Refining the Soltan argument: the parallel growth of black holes and galaxies

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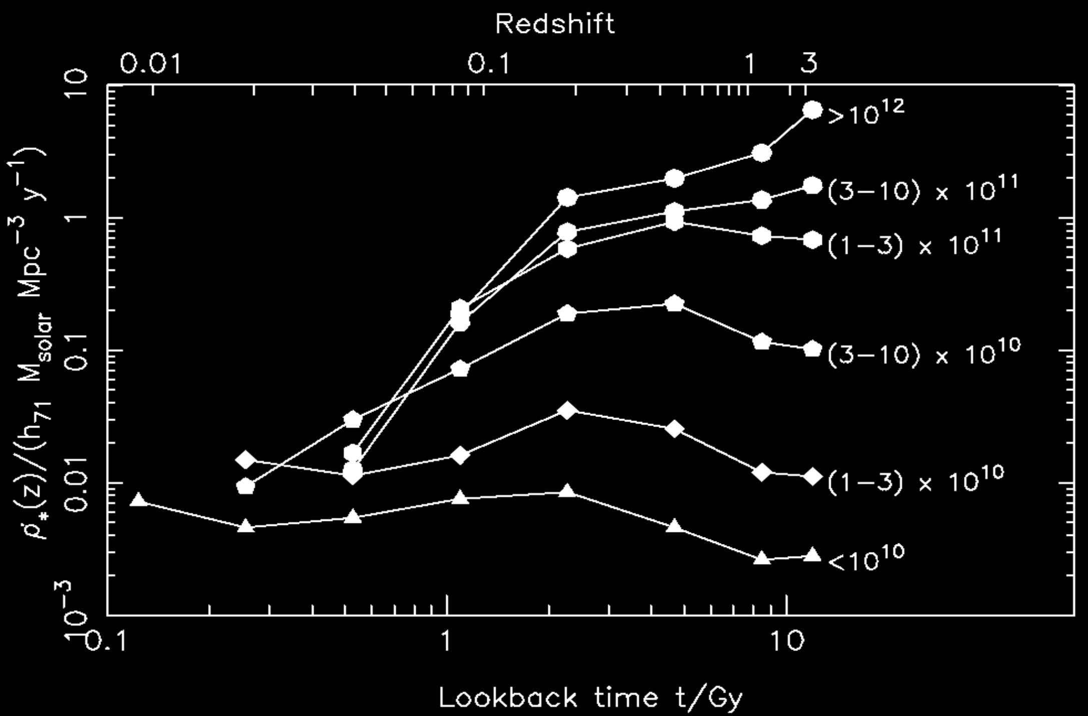
SMBH in the nuclei of nearby galaxies: how did they get there?

- Observed local (z=0) correlations (M-σ, Magorrian) are often used as indirect 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 and host spheroid growth? Evolution of SMBH/host galaxy mass function; Evolution of SMBH/host galaxy growth rate (SFR/BHAR)
- Integral constraints: The Soltan argument and the average accretion efficiency

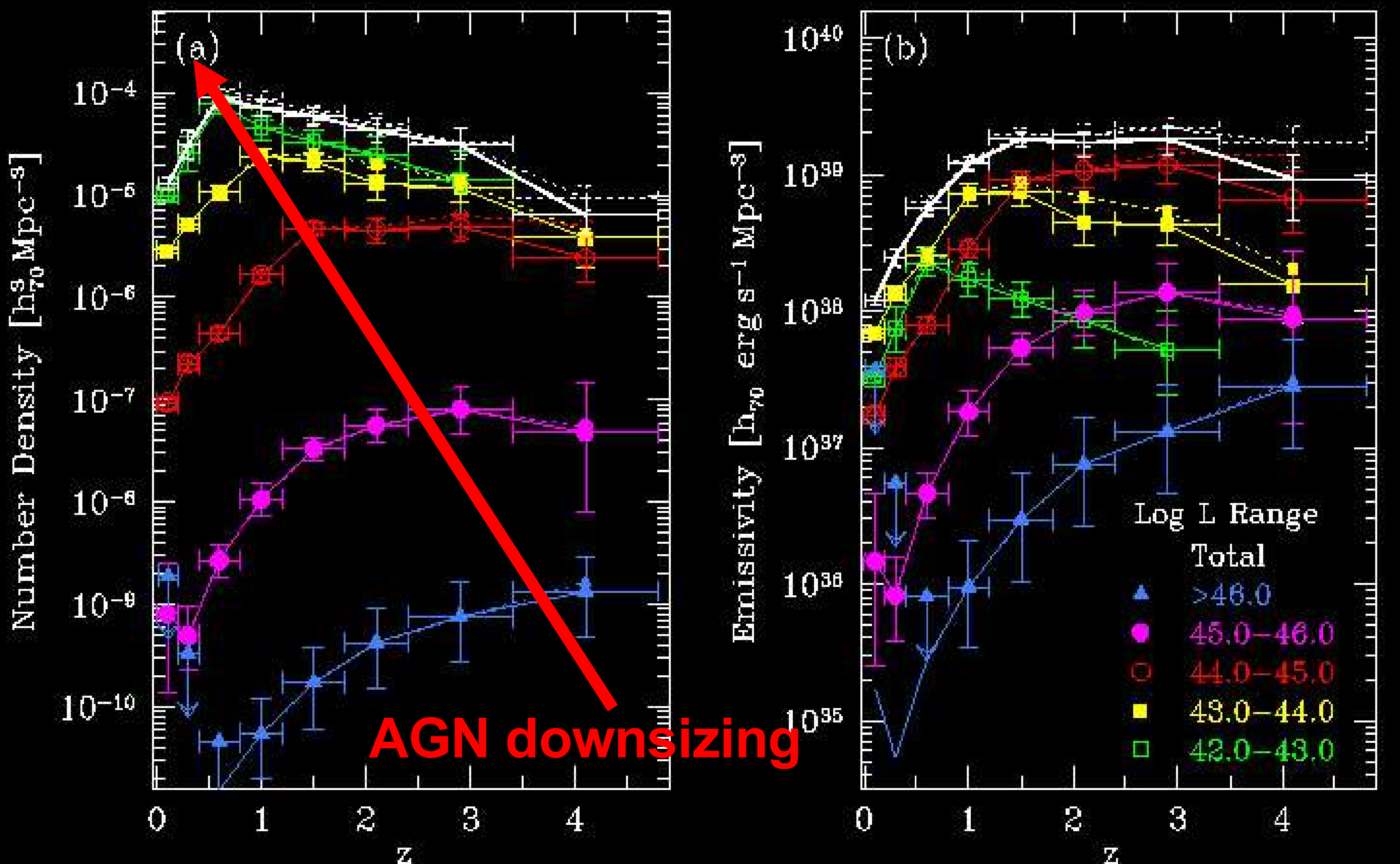
Downsizing (in galaxy evolution)

- DOWNSIZING: The most active star forming galaxies have smaller and smaller mass at progressively lower redshift (Cowie et al. 1996)
- ANTI-HIERARCHICAL: Larger objects form (assemble) later
- NOTE: In principle, the observational fact that the most massive ellipticals have the oldest stellar population does not imply an anti-hierarchical behaviour (De Lucia et al. 2005)



(Heavens et al. 2004; SDSS)

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

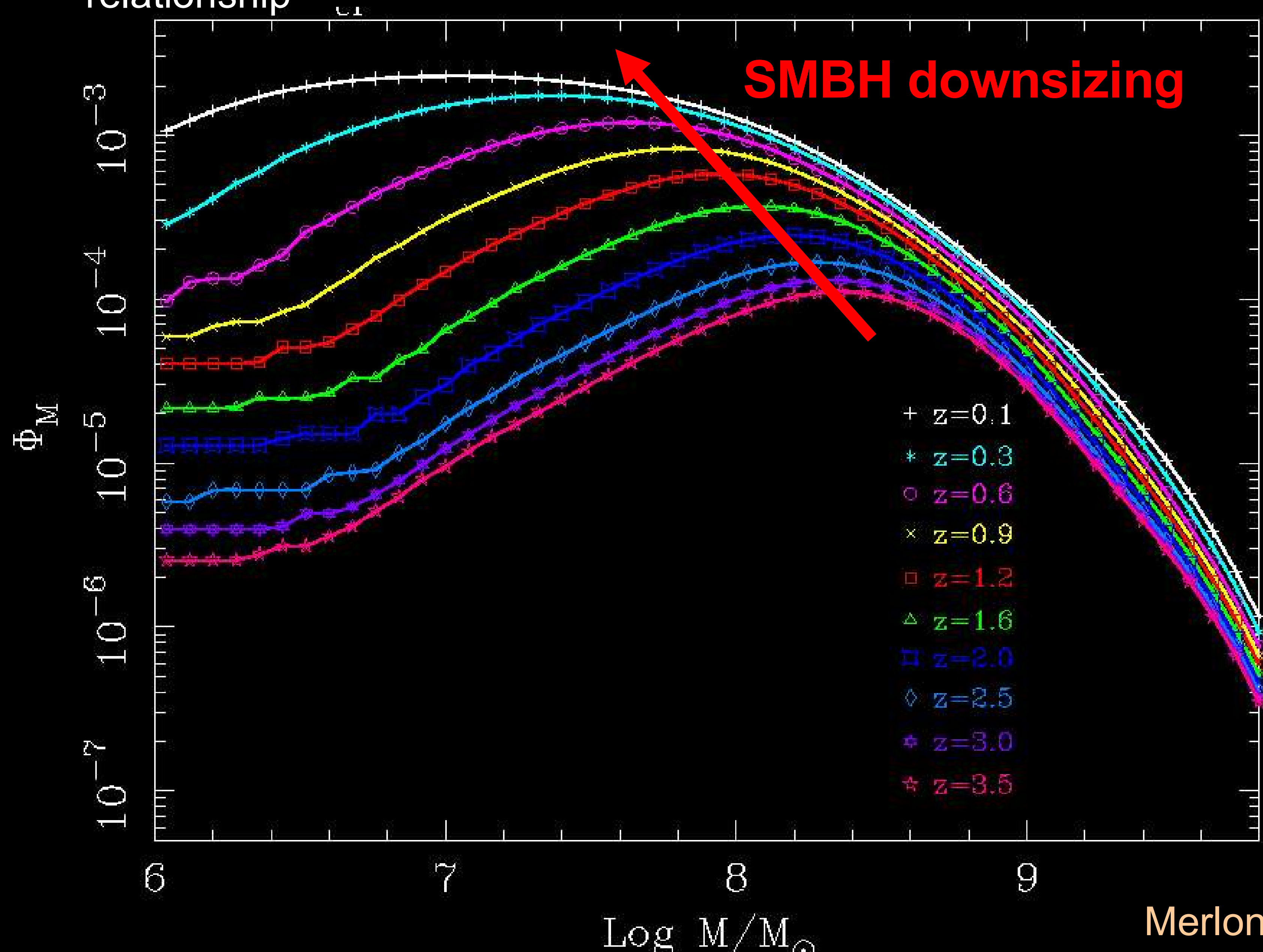


(Hasinger et al. 2005)

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

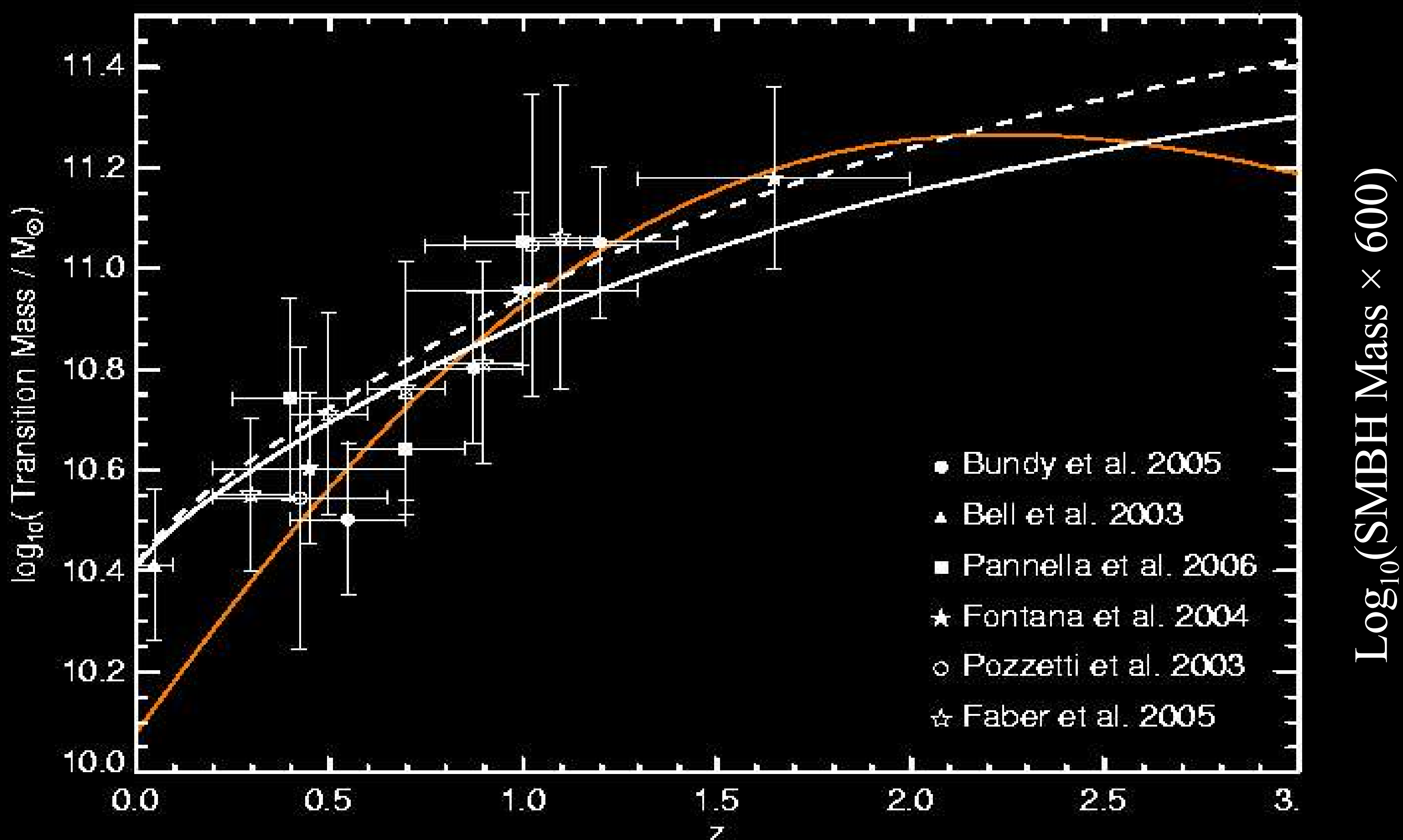
Mass function evolution

Mass/accretion rate degeneracy broken with 'fundamental plane' relationship



Merloni (2004)

Mass function evolution



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!)

Radiative efficiency

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

Bolometric luminosity *Accretion rate* *BH growth rate*

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

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

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

Simultaneous growth of BH and galaxies

(Merloni, Rudnick and Di Matteo 2004)

$$\mathrm{BHAR}(z) = \Psi_{\mathrm{BH}}(z) = \int_0^{\infty} \frac{(1-\epsilon)L_{\mathrm{bol}}(L_X)}{\epsilon c^2} \phi(L_X, z') dL_X$$

Average radiative efficiency

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

~0.0012 (Magorrian rel.)

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

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

$\lambda(z=0) \sim$ **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 tracers of the spheroid stellar mass

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

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

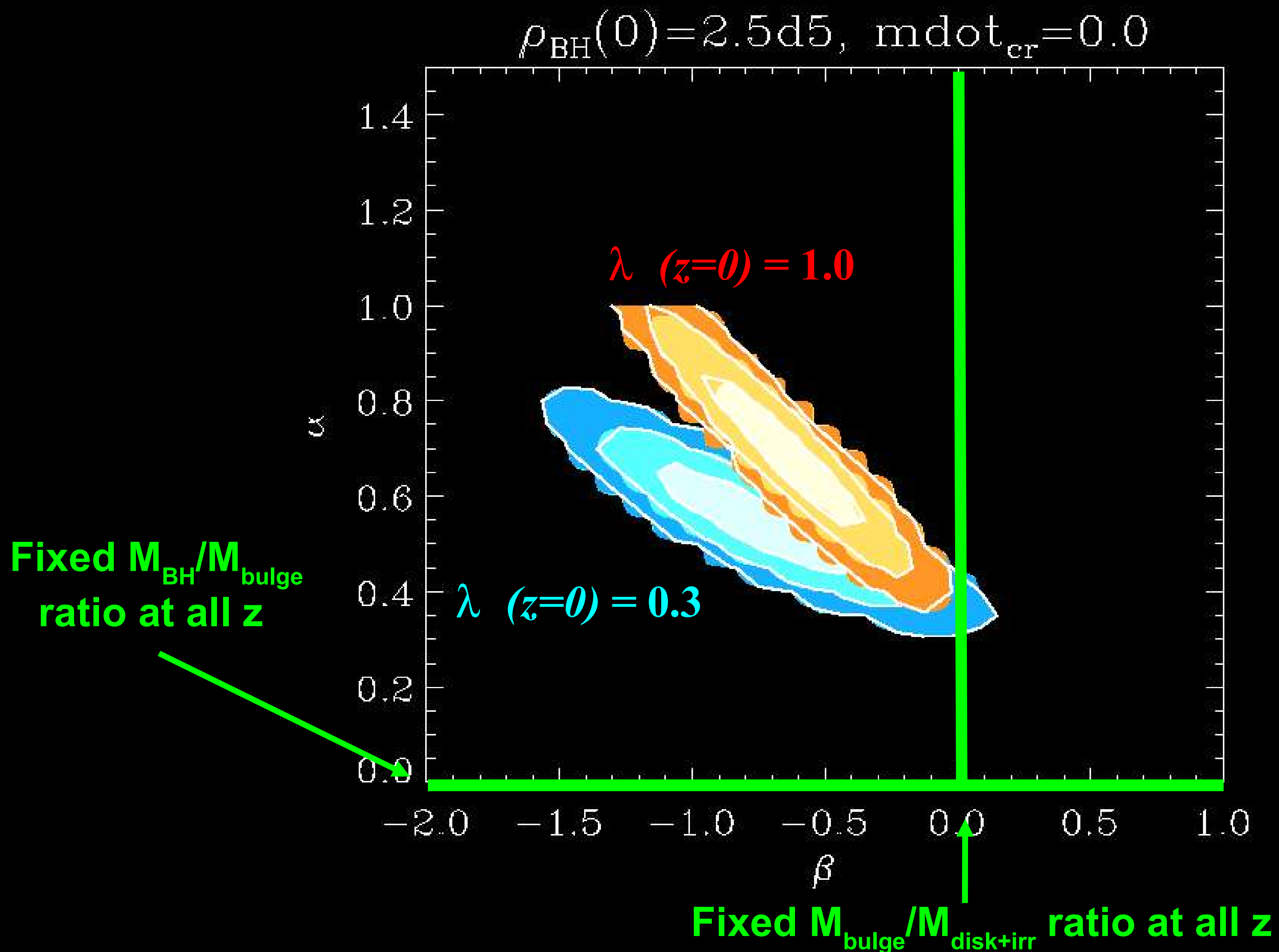
Fractional stellar mass loss (~30% in 13 Gyr)

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

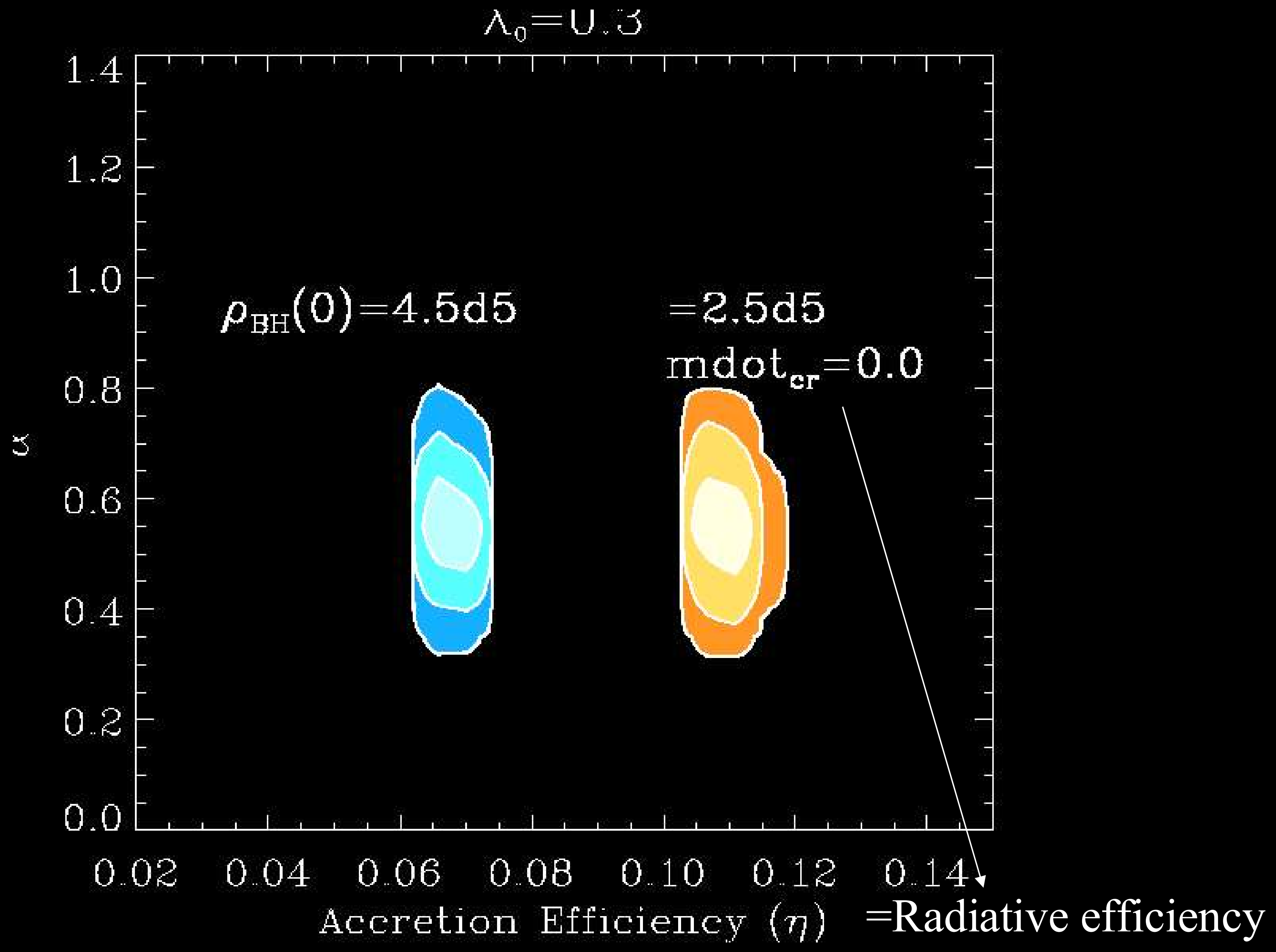
Simultaneous growth of BH and galaxies: integral constraints

- 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 $z=6$

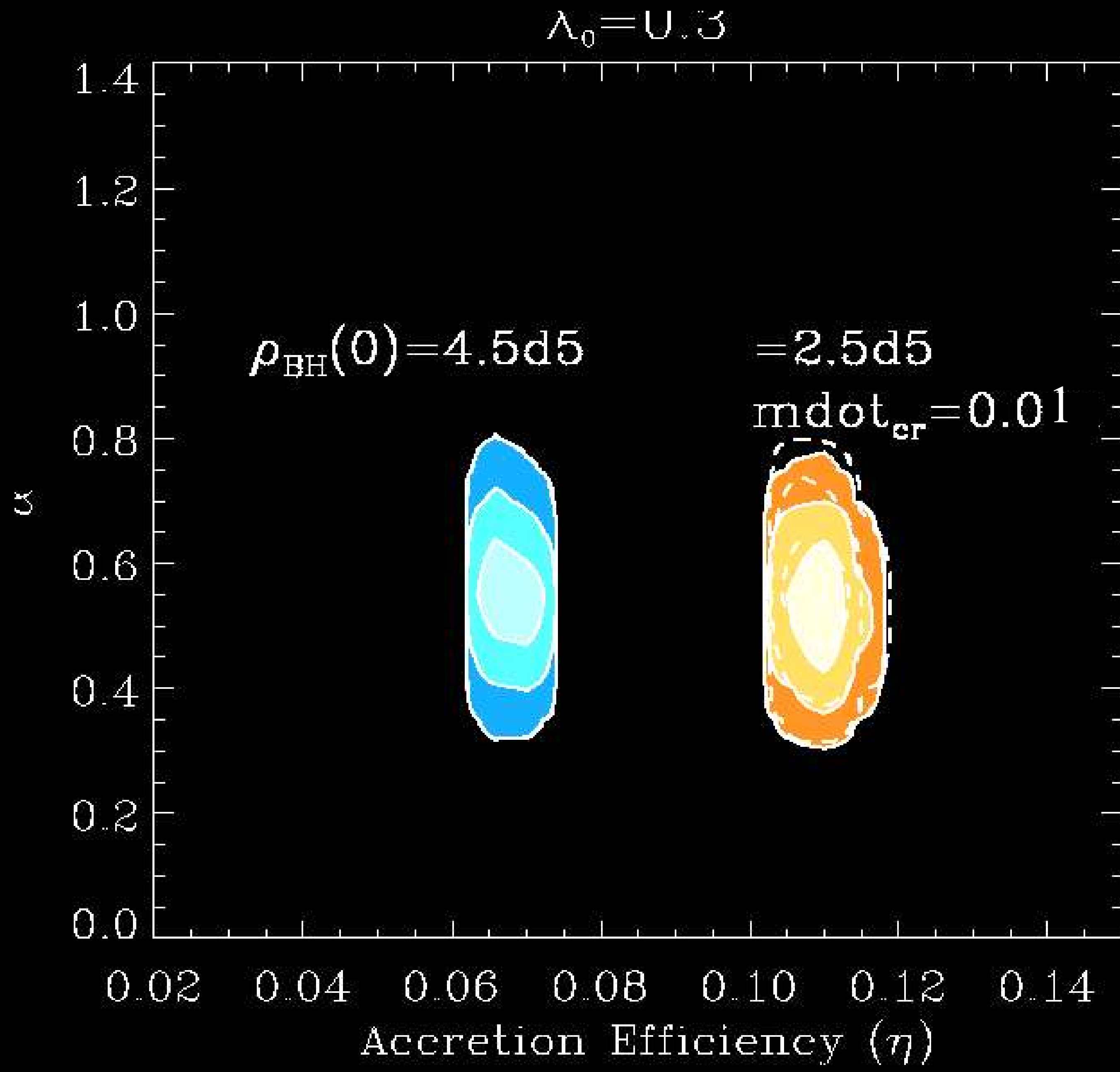
M_{BH}/M_{bulge} increases with redshift



Radiative efficiency constraints



Radiative efficiency constraints



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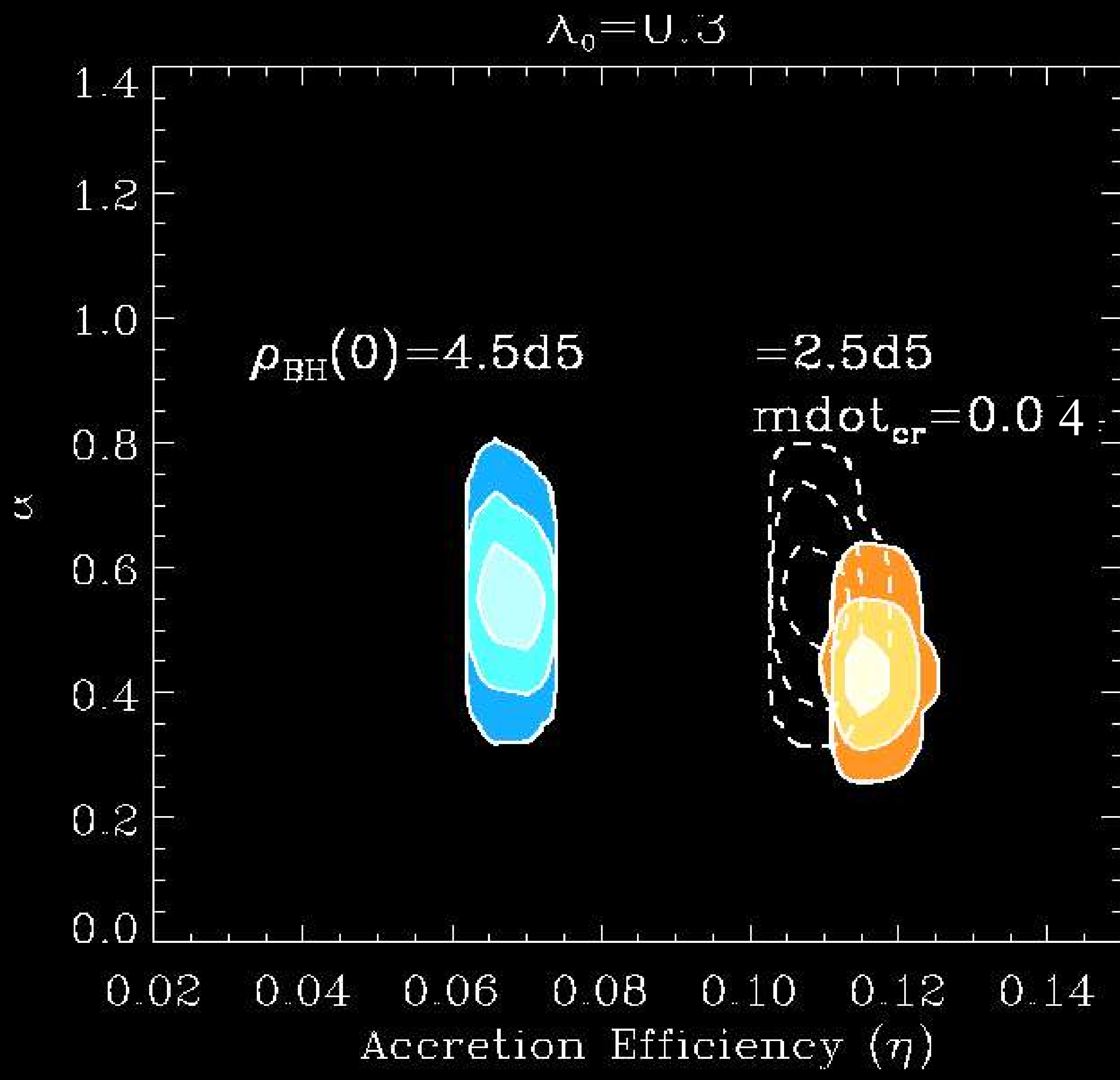
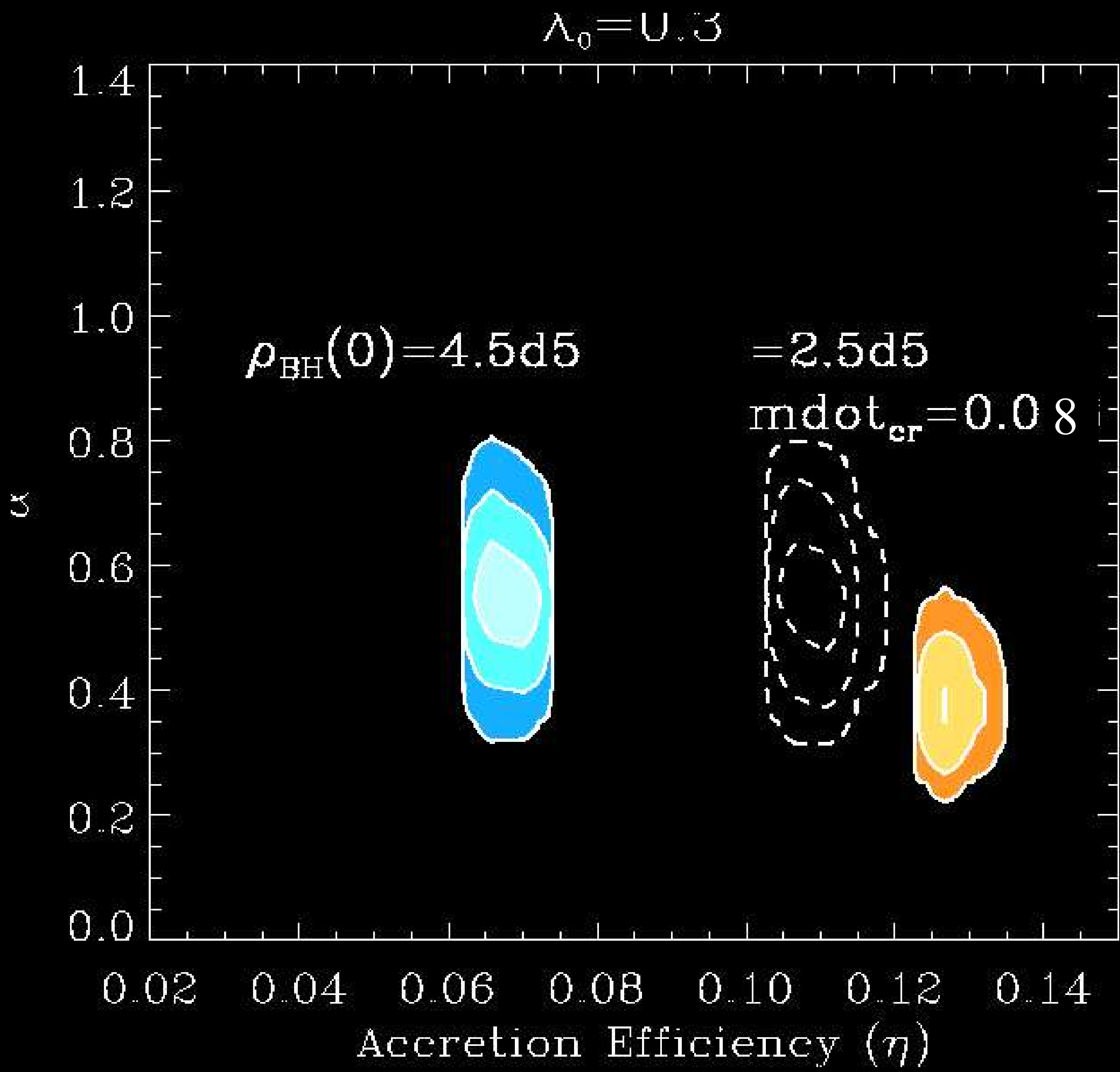
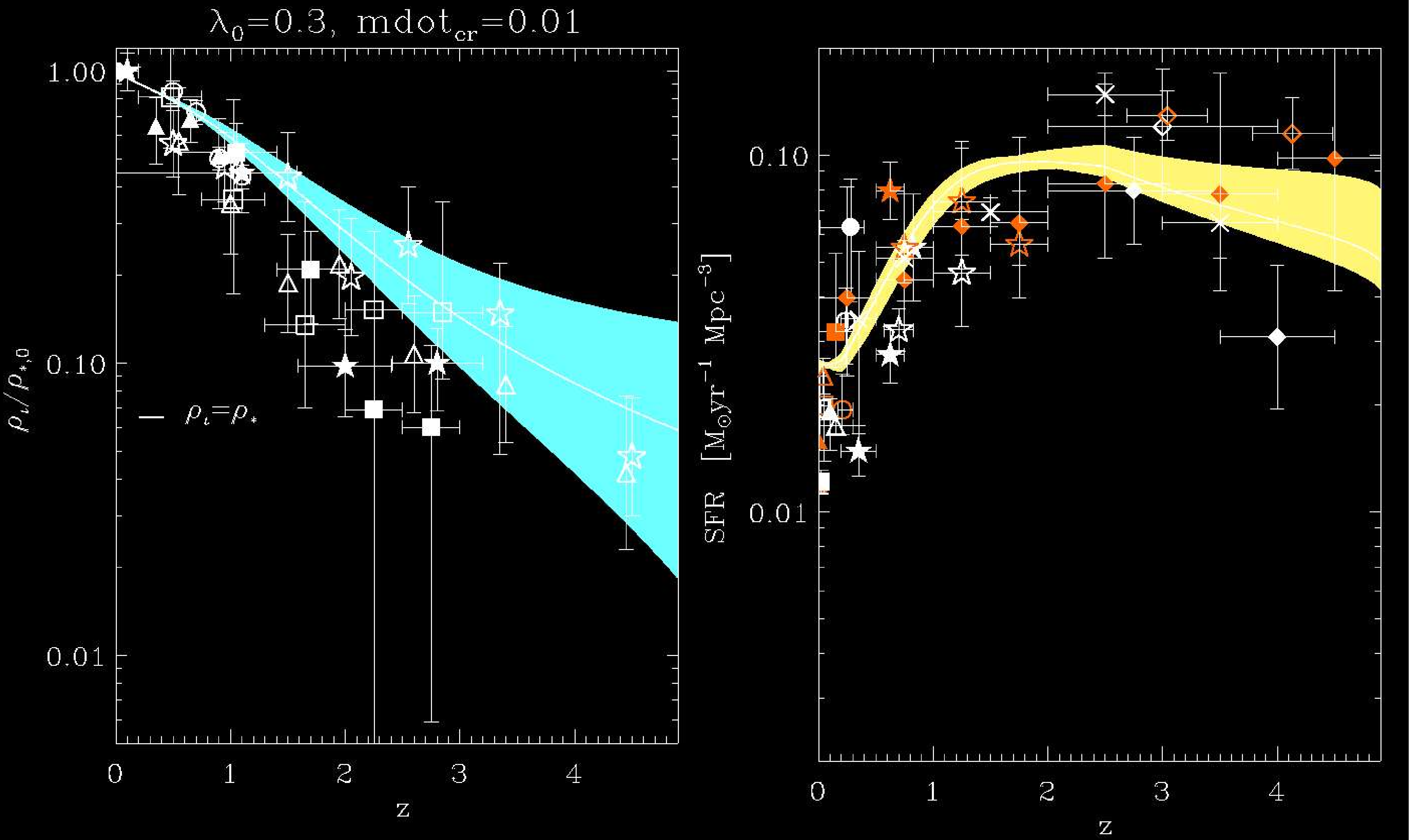


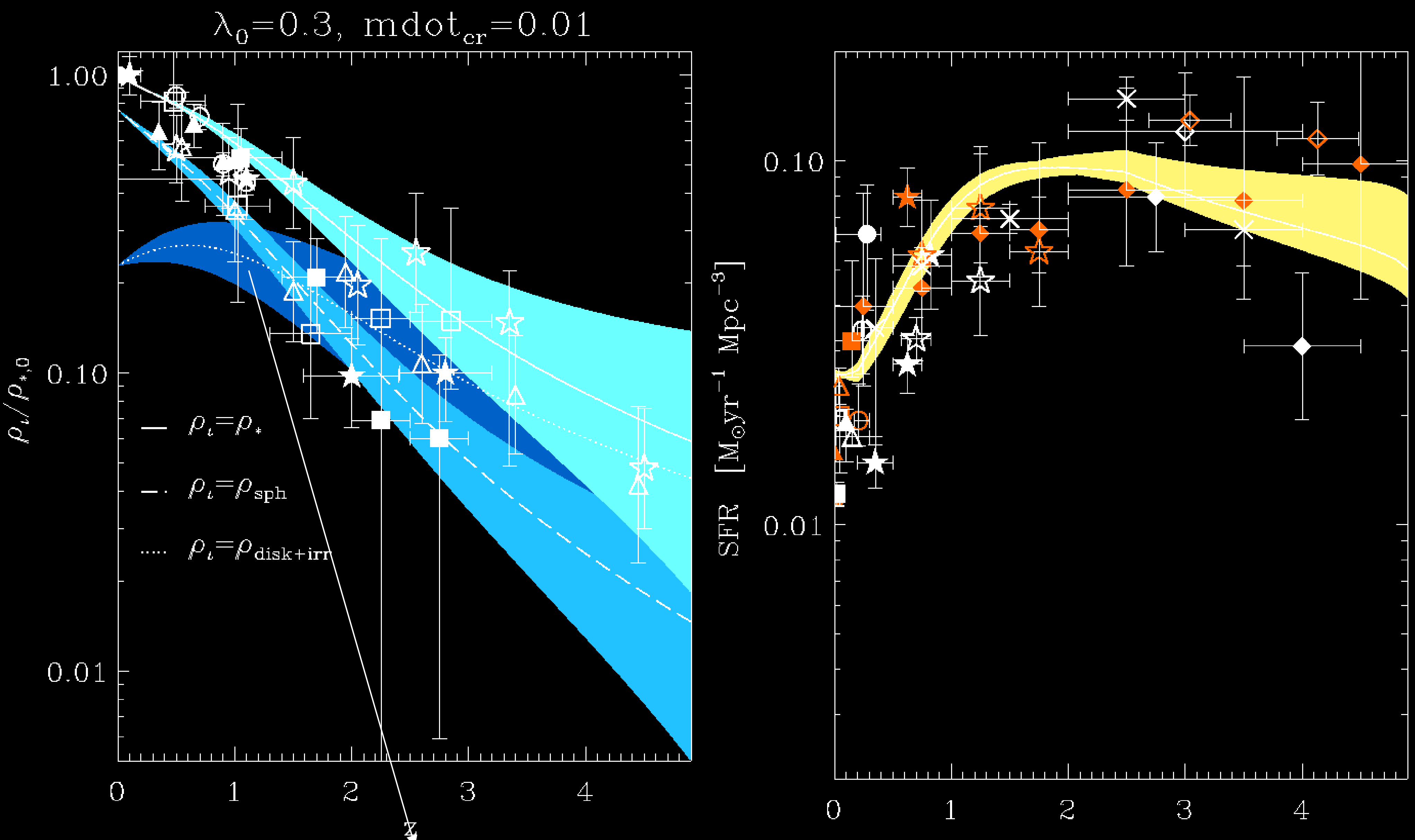
Radiative efficiency constraints



Parallel lives

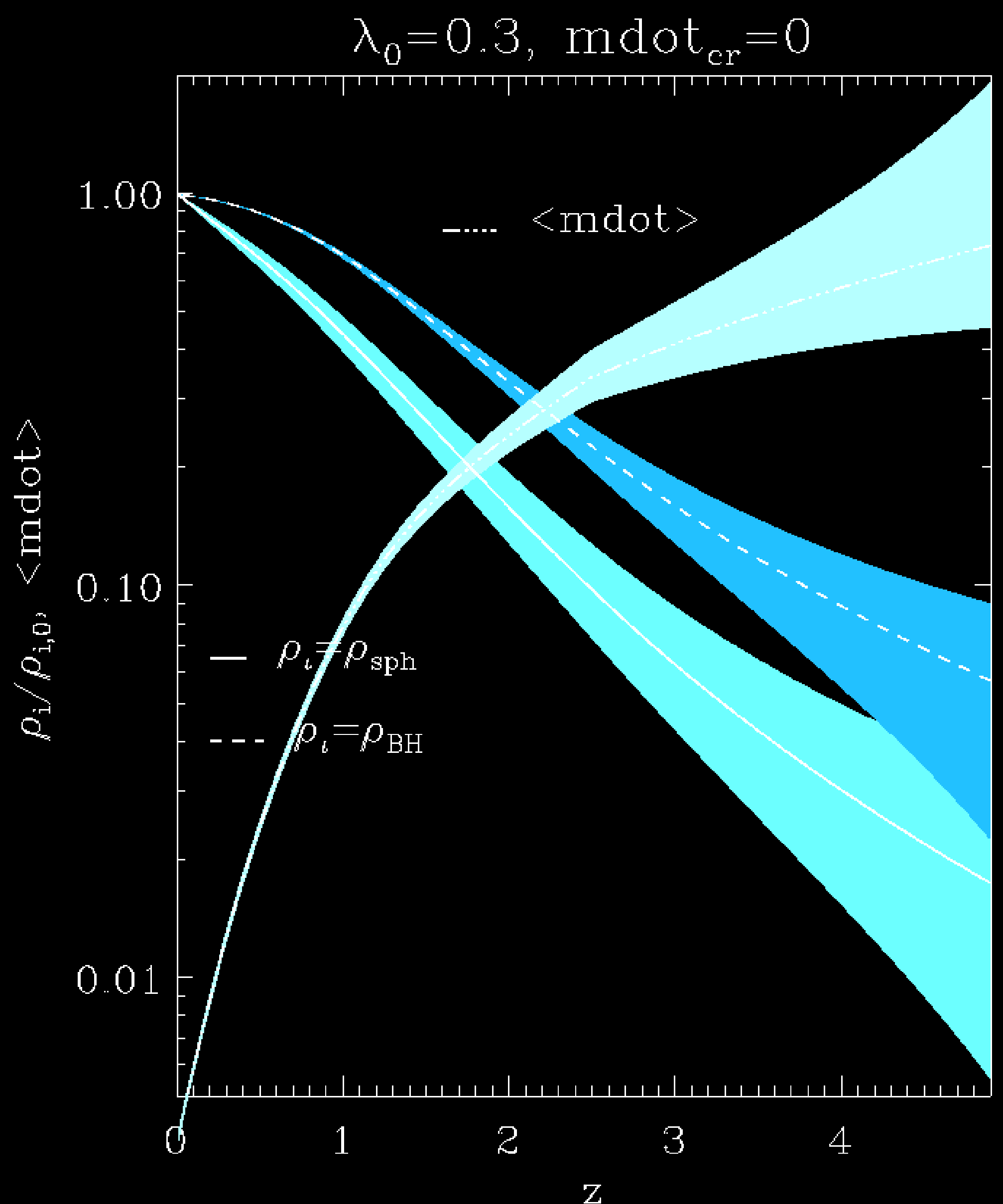


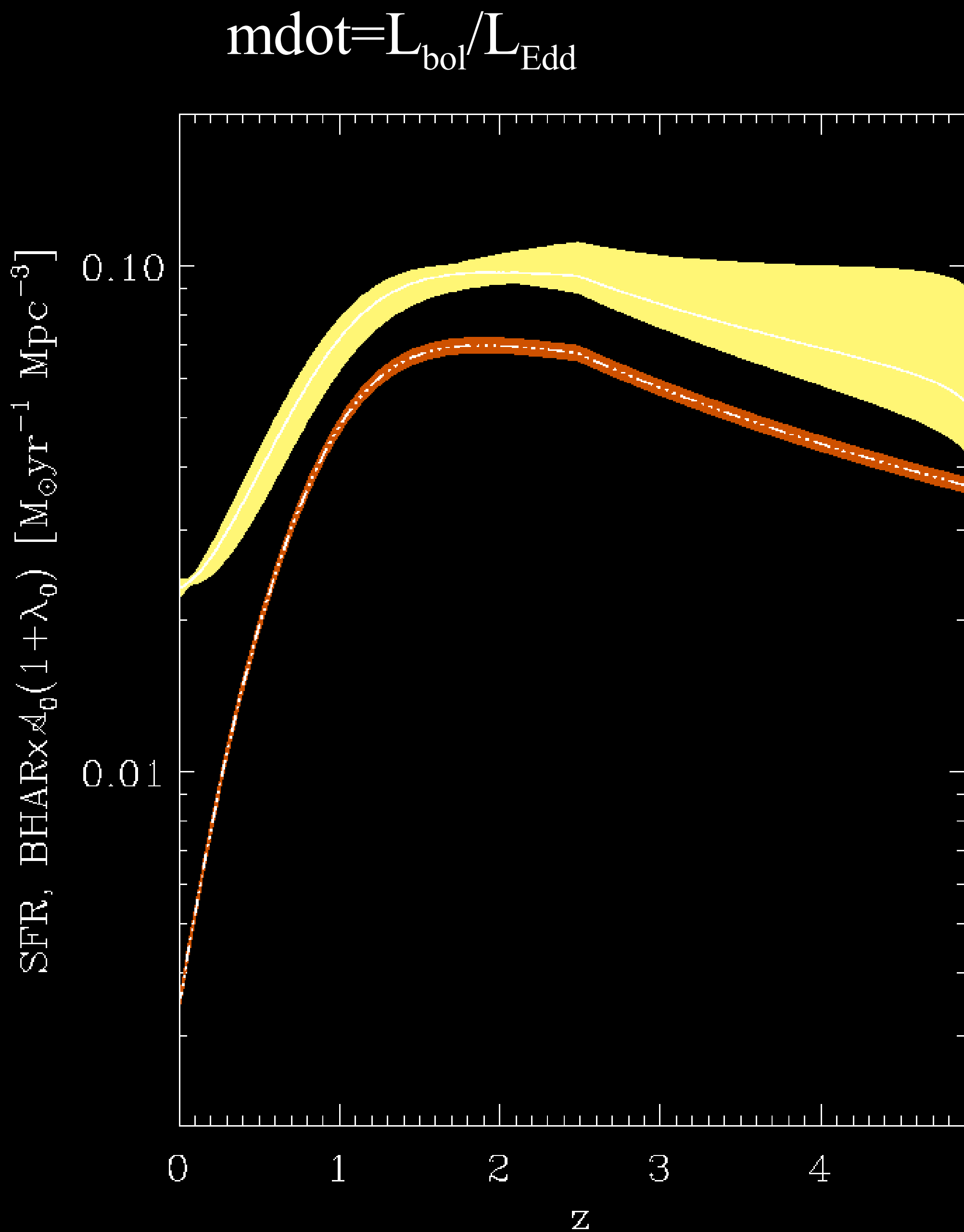
Parallel lives



At $z{\sim}1.5$ discs and irregulars start dominating the stellar mass budget

Parallel lives





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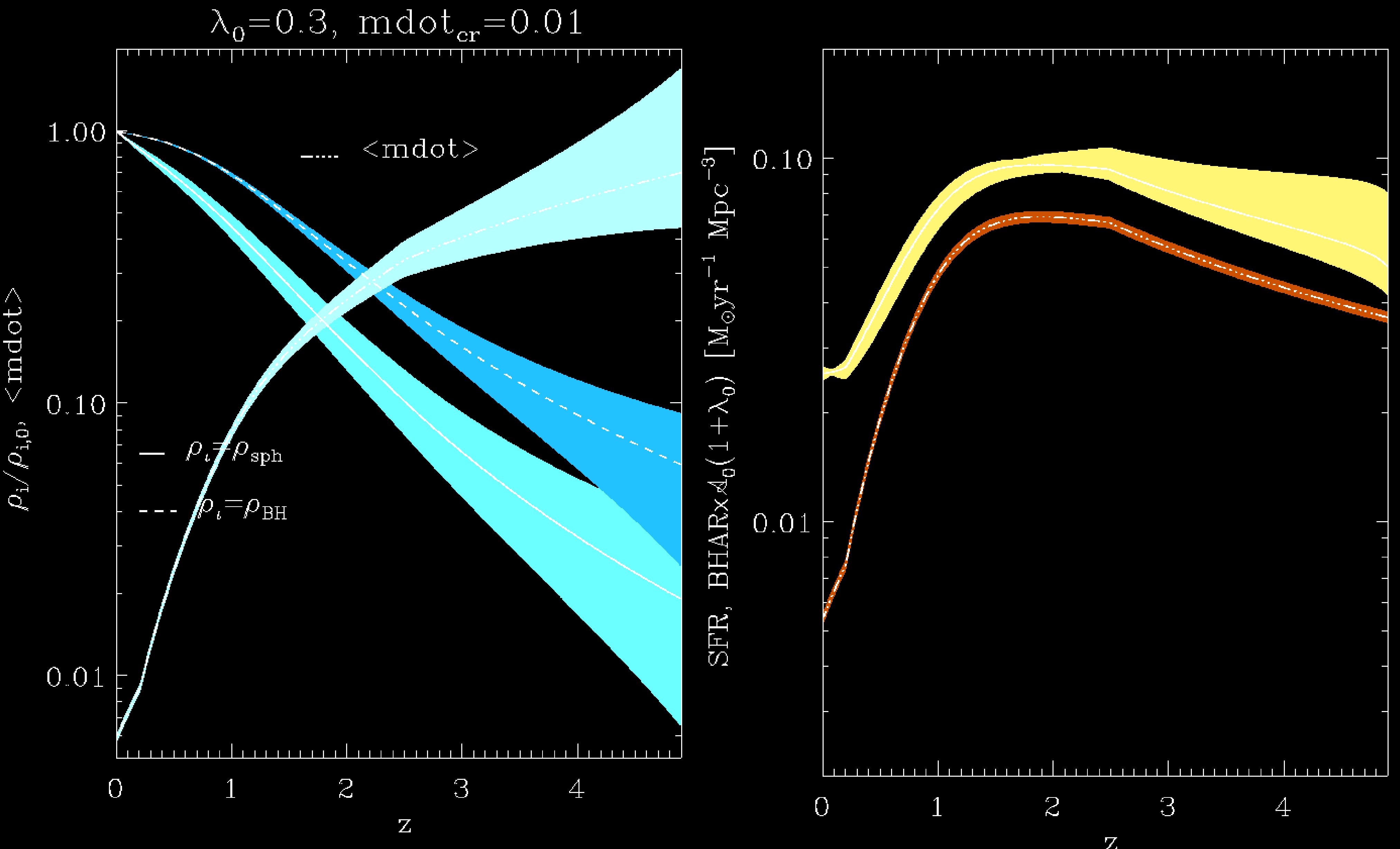

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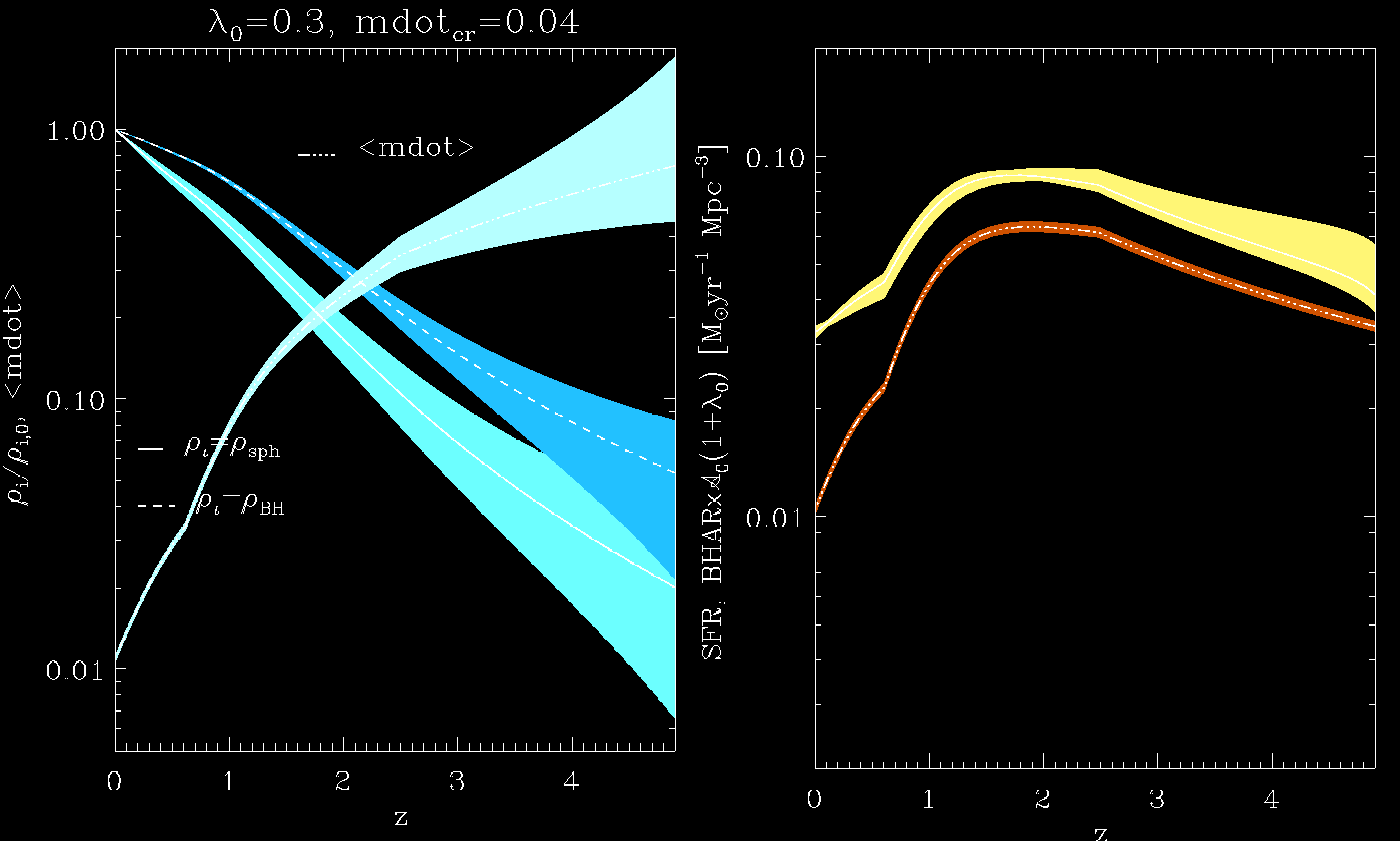

Conclusions

- 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 $\langle M_{BH}\rangle/\langle M_{sph}\rangle \sim 2.5$ times larger than the local value
- Possibly, we also found evidence for larger fraction of stars in disks and irregulars at higher redshift
- The estimated accretion efficiency depends linearly on the local BH mass density. Most of SMBH growth occurred in radiatively efficient episodes of accretion