Evolution of the $z \sim 6 - 7$ Lyman-alpha Luminosity Function

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Take home messages

Largest Lyman-alpha narrow band surveys at $z \sim 6 - 7$.

Drop in the Ly$\alpha$ LF happens for the faint sources. Little evolution on the bright end.

Hints for differential reionization.
Motivation

Neutral IGM  Ionised IGM
Motivation

Neutral IGM | Ionised IGM

Epoch of Reionization
Transition period
Neutral IGM

Ionised IGM

Epoch of reionization

Motivation

What are the main drivers?
How/when did it happen?
Lyman-alpha as a probe of high-z Universe

Lyα (1216 Å) emitted by star-forming galaxies + AGN

Observable from ground-based telescopes at z > 2

Intrinsically the brightest line
Lyman-alpha as a probe of high-z Universe

Ly$\alpha$ (1216 Å) emitted by star-forming galaxies + AGN

Observable from ground-based telescopes at $z > 2$

Intrinsically the brightest line

Resonant line - Highly affected by the IGM

“Problem” but also opportunity!

Easily scattered by neutral IGM -> Tracer of reionization
Narrow band Technique

Imaging with broad + narrow filters
Strong narrow band detection likely means an emission line at that wavelength

Two parameters $\Sigma$ and EW that quantify how significant the excess is.

We remove low redshift emitters by the position of the Lyman break.

\( z > 5 \ \text{Ly}\alpha \) must have no observed optical detection.
Lyman-alpha luminosity function

No evolution for $z \sim 3 - 6$

LF decreases for $z > 6$
(Reionization?)

Ouchi et al. 2010

Number density

Ouchi et al. 2010

0.9 deg$^2$ in UDS
NB magnitude < 26

$z=3.1$

$z=5.7$

$z=6.6$
Lyman-alpha luminosity function

Schechter fit may be failing to explain the brightest bins

Can we find more sources in larger volumes?

What are the effects of cosmic variance?

Ouchi et al. 2010

Ly\alpha Luminosity

Number density

\[ \log_{10}(\text{Number density}) \]

\[ \log_{10} L_{\text{L}y\alpha} \text{ (erg s}^{-1}) \]

\[ z=3.1 \]

\[ z=5.7 \]

\[ z=6.6 \]
Wide area narrow band survey at $z \sim 5.7$

Area $\sim 7$ deg$^2$
Volume $\sim 6 \times 10^6$ Mpc$^3$

Role of cosmic variance across 3 fields

Construct the LF right after the end of reionization

Previous results: Murayama+2007, Ouchi+2008, Hu+2010 (max $\sim 1.65$ deg$^2$)

Santos, Sobral & Matthee 2016
Selection criteria for $z = 5.7$

$\Sigma$ and Equivalent Width cuts

All line-emitters before interloper removal

LAEs
Line-emitters

Santos, Sobral & Matthee 2016
z=5.7 Luminosity Function

Up to ~ 0.4 dex separation for different paintings

Santos, Sobral & Matthee 2016

Number density

Luminosity density

log_{10}(\Phi) (Mpc^{-3} (dlogL)^{-1})

log_{10}L_{Ly\alpha} (erg s^{-1})

UDS (This work)
COSMOS (This work)
SA22-wide (This work)
SA22-deep (This work)
Westra+2006
Murayama+2007
Ouchi+2008
Ouchi+2008 Schechter fit
Hu+2010
$z=5.7$ Luminosity Function

- Number density
- Luminosity

$< 1$ source per $\sim 10^5 - 10^6 \, \text{Mpc}^3$

1 MUSE pointing
$z \sim 3 - 6$ covers $\sim 10^3 \, \text{Mpc}^3$

Santos, Sobral & Matthee 2016
$z = 5.7$ Luminosity Function

Our fit to Ouchi+2008

This work

Filter corrected

Santos, Sobral & Matthee 2016
Wide area narrow band survey at $z \sim 6.6$

Area $\sim 5 \text{ deg}^2$
Same EW cuts
Same sigma cuts
Same apertures
Similar area/volume

Same selection!

Construct the LF within reionization

Previous results Ouchi+2010 ($\sim 1 \text{ deg}^2$)

Matthee, Sobral, Santos et al. 2015
Evolution of the Luminosity function

\[ \log_{10}(\Phi) \] (Mpc\(^{-3}\)) \(\text{d}(\log L)\^{-1} \)

\[ z = 5.7 \]

\[ z = 6.6 \]

\[ z > 7 \]

Same selection

2’” aperture

\( EW_0 > 25 \)

Santos, Sobral & Matthee 2016
Luminosity function evolution

Dressler+2015: $-2.35 < \alpha < -1.95$

$-2.6 < \alpha < -1.9$ (1\(\sigma\))

Extremely steep faint end slope!

Santos, Sobral & Matthee 2016
Testing reionization – Toy model

Matthee, Sobral, Santos et al. 2015

Artist impression, NASA
Testing reionization – Toy model

**Observations**

![Graph showing observations with markers and shaded regions for different redshifts, including z = 5.7, z = 6.6, and z > 7.](image1)

**Toy model**

![Graph showing model predictions with curves for different recombination times, including τ_HI = 0.000, 0.010, 0.015, 0.020, 0.036, and 0.080.](image2)

*Santos, Sobral & Matthee 2016*

*Matthee, Sobral, Santos et al. 2015*
Testing reionization – Toy model

Observations

If the drop is caused by reionization, we would expect large Lyα sizes for the faint sources at z=6.6

Santos, Sobral & Matthee 2016
Testing reionization – Toy model

Observations

If the drop is caused by reionization, we would expect large Lyα sizes for the faint sources at $z=6.6$

*Santos, Sobral & Matthee 2016*

We can test this!
**Lya sizes and evolution at z = 5.7 - 6.6**

Median results consistent with Momose+2014

Extension of Lya

Luminosity in 2” apertures

Santos, Sobral & Matthee 2016
Lyα sizes and evolution at z = 5.7 - 6.6

Extension of Lyα

Luminosity in 2” apertures

Santos, Sobral & Matthee 2016
Lyα sizes and evolution at $z = 5.7 - 6.6$

Lyα in a more neutral medium scatters

Extended emission

Hints for differential reionization

Santos, Sobral & Matthee 2016
Follow-up of sources

Two brightest Lyman-alpha emitters at \(z=6.6\)

Sobral et al. (inc. Santos) 2015

Spectra from X-SHOOTER

Spectra from DEIMOS, KECK

\(z = 6.6\)

\(z = 5.7\)
CR7

ESO TOP 10 Astronomical Discoveries
CR7

Lyα

HeII

constrains in metal lines
First galaxy with evidence of a very hard ionising source \( (T_{\text{eff}} > 10^5 \, \text{K}) \) and extremely low metallicity \( (Z < 10^{-2.5}) \)
First galaxy with evidence of a very hard ionising source \((T_{\text{eff}} > 10^5 \text{ K})\) and extremely low metallicity \((Z < 10^{-2.5})\)

**POPIII-like or DCBH?**
Conclusions

• We constructed the largest NB surveys at $z \sim 6 - 7$

• Cosmic variance influences results (variations up to 0.4 dex)

• Steep faint end of the Ly$\alpha$ LF

• Differential evolution of the bright and faint ends

• Faint Ly$\alpha$ haloes more extended at $z \sim 6.6$

Hints for differential reionization
Thank you for your attention