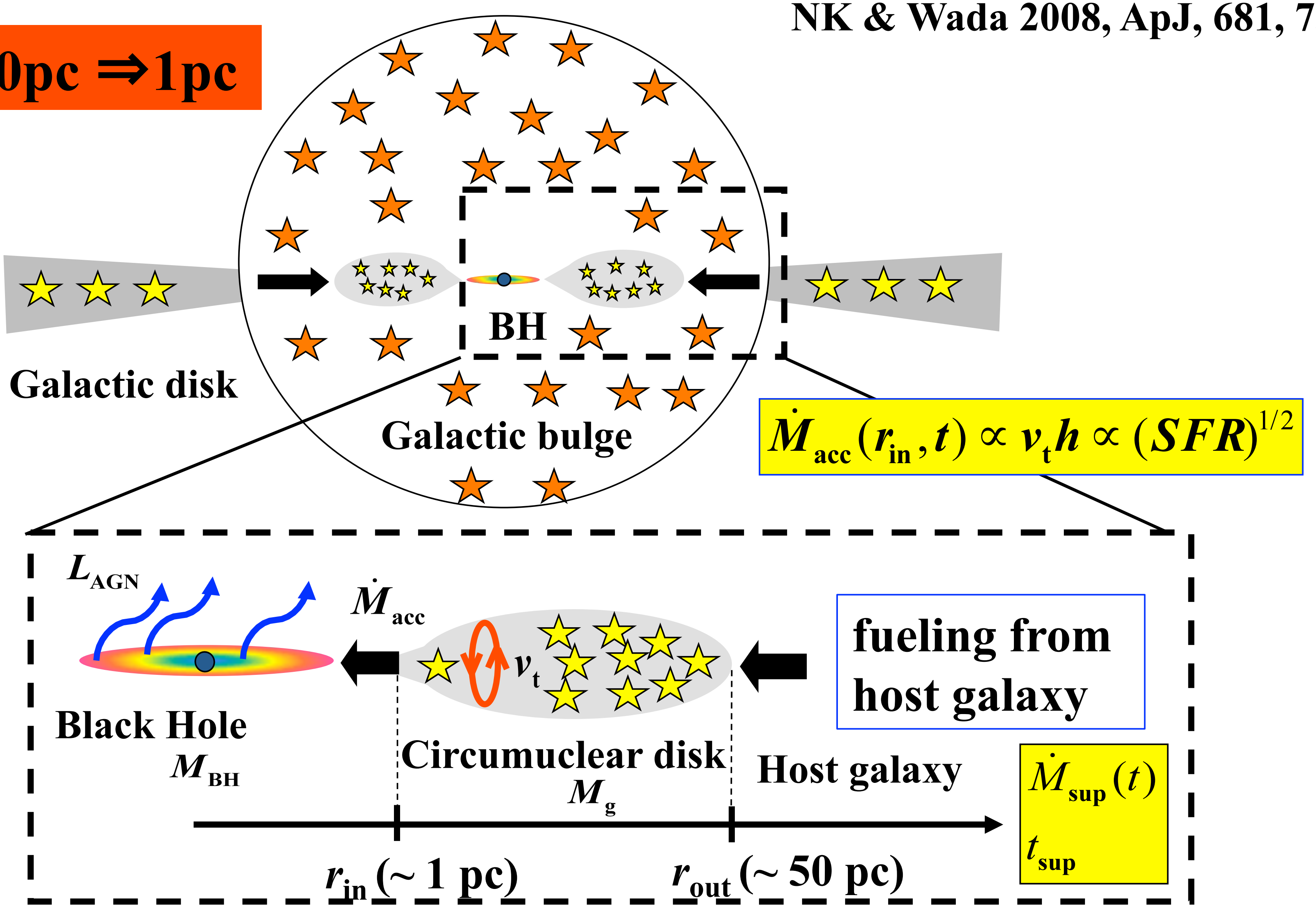
Modeling growth of SMBH and circumnuclear disk

NK & Wada 2008, ApJ, 681, 73

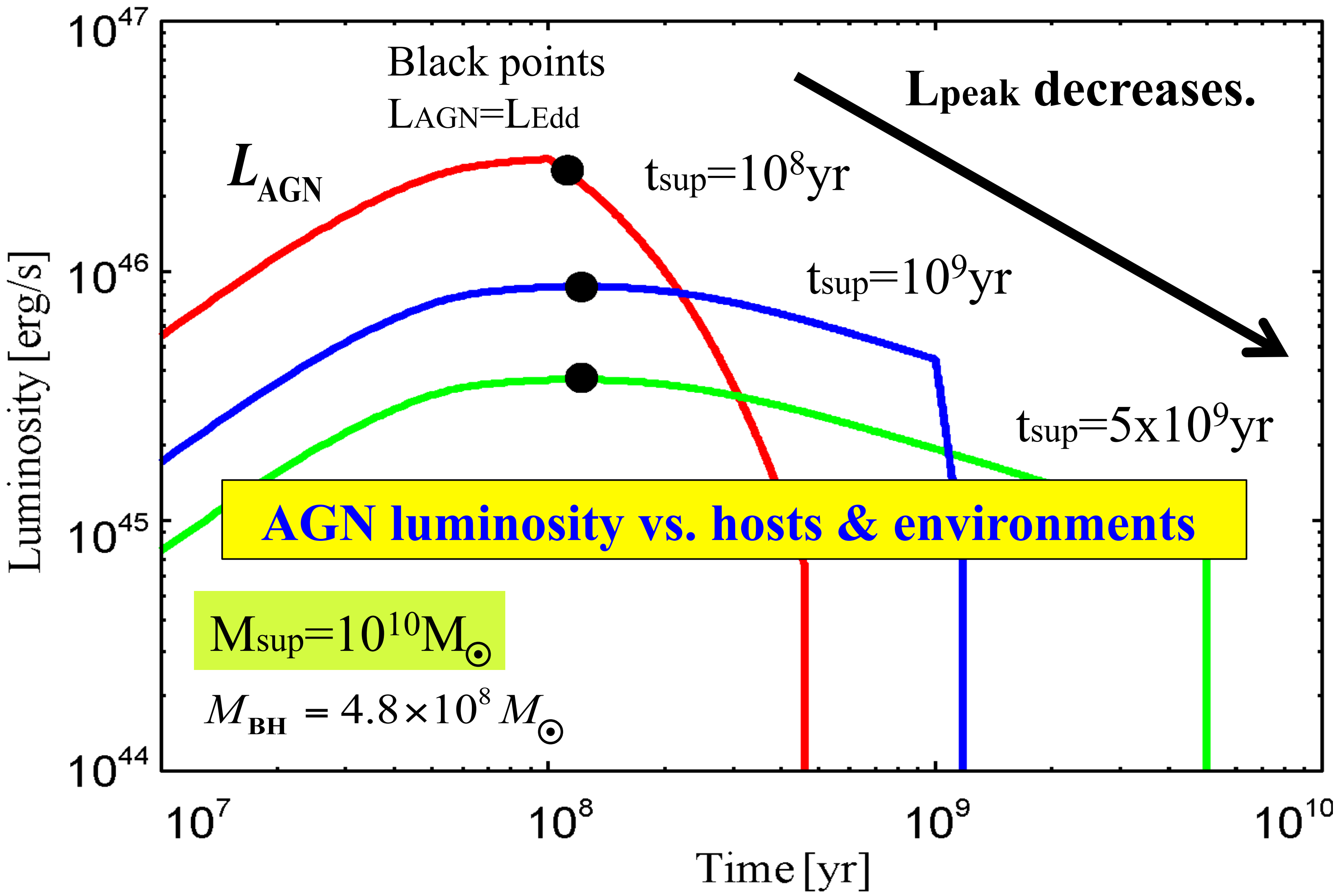
100pc ⇒1pc



$$\dot{M}_{\rm acc}(r_{\rm in}, t) \propto v_{\rm t} h \propto (SFR)^{1/2}$$

Gas accretion driven by turbulent viscosity

AGN luminosity vs. Gas supply processes



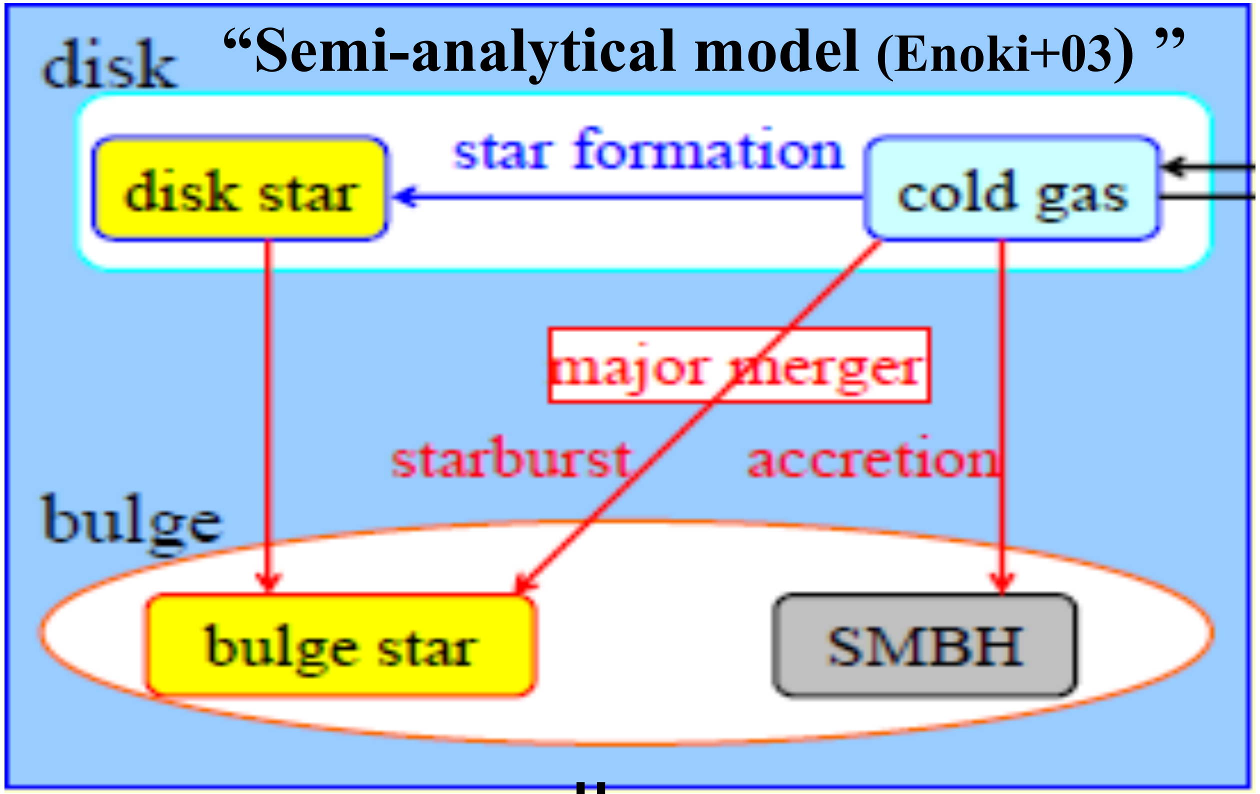
AGN luminosity vs. hosts & environments

Rapid gas fueling (e.g., major mergers) : Brighter AGNs

Slow gas fueling (e.g., bar driven) : Fainter AGNs

Semi-analytical model of AGN evolution with ~100pc scale gas fueling process

“Semi-analytical model (Enoki+03) ”



$$\dot{M}_{BH}(t) = f(M_{sup}(t) / M_{BH}(t), M_{BH}(t), t_{sup})$$

$$L_{AGN}(t) = f(\dot{m}_{BH}(t), t_{sup})$$

“AGN model (NK & Wada +08) ”

$$M_{sup}(t) = f_{BH} M_{*,burst}(t)$$

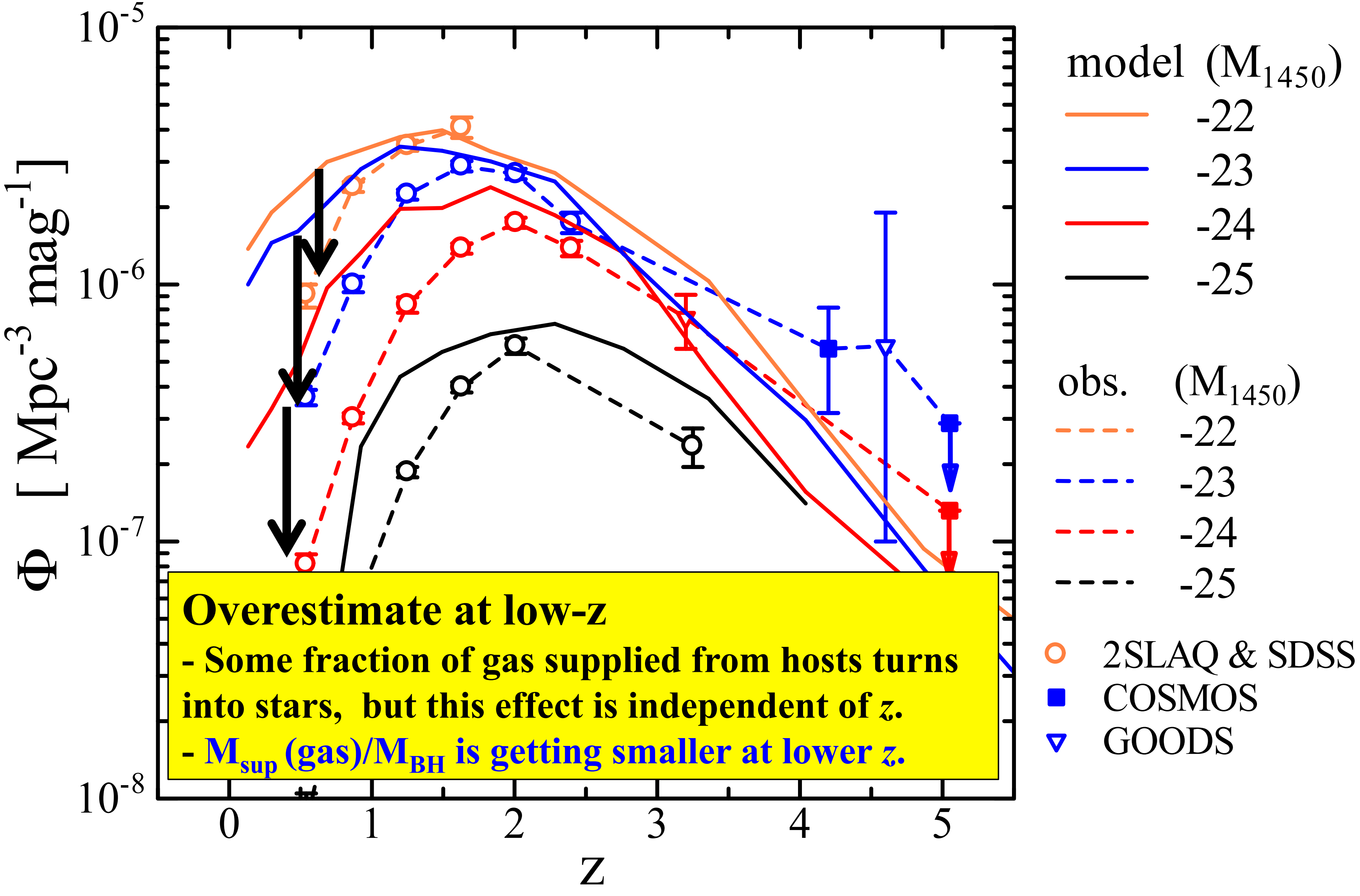
$$L_{AGN} = \frac{\varepsilon M_{sup} c^2}{t_{life}}$$

↔ **HSC survey**

Test our AGN model
(constrain “tsup”)

Physical conditions of < 100pc region

Comparison with observational data (Enoki-san's slide)

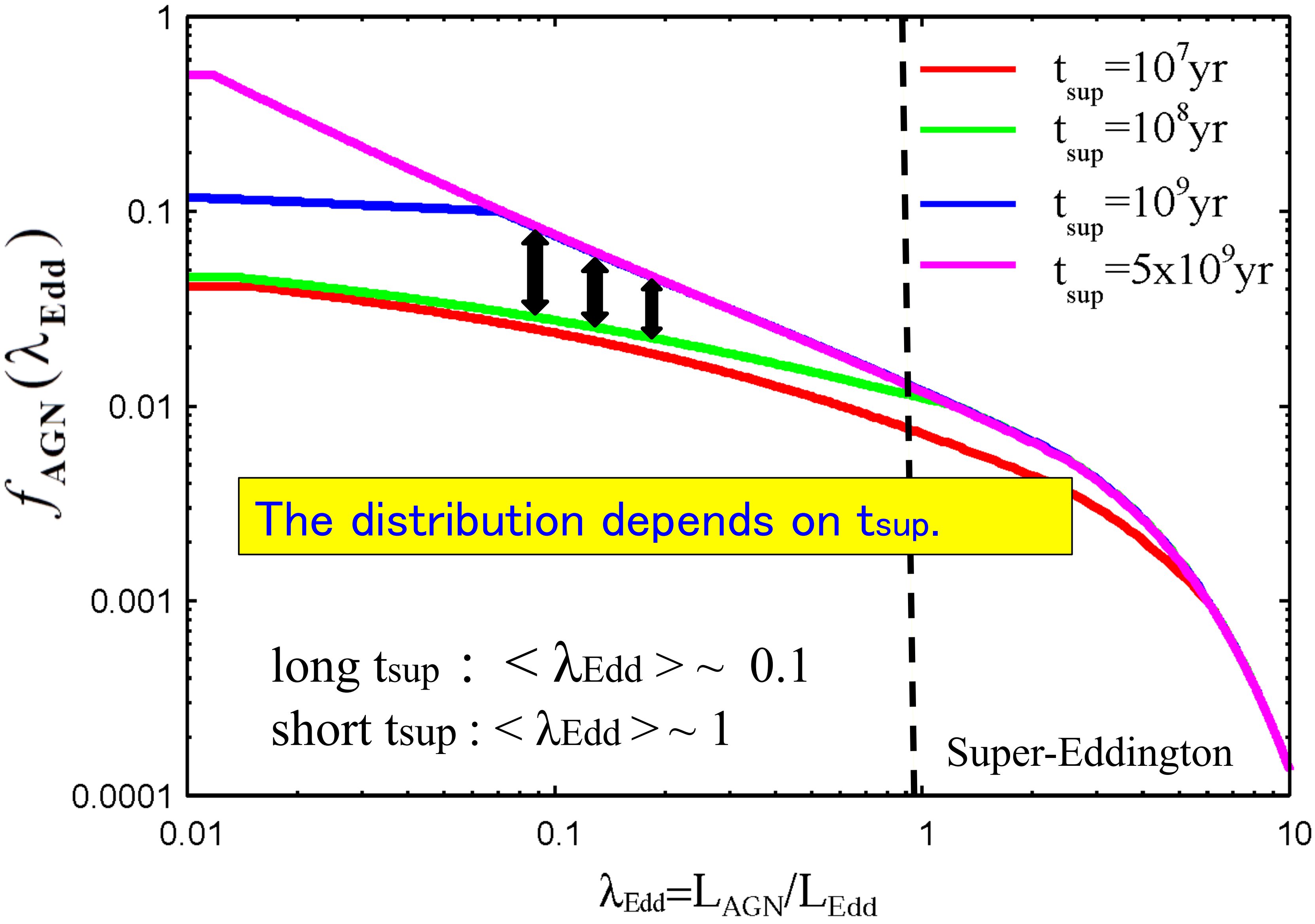


Overestimate at low-z

- Some fraction of gas supplied from hosts turns into stars, but this effect is independent of *z*.

- M_{sup} (gas)/M_{BH} is getting smaller at lower *z*.

AGN luminosity Eddington ratio distribution



The distribution depends on t_{sup}.

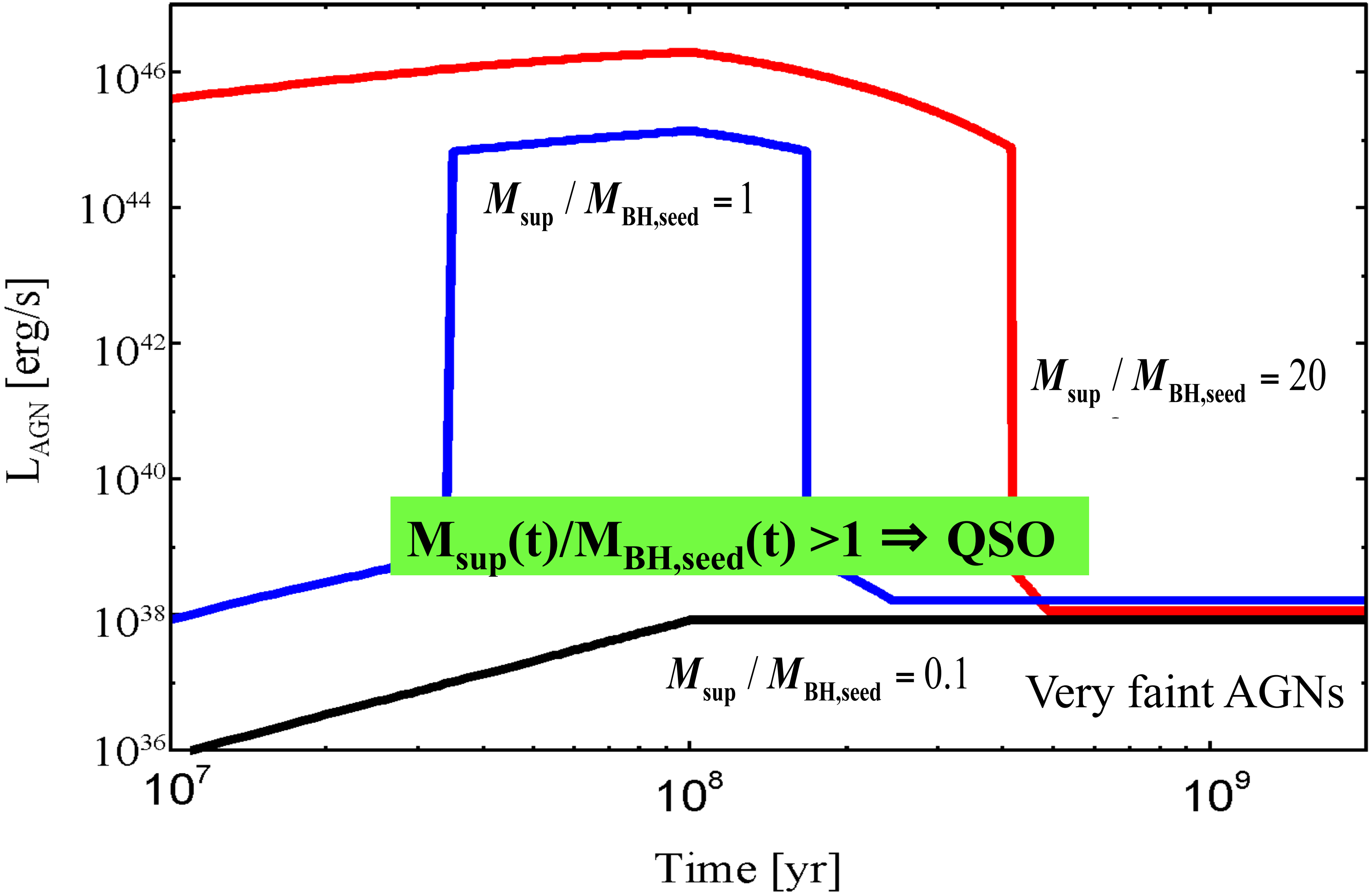
long t_{sup} : $<\lambda_{Edd}> \sim 0.1$

short t_{sup} : $<\lambda_{Edd}> \sim 1$

Super-Eddington

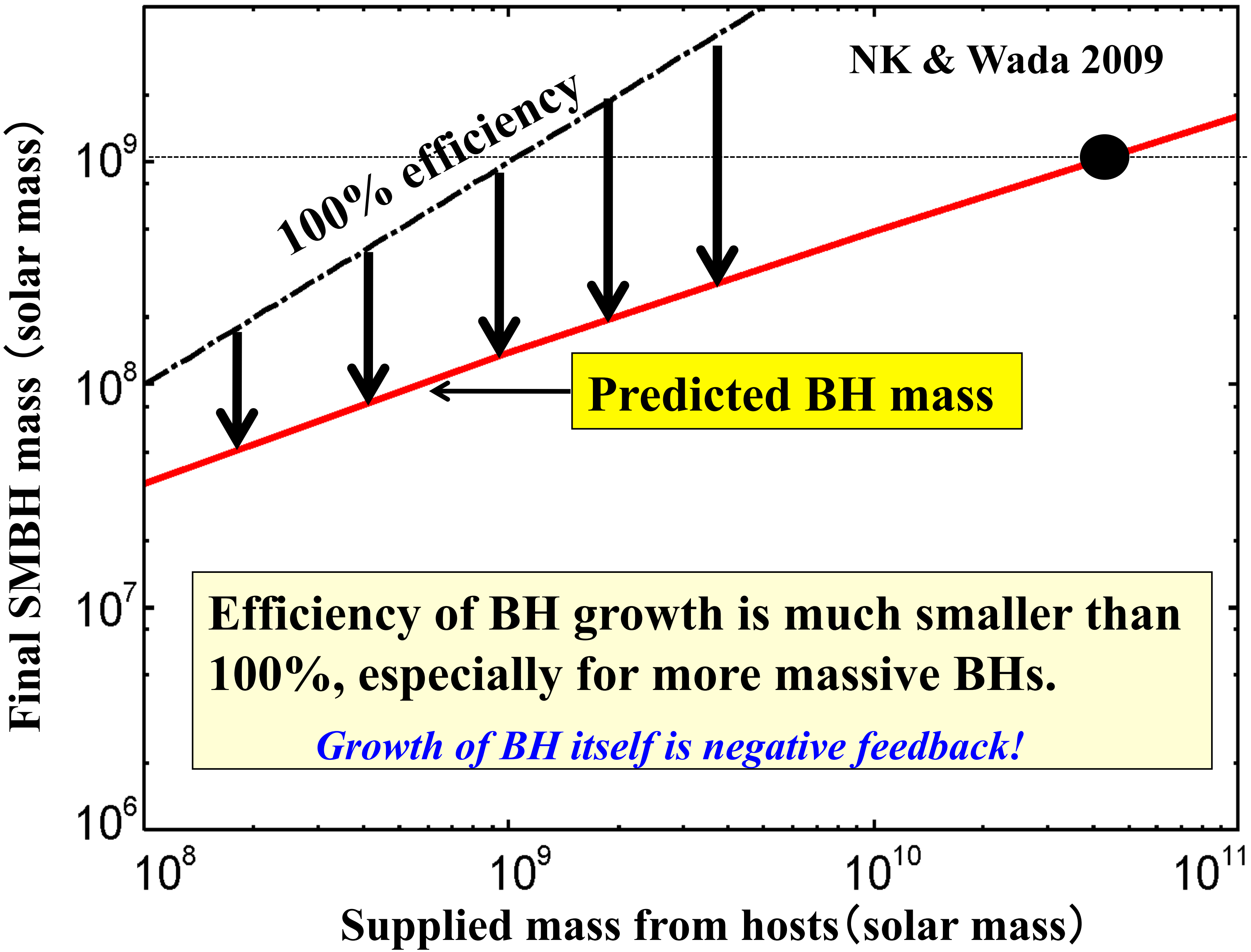
AGN luminosity vs. $M_{\mathrm{sup}}/M_{\mathrm{BH,seed}}$

$M_{\mathrm{BH,seed}} = 5\times10^{8} M_{\mathrm{sun}}, t_{\mathrm{sup}} = 10^{8}\,\mathrm{yr}$



$M_{\mathrm{sup}}(t)/M_{\mathrm{BH,seed}}(t) > 1 \Rightarrow$ QSO

Efficiency of SMBH growth

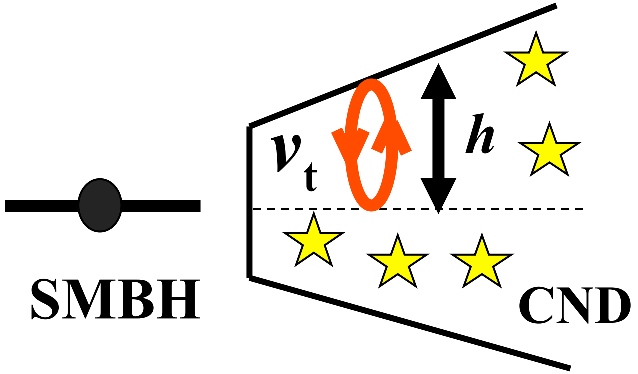


Predicted BH mass

Efficiency of BH growth is much smaller than 100%, especially for more massive BHs.

Growth of BH itself is negative feedback!

"Turbulent pressure-supported" circumnuclear disk



(see also Wada & Norman 02; Vollmer & Beckert 03; Vollmer +08; Collin & Zhan 08)

(1)+(2) ⇒ turbulent velocity and scale height

$$v_t \propto C_*^{1/2}, h \propto C_*^{1/2}$$ **(e.g., Hickes +09)**

(3) ⇒ accretion rate

$$\dot{M}(t) \propto \dot{M}_*(t)$$

Hydrodynamical equilibrium (Turbulent pressure = gravity in vertical direction)

$$\rho_g(r) v_t(r)^2 = \rho_g(r) g(r) h(r) \quad (1)$$

v_t **:turbulent velocity** ρ_g :gas density

h: **scale height of disk**

Energy balance (Turbulent Energy dissipation =Energy input from SNe)

$$\frac{\rho_g(r) v_t(r)^2}{t_{dis}} \approx \eta S_*(r) E_{SN} \quad (2)$$

$S_*(r) = C_* \rho_g(r)$:**star formation rate** per unit volume

η: heating efficiency

E_{SN}: total energy (10^{51} erg) injected by an SN

Angular momentum transfer due to the turbulent viscosity

$$\dot{M}(r) = 2\pi \nu_t \Sigma_g(r) \left| \frac{d \ln \Omega(r)}{d \ln r} \right| \quad (3)$$

$\nu_t = \alpha v_t h$:viscous parameter

$\Sigma_g = 2h\rho_g$:surface density of gaseous matter

Ω :angular velocity

SMBH growth and States of the CND

- Mass conservation（without mass loss from CNDs due to starburst wind）

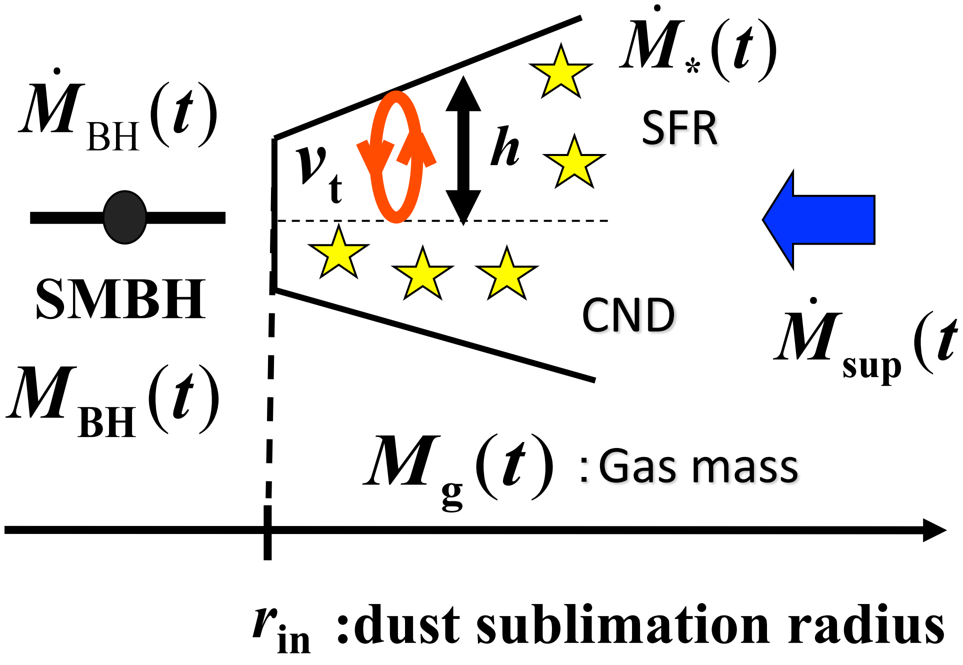
$$M_{\mathrm{g}}(t) = \int_0^t [\dot{M}_{\mathrm{sup}}(t') - \dot{M}_*(t') - \dot{M}_{\mathrm{BH}}(t')]dt'$$

- Angular momentum transfer due to turbulent viscosity

$$\dot{M}_{\mathrm{BH}}(t) = \dot{M}_{\mathrm{acc}}(r_{\mathrm{in}}, t) \propto \nu_{\mathrm{t}}$$

“viscous parameter”

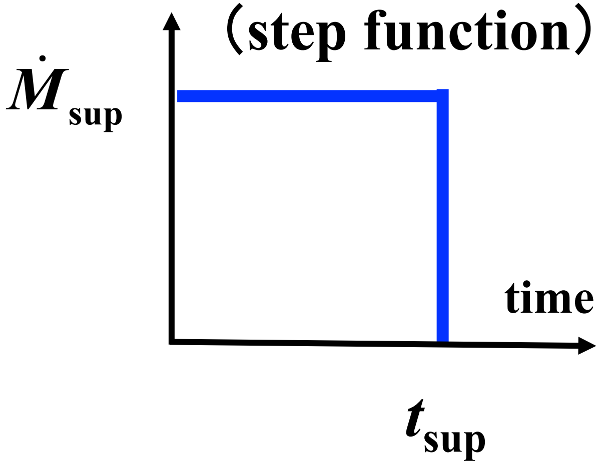
$$\nu_{\mathrm{t}} \approx v_{\mathrm{t}} h \propto (\mathrm{SFR})^{1/2}$$



$M_{\mathrm{g}}(t)$: Gas mass

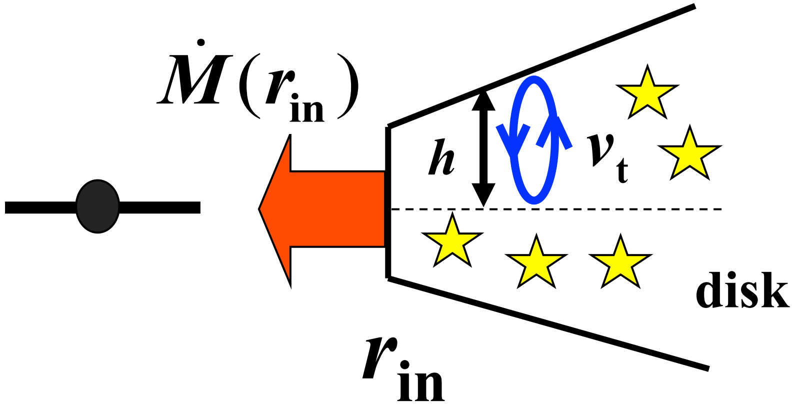
r_{in} :dust sublimation radius

Mass supply rate （step function）



Two major regimes of gas accretion depending on gravitational stability of the disk

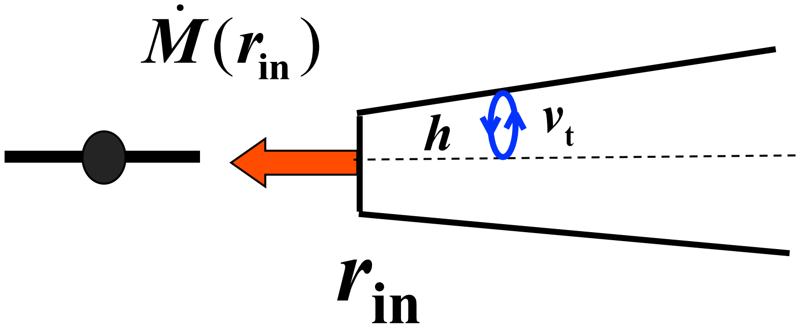
(i) Toomre Q < 1



Turbulent-pressure supported disk

(geometrically thick disk)

(ii) Toomre Q > 1



Gas pressure supported disk

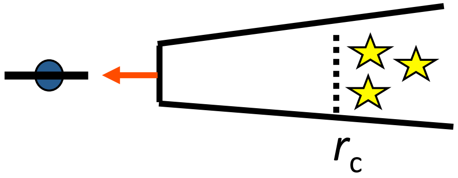
(geometrically thin disk)

$$\boxed{\dot{M}(r_{\rm in})^{(i)} \gg \dot{M}(r_{\rm in})^{(ii)}}$$

The mass accretion in the mode (i) is dominated by turbulent viscosity, and it is significantly larger than that in the mode (ii)

Toomre's stability criterion

$$\Sigma_{\mathrm{crit}}(r) = \frac{\kappa(r) c_{\mathrm{s}}}{\pi G}$$



$\kappa(r)$:epicyclic frequency

The critical radius r_{c} is determined by $\Sigma_{\mathrm{crit}}(r) = \Sigma_{\mathrm{g}}(r)$.

The fragmentation is expected at $r > r_{\mathrm{c}}$.

⬇

SF can be led by gravitational collapse of high density clump.
So, star formation time scale is $t_* \approx C_*^{-1}$.

AGN luminosity: $L_{\mathrm{AGN}} = f(\dot{M}_{\mathrm{BH}}, \dot{M}_{\mathrm{Edd}})$ *Our model*

Two types of accretion disk