Semi-analytic modelling of Lyman-alpha emitting galaxies at high redshift

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**Introduction**

**Strong emission line from HII regions**
(2/3 ionising photons reprocessed into Lyα)
- Powerful tool to probe high-z galaxies, especially faint ones undetected in UV
  - Building blocks of local L* galaxies?

- Thousands of Lyman-alpha Emitters (LAE) at z > 2
  (mostly in narrow-band surveys - Ouchi+08, Hu+10)

- Lyα emission also found in UV-selected galaxies
  (only some Lyman-break galaxies show Lyα emission)
  - How are LAEs and LBGs connected?

**Figure 14**

The largest difference between our LFs and those of previous works is at high luminosities, where our LFs are fainter than the present photometry, and it is about a factor of two lower than the Kashikawa et al. (2008) LF. It is similar to the Malhotra & Rhoads (2004) spectroscopic sample (green solid curve). Building blocks of local L* galaxies?

**How are LAEs and LBGs connected?**
Introduction

ISM optically thick to Ly\(\alpha\) photons

- Resonantly scattered by HI

\[\text{Increases travel, increases dust absorption}\]

HI kinematics

- e.g. galactic winds very common at high \(z\)
  \((\text{Steidel+10})\)

\[\text{Likely to affect Ly}\alpha\ \text{line profiles}\]
Model - Can we reproduce statistical Lyα and UV properties taking into account resonant scattering in gas outflows?
GALICS semi-analytic model

- Hatton+03 (and also Cattaneo+06, Garel+12)

WMAP-5 cosmology
$1024^3$ particles
$M_{\text{halo,min}} \sim 2 \times 10^9 M_\odot$

$100 \ h^{-1} \ \text{Mpc}$

UV luminosity functions matched at $3 < z < 7$

$f_{\text{esc}}(\text{UV}) = e^{-T_{\text{dust}}}$
Model - \textit{Lya emission}

\[ \mathcal{L}_{\text{Ly}\alpha} \propto \frac{2}{3} \dot{N}_{\text{ion}} \]

\[ \Phi \ [\text{erg s}^{-1} \text{ A}^{-1}] \]

Lyman limit

[Graph showing the relationship between the Lyman limit and the flux \( \Phi \).]
Model - Lyα radiative transfer in gas outflows (Garel+12)

Coupling with Lyα transfer simulations in expanding shells

Shells parameters in GALICS:

- \( N_{\text{HI}} \sim X_{\text{H}} \frac{M_{\text{cold gas}}}{(4\pi R_{\text{disc}}^2)} \)
- \( V_{\text{exp}} \sim \text{SFR}^{1/6} \)
  - SN-powered wind model - Bertone+05
- \( \tau_{\text{dust}} \sim \frac{Z}{Z_{\odot}} \frac{N_{\text{HI}}}{(1+z)^{-1/2}} \)
  - Empirically calibrated on local galaxies - Devriendt+99

Lyα escape fraction
Ly$\alpha$ & UV escape fraction

- Low $N_{HI}$:
  \[ f_{\text{esc}}(\text{UV}) \approx f_{\text{esc}}(\text{Ly$\alpha$}) \]
  weak effect of Ly$\alpha$ resonant scattering

- High $N_{HI}$:
  \[ f_{\text{esc}}(\text{Ly$\alpha$}) \ll f_{\text{esc}}(\text{UV}) \]
  strong effect of Ly$\alpha$ resonant scattering
Ly\(\alpha\) luminosity functions

\[ L_{\text{Ly}\alpha} = f_{\text{esc}} L_{\text{Ly\alpha,intr}} \]

Garel+14, in prep
Their data is about a factor of two lower than that of their sample of spectroscopically confirmed galaxies which are based on model reproduces nicely the observed LFs of Hu et al. We see that our surveys are small and Garel et al. will address these issues in more details in a next paper. Large homogeneous datasets are therefore still needed to may explain the discrepancy between both measurements. are probed as well as incompleteness issues or slit losses due to the rather small and elongated volumes that match with the findings Cassata et al. who measure to favour the number density reported by Rauch et al. are plotted in all panels, except for z ~ 5.7.

Observed Lyα luminosity functions well reproduced from z=3 to z=7
Lyα properties of Lyman-break galaxies

Fraction of Lyα emitters in LBG samples increases towards faint UV magnitude

Data points from Stark+10
(EW > 50 Å)

Garel+14, in prep
Lyman-alpha (Ly\(\alpha\)) and UV emission (after dust attenuation)

Model matches well the bulk of the data

Garel+14, in prep
UV properties of Lyman-alpha emitters

Lyα and UV emission (after dust attenuation)

Model matches well the bulk of the data

High EW objects (EW=100-300 A) => IMF? Starburst?

Garel+14, in prep
High Lyα equivalent widths - *Inclination effects?*

Hydro simulation (AMR) + Lyα transfer

*Verhamme, Dubois, Blaizot, TG, et al. 2012*

![Simulations](image)

**edge-on**

**face-on**

*Draine & Lee 1984*

*Inoue 2003*

*Dib et al.*
High Lyα equivalent widths - *Inclination effects?*

Hydro simulation (AMR) + Lyα transfer

Verhamme, Dubois, Blaizot, TG, et al. 2012

- Lyα photons emitted edge-on tend to escape face-on: *path of least HI opacity*
- Face-on, we can have: $EW_{\text{obs}} > EW_{\text{intr}}$
Contribution of LAEs to SFR density

Cumulative SFR density as a function of Ly\(\alpha\) flux at z=3

- Strong contribution of faint LAEs
- Predictions for MUSE surveys:
  - Shallow field
  - Medium-Deep field
  - Deep field

MUSE Medium-Deep survey should probe 2x more SFR than current NB surveys at z=3 (5x more at z=6)

Garel, Guiderdoni & Blaizot, in prep
Progenitors of z=0 objects - (work in progress)

z=0 mass distribution of halos with at least one LAE progenitor at z=6 detectable in:
- MUSE Shallow field
- MUSE Medium-Deep field
- MUSE Deep field

- For given Lyα flux range
  - minimum halo mass at z=0

- Bright LAEs ( > 10^{-17} \text{erg s}^{-1} \text{cm}^{-2} )
predicted to be progenitors of massive halos
  ( 10^{12} - 10^{15} M_{\odot} )

- Faint LAEs (~10^{-18} \text{erg s}^{-1} \text{cm}^{-2} )
probe MW-like halos

Garel, Guiderdoni & Blaizot, in prep

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Summary

- Simple model based on semi-analytic approach and Lyα transfer in outflows can reproduce many Lyα and UV statistical constrains (e.g. abundances)

- Lyα and UV cross-properties well reproduced as well, but missing ingredients to match EW distribution

- Faint-end sources predicted to be:
  - significant contributors to cosmic SFR density at z=3-6
  - progenitors of MW-like halos at z=0