Searching for the sources of Reionisation

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LCEs: Daniel Schaerer, Matthew Hayes, Anne Jaskot, Sophia Flury, and LzLCS collaboration, Yuri Izotov, Gabor Worseck
MUSE: Charlotte Simmonds, Josephine Kerutt, Eloise Vitte, Ivan Kramarenko, and the GTO consortium

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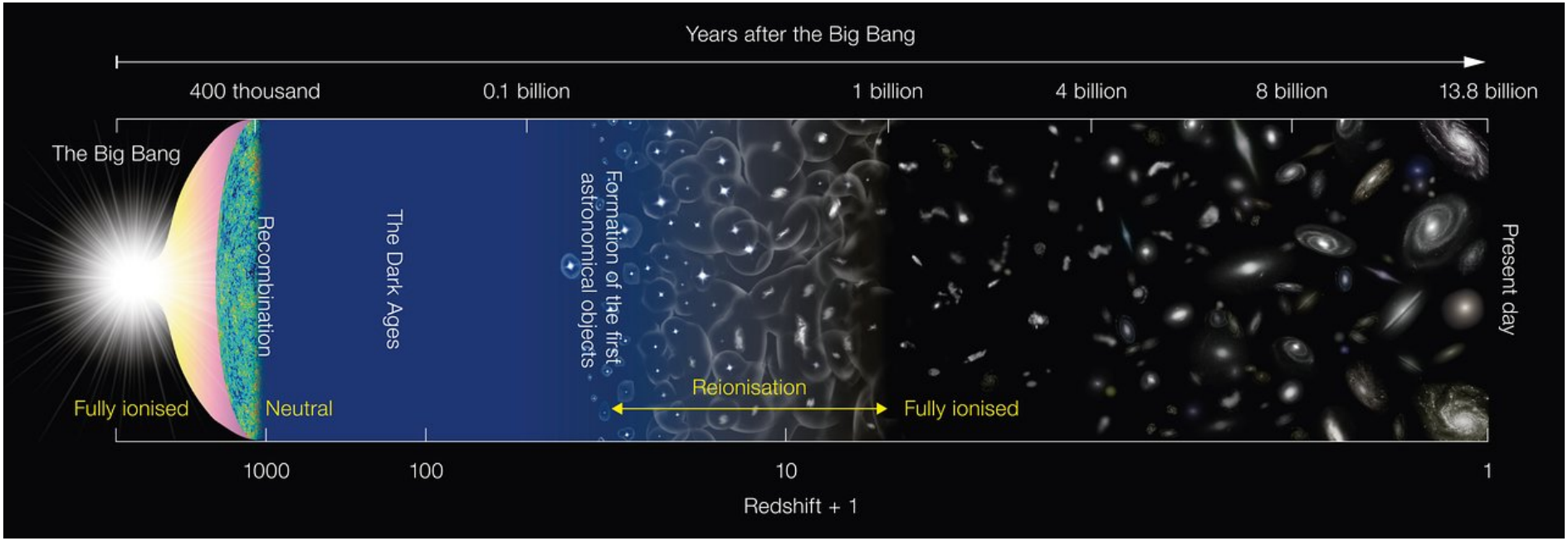
What is Cosmic Reionization ? Why is it important ?



* major phase transition in the history of the Universe
* strong impact on galaxy formation and evolution
* main unknown : the nature of the sources of Reionization

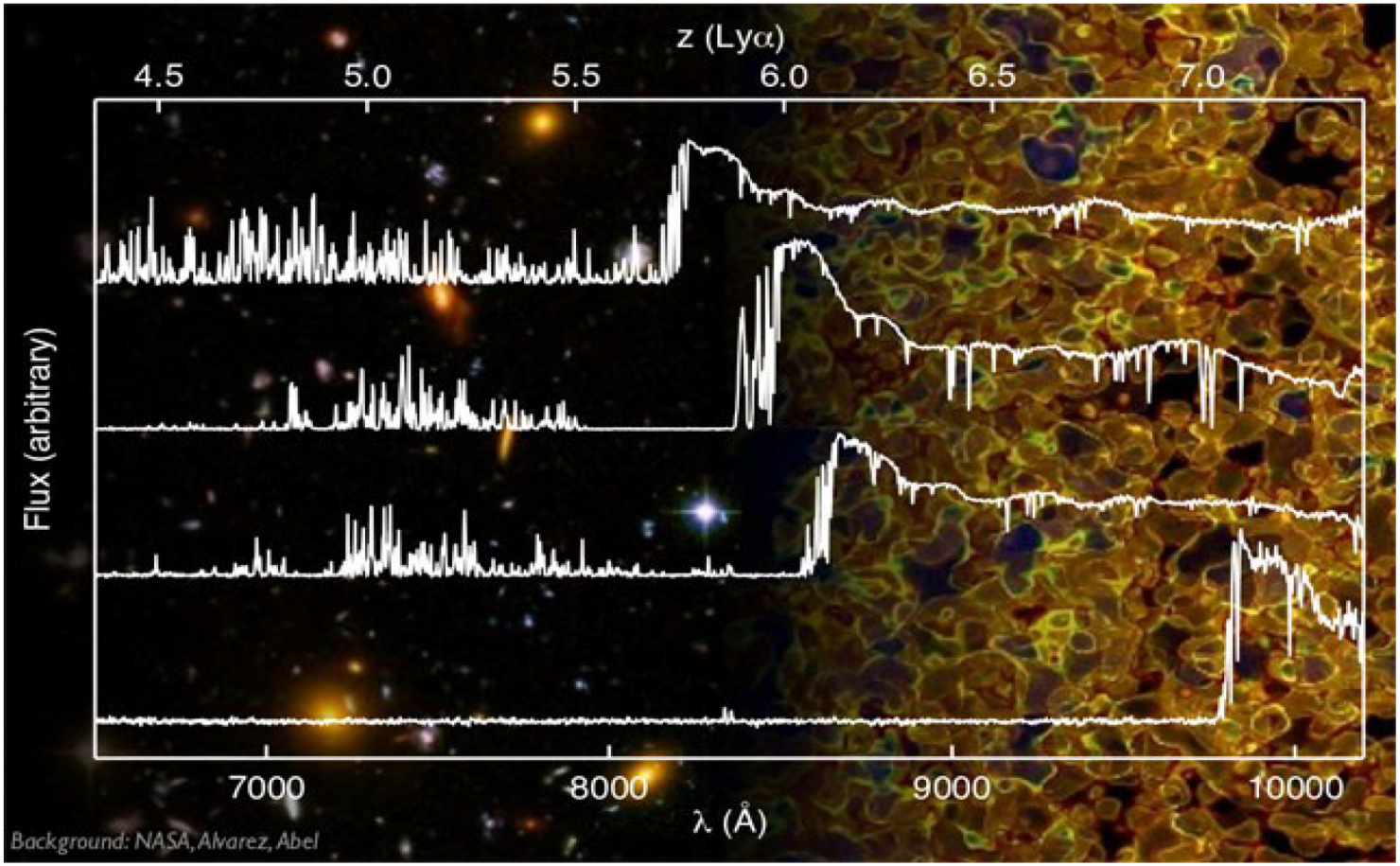
Observing the sources of cosmic Reionization in LyC ?

z ~ 5.7

z ~ 5.9

z ~ 6.1

z ~ 7.1

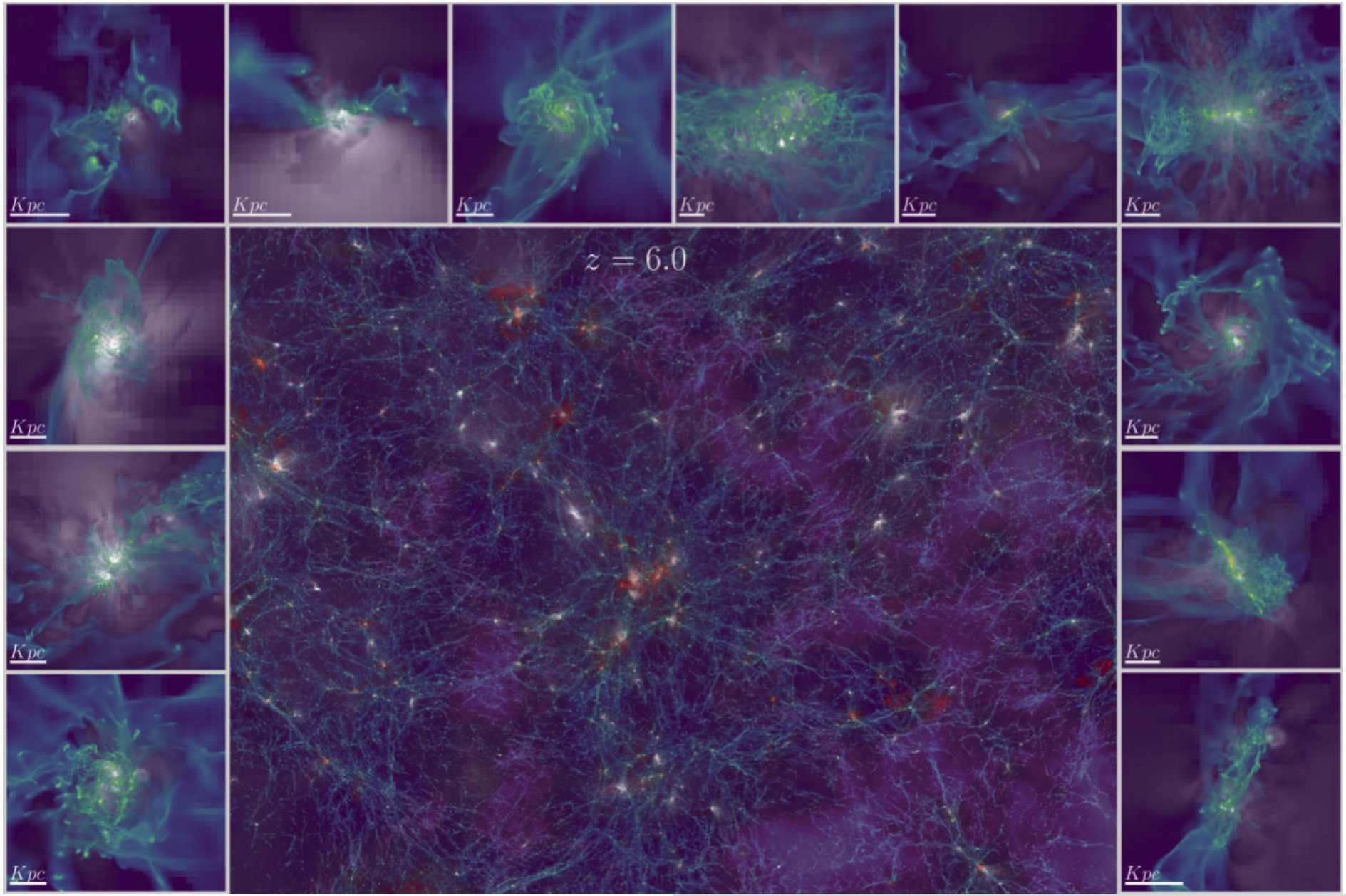


* Intergalactic medium (IGM) opacity increases with redshift
* direct detection of LyC impossible from galaxies at $z > 6$

$\longrightarrow$ need for indirect diagnostics of LyC leakage from galaxies

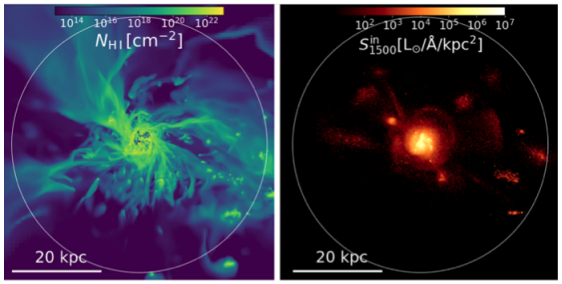
Simulate the sources of Cosmic Reionisation

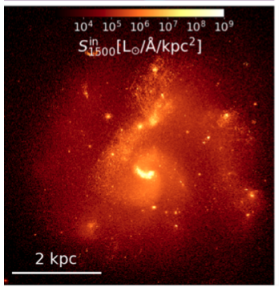
the SPHINX project : http ://sphinx.univ-lyon1.fr/, Rosdahl+18, Rosdahl+22

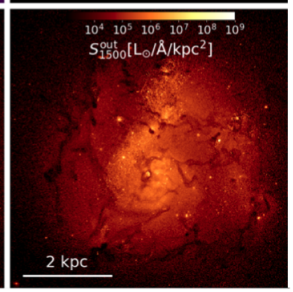


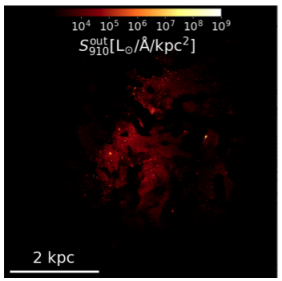
Mock observations from simulated galaxies : RASCAS

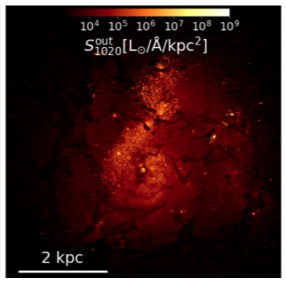
RASCAS : http ://rascas.univ-lyon1.fr, *Michel-Dansac+21*

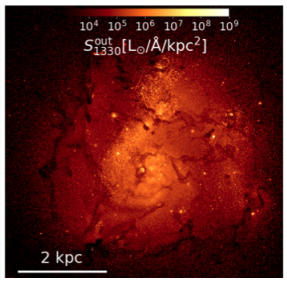


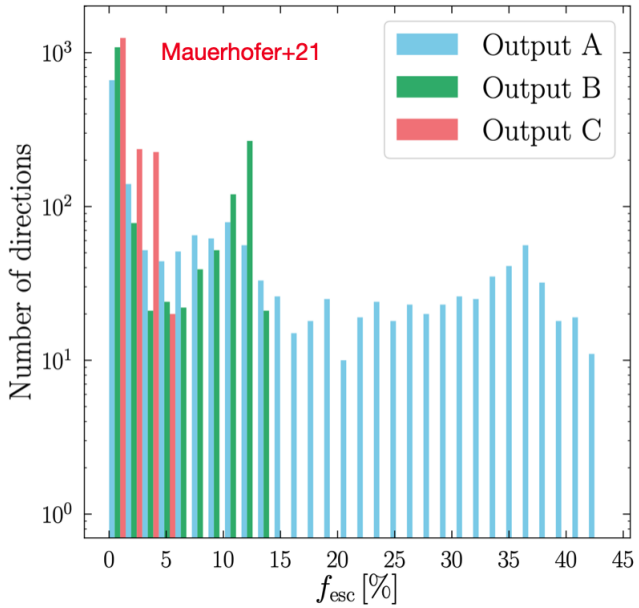


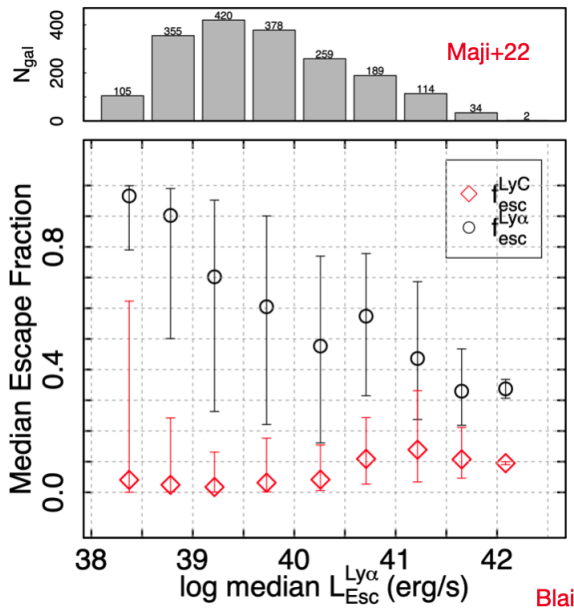


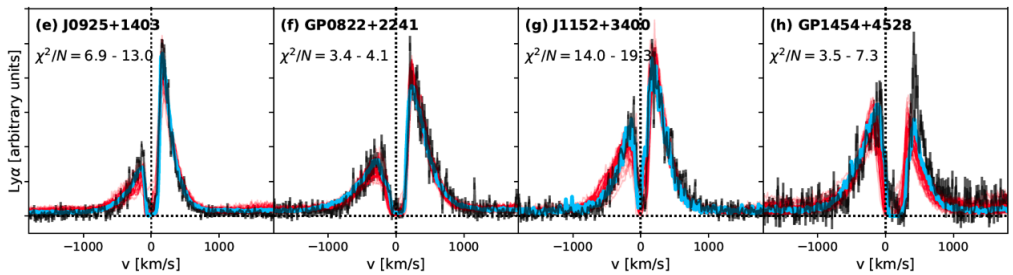












We can compute luminosities, escape fractions, spectra, images or datacubes for any wavelength of interest

$\Longrightarrow$ opens a new avenue to interpret sophisticated observations of distant galaxies and their CGM

Outline

LyC Probes On the use of resonant lines to probe LyC escape

* probing LyC escape with Lyα
* probing LyC escape with MgII
* probing LyC escape with UV lines

LyC Sources What are the sources of cosmic reionisation ?

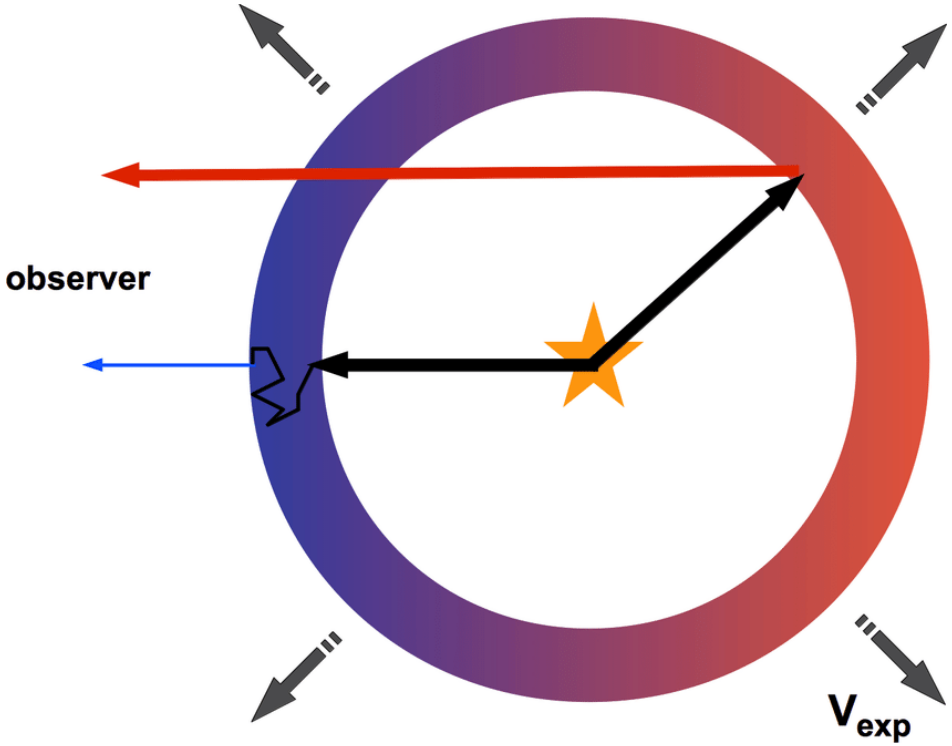
* stellar ionising radiation uncertainties
* another component : LyC nebular emission
* the need for exotic LyC sources ?

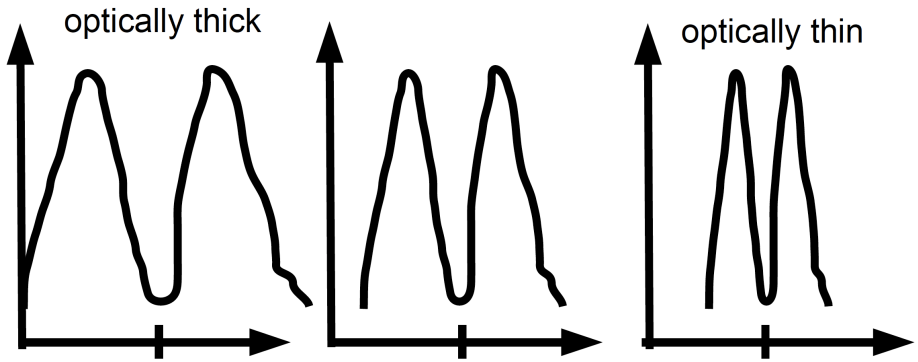
Opening Summary and next steps

* Direct observations
* indirect probes
* LyC sources

Lyα radiation transfer through expanding shells

(very) idealised models of outflows *Verhamme+06, Verhamme+08*





The Lyα peaks separation correlate with the amount of Hydrogen in the scattering medium

Lyα radiation transfer through expanding shells

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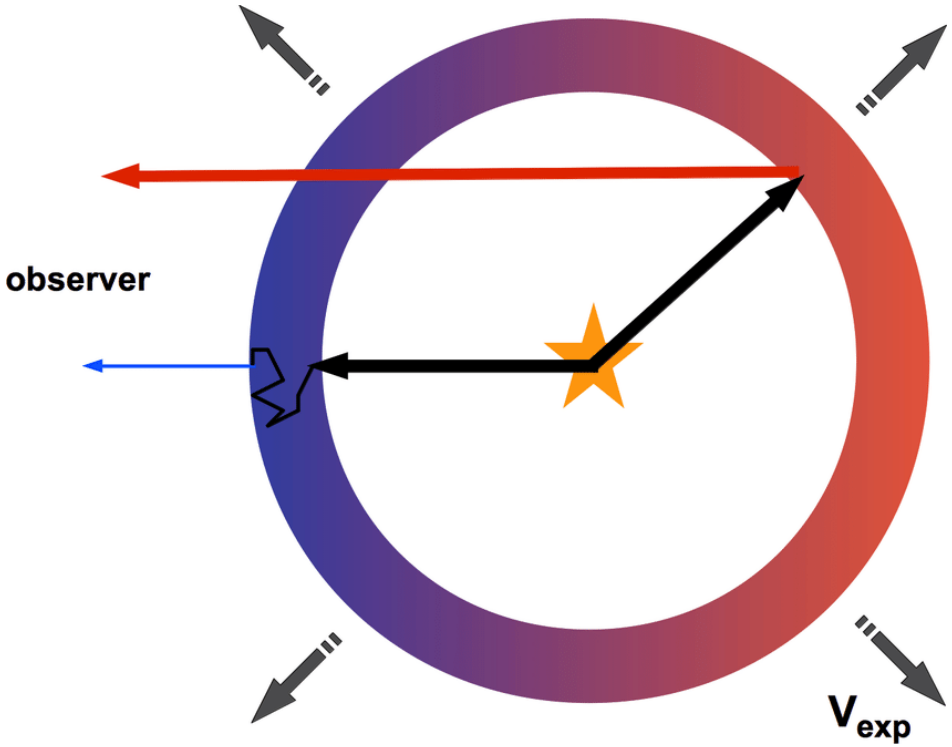
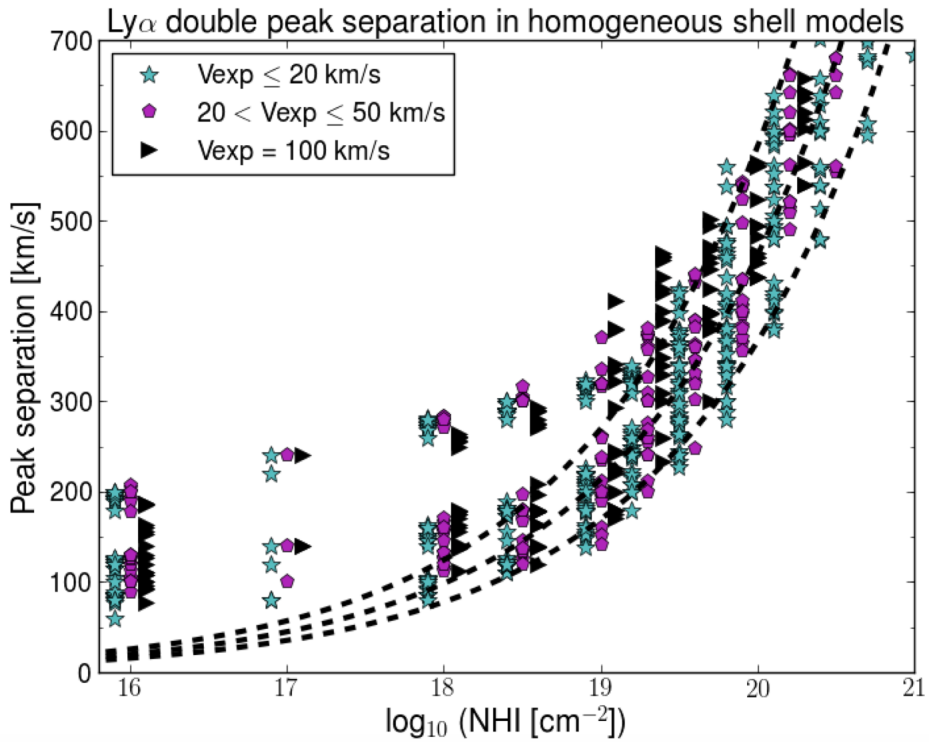


Verhamme+15

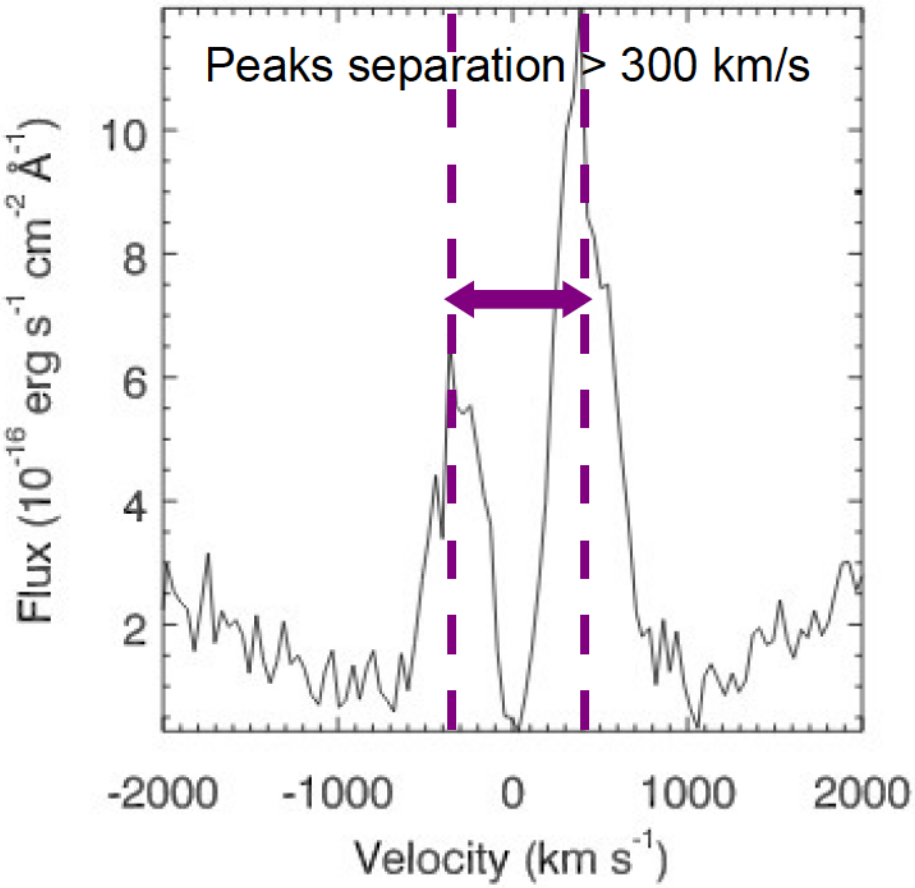


The Lyα peaks separation correlate with the amount of Hydrogen in the scattering medium

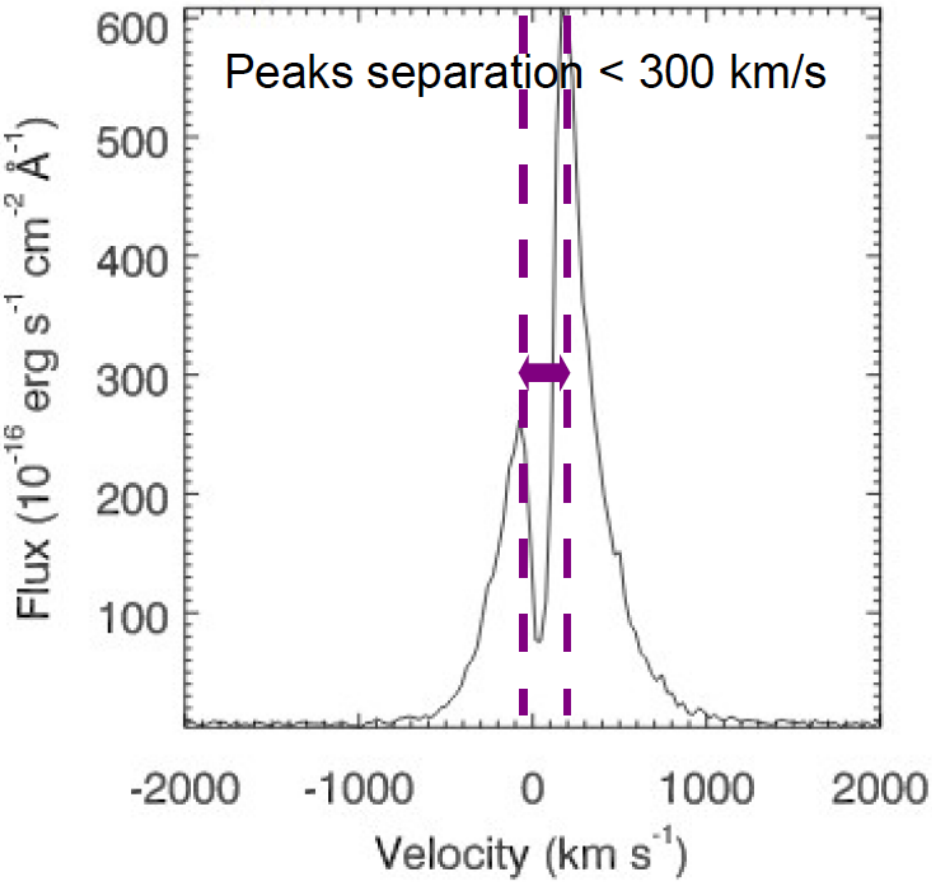
Lyα spectra of LyC Emitters

small Δ_V from optically thin H II regions, *Verhamme+15*

fesc(LyC) = 0

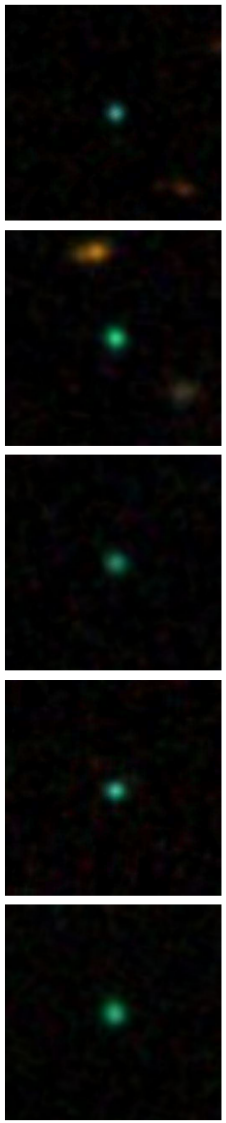


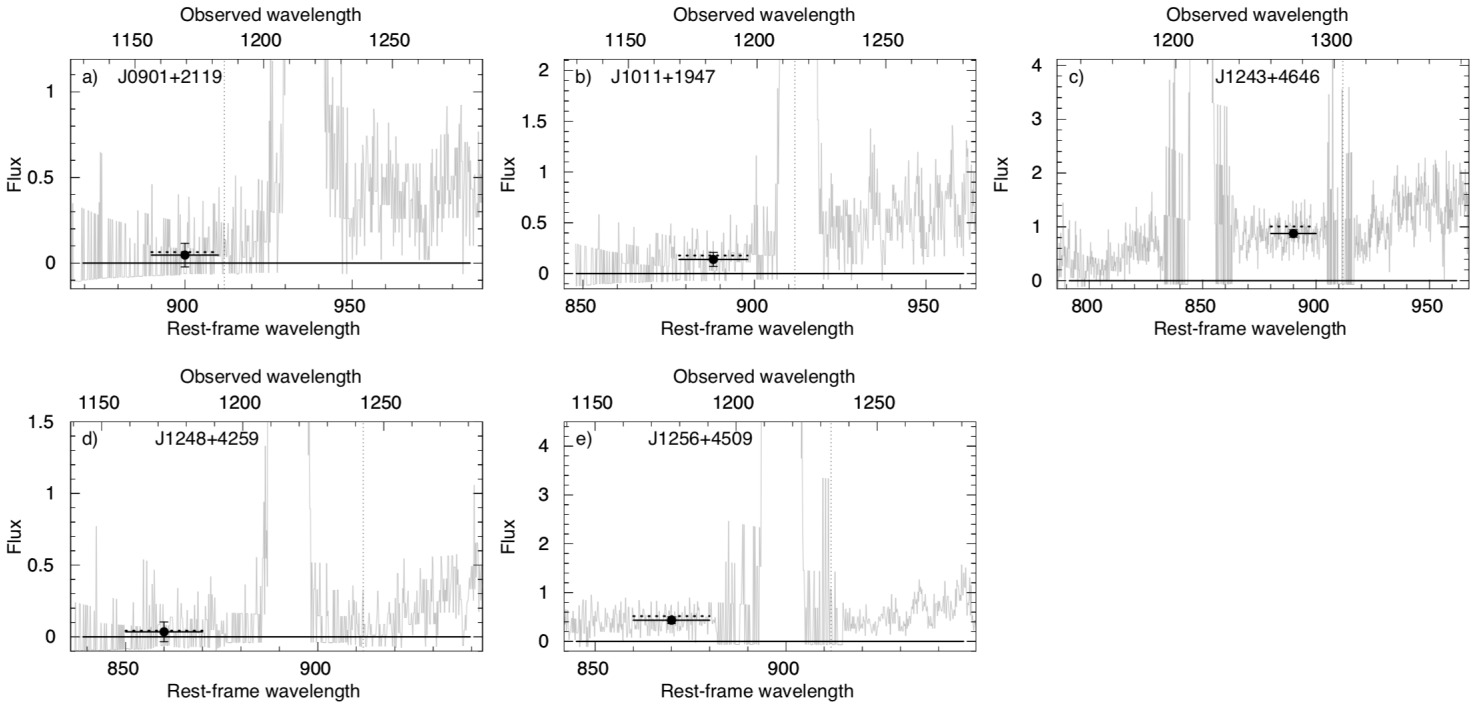
fesc(LyC) > 0



Green Pea galaxies : 15/20 LyC emitters

Izotov+16ab, Schaerer+16, Verhamme+17, Chisholm+17, Izotov+18ab, Izotov+21



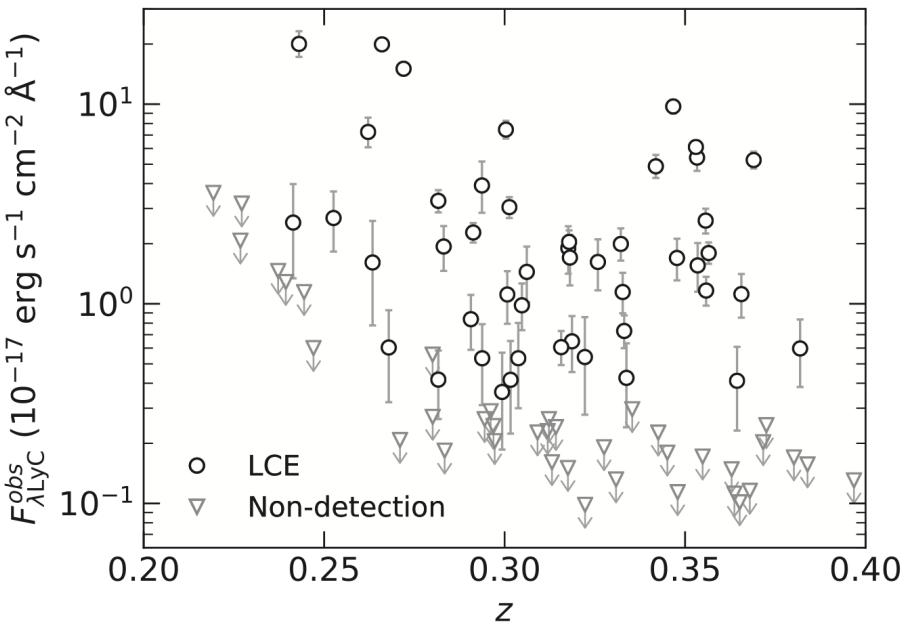


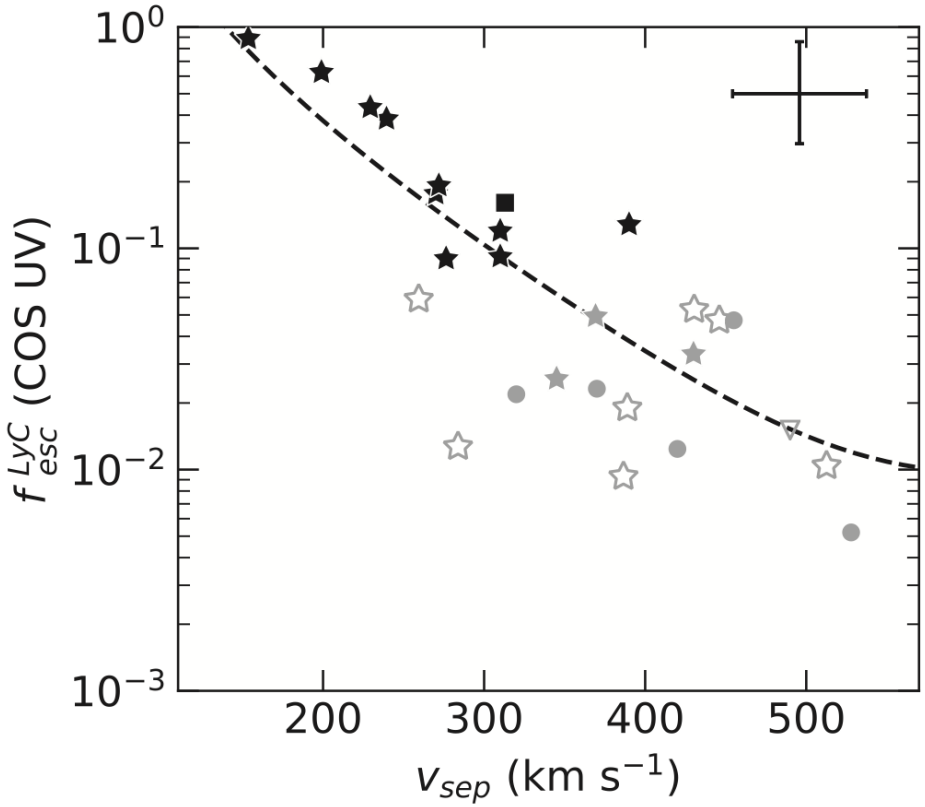
escape fraction of ionising photons

$$\mathrm{fesc(LyC)} = \frac{\text{number of escaping photons}}{\text{number of intrinsic photons}} \sim 2 - 73\%$$

Low-z Lyman Continuum Survey

Flury+22a,b, Saldana+22, Chisholm+22, Xu+23

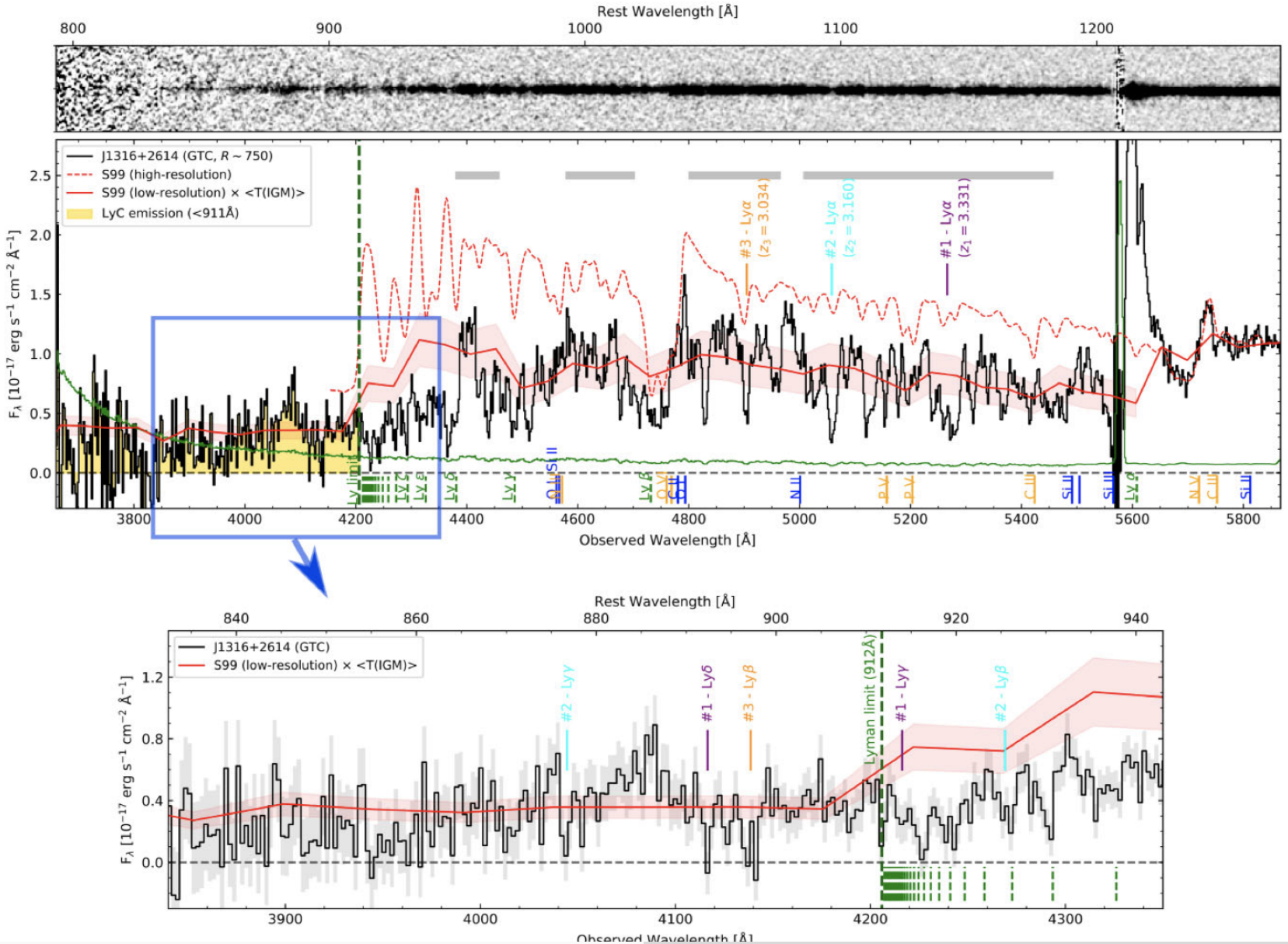




* 35 out 66 galaxies are detected in LyC
  see Anne and Sophia's talks on Thursday !
* GPs + LzLCS $\sim$ 300 HST orbits to probe the LyC flux density at 900Åof **100 galaxies at z** $\sim$ 0.3
* Lyα peaks separation anti-correlates with LyC escape fraction

Most recent updates : LyC monsters... at $z \sim 3$

Marques-Chaves+21,22, w/ Verhamme



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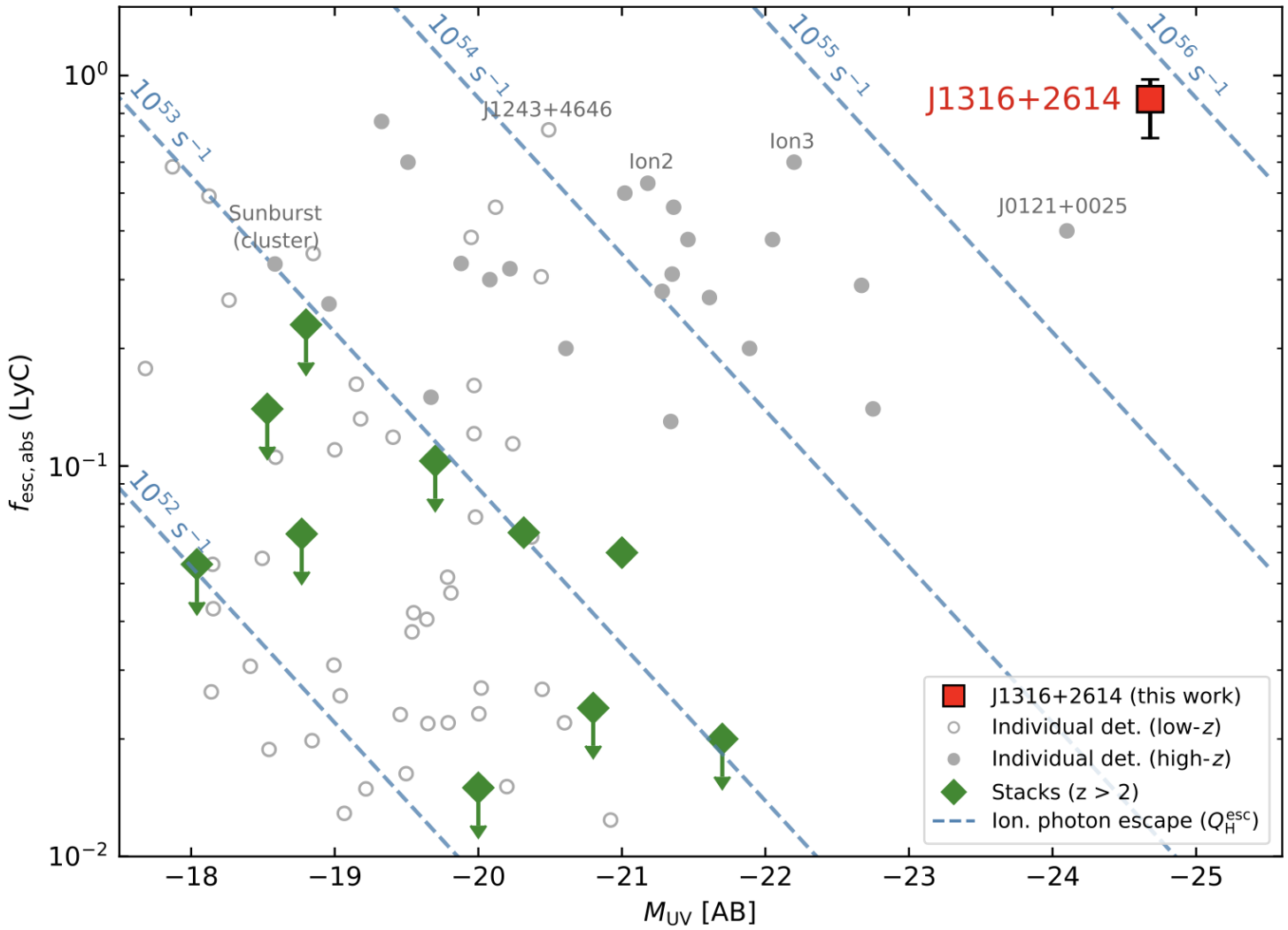
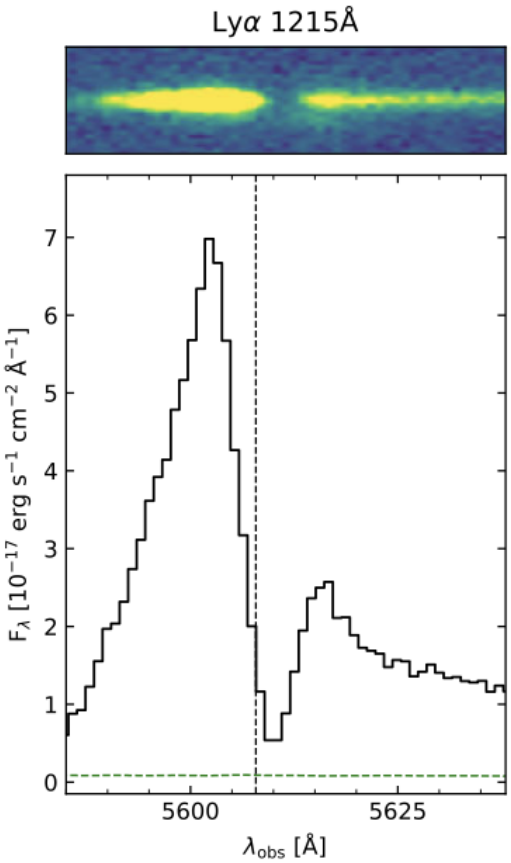
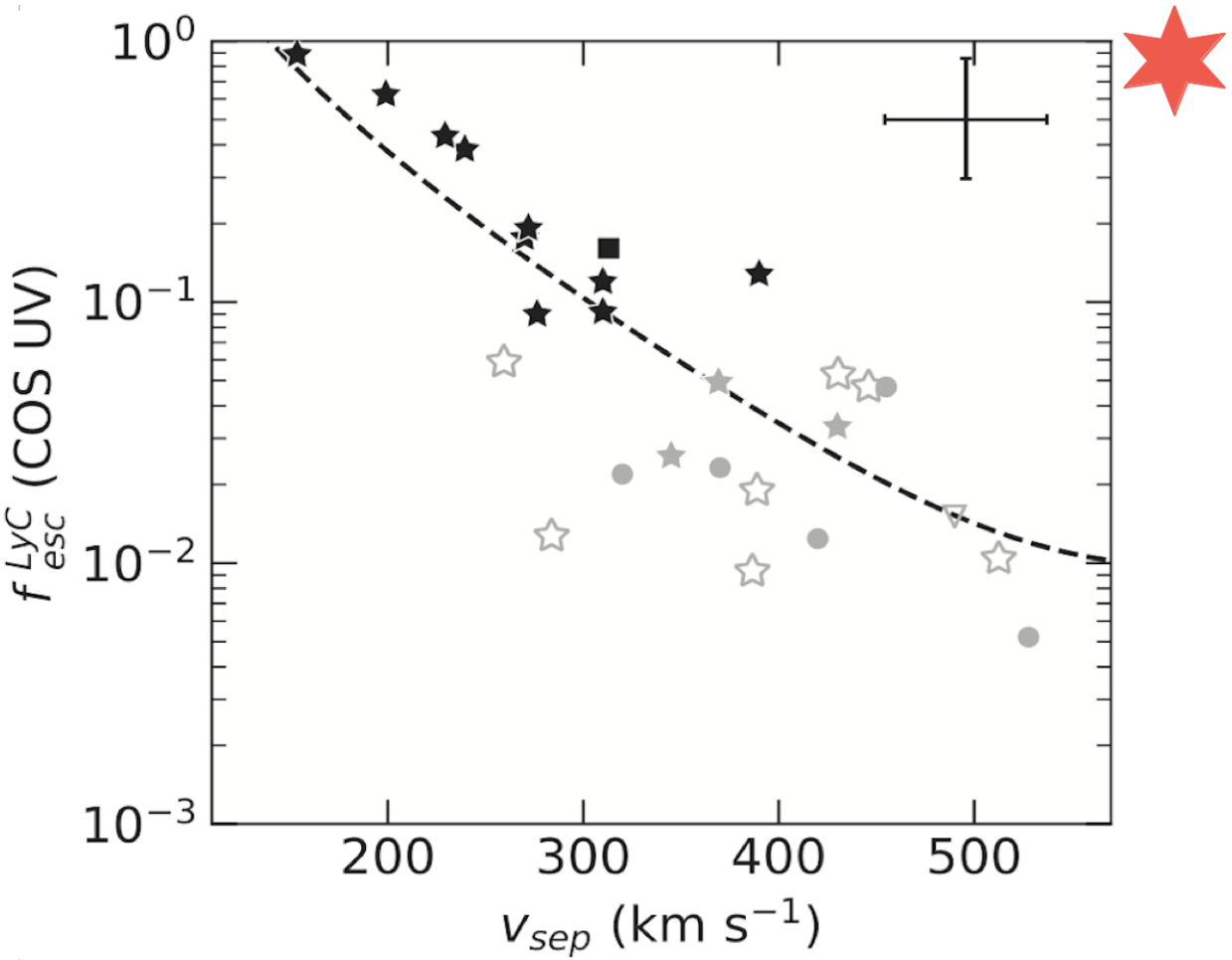


LyC monsters...have surprising Lyαspectral shapes

Marques-Chaves+21,22, w/ Verhamme

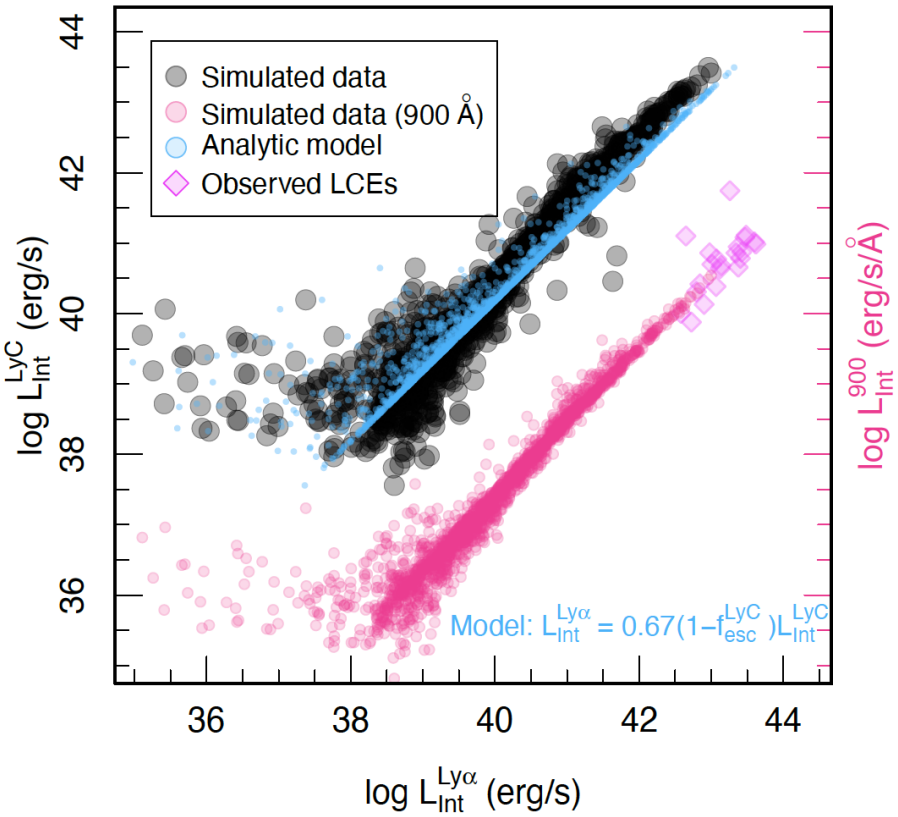


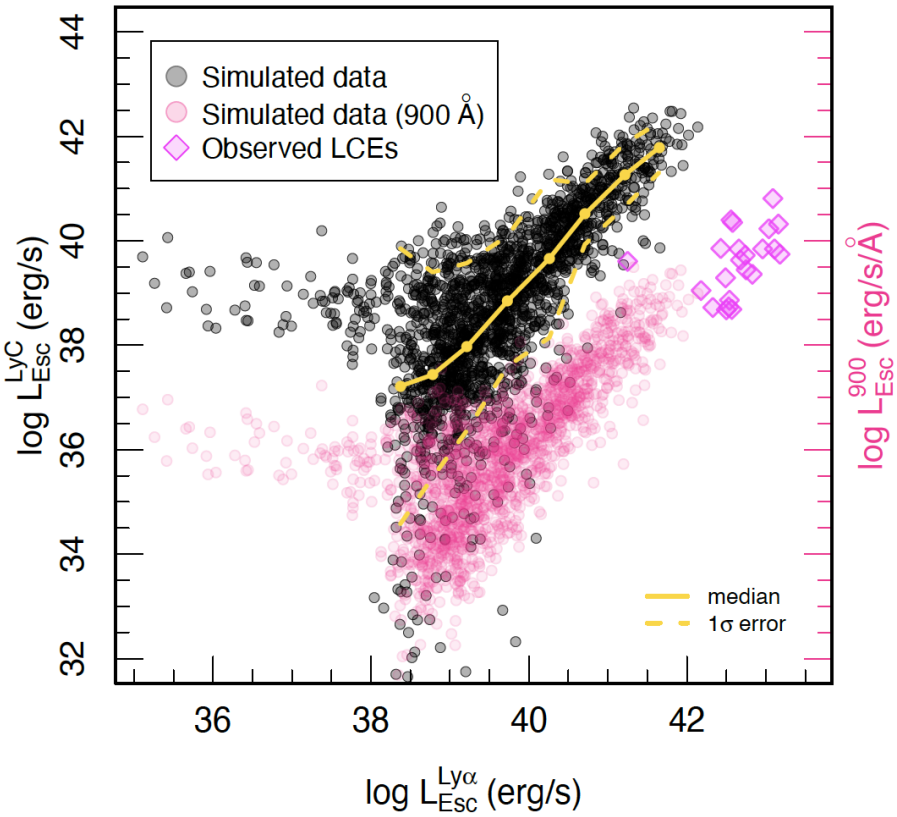


see Rui's talk on Wednesday !

Lyα-bright galaxies are strong LyC emitters

Maji, verhamme et al 2022





⟶ Lyα-bright galaxies are the main contributors to reionisation

Lyα-bright galaxies are strong LyC emitters

Maji, Verhamme et al, 2022

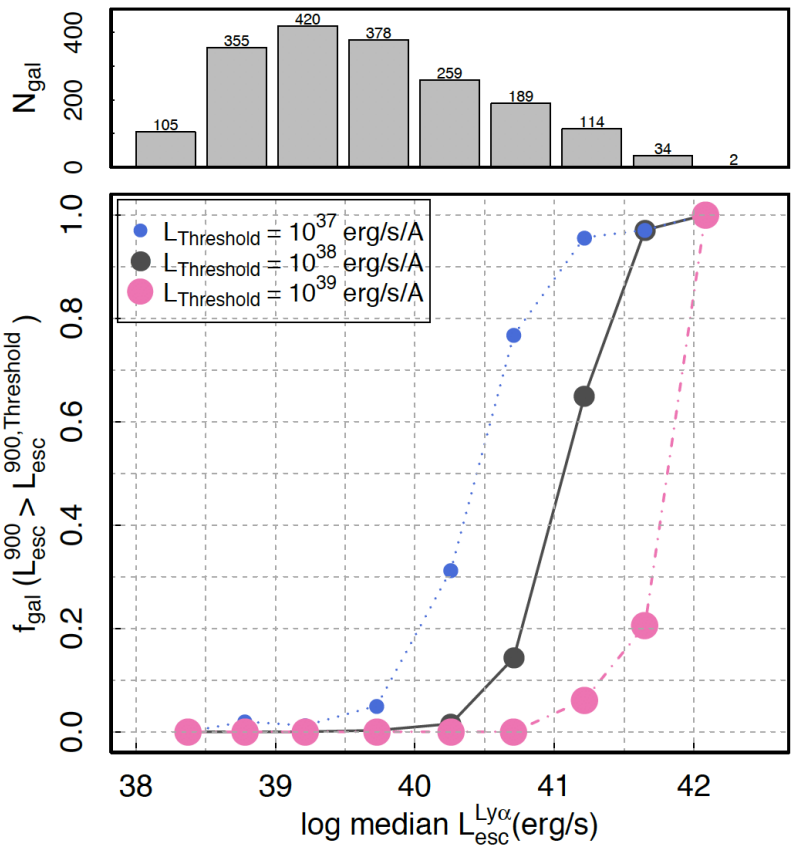
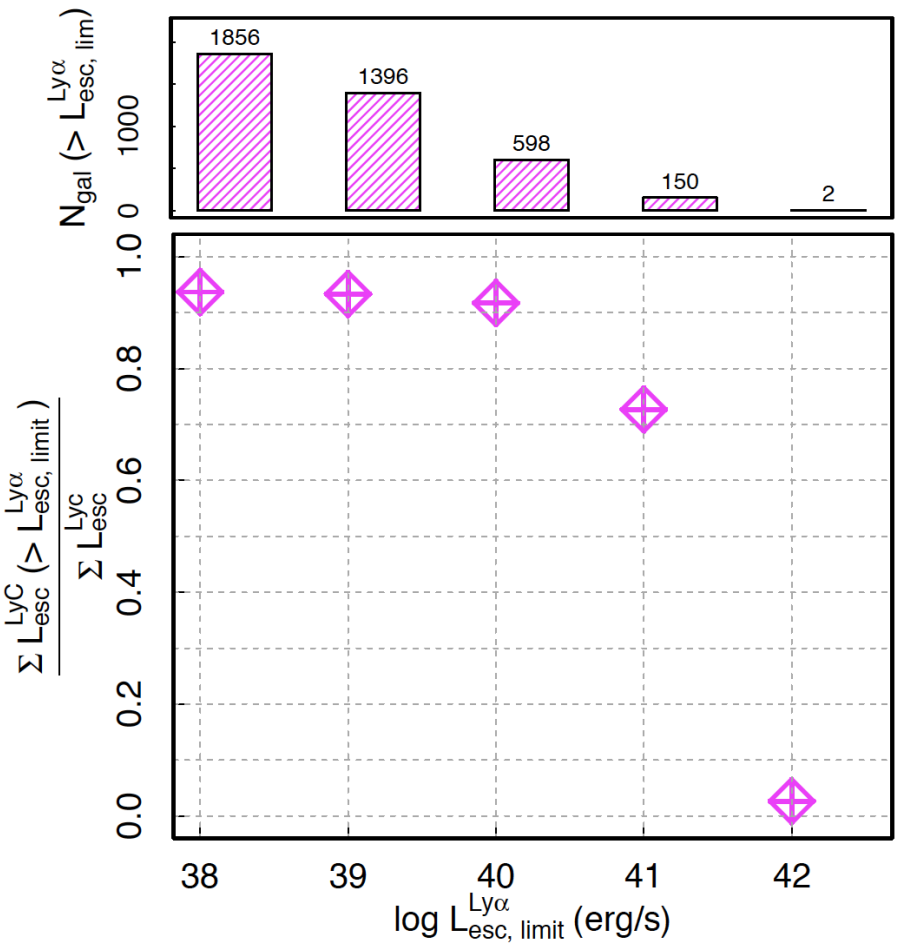


Fig. 6: Fraction of galaxies with L_{esc}^{900} luminosity above a threshold value against their median escaping Lyα Luminosity.

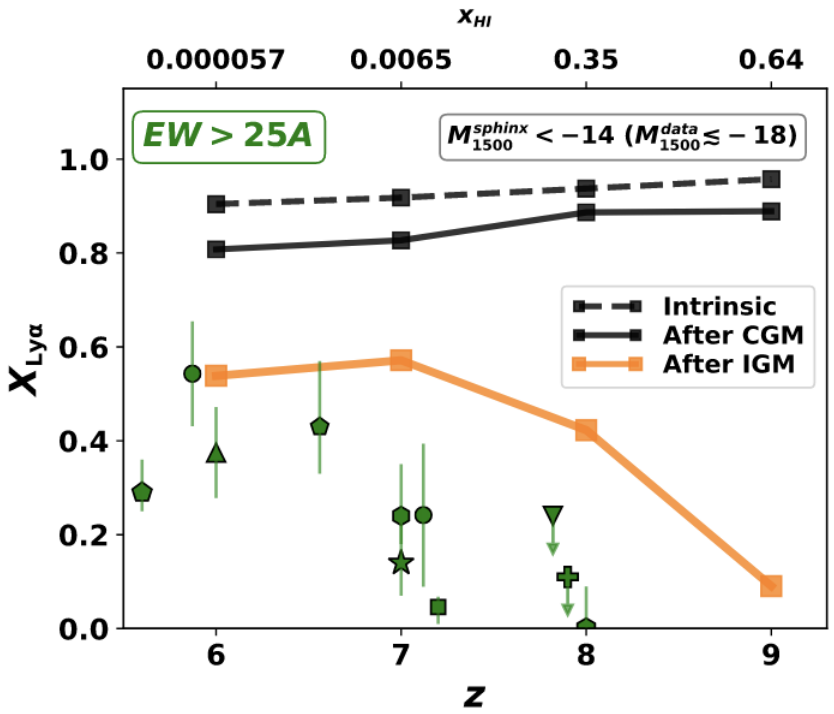


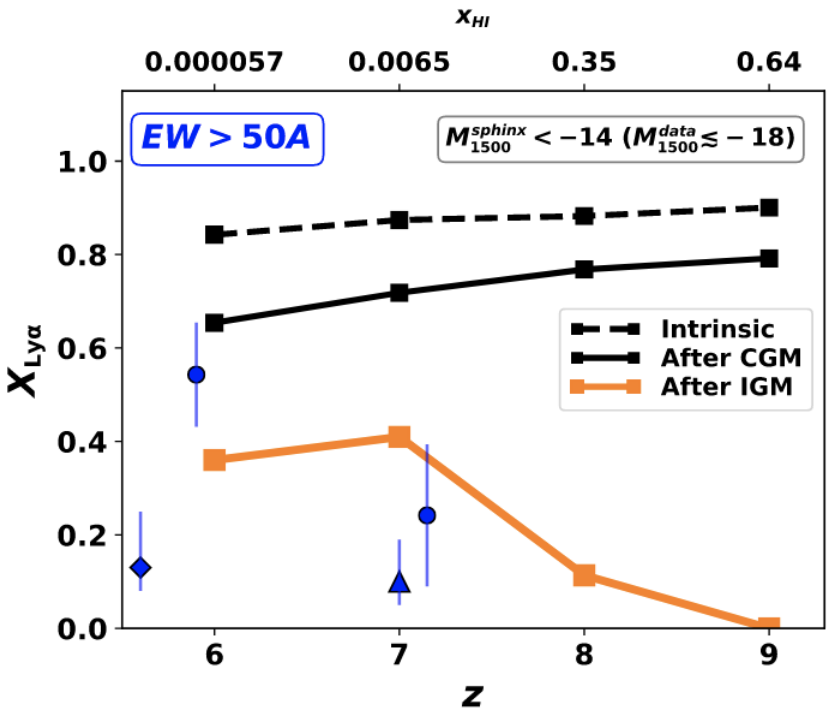
$\longrightarrow$ The fraction of LyC-bright galaxies increases with Lyα luminosities

$\longrightarrow$ LAEs with log(L(Lya)) > 40 emit more than 90% of the ionising budget

The fraction of LAEs among UV-selected galaxies traces IGM opacity

Garel et al 2021





$\longrightarrow$ The fraction of Lyα emitters among UV-selected galaxies traces the neutral state of the IGM

The fraction of LAEs among UV-selected galaxies traces IGM opacity

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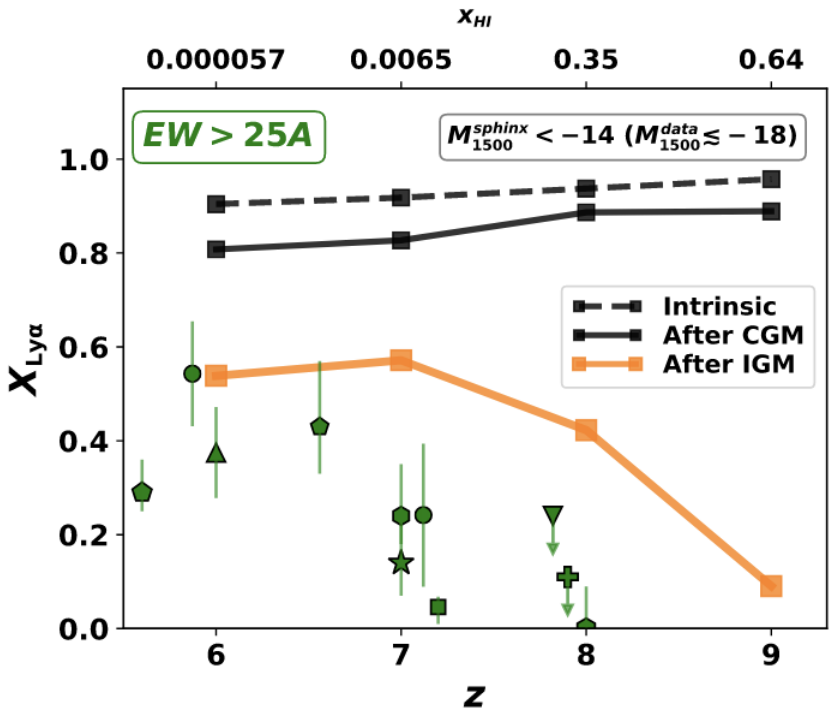
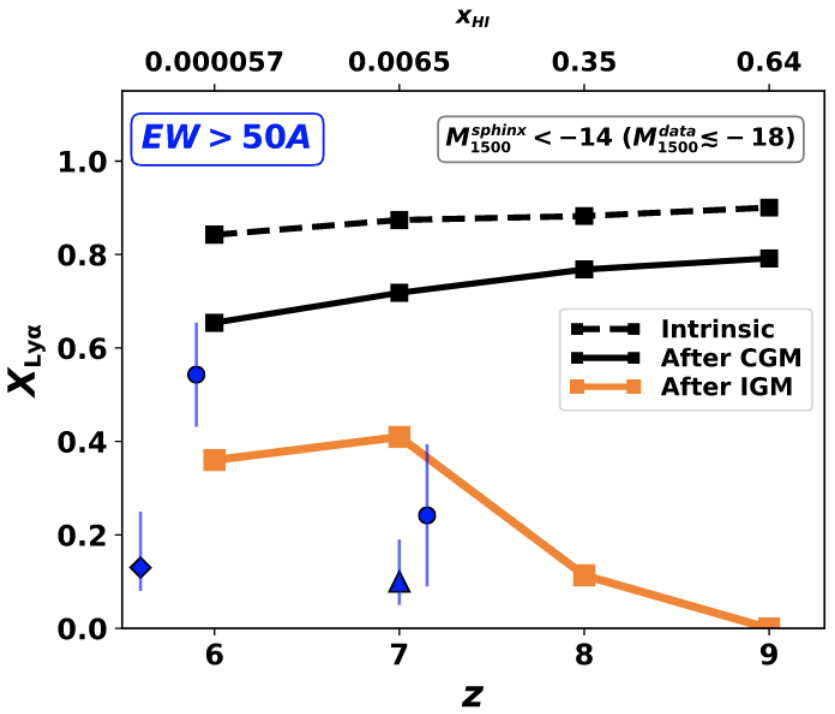


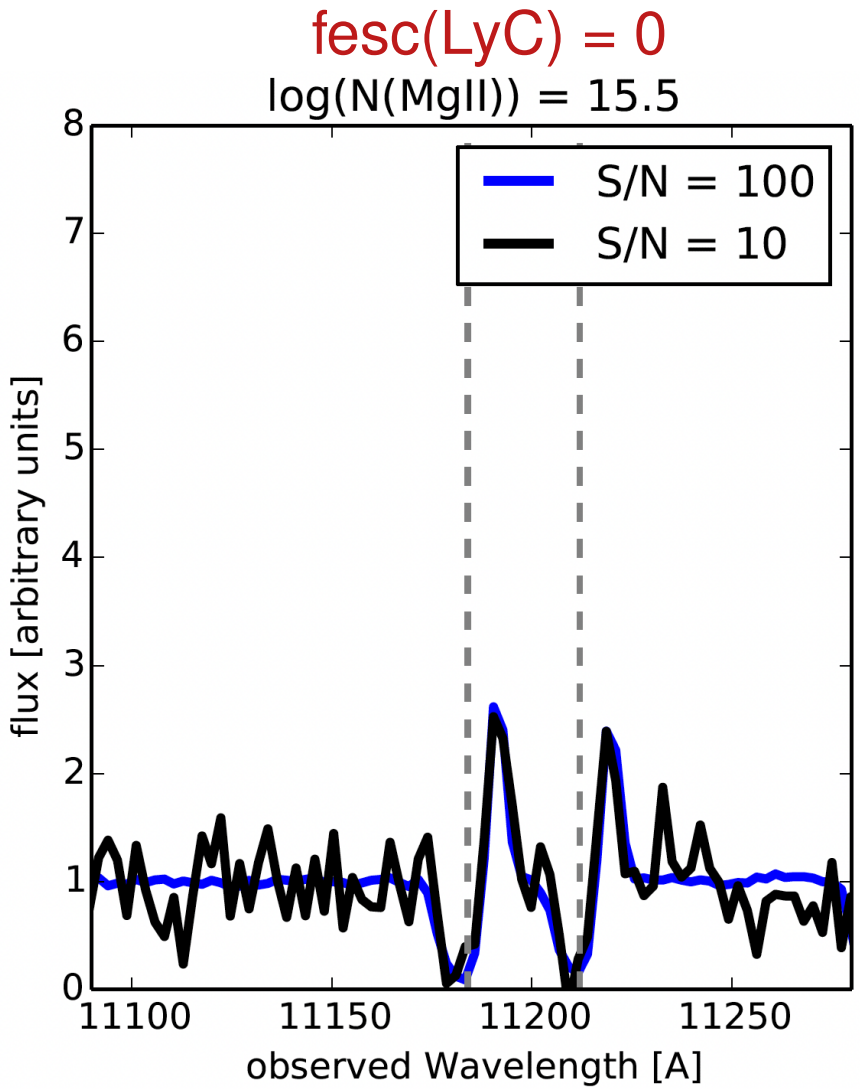


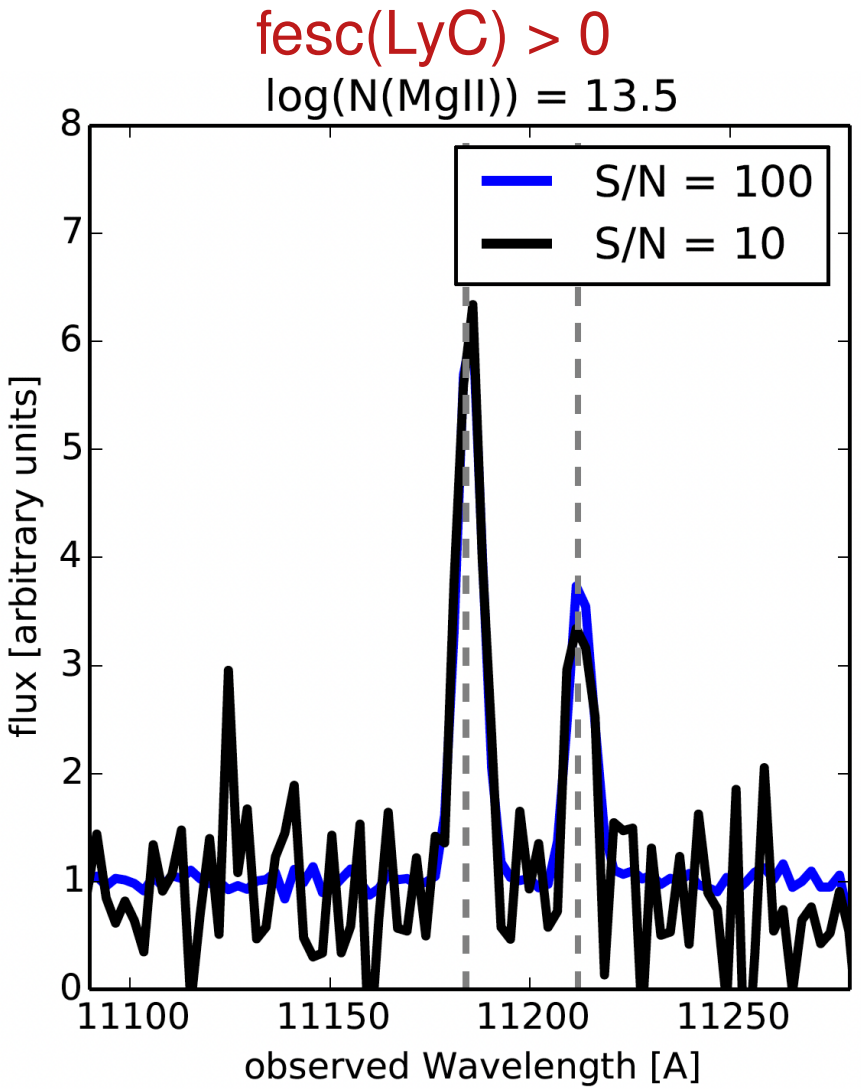
$\longrightarrow$ The fraction of Lyα emitters among UV-selected galaxies traces the neutral state of the IGM

MORE Lyα results from simulations : see Jeremy's talk this afternoon !

MgII $\lambda\lambda$2796, 2803Å spectra of LyC Emitters

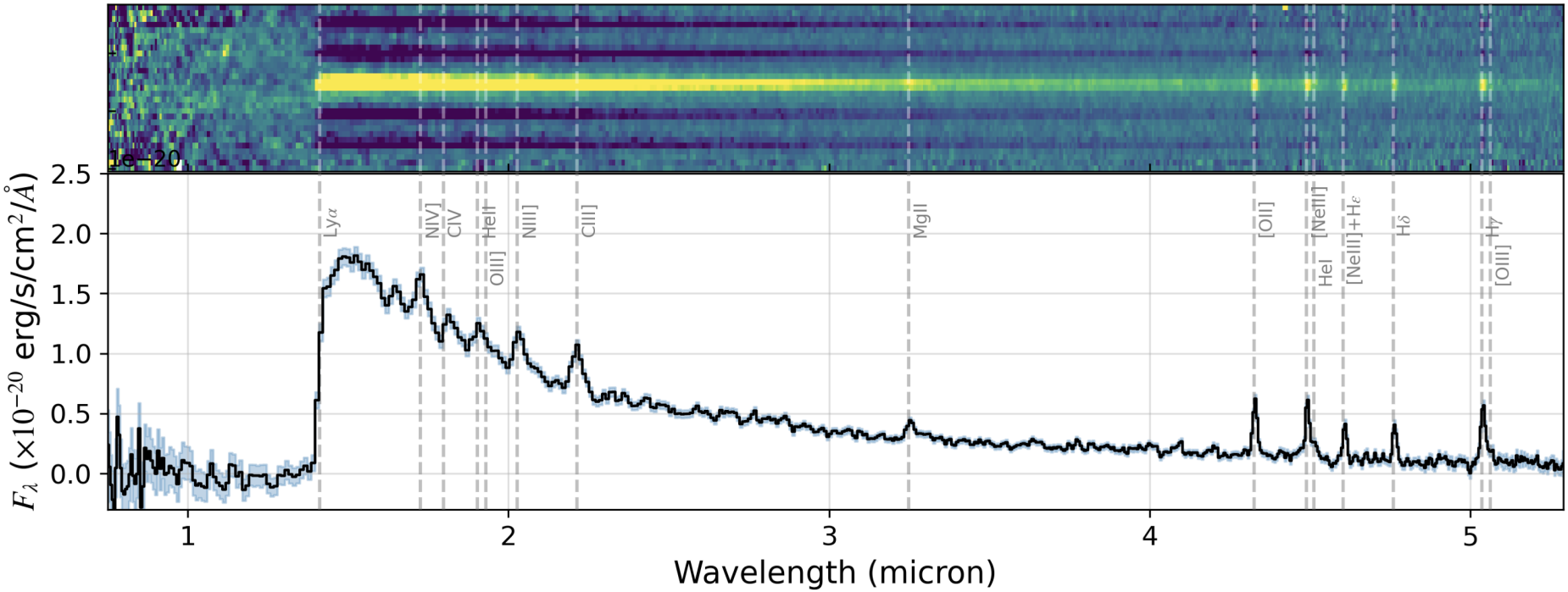
Strong emission with no peak shift *Verhamme, Garel+ in prep*





MgII is observable from a $z \sim 11$ galaxy with JWST

Bunker et al, 2023



Archetype of a distant galay UV spectrum

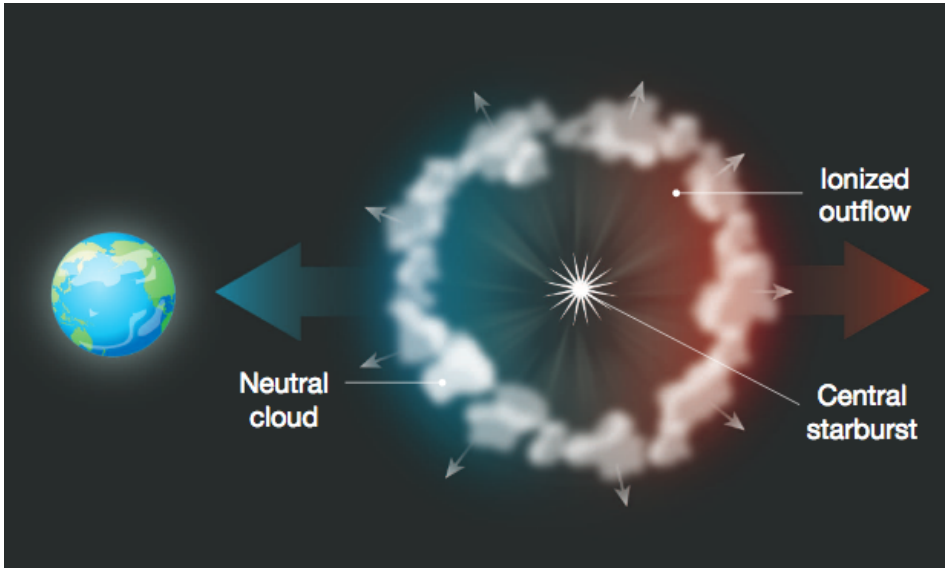
* Bright galaxy seen at z = 10.603, or 430 Myr after the Big Bang
* $\sim$ 7 hours of observation with NIRSpec PRISM/CLEAR mode

This opens new perspectives for MgII predictions

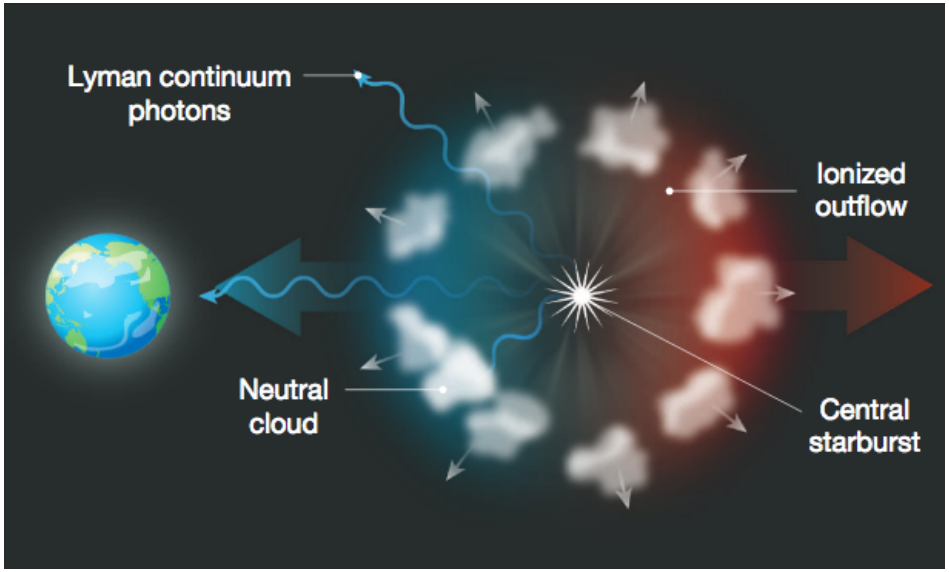
Other UV Absorption lines as LyC tracers ?

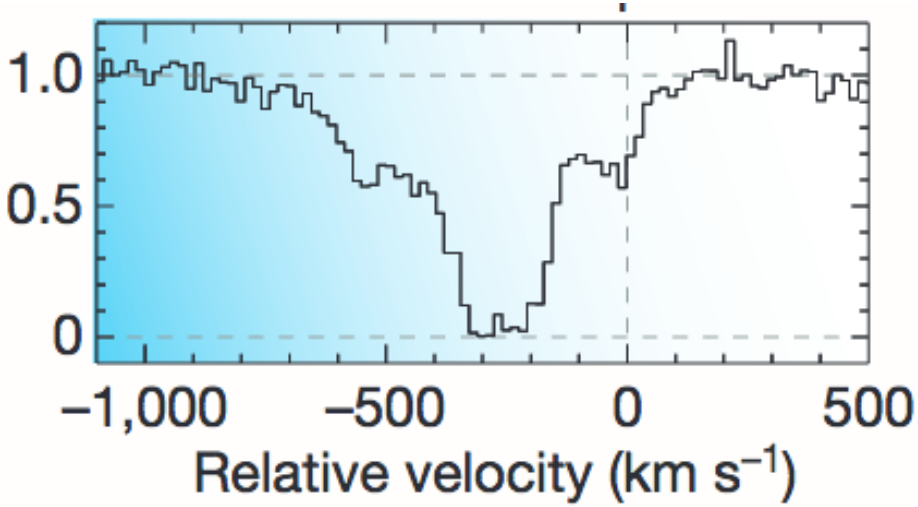
Heckman+11, Alexandroff+15, Chisholm+17, figures adapted from Erb 2015

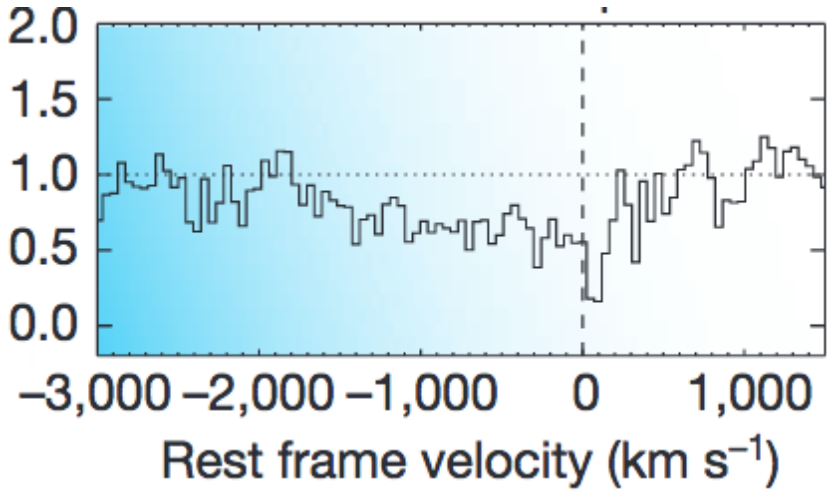
fesc(LyC) = 0



fesc(LyC) > 0

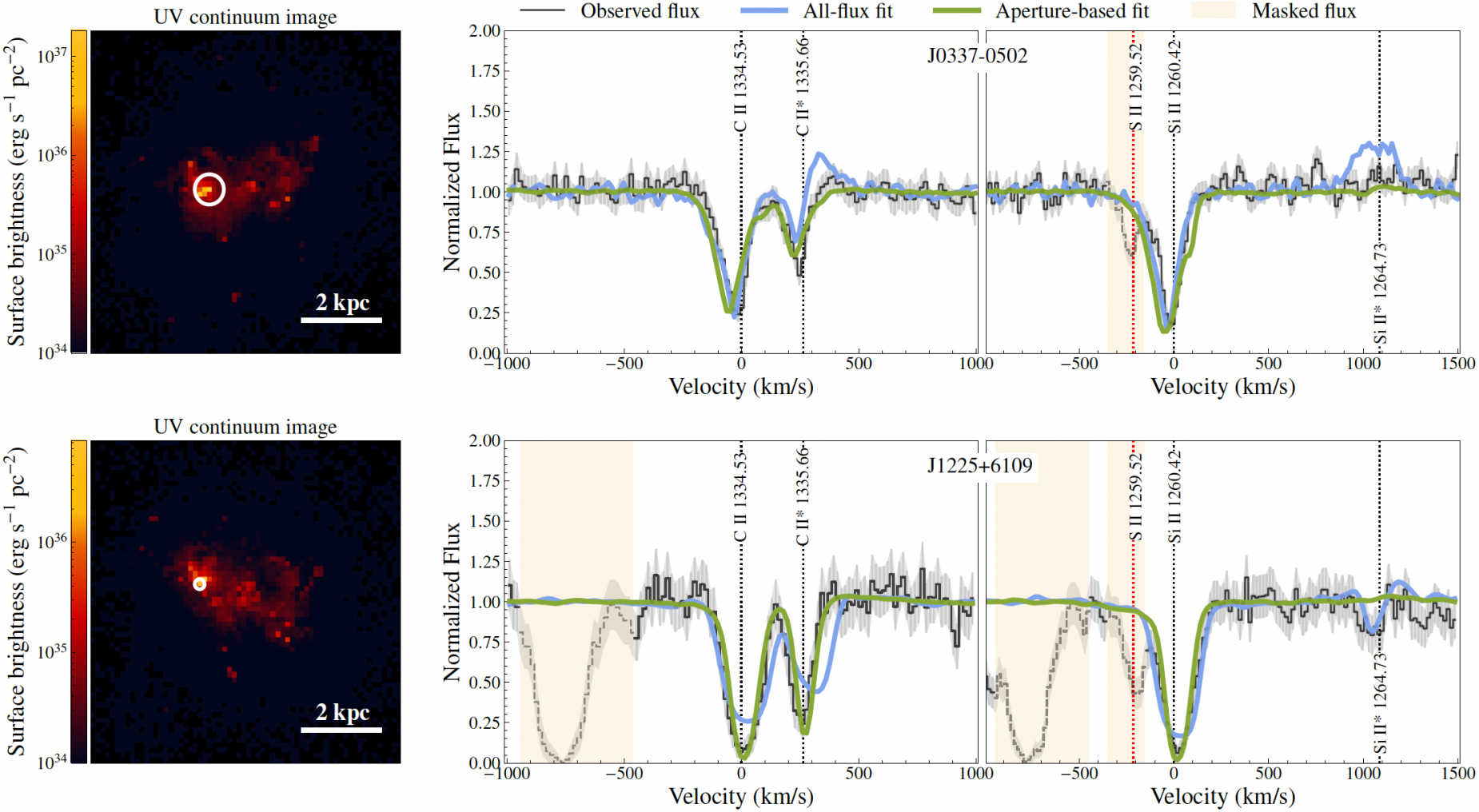






Mock UV lines observations from simulated galaxies

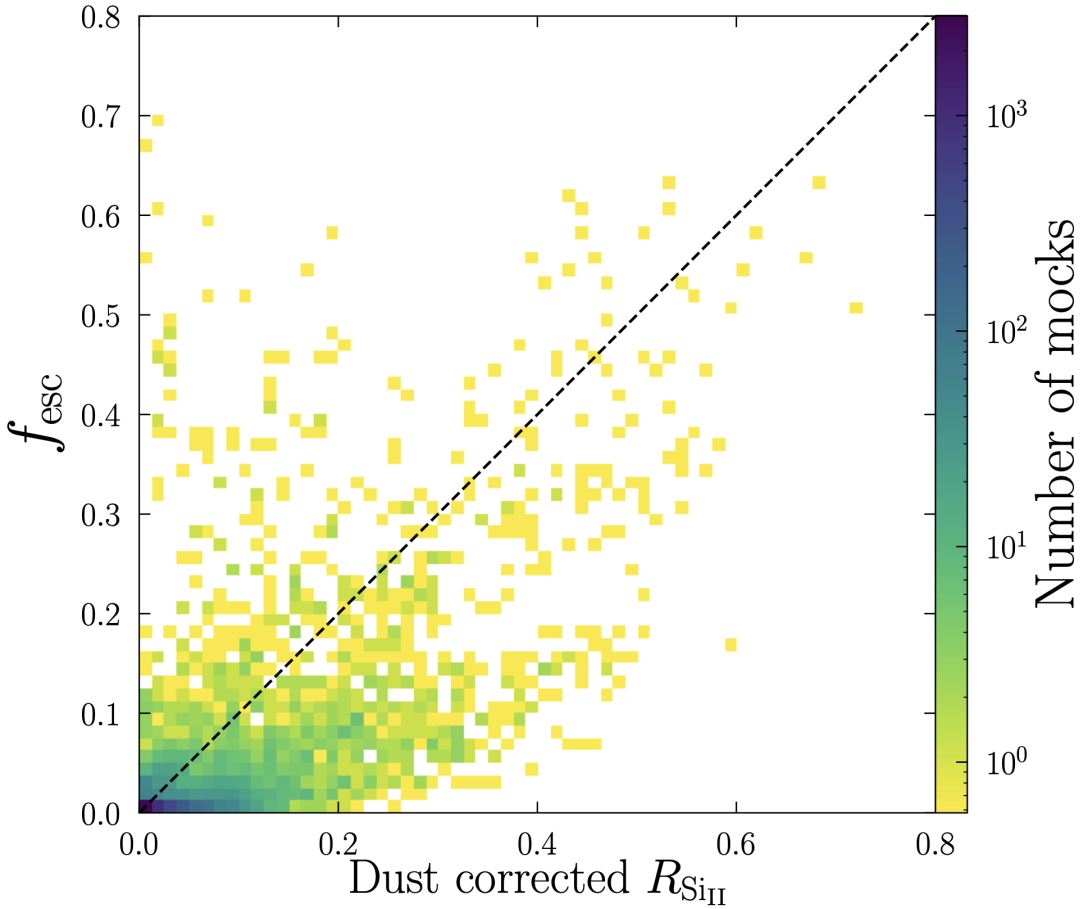
Realistic mock spectra, fitting observed spectra *Gazagnes et al, submitted w/ Verhamme*



zoom simulation of a star-forming galaxy at z$\sim$ 3 – 4, reproduces the diversity of Low Ionisation State (LIS) absorption lines, for the first time.

Mock UV lines observations from simulated galaxies

Mauerhofer, Verhamme+21

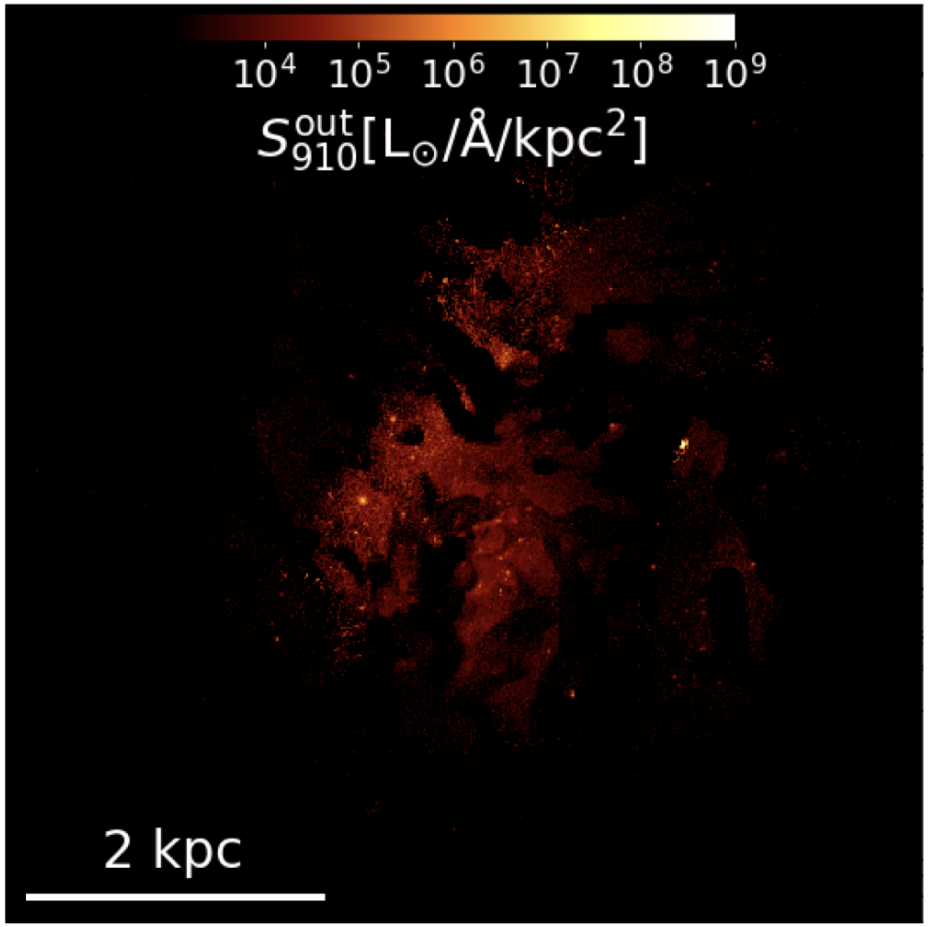


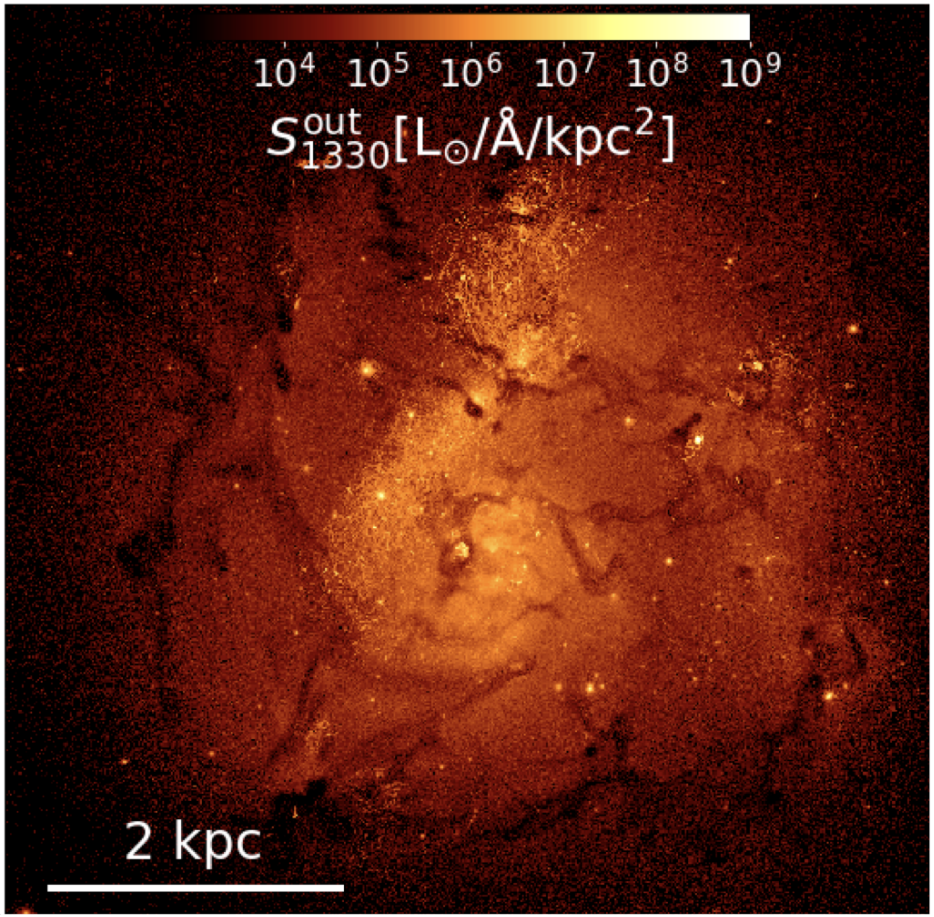
No correlation between the escape fraction of ionising radiation and the residual flux in the line

Mock UV lines observations from simulated galaxies

Reason 1 : only 50% of the observed 1330Åflux is from LyC emitting stars

Mauerhofer, Verhamme+21

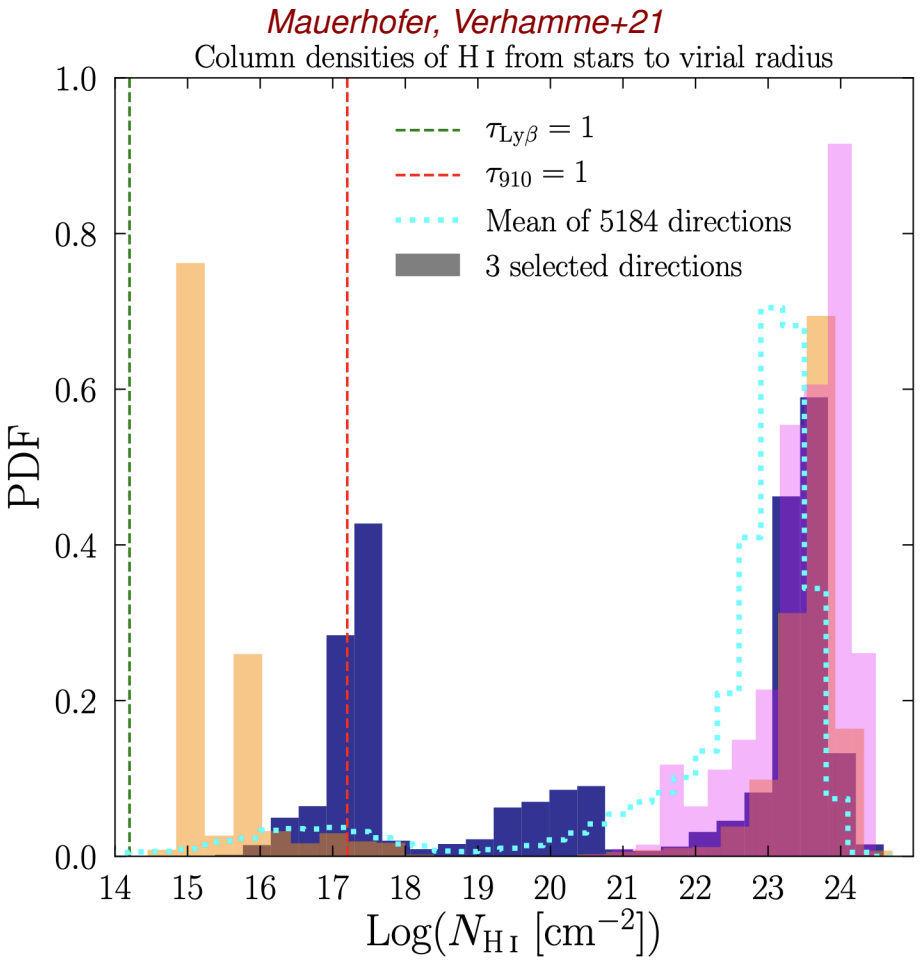




The spatial distribution of the stars emitting the 1330Åcontinuum is different from the ionsing stars

Mock UV lines observations from simulated galaxies

Reason 2 : Picket-fence approximation too simple

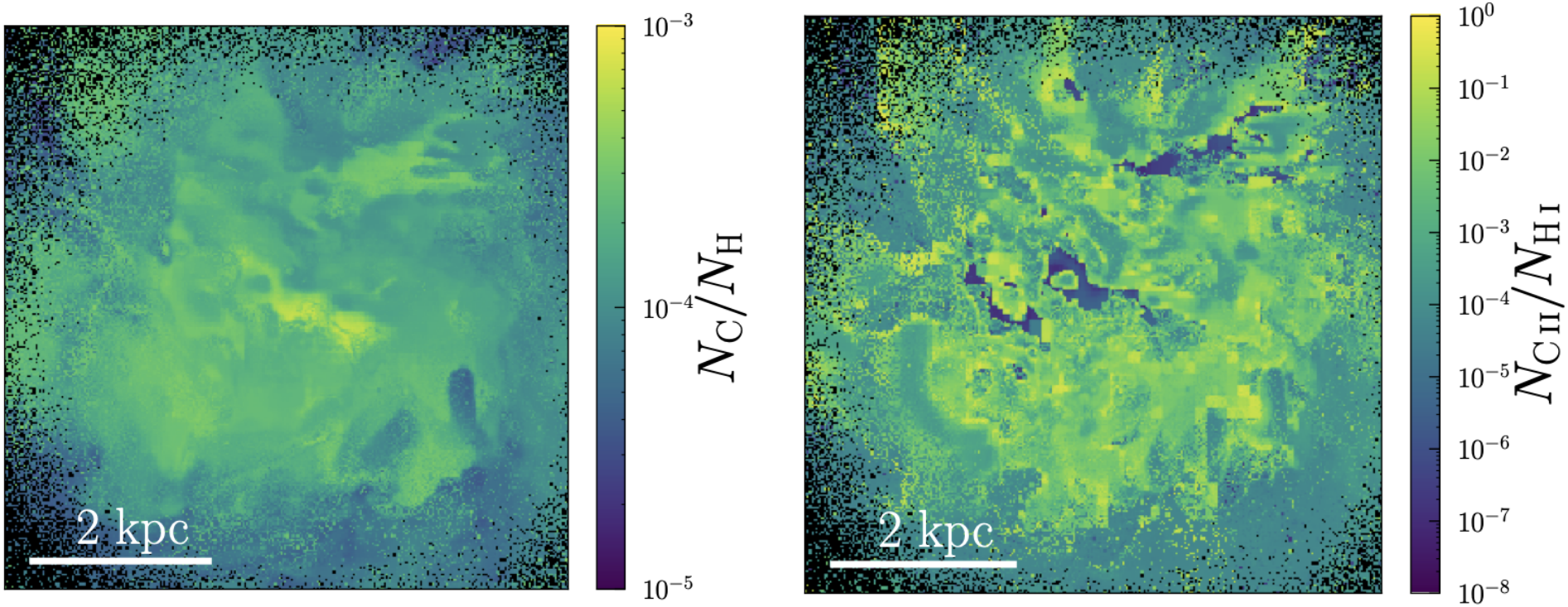


The (LyC luminosity weighted) distribution of NHI in front of ionising stars in not bimodal in all directions

Mock UV lines observations from simulated galaxies

Reason 3 : CII/HI fraction hugely varies spacially

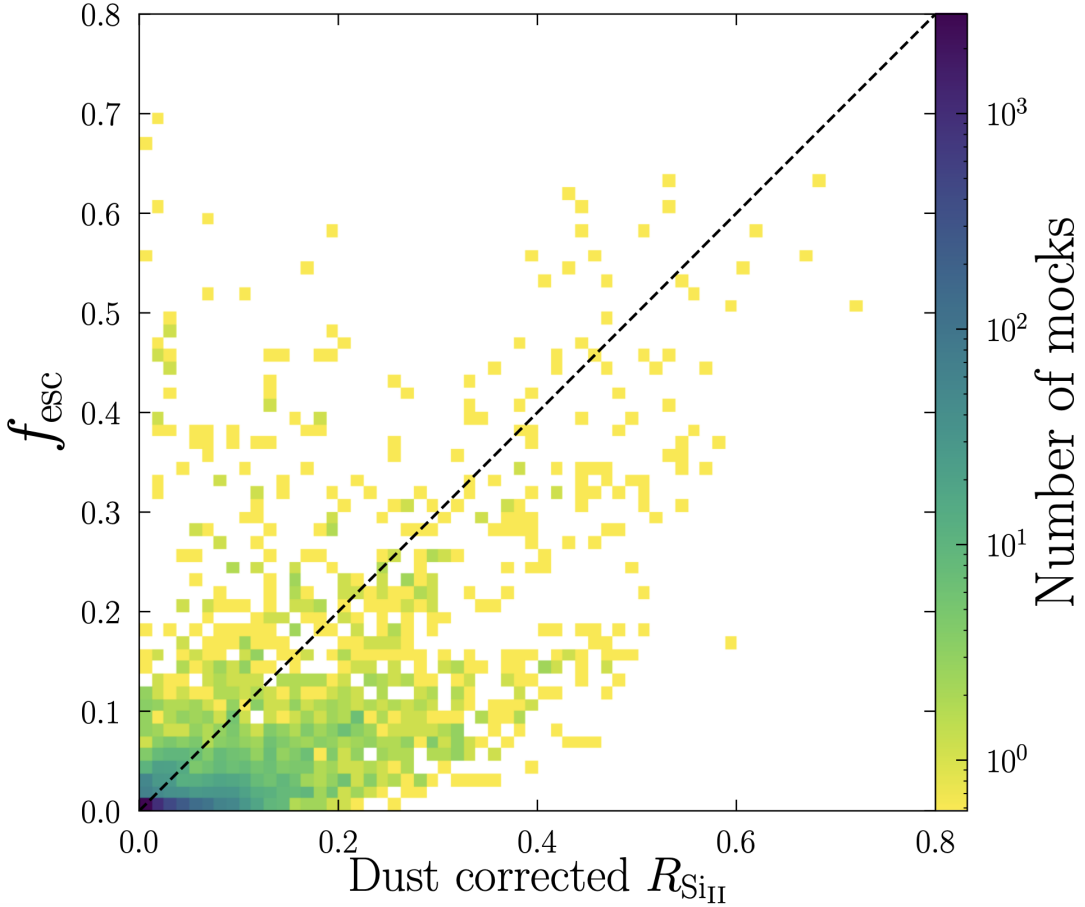
Mauerhofer, Verhamme+21



The abundance of CII over HI strongly varies locally, depending on the ionisation state of the gas.

Mock UV lines observations from simulated galaxies

Mauerhofer, Verhamme+21



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* another component : LyC nebular emission
* the need for exotic LyC sources ?

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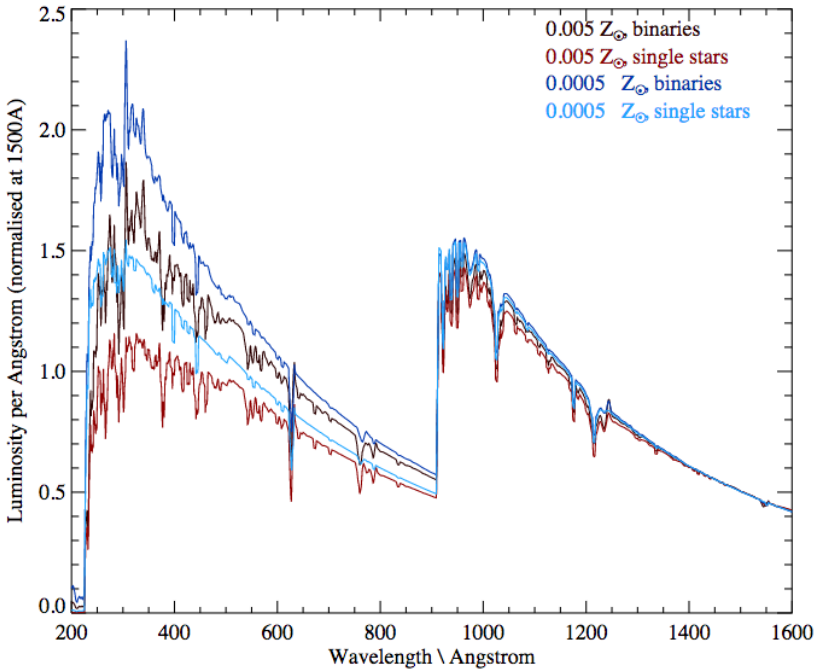
* indirect probes
* LyC sources

What is the ionising spectrum of galaxies ?

BPASS, Stanway&Eldridge 2016, 2018

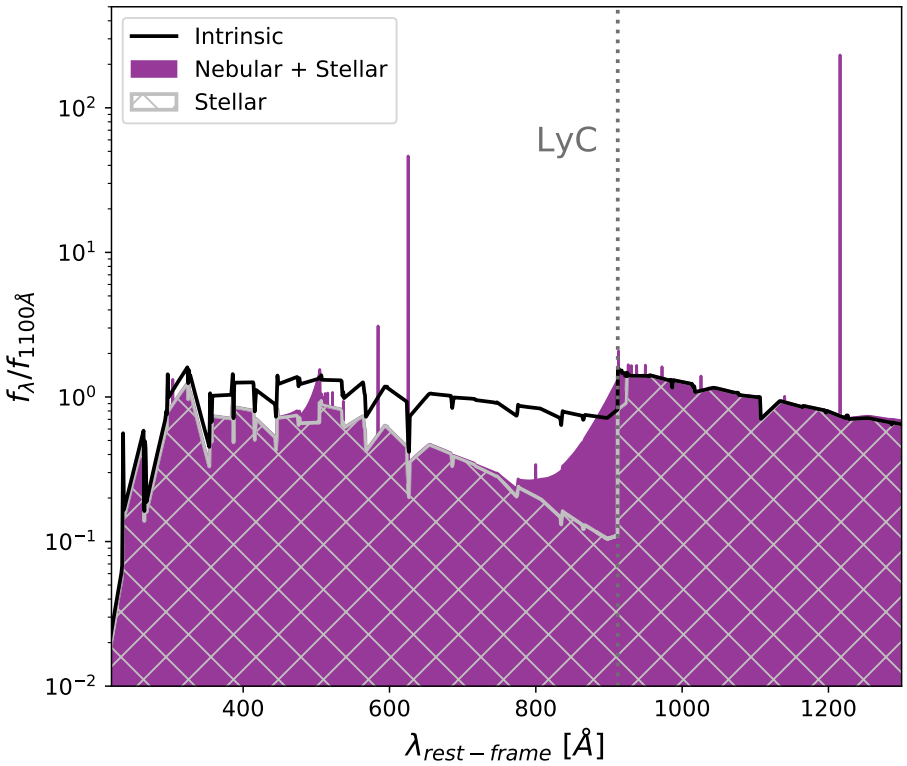


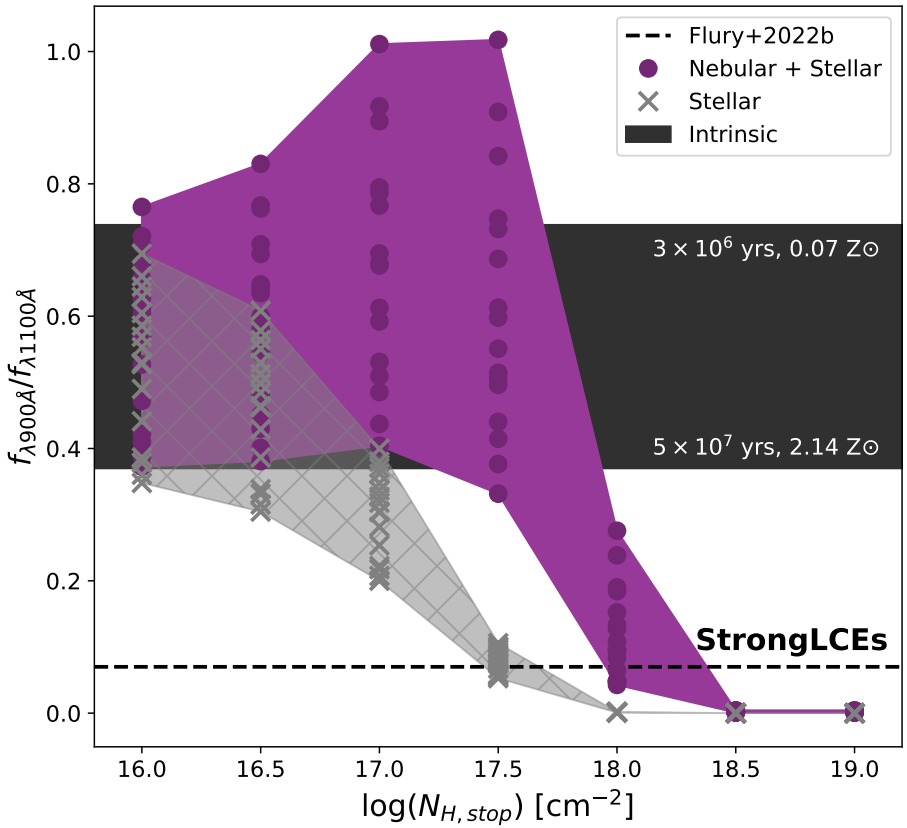
The ionsing spectrum of galaxies

* stars are the main sources of ionising photons in galaxies
* LyC is barely observable directly : EUVE in the 90's observed two B stars
* stellar population synthesis models
* model parameters : IMF, age, metallicity, binary fraction
* influences nebular emission
* soft Xray emission from Xrays binaries ?

The ionising spectrum of galaxies, only stellar ?

Simmonds, Verhamme in prep, see also Inoue10,11





The ionising spectrum of galaxies, only stellar ?

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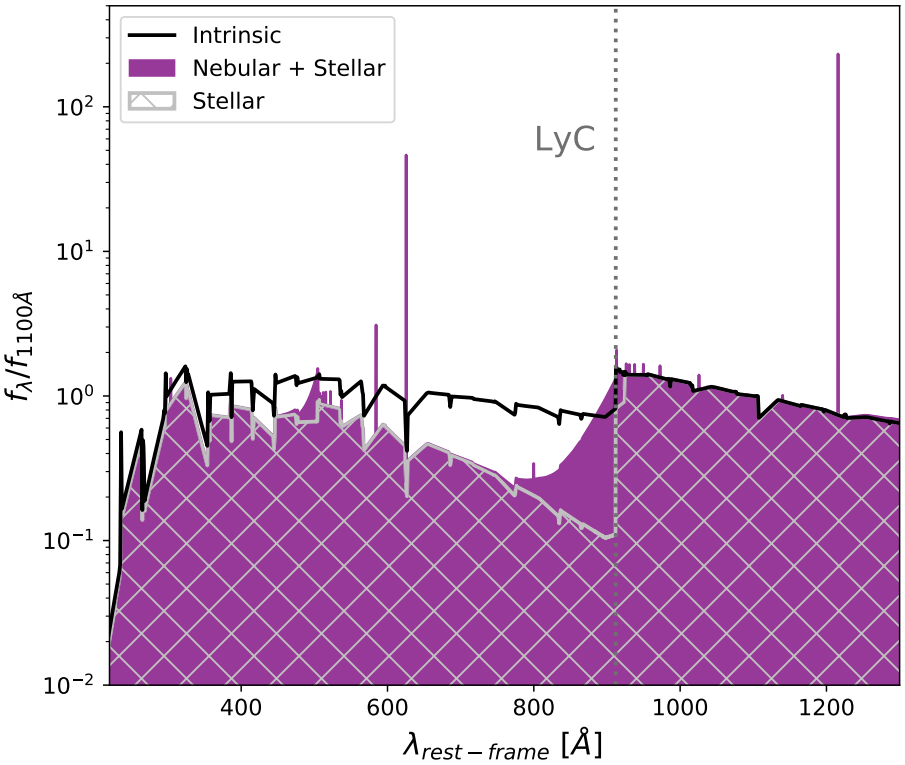
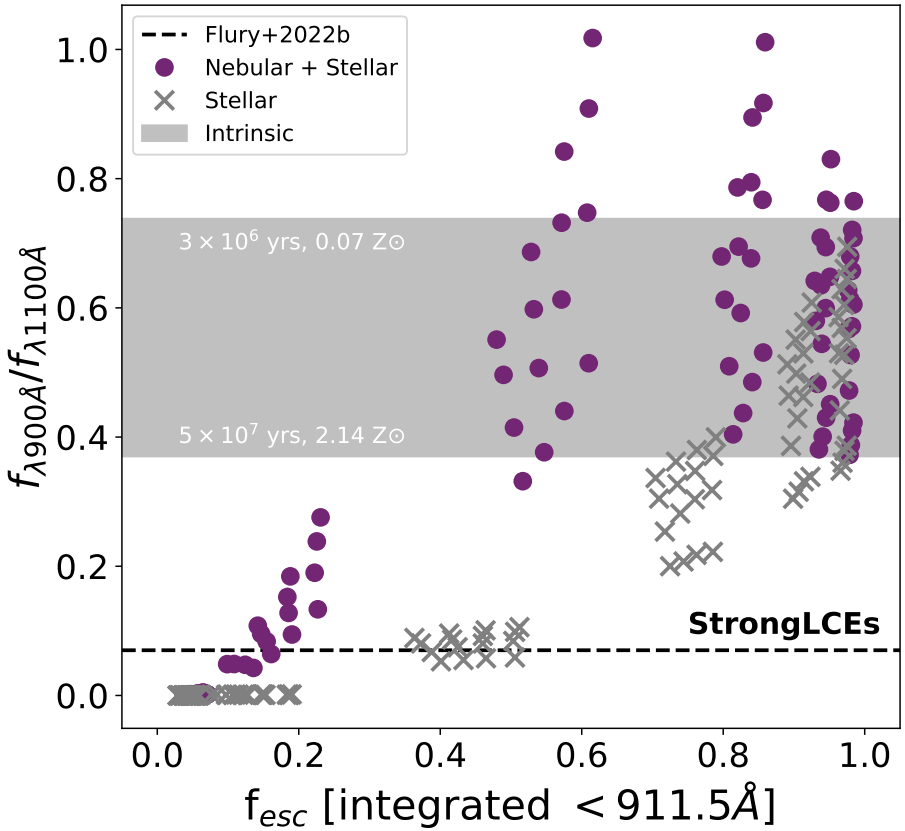
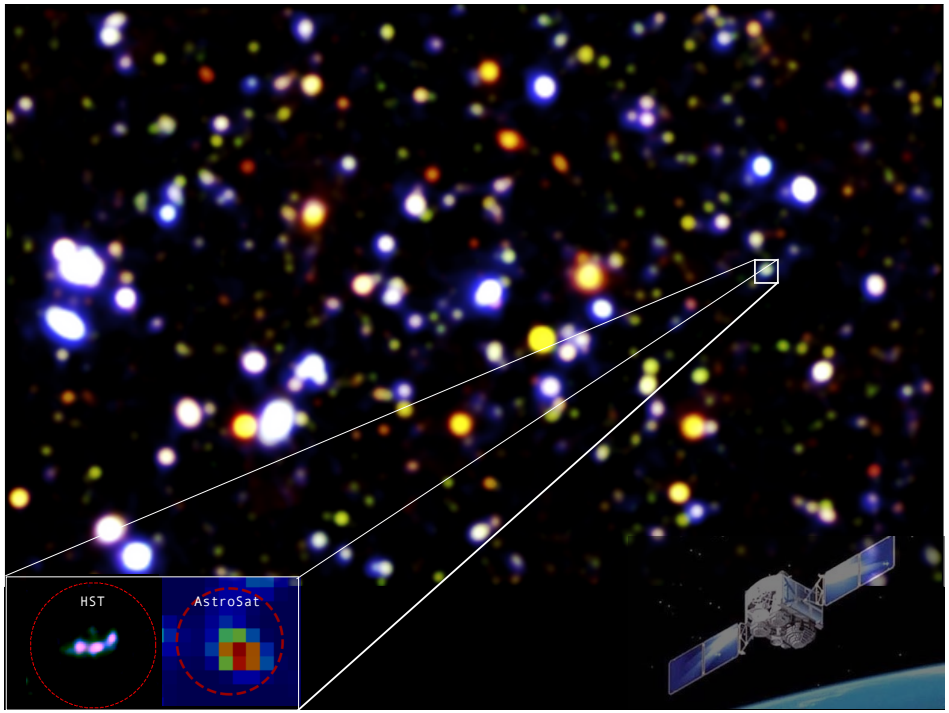
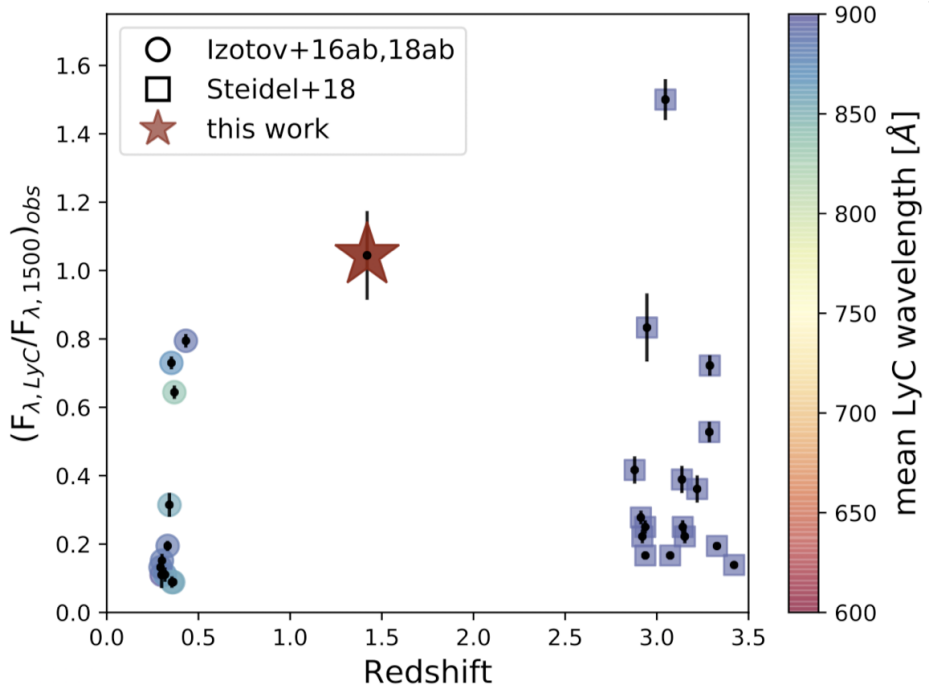




Astrosat detects a z$\sim$ 1.42 galaxy in LyC at 600Å

Saha et al, Nature Astronomy 2020, w/ Verhamme



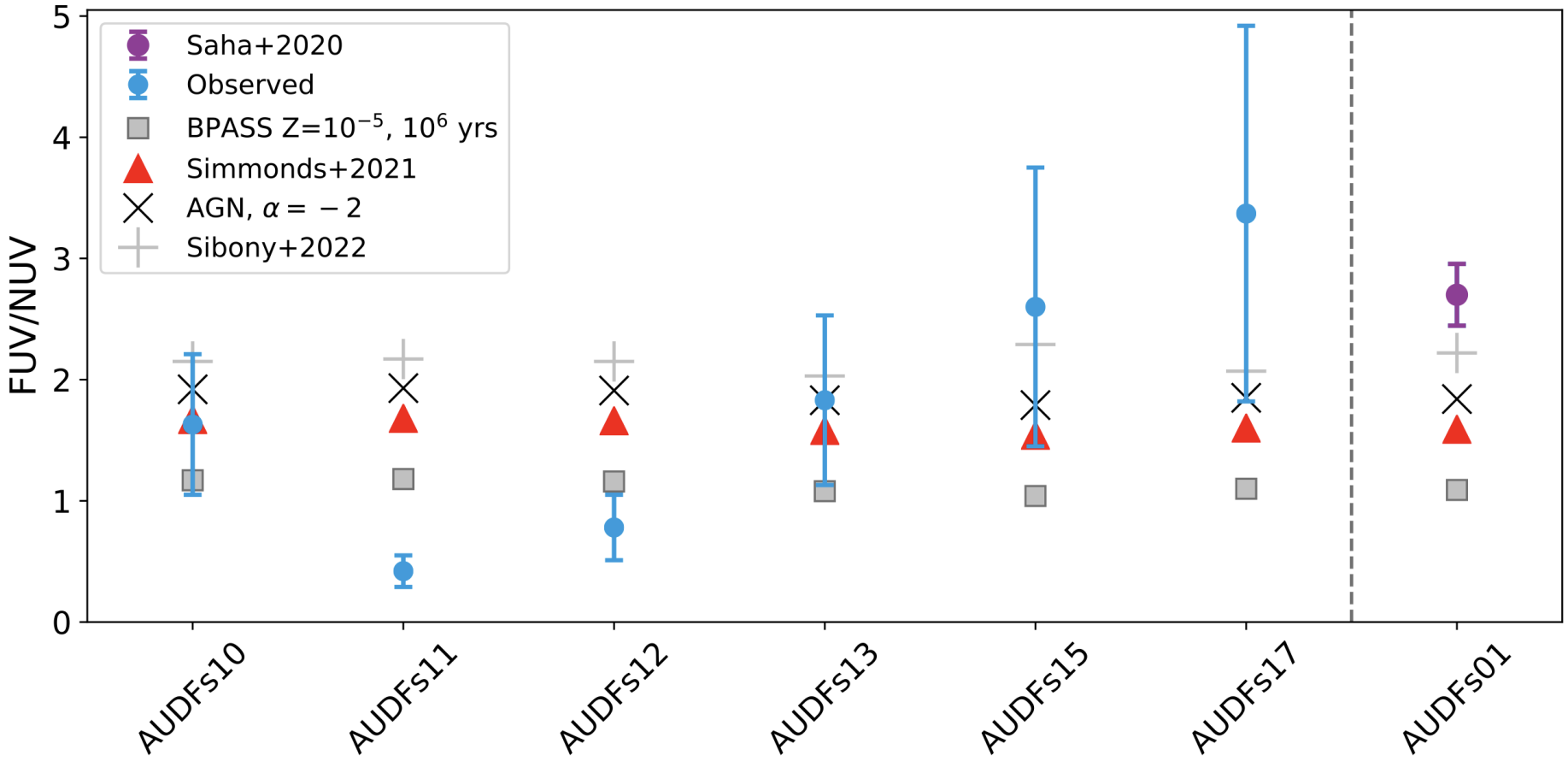


Uniqueness of Astrosat UV Deep Field (AUDF, PI K. Saha)

* blind photometric survey on Hubble Ultra Deep Fields,
* better PSF than GALEX, deeper than HST in FUV (27.9 mag)
* opens an new redshift+wavelength window to constrain LyC of galaxies

Exotic LyC emitters found with Astrosat

Simmonds, Verhamme+23



We measure unexpectedly high ionising flux at 600Å, need for exotic stellar sources ?

Searching for the sources of Reionisation

* Recent results on detections of LyC from galaxies
  * with HST at z$\sim$ 0.3 and $\sim$ 900Å : 100 galaxies
  * with Astrosat at z$\sim$ 1 $-$ 2 and $\sim$ 600Å : a dozen galaxies
  * LyC monsters at $z \sim 3$: a few galaxies
* Resonant lines as a proxi for LyC escape : maybe more challenging than expected
* Open Challenges
  * use the z$\sim$ 0.3 data, and simulations, to design predictive fesc methods (Anne, Valentin), usable at z > 6 ?
  * Reveal the LyC spectral shape : how to go beyond 900Åefficiently ?
  * fraction of LCEs among a population of galaxies ? BlueMUSE !
  * a new class of LyC tracers ? ?