The Faint-End of the Lyα Luminosity Function in the MUSE Deep Fields

Alyssa Drake
Postdoctoral Researcher, CRAL - Observatoire de Lyon, France

Bruno Guiderdoni, Jeremy Blaizot, Johan Richard, Takuya Hashimoto, Thibault Garel, Floriane Leclercq, Hanae Inami, Roland Bacon and the MUSE consortium
Science Questions & Overview

- Could star-forming galaxies have reionised the Universe?

- Results from the MUSE deep-field catalogues...

- The faint end slope of the Lyα luminosity function

- Evolution of the Lyα luminosity function?

- The contribution of LAEs to the cosmic SFRD

- Speculation: The ionising power of LAEs
MUSE Overview

• MUSE: Multi-Unit Spectroscopic Explorer
• Integral Field Spectrograph installed on UT4 at the VLT, Paranal
• Composed of 24 identical IFU modules.
• Integral Field Spectrograph
• F.o.V. 1 x 1 square arcminute
• 0.2 arcsecond sampling
• Resolution R ~ 3000
• Wavelength range 4750-9300Å
MUSE can simultaneously detect and spectroscopically identify galaxies
- it is very well suited to high redshift surveys
Predictions from MUSE mock-lightcones demonstrate that medium-deep surveys (~10 arc min, ~10 hrs) are ideal for probing the bulk of LAEs, best trade off with cosmic variance.

Garel, Guiderdoni & Blaizot (2016)
MUSE-HUDF
The MUSE Hubble Ultra Deep Field Survey PI: R. Bacon
MUSE consortium GTO

UDF10
- Single 1’x1’ field
- 30 hours exposure depth

UDF mosaic
- Mosaic of 9 1’x1’ fields
- 10 hours exposure depth
- Datacube 3681 x 947 x 945 (25 Gb)
MUSE HUDF: Catalogue

H. Inami et al. (in prep)

- “The complete 3D sky”
- Catalogues of ‘normal’ star-forming galaxies by virtue of their emission lines
- Lyα at (2.9 < z < 6.6)
Highlights:

- $\text{EW}_0$ ranges between 5 - 240 A (or more!)
- Scale length of EW distribution depends on Muv cut (lowering cut $\rightarrow$ larger scale length as including continuum-faint objects leads to more high EWs)
- At fixed Muv cut no evolution of scale length seen…
- 14 objects with $\text{EW}_0 > 200$A - no sign of AGN or mergers - i.e. v.young stellar populations and low metallicity
- See Takuya’s upcoming paper for details….

---

MUSE HUDF: Ly$\alpha$ Equivalent Widths


Using fluxes taken from Drake et al. 2017 (re-visited later…)

---

PRELIMINARY
MUSE HUDF:
The Faint-End of the Lyα Luminosity Function
Information from Luminosity Functions

LF gives simple way to parametrise the population
Number of objects per luminosity interval

Schechter Function tells us:
- Characteristic luminosity ($L^*$)
- Characteristic no. density ($\phi^*$)
- Gradient of faint end slope ($\alpha$)
Towards Lyα Luminosity Functions

Detection

Flux Estimates

Catalogue Building

Completeness ("Selection Function")

LF Method

Results

Be consistent!

Be systematic!

Irregular selection function —> impossible to reproduce.
Homogeneous Sample Selection

By definition, our MUSELET sample will be a subset of the LAEs verified by eye in the parent catalogue (Inami et al. in prep)

UDF10 123 LAEs, Mosaic 481 LAEs - Drake et al. (in prep)
LAEs are very extended!
See talks by F. Leclerq and L. Wisotzki (Wednesday afternoon)

- Leading literature LF results:
  - NB-selection efficient - but follow-up or extensive photometry required, small apertures
  - Blind spectroscopy so far generally small samples, slit loss problems, complicated selection functions

Wisotzki et al. (2016)
Flux Estimates

Aperture & Curve-of-Growth fluxes measured on continuum-subtracted NB image — the “Lyα image”
Comparison of Flux Estimates

Figure 2, Drake et al. 2016 (ArXiv1609.02920)
For brighter LAEs: C.o.G > 2” aperture…
Simulated ‘Realistic’ Halos

- Parameterised by
  - “Continuum-like” component
  - Halo component

- We draw values of halo scale length (kpc) and flux ratio (halo/core) from light profiles measured in Wisotzki et al. (2016), Leclercq et al. (in prep)
  - (See also MUSE-Wide paper including extended LAEs - Herenz et al., in prep, Potsdam team)

Drake et al. (in prep)
Flux Recovery Experiment

- Curve of growth does better for fluxes $\sim > -17.4$
- 2” systematically wrong across the flux range - but this makes it easier to correct

Detection → Catalogue Building → Flux Estimates → Completeness ("Selection Function") → LF Method

Preliminary

PRELIMINARY

PRELIMINARY
LAE-Completeness from Minicubes

- Work systematically through the MUSE cube
- Record the information of each input fake (RA, Dec, λ, z, L etc)
- This gives us the LAE selection function *for this catalogue*
In $C(z,L)$ we see the effect of sky lines on the recovery of fake LAEs.

Realistic LAEs are not recovered so readily as point sources (e.g. Herenz et al. in prep).
Pilot Study: Hubble Deep-Field South
Figure 4, Drake et al. 2016 (ArXiv1609.02920)

1/Vmax estimator in 0.35 dex bins (stars)

Narrow-band
Long-slit
Lensing

Our 27-hr “pilot study” is competitive with the depth of previous long-slit studies

• Small drop at faint end due to imperfect completeness correction & incomplete bin
The Global Lyα LF in the HUDF

Drake et al. (in prep)

1/Vmax estimator in 0.4 dex bins (stars)

With completeness using extended LAEs, the faint end picks right up

Cheat: Best fit Schechter

$\phi^* = -2.67$

$L^* = 42.59$

$\alpha = -1.93$

But, be wary of fits to binned data…
Our dynamic range reduces further when splitting into redshift bins…

Constraining φ*, L* with literature values and fitting to the combined dataset gives steep values of the faint-end slope, α (-2.44, -2.27. and ?)
Can we do better than this?
The Lyα LF in the HUDF

• Consider completeness on a fine grid of $\Delta \log f = 0.05$ Flux (erg s$^{-1}$ cm$^{-2}$) $\Delta z = 0.01$

• Bin our real objects on this grid

• Stepping through the grid create fake objects according to the completeness estimate at $(f,z)$, with fluxes distributed randomly in the box

• Use the maximum likelihood estimator to determine most likely Schechter parameters $(L^*, \alpha)$ that would reproduce the observed distribution of fluxes

• Fully exploit the data - rescale $\phi^*$ such that $(\phi^*, L^*, \alpha)$ reproduces total number of objects seen
The Lyα LF in the HUDF

Final samples with fakes...
Cutting each sample at the 25% completeness limit

<table>
<thead>
<tr>
<th>$z$</th>
<th>Volume $10^4 \text{ Mpc}^{-3}$</th>
<th>Real objects $^\dagger$</th>
<th>Total $^\dagger$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2.92 $\leq z \leq 3.99$)</td>
<td>3.10</td>
<td>193</td>
<td>328</td>
</tr>
<tr>
<td>(4.00 $\leq z \leq 4.99$)</td>
<td>2.57</td>
<td>144</td>
<td>346</td>
</tr>
<tr>
<td>(5.00 $\leq z \leq 6.64$)</td>
<td>3.64</td>
<td>50</td>
<td>176</td>
</tr>
</tbody>
</table>
The Lyα LF in the HUDF
Drake et al. (in prep)

Steep values of $\alpha$ in each redshift bin (all steeper than -2.0)

Evolution?
- $\alpha$ gets steeper with increasing redshift…
- No dramatic change in 1σ error ellipses (L*-\(\alpha\) space)
The Lyα LF in the HUDF: an experiment

• What if $L^*$, $\phi^*$ should really remain constant across all redshift bins?
• Placing a strong Gaussian prior on $L^*$, $\phi^*$:

We still see $\alpha$ get steeper!
The Contribution of LAEs to the Cosmic SFRD

Integrating to log \(L = 41.0\) erg s\(^{-1}\)

LAEs contribute 10 - 20% of the SFRD at \(z \approx 3.0\), reaching 100% by redshift \(z \approx 6.0\) — agreement with Ouchi et al. (2008) & Cassata et al. (2011).

Steep values of \(\alpha\) alone create this effect!

Any further boost in the luminosity density (e.g. IGM attenuation correction) would act to raise LAEs’ contribution…

LAEs may play a more significant role in the star-formation activity of the early Universe than first thought…?

NB. Using eq 9 of Ouchi et al. (2008) to convert \(L_{\text{Ly}a}\) to SFR i.e. I do not *currently* have the UV luminosity function to use or compare.

\[
\text{SFR}(M_\odot \text{ yr}^{-1}) = L_{\text{Ly}a}(\text{ergs s}^{-1})/(1.1 \times 10^{42}), \tag{9}
\]

combining the relation of \(H\alpha\) luminosity and star formation rate (Kennicutt 1998) and the case B approximation (Brocklehurst 1971). With the assumptions of a Salpeter IMF and solar metal-
Can we say anything about the ionising power of LAEs?

- Could star-forming galaxies have reionised the Universe?

Taking fiducial values for all these things…. Martin et al. (2008) calculate the necessary Ly\(\alpha\) luminosity density to maintain an ionised IGM at redshift 5.7:

- Escape of Ly\(\alpha\)? (0.5)
- Hard ionising spectra?
- Escape of LyC? (0.1)
- Clumping of the IGM? (6)

\[ \rho_{\text{Ly}\alpha} = 40.48 \text{ erg s}^{-1} \]

(and Dressler et al. 2011., Henry et al., 2012, Dressler et al., 2015)

NB. Actually more conservative Ly\(\alpha\) escape than the previous calculation
Can we say anything about the ionising power of LAEs?

Maximum-likelihood LF at $5.0 < z < 6.5$ using UDF mosaic LAEs

We need $\rho_{\text{Ly}\alpha} = 40.48 \text{ erg s}^{-1}$. …

Integrating to $\log L = 41.0 \text{ erg s}^{-1}$ gives $\rho_{\text{Ly}\alpha} = 40.682 \text{ erg s}^{-1}$!
Conclusions

Steep values of the faint-end slope, $\alpha$, across redshift range $(2.91 < z < 6.64)$

Tentative evidence for evolution of $\alpha$ (steeper towards higher $z$) — no dramatic evolution in $L^*-\alpha$ error ellipses

LAEs contribute more than we thought to the cosmic SFRD

LAEs at $(5.0 < z < 6.5)$ can maintain an ionised IGM (tiny extrapolation, but many assumptions)

*This is just the beginning! Thank you - stay tuned!*