Hyper-Eddington accretion flows onto massive black holes

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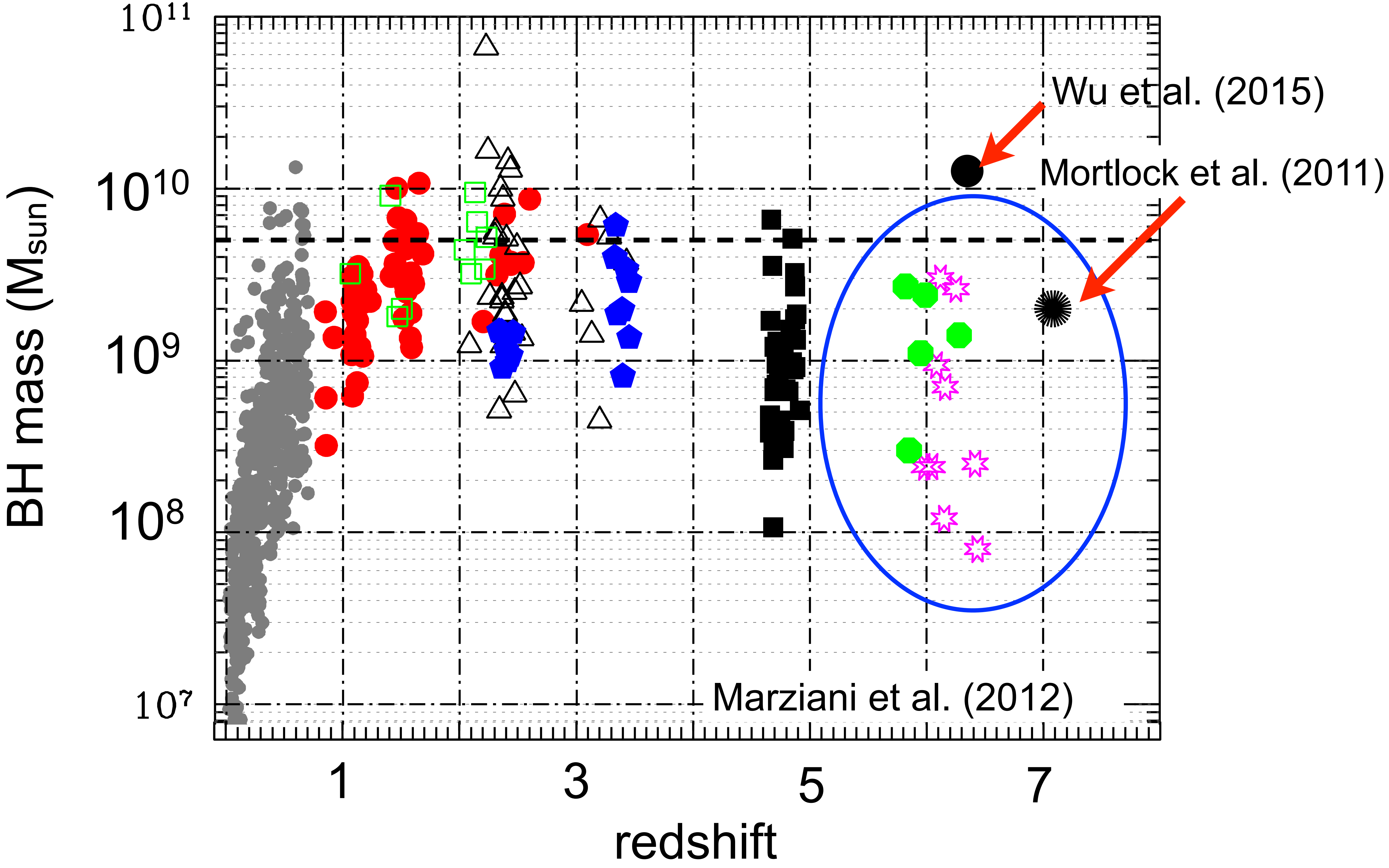
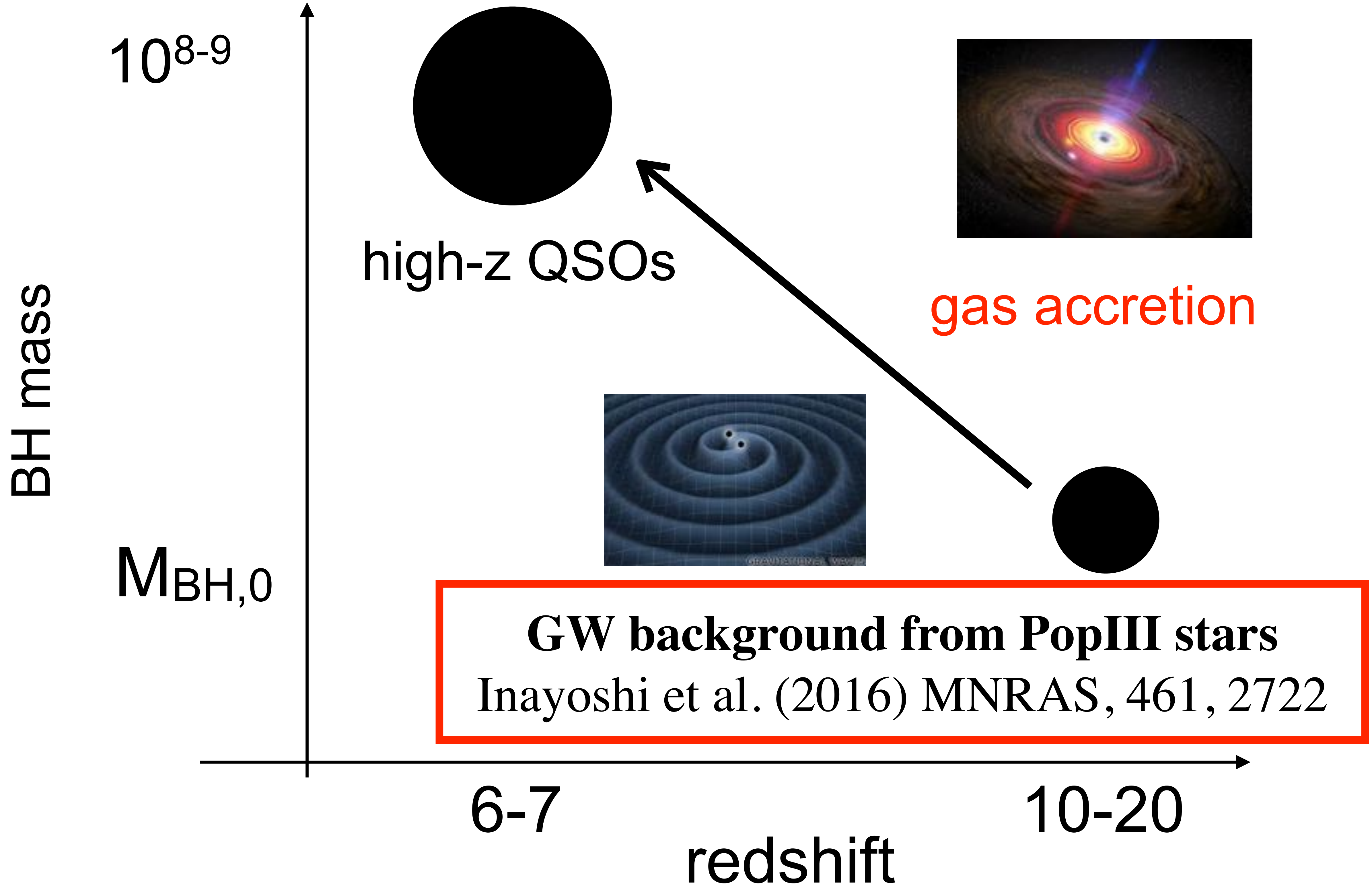
High-redshift SMBHs



BH growth processes



GW background from PopIII stars
Inayoshi et al. (2016) MNRAS, 461, 2722

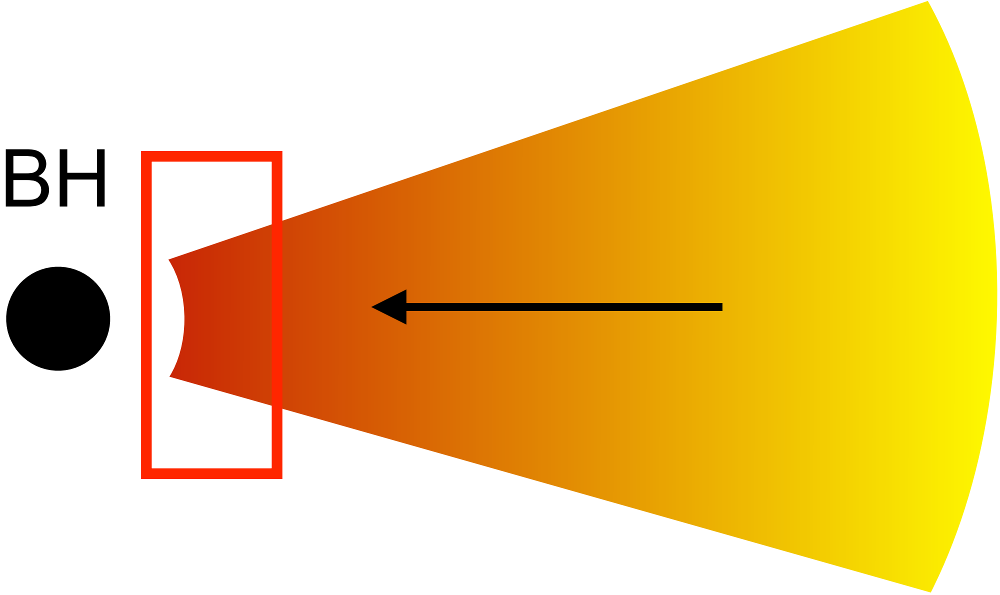
Two limits of BH growth

1. radiation pressure

$$L = \eta \dot{M} c^2 \le L_{\rm Edd}$$

⇨

$$\dot{M} \le \frac{L_{\rm Edd}}{\eta c^2} = \frac{\dot{M}_{\rm Edd}}{\eta}$$



Super-Eddington accretion

- photon trapping within flows

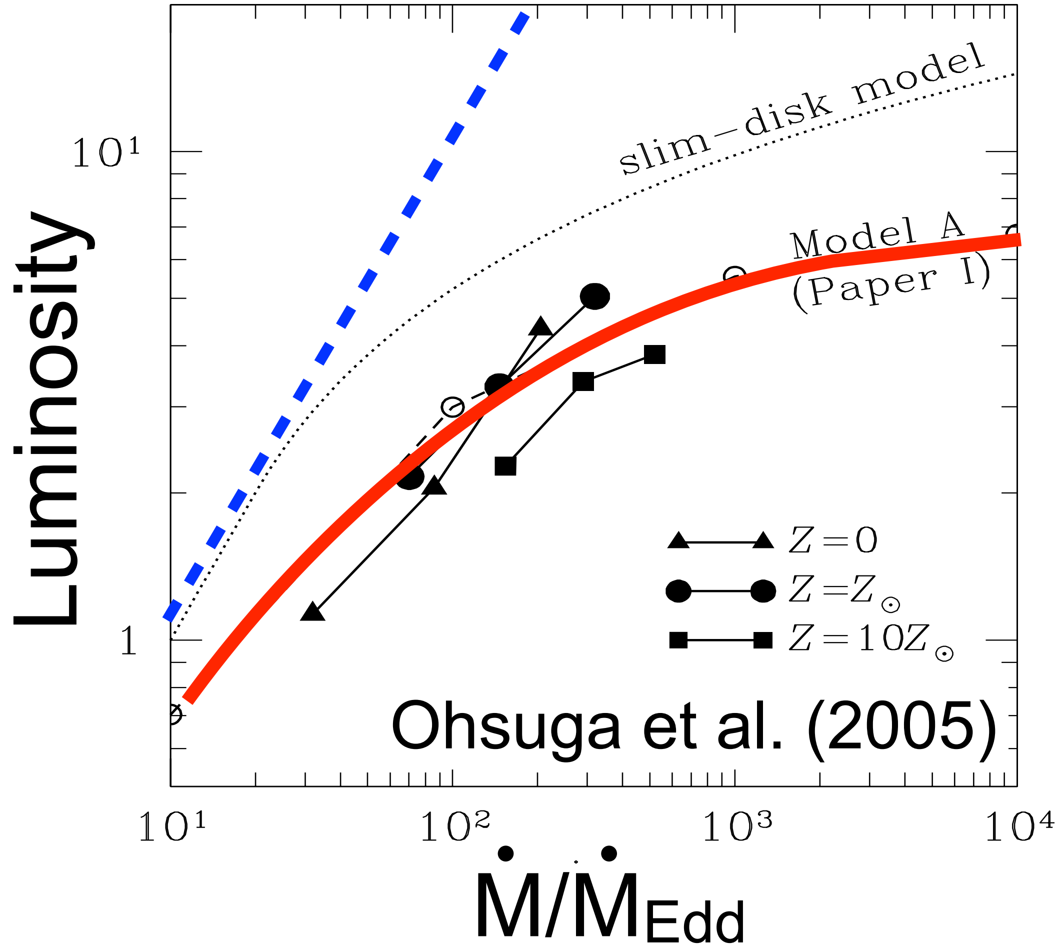
$$v > \frac{c}{\tau} \qquad (\tau \gg 1)$$

(advection > diffusion)

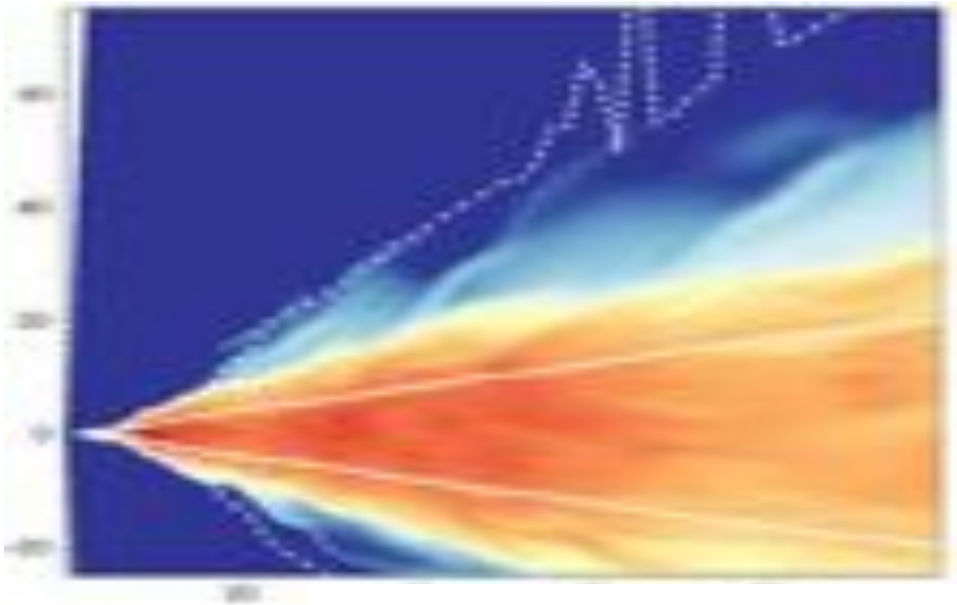
$$R < R_{\rm tr} \sim \frac{\dot{M}}{\dot{M}_{\rm Edd}} R_{\rm g}$$

$$\dot{M} \gg \dot{M}_{\rm Edd} \quad (L \sim L_{\rm Edd})$$

because of photon trapping



Ohsuga et al. (2005)



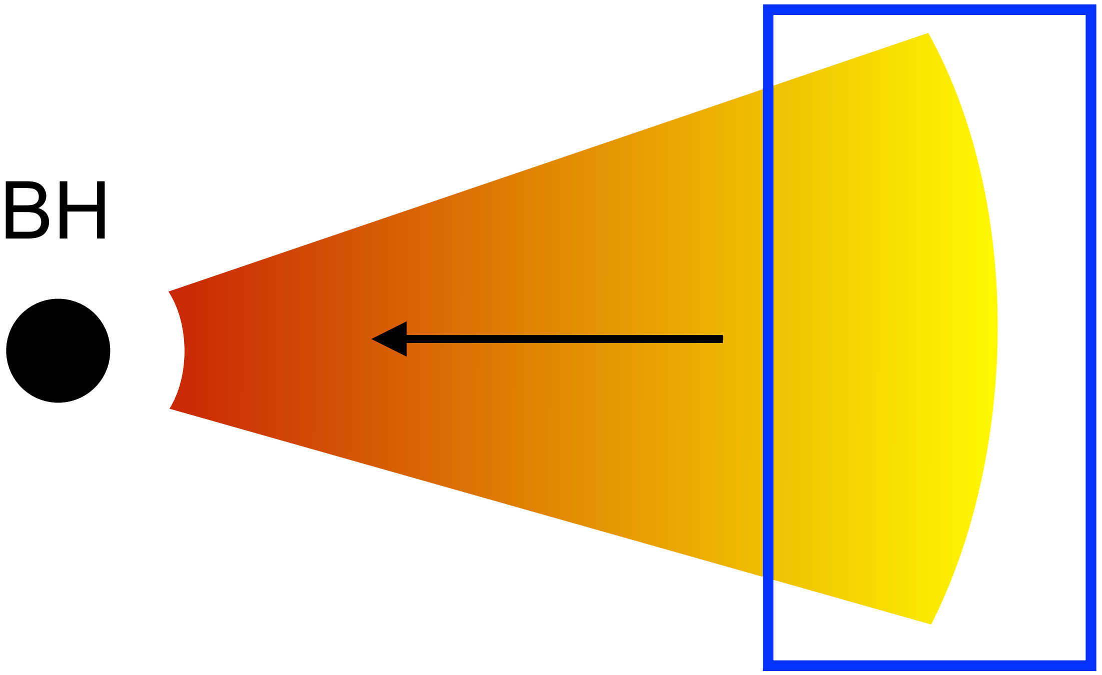
Sadowski et al.(2015)

Two limits of BH growth

1. radiation pressure

$$L \sim \dot{M}c^2 \leq L_{\rm Edd}$$

$$\Rightarrow \quad \dot{M} \leq \frac{L_{\rm Edd}}{\eta c^2} = \frac{\dot{M}_{\rm Edd}}{\eta}$$



2. radiation heating / ionization

$$R_{\rm B} \sim \frac{GM_{\rm BH}}{c_s^2}$$

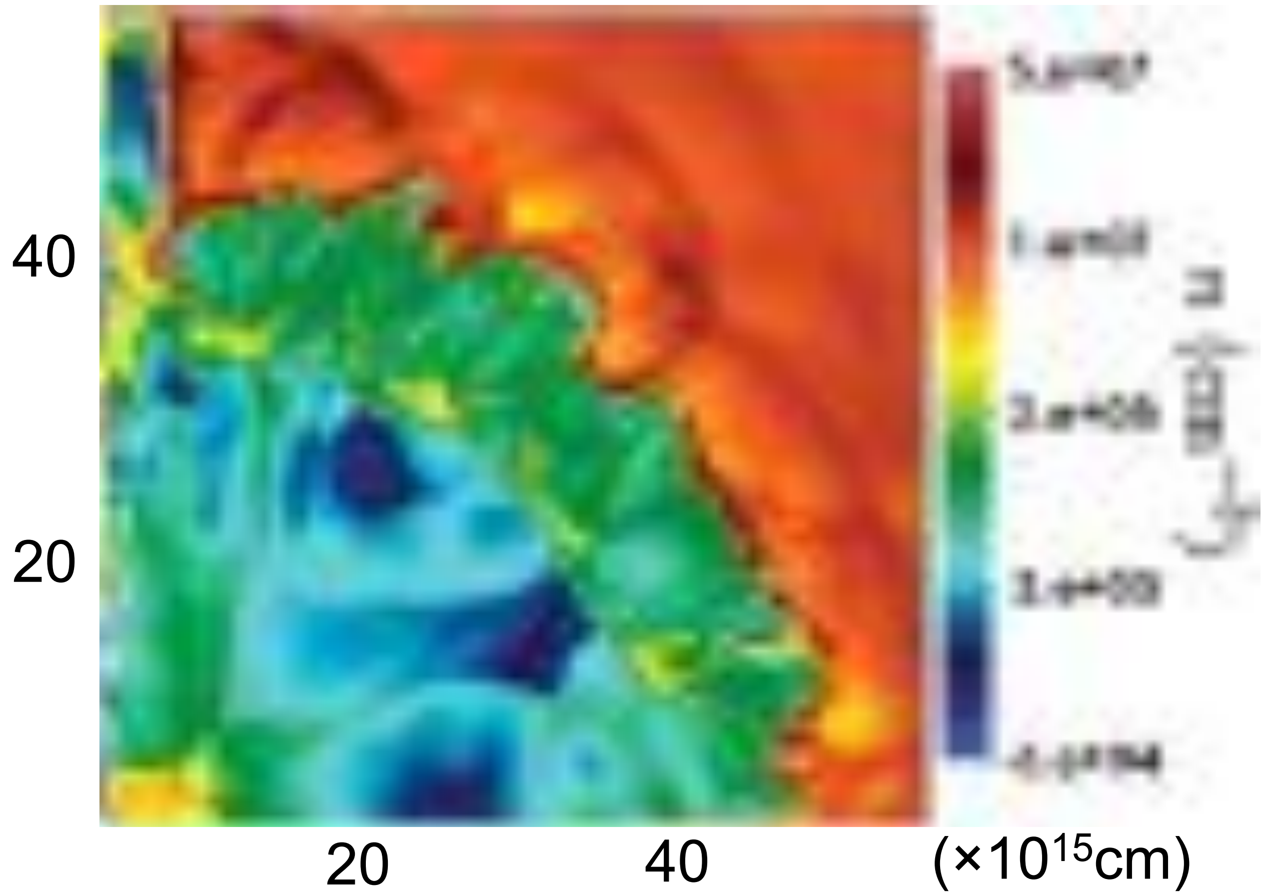
(Bondi radius)

$$\dot{M} \lesssim \rho c_s R_{\rm B}^2 \propto \rho\ M_{\rm BH}^2\ T^{-3/2}$$

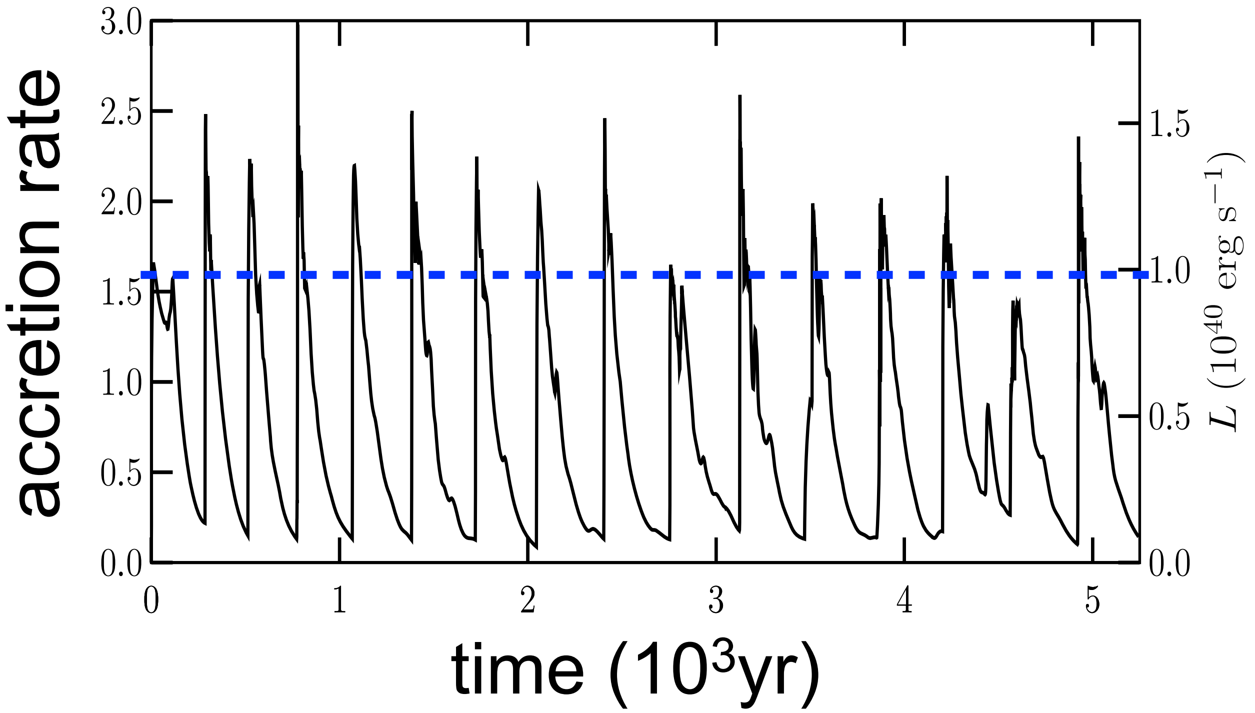
episodic accretion: $\dot{M} \nearrow$ $T \nearrow$ $\dot{M} \searrow$

Gas supply from large scales

Ciotti & Ostriker (2001), Milosavljevic et al. (2009), Park & Ricotti(2011,2012), Park et al. (2016



Milosavljevic et al. (2009) (100M$_{\rm sun}$ BH)



$$\dot{M}_{\rm B} \propto \underline{\rho_\infty \, T_\infty^{-3/2}} \, M_{\rm BH}^2$$

episodic accretion due to photo-heating;

$\langle \dot{M} \rangle \lesssim \dot{M}_{\rm Edd}$ ~~photon trapping~~

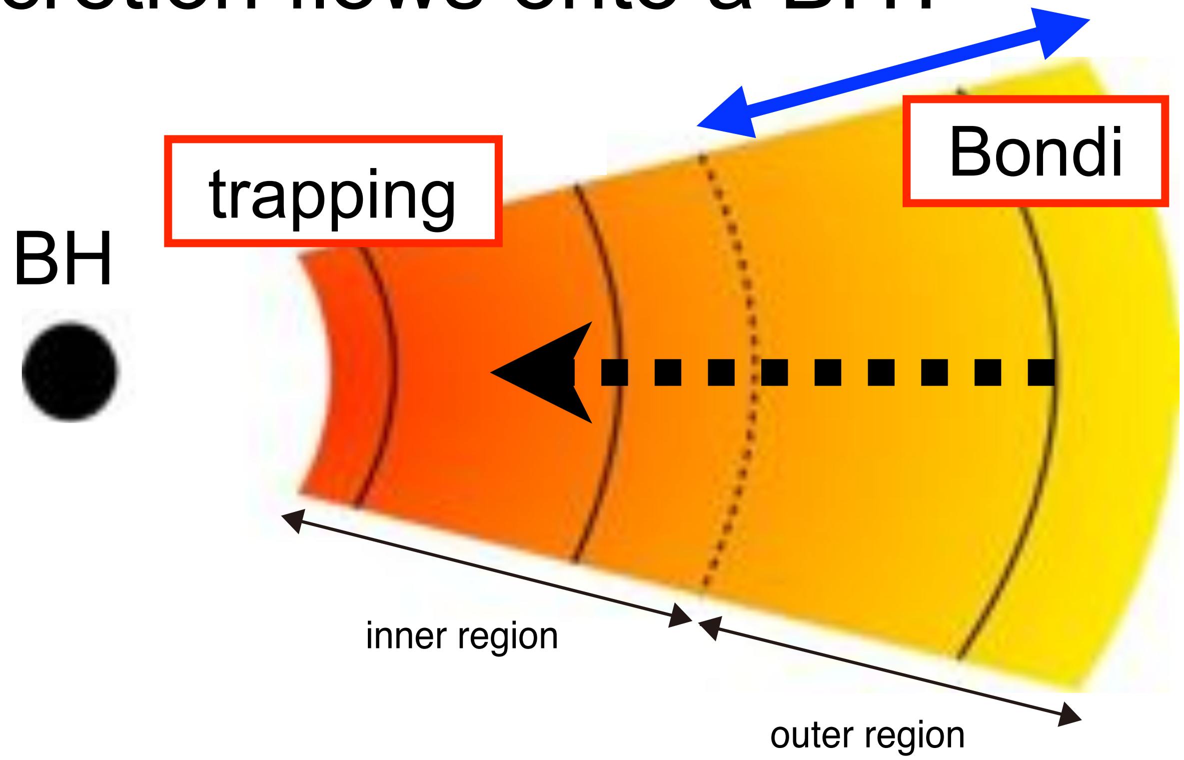
This work

KI, Haiman & Ostriker (2016)

Question

$\dot{M} \gg \dot{M}_{\rm Edd}$

What is a global solution of accretion flows onto a BH?



Methods

1D radiation hydro simulation

ZEUS
Stone & Norman (1992)
+
multi-frequency
non-eq chemistry

Goals

Find *self-consistent solutions* of *hyper-Eddington accretion* from the Bondi radius

$$L = \eta \dot{M} c^2$$

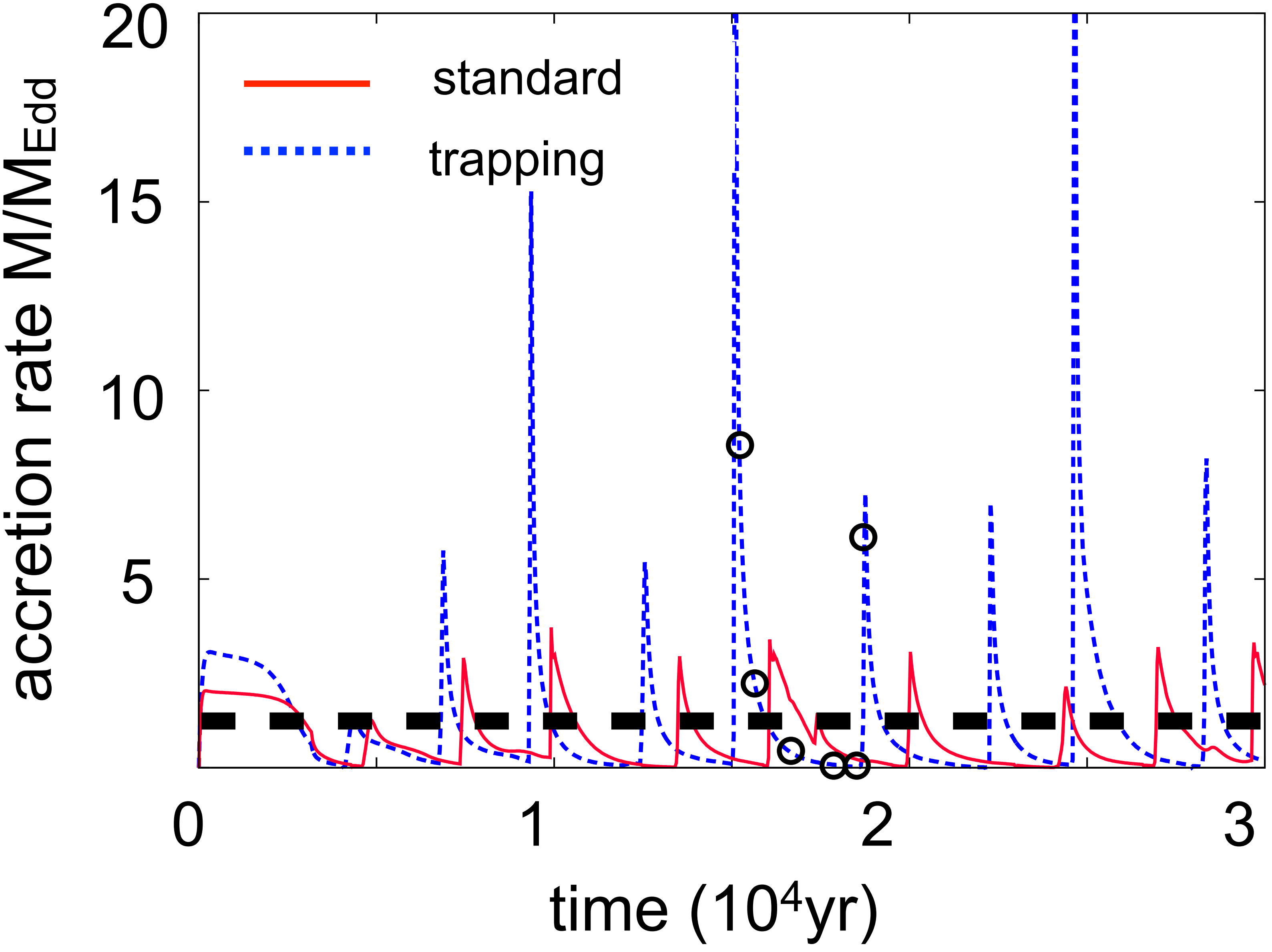
$\eta = 0.3$ (thin disk)

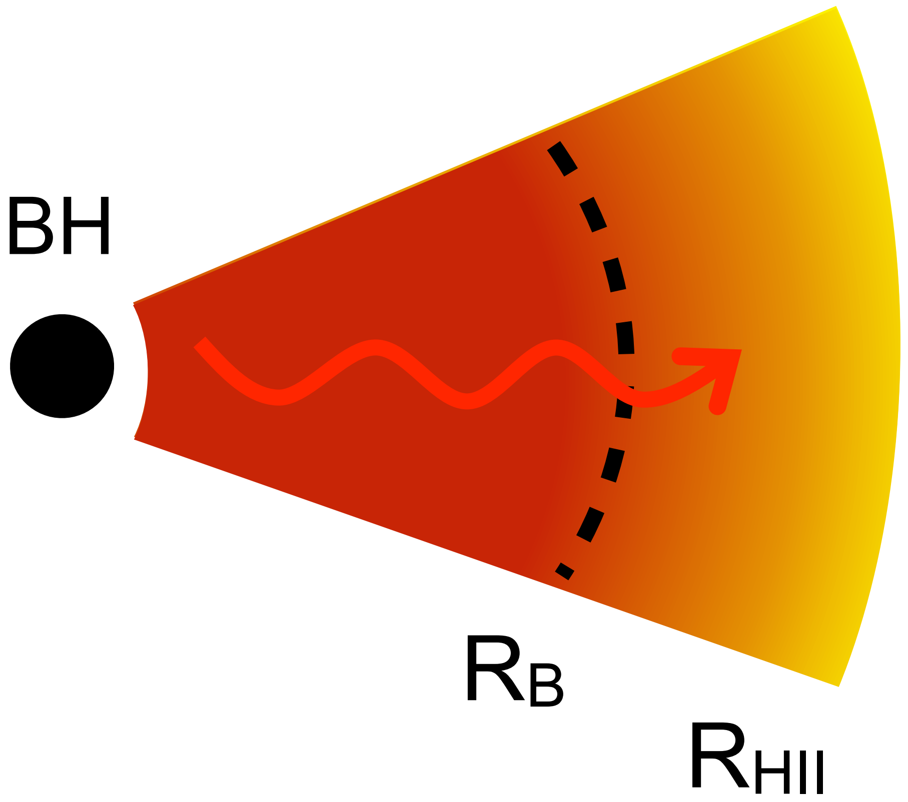
$\eta = \frac{3}{10 + 3\dot{m}}$ (slim disk)

Stella-mass BH case

$M_{BH}=100\ M_{sun}$

$n_{\infty}=10^5\ \mathrm{cm}^{-3}$

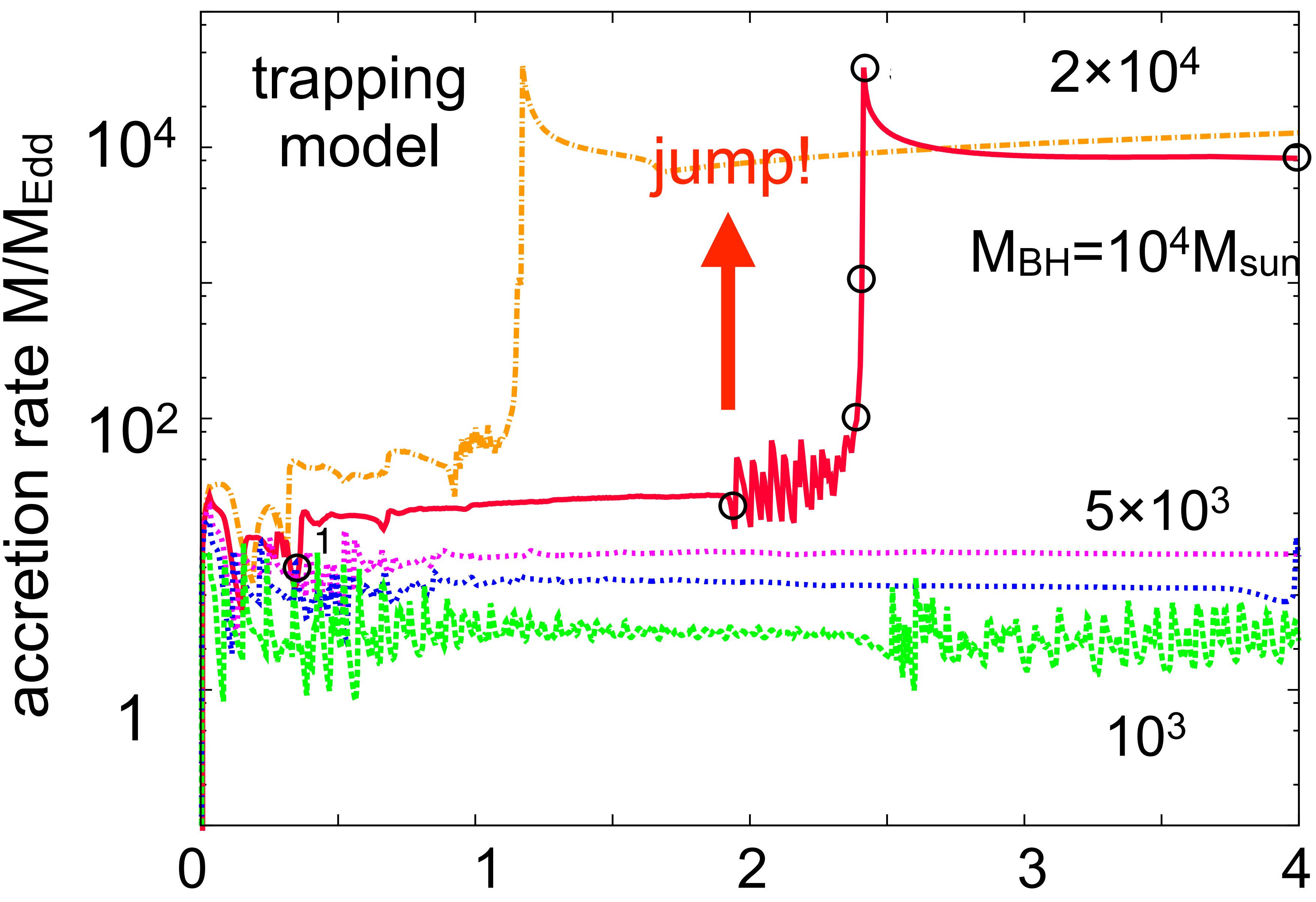


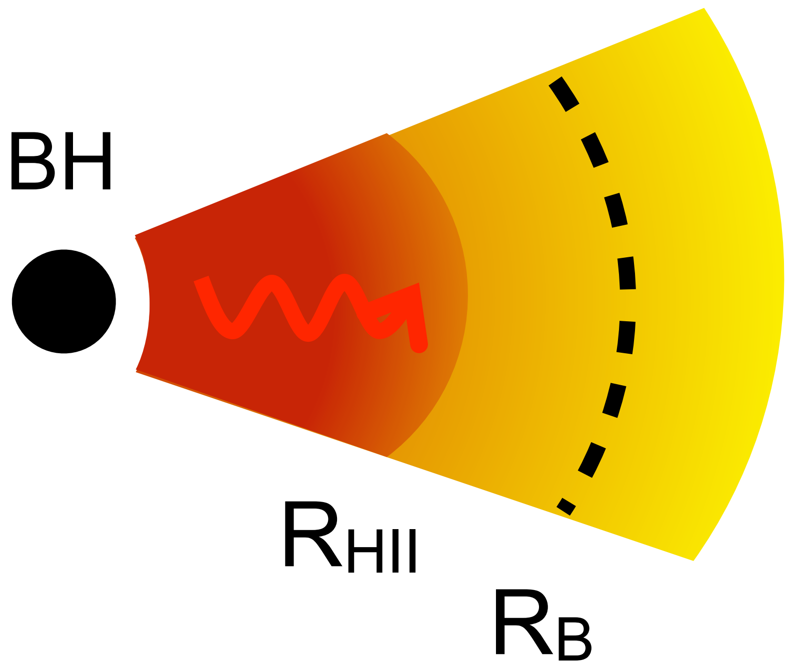


episodic accretion by **radiation heating** (**R_B < R_{HII}**) ⇒ $\langle \dot{M} \rangle \lesssim \dot{M}_{\rm Edd}$

Higher BH mass cases

$n_\infty = 10^5\ \mathrm{cm}^{-3}$
$M_{BH} >= 10^3 M_{sun}$

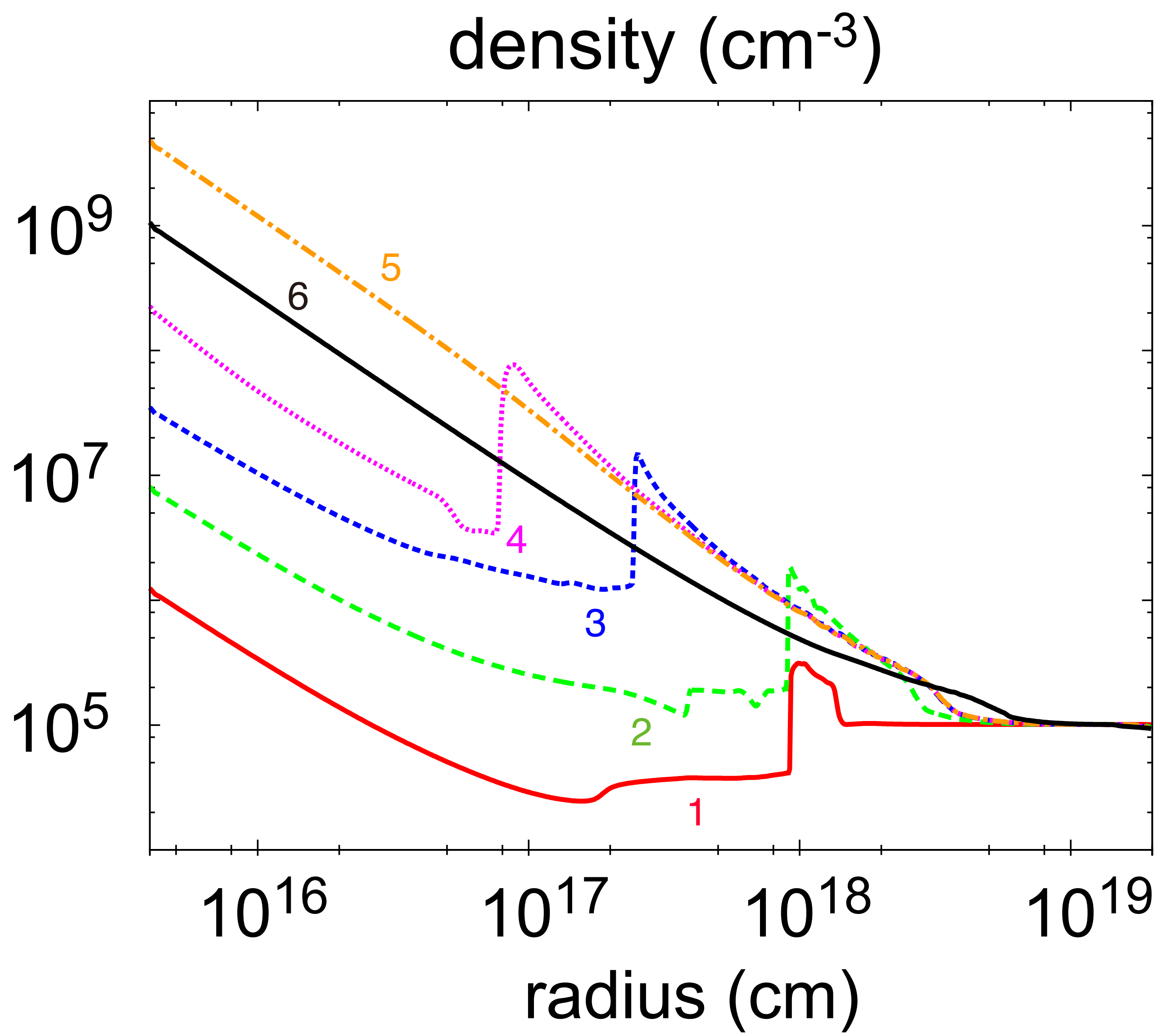


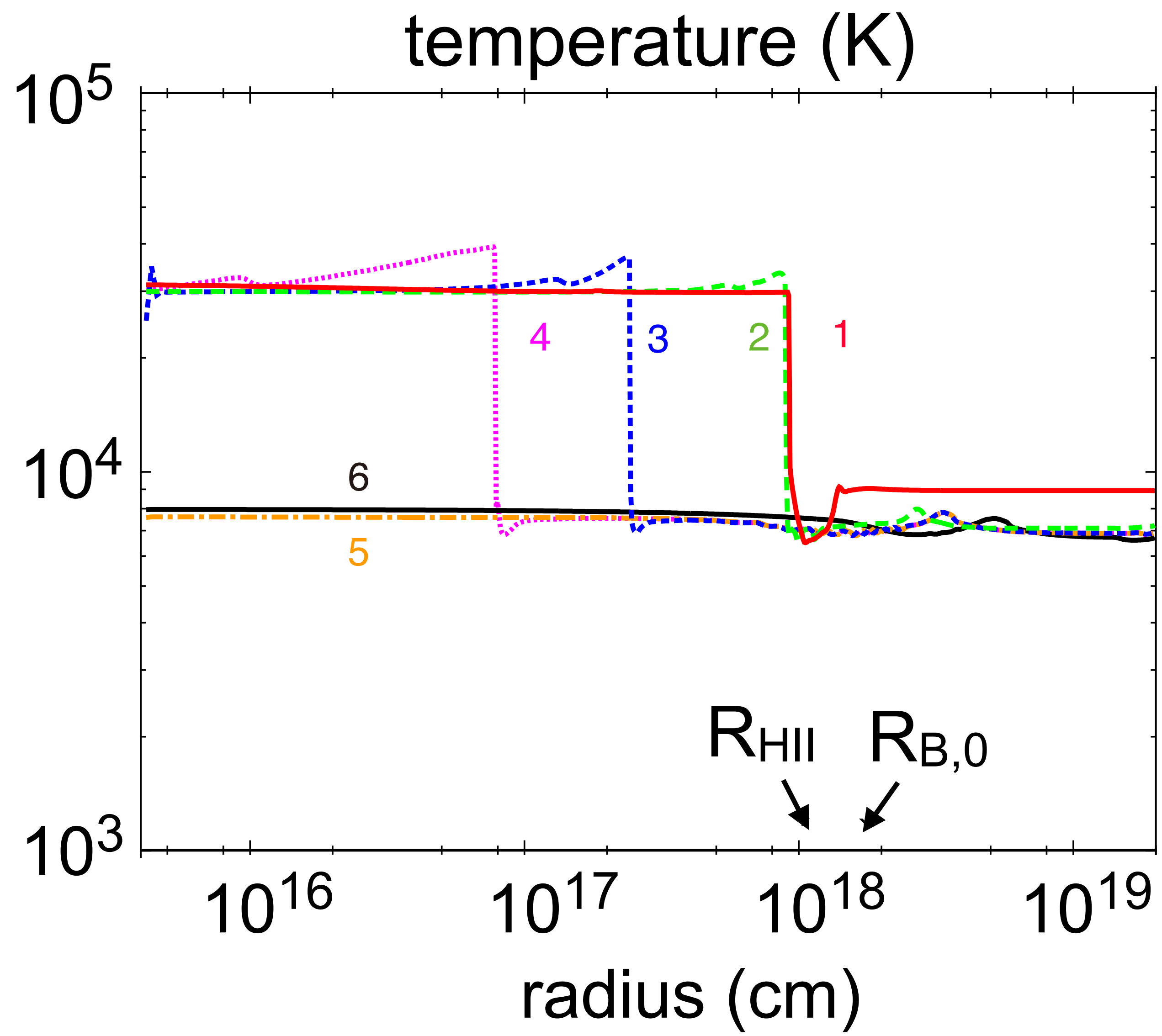


hyper-Eddington
for higher M_{BH}
→
isothermal Bondi
$\dot{M} \simeq \dot{M}_{\rm B}$

Higher BH mass cases

$n_\infty = 10^5\ \mathrm{cm^{-3}}$
$M_{BH} = 10^4 M_{sun}$





hyper-Eddington
for higher M_{BH}

➡

isothermal Bondi
$$\dot{M} \simeq \dot{M}_{\rm B}$$

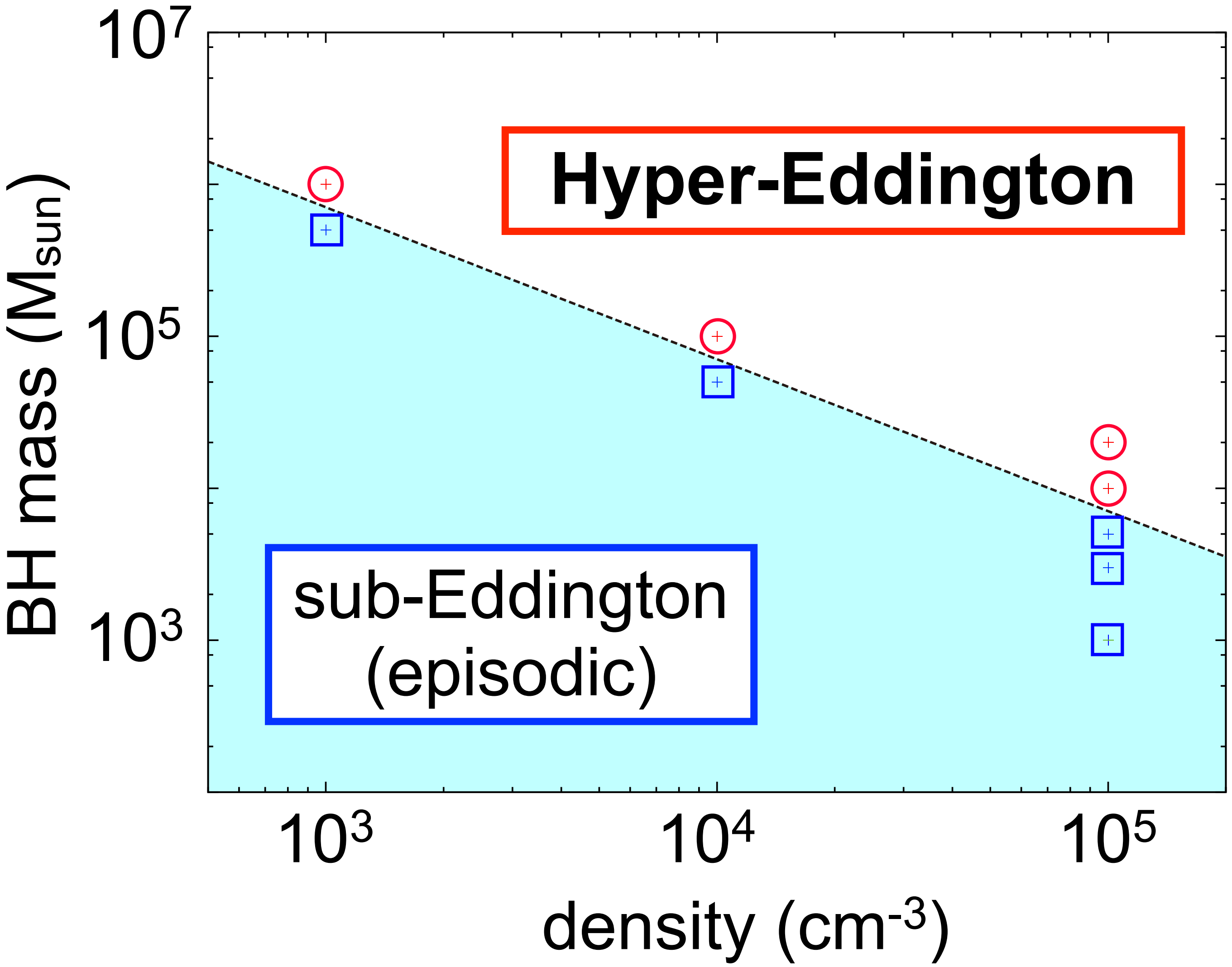
Physical interpretation

- analytical argument

$$R_{\mathrm{H_{II}}} = \left(\frac{3Q_{\mathrm{ion}}}{4\pi\alpha_{\mathrm{rec,B}}n_\infty^2}\right)^{1/3}$$

$$\propto L^{1/3}n_\infty^{-2/3} \leq \underline{M_{\mathrm{BH}}^{1/3}}\,n_\infty^{-2/3}$$

$$R_{\mathrm{B}} = \frac{GM_{\mathrm{BH}}}{c_\infty^2} \quad \propto \underline{M_{\mathrm{BH}}}\,T_\infty^{-1}$$

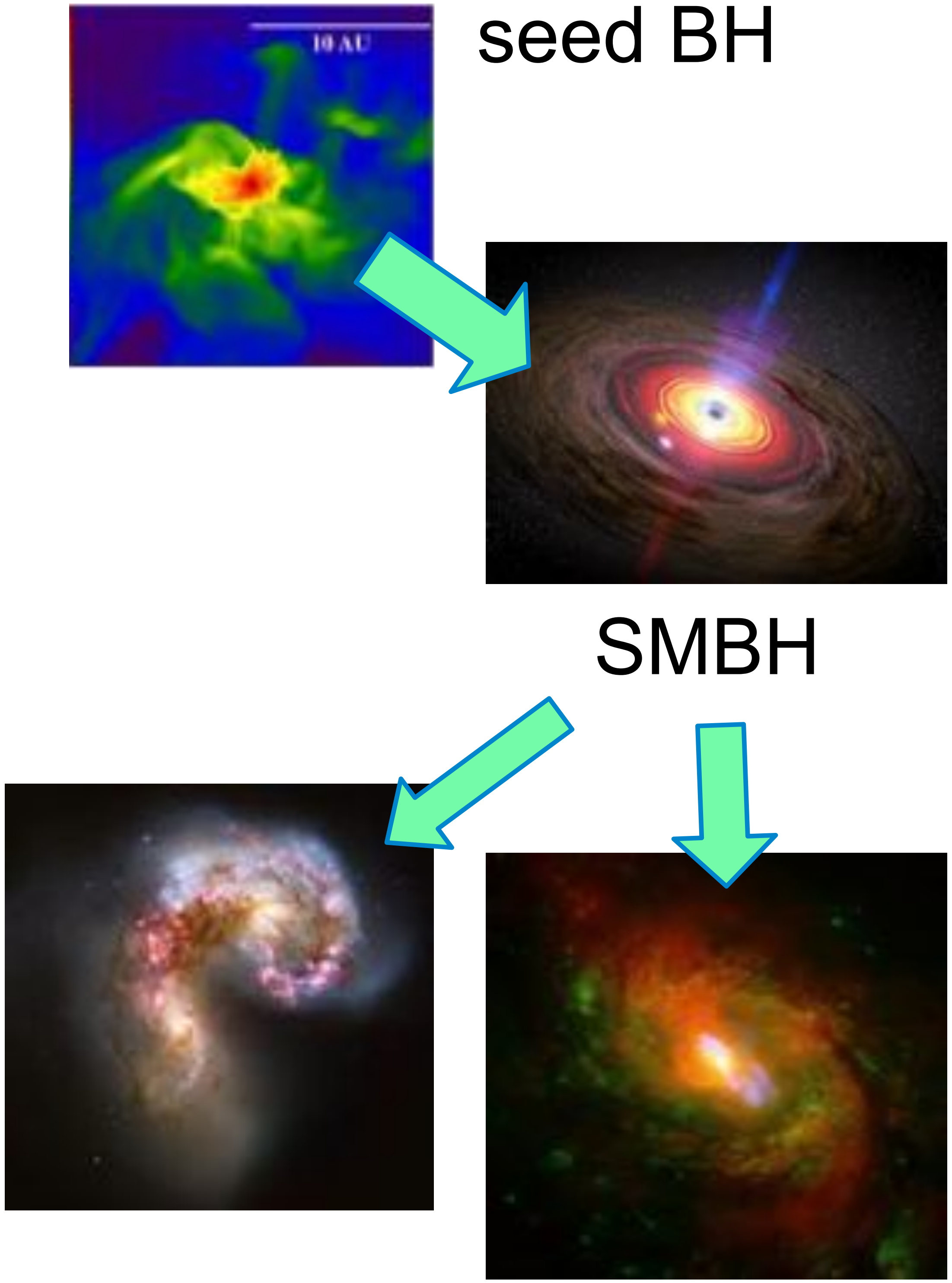


Hyper-Eddington conditions (**$R_{\mathrm{HII}}<R_{\mathrm{B}}$**)

$$M_{\mathrm{BH},4}n_{\infty,5} \gtrsim T_{\infty,4}^{3/2} \quad \Leftrightarrow \quad \dot{m} = \frac{\dot{M}}{\dot{M}_{\mathrm{Edd}}} \geq 5000$$

Applications

- BH growth in the early Universe
  - supermassive BHs at $z>6$
  - seed formation / growth
- observational signatures
  - Lyα emitters without X-rays
  - luminous infrared galaxies



seed BH

SMBH

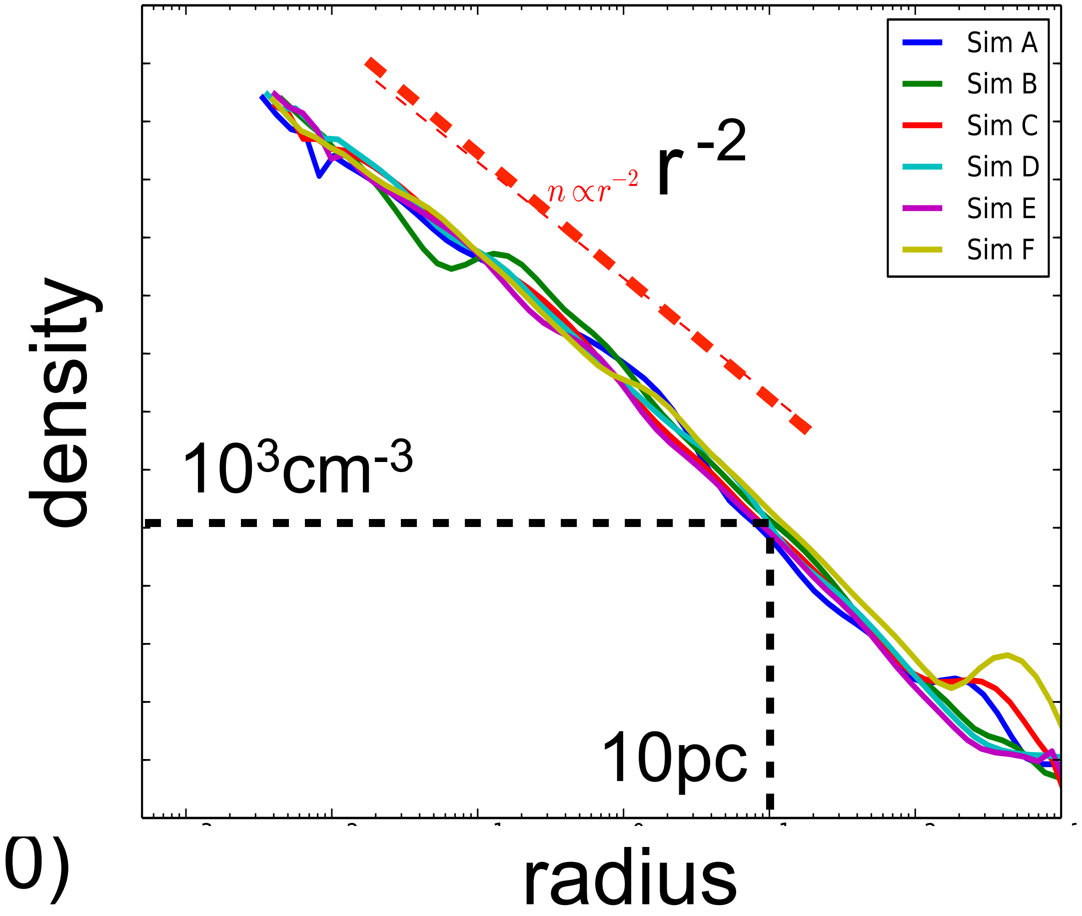
BH growth in the early Universe

- gas density in a DM halo

$$T_{\rm vir} \simeq 1.9 \times 10^4 \ M_{\rm h,8}^{2/3} \ {\rm K} \left(\frac{1+z}{21}\right)$$

$$n(r) \simeq 10^3 \ T_{\rm vir,4} \ {\rm cm}^{-3} \left(\frac{r}{10 \ {\rm pc}}\right)^{-2}$$

Regan et al. (2014) $T_{\rm vir} \sim 10^4$K



- hyper-Eddington conditions ($\dot{m}$ > 5000)

$$\frac{\dot{M}}{\dot{M}_{\rm Edd}} \propto n(R_{\rm B}) M_{\rm BH} T_\infty^{-3/2} \simeq 5 \times 10^4 \ M_{\rm BH}^{-1} \ T_{\infty,4}^{1/2} \ T_{\rm vir,4} \ {\rm M}_\odot$$

$$\boxed{M_{\rm BH} \leq 2 \times 10^5 \ T_{\infty,4}^{1/2} \ T_{\rm vir,4} \ {\rm M}_\odot}$$

independent
of seed BHs

Summary

- A steady hyper-Eddington accretion solution with $\dot{m} \geq 5000$ is found (from the Bondi radius to the BH accretion disk)

- Necessary conditions required for hyper-Eddington accretion is

$$M_{\rm BH,4}\, n_{\infty,5} \gtrsim T_{\infty,4}^{3/2} \quad \Leftrightarrow \quad \dot{m} = \frac{\dot{M}}{\dot{M}_{\rm Edd}} \geq 5000$$

- The result is applied to

  BH growth in the early Universe → rapid growth up to $M_{\rm BH} \sim 10^{5-6}\ M_{\odot}$

  Lya emitters & ultra-luminous IR galaxies

Inayoshi, Haiman & Ostriker (2016) MNRAS, 459, 3738
Sakurai, Inayoshi & Haiman (2016) MNRAS, 461, 4496

BH growth processes