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The MUSE Hubble Ultra Deep Field surveys:
Average Physical Properties of the Lyα Haloes

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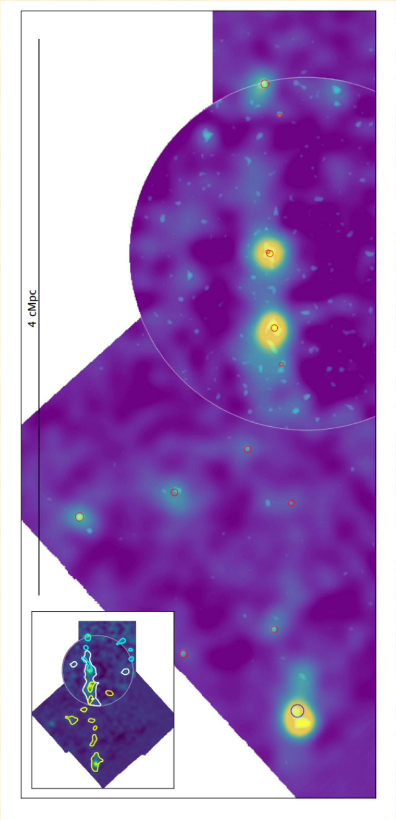
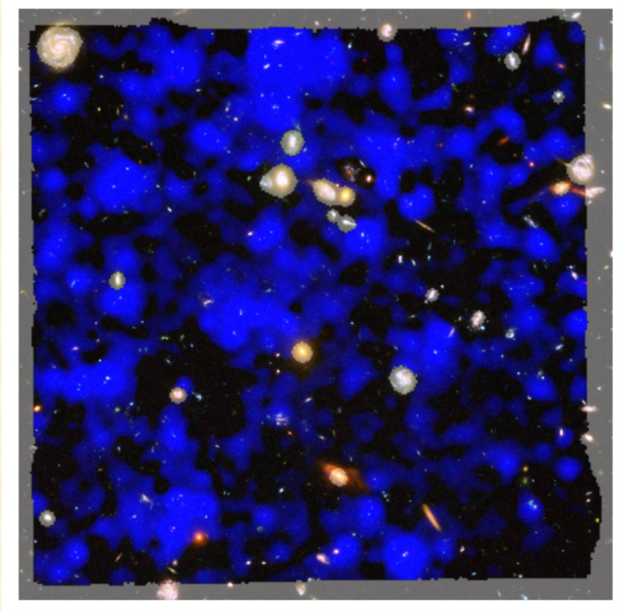
muse
multi unit spectroscopic explorer

AGENCE NATIONALE DE LA RECHERCHE
ANR

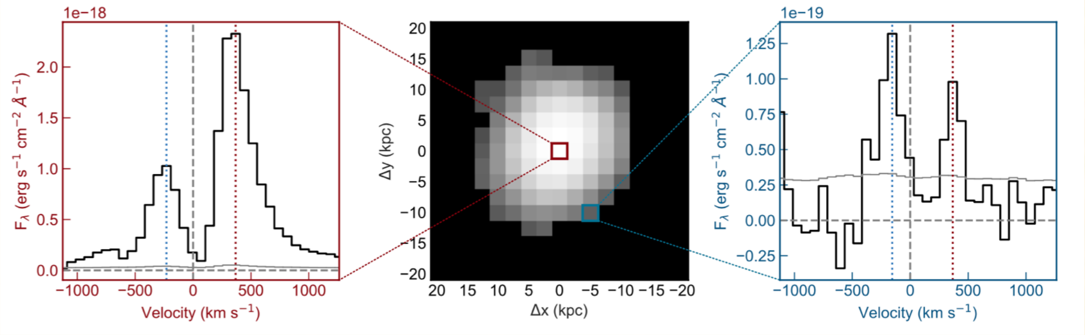
The Lyα haloes (LAHs)



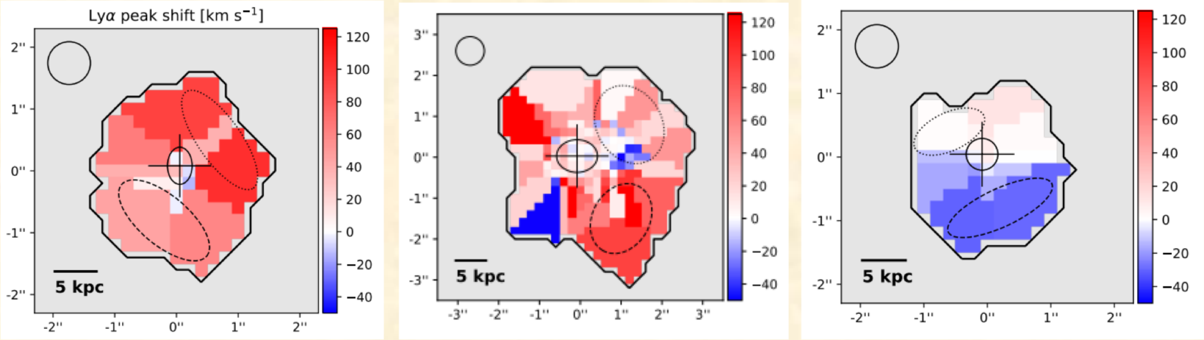
Bacon et al. 2021



Wisotzki et al. 2018



Erb et al. 2018



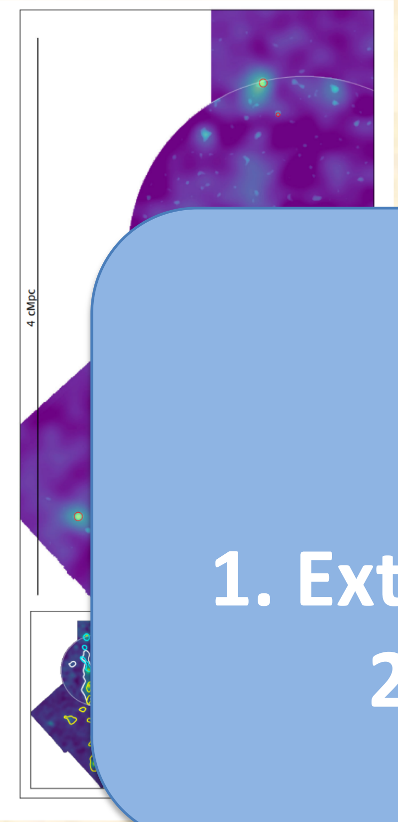
Leclercq et al. 2020

- **Lya haloes are ubiquitous around star forming galaxies at z > 3** (e.g., Steidel+11, Kusakabe+22)
- **Extend over tens of pkpc, ~10+ times more extended than continuum, trace the CGM/IGM**
- **Diversity in the Lya line profiles seen in several special LAHs**(Erb+18,22, Claeyssens+19, Leclercq+20, Li+22)
- It is difficult to disentangle the different mechanisms that power the LAHs (Efforts ongoing : e.g. Song+20 , Byrohl+21, Mitchell+21, Li+22a and others are coming…)

Observational works see also Rauch+08, Matsuda+12, Momose+14,16, Wisotzki+16, Leclercq+17, Wu+20, Bacon+21, Chen+21, Lin+22b, Erb+22, Lujan Niemeyer+22a,b, Kikuchihara+22, etc.

The Lyα haloes (LAHs)

The aim of this project:
unbiased stacking analysis of the LAHs
1. Extended Lyα emission out to hundreds of pkpc
2. Lyα spectral profile out to tens of pkpc



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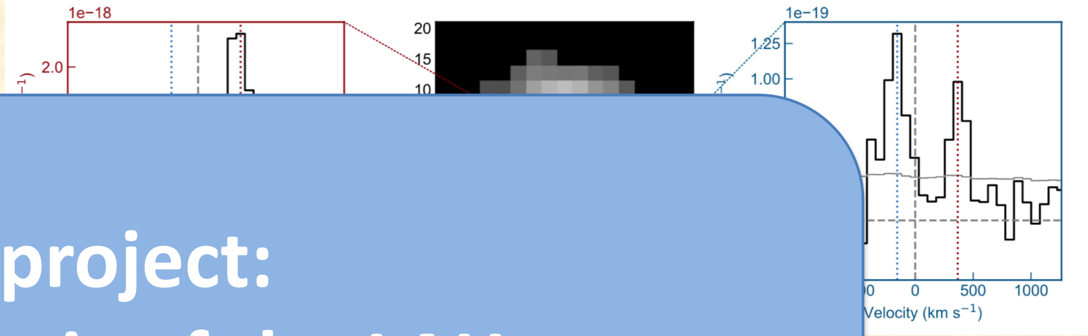

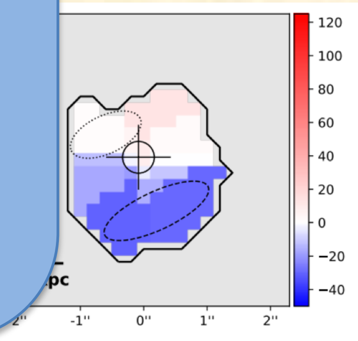

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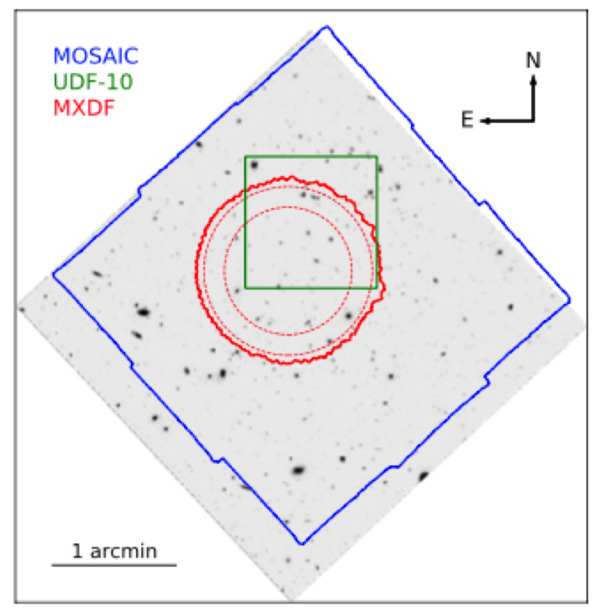
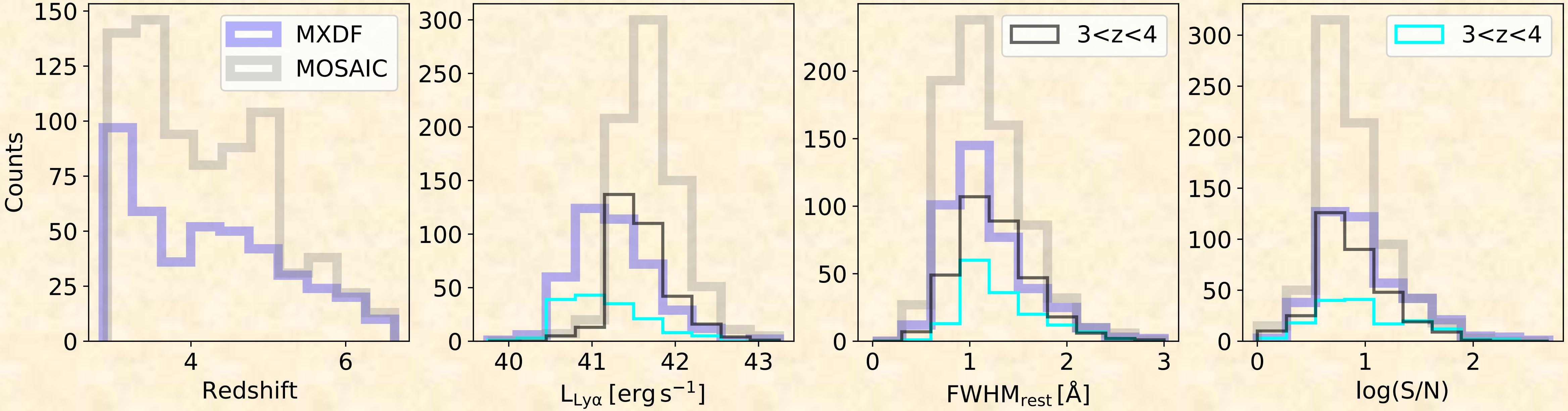
The MUSE Hubble Ultra Deep Field Surveys

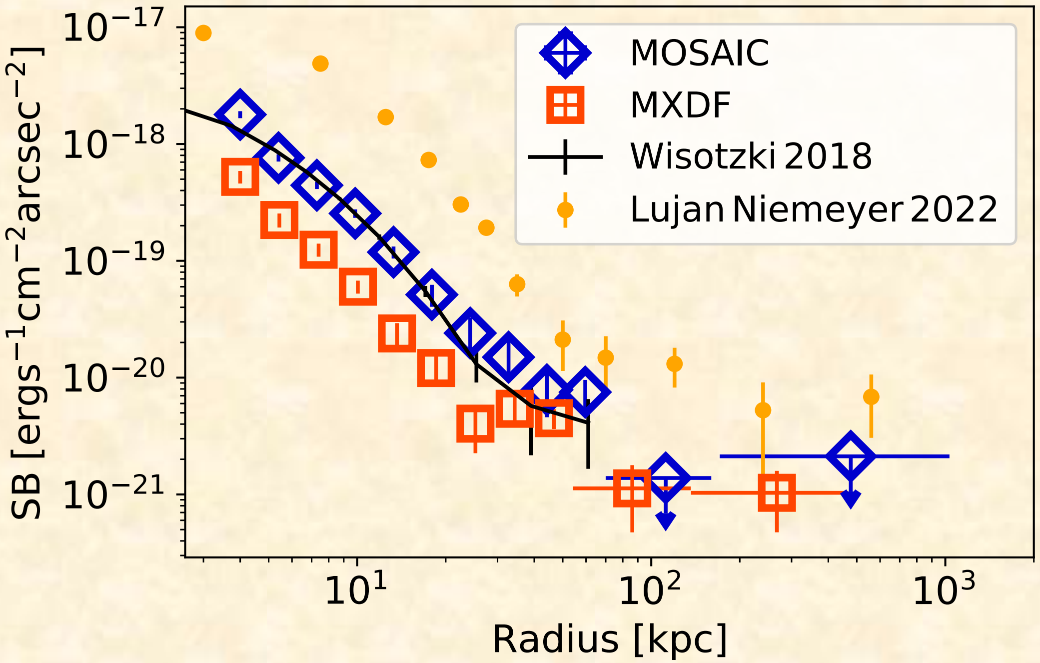
- MXDF: expT 100-140h ; FoV 1’, ~400pkpc at z=3
- MOSAIC: expT 10h ; FoV 3’, ~1200pkpc at z=3
- For LAEs at 3<z<4,
  - 155 LAEs at MXDF, 329 LAEs at MOSAIC
  - Median Lya luminosity, **$L_{lya,MXDF}=41.1$ erg/s**, $L_{lya,MOSAIC}=41.5$ erg/s
  - Median Stellar mass, **$M_{MXDF}=10^{7.6}\,M_\odot$**, $M_{MOSAIC}=10^{8.2}M_\odot$

Comparable stacking depth!





The median Lyα surface brightness profiles



Stacking of NBs centred at Lyα red peak

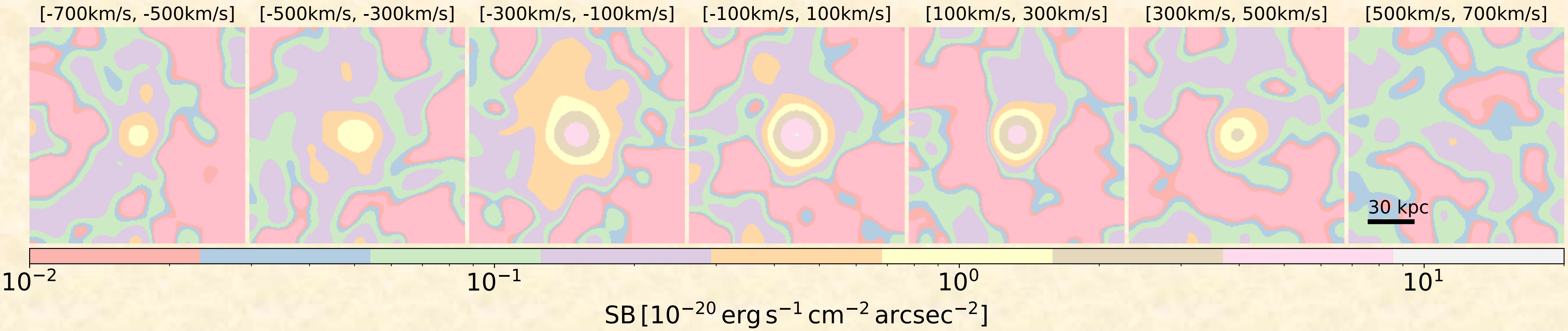
The different datasets:

- MXDF: $L_{\mathrm{ly\alpha,med}}$=41.1 erg/s, r_{vir}=20 kpc
- MOSAIC: $L_{\mathrm{ly\alpha,med}}$=41.5 erg/s, r_{vir}=25 kpc
- HETDEX (Low-luminosity subsample of Lujan Niemeyer et al. 2022): $L_{\mathrm{ly\alpha,med}}$=42.8 erg/s

- The Lyα surface brightness profiles shows similar shapes, normalization changes with Lyα luminosity
- Three components:
  - Decrease, $r \lesssim 1\ r_{\mathrm{vir}}$.
  - Flattening, $1\ r_{\mathrm{vir}} \lesssim r \lesssim 3\ r_{\mathrm{vir}}$. => ?
  - Very low SB at large radii, $r \gtrsim 3\ r_{\mathrm{vir}}$. => Dominated by neighboring bright LAEs

Wisotzki et al. 2018; Lujan Niemeyer et al. 2022; estimation of r_{vir} in Garel et al. 2016

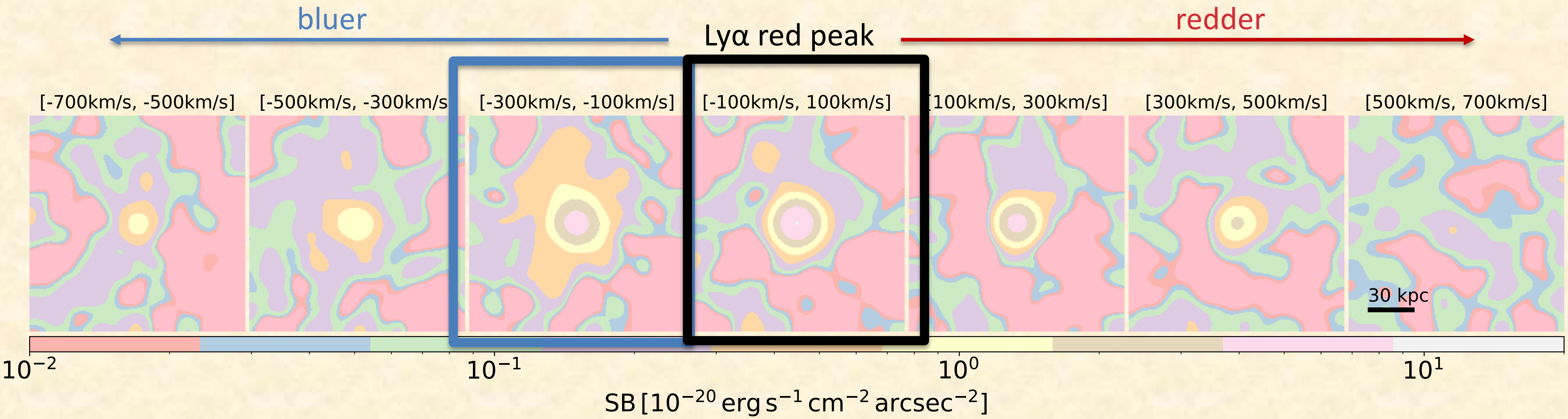
The extended Lyα emission at different velocity range



- Stacking the min-datacubes of all LAEs at the MXDF at 3<z<4, **wavelength re-aligned to the Lyα red peak**.
- The most extended Lyα emission is not around the Lyα red peak, but at ~[-300km/s, -100km/s]
- Determination of the pseudo-NB width for future studies, can not be too narrow!

Bluer Lyα emission at large distance?

The extended Lyα emission at different velocity range



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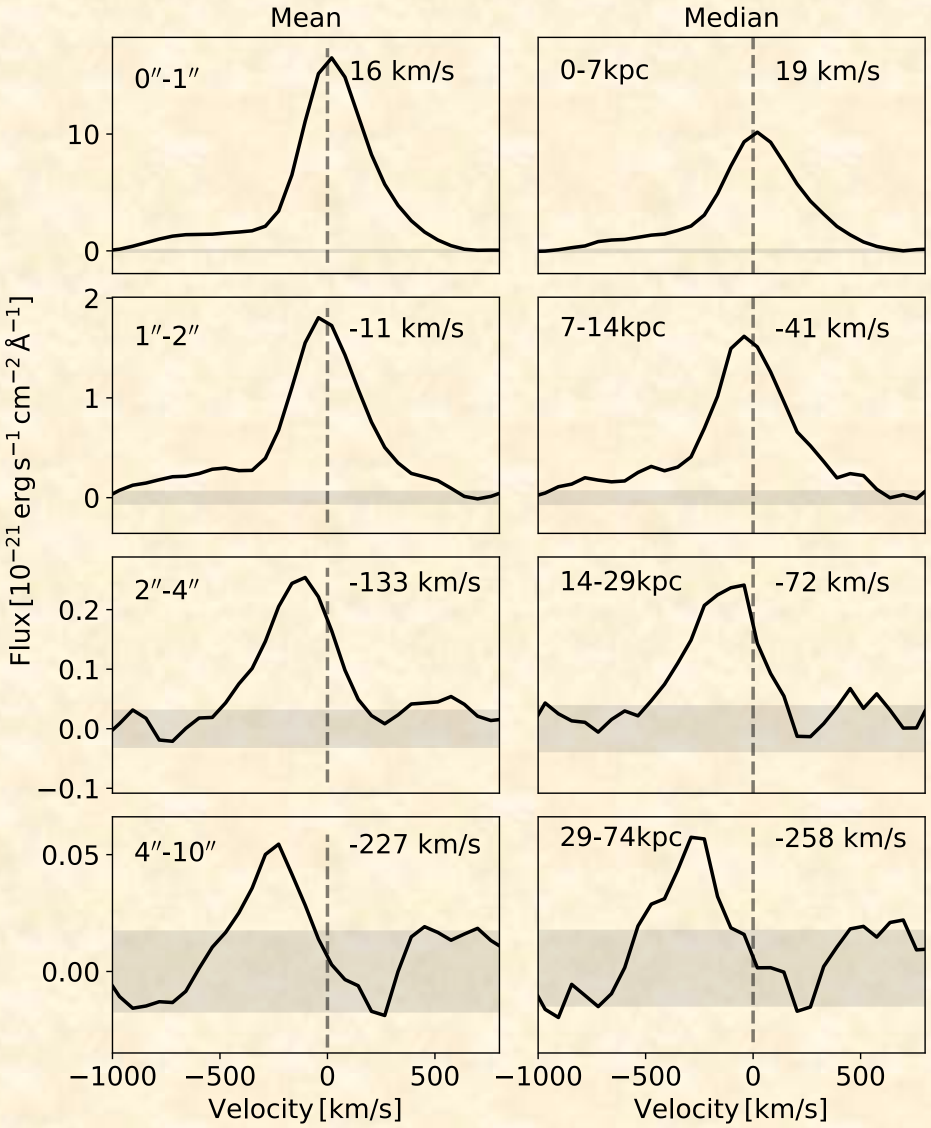
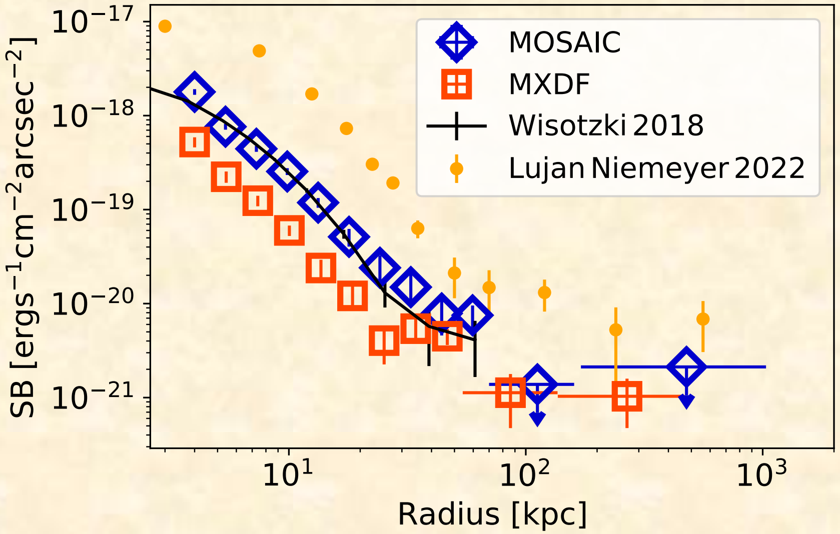
Spatially resolved spectral properties of LAHs

Matched by **Lya red peak**

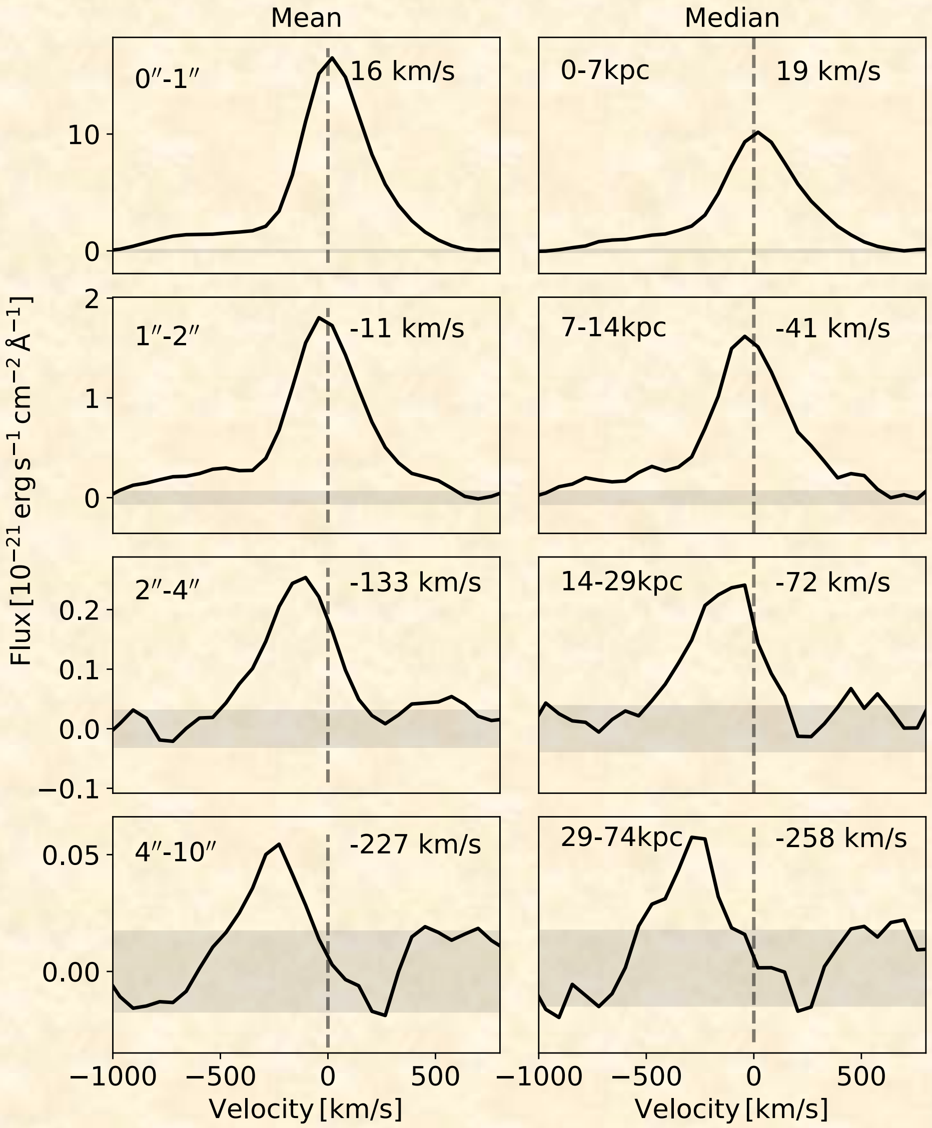


- From inner to outer region (70kpc), a clear **blueshift of Lyα emission line** (compared to Lyα red peak), **seen in mean and median**
- **Same distance as the surface brightness flattening**
- MXDF: $L_{ly\alpha,med}$=41.1 erg/s, r_{vir}~20 kpc
- The spectral resolution of MUSE ~150km/s
- Similar results for stacking LAEs at 4<z<5, where higher spectral resolution ~110km/s

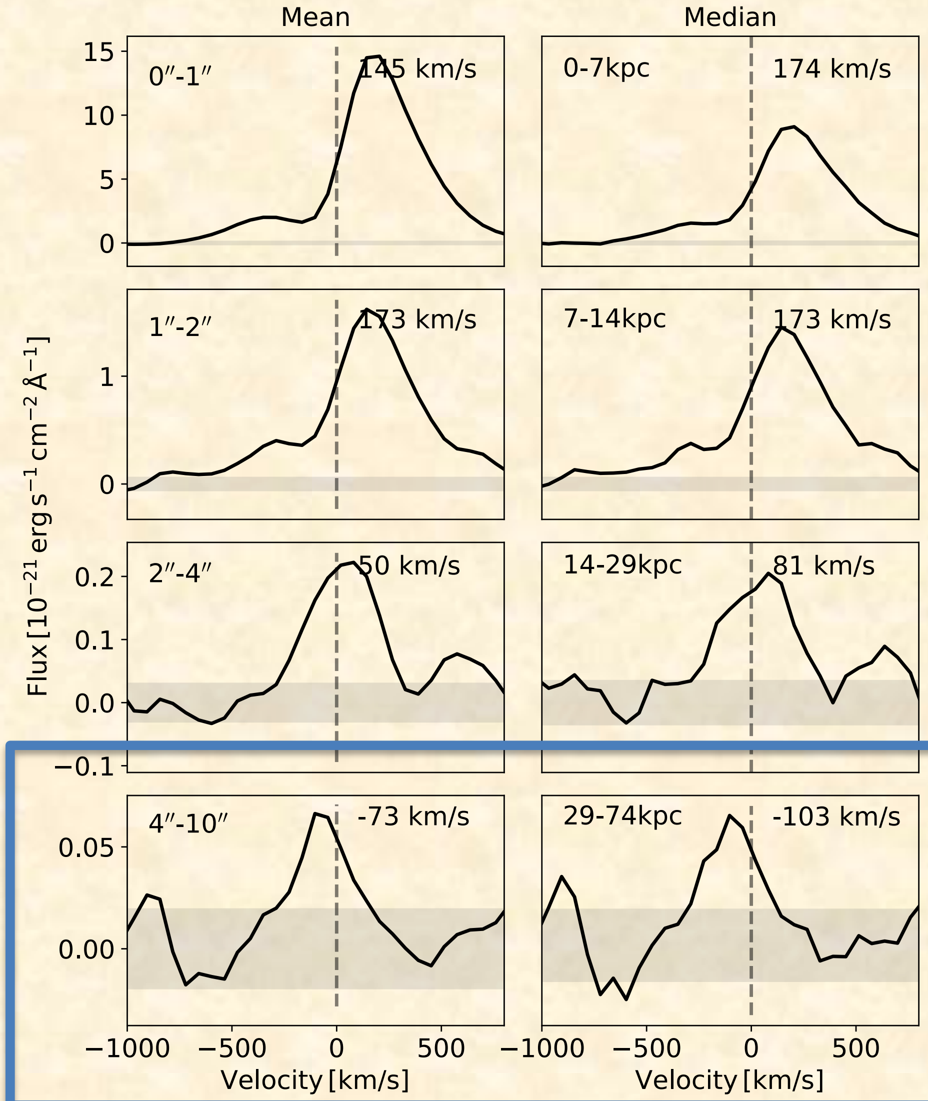


Does the blueshifted Lyα emission go to z_{sys}?

Matched by **Lyα red peak**



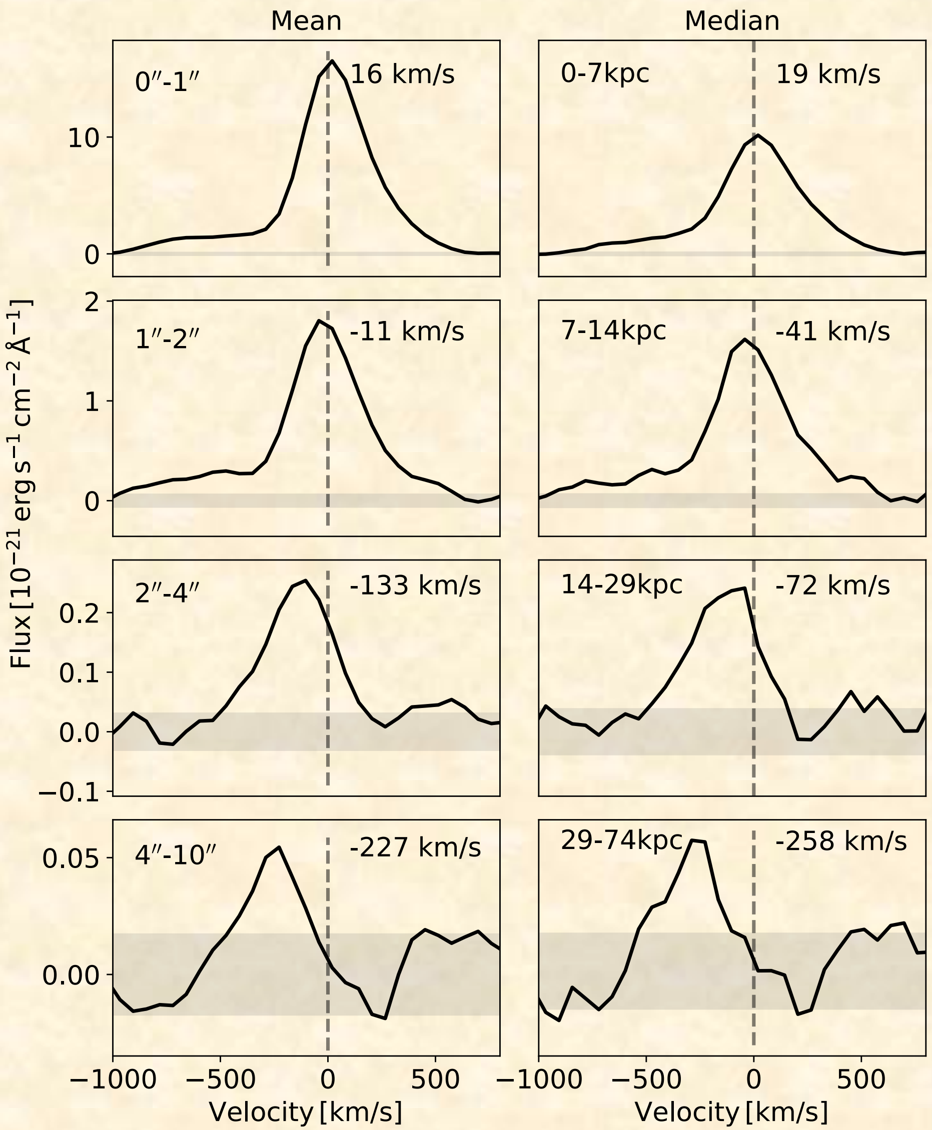
Matched by (estimated) $\mathbf{z_{sys}}$



?

z_{sys} estimated by Verhamme et al. 2018

Physical origins of Lyα blueshift at large radii



- Outflows
  - To produce the Lyα blueshift needs decelerating outflow motion
- Gravitational cooling radiation
  - Predicted to produce blueshifted and blue-skewed Lyα line at large radii
- Overlapping of bright neighbours
  - Fail to produce the blueshift
- Satellites
  - Fail to produce the blueshift
- Florescence

Summary

Average Lyα halo around LAEs with typical stellar mass of $10^{7.6}M_\odot$, Lyα luminosity 41.1 erg/s at redshift 3<z<4

- Extended Lyα emission out to **270 kpc**
- **Three components** of the median Lyα surface brightness profile: decrease in power law ($r \lesssim 1r_{vir}$), a flattening ($1r_{vir} \lesssim r \lesssim 3r_{vir}$) and low surface brightness level at very large scale ($r \gtrsim 3r_{vir}$)
- A **260 km/s blueshift from the galaxy to ≈70kpc**, possibly go to z_{sys}
- Seen in both mean and median, **ubiquitous among the LAE sample**.
- Our observation likely favors a scenario in which the outer part of the LAHs mainly dominated by cooling radiation

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