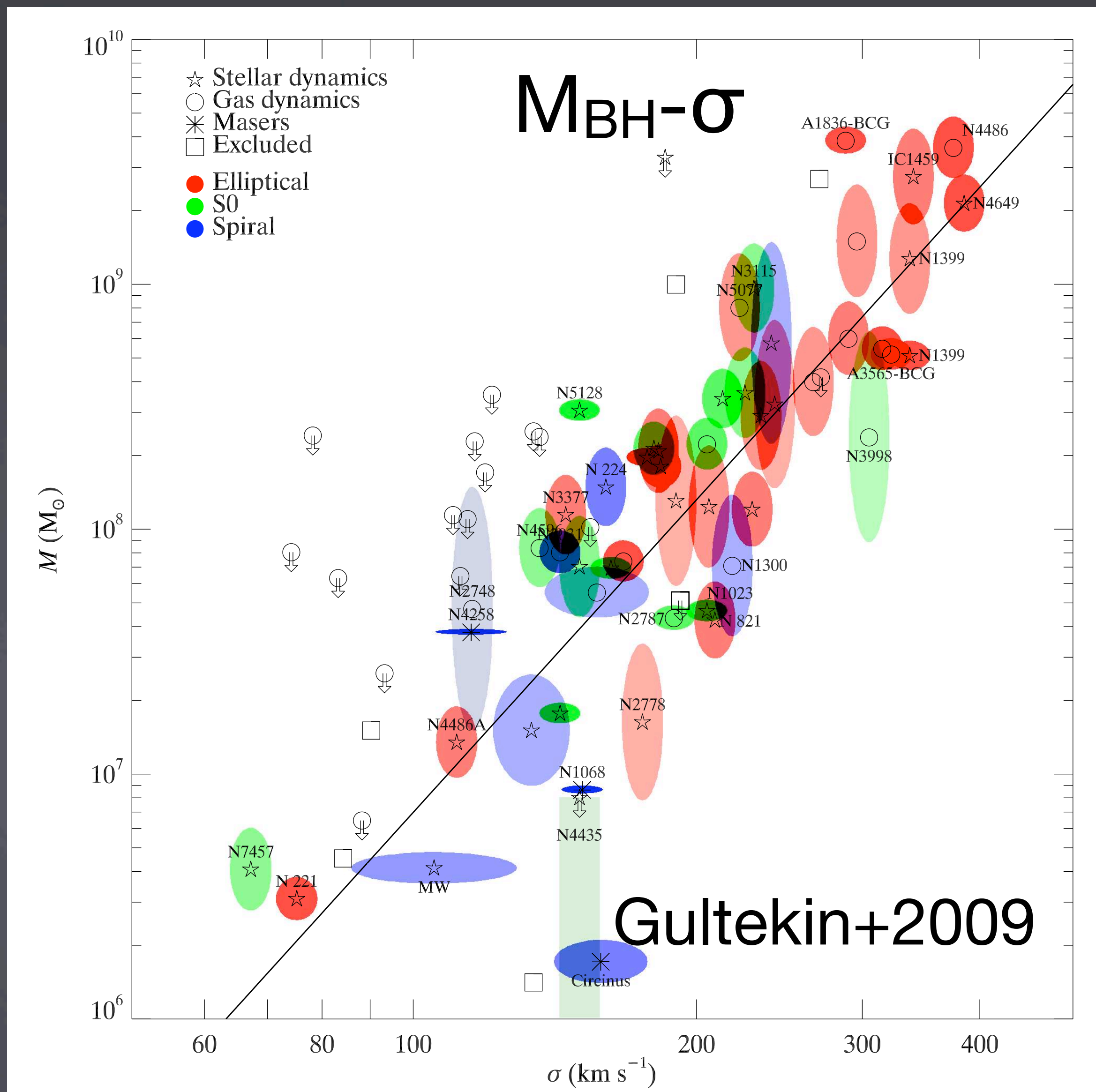
Cosmological Evolution of Supermassive Black Holes

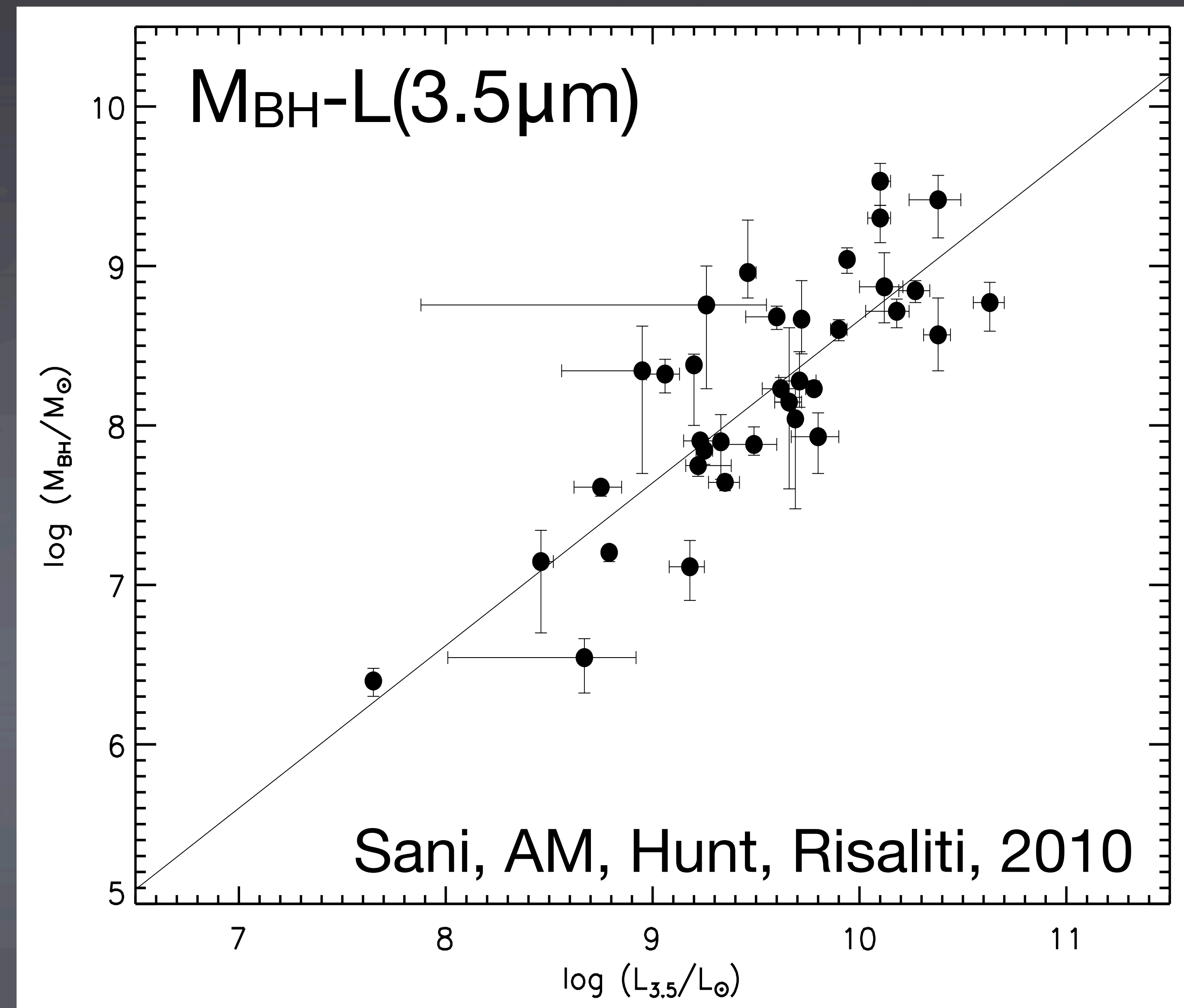
Alessandro Marconi

Dipartimento di Fisica e Astronomia
Università di Firenze

Andrea Comastri
Roberto Gilli
Roberto Maiolino
Guido Risaliti
Marco Salvati
Mauro Sirigu

BH vs host galaxy (spheroid): M_{BH} - σ, L





- Coevolution of supermassive BHs and their host galaxies;
- Link BH-galaxy is (?) provided by AGN feedback;
- Cosmological evolution of BHs important to understand galaxy evolution.

Kormendy & Richstone 1995; Magorrian+1998; Ferrarese & Merritt 2000, Gebhardt+2000; Graham+2001; Tremaine +2002; Marconi & Hunt 2003; Haring & Rix 2004; Aller & Richstone 2007; Graham 2008

Local BHs vs relics of AGN activity

Galaxy L or σ functions
@ z=0

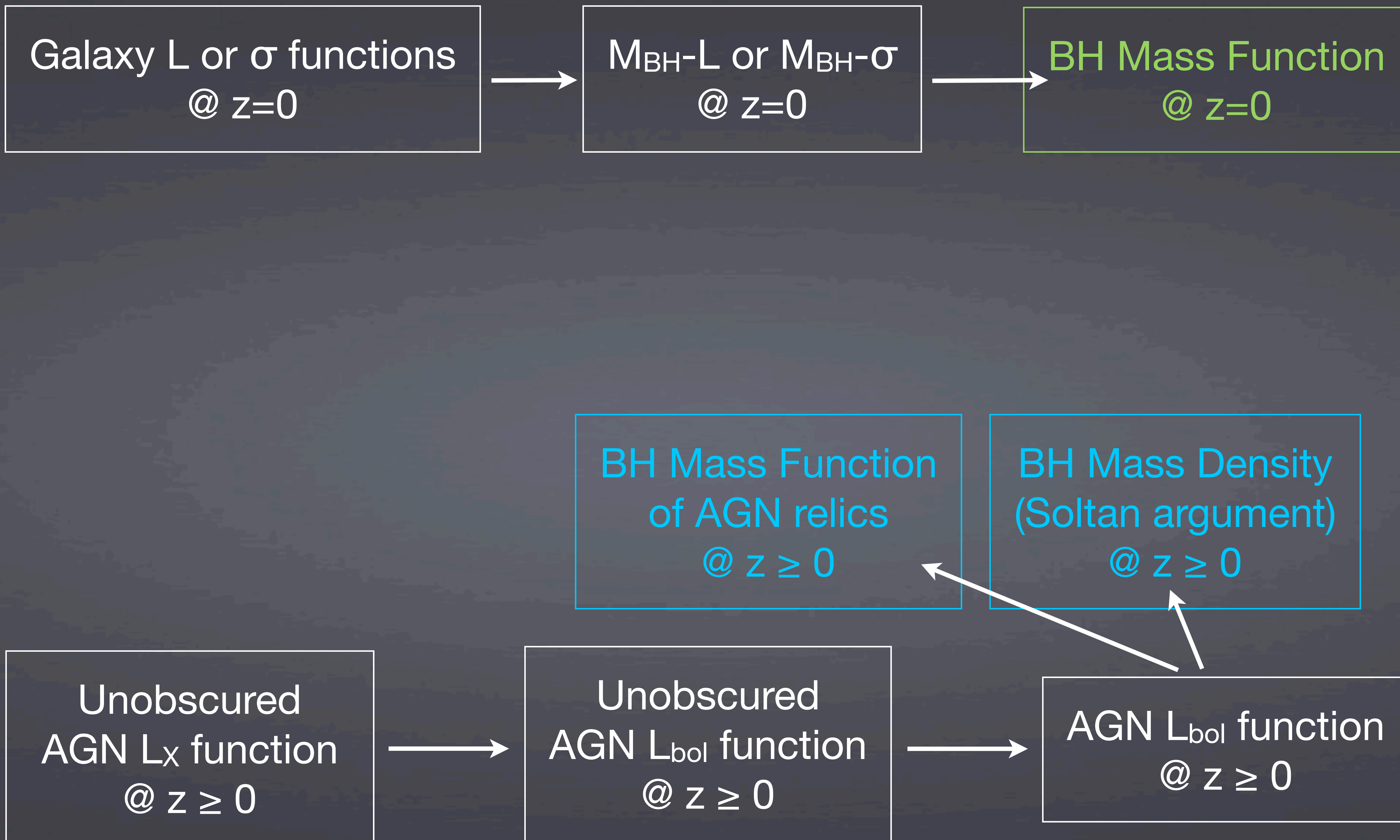
→

M_{BH}-L or M_{BH}-σ
@ z=0

→

BH Mass Function
@ z=0

Local BHs vs relics of AGN activity



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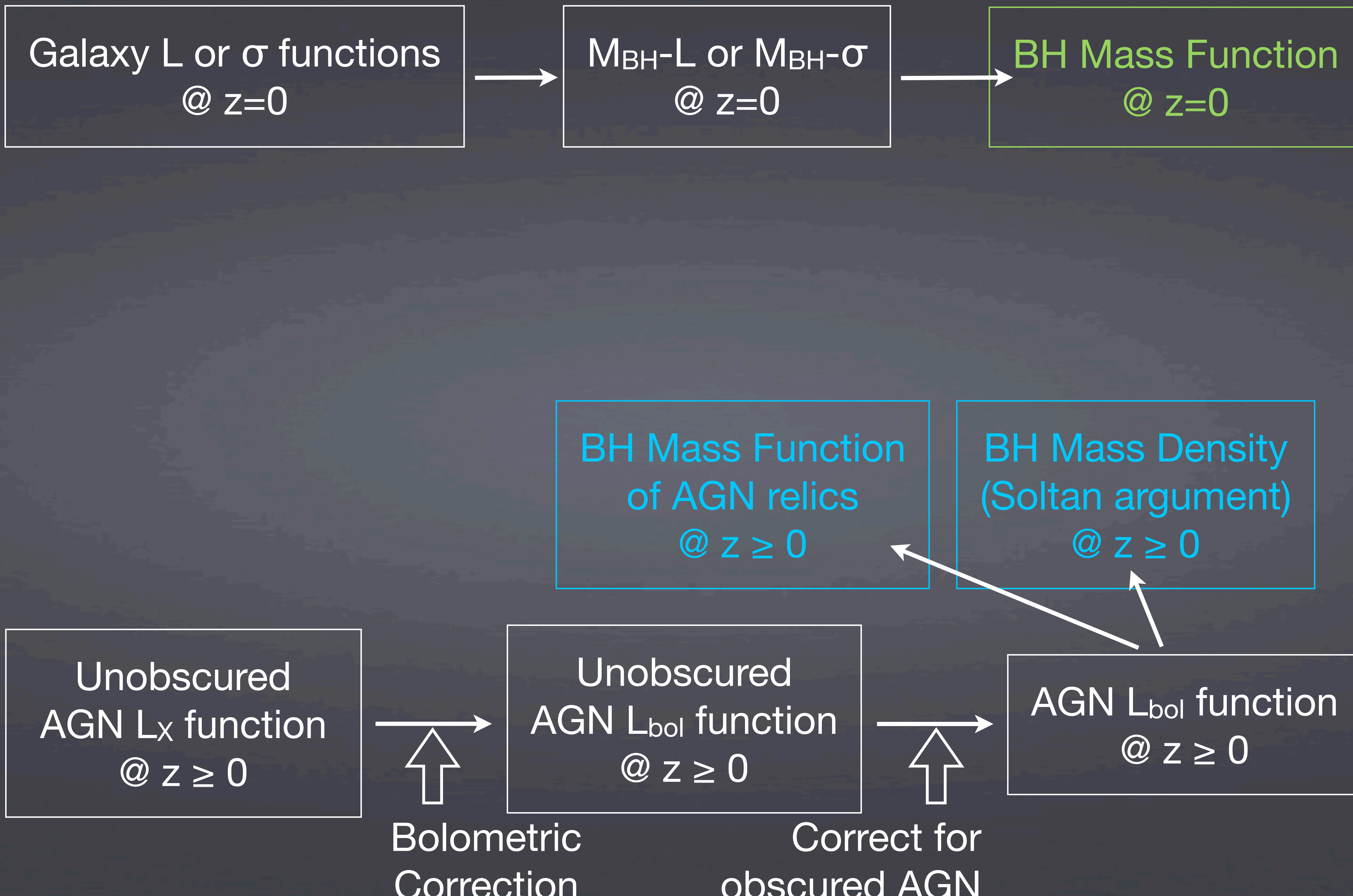

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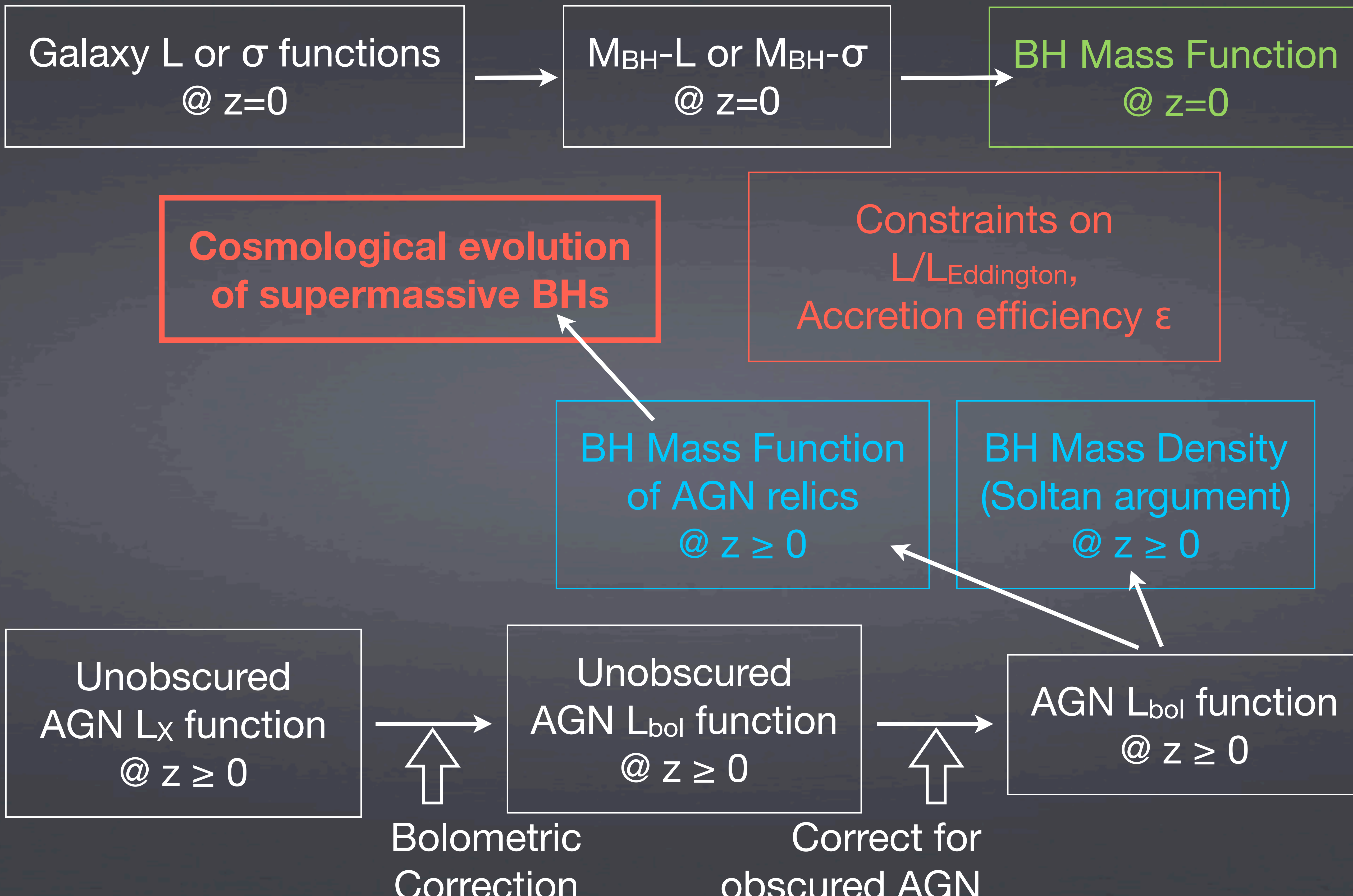

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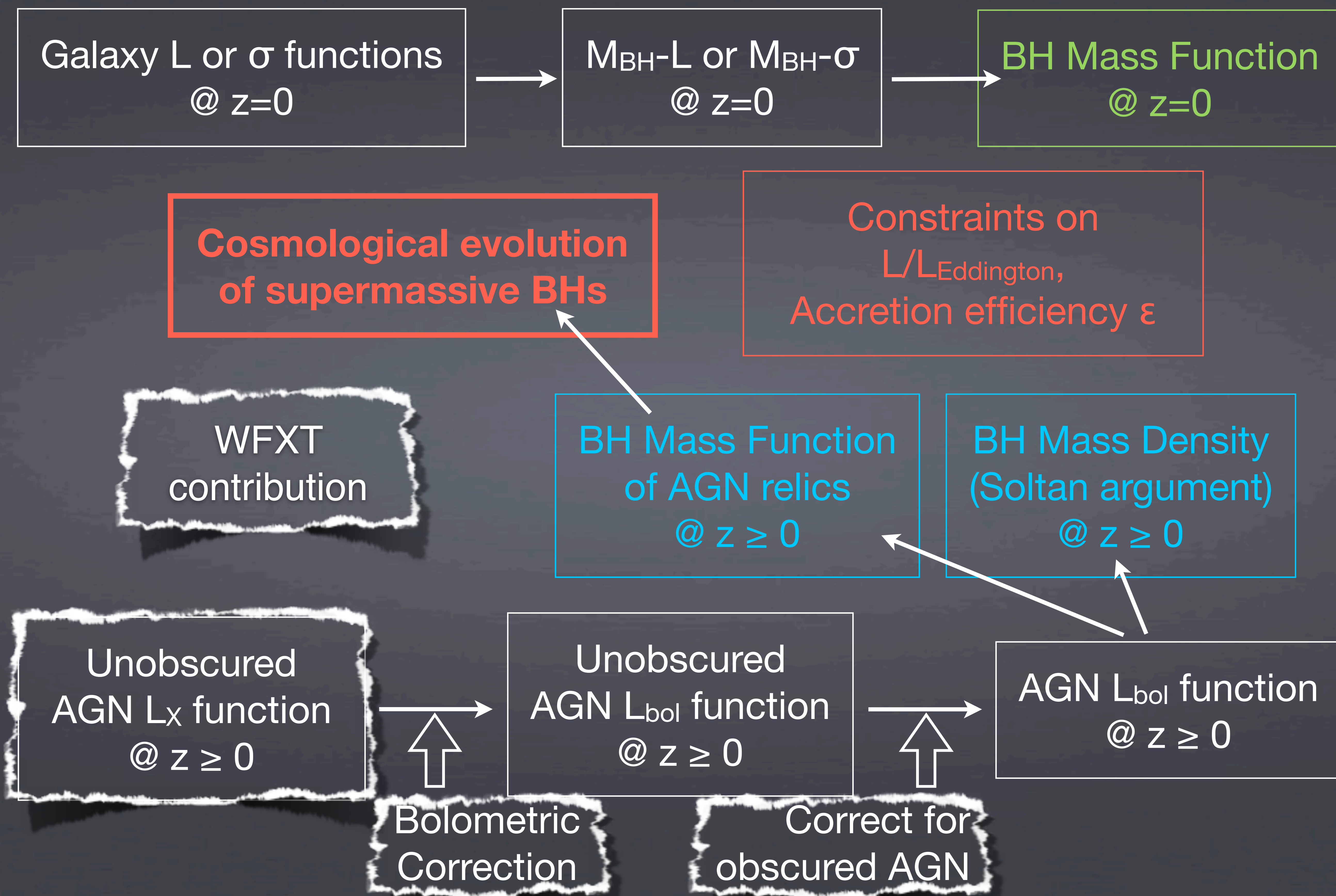
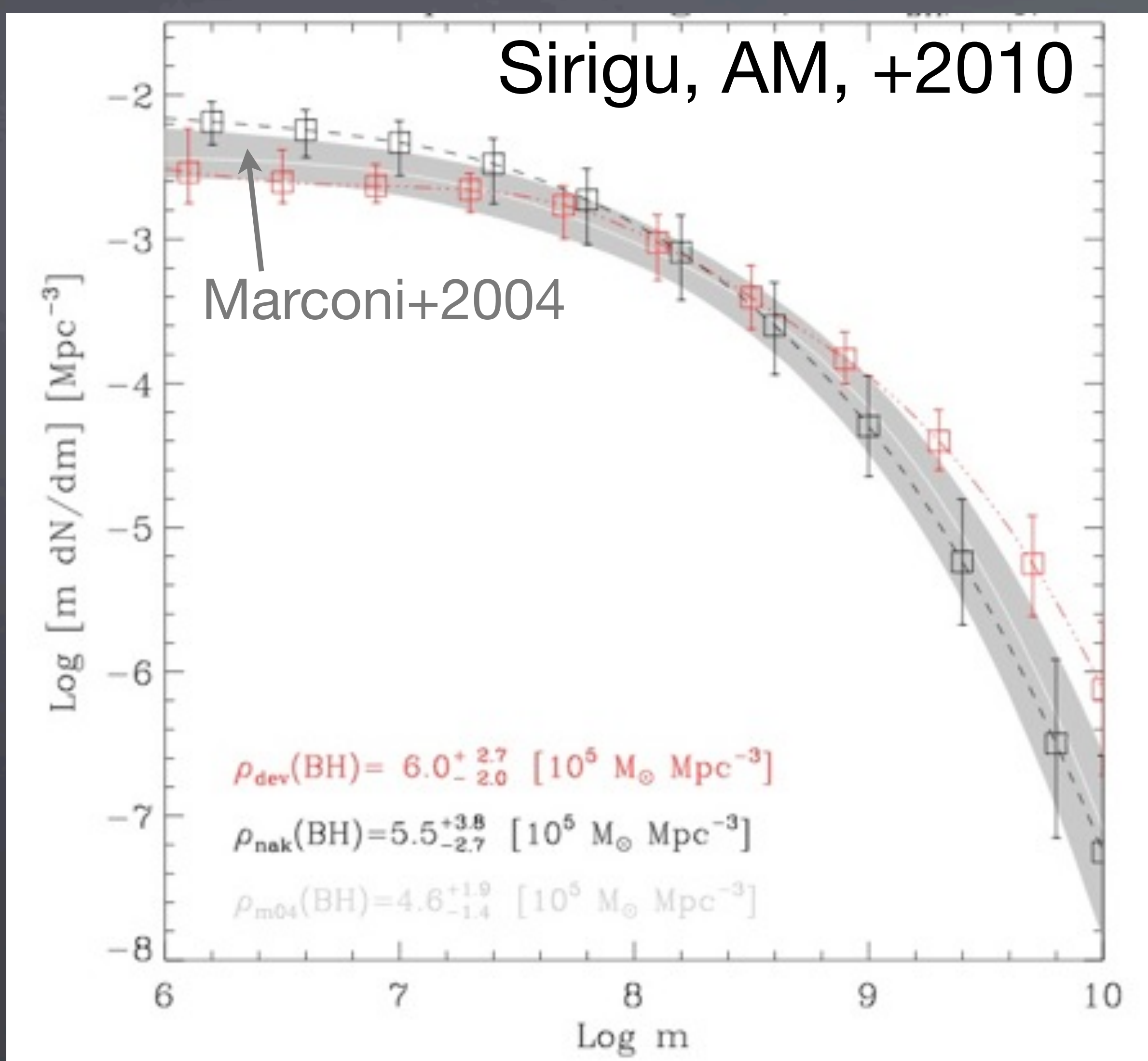


Demography of local BHs

$\left[\begin{array}{c}\phi(L_{Sph}) \\ \phi(\sigma) \\ \phi(M_{Sph})\end{array}\right]$ convolved with $\left[\begin{array}{c}M_{BH}\text{-}L_{Sph} \\ M_{BH}\text{-}\sigma \\ M_{BH}\text{-}M_{Sph}\end{array}\right]$ → $\phi(M_{BH})$ Mass Function of local BHs

$$\phi(M_{\rm BH}) = \int_0^{+\infty} P(M_{\rm BH}|L_{\rm sph})\phi(L_{\rm sph})dL_{\rm sph}$$



Overall there is a general agreement (or not so large disagreement) among estimates from different authors (with exceptions).

The integrated BH mass density is

$\rho_{BH} \simeq 3 - 6 \times 10^5\ M_\odot\ \mathrm{Mpc}^{-3}$

Uncertainties on:

* LF per morphological type;
* average Bulge/Disk ratios
* M_{BH}-L/σ relations

Salucci +99, Yu & Tremaine 02, Marconi +04, Shankar +04, Tundo +07, Hopkins +07, Graham +07,Shankar +08 et many al.

The Sołtan argument

Local black holes
$\rho_{BH} \simeq 3\text{-}6 \times 10^5\ M_{\odot}\ \mathrm{Mpc}^{-3}$

From AGN luminosity function derive relics mass density
(assuming $L = \varepsilon \dot{M} c^2$)

$$\rho_{BH} = \frac{1-\varepsilon}{\varepsilon c^2} U_T = \frac{1-\varepsilon}{\varepsilon\, c^2} \int_0^{z_{max}} \int_{L_{min}}^{L_{max}} L\phi(L,z) \frac{dt}{dz}\, d\log L\, dz$$

Accretion efficiency

Total comoving AGN energy density

AGN bolometric luminosity function

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Accretion efficiency (ε)

Total comoving AGN energy density (U_T)

AGN bolometric luminosity function ($\phi(L,z)$)

Original Sołtan Estimate (QSO LFs as of 1982): $\rho_{AGN} \simeq 8 \times 10^4\ M_\odot\ Mpc^{-3}$

Marconi +04: $\rho_{AGN} \simeq 2.2 \times 10^5\ M_\odot\ Mpc^{-3}$ (hard X LF, Ueda +03)

No correction for "obscured" AGNs ... when taken into account:
Marconi +04: $\rho_{AGN} \simeq 3.5 \times 10^5\ M_\odot\ Mpc^{-3}$ ($\varepsilon \simeq 0.1$; hard X LF, Ueda +03)
Shankar +08: $\rho_{AGN} \simeq 4.5 \times 10^5\ M_\odot\ Mpc^{-3}$ ($\varepsilon \simeq 0.07$; hard X LF, Ueda +03)

The “differential” Sołtan argument

Apply continuity equation to BHMF (Cavaliere +71, Small & Bandford 92):

$$\frac{\partial f(M,t)}{\partial t} + \frac{\partial}{\partial M}\left[\langle \dot{M} \rangle f(M,t)\right] = 0$$

Assuming

- no “source” term (no merging of BHs)
- $L = \varepsilon \dot{M} c^2$
- $L = \lambda L_{Edd} = \lambda \frac{Mc^2}{t_E}$

BH Mass Function (AGN relics) AGN Luminosity Function

$$\frac{\partial f(M,t)}{\partial t} + \frac{(1-\varepsilon)\lambda^2 c^2}{\varepsilon t_E^2}\left(\frac{\partial \phi(L,t)}{\partial L}\right) = 0$$

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* single L/L_{Edd} value for all AGN

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* L is total (bolometric) accretion luminosity (usually from L_X after applying bolometric correction)

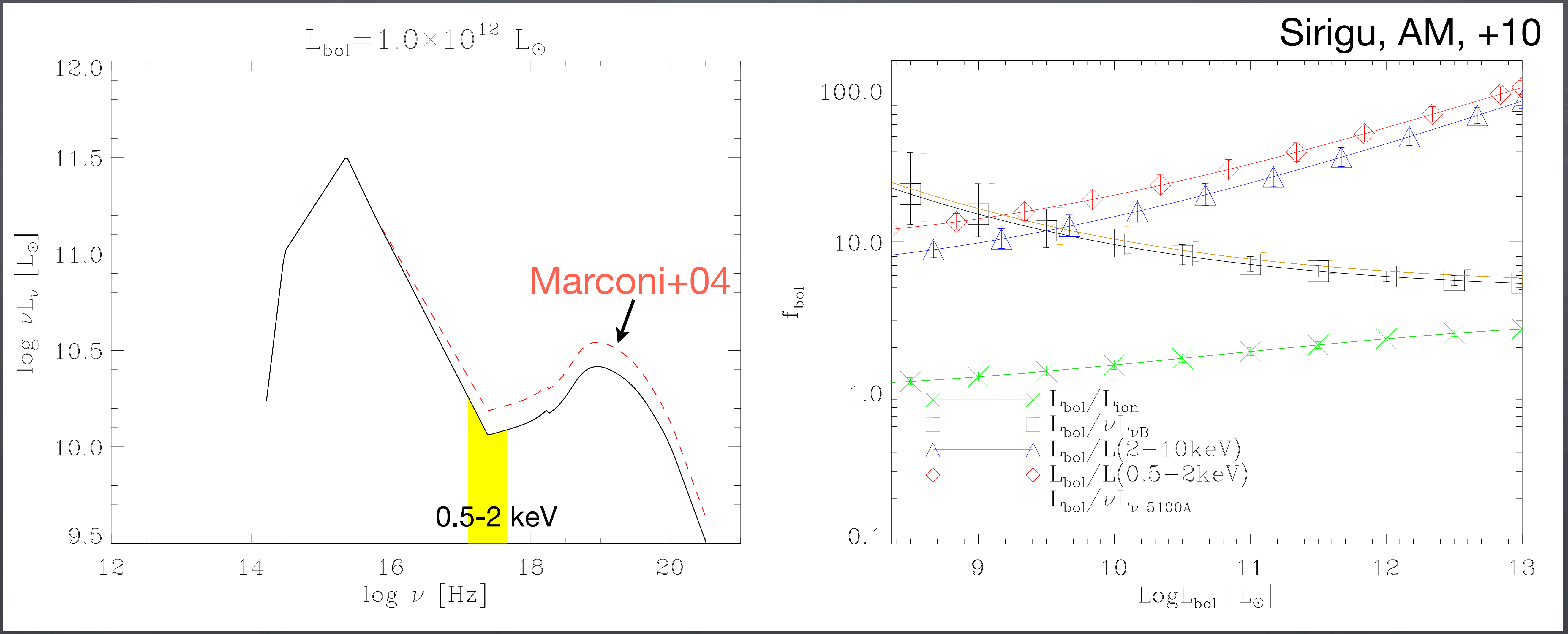
* ϕ(L,t) is the luminosity function of the whole AGN population (usually derived from X-ray LF after correcting for obscured sources)

Bolometric corrections

Build AGN template spectrum assuming:

- optical power law
- X-ray power-law+cutoff
- connect with L-dependent α_{OX} (Kelly+08)

NO IR bump (not directly from accretion!)



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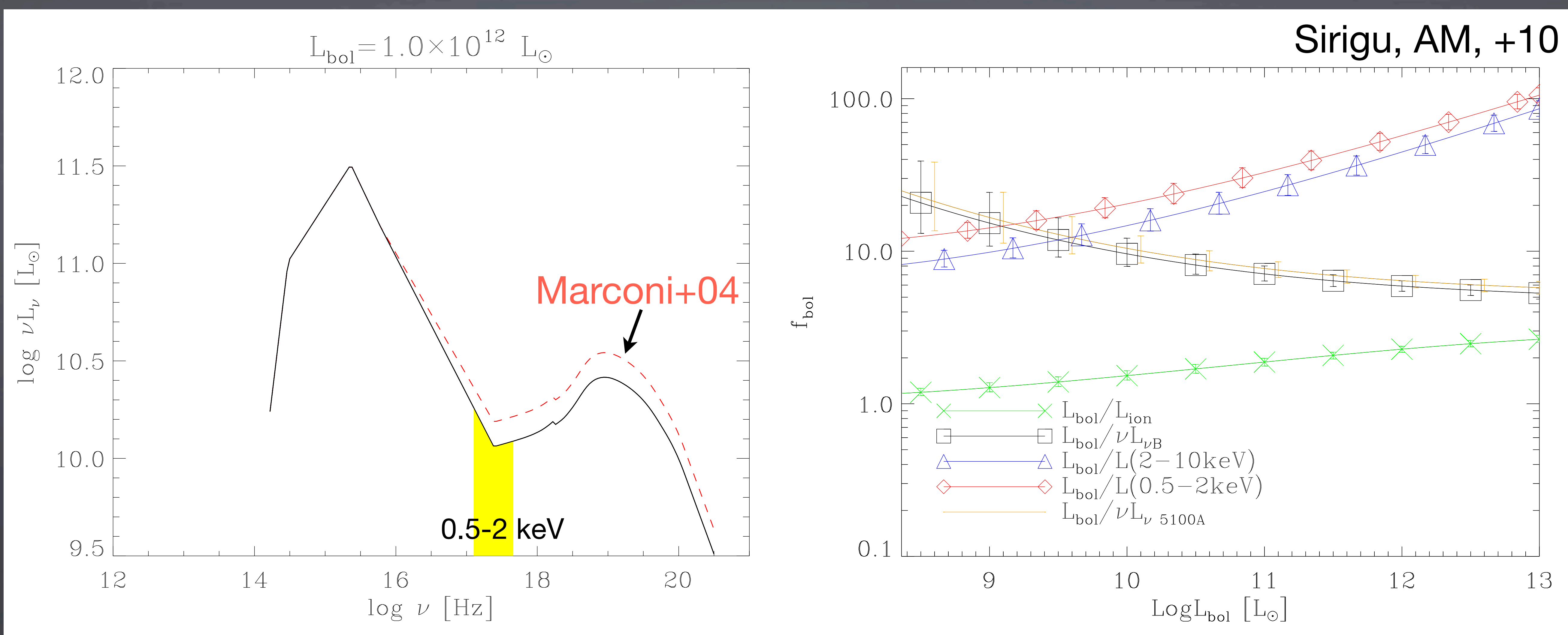
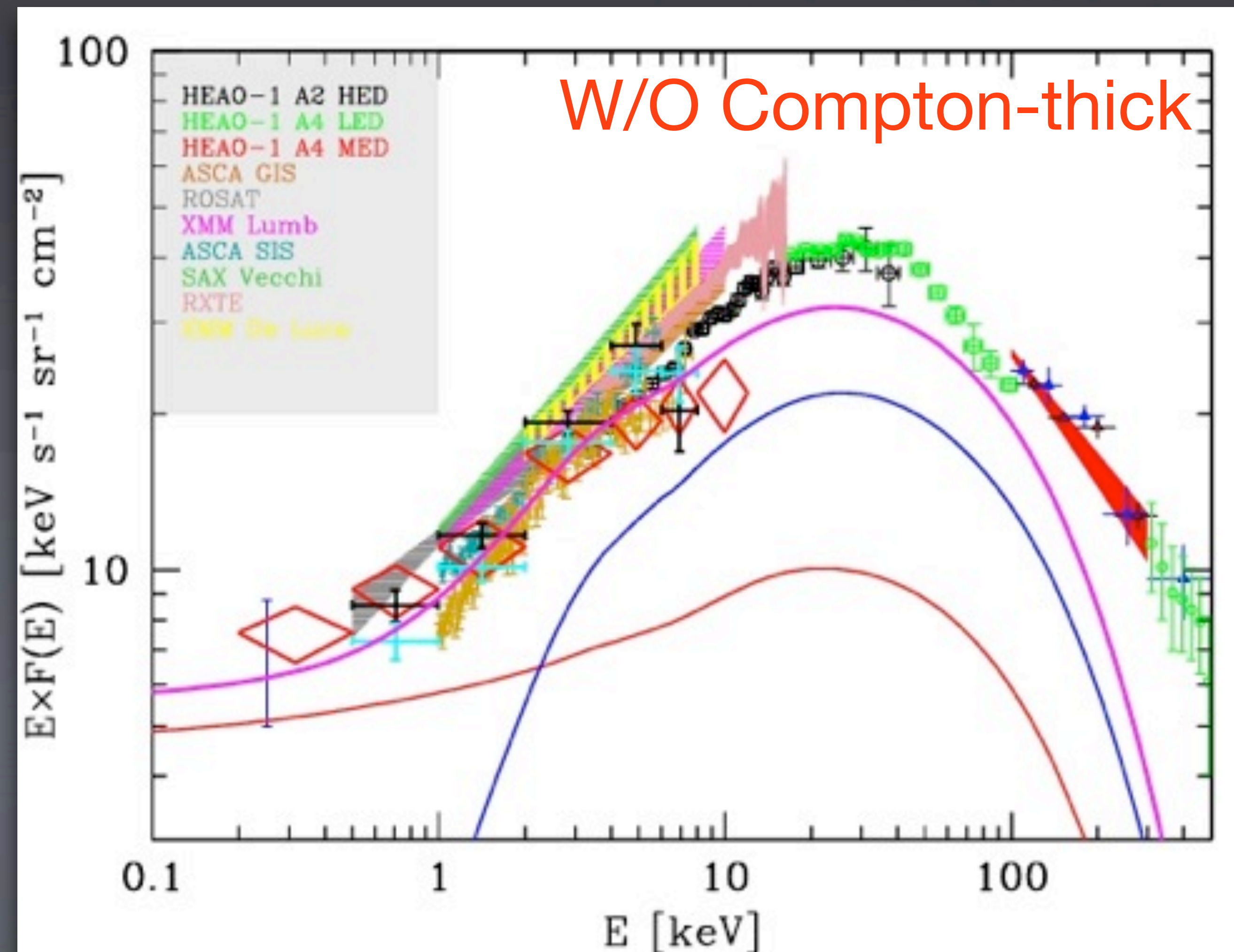
WFXT



Constraints from X-ray Background

Models of the XRB take into account the whole AGN population → also Compton-thick AGNs.

Their number density could be determined independently by XRB modeling (eg Gilli +07).



Gilli, Comastri & Hasinger +07

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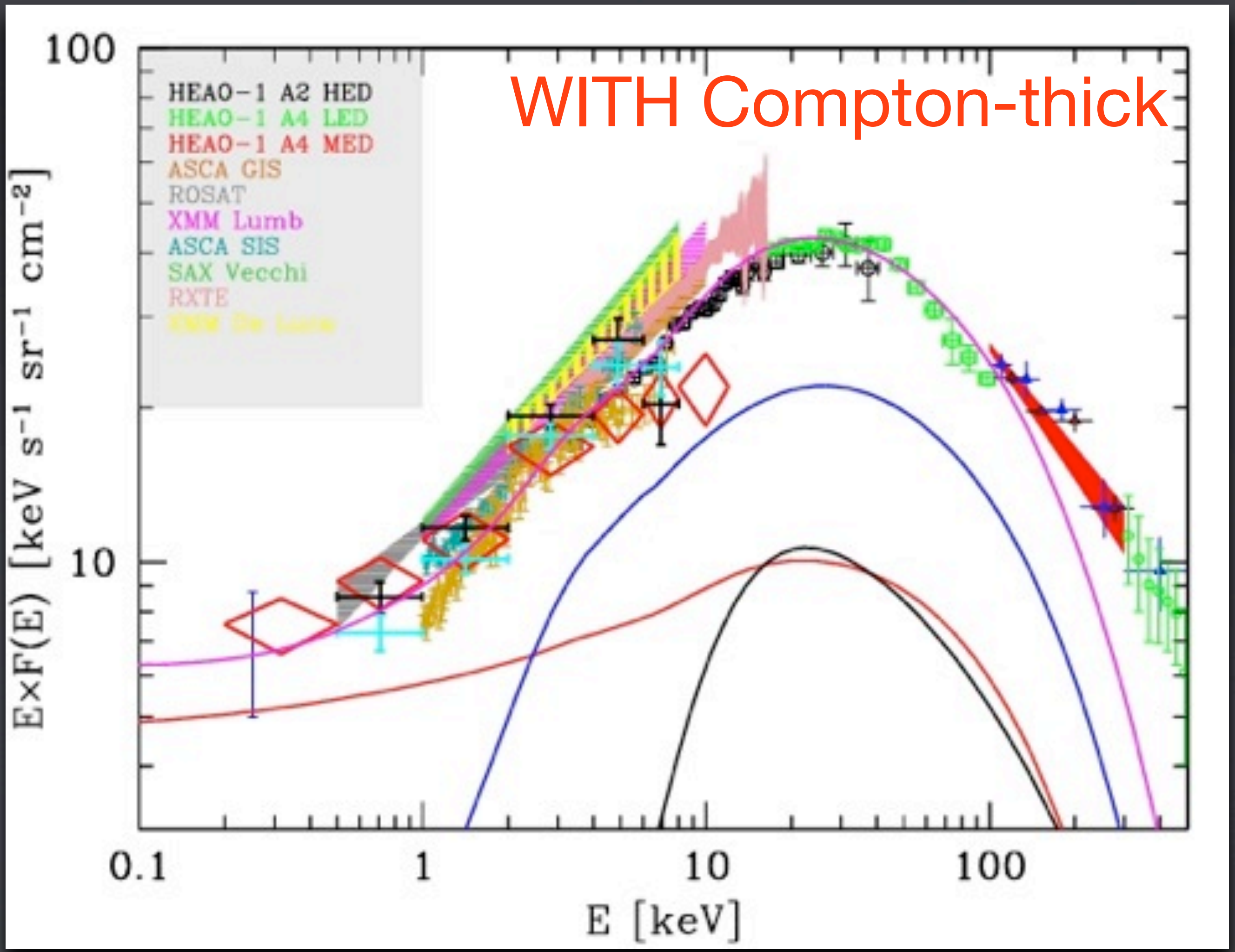

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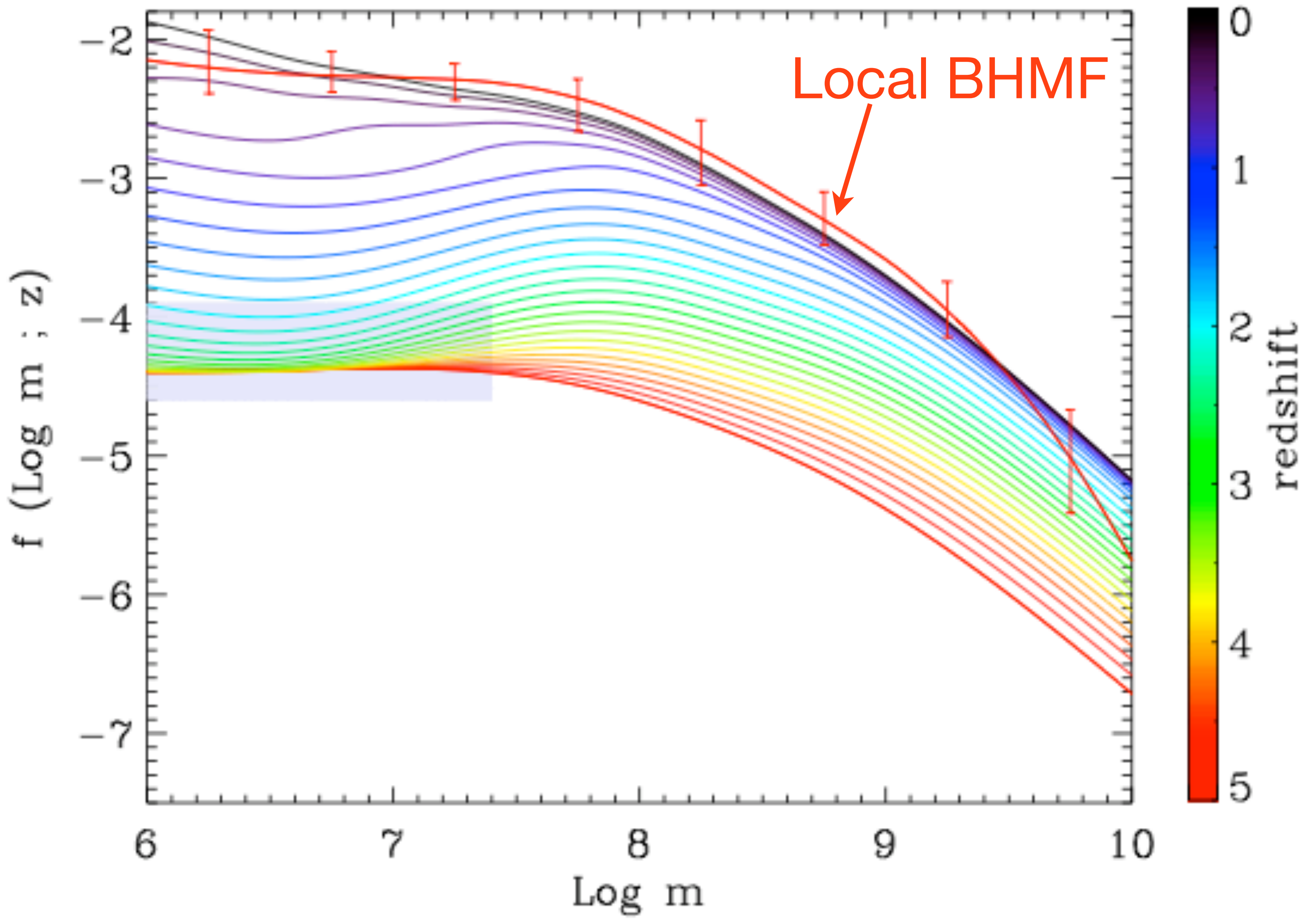
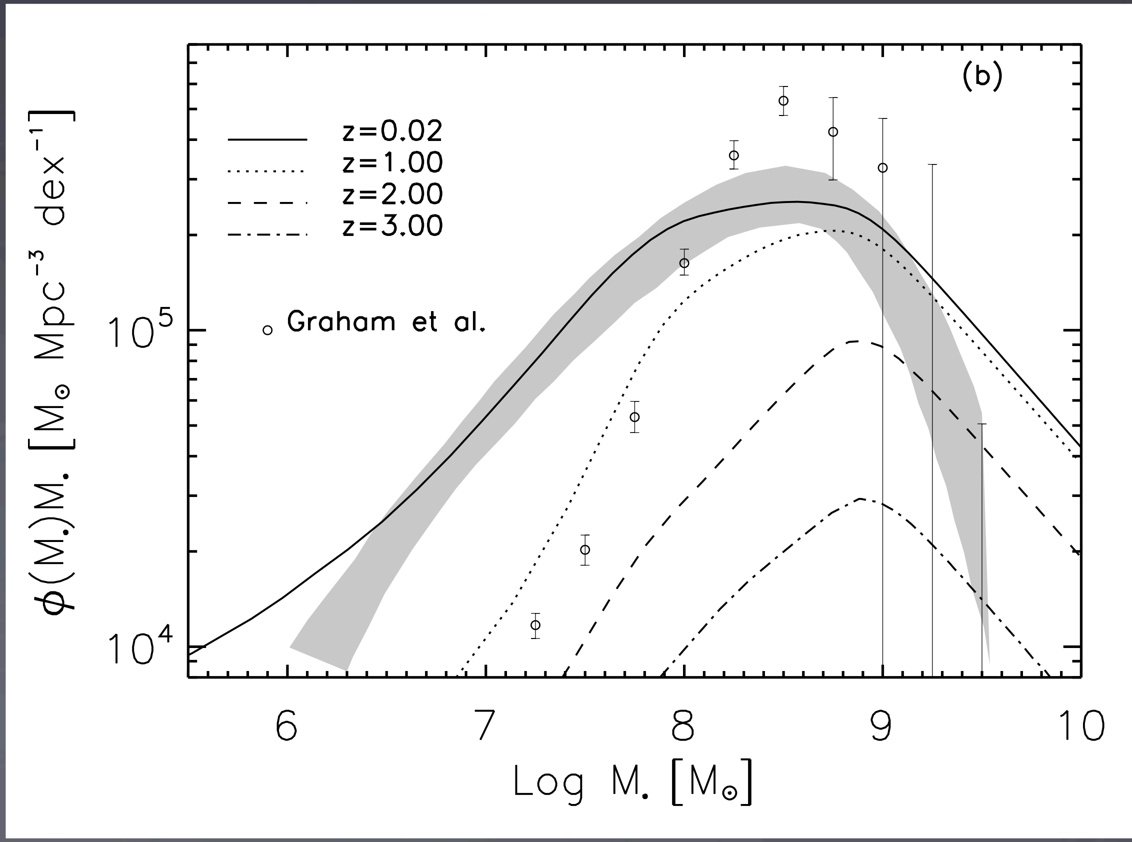
Local BHs vs AGN relics



Sirigu, AM +10 (ε=0.063, λ=0.2)

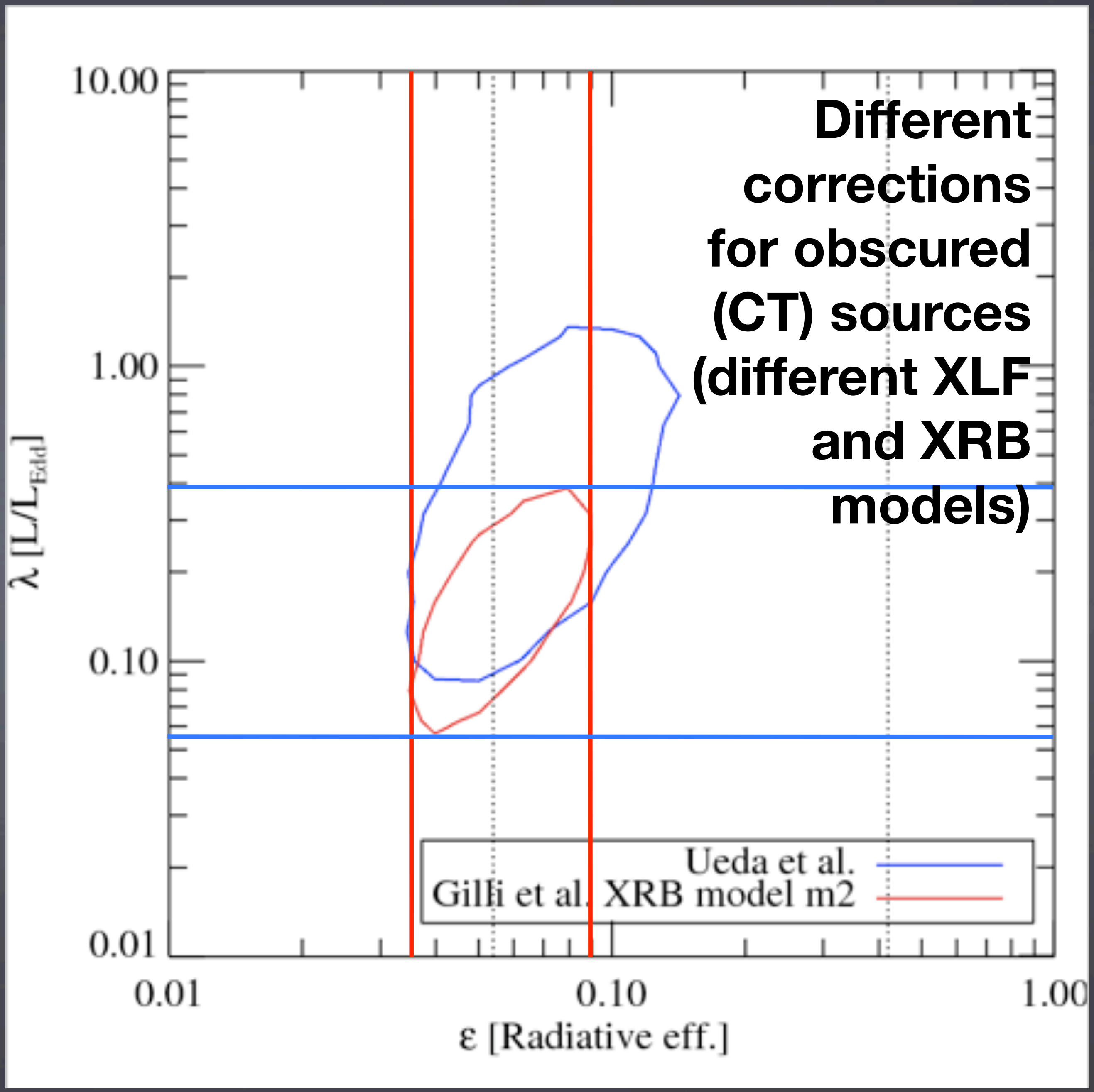


Shankar +08 (ε=0.065, λ=0.42)

In general there appears to be a good agreement between local BHs and AGN relics with ε≃0.06, λ≃0.2-0.4 (see also Merloni & Heinz 2008)

Radiative Efficiency and L/L_{Edd}

- Efficiency and fraction of Eddington luminosity are the only free parameters!
- Determine locus in ε-λ plane where there is the best match between local and relic BHMF!
- ε=0.04-0.09   λ=0.06-0.4 which are consistent with common 'beliefs' on AGNs
- Marconi et al. 2004 found using Ueda et al. 2003: ε=0.04-0.16 and λ=0.1-1.7 method is robust!



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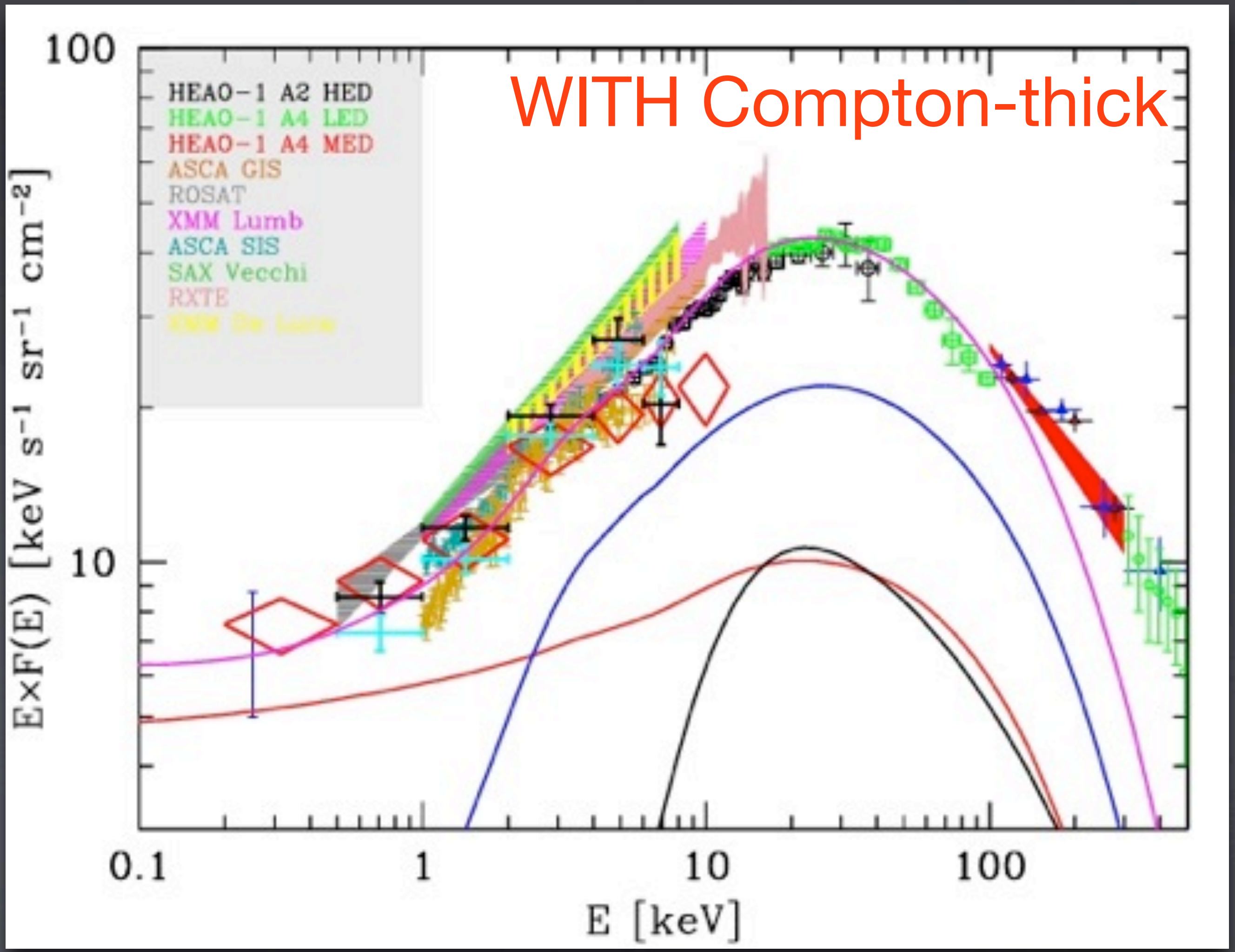

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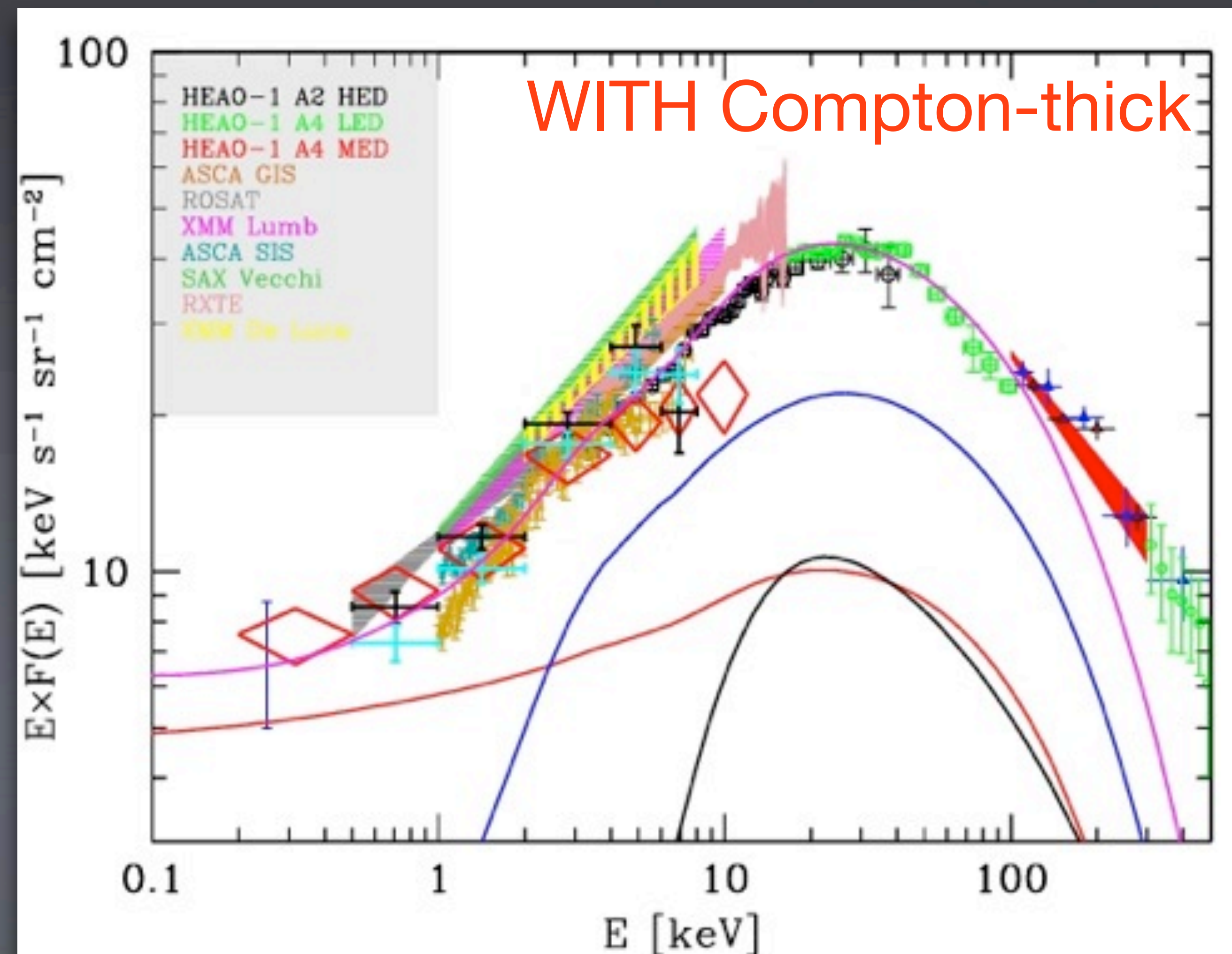
But ...



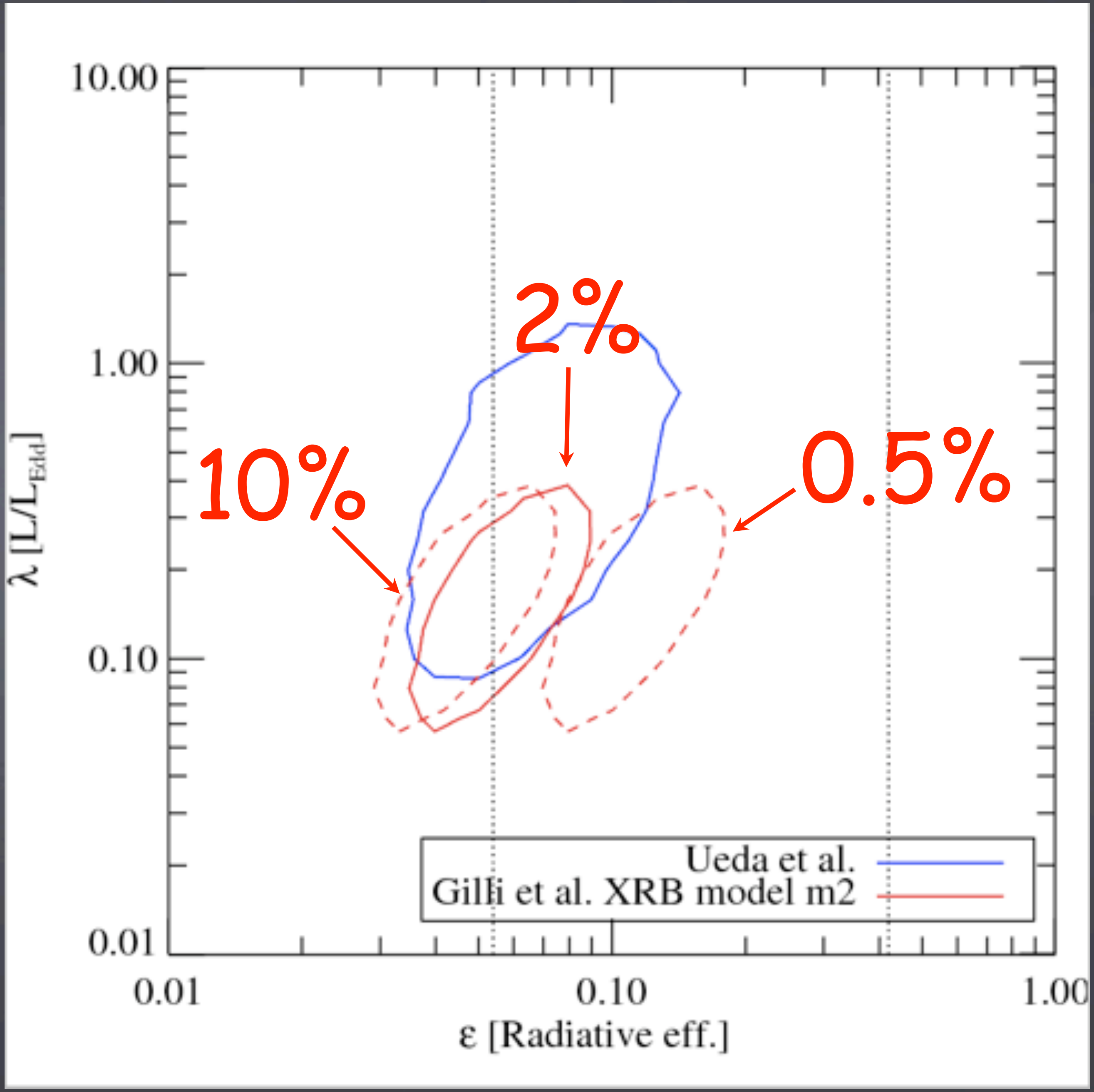
Gilli, Comastri & Hasinger +07

The spectrum of fully Compton thick AGNs is the reflection spectrum whose normalization depends of the ASSUMED average scattering efficiency!

The number of Compton-thick AGNs depends on the ASSUMED scattering efficiency (~2%) for which there are almost no estimates available!

Radiative Efficiency and L/L$_{Edd}$

- Effect of changing scattering efficiency to compute pure reflection spectra of Compton-Thick sources.
- Fundamental to constrain Obscured (CT) AGN fraction independently from the XRB background!
- Most important contribution from CT sources is at z~0-2, because of time (90% of age of universe).



Too many free parameters ...

Adopting the total AGN luminosity function as derived by the Gilli +07 model and matching the local BH mass function (Marconi +04) it is possible to write:

$$\frac{1-\varepsilon}{\varepsilon}\left[1+R_{\rm Thin}+R_{\rm MThick}+R_{\rm HThick}\left(\frac{0.02}{f_{\rm scatt}}\right)+X_{\rm Enshrouded}\right]\simeq\begin{cases}50\ \ (L>2\times 11\,{\rm L}_{\odot})\\ 150\ (L<2\times 11\,{\rm L}_{\odot})\end{cases}$$

R = Ratio obscured/unobscured

Compton Thin
(21 < log N_H < 24)

Highly Compton Thick
(log N_H > 25)

Mildly Compton Thick
(24 < log N_H < 25)

Completely obscured

Equazione G.R.A.M.A.
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using Gilli +07 best model [R = 4+4 (low L); R= 1+1 (high L); Compton-Thick are ~ lower obscuration AGNs] and ε~0.06.

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Example: assuming X~4 then with ε~0.08 (LL), 0.12 (HL) we can still satisfy the above equation! Little constraints from XRB and local BH mass function!

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Compton

(21 < log N

(24 < log N_H < 25)

G.R.A.M.A.

aliti

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Marconi

Marco Salvati

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We need to know the fraction of Compton-Thick sources independently from XRB synthesis models → WFXT

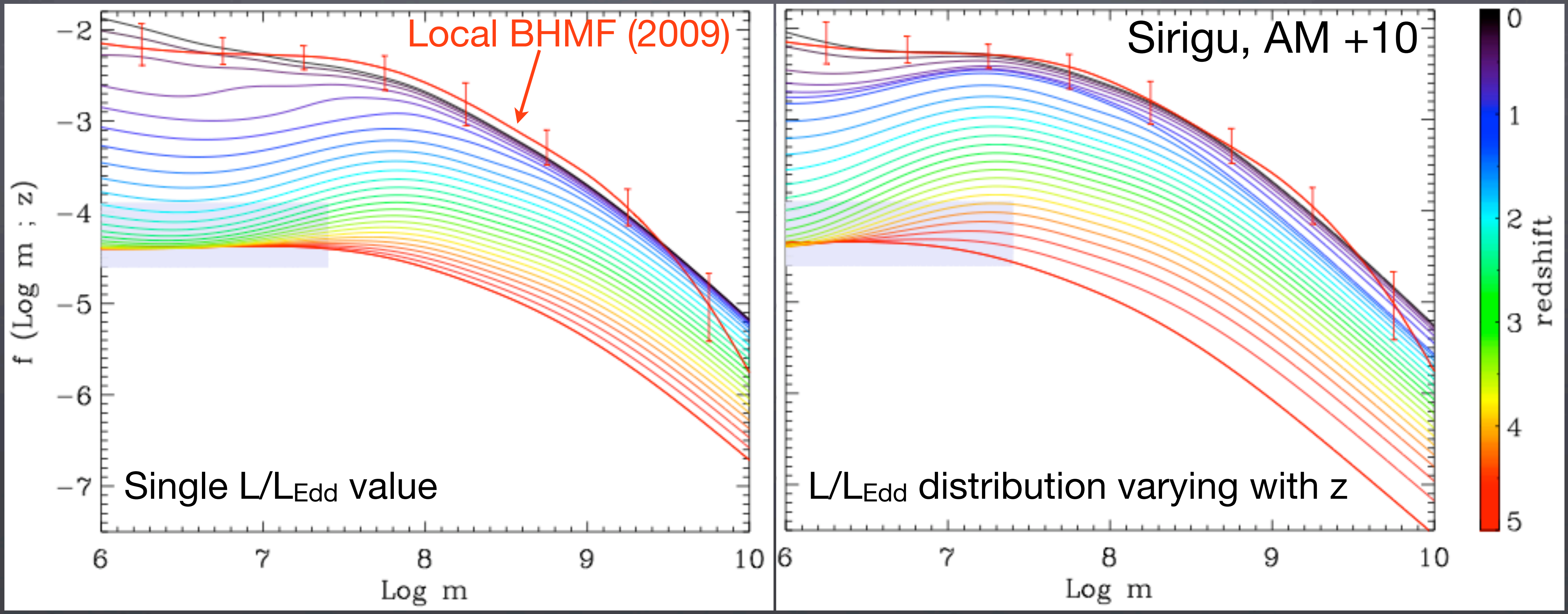
using Gilli +07 best model [R = 4+4 (low L); R= 1+1 (high L); Compton-Thick are ~ lower obscuration AGNs] and ε~0.06.

Example: assuming X~4 then with ε~0.08 (LL), 0.12 (HL) we can still satisfy the above equation! Little constraints from XRB and local BH mass function!

Allowing for a L/L_{Edd} distribution

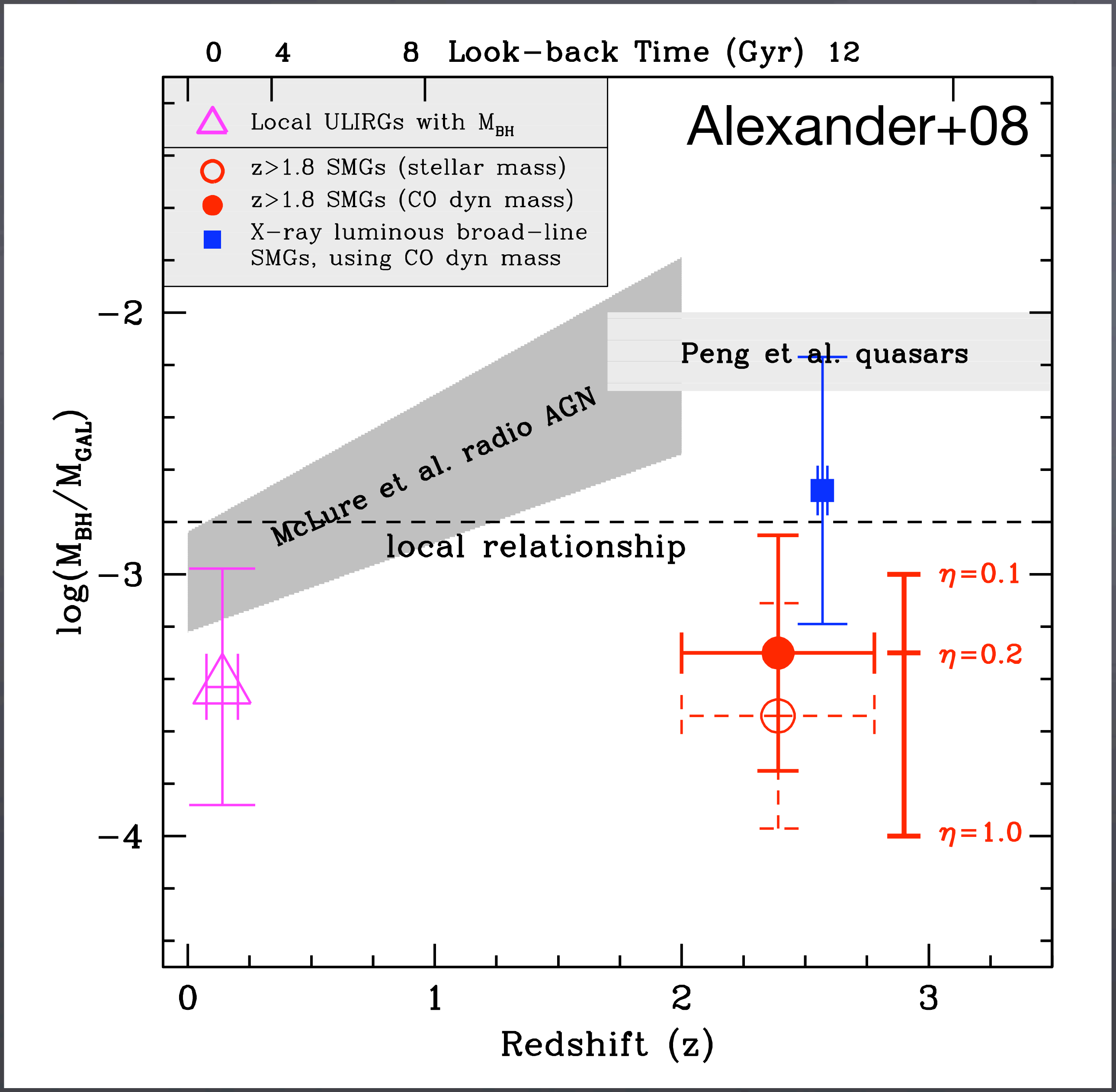
$$\frac{\partial f(M,t)}{\partial t} + \frac{1-\varepsilon}{\varepsilon c^2} \frac{\partial}{\partial M} \left(\int L\, \mathcal{P}(M|L,t)\, \phi(L,t)\, dL \right) = 0$$

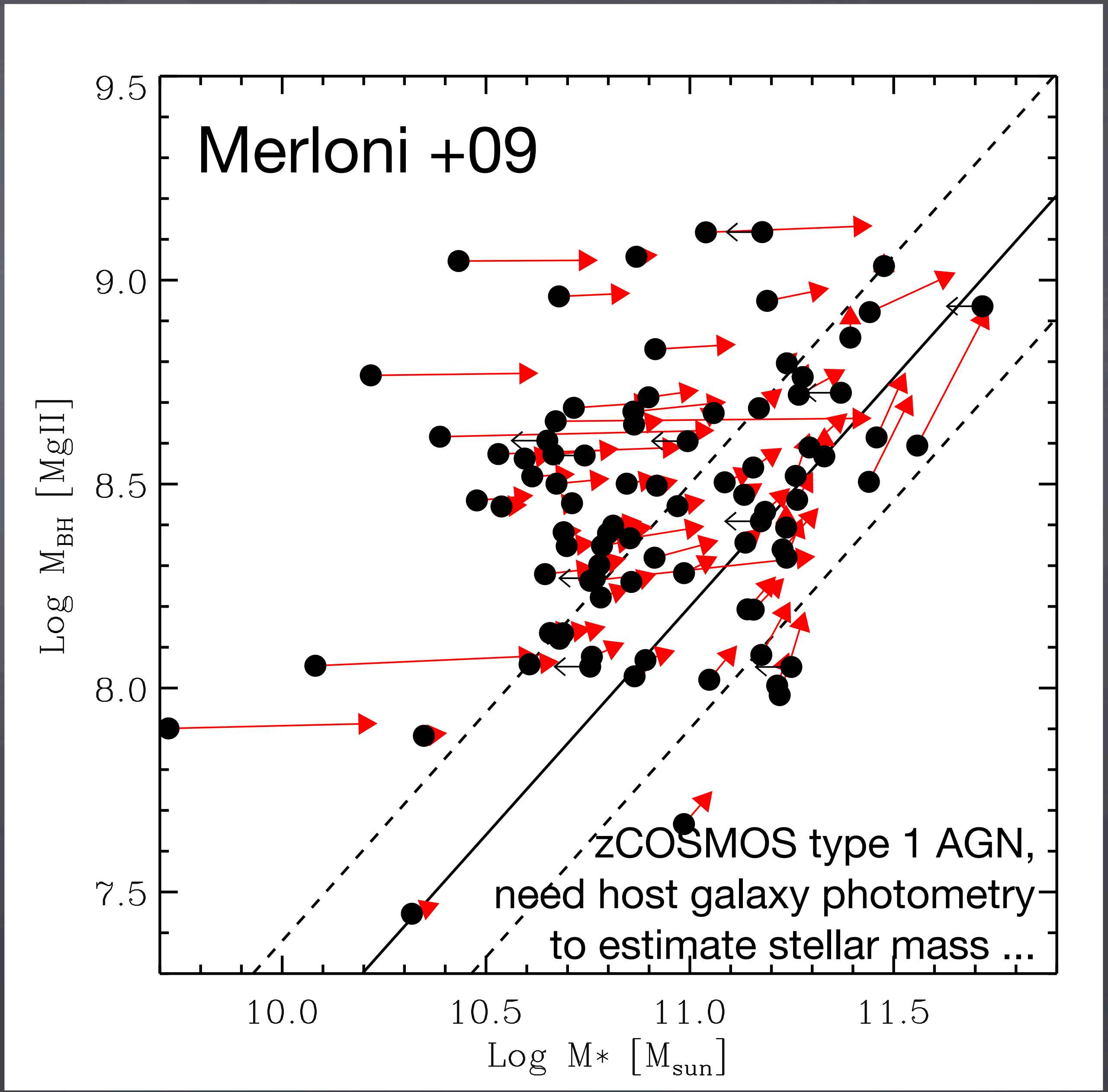
- The single L/L_{Edd} for all L, z still provides the best match of local BH MF.
- Need to take into account z, L dependence of L/L_{Edd} distributions for improvement but small changes on final results.
- Too many free parameters, need observational constraints on L/L_{Edd} distr.
- Only possibility is to measure virial M_{BH} in type 1 AGN at all z.



z evolution of BH-galaxy relations

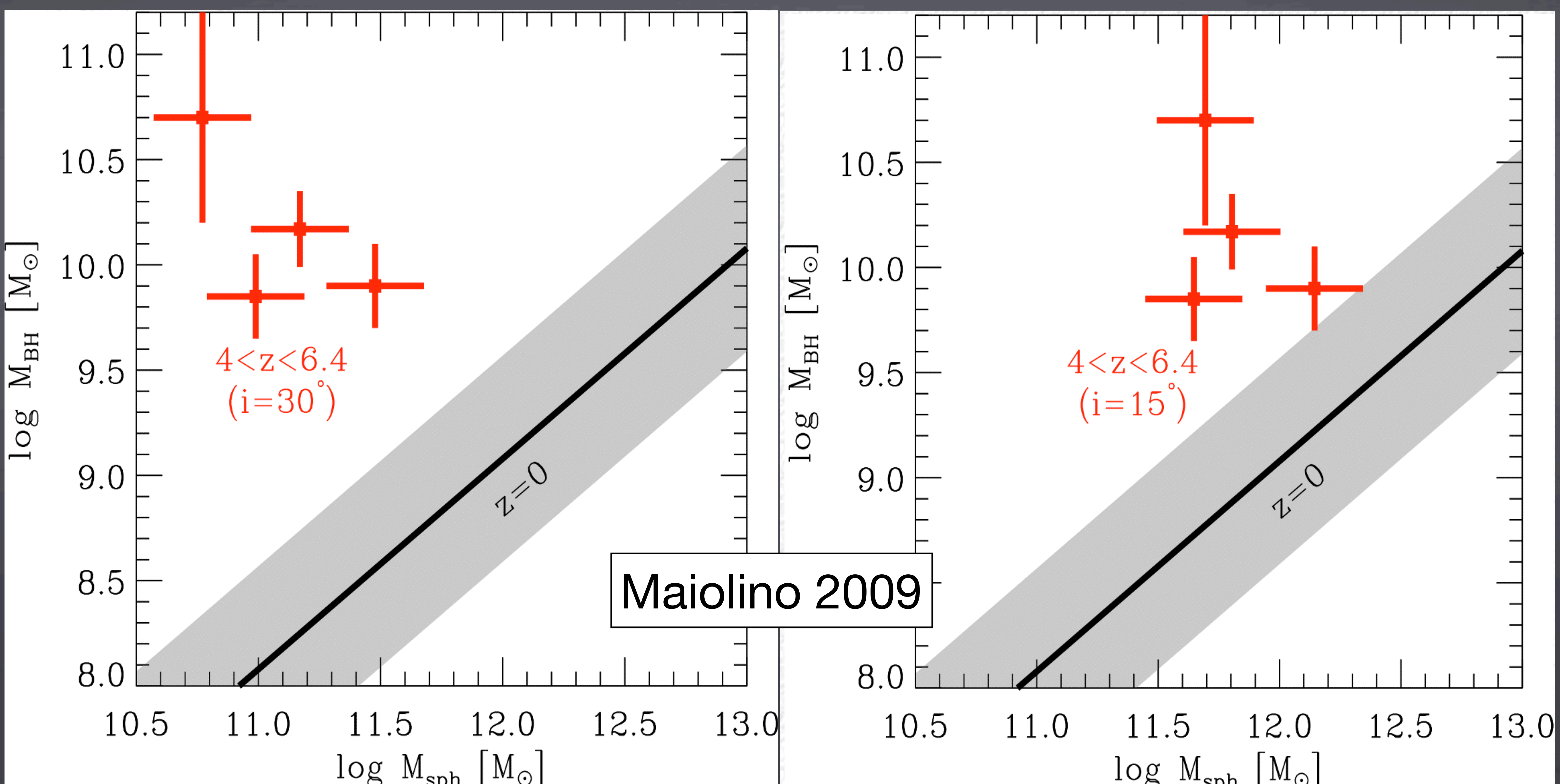
BH growth appear to precede galaxy growth in luminous quasars (but many uncertainties do BH mass estimates, deconvolution AGN-host galaxy, etc.).
Sub-mm galaxies appear to have small BHs (eg Alexandar+08).
These puzzling results might just represent selection effects (Lamastra+09)





M_{BH}-galaxy in very high-z quasars

4<z<6.4 quasars with M_{sph} estimate from CO line width (-> host galaxy mass, depends on assumed inclination) and virial M_{BH}.
Even reducing to low inclination, very high M_{BH}/M_{sph} compared to local value!



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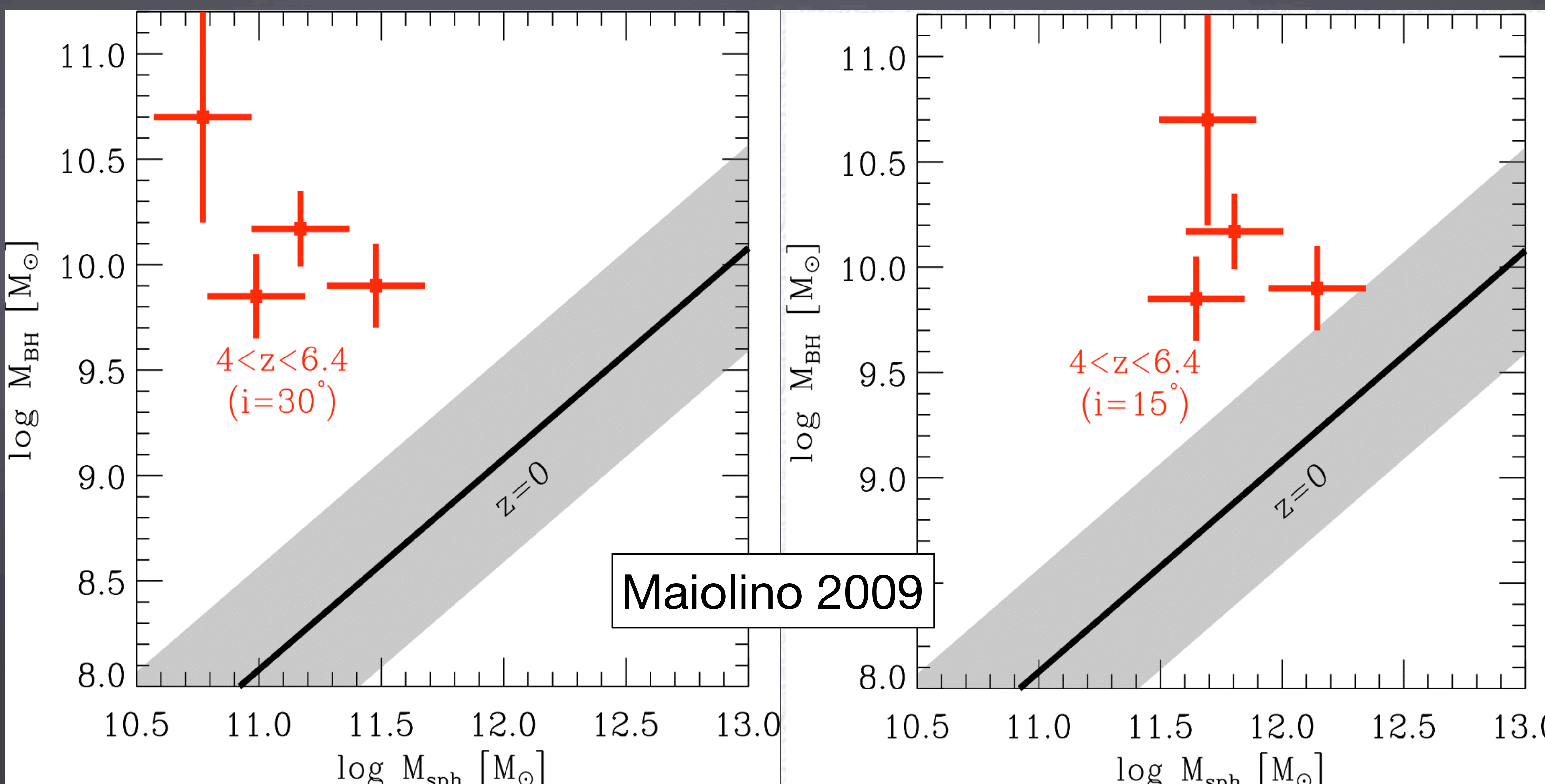
Importance of measuring host galaxy kinematics in submm → strong synergies with ALMA



Enough time to grow high z BHs?

Highest redshift quasar @z=6.41 has $M_{BH} \sim 6\times10^9\ M_\odot$ [Willot+2003, updated]

With updated virial relation: $M_{BH} \sim 1.2\times10^{10}\ M_\odot$

Was there enough time to grow the BH?

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Emission at fraction λ of Eddington Luminosity

$$L = \lambda L_{\mathrm{Edd}} = \lambda \frac{M_{BH} c^2}{t_{\mathrm{Edd}}}$$

e-folding time: $t_{\mathrm{Salp}} = \frac{\varepsilon}{(1-\varepsilon)\lambda} t_{Edd} \simeq 0.05\,\mathrm{Gyr} \quad \text{with } \varepsilon = 0.1,\ \lambda = 1$

Minimum time required for growth: $t = t_{\mathrm{Salp}} * \ln \frac{M_{BH}(t)}{M_{BH}(t_0)}$

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With direct collapse to BH (“quasistars” Begelman+2007) “seeds” have:

$$z(t_0) \simeq 30 \qquad M_{BH}(t_0) \simeq 10^3\,\mathrm{M}_\odot \qquad t_{BH} = 0.83\,\mathrm{Gyr}$$

$$M_{BH}(t_0) \simeq 10^4\,\mathrm{M}_\odot \qquad t_{BH} = 0.71\,\mathrm{Gyr}$$

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Elapsed time is: $t(z=6.41) - t(z=30) = 0.74\,{\rm Gyr}$

Summary

USING

x-ray sources from WFXT WITH accurate optical/NIR spectroscopy

$10^{7.2}$ AGN

$10^{5.9}$ AGN with $N(H)>10^{23}$ cm-2

$10^{3.4}$ at $z>6$

$10^{2.7}$ Compton-thick at $z>1$

WE CAN

Constrain average radiative efficiency (spinning BHs?) &
Obtain the cosmological evolution of supermassive BHs (BH MF @ z ~0-6)

- Luminosity function of Compton-Thin AGN (z~0-6)
- Constraints on Compton-Thick fraction (z~0-2)
- Spectral Energy Distributions (optical - X) as a function of L, M_{BH}
- L/L_{Edd} distribution of type 1 AGN as a function of L

M_{BH}-galaxy relation at high z (synergies with ALMA for host galaxy)

BH growth (& M_{BH}-galaxy) at $z>6$