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CRAL
CENTRE DE RECHERCHE ASTROPHYSIQUE DE LYON

Identifying the galaxies that reionized the universe: Connecting the **LyC** escape to **Lyα**, **Mg II** and **[O II]** emission

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Marie S. Curie fellow @CRAL Lyon France
— The LzLCS collaboration —

GECO
Café-club

Feb. 6th, 2025 @LAM

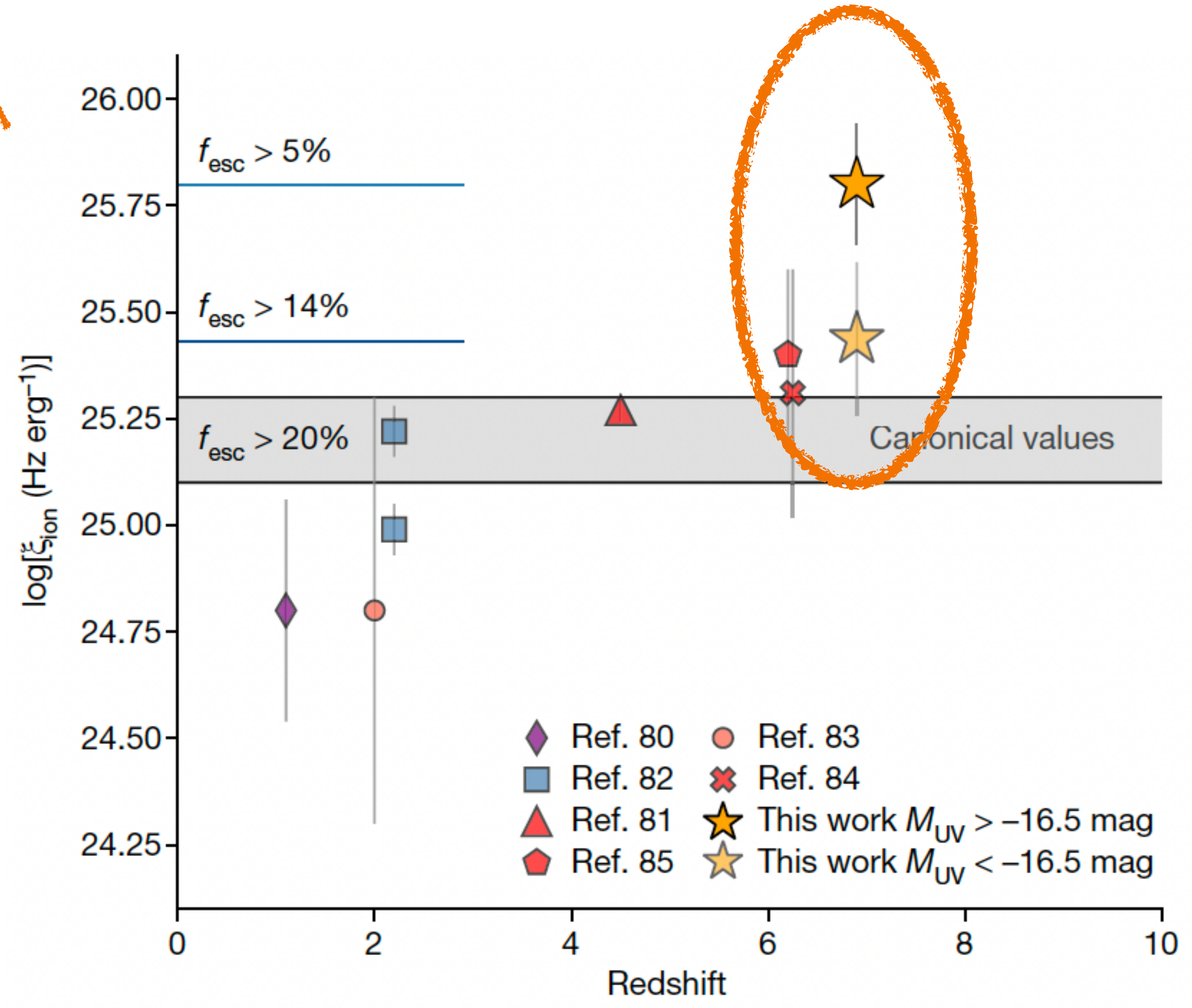
Looking for the sources that reionized the Universe

- Cosmic Reionization: at z= 5 -10, neutral IGM is ionized by the first luminous sources

- Observationally, we know *when* it was completed z=5-6 but we don't ***how***

Looking for the sources that reionized the Universe

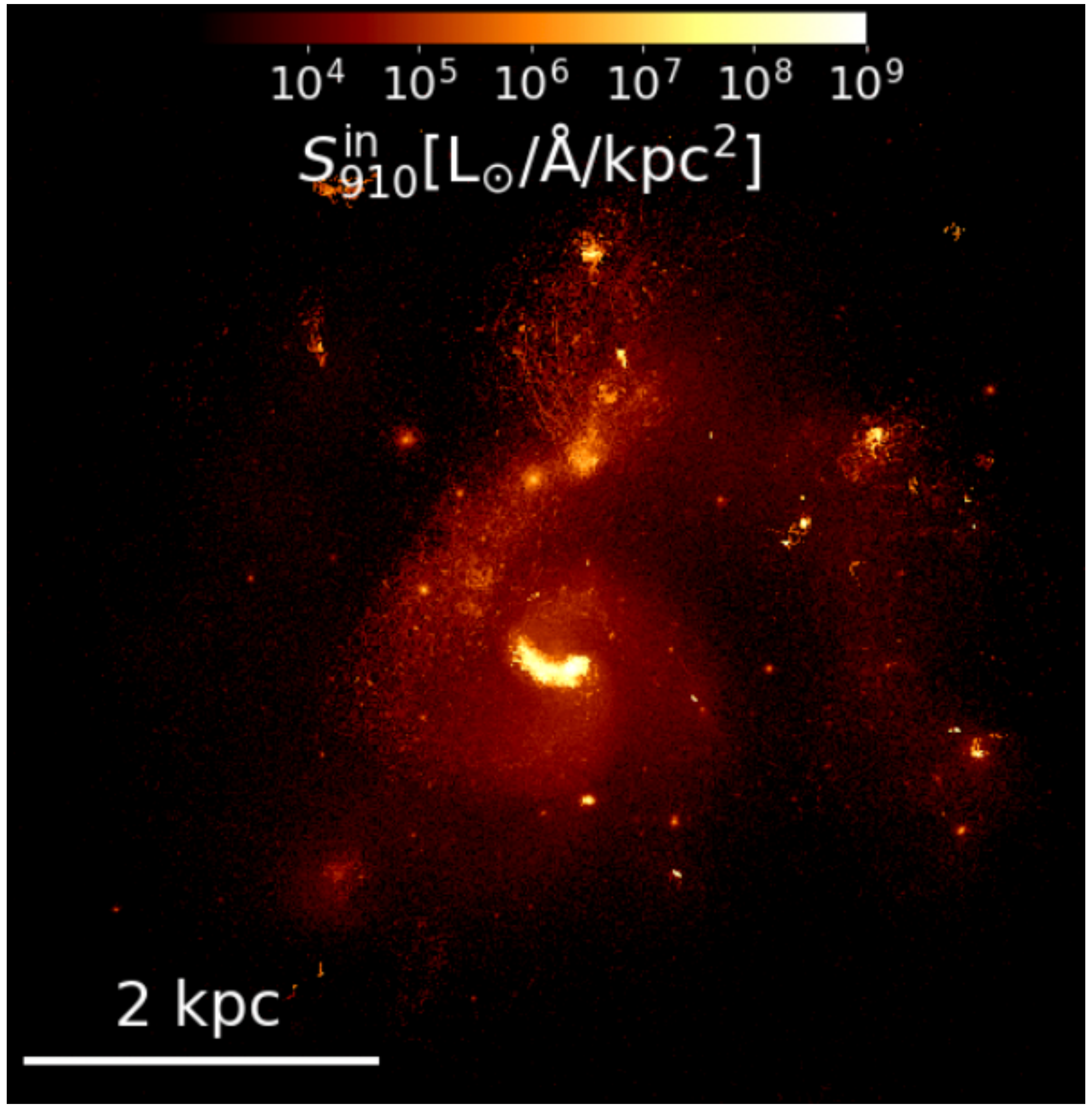
ionizing photon
PRODUCTION
efficiency



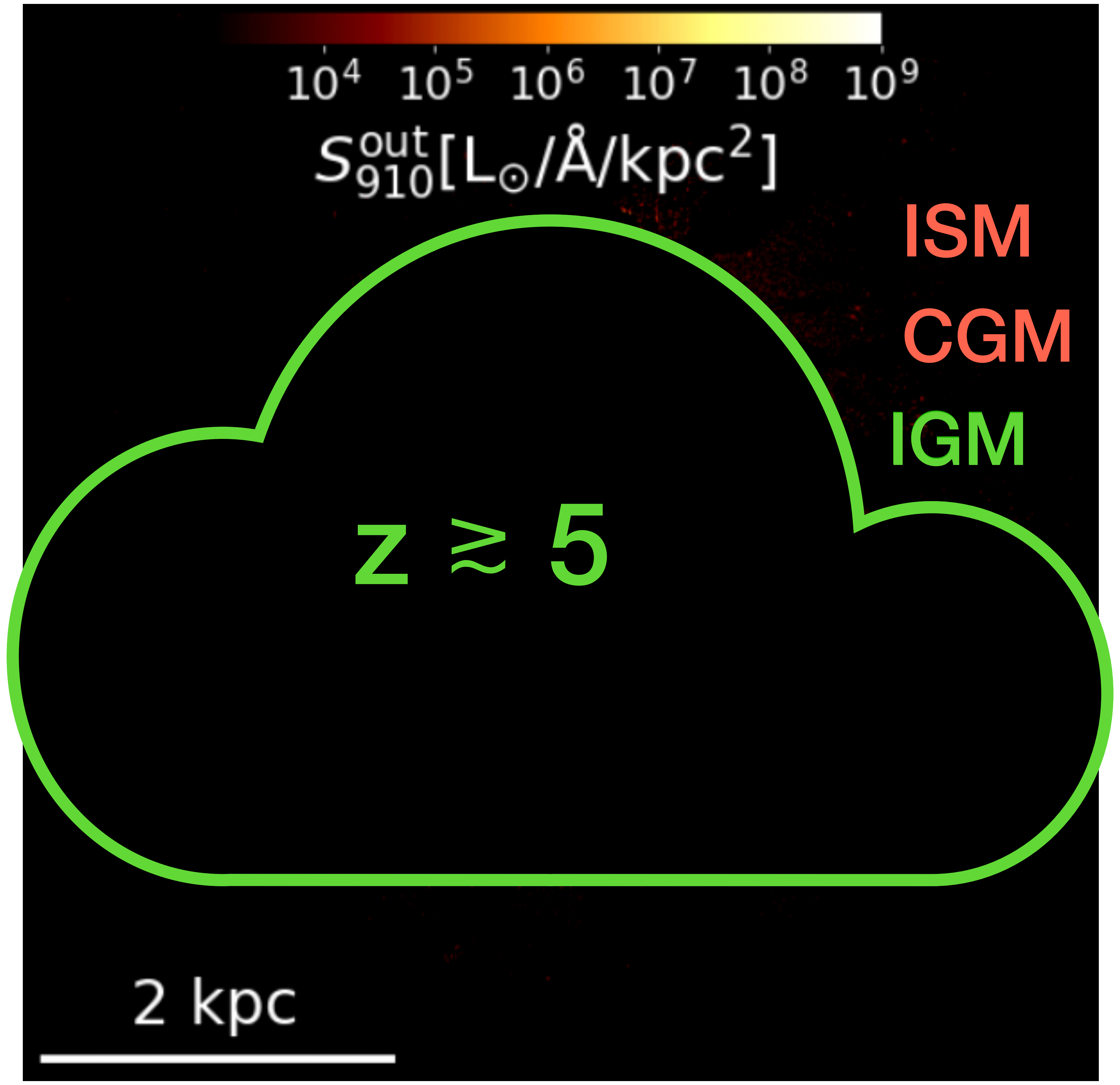
How much of the produced LyC radiation **ESCAPE** galaxies ?

Atek et al. 2024, Nature, UNCOVER program

The need for indirect tracers of LyC escape



Intrinsic LyC



Observed LyC

Mauerhofer et al. 2021

Two sinks for LyC photons :

1) Neutral gas
2) Dust

$$f_{\rm esc}^{\rm LyC} = \frac{\text{Observed LyC flux}}{\text{Intrinsic LyC flux}}$$

At $z \gtrsim 5$ LyC is NOT observable

➜ Need **indirect LyC tracers**

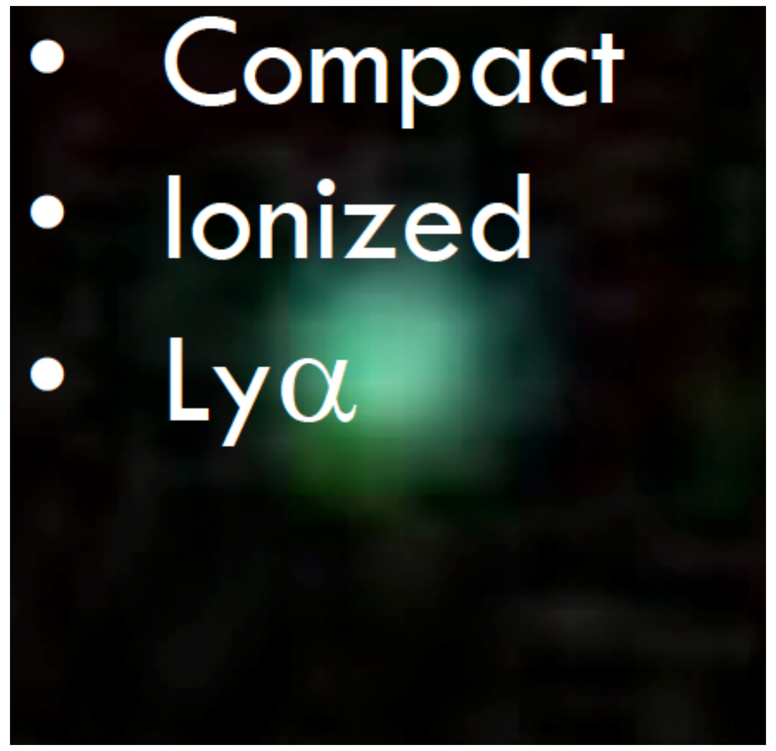
to be tested at **lower redshift** when LyC is observable

Testing indirect LyC tracers on local LyC emitters

HST/COS had led a revolution in the detection of LyC in z~0.3 galaxies !

Leitet et al. 2013; Borthakur et al. 2014; Leitherer et al. 2016; Izotov et al. 2016a,b, 2018a,b; Wang et al.2019; Izotov et al. 2021, 2022;

In 2021 : ~20 low-z LyC emitters known

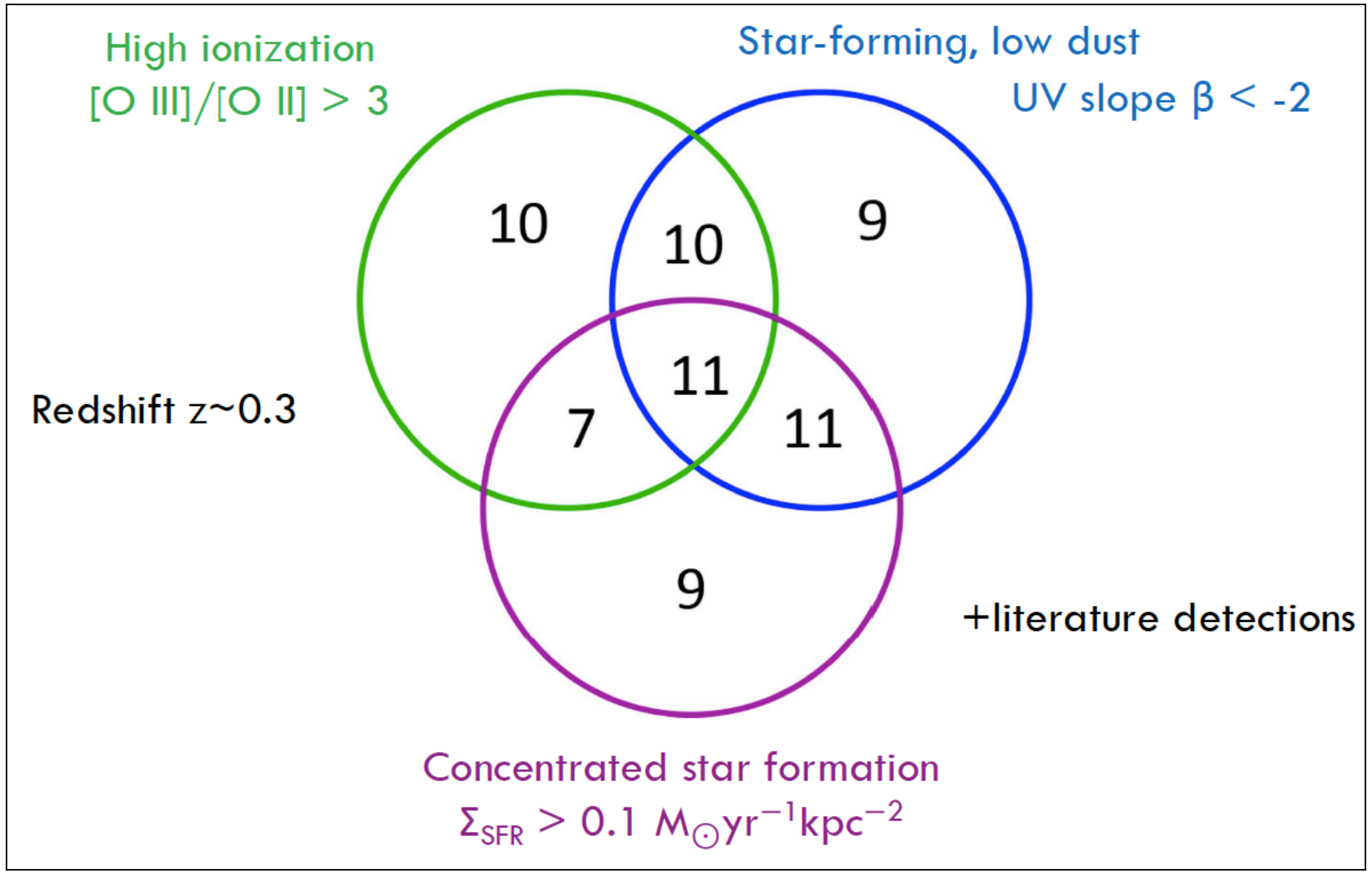


THE **LzLCS** SURVEY: LOW-REDSHIFT LYMAN CONTINUUM SURVEY

- HST/COS PID: 15626, PI: Jaskot
- Sample of 66 star-forming galaxies at z~0.3
- 35 new LyC detections
- **statistical sample of 89 LyC leakers <u>and</u> non-leakers**

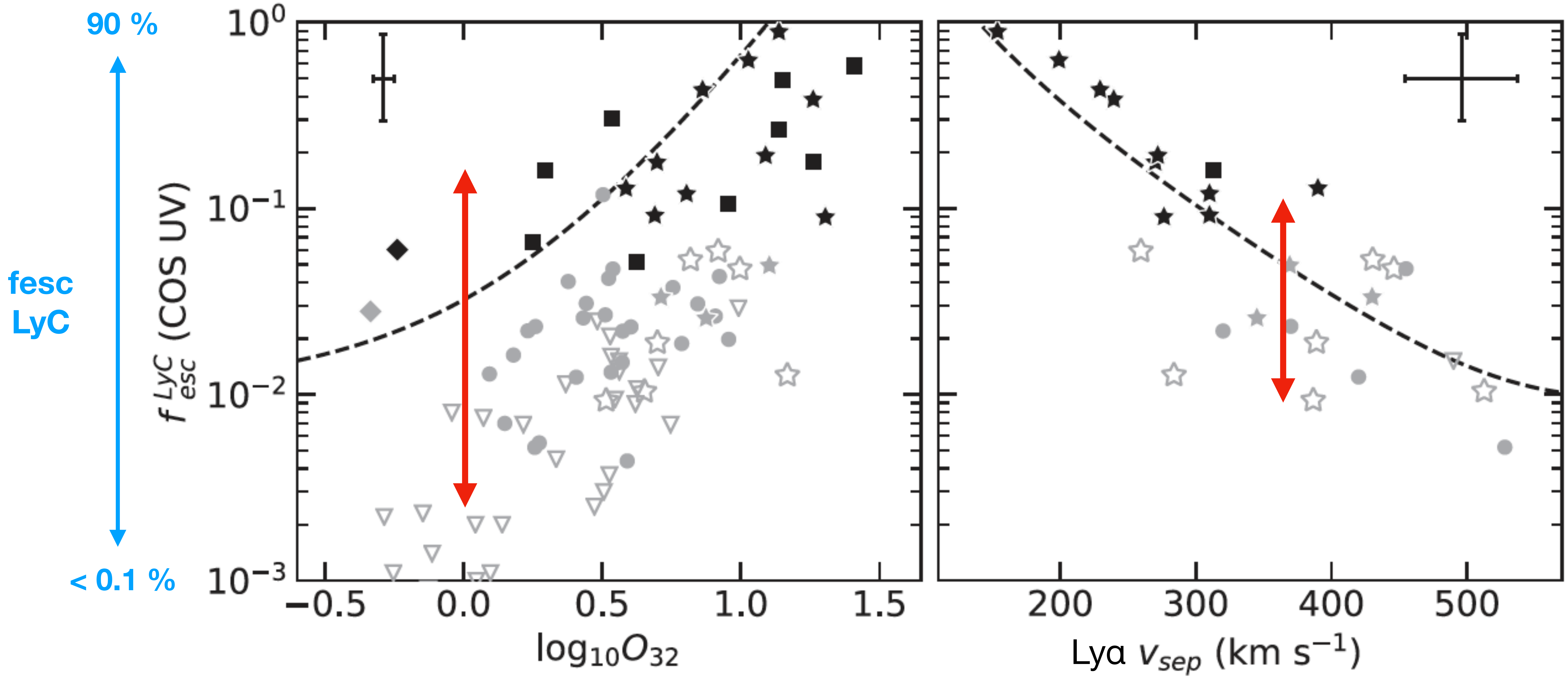
➜ **Test and calibration of the indirect LyC tracers**

Flury et al. 2022a,
Saldana-Lopez et al. 2022



Testing indirect LyC tracers on local LyC emitters

Flury et al. 2022b



Large scatter

➜ no reliable fesc(LyC)

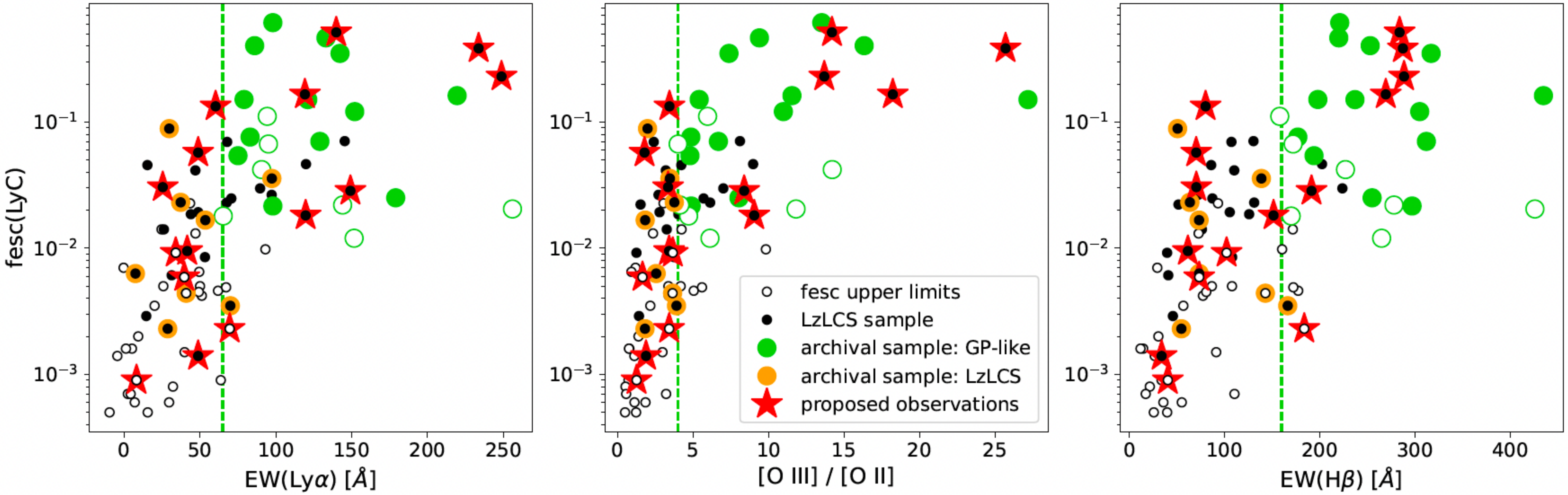
Smaller scatter

But smaller sample…

HST/COS Lyα observations of LyC leakers

Leclercq et al. in prep.

Medium HST/COS program — PI: Leclercq — 49 orbits —> **15 LzLCS galaxies**



New + Archival HST observations =

42 LzLCS galaxies with **both LyC** observations and high-resolution **LyA**

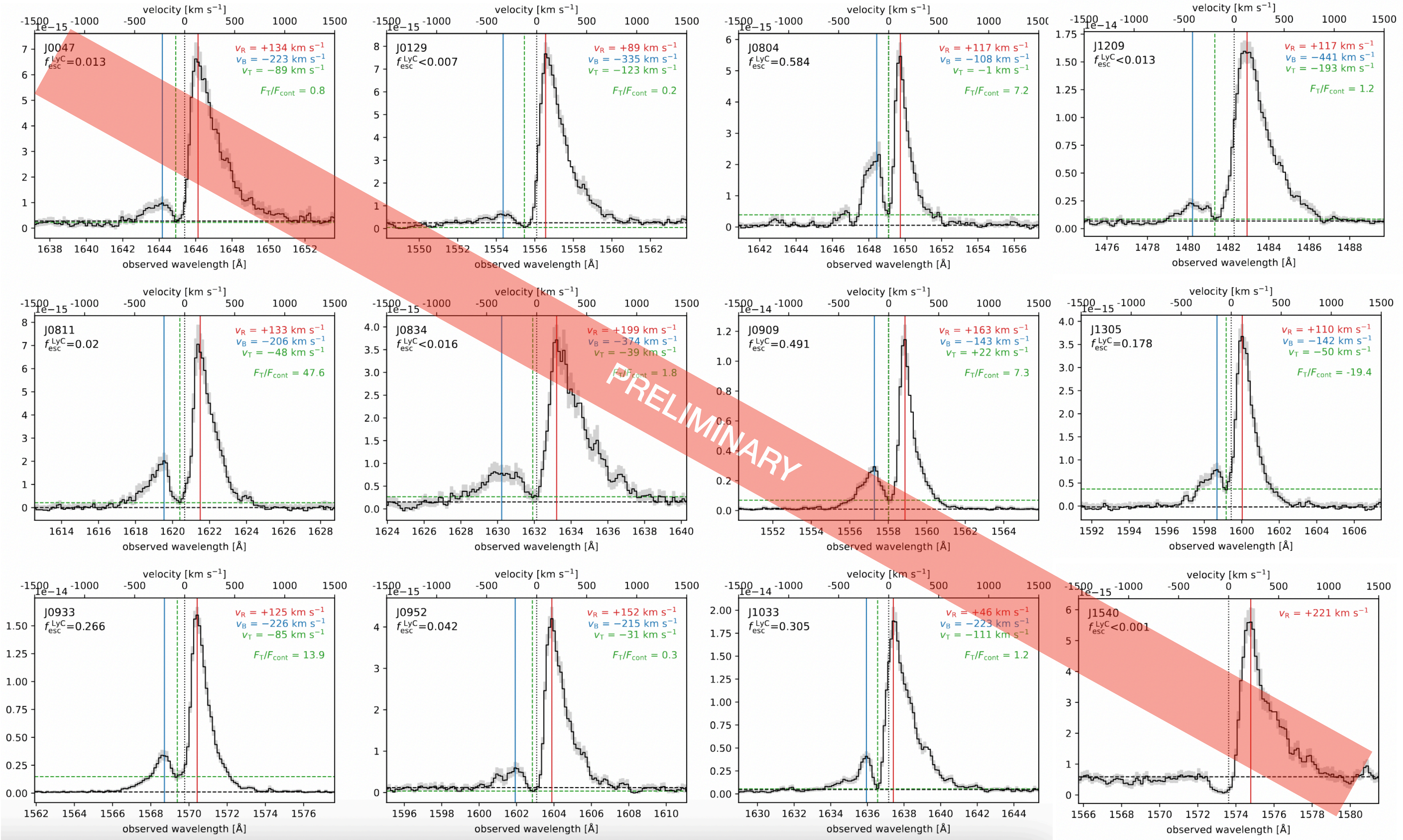
Primary goals :

- Reveal the LyA shape in a diverse and statistical sample of LCEs
- Stringently test the ability for LyA to recover fesc(LyC)
- Explore the scatter in the LyA / LyC relations

HST/COS Lyα observations of LyC leakers

New COS/G160M observations :

Leclercq et al. in prep.



+ 27 archival objects

Henry et al. 2015,
Yang et al. 2017a,
Izotov et al. 2016a,b
Izotov et al. 18a,b
Izotov et al. 2021,

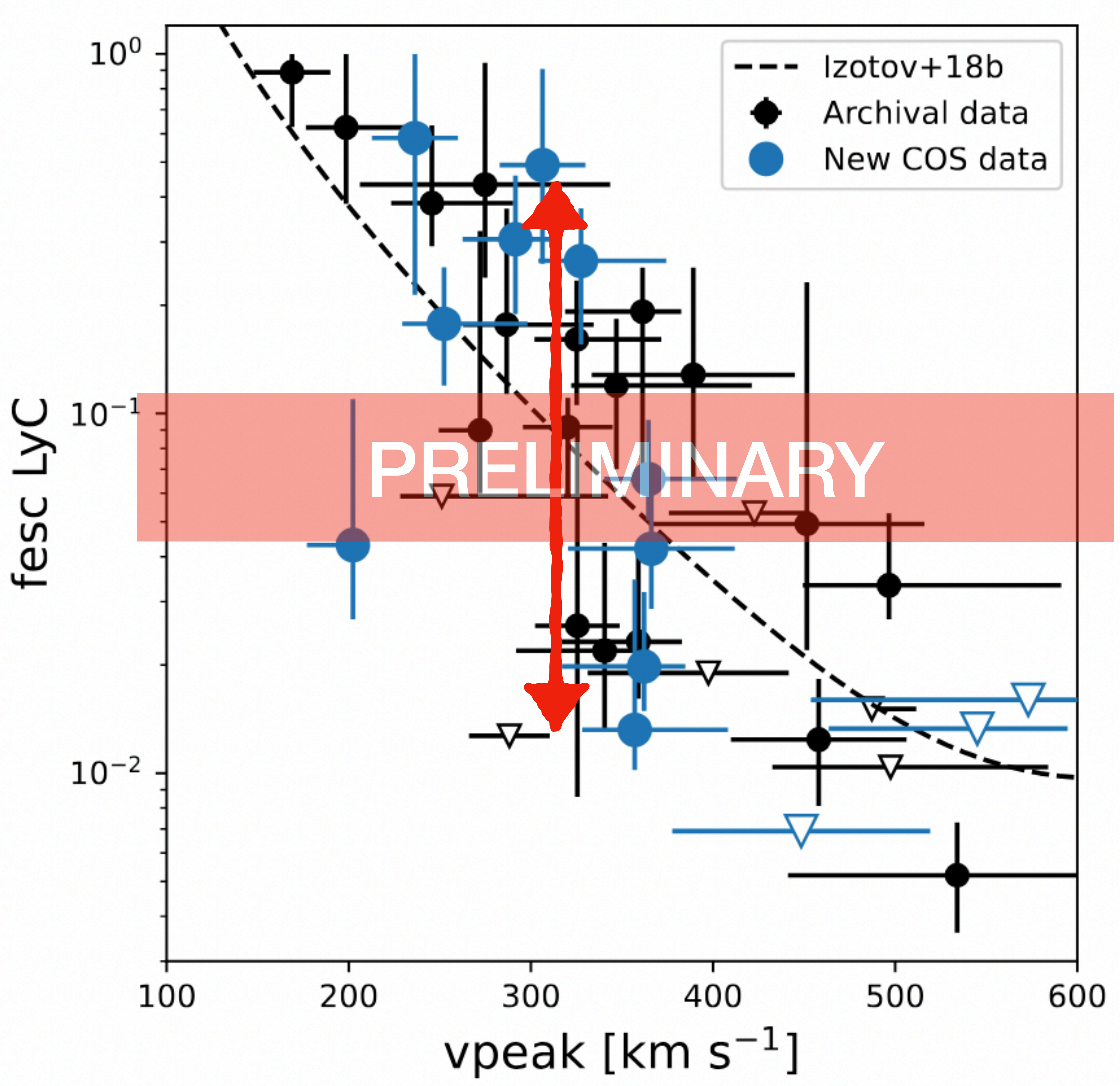
- 6 HST/COS programs
- Same data reduction
- Same spectral binning
- Same measurements

—> First homogenous and statistical sample allowing a consistent analysis

LyC escape vs. LyA peak separation

Leclercq et al. in prep.

Preliminary



➜ correlation between fesc(LyC) and Lyman alpha peak separation holds

➜ Scatter increased at vpeak ~ 300 km/s

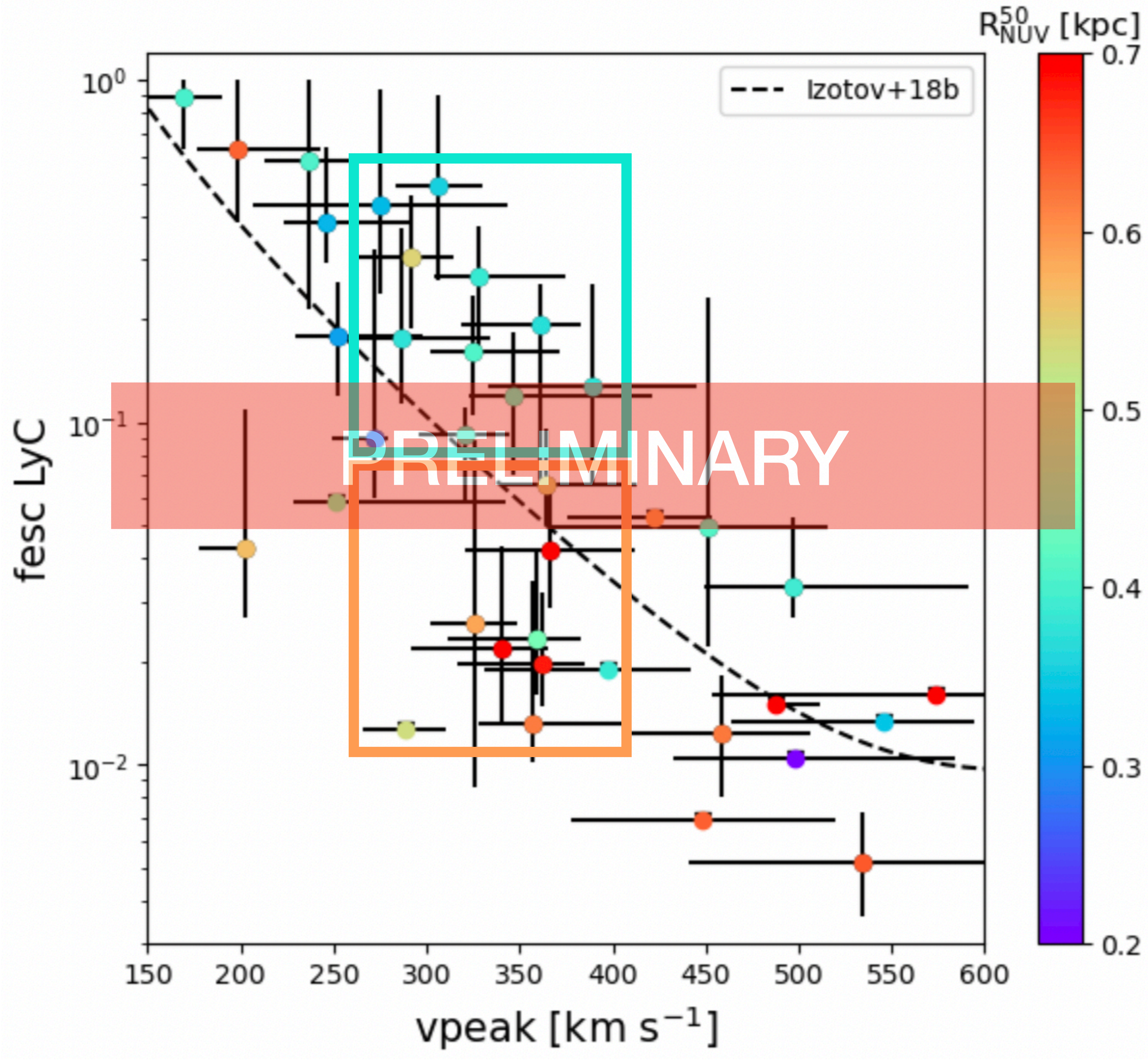
Is the scatter due to secondary parameters ?

Flury et al. 2022b

LyC escape vs. LyA peak separation

Leclercq et al. in prep.

Preliminary



For vpeak = [250 - 400] km/s :

$R_{UV} \lesssim$ 0.5 kpc ➜ fesc(LyC) $\gtrsim$ 8 %

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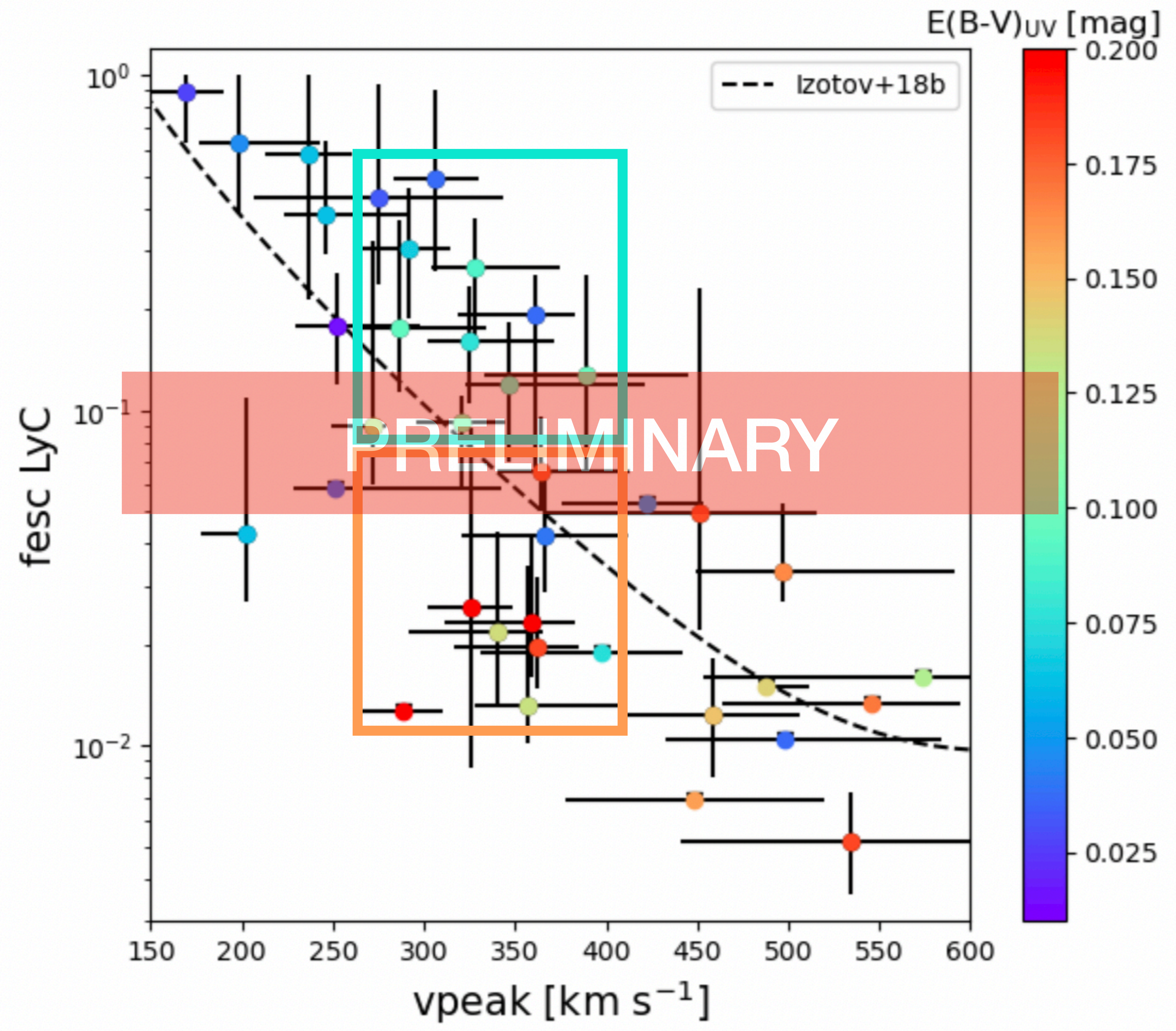
Our results suggest that the scatter in the vpeak - fesc(LyC) relation is driven by the **galaxy UV size**

LyC escape vs. LyA peak separation

Leclercq et al. in prep.

Preliminary



In the LyA vpeak = [250 - 400] km/s bin :

E(B-V) ≲ 0.1 mag ➜ fesc(LyC) ≳ 5%

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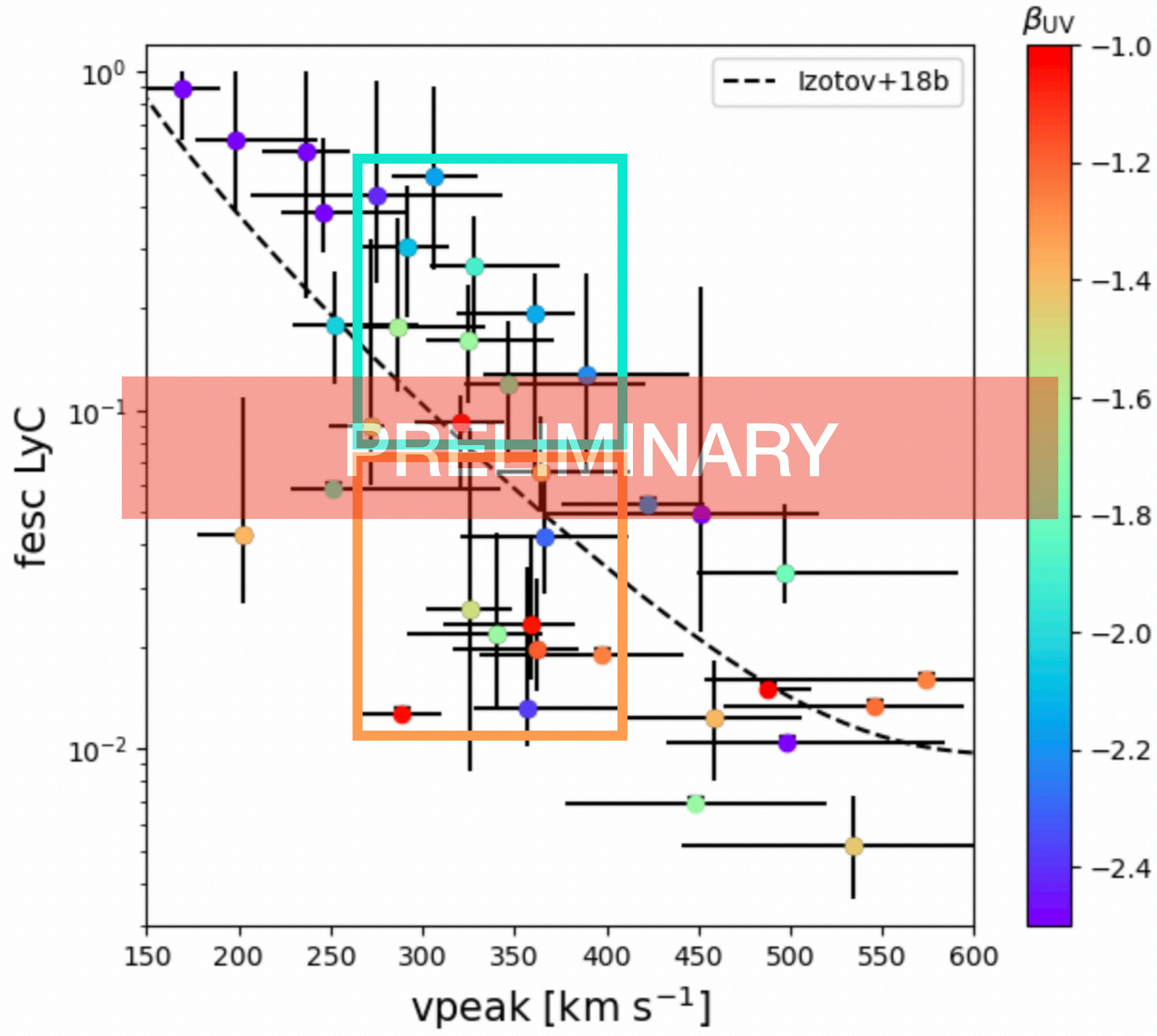
Our results suggest that the scatter in the vpeak - fesc(LyC) relation could also be driven by the **dust extinction**

LyC escape vs. LyA peak separation

Leclercq et al. in prep.

Preliminary



In the LyA vpeak = [250 - 400] km/s bin :

β slope ≲ - 1.8 ➜ fesc(LyC) ≳ 5%

β slope ≳ - 1.5 ➜ fesc(LyC) ≲ 5%

This trend is also observed with the UV beta slope

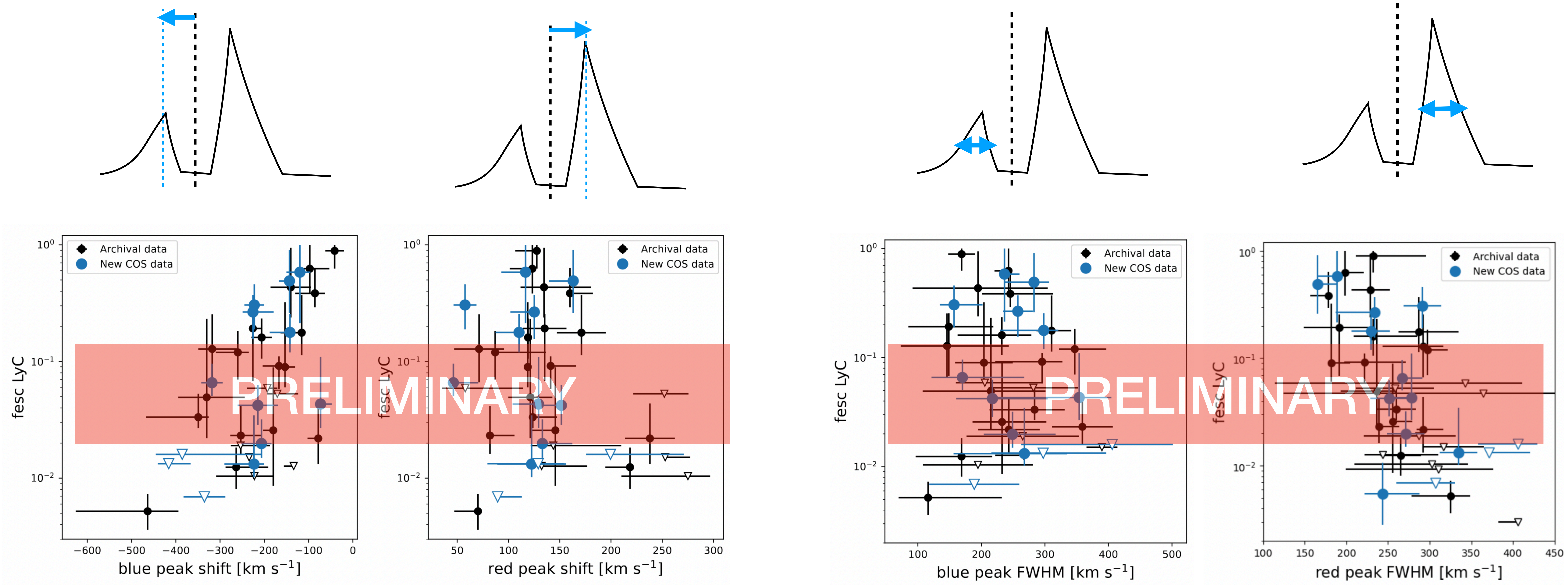
LyA peak separation + UV size + dust
= refining of the fesc(LyC) prediction

No obvious trends seen with other parameters…

fesc(LyC) vs. LyA line properties

Leclercq et al. in prep.

Preliminary



The location of the blue peak seems to correlate more strongly with the escape of ionizing photons

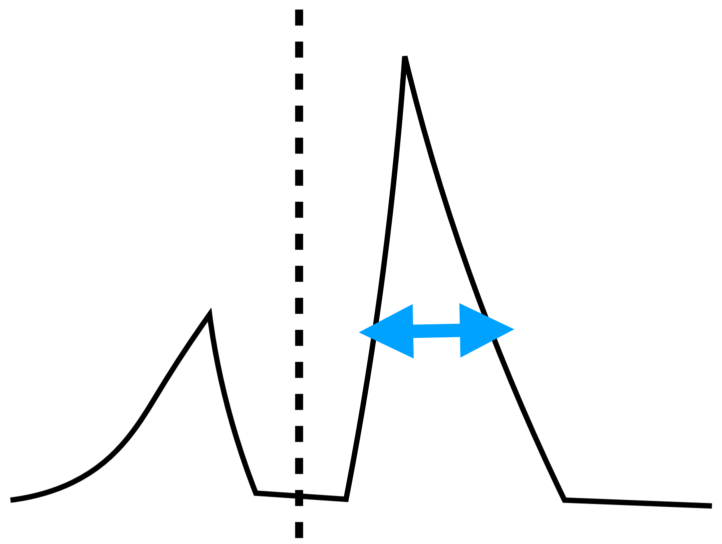
Also observed in literature (e.g., Henry+15, Verhamme+17)

The width of the red LyA line anti-correlates with fesc(LyC) with some scatter BUT can be used at EoR !

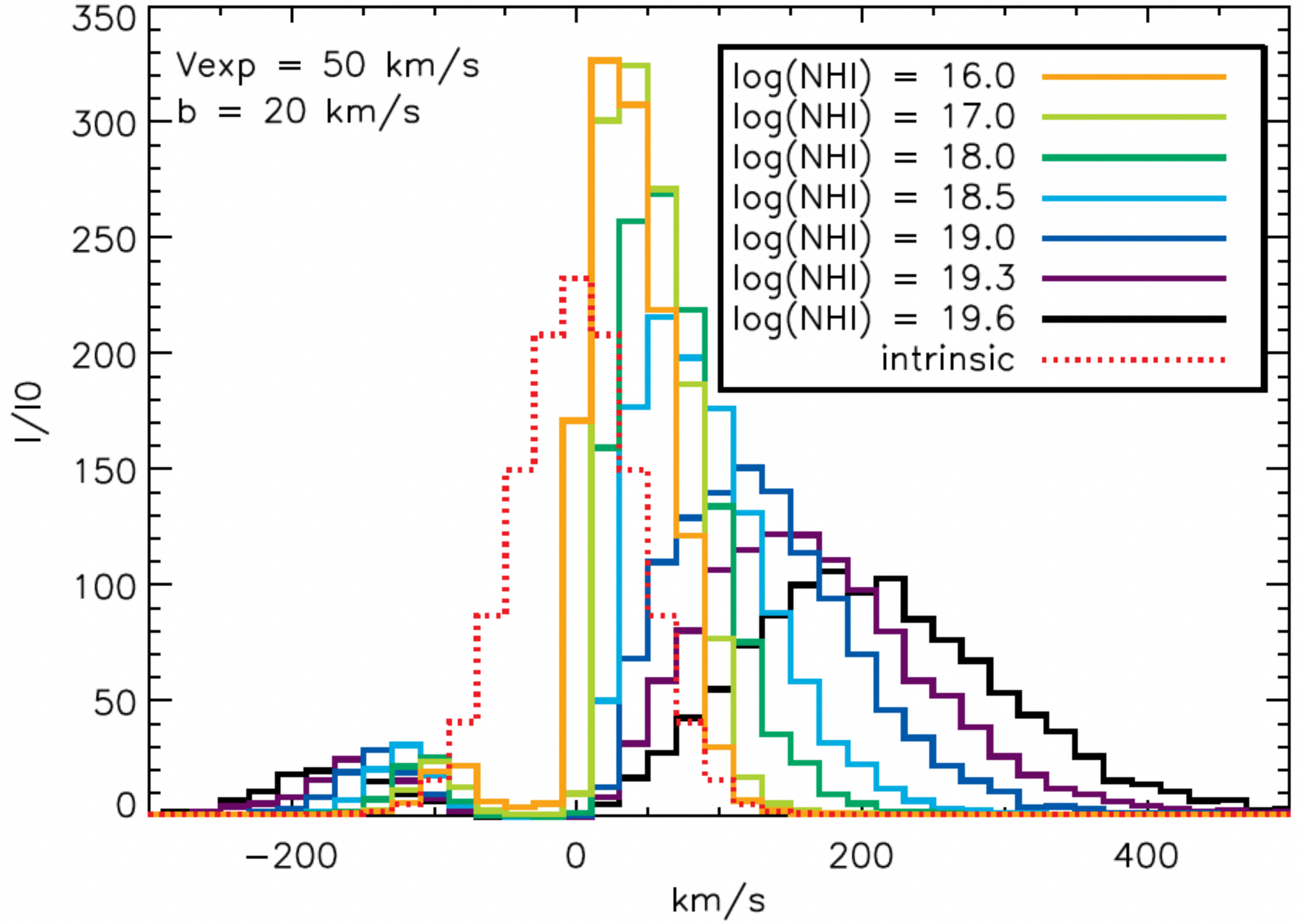
fesc(LyC) vs. LyA line properties

Leclercq et al. in prep.

Preliminary

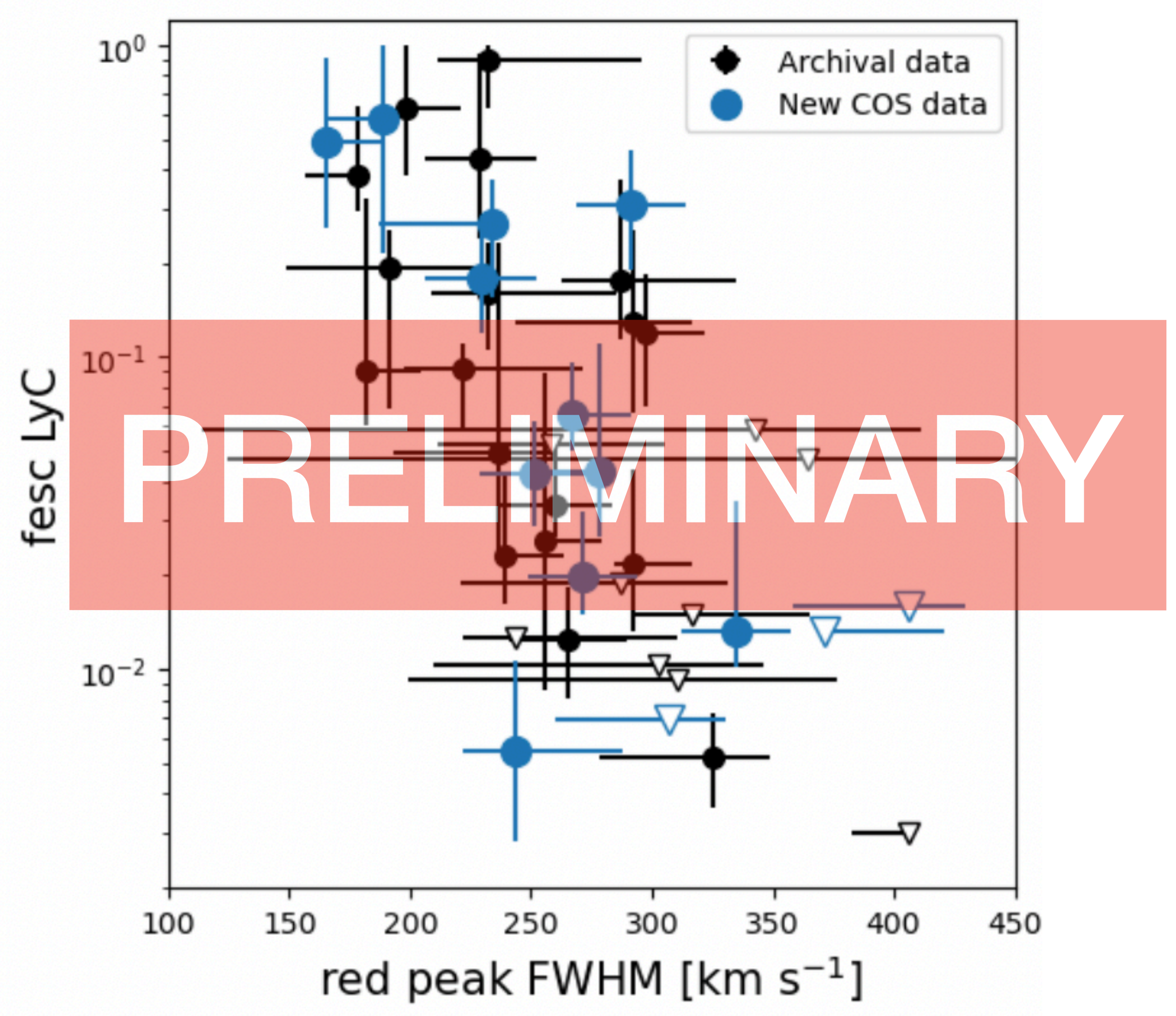


Broader LyA lines trace higher HI column densities



NEXT : comparison with models and simulations

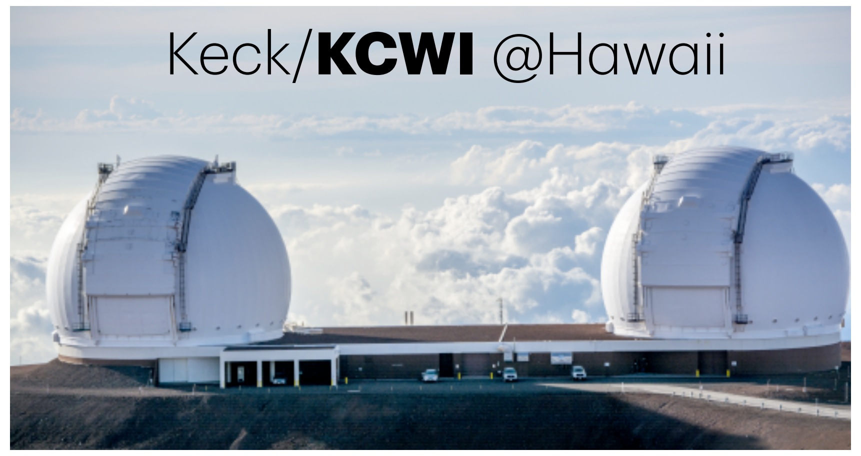
More at the **GE-circle** tomorrow



Verhamme et al. 2015

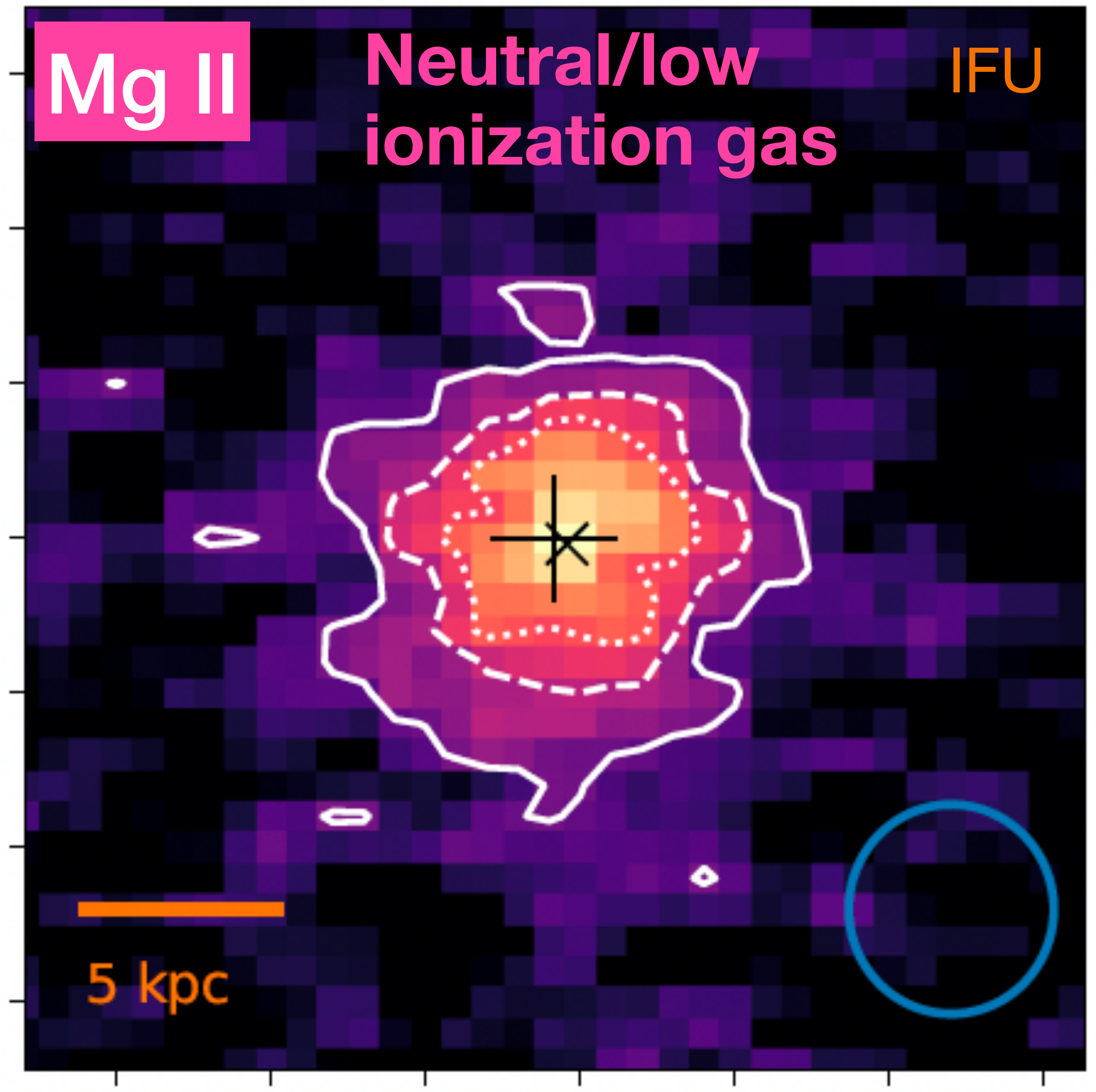
Connecting LyC escape & gas distribution

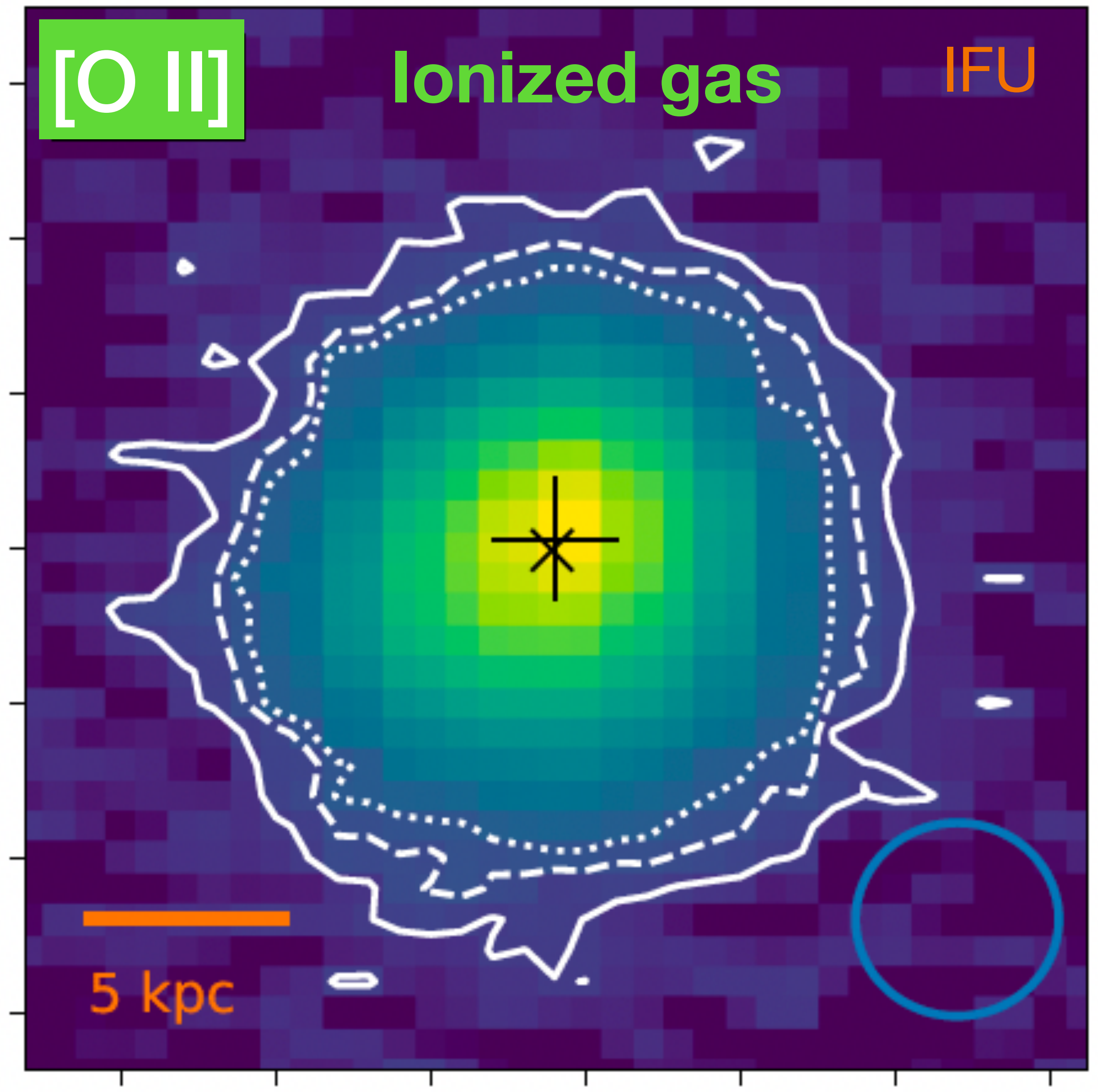
- **IFU** observations of **22** galaxies from the **LzLCS** and Izotov+22



★ **HOW DOES THE GAS DISTRIBUTION IMPACT THE ESCAPE OF IONIZING PHOTONS ?**

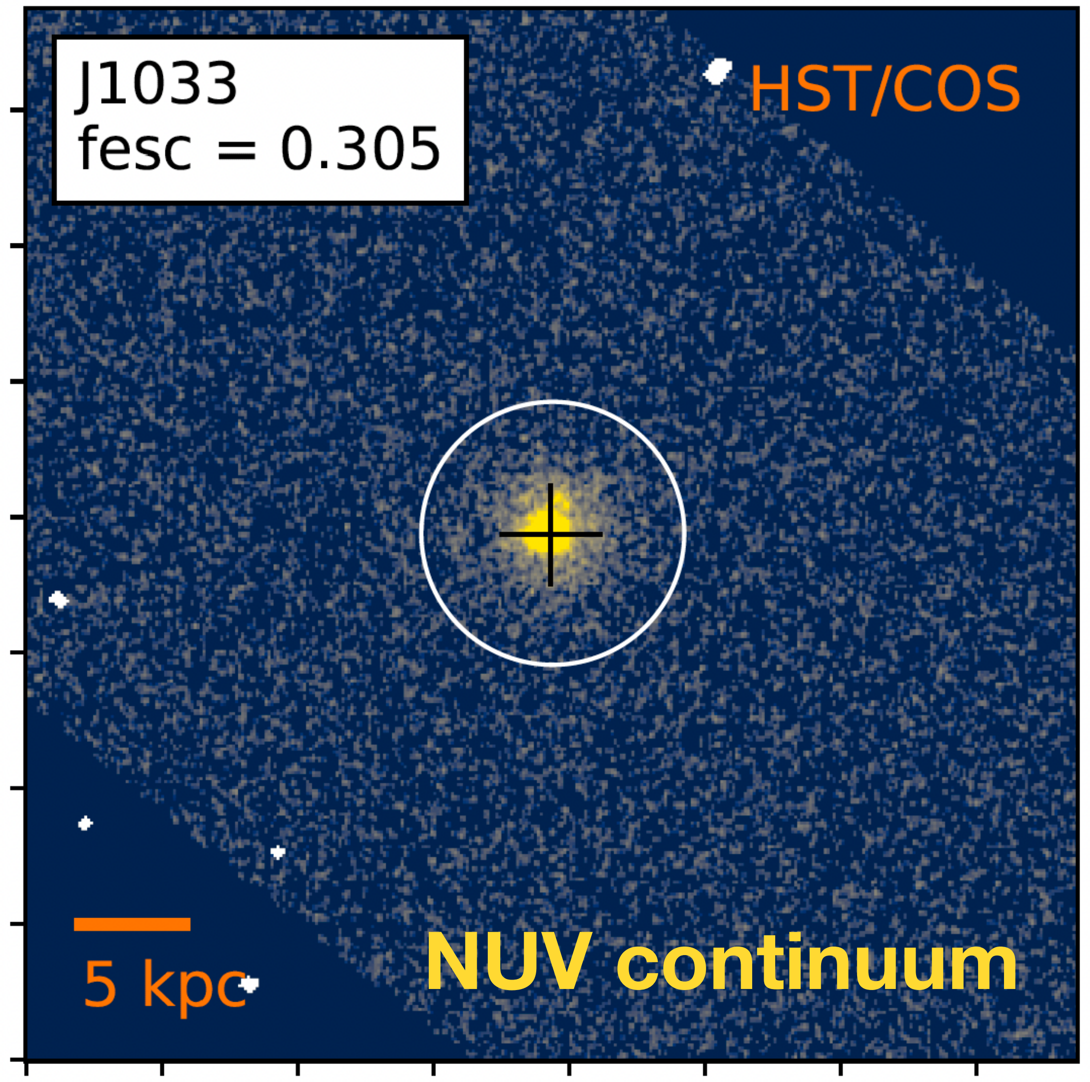
Leclercq et al. 2024





$rs_{\text{Mg II}}$ $\Delta_{\text{Mg II-cont}}$ $rs_{\text{[O II]}}$ $\Delta_{\text{[O II]-cont}}$

Flury et al. 2022a, Saldana-Lopez et al. 2022

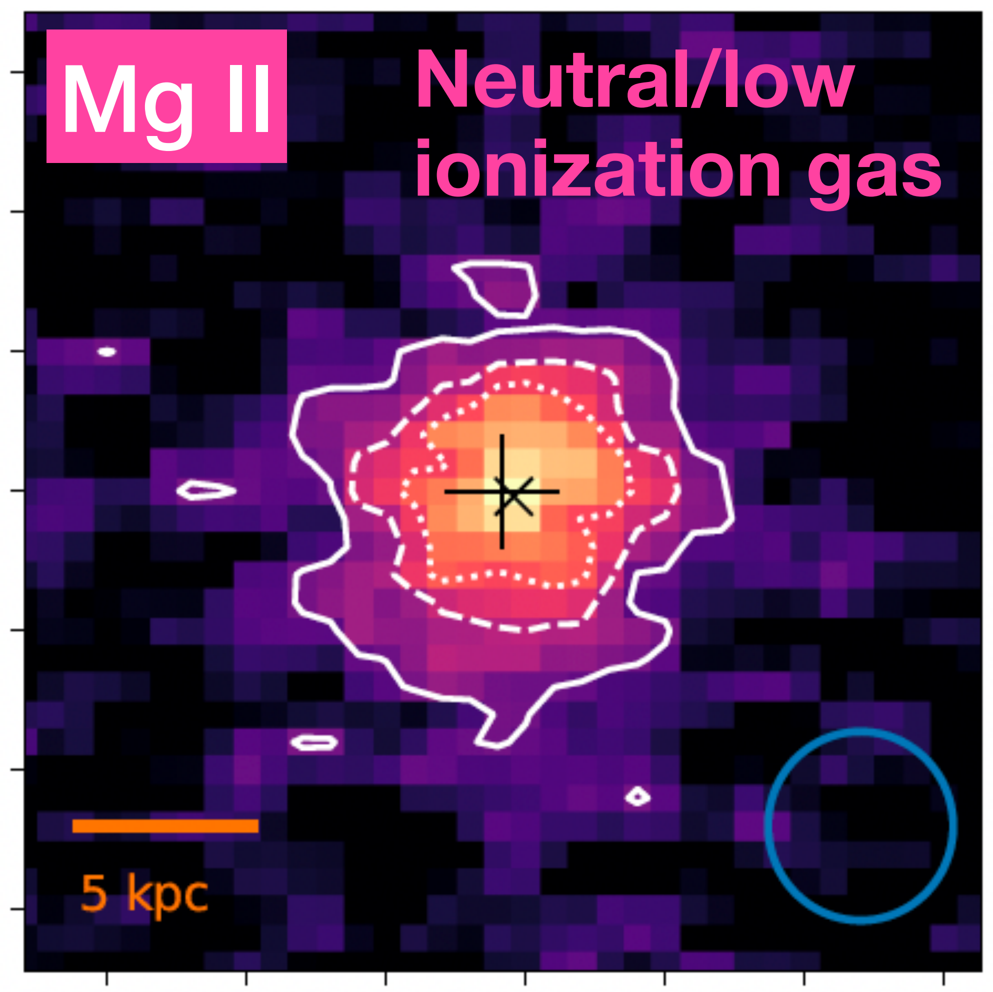


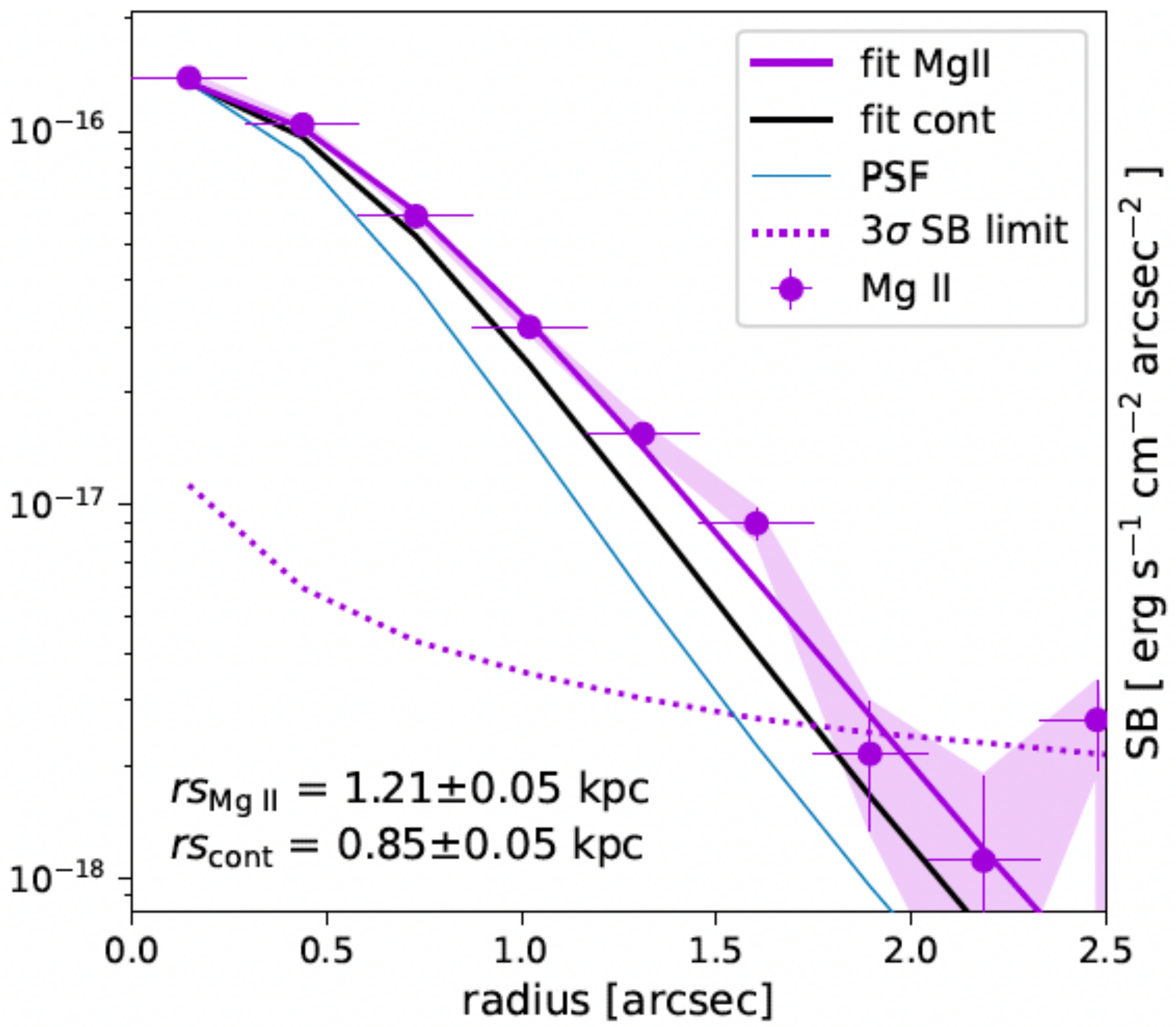
$f_{\text{esc}}^{\text{LyC}}$(UV) EW(H$\beta$) $12+\log_{10}(\frac{\text{O}}{\text{H}})$ SFR $\beta_{\text{obs}}^{1550}$

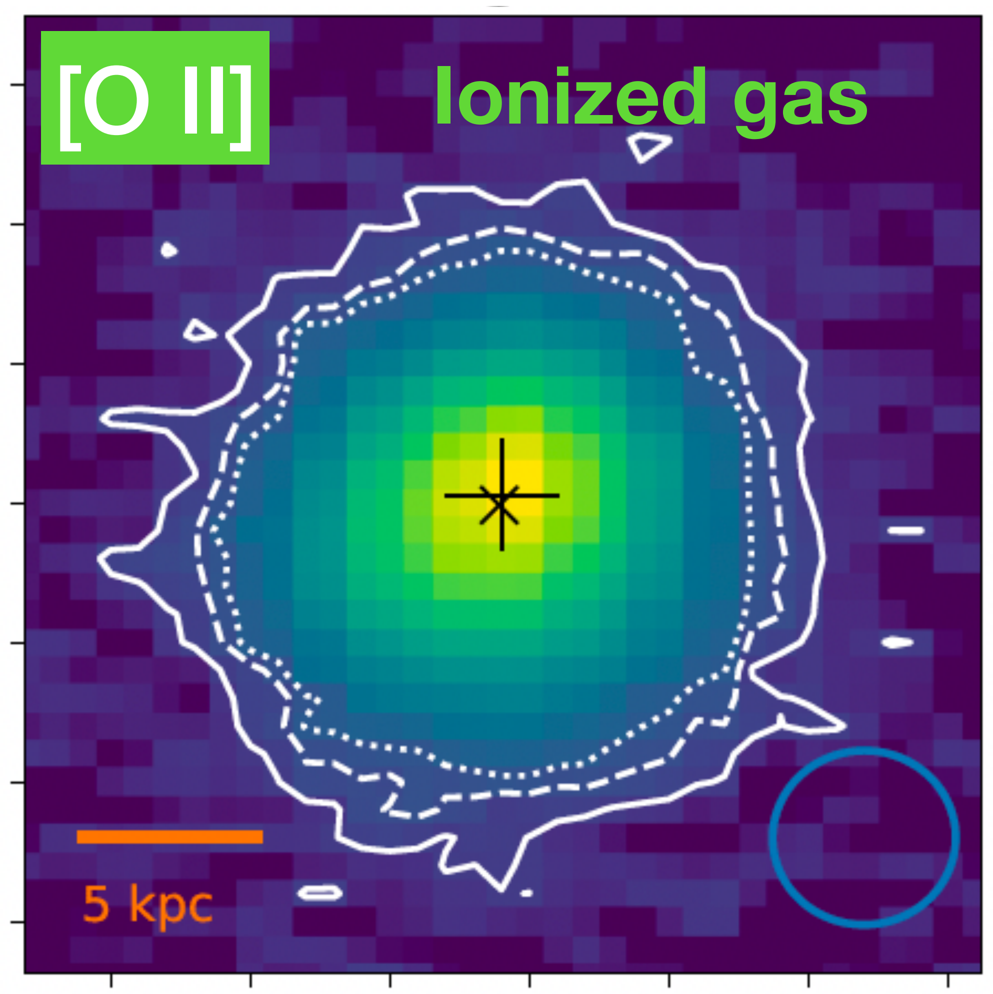
r_{50}^{UV} O_{32} $E(\text{B}-\text{V})$ M_*

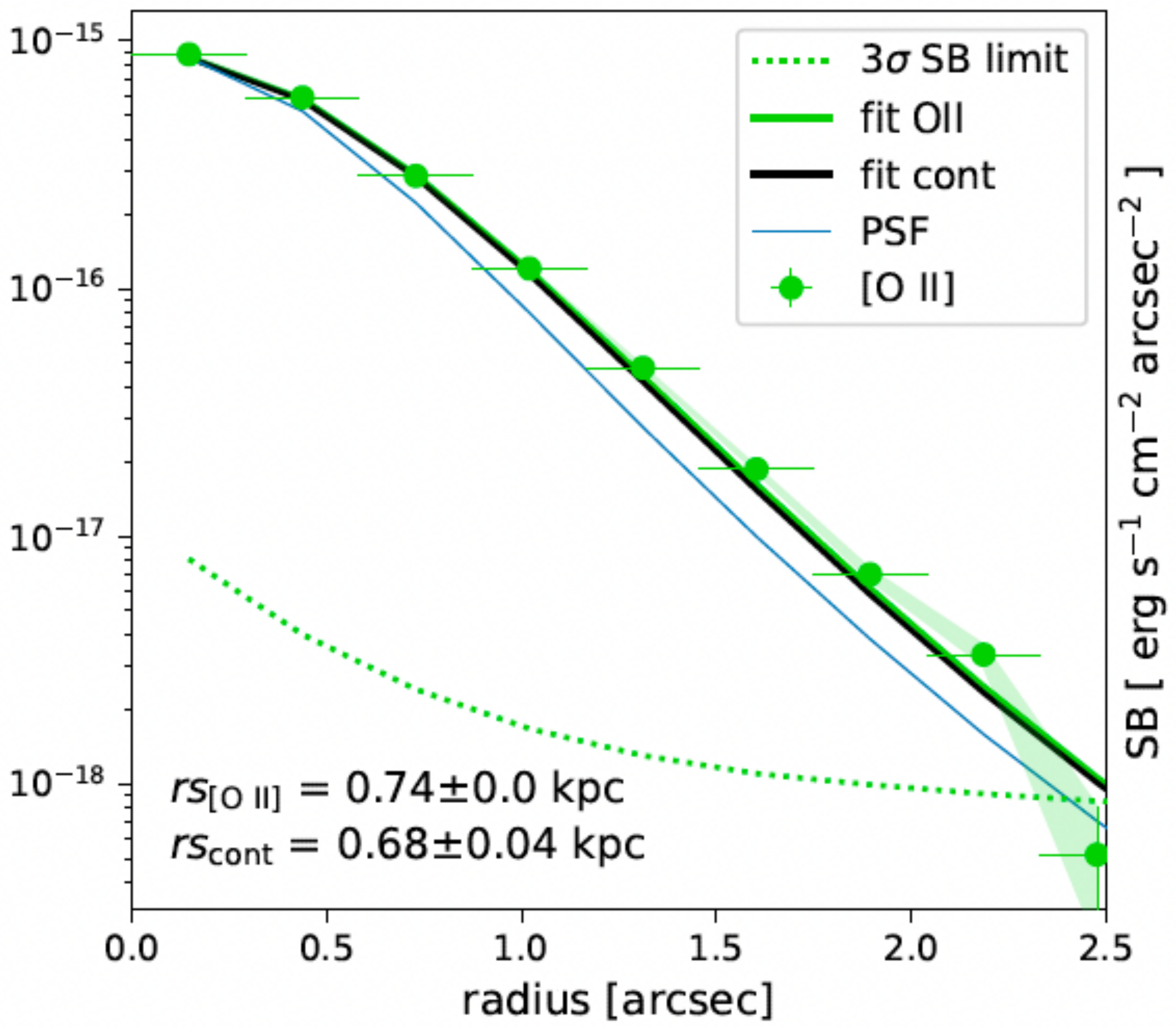
Spatial extent of the nebular emission

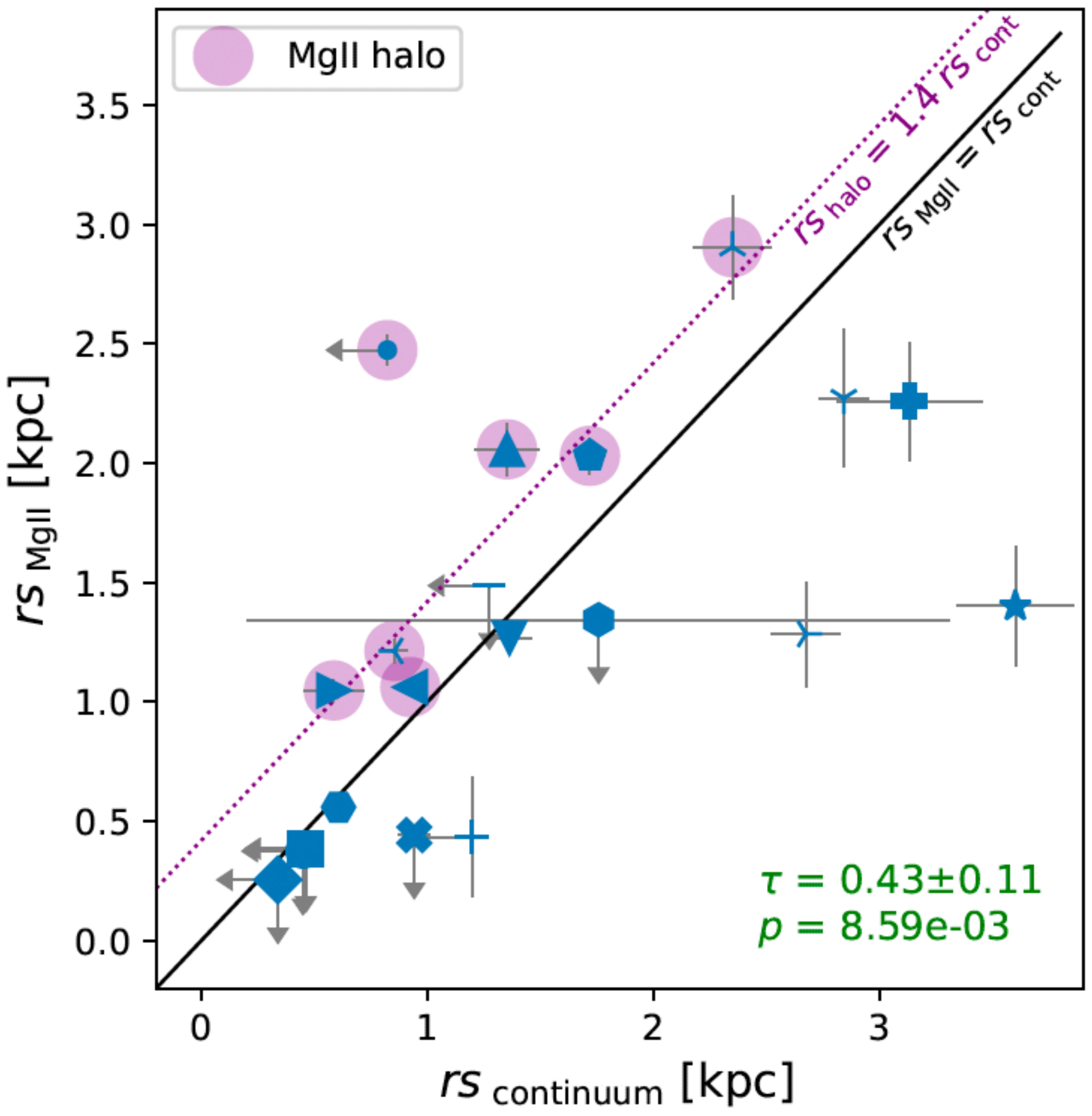
Leclercq et al. 2024











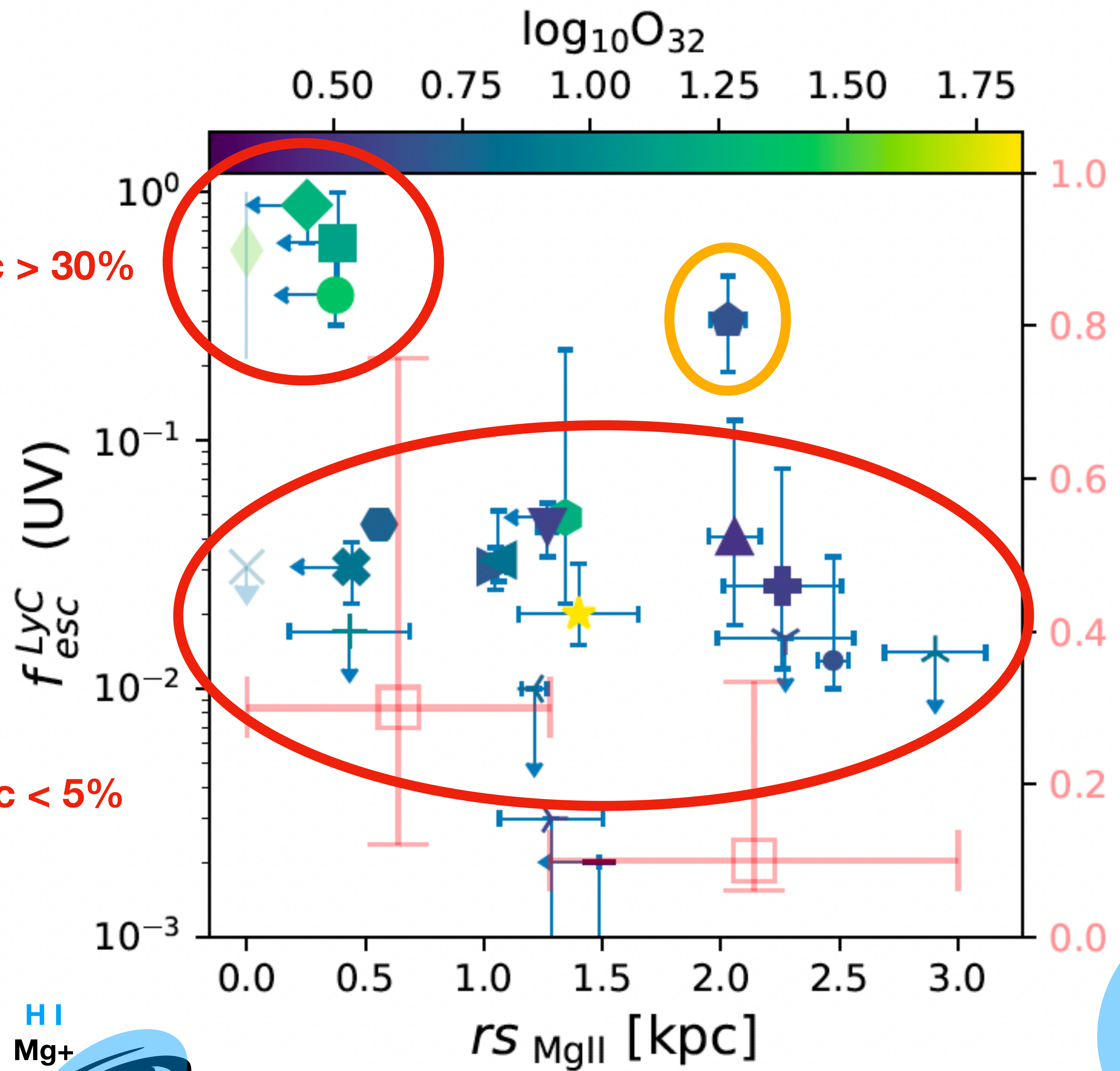
- ➜ 7 Mg II halos
- ➜ 10 [O II] halos

Nebular emission ~1.5 more extended than continuum

Now let's connect the gas distribution to the LyC escape

Leclercq et al. 2024

fesc > 30%



fesc < 5%

➜ Strong leakers are compact in both MgII and [O II], *except J1033*

➜ Weak/non leakers are diverse

➜ Compact + strong O32 ratios indicate strong LyC leakage

Gas distribution vs. LyC escape in stacks

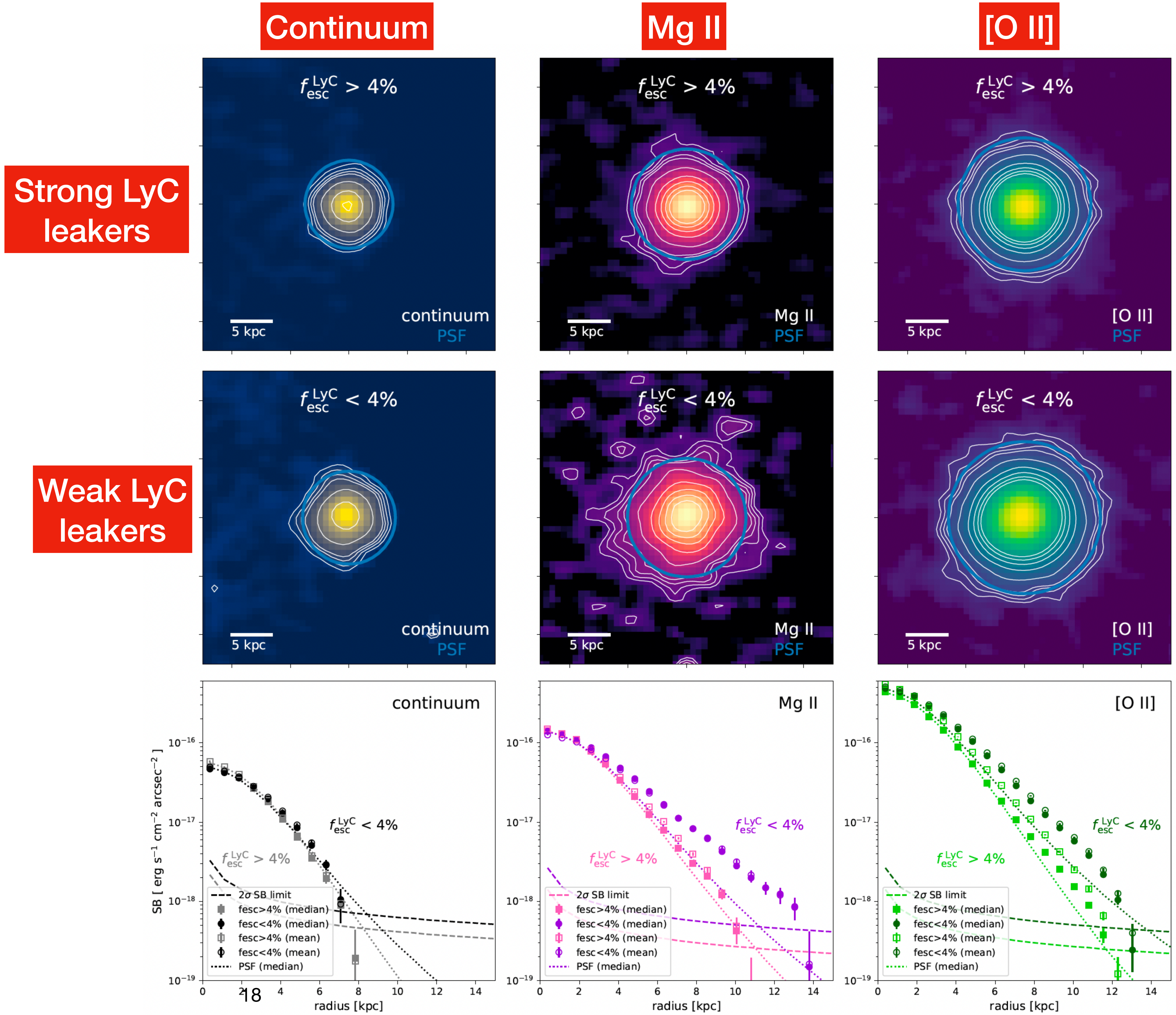
Leclercq et al. 2024

STACKING EXPERIMENTS

KCWI data only (seeing ~ 1”)

5 objects in each sub-samples
—> x 2.5 gain in SB limit (1e-18 cgs)

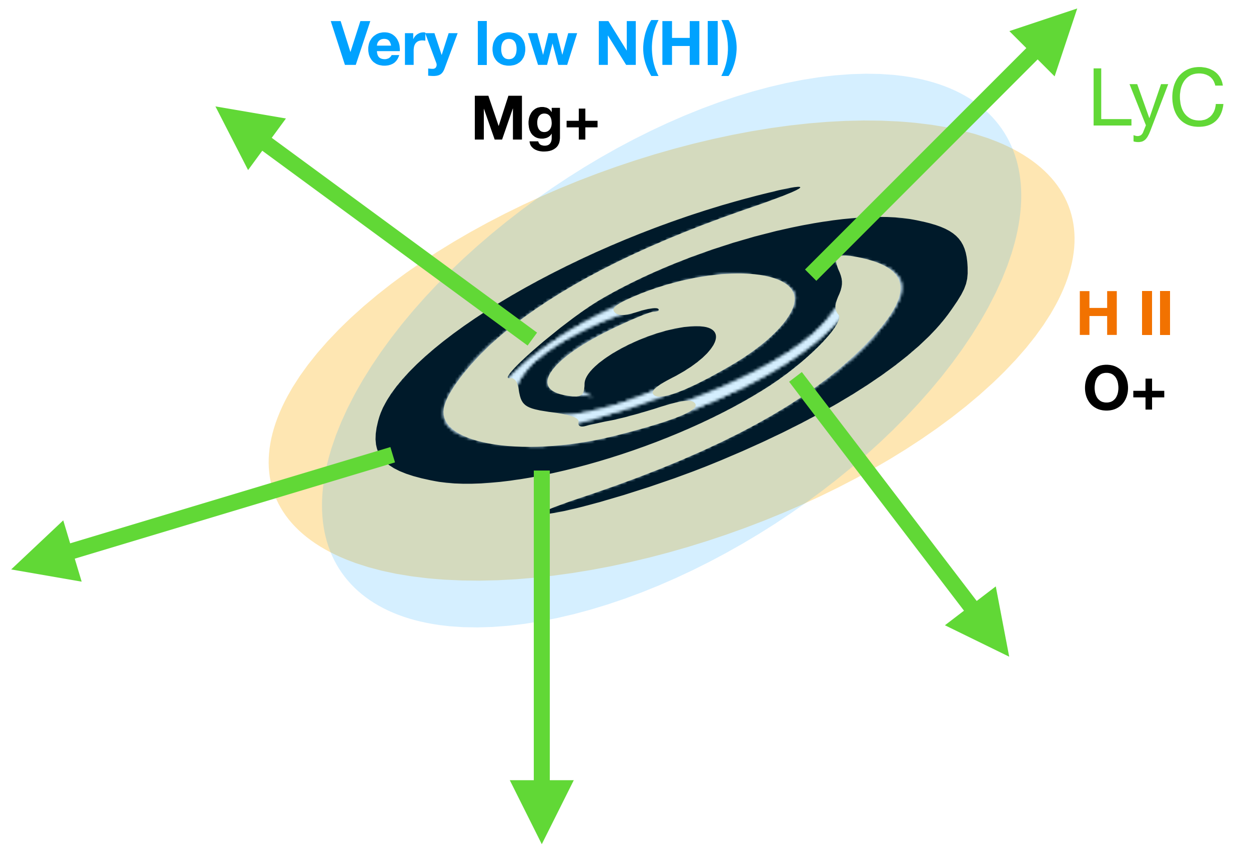
➜ **Strong and weak LyC emitters have different nebular configurations**



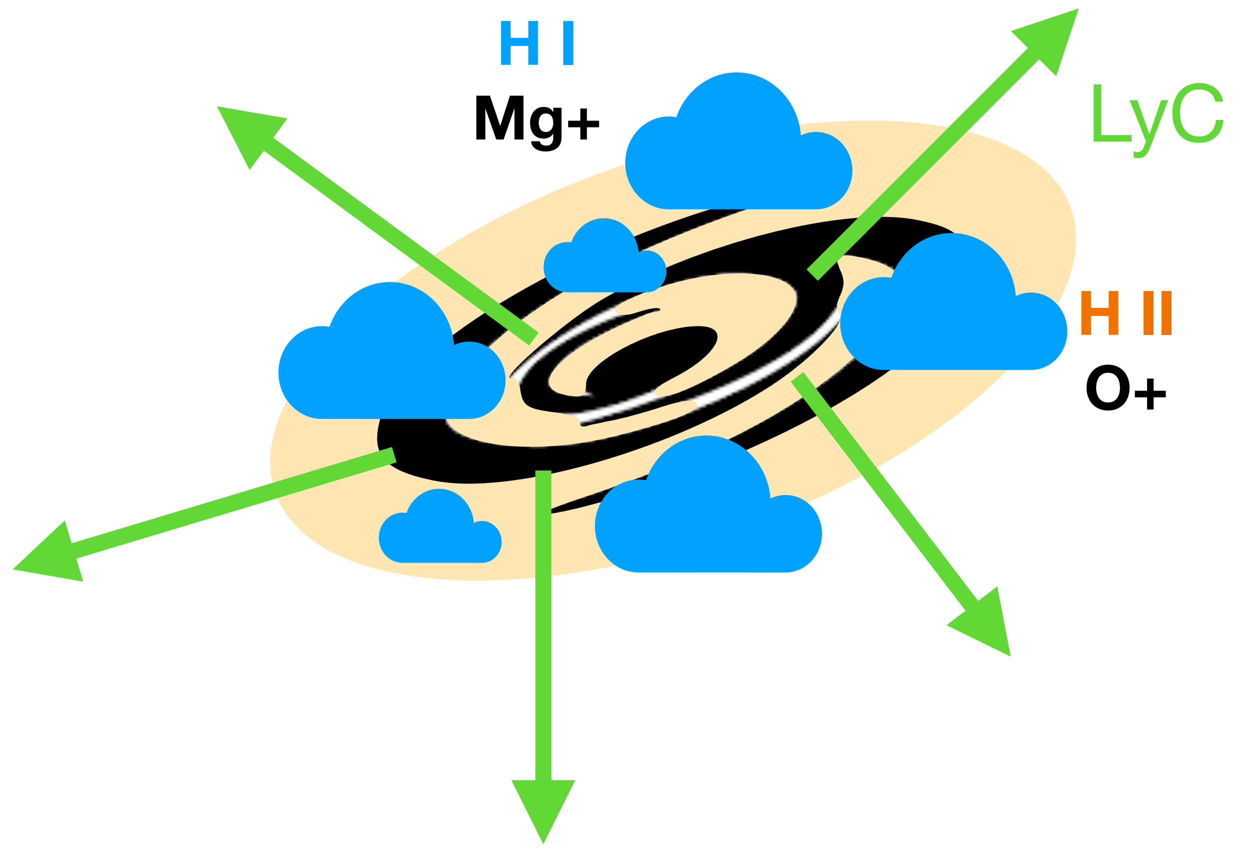
Different mechanisms for LyC escape

Leclercq et al. 2024

Highly ionized galaxies

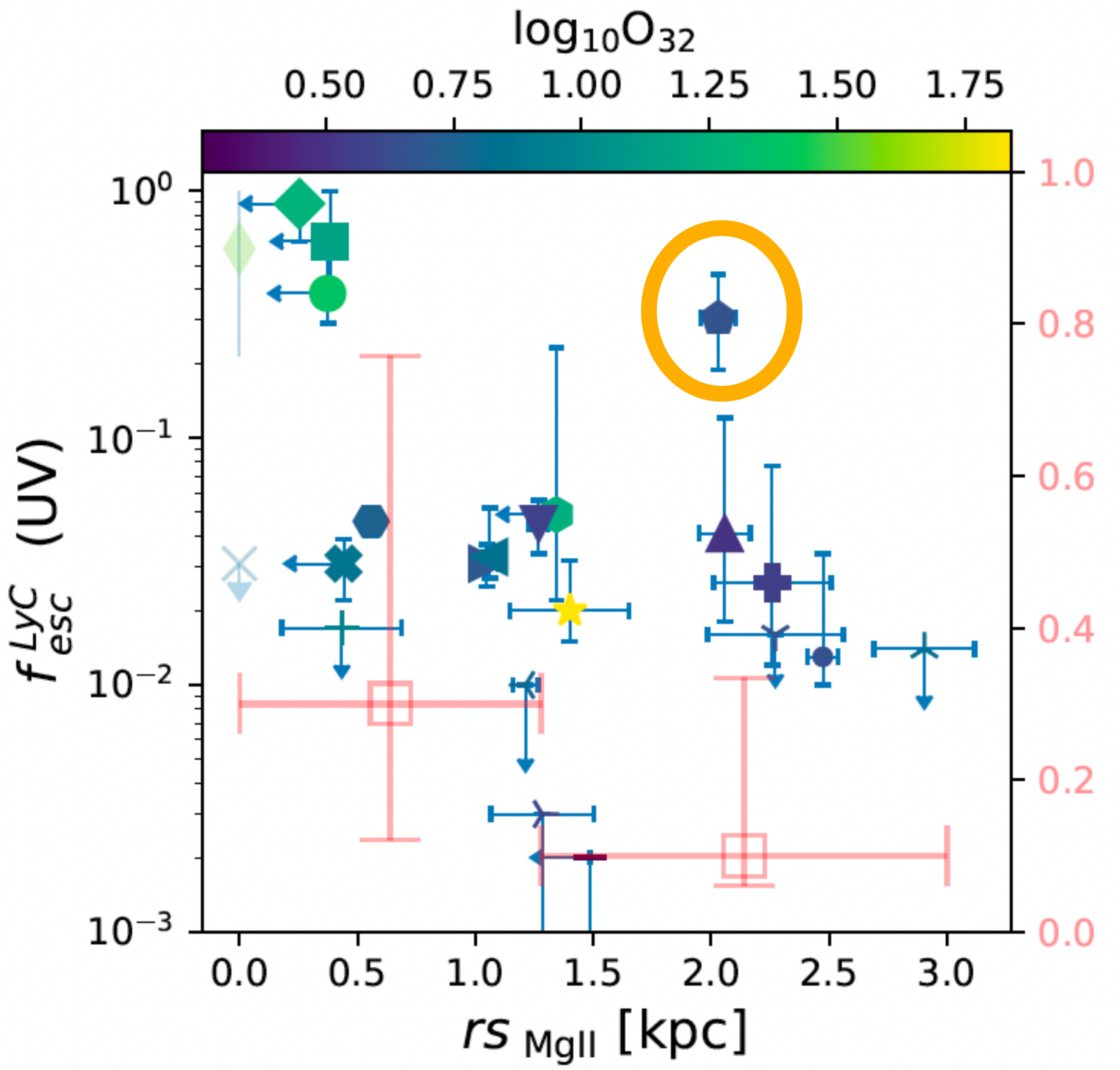


widespread ionization



numerous porous lines of sights

Low ionized galaxies



Stellar populations ionizing most of the neutral gas in the ISM/CGM

and/or

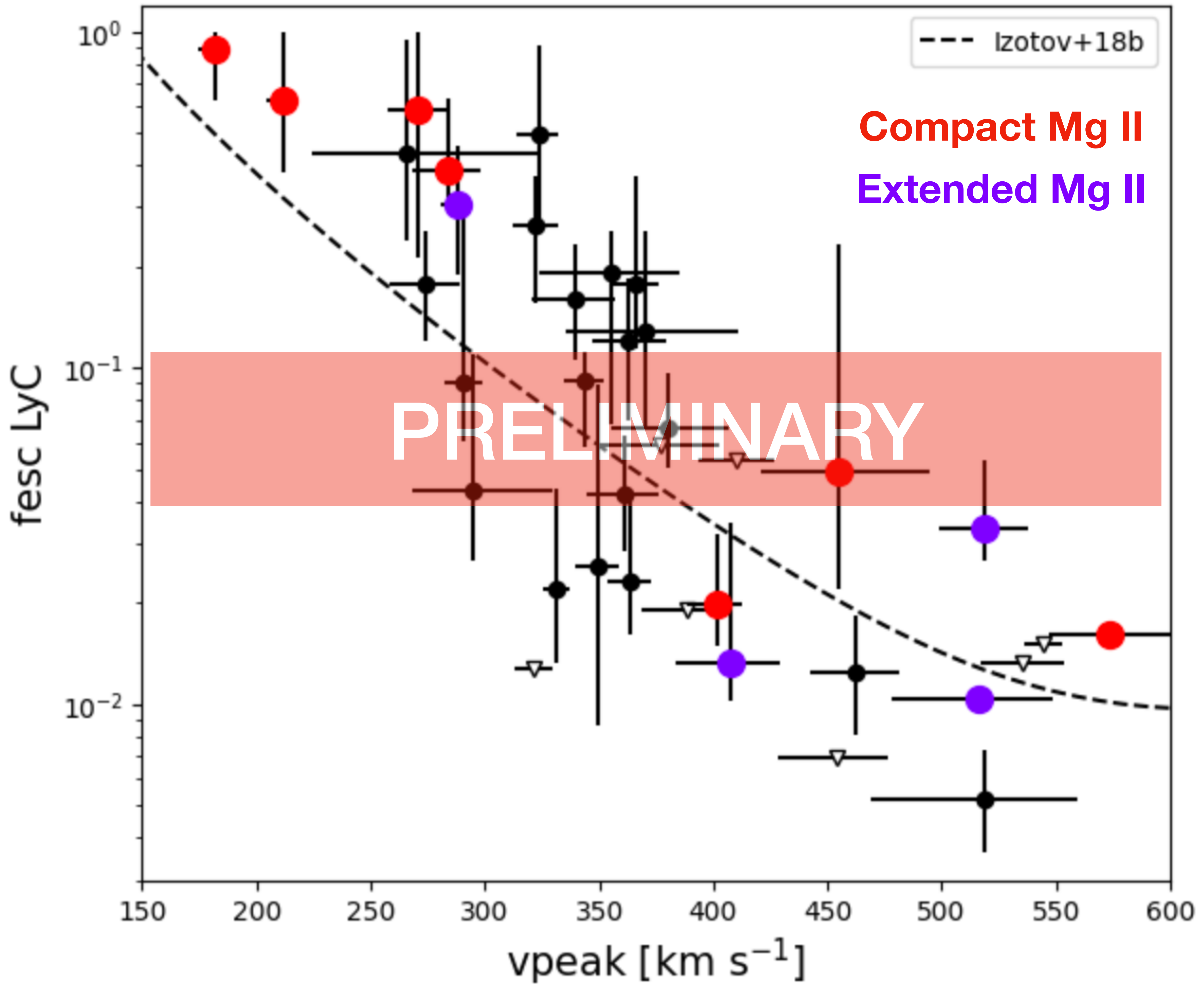
Powerful outflows and feedback effects clearing the galaxy surroundings Amorín et al. (2024)

➜ Effects even more important at high redshift Endsley et al. 2021; Rinaldi et al. 2023; Cameron et al. 2023

Nebular spatial compactness + high ionization = indicators of LyC escape in high-redshift galaxies

HI extent vs. LyA peak separation

COS LyA spectra for **11 LzLCS galaxies** with individual IFU Mg II measurements



Extended Mg II ➜ large Vpeak > 400 km/s

Compact MgII ➜ smaller Vpeak < 300 km/s

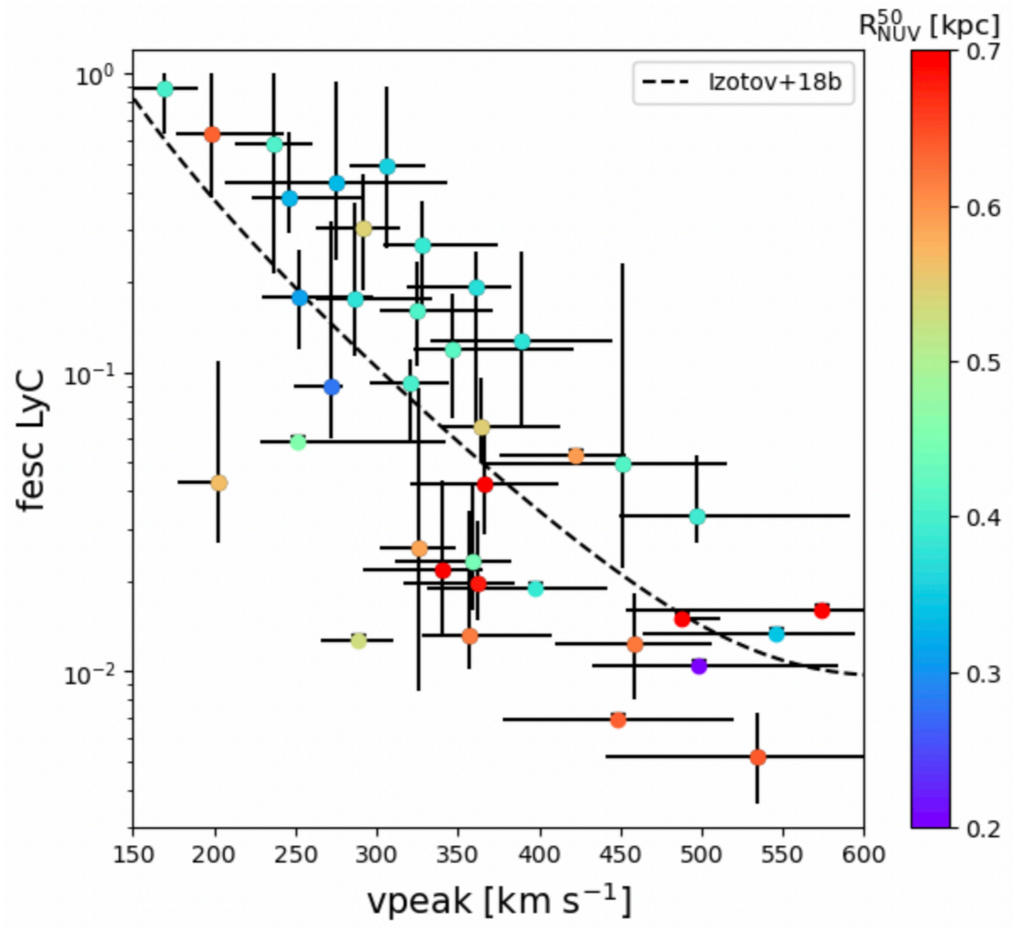
BUT not true for all objects = **diverse HI configurations / mechanisms for LyC escape …**

See discussion in Leclercq et al. 2024

Summary

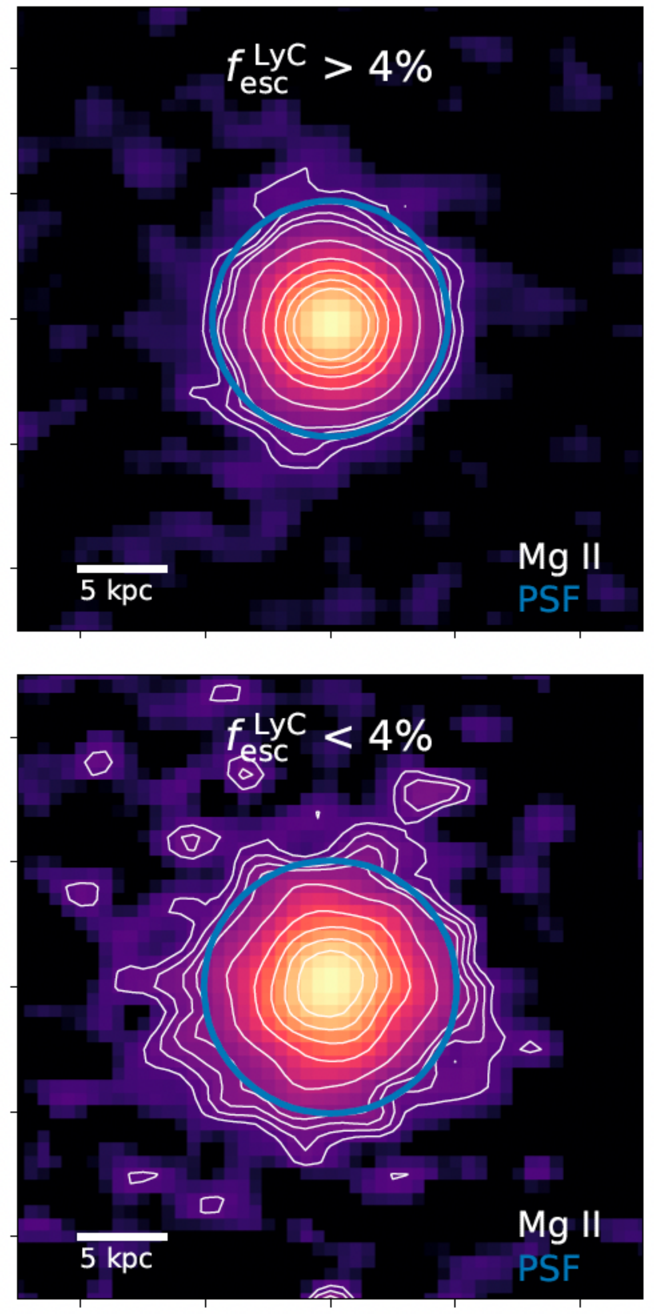
Lyα as a LyC indirect indicator ? — Leclercq+ in prep.

- Statistical sample of **42** LyC leakers with both LyC and high resolution LyA
- The fesc(LyC) and Lyman alpha peak separation correlation holds but with scatter
- **The scatter in the vpeak - fesc(LyC) relation is driven by UV size and dust**



- The blue peak velocity correlates more strongly with fesc(LyC) than vpeak…
- We find a correlation between fesc(LyC) and the red peak FWHM with large scatter but can be used at EoR

MgII & [O II] gas distribution of LyC leakers — Leclercq et al. 2024



- IFU observations of 22 LzLCS galaxies at z~0.3 to understand how LyC photons escape galaxies
- **Strong leakers are compact in Mg II and [O II]** while weaker are surrounded by extended nebula
- But individual measurements reveal **diversity** in HI configurations

— — — — — — — — — — — — — — — -

- Galaxies surrounded by a MgII halo have large LyA vsep but diversity !
- Comparison MgII / LyA ongoing
- Need models+simulations to compare diagnostics

Thank you