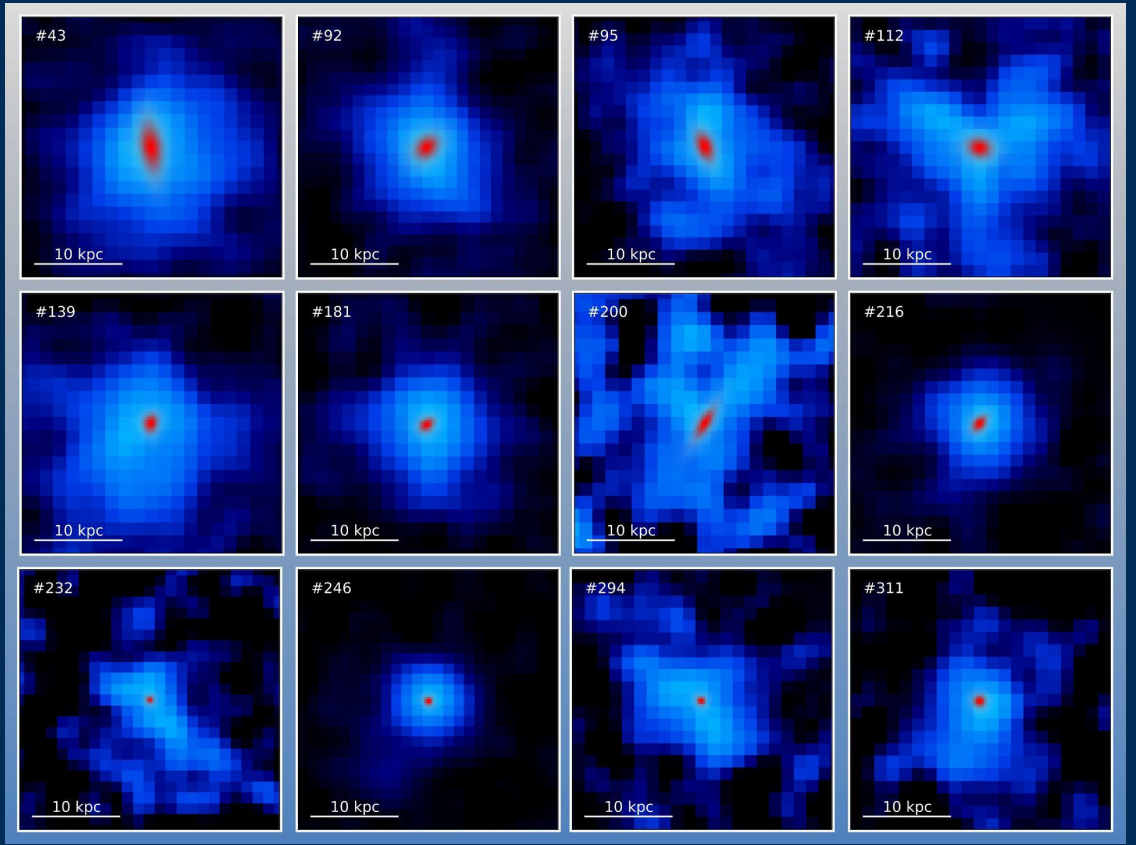
Leibniz-Institut für Astrophysik Potsdam

AIP

muse
multi unit spectroscopic explorer

What shapes the distribution of Lyman-α halos?

John Pharo, Lutz Wisotzki, and the AIP CGM Team



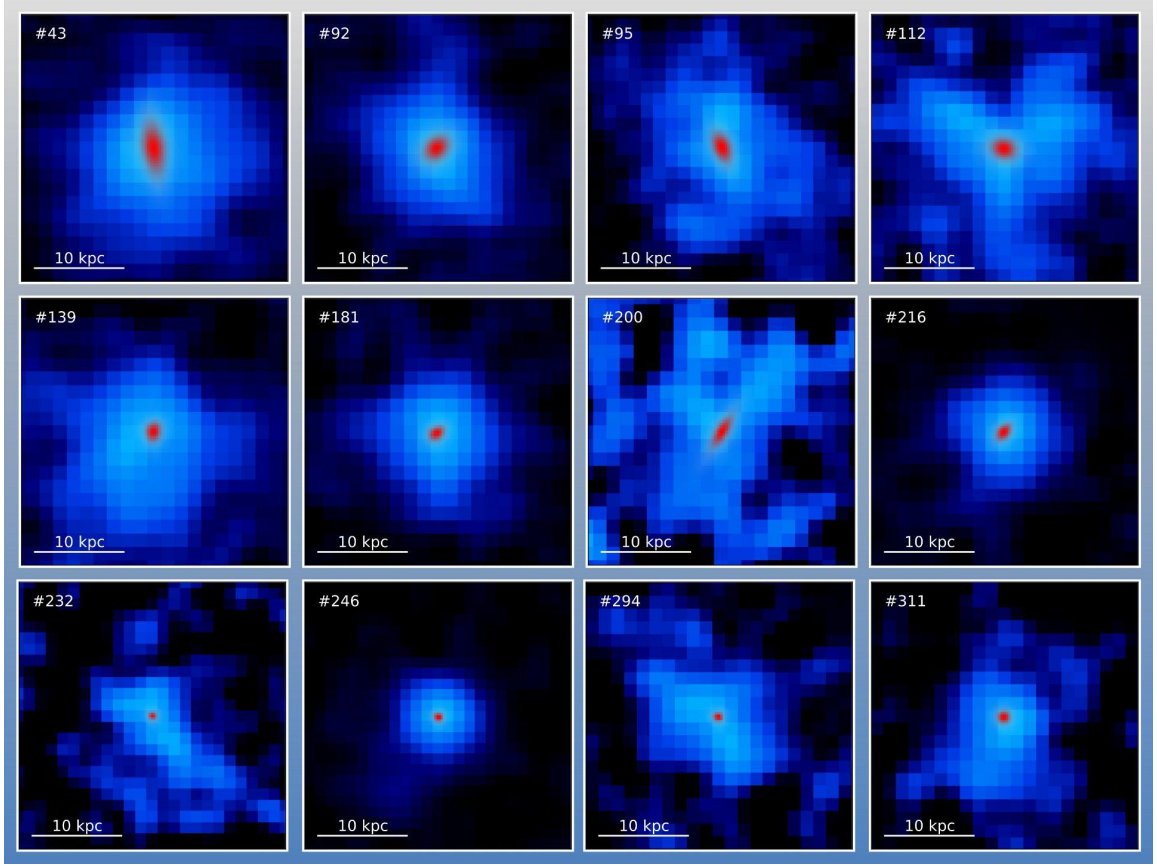
What Shapes the Distribution of Lyα Halos?

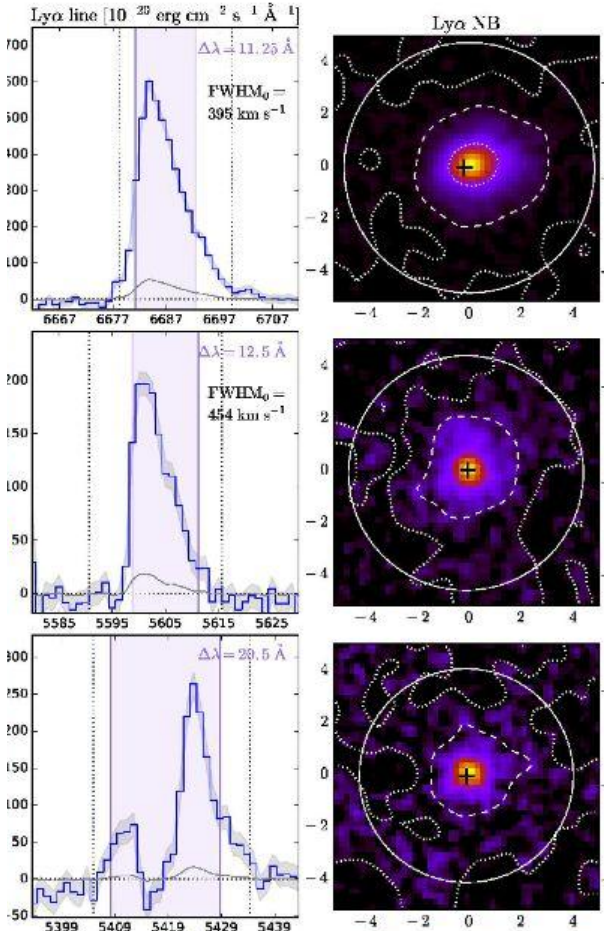
Wisotzki et al. 2016

At high redshift, we find numerous Lyα halos with diverse properties

We want to understand:

- What determines halo detectability?
- How does Lyα escape shape halos?
- How do these factors interact?





Observing Lyα Halos

Integral field spectroscopy is a powerful tool for capturing the diversity of Lyα halos, especially VLT/MUSE.

Large variety observed in both spectral profiles and spatial extension - is this linked to physical properties of the CGM?

But different spatial/spectral shapes also improve or reduce chances for detection...

To understand how Lyα escape relates to the CGM, we also need to understand this!

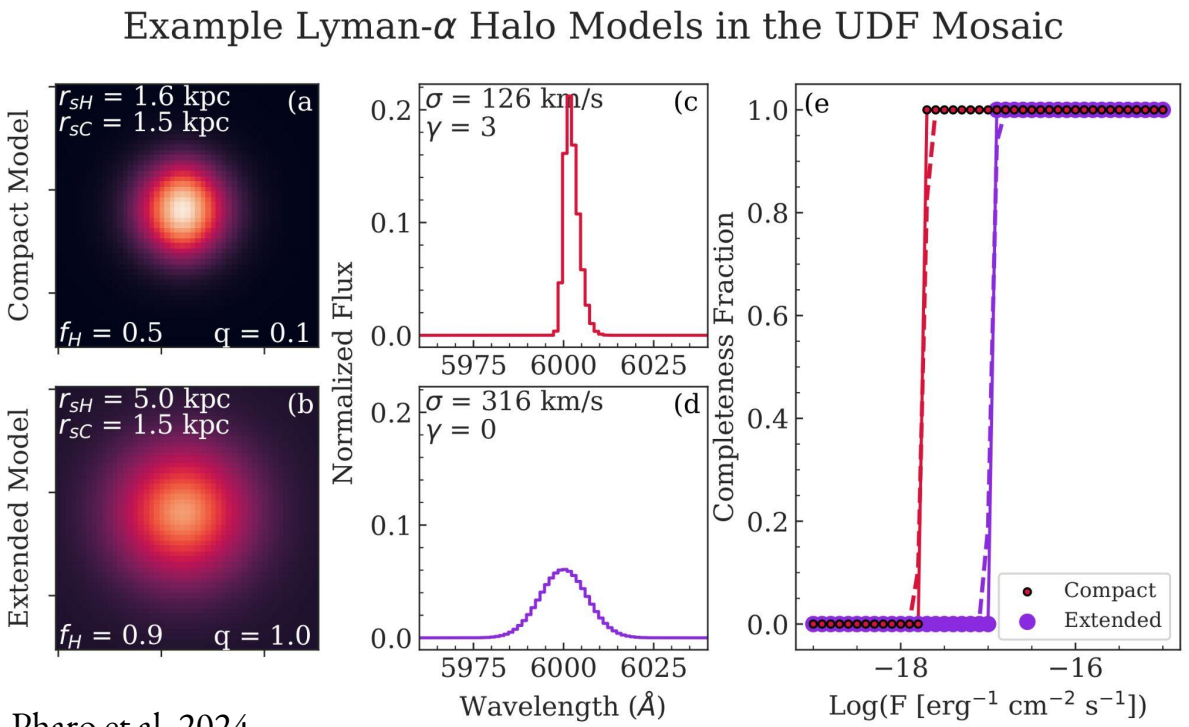
Leclercq et al. 2017

Lyα Halo Selection Function

We make a 3D model with 6 spatial/spectral halo parameters:

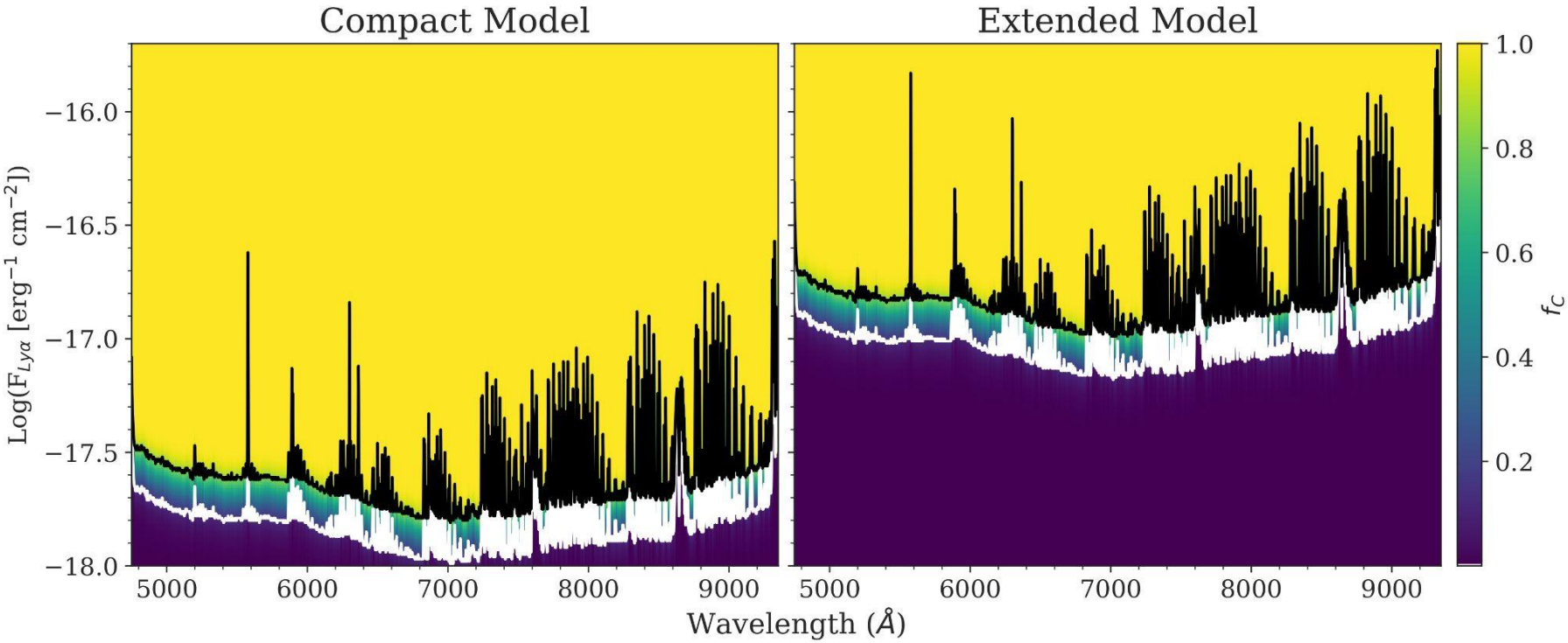
- Compact and **halo exponential scale lengths**
- **Halo flux fraction** and ellipticity
- **Spectral line width** and skewness

We insert the model into a MUSE-like datacube and test detection.



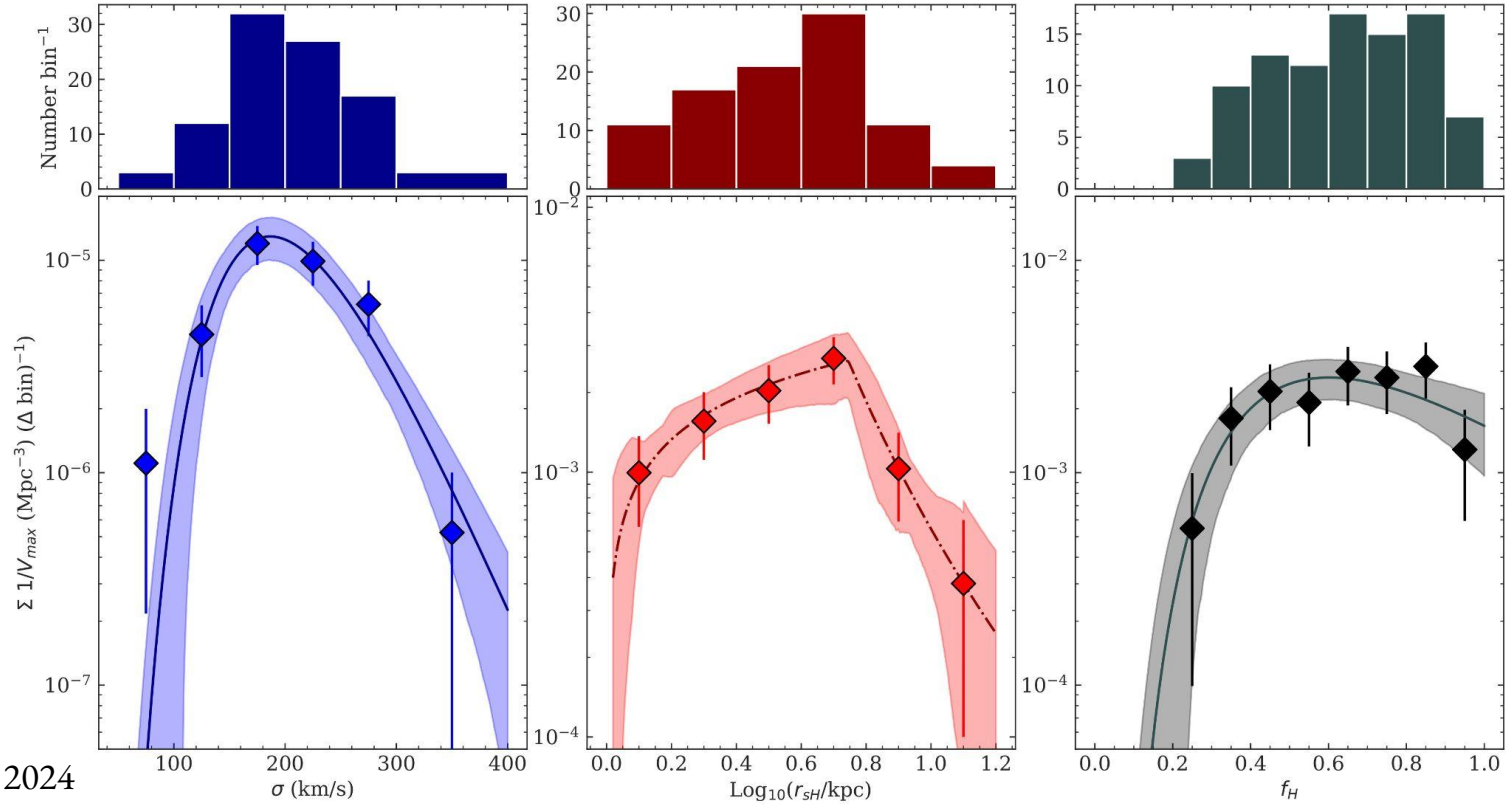
Pharo et al. 2024

Lyα Halo Selection Function



Pharo et al. 2024

The Intrinsic Distributions of Lyα Halo Properties

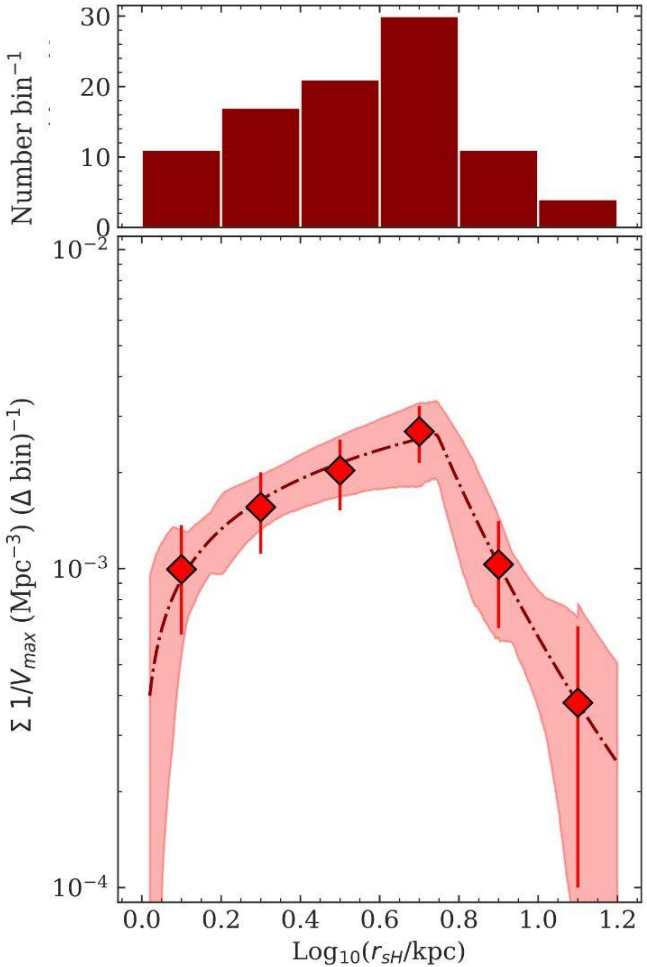


Pharo et al. 2024

The Halo Scale Length

The peak of the r_{sH} distribution is ~5 kpc - larger than the observed sample!

Extended halos are more common than we think!



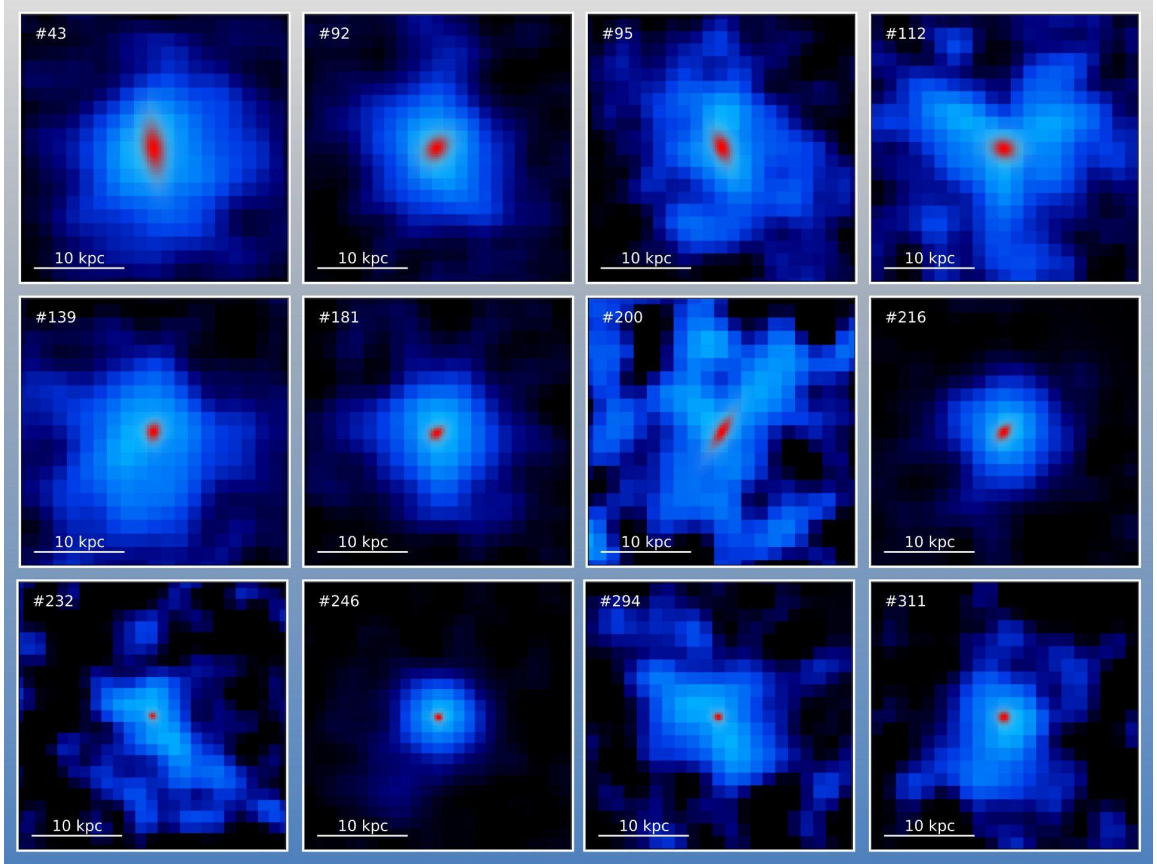
Read the paper at arXiv: 2409.04537

How Does the Halo Distribution Relate to Lyα Escape?

So far, we've only dealt with observed properties, not physical

Can we connect these observed distributions to physical mechanisms of Lyα production and escape?

We try an experiment with a simulated Lyα galaxy.



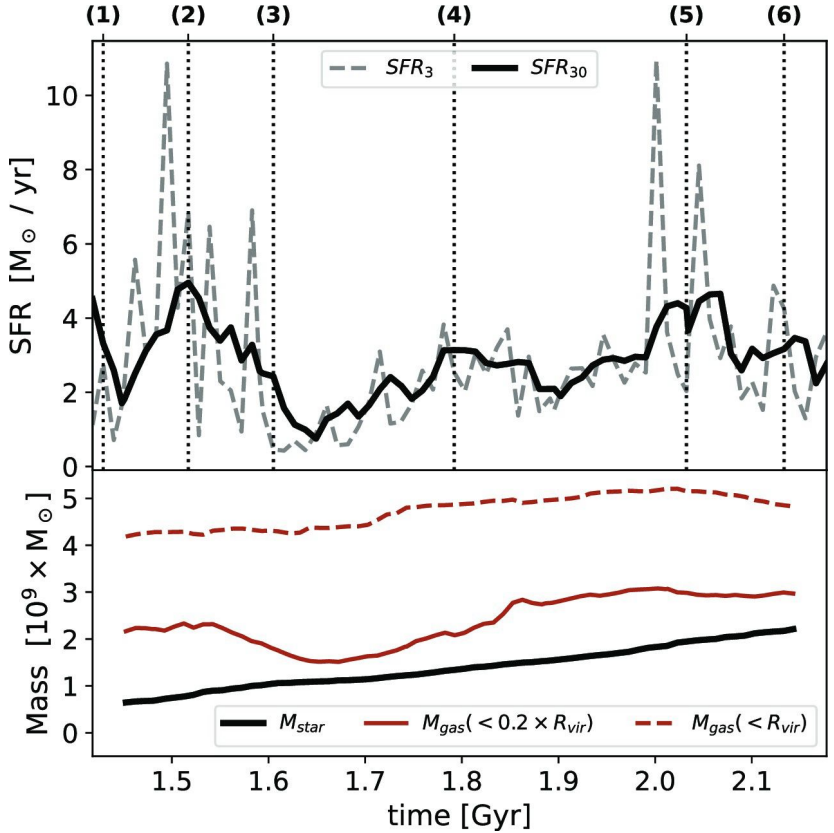
Wisotzki et al. 2016

Testing Selection Effects with Simulated Lyα Spectra

Blaizot+ 2023 simulate Lyα spectra for a low-mass, star-forming galaxy.

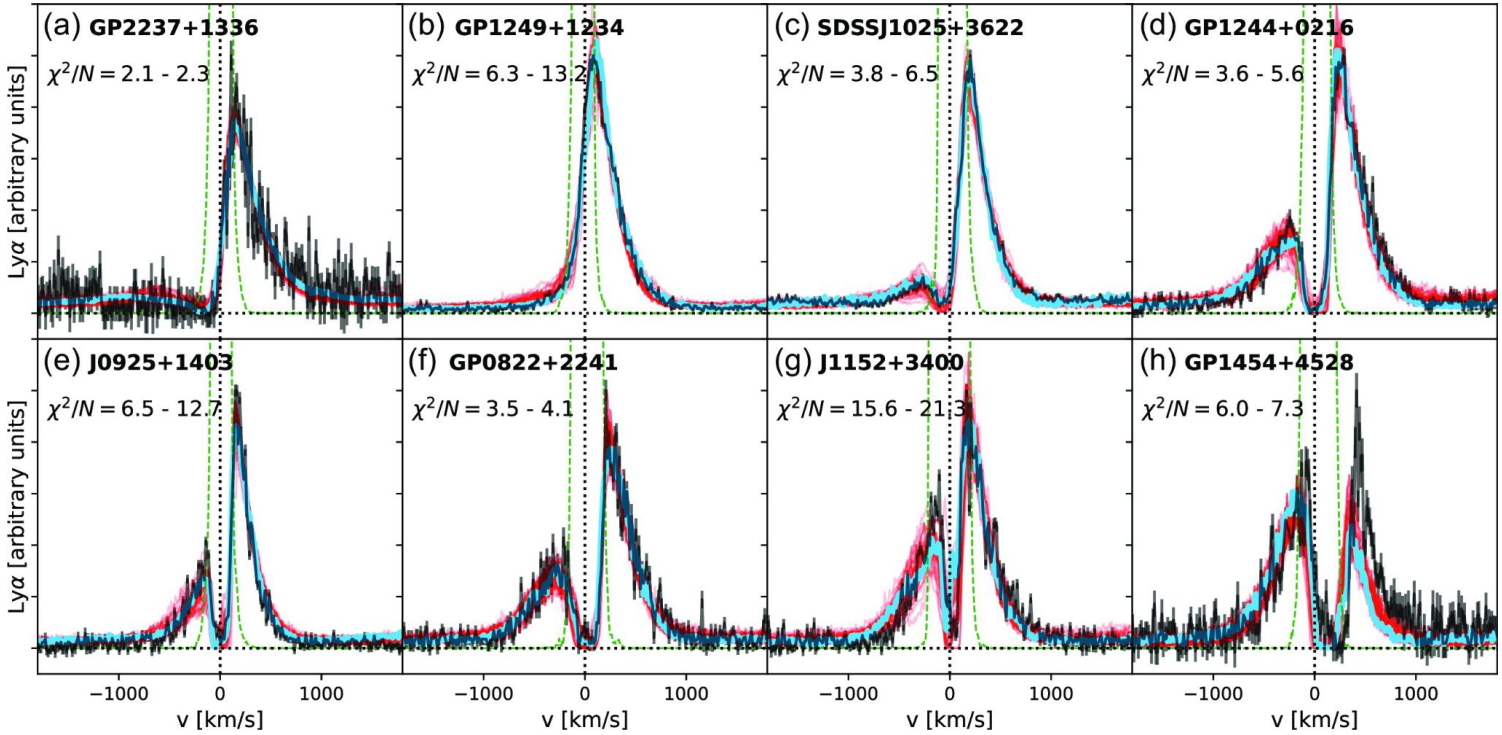
The galaxy evolves over z~4.2 to z~3, with varying SFR generally consistent with Main Sequence.

For this time period, they process Lyα production and transfer through the ISM and CGM.



Mock Spectra from Simulation

Blaizot+2023 derive ~22500 mock Lyα emission spectra from all timesteps, viewing directions.

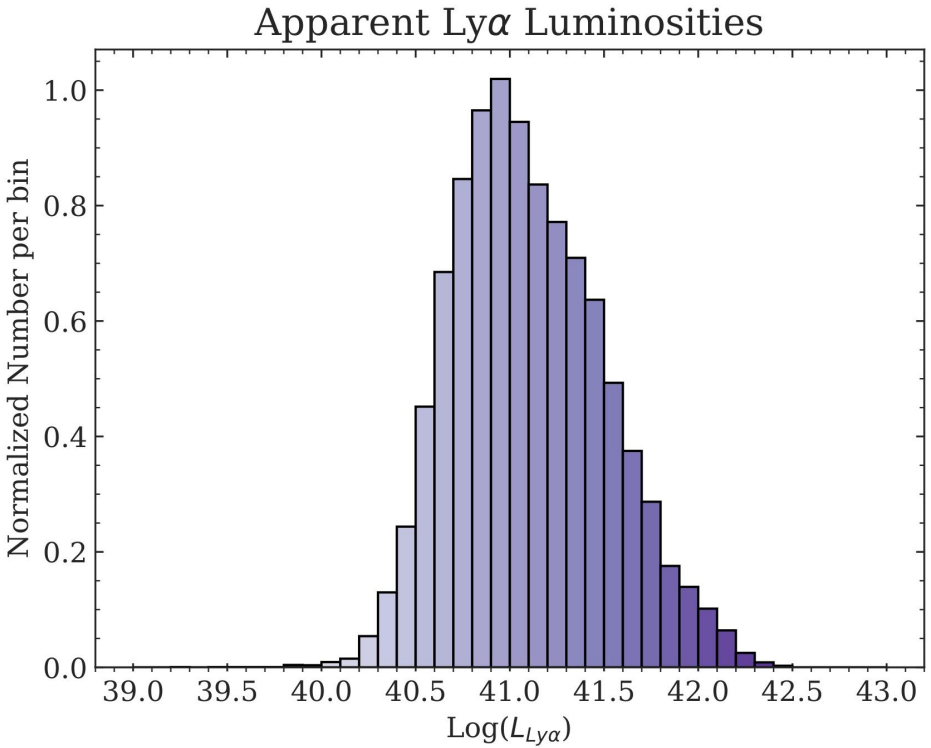


A Mock LAE Population

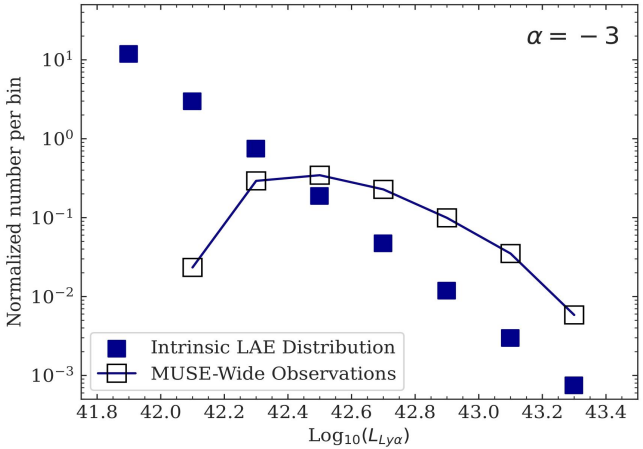
The mock galaxy shows a wide range of luminosities, depending on when/where it is observed.

An experiment: assume a population of these galaxies, scaling the intrinsic luminosity up and down

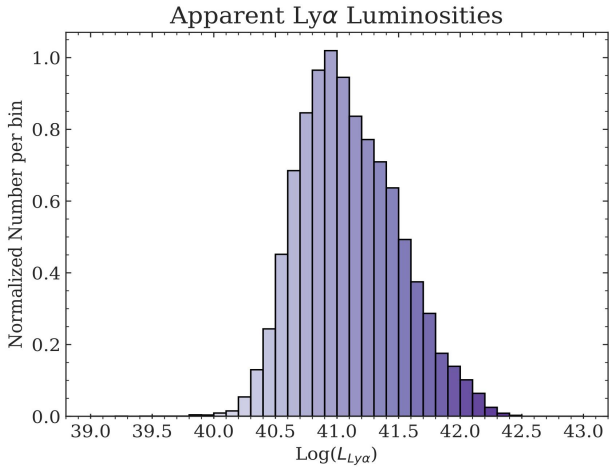
If we model observations of this population, what kinds of spectra will we detect?



A Mock LAE Population

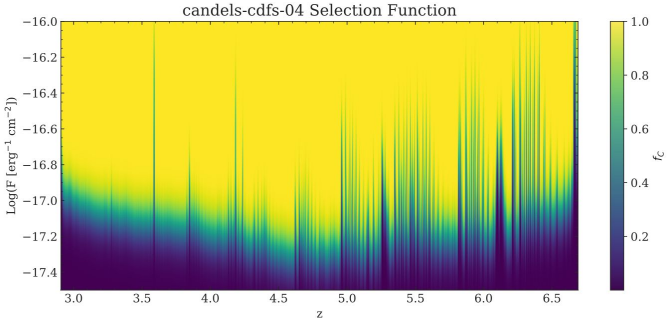


Draw N luminosities from LF



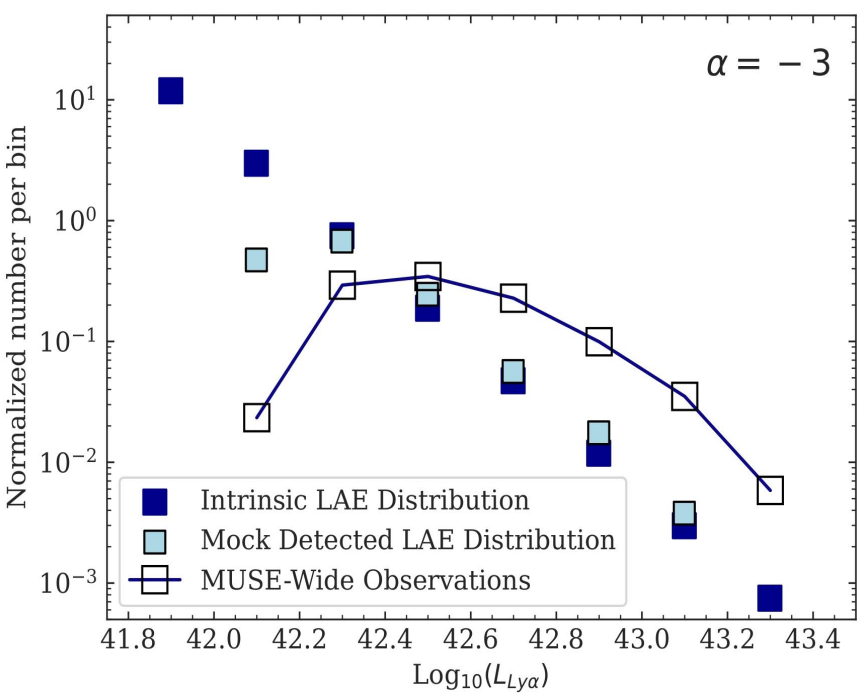
M direction/time instance luminosities

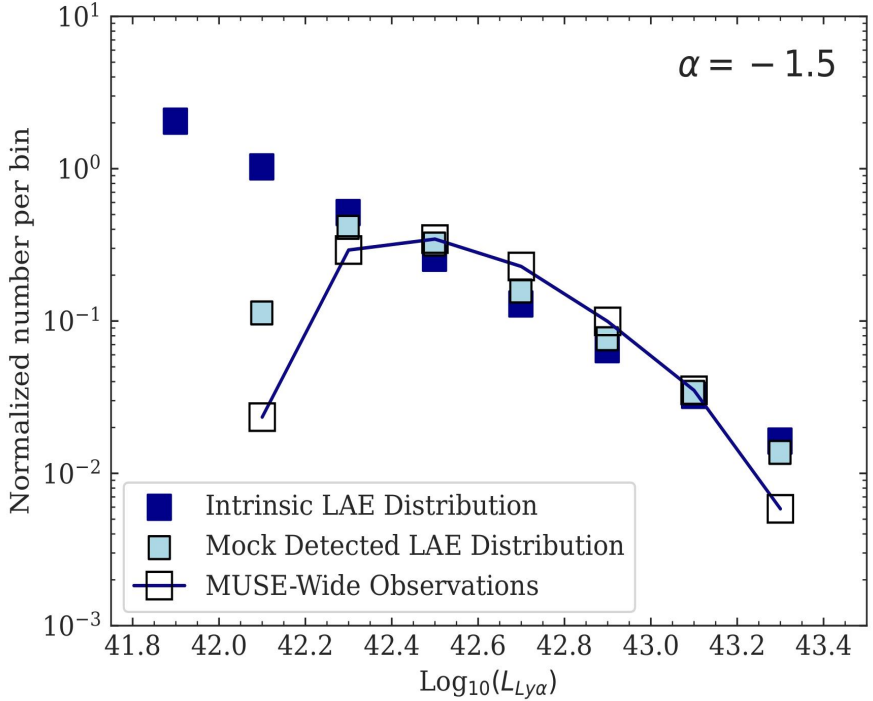
“Observe” galaxies with MUSE-Wide Selection Function at z=3.5



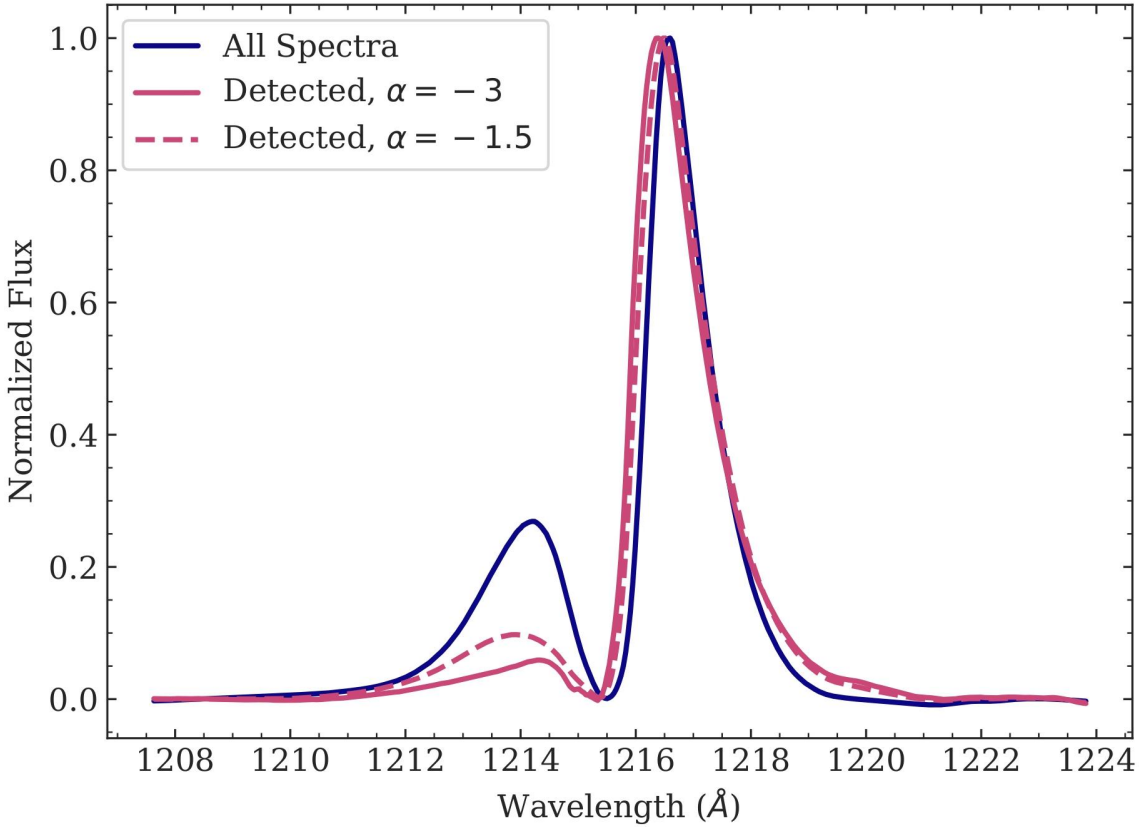
Then we have a size N × M × f_C(L) detected sample

The Observed Distribution - Two Cases





The Observed Sample - what is it like?

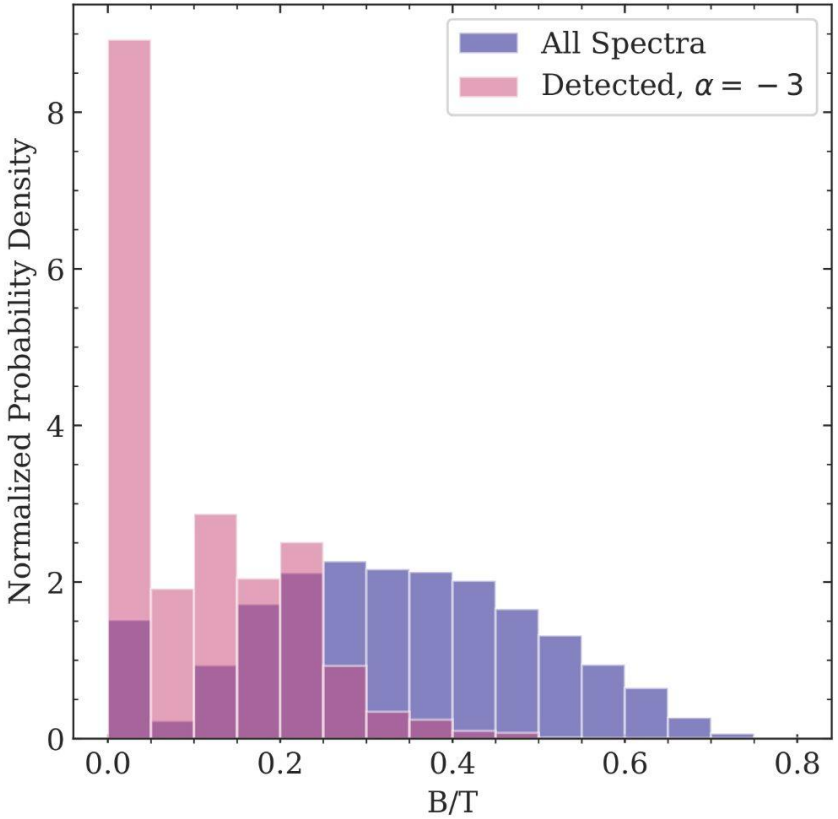


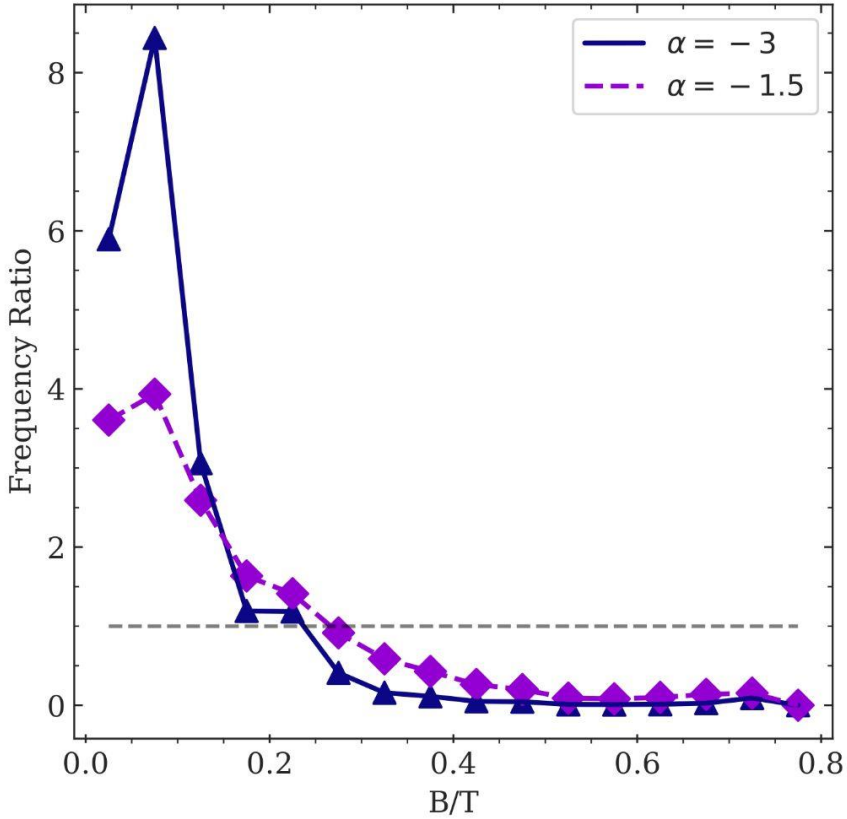
The median spectrum of all N×M instances shows a very classic double-peaked profile.

But the median of the detected spectra looks different - the blue peak is much weaker!

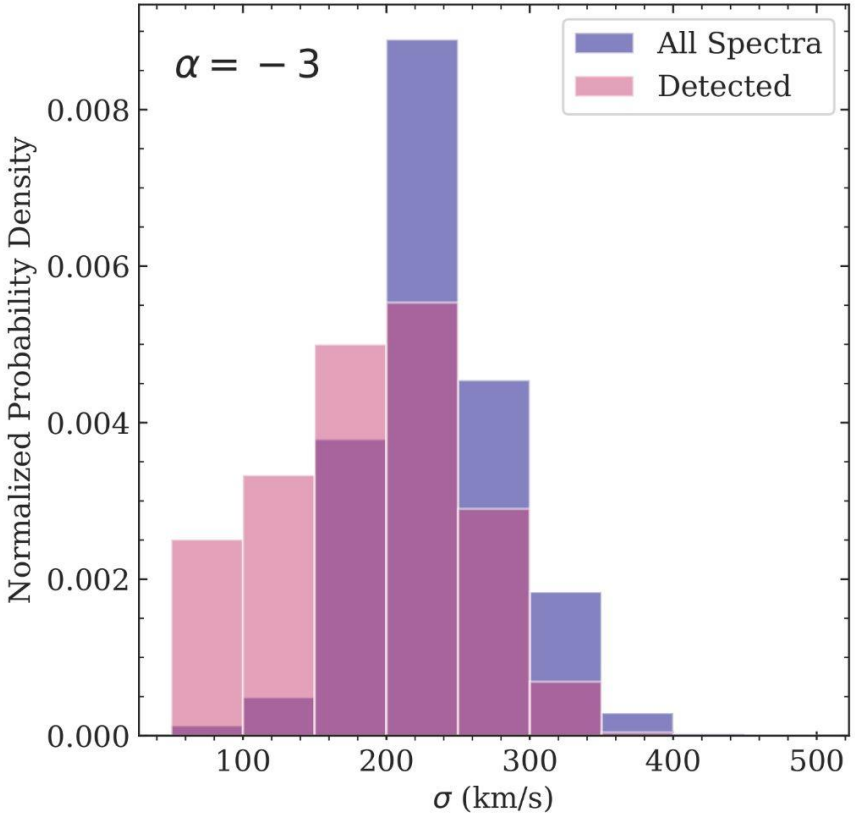
Pharo et al. in prep

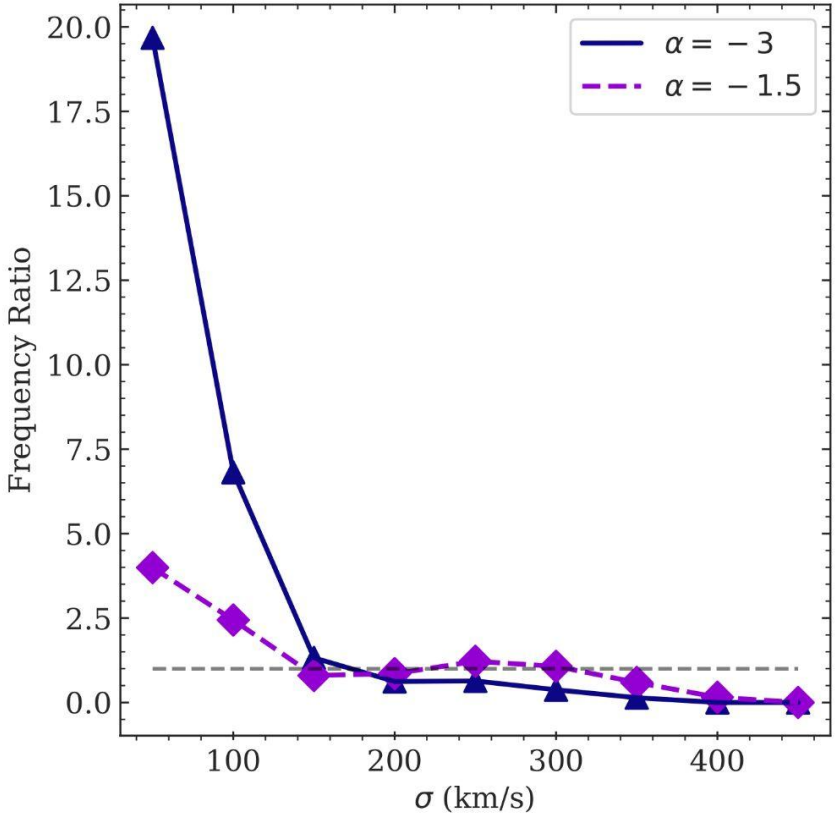
The Observed Sample - what is it like?



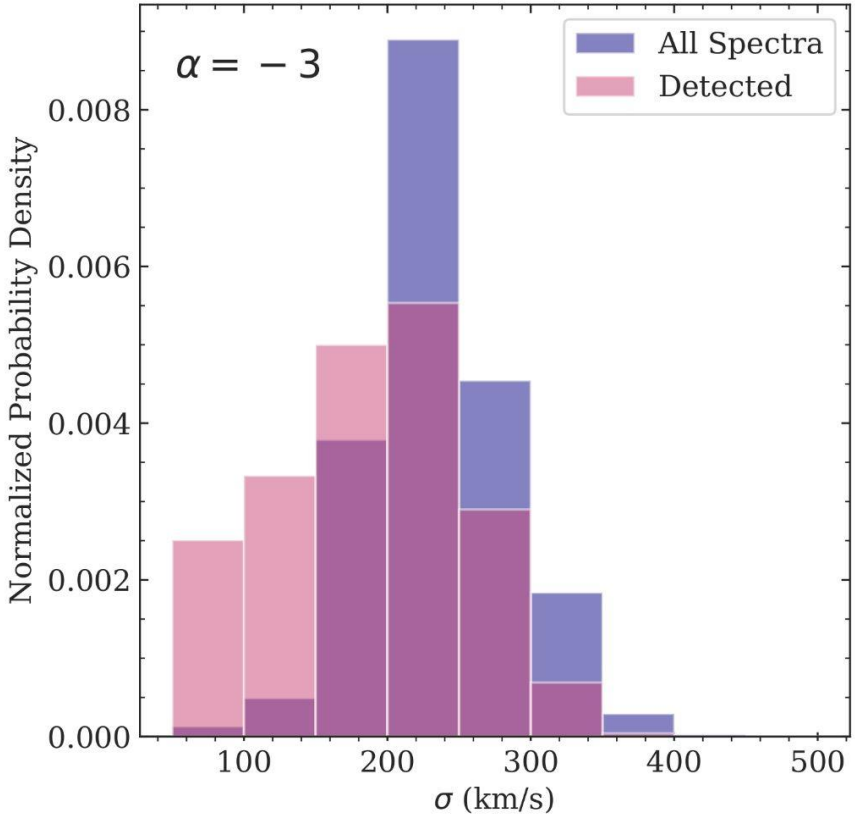


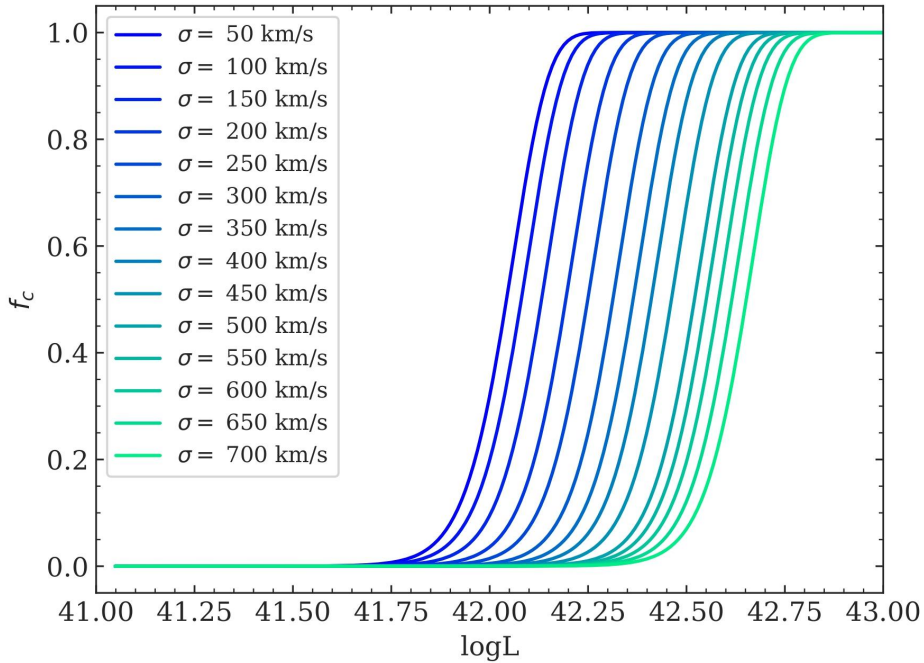
The Observed Sample - what is it like?





The Observed Sample - what is it like?





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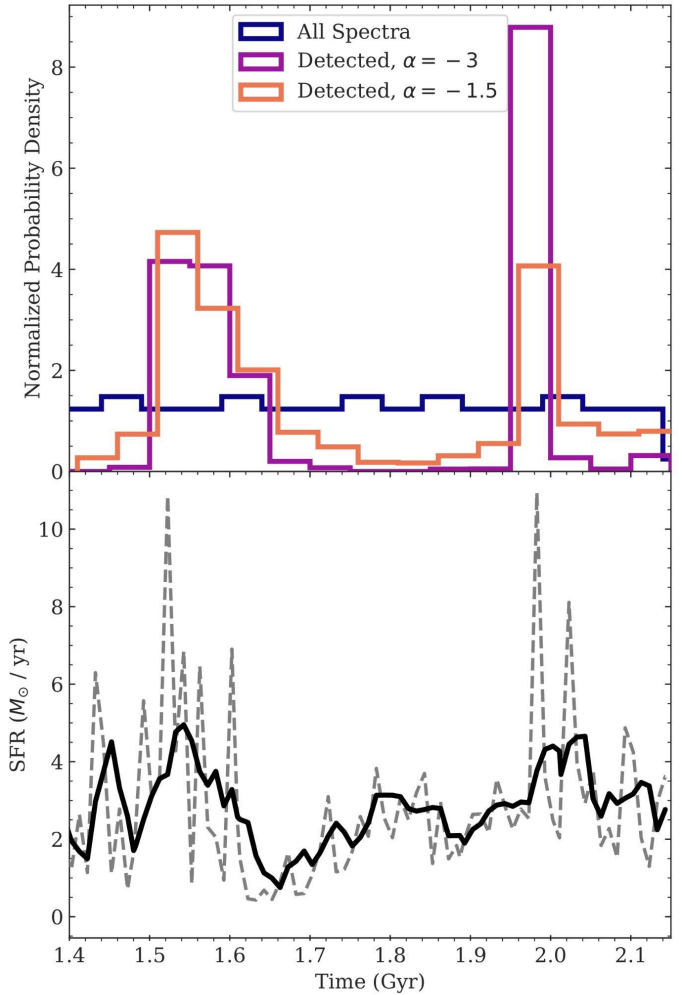
The Observed Sample - Star Formation History

Detected galaxies come mostly from two SFH epochs (~1.55 Gyr and ~2 Gyr).

These line up with periods of high star formation.



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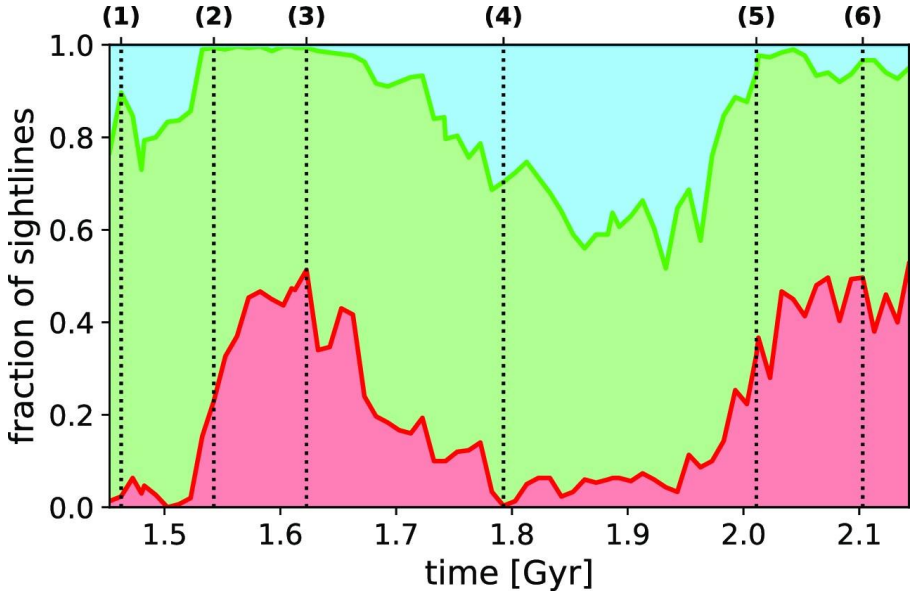
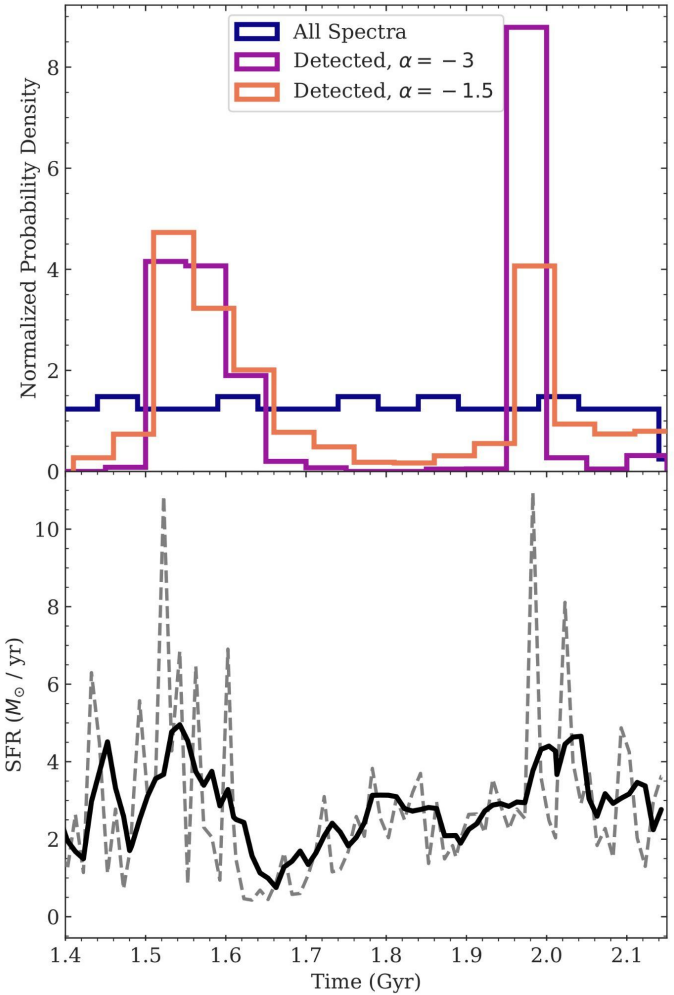
The Observed Sample - Star Formation History

This corresponds to times of red-peak domination in the simulation.



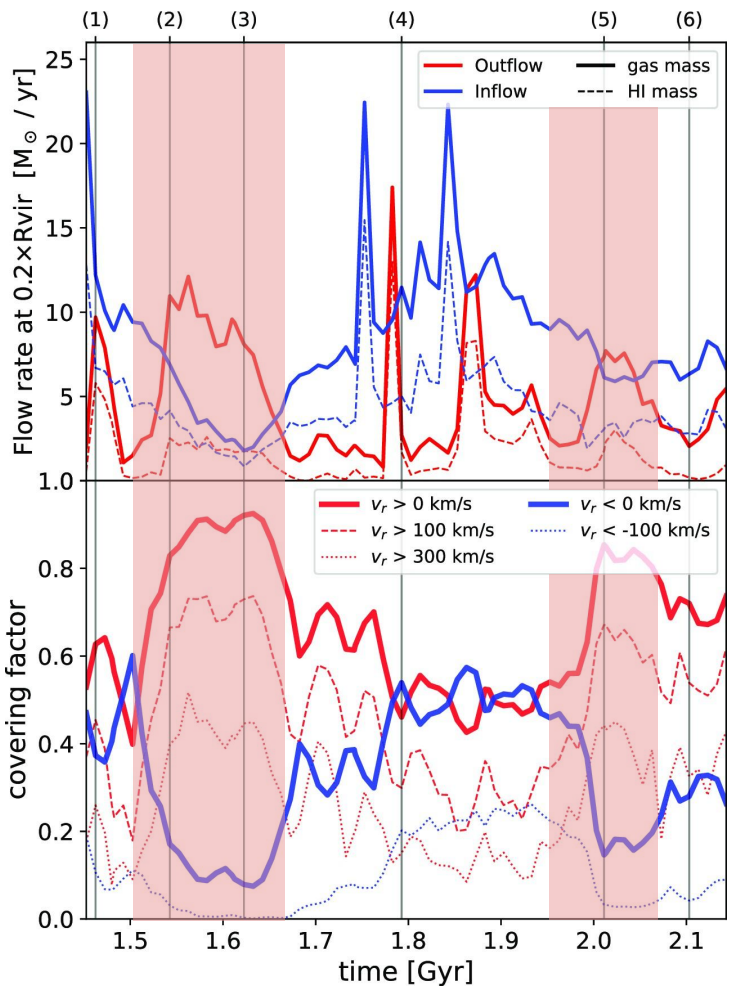


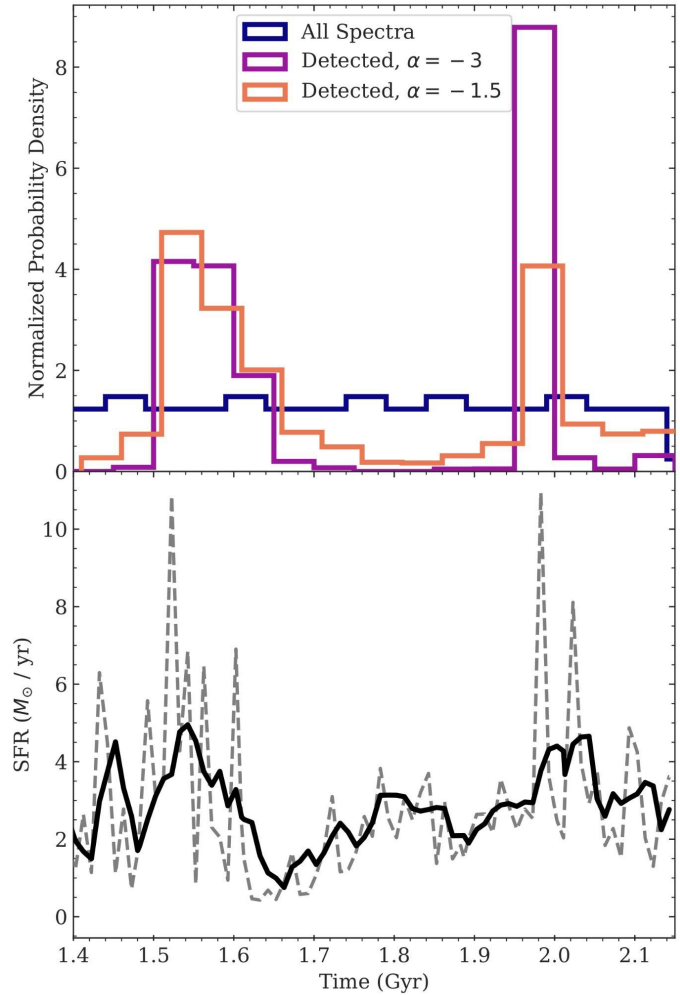
Blaizot et al. 2023

Outflows

It also corresponds to outflow-dominated times.

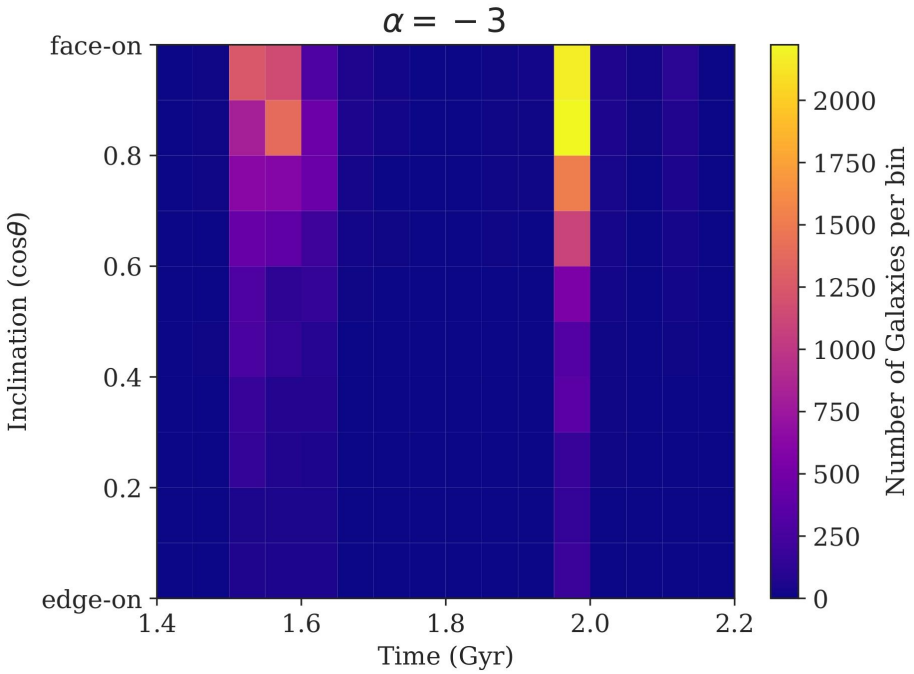
The observed spectral shape will strongly select for high-SFR stages of the SFH.

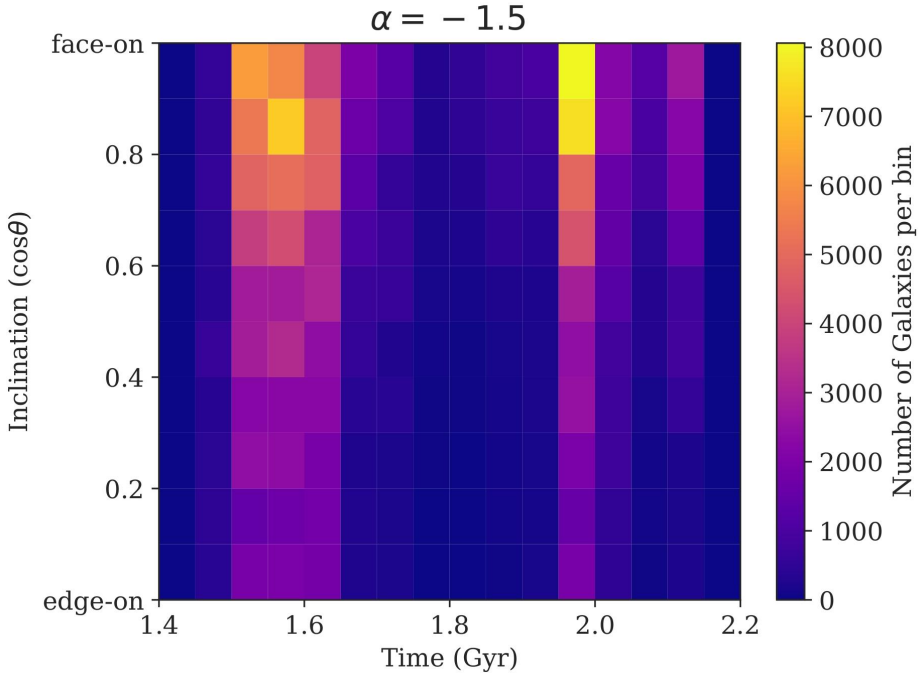




Blaizot et al. 2023

Two more effects: Inclination and LF Shape





Pharo et al. in prep

Summary

Read the first paper at arXiv: 2409.04537

We model Lyα halos in MUSE to test halo detectability, make selection functions, and recover intrinsic halo parameter distributions.

Our experiment applying a MUSE-Wide selection function to a mock LAE population generated from simulated spectra shows:

- outflow-dominated periods after SF bursts are favorably detected
- more face-on orientations are favorably detected
- near the flux-limit, narrow spectral profiles are favorably detected
- the shape of the intrinsic LF will govern how dominant these effects are in a given range of luminosity
    - as the LF gets steeper, these effects become much more important!

Contact: jpharo@aip.de

Extra

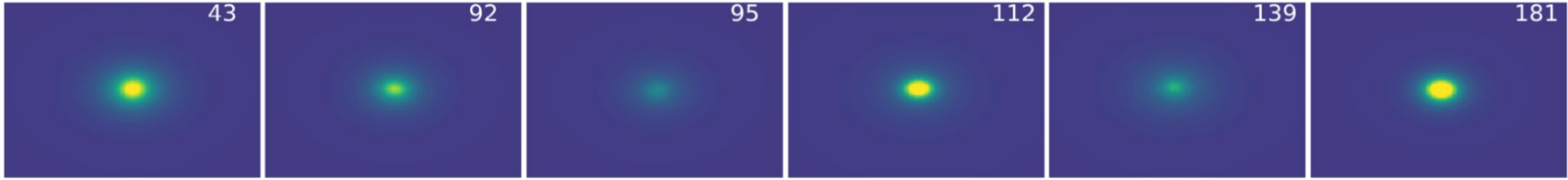
LAH Selection Function - the LAH Spatial Model

We model the spatial profile as a 2-component exponential disk

$$F(r) = \Sigma_C(r) + \Sigma_H(r) = \Sigma_{C0} e^{-r/r_{sC}} + \Sigma_{H0} e^{-r/r_{sH}}$$

Halo flux fraction: $f_H = \frac{F_H}{F_H + F_C}$

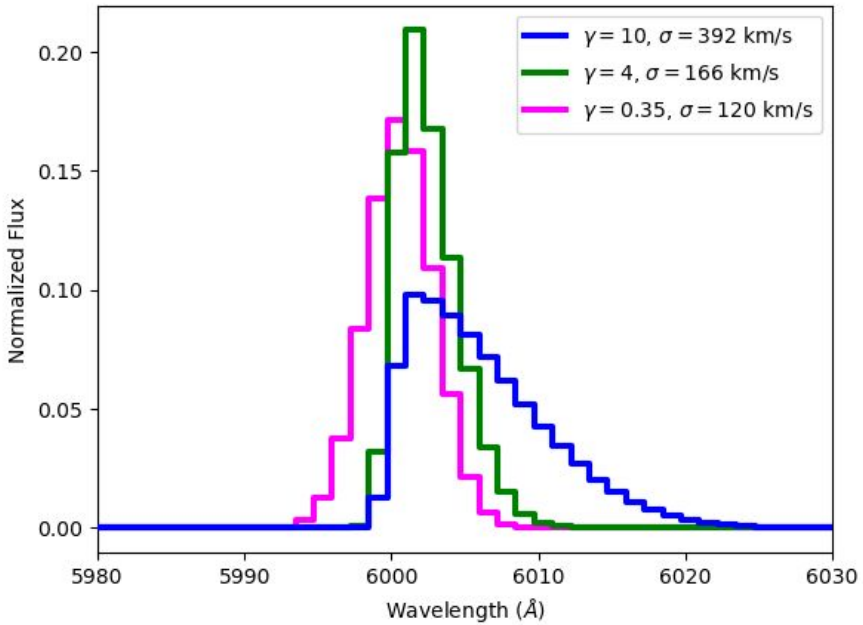
Ellipticity q

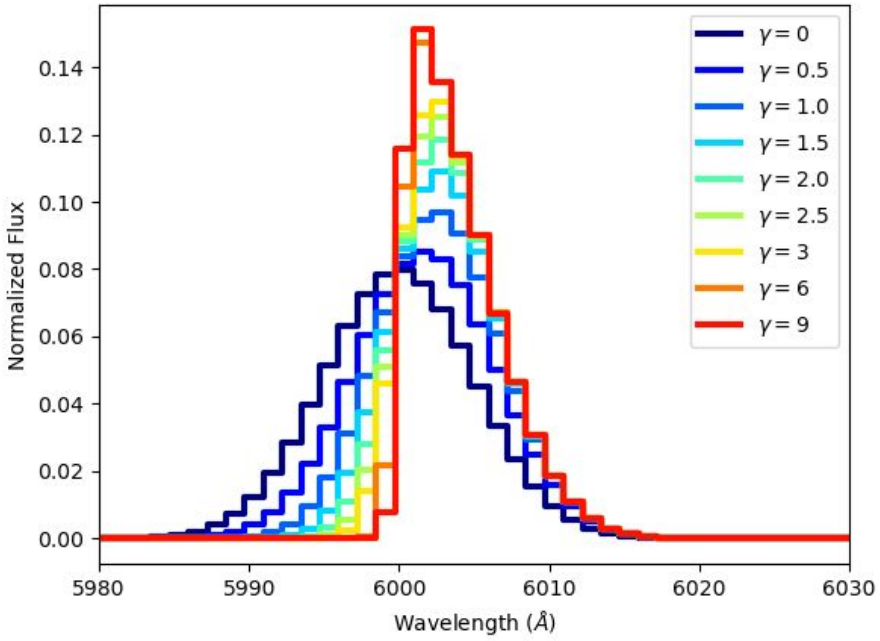


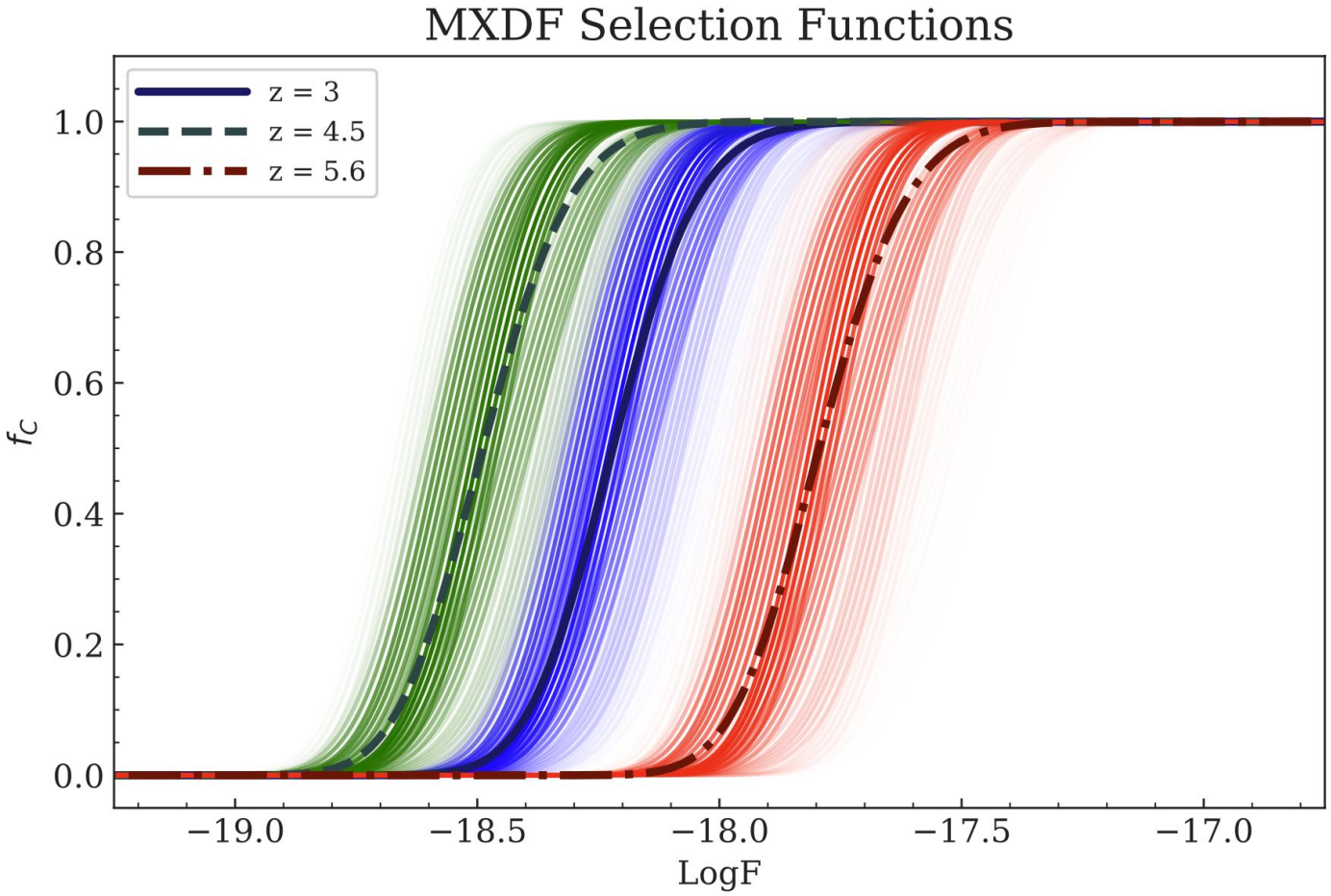
LAH Selection Function - the LAH Spectral Model

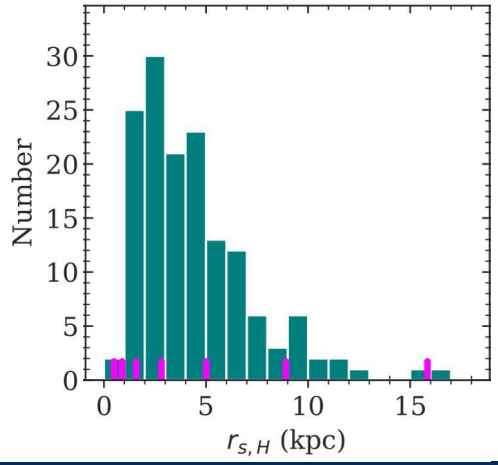
We model the spectral profile as a skewed Gaussian

$$f(x; A, \mu, \sigma, \gamma) = \frac{A}{\sigma\sqrt{2\pi}} e^{[-(x-\mu)^2/2\sigma^2]} \left\{ 1 + \mathrm{erf}\left[\frac{\gamma (x - \mu)}{\sigma\sqrt{2}} \right] \right\}$$

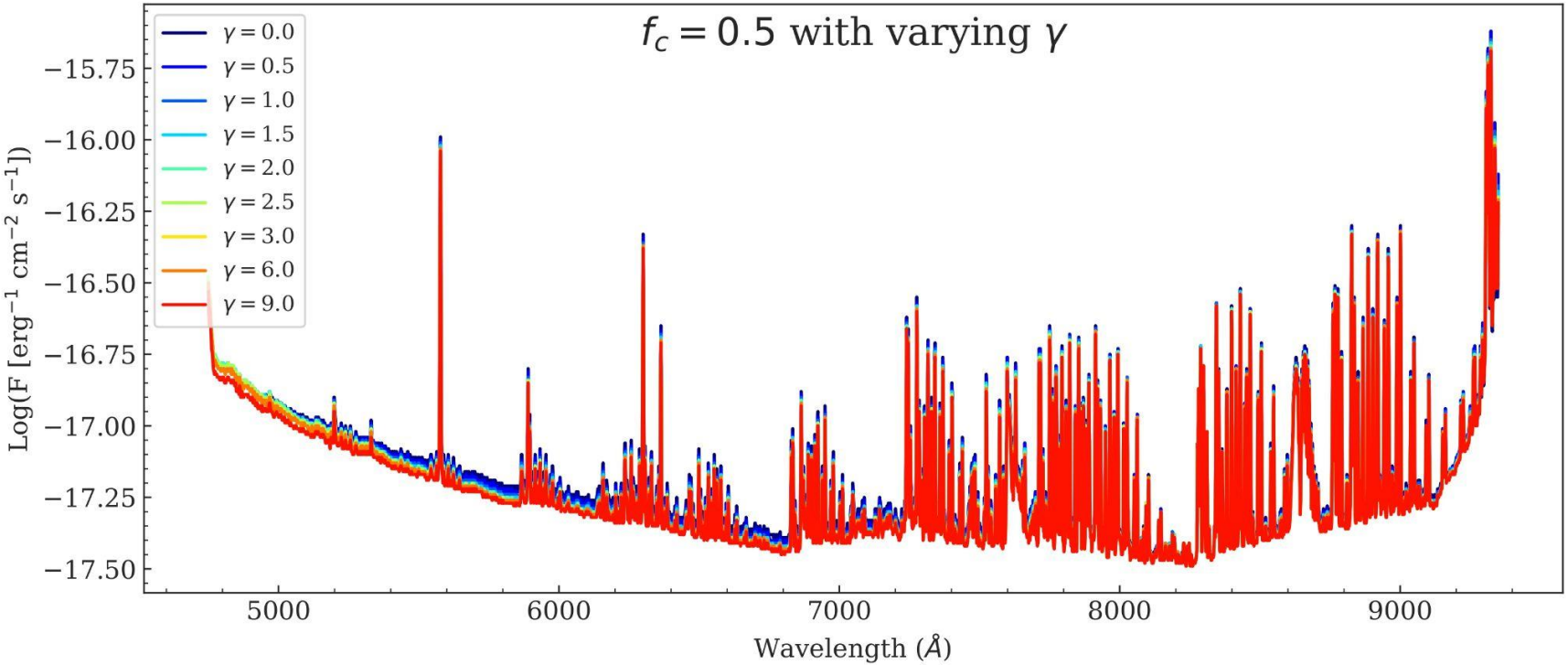


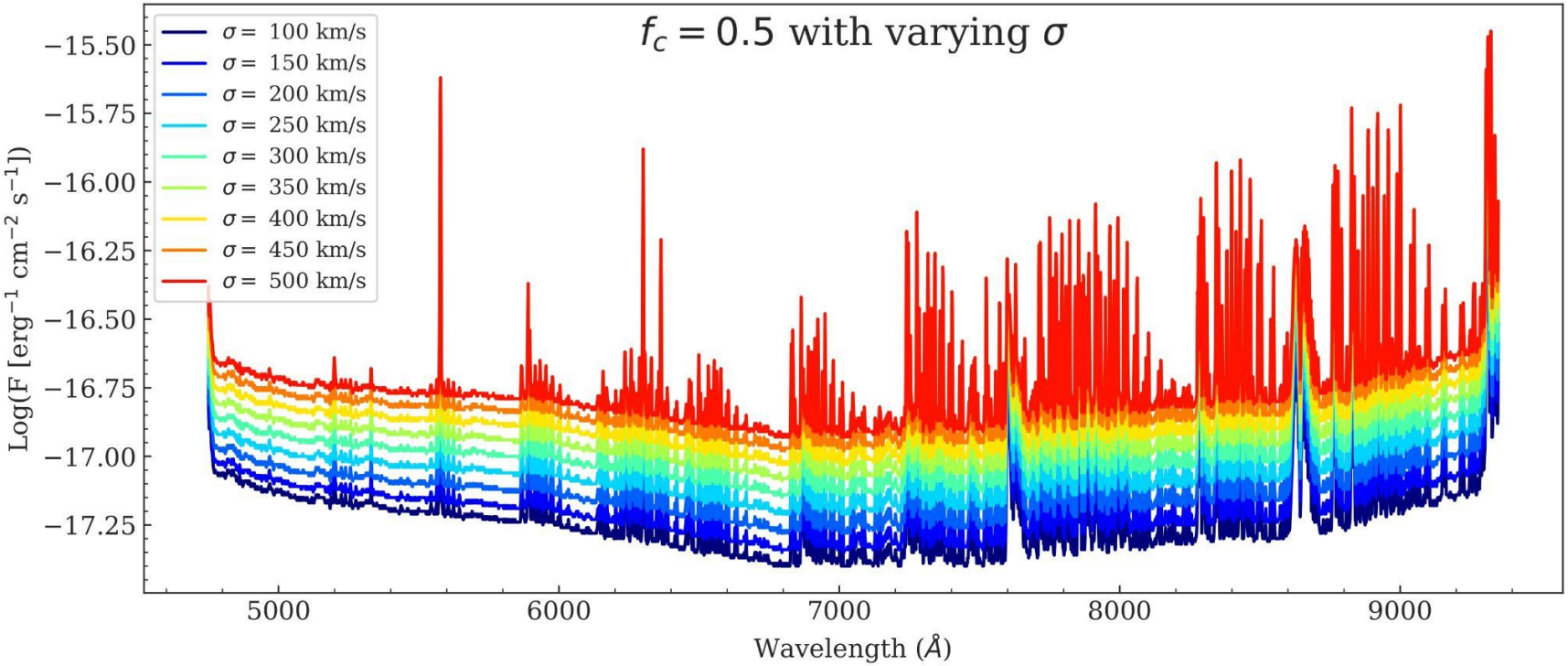



MXDF Selection Functions
z = 3
z = 4.5
z = 5.6
1.0
0.8
0.6
0.4
0.2
0.0
f_C
−19.0
−18.5
−18.0
−17.5
−17.0
LogF

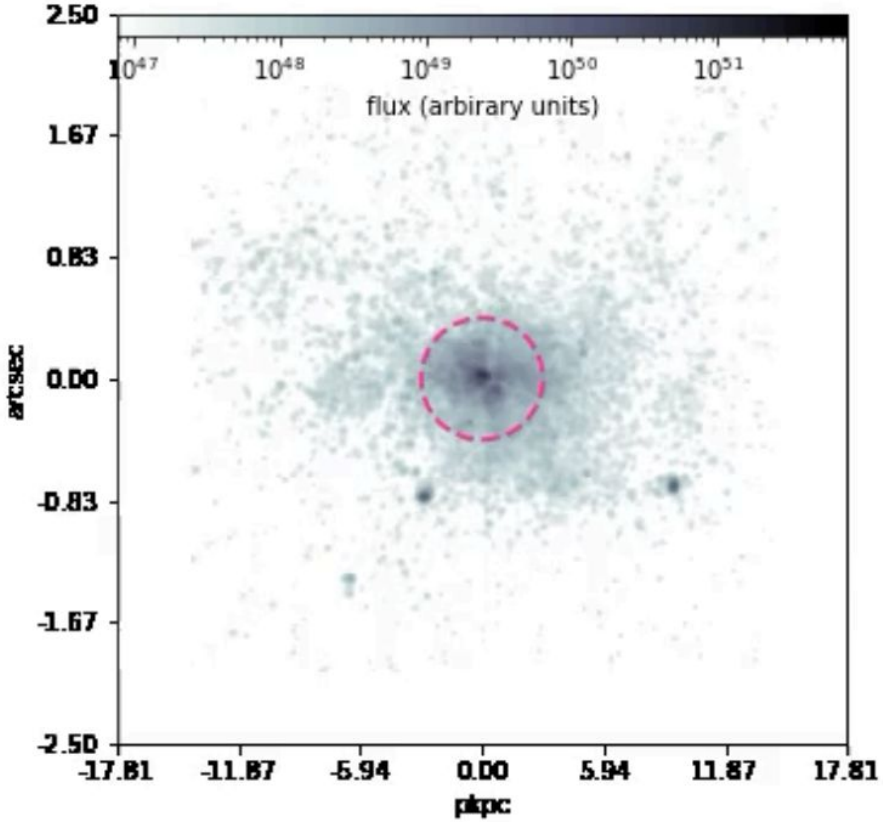

Number
30
25
20
15
10
5
0
0
5
10
15
$r_{s,H}$ (kpc)

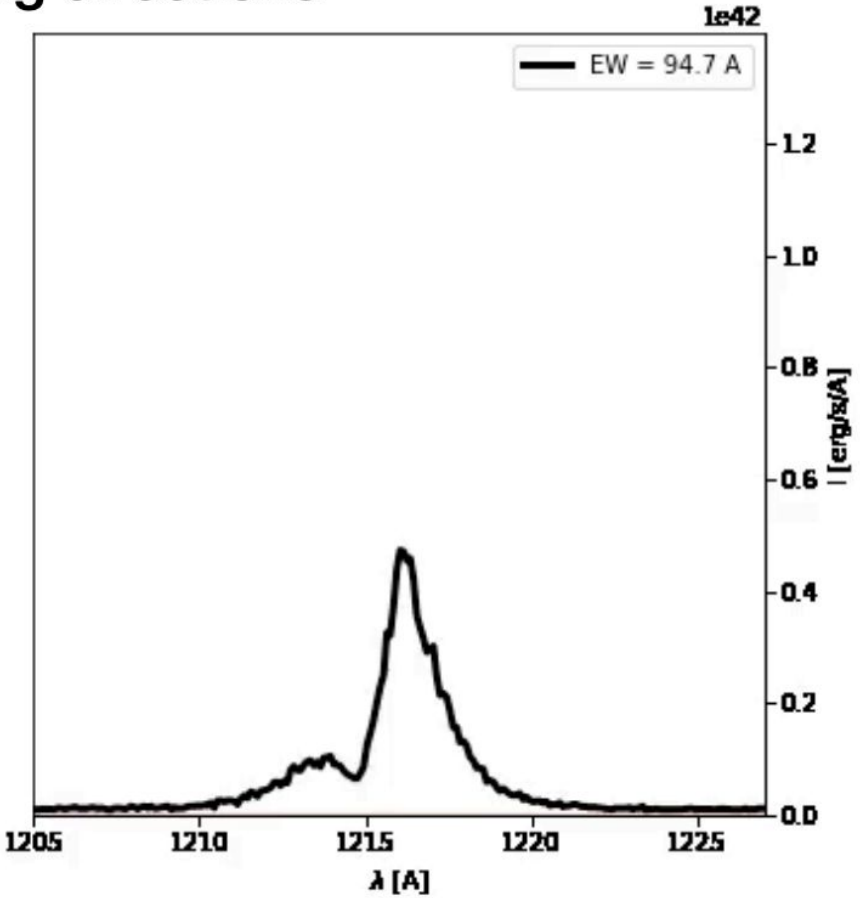
LAH Selection Function - Parameter Tests



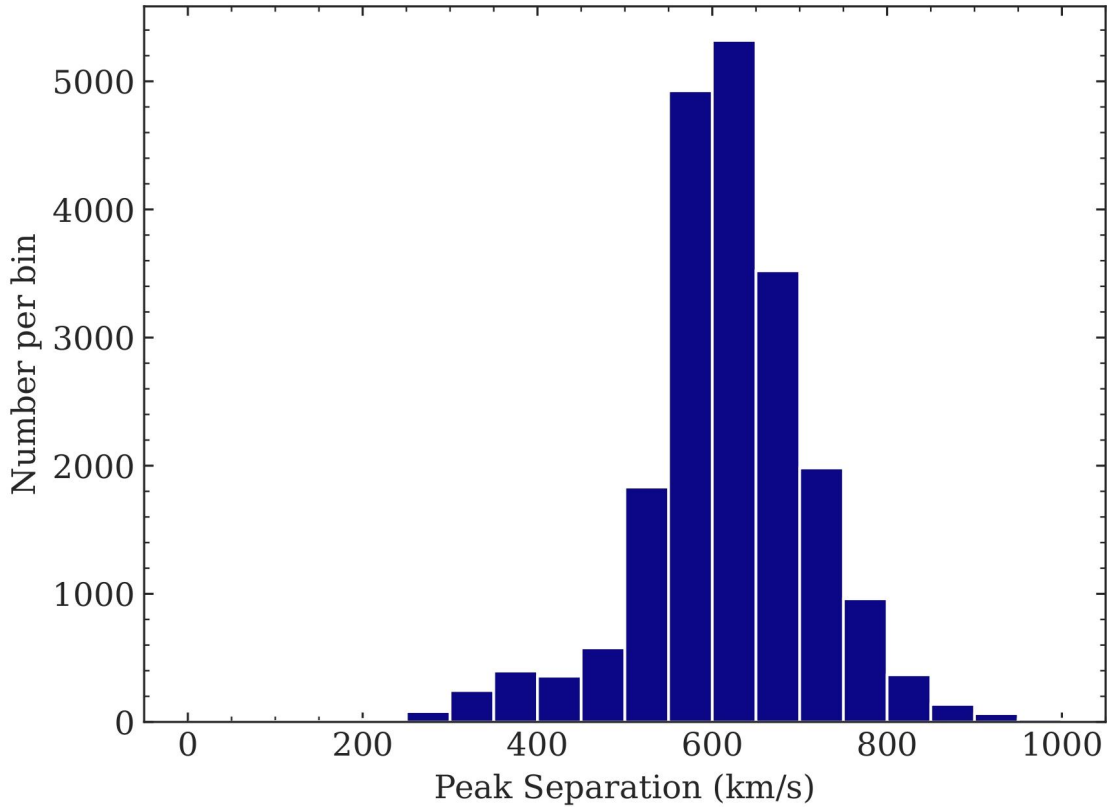

$f_c = 0.5$ with varying σ
$\sigma =$ 100 km/s
$\sigma =$ 150 km/s
$\sigma =$ 200 km/s
$\sigma =$ 250 km/s
$\sigma =$ 300 km/s
$\sigma =$ 350 km/s
$\sigma =$ 400 km/s
$\sigma =$ 450 km/s
$\sigma =$ 500 km/s
Log(F [erg^{-1} cm^{-2} s^{-1}])
−15.50
−15.75
−16.00
−16.25
−16.50
−16.75
−17.00
−17.25
5000
6000
7000
8000
9000
Wavelength (Å)

Fixed time, varying directions

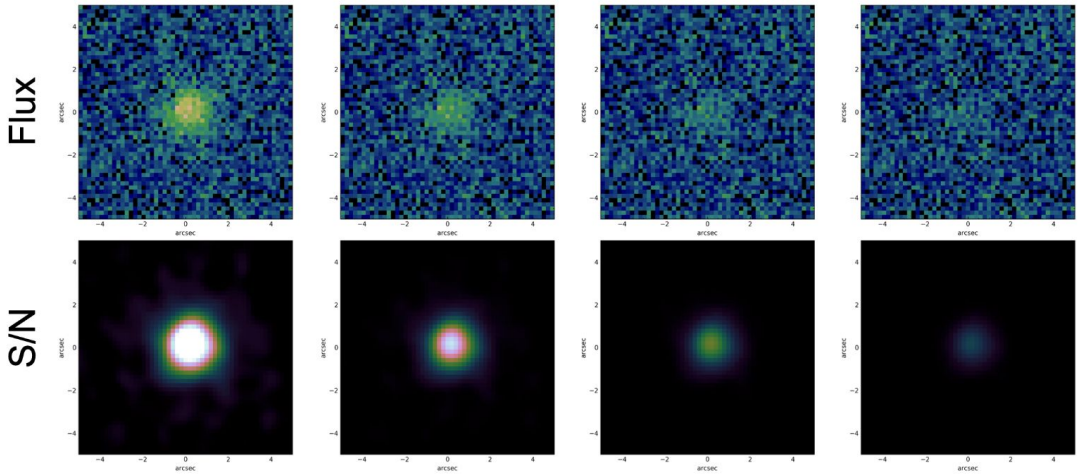




Blue and Red Peak Separations

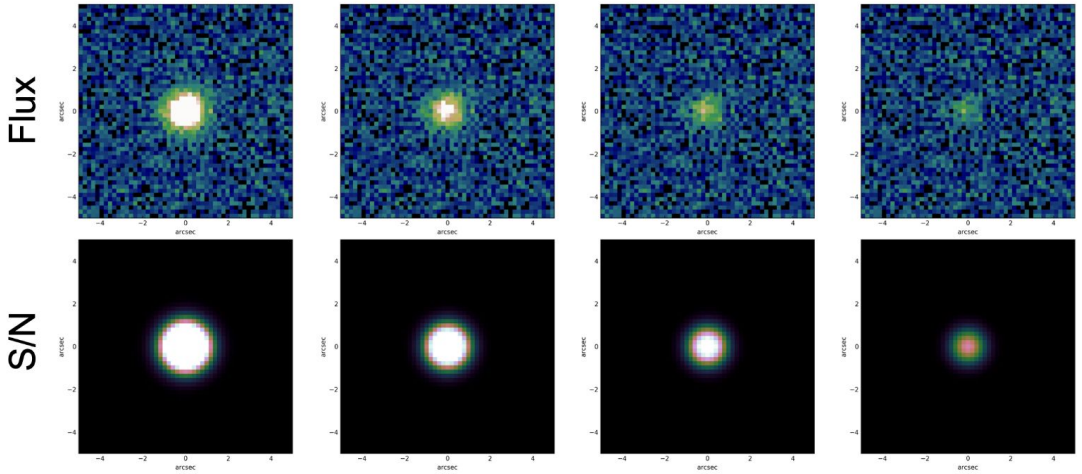


Real galaxy, typical Lyα halo



f [erg s^{-1} cm^{-2}] = 4×10^{-17} 2×10^{-17} 1×10^{-17} 5×10^{-18}

Point source



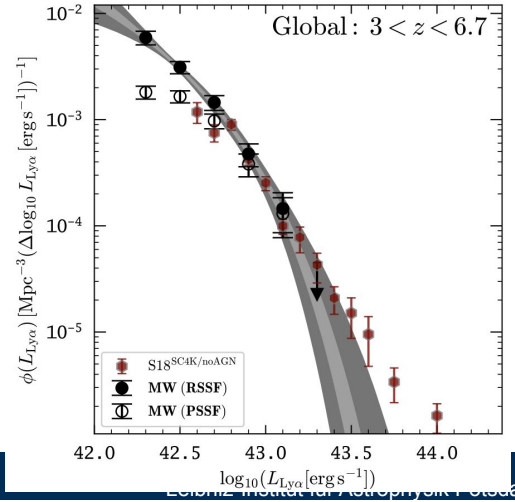
Recovering the LAH Distribution - the $1/V_{max}$ Estimator

We then correct the UDF distribution by measuring V_{max} for each LAH in the sample, using a form that incorporates the completeness fraction f_c.

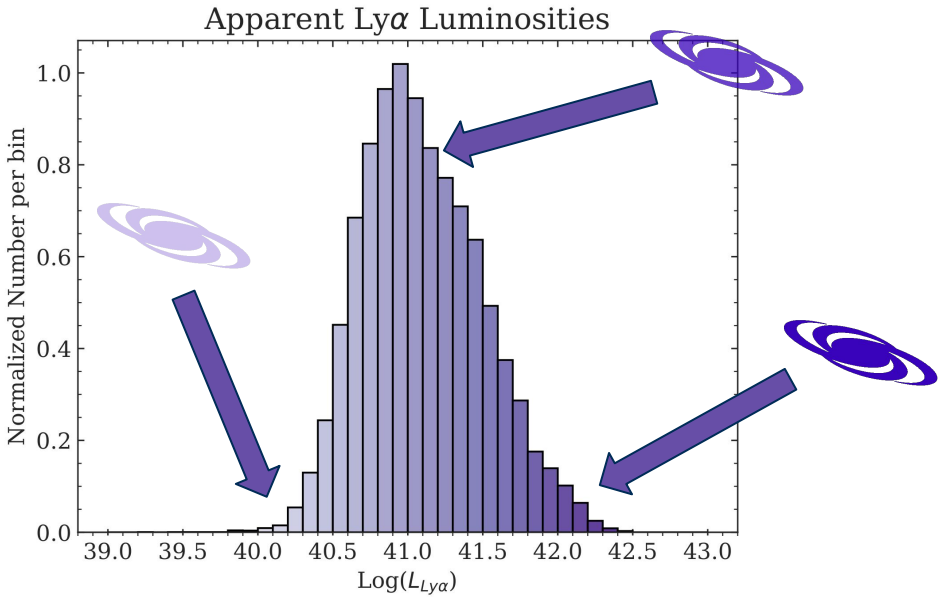
$$V_{max,i} = \omega \int_{z_{min}}^{z_{max}} f_c(L_{Ly\alpha}, z) \frac{dV}{dz} dz$$

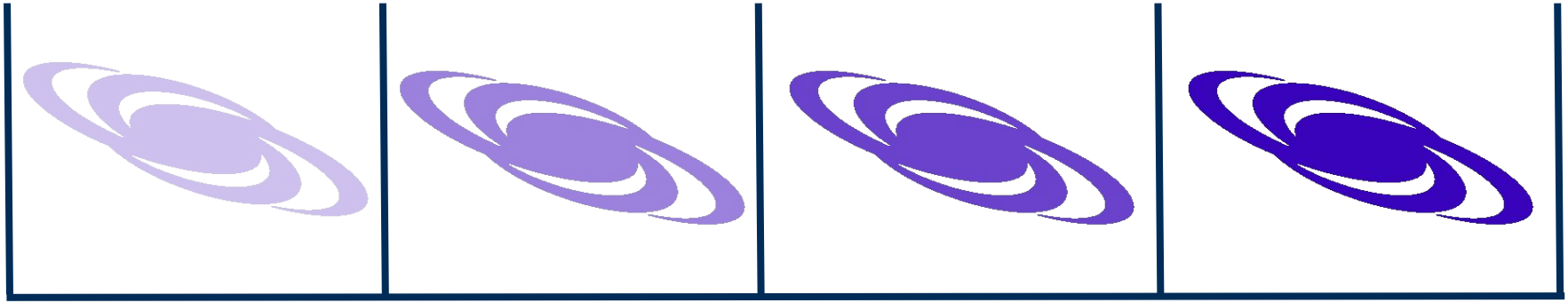
$$\phi_{1/V_{max}}(\langle X_k \rangle) = \frac{1}{\Delta X_k} \sum_i \frac{1}{V_{max,i}}$$

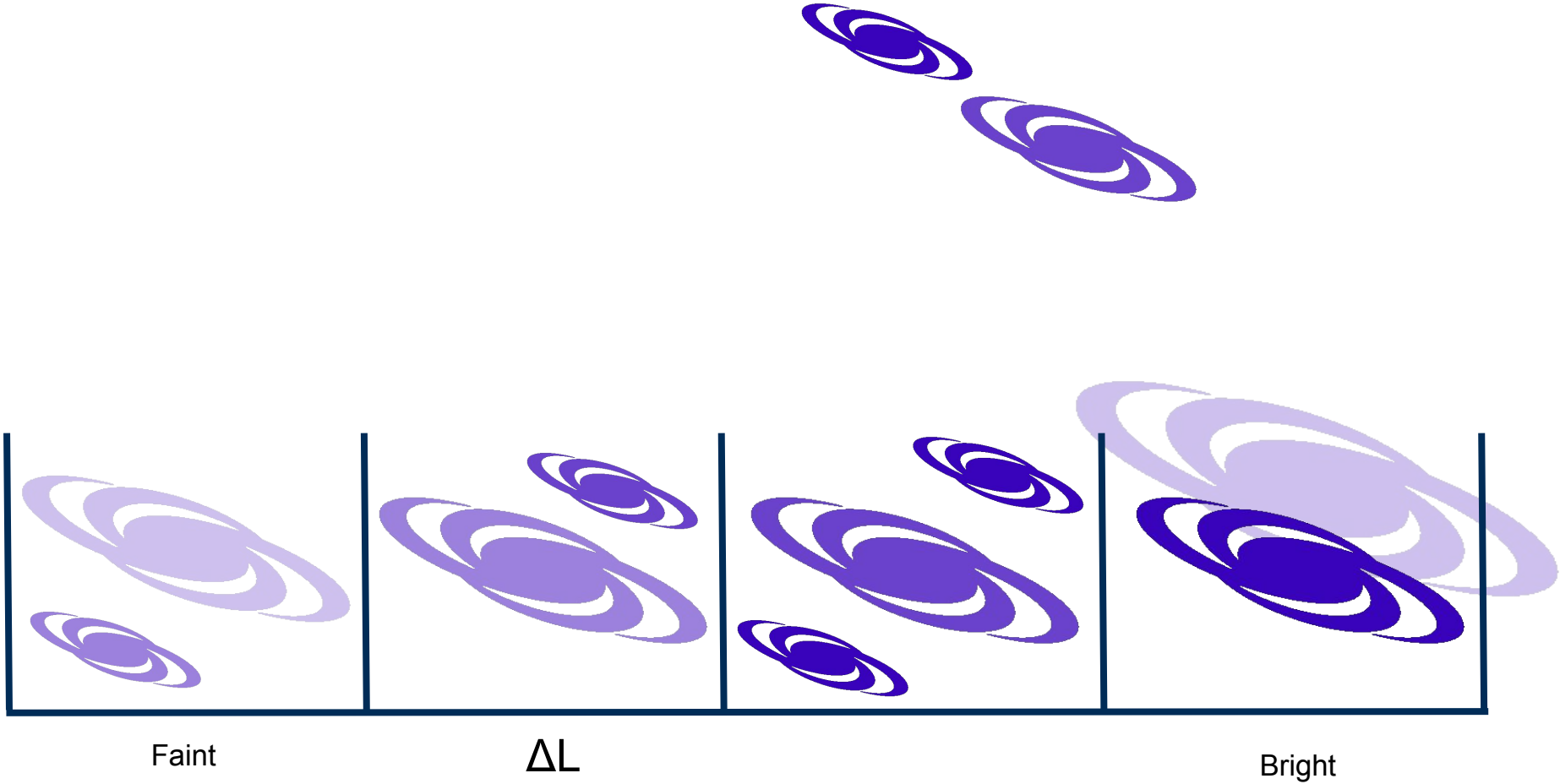
Then to estimate the corrected distributions, we bin measures of $1/V_{max}$ in each of the three main parameters: σ , r_{sH}, and f_H.



Herenz et al. 2019


Apparent Lyα Luminosities
Normalized Number per bin
0.0
0.2
0.4
0.6
0.8
1.0
39.0
39.5
40.0
40.5
41.0
41.5
42.0
42.5
43.0
Log($L_{Ly\alpha}$)


Faint
ΔL
Bright


Faint
ΔL
Bright

The Observed Sample - Star Formation History

Detected galaxies come mostly from two SFH epochs (~1.55 Gyr and ~2 Gyr).

These line up with periods of high star formation.