New analysis of LyC leaking z~3 galaxies in the SSA22 field

Genoveva Micheva
Ikuru Iwata
Akio Inoue

NAOJ Mitaka, January 15, 2015
Content

- Introduction
- Observational data
- LyC candidates
- Photometry: total magnitude, colors, models
- Conclusions
Introduction:
Lyman Continuum and Reionization

- Ionizing radiation (LyC) escapes into the intergalactic medium (IGM) and contributes to reionizing the Universe ($z>6$) or to keeping it ionized ($z<6$) → $f_{\text{esc}}$
- $f_{\text{esc}}$ very sensitive to neutral hydrogen HI
- With increasing redshift Universe becomes more opaque to LyC.
- Measuring $f_{\text{esc}}$ from individual galaxies impossible at $z\geq 4$. 
Low redshift search (z<2) has proven difficult. Only 2 galaxies with direct detections (Leitet+11, +13). The rest are upper limits (e.g. Leitherer+95, Cowie+09, Siana+07,+10).

Most fruitful redshift for LyC escape detection has proven to be redshift z~3 (e.g. Mostardi+13 @ z~2.85; Iwata+09, Nestor+11,+13 @ z~3.09)
Introduction: SSA22 proto cluster

- RA 22:17:36 Dec +00:17:00
- Redshift z=3.09
- An overdensity of LBG (Steidel+98)
- An overdensity of LAE (Steidel+00)
- LABs (“Lyα Blobs”) first discovered in SSA22
- Included in many imaging and spectroscopic surveys: GDDS, VVDS, CFRS, CDPS, etc...
Observations

- Subaru (8.2m)/Suprime-Cam:
  - 10 CCDs, FoV 34' x 27', pixel scale 0.20"
- Field: SSA22 proto-cluster
- Broadband BVRiz (Nakamura+11)
- Narrowband NB497 = Lyα (Hayashino+04)
- Narrowband NB359=LyC (Iwata+09)
- Spectroscopic data for redshift determination (SUBARU/FOCAS, VLT/VIMOS, KECK/LRIS, KECK/MOSFIRE)
Imaging Data quality

- B 2008, 2.6h, PSF=0.78'', AB=29.08 (1σ)
- V 2002, 2003, 2008, 2.1h, PSF=0.82'', AB=28.85 (1σ)
- R 2000, 2001, 2.9h, PSF=1.06'', AB=28.22 (1σ)
- i 2001, 1.4h, PSF=0.78'', AB=28.28 (1σ)
- z 2001, 2002, 2003, 2.9h, PSF=0.77'', AB=27.77 (1σ)
- NB497 2002, 7.2h, PSF=1.00'', AB=27.9 (1σ)
- NB359 2007, 22h, PSF=0.8'', AB=28.52 (1σ)
In the SSA22 field we have: 148 LBGs, 173 LAE, 7 AGN

R-band non-detections excluded (R<27.5 mag)

All redshifts spectroscopically determined

Preliminary sample selection (a “LyC candidate” has a $3\sigma$ detection in LyC filter, within 1.4'' of R or Lyα position):

- 40 LyC candidates (with $3\sigma$ detection in LyC)
  - So far 4 confirmed foreground contamination

36 LyC candidates @ z>3.06
  - 21 LAE
  - 13 LBG
  - 3 AGN

Subaru/Suprime-Cam wide field + SSA22 proto cluster => The largest LyC candidate sample at any redshift
Examples

LAE

$R = 24.8 \text{ mag}$

$f_{\text{LyC}} / f_{\text{UV}} = 0.88 \pm 0.15 \text{ @LyC}$

$f_{\text{LyC}} / f_{\text{UV}} = 0.66 \pm 0.16 \text{ @R}$

1.2" aperture

Contours: 2 & 3 $\sigma$
Examples

LBG

\[ R = 25.13 \text{ mag} \]

\[ \frac{f_{\text{LyC}}}{f_{\text{UV}}} = 0.40 \pm 0.13 \text{ @LyC} \]

\[ \frac{f_{\text{LyC}}}{f_{\text{UV}}} = 0.38 \pm 0.14 \text{ @R} \]

1.2'' aperture

Have HST F336W for some

Contours: 2 & 3 \( \sigma \)
Examples

LAE

Possible contamination
Offset substructure has no redshift

LAE

\[ R = 26.03 \text{ mag} \]

\[ \frac{f_{\text{LyC}}}{f_{\text{UV}}} = 1.02 \pm 0.09 \ @ \text{LyC} \]

\[ \frac{f_{\text{LyC}}}{f_{\text{UV}}} = \text{NaN} \ @ \text{R} \]

1.2'' aperture

Contours: 2 & 3 \( \sigma \)
Yellow: control sample

Gray:
Bluest SB99 V-i color predictions

Gray Dashed:
Bluest Schaerer03 PopIII V-i color predictions

AB mag

- Blue LAE fainter than red LAE
- Some galaxies show extreme UV slopes at all mags, violate model prediction
AB mag

Conversion to EW(Lyα) following Matsuda+09, with NB497 filter and B,V

Only for redshift range 3.063<z<3.127

Fainter galaxies have stronger Lyα

LyC leakers not the strongest LAE

Consistent with literature
Gray:
Bluest SB99 V-i color predictions

Gray Dashed:
Bluest Schaerer03 PopIII V-i color predictions

AB mag

Blue LAE have extreme LyC

Fainter galaxies leak LyC more vigorously
Lya vs LyC

Same escape route?
Stellar evolutionary models:

Gray: Starburst99

w/ Salpeter IMF (2.35)

1-100M ☼

0 Myr

no IGM

Z=0.0004

IGM added from Inoue+14

With total magnitudes

at R-band position

Dust arrow E(B-V)=0.1
Stellar evolutionary models:

Yellow: Schaerer+03
w/ Salpeter IMF (2.35)
1-100M ☼
0 Myr
no IGM
PopIII
IGM added from Inoue+14

With total magnitudes
at R-band position

Dust arrow E(B-V)=0.1
Expected Number of Foreground Contaminations

Run Monte-Carlo simulations similar to Nestor et al. (2013)

Based on spatial offset $d$ between NB(LyC) and R(UV) or NB(Lyα)

Foreground source density based on U-band number counts by Vanzella+ 2010

Among 149 LBGs, about $13-7=6$ objects (~4%) are genuine LyC leakers.
Expected Number of Foreground Contaminations

Run Monte-Carlo simulations similar to Nestor et al. (2013)

Based on spatial offset $d$ between NB(LyC) and R(UV) or NB(Lyα)

Foreground source density based on U-band number counts by Vanzella+ 2010

Among 18 objects with offset < 1.1” (8.4kpc) offset with NB497(Lyα)

Among 173 LAEs, about 18-9=9 objects (~5%) are genuine LyC leakers.
Escape Fraction

\[ f_{\text{esc}} = \frac{L_{\text{LyC, out}}}{L_{\text{LyC, in}}} = \frac{(f_{\text{LyC}}/f_{\text{UV}})_{\text{obs}}}{(f_{\text{LyC}}/f_{\text{UV}})_{\text{int}}} \times 10^{-0.4A_{\text{UV}}} \exp(\tau_{\text{IGM,LyC}}) \]

For LBGs with LyC detections
- statistically corrected for foreground contaminations
- dust attenuation corrected with UV slope
- Depending on model: median \( f_{\text{esc}} = 6\%-11\% \)

LBGs: Stacking of LyC non-detections shows no signal

For LAEs with LyC detections
- None of the models actually fit the observations
  → here indicating a range of \( f_{\text{esc}} \) is not informative
- We can stack all LAEs. For LAE stack:
  → Depending on model: \( f_{\text{esc}} = 6\%-14\% \)

LAEs: Stacking of LyC non-detections shows no signal
Conclusions

- Statistically unlikely that all LyC detections are contaminants
- LyC escape comes from fairly compact clumps
- Stacking of non-detection (<3σ) shows no significant signal
  - Escape fraction could be bimodal: some have high LyC, others none
  - Or viewing angle?
- Many LyC candidates show an offset between LyC and Lyα or UV
  - Infall of smaller object facilitates escape?
- All LyC LAE are extreme LyC leakers, and have colors inconsistent with the bluest most extreme models with Salpeter IMF, 0 Myr, no dust, no IGM, no nebular emission, low or 0 metallicity.
- Galaxies with strong LyC also have significant Lyα
  - Same escape route for LyC and Lyα photons?
Distribution of Spatial Offsets

- LyC emitting region of LBGs are often sub-component (or satellite) in R-band (rest UV).

- LyC emitting region of LAEs mostly aligns with R-band but some have spatial offsets with NB497 (Lyα).
Control sample vs LyC candidates

- Large LBGs are more often also LyC leakers compared to small LBGs → the LyC fraction tends to increase with size for LBG
- Trend preserved with filter → does not reflect mass → is likely due to the offset substructure → could indicate infall/accretion of a minor object