The Lyman α Emitter Luminosity Function at $3 < z < 6$ from MUSE-Wide

(Paper submitted to A&A)

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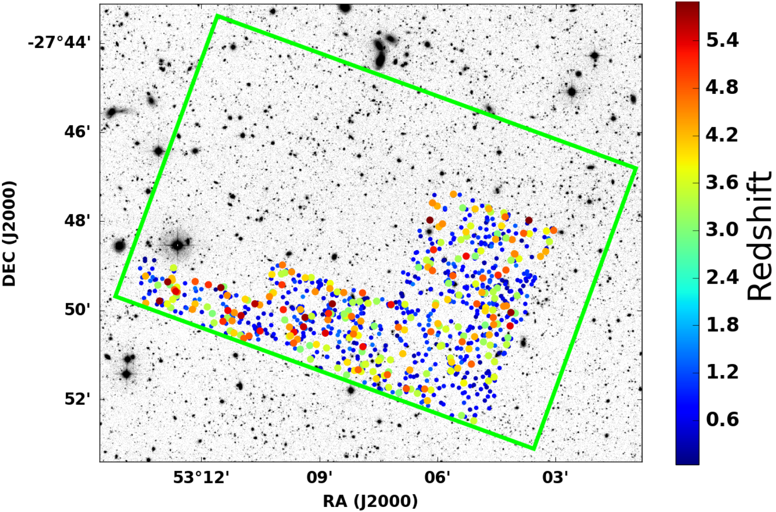
Why do we care about the Lyα Luminosity Function?

$$\mathrm{d}N_{\mathrm{LAE}} = \phi(L_{\mathrm{Ly}\alpha})\mathrm{d}L_{\mathrm{Ly}\alpha}\mathrm{d}V$$

- Luminosity functions provide the *gold standard* for summarising the changing demographics of galaxies with cosmic look back time.
- Essential physical mechanisms of galaxy formation and evolution are "frozen-in" into the LF.
- Substantial high-redshift galaxy samples:
  - Continuum Selection ($\approx$LBGs)
  - Emission Line Selection (LAEs)

  LFs connected via $\mathrm{EW}_{\mathrm{Ly}\alpha}$ distribution: $P(\mathrm{M}_{\mathrm{UV}}|\mathrm{EW}_{\mathrm{Ly}\alpha})$

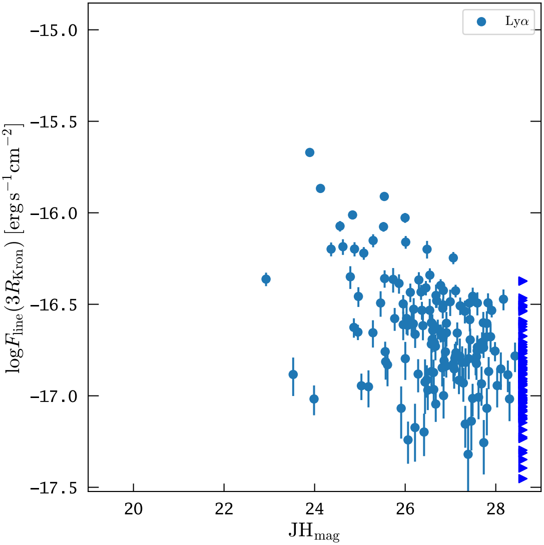
The MUSE-Wide (MW) survey



Herenz et al. (2017) - 24 MUSE pointings - 237 LAEs

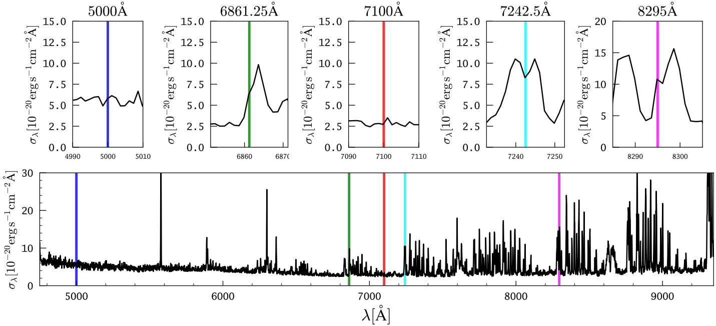
DR1: Urrutia et al. (in prep.) - 44 MUSE pointings - 479 LAEs

MW LAEs not listed in 3D/HST or CANDELS catalogues

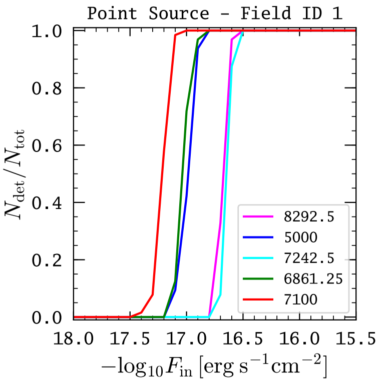


Selection function $f_c(F_{\mathrm{Ly}\alpha}, \lambda^{\mathrm{obs}}_{\mathrm{Ly}\alpha})$ from source insertion and recovery experiments

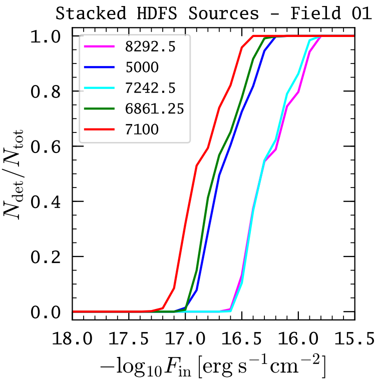
- Artificial point sources:
  3D Gaussian, FWHM(λ) as PSF, $v_{\mathrm{FWHM}} = 250\,\mathrm{km\,s^{-1}}$
  $\Rightarrow$ **PSSF** (*point source selection function*)
- Flux rescaled MUSE-HDFS LAEs (degraded to MUSE-Wide PSF)
  $\Rightarrow$ **RSSF** (*real source selection function*)



Individual selection functions

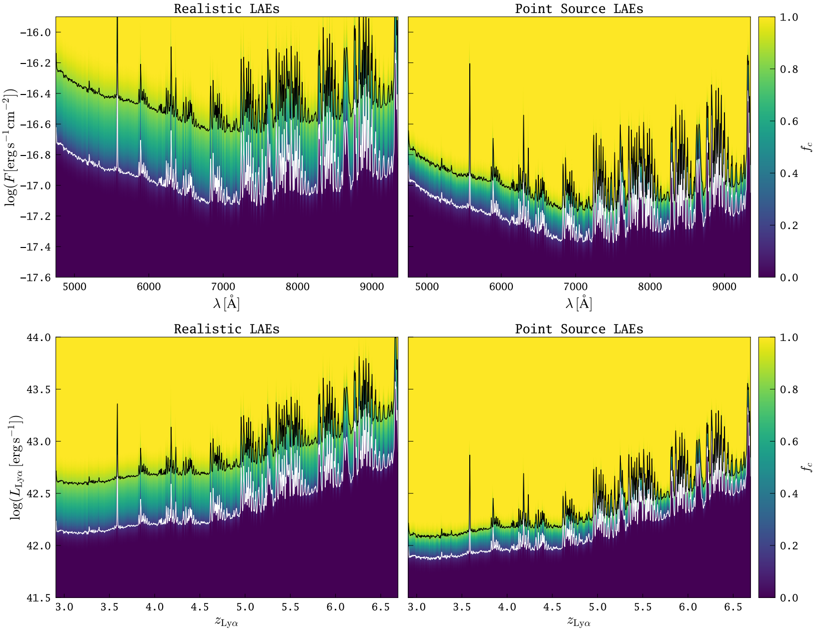


PSSF

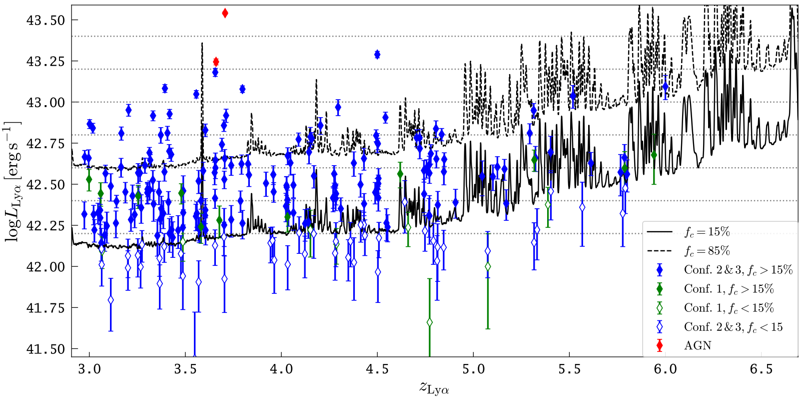


RSSF

Final selection functions



LAE Sample for LF: $f_c > 15\,\%$



179 of 237 remain (75.6 %)

Non-parametric Test for LF evolution.

Using a test developed by Efron & Petrosian (1992) we can test for seperability of the LAE LF ($\mathcal{H}_0$):

$$\Psi(L, z) = \phi(L)\rho(z)\,.$$

Redshift range	$\lvert\tau_{\rm PSSF}\rvert$	$\lvert\tau_{\rm RSSF}\rvert$	$p_{\rm PSSF}$	$p_{\rm RSSF}$
$2.9 < z \leq 4$	0.47	0.24	0.32	0.40
$4.0 < z \leq 5.0$	0.79	0.98	0.21	0.16
$5.0 < z \leq 6.9$	0.05	0.29	0.48	0.39
$\mathbf{2.9 < z \leq 6.9}$	**0.46**	**0.31**	**0.32**	**0.38**

$\Rightarrow \mathcal{H}_0$ can not be rejected. We can determine global $\phi(L)$.

3 different methods to calculate LAE LF

$1/\mathbf{V}_{\rm max}$ (Schmidt 1968):

$$V_{{\rm max},i} = \omega \int_{z_{\rm min}}^{z_{\rm max}} f_c(L_{{\rm Ly}\alpha,i}, z) \frac{{\rm d}V}{{\rm d}z}\,{\rm d}z$$

$$\phi_{1/V_{\rm max}}(\langle L_{{\rm Ly}\alpha}\rangle) = \frac{1}{\Delta L_{{\rm Ly}\alpha}} \sum_k \frac{1}{V_{{\rm max},k}} \qquad \Phi(L_{{\rm Ly}\alpha,k}) = \sum_{i\leq k} \frac{1}{V_{{\rm max},i}}$$

$\mathbf{C}^-$ (Lynden-Bell 1971):

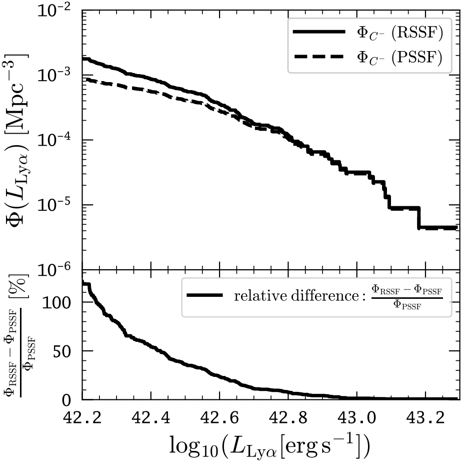
$$\Phi(L_{{\rm Ly}\alpha,{\rm k}}) = \Phi(L_{{\rm Ly}\alpha,1}) \prod_{i=2}^{k} \left(1 + \frac{1}{T_i}\right) \text{ with } T_i = \sum_{j=1}^{N_i} \frac{f_c(L_{{\rm Ly}\alpha,i}, z_j)}{f_c(L_{{\rm Ly}\alpha,j}, z_j)}$$

Page & Carrera (2000):

$$\phi_{\rm PC}(\langle L_{{\rm Ly}\alpha}\rangle) = \frac{N_{\langle L_{{\rm Ly}\alpha}\rangle}}{\omega \int_{L_{\rm min}}^{L_{\rm max}} \int_{z_{\rm min}}^{z_{\rm max}} f_c(L_{{\rm Ly}\alpha}, z) \frac{{\rm d}V}{{\rm d}z}\,{\rm d}z\,{\rm d}L}$$

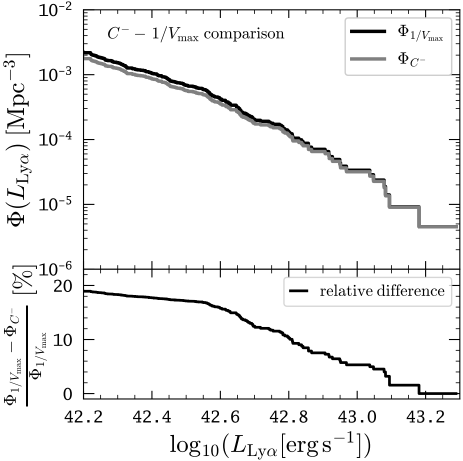
Bias in LAE LF when not accounting for Lyα haloes!

$$\Phi_{\mathrm{RSSF}}(\log L_{\mathrm{Ly}\alpha} = 42.2) = 2.5 \times \Phi_{\mathrm{PSSF}}(\log L_{\mathrm{Ly}\alpha} = 42.2)$$



C^- LAE LF $\approx 1/V_{\rm max}$ LAE LF

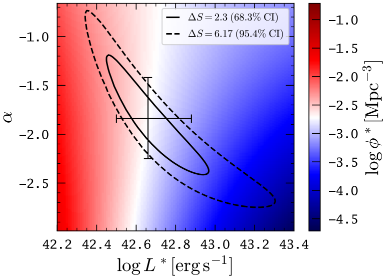
$$\Phi_{1/V_{\rm max}}(\log L_{\rm Ly\alpha} = 42.2) = 1.2 \times \Phi_{C^-}(\log L_{\rm Ly\alpha} = 42.2)$$

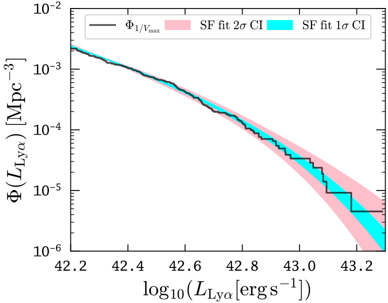


Maximum-Likelihood Analysis (Sandage 1976):

$$\phi(L)\,\mathrm{d}L = \phi^* \left(\frac{L}{L^*}\right)^{\alpha} \exp\left(-\frac{L}{L^*}\right) \frac{\mathrm{d}L}{L^*} \quad \text{(Schechter 1976)}$$

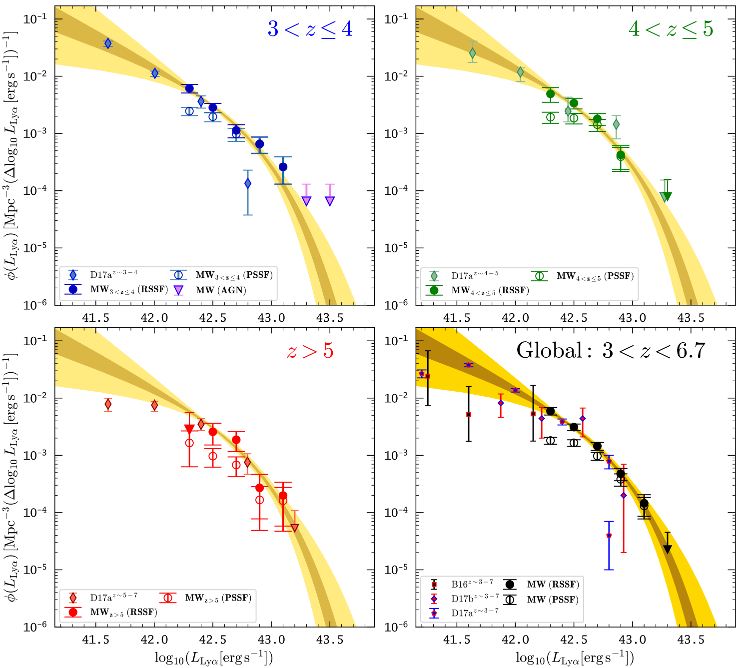
$$\mathcal{L} = \prod_{i=1}^{N_{\mathrm{LAE}}} p(L_i, z_i) \quad \Leftarrow \quad p(L_i, z_i) = \frac{\phi(L_i) f_c(L_i, z_i)}{\int_{L_{\mathrm{min}}}^{L_{\mathrm{max}}} \int_{z_{\mathrm{min}}}^{z_{\mathrm{max}}} \phi(L) f_c(L, z) \frac{\mathrm{d}V}{\mathrm{d}z}\,\mathrm{d}L\,\mathrm{d}z}$$

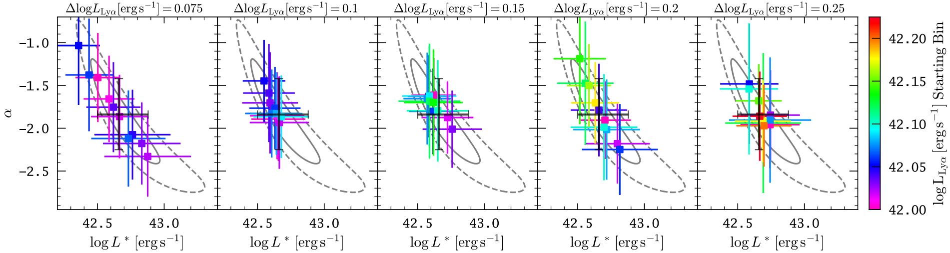




$\log L^* [\mathrm{erg\,s^{-1}}] = 42.66^{+0.22}_{-0.16}$ and $\alpha = -1.84^{+0.42}_{-0.41}$

Differential (binned) LAE LFs

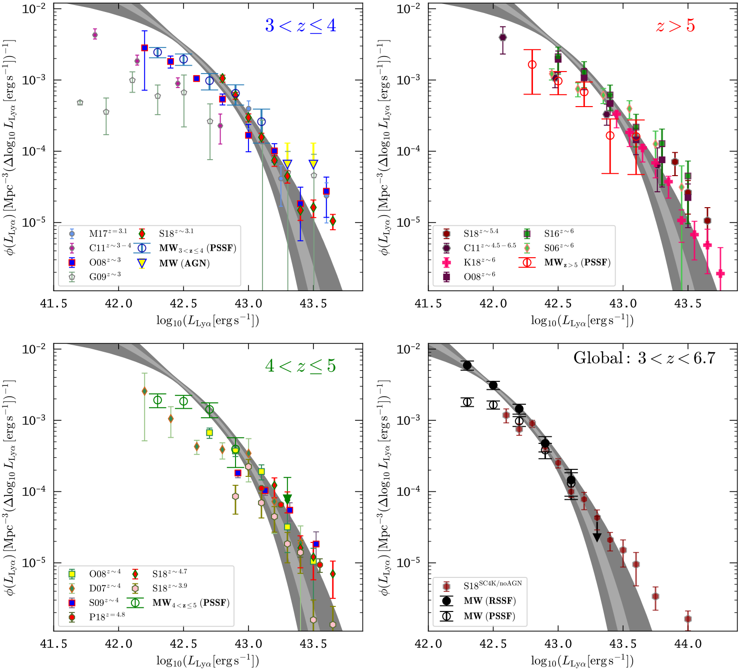




Resulting L^* and α depend sensitively on size of the bins and bin placement.

$\Rightarrow$ Don't fit to binned data!

Comparison to literature



Summary

- $(L_{\mathrm{Ly}\alpha}, z)$-space probed by MUSE-Wide:

$$42.2 \leq \log L_{\mathrm{Ly}\alpha}[\mathrm{erg\,s^{-1}}] \leq 43.5 \qquad 2.9 \leq z \leq 6.7$$

(Herenz+2017 sample: $\omega = 22.2\square' \hat{=} V = 2.3 \times 10^5\,\mathrm{Mpc}^3$)

- Within this sampled region $(L_{\mathrm{Ly}\alpha}, z)$-space LAE LF. appears non-evolving.

- Schechter parameterisation provides good fit - Power law not (see Paper).

$$\log L^*[\mathrm{erg\,s^{-1}}] = 42.66^{+0.22}_{-0.16} \qquad \alpha = -1.84^{+0.42}_{-0.42}$$

$$\log \phi^*[\mathrm{Mpc^{-3}}] = -2.71$$

- Literature LFs not accounting for extended low-SB Lyα halos (basically all, except Drake et al. 2017) are significantly biased at $L < L^*$.