The parallel lives of supermassive black holes and their host galaxies

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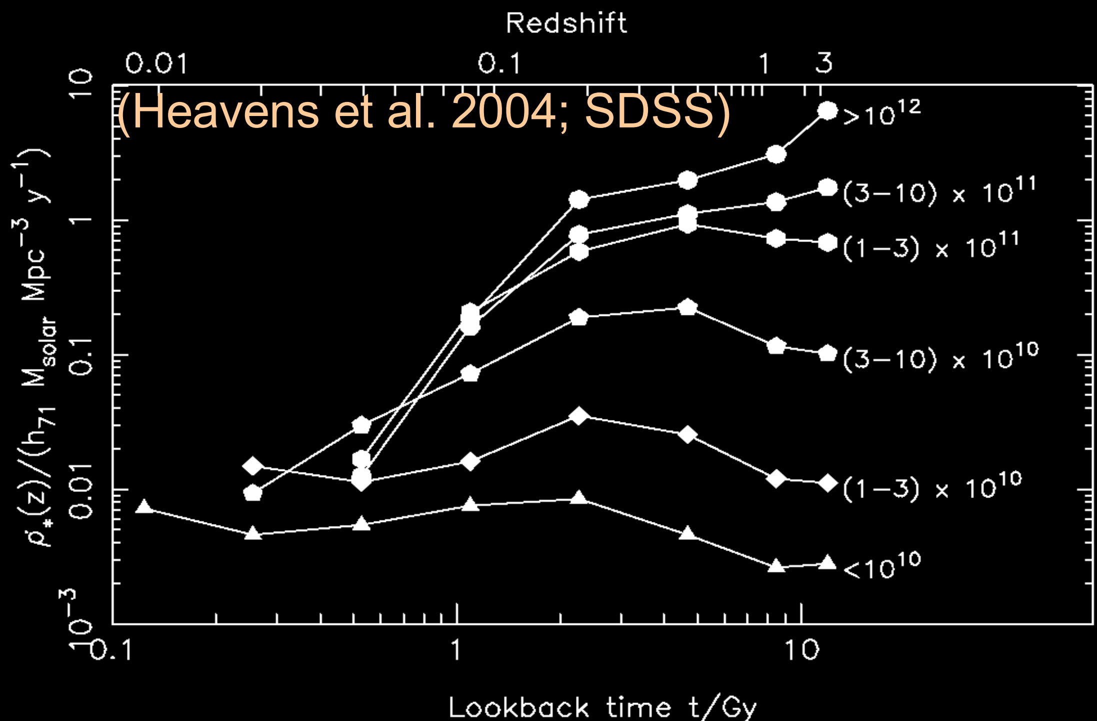
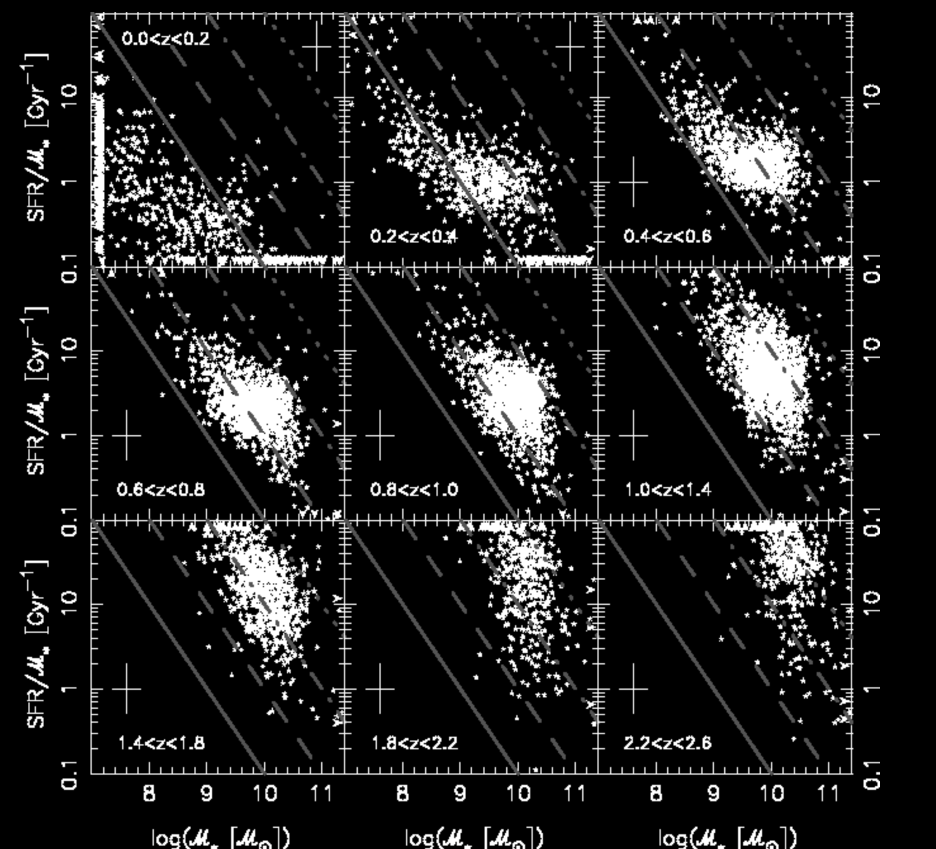
SMBH in the nuclei of nearby galaxies: how did they get there?

- Observed local correlations (M-σ, Magorrian) are often used as direct arguments for AGN feedback in models of structure formation: How do these correlations evolve at high redshift? Tests for structure formation models
- Differential constraints: What is the history of SMBH growth? Evolution of SMBH mass function: the anti-hierarchical behavior (downsizing)
- Integral constraints: The Soltan argument and the average accretion efficiency

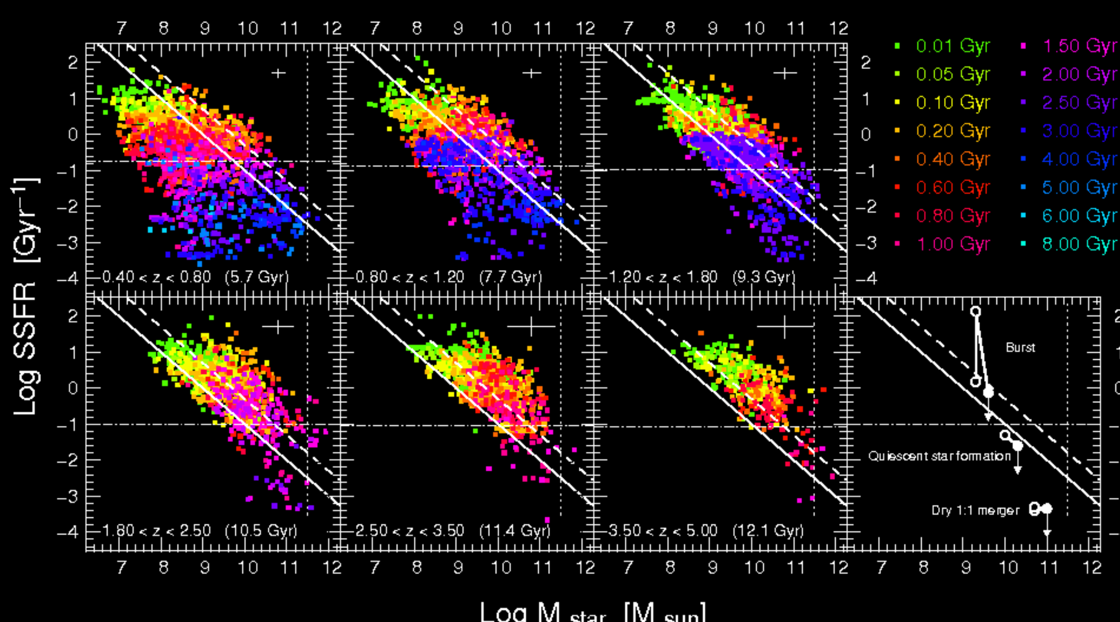
Downsizing in galaxy evolution



(Heavens et al. 2004; SDSS)



(Perez-Gonzalez et al. 2005; Spitzer 24μm)

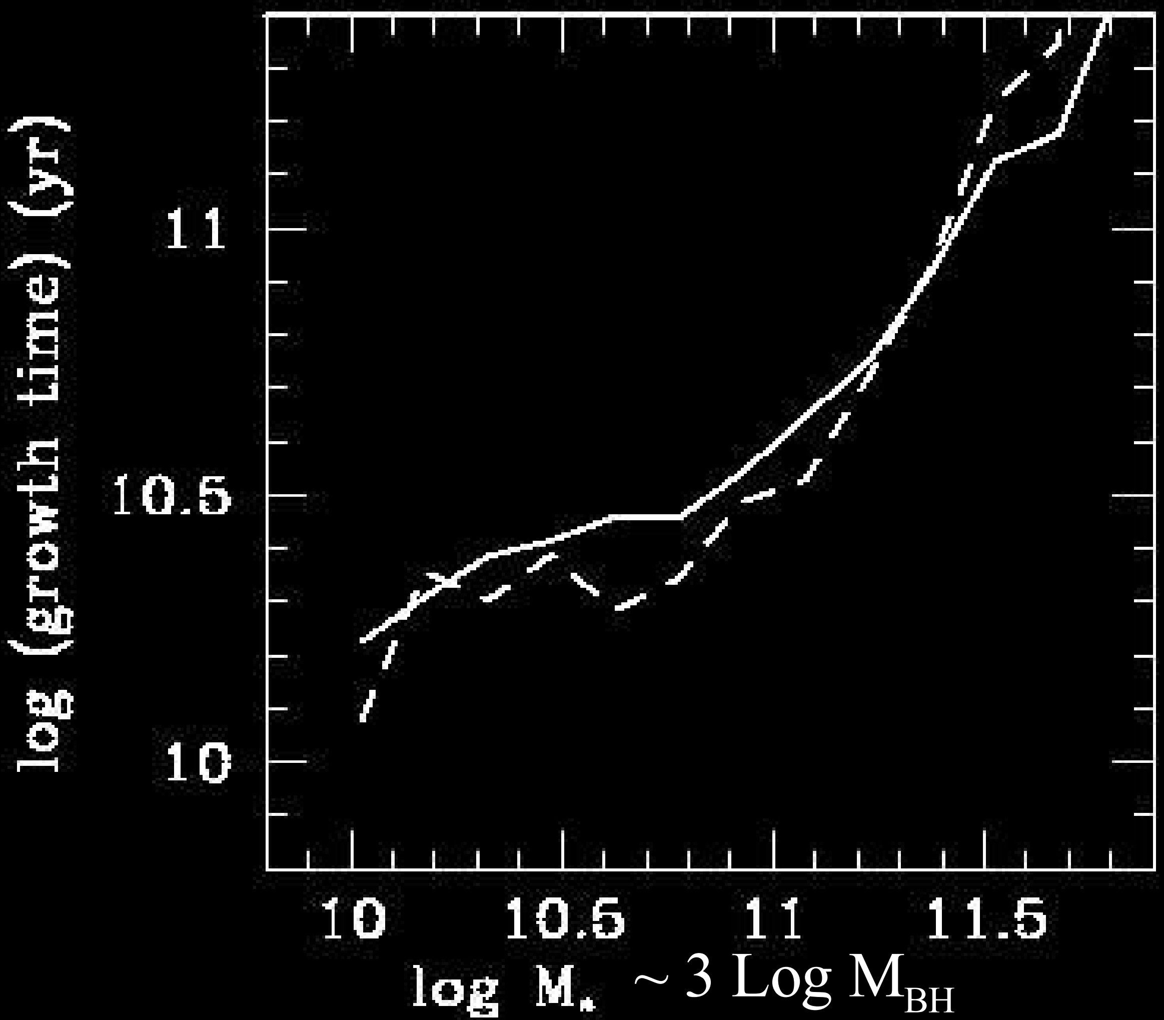


(Feulner et al. 2005; FORS DEEP + GOODS)

see also Glazebrook et al. (2004- ; Kodama et al. (2004 – SXDS); Treu et al. (2005 – DEIMOS at Keck II)

Downsizing in AGN activity: SDSS view

23,000 type 2 AGN at z<0.1

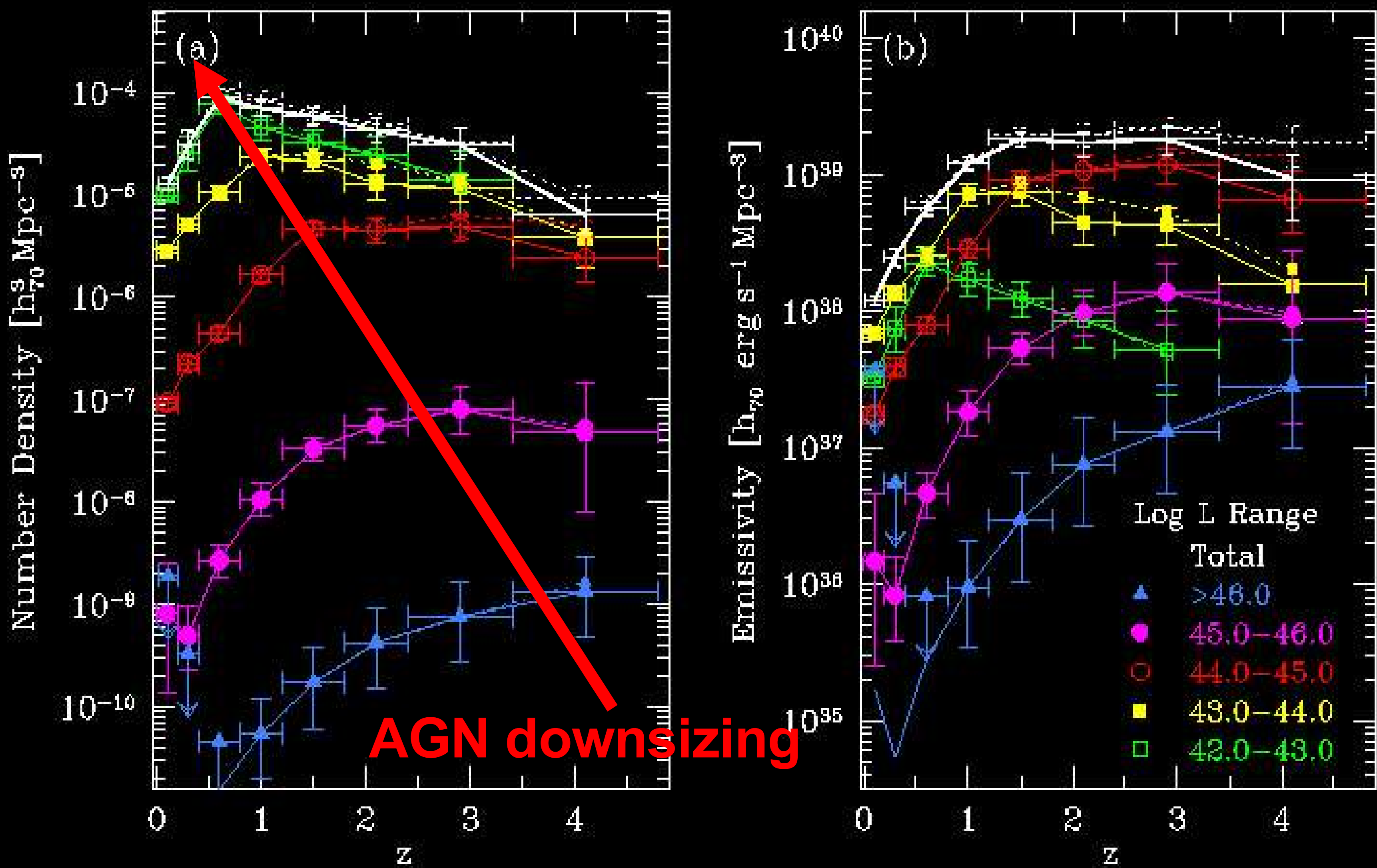


$\sim 3 \text{ Log } M_{BH}$

growth time = $M_{BH}/(dM_{BH}/dt)$

(Heckman et al. 2004)

The history of SMBH activity: clues from deep X-ray surveys

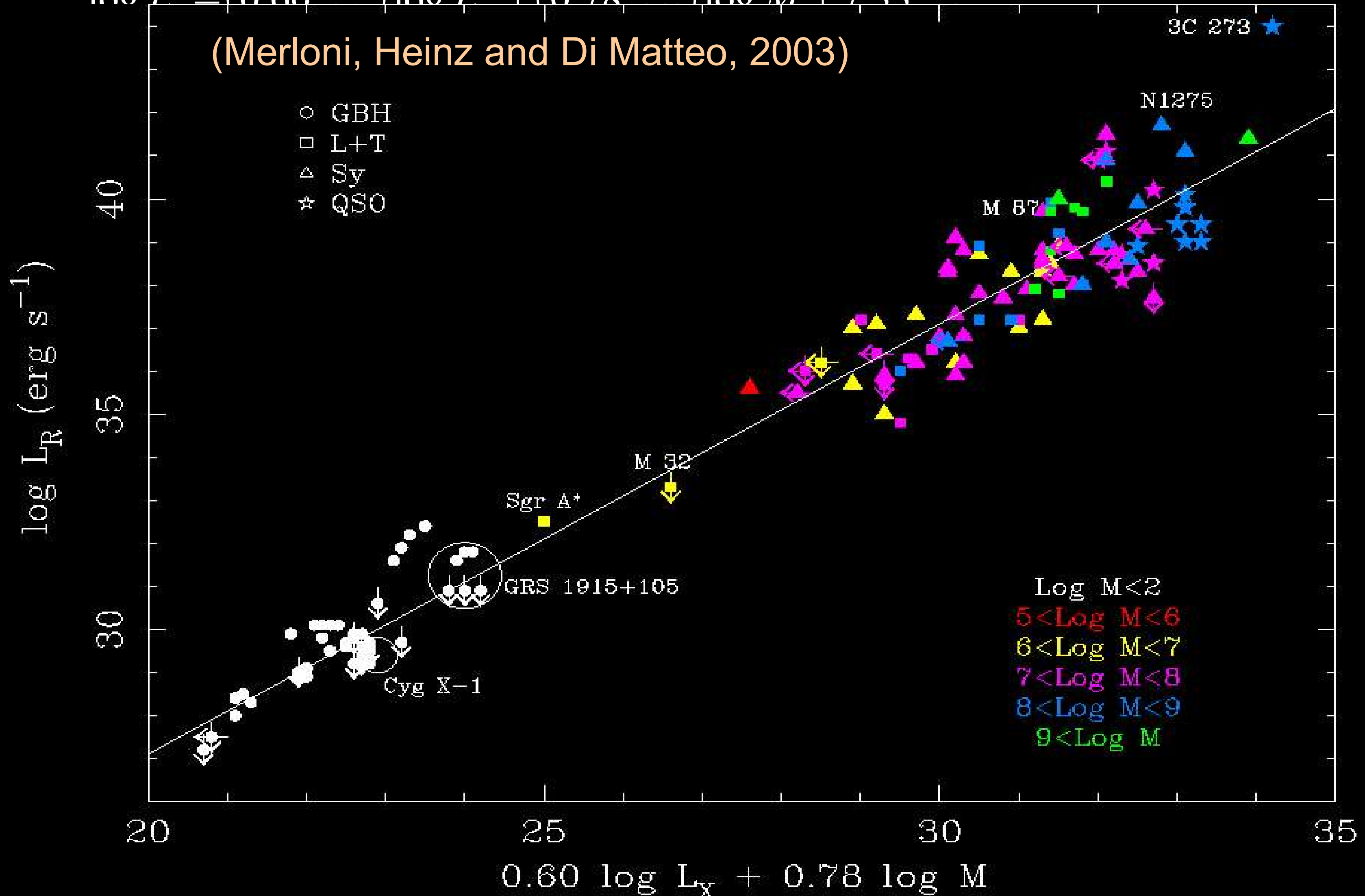


(Hasinger et al. 2005)

(see also Cowie et al. 2003; Fiore et al. 2003 Ueda et al. 2003; Barger et al. 2004)

The fundamental plane of accreting BH

$\log L_R = (0.60^{+0.11}\ldots)\log L_X + (0.78^{+0.11}\ldots)\log M + 7.33^{+4.05}\ldots$

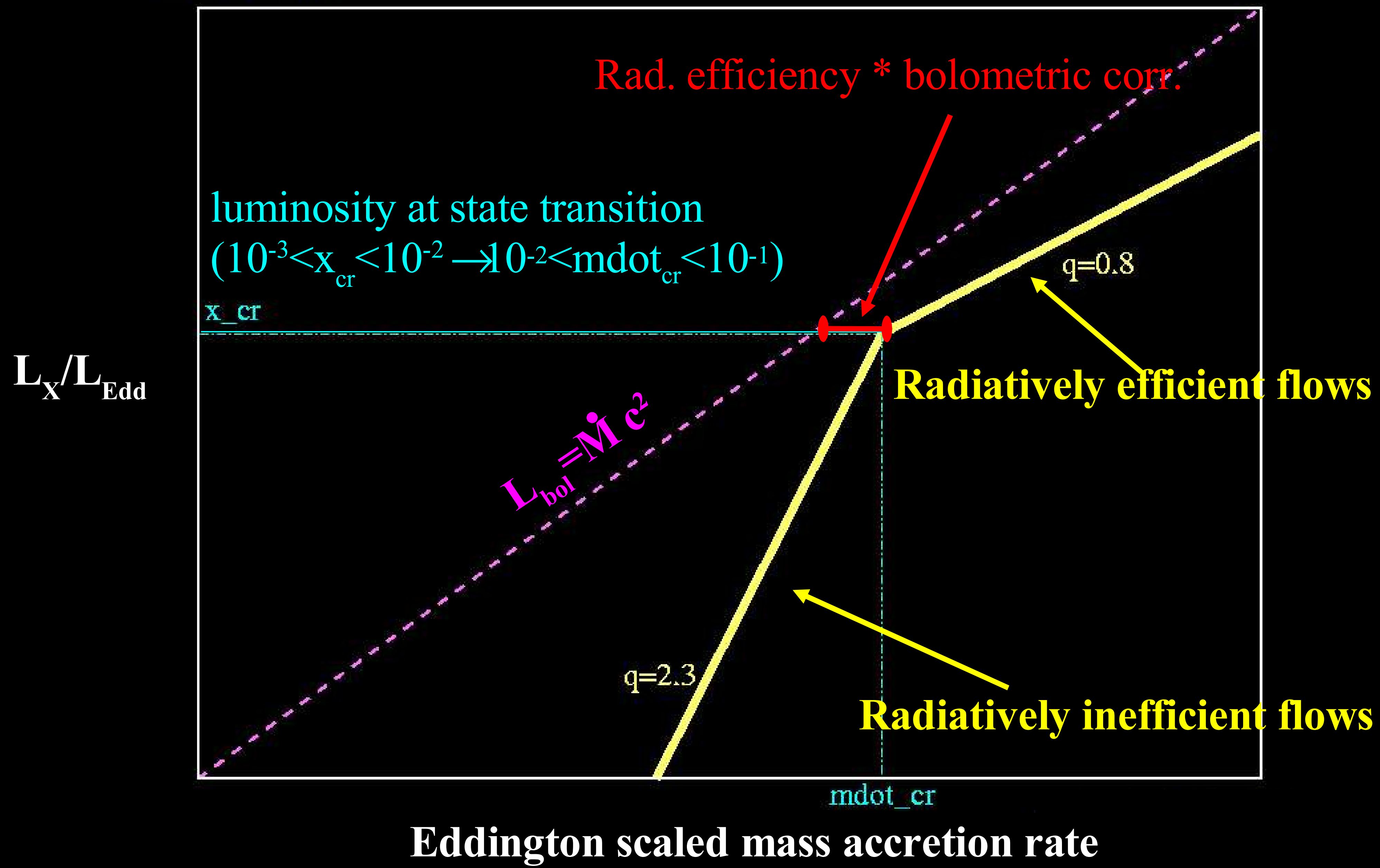


From the local BHMF and the AGN Radio and X-ray luminosity functions we can derive a local mass and accretion rate distribution function.

The history of accretion: model parameters

- For a given couple of evolving XLF (Ueda et al. 2003; La Franca et al. 2005) and RLF (Willott et al. 2001), and a given local BH Mass function, it is possible to calculate the history of accretion onto SMBH via a continuity equation with just three free parameters:
  - the global efficiency of accretion η (this *is NOT* the radiative efficiency $\varepsilon \leq \eta$)
  - the value of x_{cr}, where the accretion mode change takes place (observationally constrained to be $10^{-3} < x_{cr} < 10^{-2}$) *between radiatively efficient and inefficient accretion modes*
  - the corresponding value of the critical accretion rate or, equivalently, an X-ray bolometric correction (Marconi et al. (2004) α_{ox} dependent on luminosity)

The L_X-accretion rate relation



Radiative efficiency vs. accretion efficiency

radiative efficiency

accretion efficiency (BH spin)

$$\epsilon \equiv \epsilon(a, \dot{m}, \dot{m}_{\rm cr}) = \eta(a) f(\dot{m}, \dot{m}_{\rm cr})$$

Non Spinning BH

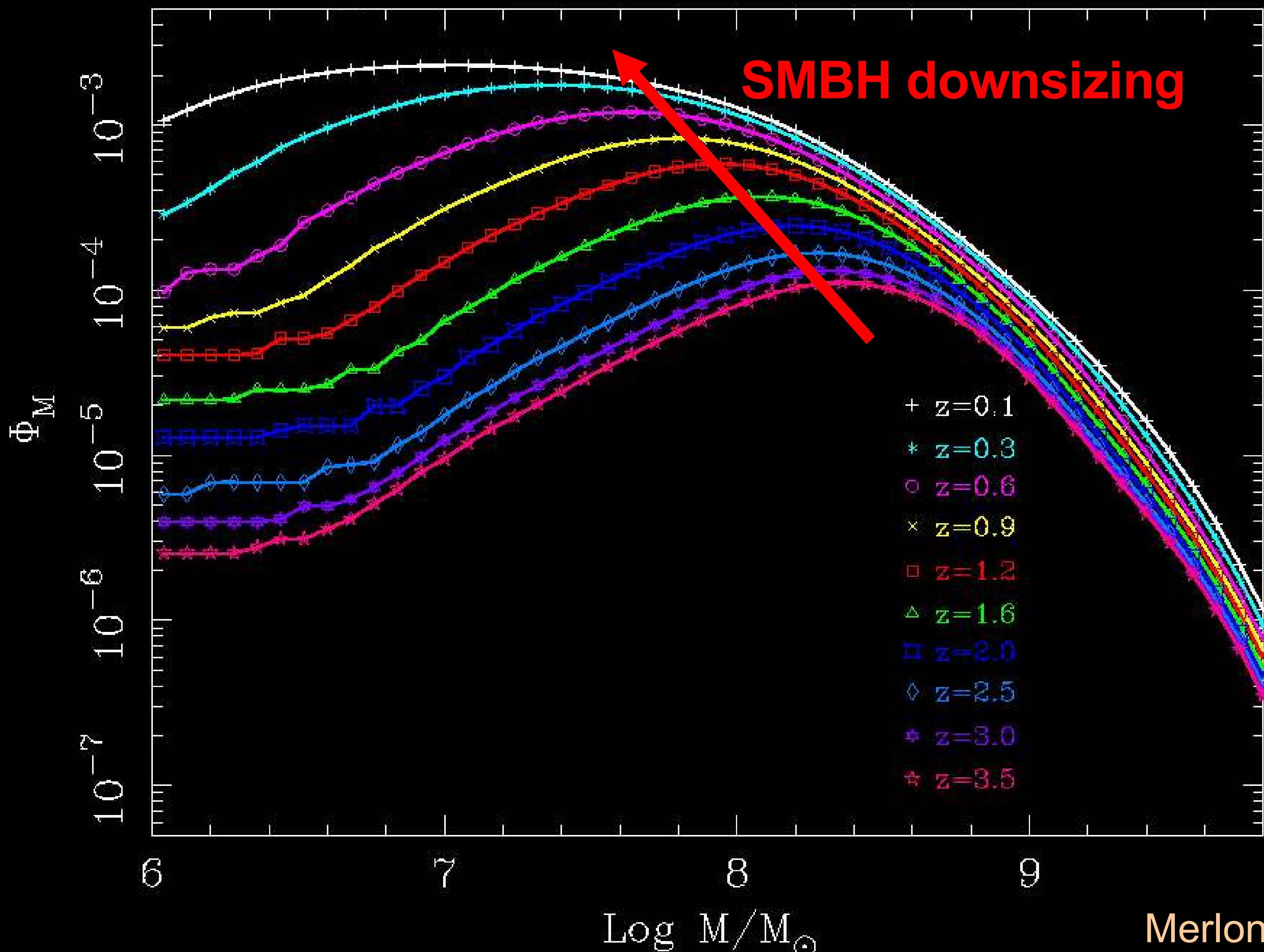
$$0.06 \leq \eta(a) \leq 0.42$$

Maximally Spinning BH

$$f(\dot{m}, \dot{m}_{\rm cr}) = \begin{cases} 1, & \dot{m} \geq \dot{m}_{\rm cr} \\ \dot{m}/\dot{m}_{\rm cr}, & \dot{m} < \dot{m}_{\rm cr} \end{cases}$$

Mass function evolution

(η=0.1, x_{cr}=10^{-3})



Merloni (2004)

Integral constraints on SMBH growth: the Soltan argument

- Soltan (1982) first proposed that the mass in black holes today is simply related to the emissivity of the Quasar population integrated over luminosity and redshift (if QSO are powered by accretion!)

$$L_{\rm bol} = \epsilon \dot{M}_{\rm acc} c^2 = \epsilon \dot{M}_\bullet c^2 / (1-\epsilon)$$

Radiative efficiency

Bolometric luminosity

Accretion rate

BH growth rate

$$\rho_{\rm BH,acc}(z) = \int_z^\infty \frac{dt}{dz'} dz' \int_0^\infty \frac{(1-\epsilon) L_i \kappa_{\rm i}}{\epsilon c^2} \phi(L_i, z) dL_i$$

Simultaneous growth of BH and galaxies

(Merloni, Rudnick and Di Matteo 2004)

$$\text{BHAR}(z) = \Psi_{\rm BH}(z) = \int_0^\infty \frac{(1-\epsilon)L_{\rm bol}(L_{\rm X})}{\epsilon c^2}\phi(L_{\rm X}, z')dL_{\rm X}$$

Average radiative efficiency

$$\frac{\rho_{\rm BH}(z)}{\rho_{\rm BH,0}} = 1 - \int_0^z \frac{\Psi_{\rm BH}(z)}{\rho_{\rm BH,0}}\frac{dt}{dz'}dz'$$

~0.0012 (Magorrian rel.)

$$\rho_{\rm sph}(z) = A_0\rho_{\rm BH}(z)(1+z)^{-\alpha}$$

$$\rho_*(z) = \rho_{\rm sph}(z) + \rho_{\rm disk+irr}(z) = \rho_{\rm sph}(z)[1+\lambda(z)]$$

$\lambda(z=0)$ **~ 0.3** (Fukugita et al. 98) **– 1.2** (Benson et al.`02)

Simultaneous growth of BH and galaxies: integral constraints

We have used SMBH as instantaneous tracers of the spheroid stellar mass

$$\rho_*(z) = A_0 \rho_{\rm BH}(\epsilon, z)(1+z)^{-\alpha}[1+\lambda_0(1+z)^{-\beta}]$$

$$d\rho_*(z)/dt = \Psi_*(z) - \int_{z_i}^{z} \Psi_*(z') \frac{d\chi[\Delta t(z'-z)]}{dt} \frac{dt}{dz'} dz'$$

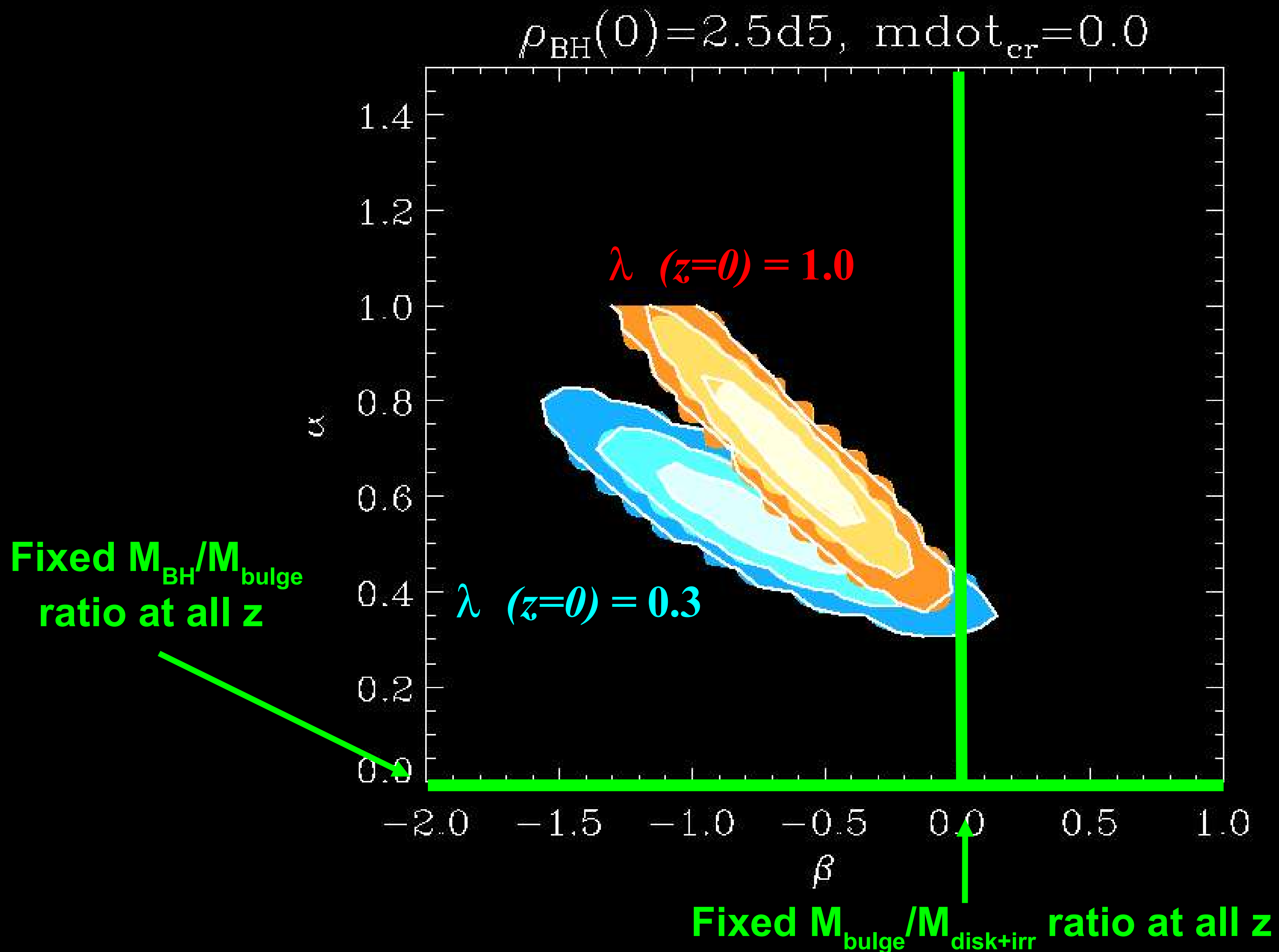
Fractional stellar mass loss (~30% in 13 Gyr)

A 3 parameters (ε, α, β) joint fit to stellar mass and SFR densities evolution

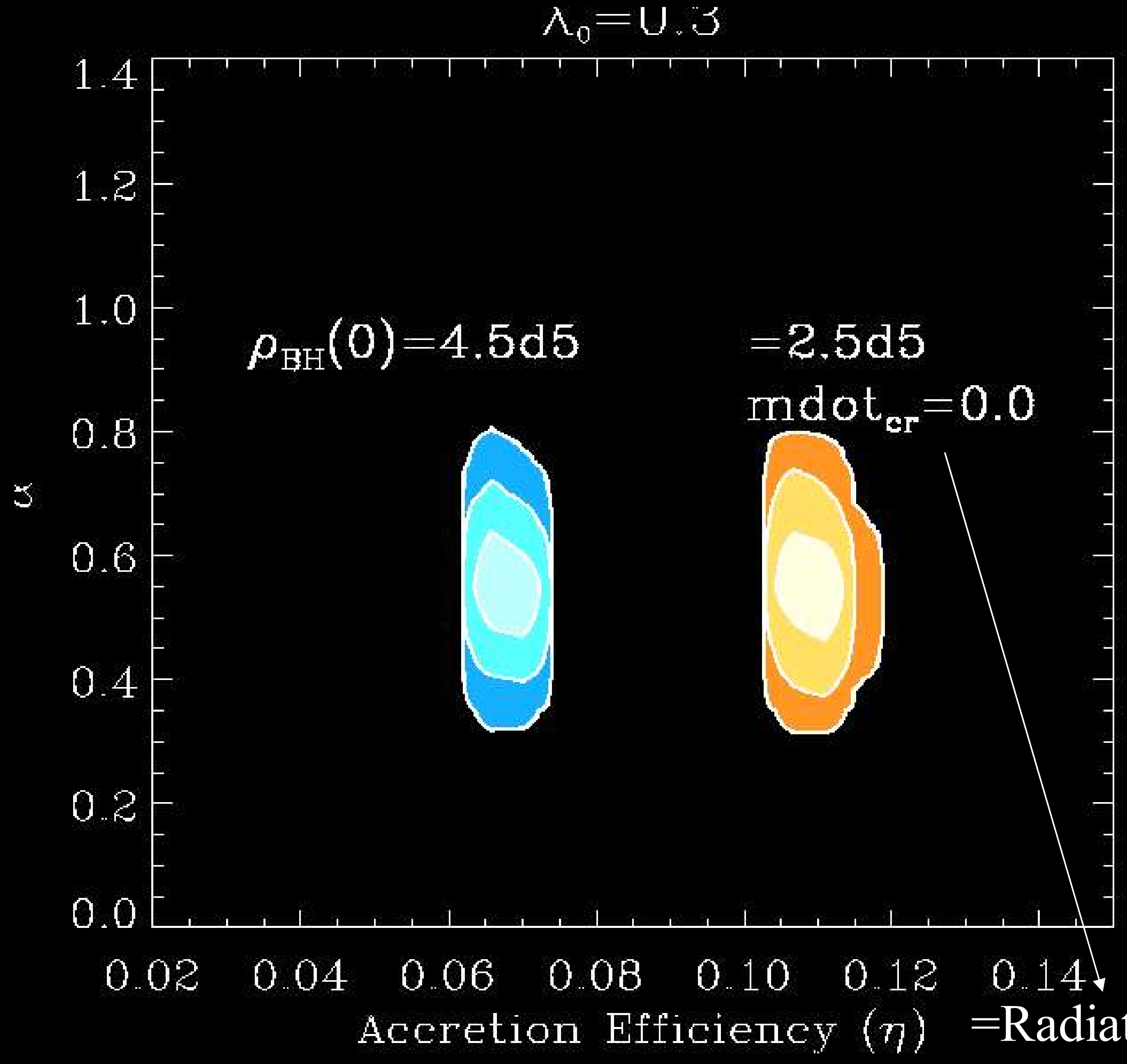
Simultaneous growth of BH and galaxies: integral constraints

- Use La Franca et al. (2005) Hard X-ray (2-10 keV) AGN Luminosity function (HELLASXMM+Piccinotti+AMSSn+HBS28+Lockman Hole+CDF-N+CDF-S)
- No Compton-thick sources (what z-distribution?)
- Stellar mass density data (31 points between $z=0$ and $z=4.5$) include, among the others MUNICS+HDF-S+HDF-N+FORS DEEP+GOODS-S surveys
- Star formation rate density data are a collection of 45 points between $z=0$ and $z=6$

M_{BH}/M_{bulge} increases with redshift

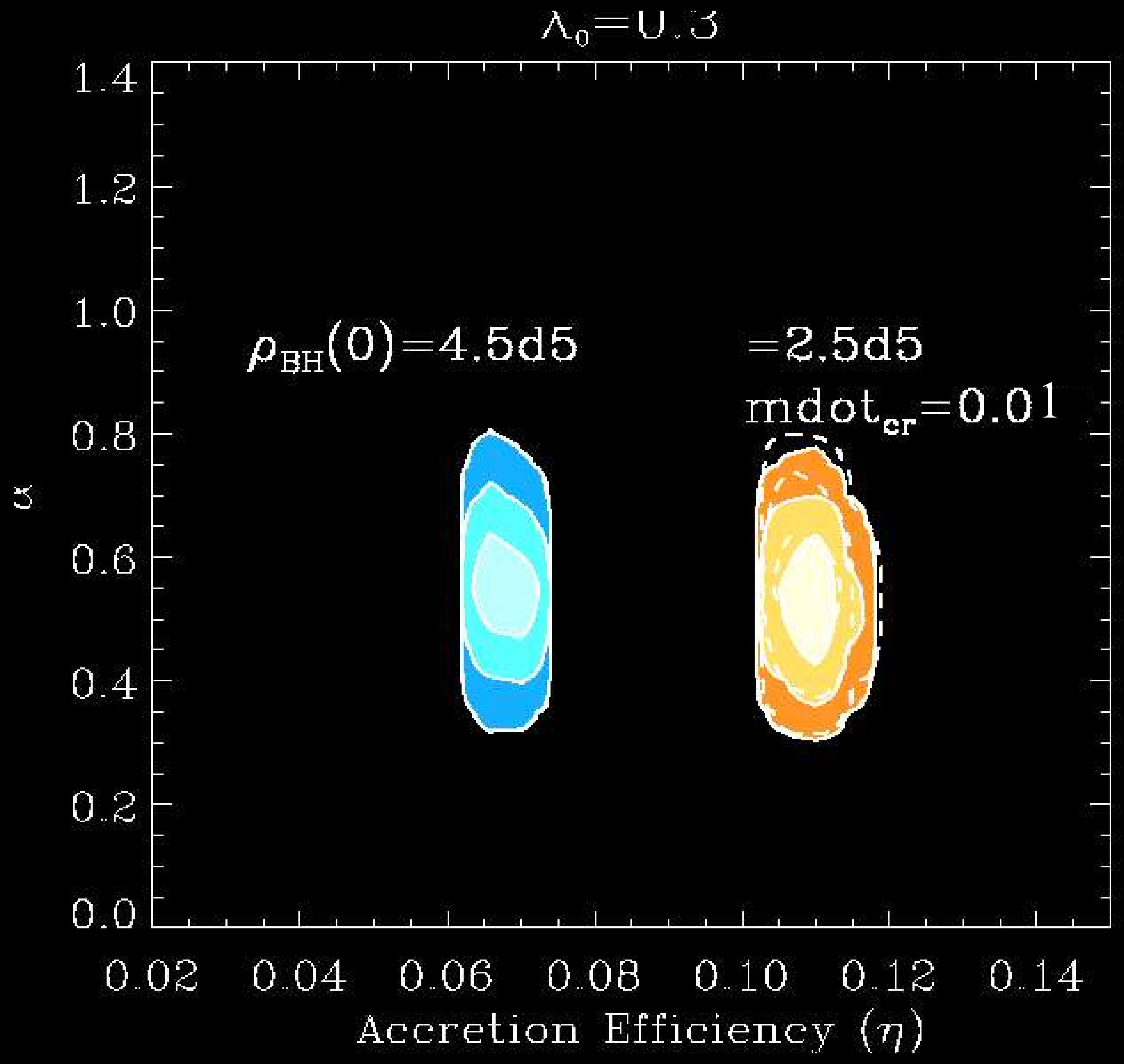


Radiative efficiency constraints



=Radiative efficiency

Radiative efficiency constraints



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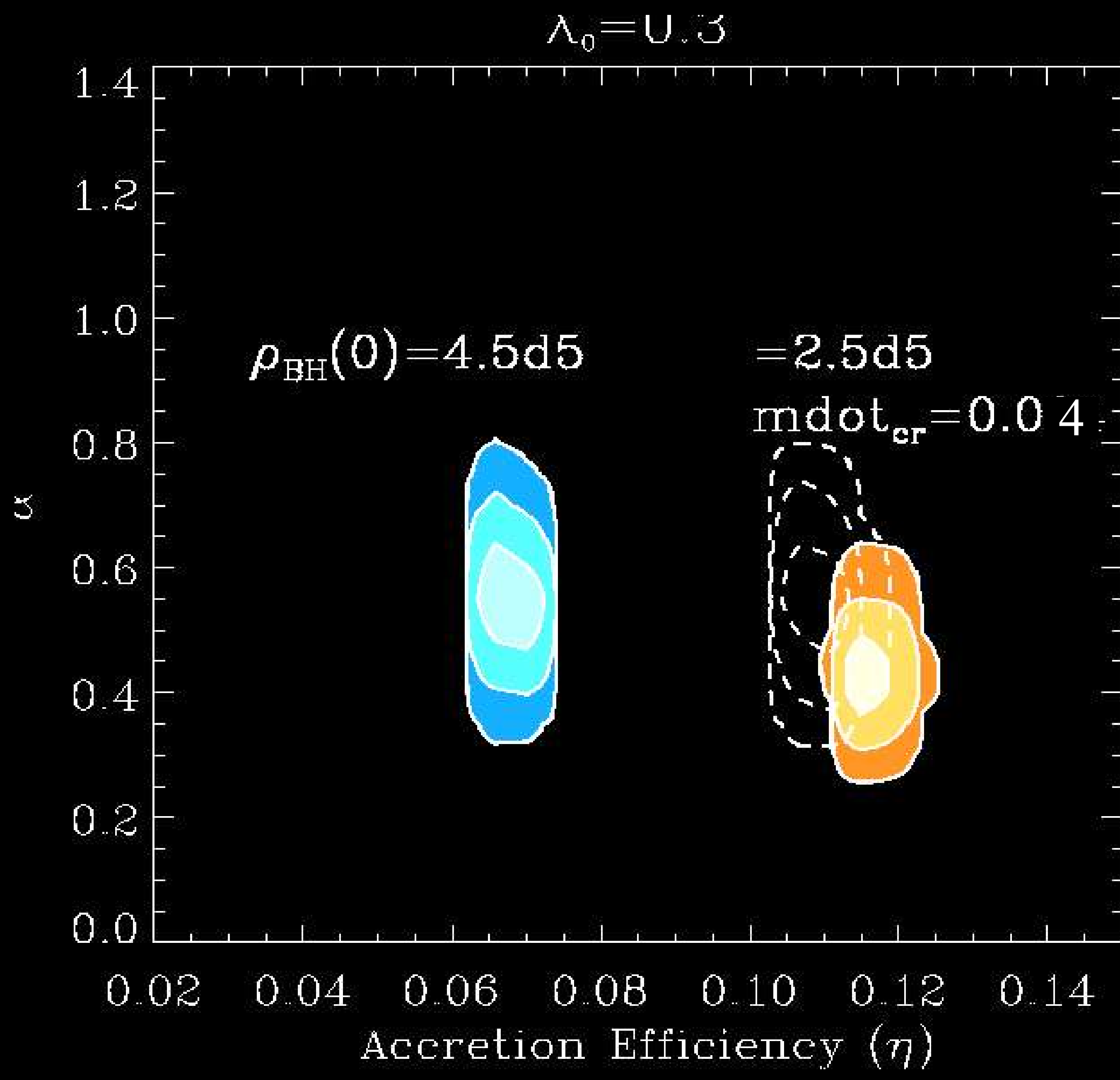
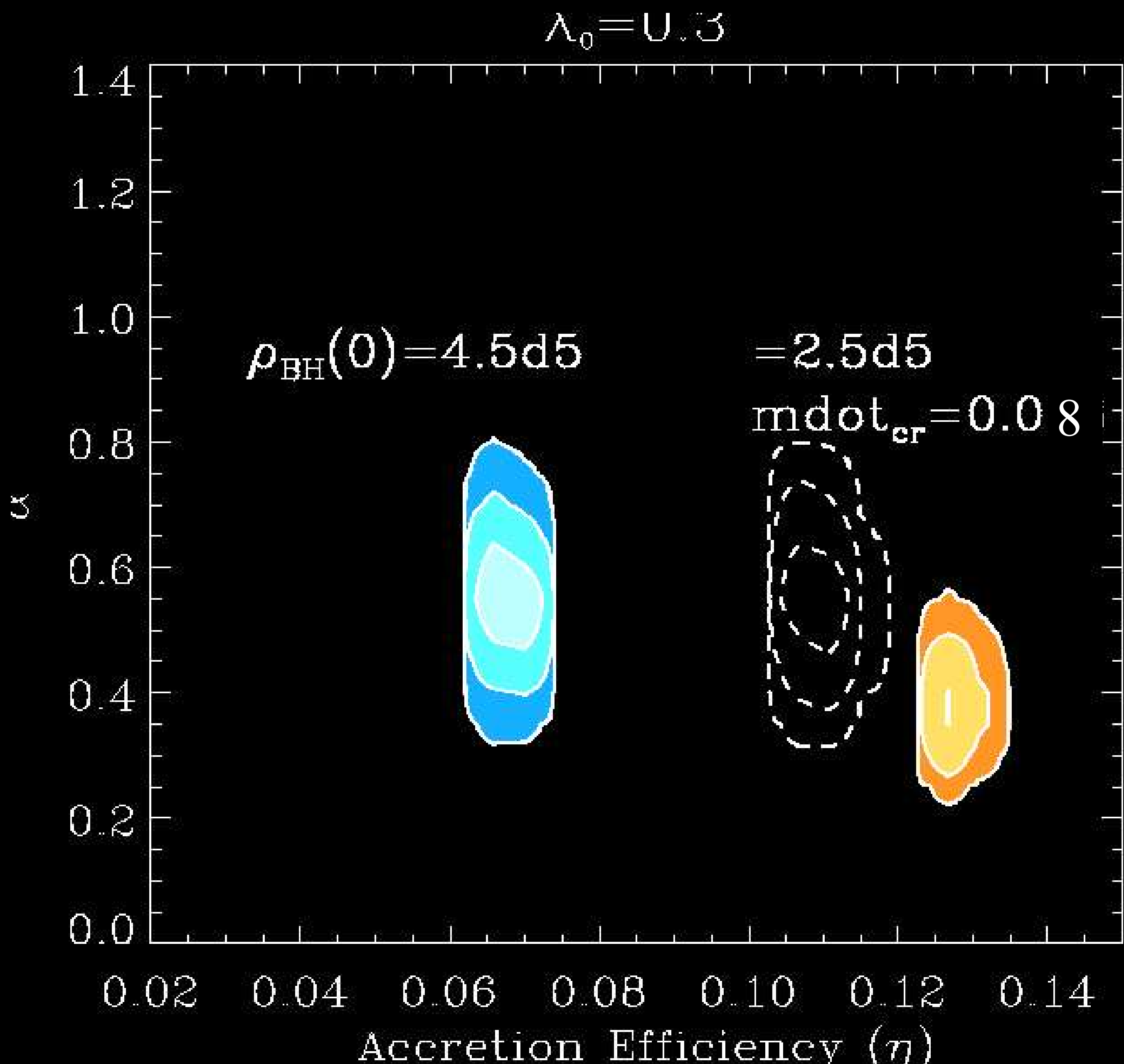
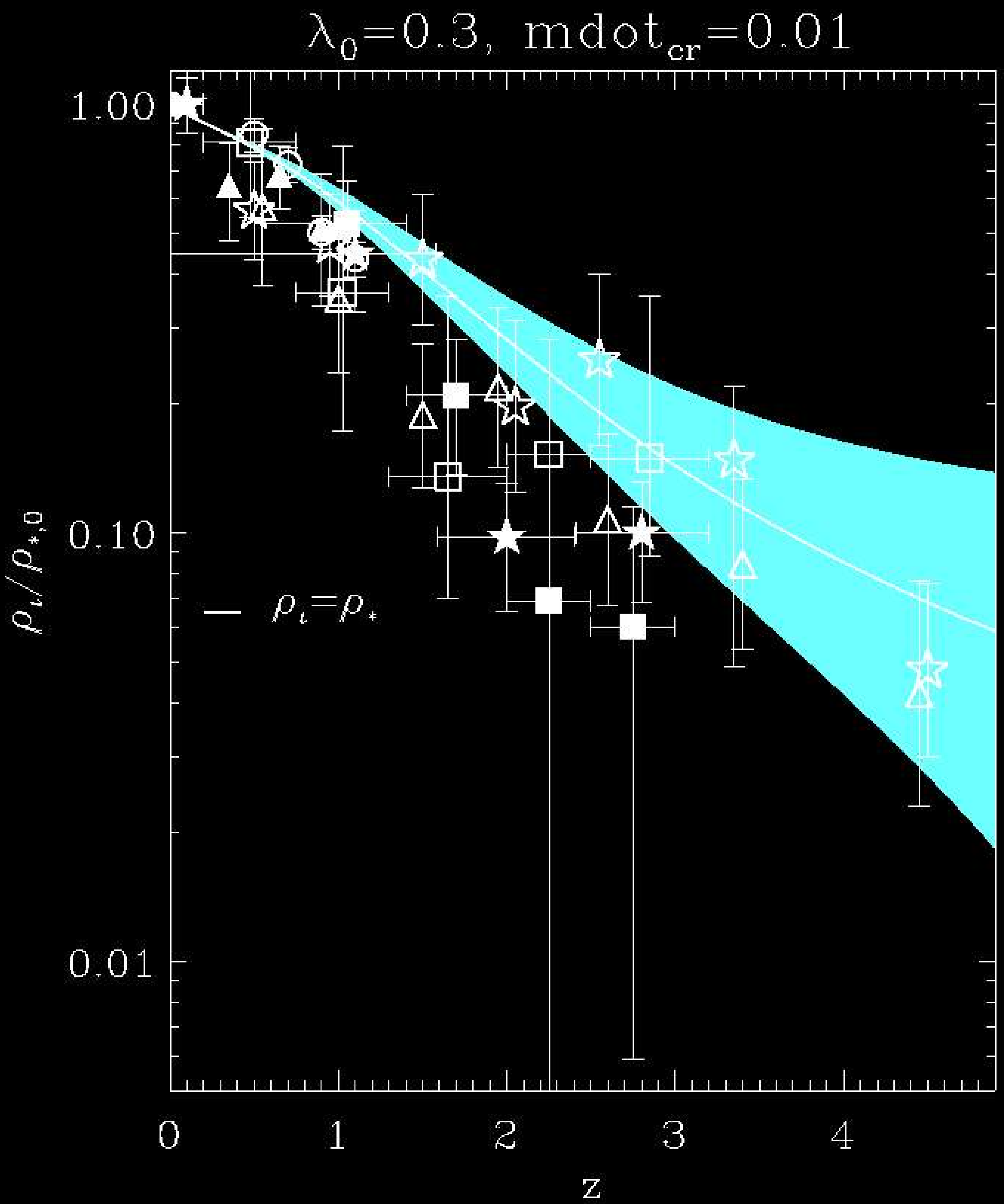
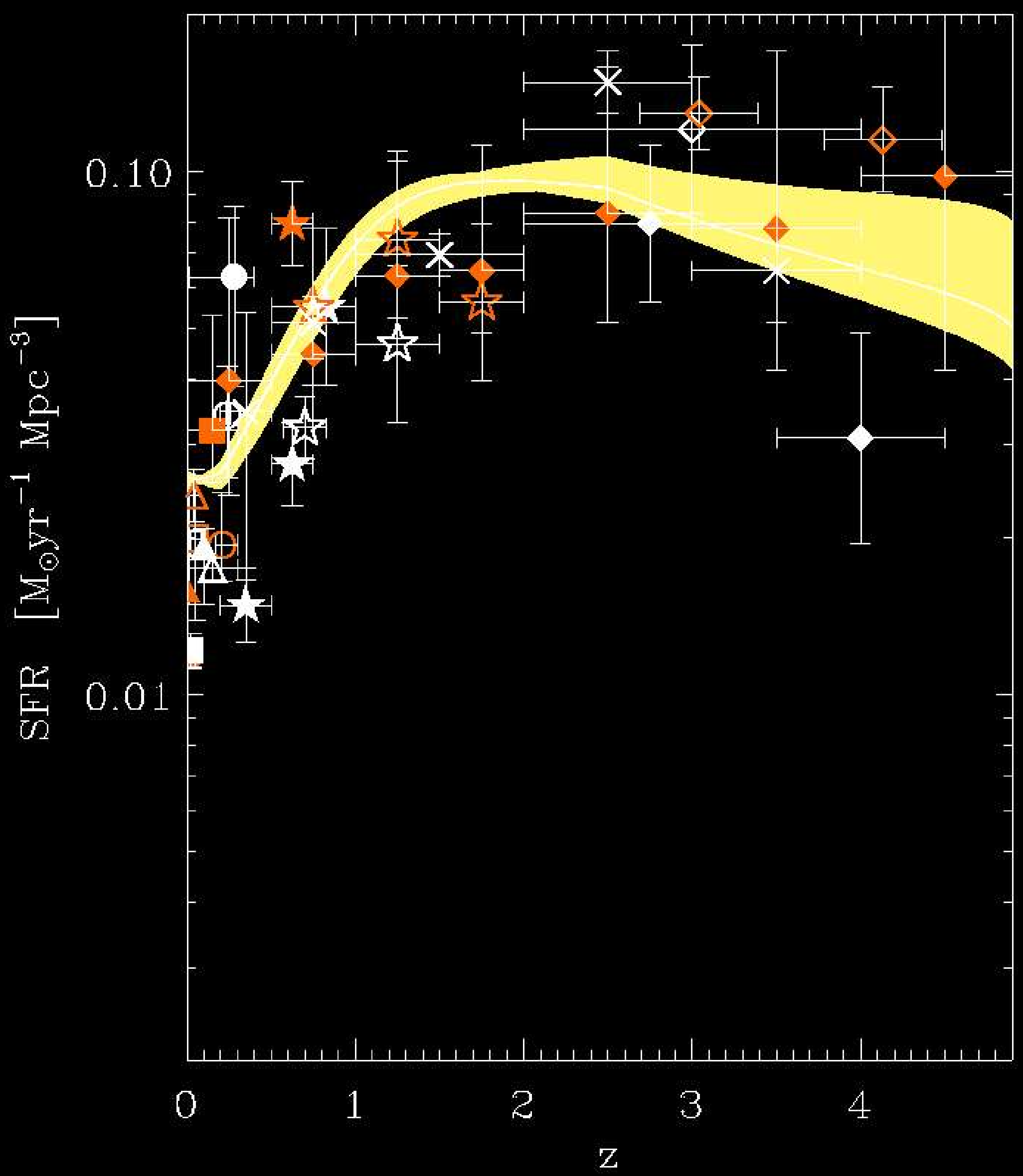


Radiative efficiency constraints



Parallel lives





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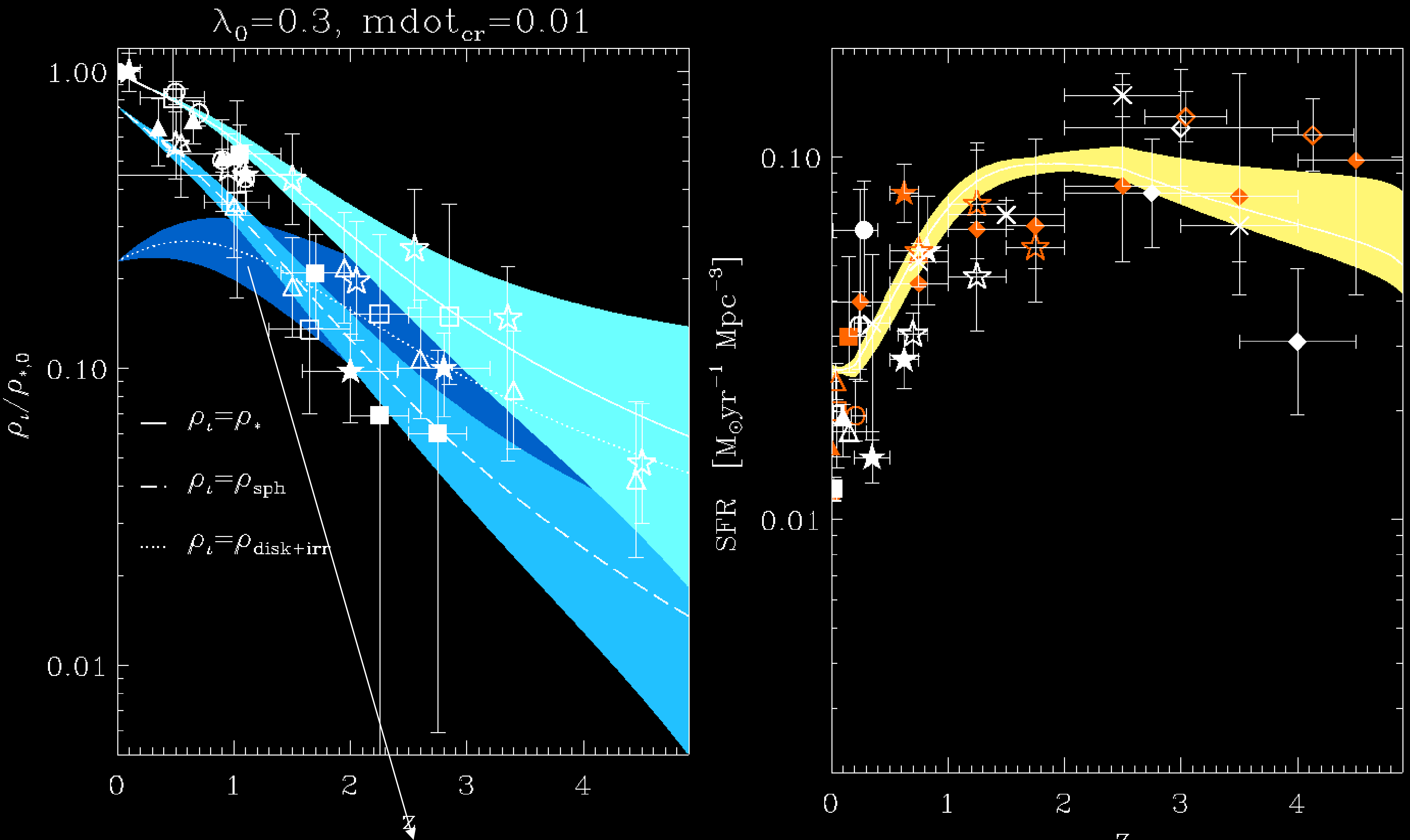
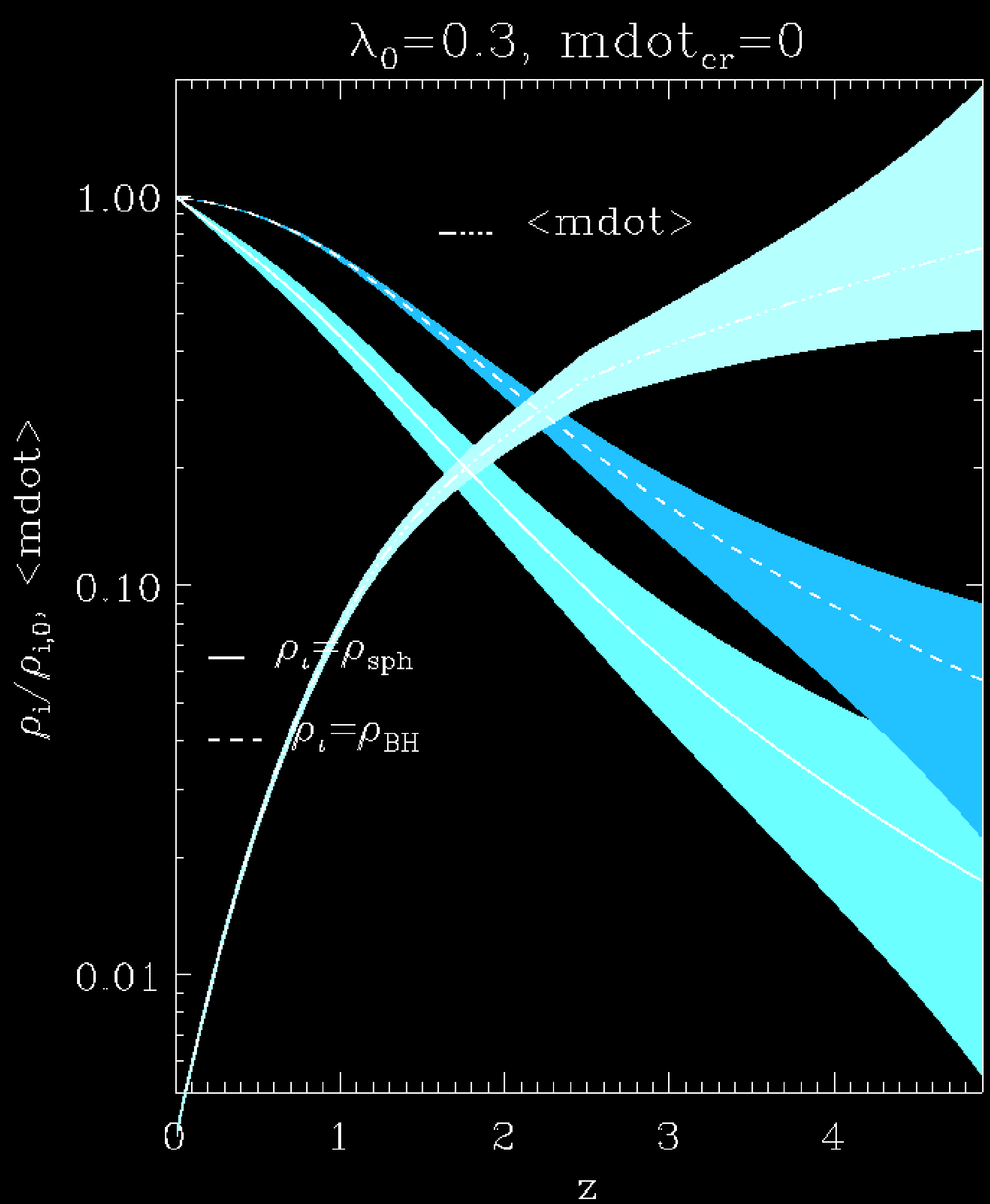
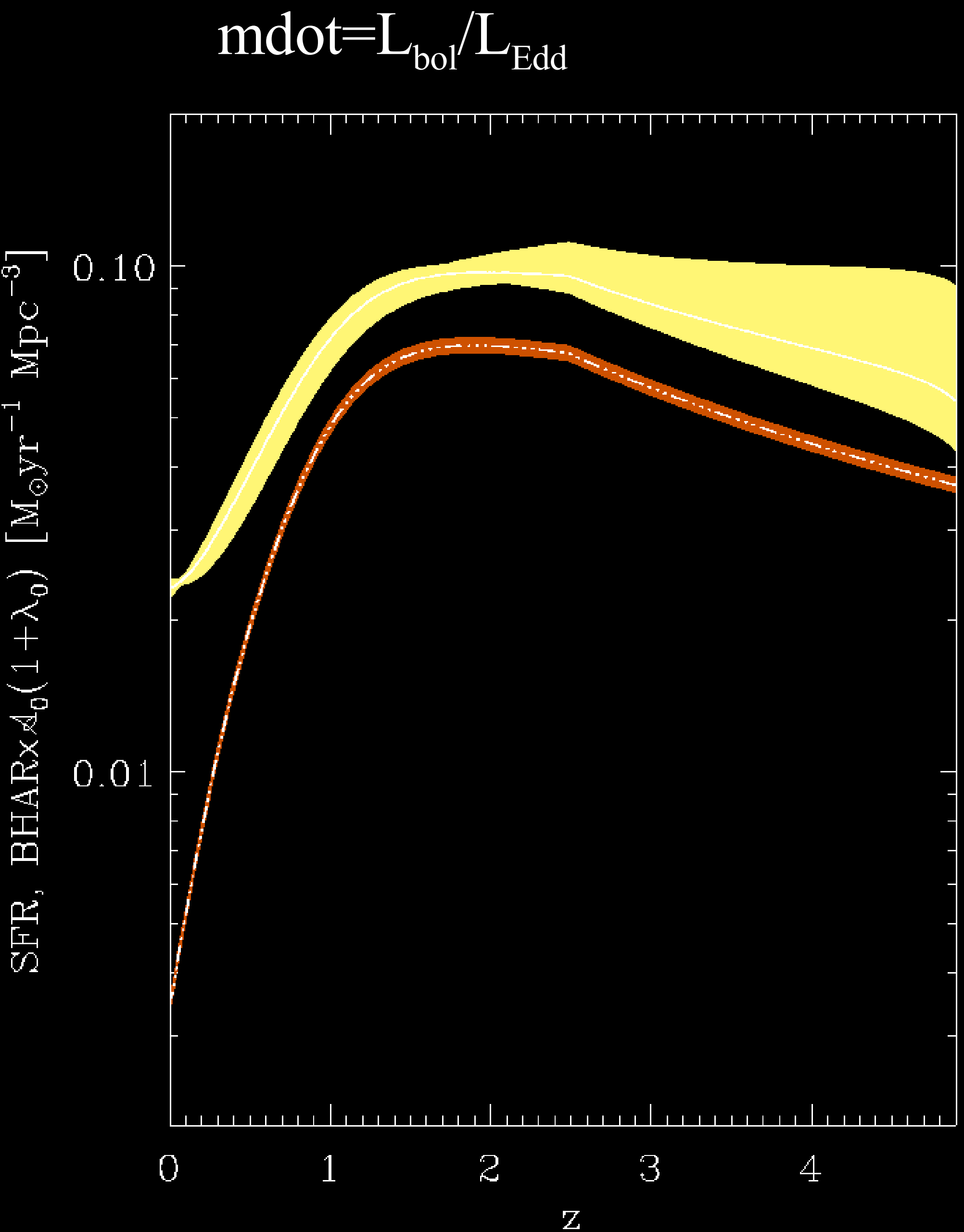


At z~1.5 discs and irregulars start dominating the stellar mass budget

Parallel lives





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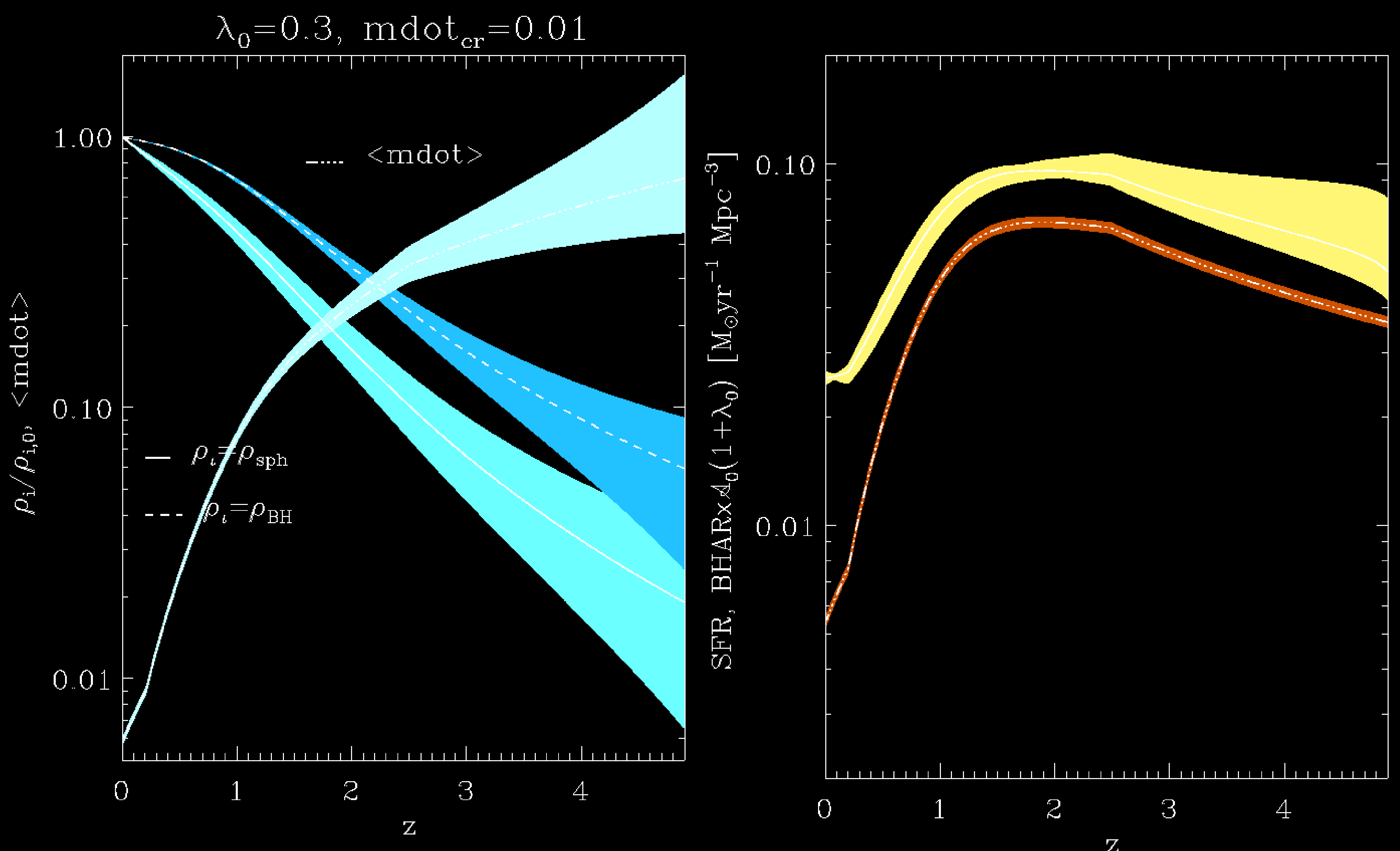

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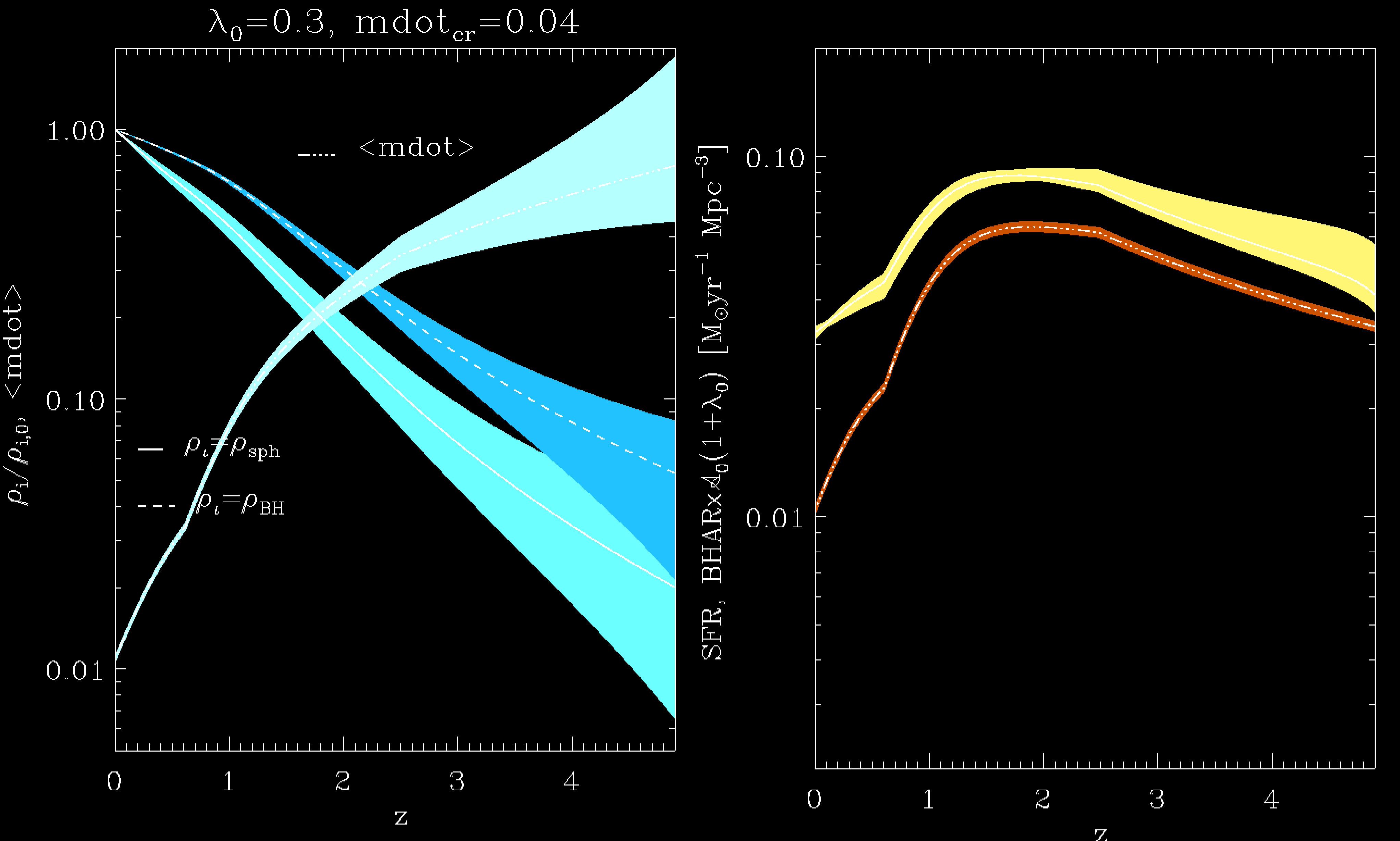


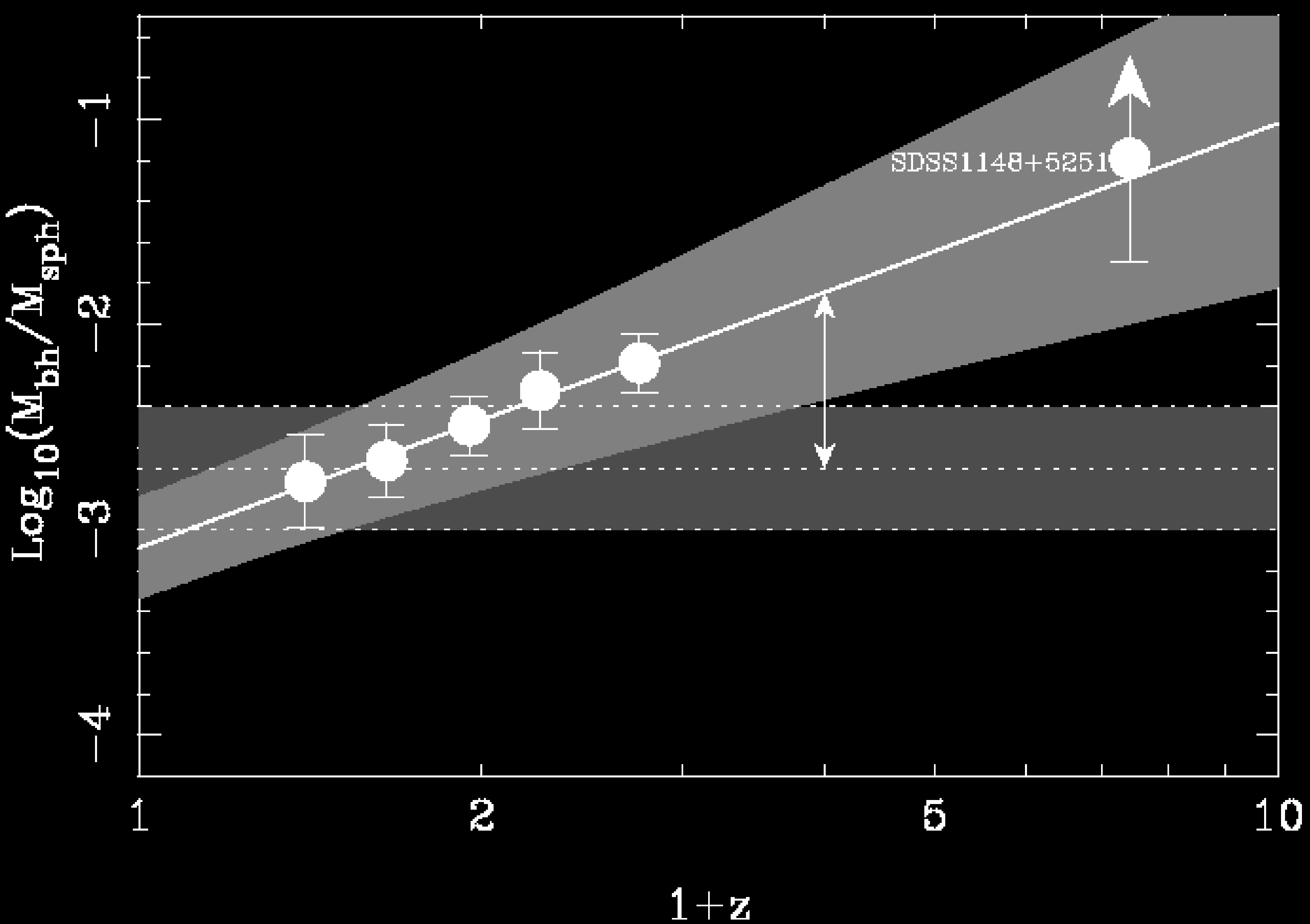
Conclusions I

- Comparing the evolution of SMBH and stellar mass densities it is already possible to put constraints on the evolution of the Magorrian relation, using SMBH as tracers
- We found that for a given host spheroid mass, BH were more massive at higher redshift. At $z=3$, for example, we predict $<M_{BH}>/<M_{sph}> \sim 2.5$ times larger than the local value
- Possibly, we also found evidence for larger fraction of stars in disks and irregulars at higher redshift
- SMBH growth follows spheroid assembly (mergers? see e.g. the simulations by Di Matteo, Springel, Hernquist 2005)
- The estimated accretion efficiency depends linearly on the local BH mass density. Most of SMBH growth occurred in radiatively efficient episodes of accretion

Conclusions II

- The redshift evolution of SMBH mass function can be determined from the joint evolution of X-ray and Radio AGN luminosity functions using the mass-L_X-L_R relationship given by the fundamental plane of black hole activity
- SMBH down-size: most massive object were formed earlier and stopped growing earlier ("anti-hierarchical evolution")
- Galaxies down-size (Cowie 1996+…): the highest mass galaxies stop forming stars at the earliest times
- The largest black holes are the first to enter the radiatively inefficient accretion regime, probably dominated energetically by kinetic energy output (cfr. low/hard state of X-ray binaries)
- The feedback from low luminosity AGN jets starts dominating high mass objects first and then objects of progressively lower mass

Constraints from radio galaxies/QSOs



(McLure et al. 2005)