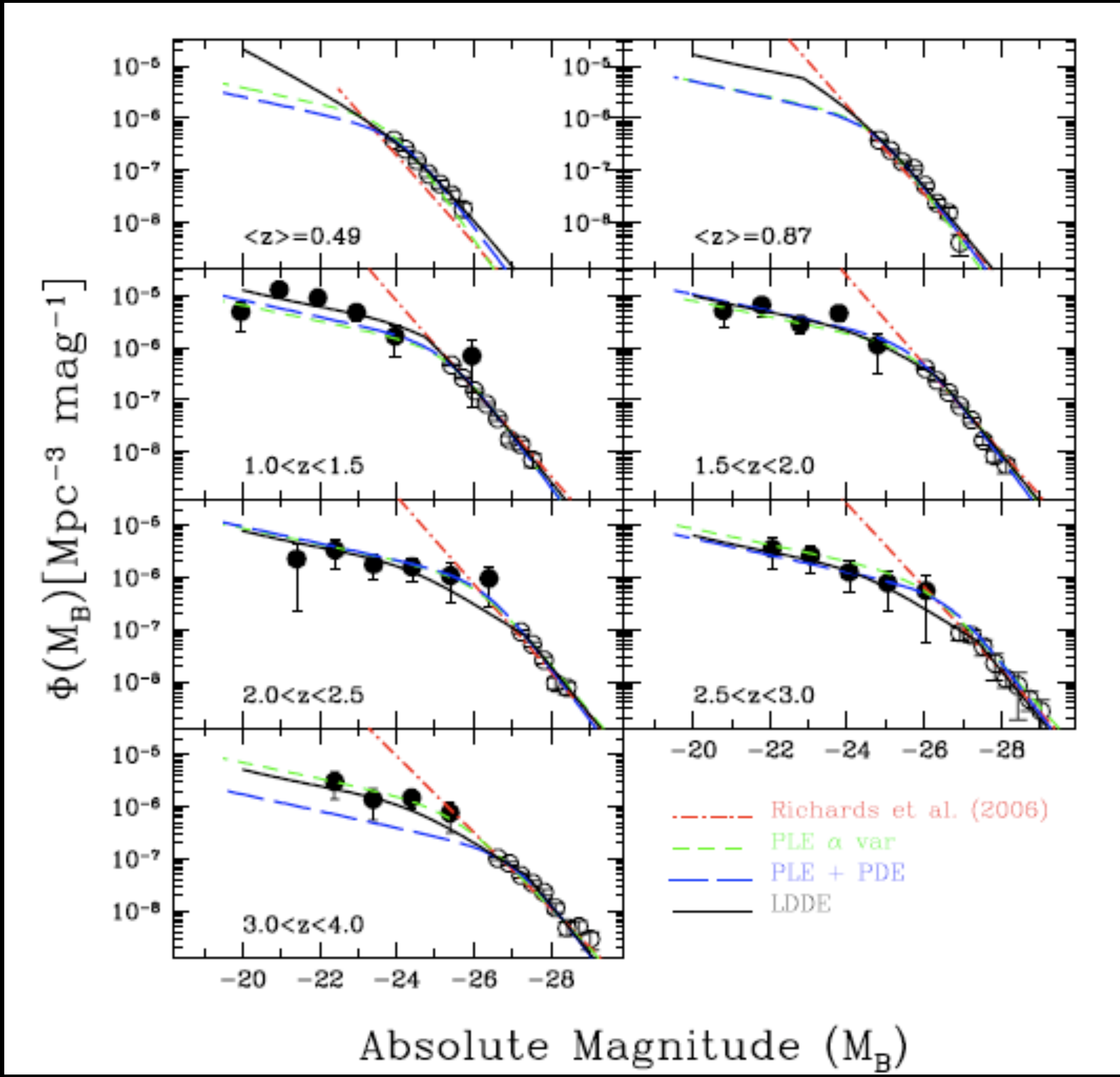
EARLY GROWTH OF MASSIVE BLACK HOLES IN QUASARS

Yan, Chang-shuo

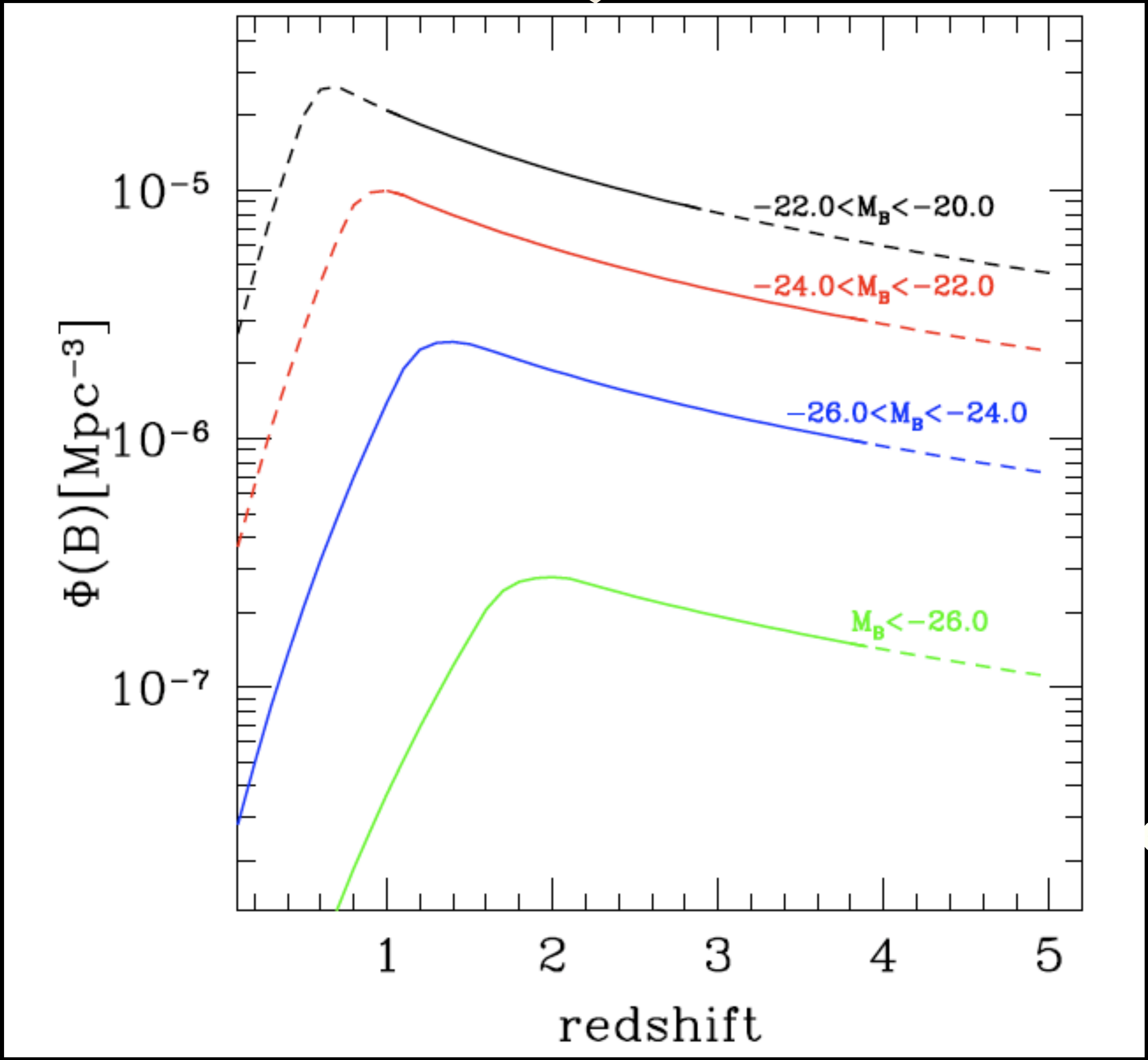
collaboration： JIAN-MIN WANG[1], YAN-MEI CHEN， CHEN HU

Luminosity Function of Quasars



Bongiorno et.al 2007

Luminosity Function of Quasars

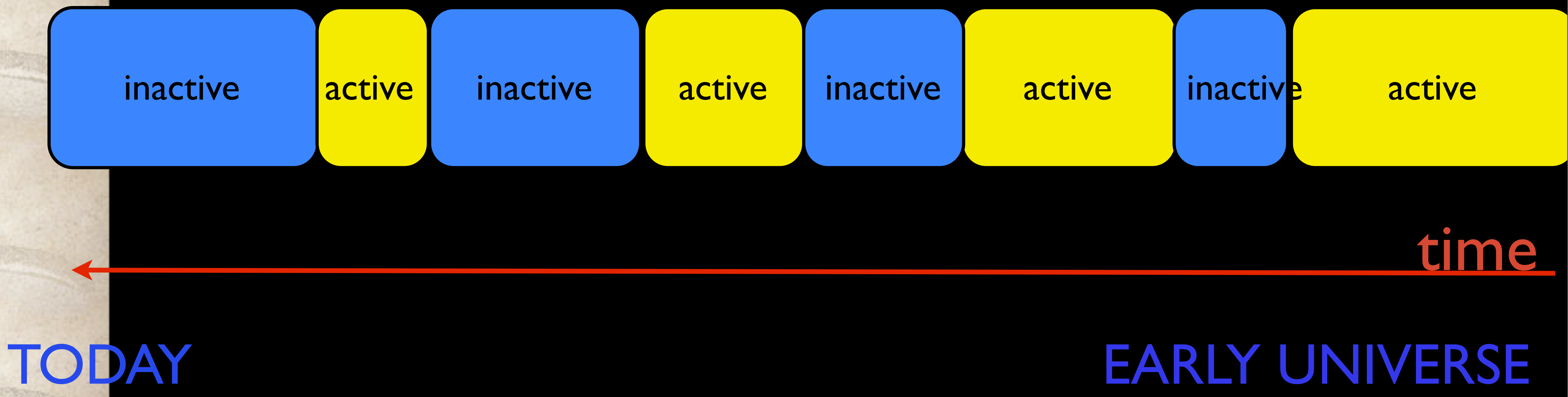


ongiorno et.al
2007

Episodic Activity of Quasars

- Accretion of gas onto SMBHs is powering the huge energy output from quasars.

Quasars' evolution



Episodic Activity of Quasars

- We can get the information of the episodic activity from the Luminosity Function of the quasars.

Duty cycle of quasars

- The duty cycle of the quasars describe the episodic activity of quasars, and is defined as a fraction of active black holes to the total:

$$\delta(M_\bullet, z) = \frac{\Psi(M_\bullet, z)}{\mathcal{N}(M_\bullet, z)},$$

- The mass averaged duty cycle is $\delta_1(z) = N_{\rm qso}(z)/N_{\rm all}(z)$
- where

$$N_{\rm qso}(z) = \int_{M^*_\bullet} \Psi(M_\bullet, z) \mathrm{d}M_\bullet \qquad N_{\rm all}(z) = \int_{M^*_\bullet} \mathcal{N}(M_\bullet, z) \mathrm{d}M_\bullet$$

- Because all the black hole is episodic active, the average mass of active BH is equal to the average mass of all BH. And the definition $\delta_2(z) = \rho_\bullet(z)/\rho_\bullet^{\rm all}(z)$ is equal to the $\delta_1(z) = N_{\rm qso}(z)/N_{\rm all}(z)$

Duty cycle of quasars

- Based on the Soltan's argument (Soltan 1982) that accretion during quasars' episodic activities is the main source of mass growth. So we can get the information of the black hole density from the accretion history.
- At the same time if we assume an average accretion rate and radiation efficiency we can get the density of active BH.

Duty cycle of quasars

$$L_{\rm Bol} = \eta \dot{M} c^2 = \eta \dot{m} M_\bullet c^2 / t_{\rm Salp}$$

$$\dot{U}(z) = \int_{L^*_{\rm Bol}} L_{\rm Bol} \Phi(L_{\rm Bol}, z) \mathrm{d}L_{\rm Bol}$$

$$\rho_\bullet(z) = \frac{1}{\eta \langle \dot{m} \rangle c^2} \dot{U}(z) t_{\rm Salp}$$

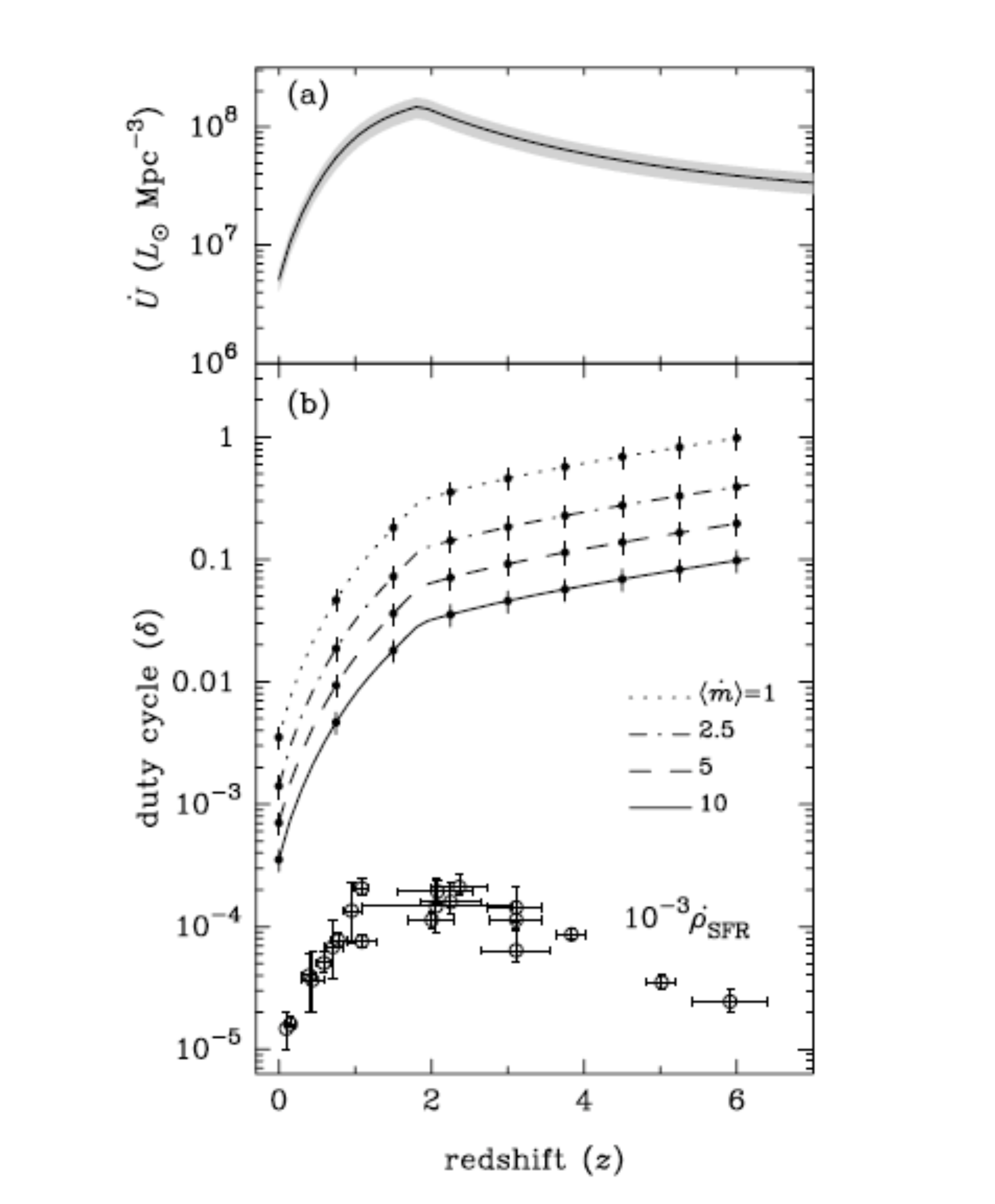
$$U(z) = \int_z^{z_{\max}} \dot{U} (\mathrm{d}t/\mathrm{d}z) \mathrm{d}z$$

$$U_{\rm S} = \eta \rho^{\rm S}_\bullet c^2$$

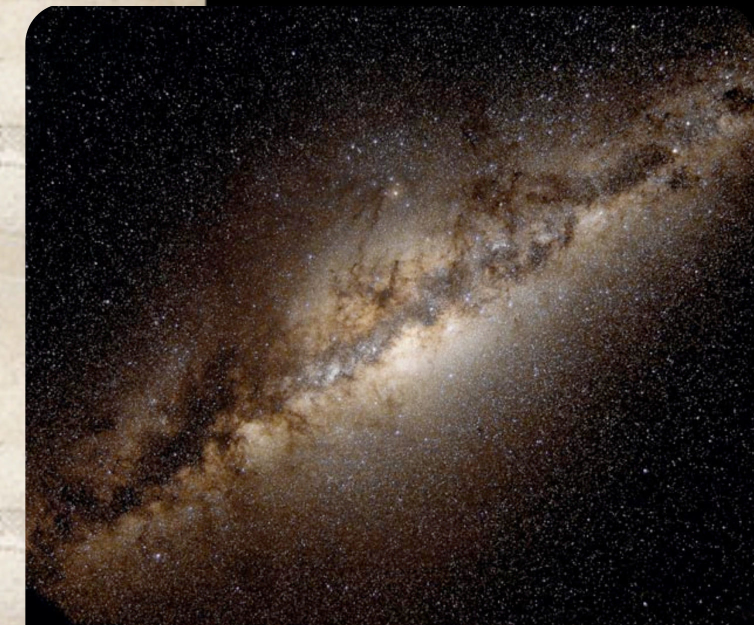
$$\rho^{\rm all}_\bullet(z) = \rho^{\rm S}_\bullet + \int_z^{z_{\max}} \frac{1-\eta}{\eta} \frac{\dot{U}(z)}{c^2} \left(\frac{\mathrm{d}t}{\mathrm{d}z} \right) \mathrm{d}z = \rho^{\rm S}_\bullet + \frac{1-\eta}{\eta} \frac{U(z)}{c^2}$$

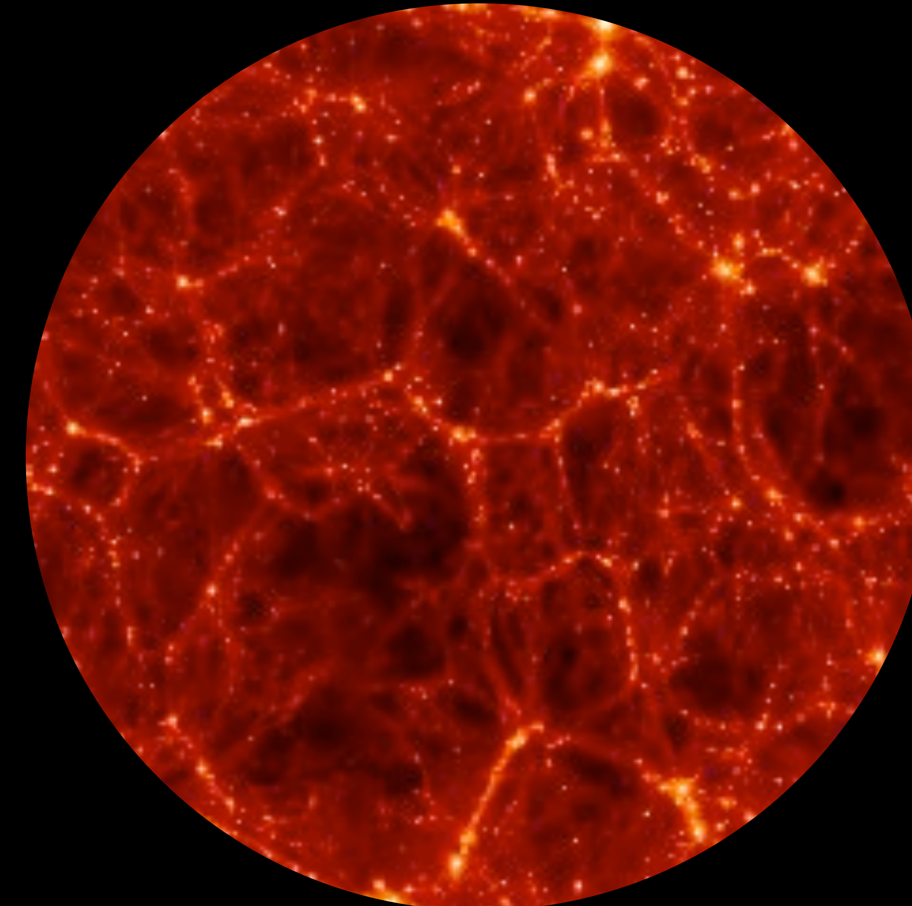
$$\delta(z) = \frac{\dot{U}(z) t_{\rm Salp}}{\langle \dot{m} \rangle [U_{\rm S} + (1-\eta) U(z)]} \approx \frac{\dot{U}(z) t_{\rm Salp}}{\langle \dot{m} \rangle (1-\eta) U(z)}$$

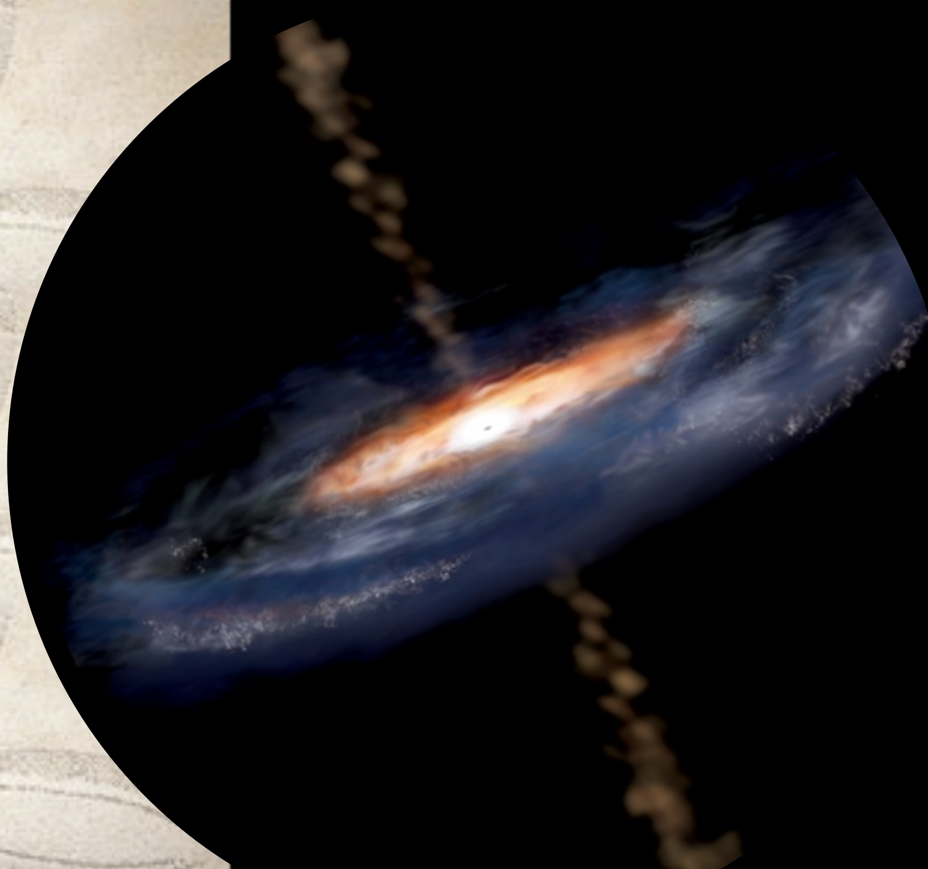
Duty cycle of quasars

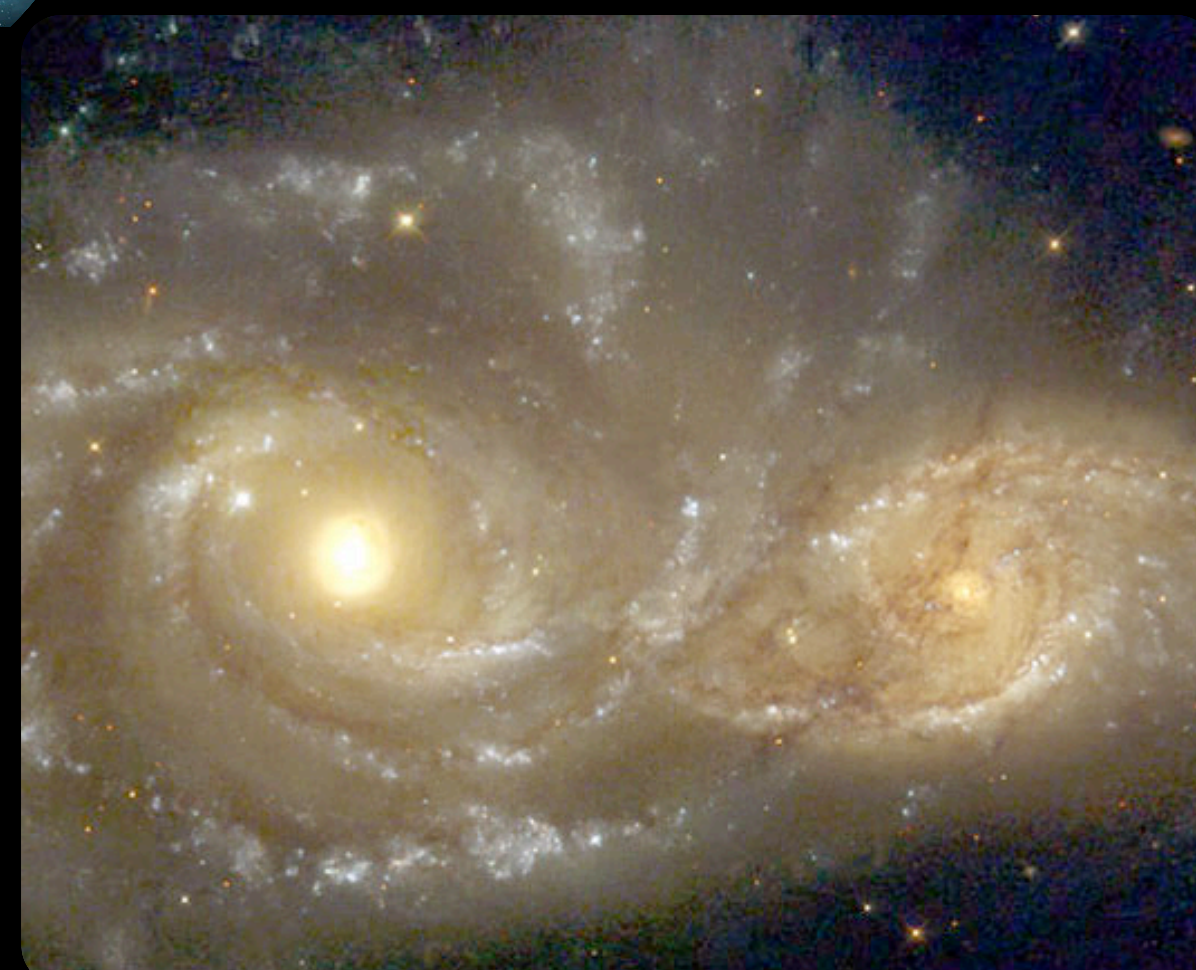


- Compare the duty cycle with the star formation history.
- remarkable change of the curve at z～2
- at low redshift, the gas is not enough.
- at high redshift, the gase is enough and the feedback restrain the star formation.









Accretion and Growth

- If we ignore the merger, and only consider the accretion than the number of the BH is conservative.

$$\frac{\rho_\bullet^{\mathrm{all}}(z)}{\langle M_\bullet(z)\rangle} = \frac{\rho_\bullet^{\mathrm{S}}}{\langle M_\bullet^{\mathrm{S}}\rangle} = \frac{\rho_\bullet^{0}}{\langle M_\bullet^{0}\rangle}$$

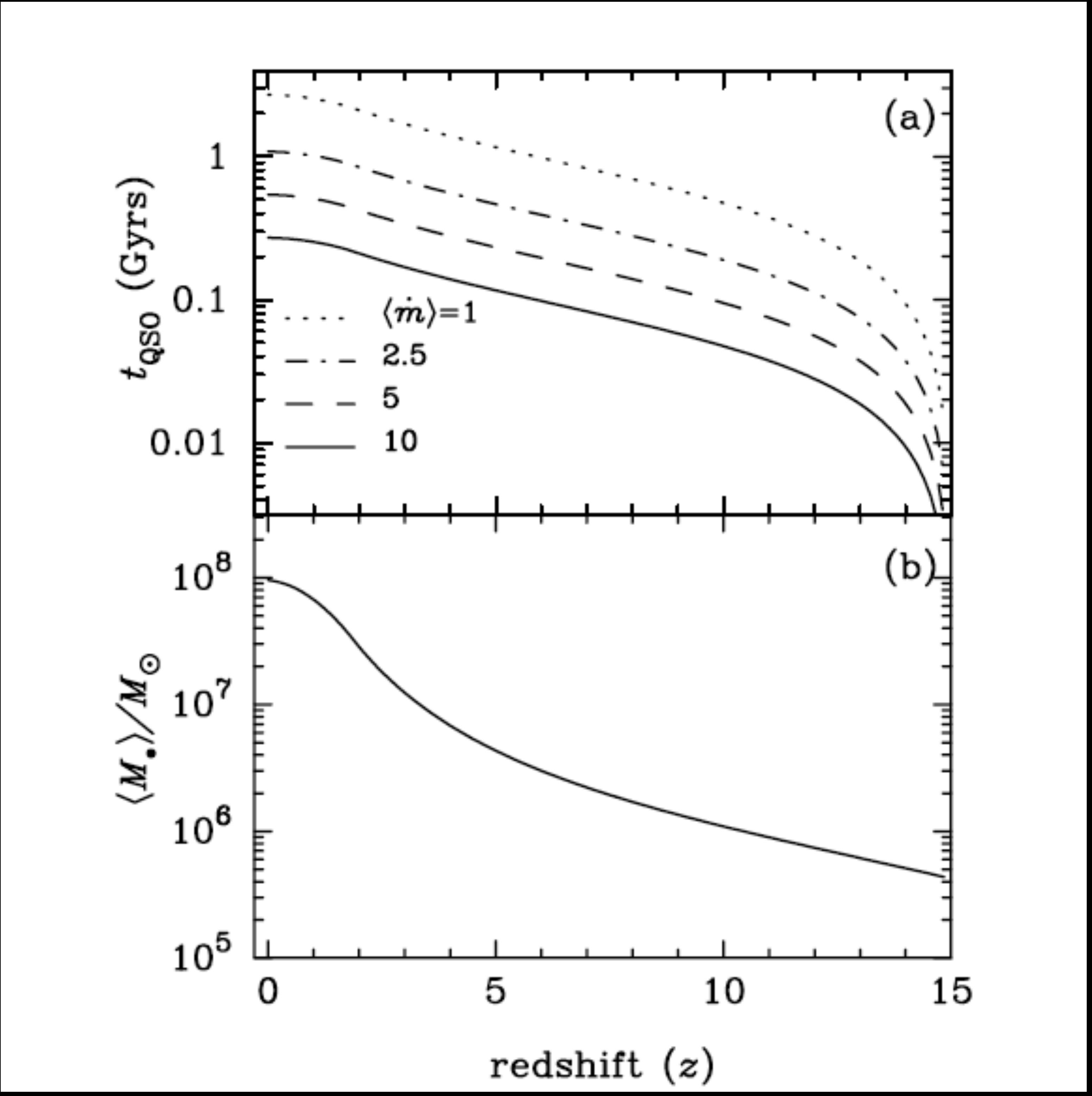
- We can get the mean mass of BH $\langle M_\bullet(z)\rangle = \left[\frac{\rho_\bullet^{\mathrm{all}}(z)}{\rho_\bullet^{0}}\right]\langle M_\bullet^{0}\rangle$
- And the mean mass of the seed BH at z~17

$$\langle M_\bullet^{\mathrm{S}}\rangle = \left(\frac{\rho_\bullet^{\mathrm{S}}}{\rho_\bullet^{0}}\right)\langle M_\bullet^{0}\rangle \approx 2.0\times 10^5 M_\odot$$

- So from the primordial BH at z~24（the mass is about 1000Msun）grow to the seed BH need the average accretion rate:

$$\dot{m}_{\mathrm{c}} = \left[\frac{t_{\mathrm{Salp}}}{(1-\eta)\Delta t}\right]\ln\left(\frac{\langle M_\bullet^{\mathrm{S}}\rangle}{\langle M_\bullet^{\mathrm{P}}\rangle}\right) \approx 30$$

Accretion and Growth



Accretion and Growth

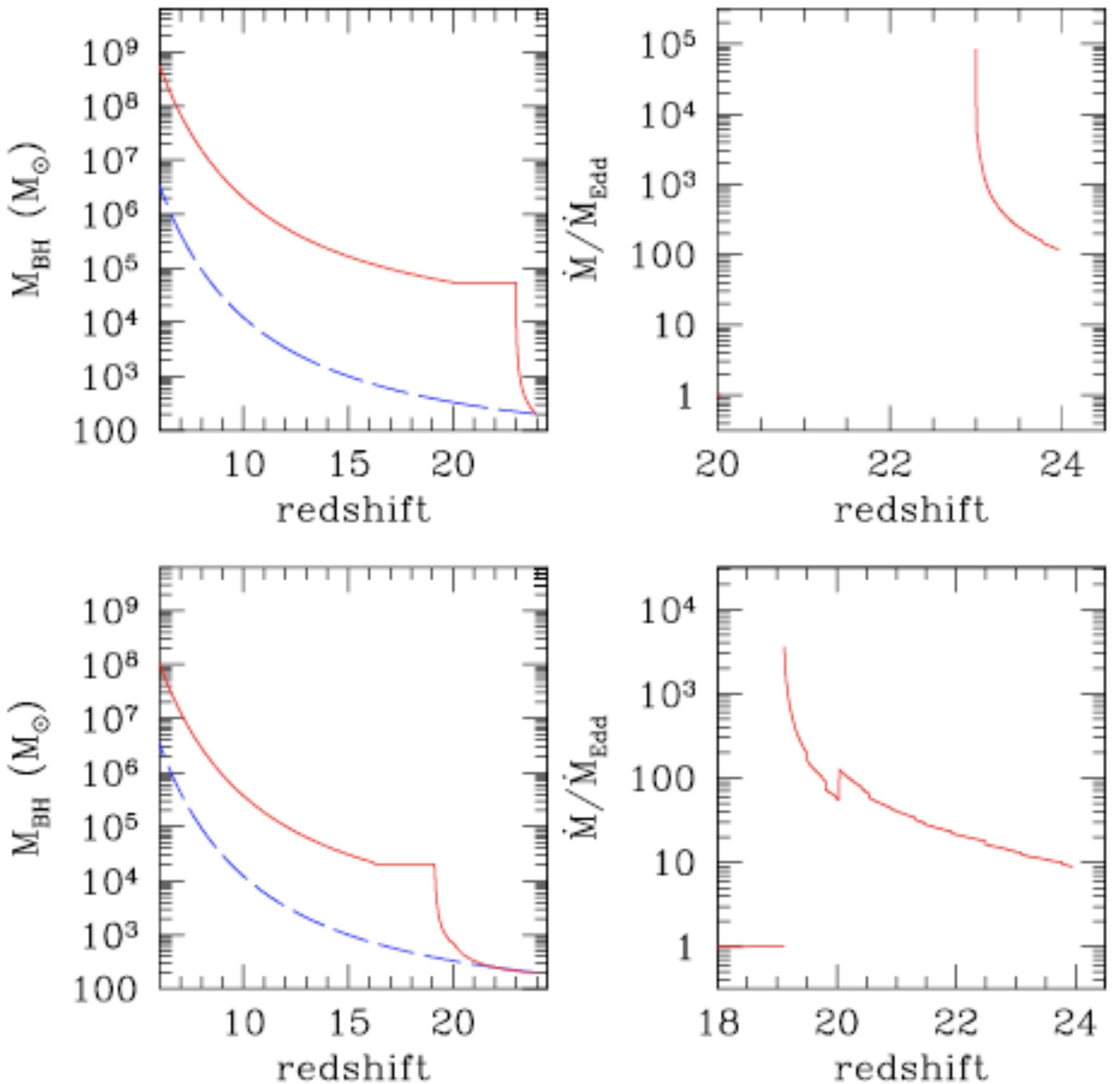


Fig. 1.— Evolution of the accretion rate and MBH mass growth in the main halo of the merger trees, $M_h = 10^{13}\,\mathrm{M}_\odot$ at $z = 6$. *Top:* $f_d = 0.5$. *Bottom:* $f_d = 0.1$. *Left panel:* MBH mass as a function of redshift for the model discussed in this paper (*solid line*) and assuming Eddington accretion rate at all times, with $\epsilon = 0.15$ (*dashed line*). *Right panel:* MBH accretion rate, in units of the Eddington rate.

Volonteri&
Rees 2005

Accretion and Growth

$$\tau_{\rm BH} = \left(\mathrm{d}\ln M_\bullet/\mathrm{d}t\right)^{-1}$$

$$\tau_{\rm dyn} = R_{\rm Bondi}/c_s$$

$$\tau_{\rm BH}/\tau_{\rm dyn} = c_s^6/4\pi G^3 M_\bullet^2 m_{\rm p} n_0 = 0.1\ T_{0.8}^3 M_5^{-2} n_4^{-1}$$

- Maybe they use the Bondi accretion like this:

$$\dot{m} = \dot{m}_0 m_\bullet^0 / \left[1 - m_\bullet^0 \left(t/\tau_0\right)\right]$$

- A self-consistent treatment of time-dependent Bondi accretion onto a growing black hole is needed for such a context.

CONCLUSIONS

- We develop a convenient way to calculate the duty cycle based on LF, which applies to any redshifts.
- The mean mass of the seed black holes is up to $2*10^5 M_\odot$ at $z \sim 17$, which is able to grow up from the primordial($\sim 10^3 M_\odot$) at $z = 24$ via moderate super-Eddington accretion.
- More deeper surveys are expected to improve the LFs for more sophisticated investigations of growth of black holes in high redshift universe.

Thank You!