Probing galaxy kinematics and the epoch of reionization using Lyman-alpha emission

Tamal Mukherjee

School of Mathematical and Physical Sciences

Macquarie University, Sydney

Supervisors: Dr. Tayyaba Zafar, Dr. Themiya Nanayakkara

MACQUARIE University
SYDNEY·AUSTRALIA

ASTRO 3D

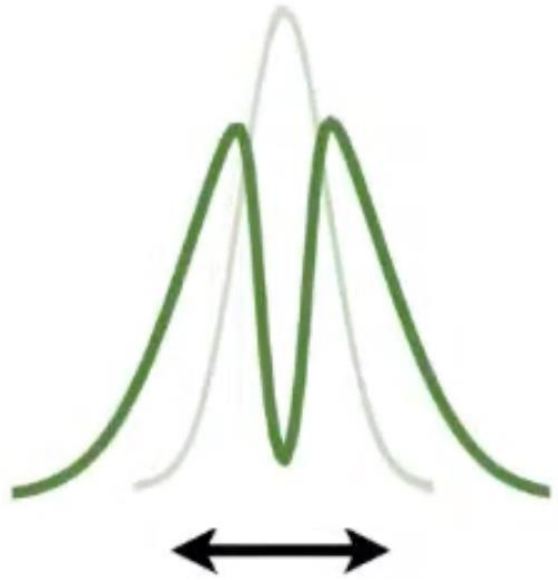
LYMAN 2025 Conference

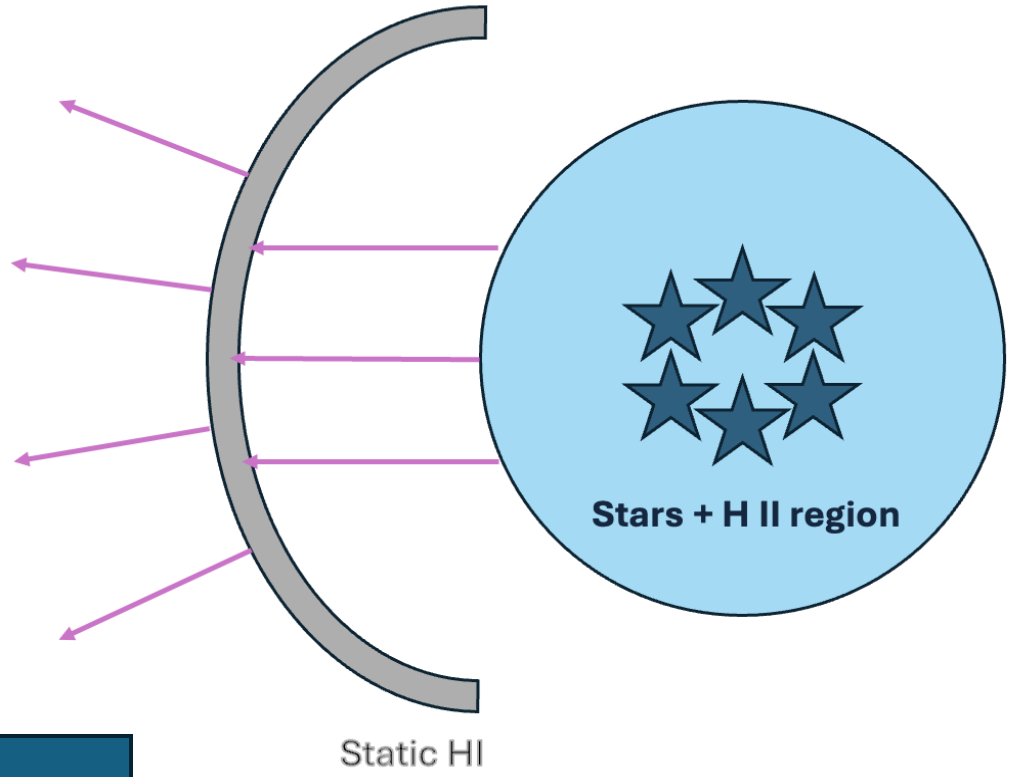
Orthodox Academy of Crete, Greece, 09 April 2025

Lyα emission line profiles

Intrinsic Lyα (motion and turbulence in the ISM)

Lyα emission line profiles

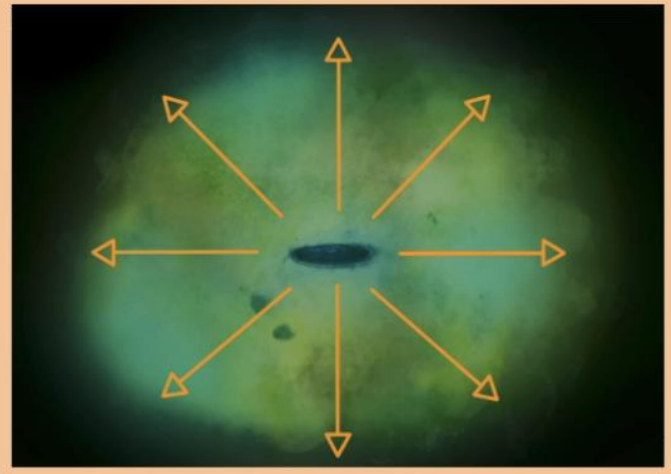


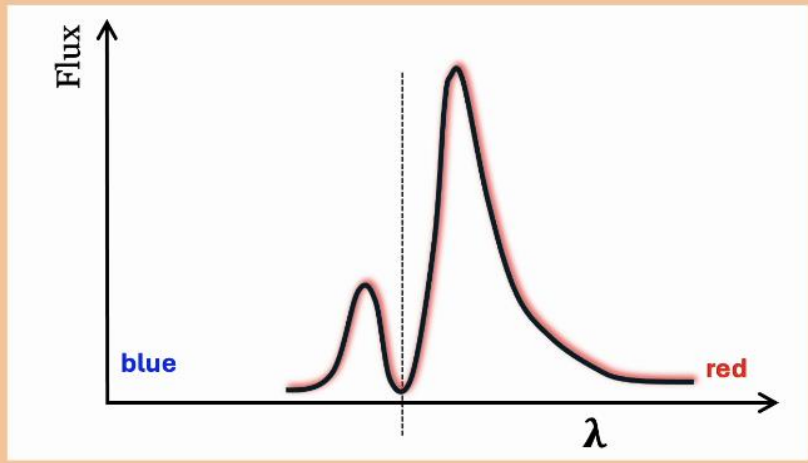


After scattering through static HI medium

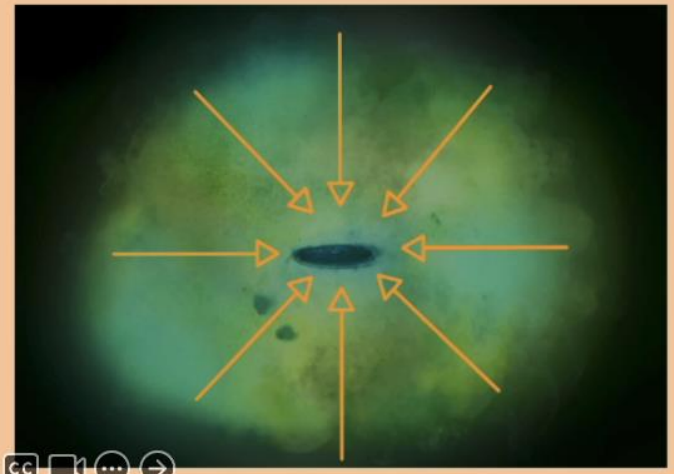
Lyα emission line profiles: Outflows and Inflows

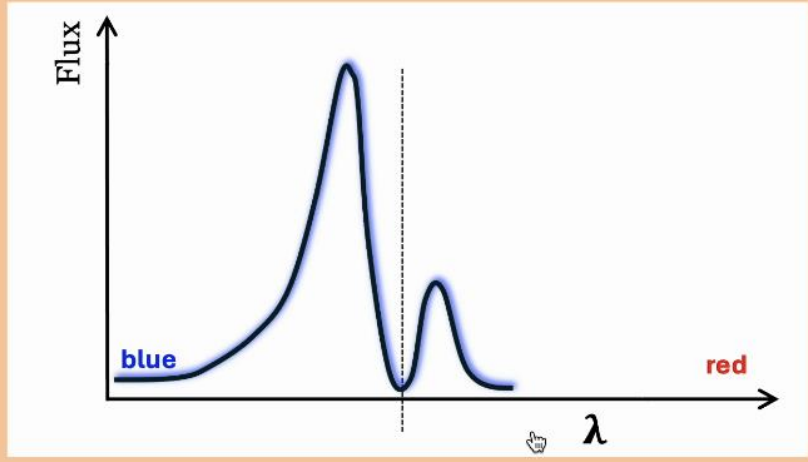
Outflow





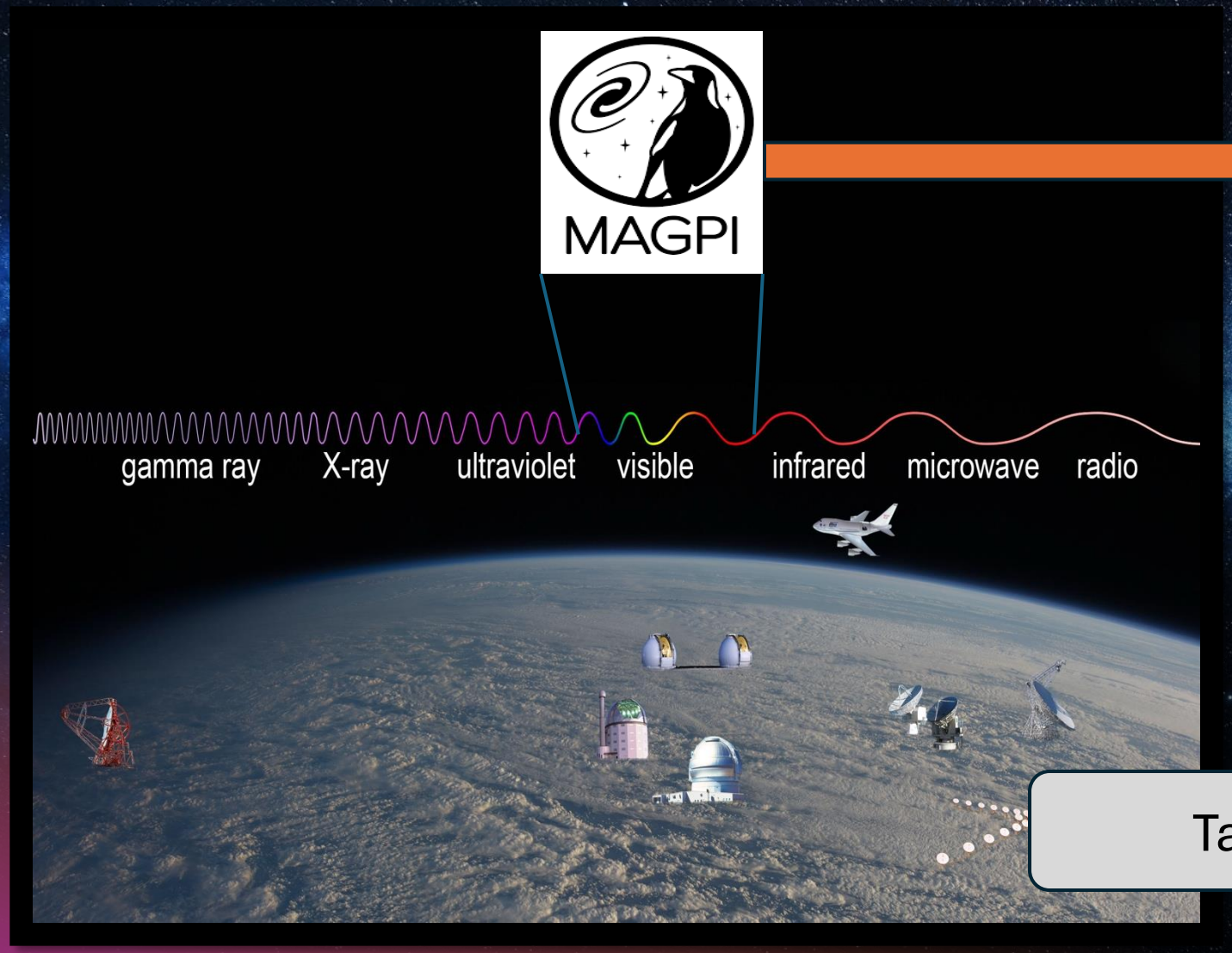
Inflow





1. Lyα as a probe to the CGM gas kinematics

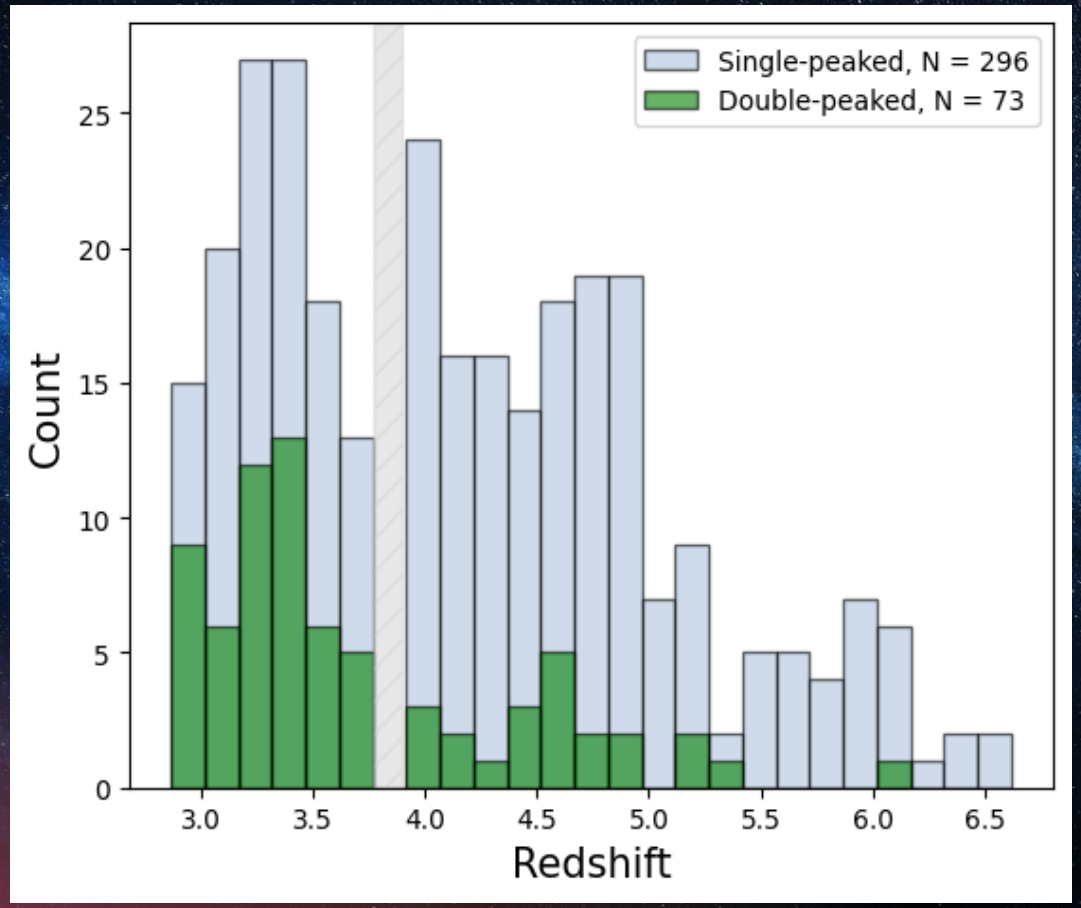
The MAGPI Survey: VLT/MUSE Large Program

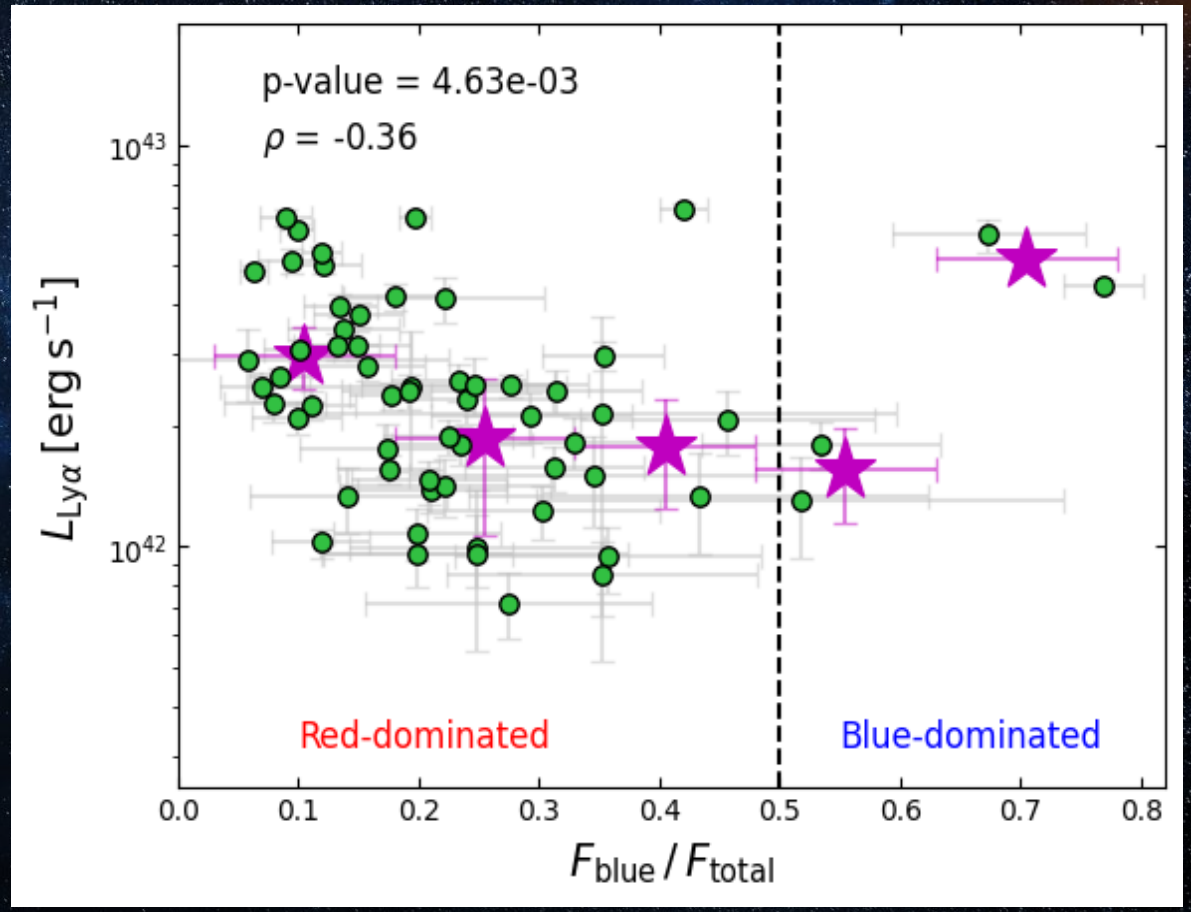


Spatially-resolved spectroscopy of stars and ionized gas for galaxies

Targeting LAEs at z = 2.9 – 6.6

MAGPI LAE Sample

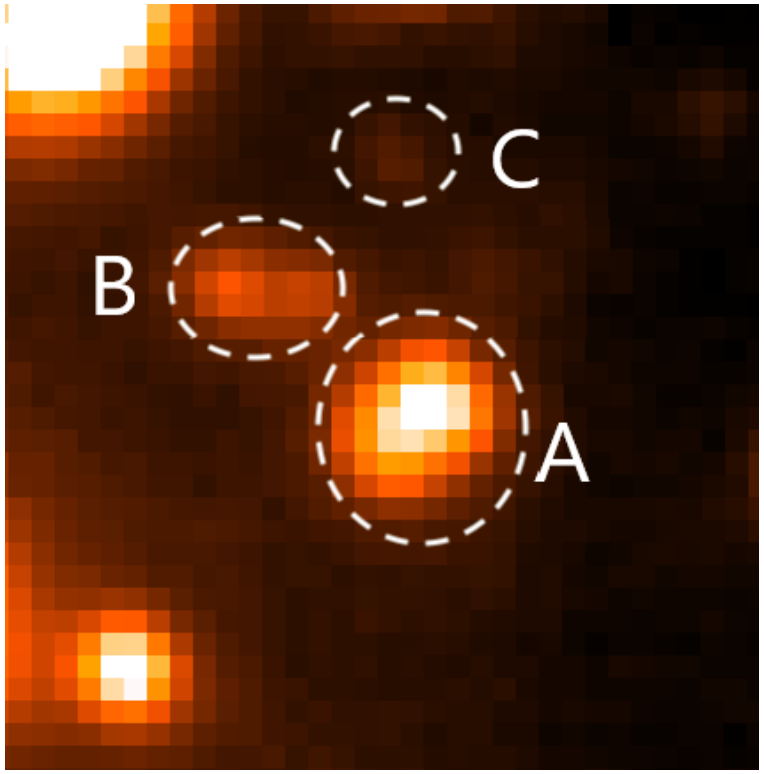




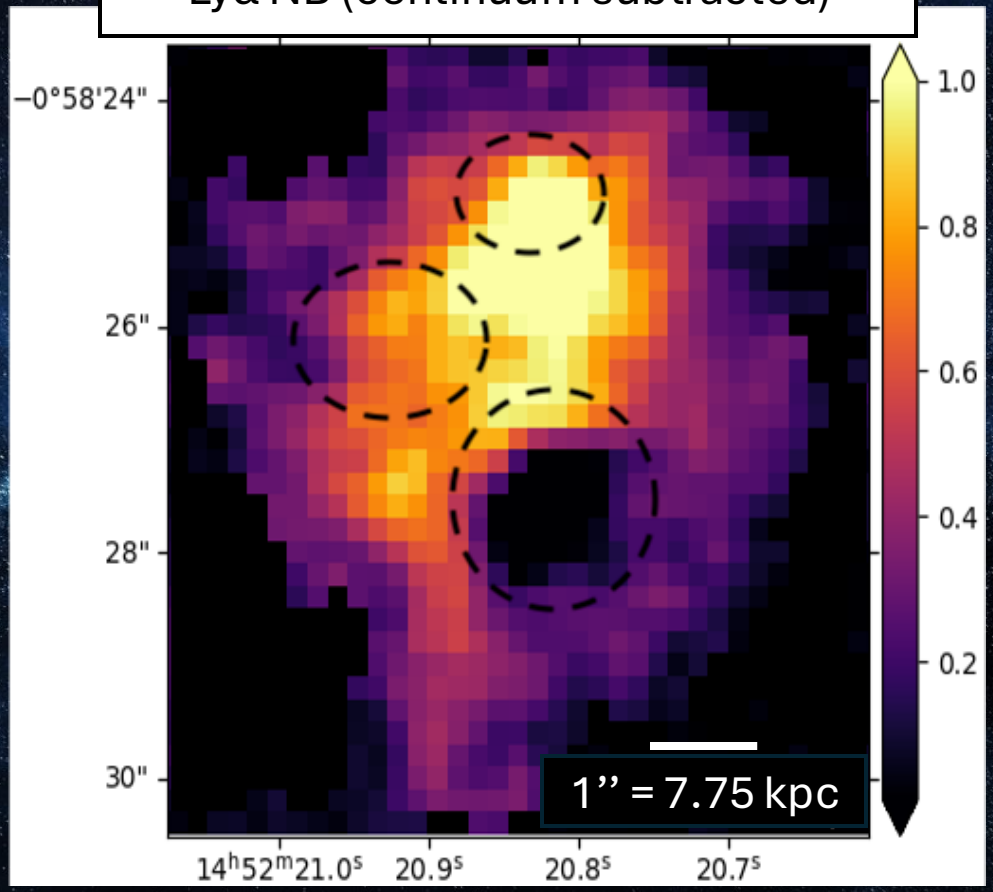
Mukherjee T. et al. in prep.

Blue-dominated Lyα halo in MAGPI

MUSE Stellar Continuum



Lyα NB (continuum subtracted)

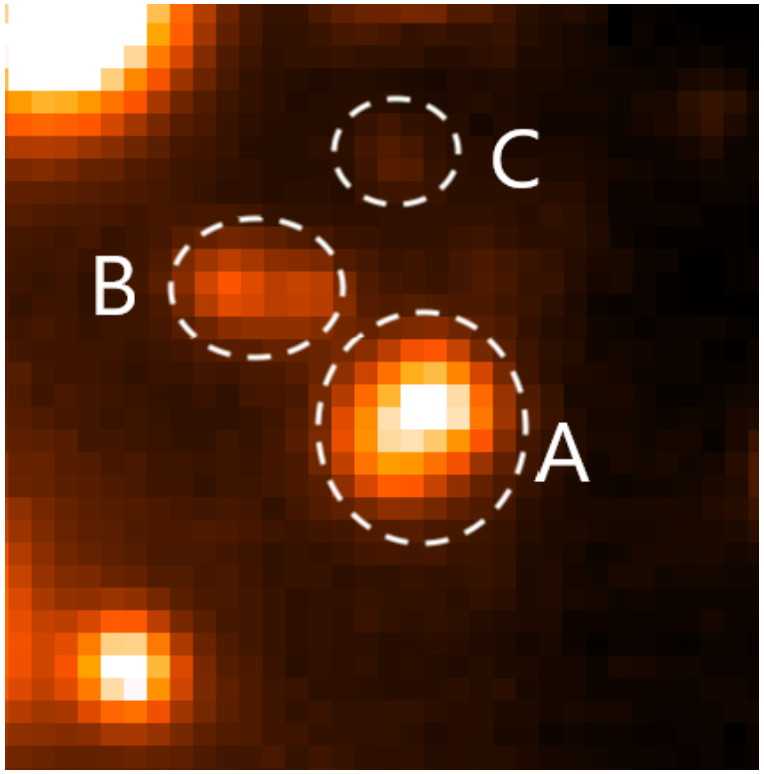


z = 2.948

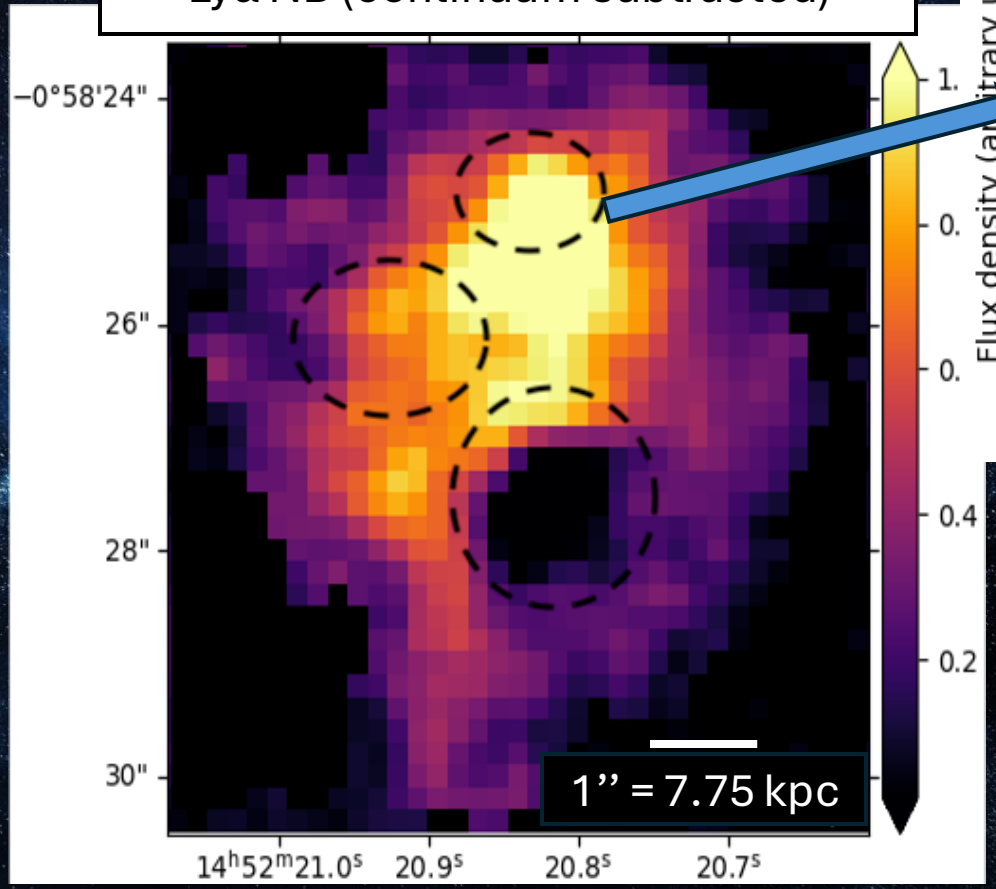
Mukherjee T. et al. 2023, A&A, 680, L5

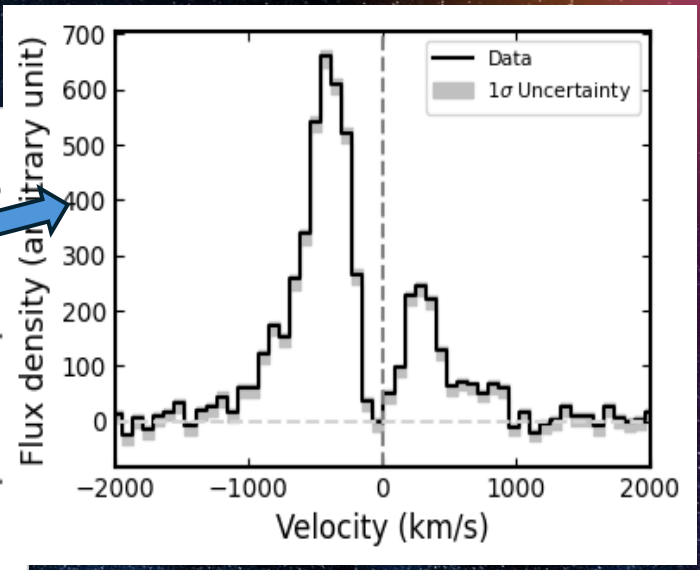
Blue-dominated Lyα halo in MAGPI

MUSE Stellar Continuum



Lyα NB (continuum subtracted)





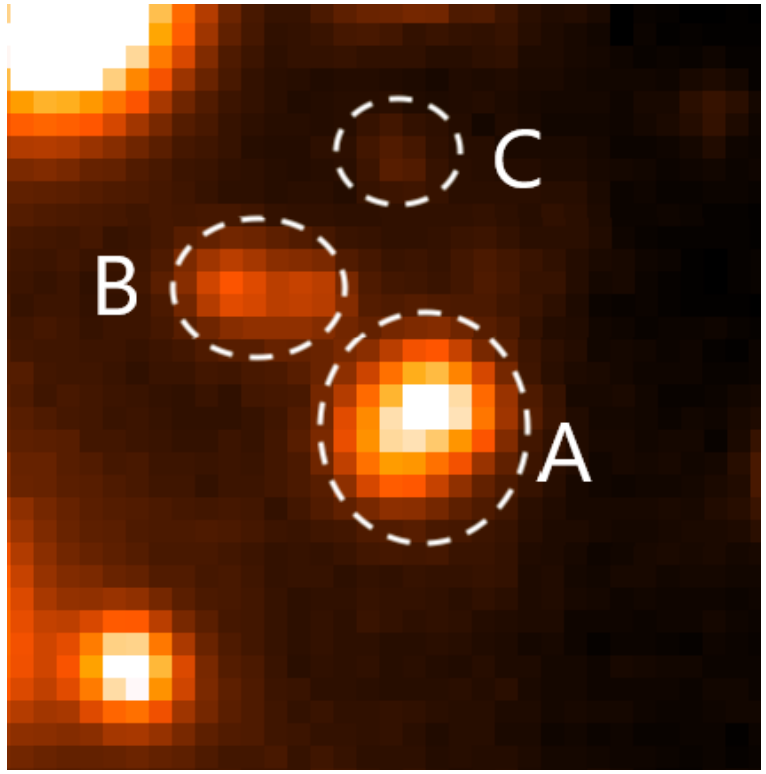
Gas Accretion

z = 2.948

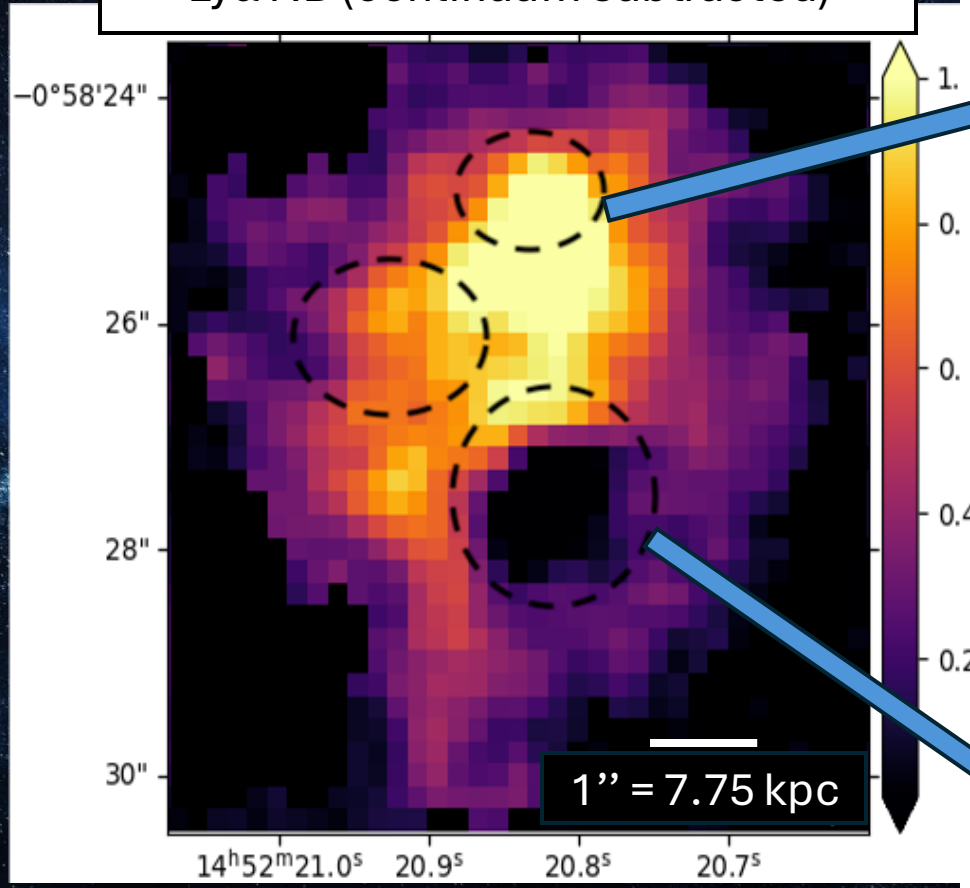
Mukherjee T. et al. 2023, A&A, 680, L5

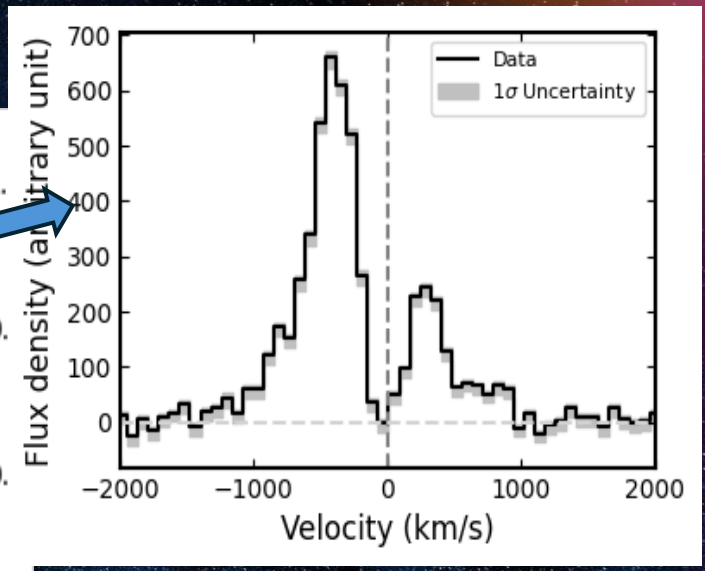
Blue-dominated Lyα halo in MAGPI

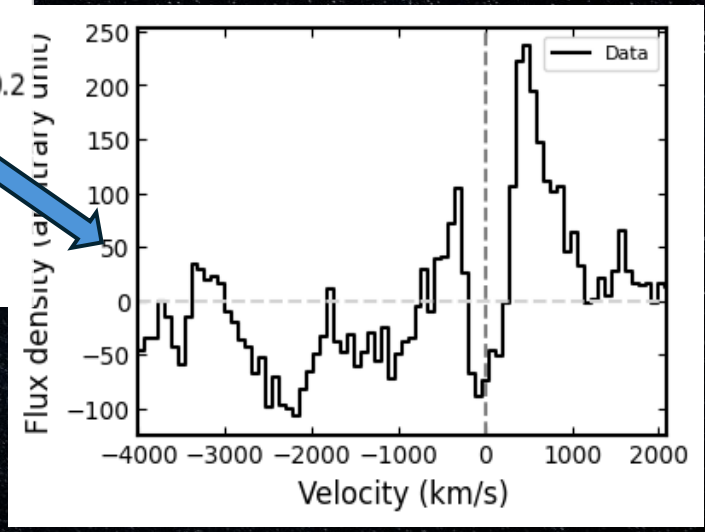
MUSE Stellar Continuum



Lyα NB (continuum subtracted)





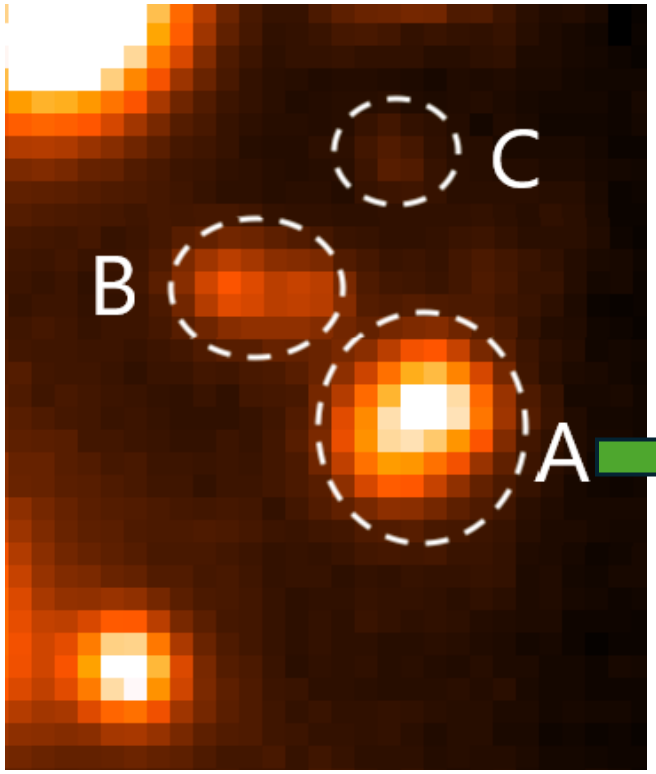


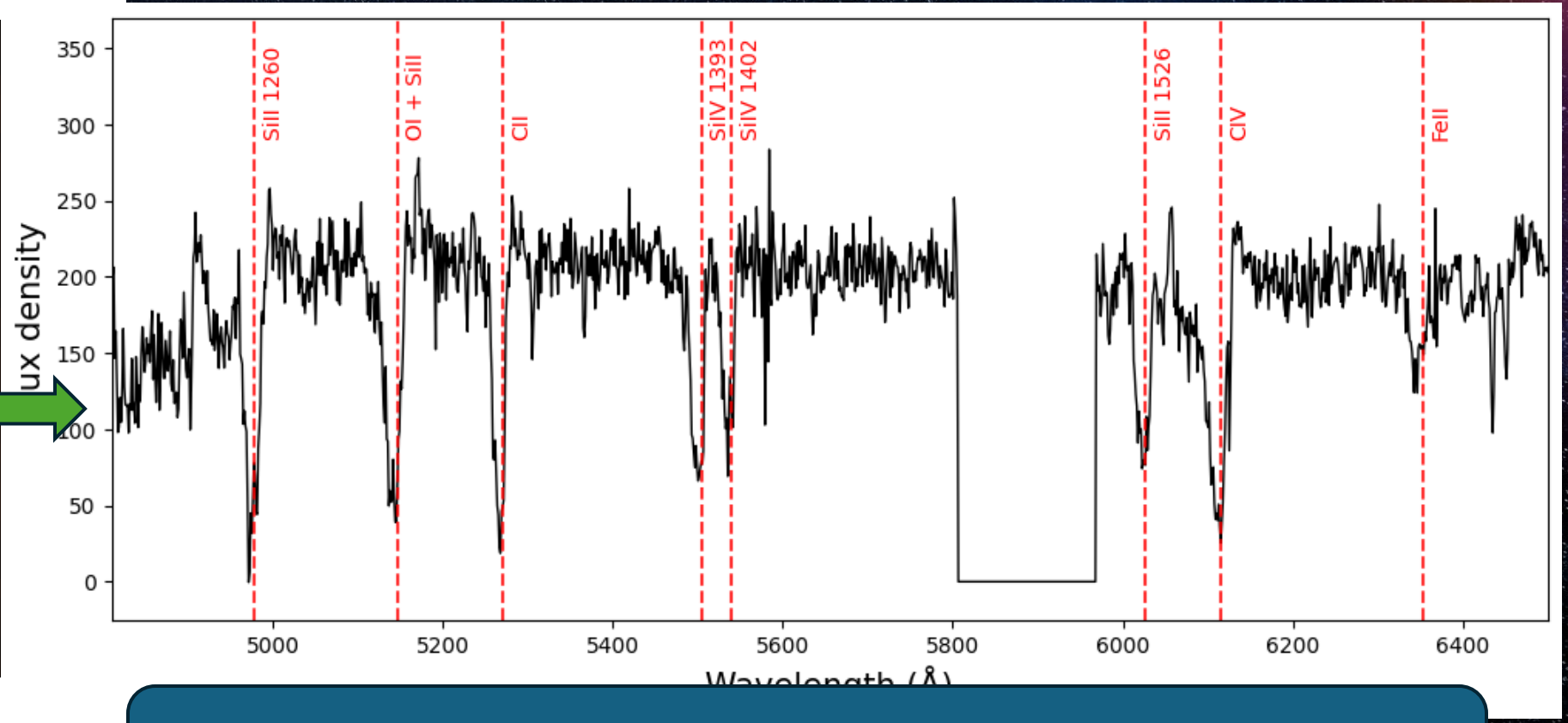
z = 2.948

Mukherjee T. et al. 2023, A&A, 680, L5

Blue-dominated Lyα halo in MAGPI

MUSE Stellar Continuum

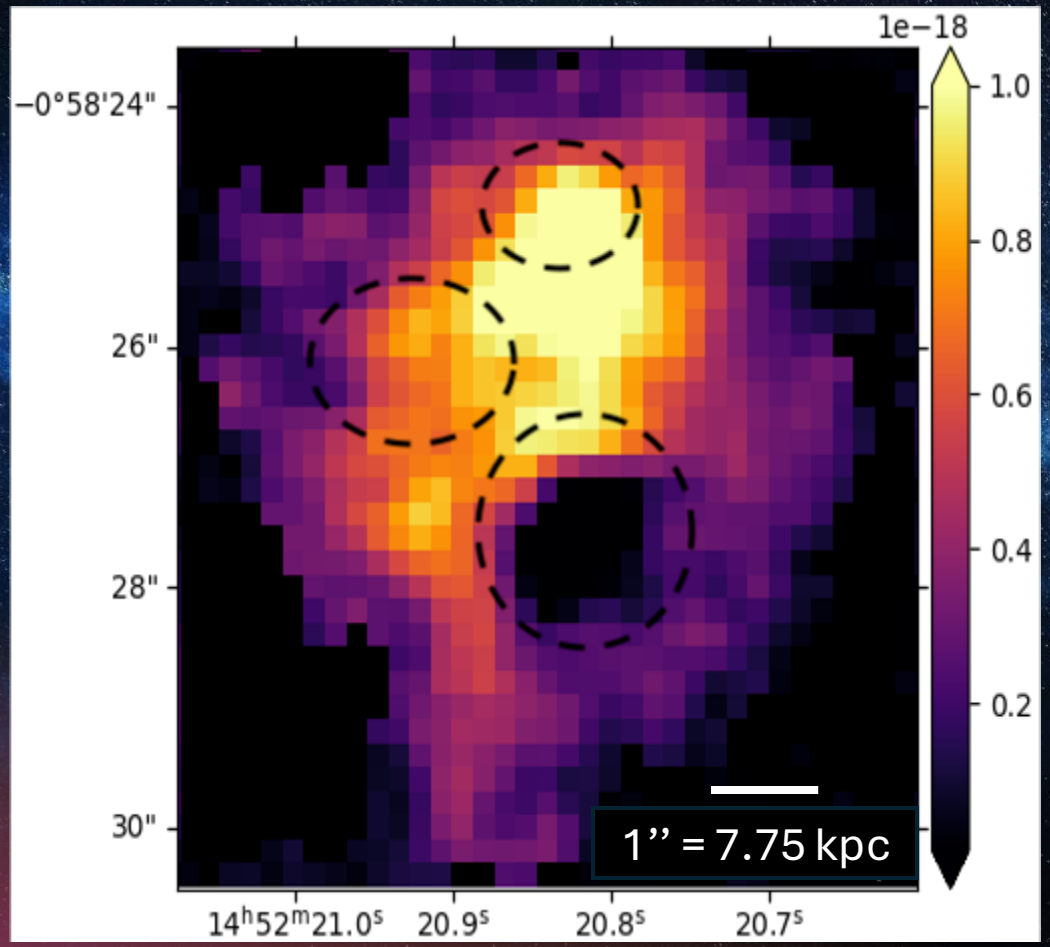


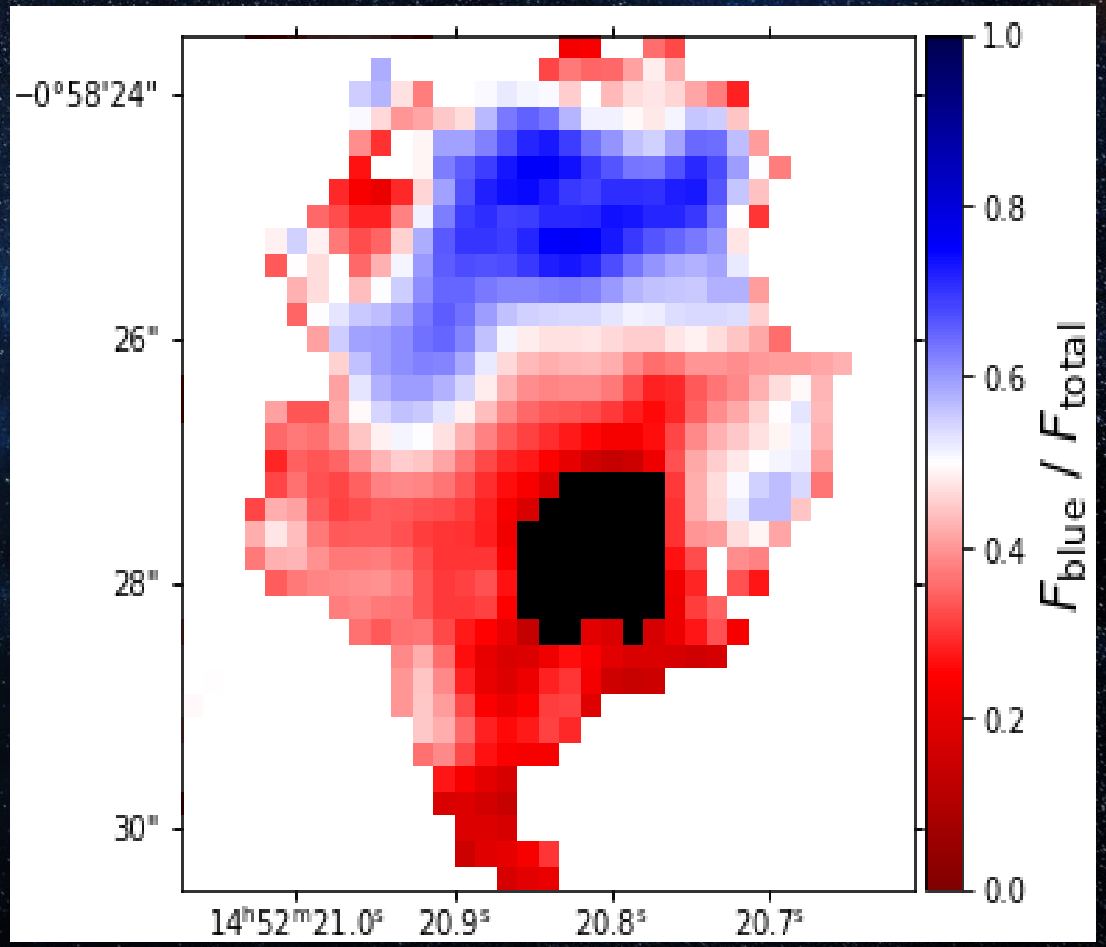


Multiphase ISM, blueshifted absorptions → outflows

Mukherjee et al. in prep

Blue-dominated Lyα halo in MAGPI





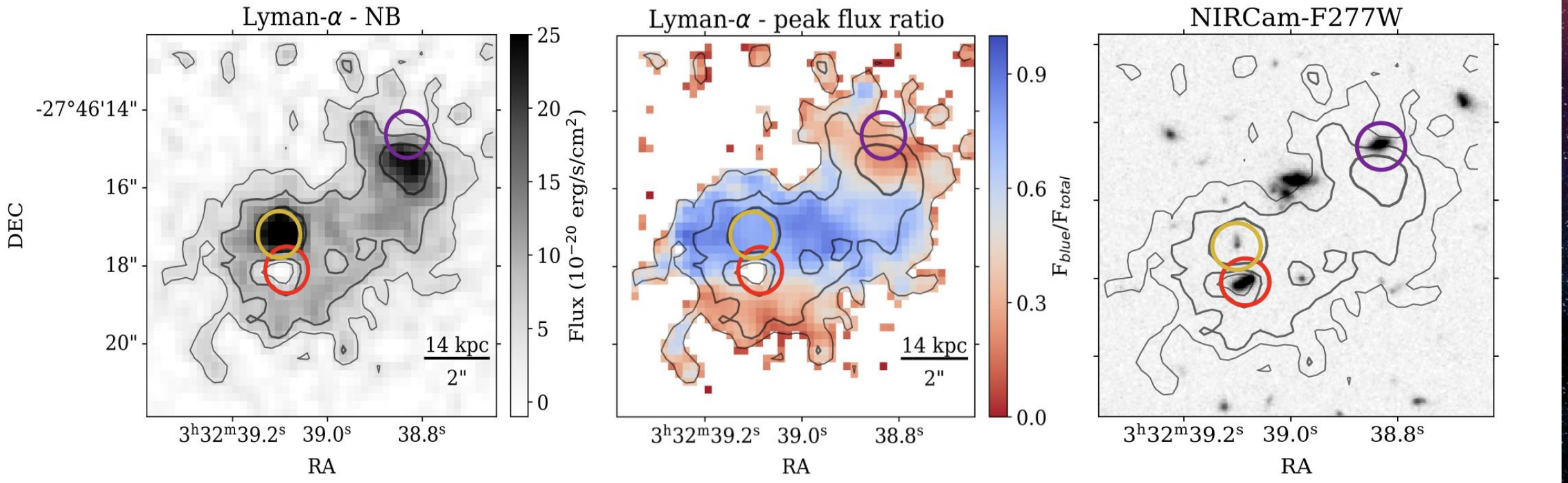
Mukherjee et al. 2023, A&A, 680, L5

Blue-dominated Lyα halo in MAGPI

Unfortunately!

No deep IR imaging and Spectroscopy

Blue-dominated Lyα nebula in HUDF



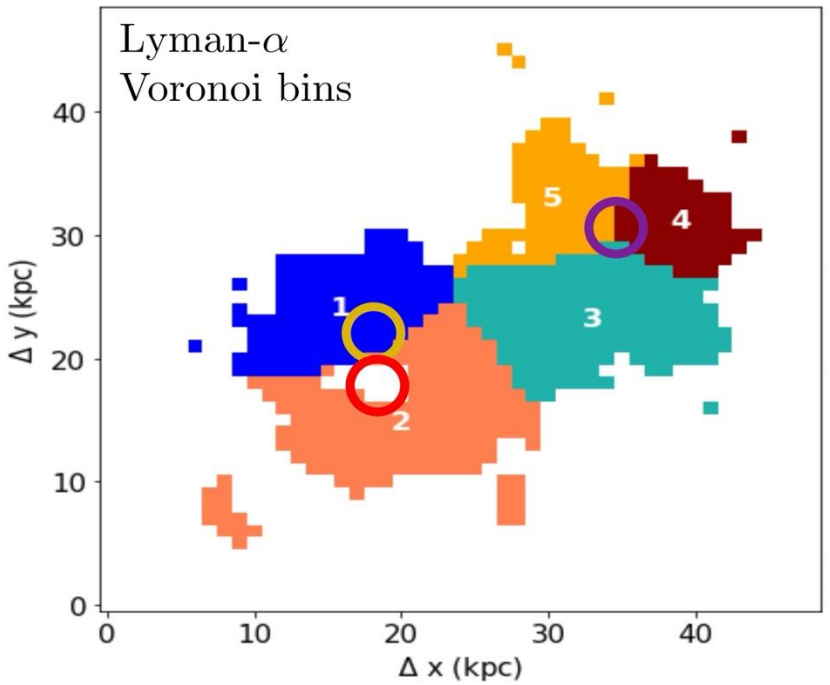
z = 3.328

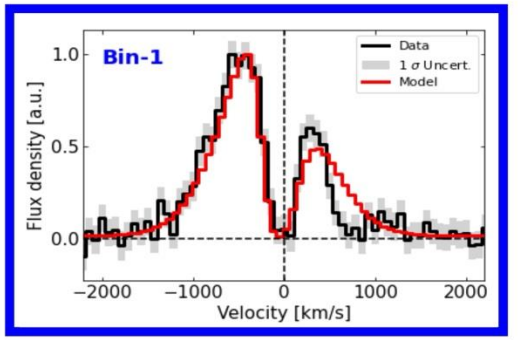
75 kpc extended

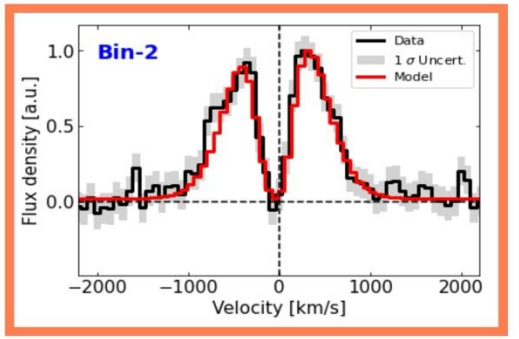
Gupta A., Mukherjee T. et al. in prep.

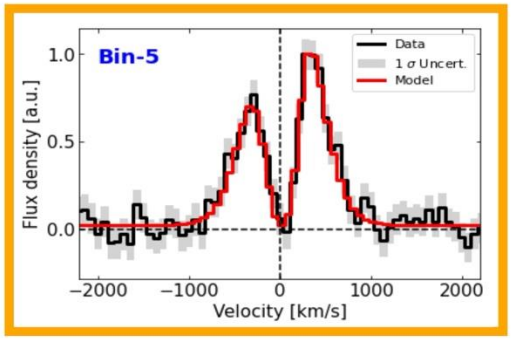
Blue-dominated Lyα nebula at z = 3.328

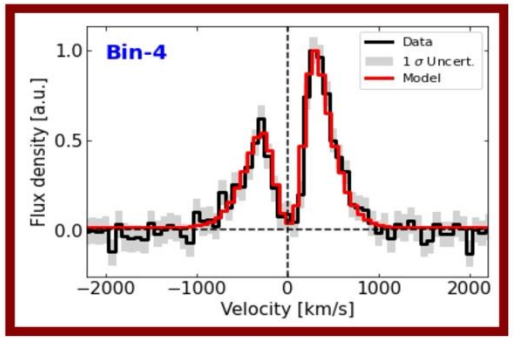
$\log(N_{HI}) = 19.5 - 19.8$ cm^{-2}

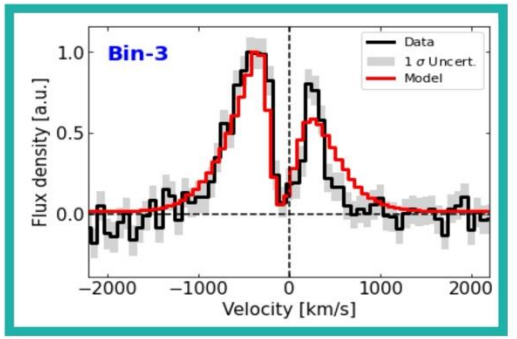






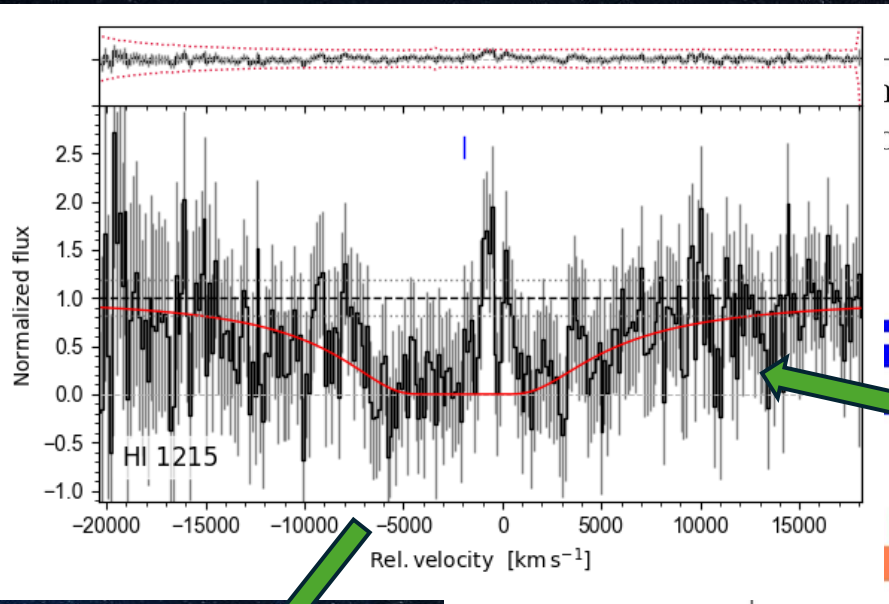


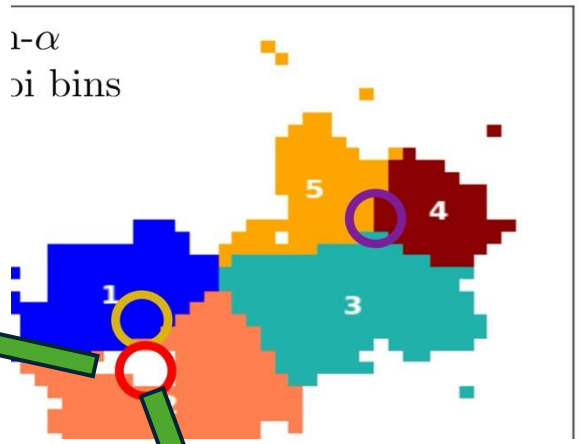


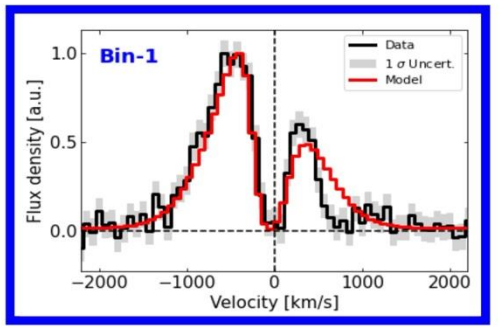


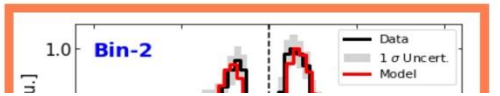
Gupta A., Mukherjee T. et al. in prep.

Blue-dominated Lyα nebula at z = 3.328

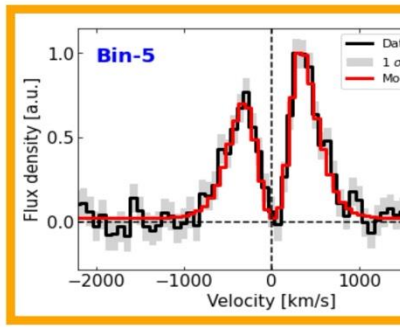


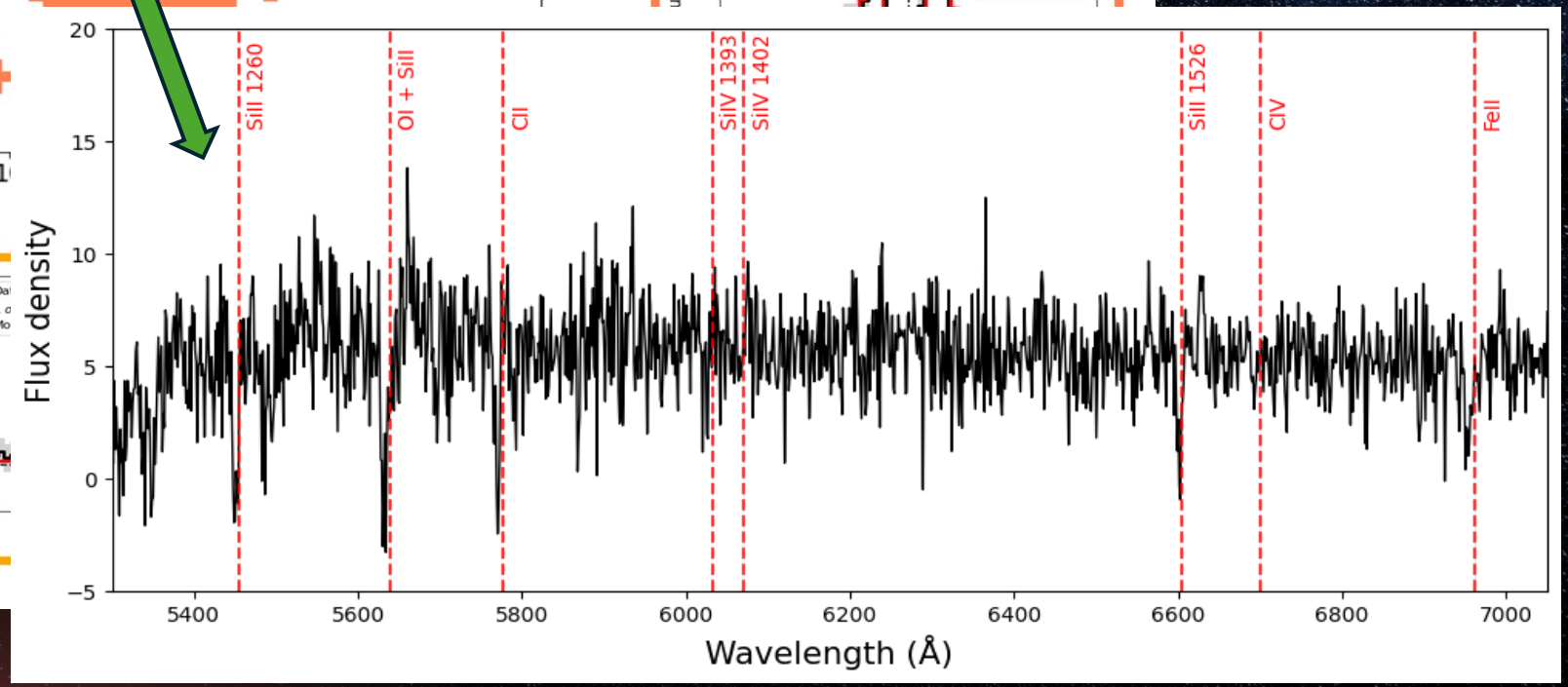






$\log(N_{HI}) = 22.1$ cm^{-2}





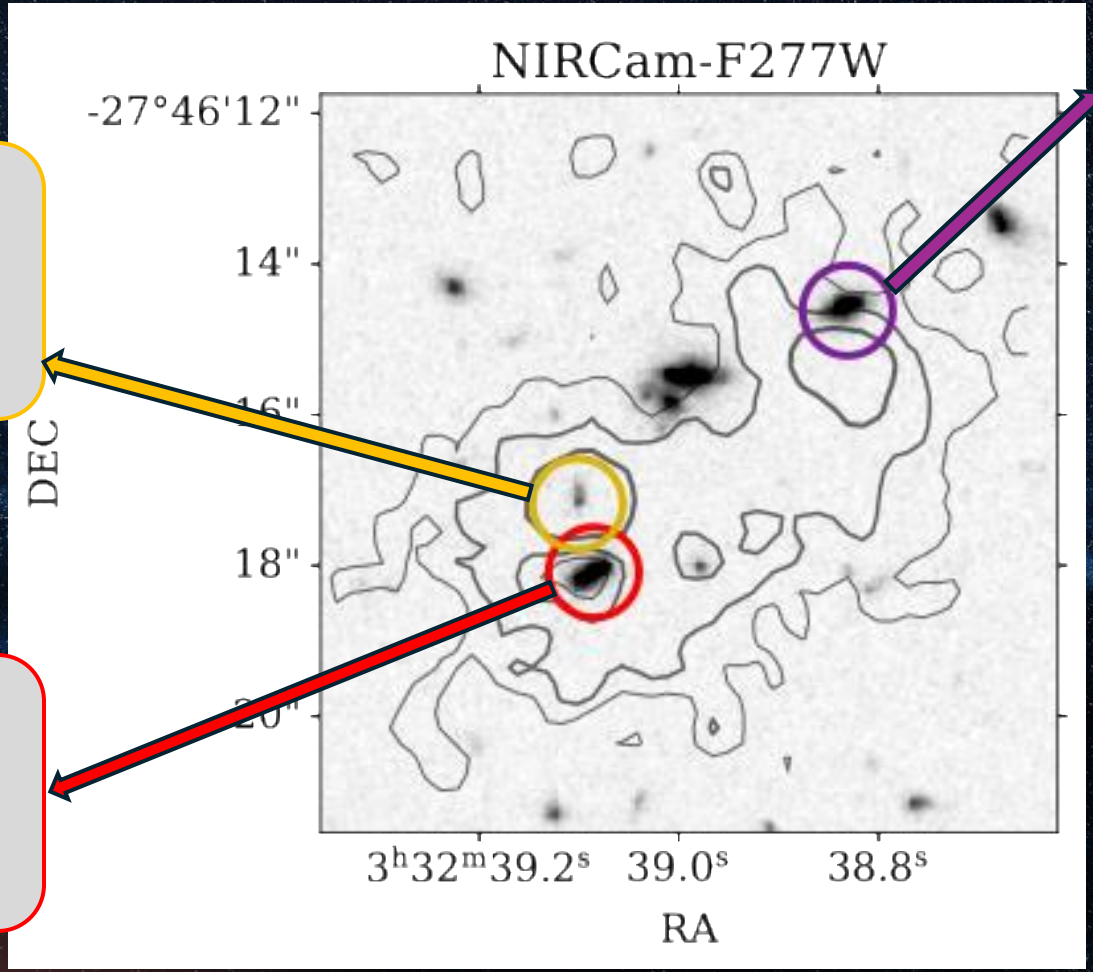
Gupta A., Mukherjee T. et al. in prep.

Blue-dominated Lyα nebula in HUDF

SOMA 3
SFR = 22 $M_\odot$ / yr
$M_* = 10^{9.4} M_\odot$

SOMA 2
SFR = 1.3 $M_\odot$ / yr
$M_* = 10^{7} M_\odot$

SOMA 1
SFR = 18 $M_\odot$ / yr
$M_* = 10^{9.5} M_\odot$



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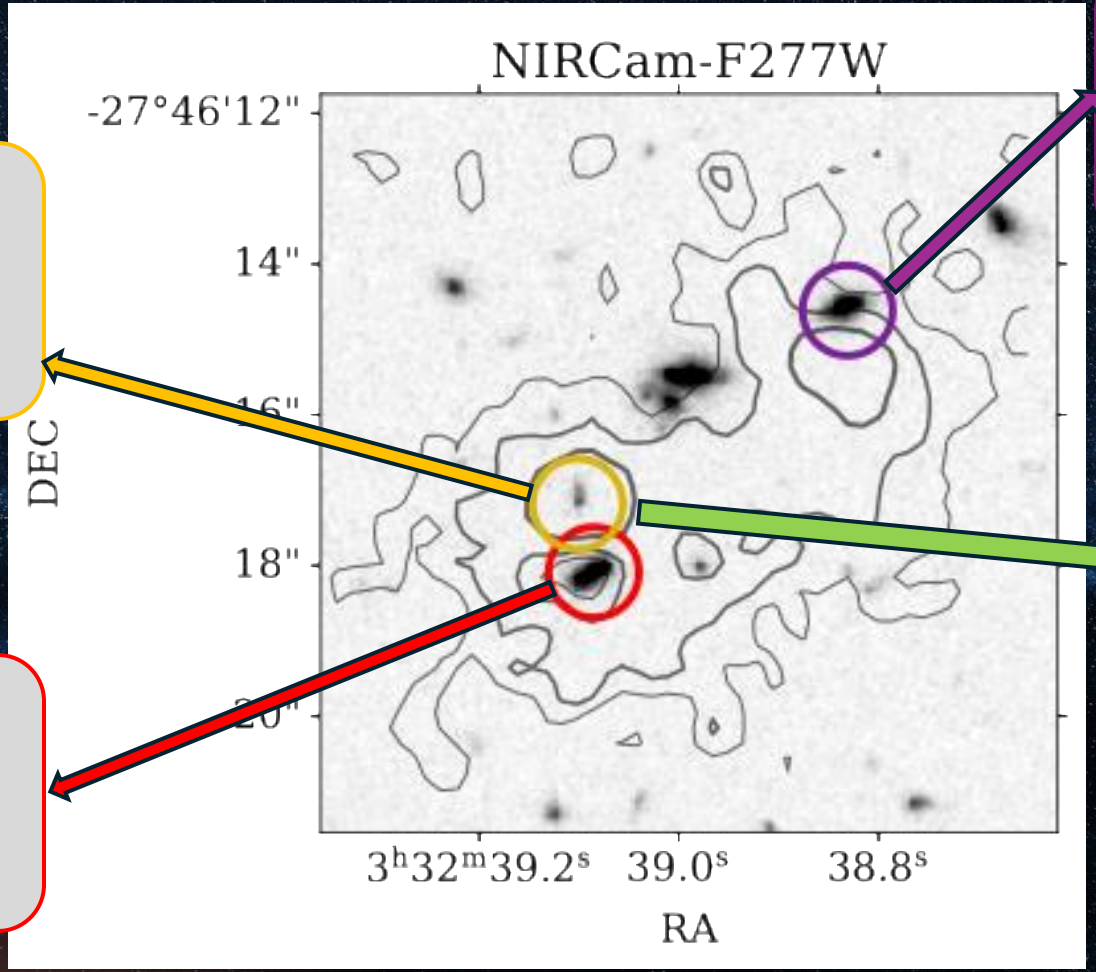


SOMA 1
SFR = 18 $M_\odot$ / yr
$M_* = 10^{9.5} M_\odot$

$$\mathrm{sSFR}_{\mathrm{H}\alpha} = 10^{-7.3}\,\mathrm{yr}^{-1}$$

Starburst !
(Rinaldi et al. 2025)

Gupta A., Mukherjee T. et al. in prep.

An efficient galaxy formation mode

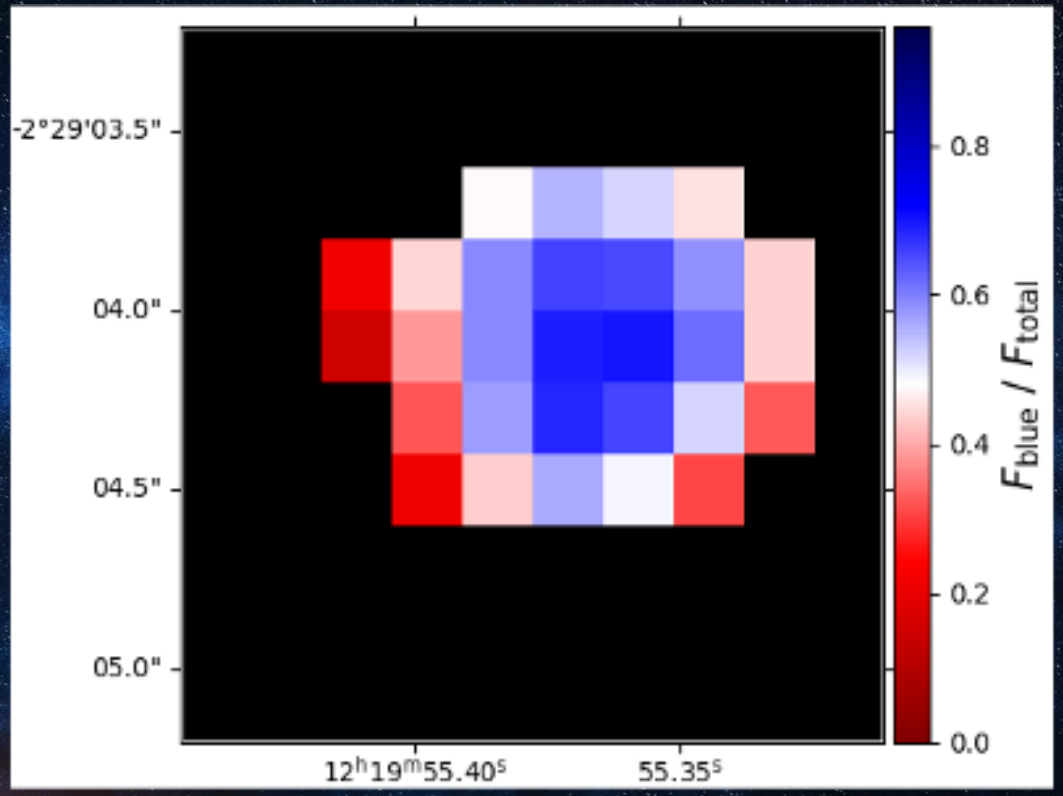
Interaction driven starburst

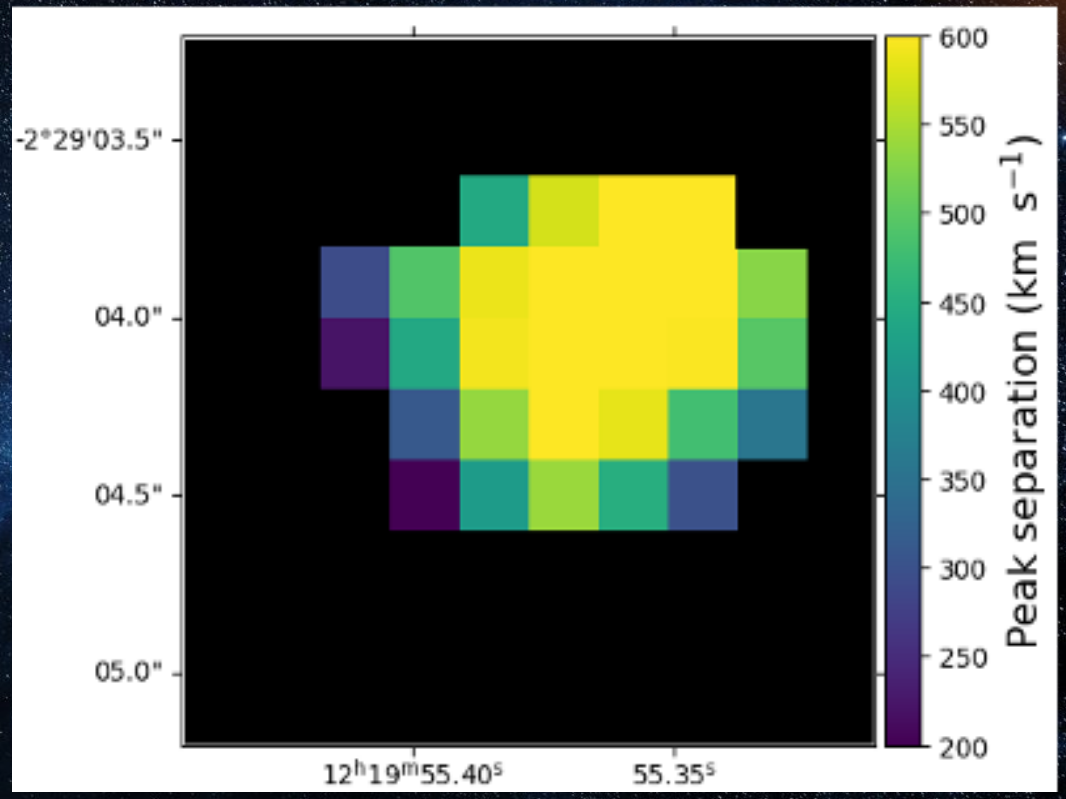
A primary galaxy outflowing gas (low metallicity), which is getting reaccreted onto a new galaxy (low in stellar mass), and fueling new star formation

Add on: HST data reveals LyC emission detections (> 5 sigma) at the location of primary galaxy driving outflows

A nice talk from **Alexandra Le Reste** this morning!

Blue-dominated Lyα in MAGPI





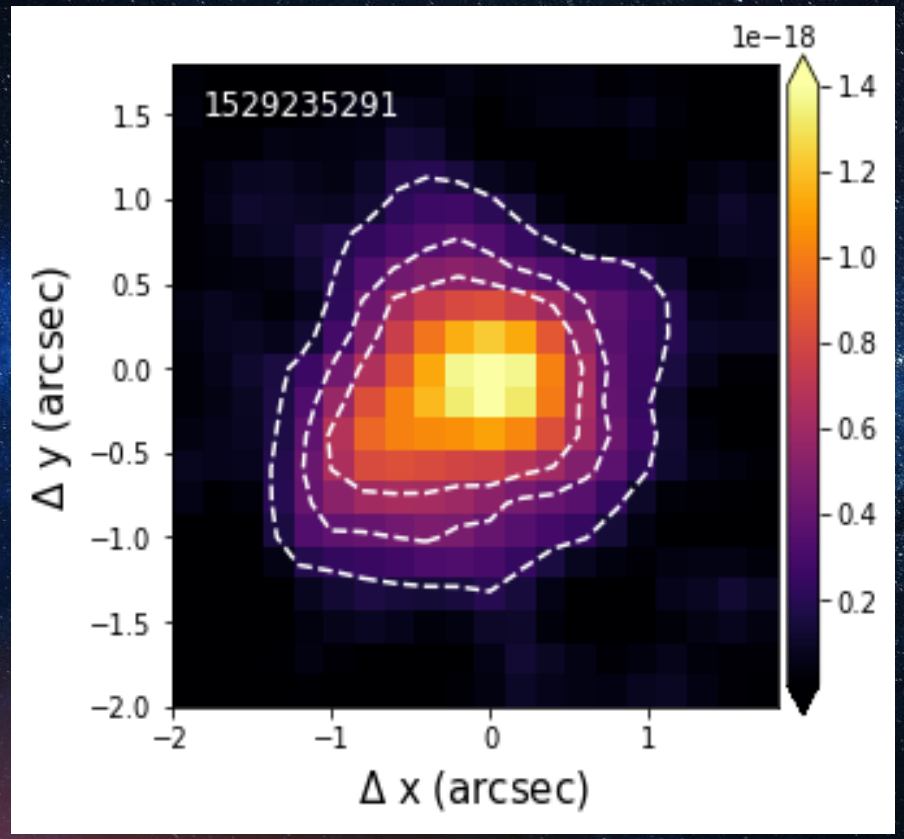
Blue flux decreases in the outskirts

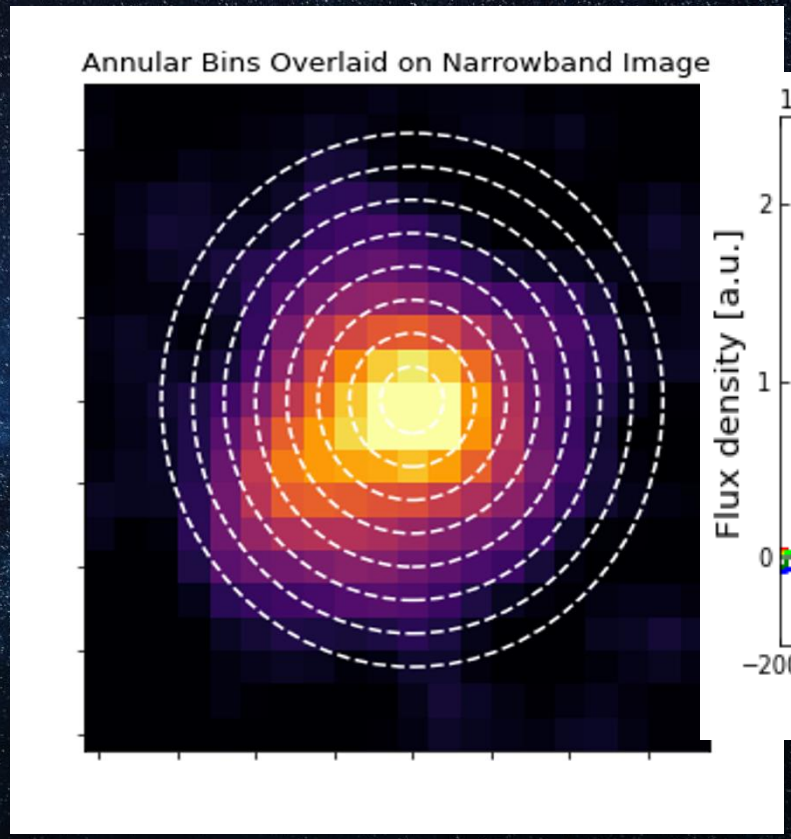
z = 4.788

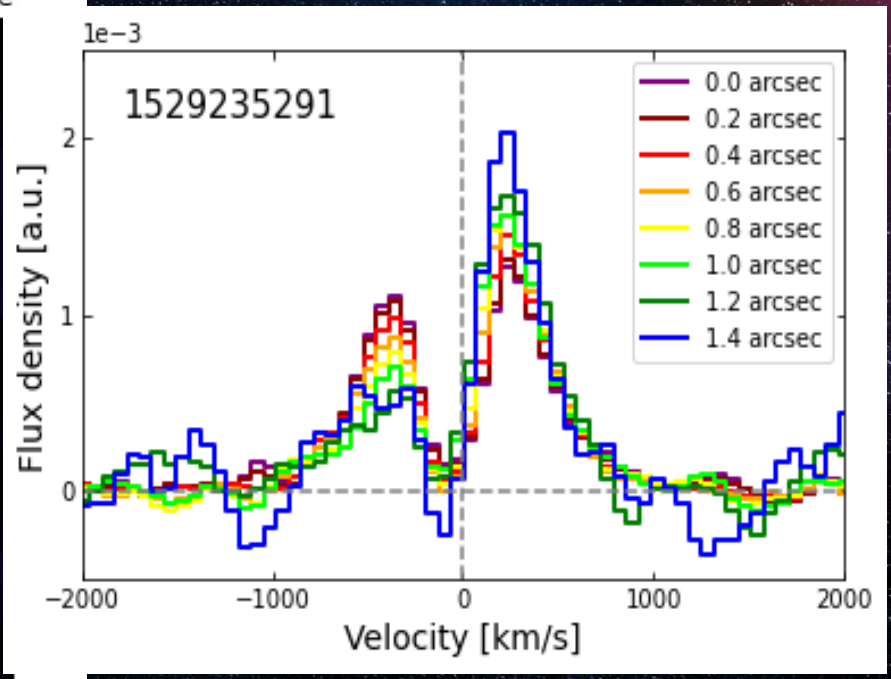
Peak sep. decreases in the outskirts

Mukherjee T. et al. 2023, A&A, 680, L5

Spatially-resolved study of red-dominated halos



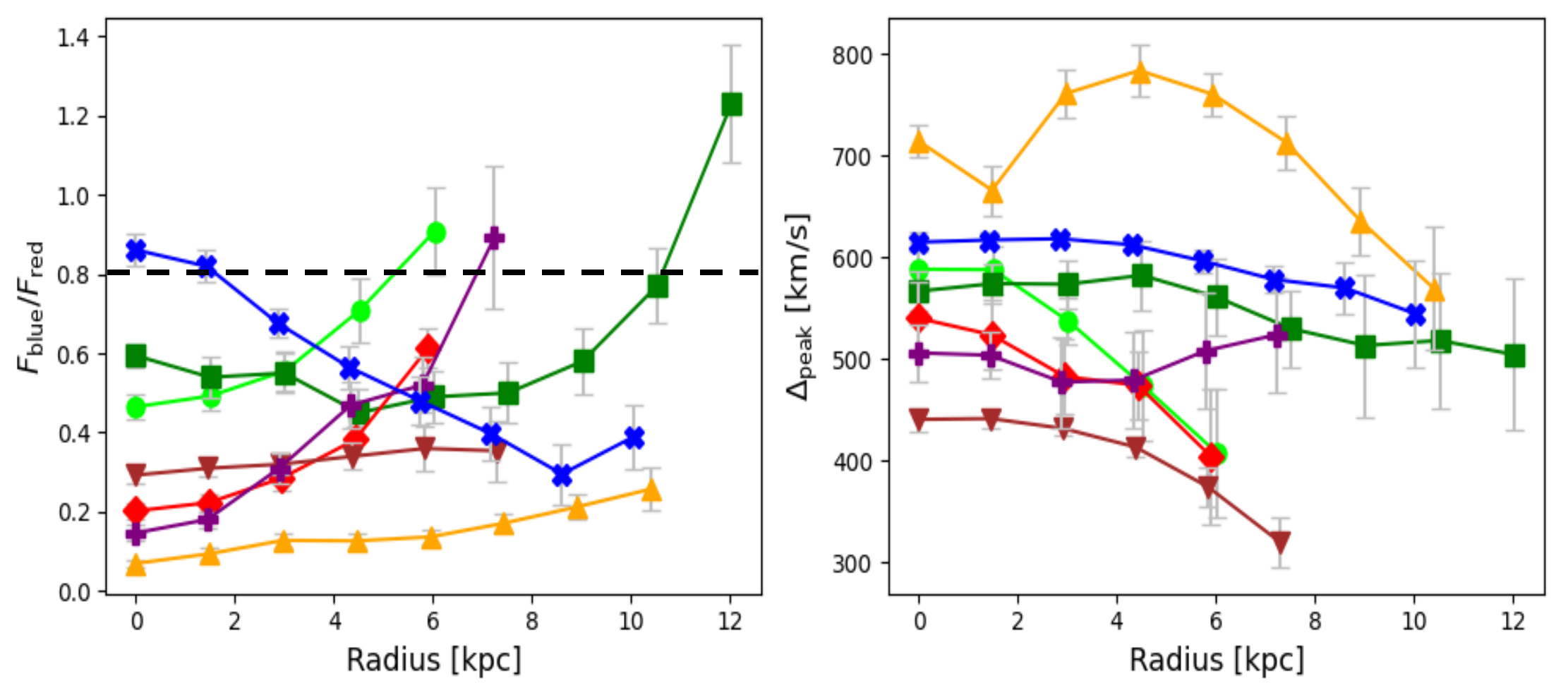




Red-dominant Lya → Outflows

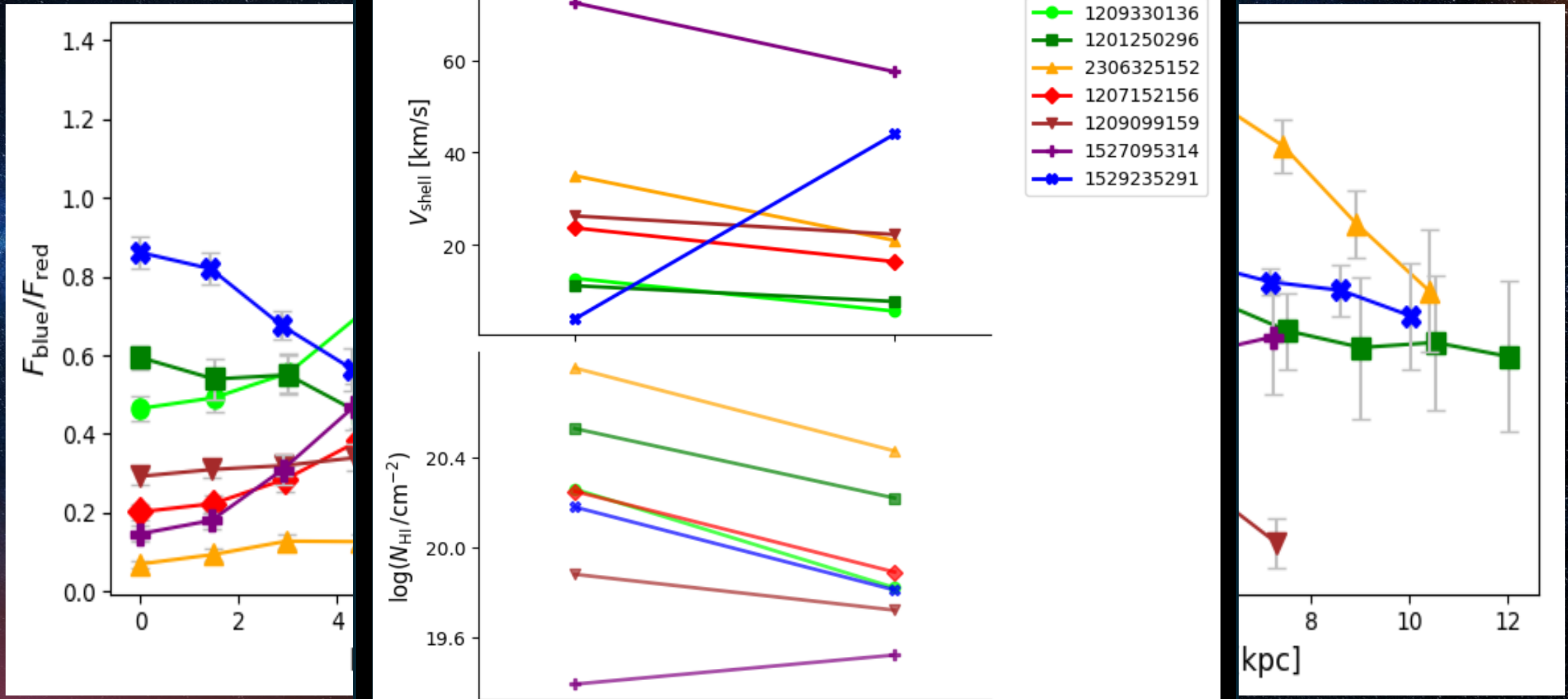
Mukherjee T. et al. in prep.

Spatially-resolved study of double-peaked halos



Mukherjee T. et al. in prep.

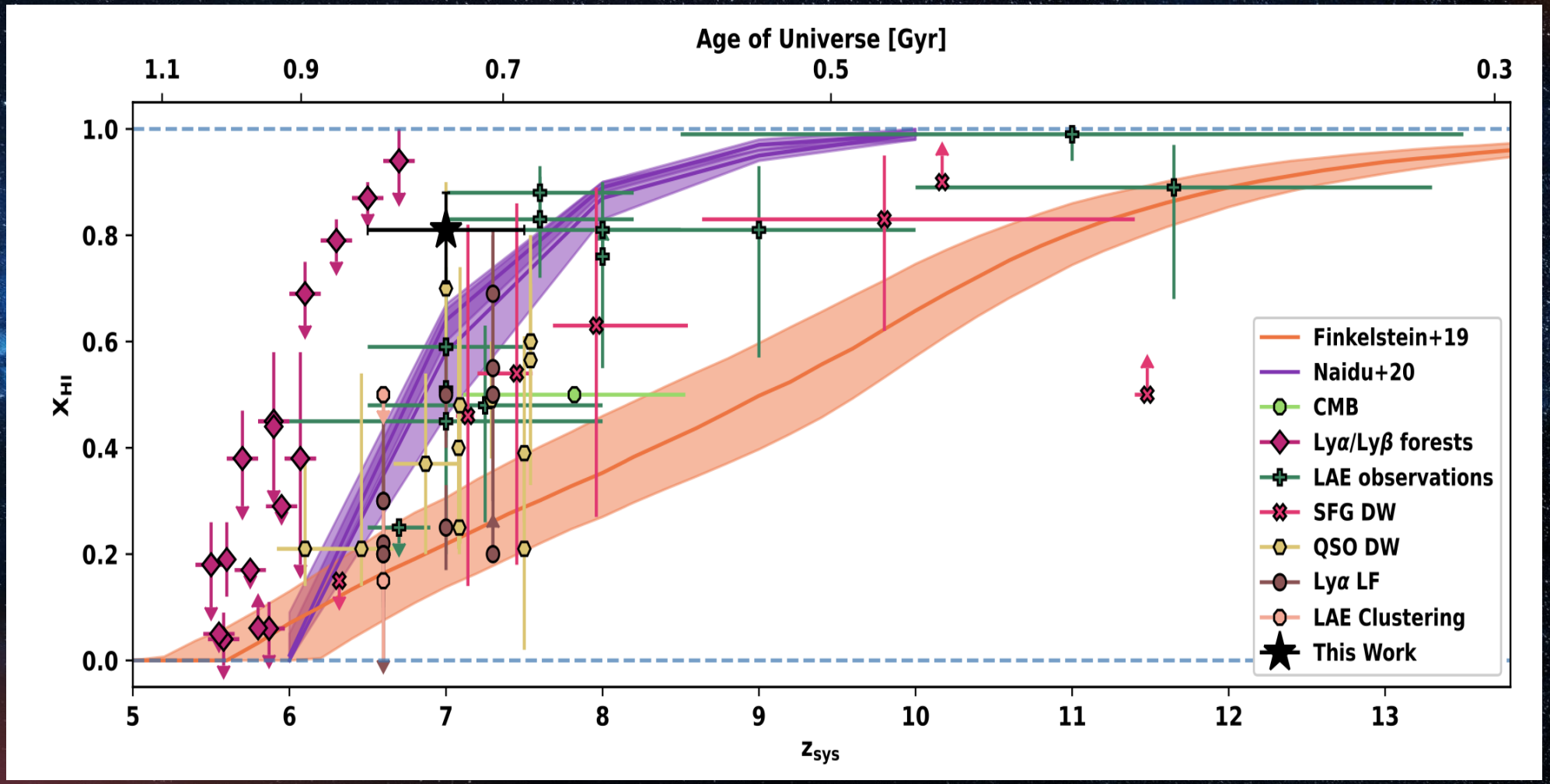
Spatially-resolved study of double-peaked halos



Mukherjee T. et al. in prep.

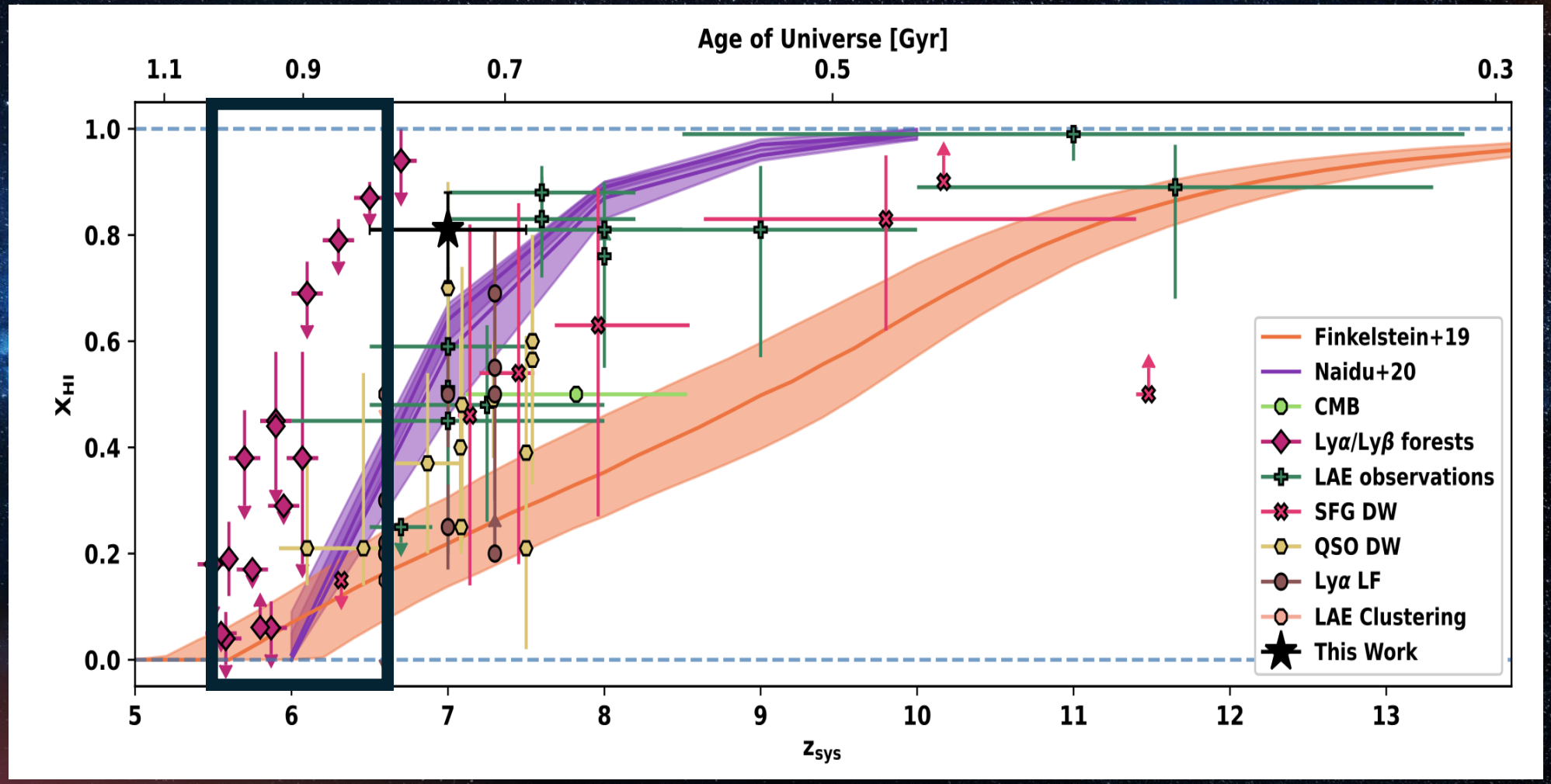
2. Lyα as a probe to the cosmic reionization

IGM neutral fraction



Jones et al. 2024

IGM neutral fraction

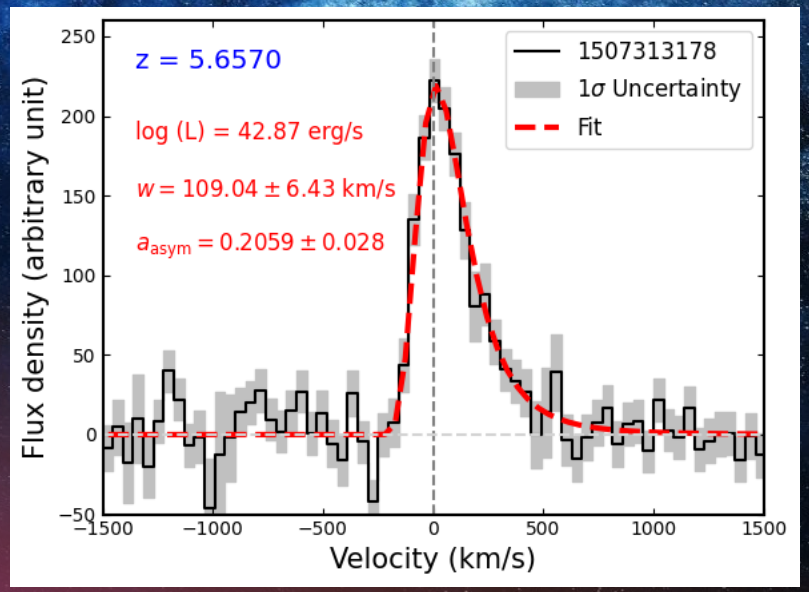


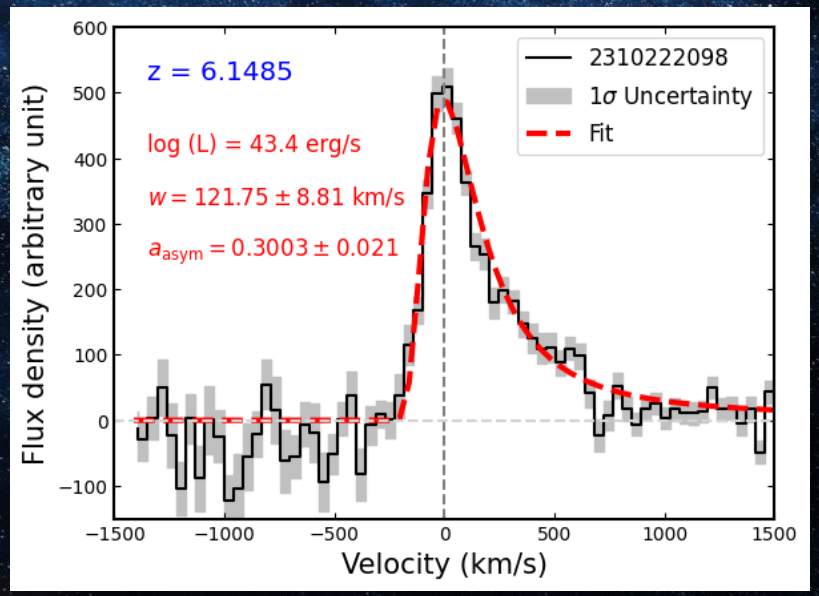
Jones et al. 2024

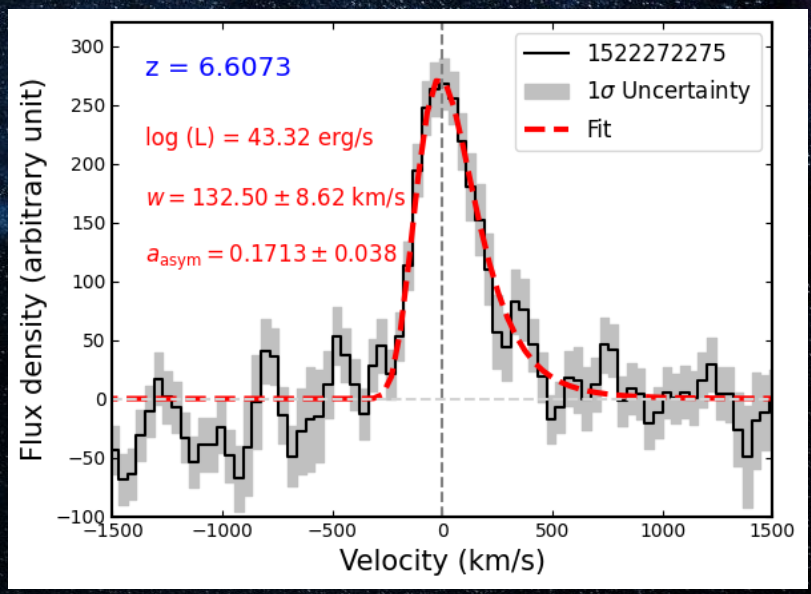
A sample of 22 MAGPI LAEs at z = 5.5 – 6.6

Asymmetric Gaussian fitting:

$$F(\lambda) = f_{\max} \exp\left(-\frac{\Delta v^2}{2(a_{\text{asym}}(\Delta v) + w)^2}\right)$$

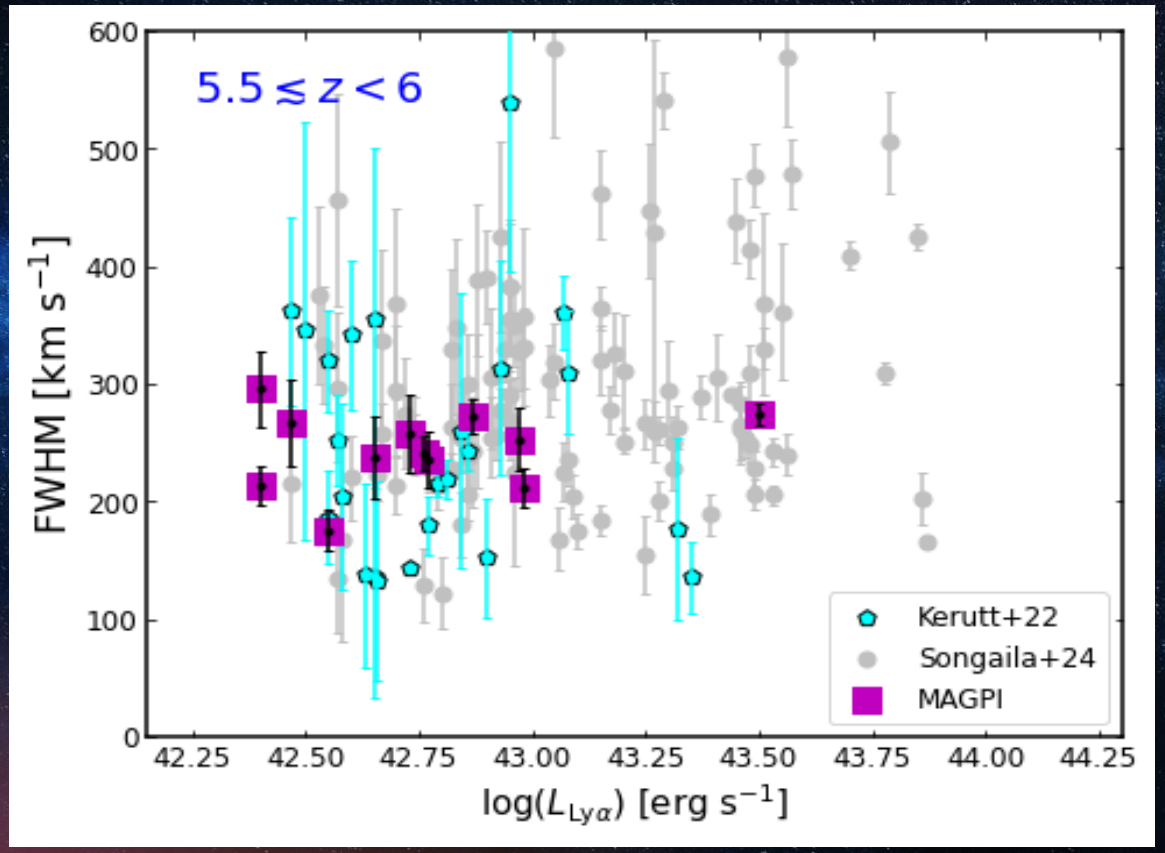


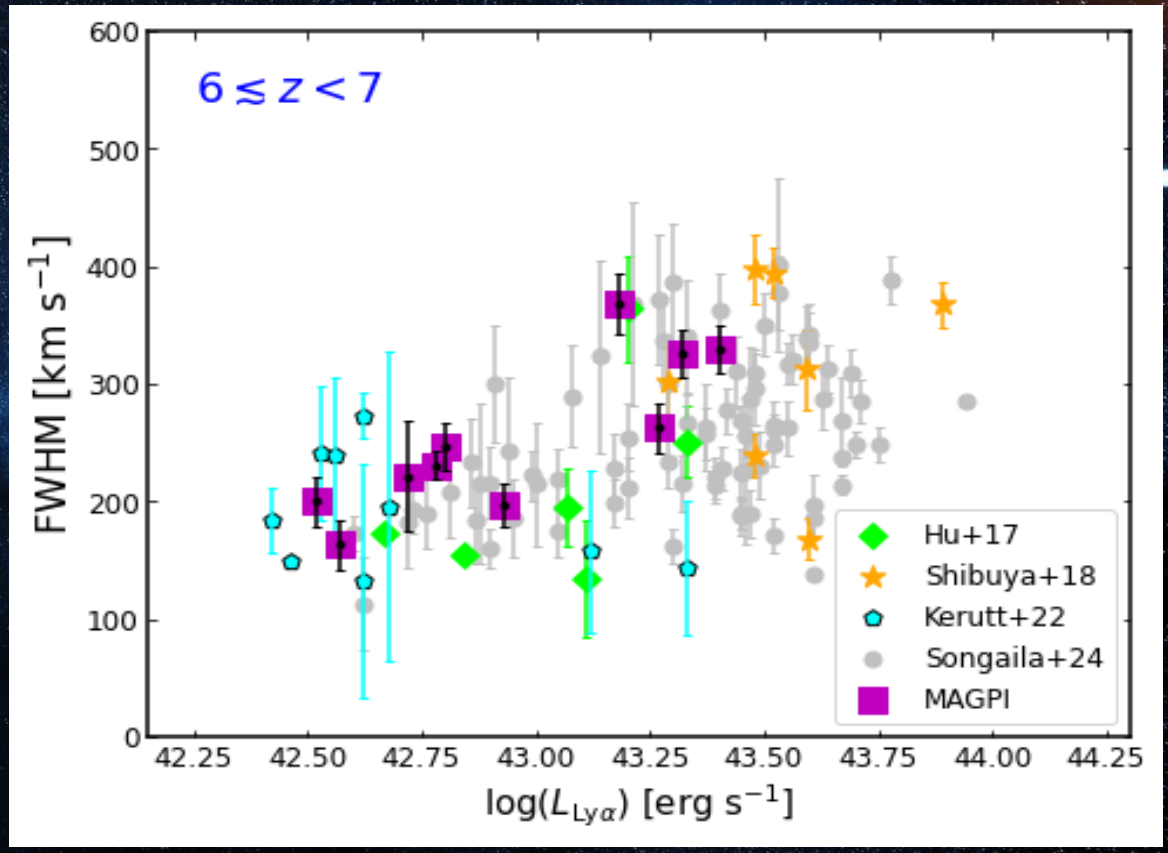




Mukherjee T. et al. 2024, PASA, 41, e105

Evolution of Lyα line widths during reionization





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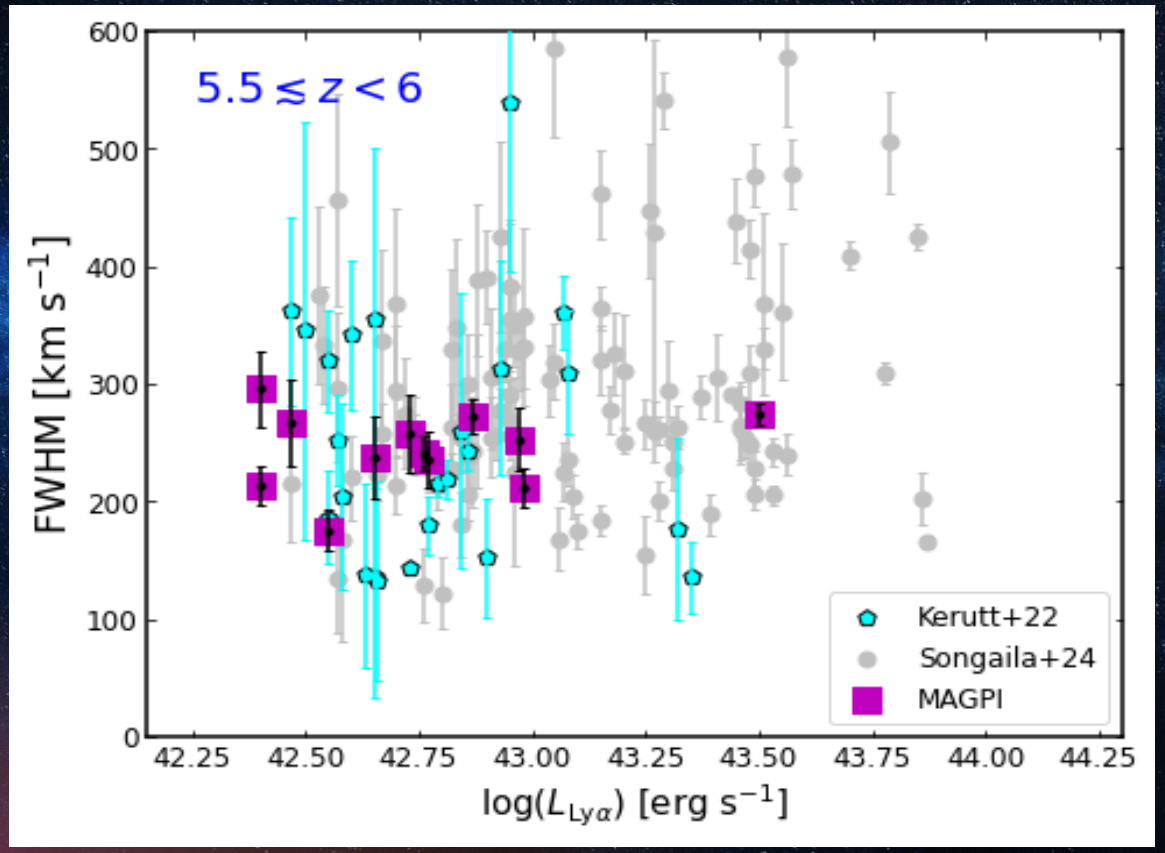
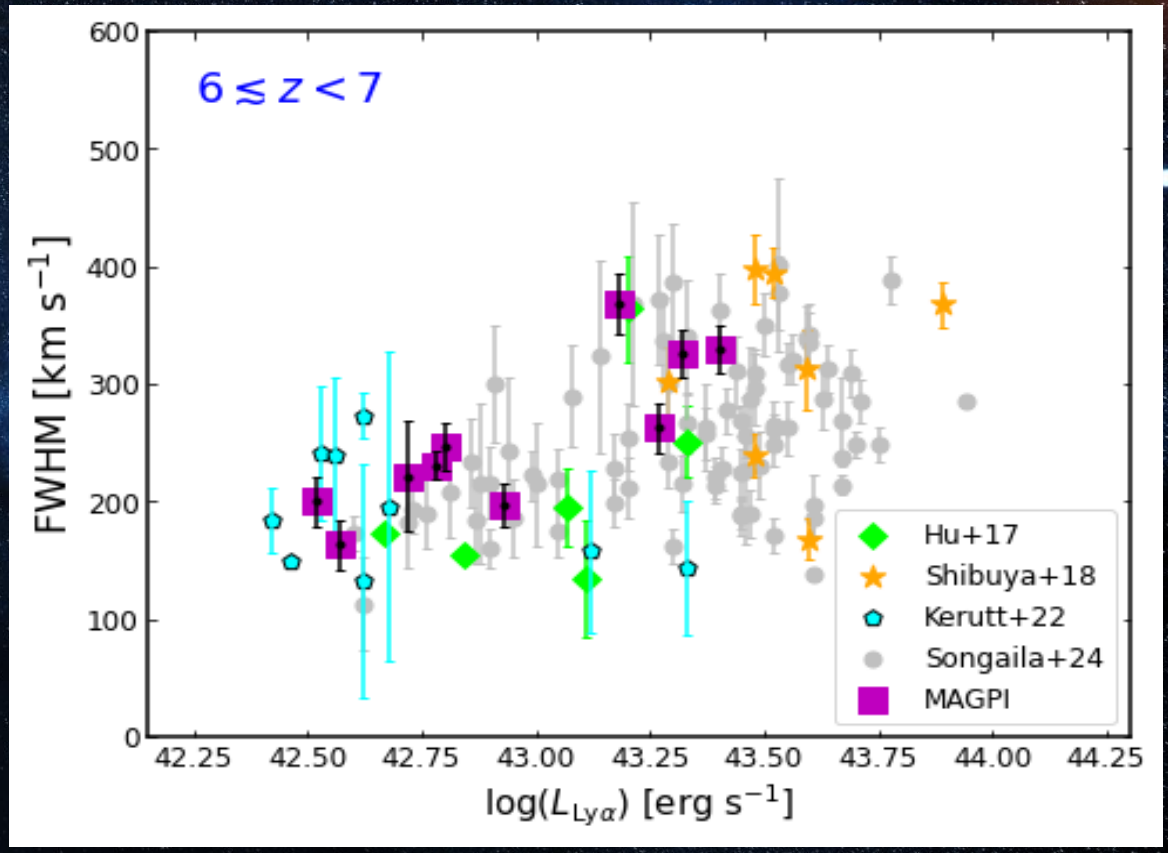
Evolution of Lyα line widths during reionization





At z > 6, high-luminosity LAEs are showing larger line widths !

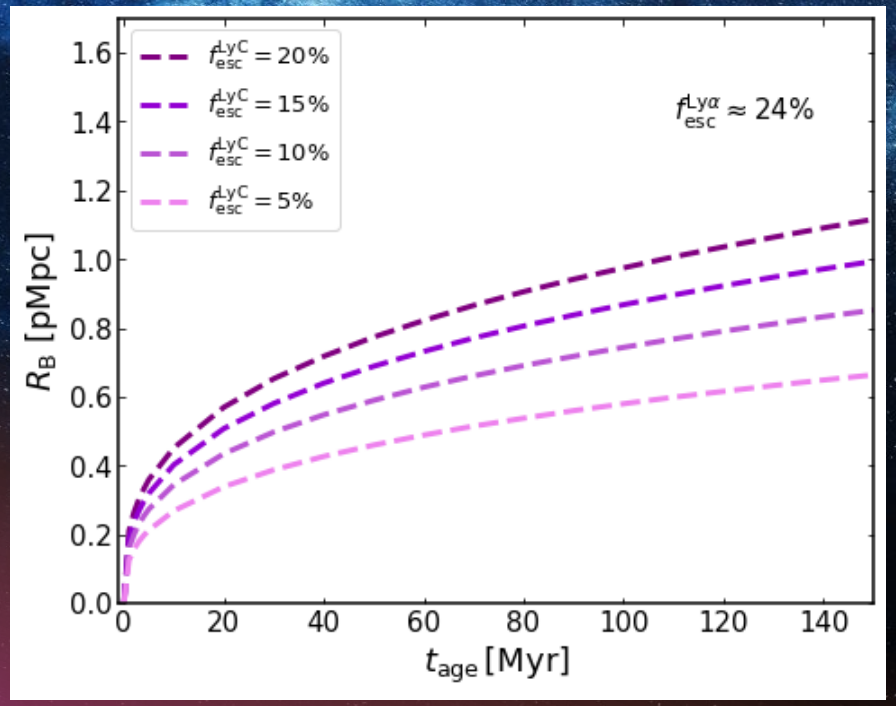
Mukherjee T. et al. 2024, PASA, 41, e105

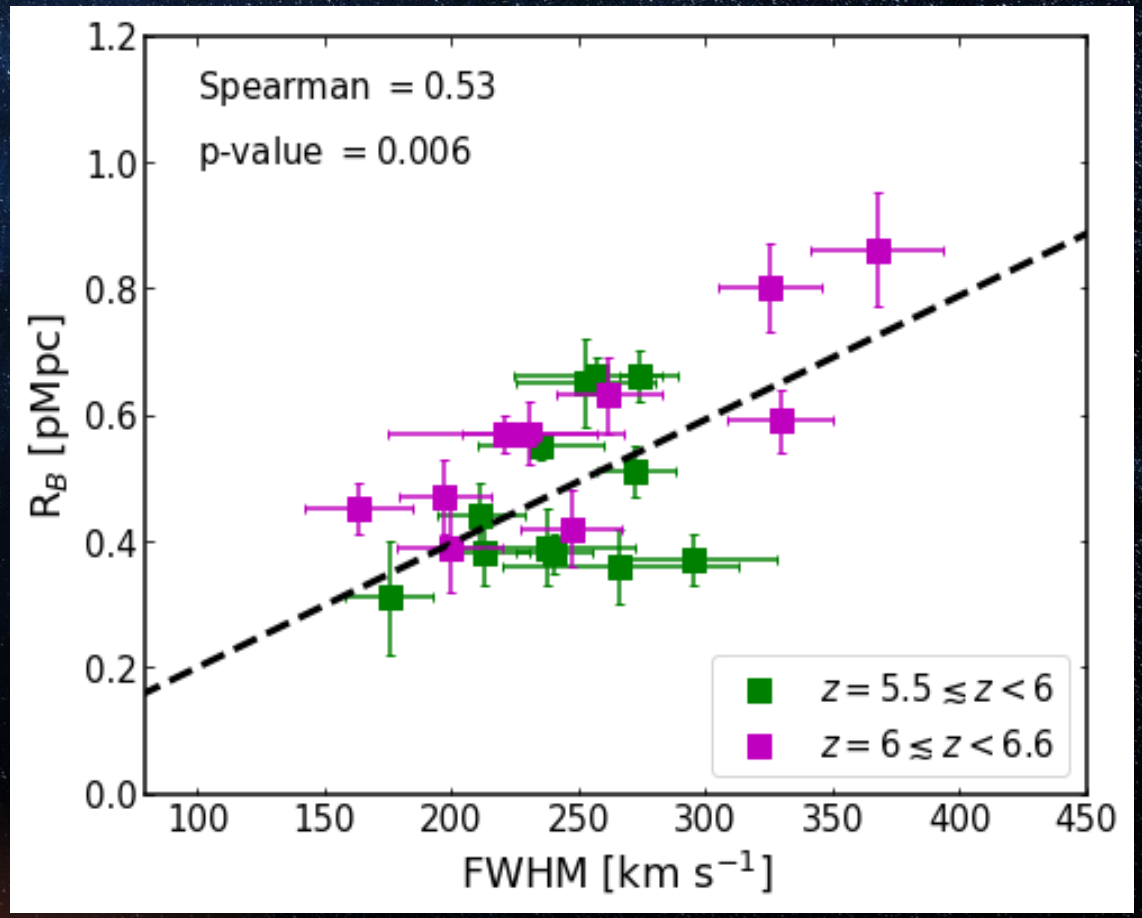
Size of ionized bubbles around LAEs

$$R_{\rm B} \approx \left(\frac{3\, Q_{\rm ion} f_{\rm esc}^{\rm LyC}\, t_{\rm age}}{4\pi\, n_{\rm H}(z)} \right)^{1/3}$$

Cen & Haiman 2000

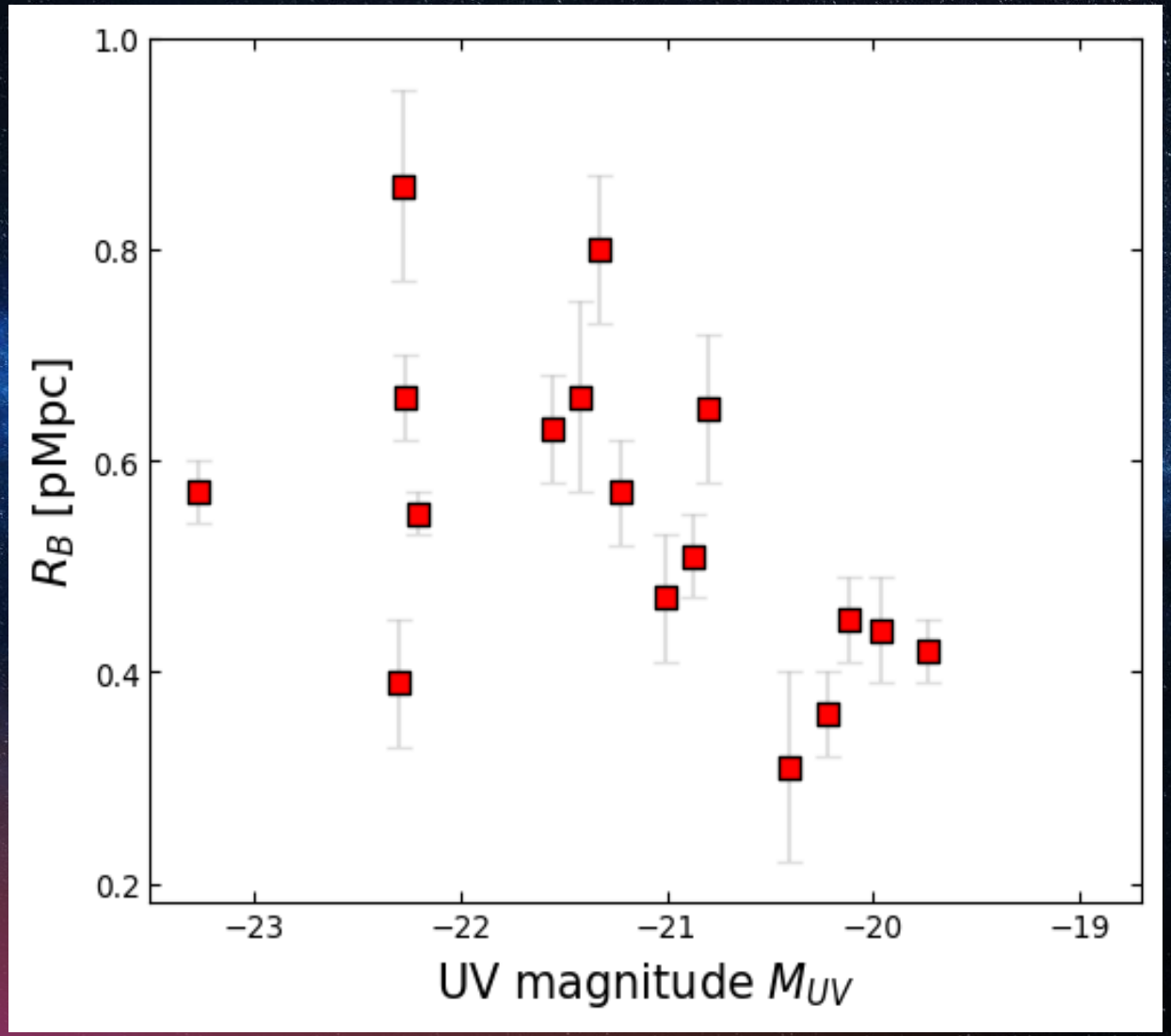
f_{esc} = 5 %, t_{age} = 100 Myr

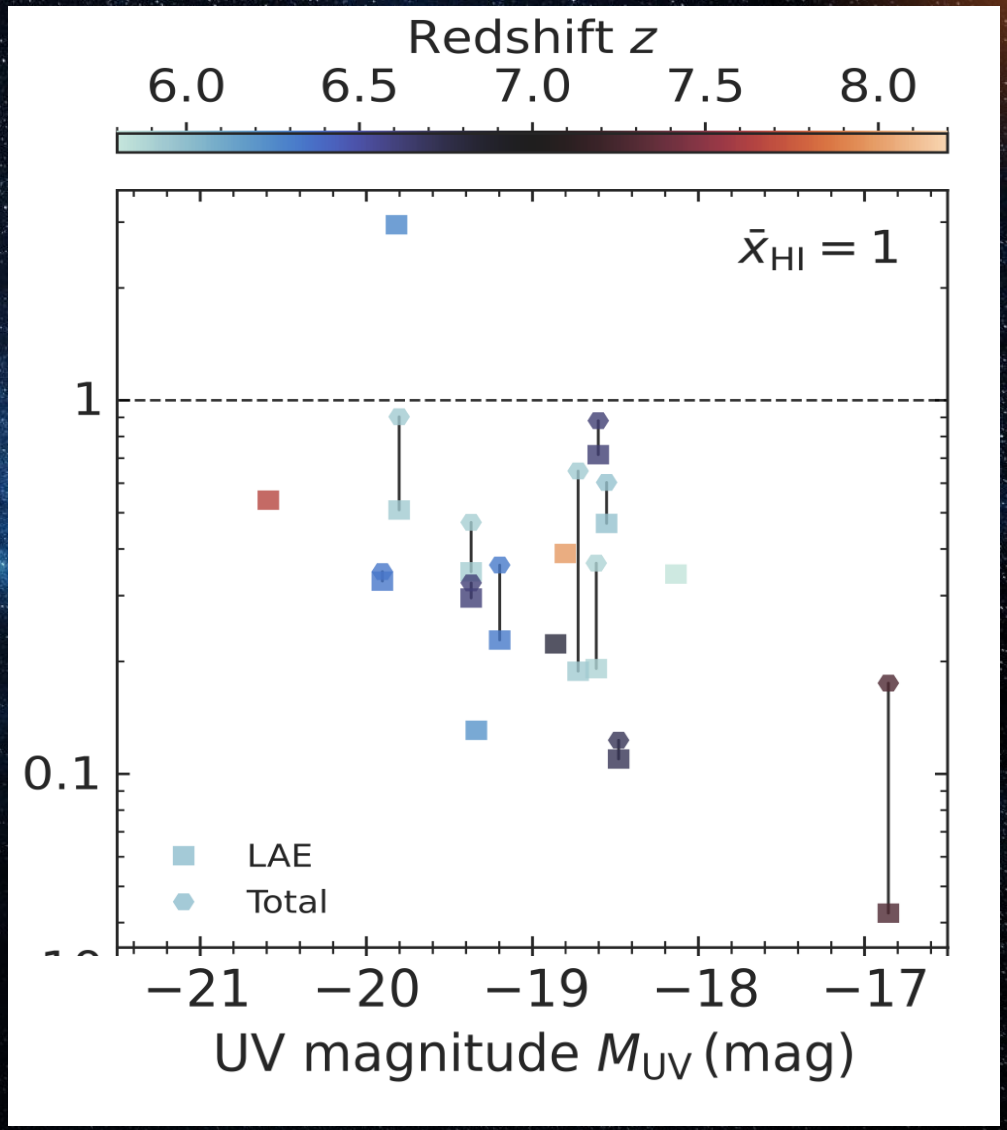




Mukherjee T. et al. 2024, PASA, 41, e105

UV-bright galaxies blowing larger bubbles!

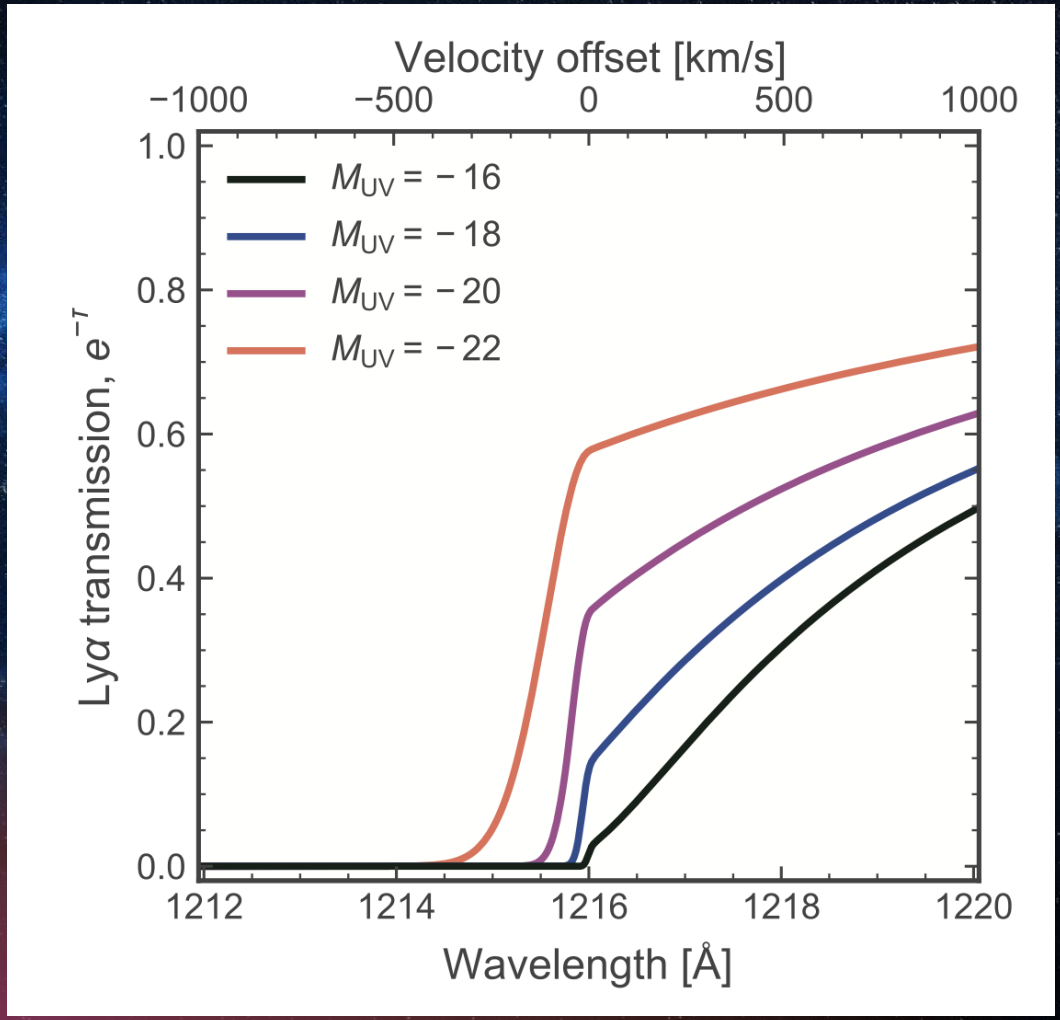




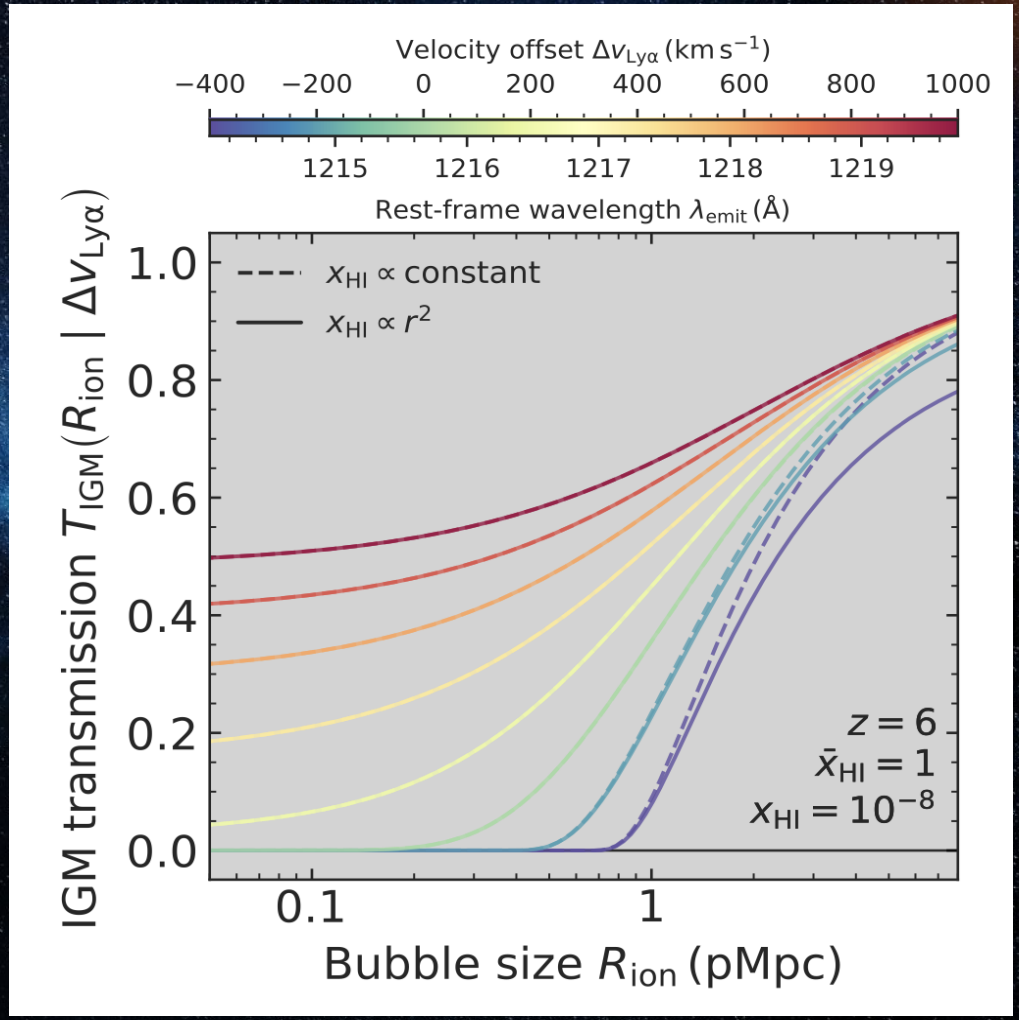
Mukherjee T. et al. 2024, PASA, 41, e105 and in prep.

Witstok et al. 2024

IGM transmission and bubble sizes

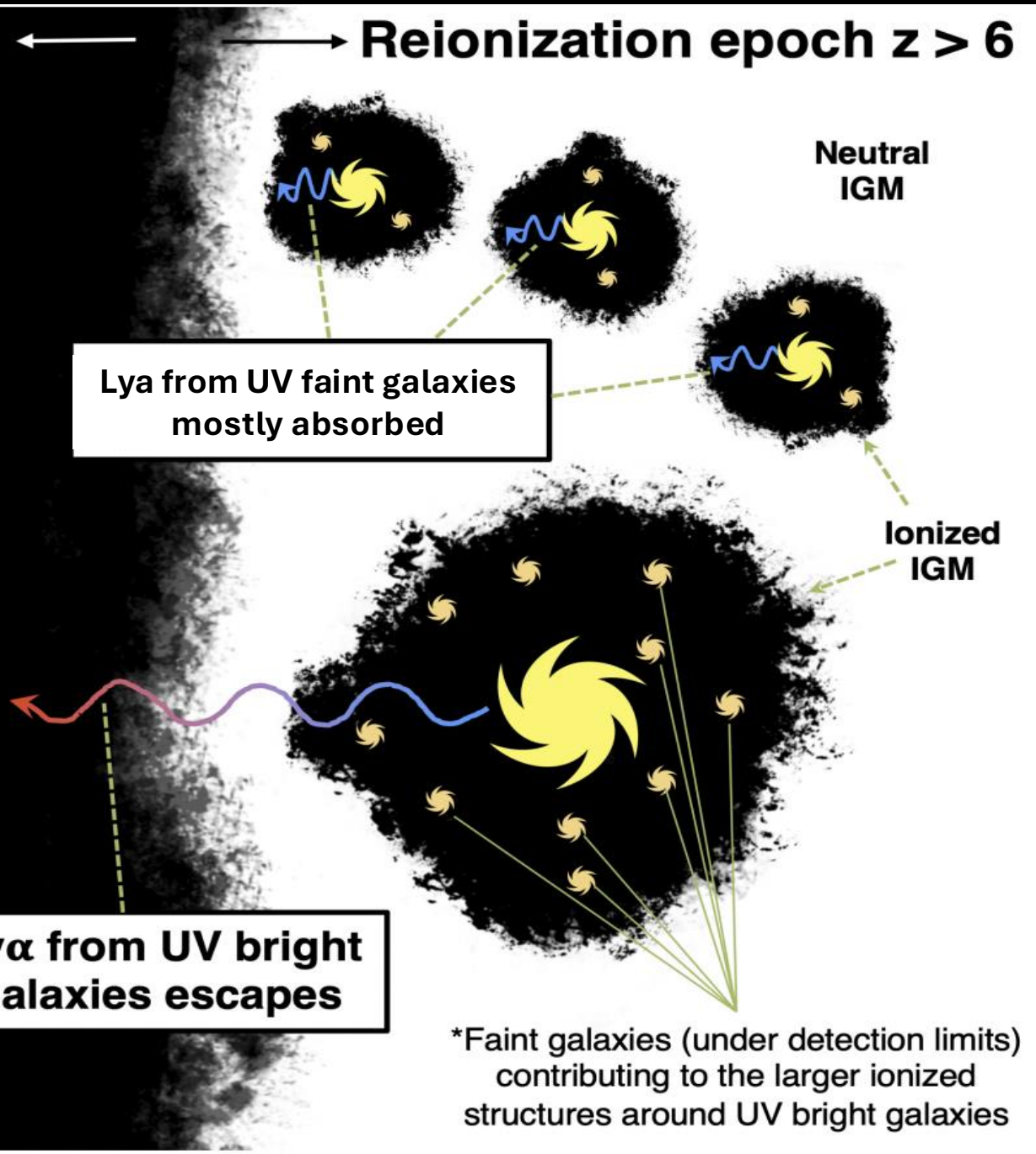


Mason & Gronke 2020



Witstok et al 2024

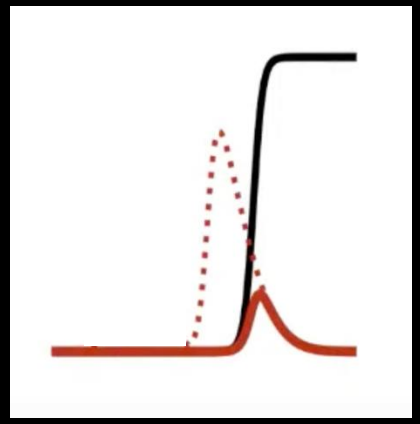
Following the talk of Pratika Dayal:
Patchy reionization



Jung et al. 2022

After reionization z < 6 ⟵

⟶ Reionization epoch z > 6



Neutral IGM

Lya from UV faint galaxies mostly absorbed

Ionized IGM

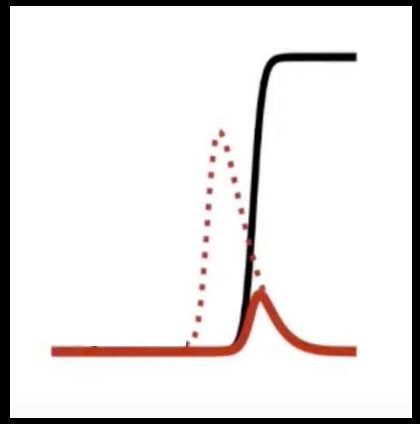
Lyα from UV bright galaxies escapes

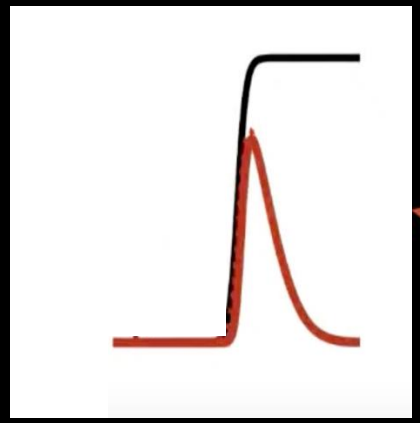
*Faint galaxies (under detection limits) contributing to the larger ionized structures around UV bright galaxies

Transparent IGM to Lyα after reionization

After reionization z < 6 ⟵

⟶ Reionization epoch z > 6





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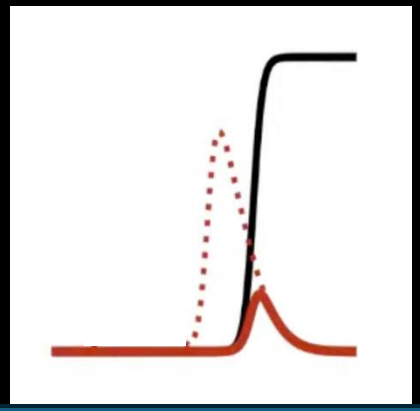
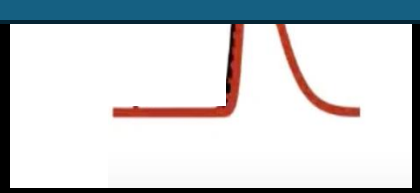




Neutral IGM

Lya from UV faint galaxies mostly absorbed

Ionized IGM

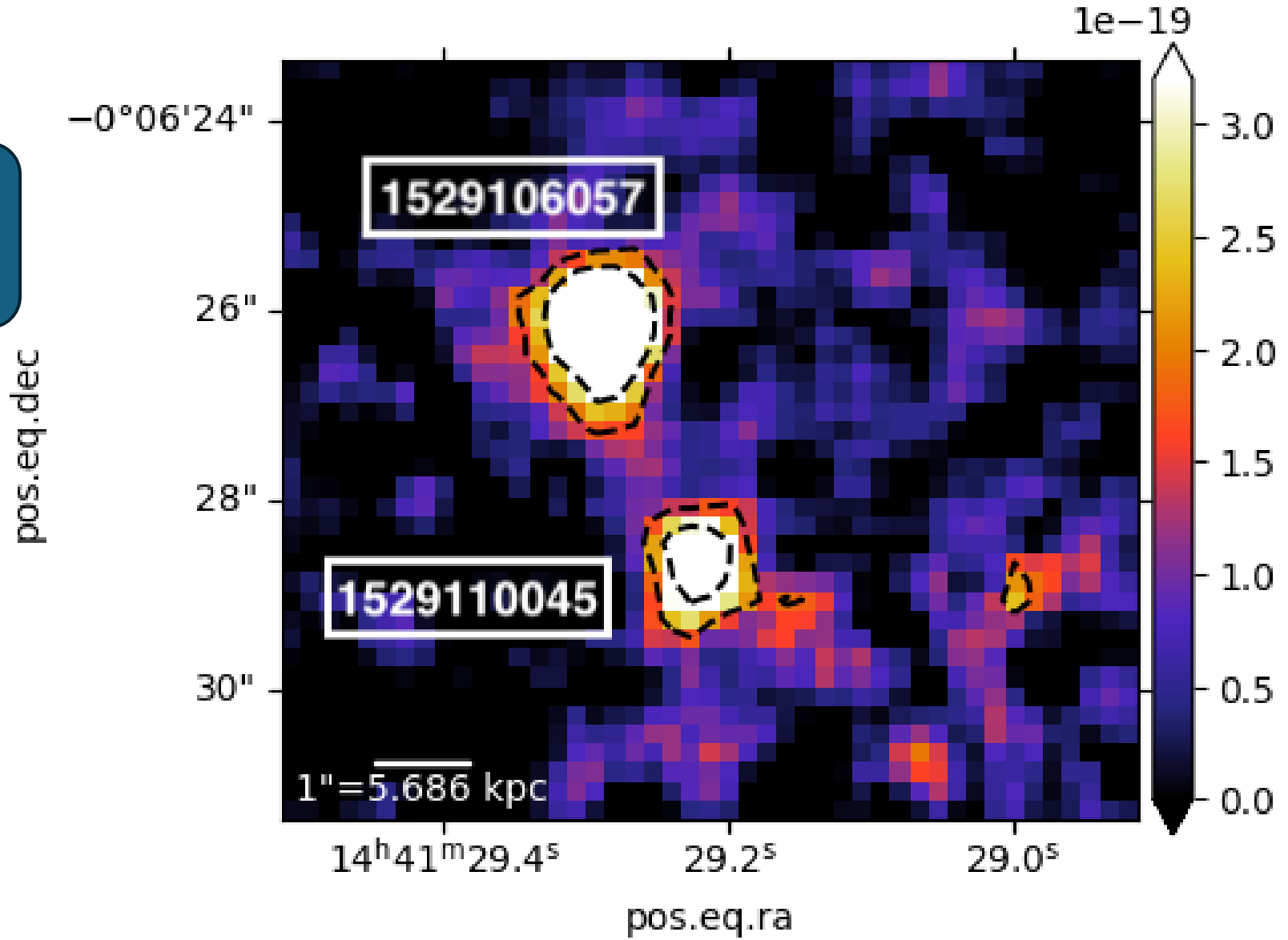
Bubbles can be large enough to allow blue peak to escape at z > 6:
See **Cristobal Moya's** talk on Friday

Lyα from UV bright galaxies escapes

*Faint galaxies (under detection limits) contributing to the larger ionized structures around UV bright galaxies

Transparent IGM to Lyα after reionization

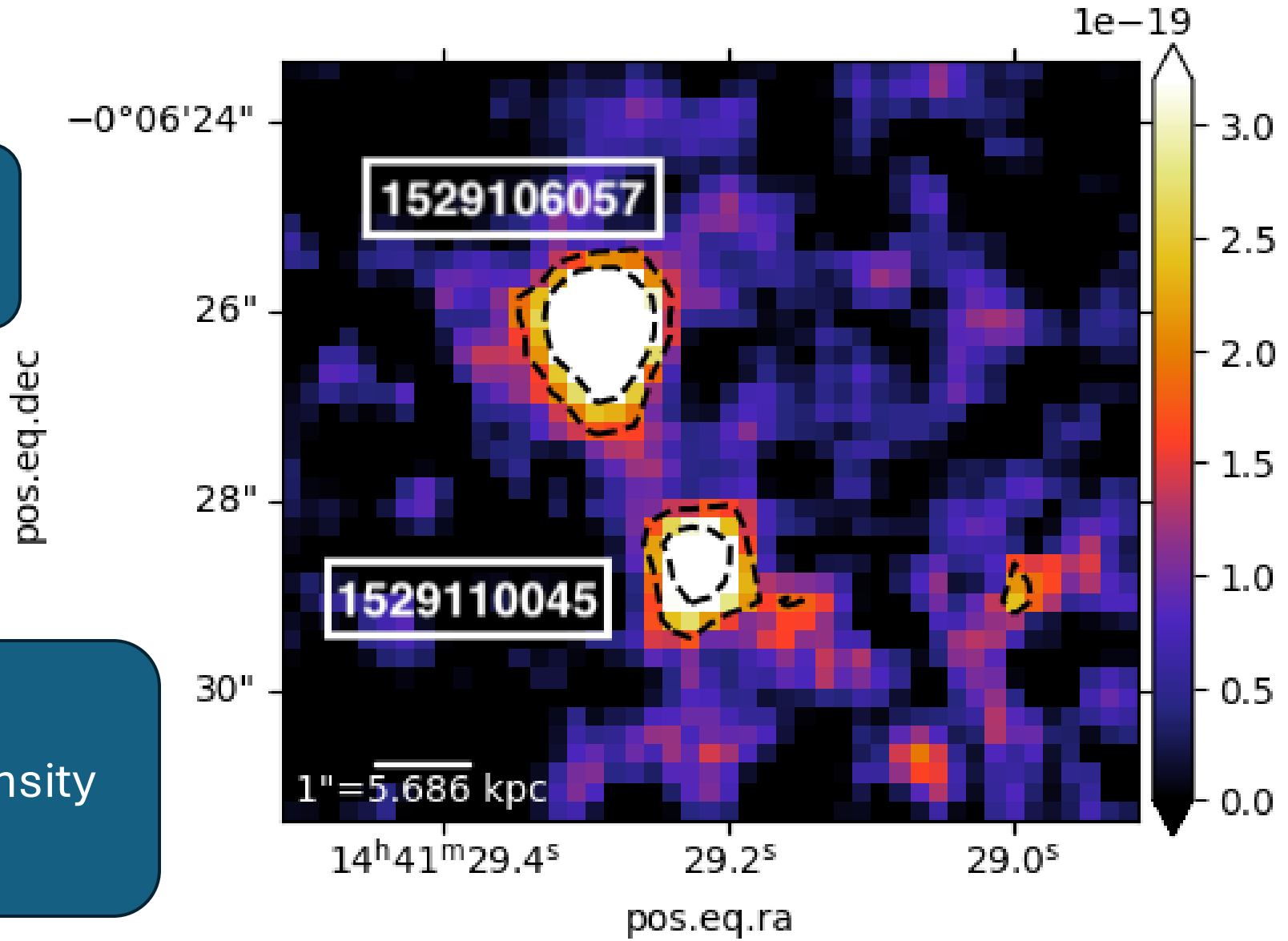
z = 6.046



Mukherjee et al. 2024, PASA, 41, e105

z = 6.046

Lyα overdensity



Mukherjee et al. 2024, PASA, 41, e105

Summary

- We discovered blue-dominated Lyα haloes in MAGPI data and a blue-dominated Lya nebula in HUDF, tracing CGM gas inflows → a unique laboratory to study gas accretion processes in galaxies

- We conclude that these systems are interaction driven, where a primary galaxy is outflowing gas (metal poor), which is getting reaccreted onto a new galaxy (low in stellar mass), and fueling new star formation → an efficient galaxy formation mode

- We study spatially resolved properties of Lya halos through spectroscopy and modeling: blue-to-red flux ratio (shell velocity) and peak separation (column density) decreases with increasing radius. One halo deviates from this → warrant further study

- We studied the evolution of Lyα line width with luminosity during reionization epoch. We found that at $z > 6$, high-luminosity LAEs are showing wider Lyα, potentially indicating that they are residing in larger ionized bubbles.


Thank You for your attention!