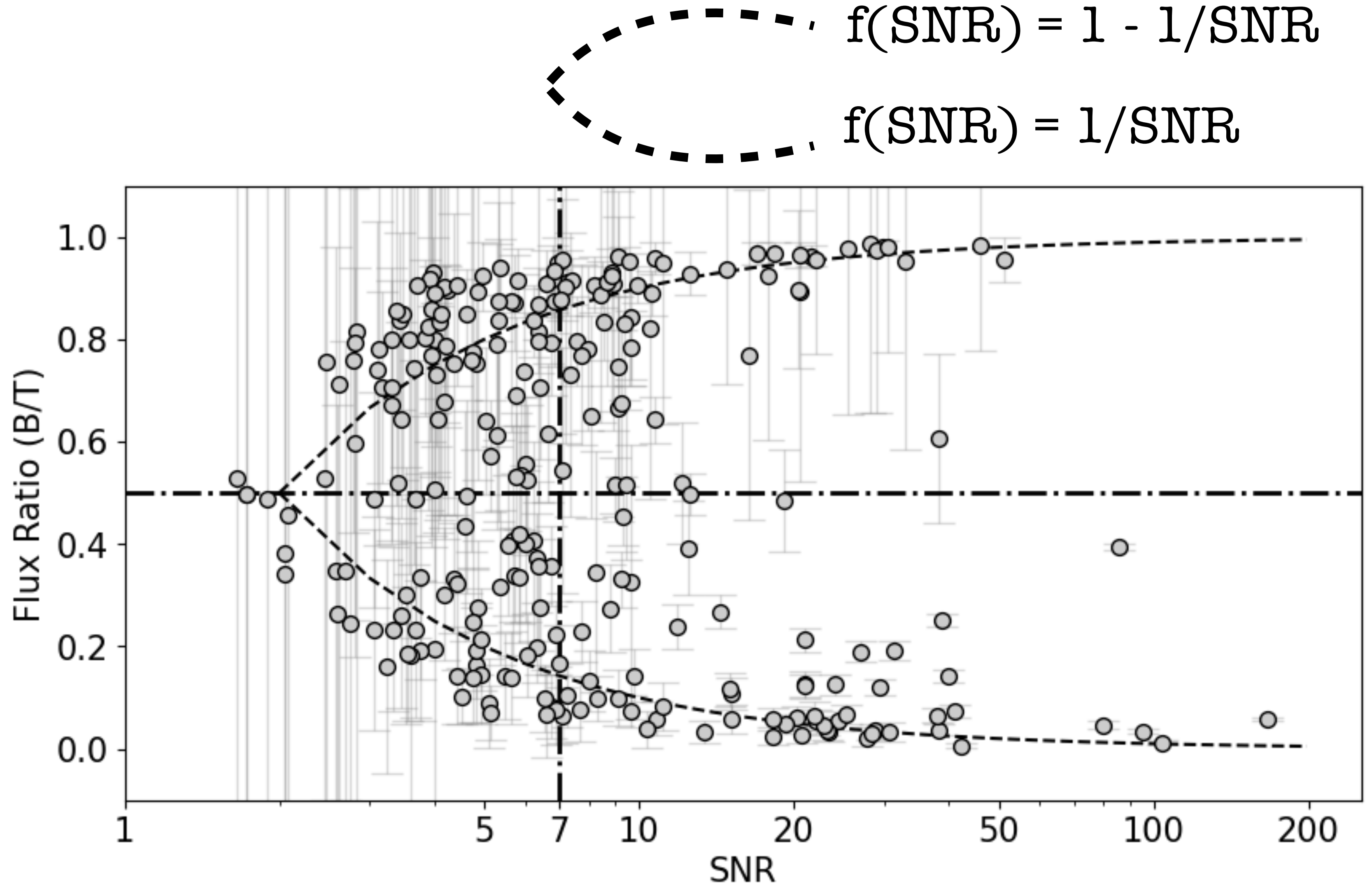
Observational limitations:



Redshift dimming



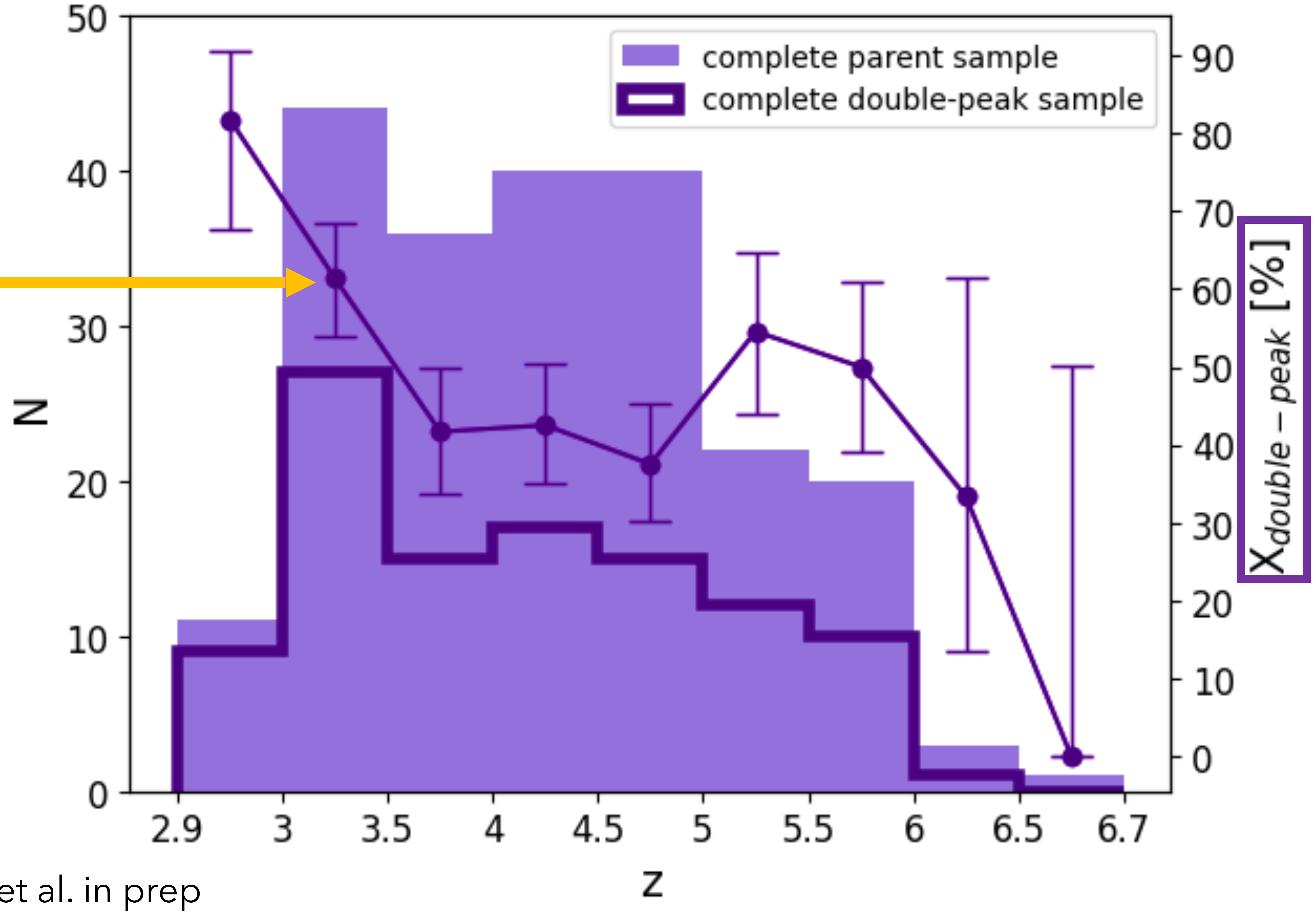
LSF+redshift effect



B/T cannot be < 1/SNR

Study of the IGM opacity

Fraction of double-peaks compared to the complete parent sample



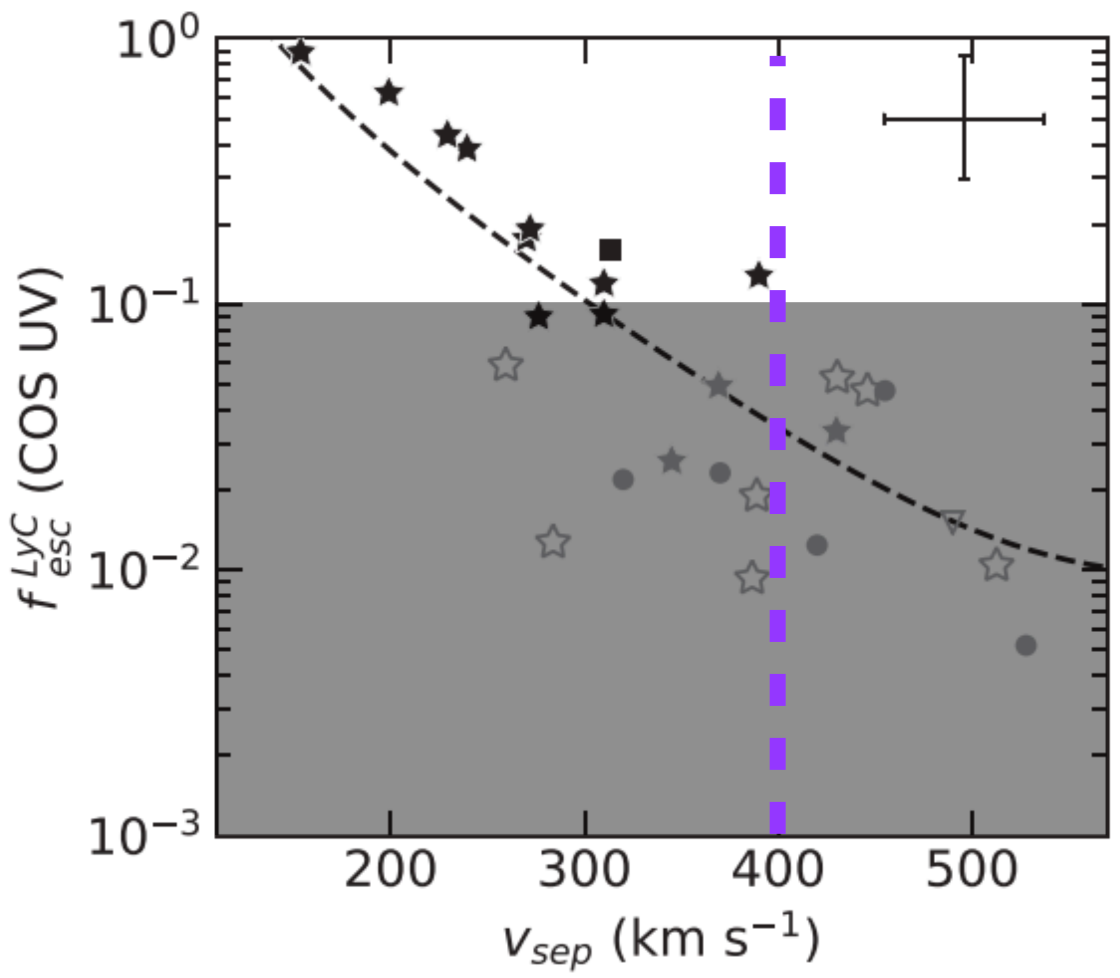
Vitte et al. in prep

The fraction of double-peaks decreases with redshift: **from ~80% at z~3 to 0% at z>6.5**

The strong evolution of the fraction of double-peaks with redshift opens new horizons for the study of **the IGM opacity** (Hayes+21)

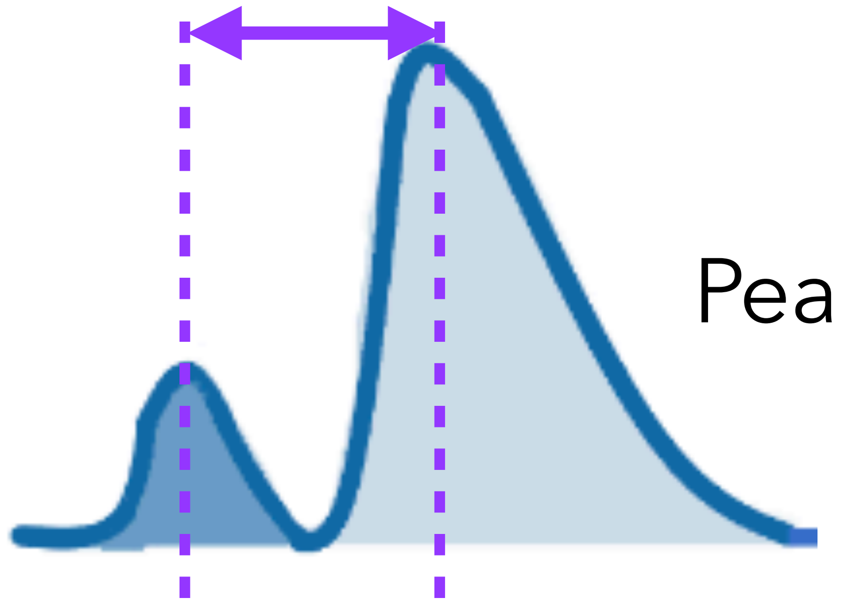
Leaker candidates

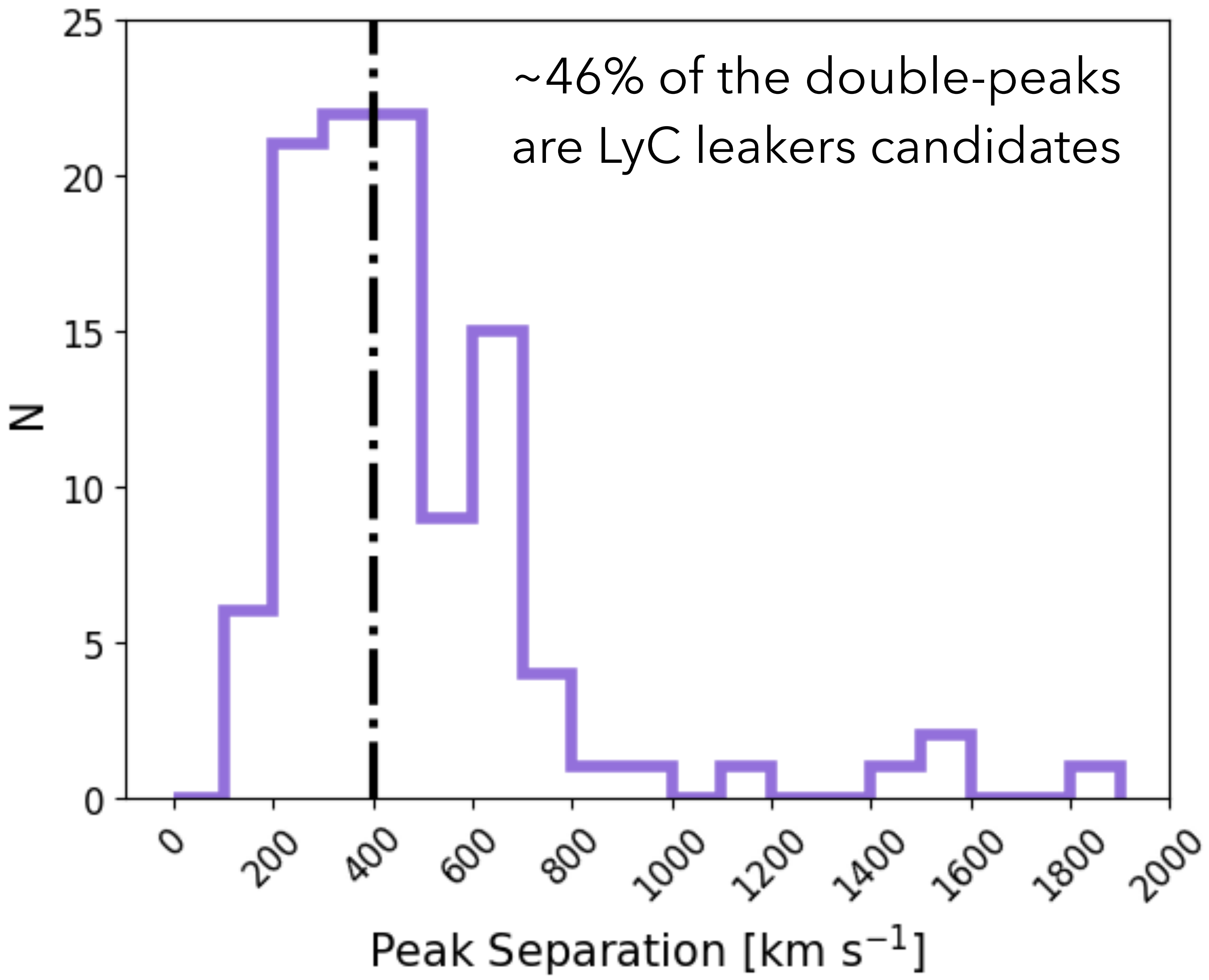
Flury+22b



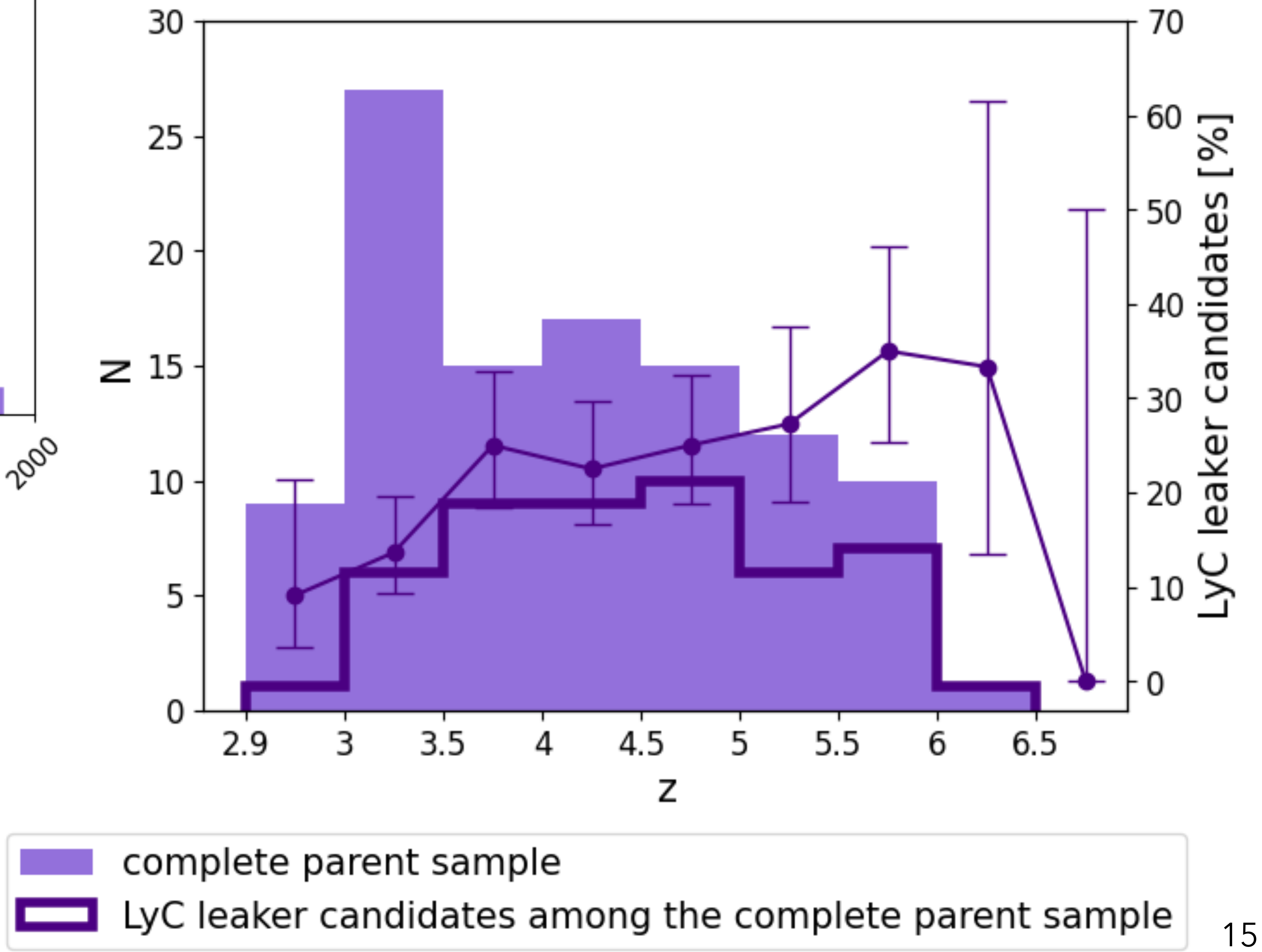
Objects above 10% of Lyman continuum escape
All have peak sep below 400 km/s

23% of the complete parent sample are candidates for LyC leakage





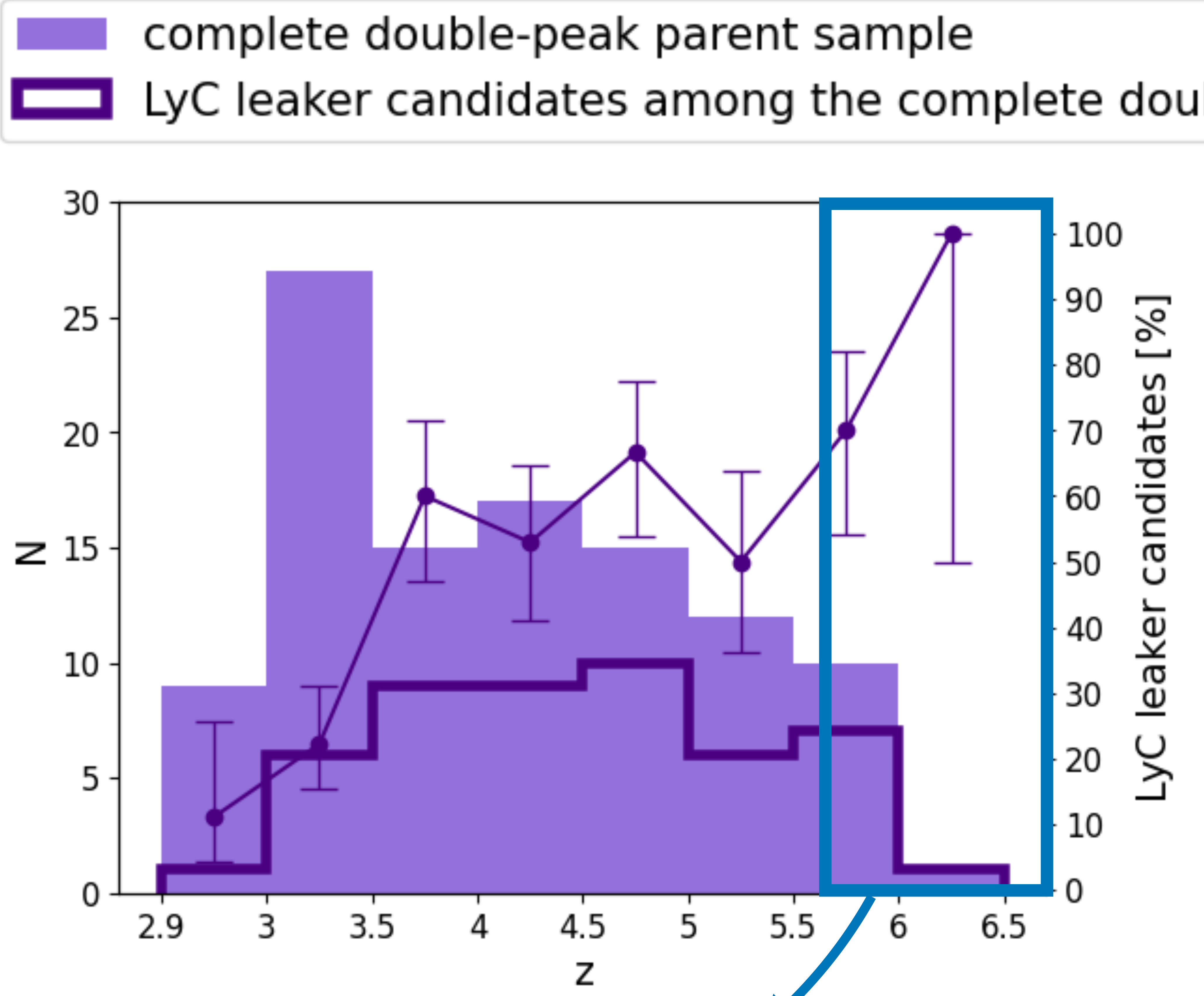
Vitte et al. in prep



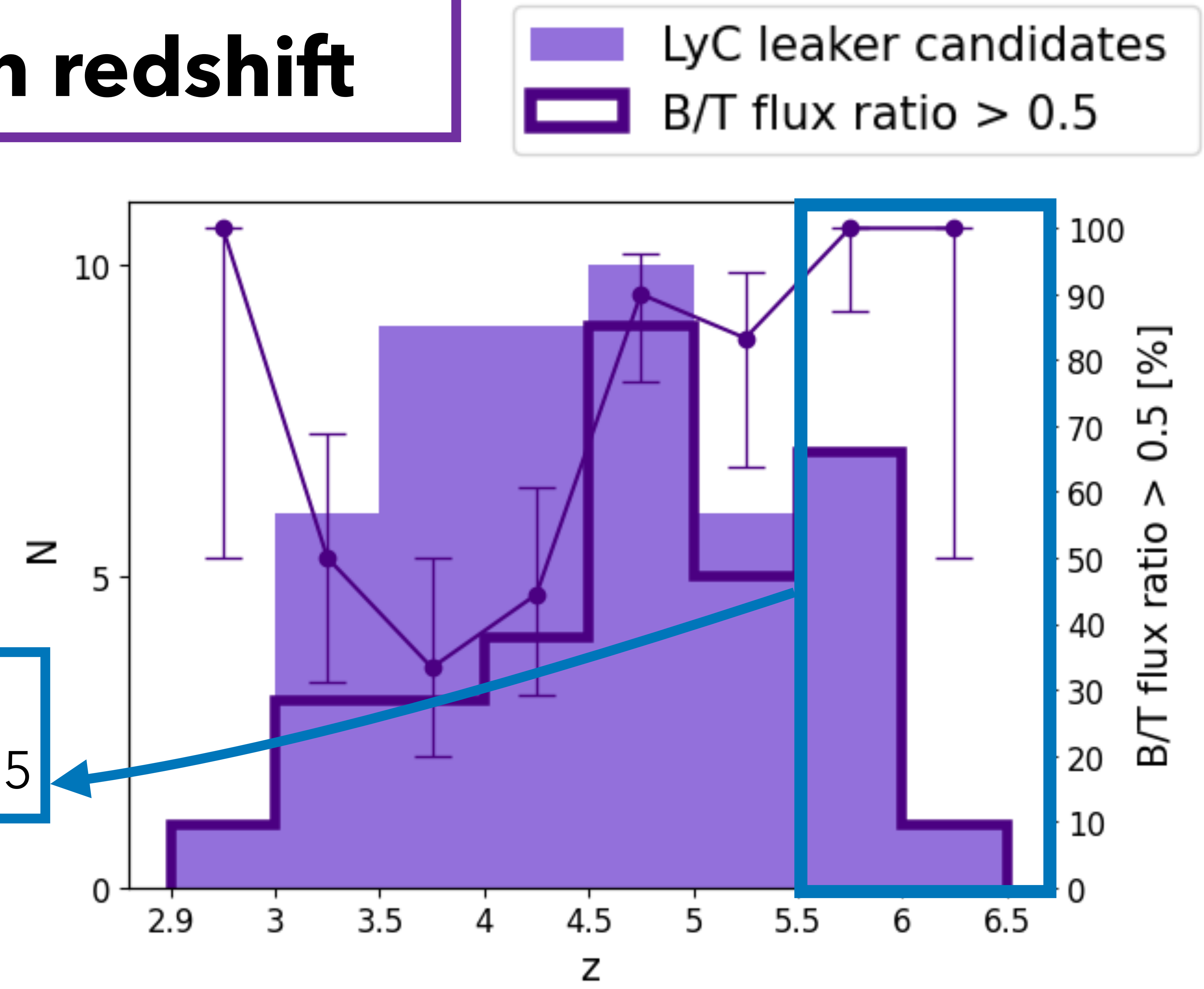
Potential increase of the fraction of LyC leaker candidates with redshift

Leaker candidates

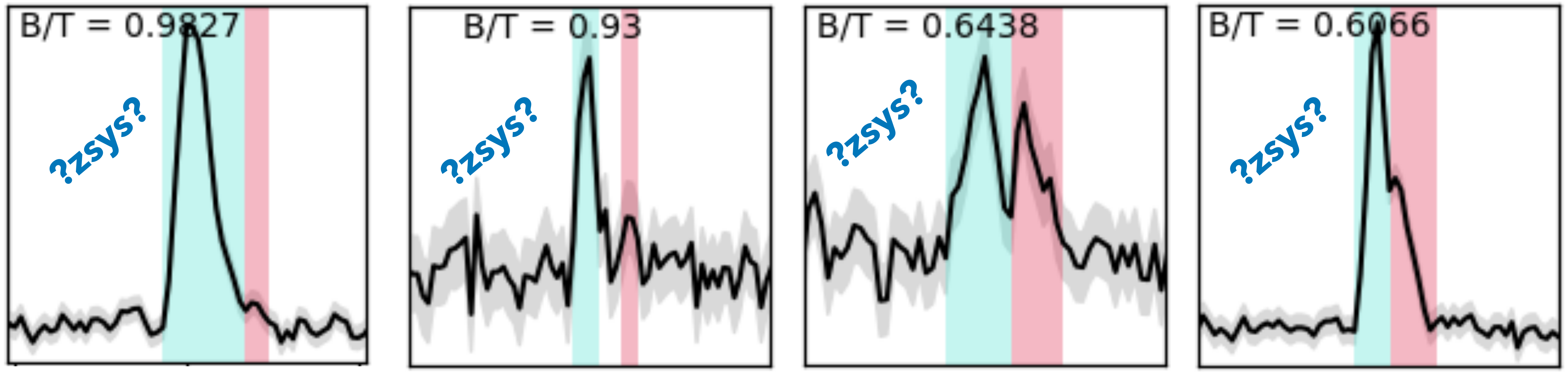
Potential increase of the fraction of LyC leaker candidates with redshift



At z > 5.5, more than half of the double-peaks of the complete parent sample is candidate for LyC leakage



B/T > 0.5 for all the objects at z > 5.5



Summary

➢Aim: Study of exotic LAEs and especially with a **double-peak spectral profile**

➢Data: **MXDF**, deepest data observed by MUSE within a redshift range between **2.8** and **6.6**

➢Method: **Classification Method** dividing the parent sample into 5 categories

➢Result 1: **Double peaks** represent **49%** (106/217) of the sample with $SNR \geq 7$, $L_{Ly\alpha}\,[erg/s] \geq 3 \times 10^{40}$ and $v_{sep} \geq 150\,km\,s^{-1}$

➢Result 2: The fraction of double-peaks decreases with redshift: **from ~80% at z~3 to 0% at z>6.5**, interpreted as **IGM opacity**

➢Result 3: **Half of the double peaks** are candidates for **Lyman-continuum leakage** (peak separation <= 400 km/s) and **have a blue dominant peak** (B/T flux ratio > 0.5)

Next steps

- ❋Apply my method to other datasets to unveil the composition of the LAE samples (LLAMAS of Claeyssens+22, high-EW LAEs of Kerutt+22, …)
- ❋Multi-wavelength study of the parent sample: ESO archives, ALMA, JWST, …

What I want to know	The data I need
Systemic redshift	H-alpha line from JWST
Inclination	HST images
Dust content	CO line from ALMA
Environment	HST images, MUSE images
LyC leakage	Strong nebular HeII and CIV emission in JWST data
…	…