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Contribution of faint AGN to the ionising background

Konstantina Boutsia[(1)], A. Grazian[(2)], E. Giallongo[(2)] et al.

(1) Las Campanas Observatory

(2) INAF - OAR

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Contribution of faint AGN to the ionising background

Escape of Lyman radiation from AGN labyrinths

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Sources of reionization

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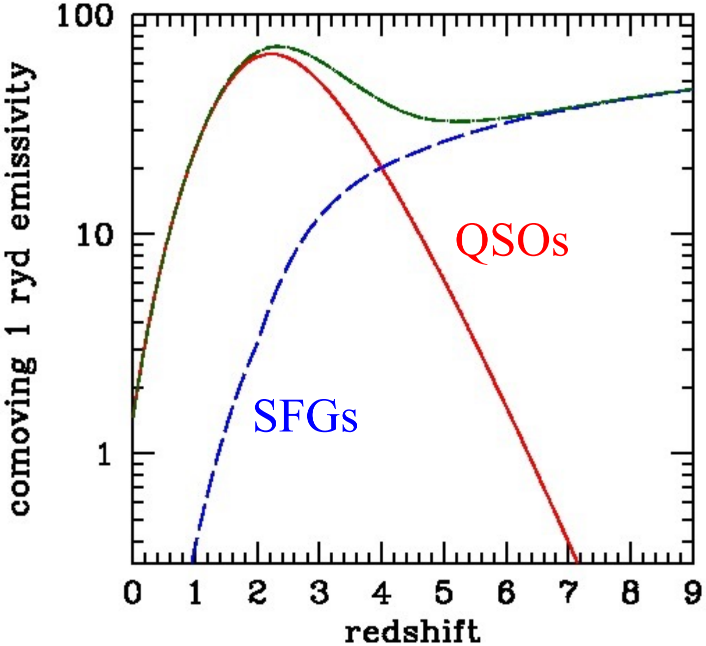
The apparent number density of bright QSOs and AGNs is rapidly decreasing at $z > 3$
(e.g., Faucher-Giguère et al. 2008; Cowie et al. 2009)

Faint Galaxies have a steep LF at z>3 so simulations indicate large contribution of faint galaxies (Muv=-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)

Haardt & Madau 2012



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…)

Determining LyC escape fraction

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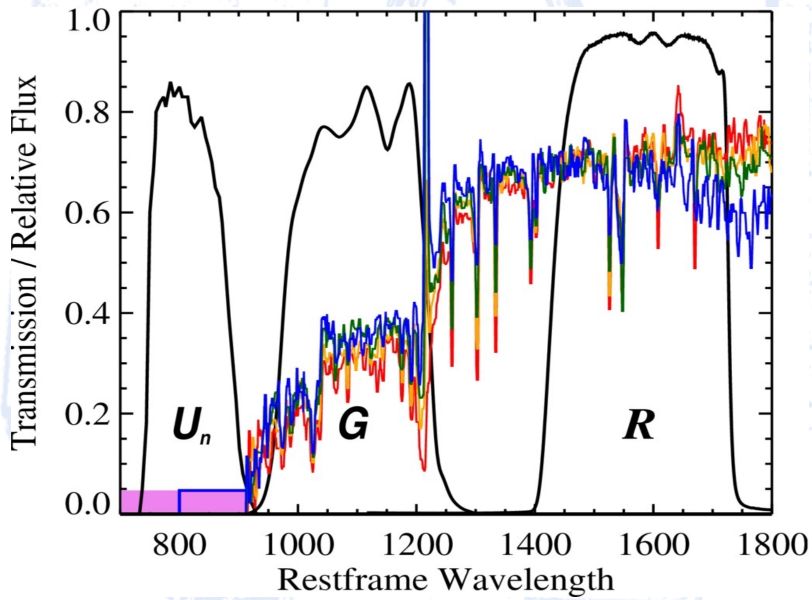

$$f_{esc,rel} = \frac{(L_{1500}/L_{900})_{int}}{(f_{1500}/f_{900})_{obs}} exp(\tau_{900}^{IGM})$$

Models (1.5-8 depending on age and SFH)

observed

IGM correction

Steidel et al. 2001

Goal

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

Method

1. Deep imaging in U and R bands (900 and 1500 A rest frame at z~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~3.3

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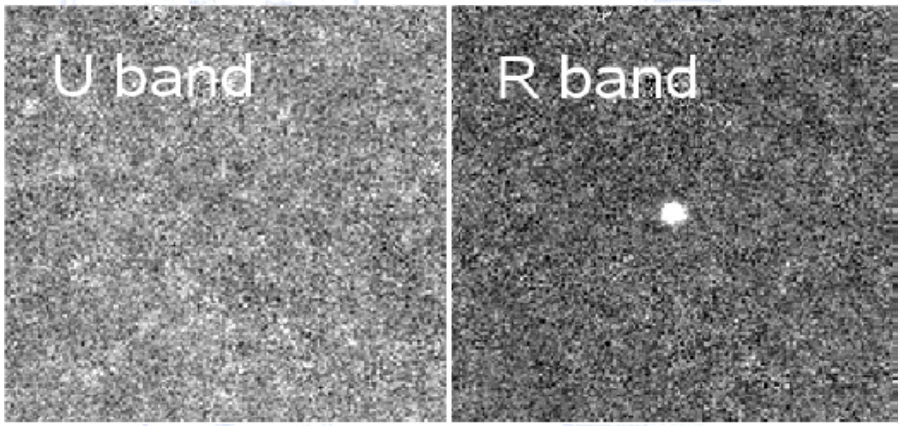

Boutsia et al. 2011

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>~3.3) for LBC U-band - sample of 11 sources

Effective wavelength: 860 A rest frame

$f_{esc,rel} \leq$ **0.05 (5%) at 1σ**

Table 1. Summary of the f^{rel}_{esc} Values for the Individual LBGs

ID	R.A.	Decl.	z	R mag.	U mag.	f^{rel}_{esc}
				±0.07	1σ (u.l.)	1σ (u.l.)
3400	143.35424	+28.80694	3.27	24.88	29.75	0.203
12646	143.32868	+28.71913	3.33	25.13	29.61	0.329
8556	143.38236	+28.75308	3.33	24.91	29.66	0.258
10849	143.36004	+28.73414	3.35	25.59	29.66	0.357
17175	246.46910	+26.89244	3.34	24.69	29.05	0.235
74113	149.88620	+2.276064	3.33	23.56	29.66	0.062
50989	149.83421	+2.416729	3.31	24.61	29.25	0.223
32388	149.77887	+2.229502	3.30	24.63	29.60	0.163
51227	149.89208	+2.414816	3.28	24.45	29.28	0.202
1723	150.44702	+2.347633	3.30	23.63	28.23	0.234
13903	150.41495	+2.158999	3.29	22.59	28.79	0.056
Stack	···	···	3.3	24.85	30.73	0.050

Escape fraction of galaxies at z~3.3

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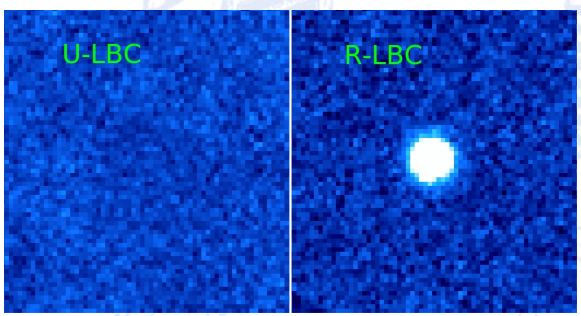
Revisited COSMOS in 2016 after spectroscopic redshifts became available

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

Vimos Ultra Deep Survey

Le Fevre et al. 2015

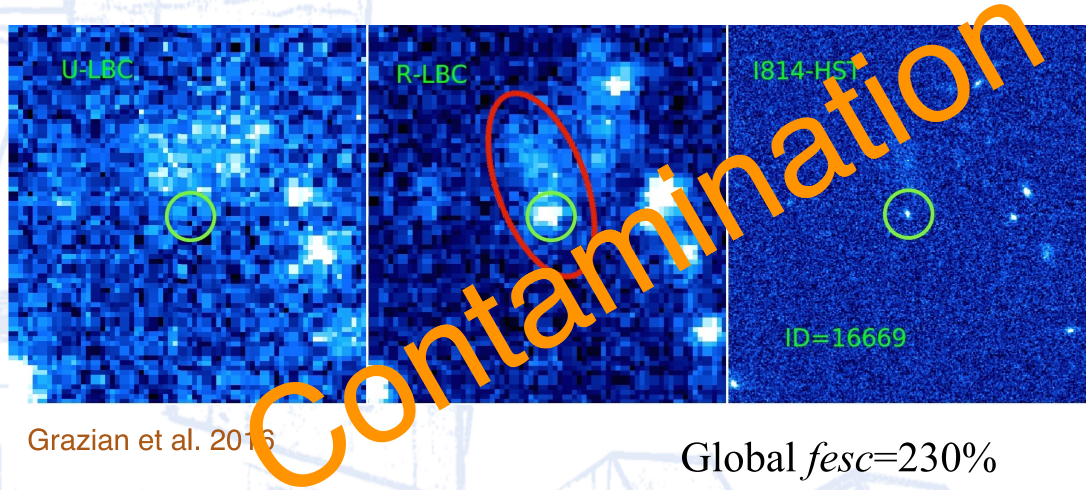
Stack of 37 galaxies at 3.27<z<3.4



Grazian et al. 2016

U = 31.4 at S/N = 1

$f_{esc,rel} \leq 2\%$ **at 1σ**



Grazian et al. 2016

Global *fesc*=230%
Local *fesc*=520%

Evidence of contamination was found for 8 out of 45 galaxies ➢ 18% of contamination

Expected contamination assuming a depth of U=28.5-29.5 and seeing of 1.0arcsec would be 12-15% (Vanzella et al. 2010)

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)

CANDELS GOODS-North

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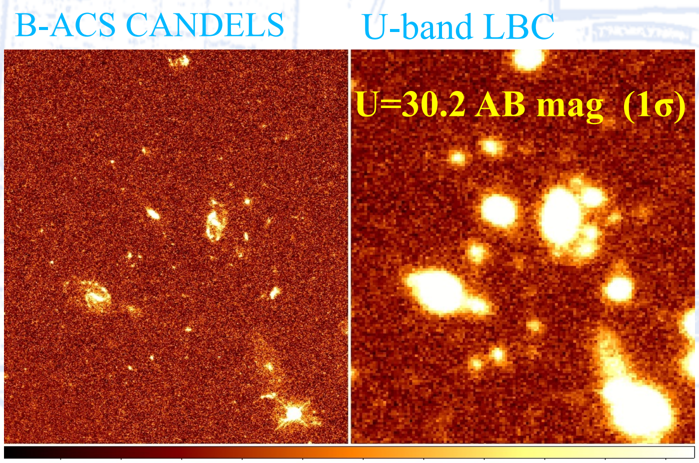


Giavalisco et al. 2004

69 galaxies in COSMOS+GOODS-NORTH+EGS

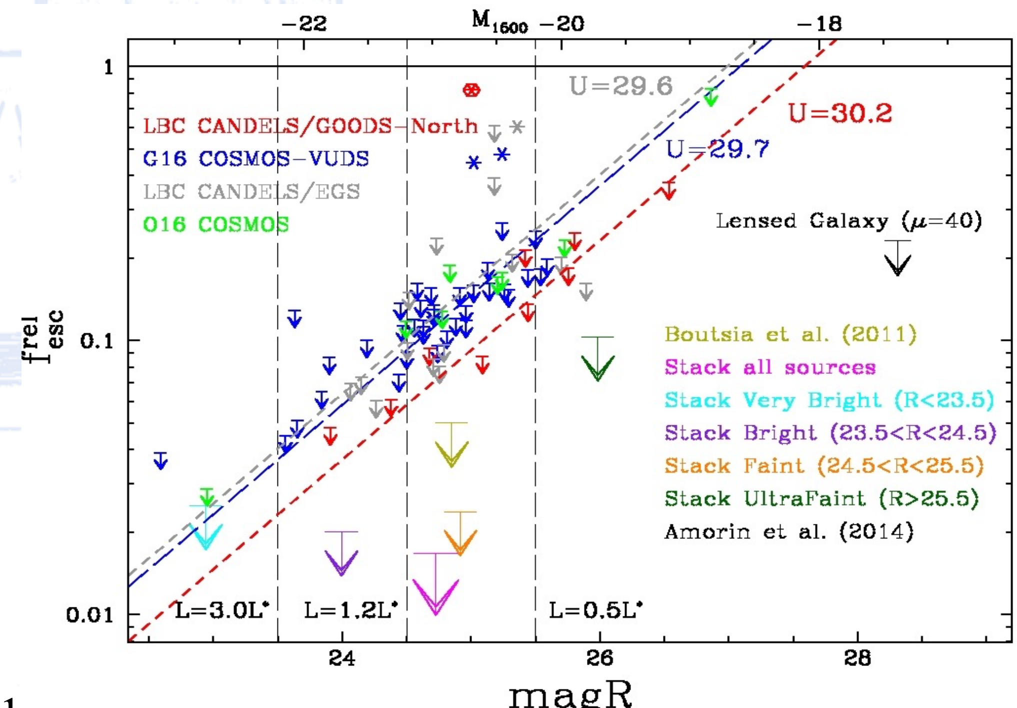
No detection at U=31.74(AB) at S/N=1

f_{1500}/f_{900obs}>640.2

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

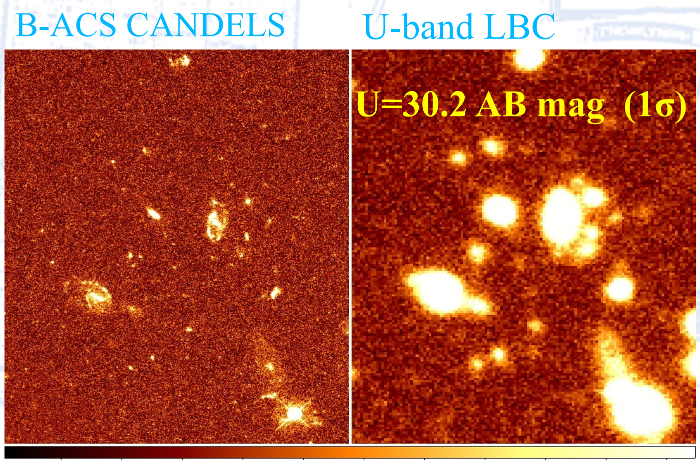
Grazian et al. 2017

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

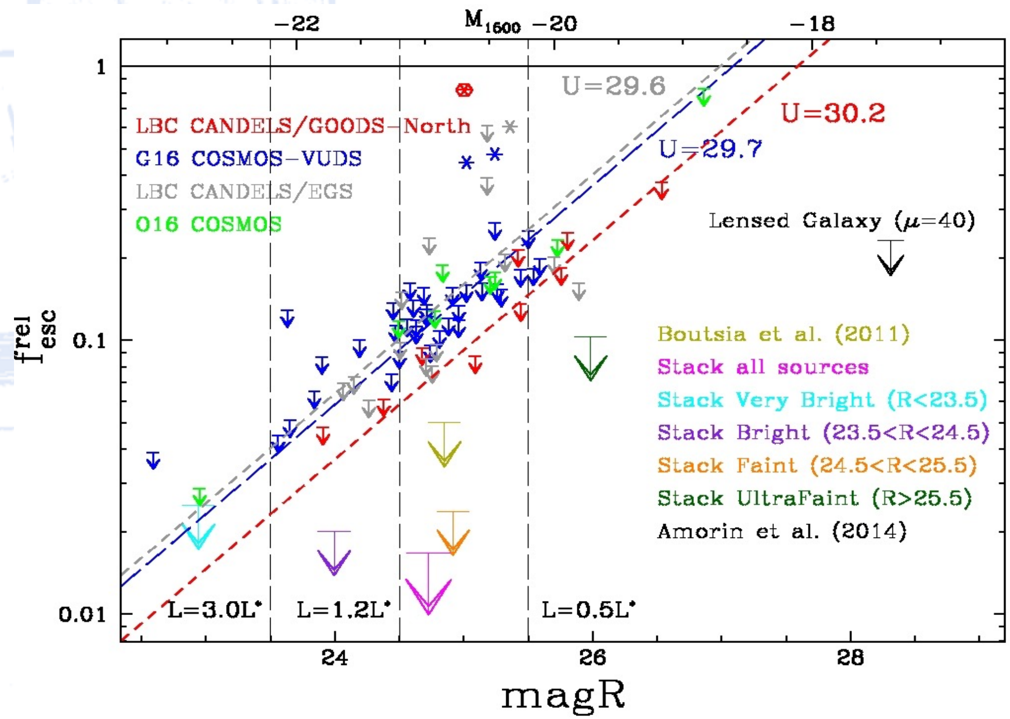


Recent results (i.e. Fletcher et al. 2018, Tanvir et al. 2018) also indicate difficulties for both faint galaxies and galaxies with high [OIII]/[OII] ratio.
Anyhow this debate is still open (see Steidel et al. 2018).

CANDELS GOODS-North



Giavalisco et al. 2004



Bright galaxies (L>0.5L*) at z~3 are not able to keep the Universe ionised

LyC escape fraction of bright QSOs

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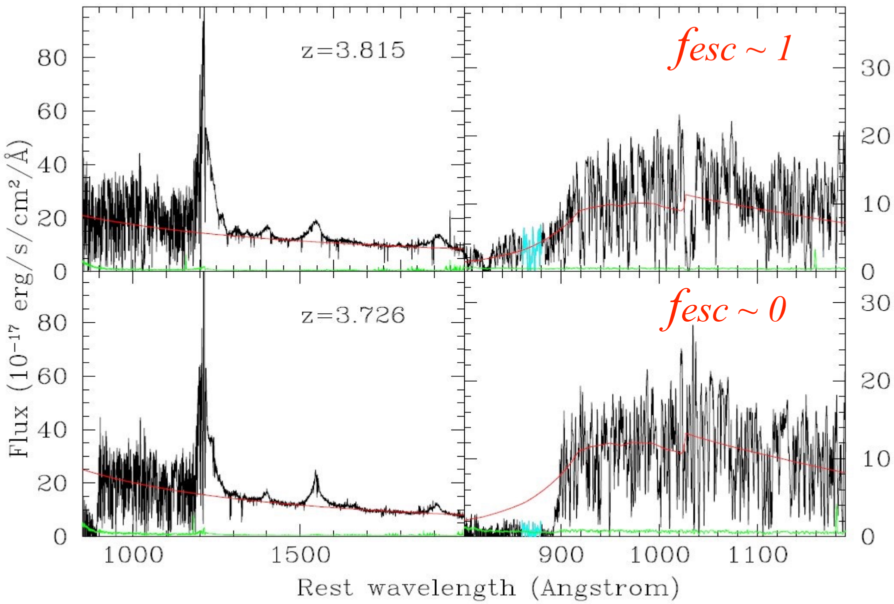
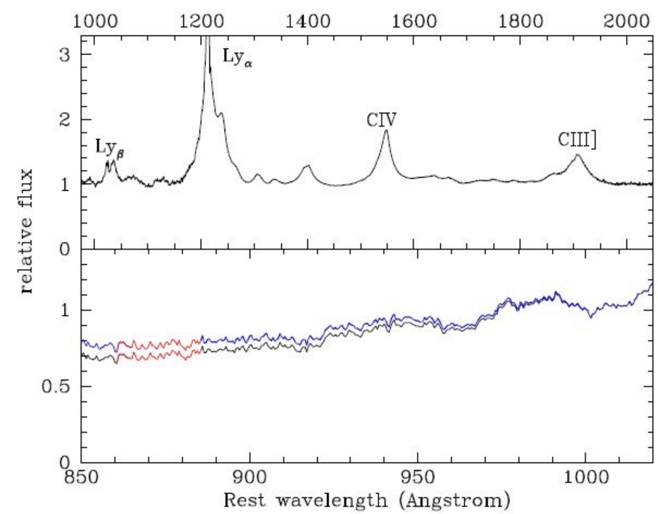


Cristiani et al. 2016

1669 QSOs from BOSS



Cristiani et al. 2016

M_{1450} < -26 QSOs (L~5L*) at 3<z<6 have *fesc*~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)

LyC escape fraction of faint AGN

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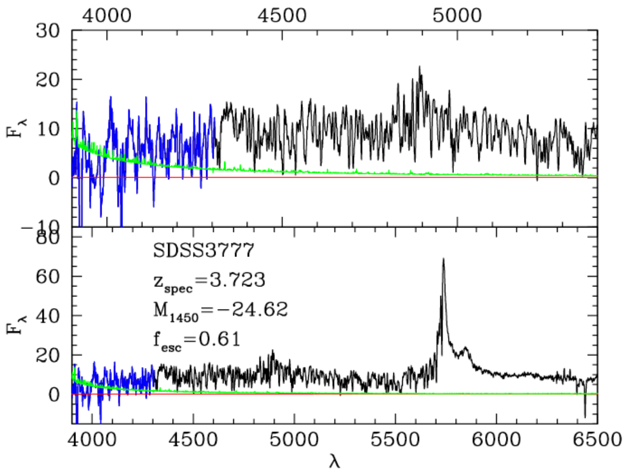
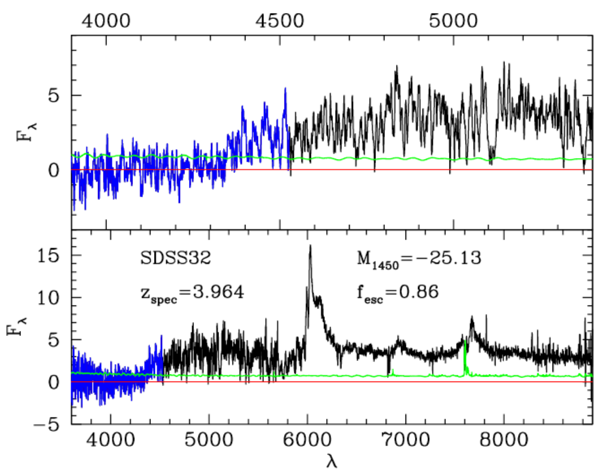
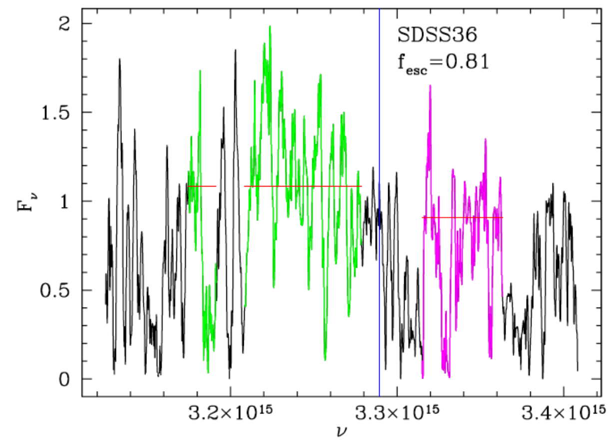
LDSS-3



MODS-1/2



Grazian et al. 2018



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

LyC escape fraction of faint AGN

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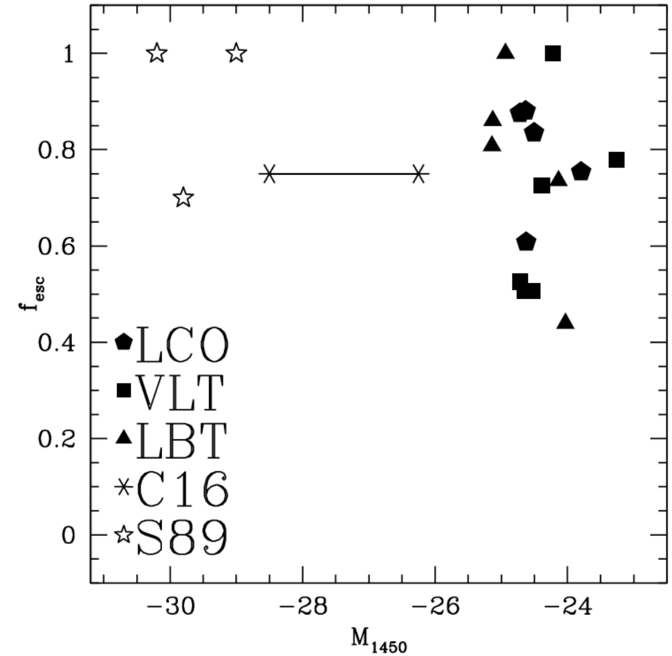
Table 2. The measured properties of faint AGNs in our sample

Name	z_{spec}^{new}	$f_{esc}(LyC)$	S/N	M_{1450}
SDSS36	4.047	0.81	87	-25.14
SDSS32	3.964	0.86	33	-25.13
COSMOS775	3.609	0.74	31	-24.14
SDSS37	4.173	1.00	121	-24.94
NDWFSJ05	3.900	0.44	12	-24.03
SDSS04	3.768	0.73	96	-24.39
COSMOS1782	3.748	0.78	72	-23.26
SDSS20	3.899	0.53	58	-24.71
SDSS27	3.604	1.00	42	-24.22
COSMOS955	3.715	0.51	84	-24.65
COSMOS1311	3.736	0.51	29	-24.53
SDSS3777	3.723	0.61	26	-24.62
SDSS3793	3.743	0.84	12	-24.51
SDSS3785	3.769	0.88	20	-24.63
SDSS3832	3.663	0.88	11	-24.72
UDS10275	4.096	0.75	27	-23.80
MEAN	3.82	0.74		-24.46

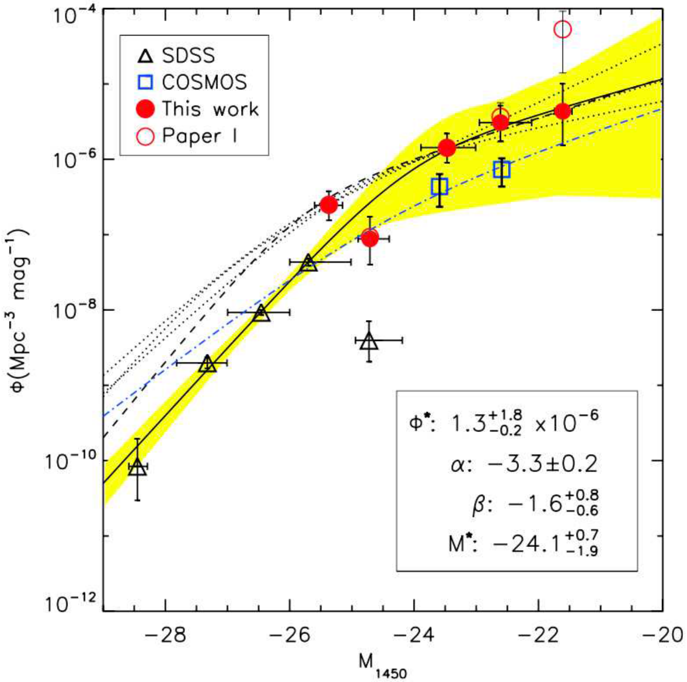


Grazian et al. 2018

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.

z>4 AGN Luminosity Function

Glikman et al. 2011



To verify faint AGN contribution, robust constraints must be provided for two quantities:

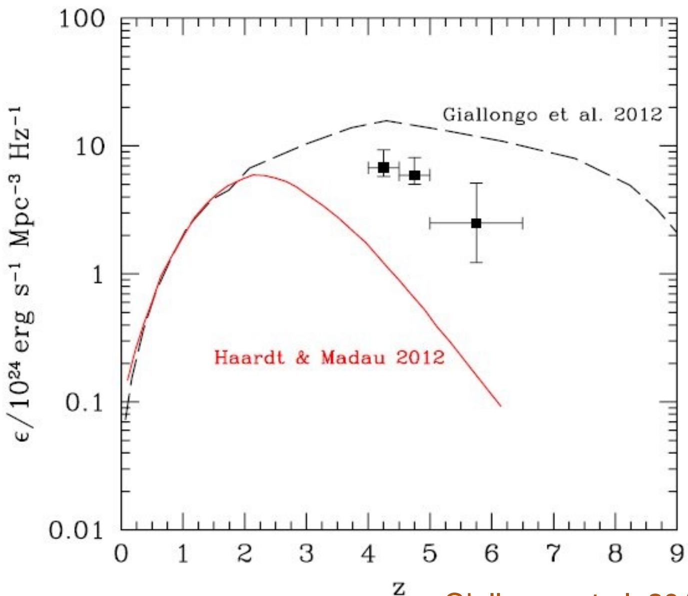
(i) their typical escape fraction of ionizing photons into the surrounding IGM (bright and faint AGN show ~75% *fesc*)

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

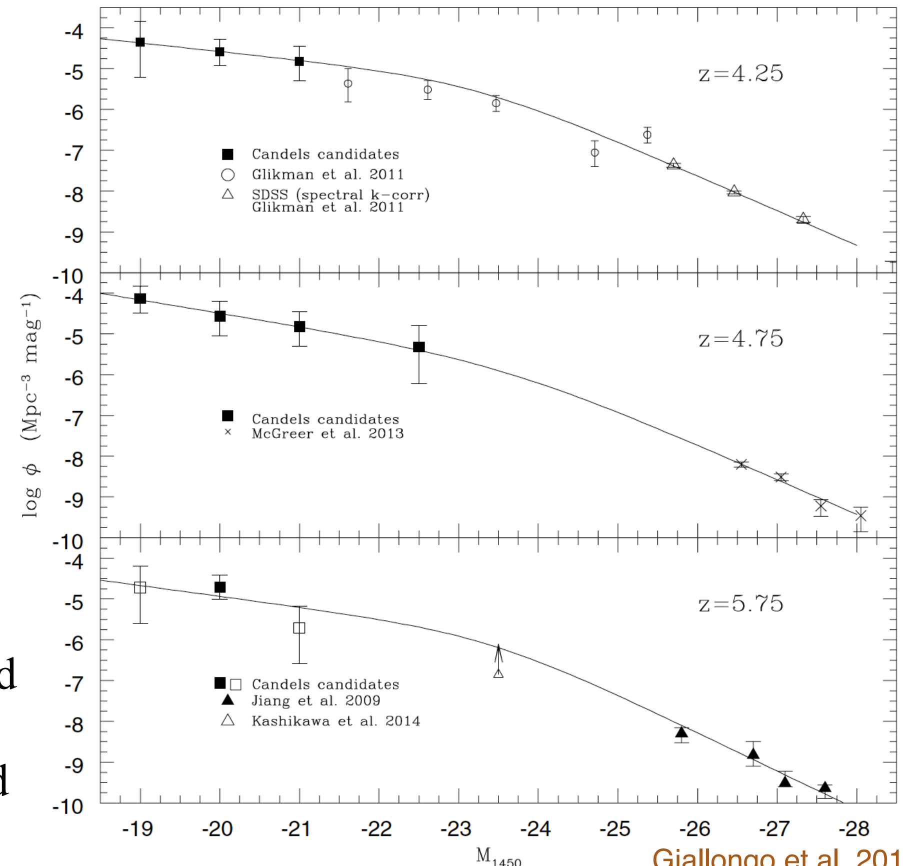
Deep optical surveys at z = 3 - 5 with almost complete spectroscopic information (Glikman et al. 2011) show the presence of a considerable number of faint AGNs (L < L*) producing a rather steep luminosity function.

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.

z>4 AGN Luminosity Function



Giallongo et al. 2015



Giallongo et al. 2015

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.

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Pilot program with IMACS

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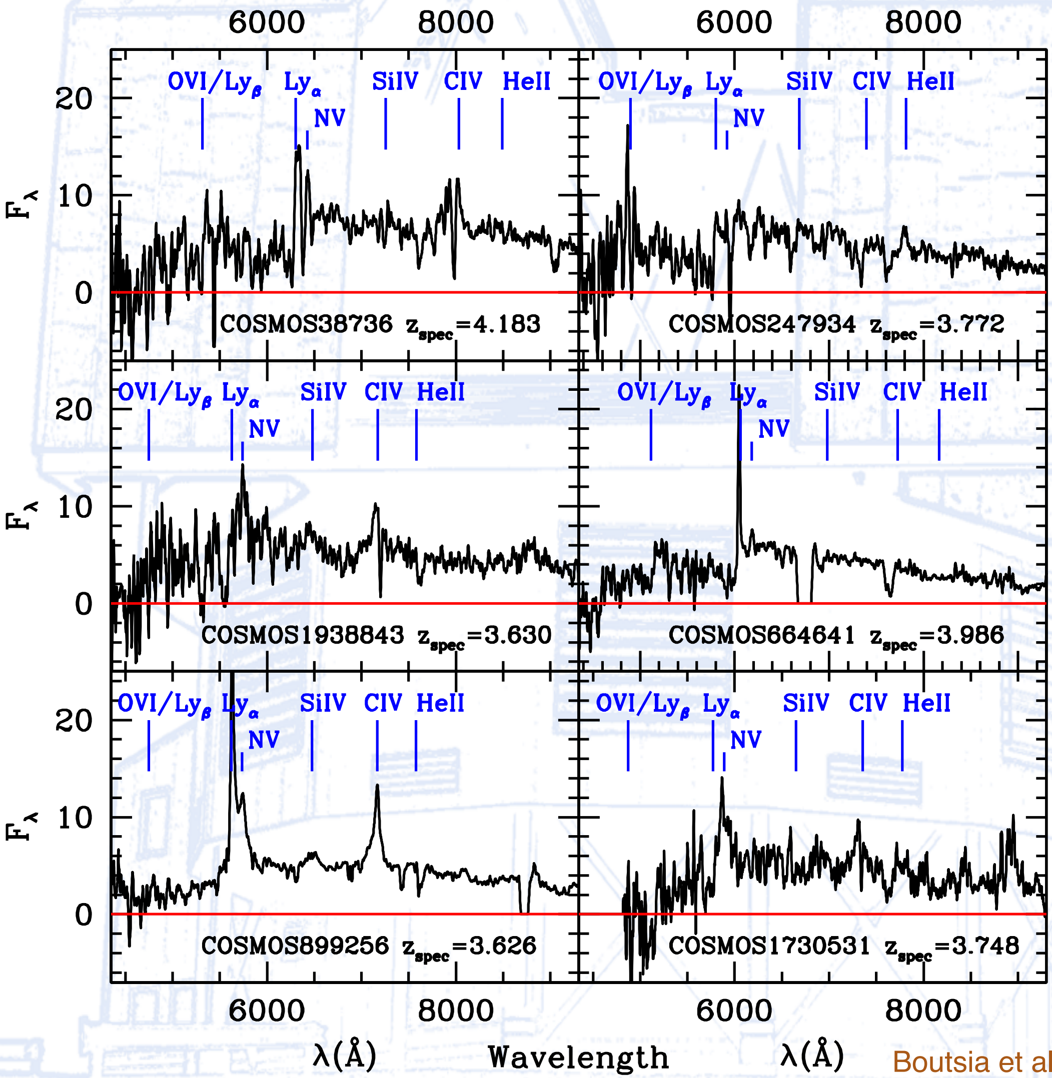

Bright part of our sample: 92 sources down to i_{AB} =23.0 (entire sample extends to i_{AB} =24.0)

2018A: obtained 4 masks covering 0.7sq.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)

Boutsia et al. - sumbitted

Preliminary LF at z~4

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

Table 3. AGN space density

M_{1450}	Φ $Mpc^{-3}Mag^{-1}$	σ_{Φ}^{up}	σ_{Φ}^{low}	N_{AGN}	Φ_{corr}
-24.5	3.509e-07	2.789e-07	1.699e-07	4	7.018e-07
-23.5	7.895e-07	3.616e-07	2.595e-07	9	1.579e-06

Consistent with G15 and marginally with Parsa18. All the rest under predict AGN numbers.

Contribution of faint AGN to UVB

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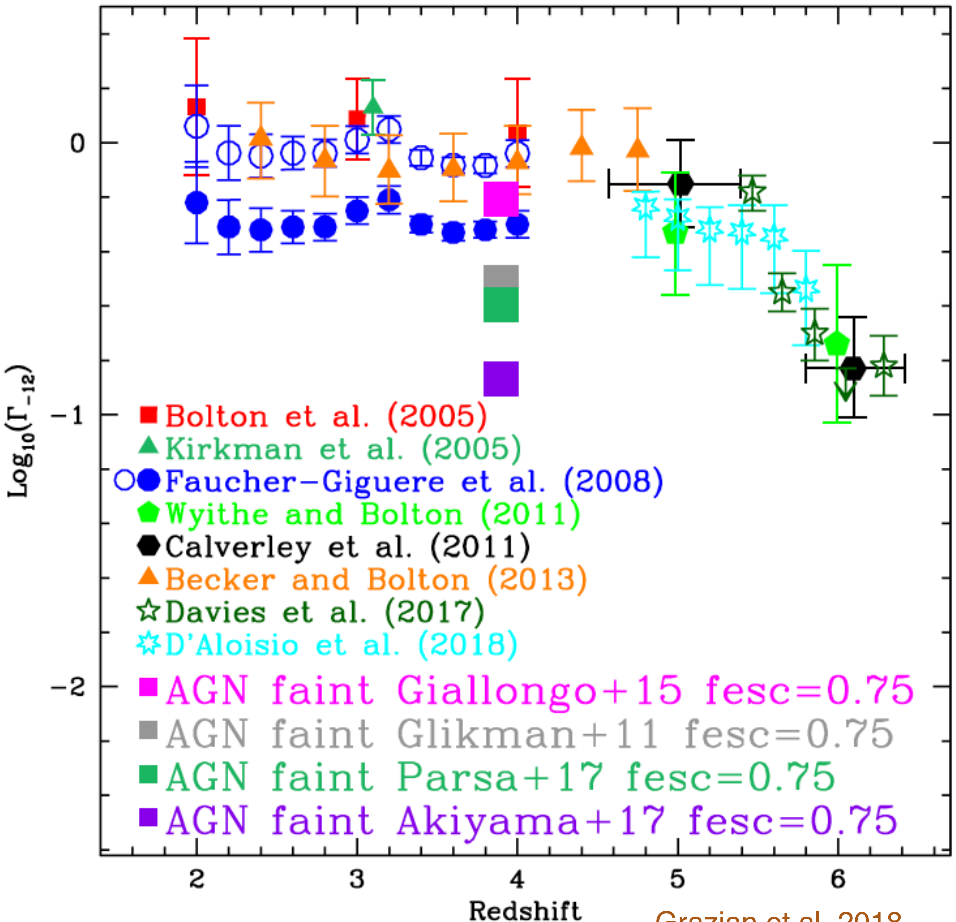

Grazian et al. 2018

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

THUS

assuming G15 LF and *fesc*=75% down to **M1450= -18** (0.01L*), AGNs at z~4 can produce >65-85% of the UVB.
To **M1450= -21** this becomes 54% for G15 and 28% for Glikman+11.

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

Luminosity Function	Γ_{-12} $M_{1450} \leq -23$	Γ_{-12} $M_{1450} \leq -18$
Glikman et al. (2011)	0.140 (16.5%)	0.307 (36.3%)
Giallongo et al. (2015)	0.208 (24.6%)	0.617 (72.9%)
Akiyama et al. (2018)	0.113 (13.4%)	0.135 (15.9%)
Parsa et al. (2018)	0.088 (10.4%)	0.255 (30.0%)

Grazian et al. 2018

Summary

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Galaxies:

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

Galaxies alone cannot provide the observed UVB at z~3.3 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 ~75%

Faint AGNs could give a substantial contribution to the ionizing background at z~4

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Thank you very much!