Lyα as indirect probe of LyC escape from galaxies

Anne Verhamme

Observatoire de Genève & CRAL Lyon

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LCEs: Ivana Orlitova, Daniel Schaerer, John Chisholm, Matthew Hayes, Yuri Izotov, Gabor Worseck, Natalia Guseva, Trin Thuan
MUSE: Josie Kerutt, Hanae Inami, Johan Richard, Mieke Paalvast, Peter Weilbacher and the GTO consortium

On ArXiv next week :

Recovering the systemic redshift of galaxies from their Lyman-alpha line profile

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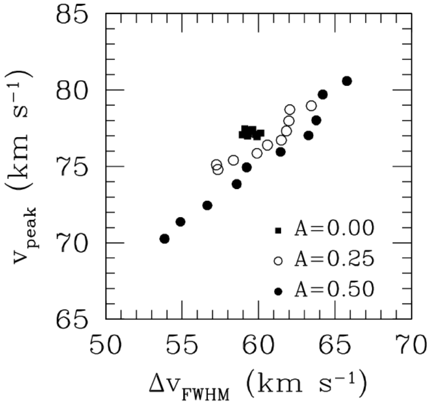
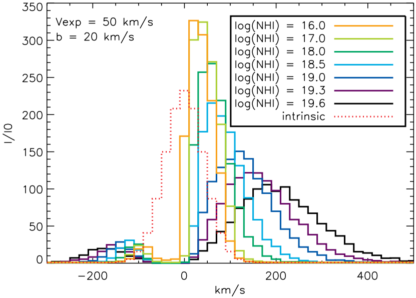
Recovering systemic redshif from the Lya emission

Zheng & Wallace 2014



Verhamme et al 2015



A sample of LAEs with known systemic redshift

13 CIII]+Lyα emitters from the MUSE GTO programs :

ID	RA	DEC	$V_{\rm peak}^{\rm red}$ [km s^{-1}]	FWHM [km s^{-1}]	ΔV [km s^{-1}]	$z_{\rm sys,\ CIII]}$	observations
sys 1	307.97040	-40.625694	176 ± 11	248 ± 9	–	3.5062	commissioning
mul 11	342.175042	-44.541031	215 ± 35	150 ± 35	375 ± 35	3.1163	AS1063
mul 14	342.178833	-44.535869	385 ± 35	300 ± 35	–	3.1150	AS1063
sys 44	64.0415559	-24.0599916	303 ± 35	360 ± 35	570 ± 35	3.2886	MACS0416
sys 132	64.0400838	-24.0667408	331 ± 35	288 ± 35	510 ± 35	3.2882	MACS0416
106	53.163726	-27.7790755	379 ± 13	414 ± 13	828 ± 35	3.2767	udf-10
118	53.157088	-27.7802688	301 ± 28	284 ± 28	568 ± 35	3.0173	udf-10
1180	53.195735	-27.7827171	220 ± 23	348 ± 32	–	3.3228	udf mosaic
6298	53.169249	-27.7812550	582 ± 38	512 ± 56	–	3.1287	udf-10
6666	53.159576	-27.7767193	284 ± 13	377 ± 11	754 ± 35	3.4349	udf-10
50	150.149656	2.061272	431 ± 42	268 ± 39	–	3.8237	GR30
48	149.852989	2.488099	294 ± 35	214 ± 35	$705 \pm 35.$	3.3280	GR34
102	150.050268	2.600025	299 ± 15	229 ± 15	$385 \pm 35.$	3.0400	GR84

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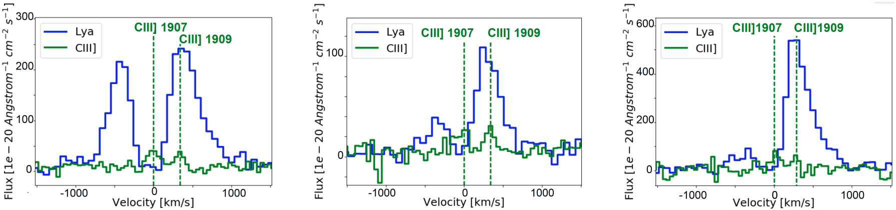
plus LAEs from the litterature with known systemic redshift :

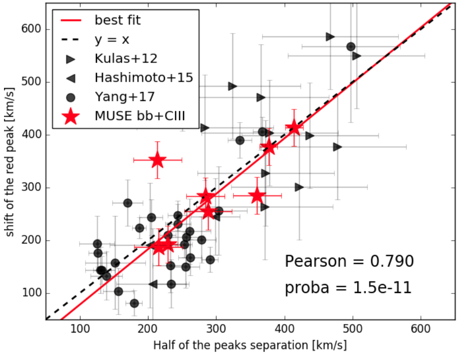
* 43 Green Peas at $z \sim 0.3$ *Yang+17*
* 6 LAEs and 20 LBGs at $z \sim 2-3$ *Hashimoto+15, Kulas+12*
* few rare objects at high redshit with Lyα + CIII] *Stark+17, Vanzella+16*

CIII]+Lyα emitters from the MUSE GTO programs



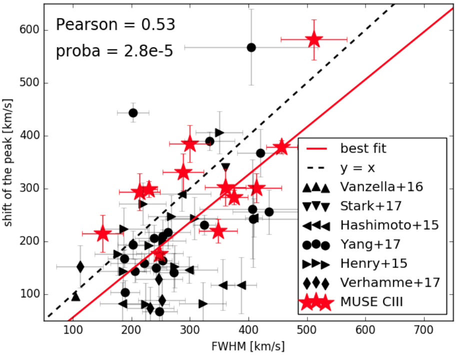
Recovering systemic redshift from Lyα : data

Method 1 : double peaks



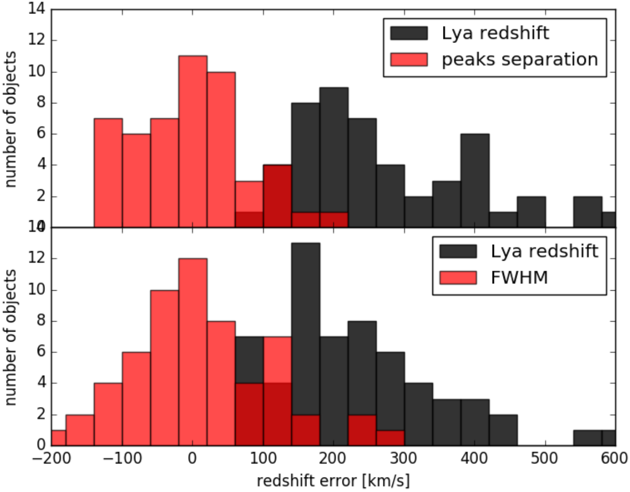
$$V_{peak}^{red} = 1.05(\pm 0.11) \times \Delta V_{1/2} - 12(\pm 37)\mathrm{km.s}^{-1}$$

Method 2 : single peaks



$$V_{peak}^{red} = 0.90(\pm 0.14) \times \mathrm{FWHM(Ly}\alpha) - 34(\pm 60)\mathrm{km.s}^{-1}$$

Recovering systemic redshift from Lyα



Lyα as indirect probe of LyC escape from galaxies

Theoretical Expectations

- spectral shape
- escape fraction
- spatial extent

Lyα as indirect probe of LyC escape from galaxies

Theoretical Expectations

- spectral shape
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Observations, today

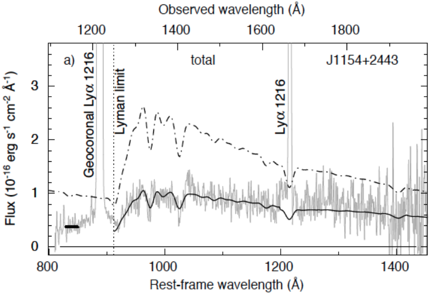
- 14 LyC emitters at z < 0.4

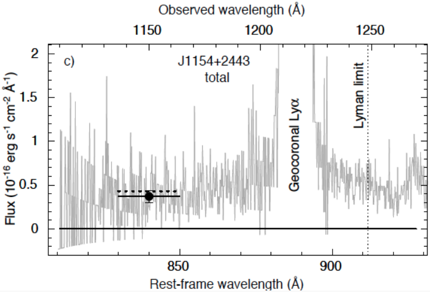
  Bergvall+06, Leitet+13, Borthakur+14, Leitherer+16, Izotov+16a,b,18
- 4 LyC emitters at 2 < z < 4

  Vanzella+16, Shapley+16, Bian+17, Vanzella+18
- upper limits on the escape fraction from galaxy populations

  Rutkowski+16,17, Grazian+17

$J1154+2443$: Green Pea with fesc(LyC) $\sim$ 46%





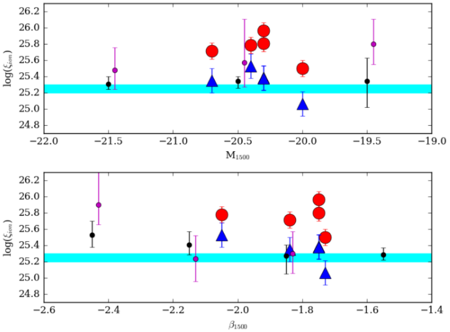
Izotov+18

Table 2. Extinction-corrected emission-line fluxes and equivalent widths in the SDSS spectrum

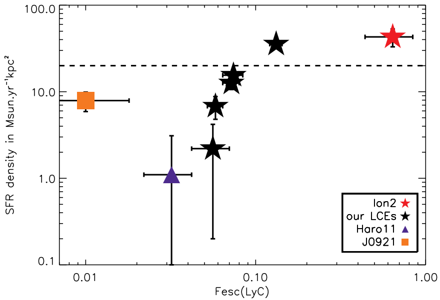
Line	λ	$I^{a,b}$	$I^{a,c}$	$EW_{obs}{}^{d}$
Mg II	2796	15.8±2.4	11.9±1.8	5
Mg II	2803	9.7±1.9	7.3±1.5	4
[O II]	3727	60.5±4.0	50.4±3.5	44
H9	3836	10.8±3.9	9.3±3.4	8
[Ne III]	3869	48.2±3.5	42.8±3.1	33
H8+He I	3889	24.4±4.0	21.4±3.5	20
H7+[Ne III]	3969	30.1±4.2	26.7±2.7	25
Hδ	4101	30.3±4.1	27.3±3.7	26
Hγ	4340	50.7±3.9	47.4±3.7	74
[O III]	4363	17.8±2.4	16.8±2.2	19
He I	4471	5.7±2.8	5.5±2.3	11
Hβ	4861	100.0±5.1	100.0±5.0	220
[O III]	4959	194.2±7.5	196.5±7.5	466
[O III]	5007	568.0±16.	577.5±16.	1121
He I	5876	10.8±1.8	11.7±1.9	33
Hα	6563	281.5±11.	318.7±12.	1150
[N II]	6583	3.5±1.8	3.9±2.0	10
[S II]	6717	4.6±1.5	5.3±1.7	16
[S II]	6731	5.4±1.3	6.2±1.5	22
He I	7065	10.6±2.1	12.4±2.5	65
$C(H\beta)^{e}$		0.250	0.070	
$I(H\beta)^{f}$		13.8	9.1	

Green Peas : local analogues of the sources of reionisation ?

ξ_{ion}, *Schaerer+16, Izotov+17*



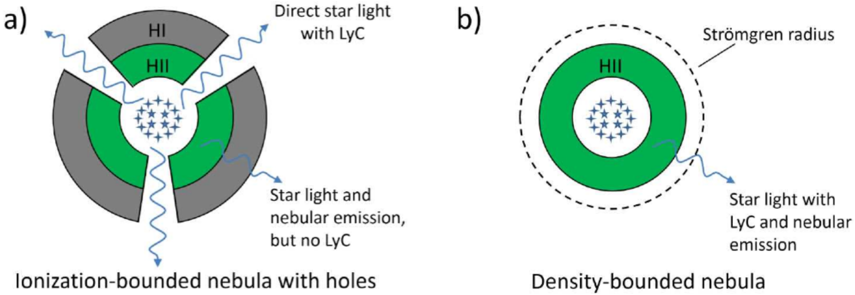
SFR density, *Verhamme+17*



Lyα spectra

Lyα spectra of LyC Emitters : two possible geometries

Zackrisson+13



Lyα spectra of LyC Emitters – Triple peaks from holes

Beamed Lyα Emission through Outflow-Driven Cavities

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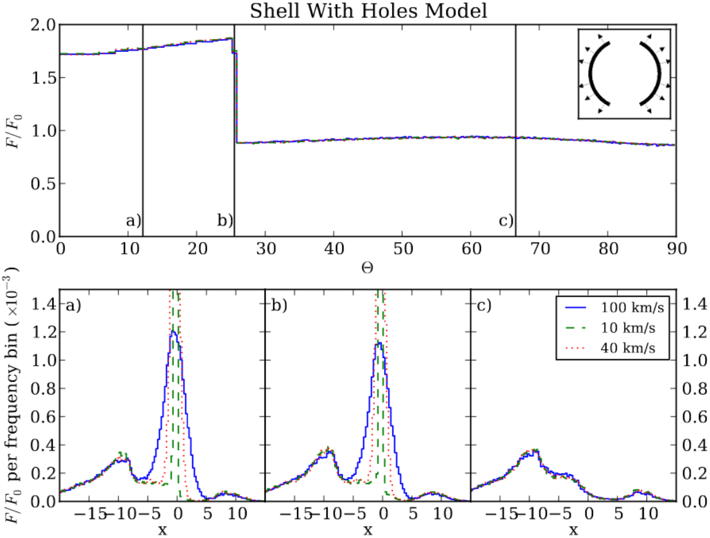
ABSTRACT

We investigate the radiative transfer of Lyα photons through simplified anisotropic gas distributions, which represent physically motivated extensions of the popular 'shell-models'. Our study is motivated by the notion that (*i*) shell models do not always reproduce observed Lyα spectral line profiles, (*ii*) (typical) shell models do not allow for the escape of ionizing photons, and (*iii*) the observation & expectation that winds are more complex, anisotropic phenomena. We examine the influence of inclination on the Lyα spectra, relative fluxes and escape fractions. We find the flux to be enhanced/suppressed by factors up to a few depending on the parameter range of the models, corresponding to a boost in equivalent width of the same amplitude if we neglect dust. In general, lower mean optical depths tend to reduce the impact of anisotropies as is expected. We find a correlation between an observed peak in the – occasionally triple-peaked – spectrum at the systemic velocity and the existence of a low optical depth cavity along the line of sight. This can be of importance in the search for ionizing photons leaking from high- redshift galaxies since these photons will also be able to escape through the cavity.

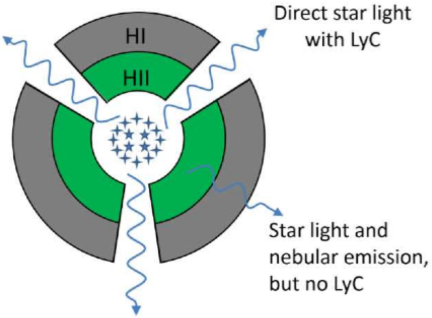
Key words. High-redshift Galaxies – Radiative Transfer

Lyα spectra of LyC Emitters – Triple peaks from holes

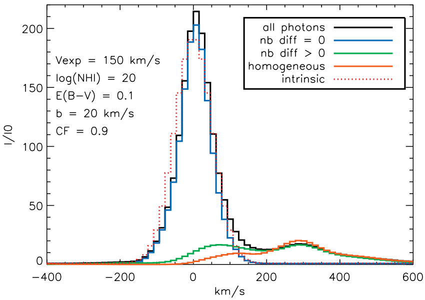
Behrens, Dijkstra, Niemeyer 2014



Lyα spectra of LyC Emitters – Triple peaks from holes

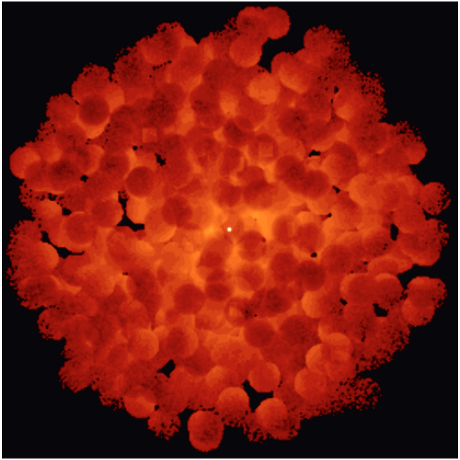


Verhamme+15

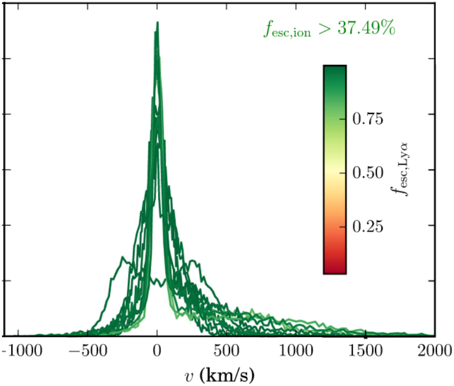


Lyα spectra of LyC Emitters – Triple peaks from holes

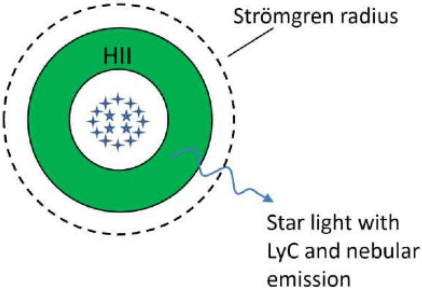
Laursen+13



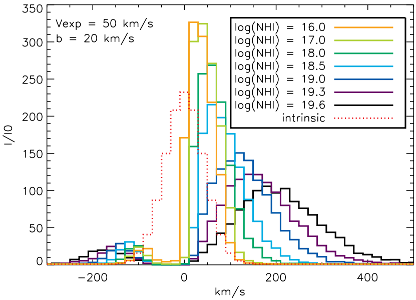
Dijkstra & Grönke 2016



Lyα spectra of LyC Emitters – small Δ_V from optically thin H II regions



Verhamme+15



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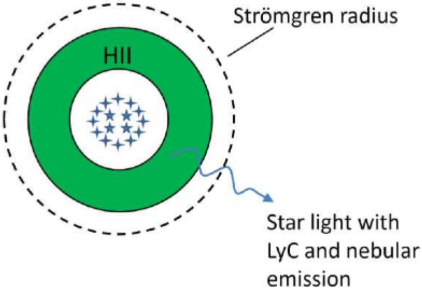
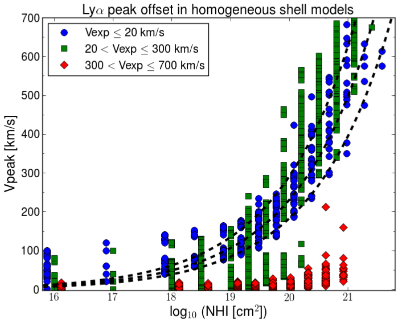
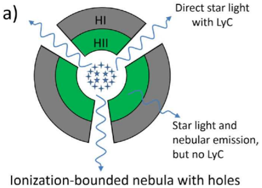
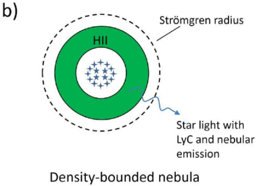


Verhamme+15

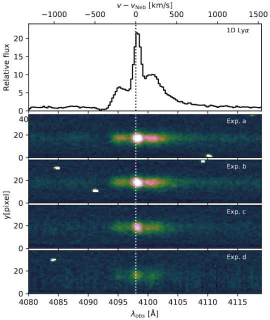


Lyα spectra of LyC Emitters : observations

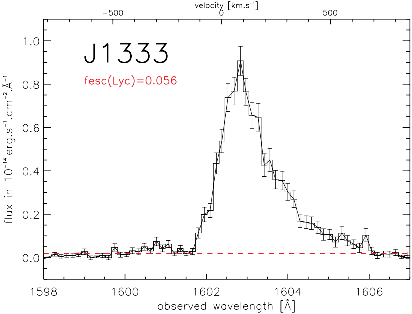




Rivera-Thorsen+17



Verhamme+17



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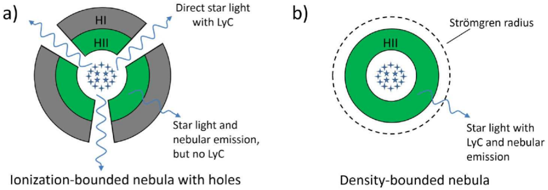

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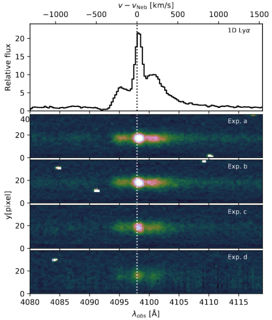
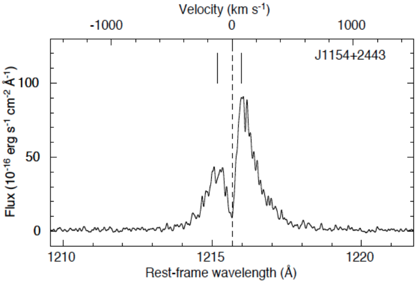
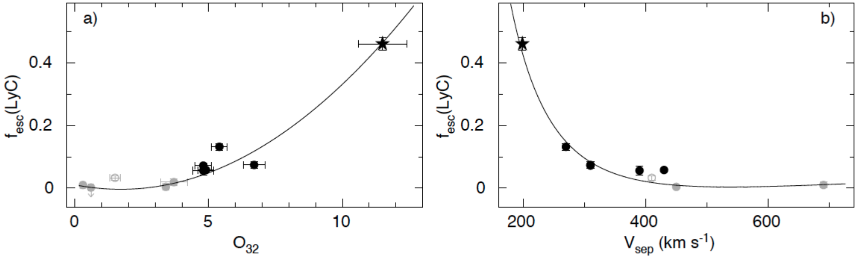


fesc(LyC) = 46% !, *Izotov+18*



Lyα spectra of LyC Emitters : observations

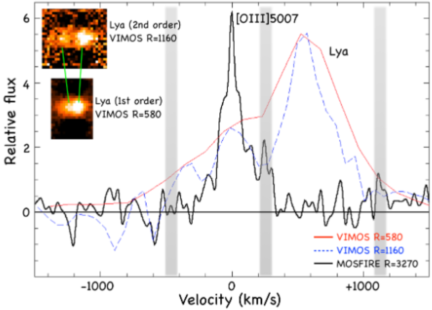
Verhamme+17, Izotov+18



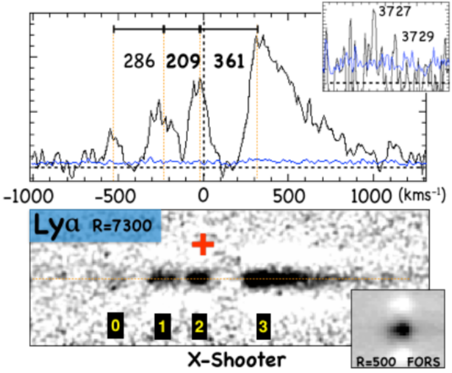
Lessons from local LyC Emitters

* [OIII]/[OII] ratios increase with increasing fesc(LyC)
* Lyα peaks separation decreases with increasing fesc(LyC)

ION 2, *de Barros+16*



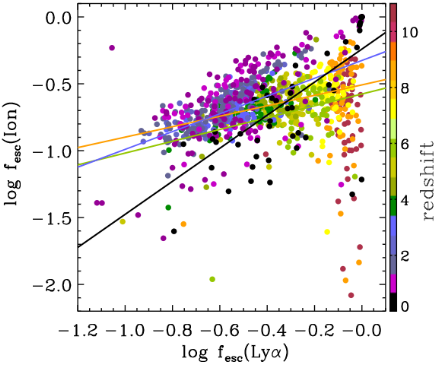
ION 3, *Vanzella+18*



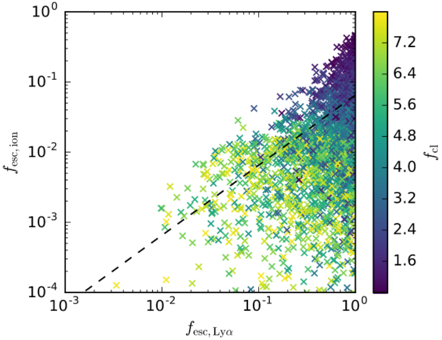
Lyα escape fractions

Lyα vs LyC escape fractions : predictions

Yajima+14

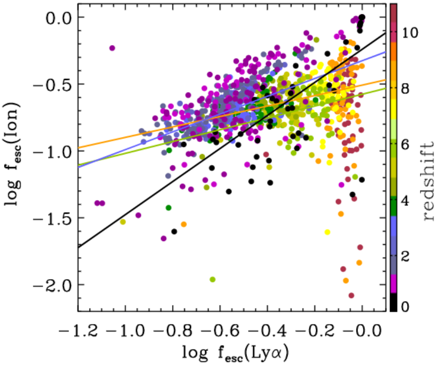


Dijkstra&Grönke, 2016

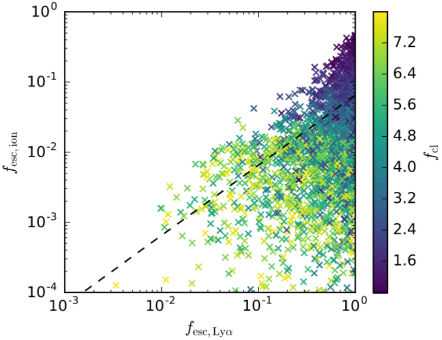


Lyα vs LyC escape fractions : predictions

Yajima+14

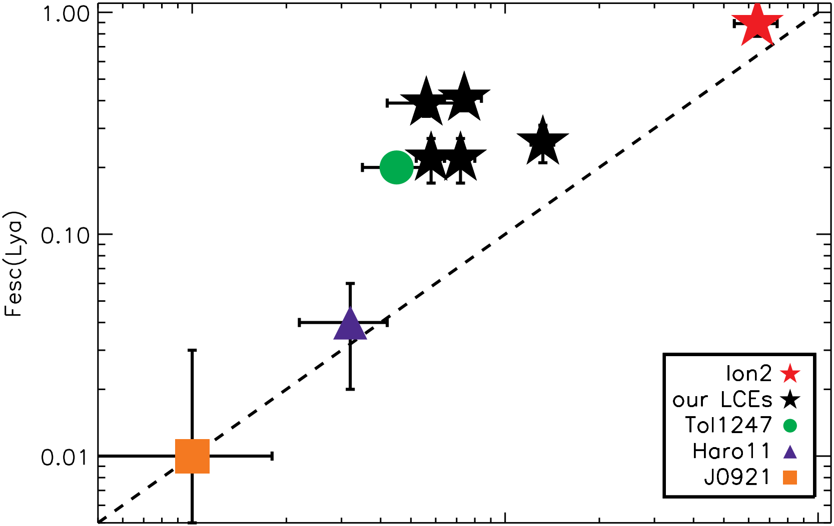


Dijkstra&Grönke, 2016



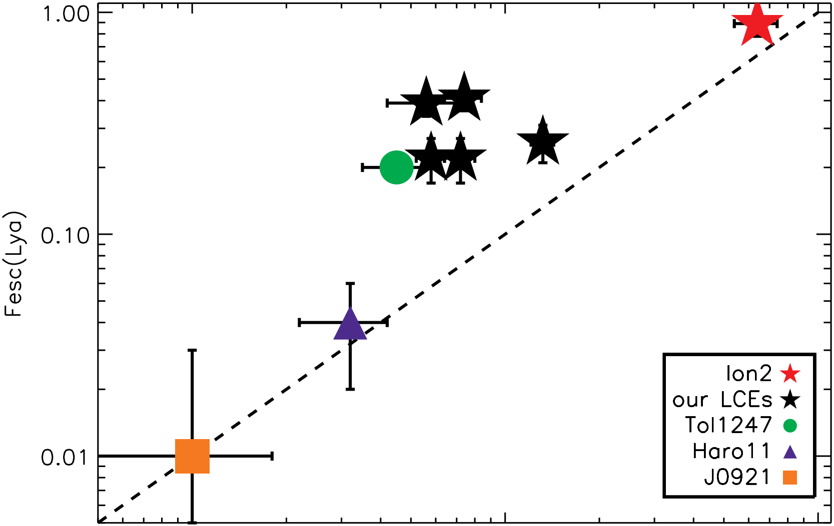
Lyα escape fraction > LyC escape fraction

Verhamme+17



Lyα vs LyC escape fractions : observations

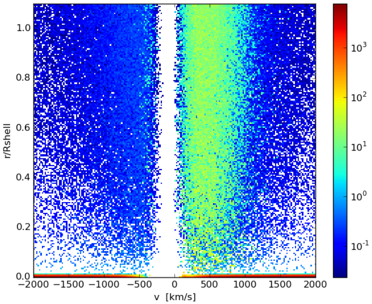
Verhamme+17

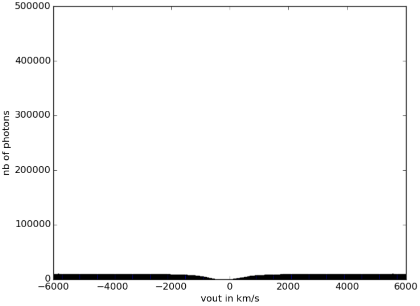


Lyα spatial distribution

Lya spatial vs spectral escape from expanding shells

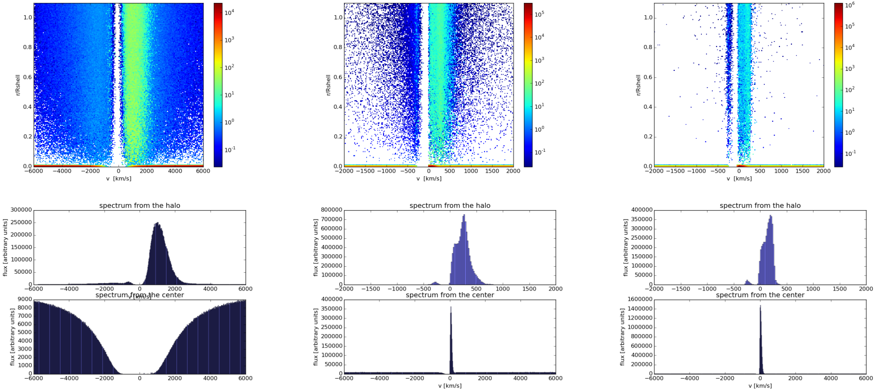
Verhamme, Garel et al, in prep
log(NHI) = 20.2, Vexp = 150 km/s





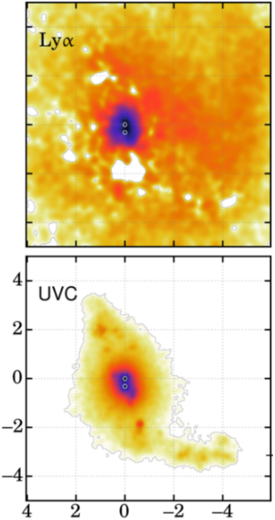
LCEs have no/faint halos

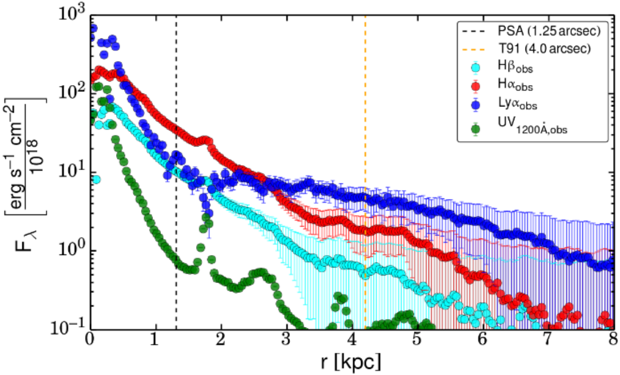
log(NHI) = 21.1 (LBG)	log(NHI) = 19.2 (LAE)	log(NHI) = 17.2 (LCE)



Lya halos of LyC Emitters : insights from observations ?

Puschnig+18, fesc(LyC) $\sim 1 - 4\%$





Lya halos of LyC Emitters : insights from observations ?

Marchi+17, see also Yang+16

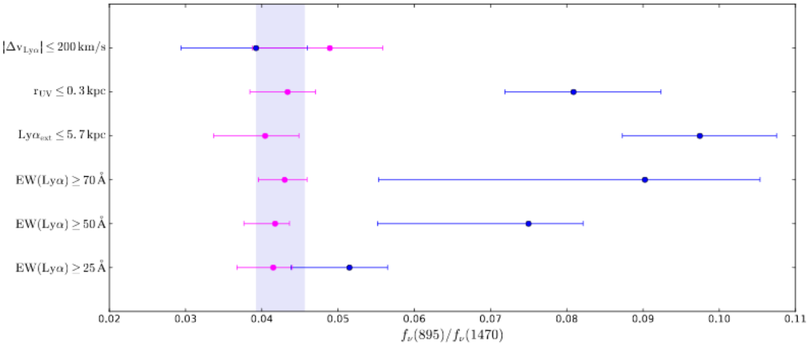


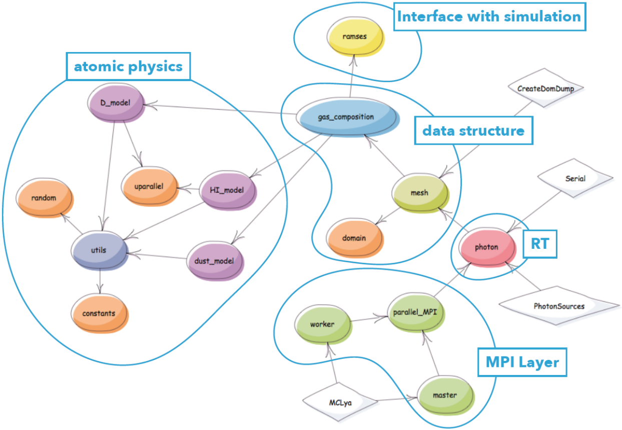
Fig. 3. Flux density ratios evaluated from the stacks of the samples in the y-axis (blue dots) and from the complementary samples (magenta dots) as indicated in Table 1. The lavender vertical band is the 1σ confidence interval evaluated for the total sample of 201 galaxies.

PRELIMINARY : Lyα properties of a virtual LyC emitter

New RT code : RASCAS (aka MCLya v.2.0)

A massively parallel code for line transfer in AMR simulations

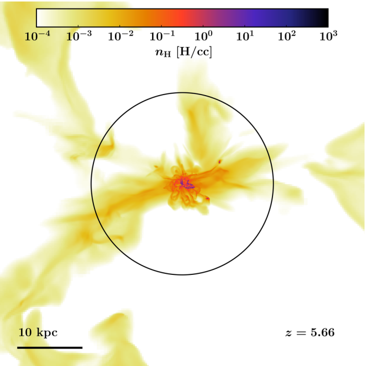
Michel-Dansac+17 in prep /w Verhamme

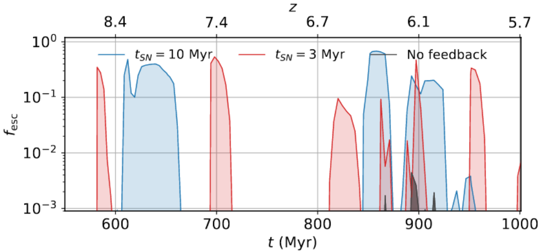


- memory footprint
- load balancing
- modularity

Lyα emission from a virtual $z \sim 6$ LyC Emitter

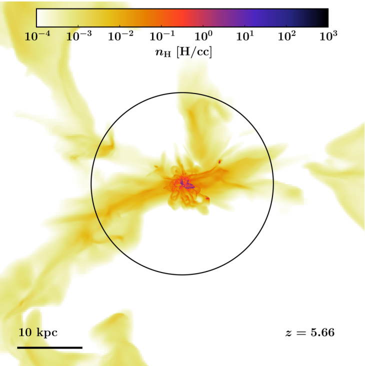
Trebitsch+17



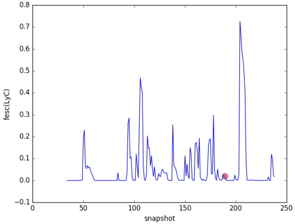


Lyα emission from a virtual $z \sim 6$ LyC Emitter

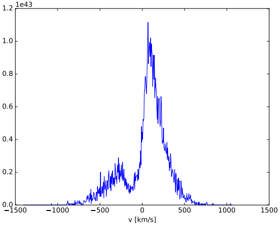
Trebitsch+17



LyC

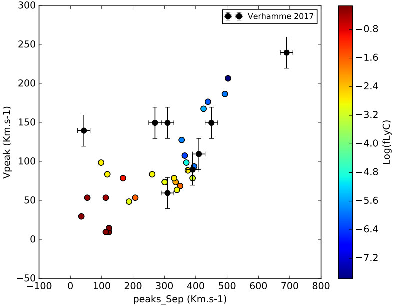


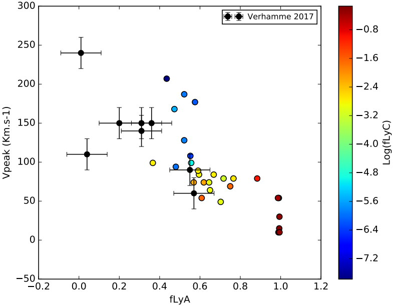
Lyα



Lyα emission from a virtual $z \sim 6$ LyC Emitter

Verhamme+18 in prep

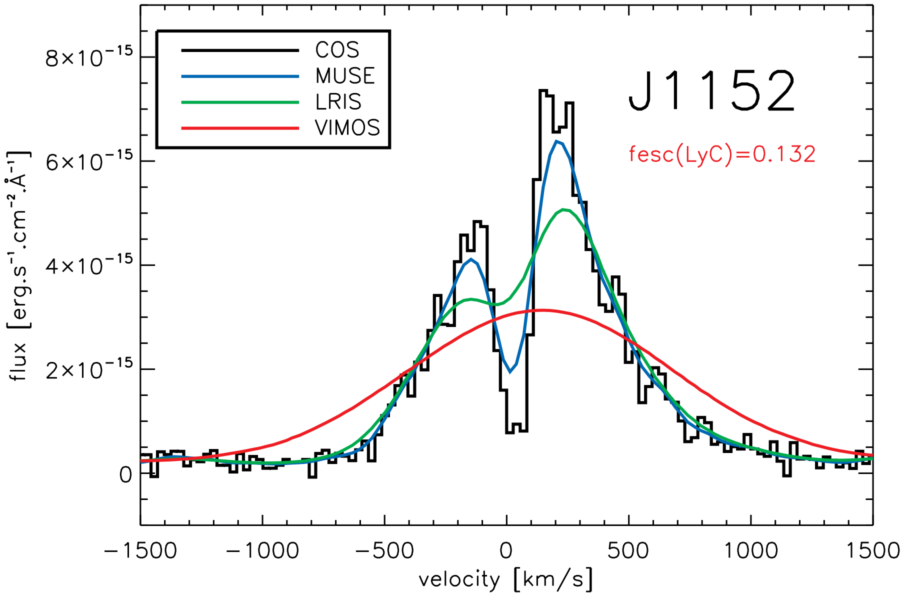




Conclusions

Lyα can trace LyC escape from galaxies :
LyC leakers have strong narrow Lyα lines with small peaks separations, high Lyα escape fractions, and are compact in Lyα.

Back-up slides



COS
MUSE
LRIS
VIMOS
J1152
fesc(LyC)=0.132
8×10⁻¹⁵
6×10⁻¹⁵
4×10⁻¹⁵
2×10⁻¹⁵
0
flux [erg.s⁻¹.cm⁻².Å⁻¹]
−1500
−1000
−500
0
500
1000
1500
velocity [km/s]