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The role of AGN in the hydrogen reionization

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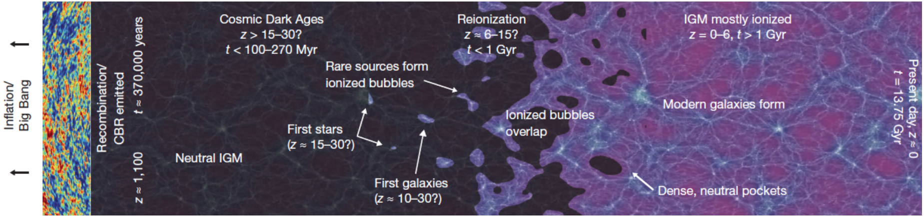
Cosmic reionization

The transition from the so called dark ages to an ionized Universe involves the cosmological transformation of neutral hydrogen, which mostly resides in the IGM, into an ionized state.



- Neutral IGM ionized between $6<z<15$ $\rightarrow$ the Universe is less than 1 Gyr old!
- Evidences: measures of neutral hydrogen absorption in distant QSO and GRB (Fan+02, Kawai+06), integrated depth of Thomson scattering from CMB (Planck collaboration), Gunn & Peterson tests for QSOs..
- UV ionizing photons E>13.6 eV, i.e. λ <912Å$\rightarrow$ available ionizing astrophysical sources: AGN and stars in star forming galaxies.

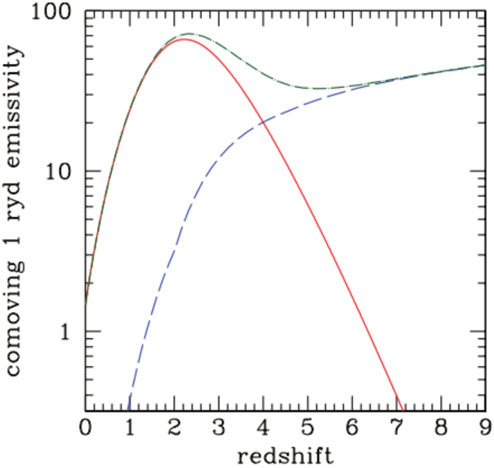
However, given the properties of observed galaxies and AGN **none** of the two populations is able to complete **alone** the reionization at z>6

The traditional view: AGN+SFGs

Haardt&Madau+12

$$\epsilon_{912}(z) = \langle f_{esc} \rangle \int_{L_{min}} \Phi(L_{UV}, z) L_{UV} dlogL_{UV}$$

1. QSOs $\rightarrow$ main contributor up to $z = 3$, then modest role (steadily decreasing number density, Masters+12, Jiang+16, Onoue+17, McGreer+18 etc)
2. SFGs $\rightarrow$ at $z \gtrsim 4$ massive stars in galactic systems provide the additional ionizing flux
3. $f_{esc}^{GAL} << f_{esc}^{AGN}$

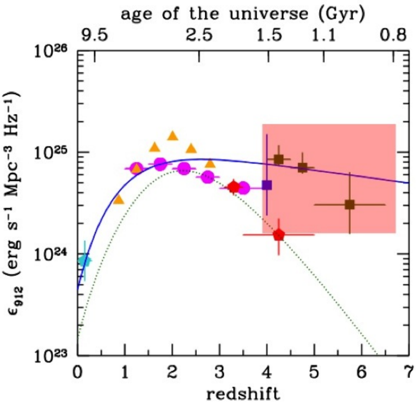


The traditional view: AGN+SFGs
BUT!

Open issues with the standard picture:

- SFGs at $z > 5$ can keep the IGM substantially ionized only assuming high values of leaking LyC f_{esc}^{GAL} radiation (>0.2, not observed so far, Shapley+06, Vanzella+10)
- f_{esc}^{GAL} few measurements with large scatter (Bridge+10, Bergval+13, Vanzella+10,+16, Smith+16, Vasei+16, Grazian+17)
- f_{esc}^{AGN} usually adopted 1, consistent for bright QSOs (Guaita+16, Cristiani+16) but probably too high for low-L AGN (Micheva+17)

AGN-dominated scenario?

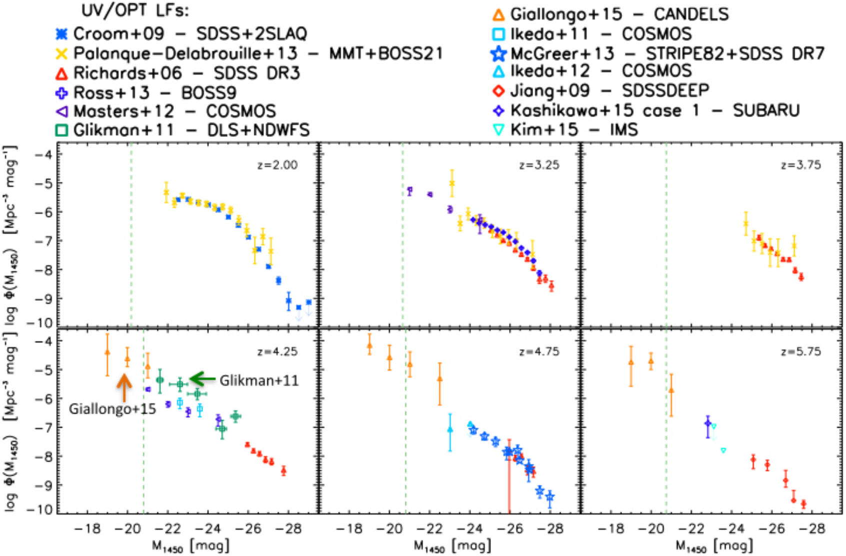


- The Planck measurements of a sudden reionization event at z=8.8 reduces the need for a large LyC background at very early times
- Some multi-λ surveys detected a large number density of faint AGN at high z, possibly implying a more substantial AGN contribution to HI reionization → AGN-dominated reionization scenario (Madau & Haardt 2015)

However these results are controversial since other groups were not able to confirm these larger number densities (e.g., Weigel+15, Georgakakis+15, Cappelluti+16, Vito+16,+18, Parsa+18)

AGN UVLF: UV/OPT-selected type 1 AGN

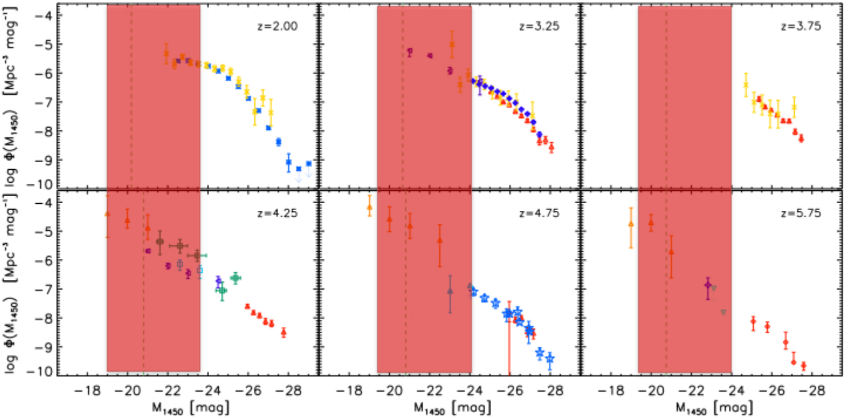
Usually the 1 ryd ϵ is computed starting from the UV LF of OPT-selected AGN



AGN UVLF: caveats

high-z OPT/UV AGN selection

- possible galaxy contamination (e.g. due to star formation)
- at low luminosity the selection becomes less reliable → disagreeing faint-ends
- standard lower limit to compute the ϵ: $0.01L_*$ → 5 mag fainter than the break!! **EXTRAPOLATION!**

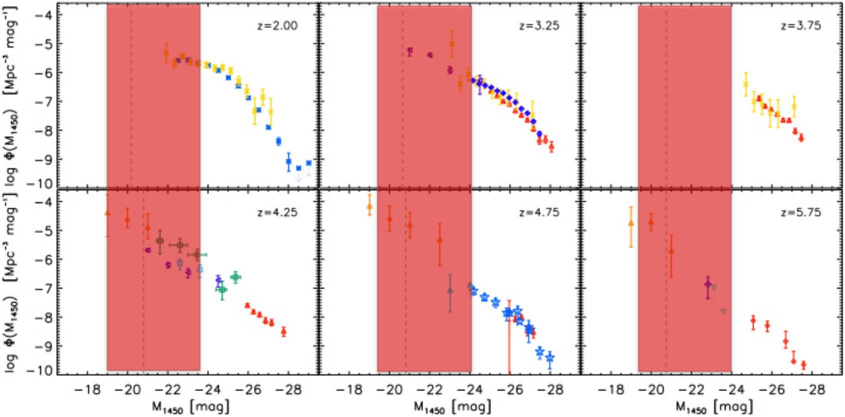


AGN UVLF: X-ray could be the solution!

high-z X-ray AGN selection

- no bias toward line-of-sight obscuration, extinction and galaxy dilution → **RELIABLE FAINT-END**
- almost no need to extrapolate!

To constrain the faint-end of the AGN UVLF at high redshift, we test if the XLF separated according to N_H can be used as an **unbiased** proxy of the ionizing AGN space density

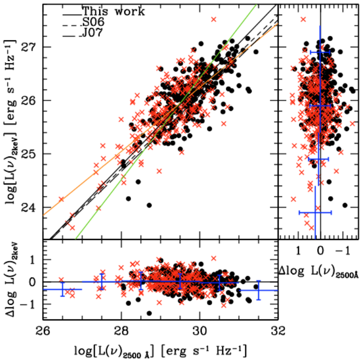


Connect X-ray to UV: How to

We use 3 XLFs:

1. Ueda+14 XLF: LDDE model $0 < z < 5$, $42 < logL_{2-10keV} < 46.5$ erg s^{-1}, divided in N_H
2. Vito+14 XLF: PDE model, $3 < z \leq 5$ and $43 < logL_{2-10keV} < 45$ erg s^{-1}, including CT
3. Marchesi+2016: COSMOS-Legacy data $3 < z < 6$, divided into type-1 and obscured

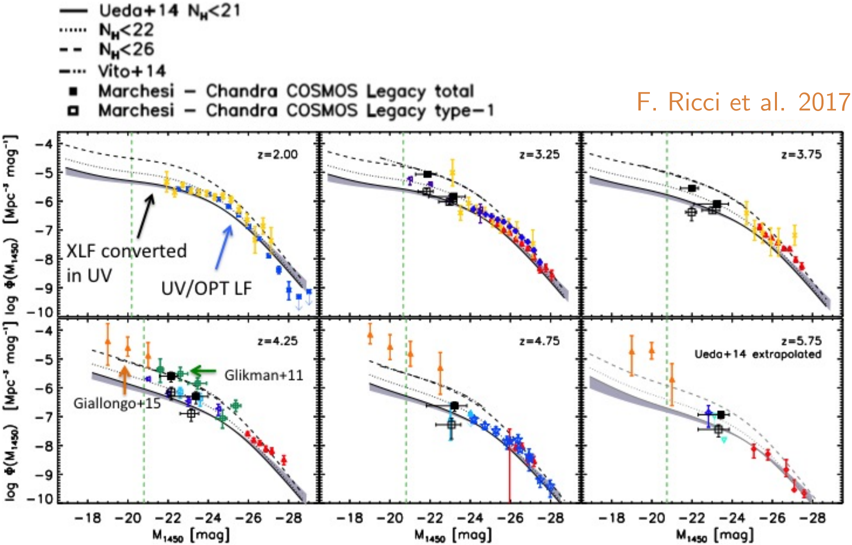
- $L_{2-10keV} \rightarrow L_{2keV}$: photon index Γ=1.8
- $L_{2keV} \rightarrow L_{2500}$: Lusso+10 relation with L_{2500} as **dependent** variable $logL_{2500} = (1.050 \pm 0.036) logL_{2keV} + (2.246 \pm 1.003)$ convolved with a Gaussian σ=0.4 dex (observed!) scatter.
  Note: no redshift dependence, in agreement with the works on α_{ox} (Risaliti&Lusso+15 etc)
- SED: $L_\nu \propto \nu^{-\alpha_\nu}$ double power law



Ionizing AGN LF: X/UV connection via N_H

XLF converted into UV

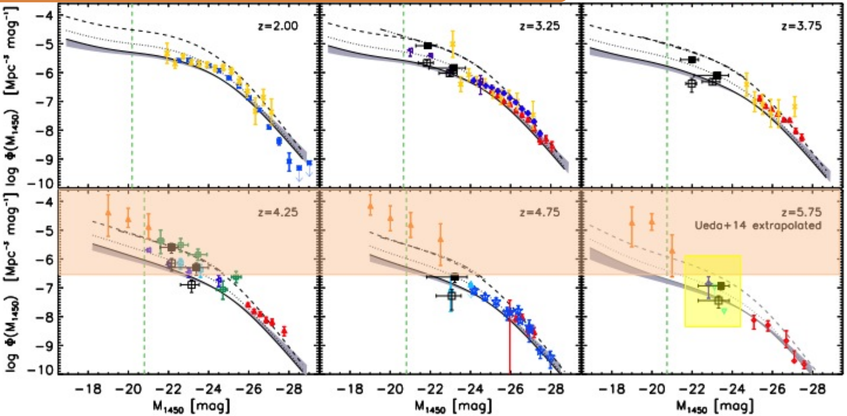
F. Ricci et al. 2017



Ionizing AGN LF: X/UV connection via N_H

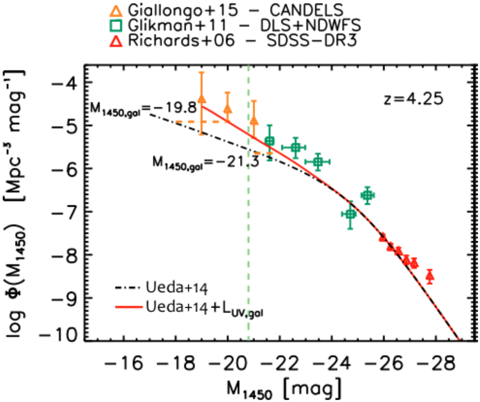
- Chandra COSMOS-Legacy data confirm the Ueda+14 XLF extrapolation!
- Always good agreement between the $\log N_H < 21-22$ cm^{-2} AGN and the UV/OPT-selected AGN in the break region ($M_{UV} \leq -23$)
- The XLF under-predicts the faint-end of the UV-selected AGN at $z > 4$

F. Ricci et al. 2017



Faint-end at $z > 4$

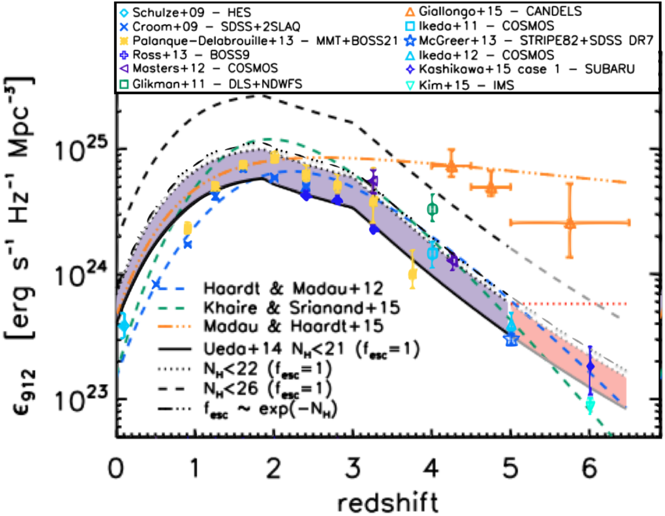
A small fraction of contamination of the UV emission from L_* galaxies can displace the XLF and reproduce the UV samples



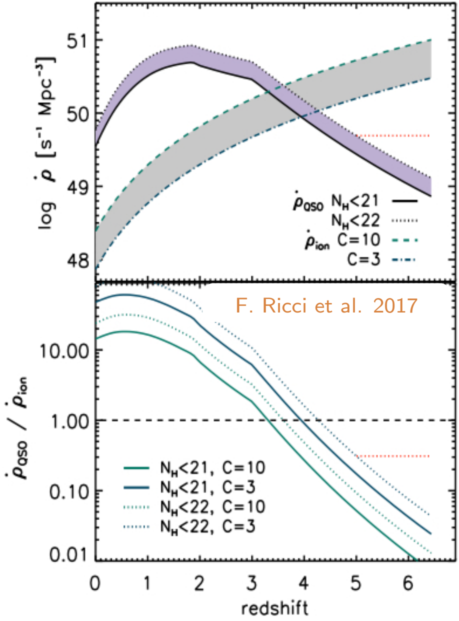
AGN outflows and positive feedback could increase the star formation in their host (see, e.g. Cresci+15) and enhance the porosity of the ISM (see, e.g. Giallongo+15, Smith+16, Stark+16, Kaaret+17, however see Chisholm+17 and Trebitsh+18)

HI emissivity: comparing X and UV

- Agreement between the $\log N_H < 21-22$ cm^{-2} X-ray AGN and the UV/OPT selected AGN (all assumed $f_{esc}^{AGN} = 1$)
- Agreement with other independent estimates of the evolution of the 1ryd AGN only emissivity



Implications: AGN can not do it all!



Comoving emission rate of hydrogen Lyman continuum photons as derived from X-ray AGN

$$\dot{\rho}_{QSO}(z) = \int_{\nu_{HI}}^{\nu_{HeII}} \frac{\epsilon_\nu(z)}{\mathrm{h}\nu}\, d\nu$$

compared to the minimum rate needed to fully ionize the Universe (Madau+1999)

$$\dot{\rho}_{ion}(z) = 10^{51.2}\left(\frac{C}{30}\right)\left(\frac{1+z}{6}\right)^3\left(\frac{\Omega_b h_{70}^2}{0.0461}\right)^2 \mathrm{Mpc}^{-3}\,\mathrm{s}^{-1}$$

AGN contribution at z=6 between 1-7% (~30% at maximum)

Our findings do not support an AGN-dominated scenario at z$\gtrsim$4 (see also Qin+17, Micheva+17, Hassan+17,+18, Kulkarni+18), SFGs contribution must be relevant!

Take home message

1. To better constrain the faint end of the AGN LF at high redshift, we investigated whether the XLF could be used as an unbiased proxy of the ionizing AGN space density $\rightarrow$ matching between X-ray $\log N_H < 21 - 22$ cm^{-2} AGN and the OPT/UV AGN
2. X-ray data allow to compute the 1 ryd emissivity up to $z \sim 5$ without any luminosity extrapolation, extending at ~ 5 lower magnitudes than the limits probed by current UV/OPT LF!
3. The faint-end of the UV selected AGN LF at $z > 4$ can be reproduced taking into account a small host galaxy contamination from typical L_* galaxies
4. Our updated ionizing AGN emissivities exclude an AGN-dominated scenario at high redshifts, as instead recently suggested by other studies.

THANKS!

AGN XLF used

1. Ueda+14 XLF: LDDE model
   - 13 different X-ray surveys performed with Swift/BAT, MAXI, ASCA, XMM-Newton, Chandra and ROSAT
   - $0 < z < 5$, $42 < logL_{2-10keV} < 46.5$ erg s^{-1}
   - XLF computed in various absorption ranges (i.e., at different N_H) → anti-correlation between the fraction of absorbed objects and the 2-10 keV luminosity (in line with earlier results, Lawrence&Elvis+1982,LaFranca+05, Hasinger+08)
2. Vito+14 XLF: PDE model
   - $3 < z \leq 5$ and $43 < logL_{2-10keV} < 45$ erg s^{-1}
   - all X-ray population, not divided according to the N_H
3. Marchesi+16b: COSMOS-Legacy data $z > 3$
   - space density of AGN divided into type-1 and obscured
   - up to redshift 6!

We can divide X-ray AGN in different N_H classes!