A resolved Lyman-Alpha profile with doubly peaked emission at z~7

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Reionization and it's parameters

- Reionization is a landmark in structure formation.
- Photons from the first radiating sources began ionizing the neutral Intergalactic medium.
- However, how and when ionization occurred is still up for debate.

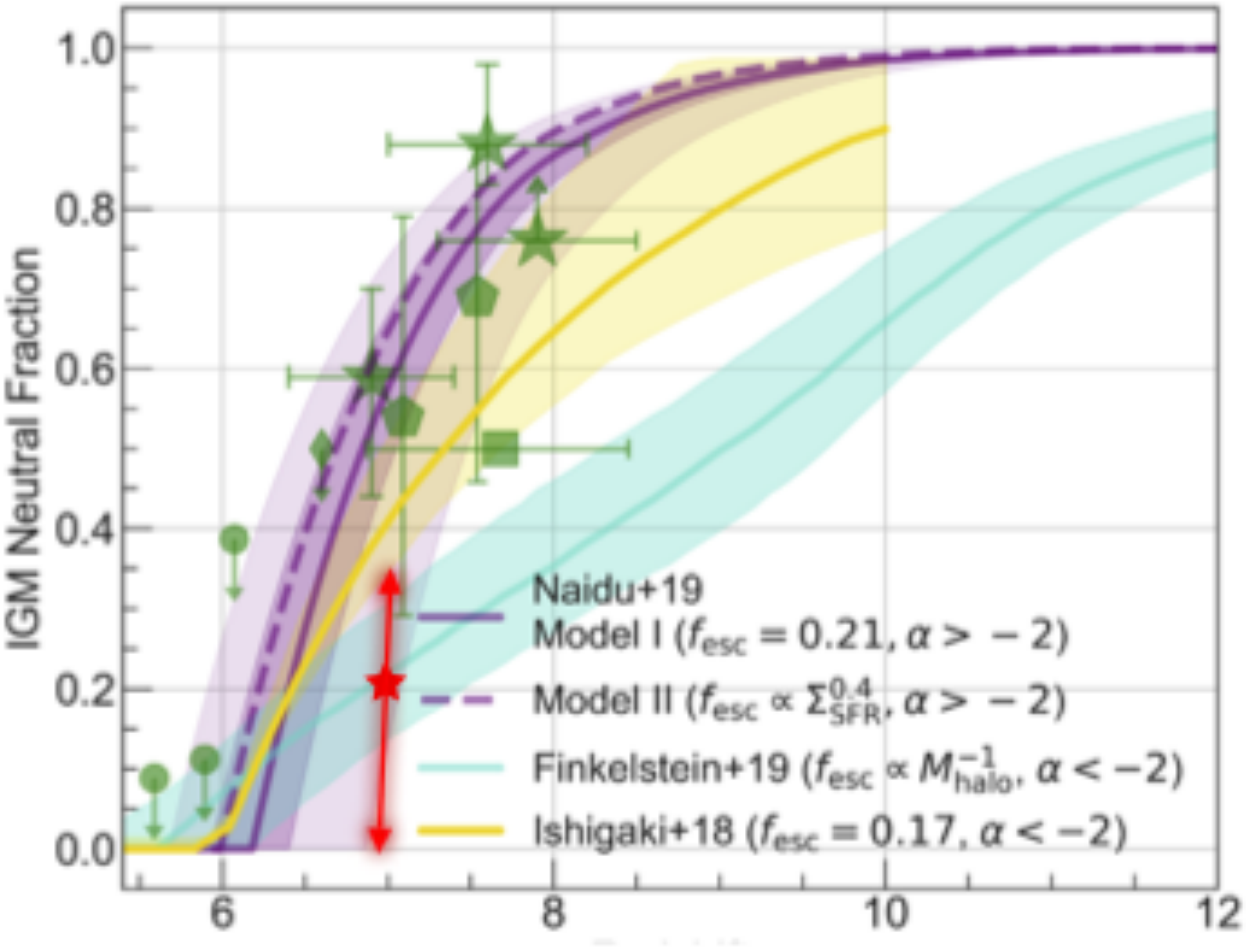


Figure adapted from Naidu+20
Red star from Wold+22

Ionized Bubbles

- Ionized regions of the universe allow photons with λ <1215.67AA to move freely.
- This regions of ionized gas, or "bubbles" would grow and merge with other bubbles until reionization was complete.

14 *Garel et al.*

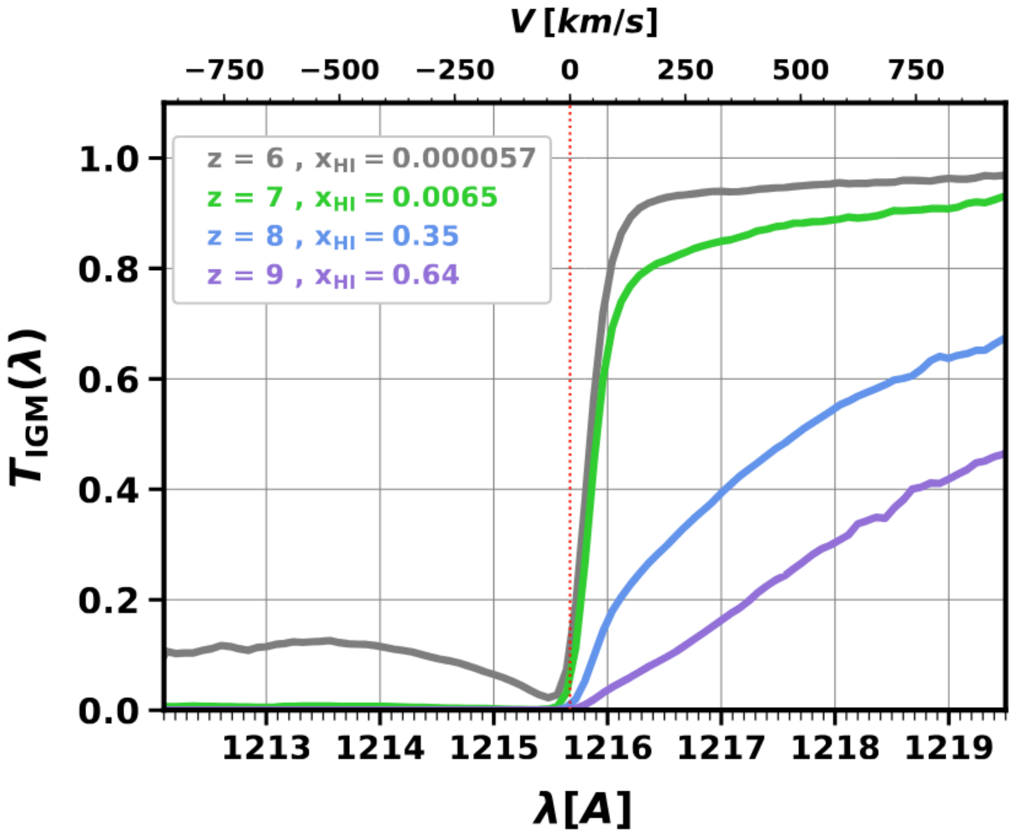


Figure 13. Lyα IGM transmission as a function of rest-frame wavelength at $z = 6, 7, 8$, and 9. The vertical red dotted line indicates the line centre ($V = 0$). The evolution of T_{IGM} with redshift reflects the increase of the volumetric neutral fraction x_{HI} towards higher z (see legend).

Ionized Bubbles

Mason & Gronke 20

- Bubbles are interesting because they host the objects contributing most of the ionizing budget.
- Bubbles should trace overdensities.
- Measuring the extent of the Lya line constrains the minimum size of the bubble.

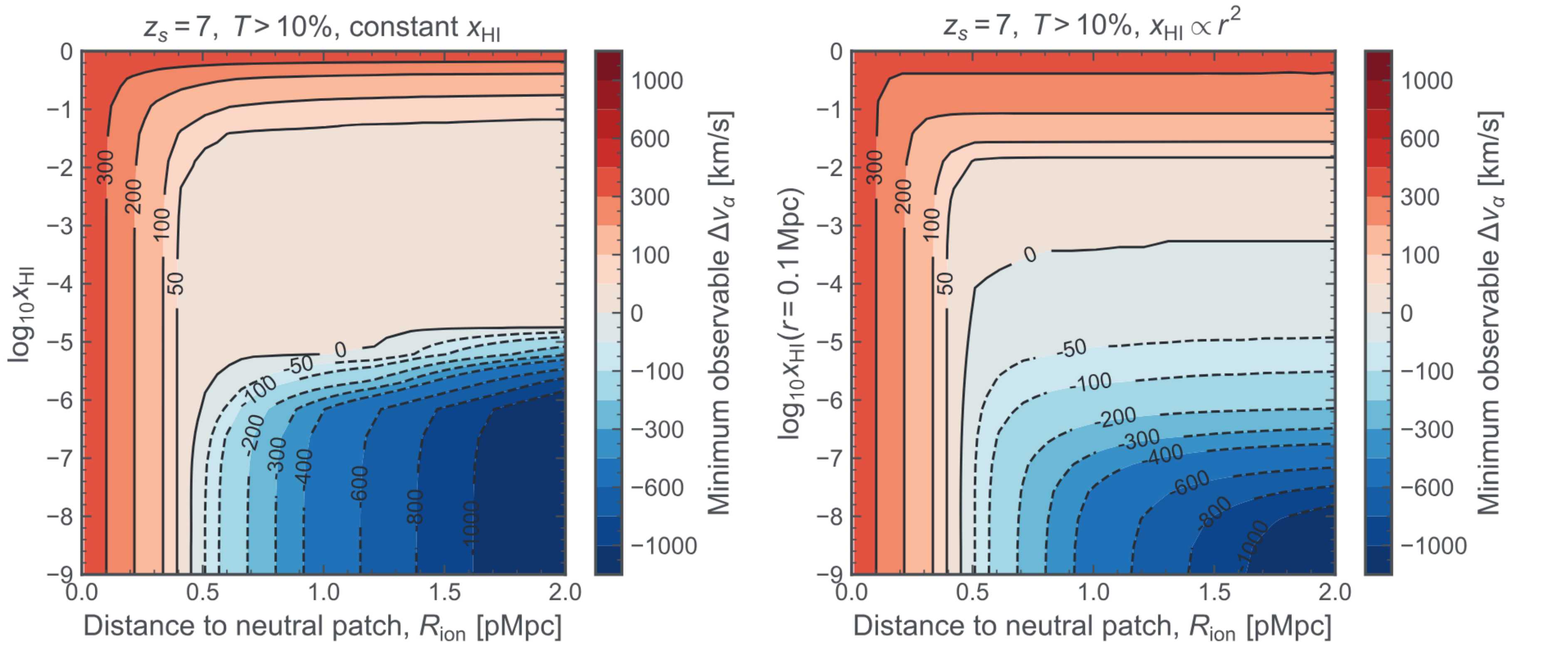
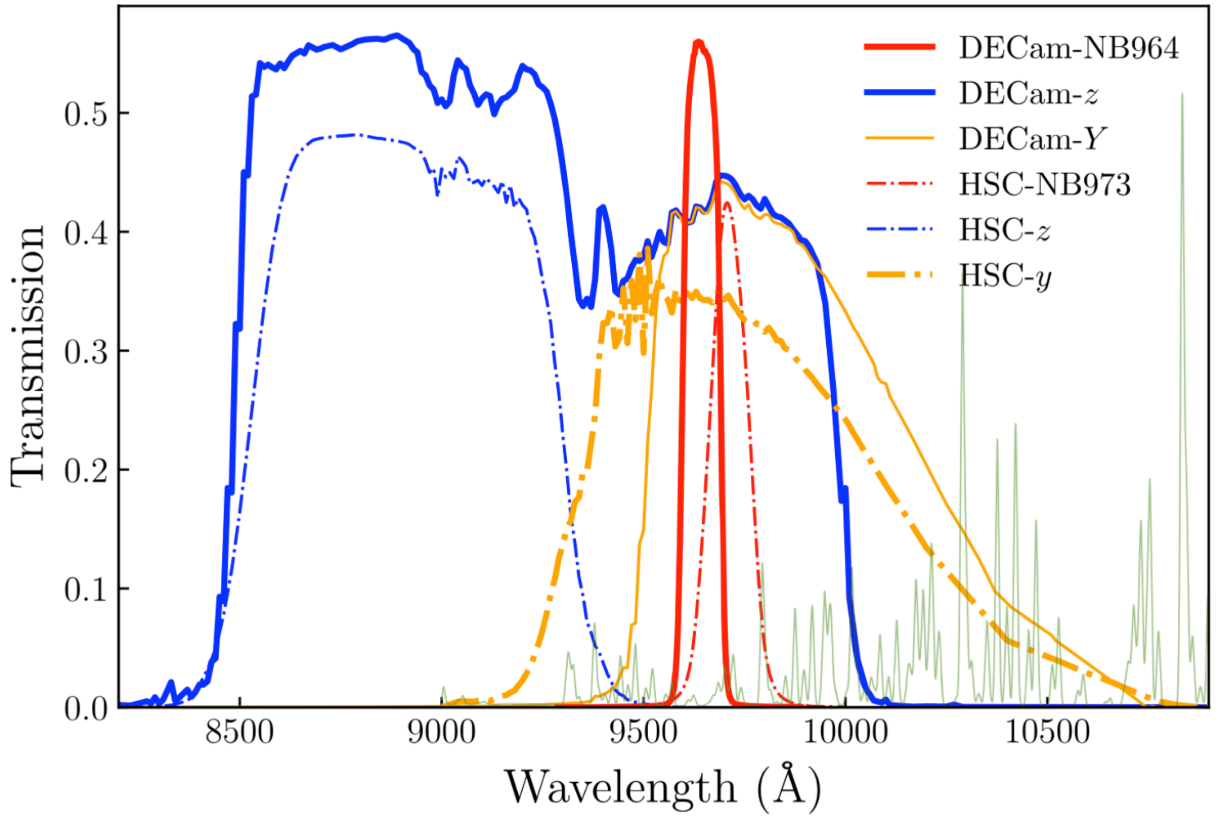


Figure 5. Minimum observable Lyα velocity offset, Δv_α as a function of bubble size and residual neutral fraction, assuming > 10 per cent transmission on the red or blue sides. Left-hand panel: for a constant residual neutral fraction, x_{HI}, inside the ionized bubble. Right-hand panel: $x_{HI} \propto r^2$, with the quoted value at 0.1 Mpc.

LAGER

- Narrow band survey using the 4mt Blanco Telescope + DECam
- Filter centered on 9640AA -> Lya at z~6.9.
- Four fields published so far (Hu+19, Wold+22) and a fifth field in progress (Moya-Sierralta in prep).
- ~300 candidates and ~40 spectroscopic confirmations.



Yang+19

- Yang+19 presented spectroscopic confirmation of two z~7 LAEs.
- One of them (LAGER-CDFS1) was observed with Magellan/FIRE.
- No metal lines were detected.
- Hint of two peaks?

The Astrophysical Journal, 876:123 (5pp), 2019 May 10 Yang et al.

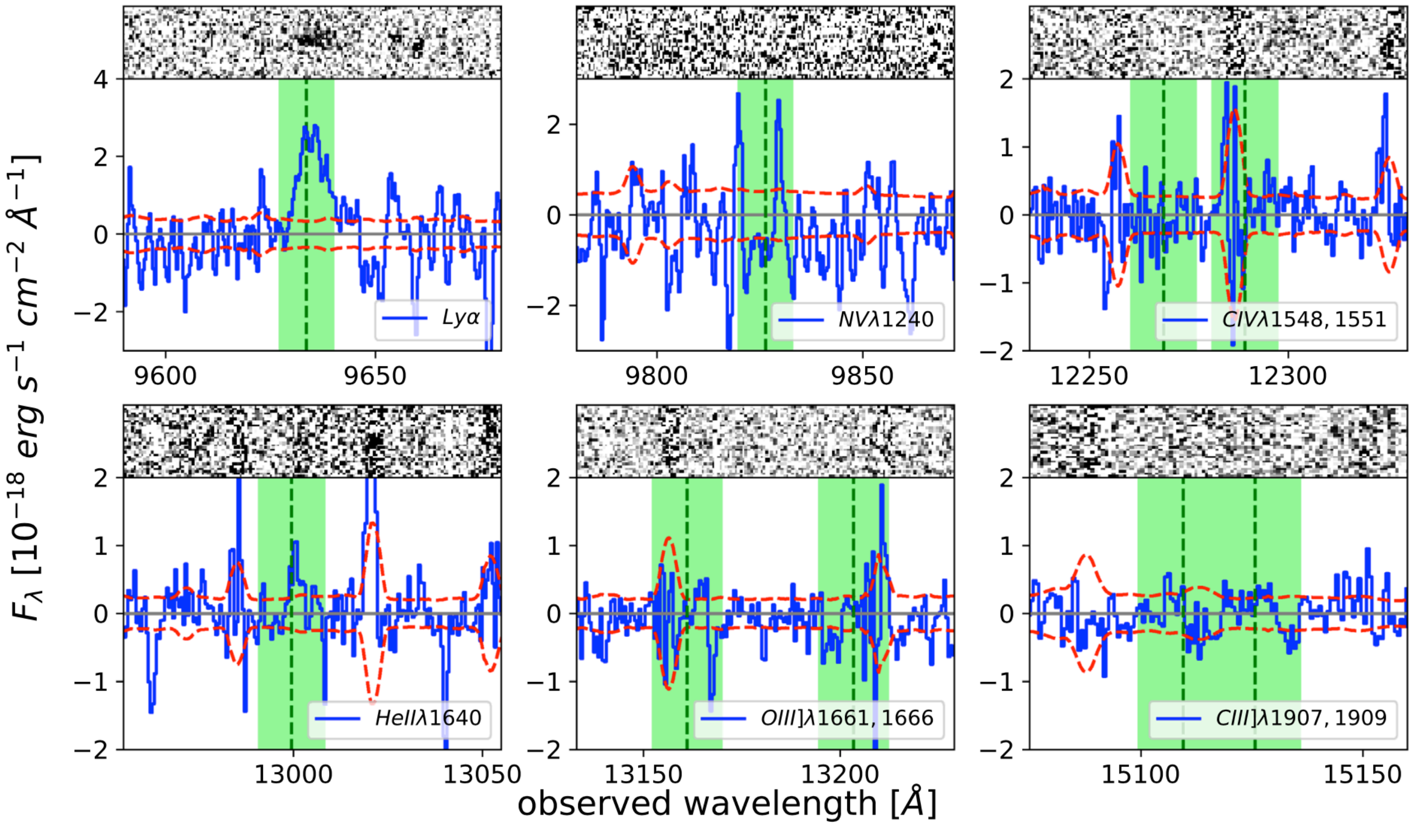
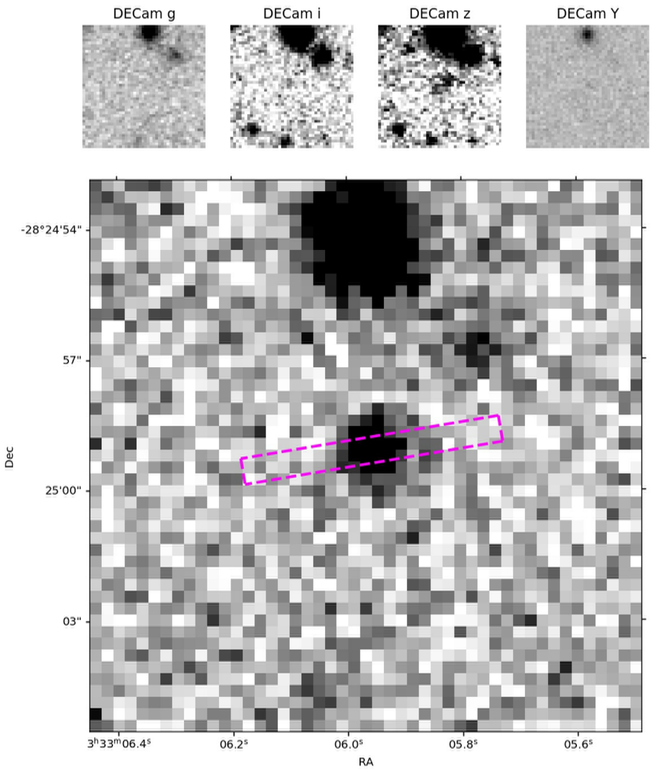
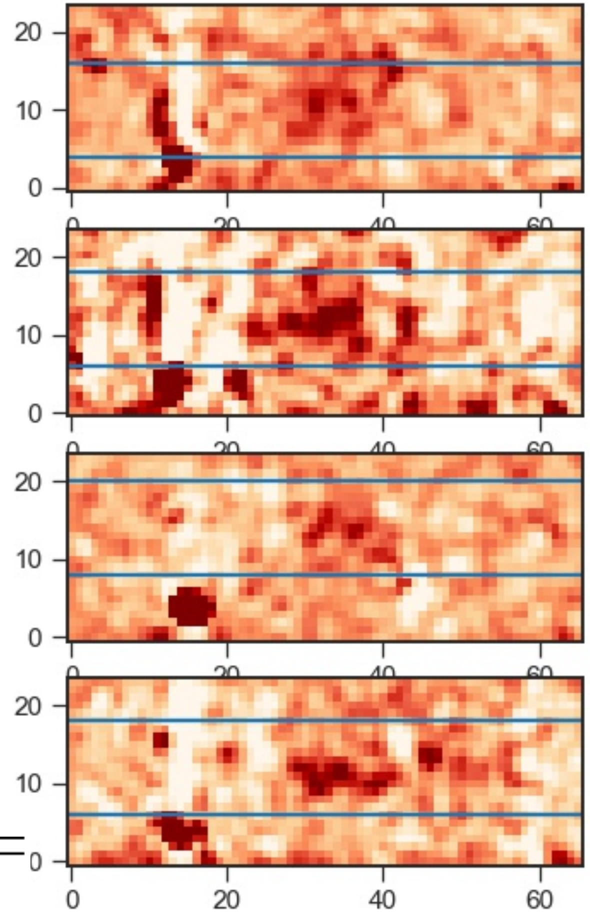


Figure 3. FIRE 2D and 1D spectra of CDFS-LAE1 at the wavelength of Lyα, N Vλ1240, C IVλ1548,1551, He IIλ1640, O III]λ1661,1666, C III]λ1907,1909 lines. The blue solid line is the spectra and the red dashed line is the 1σ error. The green vertical dashed line shows the expected line positions assuming redshift = 6.9245, which is derived from the peak of the observed Lyα profile. The green shades show $\pm$200 km s^{-1} wavelength regions around the expected line position. No UV metal lines are detected at S/N > 5.

Observations

- We observed CDFS1 during the nights of December 12th, 13th and. 14th of the year 2020.
- We used Magellan/FIRE with the 0.6” slit.
- After discarding bad exposures, we are left with 4x1 hour frames.

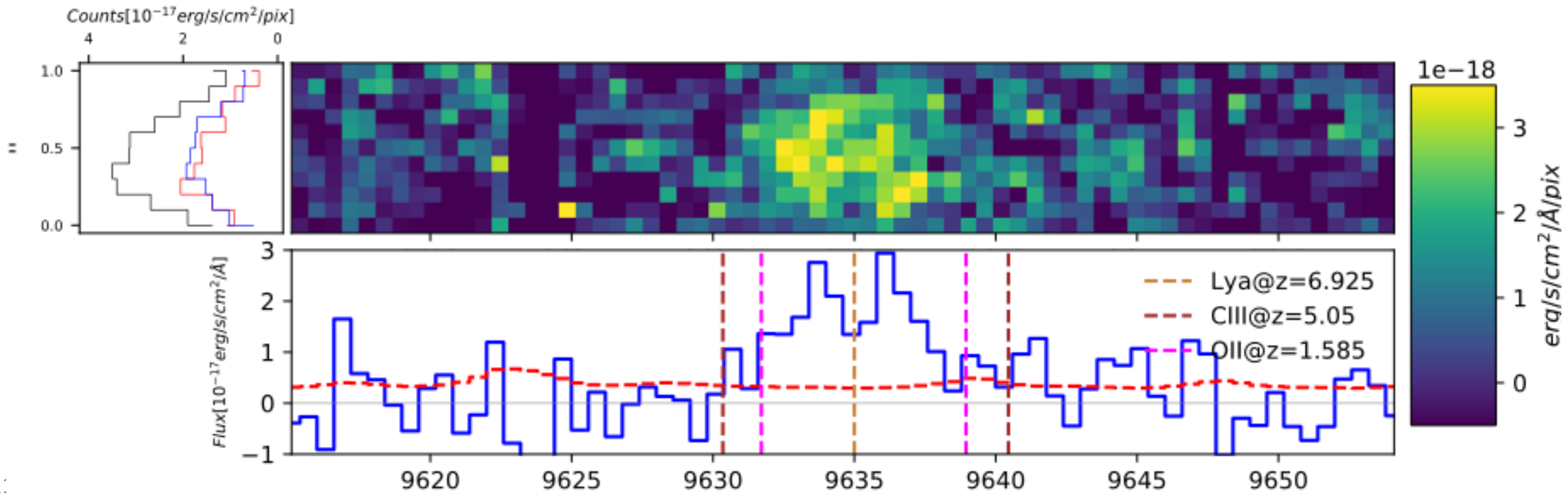




Parameter	Measurement
$z_{\mathrm{Ly}\alpha}$	6.9245
$\log L$	$43.3^{+0.03}_{-0.04}$
$\mathrm{EW}_{\mathrm{Ly}\alpha}$	79^{+54}_{-23}
$f_{\mathrm{esc}}(\mathrm{Ly}\alpha)$	$0.8^{+0.09}_{-0.1}$

Reduction and output spectra

- Data was reduced with the FIREHOSE pipeline and with pypeit.
- FIREHOSE yielded a higher SNR so we stuck with it.
- No continuum is seen on the data. Thus, we stack the exposures by centering on the emission line after visual inspection.
- A double peak with a separation of ~100 km/s is detected.



Modelling

- We use FLaREON to model the profile, which takes three parameters.
- V_exp is the expanding medium velocity.
- Log(NH) is the neutral hydrogen column density, which regulates the number of scattering events.
- Log(Tau) is the dust optical length, which regulates how many scattering events lead to absorption

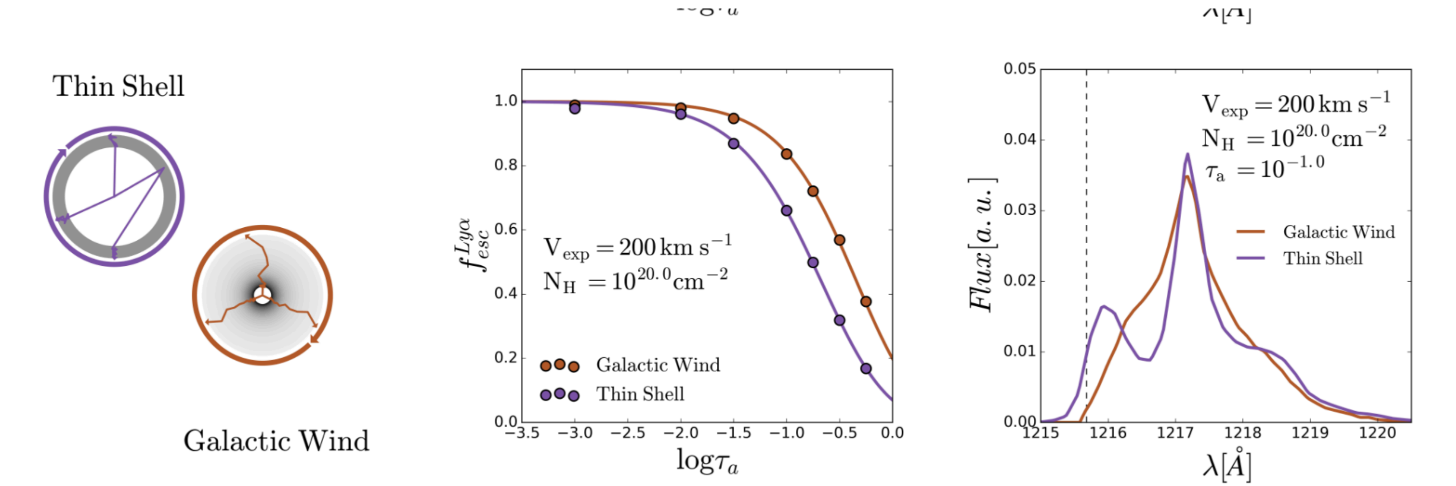


Figure 1. The Lyα line properties in different geometries. The left panels show a cartoon of the Biconical wind, Thin shell and Galactic wind. The middle panels show the Lyα escape fraction as a function of dust optical depth of absorption τ_a for the three geometries and outflow configuration as shown in the legend. The right panels show examples of Lyα line profiles for the configurations described in the legend.

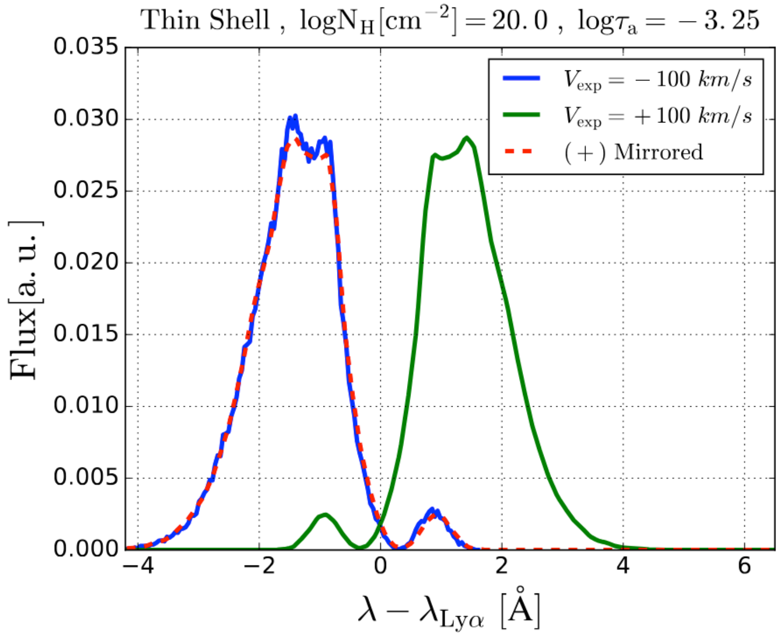


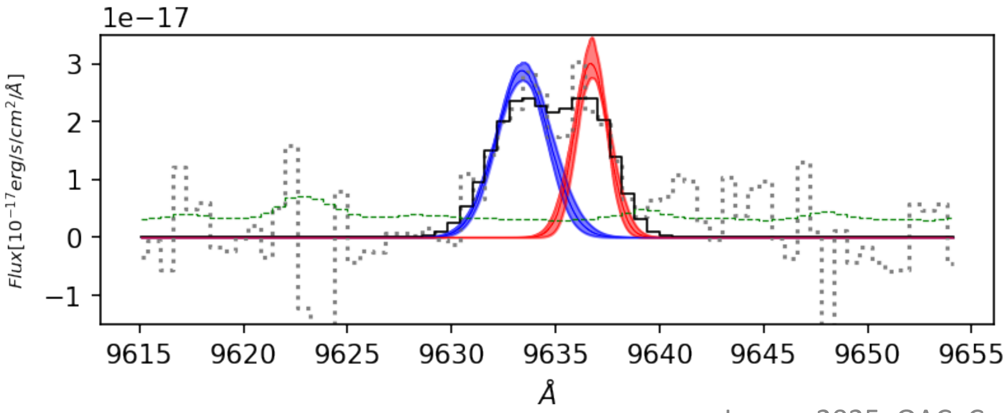
Figure 7. Comparison between the proper calculation of a Lyα line profile emerging from an inflow configuration using LyaRT and the outputs of FLaREON. This example was built with the Thin shell as gas geometry, $\log N_{\mathrm{H}}[\mathrm{cm}^{-2}] = 20$, $\log\tau_{\mathrm{a}} = -3.25$ and $|V_{\mathrm{exp}}| = 100$ km/s. In blue we show the full RT computation by LyaRT using $V_{\mathrm{exp}} = -100$ km/s. In green we show the FLaREON's prediction using $V_{\mathrm{exp}} = +100$ km/s. In dashed red we show FLaREON's output after the remapping of the wavelength (Eq.8).

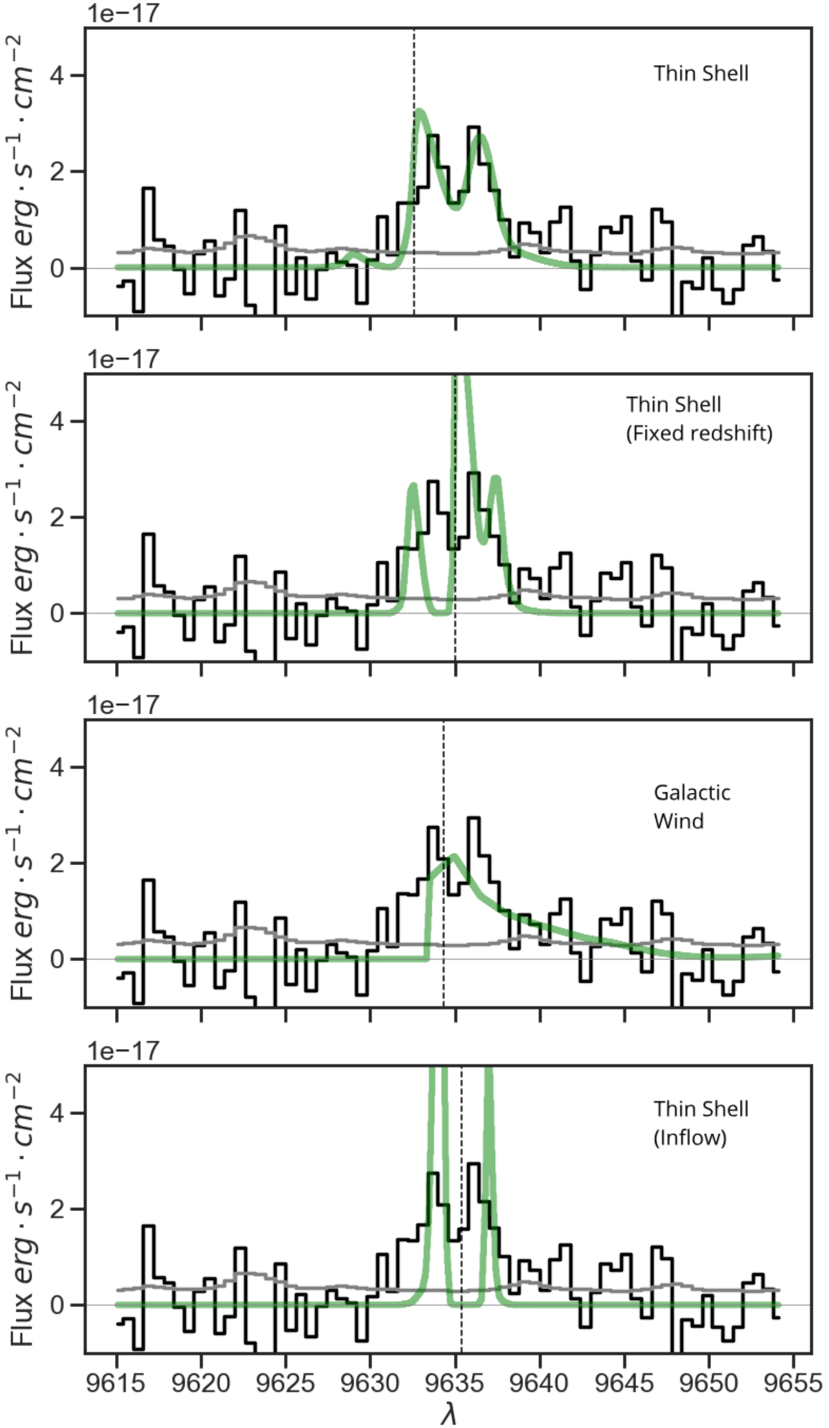
Gurung-López+19

Modelling

- We first model the line as a double gaussian to measure the redshift and B/R ratio.
- We then use the FLaREON python library to fit radiative transfer models to our data.
- Our model fitting considers five parameters: Vexp, LogNH, dust absorption tau, systemic redshift, and a scaling factor..

B/R>1!

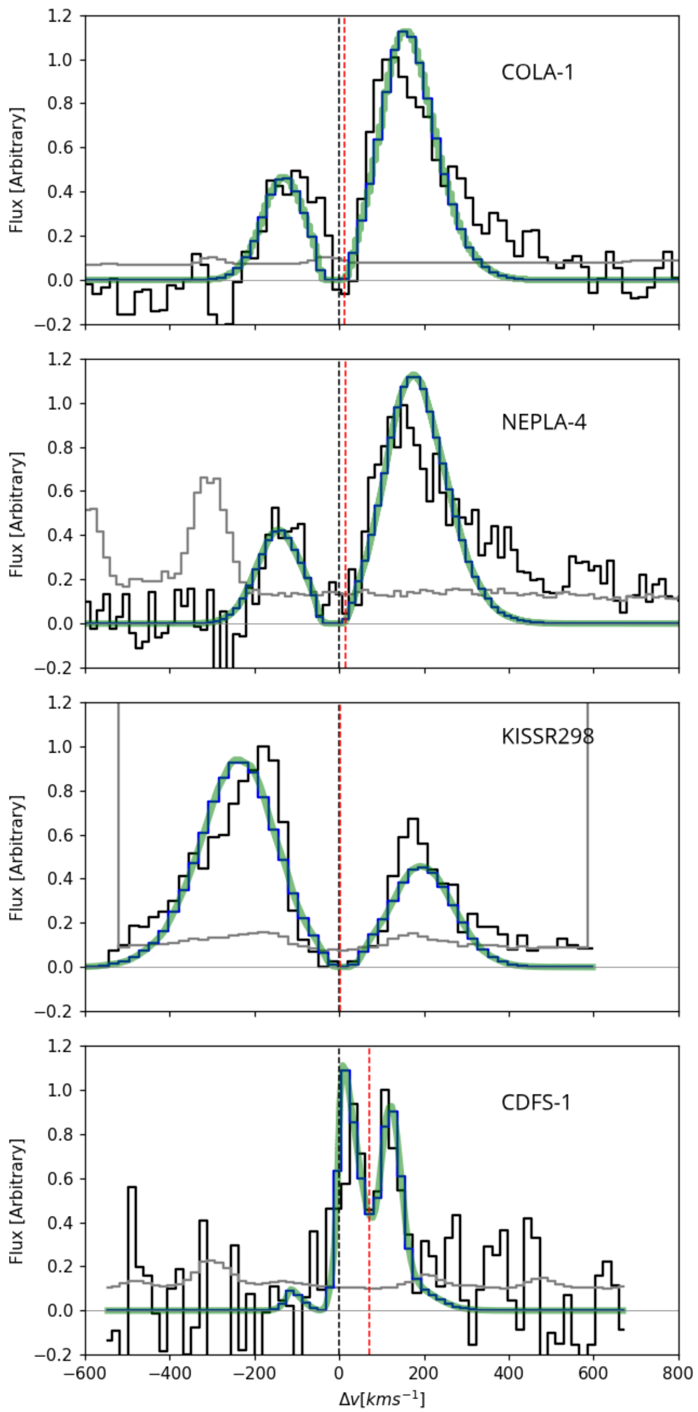




Model comparison

- In order to put the models in context, we attempt to model other double peaks in the literature.
- We find that FLaREON is able to model these sources WITHOUT THE NEED OF AN IGM COMPONENT.
- We also see how different CDFS1 is from these systems.
- All systems show fesc(Lya)>0.9 (Using FLaREON's analytical model).

z sys	LogNH	V	logTau
6.5908	19.6±0.3	13.7±11	-3±0.6
6.543	19.7±0.2	15.9±12	-3±0.6
0.0491	20.1±0.1	-2.3±5	-2.8±0.4
6.924	18.3±0.5	69.9±8	-2.4±0.8



Model comparison

- Results are highly model dependent.
- Nevertheless, FLaREON allows us to estimate sytemic redshifts and compare different Lya profiles in a systematic fashion.

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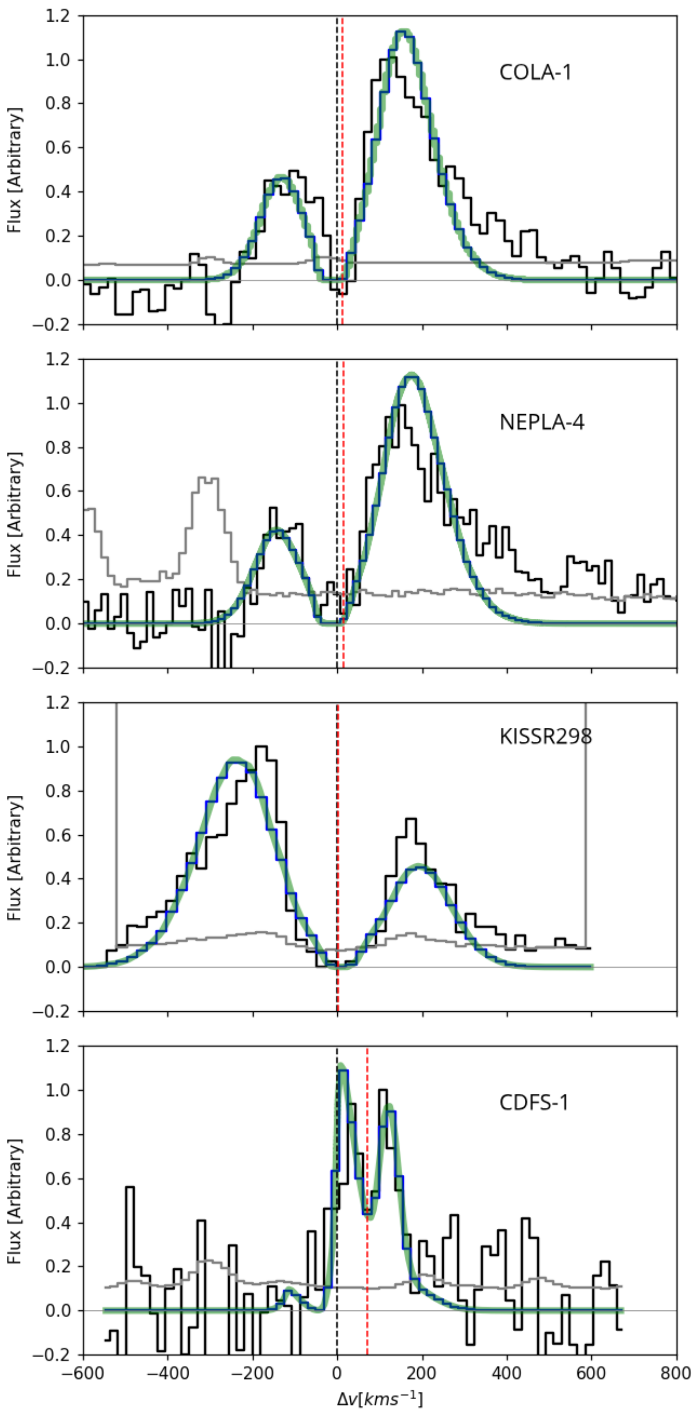
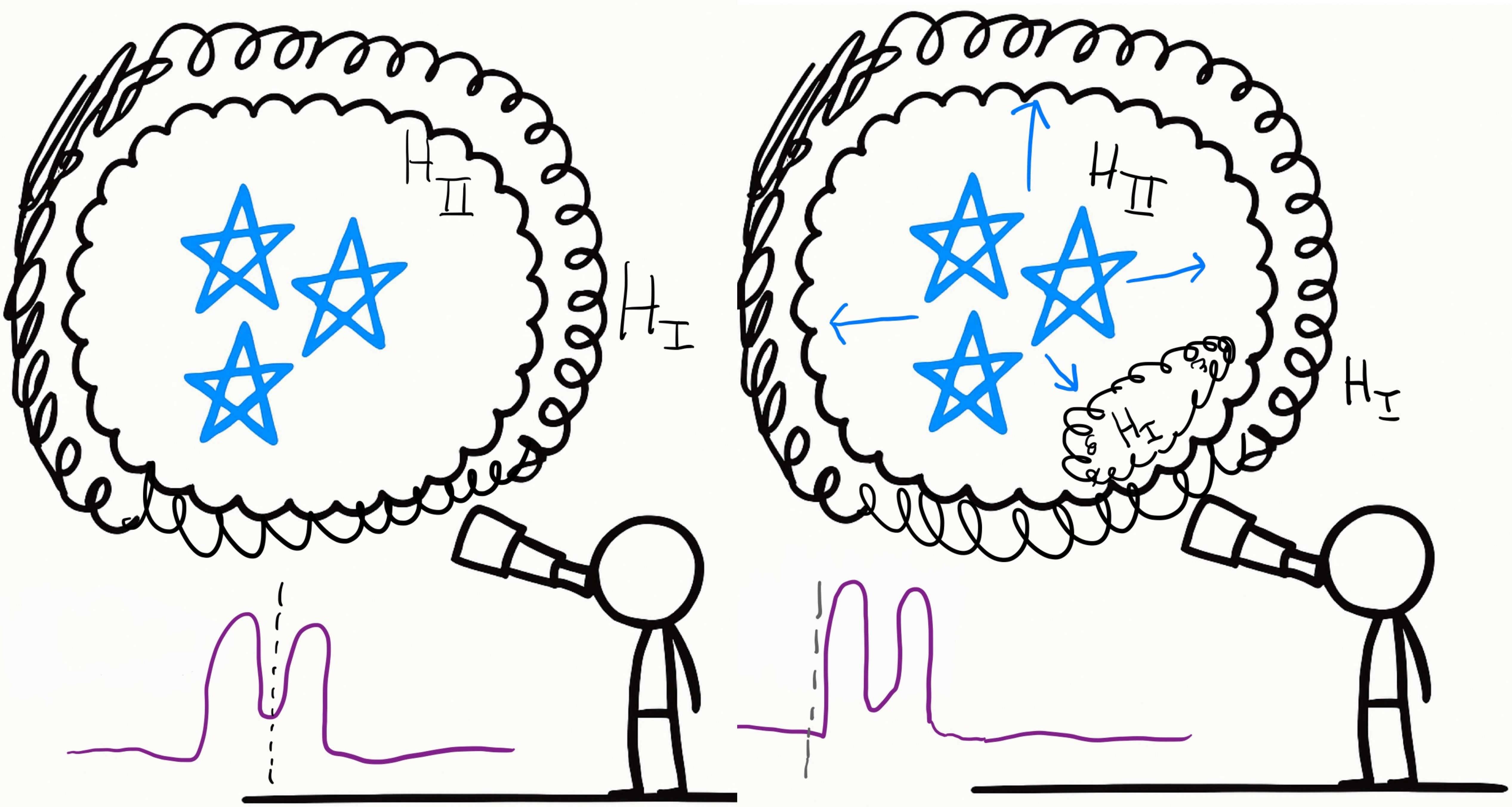


Origin of the doubly peaked line

- While CDFS1 might not be a “canonical” double peak, our inferred z_sys yields a small velocity offset (~70 km/s). Implying that radiation can easily escape the galaxy.
- The systemic redshift could fall between the peaks, making CDFS1 a highly ionizing source.
- The double peak could come from kinematic effects. We compute a dynamical mass of 10^10 Msol in that scenario.


H II
H I
H II
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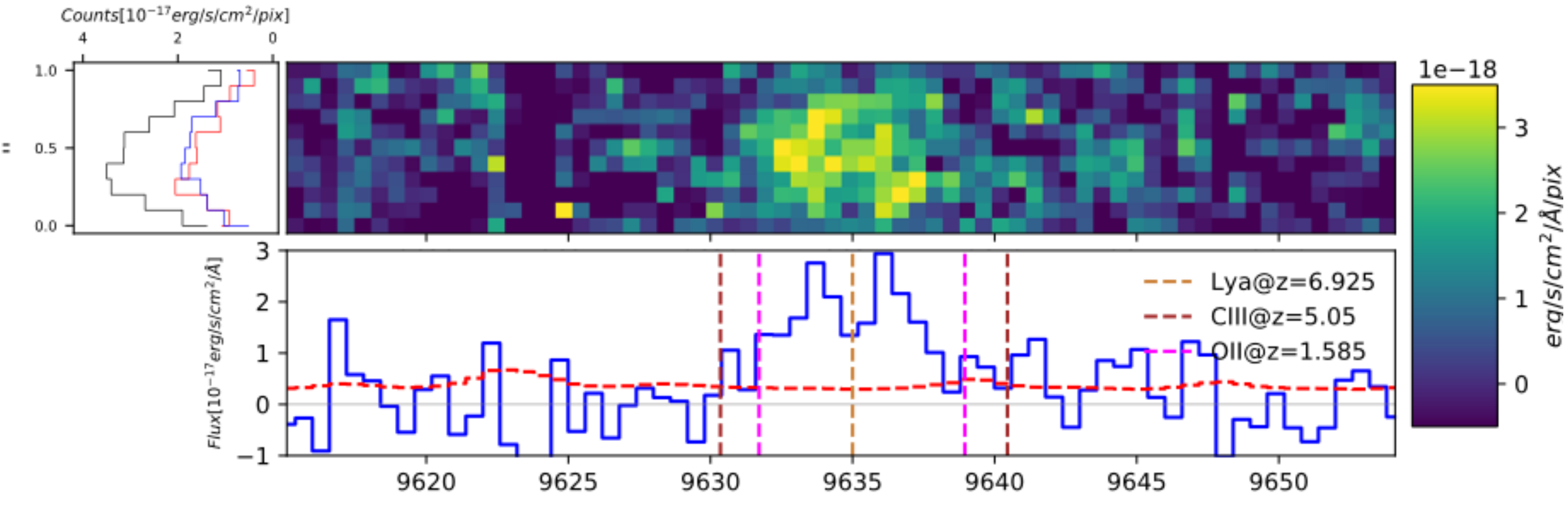
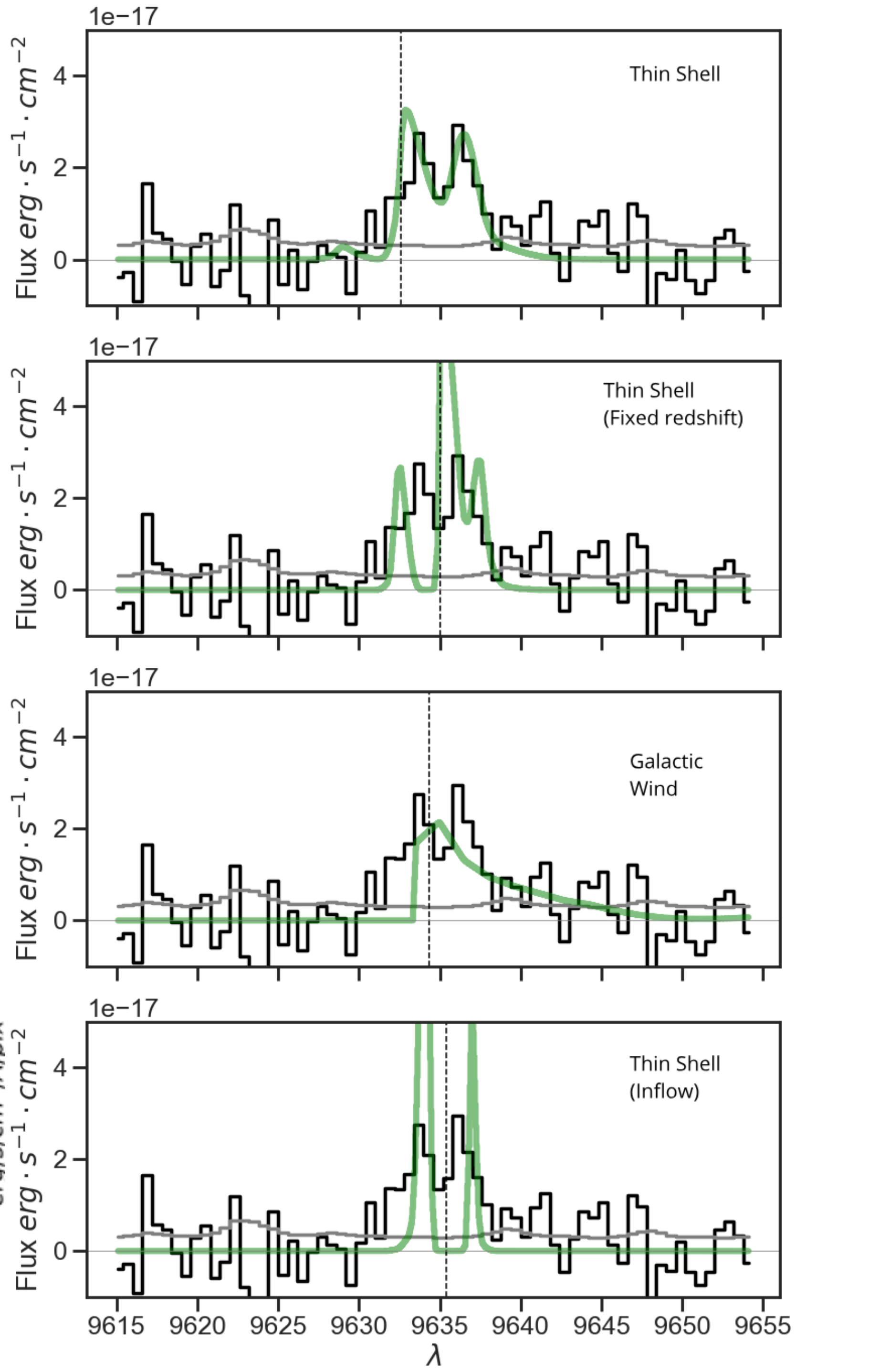
H I

CDFS-1

- We have found the highest redshift (6.93) doubly-peaked LAE.
- At first glance, this could suggest the presence of an ionized bubble around this source.
- However, the differences between CDFS1 and similar sources might indicate a different origin for the line profile.
- Measuring the systemic redshift for objects like CDFS1 is crucial.





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THANK YOU FOR YOU ATTENTION!

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