Coevolution of Supermassive Black Holes and Circum-nuclear Disks

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Abstract

We propose a physical model of a SMBH growth, self-consistently connecting between the mass-supply from a host galaxy and the physical states of a circum-nuclear disk in the central 100 pc around the SMBH. We assume the growth rate of SMBH is determined by a local turbulent viscosity at the inner edge of the disk. We find the growth rate of SMBH is time-dependent, and there are two accretion phases; One is the high accretion phase ($\dot{M}_{\rm BH} > \dot{M}_{\rm Edd}$), the other is the low accretion phase ($\dot{M}_{\rm BH} \approx 10^{-3} \dot{M}_{\rm Edd}$). These two phases are separated by whether stars can be formed at the inner edge of the disk. Moreover, it is found that the AGN luminosity tightly correlates with the nuclear starburst only in the high accretion phase. This suggests that the starburst-AGN connection depends on the evolution of the AGN activity (*Kawakatu & Wada in preparation*).

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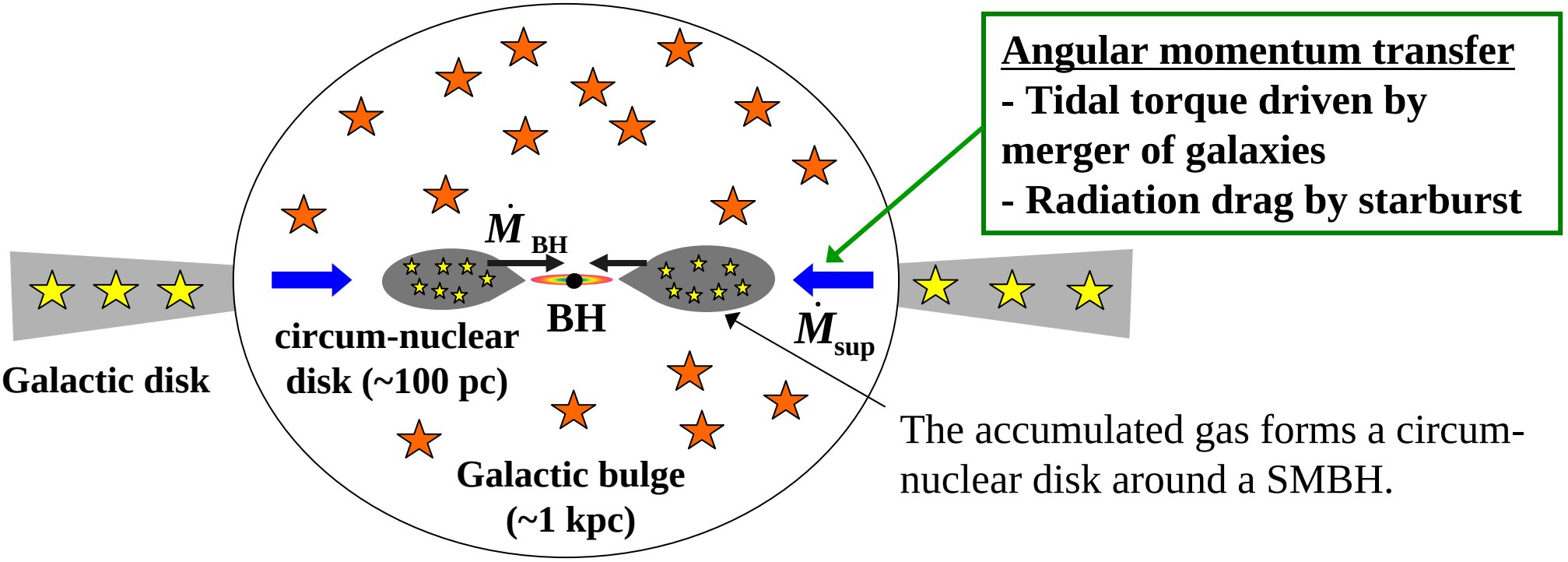
Introduction

☆ **Tight connection between SMBH mass and bulge mass** e.g., Kormendy & Richstone 1995; Marconi & Hunt 2003

☆ **Co-evolution models of SMBHs and bulges** e.g., Silk & Rees 1998; King 2003; Umemura 2001; NK et al. 2003

The physics on the angular momentum transfer is inevitable for SMBH formation.



Angular momentum transfer
- Tidal torque driven by merger of galaxies
- Radiation drag by starburst

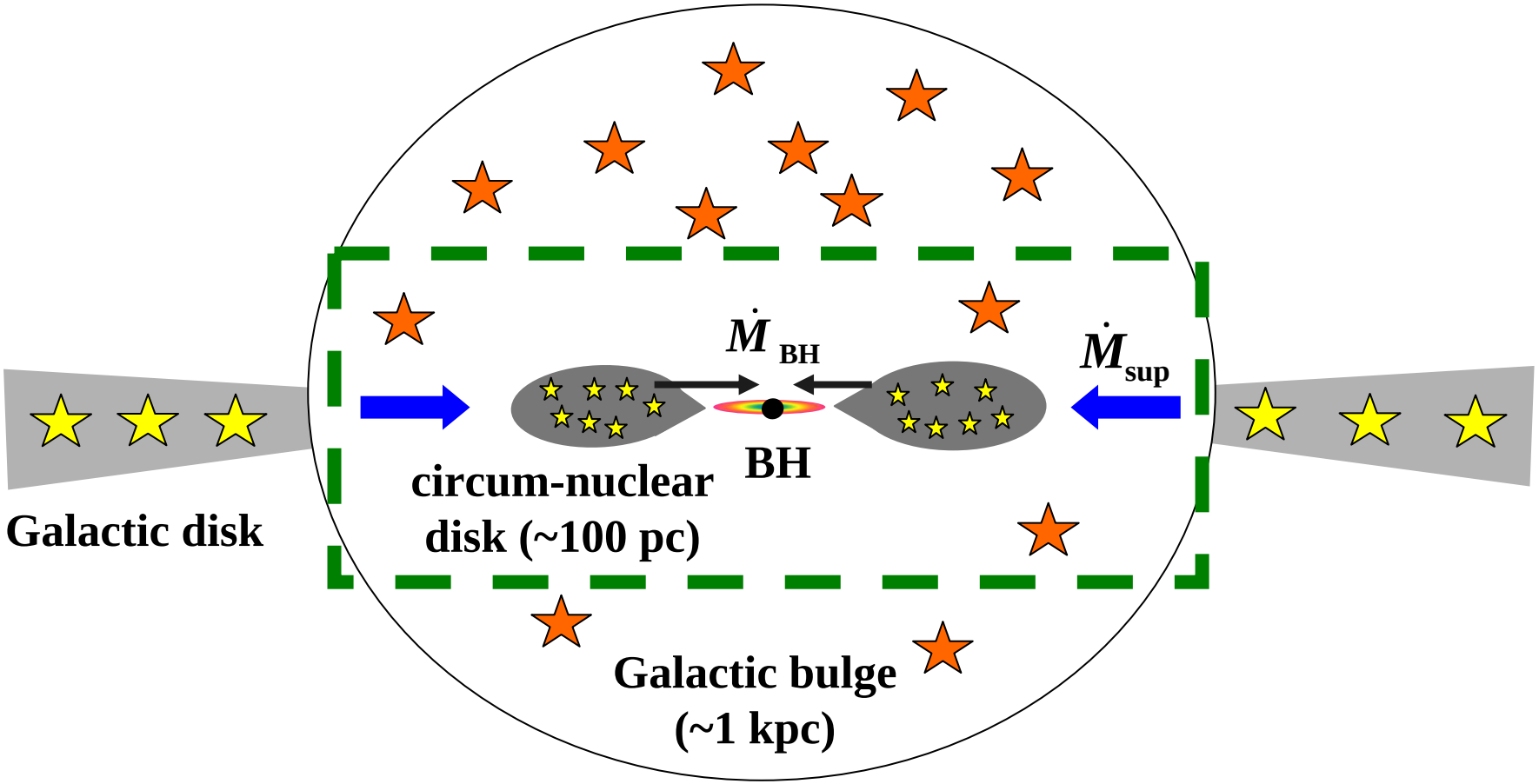
The accumulated gas forms a circum-nuclear disk around a SMBH.

Previous works assumed $\dot{M}_{BH} \approx \dot{M}_{Edd}$ *or* $\dot{M}_{BH} \approx \dot{M}_{sup}$, though SF is expected in such a disk.

(The nuclear starburst (< 100 pc) has been detected (e.g., Imanishi & Wada 2004; Davies et al. 2007)

It is crucial to link the mass accretion process from galactic scale into a BH, via the circum-nuclear disk formed by the gas-supply from host galaxy.

This work



We focus on the mass accretion from the outskirts of a circum-nuclear disk into a SMBH, considering the mutual connection between the mass-supply from hosts and physical states of the disk accompanied with SF consistently.

Models

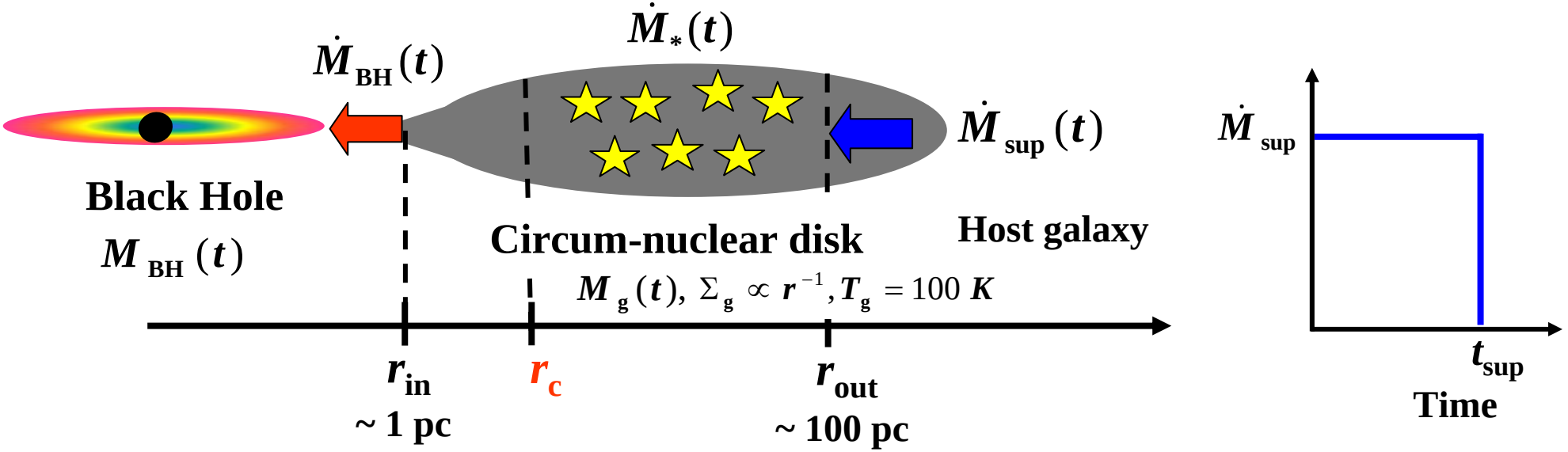
The supplied gas from hosts is eventually consumed to form SMBH or stars, otherwise it accumulates. Thus, by mass conservation, the time-evolution of gas mass in disk is given by

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

input parameter

SF occurs in the disk outside a critical radius r_c, where the disk is gravitational unstable.

$$\dot{M}_*(t) = f_{\rm a}\kappa M_{\rm g}(t)$$ κ **: star formation efficiency;** $f_{\rm a} = 1-(r_{\rm c}/r_{\rm out})^2$



Growth rate of SMBH: $\dot{M}_{\rm BH}$

We adopt the formula of mass accretion rate in a viscous accretion (Pringle 1981) .

$$\dot{M}_{\rm BH} \equiv \dot{M}(r_{\rm in}) = -\left[\frac{\frac{\partial}{\partial r}G(r,t)}{\frac{d}{dr}[r^2\Omega(r)]}\right]_{r=r_{\rm in}}$$

$G(r,t) = 2\pi\nu\,\Sigma_g r^3 \frac{\partial\Omega}{\partial r}$: viscous torque

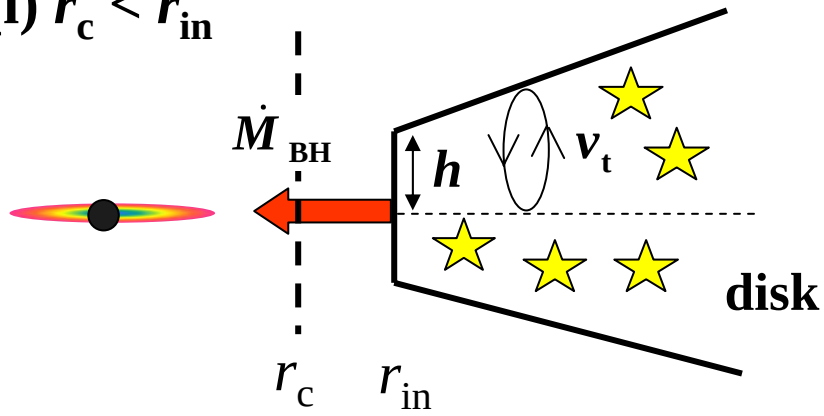
$\nu = v_t h$: viscous parameter

v_t :turbulent velocity h: scale height of disk

BH growth rate depends on the turbulent velocity and scale height of disk at $r_{\rm in}$.

Thus, we need to determine the turbulent velocity and scale height of disk .

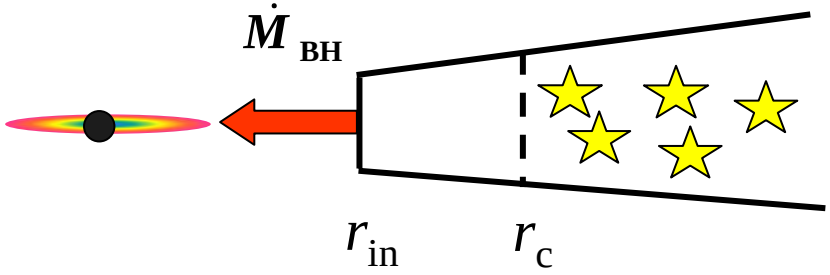
(i) $r_c < r_{\rm in}$



Turbulent pressure = gravity in vertical direction

Turbulent Energy dissipation =Energy input from SNe

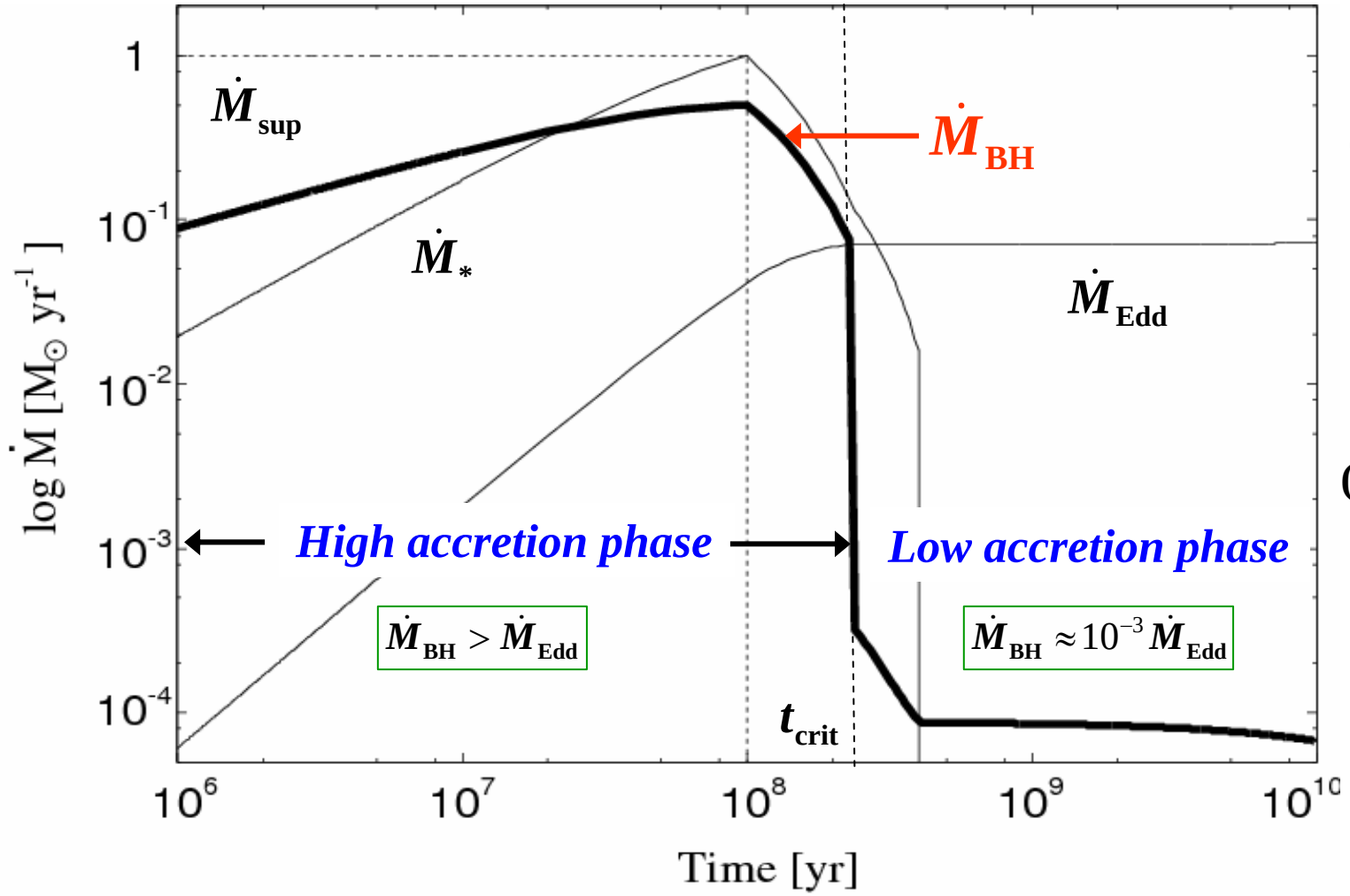
(ii) $r_c > r_{\rm in}$



Gas pressure = gravity in vertical direction

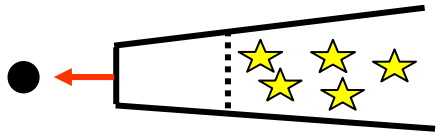
3D hydrodynamic simulations support this treatment (Wada & Norman 2002).

Results: Two phases for SMBH growth



(i) High accretion phase

(ii) Low accretion phase

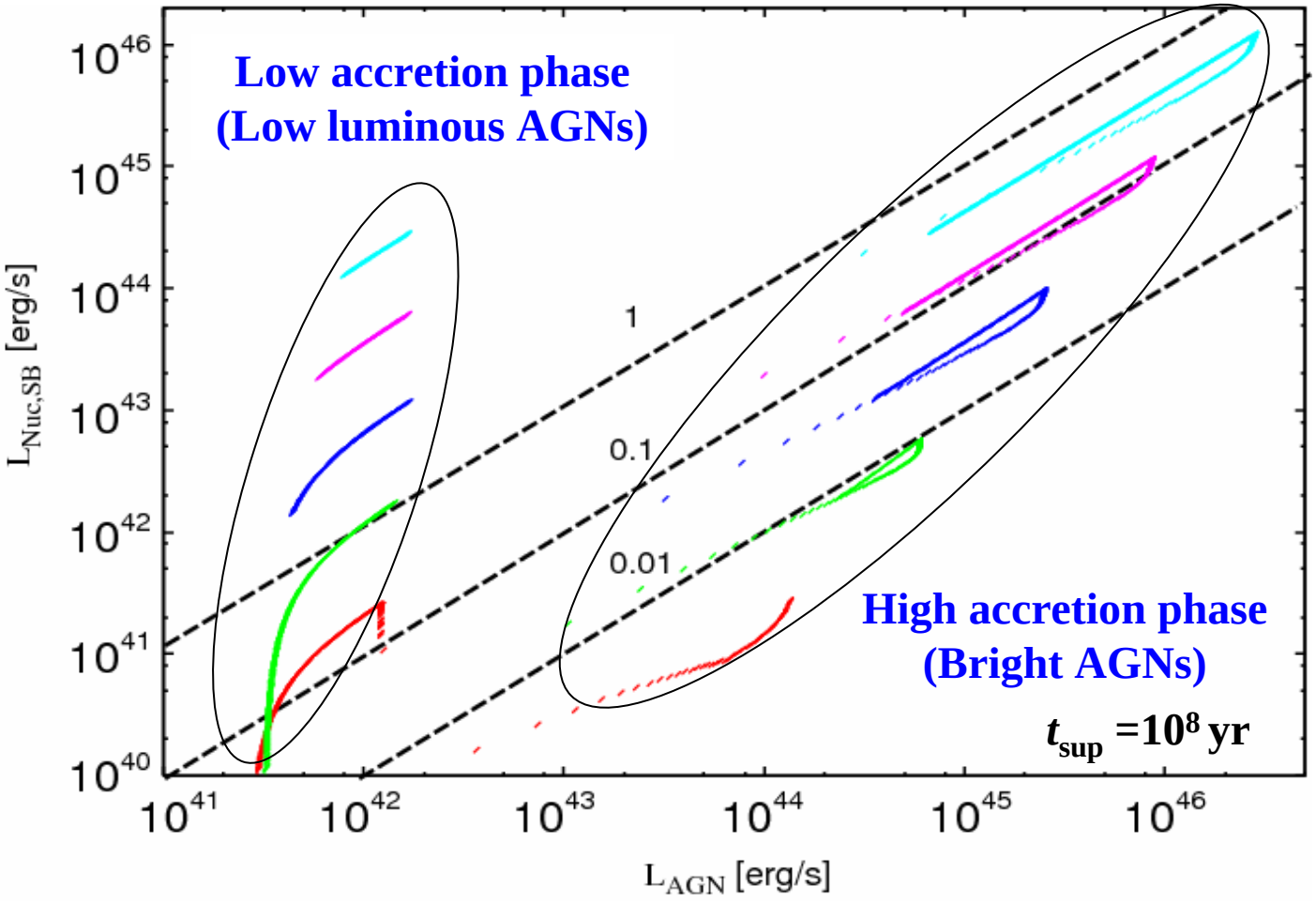


The growth of SMBHs is drastically changed from high accretion phase to low one.

The two phases are separated by whether stars can be formed at the inner edge of disk.

Results: AGN-Nucear SB connection

Based on out model, we examine the relation between $L_{\rm AGN}$ and $L_{\rm Nuc,\,SB}$.



- $M_{\rm BH,final} = 4.9\times10^8\,M_\odot$
- $M_{\rm BH,final} = 1.4\times10^8\,M_\odot$
- $M_{\rm BH,final} = 3.6\times10^7\,M_\odot$
- $M_{\rm BH,final} = 6.7\times10^6\,M_\odot$
- $M_{\rm BH,final} = 8.3\times10^5\,M_\odot$

Luminosity:

$$L_{\rm AGN}\begin{cases} 2\left(1+\ln\dfrac{\dot m_{\rm BH}}{20}\right)L_{\rm Edd}\,;\,\dot m_{\rm BH}\geq 20, \\ \left(\dfrac{\dot m_{\rm BH}}{10}\right)L_{\rm Edd}\,;\,\dot m_{\rm BH}<20, \end{cases}$$

$$\dot m_{\rm BH}\equiv \dot M_{\rm BH}/\dot M_{\rm Edd}$$

(Watarai et al. 2000)

$$L_{\rm Nuc,SB}=0.14\varepsilon\dot M_* c^2\;;\varepsilon=0.007$$

The AGN luminosity tightly correlates with the nuclear SB for bright AGNs, but LLAGNs do not follow this correlation. This implies that the starburst-AGN connection depends on the evolution of AGN activity.

Summary

We propose a physical model of a SMBH growth, self-consistently connecting between the mass-supply from a host galaxy and the physical states of a circum-nuclear disk around a central SMBH.

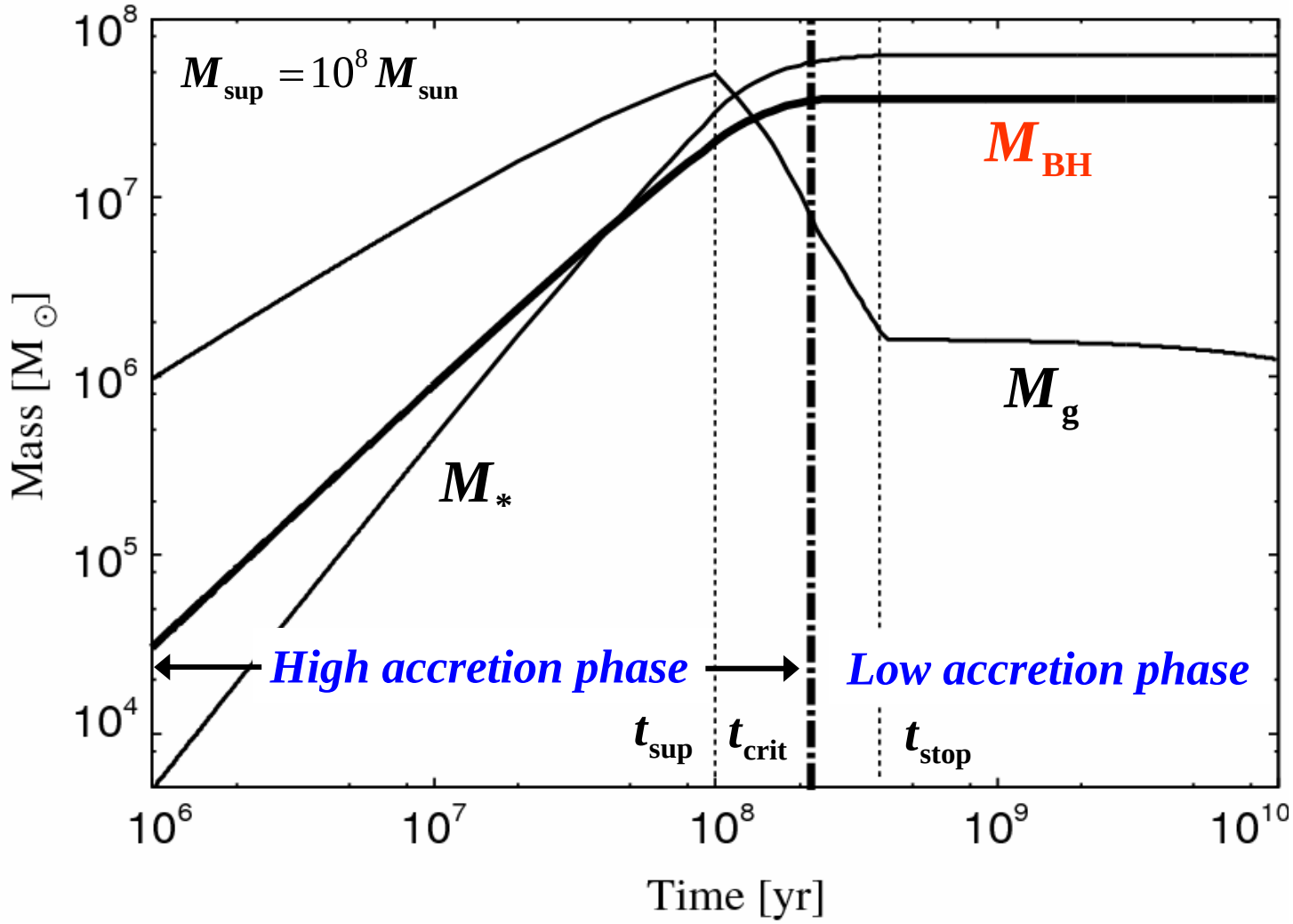
1. We find that the growth rate of SMBHs is drastically changed from the high accretion phase to low one. The two phases are separated by whether stars can be formed at the inner edge of the circum-nuclear disk.

2. The AGN luminosity ($L_{\rm AGN}$) tightly correlates with the nuclear SB ($L_{\rm Nuc,\ SB}$) luminosity in bright AGNs. We also predict $L_{\rm AGN}/L_{\rm Nuc,\ SB}$ is larger for more luminous AGNs. This is not the case in LLAGNs. Therefore, our models suggest the AGN-starburst connection depends on the evolution of AGN activity.

3. We examine the connection between nuclear activities and states of circum-nuclear disk. As a result, the following things are predicted;
   -- High accretion phase (Bright AGNs): ***massive gas torus*** ($M_{\rm g} > M_{\rm BH}$)
   -- Low accretion phase (LLAGNs): ***gas-poor massive stellar disk*** ($M_{*} > M_{\rm BH}$)
   This suggests the states of circum-nuclear ISM or stellar system are important to understand the nature for different type of AGNs with ALMA and VLTI.

If you are interested in result (3), I can show you some figures. Please contact me!

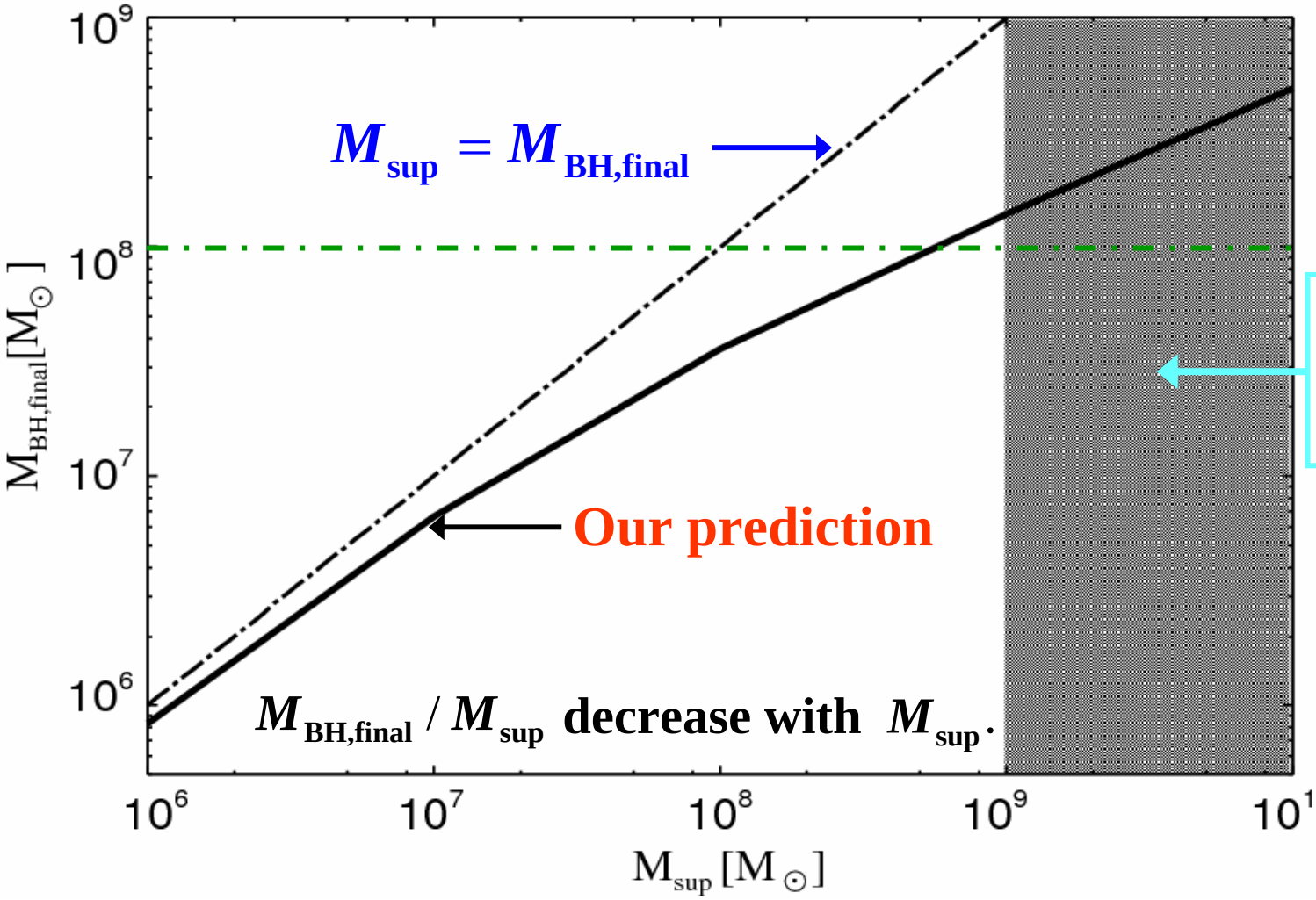
Results: Evolution of states of circum-nuc. disk



High accretion phase : ***massive gas torus*** ($M_g > M_{BH}$)

Low accretion phase : ***gas-poor massive stellar disk*** ($M_* > M_{BH}$)

Results: $M_{BH,\,final}$ vs. M_{sup} relation



$M_{sup} \equiv \dot{M}_{sup} t_{sup}$
:total gas mass supplied from hosts

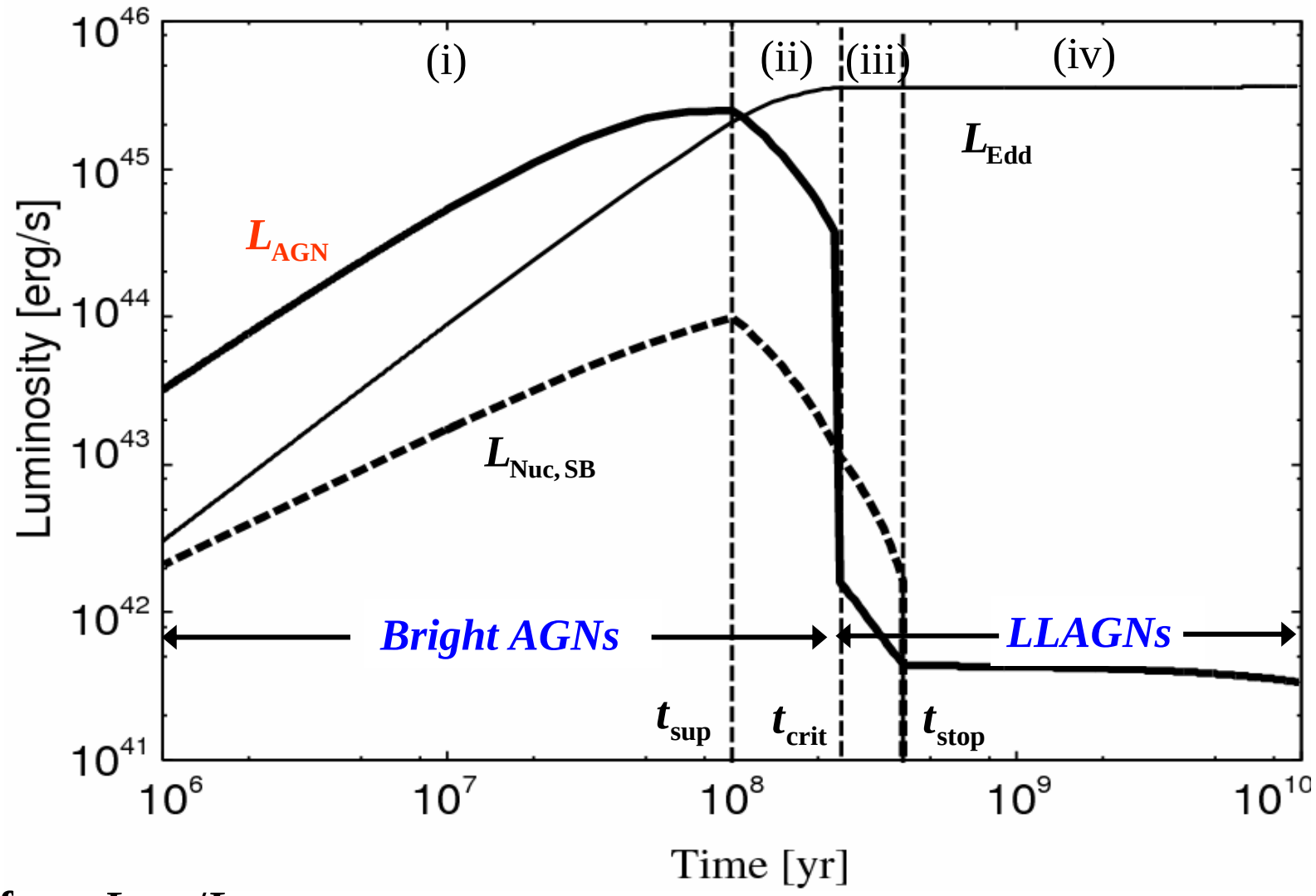
It may be hard to accrete such a plenty of gas from hosts

$\dot{M}_{sup} = 0.1-1 M_\odot \mathrm{yr}^{-1}$

$t_{sup} = 10^{8-9}\,\mathrm{yr}$

It is hard to form huge SMBH with ~$10^9 M_\odot$ observed in luminous QSOs, only by the gas accretion process.

Results: Evolution of AGN and Nuc. SB luminosity



Judging from L_{AGN}/L_{Edd},

phase (i): NLS1s or ULIRGs, phase (ii): BLS1s or QSOs, phase (iii) and (iv): LLAGNs