The inward and outward starburst feedback and the growth of supermassive black hole

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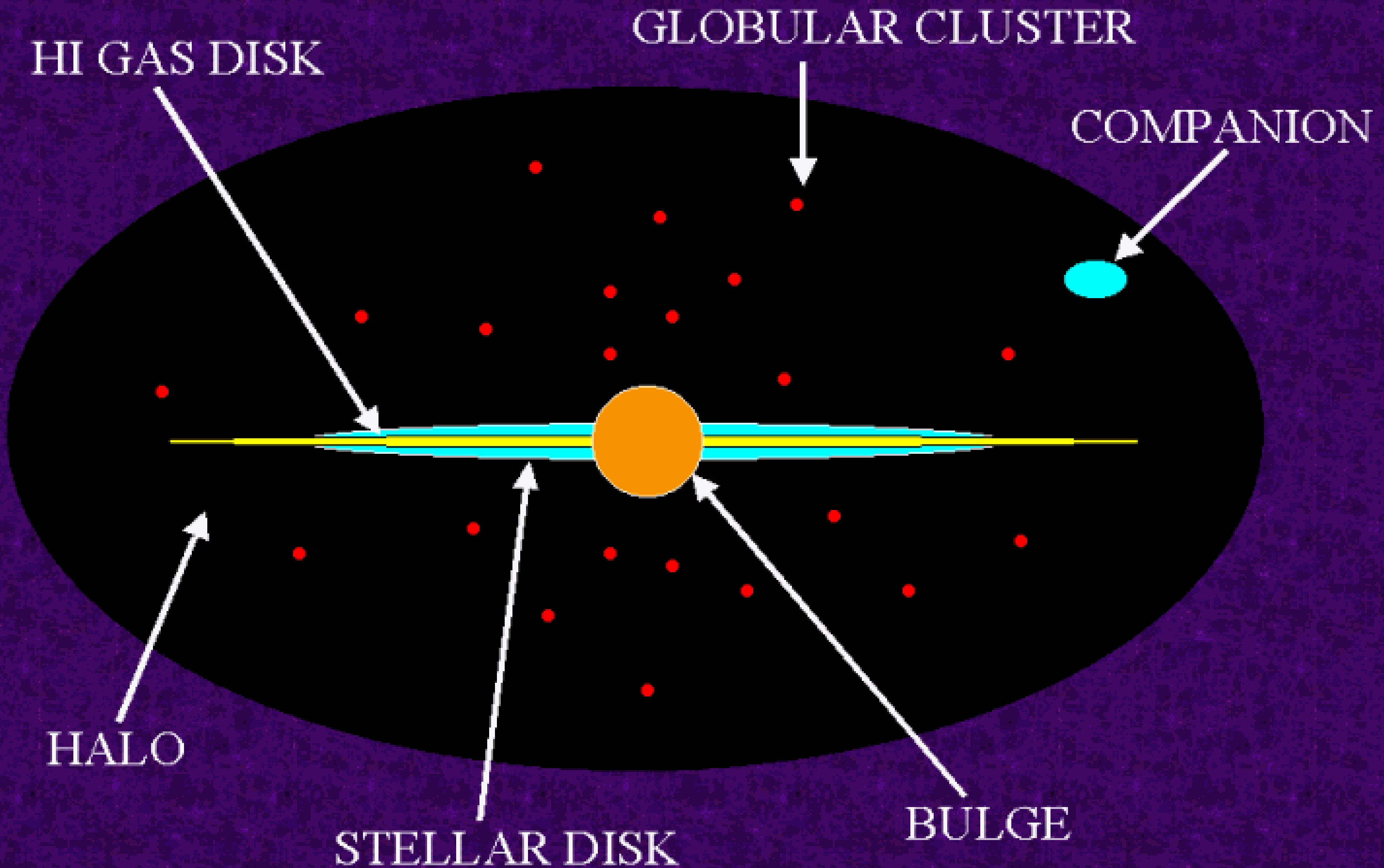
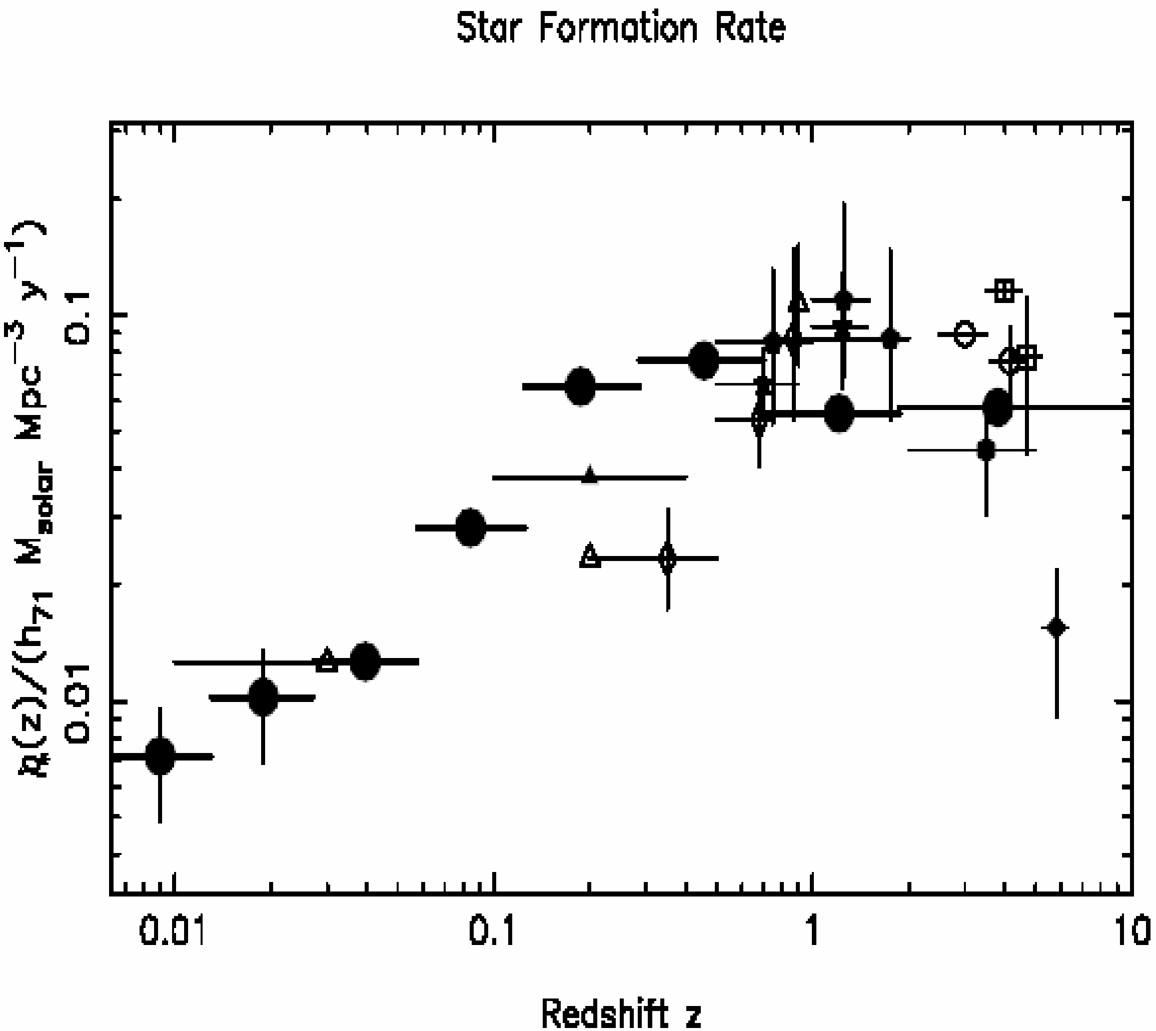
OUTLINE

- Background introduction
- Brief introduction of our work
- Discussion and conclusion

Our Working Galaxy Model



Space density of star-forming galaxies



Similar with that of quasar

Peak: z~2

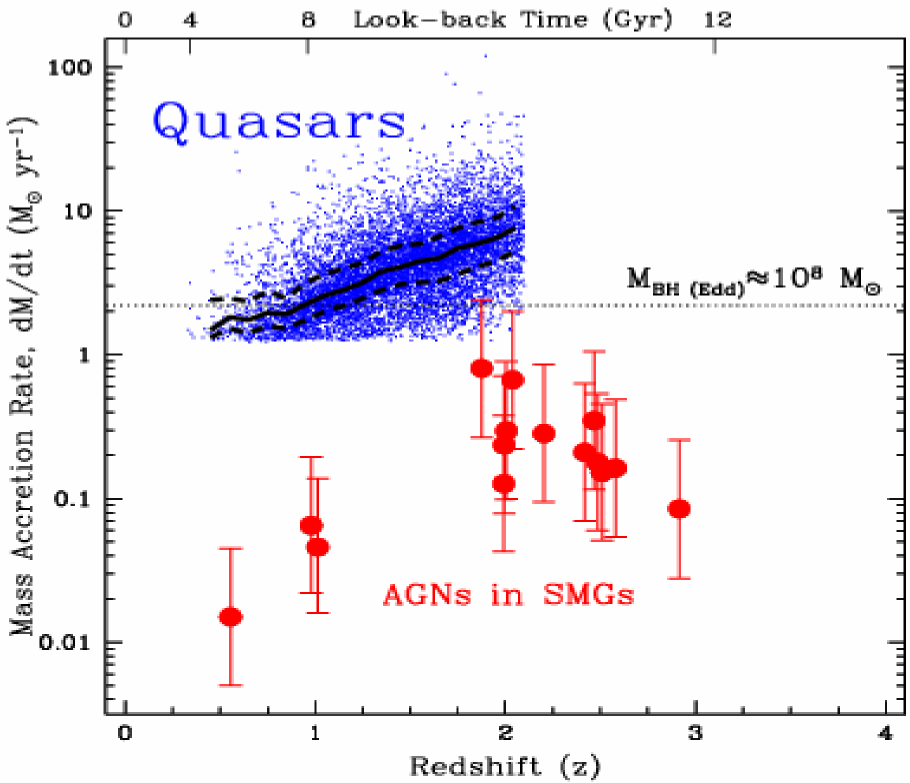
Galaxy merger

Intense site of star formation: SMGs, ULIRGs,…

X-ray observation

$\Downarrow$ SMGs, ULIRGs

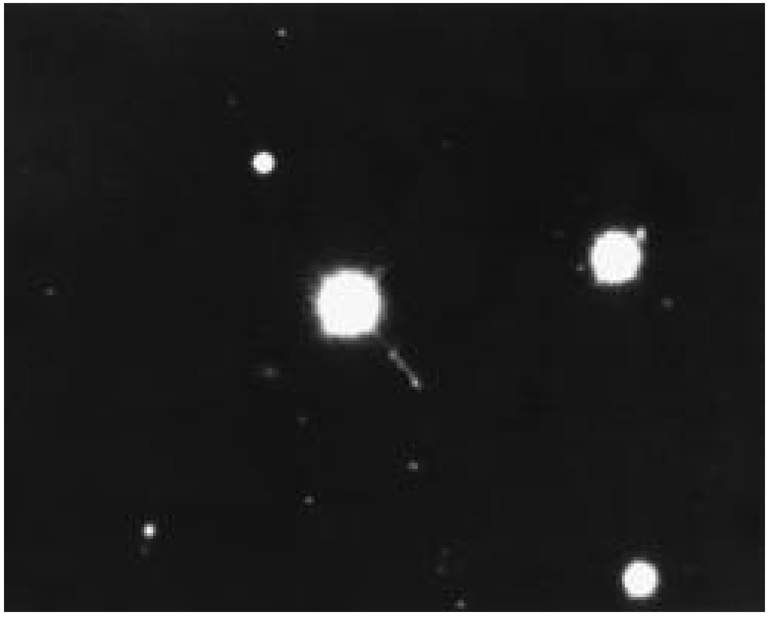
Many of them habour AGN



The central BH

- high accretion rate
- relatively small mass

Typical quasar



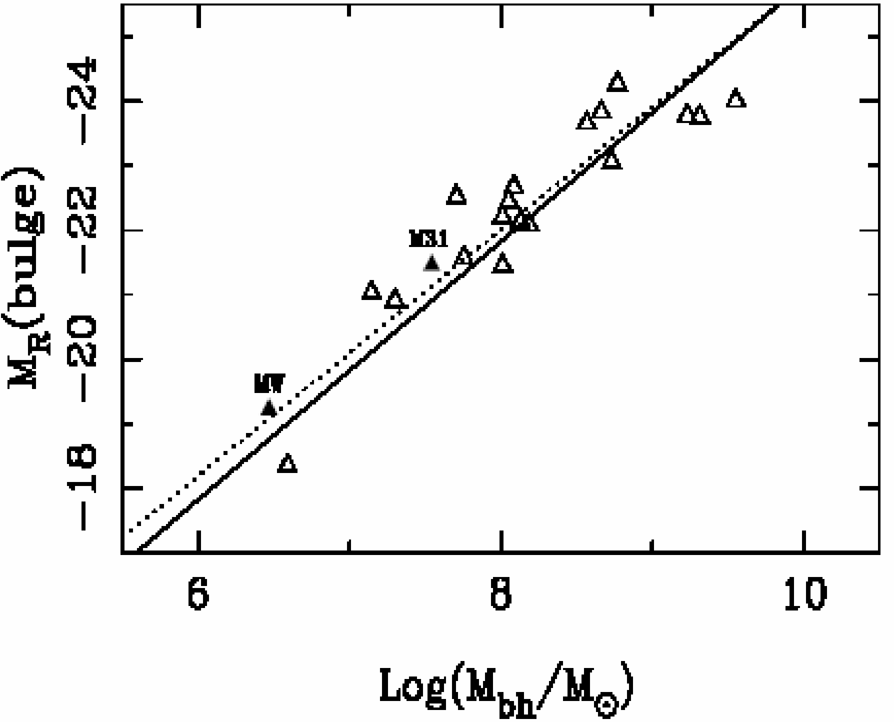
- No intense star formation
- Already supermassive $\sim 10^8 - 10^9 M_{sun}$

$$\Downarrow$$

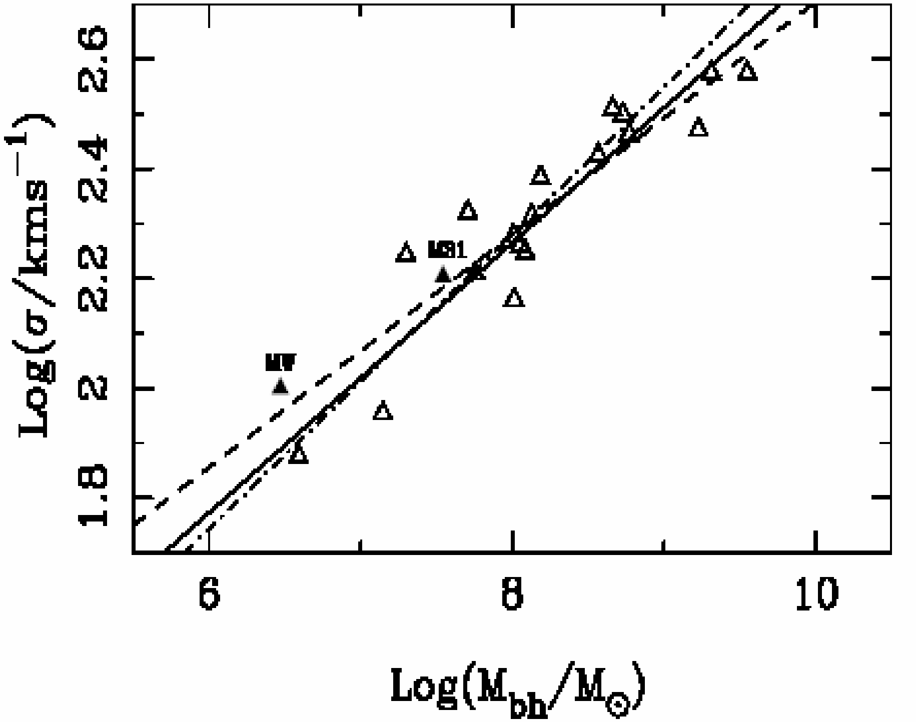
Luminous quasar may be not at its main growth phase (pre-quasar ?)

Tight relationship between the BH and the galactic bulge

$$M_{BH} - M_{bulge}$$



$$M_{BH} - \sigma$$



Theoretical models

- Energy driven model (Silk & Rees 1998; Wyithe & Loeb 2003)
- Momentum driven model (King 2003; Murray, Quataert & Thompson 2005)
- Rediative heating model (Sazonov, Ostriker & Sunyaev 2004)
- Other curious model (Miralda-Escude 2005)

Current models' shortage

- Lacking discussions about the effects of the starburst
- Having difficulties in calculating the total mass of stars
- Having difficulties in explaining some features

Motivation

Try to connect the stuff mentioned above and explain the nature more reasonably

Our work

Main target

- To connect the starburst and AGN activities
- To explain two relations and more features
- To describe the “pre-quasar” phase and the obscured growth of black hole

Property of the protogalaxy

The virial radius

$$r_{vir} = 169 \left(\frac{M_h}{10^{12}h^{-1}M_\odot}\right)^{1/3} [\xi(z)]^{1/6}(1+z)^{-1}h^{-1}kpc,$$

The circular velocity

$$v_c = 160 \left(\frac{M_h}{10^{12}h^{-1}M_\odot}\right)^{1/3} [\xi(z)]^{1/6}(1+z)^{1/2}kms^{-1},$$

The mass of the protogalactic disk

$$\begin{aligned} M_d &= 1.93 \times 10^{11}h^{-1}M_\odot \left(\frac{m_d}{0.05}\right)\left(\frac{V_c}{250kms^{-1}}\right)^3 \\ &\times [\xi(z)]^{-1/2}(1+z)^{-3/2}. \end{aligned}$$

Spherical top-hat collapse:

(Barkana & Loeb 2001)

$$\xi \equiv \frac{\Omega_m}{\Omega_m^z}\frac{\Delta_c}{18\pi^2} \ ,$$

$$\Omega_m^z \equiv \left[1 + \left(\frac{\Omega_\Lambda}{\Omega_m}\right)(1+z)^{-3}\right]^{-1} \ ,$$

$$\Delta_c = 18\pi^2 + 82d - 39d^2 \ , \ \ d = \Omega_m^z - 1$$

Toomre value: $Q = \kappa c_s / \pi G \Sigma_g \approx 1$

$$\Downarrow$$

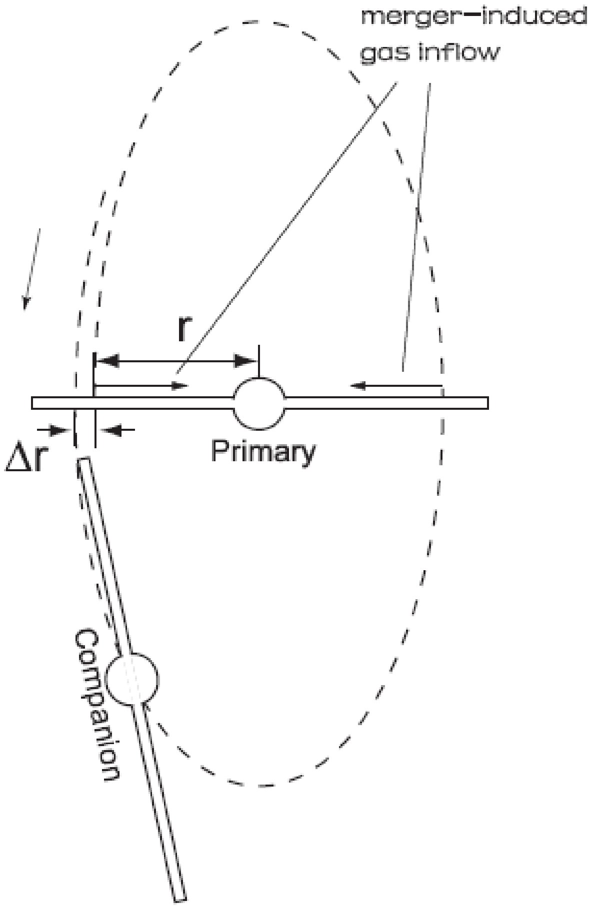
$$\Sigma(R) = \frac{\Sigma_g R_g}{R},$$

$$\Downarrow$$

$$\begin{aligned} R_g &\approx 37.5 h^{-1} kpc \left(\frac{\lambda}{0.05}\right) \left(\frac{V_c}{250 kms^{-1}}\right) \left(\frac{j_g}{m_g}\right) \\ &\times [\xi(z)]^{-1/2} (1+z)^{-3/2}, \end{aligned}$$

$$\begin{aligned} \Sigma_g &\approx 3 \times 10^{-3} gcm^{-2} \left(\frac{m_g}{0.03}\right) \left(\frac{\lambda}{0.05}\right)^{-2} \left(\frac{m_g}{j_g}\right)^2 \\ &\times \left(\frac{V_c}{250 kms^{-1}}\right) [\xi(z)]^{1/2} (1+z)^{3/2}, \end{aligned}$$

Dynamical friction (Dark matter particle)



The time-scale of the disk spiral inward due to the dynamical friction t_{DF}

$$t_{DF} = \frac{1.17}{\ln \Lambda} \frac{R_g^2 V_c}{G M_d} = 2.8 \times 10^8 h^{-1} yr [\xi(z)]^{-1/2} (1+z)^{-3/2},$$

$$\Lambda = \frac{2 R_g V_c^2}{G M_d}$$

Radial velocity: $V_R = R_g/t_{DF}$

Mass of gas participating in interaction during the time interval Δt

$$\Delta M = 2\pi\Sigma(r) r V_R \Delta t$$

In the reference of the primary galaxy

$$\dot{M}_{in}^{c} = \begin{cases} 0 & 0 < t \le R_g/V_c; \\ \frac{2\pi\Sigma_g R_g V_R}{1 - V_R/V_c} & R_g/V_c < t \le t_{DF}. \end{cases}$$

Microscopic process

Gas cloud collision $\Rightarrow$ $T = \frac{m_p V_c^2}{3k} = 2.5 \times 10^6 \left(\frac{V_c}{250kms^{-1}} \right) K$

The gas cooling time-scale:

$$t_{cool} \sim \frac{E}{\Lambda} \sim 1.8 \times 10^6 \left(\frac{m_g}{0.03} \right)^{-1} \left(\frac{V_c}{250kms^{-1}} \right)^{-1} \left(\frac{r}{1kpc} \right)^2 .$$

$$\Downarrow$$

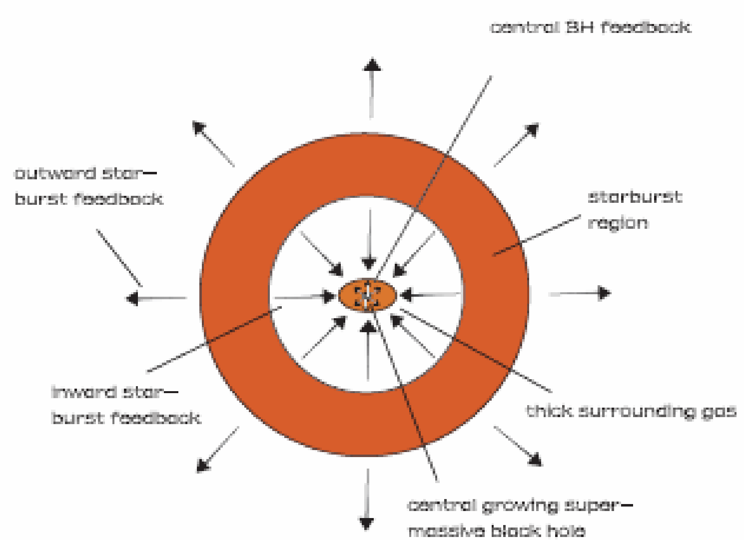
$$t_{cool}/t_{dyn} \sim 1 \quad \Rightarrow \quad r_{cool} = 2.3kpc(\frac{m_g}{0.03}),$$

Star formation and BH growth (obscured)

$$\dot{\rho}_\star = \frac{\rho_g}{t_\star} = \eta \frac{\rho_g}{t_{dyn}}, \qquad \Rightarrow \qquad t^c_{dur} = t_{DF} - R_g/V_c < 0.2 t_\star$$

$$\dot{M}_\star = \dot{M}^c_{in}(1 - e^{-\frac{t}{t_\star}}) \approx \frac{\dot{M}^c_{in} t}{t_\star}.$$

$$\dot{M}^{max}_\star \approx \frac{\dot{M}^c_{in} t^c_{dur}}{t_\star} = \eta \frac{\dot{M}^c_{in} t^c_{dur} V_c}{r_{cool}}.$$



Supernovae

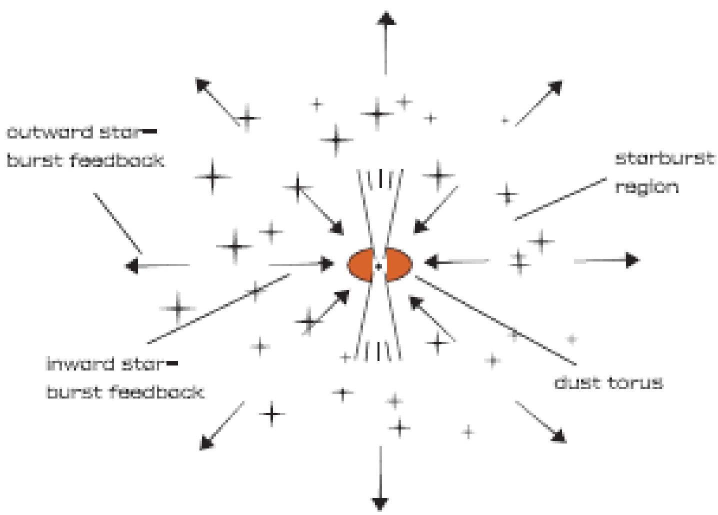
$\Downarrow$

Large amount of dust

$\tau_{Dust} \approx 1$ (short time)

Final stage of the merger

$$F_R^{max} = \frac{L_{SB}^{max}}{c} \approx \epsilon \dot{M}_*^{max} c, \qquad F_R^{BH} = \frac{\Gamma L_{EDD}}{c} = \frac{4\pi G M_{BH} \Gamma}{\kappa},$$



MOMENTUM FEEDBACK $\Downarrow$ BALANCE

$$\epsilon \dot{M}_*^{max} c = \frac{4\pi G M_{BH}^{Final} \Gamma}{\kappa}.$$

$$\Downarrow$$

$(M_{BH} - \sigma)$

$$M_{BH}^{Final} = 1.6 \times 10^8 h^{-1} M_\odot \Gamma^{-1} \eta_{0.017} \epsilon_3 \sigma_{200}^4 \times [\xi(z)]^{-1/2} (1+z)^{-3/2},$$

The mass of the bulge

$$M_{bulge} = \int_{R_g/V_c}^{t_{DF}} \dot{M}_\star dt = \frac{\dot{M}_\star^{max}(t_{DF} + R_g/V_c)}{2}.$$

$$\Downarrow$$

$$(M_{BH} - M_{bulge}) \quad \frac{M_{BH}^{Final}}{M_{bulge}} = \frac{\epsilon c \kappa}{2\pi G(t_{DF} + R_g/V_c)\Gamma}$$

$$= 2 \times 10^{-3}\Gamma^{-1}[\xi(z)]^{1/2}(1+z)^{3/2}.$$

ANTI-HIERACHICAL GROWTH MODE!

Discussion and conclusion

- Main difference from other models: consideration of the inward and outward starburst feedback
- Check the blowing ability of the outward feedback from starburst (available)
- Insensitive to the gas fraction of the primary disk
- The redshift evolution of the two relations (consistent with the recent simulations : Robertson et al. 2005)
- Small ratio of high redshift SMGs and corresponding obscured “pre-quasar” phase
- Possible explanation to the formation of the dust torus

Thank you!