The first accreting black holes

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Outline

- Some open questions
- Current knowledge of high-z (> 3) AGN from X-ray (and optical) surveys
- Overview of theoretical models for early BHs formation and growth
- Prospects for IXO observations of early BHs

Some key questions on the high-z Universe

Future facilities (JWST, ALMA, ELT, EVLA) will investigate high-z galaxies and AGN in many bands. Questions for a future X-ray observatory:

How do early BHs form and grow?

What triggers nuclear activity?
External perturbations (mergers, fly by) or internal processes?

What formed first, BH or galaxy?
Some evidence for larger BH per fixed stellar mass at z~0.3-0.6 (Woo+08).
Also, suggestions for M_{BH}/M_{*}~0.1-0.3 in bright QSOs at z>4
(Walter+04, Maiolino+07, Riechers+08)

What is the high-z BH mass function?

How do accretion modes evolve? [radiative efficiency, L/L_{Edd}, SED(α_{ox})]

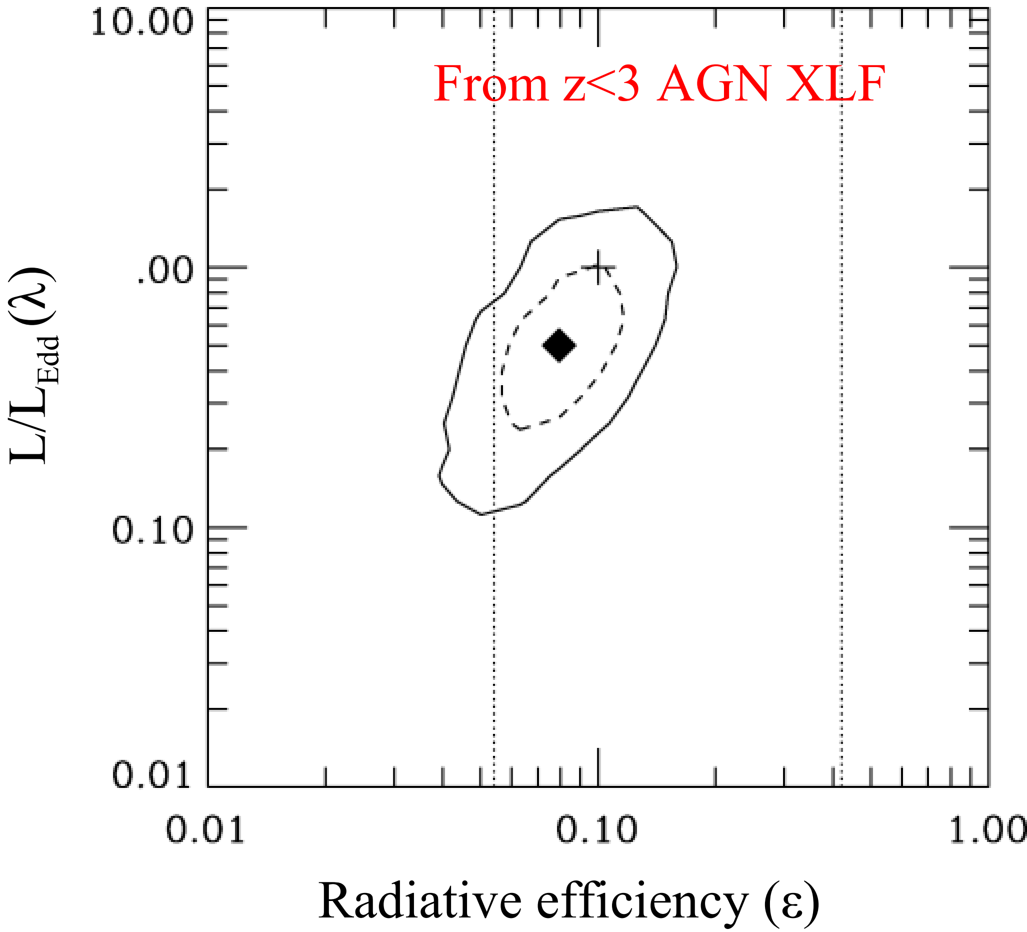
Average radiative efficiency and Eddington ratio

$< \varepsilon > = 0.06 - 0.10$
$< \lambda > = 0.2 - 1.0$

Details of the evolution of accretion onto BH still lacking.

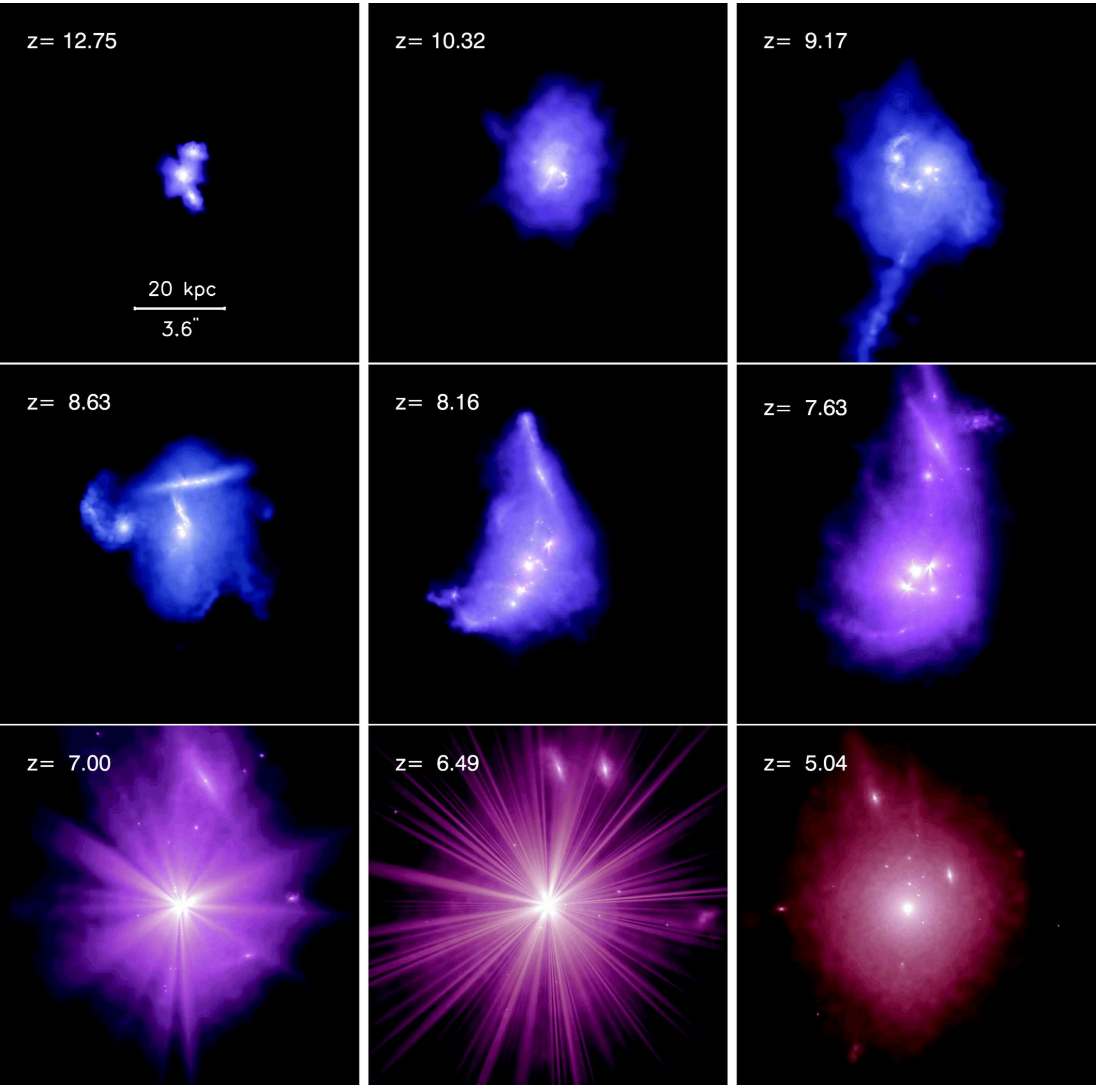
Also, the average radiative efficiency depends on the obscured AGN fraction, especially C-thick AGN, unknown at high-z. Obscured AGN census (see next talk) needed to get meaningful values

Is there any dependence on redshift?
Is spin (i.e. ε) dependent on z or BH mass? (see eg. Volonteri+05)



From Marconi+04 (see also Yu&Tremaine02, Shankar+04, Merloni+08,…)

Simulated formation of a ~10^9 M_{sun} BH at z=6.4



From Li+07

Eddington limited accretion since z~20 needed to explain the ~10^9 M_{sun} BHs found in luminous SDSS QSOs at z > 6.

Li+07: multiple mergers with Eddington limited accretion can explain both BH and host galaxy properties of SDSS QSOs at z>6 (ε fixed to 0.1)

Where do we stand?

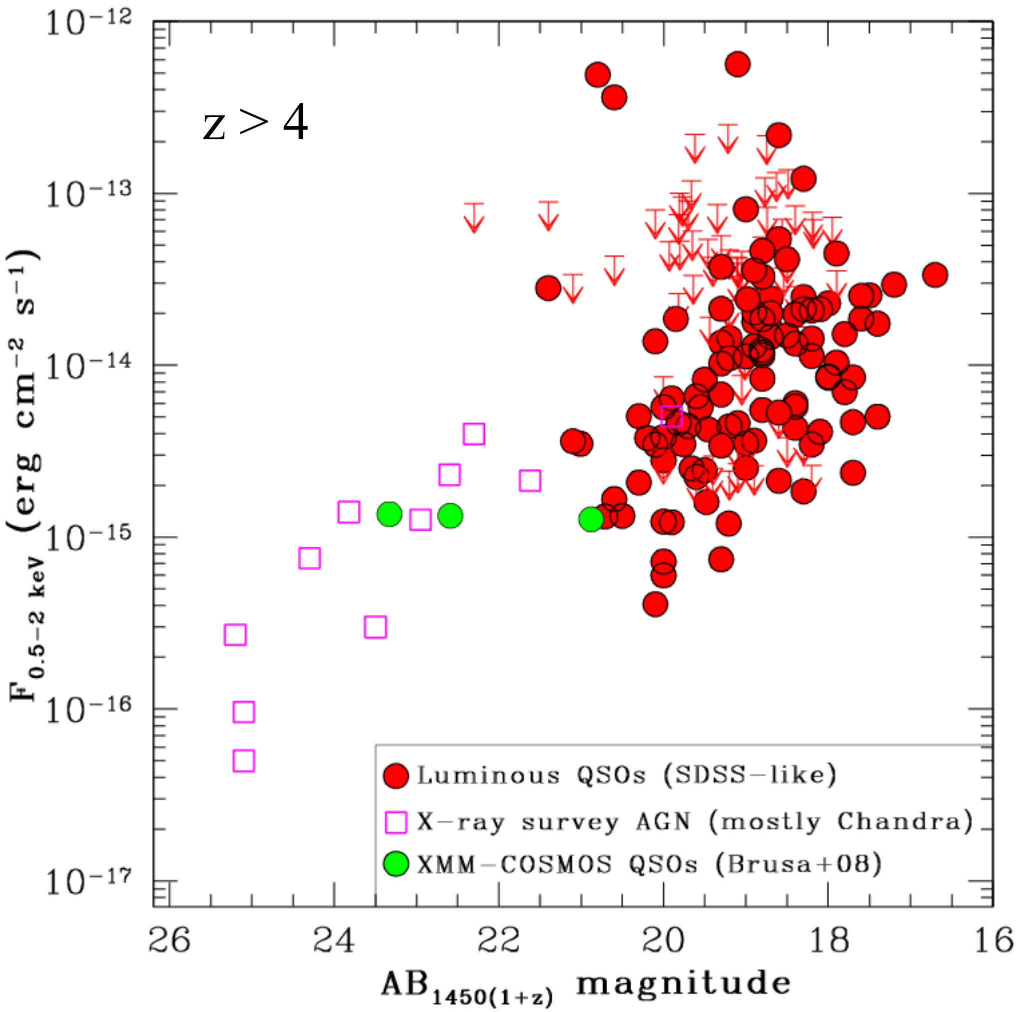
The number of high-z AGN detected so far

	SDSS*	X-ray sel.$
z > 3	8000	50
z > 4	1500	11
z > 5	150	2
z > 6	10	0

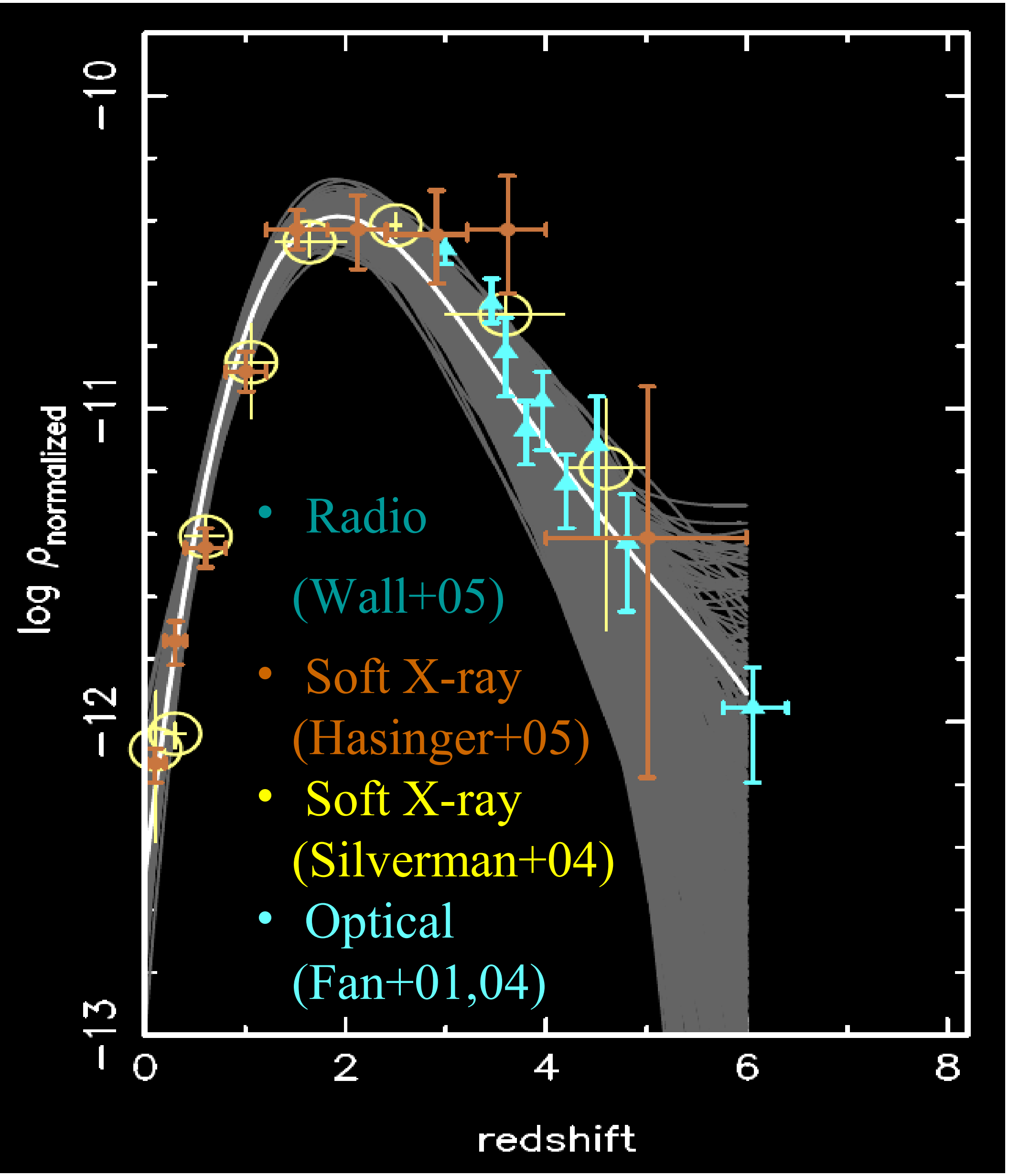
*from DR6 "SpecObjAll" table

$see eg. compilations by Silverman+08, Hasimger08

Vignali et al



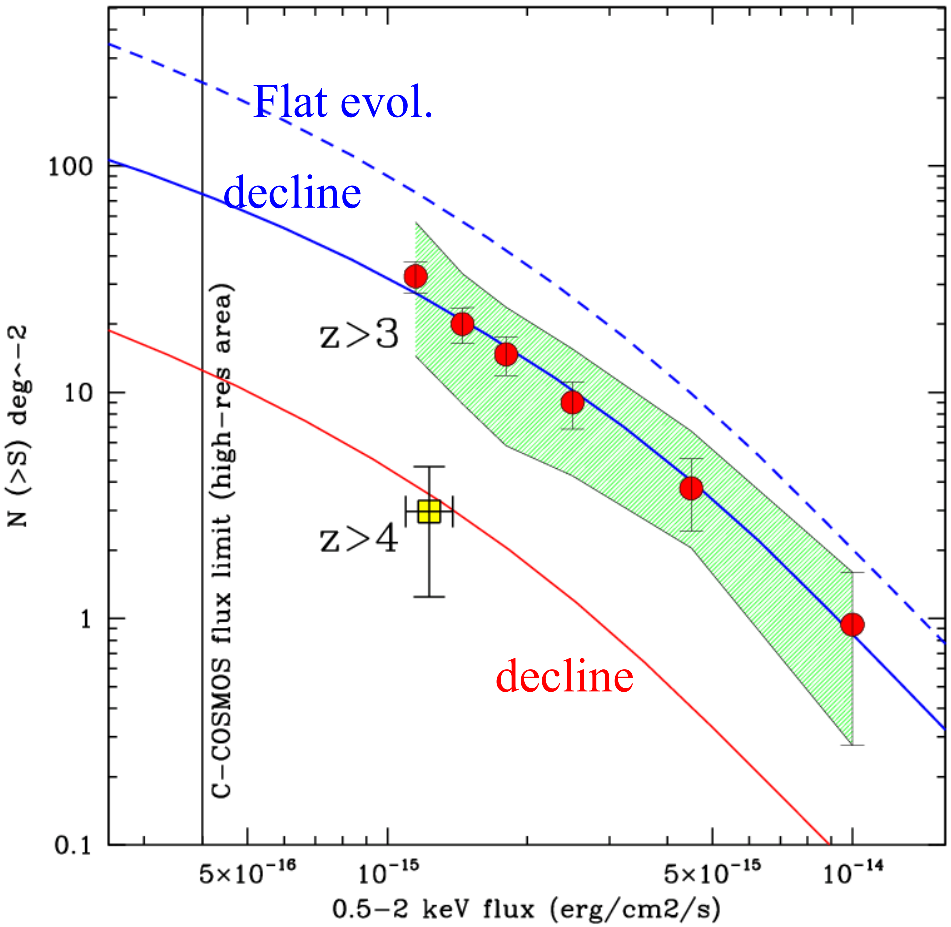
X-rays needed to get the LF faint end

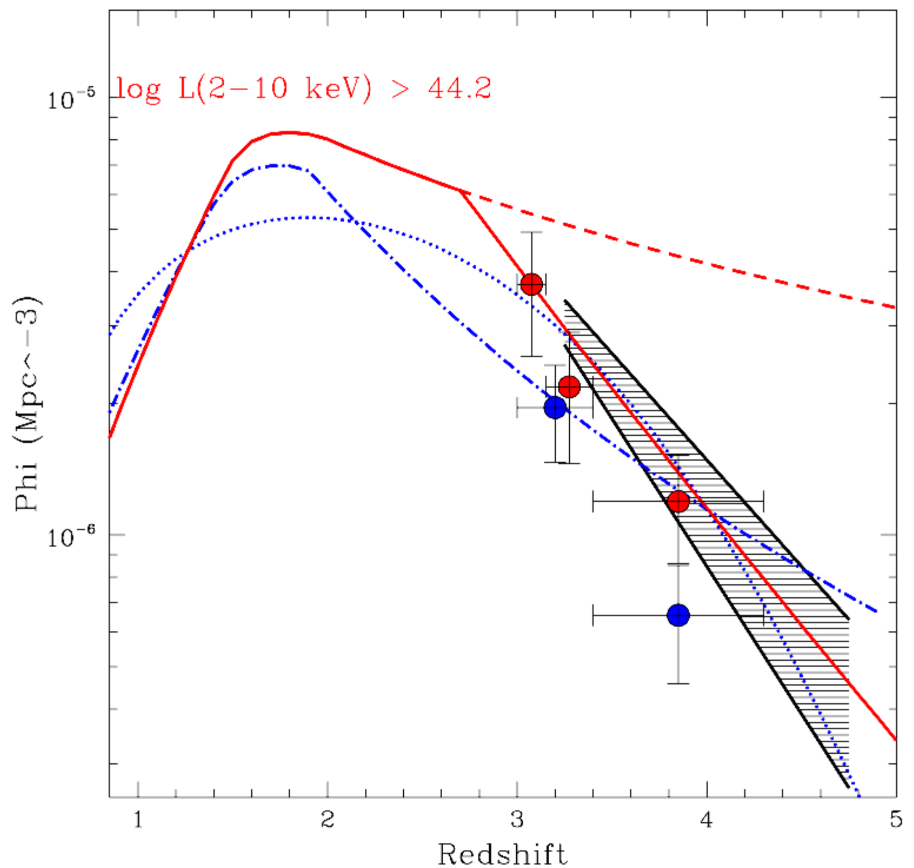


Density of luminous QSOs (L_X>10^{45} erg/s) traced up to z=6: decline observed at z>2.5-3

Less luminous QSOs (L_X> 10^{44} erg/s): decline goes up to z~4

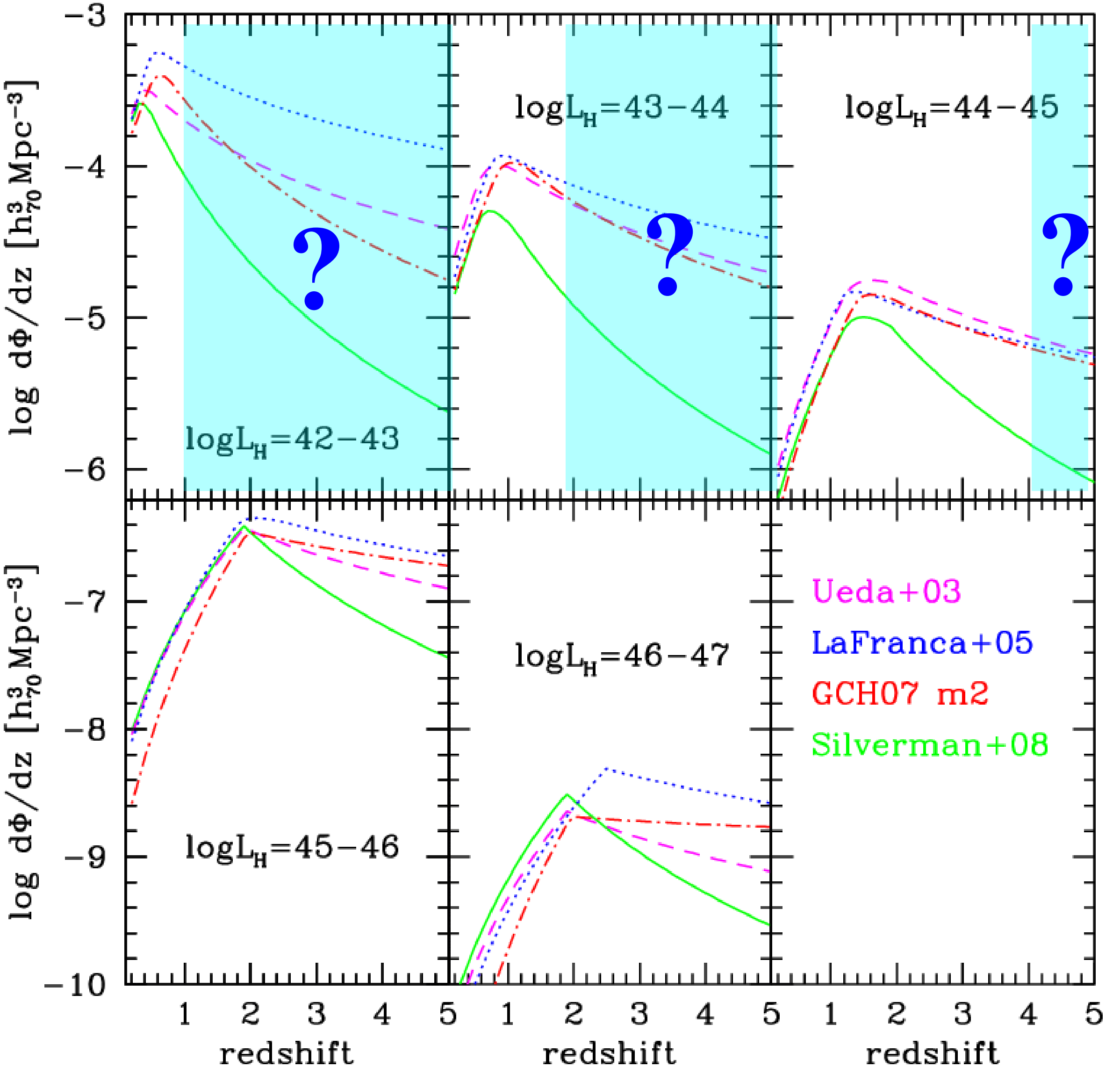
Brusa+08, arXiv:0809.2513





XMM-COSMOS: the largest sample of X-ray selected AGN at z>3

What is the space density of low L_X, high-z AGN?



Best fit XLF from current X-ray surveys compilations

Evolution of the bulk of the AGN population still to be determined at moderate to high-z.

Flatter evolution or decline as for high luminosity?

Sensitivity needed for high-z AGN census

<u>What do we expect?</u>

Formation of primordial black holes

Black holes at very high redshift can form:

- as remnants of PopIII ($M>260\ M_{sun}$) stars (Madau&Rees01): $M_{BH} \sim M_{popIIIstar}$, zero metallicity, no mass loss

- By direct collapse of dense gas clouds with low angular momentum via gravitational instabilities (Begelman+06; $M_{seed} \sim 20 M_{sun}$). Massive seeds ($10^4\ M_{sun}$) also possible (Koushiappas+04, Volonteri+08).

Primordial black holes are expected to form in high density ($>\sim 3\sigma$?) peaks

Semi analytic models of BH growth

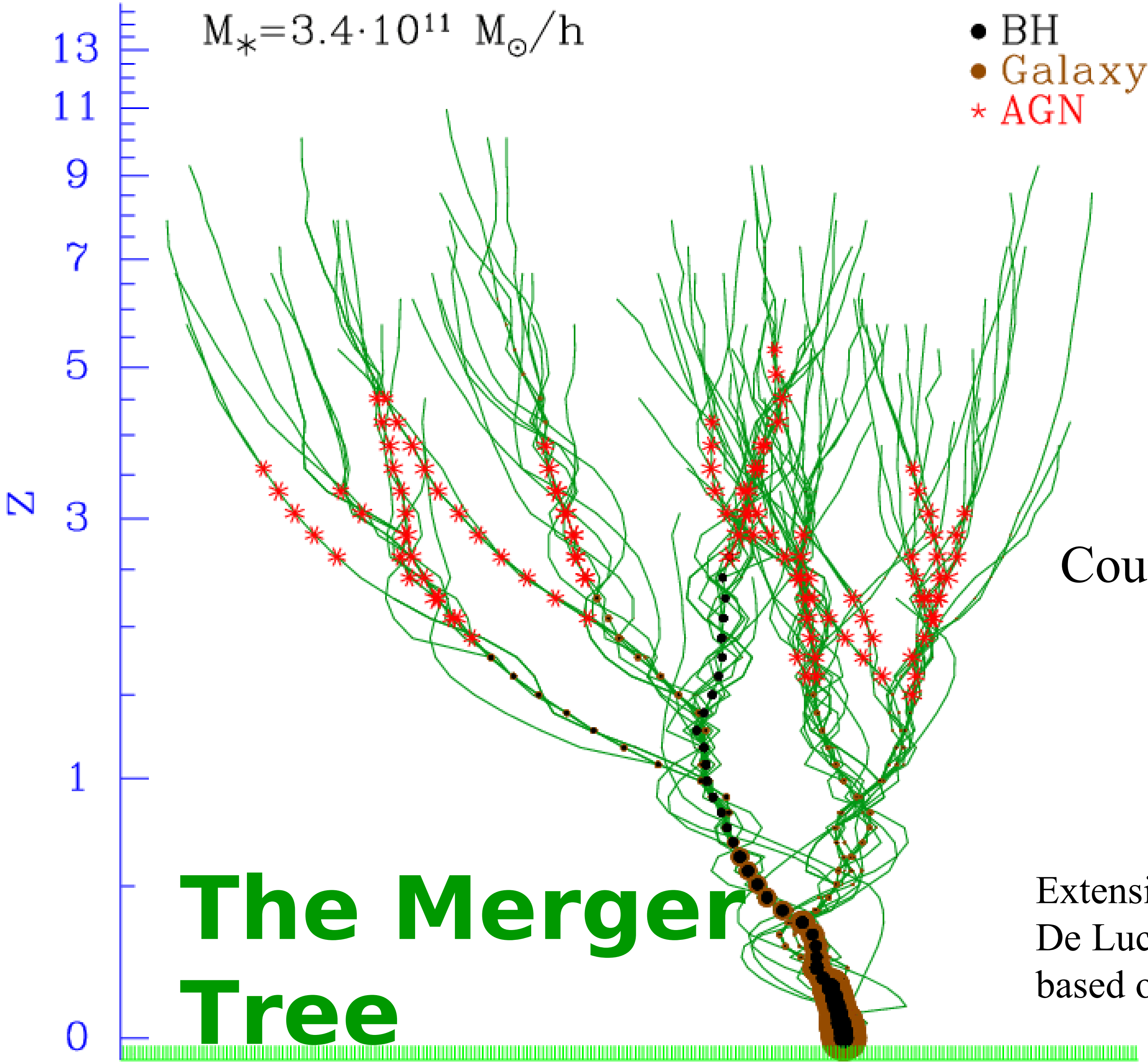
Many semi-analytic models based on LCDM:
Volonteri+06, Salvaterra+06, Rhook&Haehnelt08, Menci+08, Marulli+08.
These follow the evolution and merging of Dark Matter Halos with cosmic time and use analytic recipes to treat the baryon physics. Some use the Press-Schechter formalism to get halo merger trees, others are based on the Millennium simulation.

Common assumption: nuclear trigger at merging

Free parameters:

- BH seeds (from ~20 to 10^4 M_{sun})
- recipes for accretion (radio mode and QSO mode) ➔ Eddington ratio, AGN lightcurves
- relation between initial BH mass and halo mass (eg bias)
- SED (eg obscuration)
- room for accretion due to internal processes (i.e. not related to mergers)

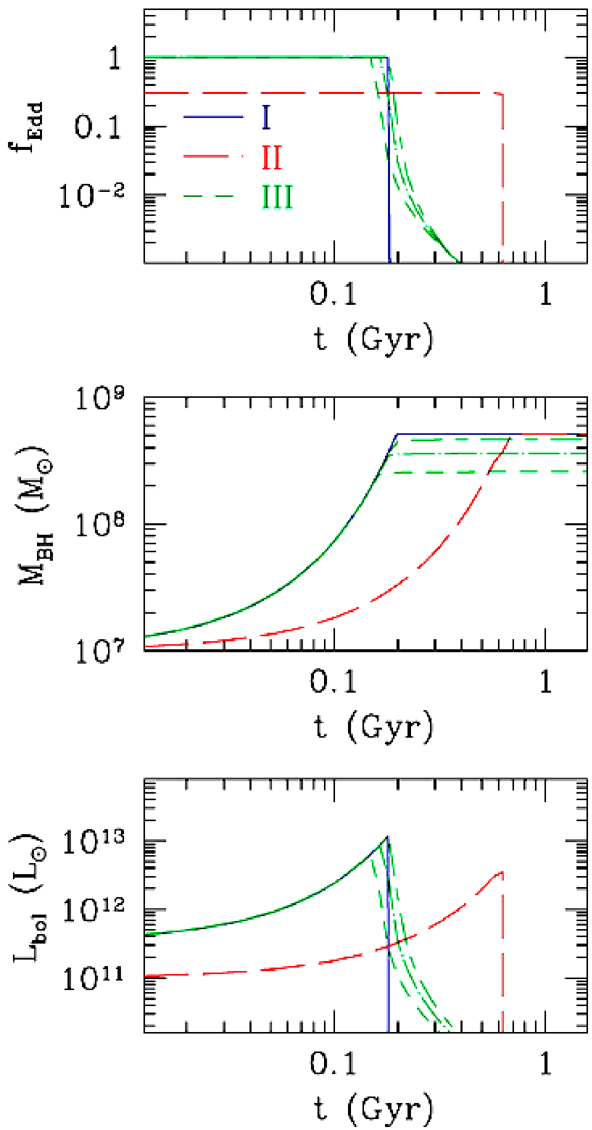
The Merger Tree



Courtesy F. Marulli

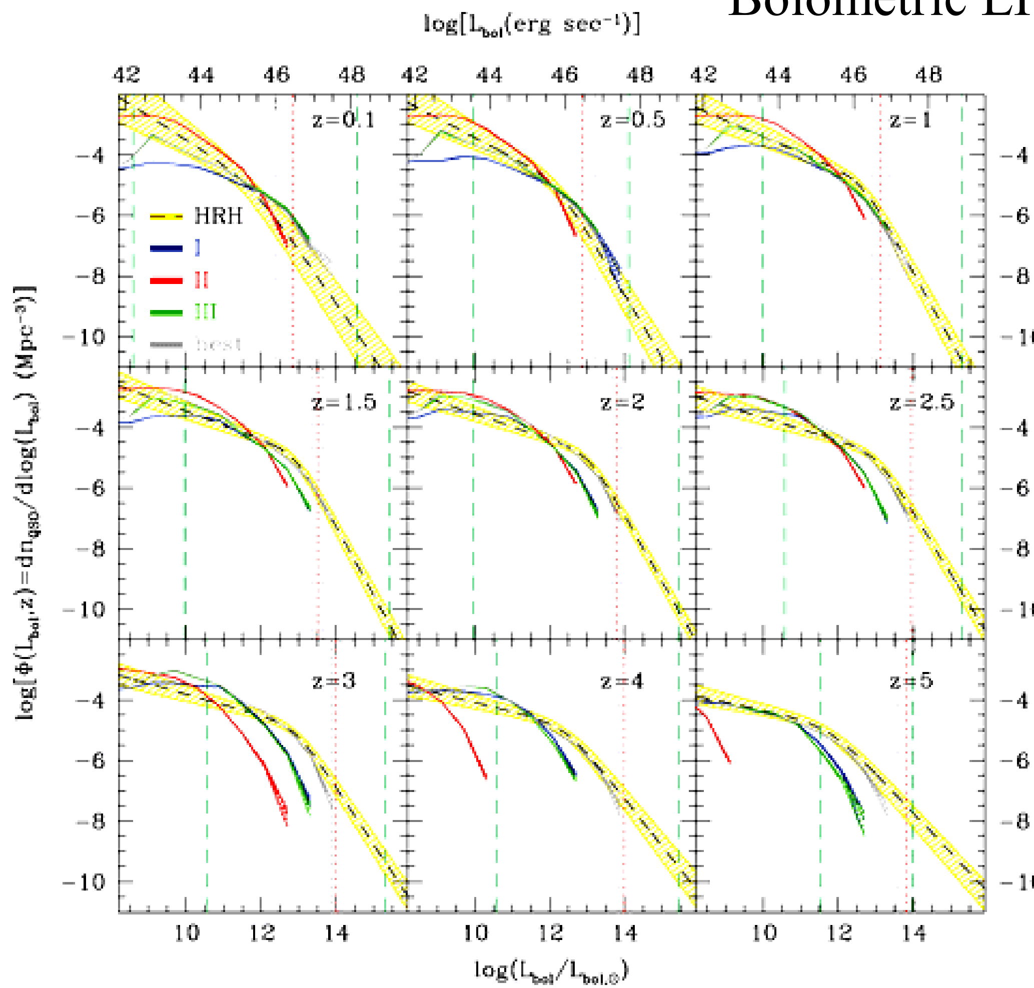
Extension of Croton+06 & De Lucia+07 SAM models based on Millennium

AGN lightcurves and luminosity functions



Example of ligthcurves for a 10^7 M_{sun} BH

Bolometric LF



From Marulli+08

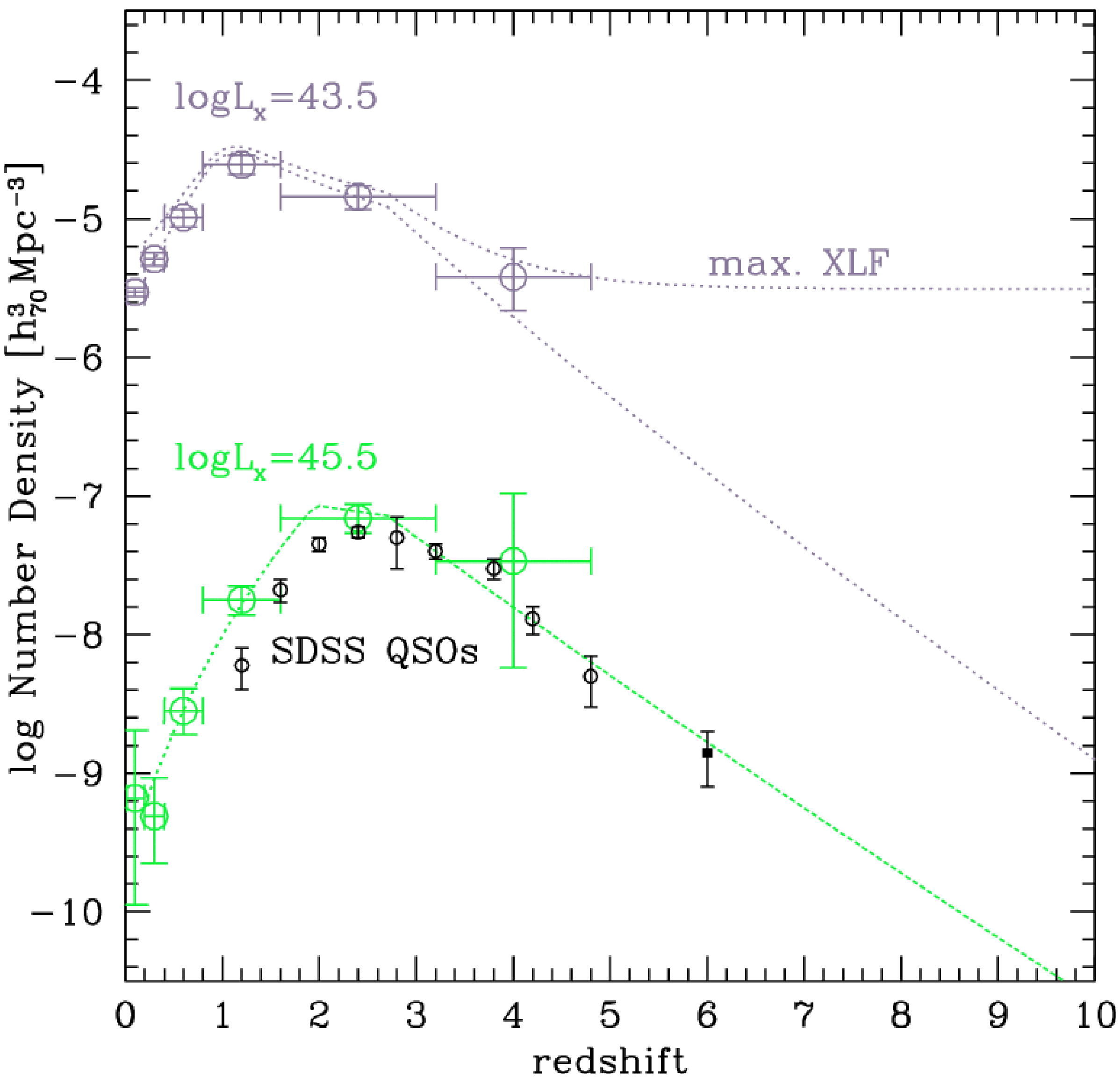
What will we see? Prospects for IXO

Two possible ways to make predictions on the high-z Universe:

1) use simple extrapolations from known XLF towards high-z and low luminosities

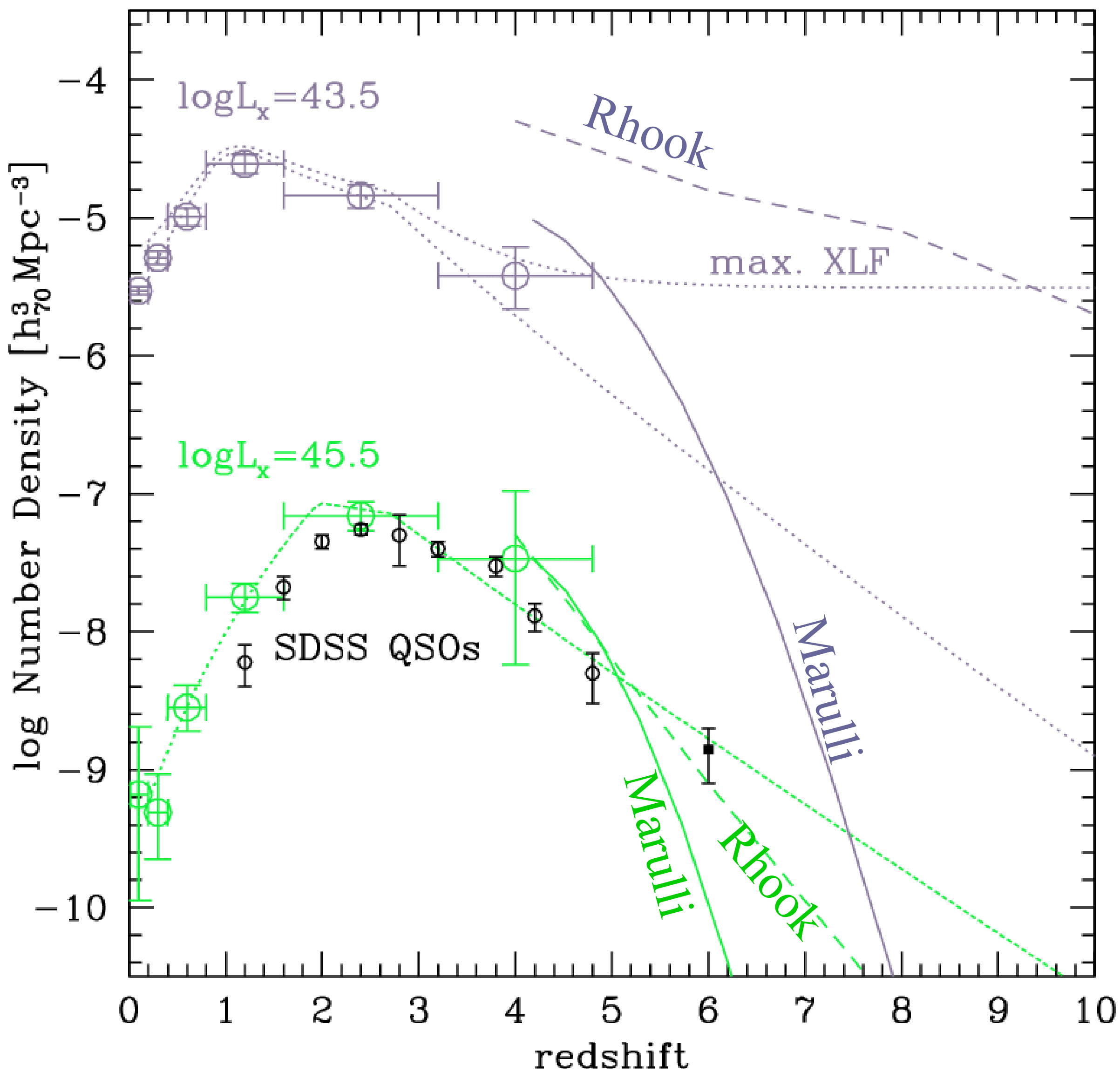
2) use SAM models for early BH growth from seed BHs

1) Extrapolations of known XLF

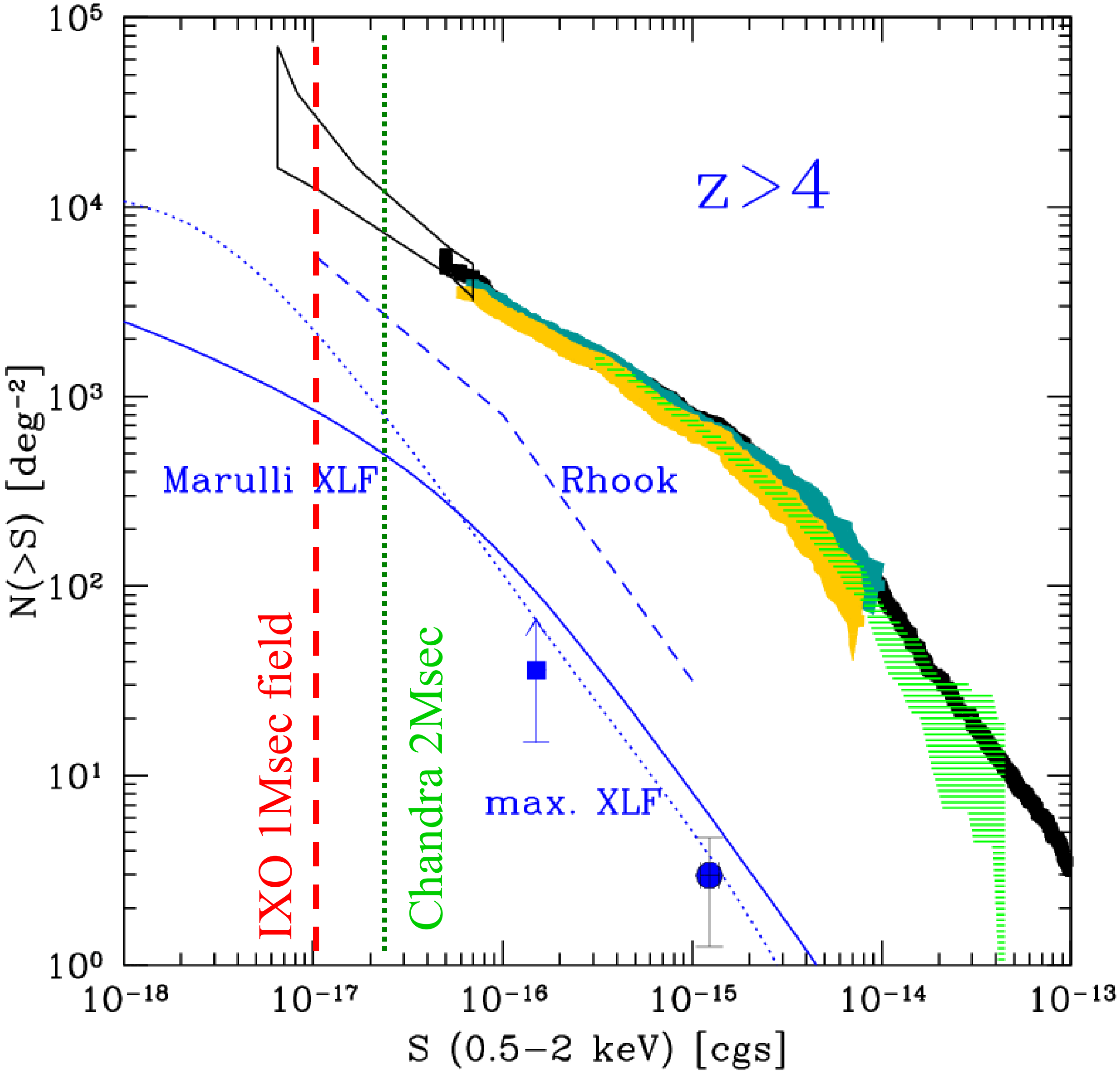


max. XLF:
XLF that predicts the maximum number of high-z AGN while being in agreement with current “low-z” XLF.

2) SAM models for early BH growth



Predictions for high-z Universe very uncertain, even by a few orders of magnitude



Sensitivity reduced wrt XEUS, but larger FOV compensates for the high-z AGN yield

Angular resolution, HEW:

Chandra 1”

IXO ≤5”

XMM 15”

Assuming beam radius = HEW/2 and 30 beams per source, confusion limit at N(>S) ~ 2x10^4 deg^{-2}, i.e. S ~ 10^{-17} erg/cm^2/s

Confusion limit expected in ~1 Msec (depending on the bkg level)

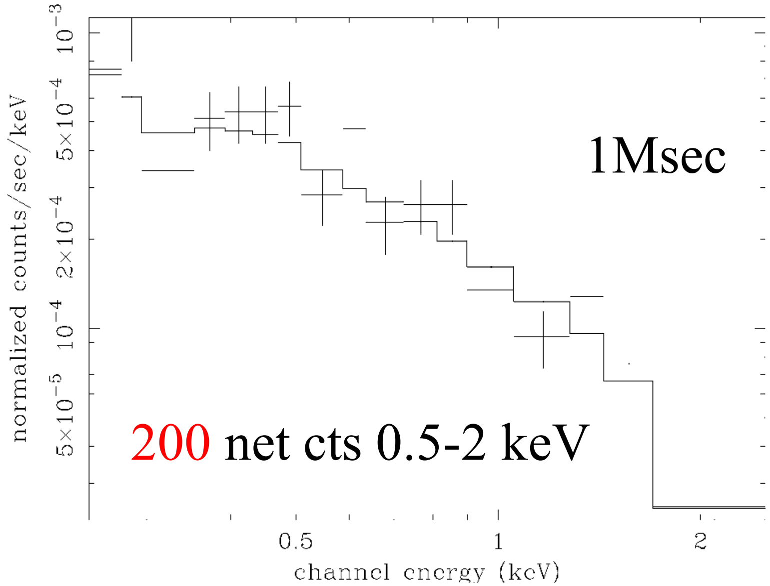
WFI FOV~150 $arcmin^2$, then >33 (up to 100?) AGN at z>4 expected in an IXO Msec field (in absence of vignetting)

Increase by 4x if FOV 25x25arcmin

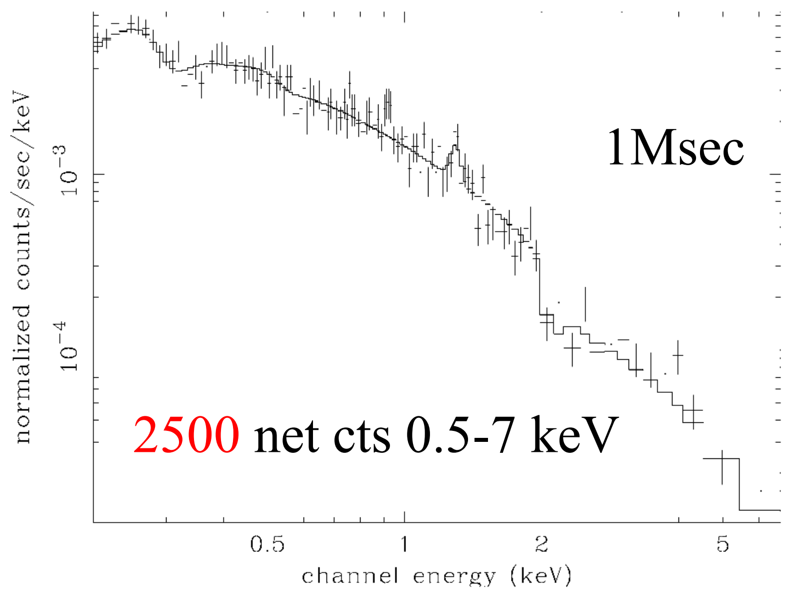
Simulated spectra for faint z=4 AGN

(based on a very preliminary response matrix: eff. area = $3m^2$@1keV, $1m^2$@6keV)

F(0.5-2)=10^{-17} cgs
L_x=1.4x10^{42} erg/s, Γ=1.9

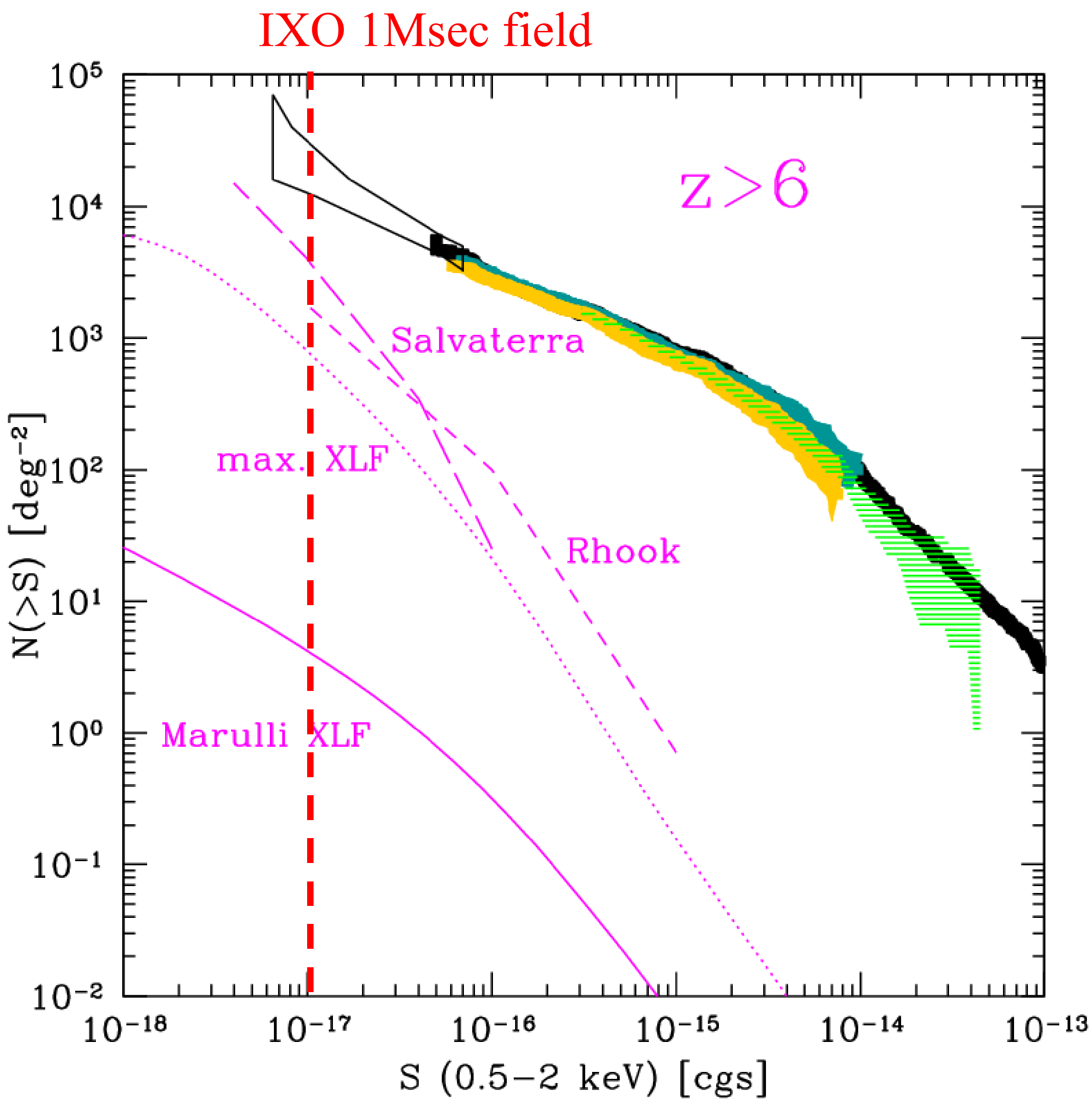


F(0.5-2)=10^{-16} cgs
L_x=1.4x10^{43} erg/s, Γ=1.9



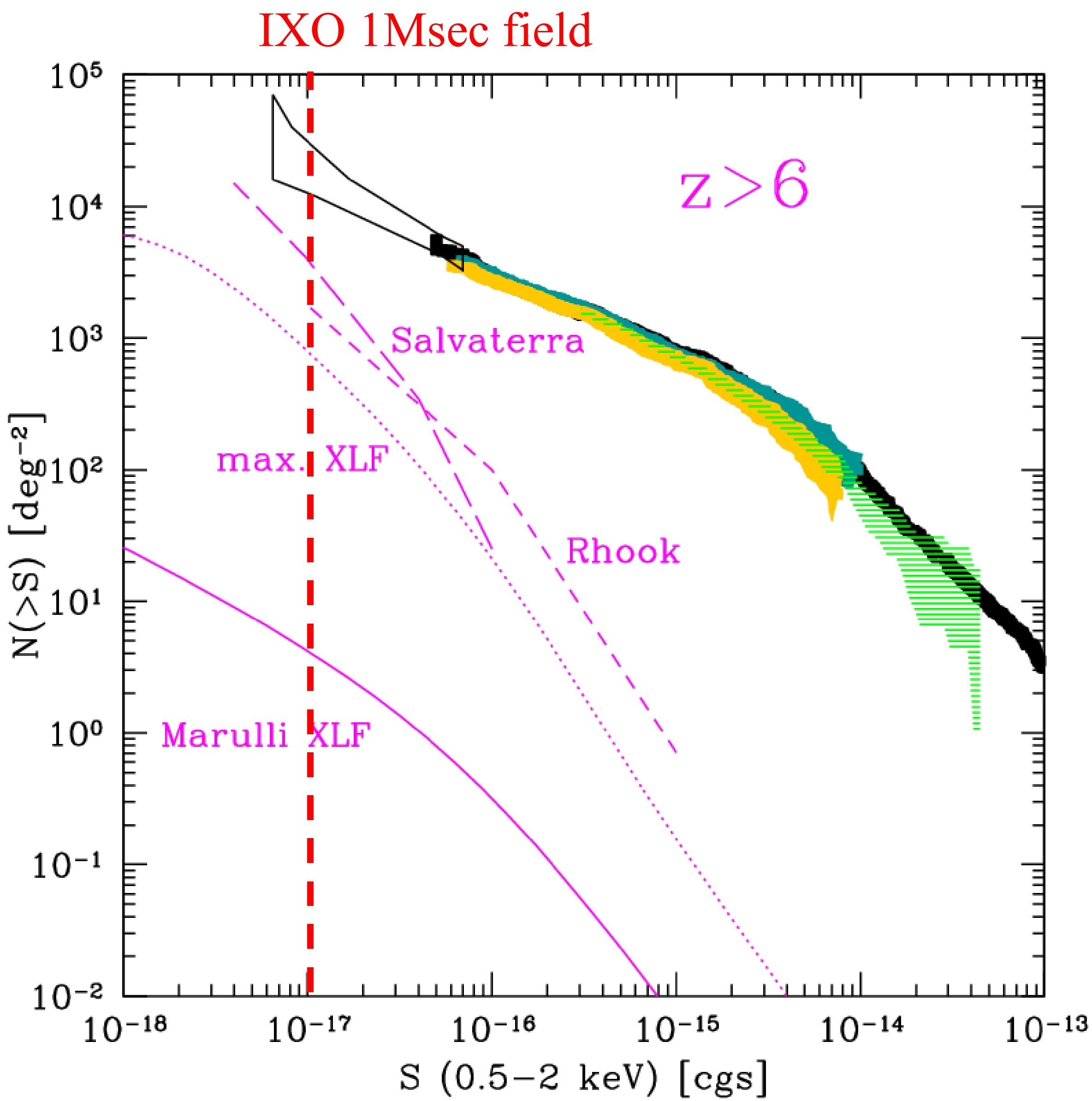
Seyfert galaxies at z=4

**no background assumed in these simulations: depending on the bkg level a 1 Msec obs. of a 10^{-17} cgs source might provide from a fairly good X-ray spectrum to just a detection

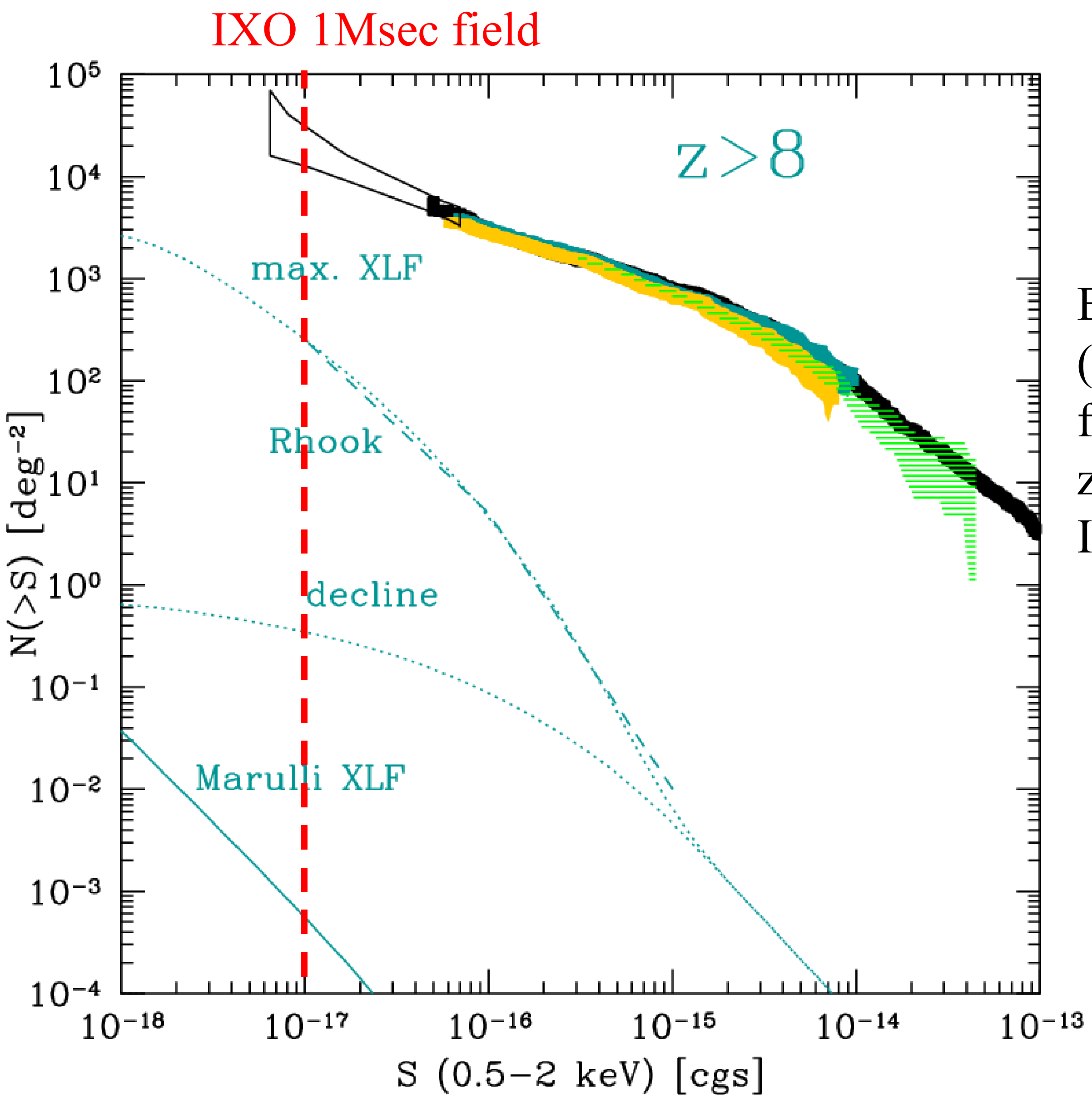


Very wild range of predictions for z>6 AGN: from 0.2 to 160 expected in an IXO Msec field (in absence of vignetting)

Observations of significant samples at z>6 would constrain the physics of early BH formation disentangling between several scenarios e.g. providing info on mass of BH seeds, accretion mechanisms (only mergers or also internal processes, and so on).



Also, it is not straightforward to establish an observing strategy which maximizes the high-z AGN yields: this depends on the logN-logS slope α, which is uncertain. In photon limited regime $N_{tot} \approx S^{1-\alpha}$ then if α>1 the largest number of detections is obtained going deep in a single field (the opposite is true for α<1).



Expectation range (no vignetting): from 6 10^{-5} to 10 z>8 objects per IXO WFI Msec field

Final remarks

- IXO would provide excellent spectra for moderately bright, known, high-z QSOs. X-ray survey missions with large FOV like eROSITA or WFXT (1deg^2 FOV), or other wide field survey instruments like LSST and Pan-STARRS, would provide the ideal database of moderately bright high-z AGN to be followed up by IXO for spectral analysis. However no z=6 XLF from these samples (apart from WFXT).

- If angular resolution is 5” HEW or better, then sensitivity (confusion limit at ~10^{-17} cgs) coupled with the 150 arcmin^2 FOV or larger, might allow IXO to collect z>6 objects in sufficient numbers to build up an XLF and constrain early BH formation and growth.

- IXO appears to be well matched to the sensitivity of other future facilities like JWST and ALMA for observing high-z objects.