The Lyman Continuum escape fraction of z~3 star forming galaxies with LBC/LBT in the COSMOS and CANDELS fields

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Gunn-Peterson troughs suggest reionization ending at \( z = 6 \)
But \( 10^{-4} \) HI fraction gives \( \tau(\text{HI}) \gg 1 \)

Planck 2016 result: \( \tau = 0.055 \pm 0.009 \) \( z_{\text{reion}} = 7.8 \pm 1.0 \)
- Implies reionization at \( z < 9 \). Rapid process
- With SPT kSZ: \( \Delta z < 2.8 \)
Sources of Reionization

Reionization: driven by Galaxies or AGNs?

At high-z bright QSOs are rare. Low ionizing emissivity at $z>3$.

Faint Galaxies can be important at $z>3$. Steep Luminosity Functions. Simulations indicate high $f_{esc}$ for faint galaxies ($M_u=-10$).

At high redshift it is assumed that the escape fraction is $>10-20\%$.

At $z<3$ the escape fraction of SFGs is $<1\%$.
Local LyC Emitters

Local galaxies with OIII/OII > 5 and compact morphology. Muv ~ -20
High ionizing photon production efficiency (Schaerer et al. 2016)
See also Leitet et al. 2013; Borthakur et al. 2014; Leitherer et al. 2016; Bergvall et al. 2016;

(Izotov et al. 2016)
LyC Emitter at $z=3.2$

Important to understand their physical properties at $z<4$:
Find LyC emitter analogs at $z>6$
With indirect technique.

Study the LyC emission of whole population of SFGs

Similar properties of galaxies by Izotov et al. 2016
OIII/OII>10 and compact morphology in LyC. $M_{UV} \sim -21$
See also Steidel et al. 2001; Shapley et al. 2006; Nestor et al. 2013; Shapley et al. 2016; Reddy et al 2016;

(Vanzella et al. 2016)
Required Ingredients...

To measure the relative escape fraction of galaxies with deep imaging

1-Deep imaging at 900 A and 1500 A rest frame (U and R band): LBC/LBT

2-HST imaging to avoid spurious contamination by foreground sources

3-Spectroscopic redshifts in a narrow range (3.27<z<3.40 for LBC U-band)

4-Large numbers of galaxies to beat down the IGM stochasticity

5-X-ray data to avoid AGNs

COSMOS; CANDELS/GOODS-North; CANDELS/EGS
Id=16669   magR=24.4

Global fesc=230%
Local fesc=520%
Contamination by Foreground galaxy

See also Siana et al. (2015)
Id=63327  magR=25.02

Fesc=45%
Possible LyC emitter!!!
Detailed analysis on-going...
Contamination ???
Starting Sample
Deep U and R band imaging with LBC at LBT

3 LBC fields in UGR (Q0933, COSMOS, Q1623)
exptime\(U=2-8\text{h}\) each
\(U=29.7\text{(AB)}\) at S/N=1
Area\(>2400\) sq. arcmin.
Boutsia et al. (2014)

Lots of zspec available

Le Fevre et al. (2015)
10000+ zspec \(2<z<6.7\)
Enlarging the Sample....

CANDELS EGS field

2 LBC pointings in U band R band from CFHT
exptimeU=7h
U=29.6(AB) at S/N=1
Area~600 sq. arcmin.

zspects from DEEP2 (Cooper et al. 2006)

15 galaxies with
3.27<z<3.40
33 hours in the U-band
Seeing=1.1"

26 hours in the R-band
Seeing=1.0"

Data reduced by LSC
(INAF-OARoma)
Ultra Deep U-band

LBC 33 hours

KPNO 50 hours
One of the Deepest U-band images of the World...

Giavalisco et al. (2004)

U-band LBC

U=30.2 AB mag (1 sigma)
z=3.3 galaxies in GOODS-North

9 galaxies at z~3.3 have been added to the original sample.
Galaxy-Galaxy strong lensing

$z=3.417$ \ $\mu=40x$

$U_{\text{obs}}>28.9$ \ $R_{\text{obs}}=24.3$ \ $R_{\text{intr}}=28.3$

$F_{\text{esc}}<23\%$ (1 sigma) \ $L=0.05L^*$

LBT LUCI+LBC; van der Wel et al.2013

Amorin et al. (2014)
LyC Escape Fraction of $z \sim 3$ Galaxies

<table>
<thead>
<tr>
<th>Survey</th>
<th>Fraction</th>
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<tbody>
<tr>
<td>GOODS North</td>
<td>10%</td>
</tr>
<tr>
<td>CANDELS/LBC</td>
<td>2%</td>
</tr>
<tr>
<td>COSMOS VUDS</td>
<td>2.4%</td>
</tr>
<tr>
<td>EGS LBC CANDELS</td>
<td>3.9%</td>
</tr>
<tr>
<td>Grazian et al.</td>
<td>In prep.</td>
</tr>
<tr>
<td>Siana et al. 2015</td>
<td>23%</td>
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</tbody>
</table>

Lensed Galaxy ($\mu=40$)
- Boutsia et al. (2011)
- Stack all sources
- Stack Very Bright ($R<23.5$)
- Stack Bright ($23.5<R<24.5$)
- Stack Faint ($24.5<R<25.5$)
- Stack UltraFaint ($R>25.5$)

69 galaxies
Image stacking in U and R

No detection at U=31.74(AB) at S/N=1
f1500/f900obs>640.2
fesc_rel<1.7% (1 sigma) at z=3.3 for R<26.5
Consistent with Vanzella et al. (2010) and Guaita et al. (2016):
GOODS-South
Grazian et al. (in prep)
COSMOS+GOODS-NORTH+EGS
HI Photoionization rate
UVB by bright galaxies \((L>0.5L^*)\)

Grazian et al. 2016

\[ \Gamma_{12} \]

\[ \text{Gamma} < 0.29 \]

- Bolton et al. (2005)
- Kirkman et al. (2005)
- Faucher-Giguere et al. (2008)
- Wyithe and Bolton (2010)
- Calverly et al. (2011)
- Becker and Bolton (2013)

\( \text{VUDS/LBC } L>0.5L^* \text{ Galaxies (3\sigma)} \)
Bright Galaxies have low fesc

What about faint galaxies?

Evolution of fesc with Luminosity
Faint Galaxies: they can keep the Universe reionized at $z=3.3$, only if the Luminosity Function is steep ($<-1.7$) and going down to $M_{uv}=-13$.

The slope of the LF at the faint end at $z\sim3$

Is still uncertain

Alternative solutions to study Reionization

Bright QSOs are very rare.

What about Faint AGNs ?....

See talk by E. Giallongo
Conclusions

Bright galaxies (L>0.5L*) are not able to keep the Universe reionized at z~3. Faint galaxies are providing the measured UVB at z~3 only if their escape fraction increases at faint luminosity and LF is steep.

Our results are consistent with evidence of late and rapid reionization by Planck 2016. Patchy reionization scenario: Treu et al. (2012) and Pentericci et al. (2014).
Thank you!