Andrea Grazian (INAF-Padova)

Born: 10/10/1974 in Italy
Master degree in Astronomy in 1998 (Padova)
2000-2002 Studentship at ESO Garching
PhD in Astronomy in 2003 (Padova)
2003-2006 PostDoc at INAF-OARoma
2006-2008 PostDoc at ASI SDC
2008-2018 Staff Astronomer at INAF-OARoma
2019-current Staff Astronomer at INAF-Padova

MAIN INTERESTS

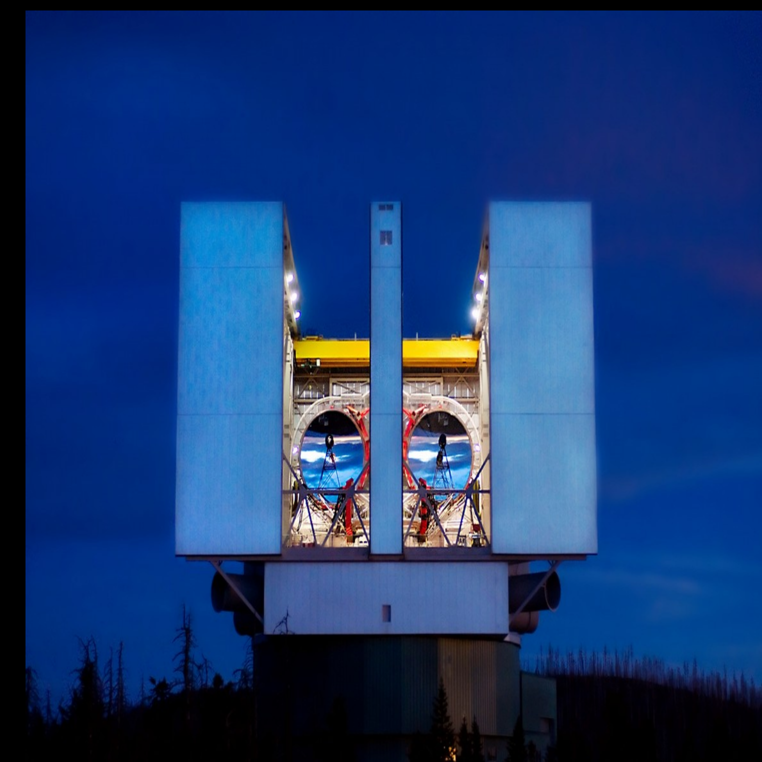
Formation and Evolution of galaxies and AGNs
Observational Cosmology
Reionization
Adaptive Optics, PSFR (MICADO-ELT)

Anecdotal

Cosmological Redshift Drift (talk by Stefano last week): do not be afraid to propose strange ideas and to make mistakes.

Curiosity Driven Research: the only secure answer you must have, should be “I don’t know”.

High-z AGNs and their possible role on Reionization



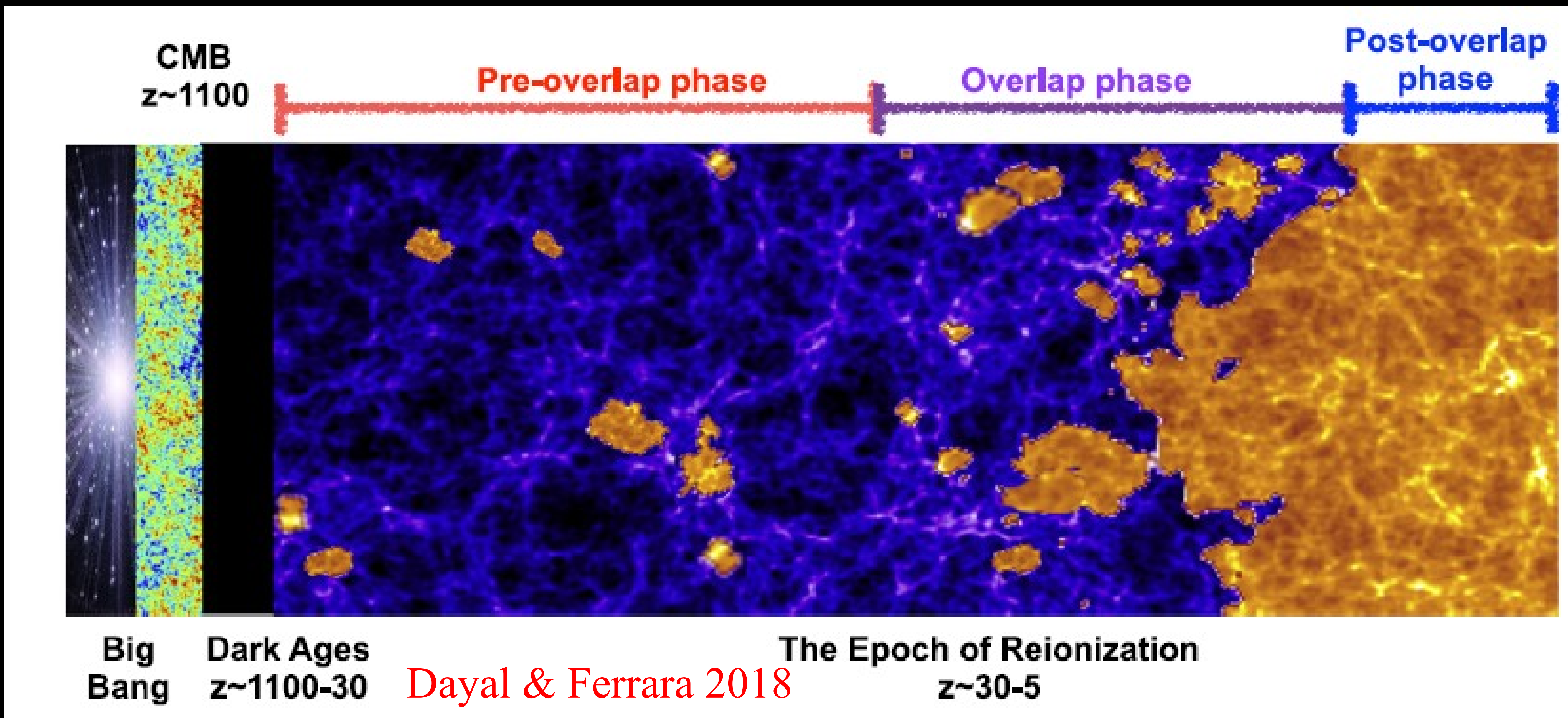
Andrea Grazian (INAF-OAPd)

S. Cristiani, G. Calderone, et al.

VOSS2023 - June 16th, 2023

Reionization: What ?

Hydrogen Reionization: major phase transition of the Universe



Dayal & Ferrara 2018

Hydrogen reionization

End of Dark Ages

Why is it important to study Reionization ?

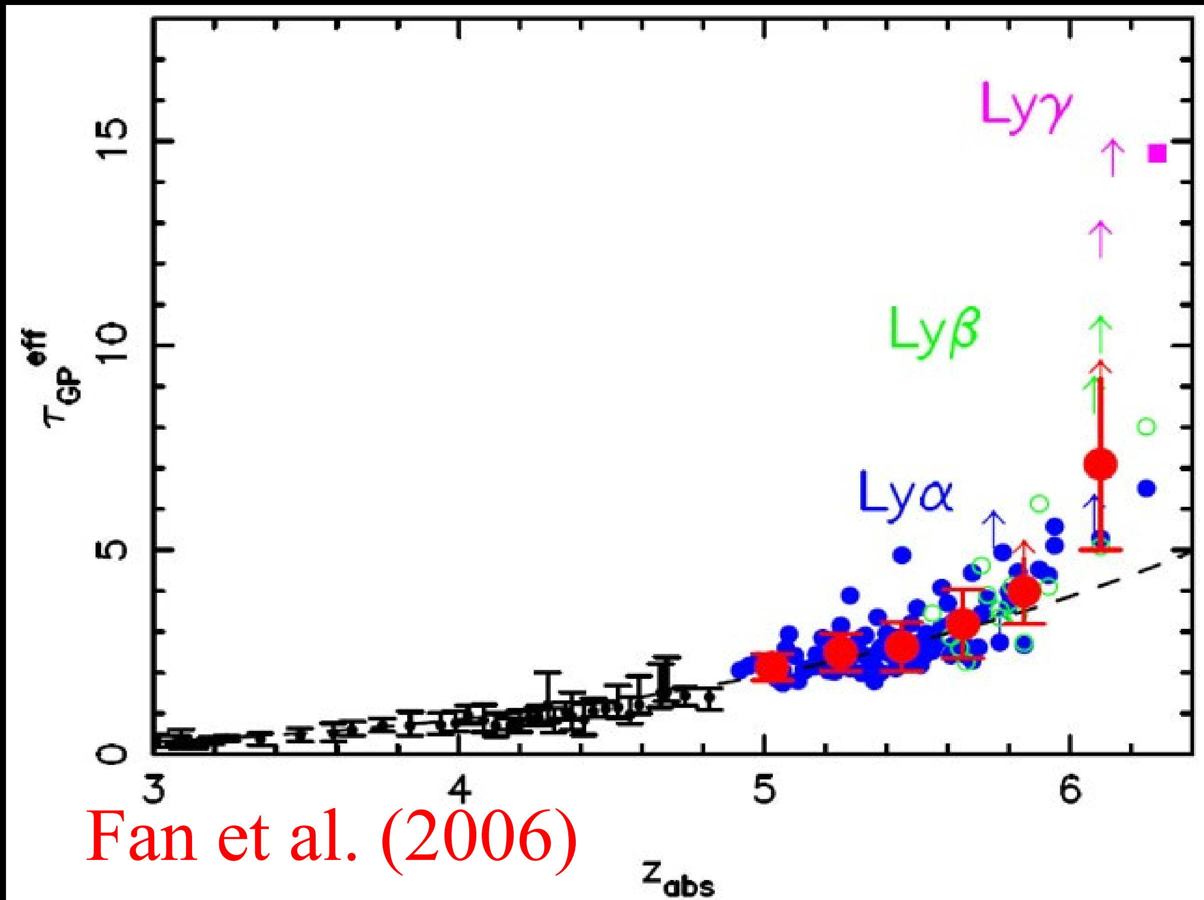
Last phase transition experienced by baryons in our Universe: 2nd major change in the ionization state of Hydrogen.

Radiative Feedback: quenching of small/faint galaxies at high-z.

Reionization changes the thermal state of the IGM: influence subsequent gas collapse and star formation events.

Reionization affects the visibility of distant objects and modifies the observed properties of the CMB.

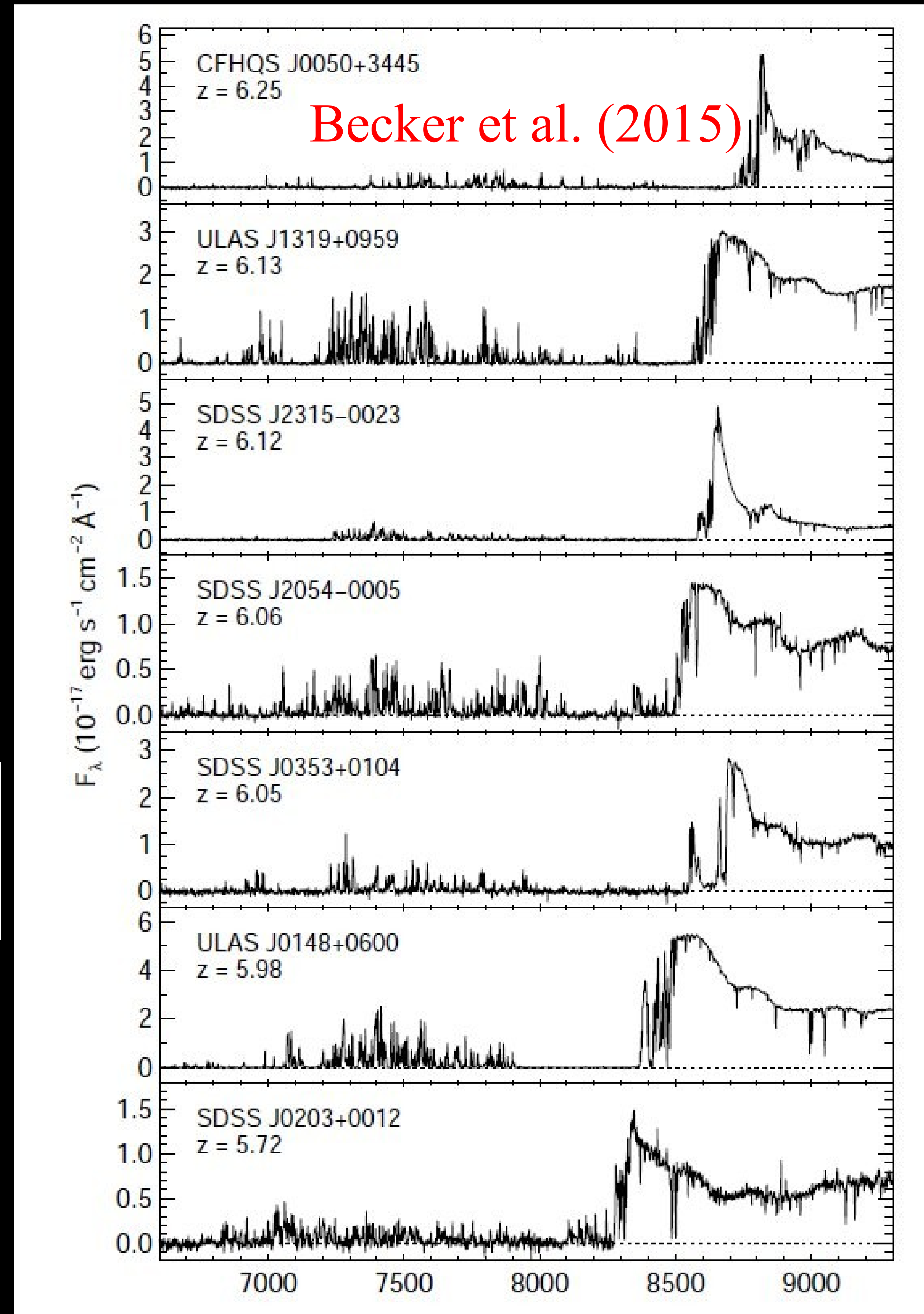
Epoch of Reionization: When ?



$$\tau_{\rm GP}(z) = 4.9 \times 10^5 \left(\frac{\Omega_m h^2}{0.13}\right)^{-1/2} \left(\frac{\Omega_b h^2}{0.02}\right) \left(\frac{1+z}{7}\right)^{3/2} \left(\frac{n_{\rm HI}}{n_{\rm H}}\right)$$

Even a tiny neutral fraction xHI~10^-4 gives rise to complete GP absorption
τ(HI) >> 1

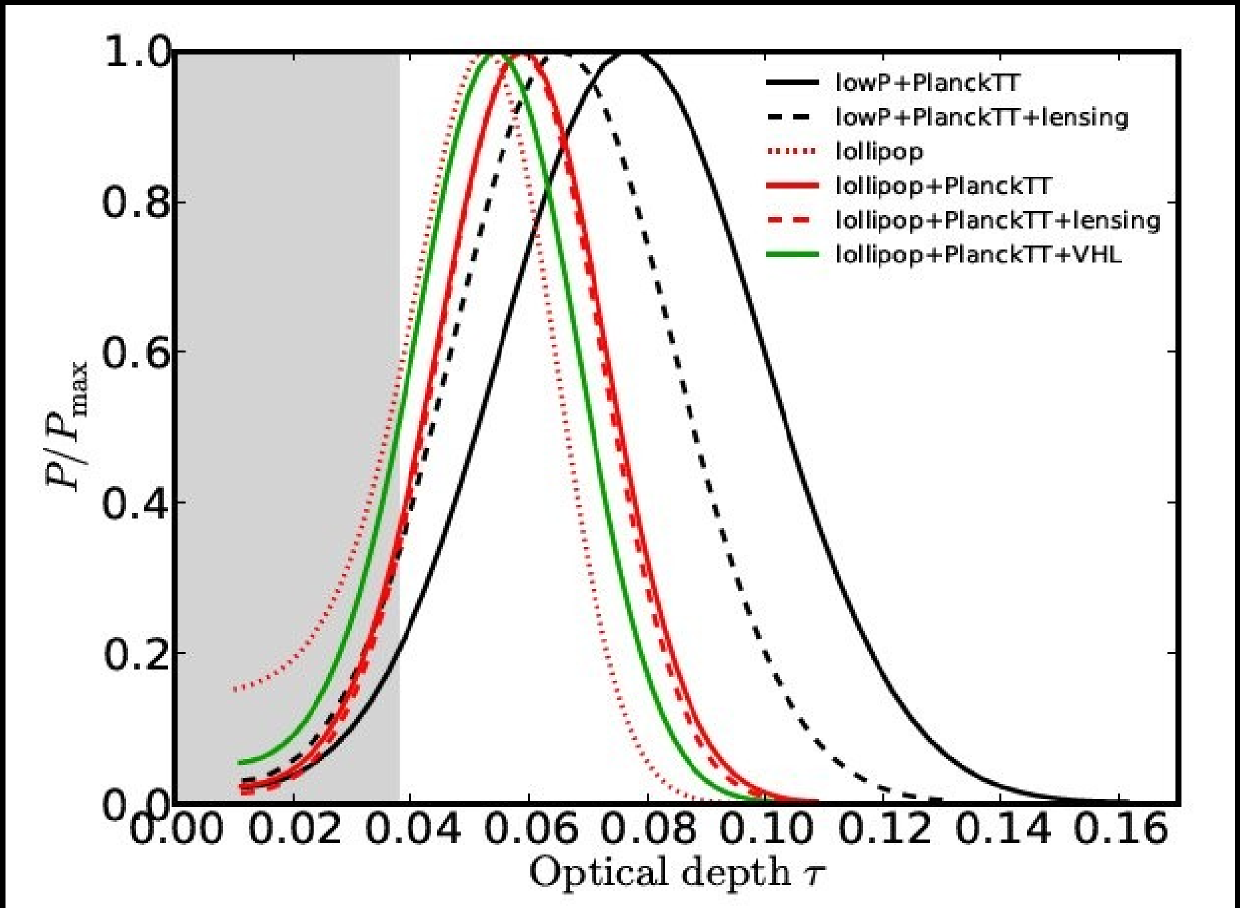
Gunn-Peterson troughs suggest reionization ending at z=5.2-55 (Fan et al. 2006; Becker et al. 2015; Bosman et al. 2018)



Epoch of Reionization: When ?

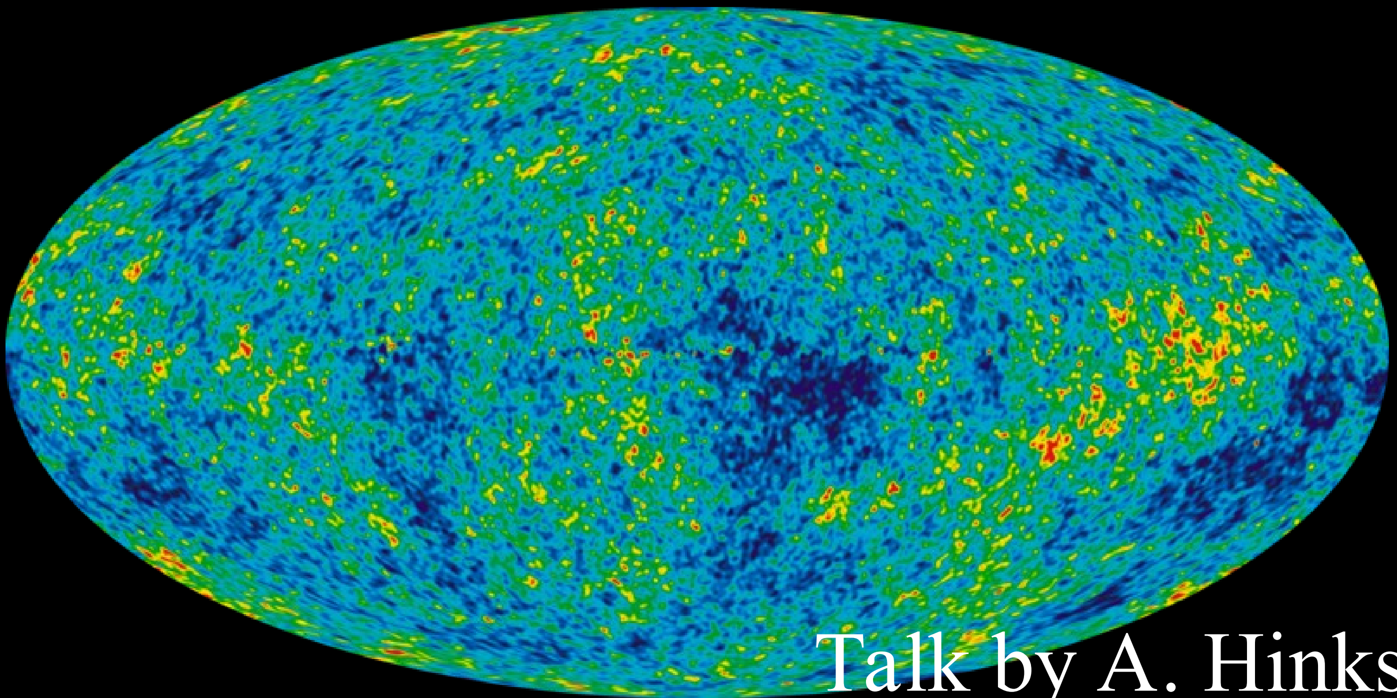
Thomson scattering optical depth measured in CMB

Planck 2018 result: τ=0.0544+/-0.008
z_reion=7.68+/-0.79   Delta_z<2.8
Implies reionization at z<~8. Rapid process



$$\tau = \int n_e \sigma_T dl.$$

$$x_e(z) = \frac{f}{2}\left[1 + \tanh\left(\frac{y - y_{re}}{\delta y}\right)\right],$$



Talk by A. Hinks

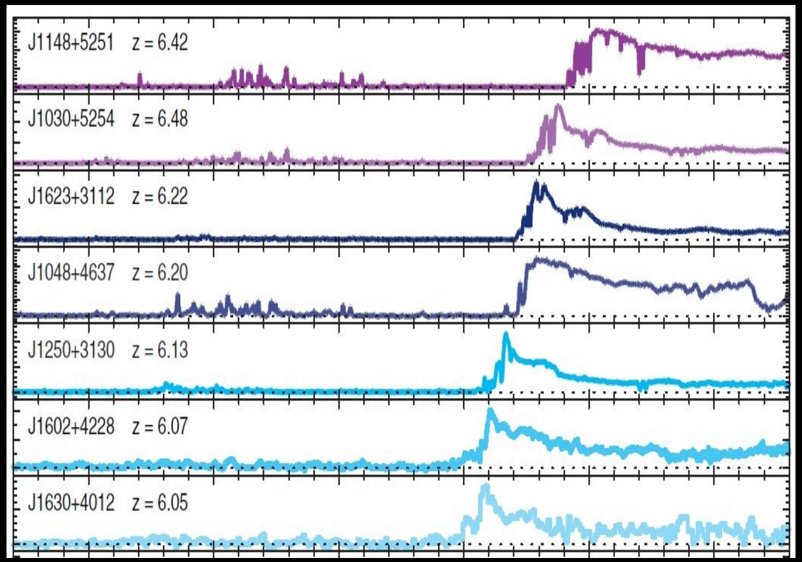
CAVEAT: simple parameterization is assumed for electron density evolution

Epoch of Reionization: When ?

Gunn-Peterson troughs suggest reionization ending at z=5.2-5.5
Ultra Late Reionization
(Fan et al. 2006; Keating et al. 2020; Becker et al. 2021; Bosman et al. 2021; Zhu et al. 2022; Gaikwad et al. 2023)

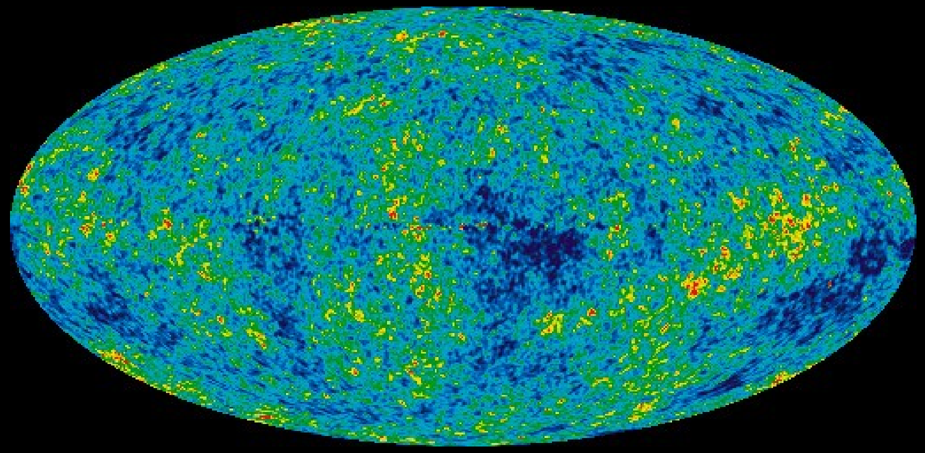
Planck 2020 result: τ=0.0506+/-0.0086
z_reion~7.0   Delta_z<1.1-2.8
Rapid process
(Akrami et al. 2020; Reichardt et al. 2021)
CAVEAT: simple parameterization is assumed for electron density.

Gunn-Peterson effect



Thomson scattering optical depth measured in CMB

+



=> **5.2 < z < 8.0**

z_reion>5.2

z_reion<8.0

Fast and Ultra Late Reionization

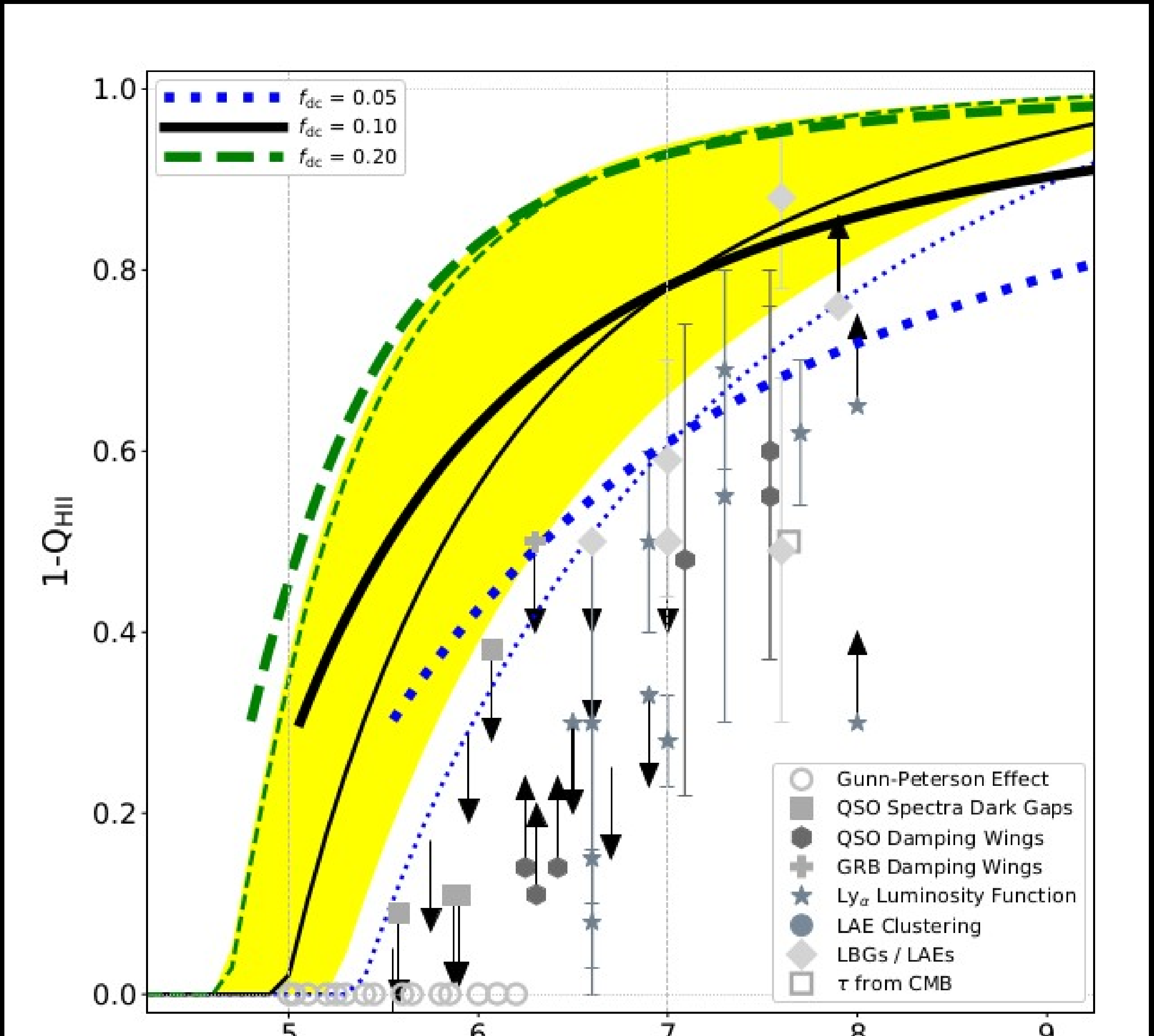
Constraining Reionization

CMB optical depth
Gunn-Peterson optical depth

Lyman Alpha Emitter Luminosity Function evolution at z>6
Lyman Alpha fraction in Lyman Break galaxies at z>6
Lyman Alpha Emitter Clustering
Damping wing in high-z QSOs and GRBs
Dark fraction of pixels in deep QSO spectra (Dark gap statistics)
Size of near-zone of QSOs
Patchy kinetic SZ effect (kSZ)

21cm power spectrum

Reionization after Planck



Fontanot et al. (2023)

Consistent picture: late and fast Reionization, almost complete at z~7.5; Greig & Mesinger (2017): z_reion=7.57+0.78-0.73, Delta_z_reion=1.7

Sources of Reionization

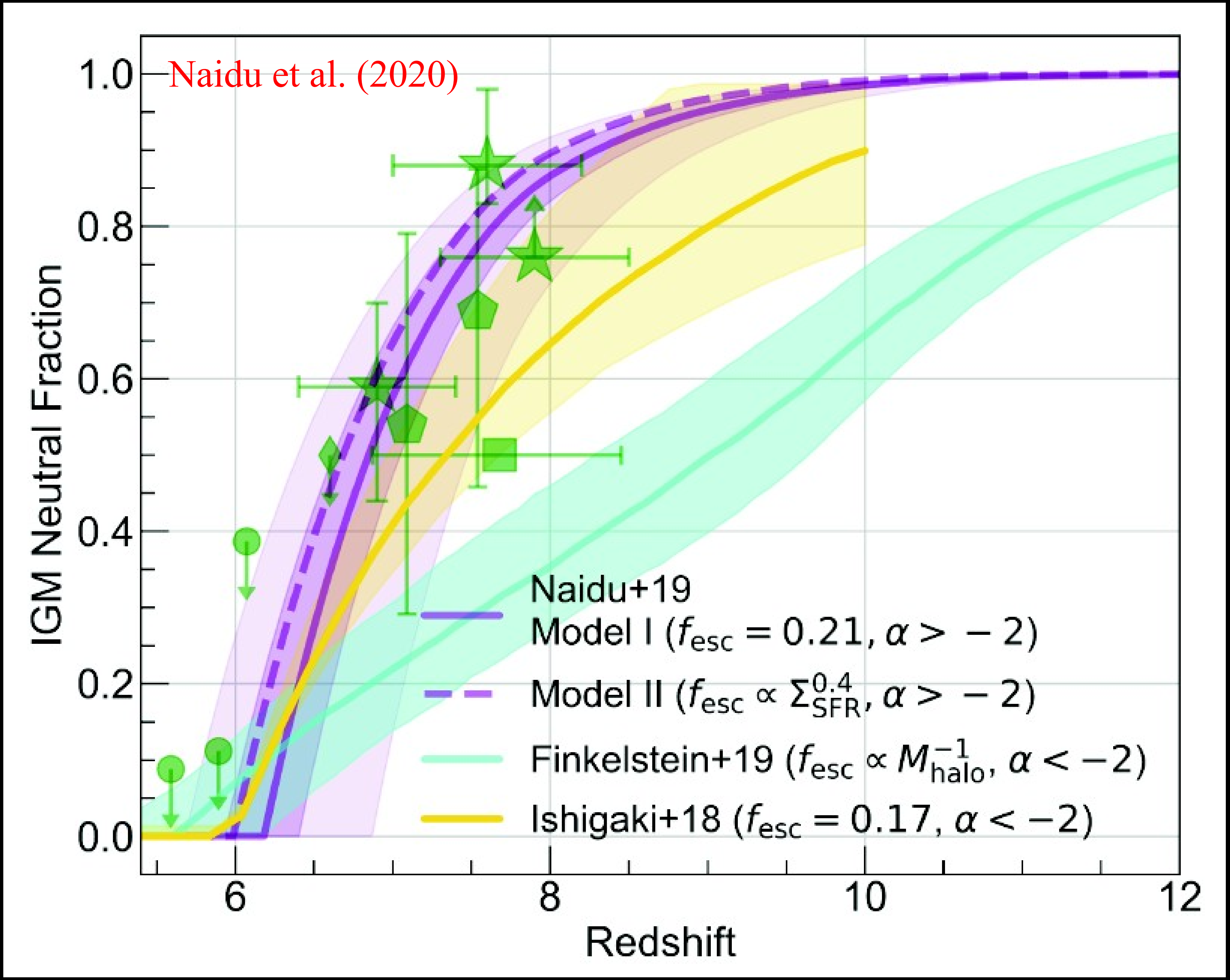
What are the sources of first light ?
Can they sustain reionization ?

Galaxies

AGN

(C. Marusa Bradac)

Faint Star Forming Galaxies: too long reionization process. Bright and rare sources are required to match current data.



Production of ionizing radiation

$$\dot{N}_{ion}(z) = \int_{\nu_H}^{\nu_{up}} \frac{\rho_\nu}{h_p \nu} d\nu$$

Ionization rate

$$\rho_\nu = \int_{L_{min}}^{\infty} f_{esc}(L, z)\Phi(L, z)L_\nu(L)dL \,,$$

UV Luminosity Density

Luminosity Function at 1450A rest frame

Spectral Energy Distribution (L1450/L900 ratio)

f_{esc} Escape fraction of LyC photons

How to find (high-z) QSOs/AGNs

UV-Optical-IR color selections (talk by Stefano Cristiani)

X-ray

Radio

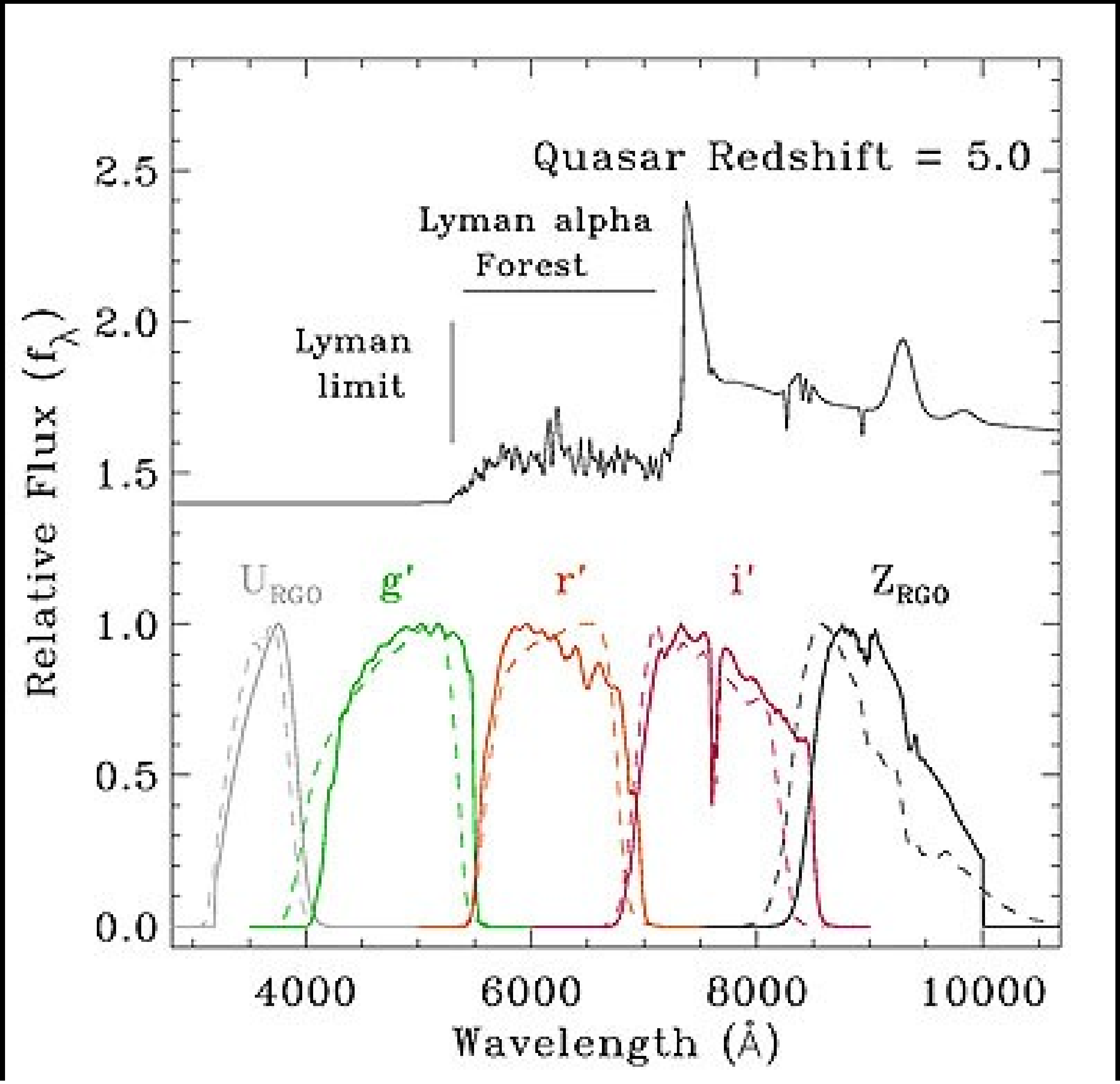
Variability

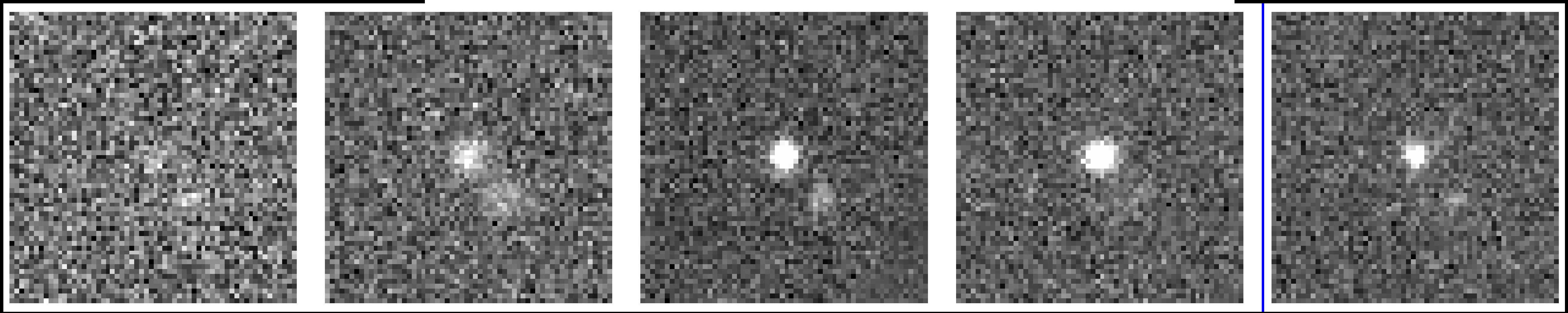
Machine Learning (talk by Giorgio Calderone)

UV-Optical-IR spectroscopy

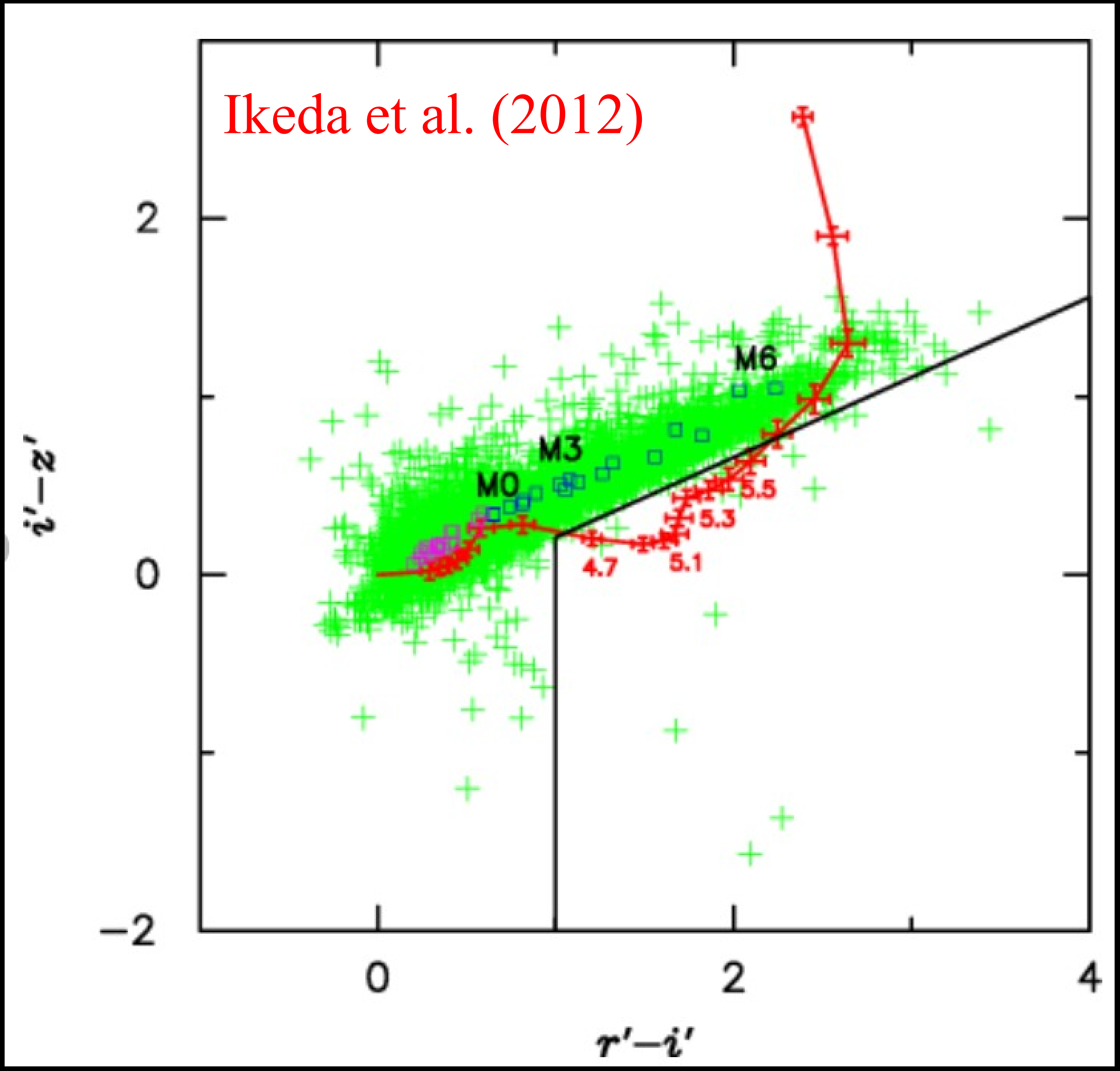
Etc...

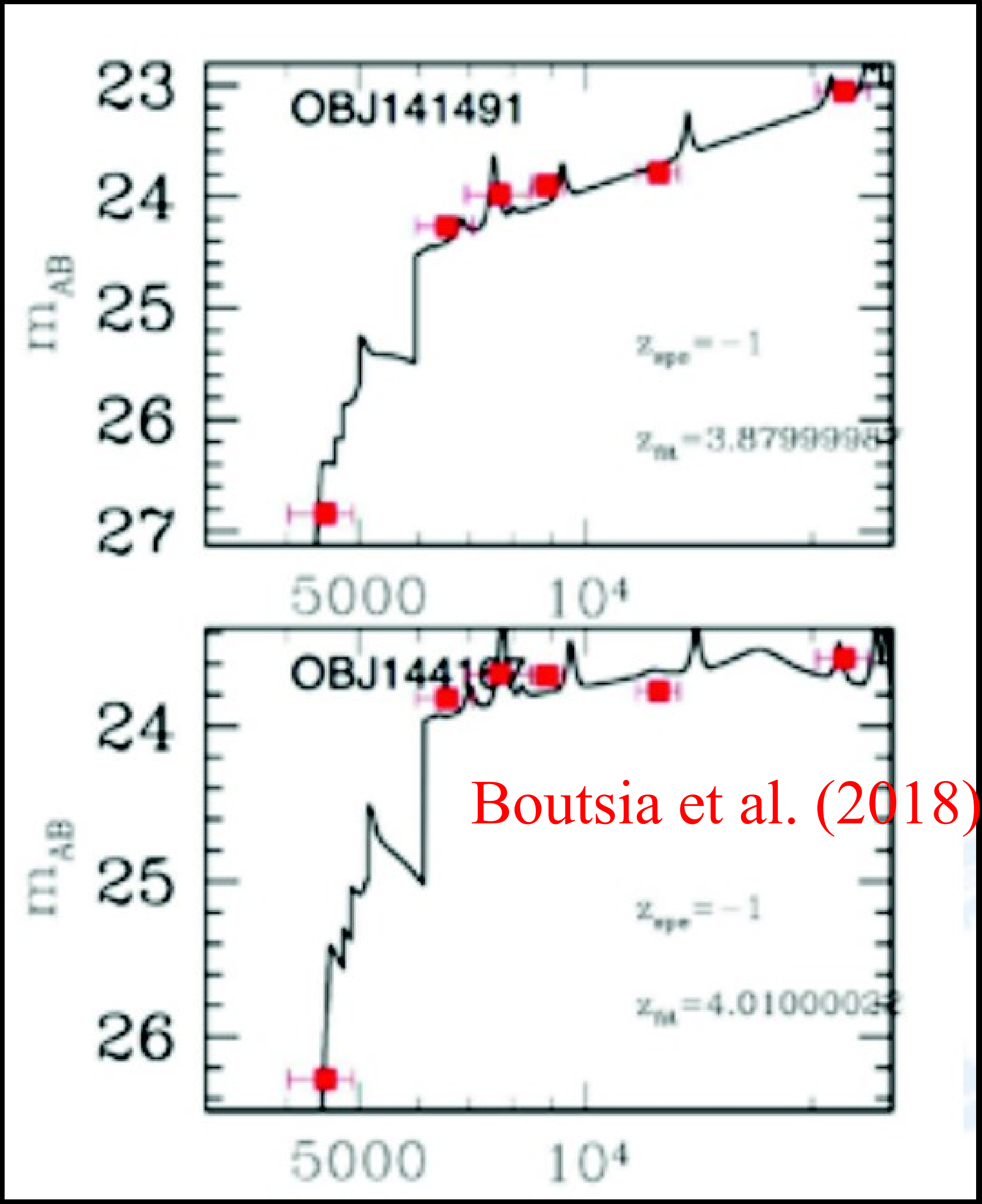
Selection of high-z QSOs





Selection of high-z QSOs





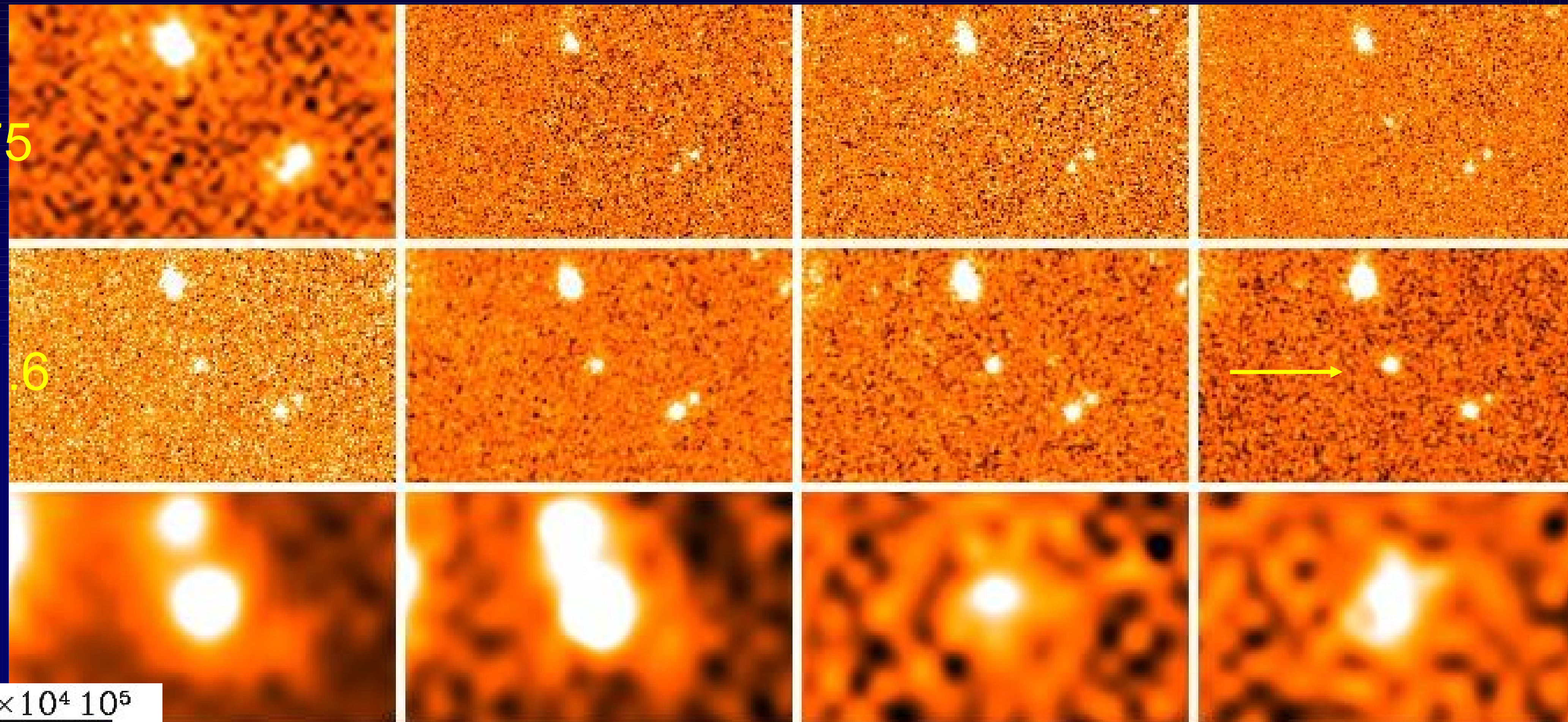
High-z QSO candidates can be selected with color criteria (r-i vs i-z), or through photometric redshifts.

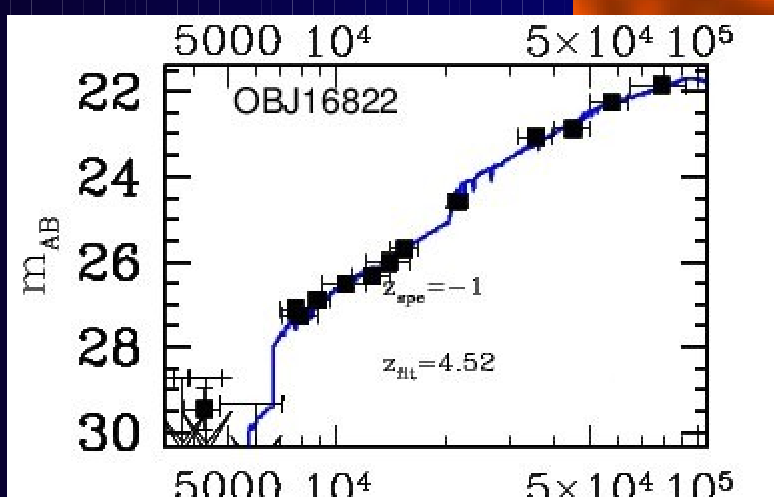
Candels GDS16822   z=4.5

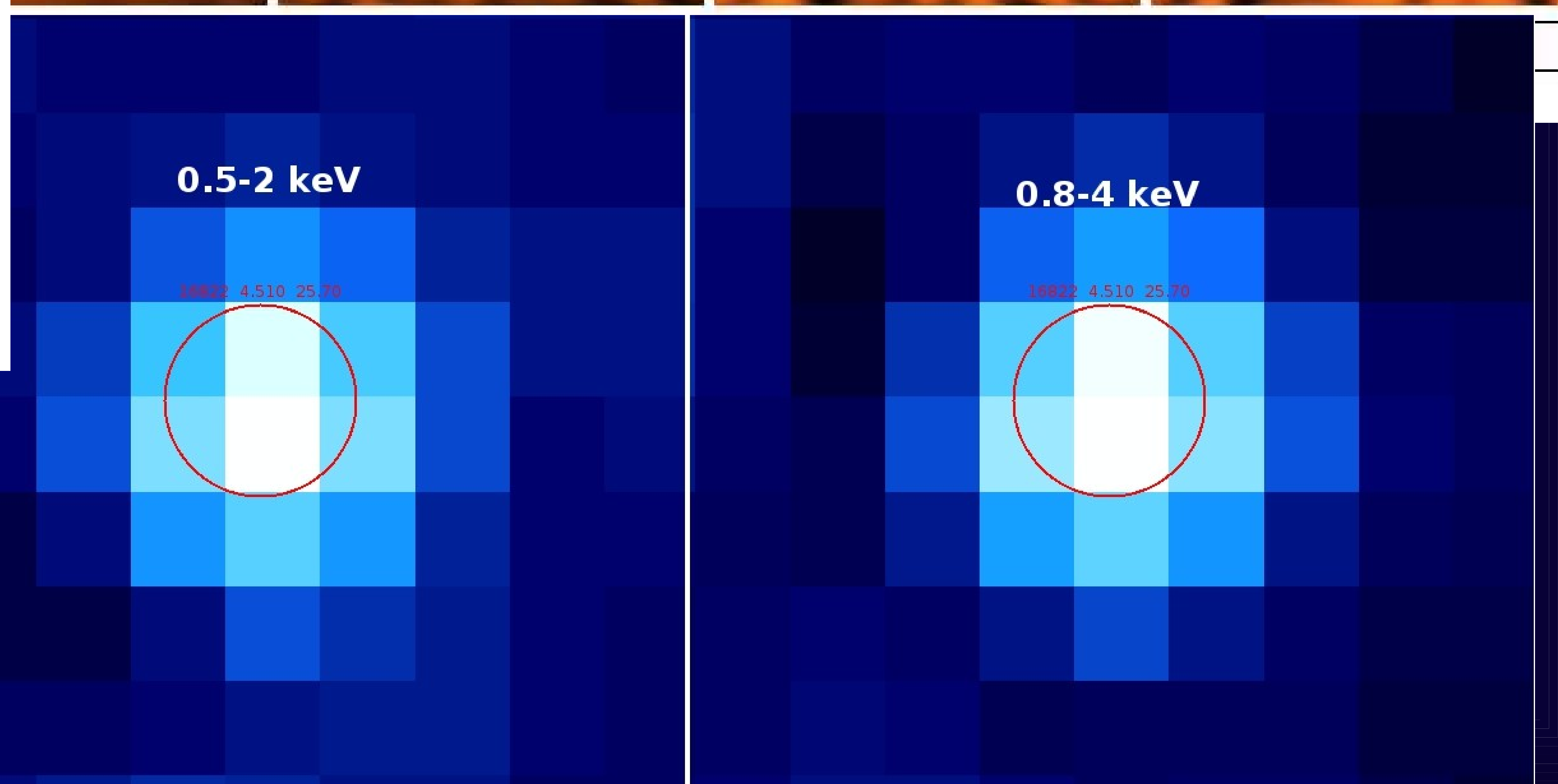
U,B435,V606,I775

850,Y1.05,J1.25,H1.6

Irac 3.6,4.5,5.8,8



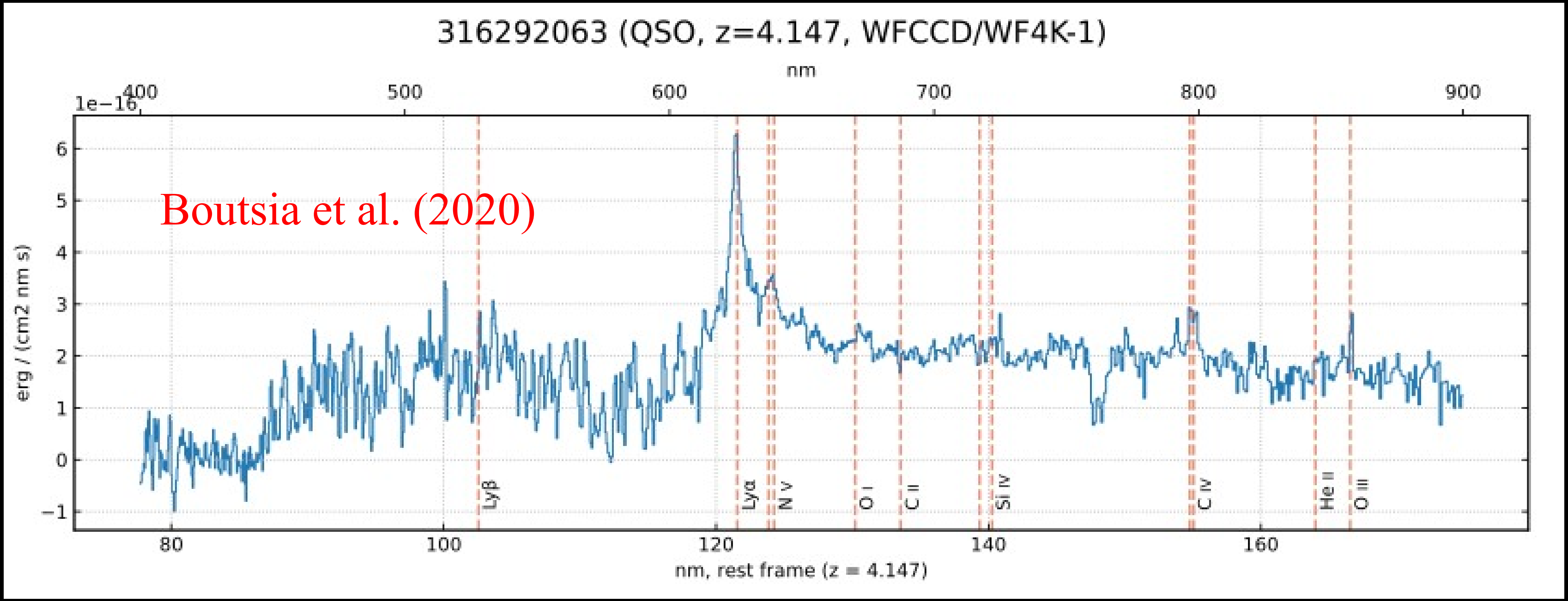




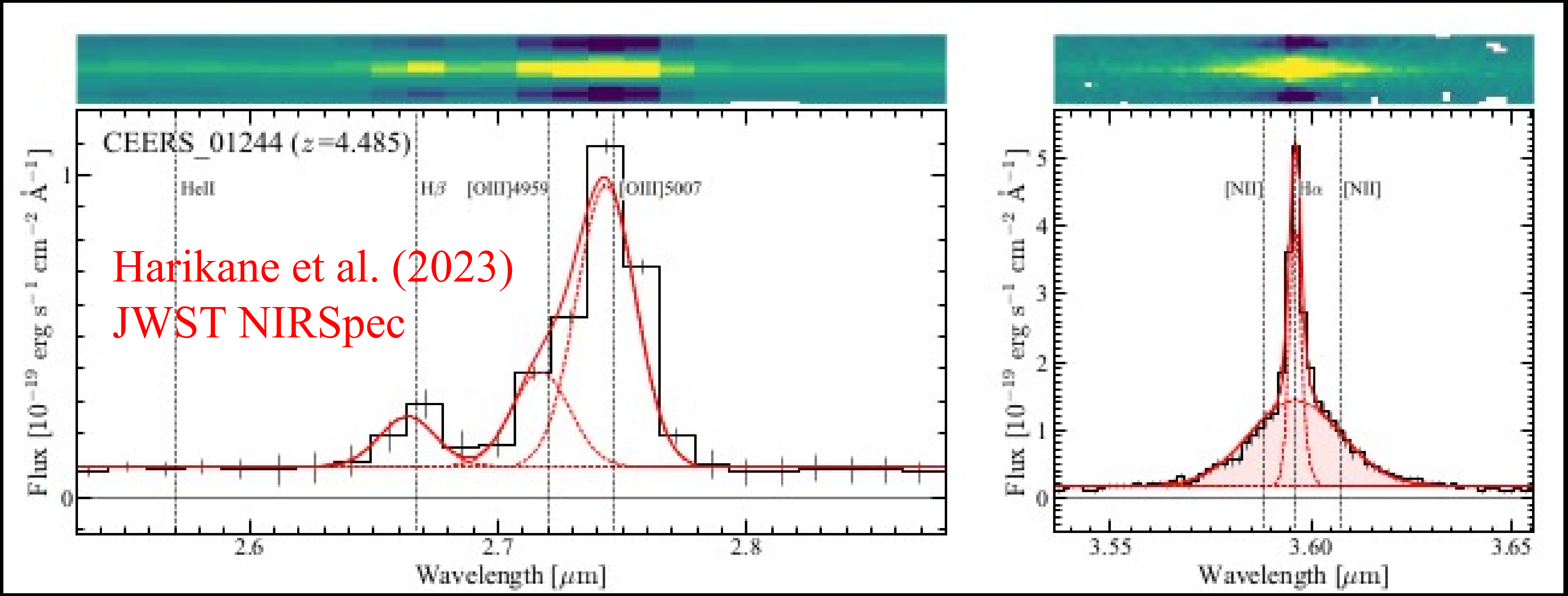
Giallongo et al. (2015, 2019)

Spectra of high-z QSOs

Spectroscopic confirmation of high-z QSO candidates is mandatory to ensure their nature and measure their redshift.



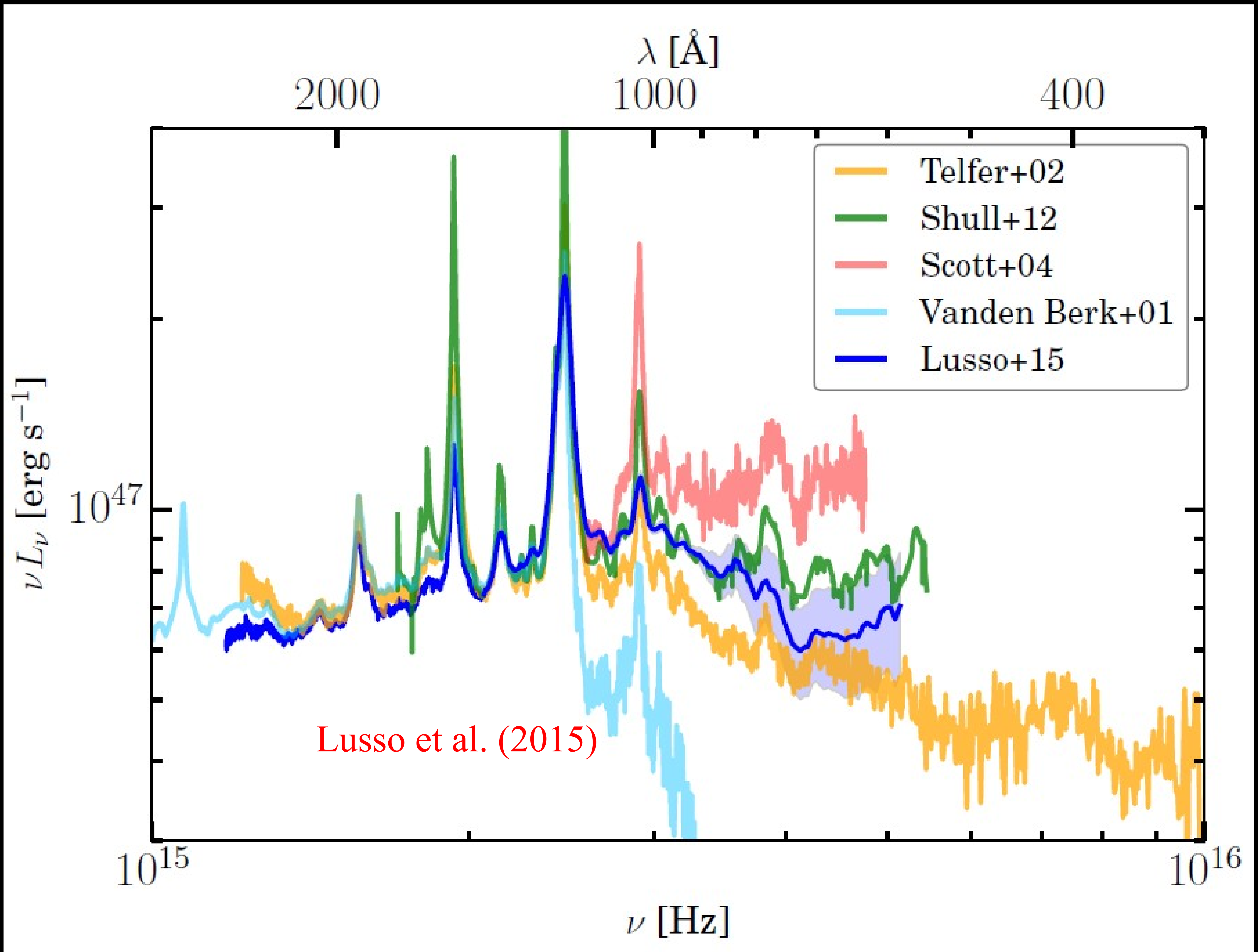
Selection of high-z AGNs: spectra



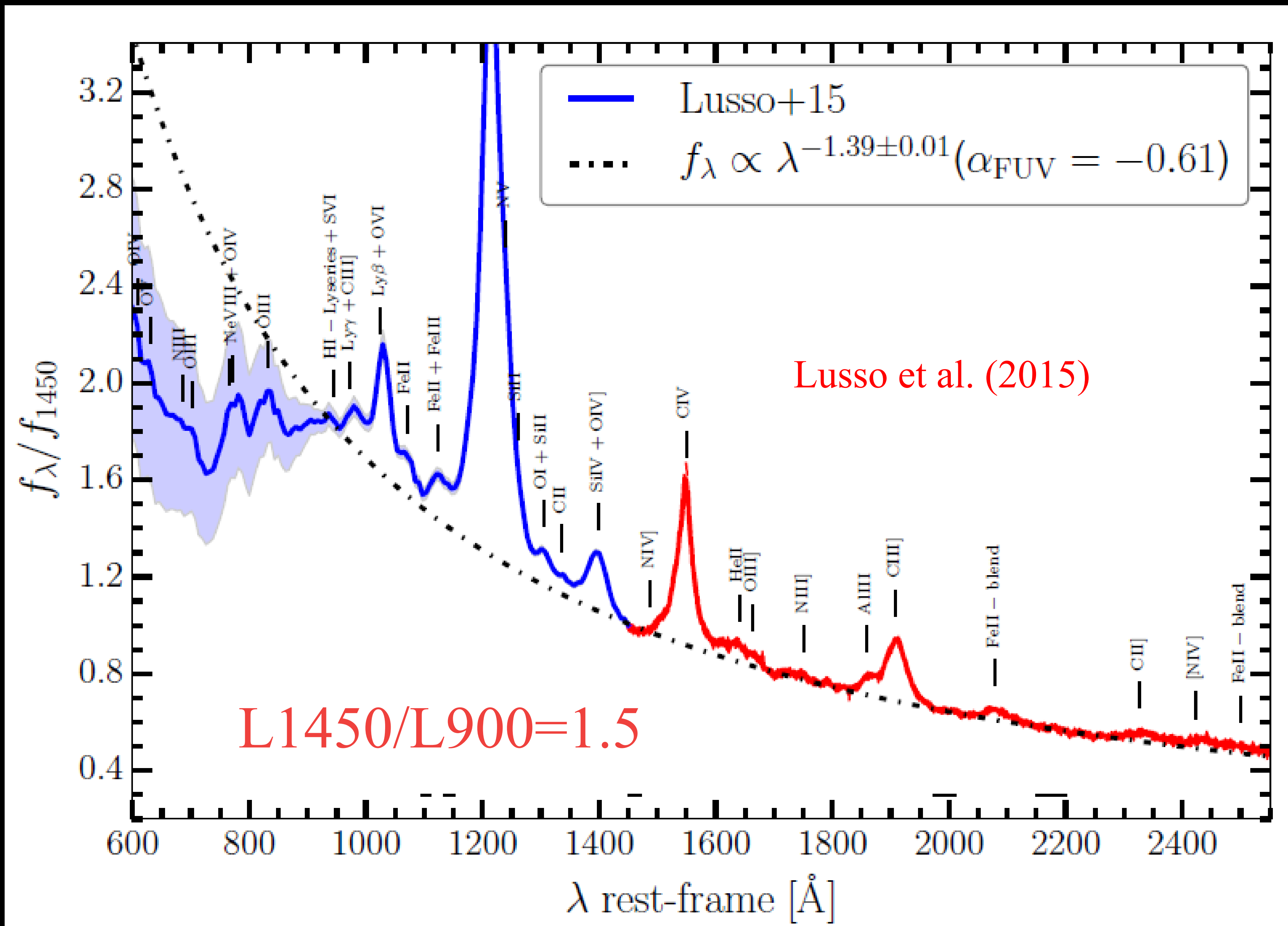
High-z AGNs can be selected with deep spectra: broad Balmer lines (Kocevski et al. 2023; Matthee et al. 2023)

Spectral Energy Distribution

L900/L1450 flux ratio

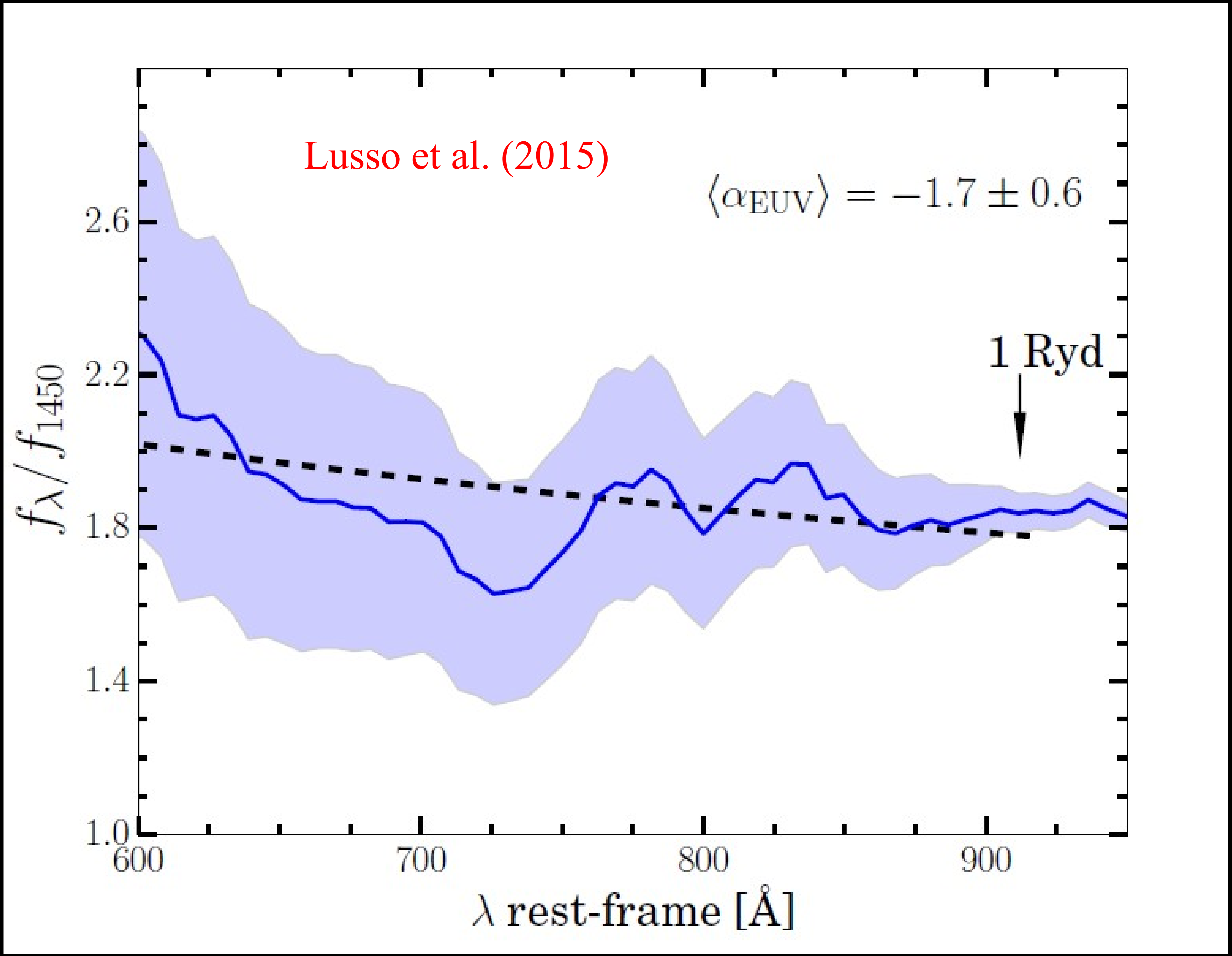


Spectral Energy Distribution QSOs



Spectral Energy Distribution

L900/L1450 flux ratio (0.75)



QSOs

The luminosity function of high-z QSOs/AGNs

Method of accessible Volume Vmax
(non-parametric)

$$\frac{\mathrm{d}V}{\mathrm{d}\Omega\mathrm{d}z} = \frac{(1+z)^2 D_A^2}{H(z)}$$

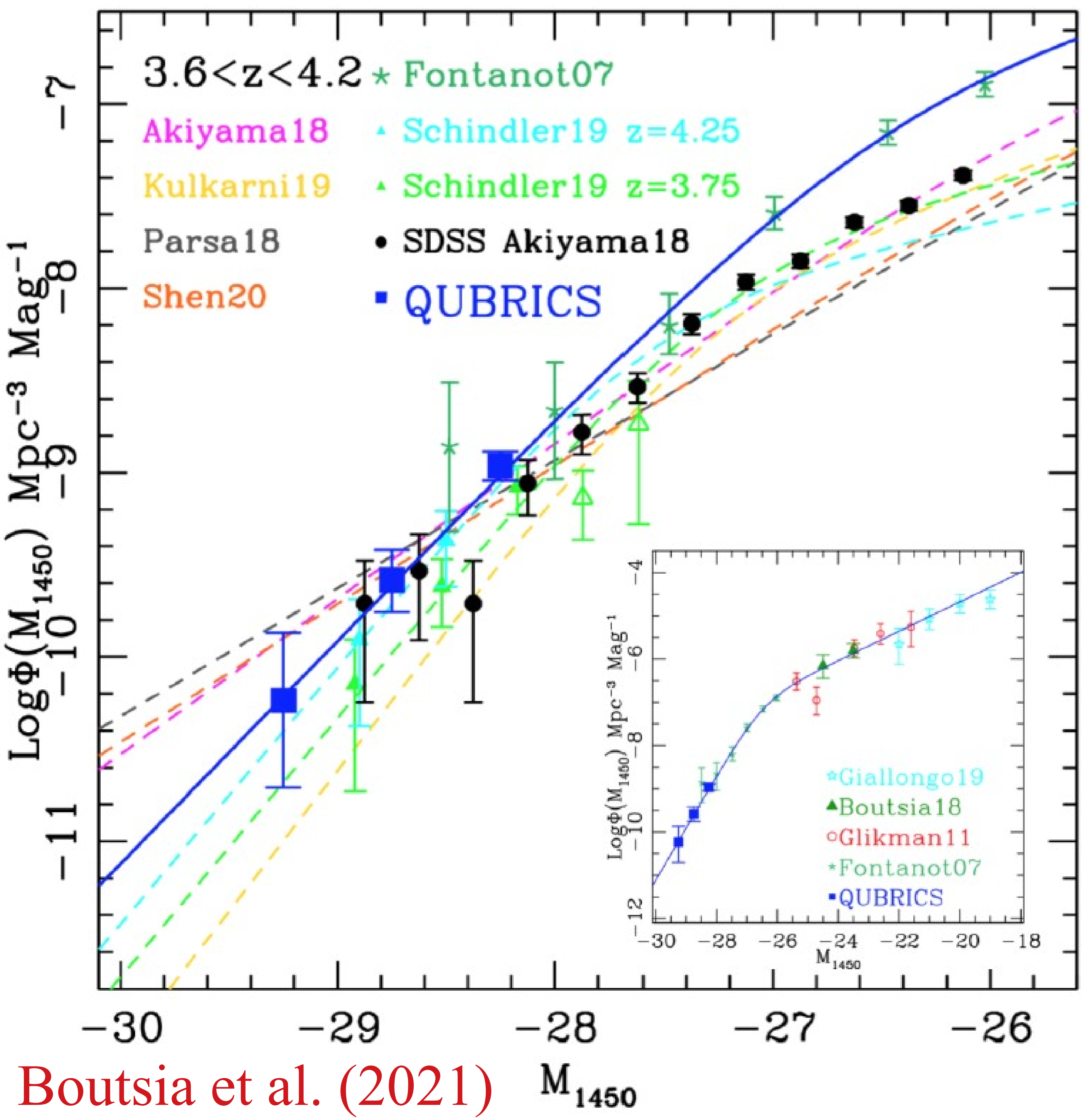
Vmax(zmin,zmax)
zmin and zmax depend on observed magnitude and survey limit

$$n(L) = \frac{1}{\Delta L} \sum_{i=1}^{N} \frac{1}{V_{\max}(L_i)},$$

Sum on all the QSOs of the survey

Completeness

The QSO LuminosityFunction at z~4



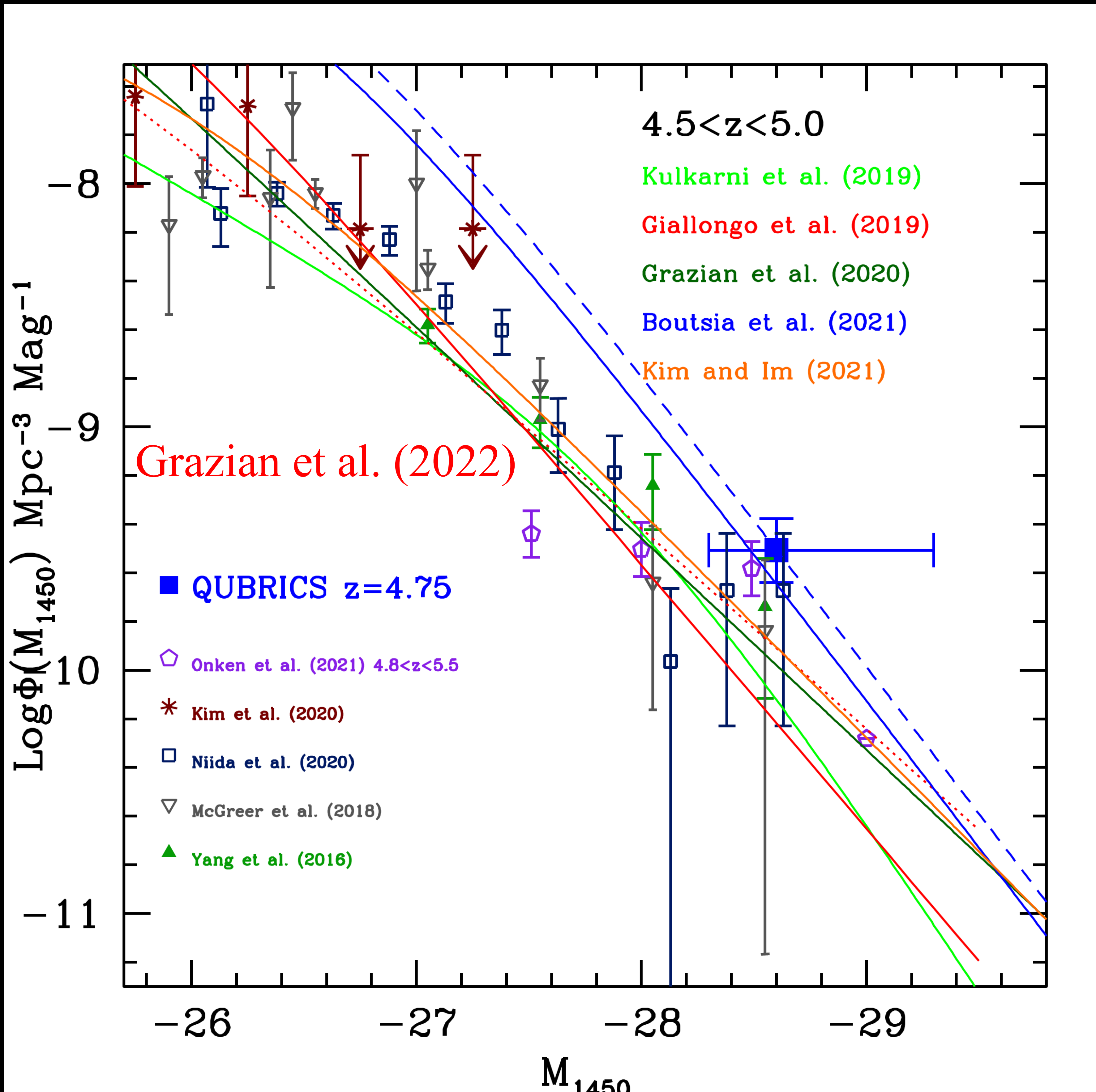
Boutsia et al. (2021)

QUBRICS:
58 QSOs
At 3.6<z<4.2 and
MagI<=18.0
In 12400 sq. deg.
84% completeness

QSO Space density is 2-3 times higher than previous estimates.

Bright-end slope
Beta=4.0

Luminosity Function of z~5 QSOs

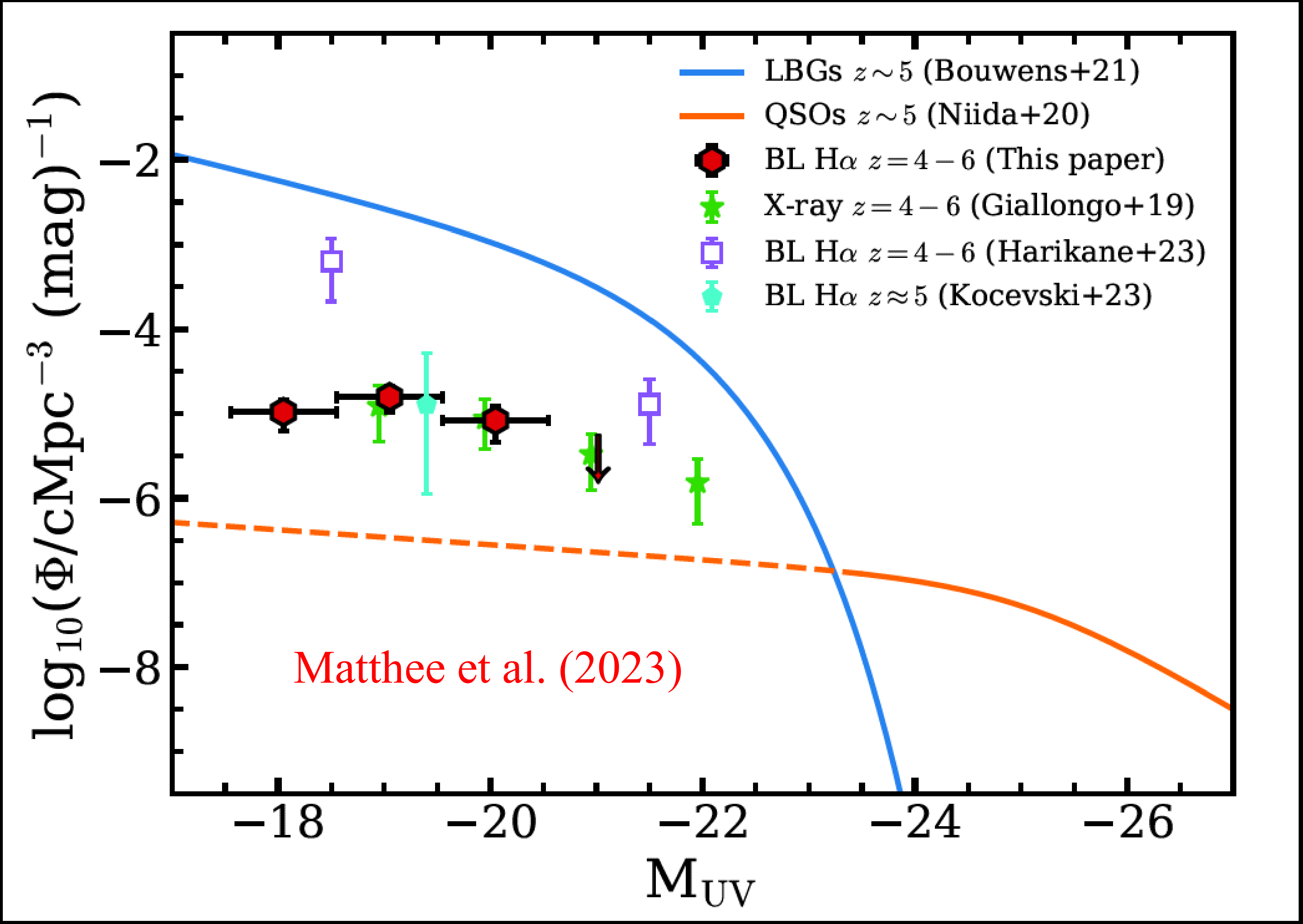


QUBRICS:
14 bright QSOs at
$4.5<z<5.0$ and
$I<18.0$ (AB) in
12400 sq. deg.
Completeness~92%

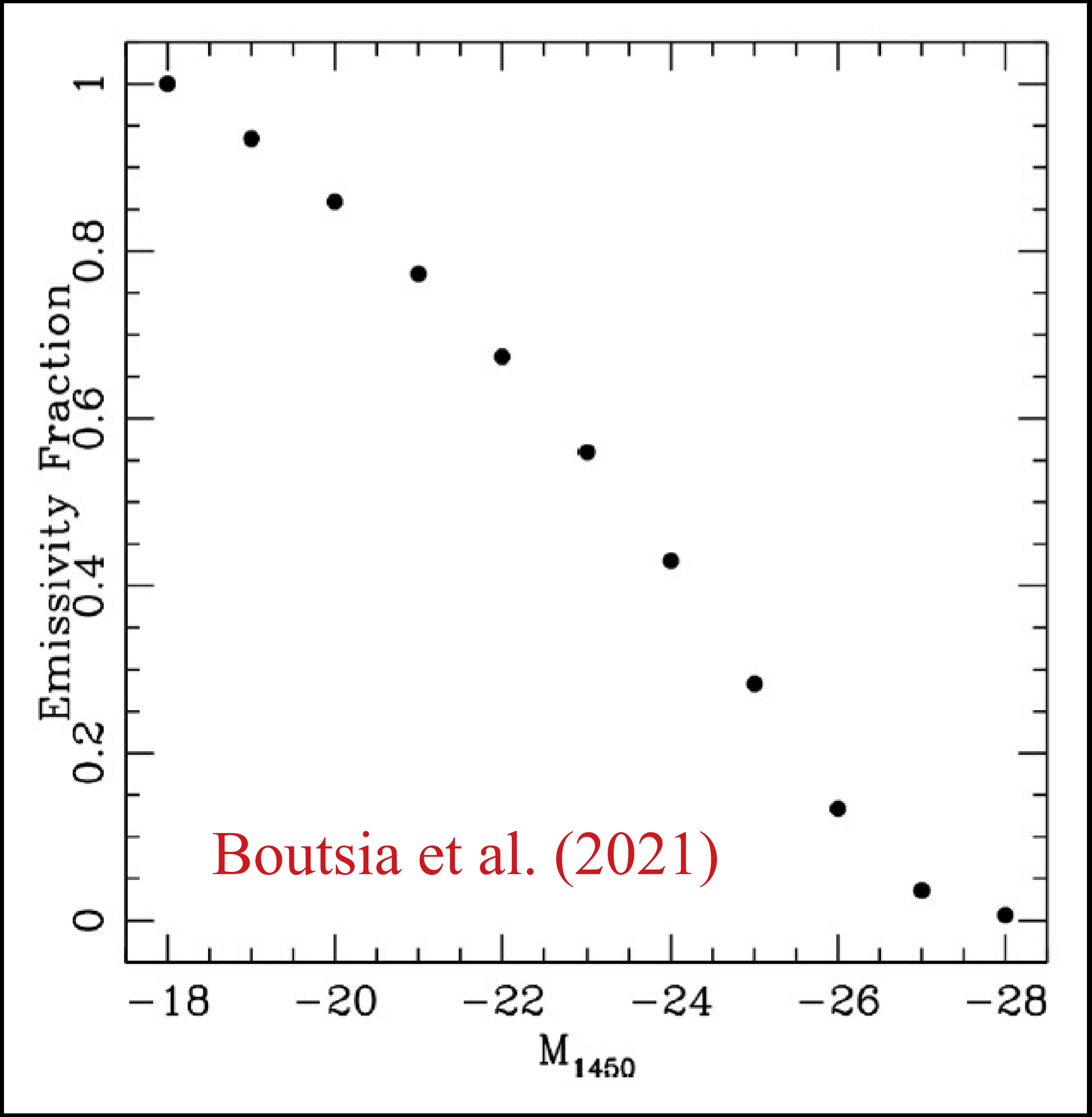
Previous surveys
are incomplete by a
factor of ~2-3.

Faint side of LF ?
Work in progress...

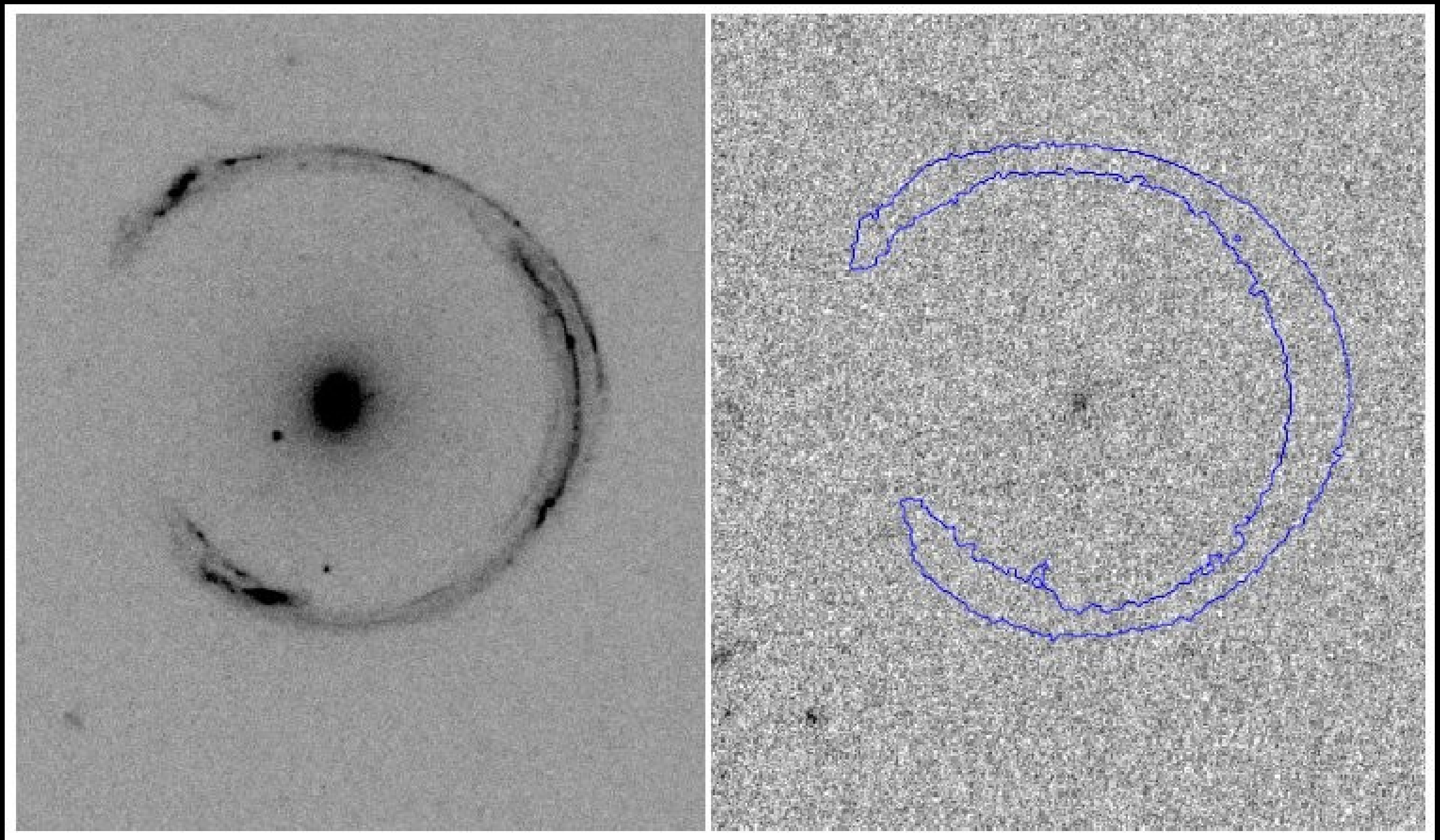
The faint side of AGN Luminosity Function at z~4-6



The bulk of the AGN luminosity density is produced close to L*
More than 50% of AGN radiation is produced by QSOs brighter than M1450=-23



LyC escape fraction of QSO/AGN: how to measure it ? Imaging



Steidel et al. (2001)

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

Vasei et al. (2016)

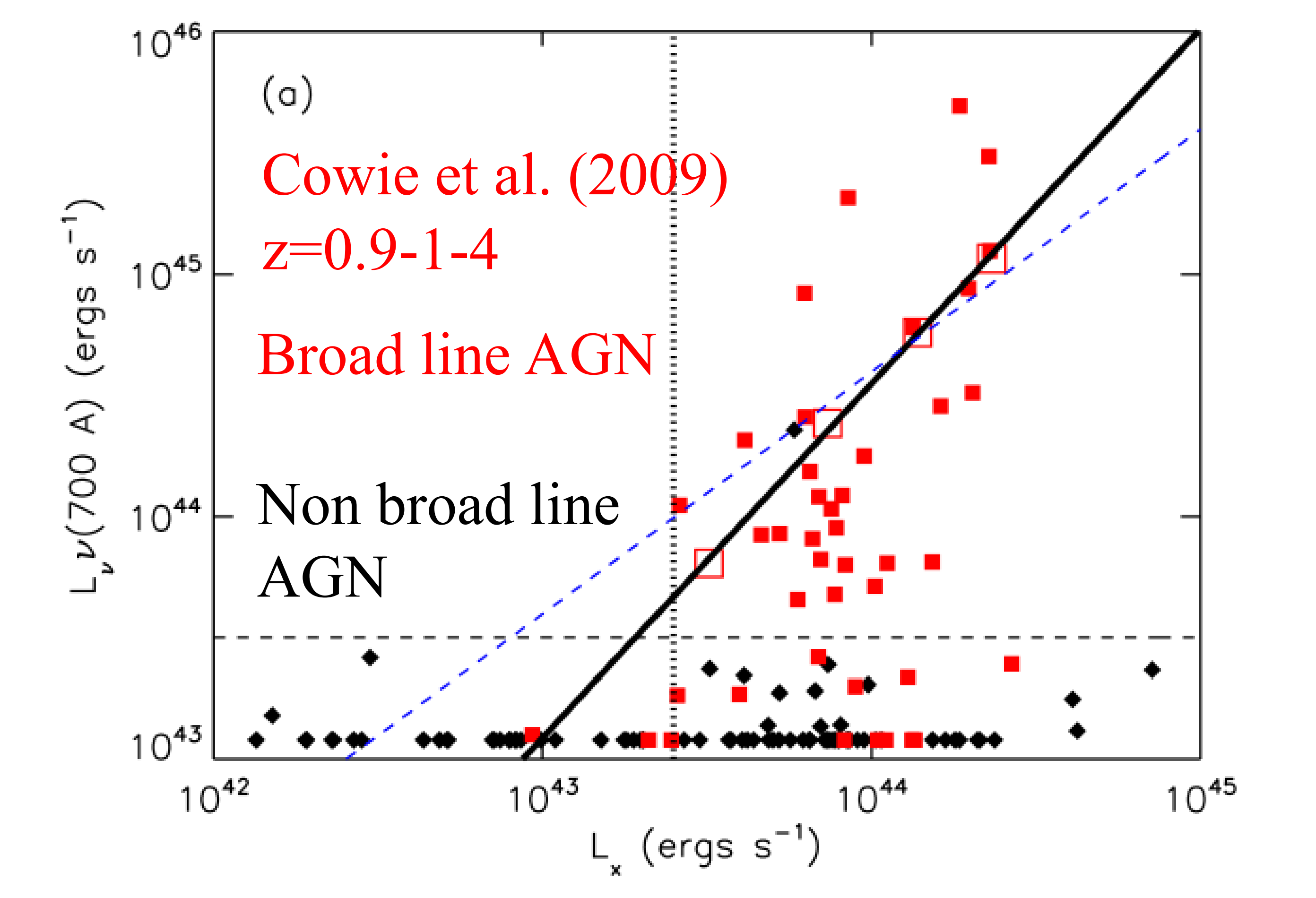
F606W
L1500

F275W
L900

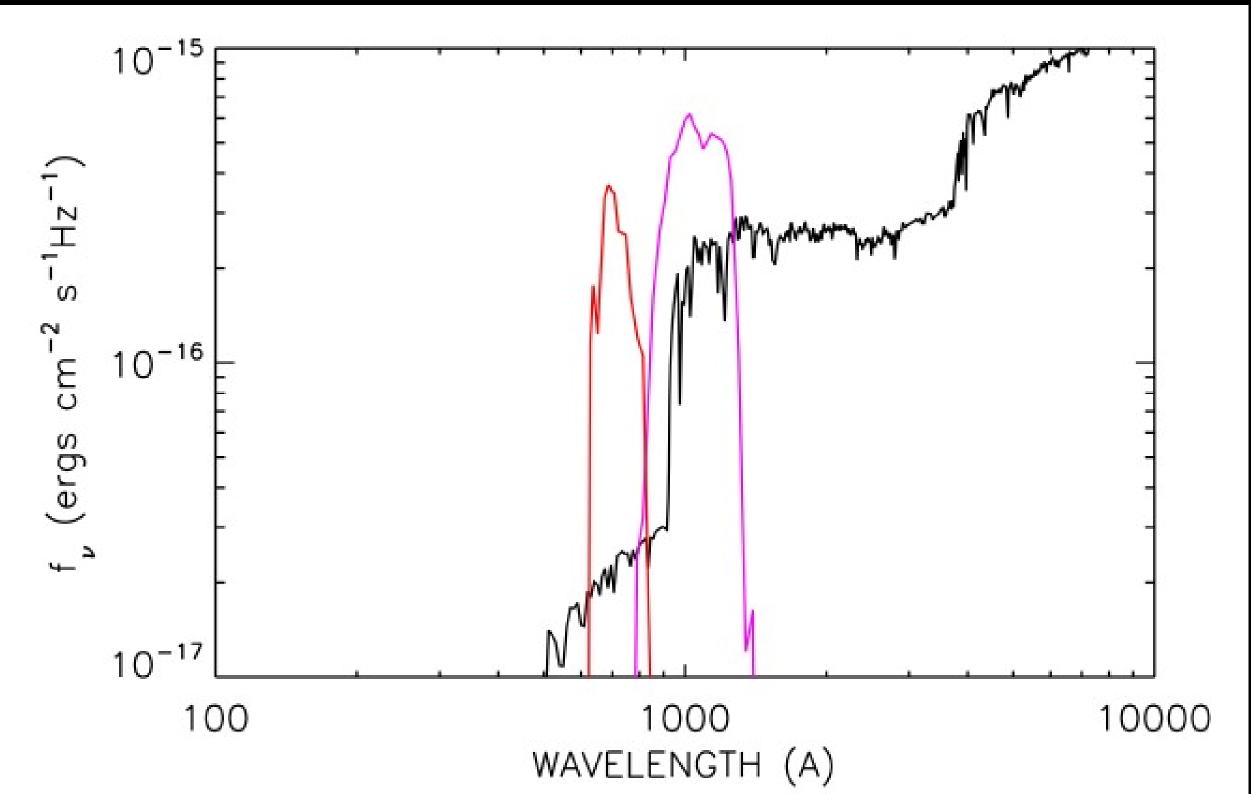
Star Forming Galaxy
z=2.38 Mag606W=19.83 magnification=24
Fesc<8% (3 sigma)

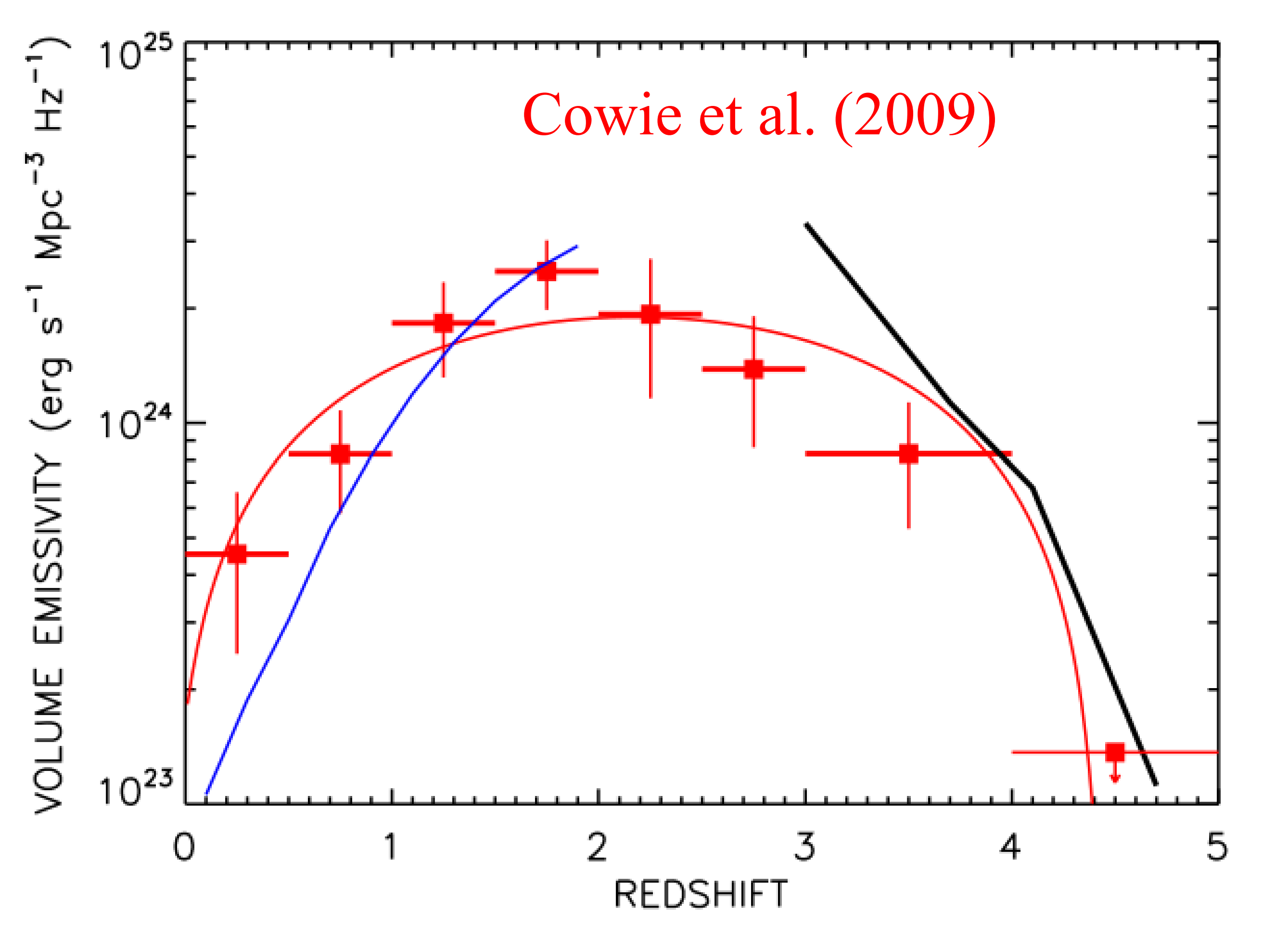
Deep imaging in the F275W and F606W bands of HST
At z~2.4 the F275W band corresponds to 900 A rest frame

LyC fesc of AGN: imaging

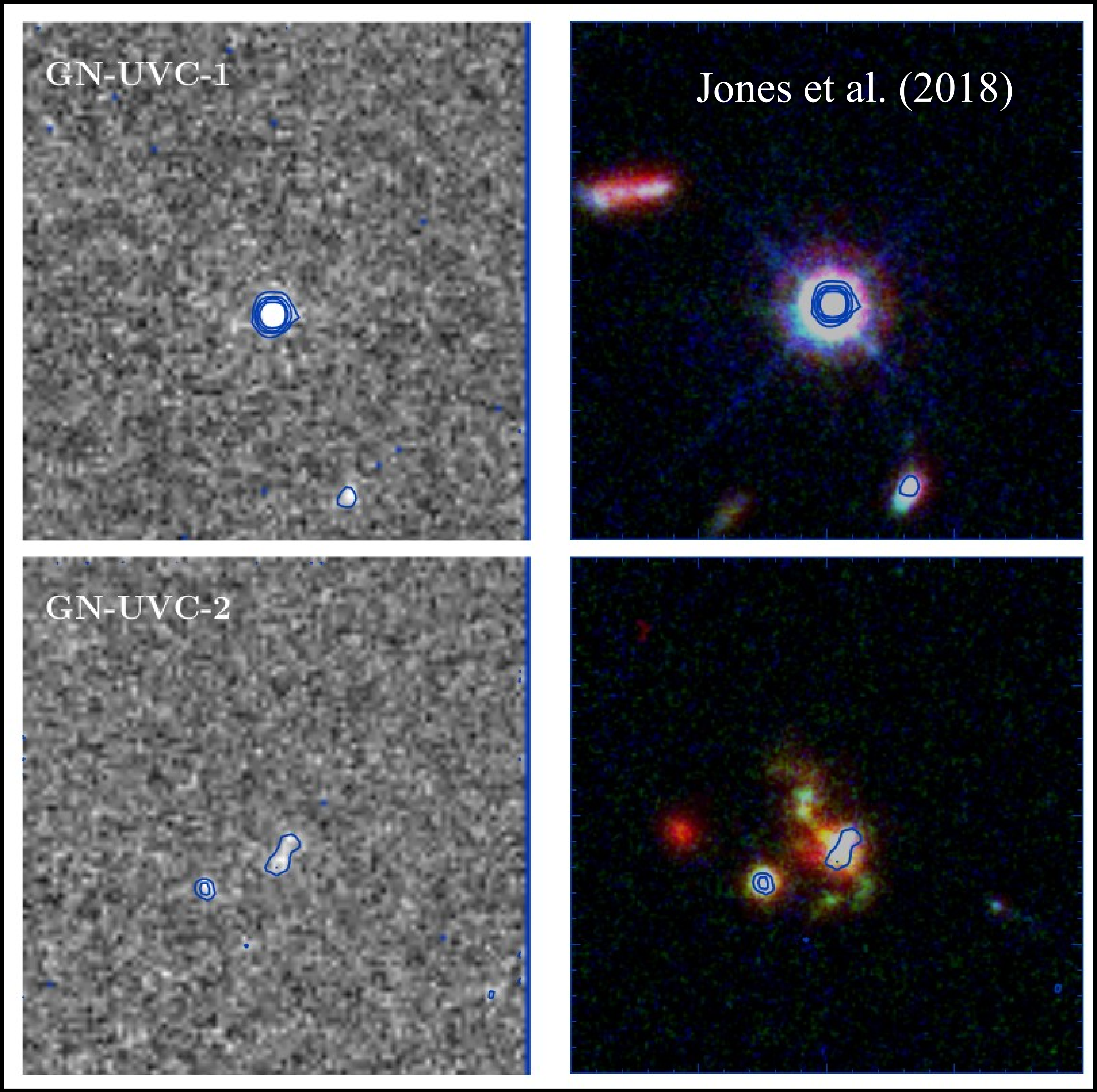


Broad line AGN at z~1 show significant LyC escape fraction (~100%)



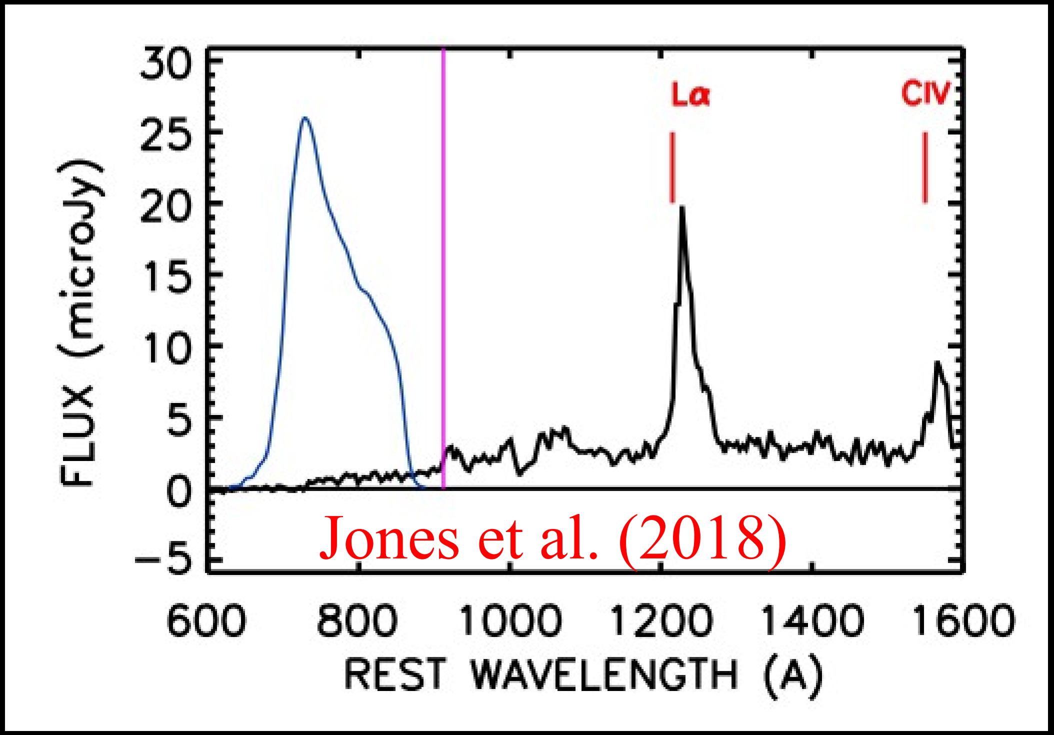


F275W F435W+F606W+F160W



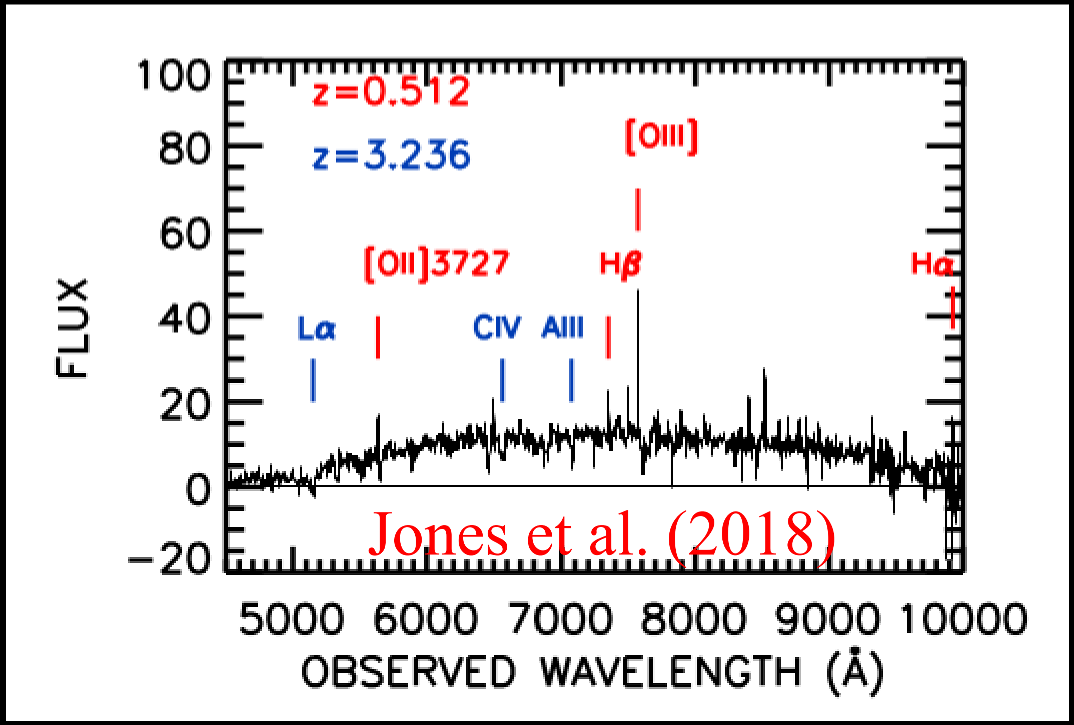
AGN

SFG



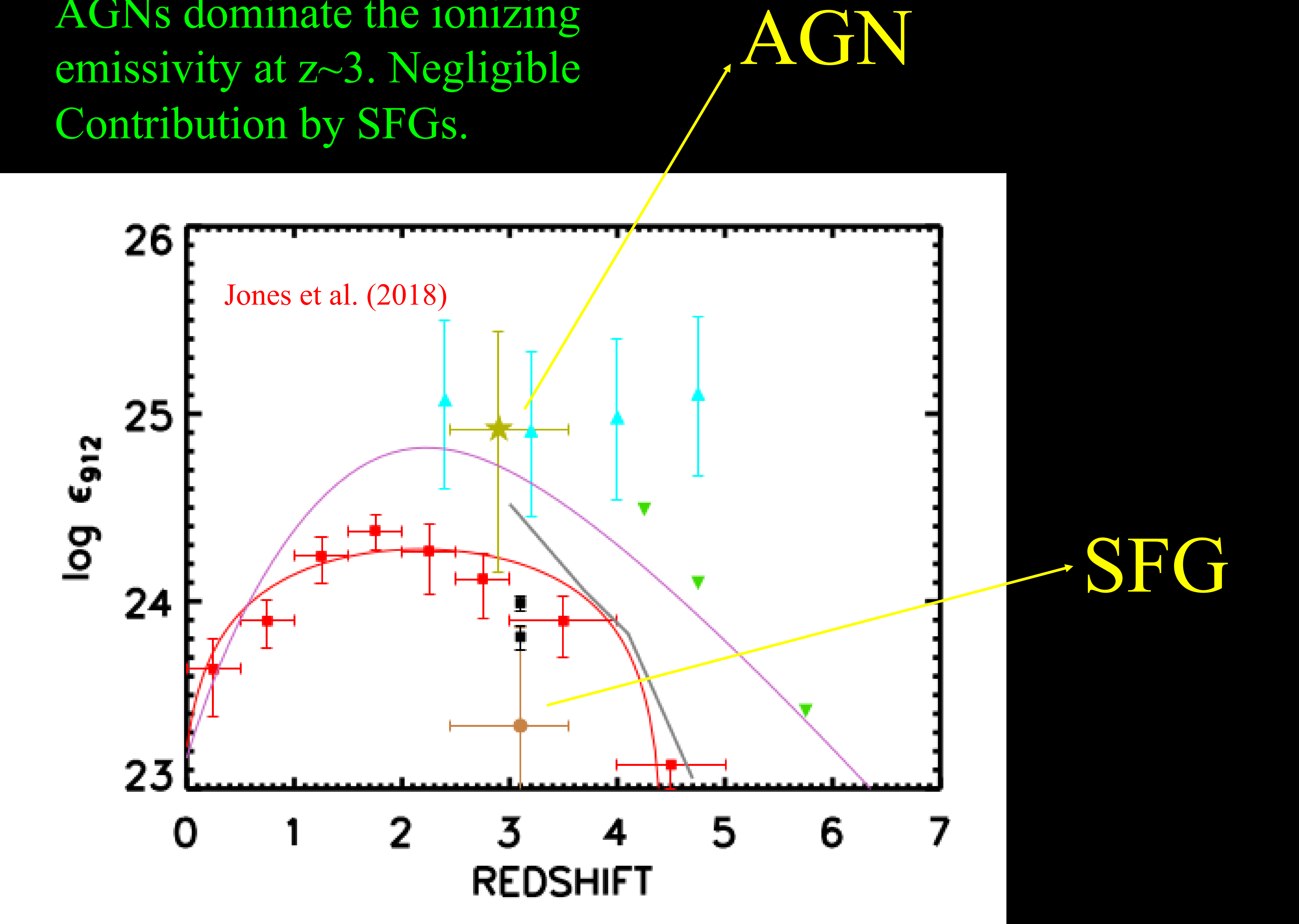
AGN

SFG



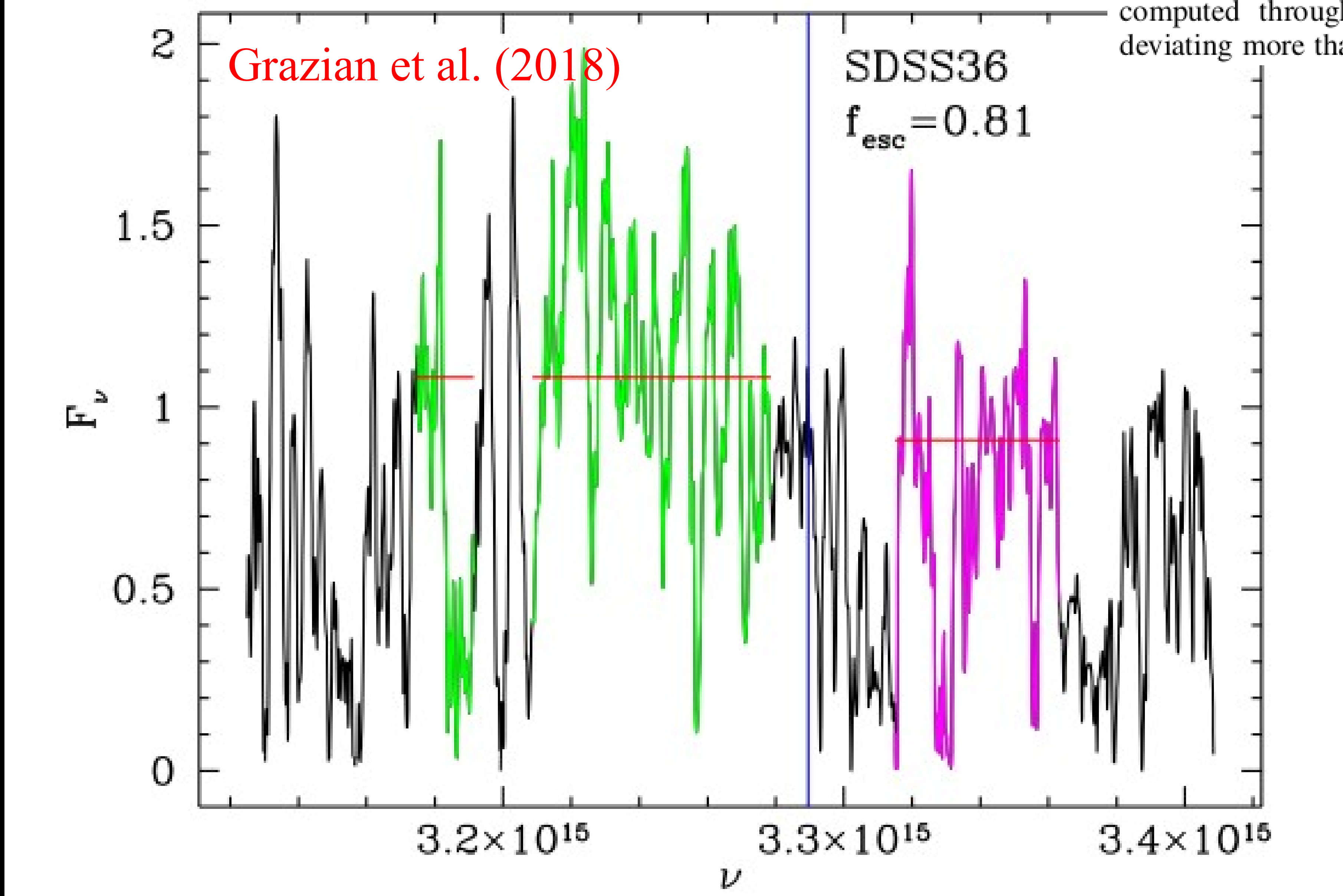
All the SFGs detected in LyC at z~2-3 by Jones et al. (2018) show contamination by low-z interlopers. The only confirmed LyC detection is from an AGN at z=2.5.

AGNs dominate the ionizing emissivity at z~3. Negligible Contribution by SFGs.



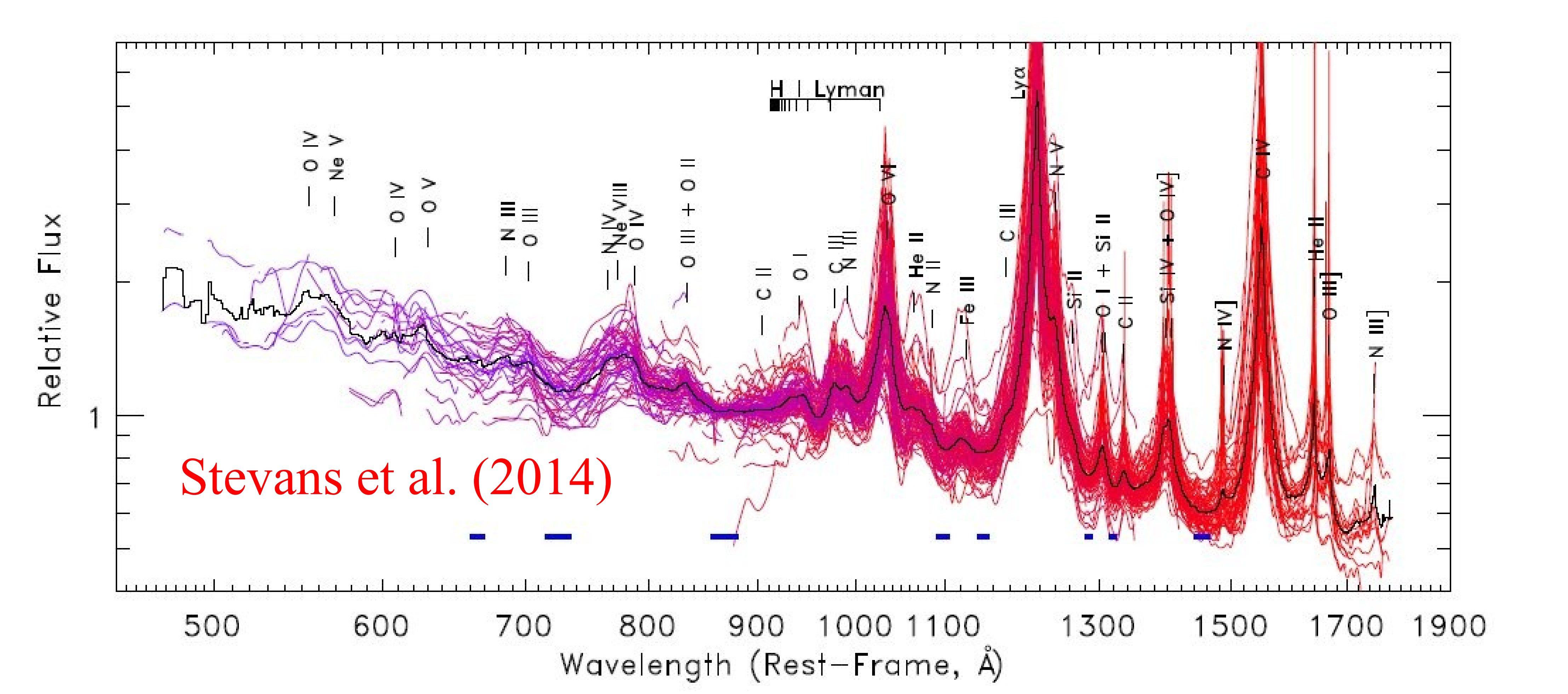
LyC escape fraction: spectroscopy

we estimate the mean flux above and below the Lyman limit (912 Å rest frame) and measure the escape fraction as $f_{esc} = F_\nu(900)/F_\nu(930)$, where $F_\nu(900)$ is the mean flux of the AGN in the Lyman continuum region, namely between 892 and 905 Å rest frame, while $F_\nu(930)$ is the average flux in the nonionizing region redward of the LL, between 915 and 945 Å rest frame, avoiding the region between 935 and 940 Å due to the presence of the Lyman-ϵ emission line. These average fluxes have been computed through an iterative clipping of spectral regions deviating more than 2σ from the mean flux values, as shown in



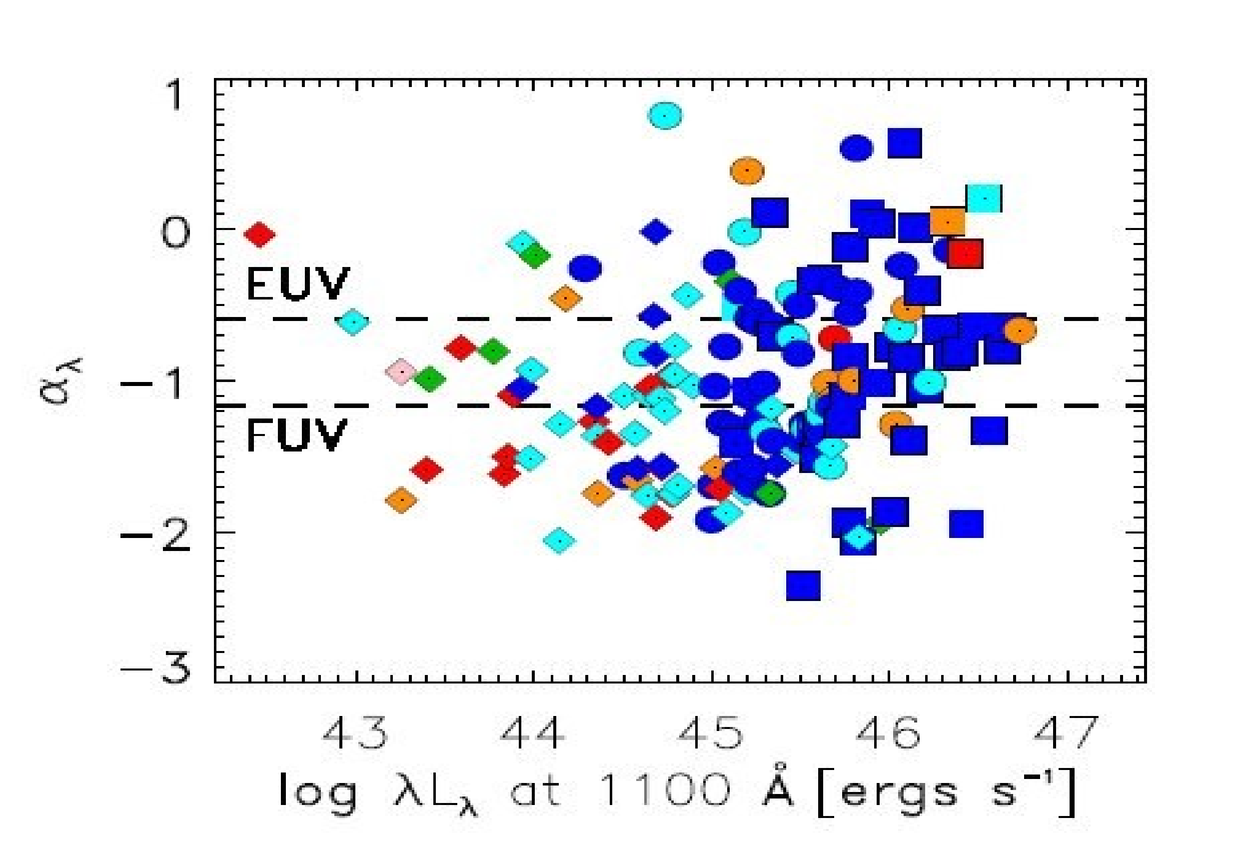
LBT MODS

AGN LyC fesc from spectra



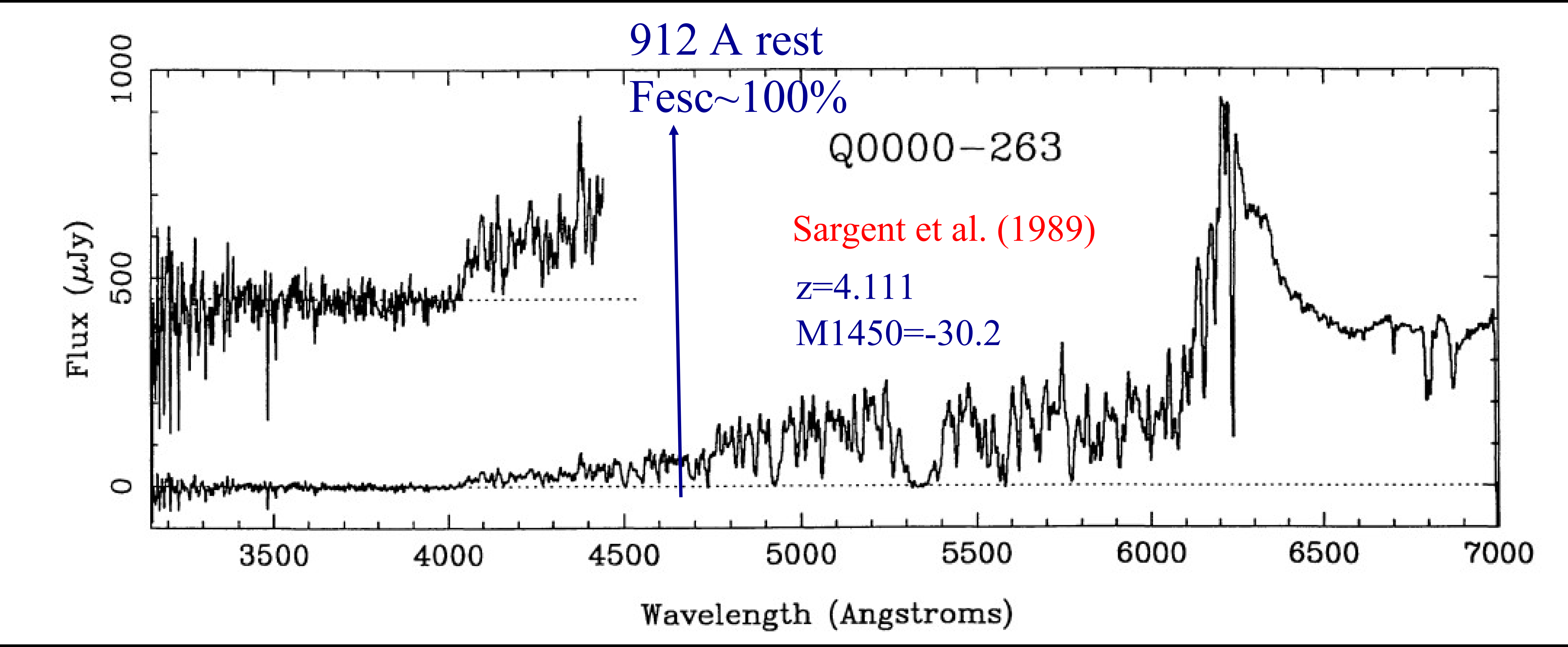
Stevans et al. (2014) find significant LyC emission in 159 low-luminosity AGNs at z<1.5

(both type 1 and type 1.8-1.9 AGNs)



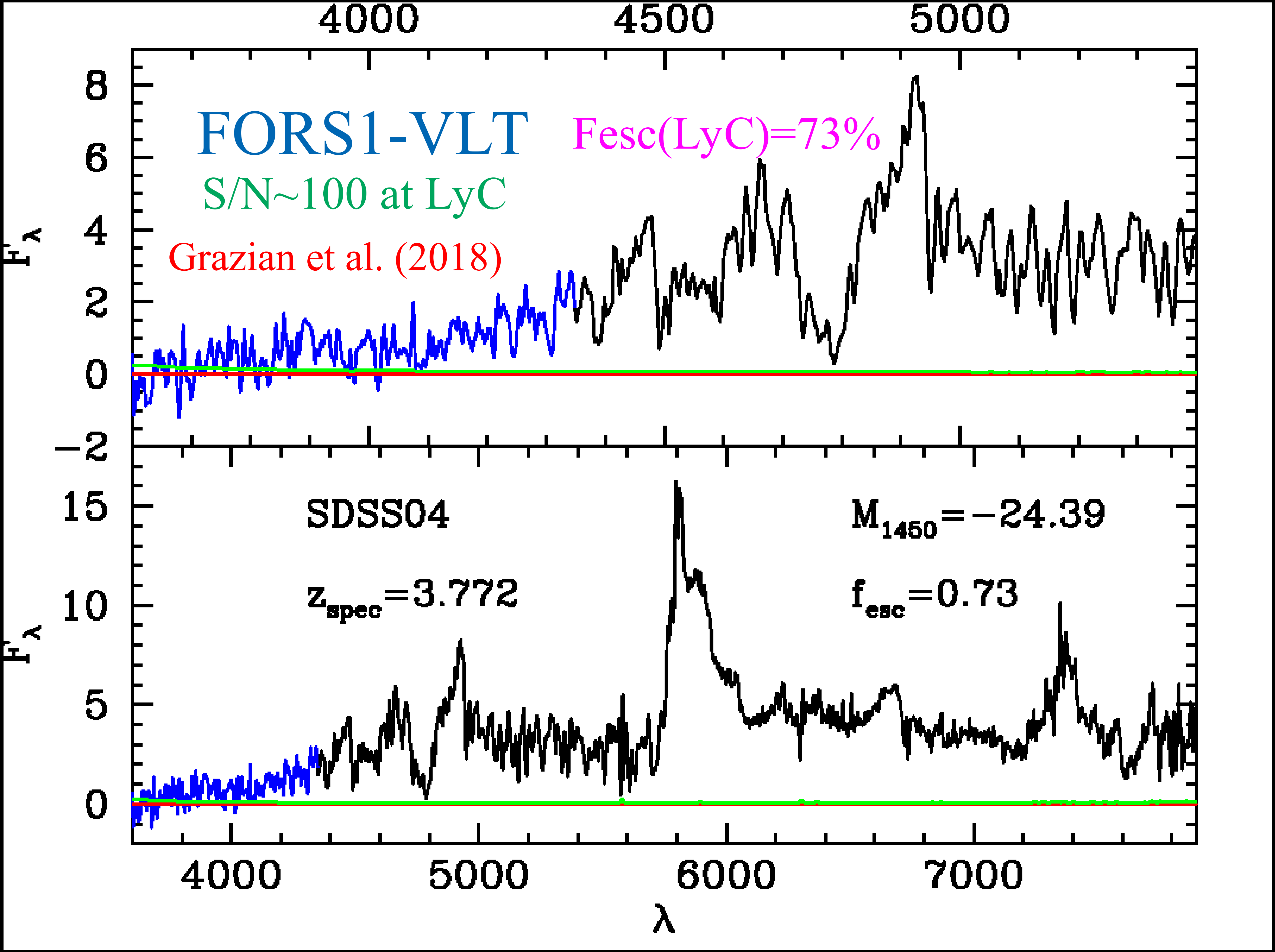
Escape fraction of AGNs is ~100% at low-z

LyC escape fraction: spectroscopy

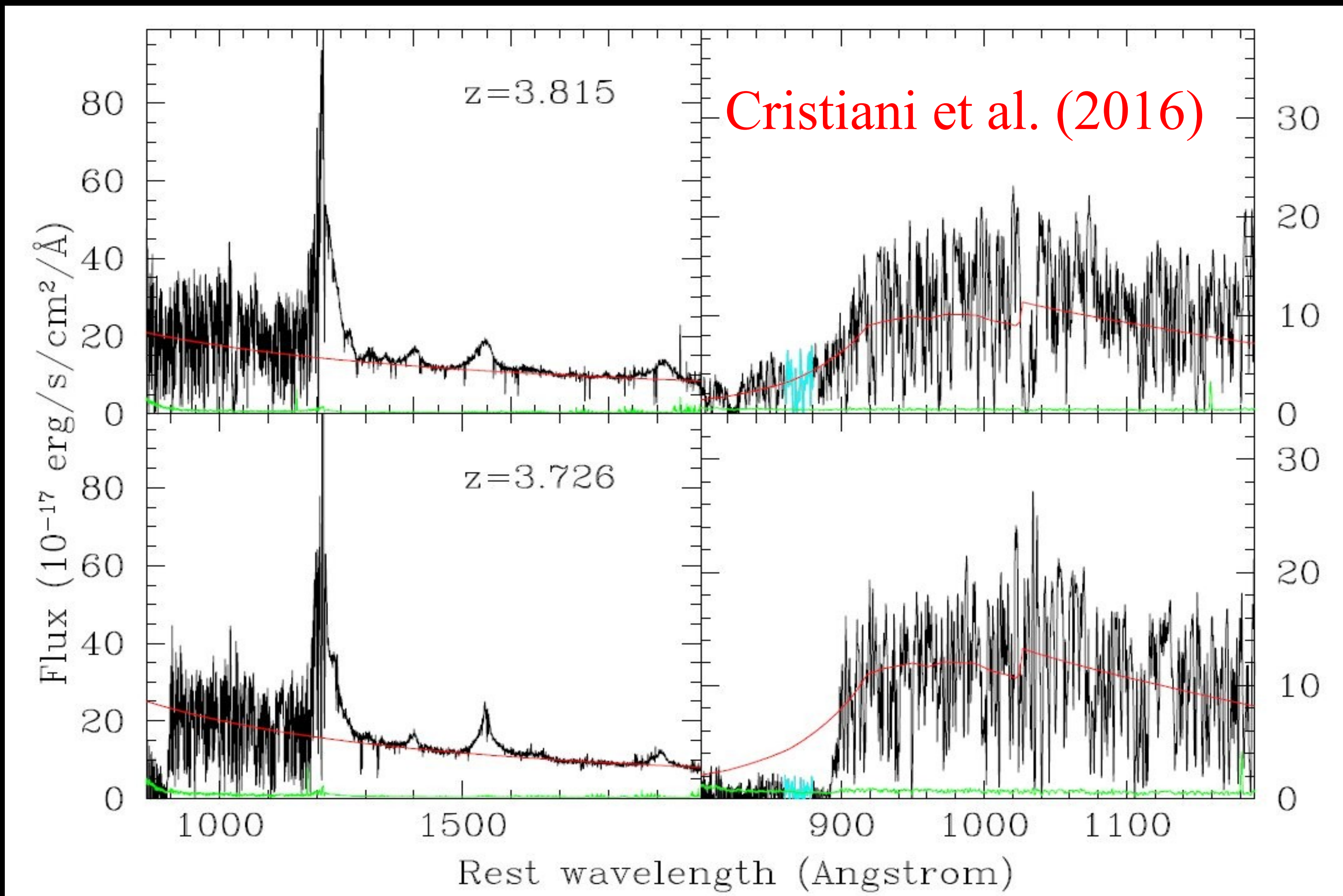


Very bright QSOs at high-z show high LyC fesc

The LyC Escape Fraction of faint AGNs



The LyC Escape Fraction of QSOs/AGNs

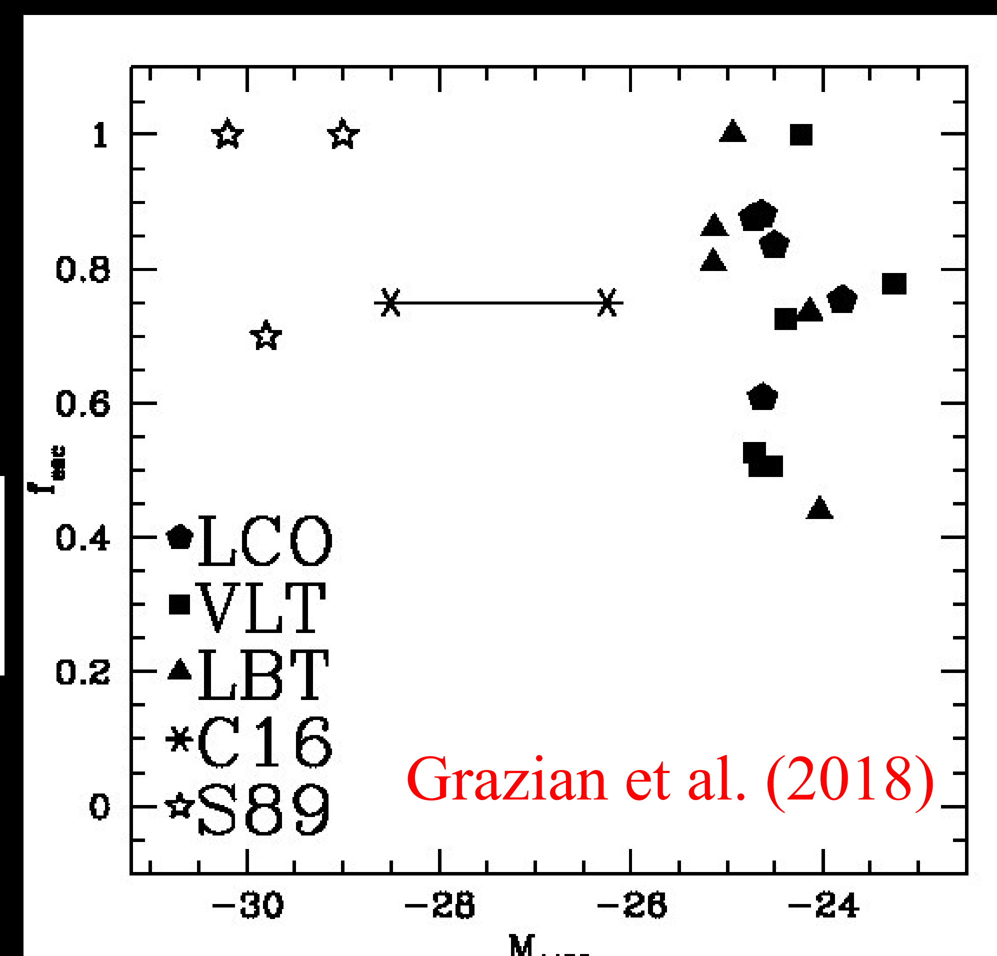


~1600 QSOs M1450=-26 (L~5L*) have average fesc~75% (or more). See also Romano et al. (2019)

What about fainter AGNs ?

No dependence of LyC fesc from Luminosity has been detected

f_{esc}



LARGE ESCAPE FRACTION for AGNs, down to M1450=-23 at z~4

LyC emission of high-z QSOs

Bright high-z QSOs are strong LyC emitters

Direct detection of LyC up to z=5.5

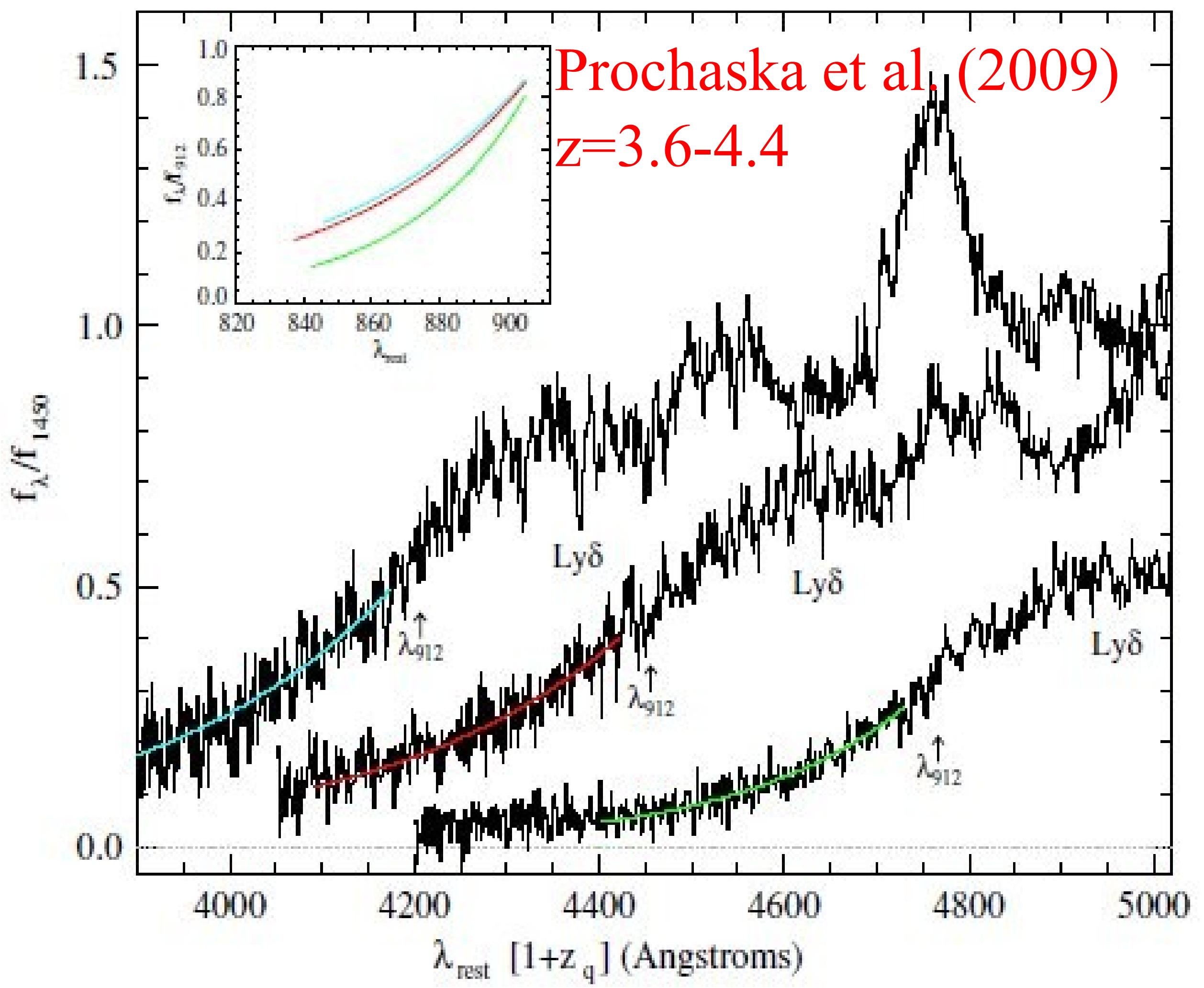


Figure 2. Stacked spectrum for three of our redshift bins (cyan: $z = [3.59, 3.63]$; red: $z = [3.86, 3.92]$; green: $z = [4.13, 4.34]$) plotted against rest-frame wavelengths redshifted to the mean quasar redshift for the bin. Overplotted on each spectrum is our best-fit model for the absorbed flux below λ_{912} due to the Lyman limit opacity. These same curves are shown in the sub-panel against rest wavelengths. The emission lines are from Lyman series and metal-line transitions.

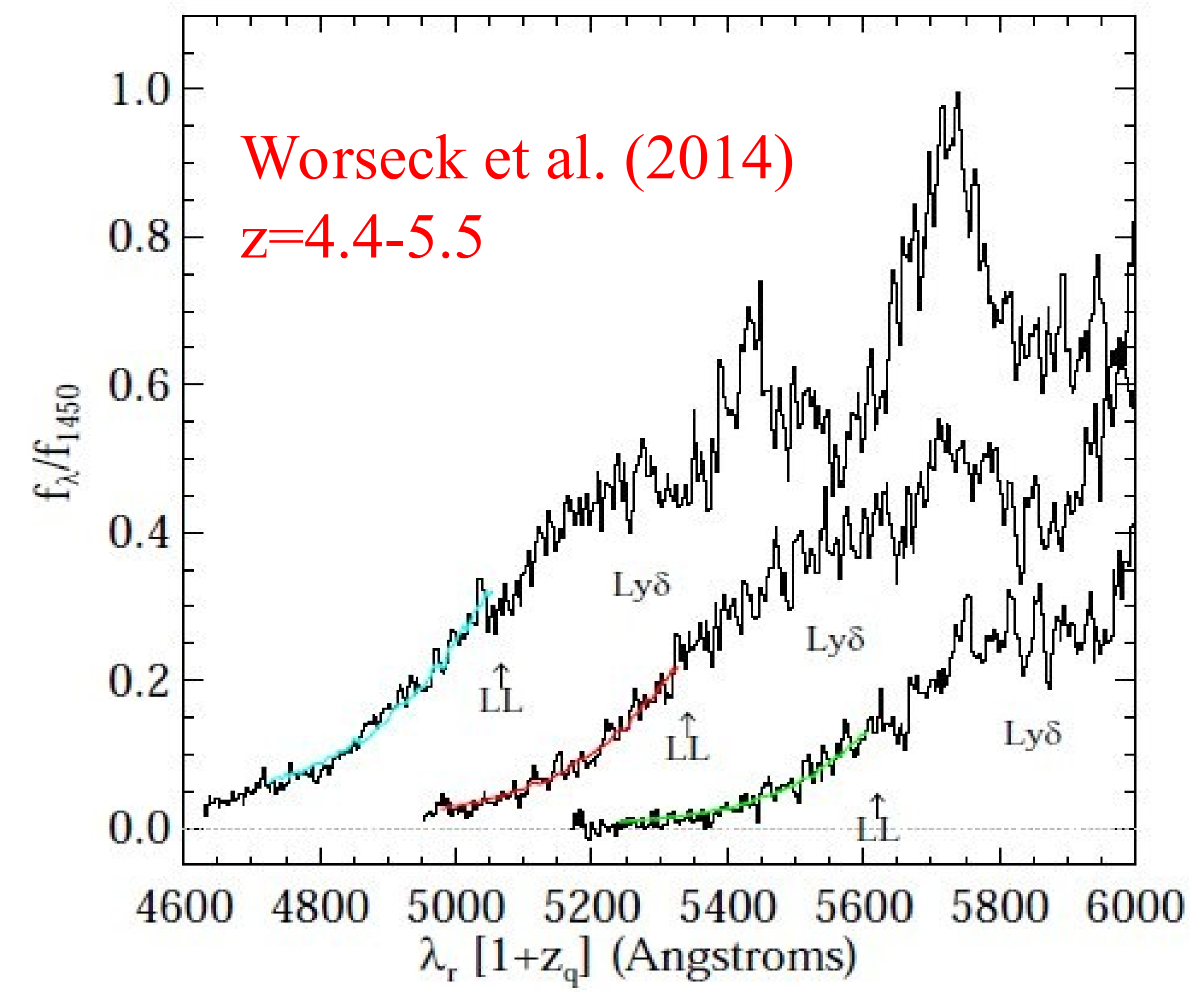
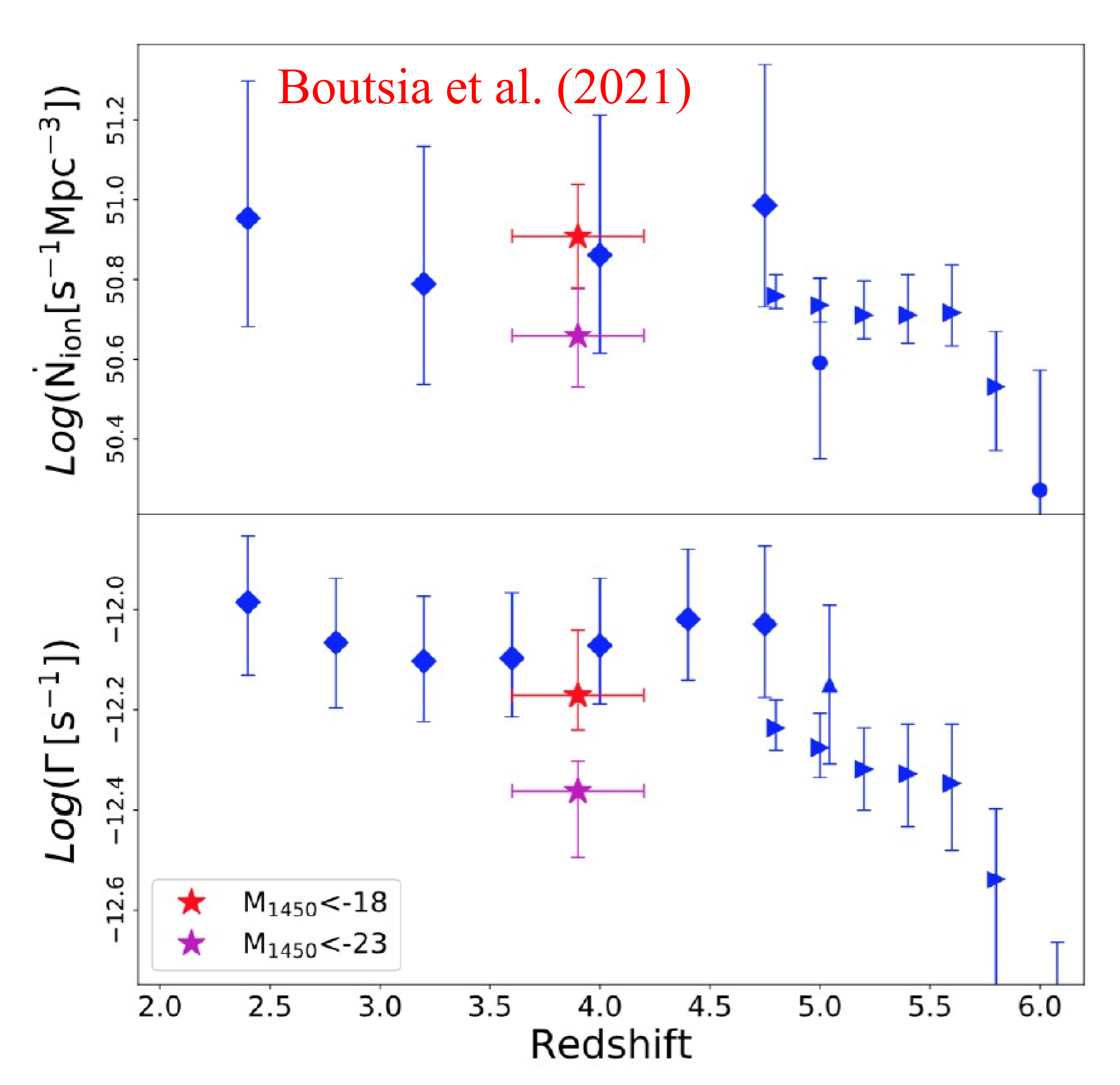


Figure 6. Stacked normalized rest-frame quasar spectra from the GGG survey generated for three redshift intervals: $z_{\rm em} = [4.4, 4.7]$, $[4.7, 5.0]$, and $[5.0, 5.5]$. These spectra are plotted in a pseudo-observer frame defined as $\lambda_r\,(1 + z_q)$ with, z_q the average redshift of the quasars in each interval. The Lyδ emission (strongly affected by IGM absorption for the two high-z bins) and the onset of the Lyman limit are marked for each stacked spectrum. Lyβ and Lyγ emission lines of the background quasars are clearly visible. Overplotted on these stacked spectra are the best-fitting models which provide measurements for the mean free path $\lambda^{912}_{\rm mfp}$.

The contribution of faint AGNs to the Photoionization rate at z~4

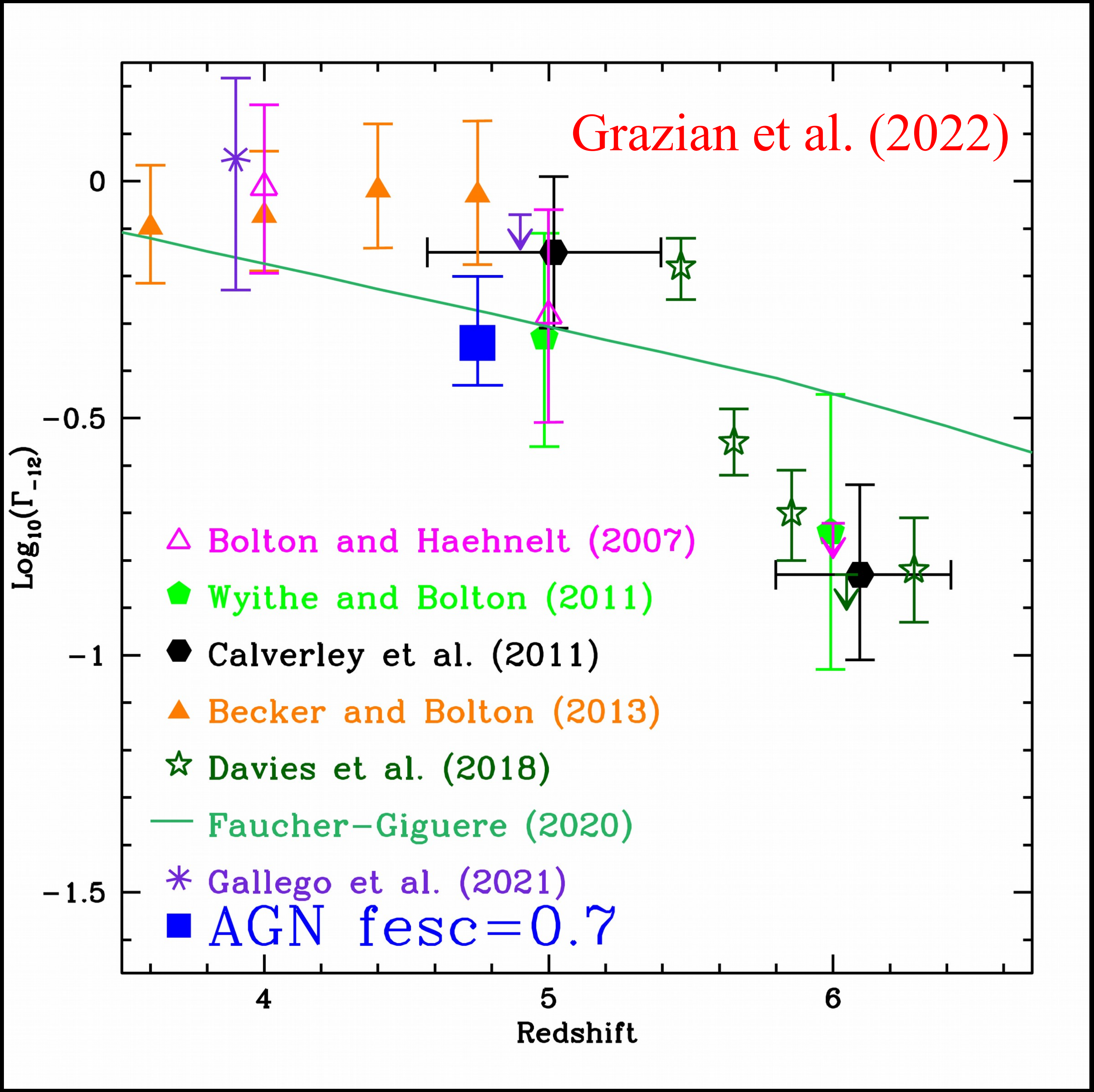


AGNs at z~4 produce ~100% of the UVB, assuming the new Luminosity Function (Boutsia et al. 2021) and fesc=70% down to M1450=-18 (0.01L*).

MFP=41.3 pMpc at z=3.9 (Worseck et al. 2014)

The contribution of AGNs to the Photoionization rate at z~5

z~5 AGNs produce 50-100% of ionizing UV Background



Summary

AGNs:

1-New clues from QUBRICS on reionization process.

2-Strong LyC escape fraction of faint (M1450<-23) AGNs at z>4 is substantial (~70%). No evolution of LyC escape fraction with Luminosity (Cristiani et al. 2016; Grazian et al. 2018).

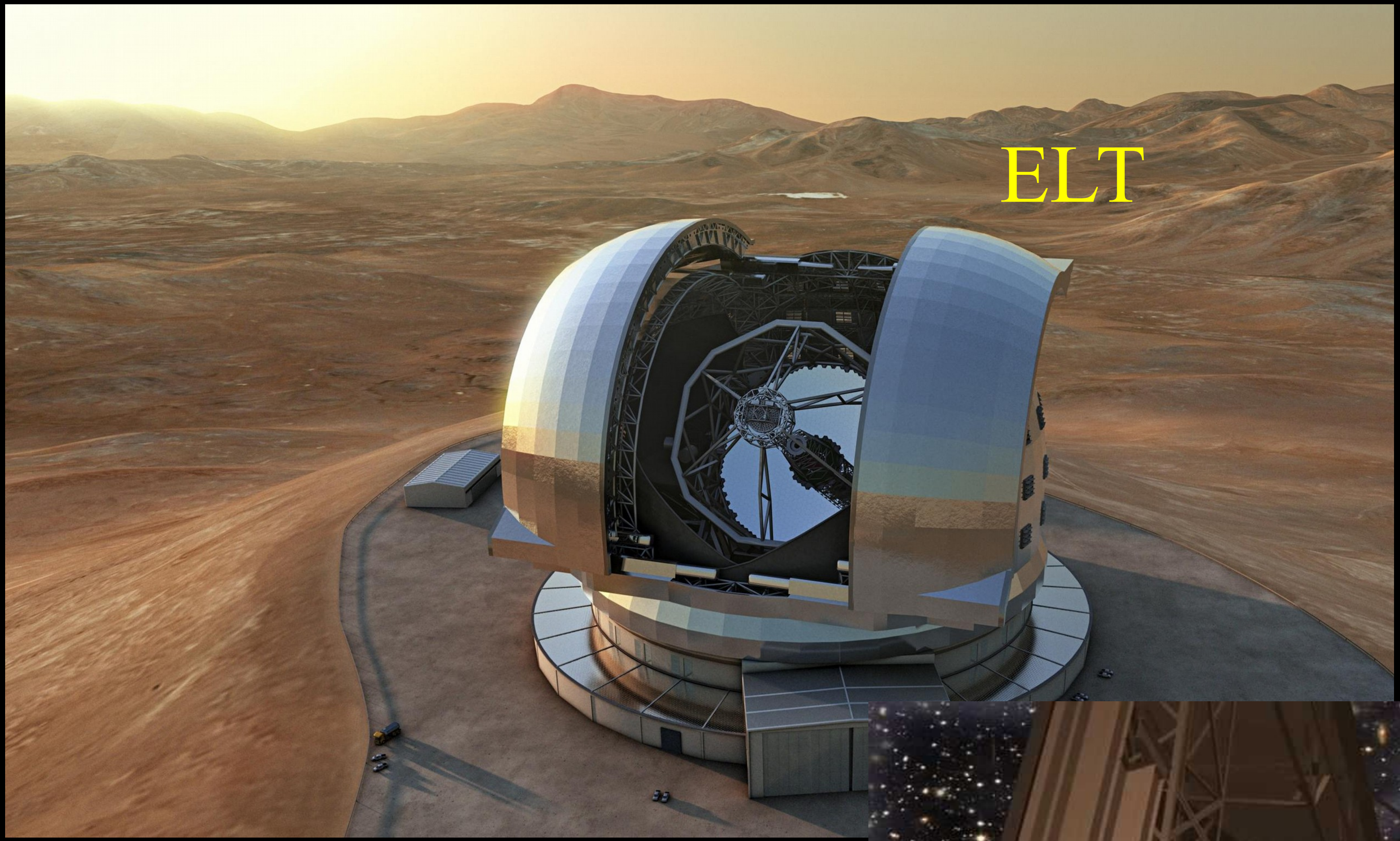
3-High space density of bright QSOs and faint AGNs at z~4 (Boutsia et al. 2018, 2021). High space density of bright QSOs at z~5 (Grazian et al. 2022).

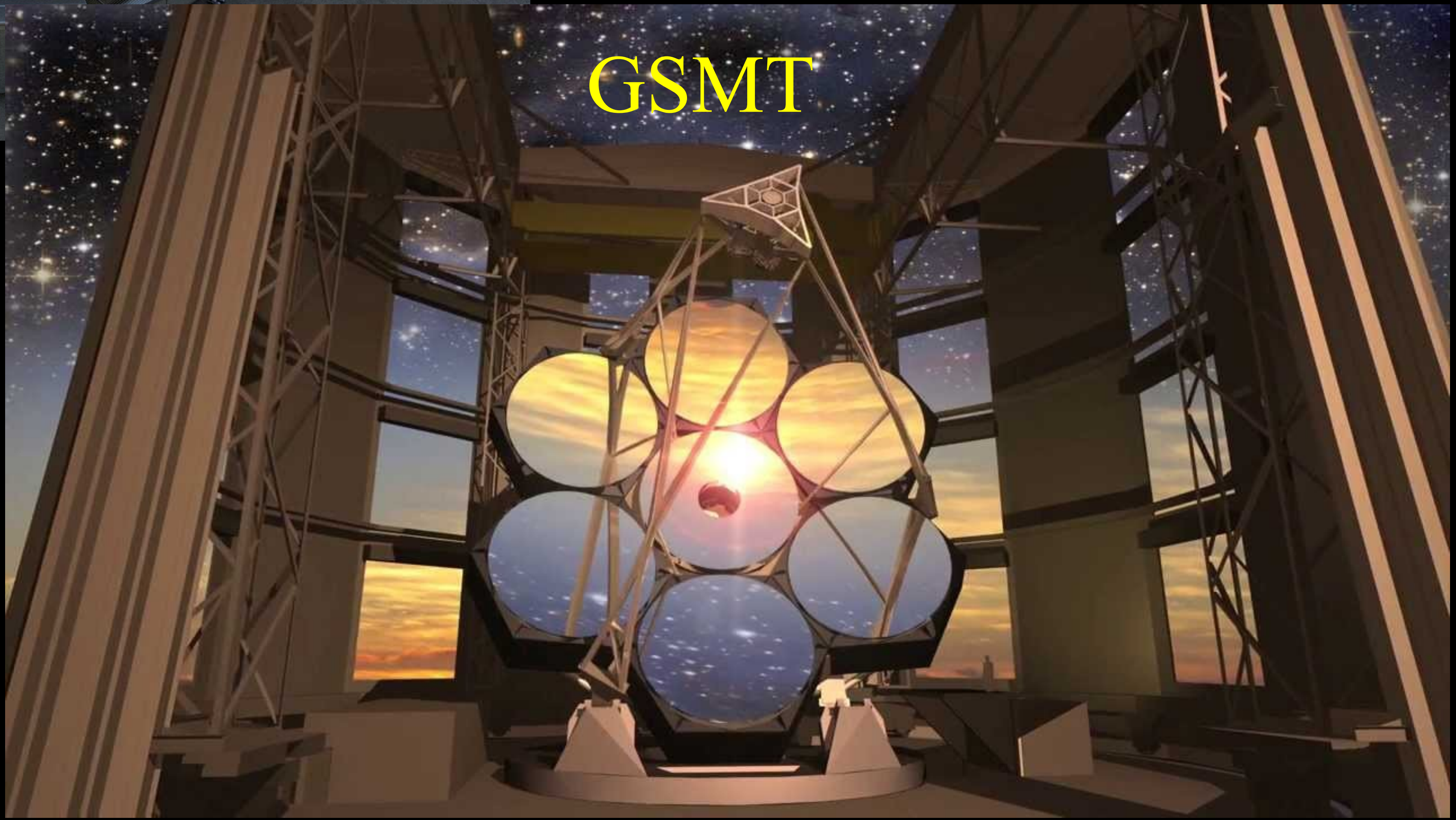
4-The bright end of the QSO Luminosity Function at z>4 is ~2-3 times higher than previous determinations.

At z~4-5 AGNs produce 50-100% of HI ionizing background.

AGNs could be the main producers of HI ionizing background at z>4.

Future Facilities





LSST, Euclid, MOONS, 4MOST, SPHEREx, WFST, WFIRST, ELTs, Athena, SKA, LUVOIR, HWO….

Thank you!