Contribution of faint AGN to the ionising background

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The apparent number density of bright QSOs and AGNs is rapidly decreasing at \( z > 3 \) (e.g., Faucher-Giguère et al. 2008; Cowie et al. 2009).

Faint Galaxies have a steep LF at \( z > 3 \) so simulations indicate large contribution of faint galaxies (\( M_{uv} = -10 \)) to the ionizing background.

**THUS**

it is **assumed** that the contribution to the ionizing flux of the SF galaxies **should** become dominant at \( z > 3 \) (Robertson et al. 2015; Schmidt et al. 2016, Stark 2016).

**Critical assumption:**

At high redshift \( f_{esc} > 10 - 20\% \) must be assumed for all SFGs down to \( M_{1500} = -13 \) in order to keep the Universe ionized (Finkelstein et al. 2015; Bouwens et al. 2015, Xu et al. 2016; Anderson et al. 2017, Naidu et al. 2018 and more…).
**Goal**

Study the LyC escape fraction of the whole population of SFGs at $z \sim 3$ and estimate their contribution to the ionizing UVB.

**Method**

1. Deep imaging in U and R bands (900 and 1500 Å rest frame at $z \sim 3$) with LBC camera at LBT telescope (Giallongo et al. 2008)
2. HST imaging (multiband) to avoid spurious contamination by foreground sources
3. Spectroscopic redshifts in a narrow range
4. X-ray data to avoid AGNs
5. Large numbers of galaxies to address IGM stochasticity
Escape fraction of galaxies at $z\sim 3.3$

Boutsia et al. 2011

Escape of Lyman Radiation, Kolymbari, September 2018

3 LBC fields in UGR (Q0933, COSMOS, Q1623) - area $>2400$ sq. arcmin

U=29.7(AB) at S/N=1

Redshift selection: $3.27<z<3.4$ ($<z>\sim 3.3$) for LBC U-band - sample of 11 sources

Effective wavelength: 860 Å rest frame

$f_{esc,rel} \leq 0.05$ (5%) at 1σ
Escape fraction of galaxies at z~3.3

Revisited COSMOS in 2016 after spectroscopic redshifts became available

VUDS: 10000+ z_{spec} 2<z<6.7

Stack of 37 galaxies at 3.27<z<3.4

\[ f_{esc,rel} \leq 2\% \text{ at } 1\sigma \]

\[ U = 31.4 \text{ at } S/N = 1 \]

In GOODS-N at z=2.5-3 it was found that one AGN totally dominates ionizing flux in the region, while 4 out of 6 candidates are contaminated by foreground sources (Jones et al. 2018)
69 galaxies in COSMOS+GOODS-NORTH+EGS

No detection at U=31.74(AB) at S/N=1

$f_{1500}/f_{900}\text{obs}>640.2$

$f_{esc,rel}<1.7\%$ (1σ) at $z=3.3$ for $R<26.5$

Recent results (i.e. Fletcher et al. 2018, Tanvir et al. 2018) also indicate difficulties for both faint galaxies and galaxies with high [OIII]/[OII] ratio.

Anyhow this debate is still open (see Steidel et al. 2018).

Consistent with Vanzella et al. (2010), Guaita et al. (2016), Smith et al. (2016), Japelj et al. (2017) and Marchi et al. (2017)

Escape of Lyman Radiation, Kolymbari, September 2018
Bright galaxies (L>0.5L*) at z~3 are not able to keep the Universe ionised.
LyC escape fraction of bright QSOs

M_{1450} < -26 QSOs (L~5L*) at 3<z<6 have f_{esc} \sim 75\% (or more) (Worseck et al. 2014, Cristiani et al. 2016)

Noticeable ionising escape fraction (>70\%) has also been confirmed for fainter AGNs (M<-19) at lower redshift (z<1) (Stevans et al. 2014)

1669 QSOs from BOSS

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LyC escape fraction of faint AGN

**Method**
- **green**: spectral region between 915 and 945 Å rest frame
- **magenta**: ionizing photons emitted between 892 and 905 Å rest frame
- **blue** vertical line: location of the 912 Å rest frame break
- **red** horizontal lines: mean values above and below the Lyman limit, after the iterative 2-σ clipping

escape fraction is the ratio between these two mean fluxes
The Lyman Continuum escape fraction is between 44 and 100% for all the observed faint AGNs, with a mean value of 74% at 3.6 < z < 4.2 and −25.1 < M_{1450} < −23.3. In agreement with the value found in the literature for much brighter QSOs (M_{1450} < −26) at the same redshifts.
To verify faint AGN contribution, robust constraints must be provided for two quantities:

(i) their typical escape fraction of ionizing photons into the surrounding IGM (bright and faint AGN show ~75% $f_{esc}$)

(ii) their abundance at low luminosities ($M_{1450} > -24$) in the redshift interval $z=4-6$ (still uncertain)

Deep optical surveys at $z = 3 - 5$ with almost complete spectroscopic information (Glikman et al. 2011) show the presence of a considerable number of faint AGNs ($L < L^*$) producing a rather steep luminosity function. The presence of a faint ionizing population of AGNs, if confirmed, could strongly contribute to the ionizing UVB (Madau & Haardt 2015), provided that a significant fraction of the produced LyC photons is free to escape from low-luminosity AGNs.
First indication that at redshifts $z>4$ the probed AGN population could produce the necessary ionization rate to keep the IGM highly ionized

This result is still controversial with recent works claiming the opposite (i.e. Parsa et al. 2017; Hassan et al. 2017; Akiyama et al. 2017; D’Aloisio et al. 2017) but most results are based on photometric redshifts and simulations.
Bright part of our sample: 92 sources down to $i_{AB} = 23.0$ (entire sample extends to $i_{AB} = 24.0$)

2018A: obtained 4 masks covering 0.7 sq.deg of the total field

After our spectroscopic campaign we have:
- 36 source with robust redshift estimate
- 7 source with tentative redshift
- 49 source with no redshift

Thus spectroscopic confirmation still needed for 53% of our “bright” sample ($i_{AB} < 23$)
Preliminary LF at z~4

Considering 13 AGN with redshift $3.6 \leq \text{z}_{\text{spec}} \leq 4.2$ and $\text{magI} < 23.0$ without completeness correction; for an area of 1.73 sq.deg we calculated the space density in 2 magnitude bins.

<table>
<thead>
<tr>
<th>$M_{1450}$</th>
<th>$\Phi$</th>
<th>$\sigma_{\Phi}^{\text{up}}$</th>
<th>$\sigma_{\Phi}^{\text{low}}$</th>
<th>$N_{\text{AGN}}$</th>
<th>$\Phi_{\text{corr}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-24.5</td>
<td>3.509e-07</td>
<td>2.789e-07</td>
<td>1.699e-07</td>
<td>4</td>
<td>7.018e-07</td>
</tr>
<tr>
<td>-23.5</td>
<td>7.895e-07</td>
<td>3.616e-07</td>
<td>2.595e-07</td>
<td>9</td>
<td>1.579e-06</td>
</tr>
</tbody>
</table>

Consistent with G15 and marginally with Parsa18. All the rest under predict AGN numbers.
Contribution of faint AGN to UVB

The intensity of the ionizing UVB is characterised by the total hydrogen ionisation rate, $\Gamma_{-12}$

THUS assuming G15 LF and $f_{esc}=75\%$ down to $M_{1450}=-18$ (0.01L*), AGNs at $z\sim4$ can produce $>65-85\%$ of the UVB.

To $M_{1450}=-21$ this becomes 54\% for G15 and 28\% for Glikman+11.

**Table 3.** HI photo-ionization rate $\Gamma_{-12}$ produced by AGN at $z \sim 4$.

<table>
<thead>
<tr>
<th>Luminosity Function</th>
<th>$\Gamma_{-12}$ for $M_{1450} \leq -23$</th>
<th>$\Gamma_{-12}$ for $M_{1450} \leq -18$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glikman et al. (2011)</td>
<td>0.140 (16.5%)</td>
<td>0.307 (36.3%)</td>
</tr>
<tr>
<td>Giallongo et al. (2015)</td>
<td>0.208 (24.6%)</td>
<td>0.617 (72.9%)</td>
</tr>
<tr>
<td>Akiyama et al. (2018)</td>
<td>0.113 (13.4%)</td>
<td>0.135 (15.9%)</td>
</tr>
<tr>
<td>Parsa et al. (2018)</td>
<td>0.088 (10.4%)</td>
<td>0.255 (30.0%)</td>
</tr>
</tbody>
</table>

Grazian et al. 2018
Summary

Galaxies:
• At $z=3.3$ bright galaxies have $f_{esc,rel} < 1.7\%$!

   Galaxies alone cannot provide the observed UVB at $z\sim3.3$ unless their LyC escape fraction increases at low luminosities.

AGNs:
• HST+Chandra deep data in the CANDELS fields indicate that the space density of faint AGNs at $z>4$ is relatively high.
• Ongoing work on deriving the $z>4$ LF of faint AGN seems to confirm this result
• A pilot project with VLT, LBT, Magellan indicates that the escape fraction of faint ($M_{1450}<-23$) AGNs at $z>4$ could be as high as $\sim75\%$

   Faint AGNs could give a substantial contribution to the ionizing background at $z\sim4$
Thank you very much!