

Limits on the high redshift growth of massive black holes

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The Cosmic X ray background: what's left unresolved 50 years since the discovery.

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ABSTRACT

Aims. We study the spectral properties of the unresolved cosmic X-ray background (CXRB) in the 1.5-7.0 keV energy band with the aim of providing an observational constraint on the statistical properties of those sources which are too faint to be individually probed.

Methods. We make use of the Swift X-ray observation of the Chandra Deep Field South complemented by the Chandra data. Exploiting the lowest instrument background (Swift) together with the deepest observation ever performed (Chandra) we measure the unresolved emission at the deepest level and

Results. We find that the unresolved CXRB emis

and a flux of $5^{+3.2}_{-2.6} \times 10^{-12}$ erg s⁻¹ cm⁻² deg⁻² in t

we significantly improved the accuracy with resp

Conclusions. This spectrum is not completely ex

significant, hard component uncovered. This dis

AGN population from local Universe towards hig

A&A in press

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ABSTRACT

We place firm upper limits on the global accretion history of massive black holes at $z \gtrsim 5$ from the recently measured unresolved fraction of the cosmic X-ray background. The maximum allowed unresolved intensity observed at 1.5 keV implies a maximum accreted mass density onto massive black holes $\rho_{\text{acc}} \lesssim 1.4 \times 10^4 M_{\odot} \text{Mpc}^{-3}$ for $z \gtrsim 5$. Considering the contribution of lower- z AGNs the value reduces to $\rho_{\text{acc}} \lesssim 0.66 \times 10^4 M_{\odot} \text{Mpc}^{-3}$. The tension between the need of efficient and rapid accretion required by the observation of massive black holes already in place at $z \gtrsim 7$ and the strict upper limit on the accreted mass derived from the X-ray background may indicate that black holes are rare in high redshift galaxies, or that accretion is efficient only for black holes hosted in rare galaxies.

Key words. cosmology: observations – X-ray: diffuse background – galaxies: active

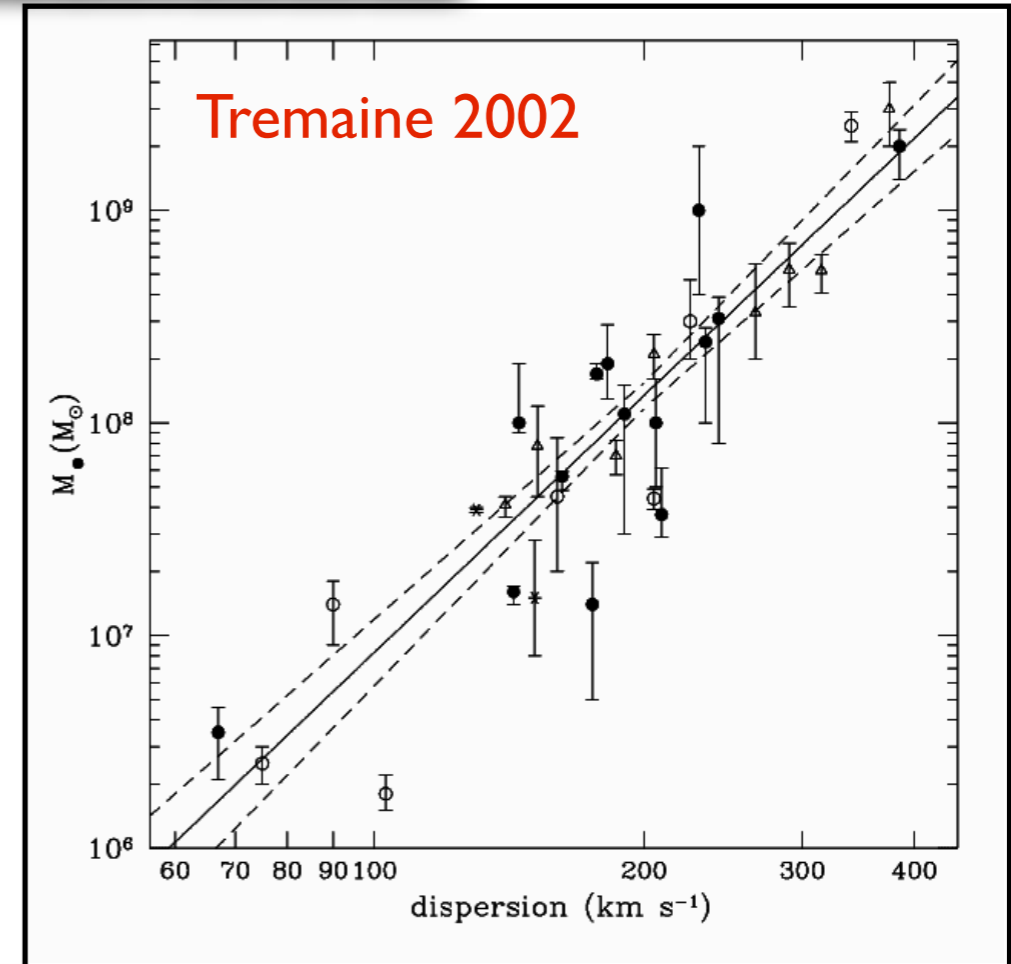
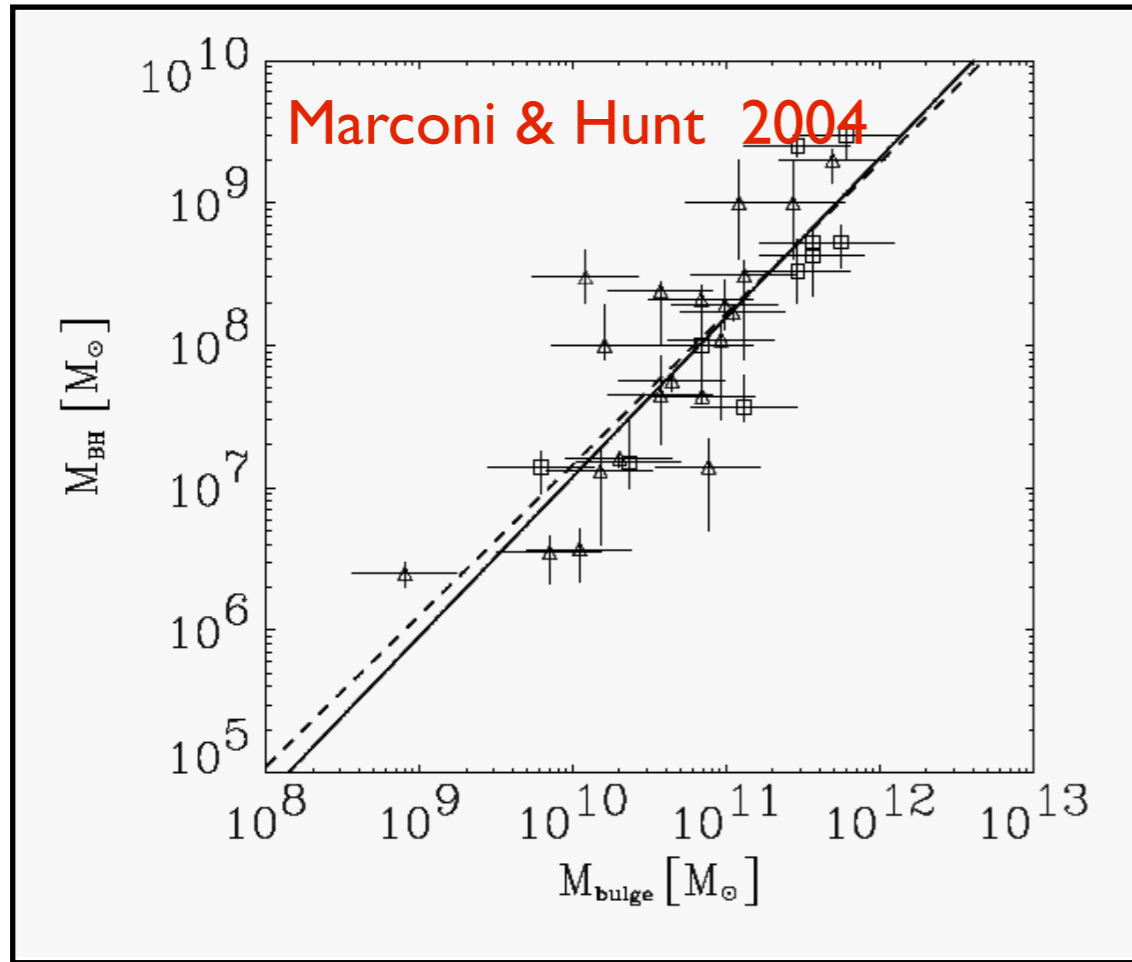
2012, A&A, 545, L6

Understanding the formation and growth of MBHs along the Cosmic history.

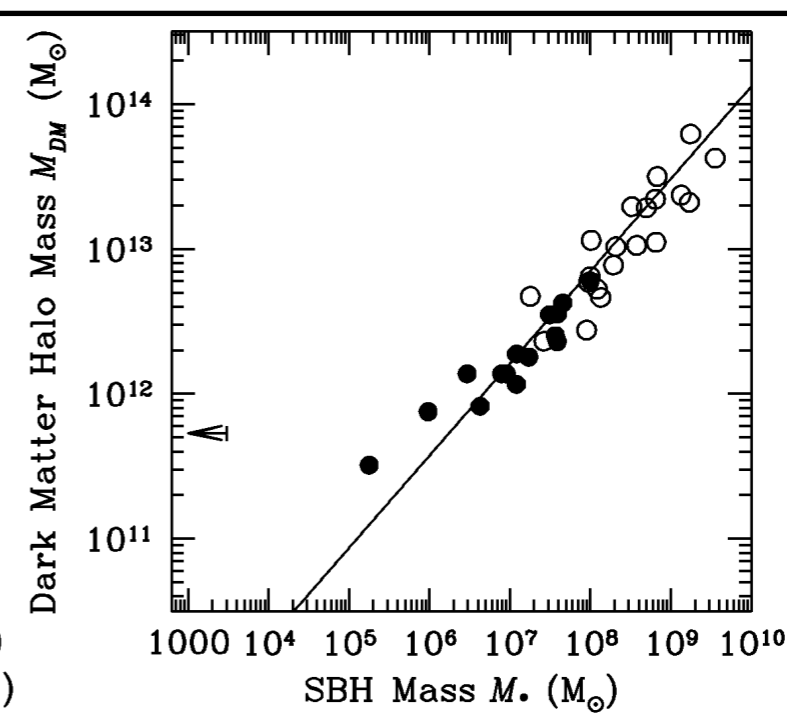
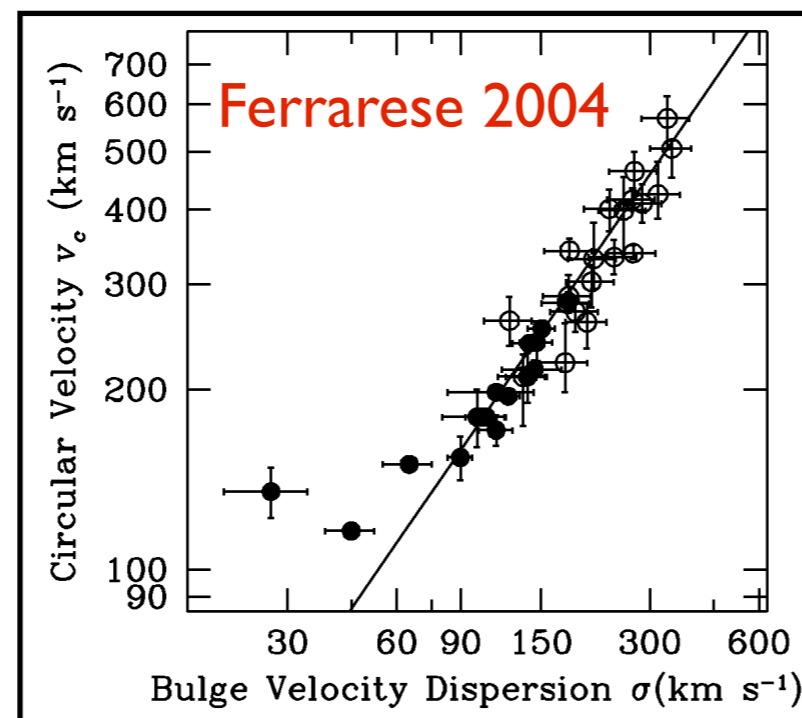
1. How fast can MBHs grow to 10^9 - $10^{10} M_{\text{sun}}$?
2. How many of them along the Cosmic history?

We need to understand the physics of black hole *and* galaxy mergers.

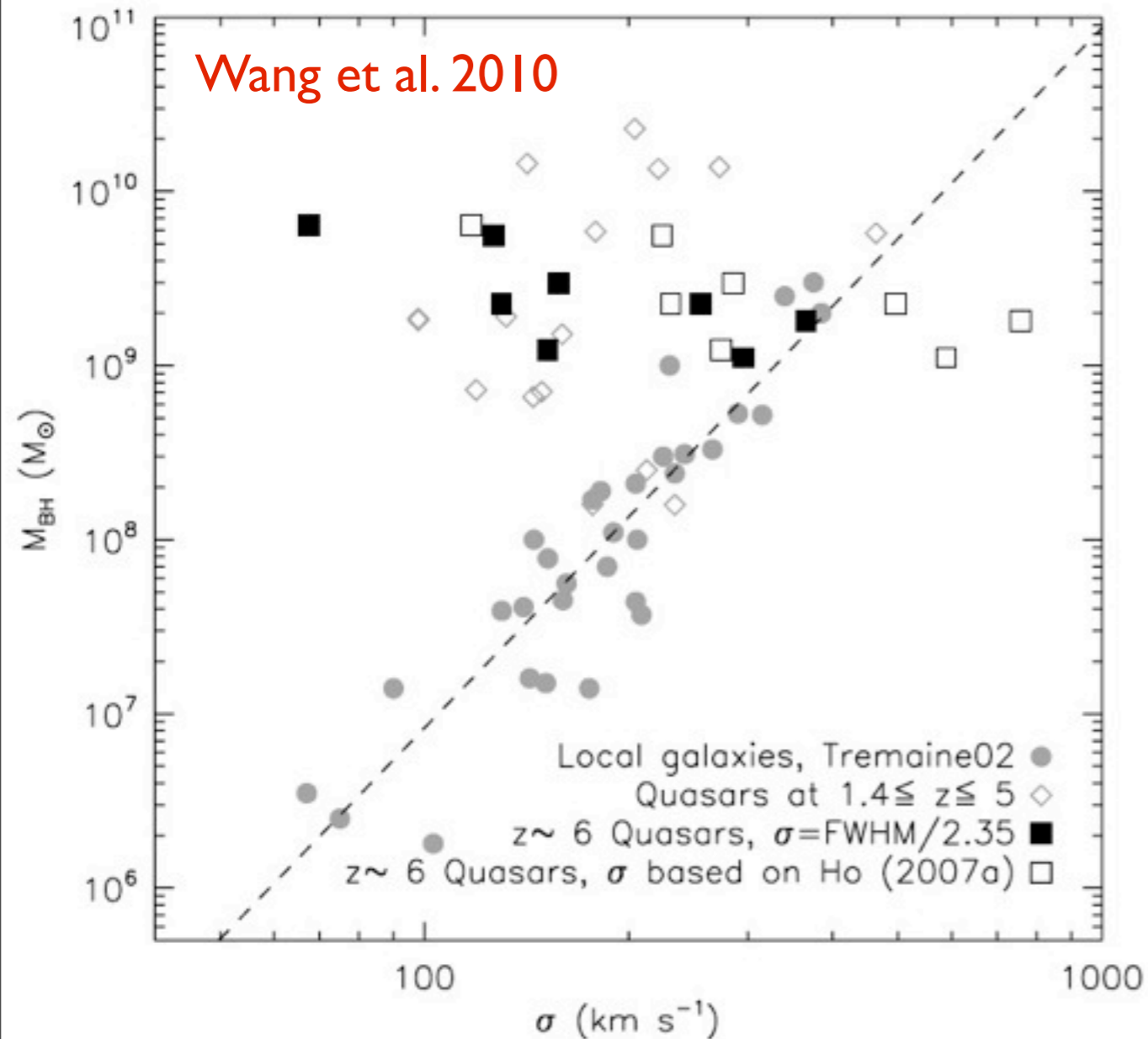
Co-evolution of SMBHs and host galaxies



**LOCAL
SCALING
RELATIONS**



High- z SMBHs



1. There seems to be little or no correlation between mass and velocity dispersion (Wang et al. 2010).

2. Typically black holes are 'over massive' at fixed mass/velocity dispersion compared to $z=0$ counterparts (e.g. Walter et al 2004; Decarli et al. 2010; Merloni 2010).

3. Studies suggest that either many massive galaxies do not have MBHs or these BH are less massive than expected (Willott et al. 2010).

When do you make the first SMBHs?

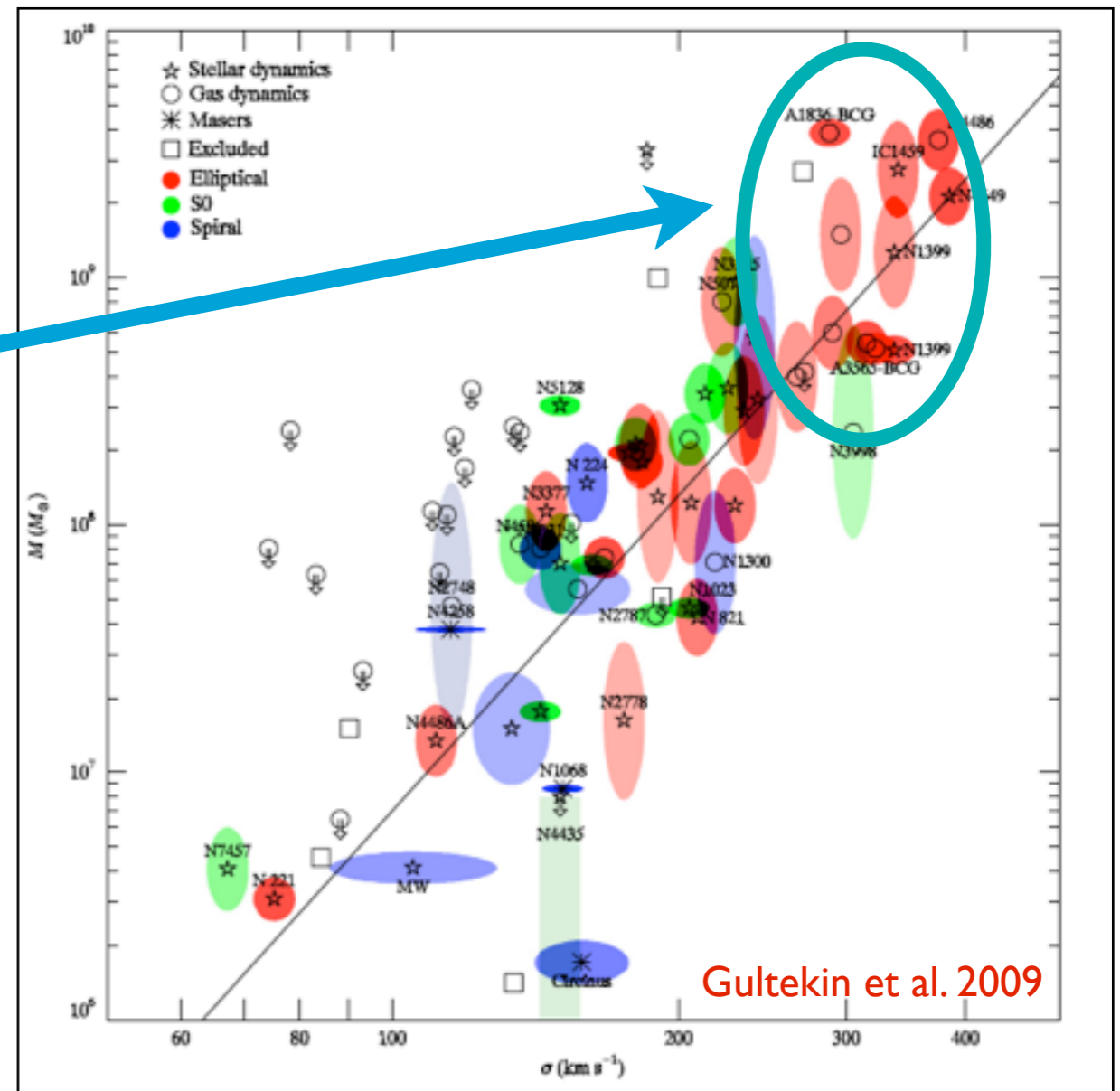
The highest redshift QSO currently known

ULASJ12010641

at $z=7.1$ has an estimated SMBH mass

$$M_{\text{BH}} \sim 2 \times 10^9 M_{\text{sun}} \quad (\text{Mortlock et al. 2011})$$

As massive as the largest SMBHs today, but when the Universe was only 0.75 Gyrs old



How can you make a (S)MBH @ $z=10-30$?

POPIII remnants:

$M_{\text{BH}} \sim 100-600 M_{\text{sun}}$
 $z > 20$

(Abel, Bromm, Fryer, Wosley, Heger, et al.)

Direct Collapse:

$M_{\text{BH}} \sim 10^4-10^6 M_{\text{sun}}$
 $10 < z < 15$

Viscous transport+supermassive star
Efficient viscous angular momentum
transport.

Molecular cooling.

(Haenelt, Rees, Loeb, Bromm, Koushiappas, et al.)

Bar-unstable self-gravitating gas+large
“quasistar”.

Atomic cooling.

(Begelman, Rees, Volonteri)

Accretion time needed by a BH to reach a given final mass:

$$t_{\text{acc}} = 0.45 \text{ Gyr} \frac{\epsilon}{1 - \epsilon} f_{\text{Edd}}^{-1} \ln(M_{\text{fin}}/M_{\text{in}})$$

$$M_{\text{fin}} = 10^9 M_{\text{sun}}$$

$$M_{\text{in}} = 10^2 M_{\text{sun}} \quad (10^5 M_{\text{sun}})$$

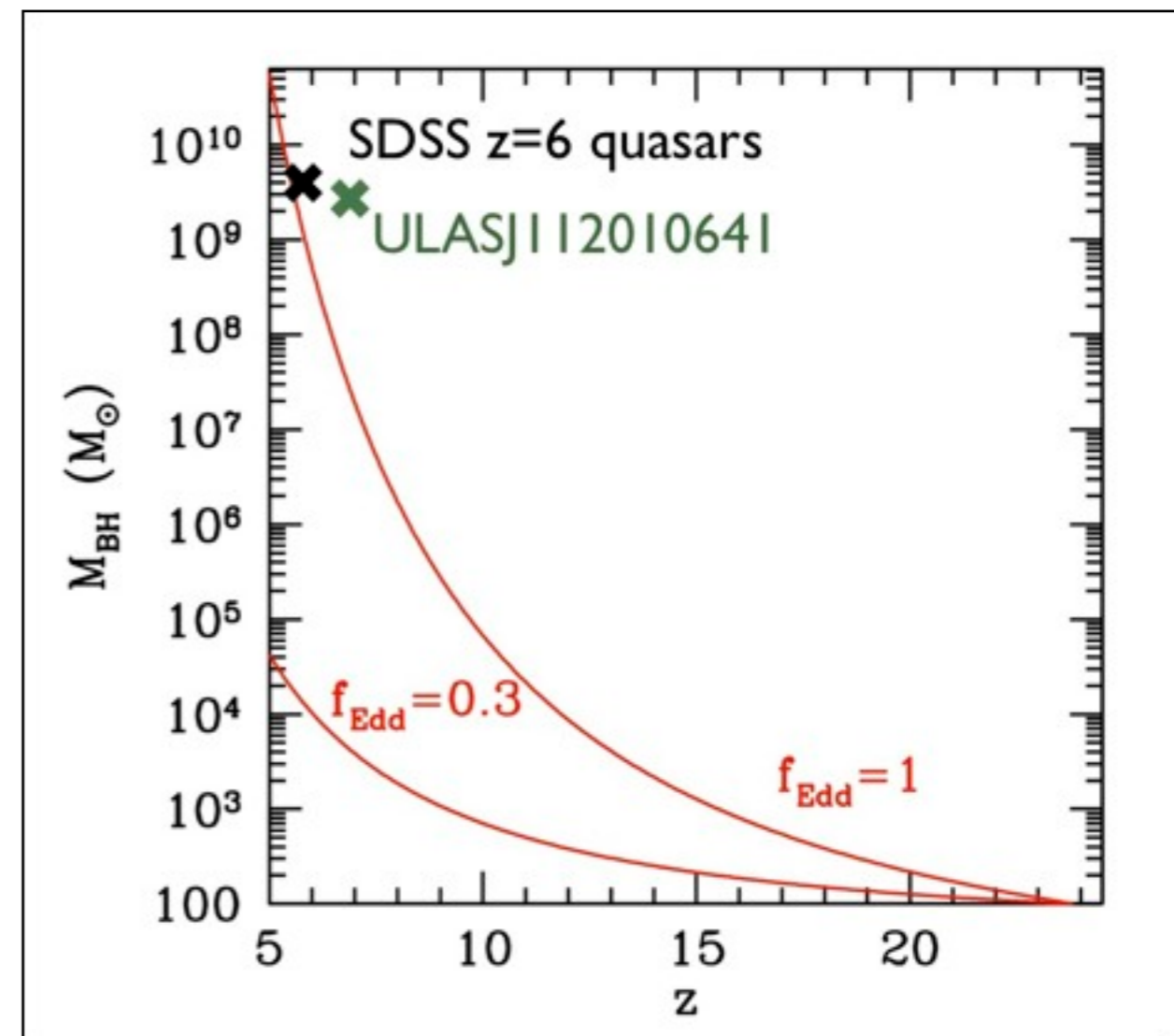
$$f_{\text{Edd}} = 1$$

$$\epsilon = 0.1$$

$$\Rightarrow t_{\text{acc}} = 0.8 \text{ Gyrs} \quad (0.45 \text{ Gyrs})$$

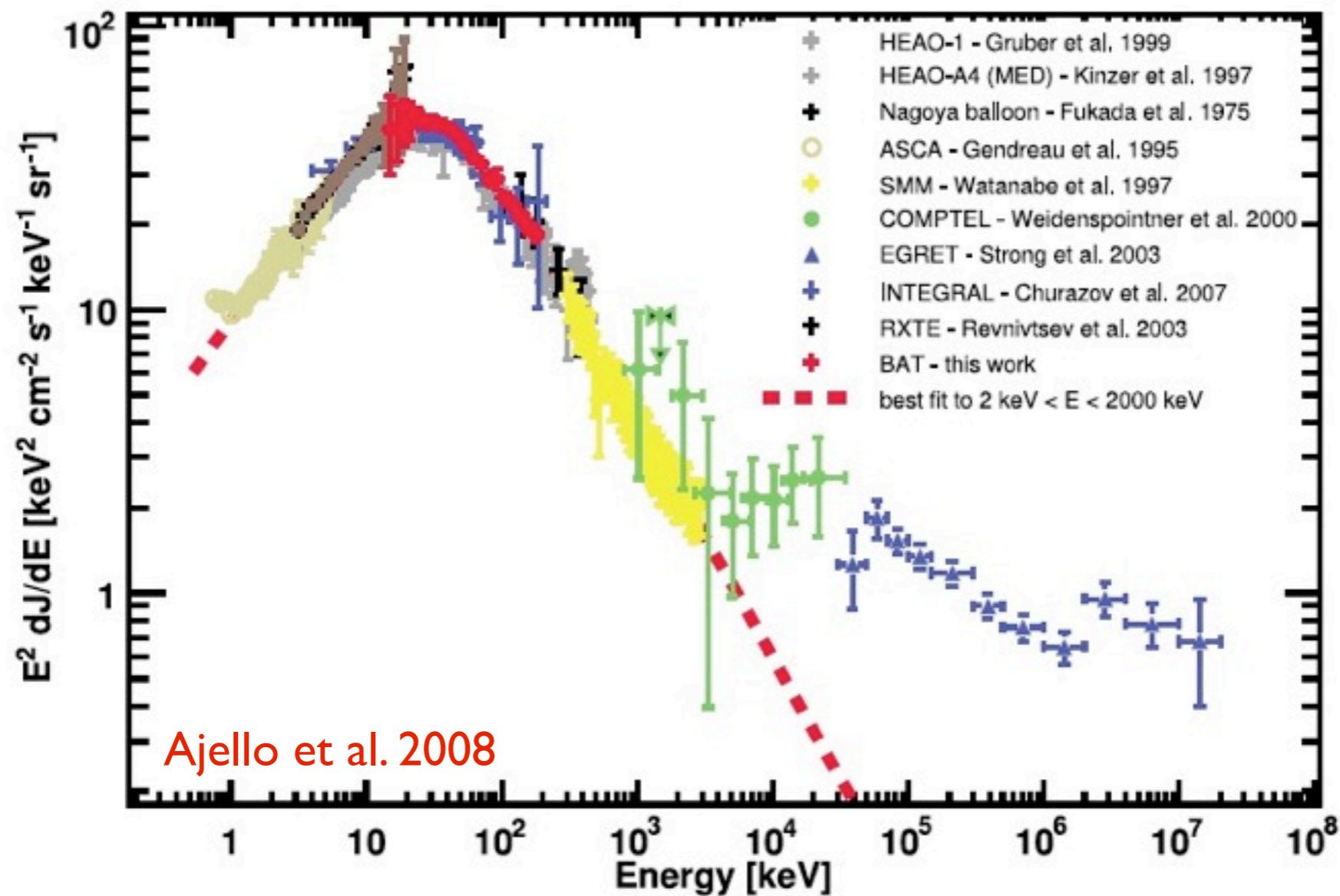
$$t_{\text{H}}(z=7) = 0.75 \text{ Gyrs}$$

$$t_{\text{H}}(z=6) = 0.9 \text{ Gyrs}$$



Aim: understanding the nature of the high- z MBH population.

Method: measuring the unresolved fraction of the Cosmic X-ray background (CXRB).



Facts:

Chandra deep observations resolved 80-90% of the CXRB in the [0.5-8] keV band.

CXRB sources are mostly AGNs, with some contribution at $E < 2$ keV from clusters and starbursts galaxies.

Most of the signal comes from $z < 2$, only 1% produced at $z > 4$. This is what we are interested in.

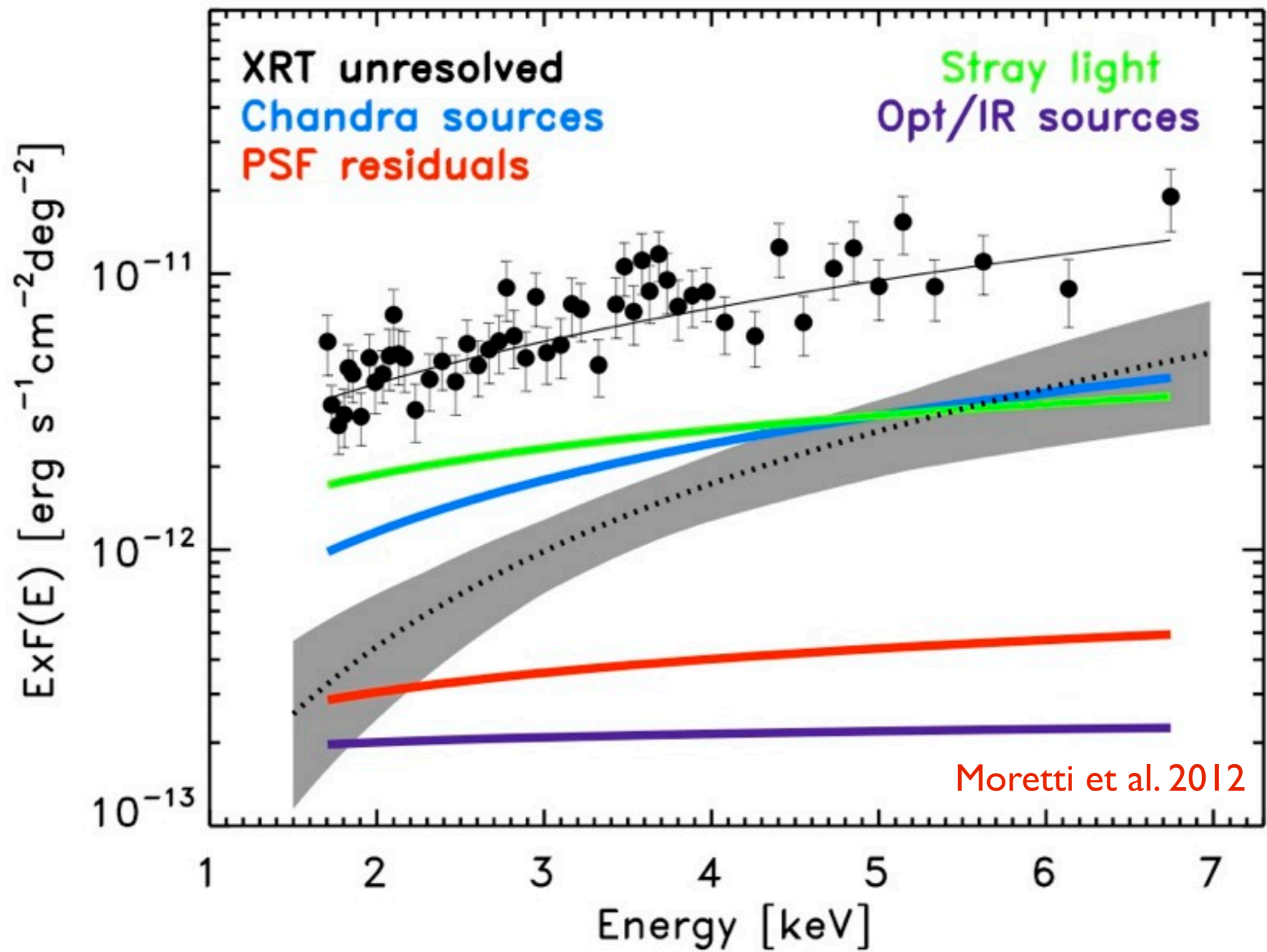
(Moretti et al. 2012, Xue et al. 2011, Lehmer et al. 2012, etc.)

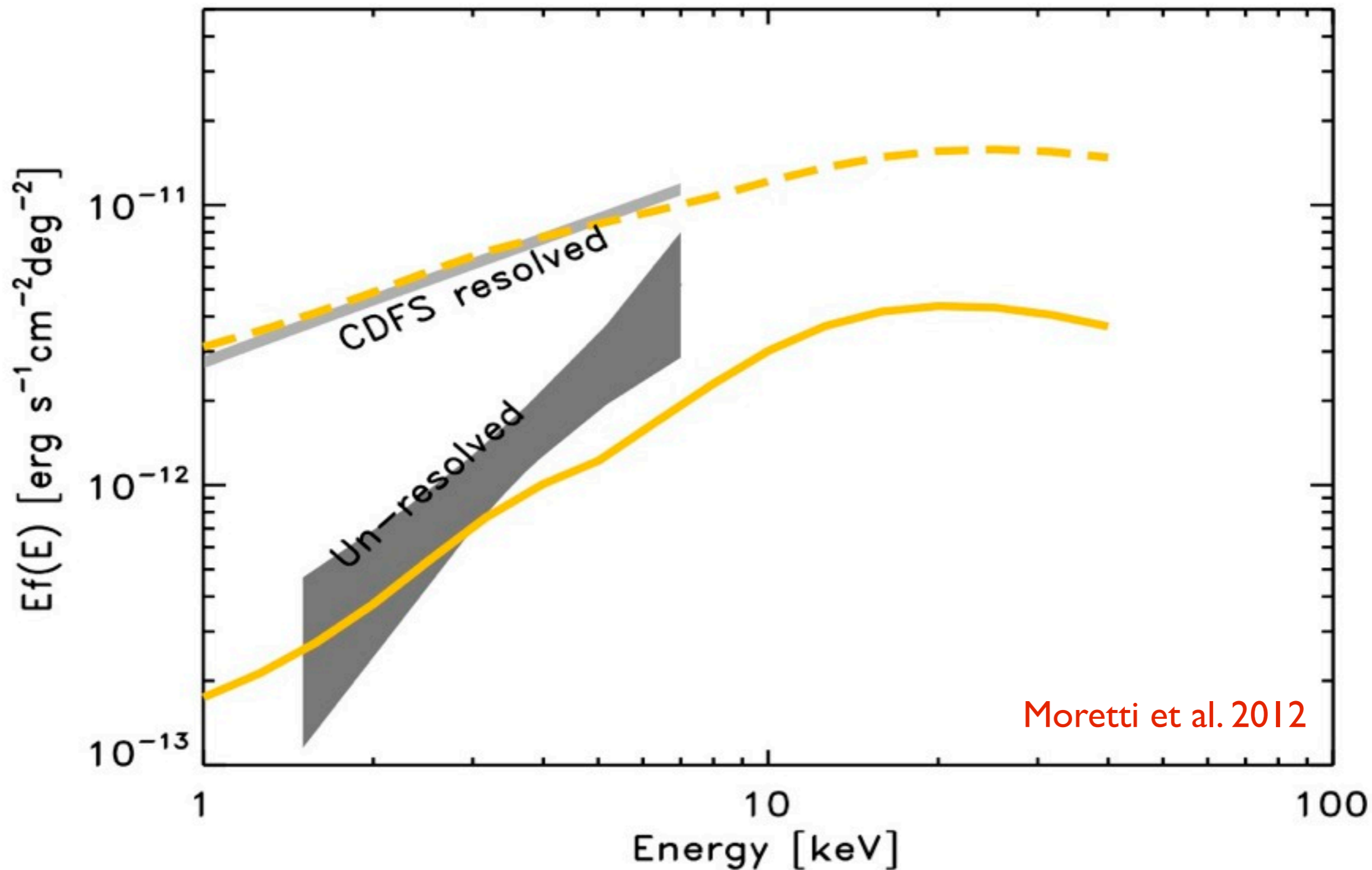
Strategy:

Directly measure the unresolved CXRB in the Swift observation of the CDF-S, subtracting the Chandra sources. This exploits the low instrumental noise of the Swift XRT, *and* the depth of the Chandra observation.

Details in Moretti et al. 2012.

Results: PL with flux $E_{1.5}J_{1.5}=0.23 \times 10^{-12}$ erg/s/cm²/deg²
photon index $\Gamma=0$





Unresolved and resolved CXRB compared to Gilli et al. 2007 AGN population models: possible indication of missing low- z Compton thick sources.

Soltan (1982) translated the observed emission of AGNs integrated along the cosmic history into mass accreted onto the SMBH population.

As no X-ray sources are resolved at $z > 5$, by assuming that the unresolved CXRB stems from AGNs at such high redshifts, gives a *strict upper limit* on the mass accreted then.

$$\rho_{\text{acc}}(\bar{z}) = \frac{(1 - \epsilon)}{\epsilon c^2} \int_{\bar{z}}^{\infty} dz \frac{dt}{dz} \int_0^{\infty} dE j(E, z)$$

Accreted mass density

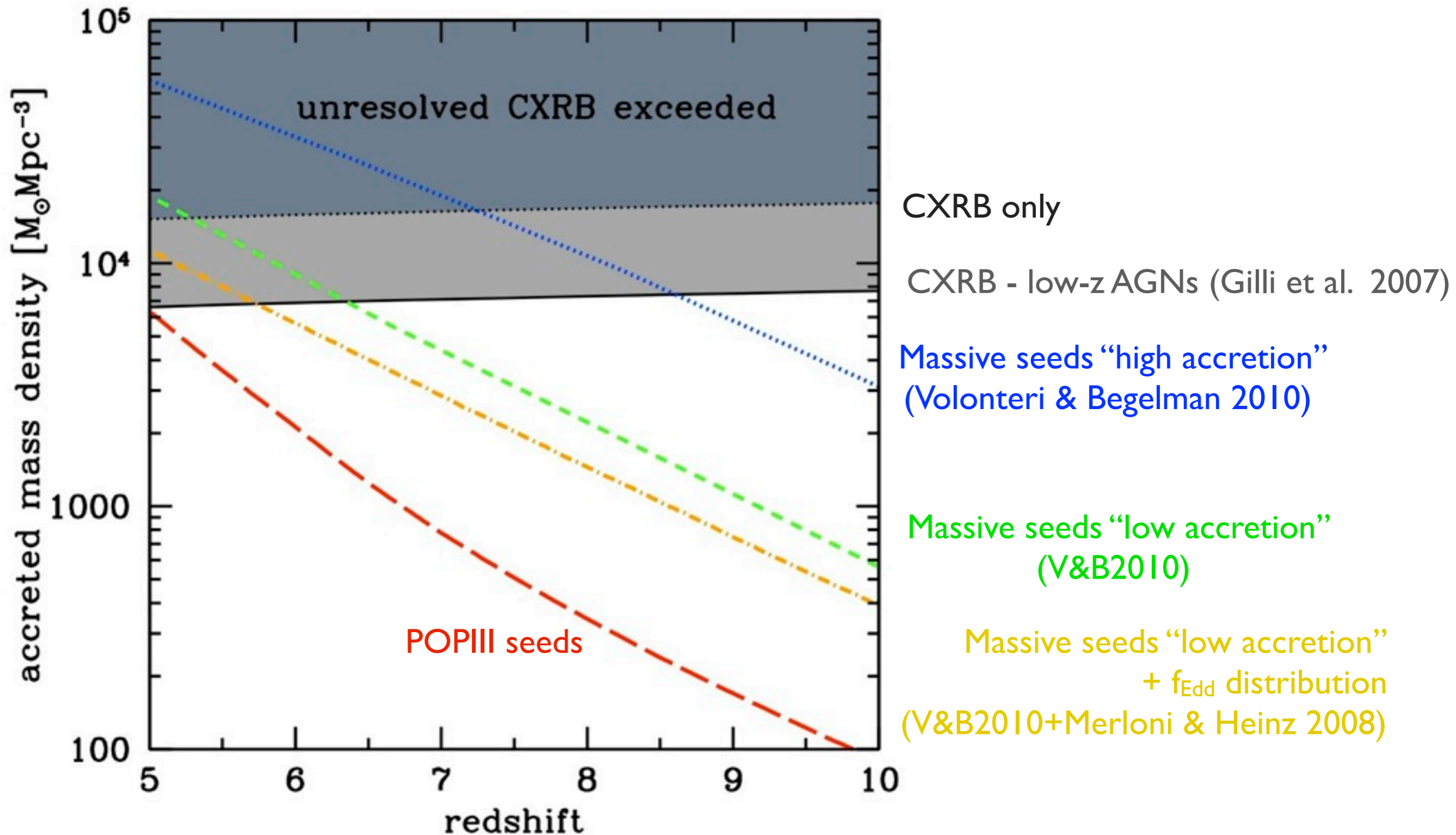
$$j(E, z) = j_{\star} \left(\frac{E}{E_{\star}} \right)^{-\alpha} f(z)$$

AGN's X-ray emissivity

$$J_{E_0} = \frac{1}{4\pi} \int_{\bar{z}}^{\infty} dz \frac{dl}{dz} j(E, z)$$

Normalize it to the observed CXRB due to high-z sources

$$\rho_{\text{acc}}(z) = 3.4 \times 10^4 \left(\frac{E_{1.5} J_{1.5}}{10^{-12}} \right) \left(\frac{0.04}{f_X} \right) \left(\frac{1+z}{7} \right)^{0.25} M_{\odot} \text{Mpc}^{-3}$$



Stricter upper limits on ρ_{acc} @ $z=6.5$ from stacking analysis of X-ray emission of *i*-dropouts. No emission found, translates into $\rho_{\text{acc}} < 0.4 \times 10^4 M_{\text{sun}}/\text{Mpc}^3$ (Willott 2011, Fiore et al. 2012, Cowie et al. 2012...).

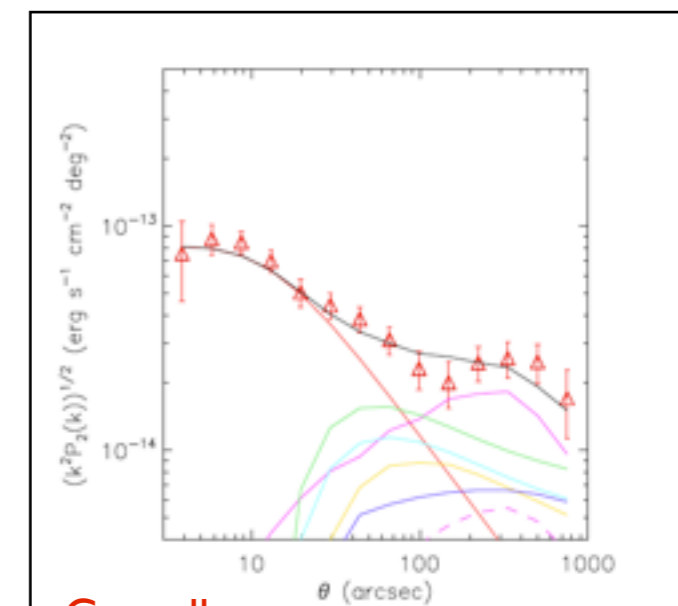
Note: our different methodology is free from biases due to incompleteness and dust correction of the dropout sample, does not implicitly introduce a lower limit in the BH mass probed, and is (almost) independent on any assumption on the high- z evolution of sources.

The background intensity directly measures the time-integrated accreted mass.

Issues: Are we missing something? Objects at $z > 5$ rarer than 10^{-6} Mpc^{-3} are not in the CDF-S. If all such objects accreted up to $10^8 M_{\text{sun}}$, ρ_{acc} would be much lower than our limit. Tension with models increased further.

Is the unresolved CXRB due to heavily obscured high- z AGNs? Not quite, the spectral shape wouldn't fit.

The unresolved CXRB most probably due to obscured faint sources at low- z not accounted by, e.g., Gilli et al. synthesis model, plus galaxies plus IGM (Cappelluti et al. 2012 [1208.4105], Xue et al. 2012 [1209.0467]).



Results: MBH growth models predict ρ_{acc} above observational limits. Tension exists between those limits and the need of efficient and rapid accretion required by SMBHs already in place at $z=7$.

Consequences: the obvious consequence is that, on average, high- z MBHs must accrete at low Eddington ratios (<0.3 , as observed in lower- z AGNs), while the most massive SMBHs at very high- z must be (super?) Eddington. Selective Accretion.

Our limit translates into less than one H I -ionizing photon per baryon produced by accreting MBHs at $z=6$. IGM reionization most probably driven by stellar-like sources.