Faint z>4 AGNs in GOODS-S looking for contributors to reionization

Giallongo, Fiore, Grazian, Fontana, Pentericci et al. (INAF-Observatory of Rome)

Giallongo et al. 2015; Fiore et al. 2016 in prep.; Giallongo et al. 2016 in prep

Reionization history controls galaxy formation and evolution

CHANDRA deep imaging can give an important contribution to this topic

When: z_{ion}~6-8

Gunn-Peterson absorption in QSO spectra $z_{ion}>6$
Planck Thomson scattering z_{ion} ~8.5 but z~7 is allowed (Adam et al. 2016)

How: which are the sources responsible for the reionization ?

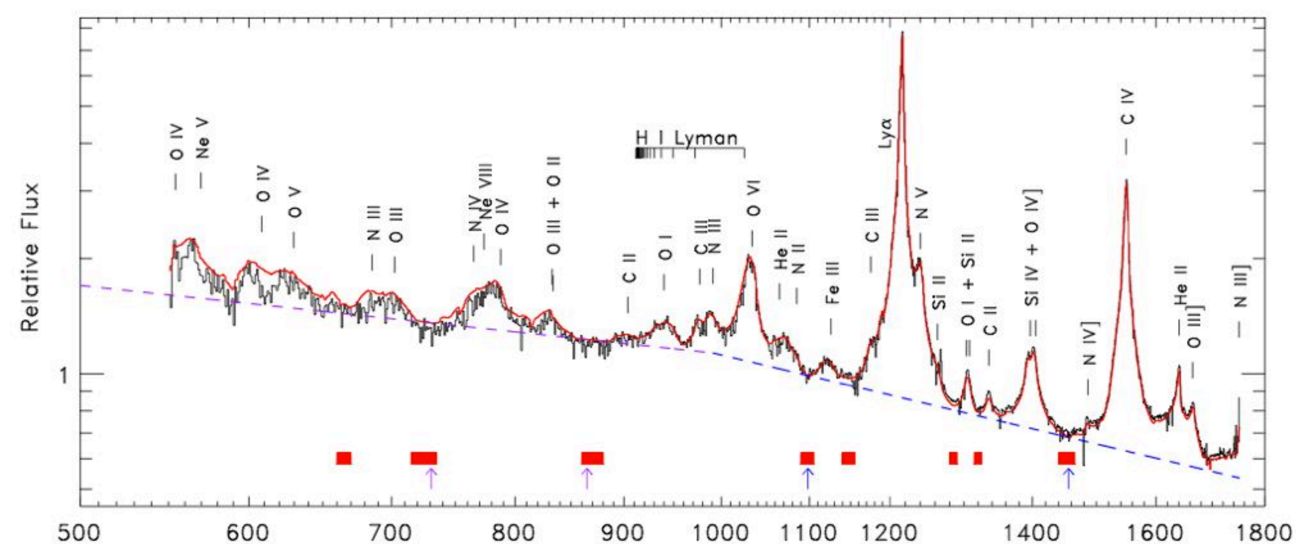
Obvious candidates: QSOs and/or star forming galaxies

$M_{UV} \sim -21$ (I~25 at z~3)

Faint	Bright
Galaxies	**Galaxies**

$M_{UV} \sim -24$

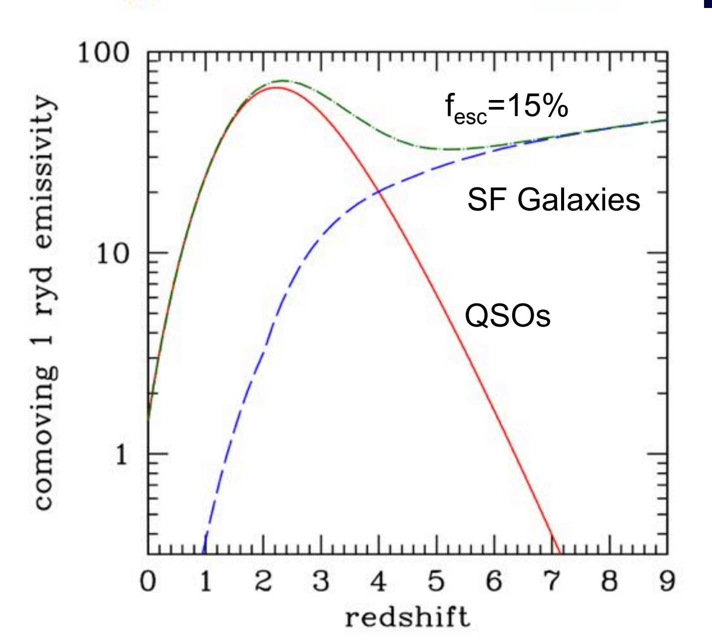
Faint	Bright
AGN	QSOs



Composite HST/COS spectrum
159 AGNs z<1.48
From Shull, Stevans, Danforth 2012
Stevans, Shull et al. 2014

Bright AGNs are known to ionize their neighbourhood but they are too few at z>3 to provide the needed ionizing UV background (e.g. Haardt & Madau 2012)

$$\epsilon = \int \langle f(L) \rangle N(L)\, L\, \frac{E_{912}}{E}\, dL,$$



More common star forming galaxies are thought to be responsible for reionization at z>4

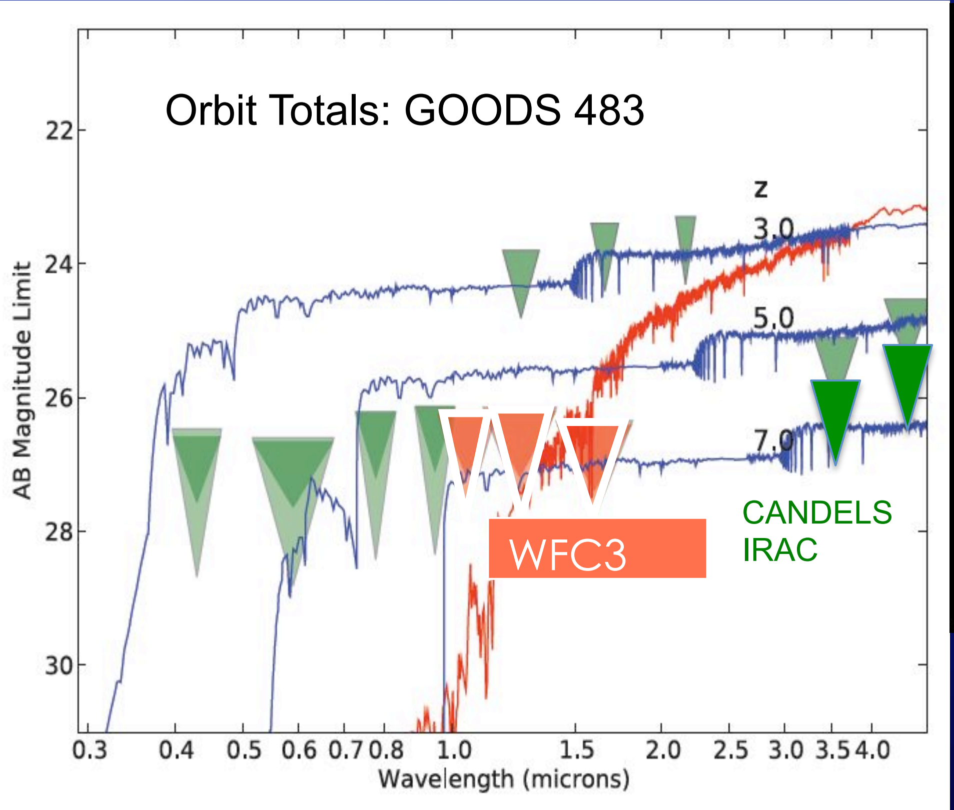
Their contribution depends on their abundance at faint magnitudes and on the escape fraction of ionizing photons

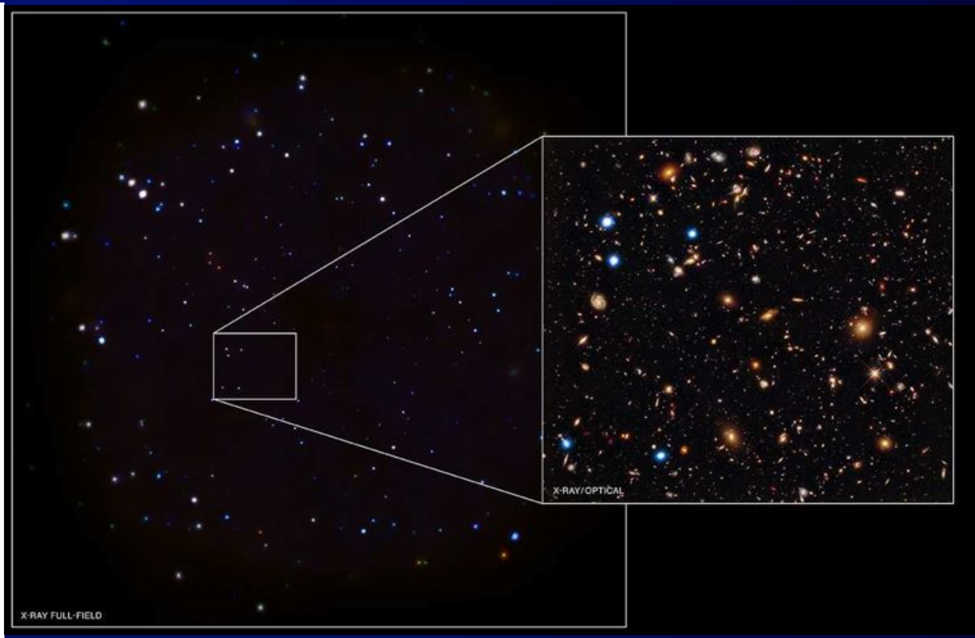
Uncertainties on f_{esc} of SF galaxies leave room for a significant contribution by fainter AGNs if their f_{esc} keeps as high as in the brighter population

First step: looking for faint AGNs close to the reionization epoch
Difficult task: requires very deep multiwavelength surveys like GOODS-S

CANDELS
Cosmic Assembly NIR Deep Extragalactic Legacy Survey

+ Chandra Deep Field South 4/7Msec





AGN selection proceeds in two steps.

Very deep selection in NIR H band (UV-rest at z>4) + X-ray detection (Fiore et al. 2012)

1. Parent sample selection:

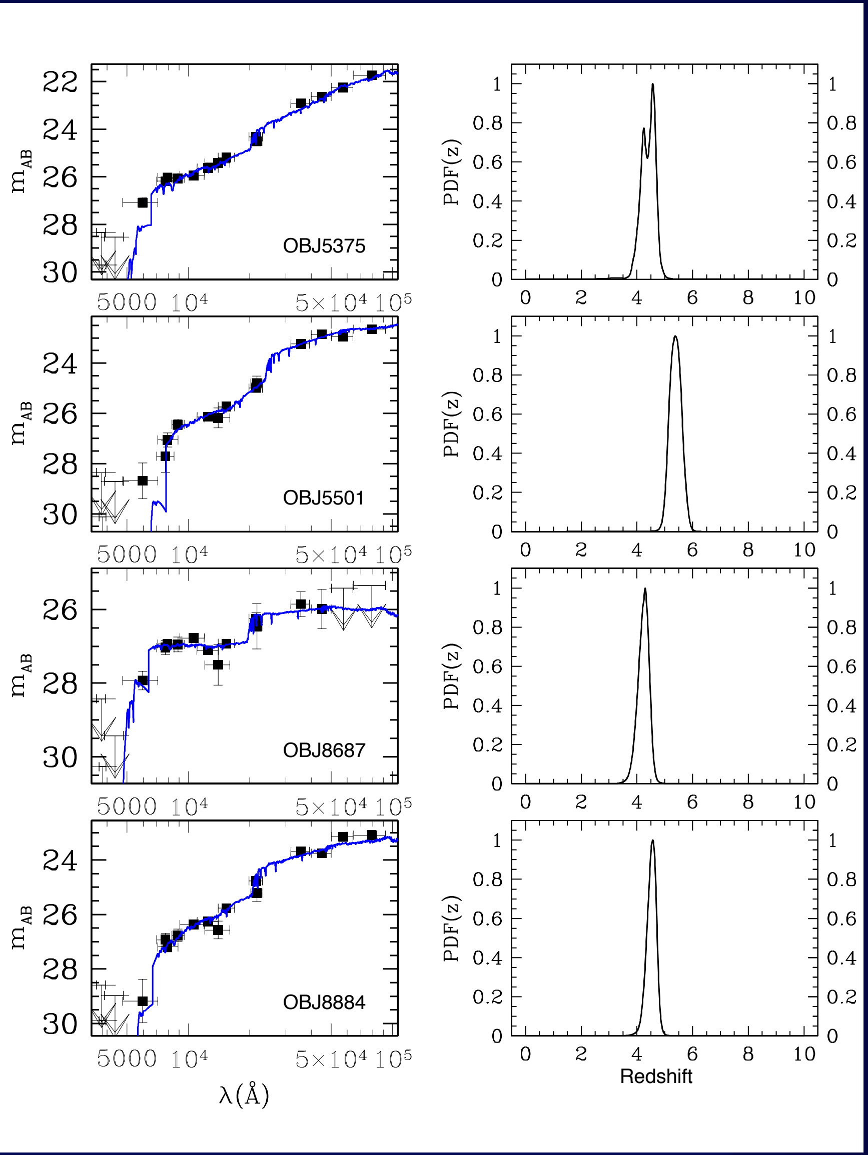
CANDELS SEDs and phot. z catalog (Guo et al. 2013, Dahlen et al. 2013)

CANDELS H_{AB}<27 galaxies in GOODS-S 170 arcmin^2 1113 sources at z>4

Phot. z constrained by UV-rest dropout due to IGM absorption

Selection of best candidates with narrow PDFs or PDFs located at high z

Very few low-z interlopers

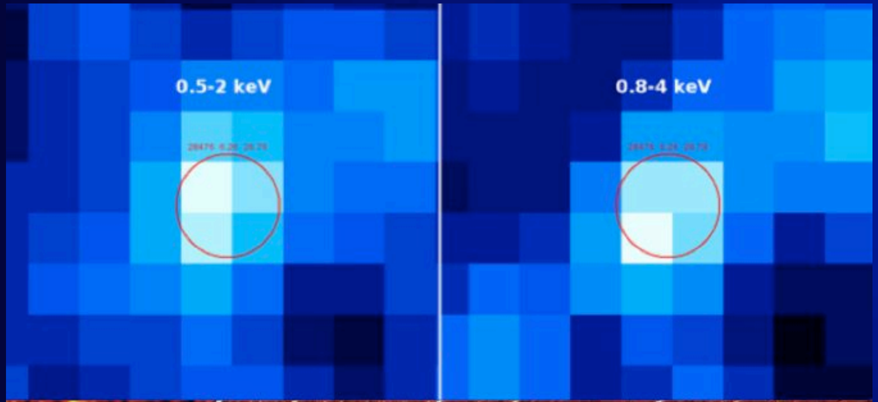


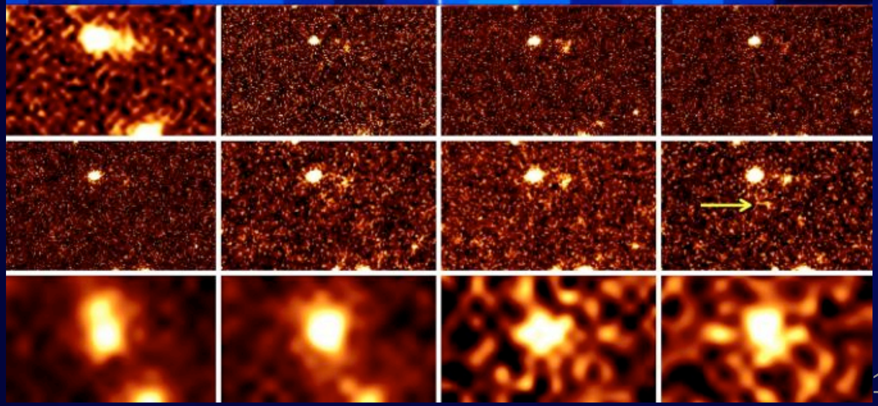
2. AGN selection of z>4 candidates

Measuring X-ray flux in the H band position

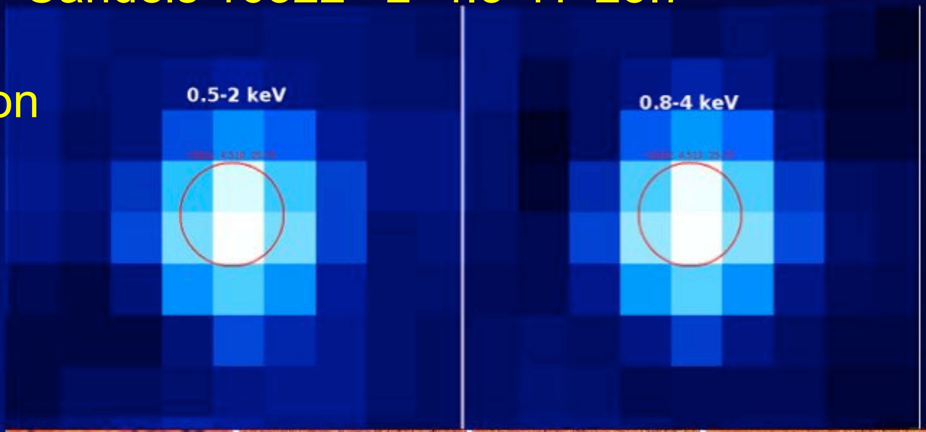
AGNs with $F_X \geq 1.5\times10^{-17}$ erg/cm^2/s correspond to a probability of spurious detection of 2×10^{-4}

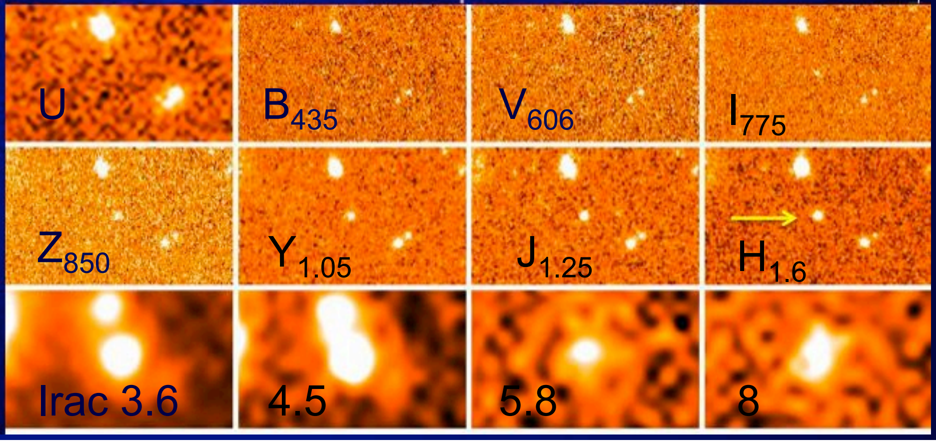
Candels 28476 z=6.3 H=26.8

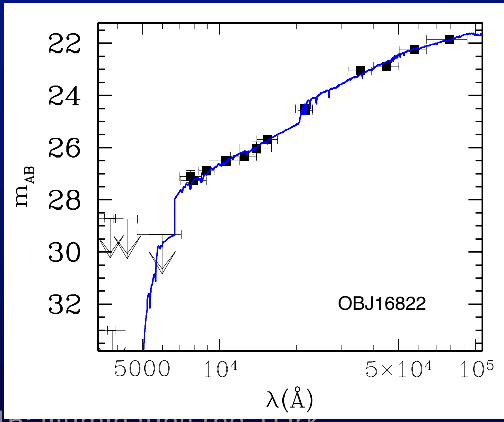


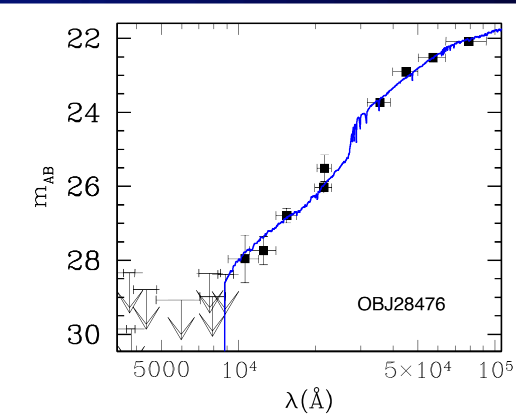


Candels 16822 z=4.5 H=25.7









In G15 we provided a list of 22 AGN candidates at z>4

8 previously X-ray selected AGNs from Xue (2011)

z>4 implies Log L_X ~43.2 (2-10 keV)

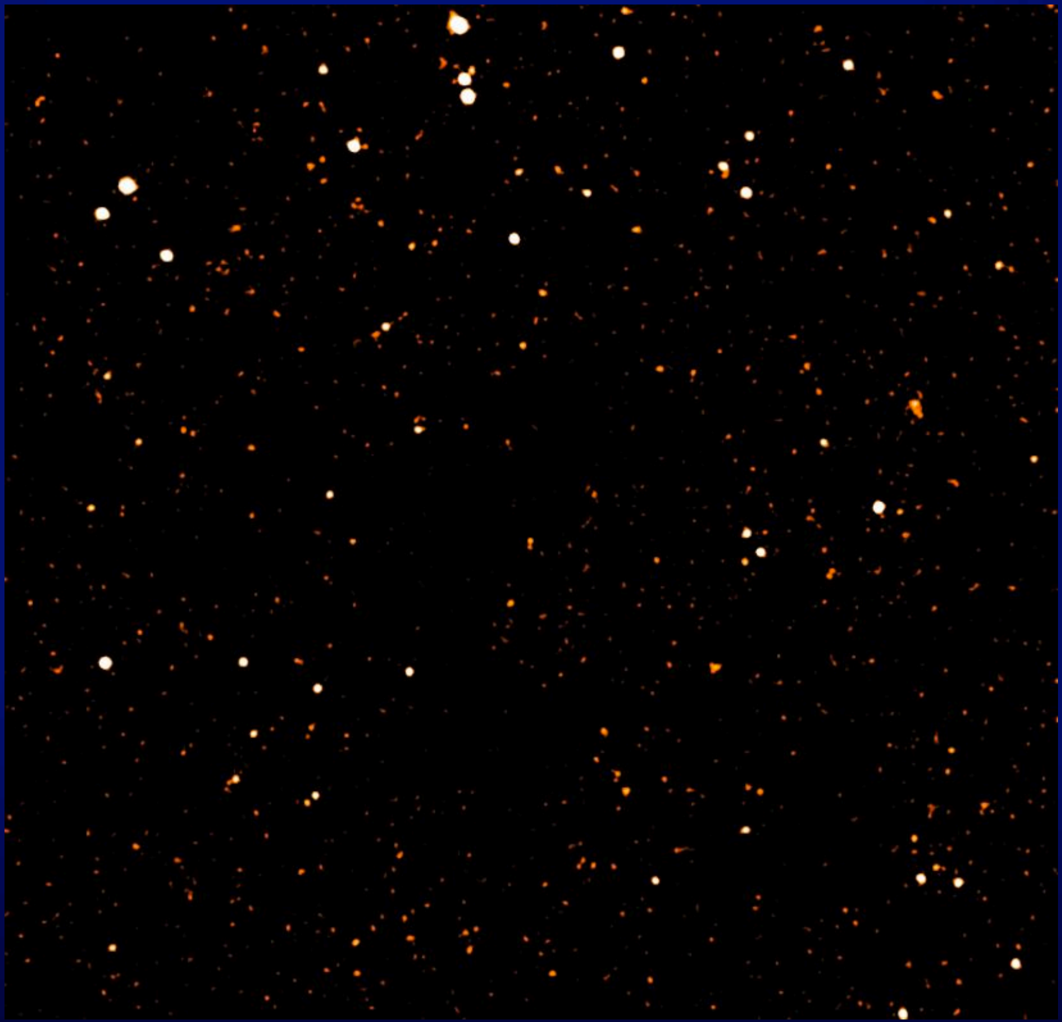
ID	RA	Dec	zphot	zspec	C	H	mag [1450 (1+z)]	log F_X erg/cm^2/s	log L_X erg/s	Previous Catalogs
273	53.1220463	-27.9387409	4.49	4.762[1]	c	23.96	24.95	-15.97	43.80	M208,X403
4285	53.1664941	-27.8716803	4.28		cf	25.57	25.92	-16.46	42.90	–
4356	53.1465968	-27.8709872	4.70		cf	26.36	27.86	-16.38	43.40	M70437,L306,X485
4952	53.1605007	-27.8649890	4.32		c	25.47	25.96	-16.50	42.90	–
5375	53.1026292	-27.8606307	4.41		c	25.16	26.03	-16.66	42.75	X331
5501	53.1280240	-27.8593930	5.39		c	25.71	26.29	-16.45	43.10	–
8687	53.0868634	-27.8295859	4.23		c	26.90	26.94	-16.43	42.90	–
8884	53.1970699	-27.8278566	4.52		c	25.74	27.19	-16.77	42.65	–
9713	53.1715890	-27.8208052	5.86	5.70[2]	c	26.54	26.74	-16.46	43.15	HUDF322
9945	53.1619508	-27.8190897	4.34	4.497[3]	cd	24.99	25.29	-16.65	42.75	–
11287	53.0689924	-27.8071692	4.94		c	25.06	25.90	-16.42	43.10	M8728
12130	53.1514304	-27.7997601	4.43	4.62[4]	c	25.54	25.67	-16.58	42.85	HUDF3094
14800	53.0211735	-27.7823645	4.92	4.823[5]	c	23.43	23.83	-16.38	43.10	M10548
16822	53.1115637	-27.7677714	4.52		c	25.67	27.27	-15.91	43.85	M70168,L245,X371
19713	53.1198898	-27.7430349	4.84		c	25.31	28.21	-16.48	43.00	E1516,X392
20765	53.1583449	-27.7334854	5.23		f	24.44	25.42	-16.29	43.25	E2551
23757	53.2036444	-27.7143907	4.13		c	24.56	25.36	-16.49	42.85	–
28476	53.0646867	-27.8625539	6.26		f	26.77	27.74	-16.60	43.10	M70407
29323	53.0409764	-27.8376619	9.73		cf	26.33	27.94	-15.96	44.00	M70340,L103,X156
31334	53.2131871	-27.7816486	4.73		f	26.41	26.70	-15.69	43.75	–
33073	53.0547529	-27.7368325	4.98		c	26.89	27.21	-16.44	43.10	E2199
33160	53.0062504	-27.7340678	6.06		cf	25.90	26.73	-16.26	43.65	E2498,L57,X85

NEW 7 Ms CHANDRA DF

G15 Archival Image

7Ms New co-adding with careful removal of spurious events (Puccetti, Fiore et al. 2016) resulting in lower background

6'x6'



Criterion for X-ray Detection
(Fiore et al. 2012, 2016)

Multidimensional source detection as clustering of events in space, energy and time at the H band position

The background is fitted in three different circular spatial regions

In each source extraction region (10" radius) the B. shape is normalized at 7-11 kev where the source contribution is small and then subtracted to the source counts in the chosen energy band (e.g. 0.8-2 KeV)

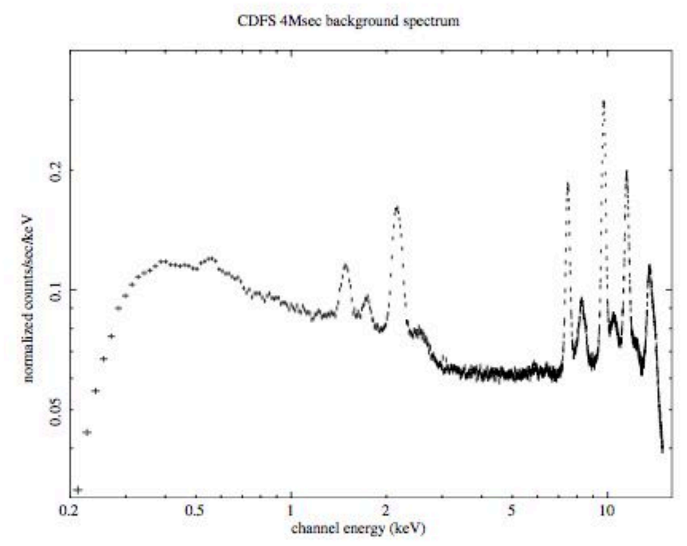


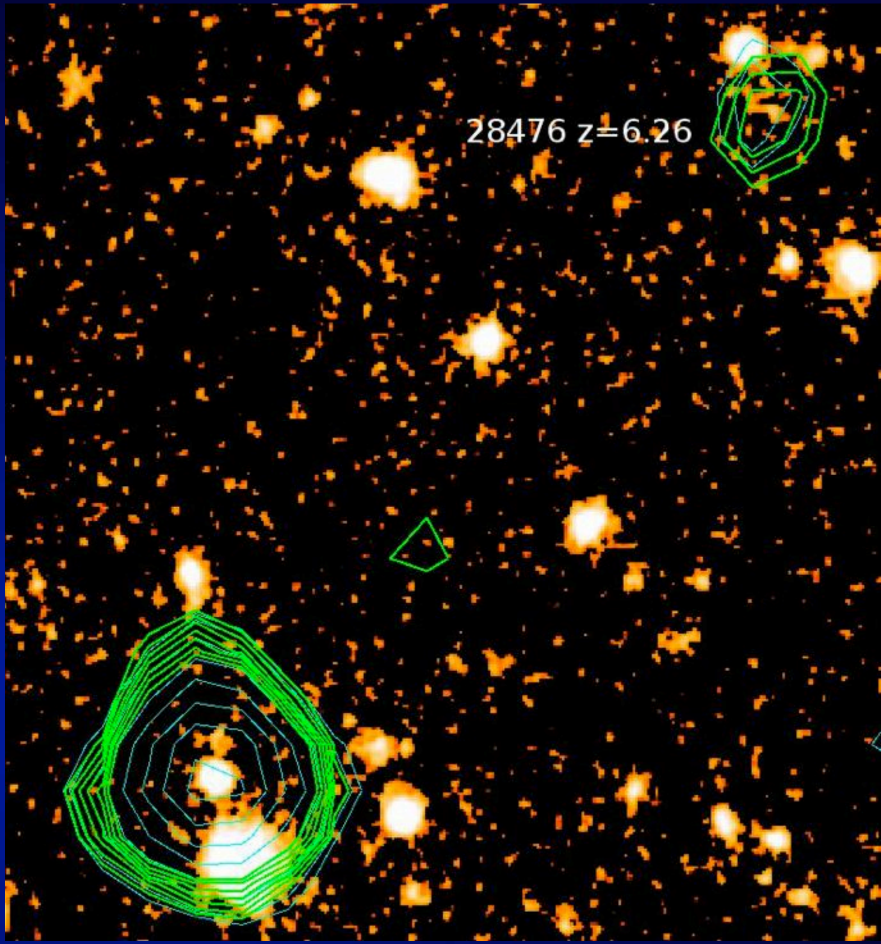
Fig. A.1. The spectrum of the background in the *Chandra* 4 Ms exposure of the CDFS. The spectrum has been extracted from a circle of 8 arcmin radius, after excluding 5 arcsec radius regions around all detected sources (10–20 arcsec for bright sources and extended sources).

The standard energy band in the 7Ms is 0.5-2 KeV (efficiency low at <1 KeV where noise is mainly added to faint sources)

Accuracy of the average relative astrometry is ~1 arcsec up to 9 arcmin off-axis

CHANDRA high resolution is crucial to select faint high z AGNs some of which near local brighter H band sources

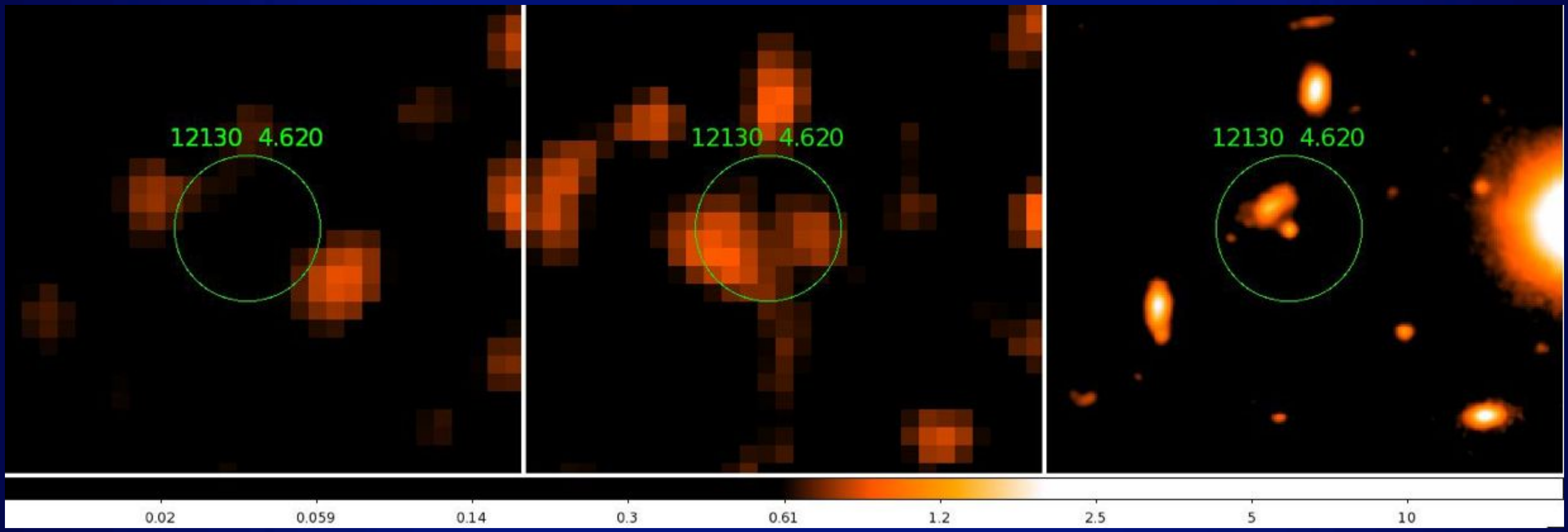
Nevertheless, still insufficient to disentangle multiple possible associations at the HST resolution



New catalog 19 AGN candidates in 7Ms GOODS-S

Example of AGN candidates excluded because of possible contamination

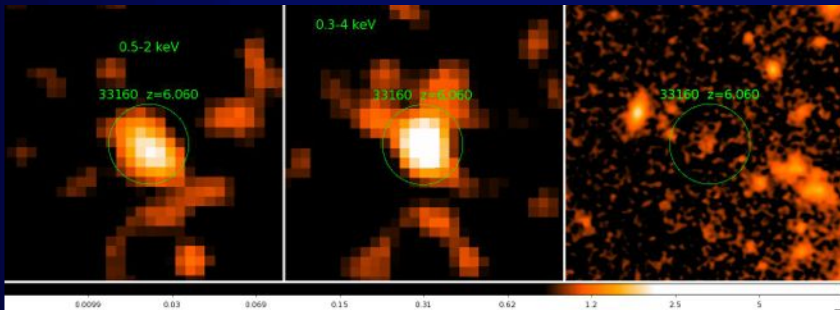
G15 0.2-5 KeV 1-4 KeV 0.5”/pxl H- HST



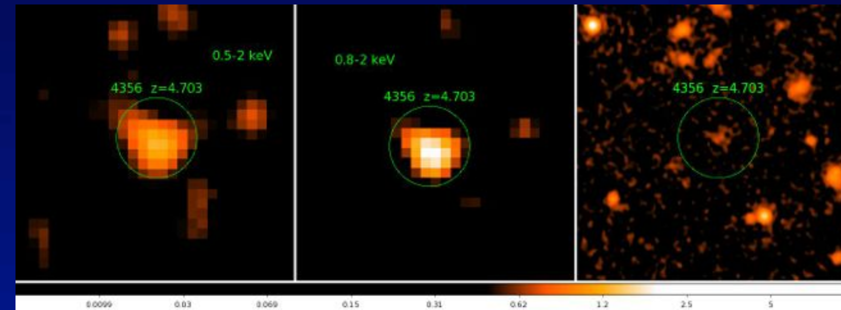
Circle r=2”

Examples of AGN candidates included in the 7Ms sample

Xue11,G15

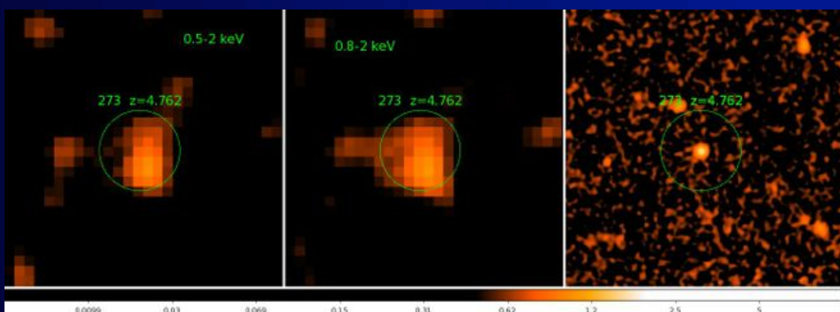


Xue11,G15

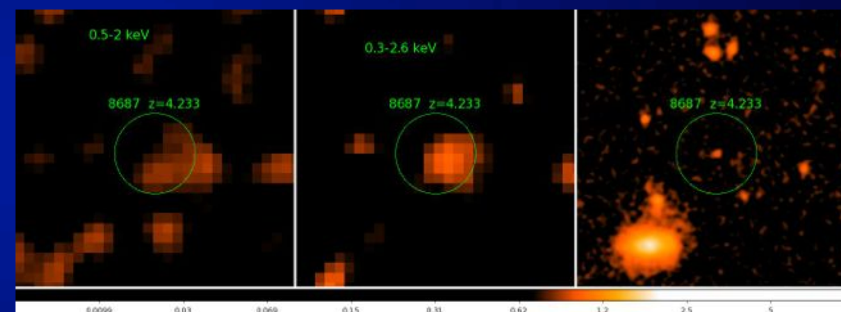


Xue11,G15

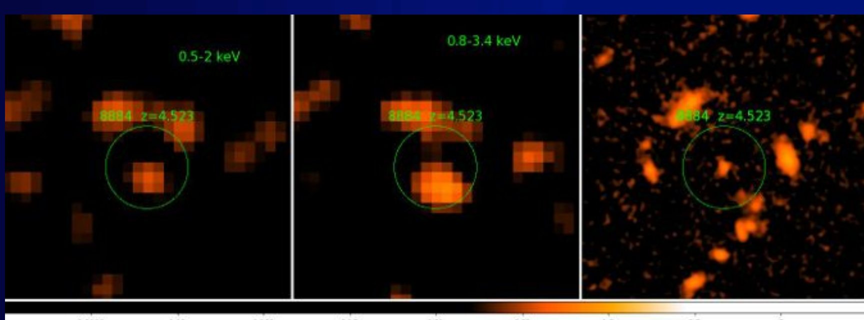
Circle r=2”



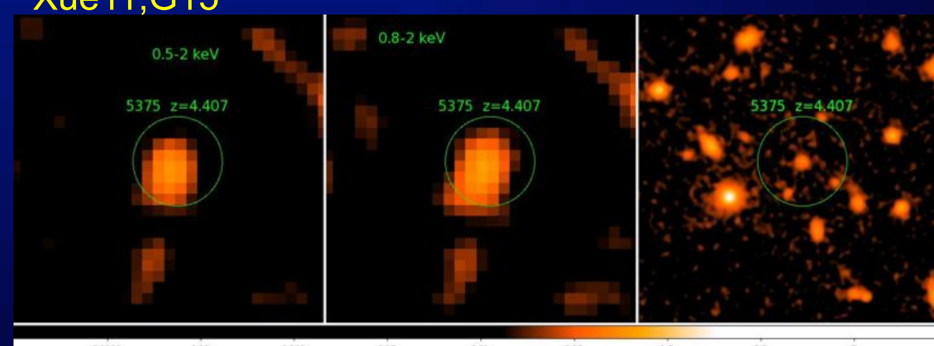
G15

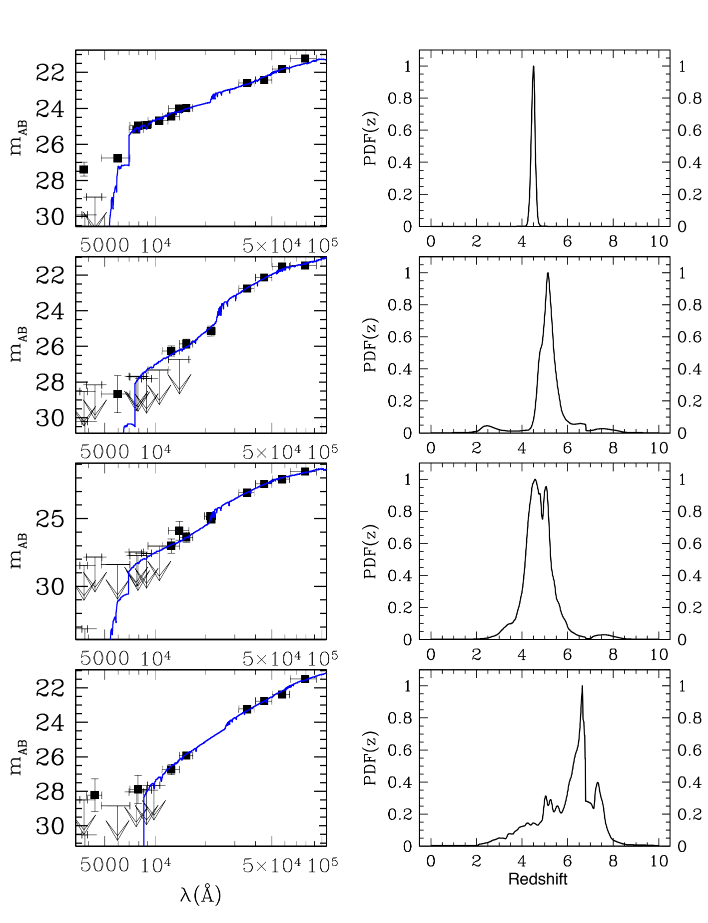


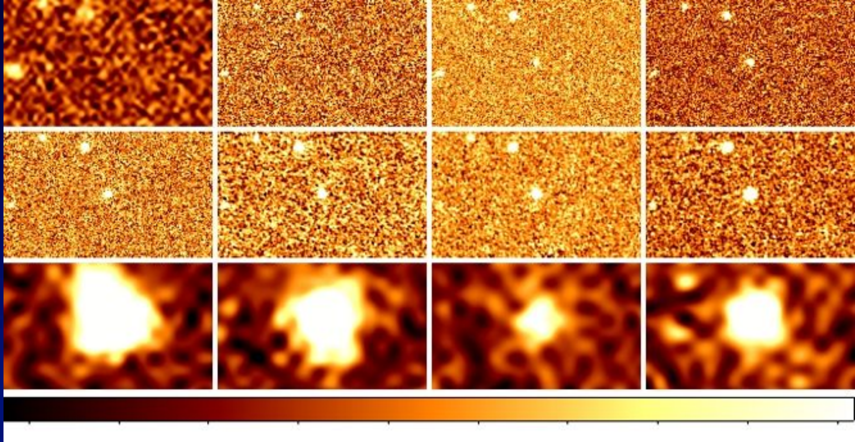
G15

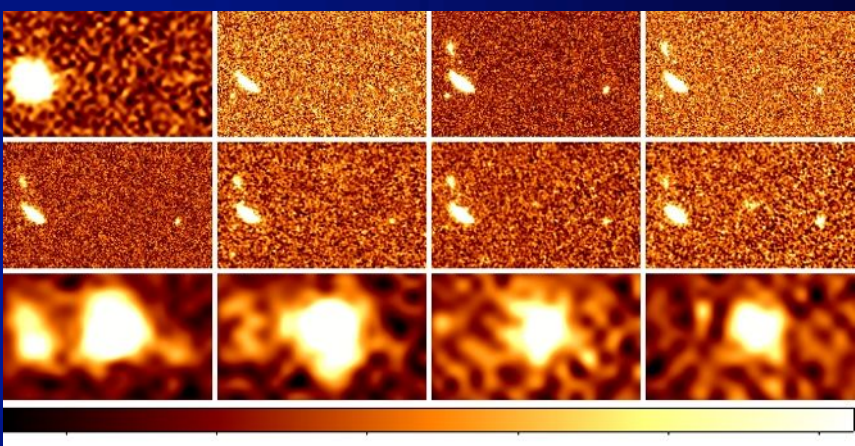


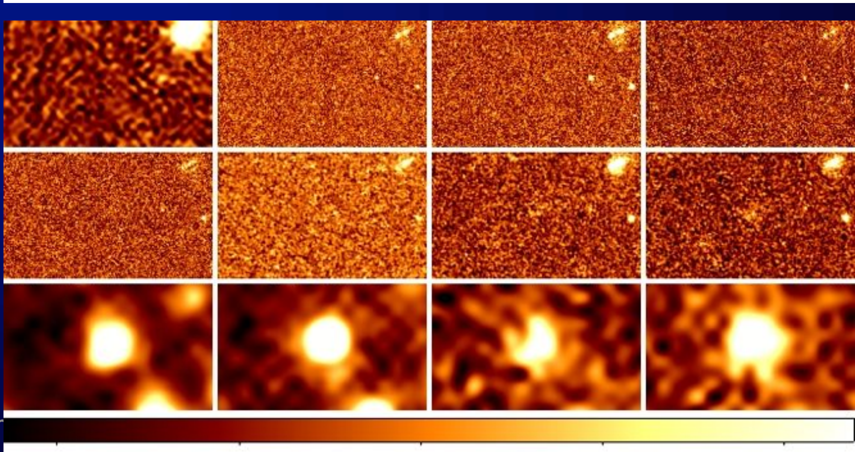
Xue11,G15

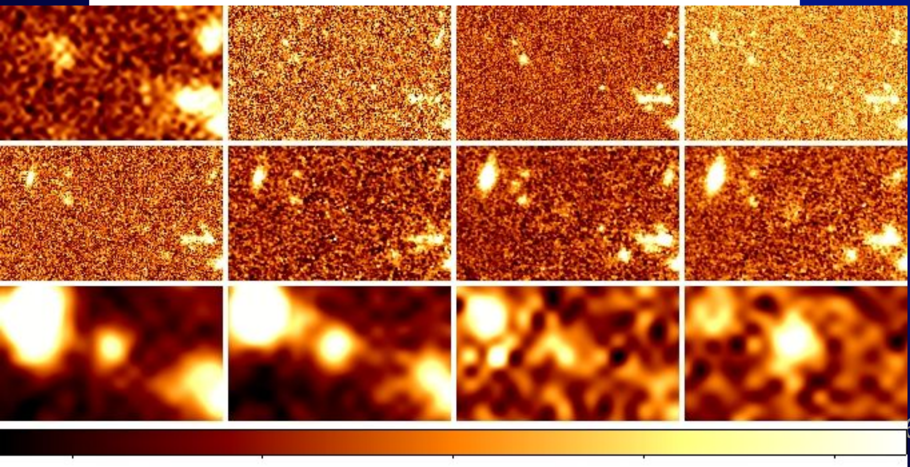




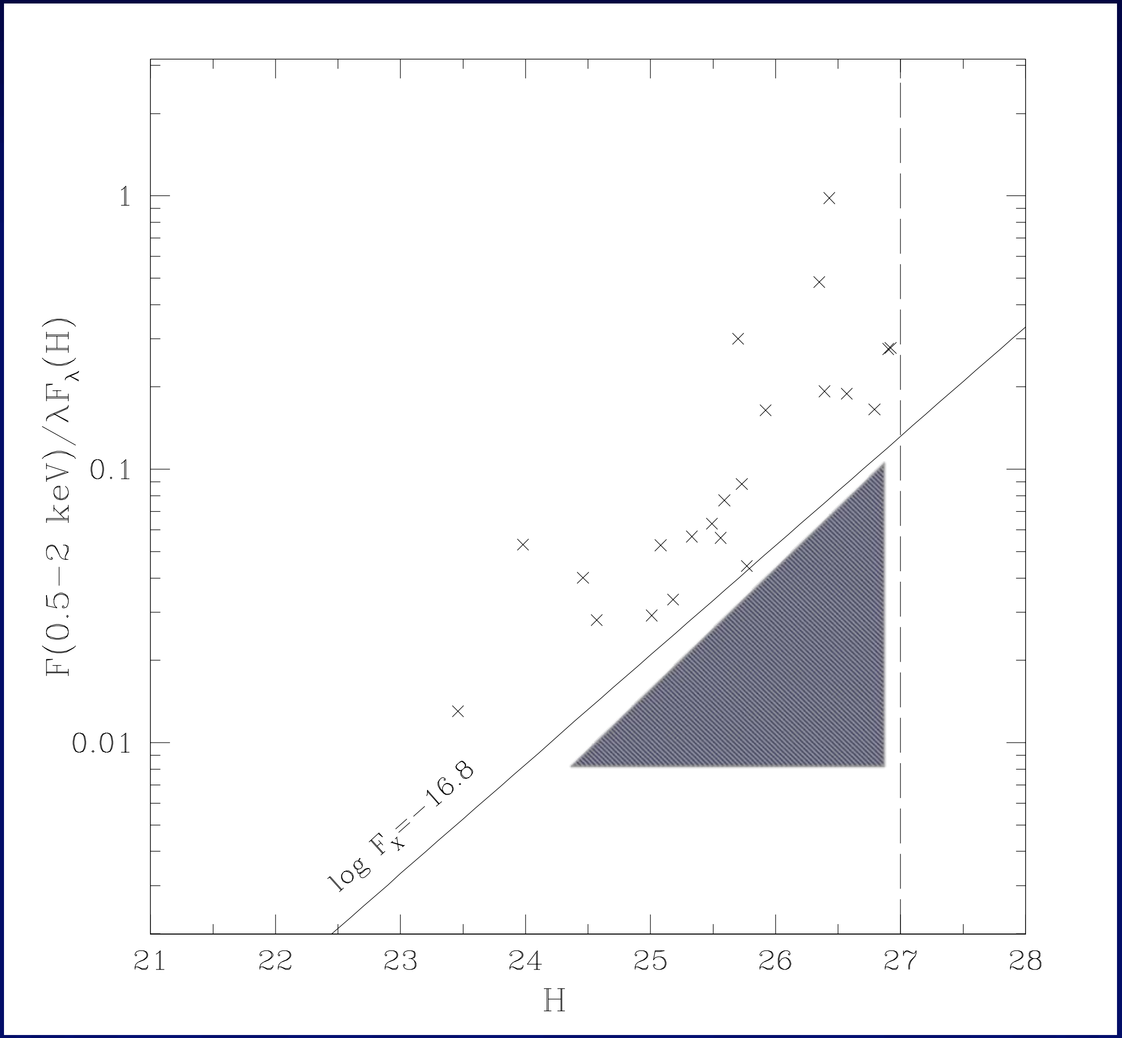








6: Illuminatir
Ages



Only relatively bright X-ray sources are detected at H=27

Average correction for incompleteness by more than a factor 2 at the faint end

X-ray non-detection is expected not only for faint AGN candidates in the H band

Example of bright AGN without X-ray detection in deep Chandra field

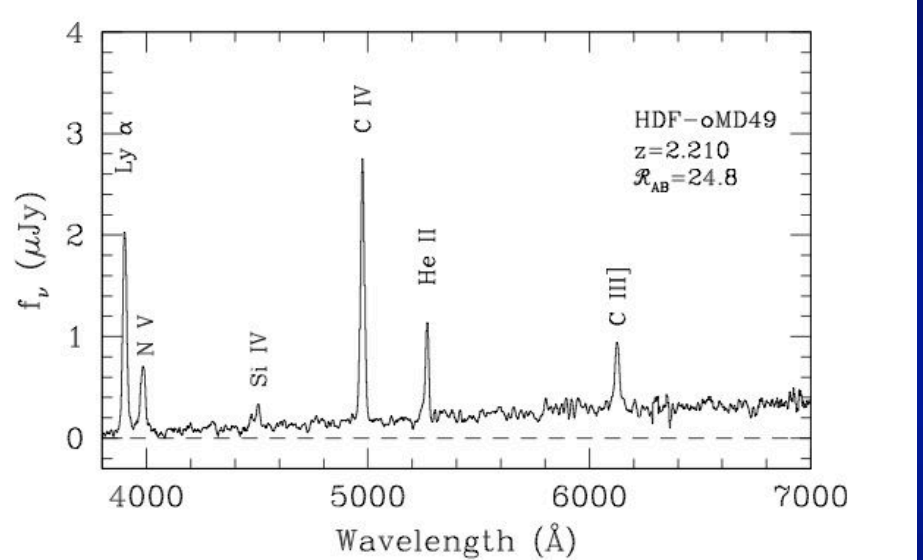
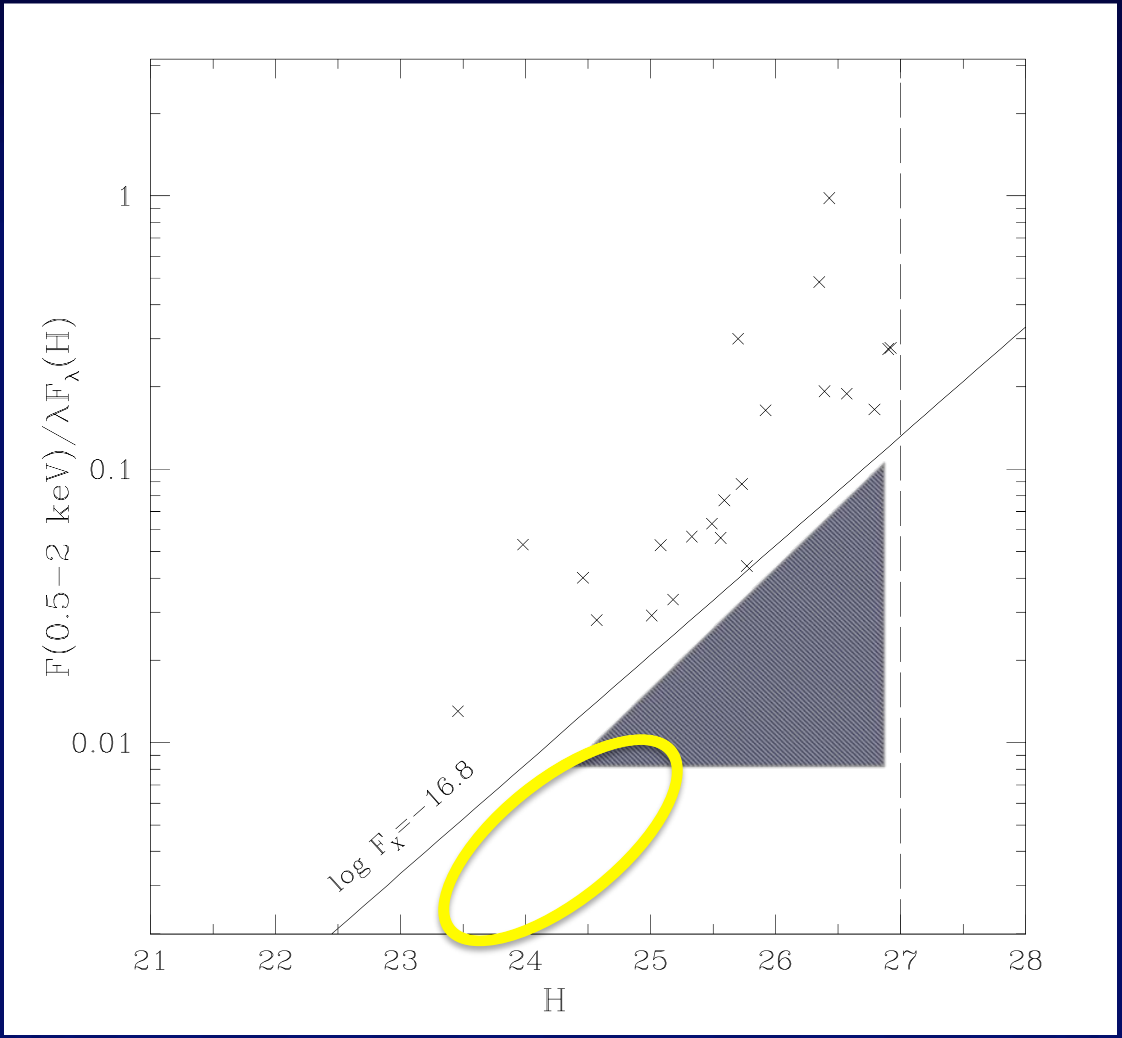


FIG. 2.—Observed spectrum of HDF-oMD 49, a narrow-lined AGN that is undetected in the 1 Ms Chandra Deep Field–North X-ray image (R.A. = $12^{h}37^{m}4^{s}.34$, decl. = $62°14'46''.2$ [J2000.0]). This object has an unusually weak Lyα emission line with respect to the high-ionization N V and C IV lines, possibly indicating a large amount of extinction in the narrow-line region.

R=24.8 z=2.2 AGN
not detected
in the 2Ms Chandra image
GOODS-N
(Steidel et al. 2002, Grazian priv. comm.)



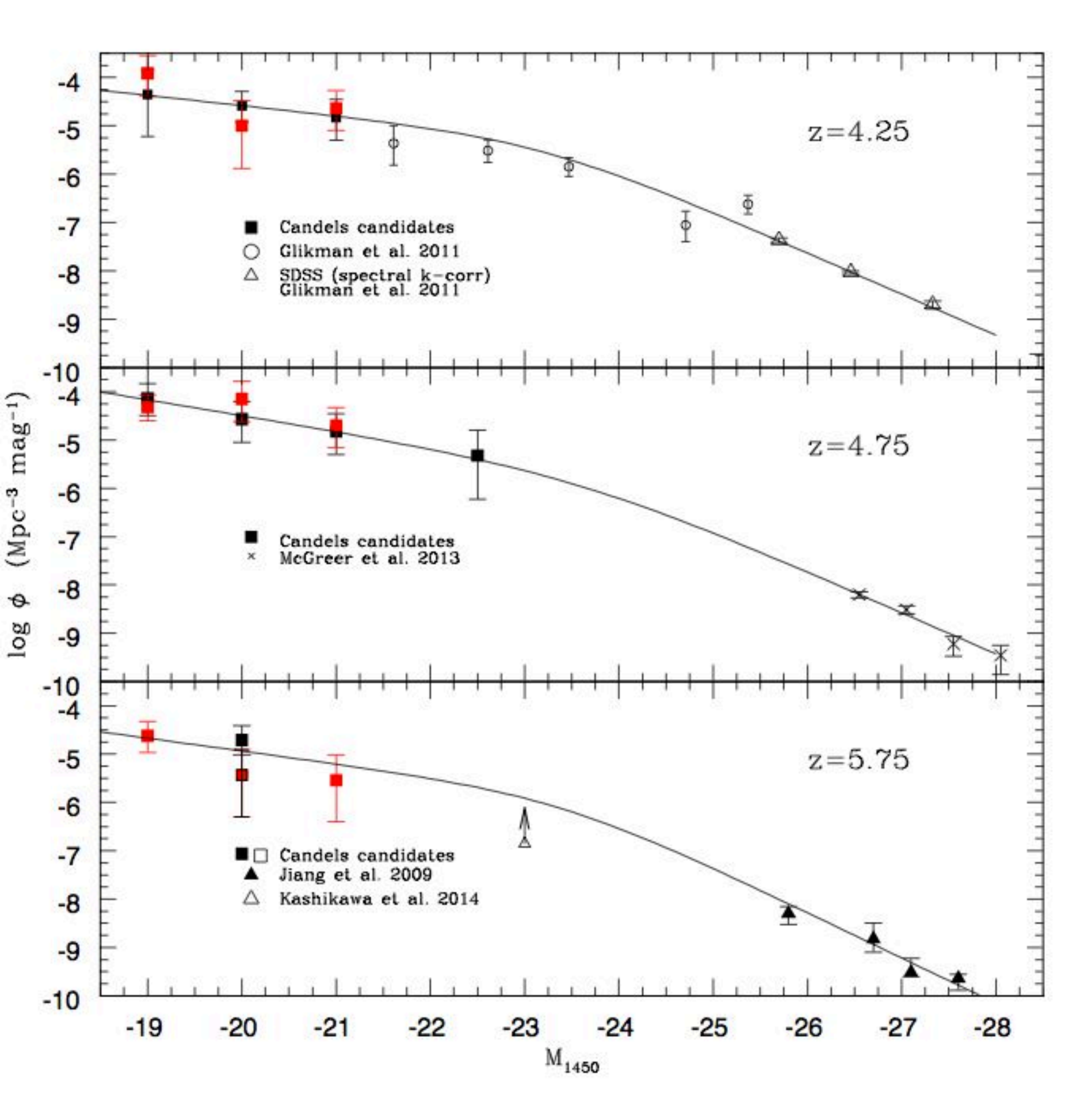
Only relatively bright X-ray sources are detected at H=27

Average correction for incompleteness by a factor ~2 at the faint end

LF corrected for:
H band counts incompleteness
and
X/H incompleteness

Adding SLOAN QSOs
2 power-law fit
Faint slope 1.5-1.8
Bright slope 3.1-3.3

L (break) is unconstrained
M_{1450} = -23.2 ÷ -23.6

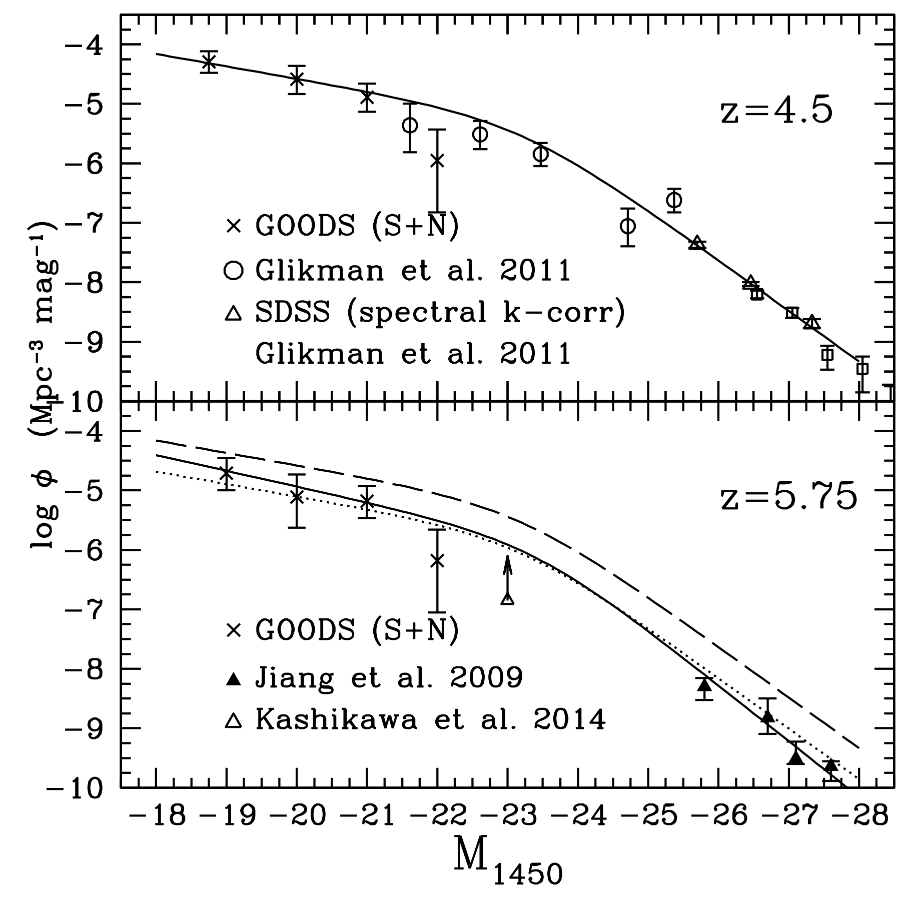


Work in progress on GOODS-N
175 $arcmin^2$
H<27 from CANDELS

BUT

$f_{lim}(x) \sim 2 * f_{lim}$(GOODS-S)~**3x10^{-17}**

12 candidates consistent with GOODS-S considering incompleteness due to shallower X-ray flux limit

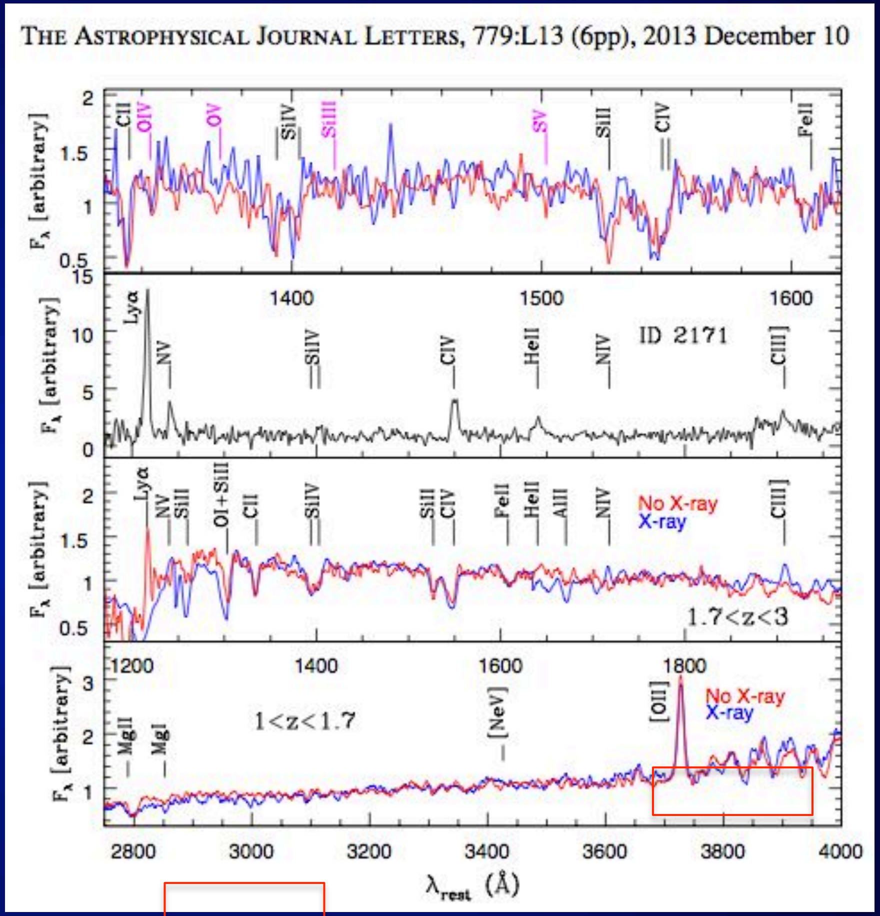


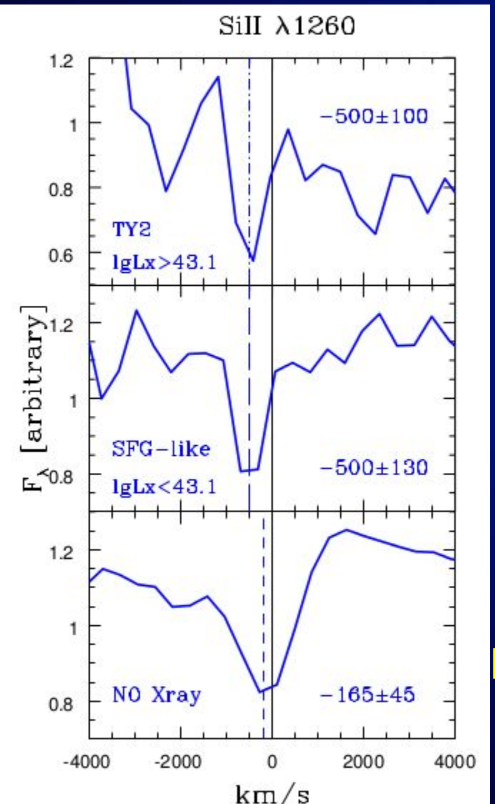
AGN activity/feedback in active galaxies in GOODS-S

Cimatti, Talio et al. 2013, 2016

Brighter galaxies with hidden AGN activity show rather normal UV spectra

Active X-ray galaxies have Log L_X>42.3
Threshold between SF dominated and AGN dominated X-ray flux
(Ranalli et al. 2003; Bauer et al. 2004)



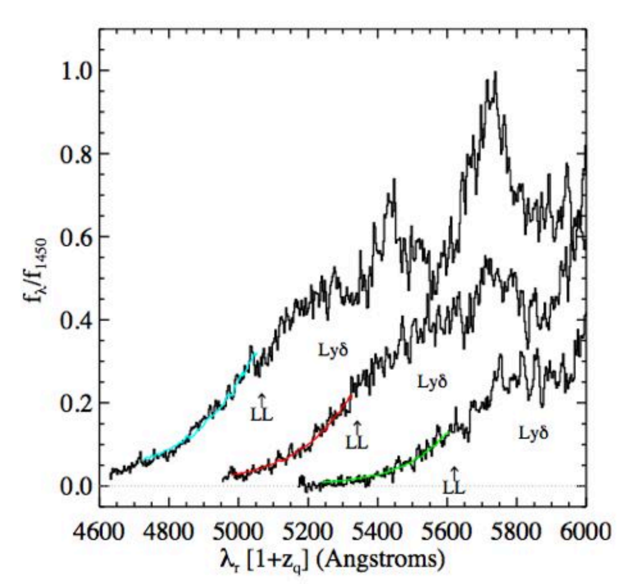


outflows 500-700 km/s → X-ray – outflow connection for active SFGs.
Probable mechanical feedback in action

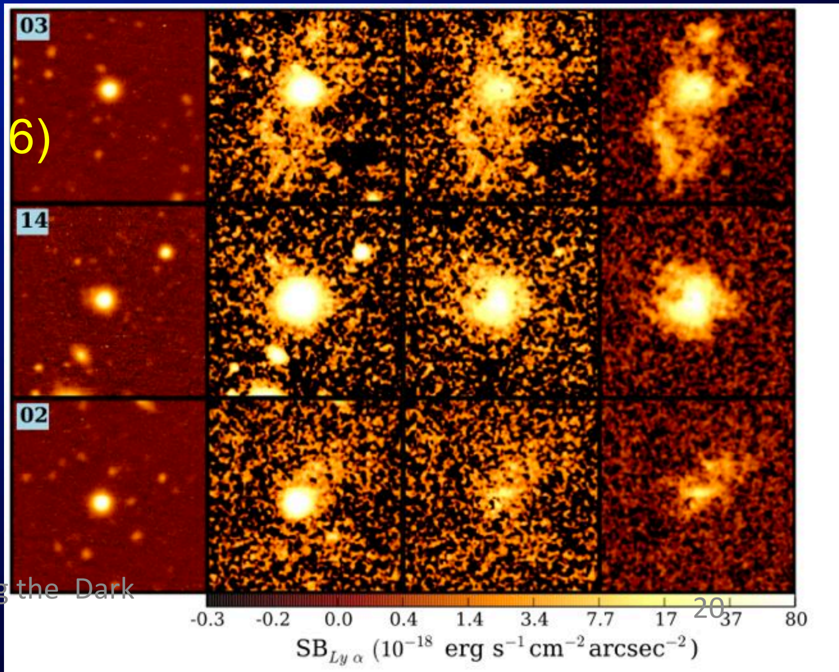
fesc from AGNs

SSDS spectra show significant ionizing flux escaping from high z QSOs with significant ionizing photon path

(Prochaska et al. 2009, Worseck et al. 2014)



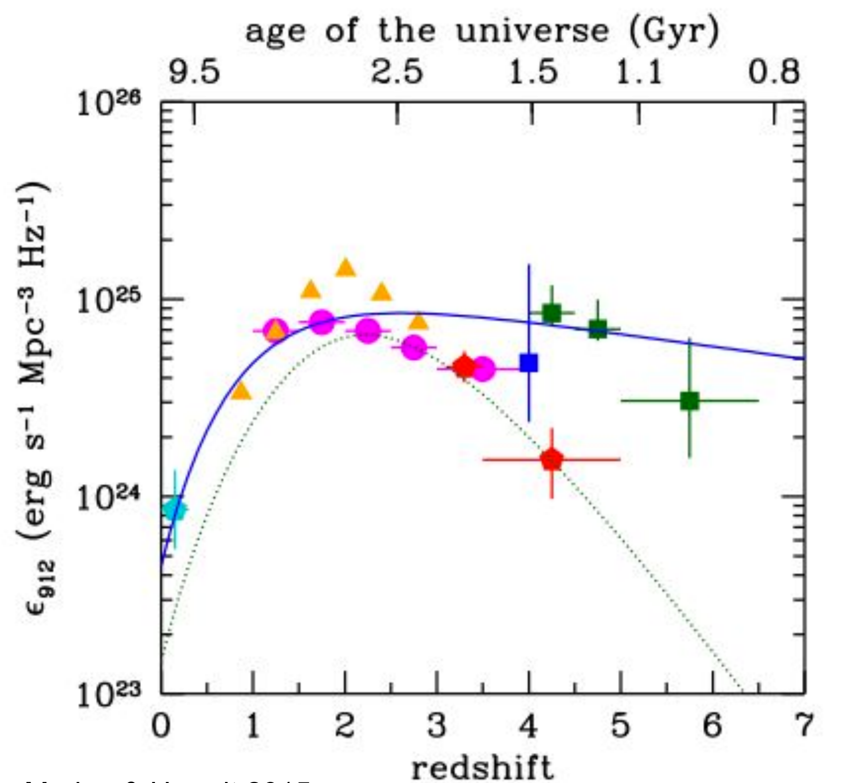
MUSE data show large Lya halos around bright AGNs up to 300 kpc with gas at T ~10^4K (17 QSOs at 3<z<4 Borisova, Cantalupo et al. 2016)



AGNs Ionizing Emissivity at 912 Å

$$\epsilon_{ion}(z) = \langle f \rangle \epsilon_{912} =$$

$$\langle f \rangle \int \phi(L_{1450}, z) L_{1450} \left(\frac{1200}{1450}\right)^{0.44} \left(\frac{912}{1200}\right)^{1.57} dL_{1450}$$



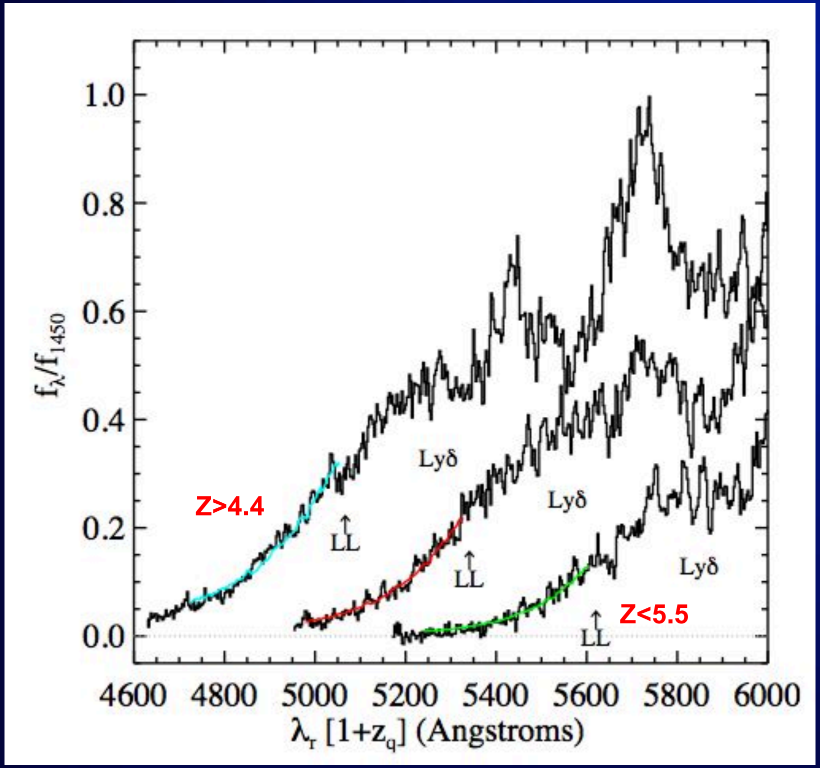
Madau & Haardt 2015

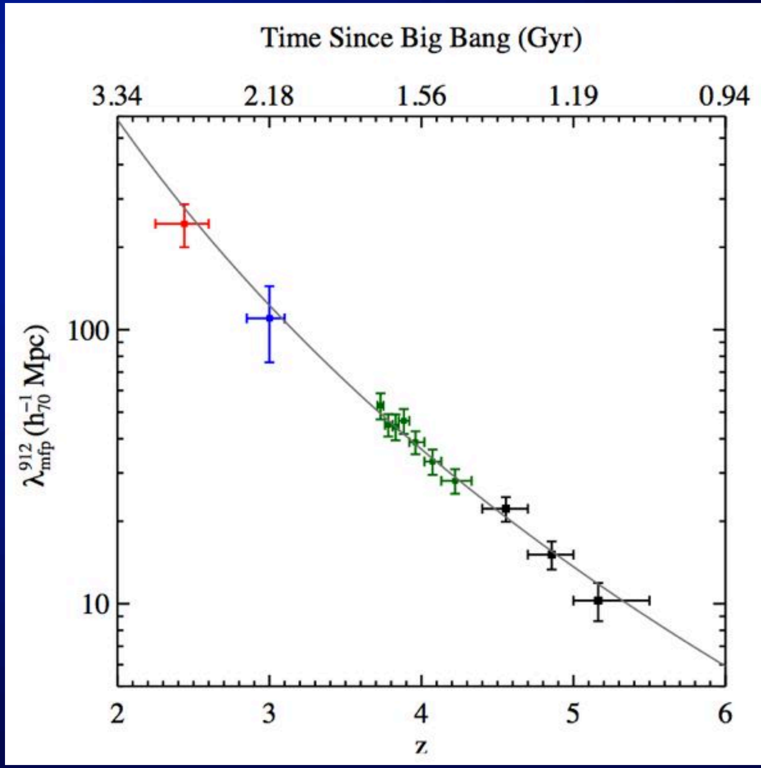
We assume < f > =1
and
average AGN spectral template at λ<1450 Å

Predicted Photoionization Rate

Γ(z) depends on emissivity and mfp redshift evolution

$$\Gamma_{-12}(z) \simeq 0.6 \frac{\epsilon_{24}(z)}{3+ \mid \alpha_{UV} \mid} \left(\frac{\Delta l}{65 Mpc}\right) \left(\frac{1+z}{4.5}\right)^{3-\eta}$$

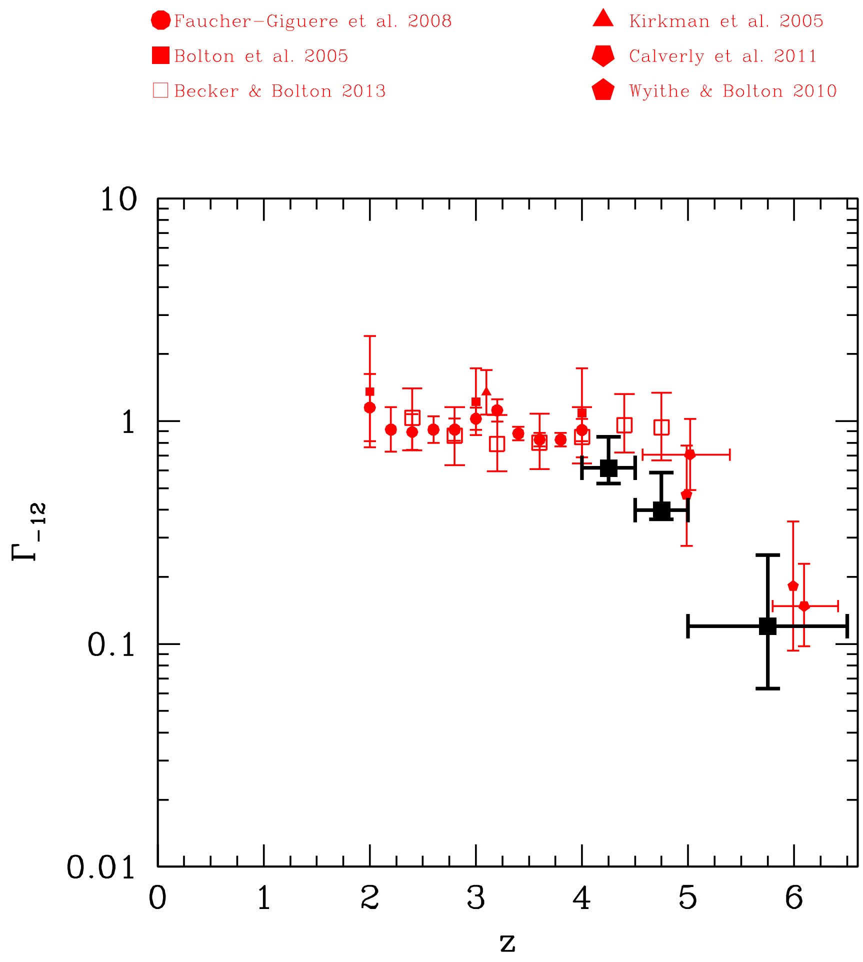




Worseck et al. 2014

A decline by a factor ~7
from z~4 to z~6
due to decrease of both
emissivity and mfp

Still consistent with the level
of ionization of the IGM



Future prospects: we are planning to add Chandra/HST GOODS-N and COSMOS field to the analysis

SUMMARY

Possible Scenario emerging from the present study:

- Few % of z>4 galaxies show X-ray emission at AGN levels (Log L_X>43) in GOODS

- Brighter X-ray galaxies show outflows 500-1000 km/s possibly connected with large escape fractions of ionizing photons

- The volume density of faint AGNs at M_{1450}> -22 is ~$3x10^{-5}$ and it is consistent with double power-law LFs predicting ionization parameters at z>4 in agreement with that derived from the IGM ionization level if f_{esc}=50%-100%

It's time to reconsider the role of AGNs as important driver of the ionization history of the Universe

What next: Ideally a CDF in COSMOS, in practice 500ks per pointing i.e. 7 Ms
Sampling the LF at M_{1450} ~ −22 ÷ −24 where we expect the bulk of the emissivity contribution