Outside the Lyman-break box: detecting Lyman continuum emitters at $3.5 < z < 5.1$ with CLAUDS

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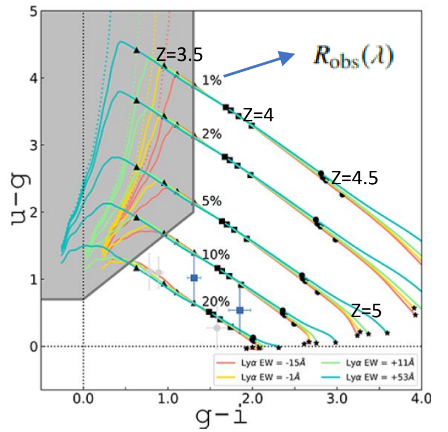
ABSTRACT

Identifying non-contaminated sample of high-redshift galaxies with escaping Lyman continuum (LyC) flux is important for understanding the sources and evolution of cosmic reionization. We present CLAUDS u-band photometry of the COSMOS field to probe LyC radiation from spectroscopically confirmed galaxies at $z \geqslant 3.5$ and outside the standard Lyman-break galaxy colour selection expectations. Complementary to the CLAUDS data, we use Subaru multi-filter photometry, *Hubble Space Telescope* (*HST*) multi-filter imaging, and the spectroscopic surveys D10K, VUDS and 3D-HST. We present a sample of Lyman continuum galaxy (LCG) candidates in the redshift range $3.5 \lesssim z \lesssim 5.1$. Here, we introduce 5 LCG candidates, where two are flagged quality 1 and three quality 2. The estimated f_{esc}^{abs} for quality 1 candidates are in the range $\sim 5\% - 73\%$ and $\sim 30\% - 93\%$. These estimates are based on our derived parameters from individual galaxies as inputs to a range of BPASS models as well as mean intergalactic medium (IGM) and maximal intergalactic and circumgalactic media (IGM+CGM) transmission. We conclude that our search for LCGs is most likely biased to lines of sight with low HI densities or free from Lyman limit systems. Our two best LCG candidates have EW (Lyα) $\leqslant$ 50Å and we find no correlation or anti-correlation between EW (Lyα), f_{esc}^{abs}, and R_{obs}, the ratio of ionizing to non-ionizing observed flux in the measured passbands. Stacking candidates without solid LyC detections ($S/N < 3$) results in an estimated f_{esc}^{abs} from galaxies not greater than 1%.

Lyman Continuum Galaxy, z > 3.42



Sub-sample	Number of objects	percentage
detection	2	0.5%
detection close pairs	5	1.2%
non-detection	87	21.4%
multiple objects	118	29%
flux contaminated	13	3.2%
negative flux - contaminated	182	44.7 %
TOTAL	**407**	**100%**

Target selection steps:

1. Select candidates (z > 3.5) from spectroscopy survey in COSMOS (407, mainly from DEIMOS 10K)
2. Cross-matched to Subaru HSC (< 0.5”) (372 success)
3. Check flux detection in the CLAUDS u-band (a clean LyC detection) with 1.2” aperture. → 22 candidates, S/N > 3
4. Combine with HST image to avoid contamination from surrounding.
5. Double check spectra

id	EW(Lyα)$_{rest}$ (Å)	quality (q)	sub-sample
1	48 ± 10	1	close pairs
326	$\leqslant 0$	2	close pairs
330	60 ± 20	2	close pairs
368	25 ± 5	1	close pairs
421	$\leqslant 0$	2	detection

f_{esc}^{abs} : the fraction of the ionizing photons that escape without being absorbed by ISM or circumgalactic medium (CGM) into the IGM

1) $$f_{esc}^{rel} = \frac{(F_{LyC}/F_{1500})_{obs}}{(L_{LyC}/L_{1500})_{int}} \begin{Bmatrix} \exp(\tau_{IGM}^{LyC}) \\ \langle 1 - D_b \rangle \end{Bmatrix} \qquad f_{esc}^{abs} = f_{esc}^{rel} \times 10^{-0.4(k_{1500}E(B-V))},$$

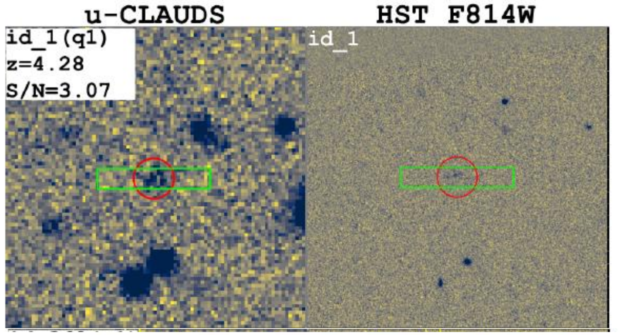
2) $$R_{obs}(\lambda) \equiv \frac{F_{obs}^{LyC}}{F_{obs}^{UV}}, \rightarrow (f_{1500}/f_{900})\_obs$$

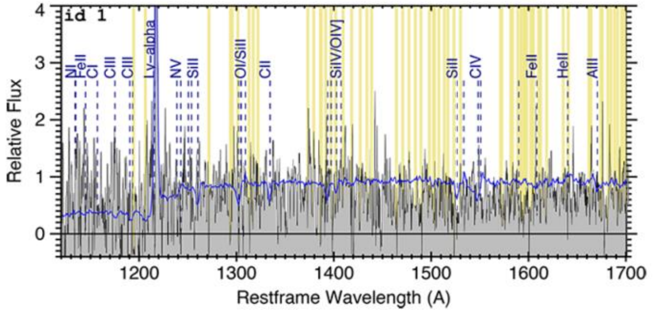
Bias selection: low HI densities along lines of sight

id	z_{spec}	τ_{IGM}^{LyC} [1]	$\langle 1 - D_b \rangle$[2]	LyC λ_{rest}(Å)[3]	$R_{obs}(\lambda)$	E(B-V)[4]	f_{esc}^{abs}
1	4.28	0.006	0.334	568 - 763	0.11 ± 0.03	0.4	$\gtrsim 5 - 73\%$
326	3.57	0.097	0.565	657 - 882	0.16 ± 0.04	0.3	$\gtrsim 4 - 15\%$
330	5.09	0.00016	0.233	493 - 662	0.15 ± 0.04	0	$> 100\%$ [5]
368	3.64	0.08	0.565	647 - 869	0.12 ± 0.04	0.1	$\gtrsim 30 - 93\%$
421	3.60	0.09	0.565	652 - 876	0.17 ± 0.04	0.2	$\gtrsim 8 - 47\%$

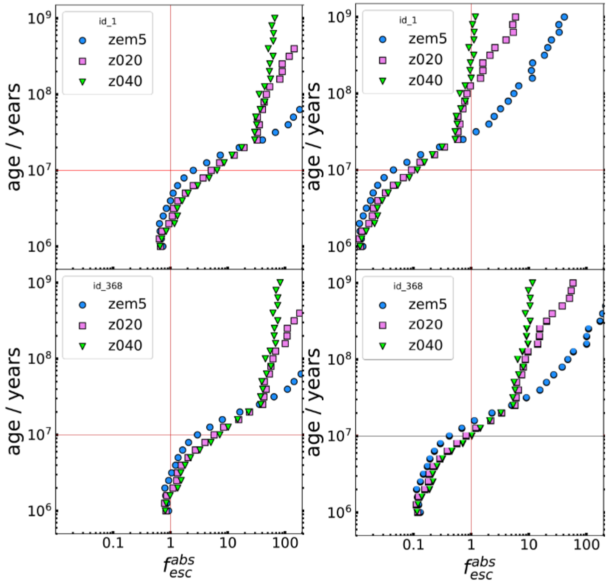
[1] Mean IGM transmission estimated from Inoue et al. (2014).

[2] Close approximation to the maximum IGM+CGM transmission (Steidel et al. 2018).





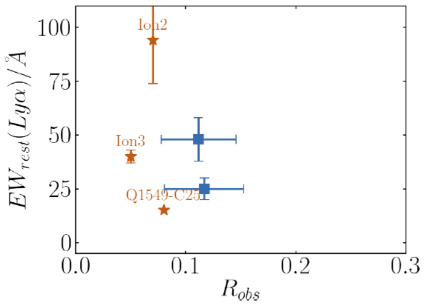
BPASS model (Stanway & Eldridge 2018):



Age of the stellar population also can be interpreted as different $(L_{LyC}/L_{1500})_{int}$

Result :

1. Metallicity: small influence on the early evolutionary stage
2. Even with a clean detection of the LyC flux, it is extremely difficult to estimate the amount of LyC photons that are leaking into the IGM. (two unconstrained parameter)



3. It is not possible to rule out the correlation or anti-correlation between emitted LyC flux and Ly line

4. Color diagram: Z > 3.3 LCGs, ugi diagram is powerful for selection. q1 candidates (id: 1 & 368) are consistent with the prediction on color diagram. ($R_{obs}(\lambda)$ 15%) Similar result in gri diagram.

5. Non-detection candidates (39) If galaxies at z > 6 have similar case, then galaxies alone are not able to emit enough LyC radiation to reionize the Universe. (f_{esc}^{abs} = 0.001 ~ 0.006)