Is there a maximum mass for SMBHs in galactic nuclei?

KI & Haiman (2016); Ichikawa & KI (2017);
KI, Ostriker, Haiman & Kuiper (2018)

A: Yes, there is! $M_{max} \sim 10^{10} M_{sun}$

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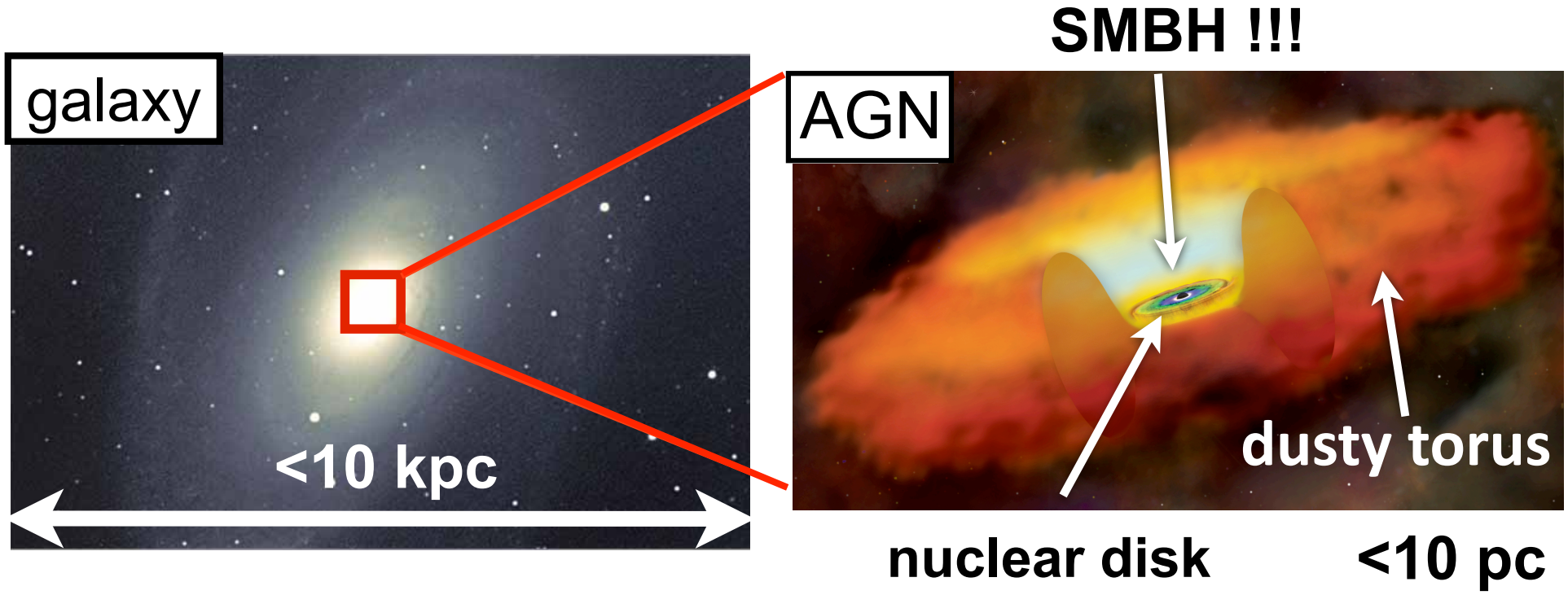
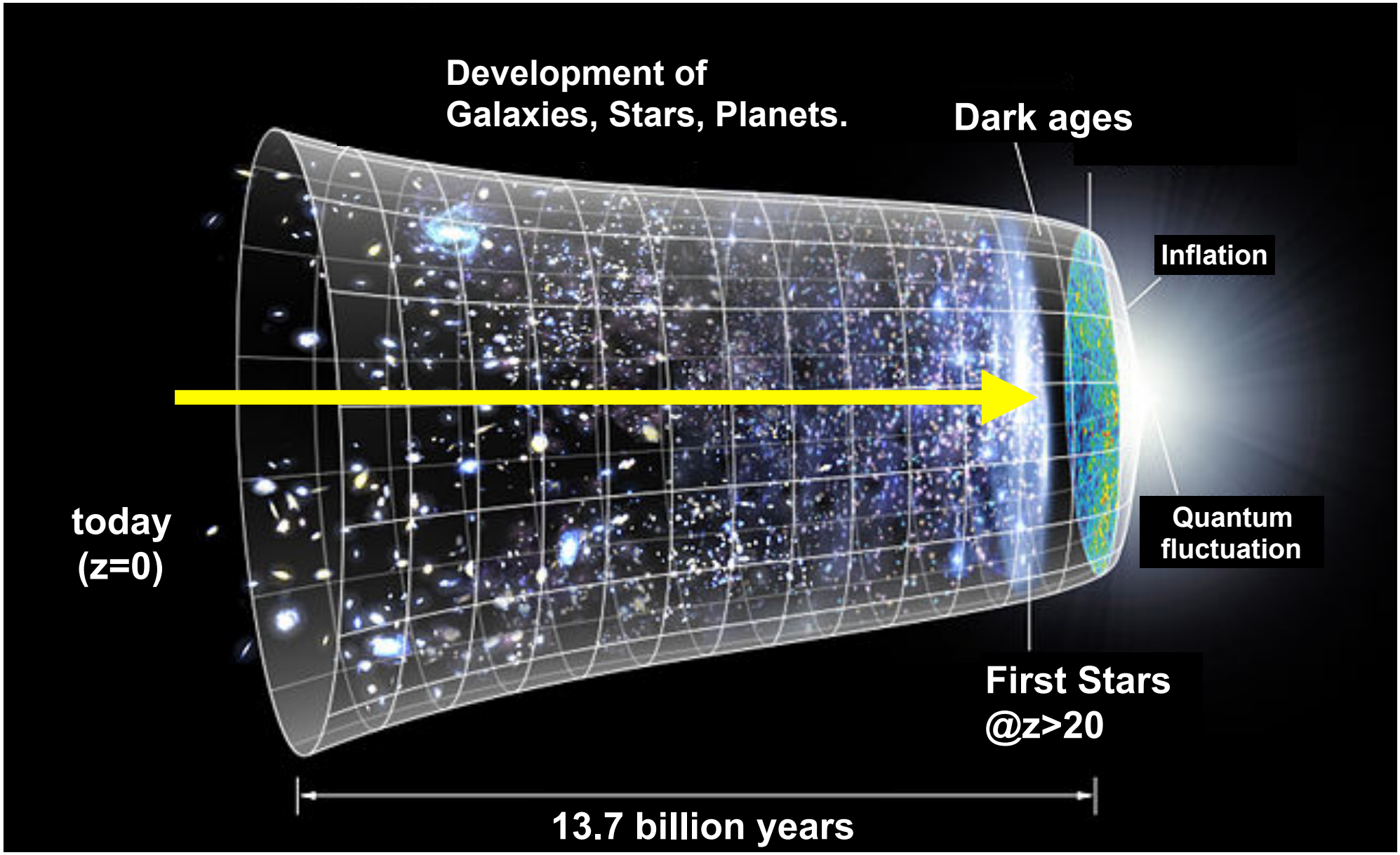
Supermassive black holes (SMBH)

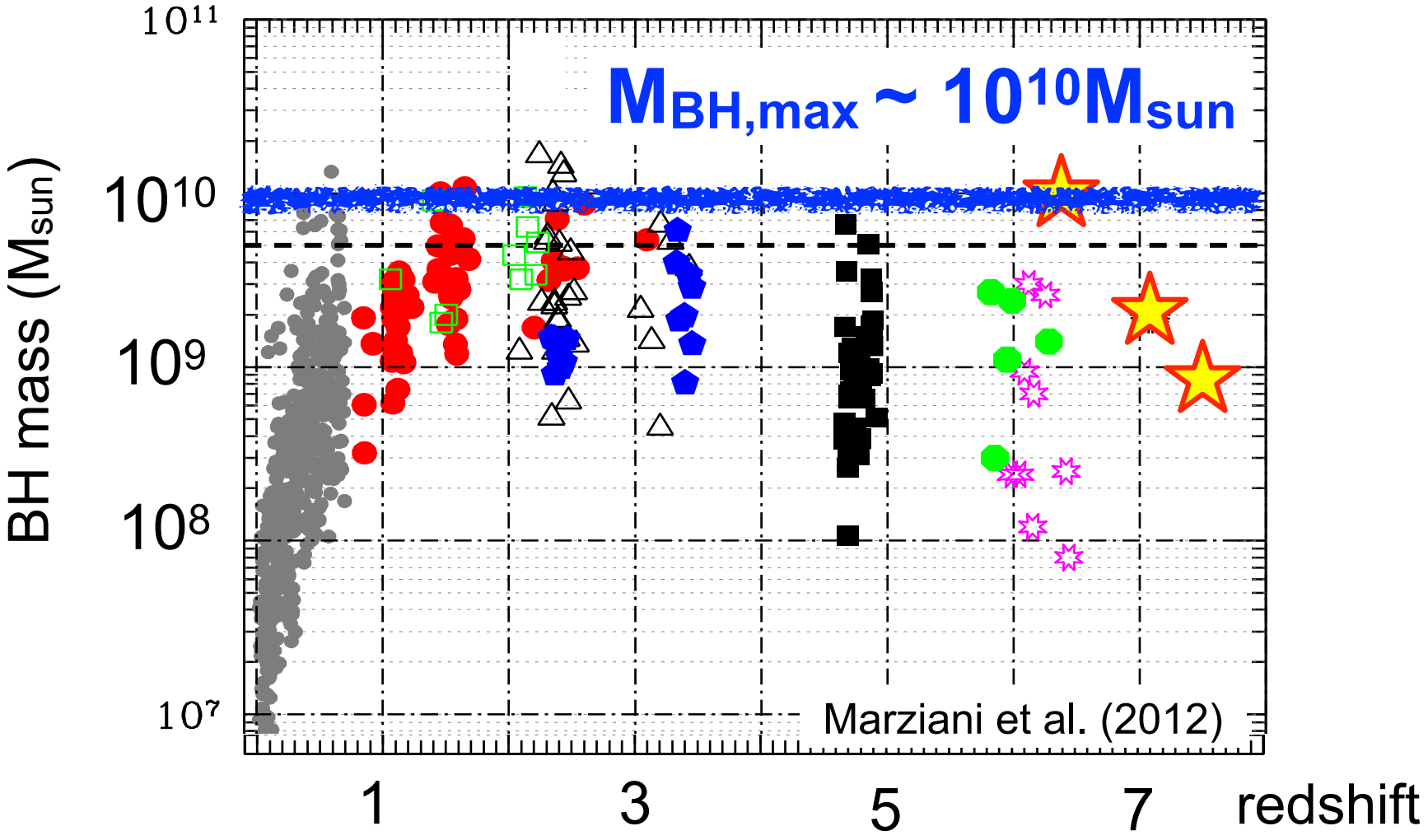


- very massive objects: $M_{BH} \sim 10^6 - 10^{10} M_{sun}$
- very luminous sources: AGN, ULIRGs
- coevolution with host galaxies

A long time ago in galaxies far, far away....



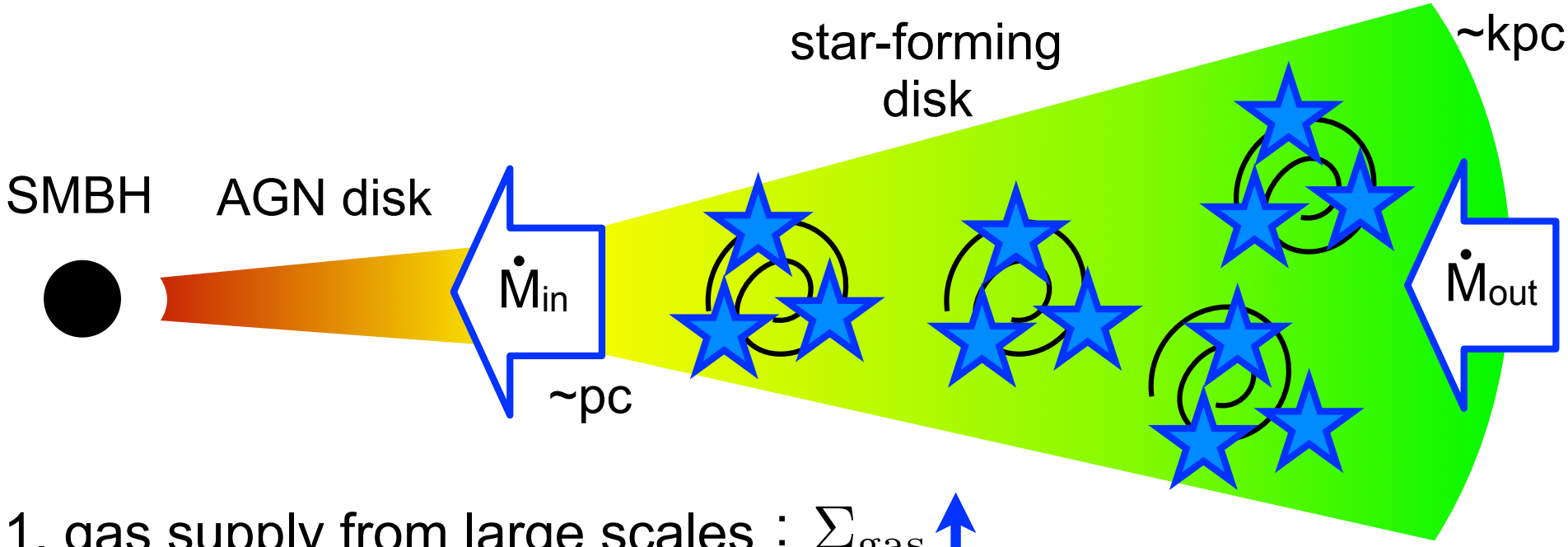
Maximum mass of SMBHs



$M_{BH,max}$ seems independent of redshift

see McConnell+11; Kormendy & Ho 13 for the local SMBHs,
and Netzer+03; Trankhtenbrot 14; Wu+15 for high-z SMBHs

Star-forming + AGN accretion disk



Thompson et al. (2005)

1. gas supply from large scales : $\Sigma_{\rm gas}$ ↑

2. gravitationally unstable: $Q = \dfrac{c_s \Omega}{\pi G \Sigma_{\rm gas}}$ < 1

3. star formation

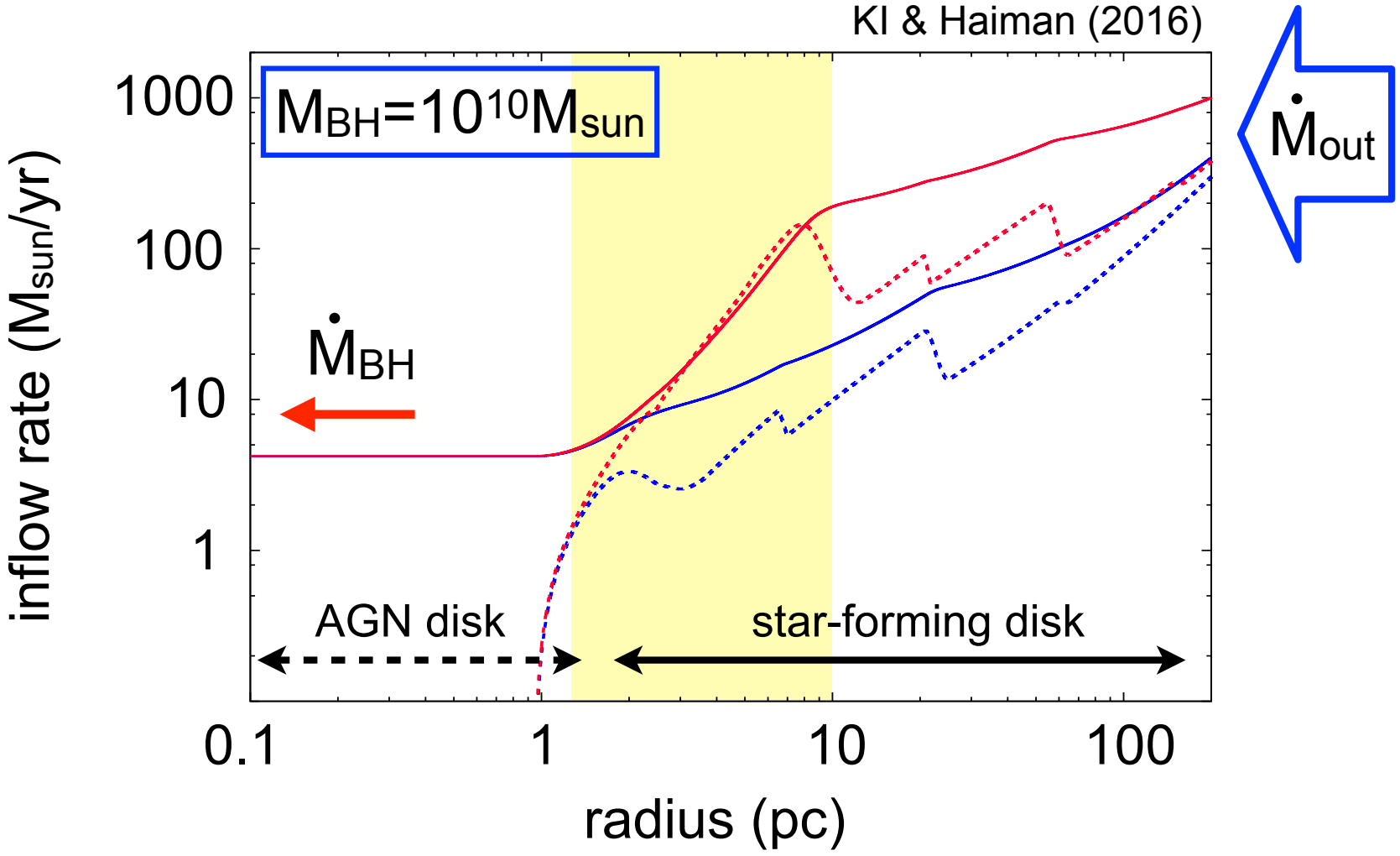
   gas consumption $\Sigma_{\rm gas}$ ↓

   rad. pressure on dusts $p_{\rm rad} \propto \tau_{\rm d} \dot{\Sigma}_*$ ↑

self-gravitating /
star-forming disk

$Q \simeq 1$

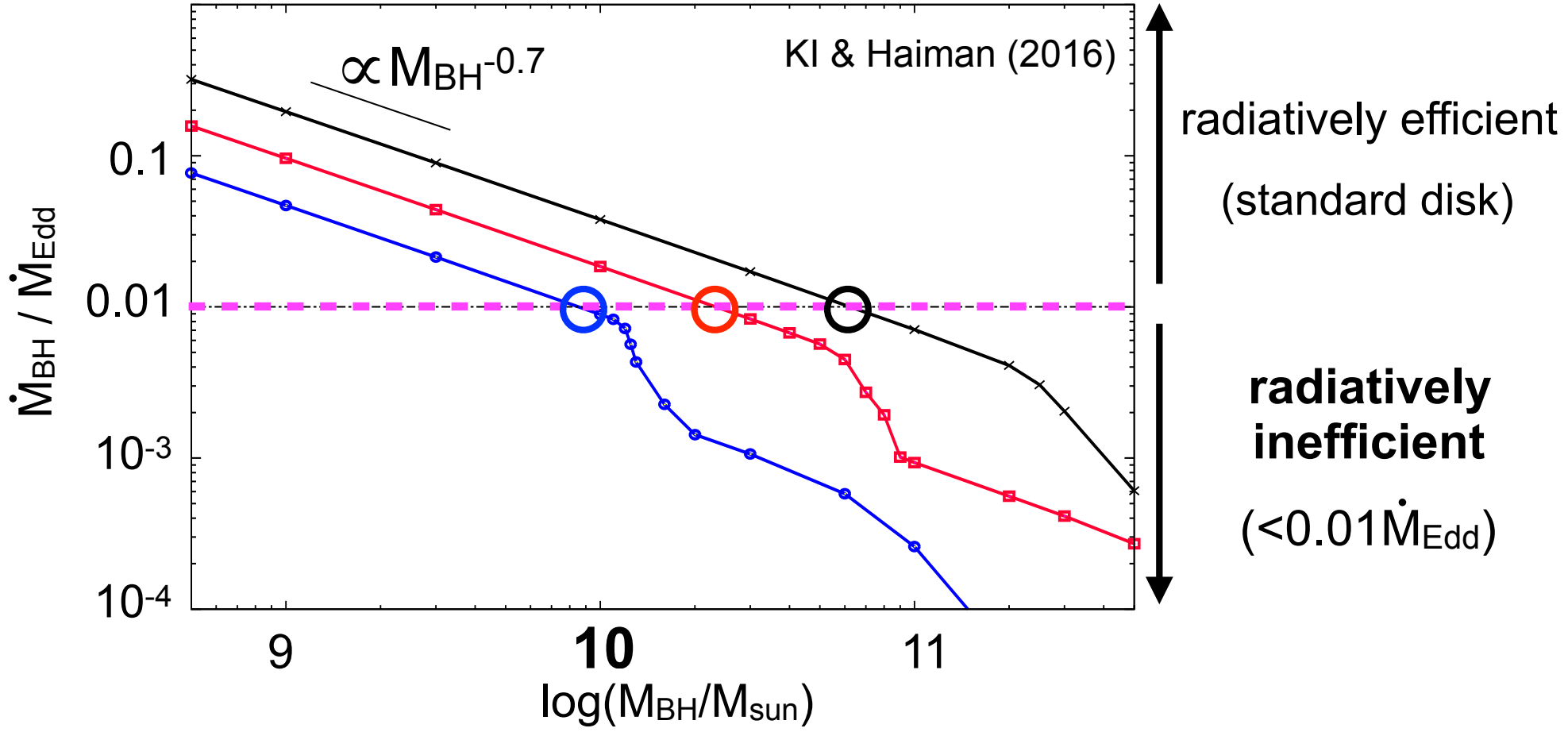
SMBH feeding rates



BH feeding rate = $f(M_{\rm BH}, m_r, \cancel{\dot{M}_{\rm out}, a, b, c, \ldots})$

galaxy properties

BH mass vs. feeding rate

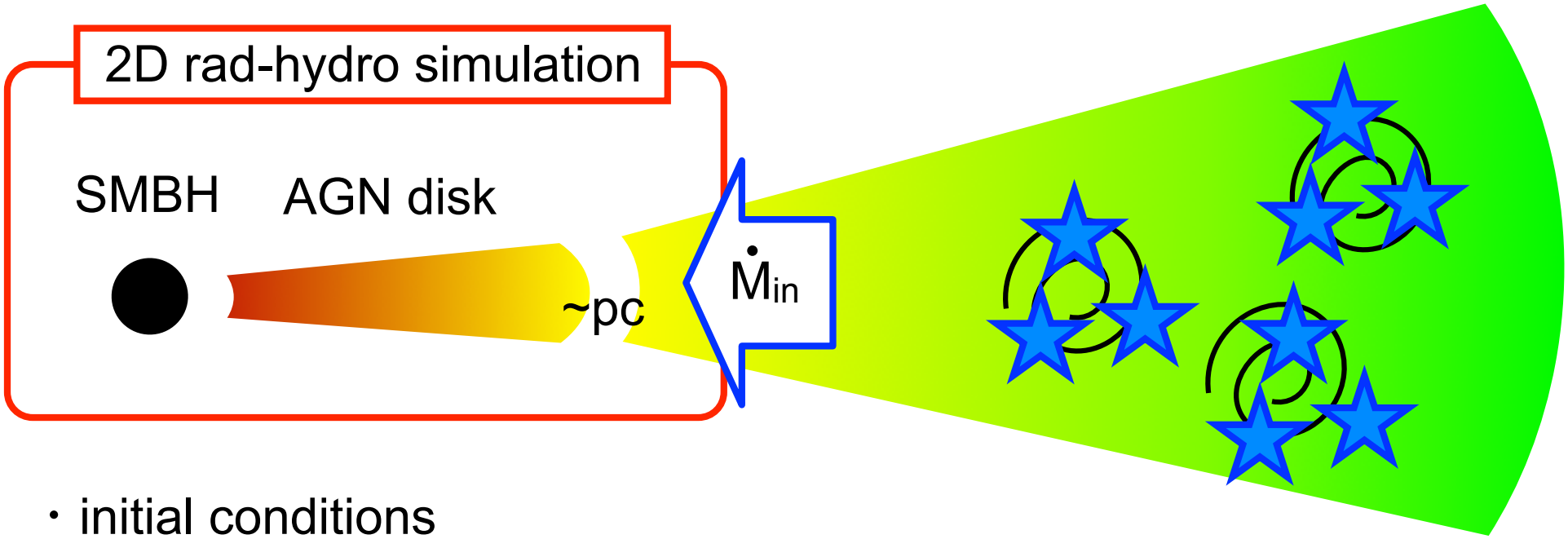


1% of Eddington acc.

$M_{BH} > 10^{10\text{-}11}\ M_{sun}$

radiative inefficient
AGN disk

Numerical simulation setup



- initial conditions

  Bondi profile for given ρ_∞, T_∞, M_{BH}

  $0.01R_B < r < 10R_B$, $0 < \theta < \pi$

- rotation (specific angular mom)

  $j(R,\theta) = j_0 \quad (j_0 = \sqrt{R'_c} R_B c_\infty)$

- Viscosity

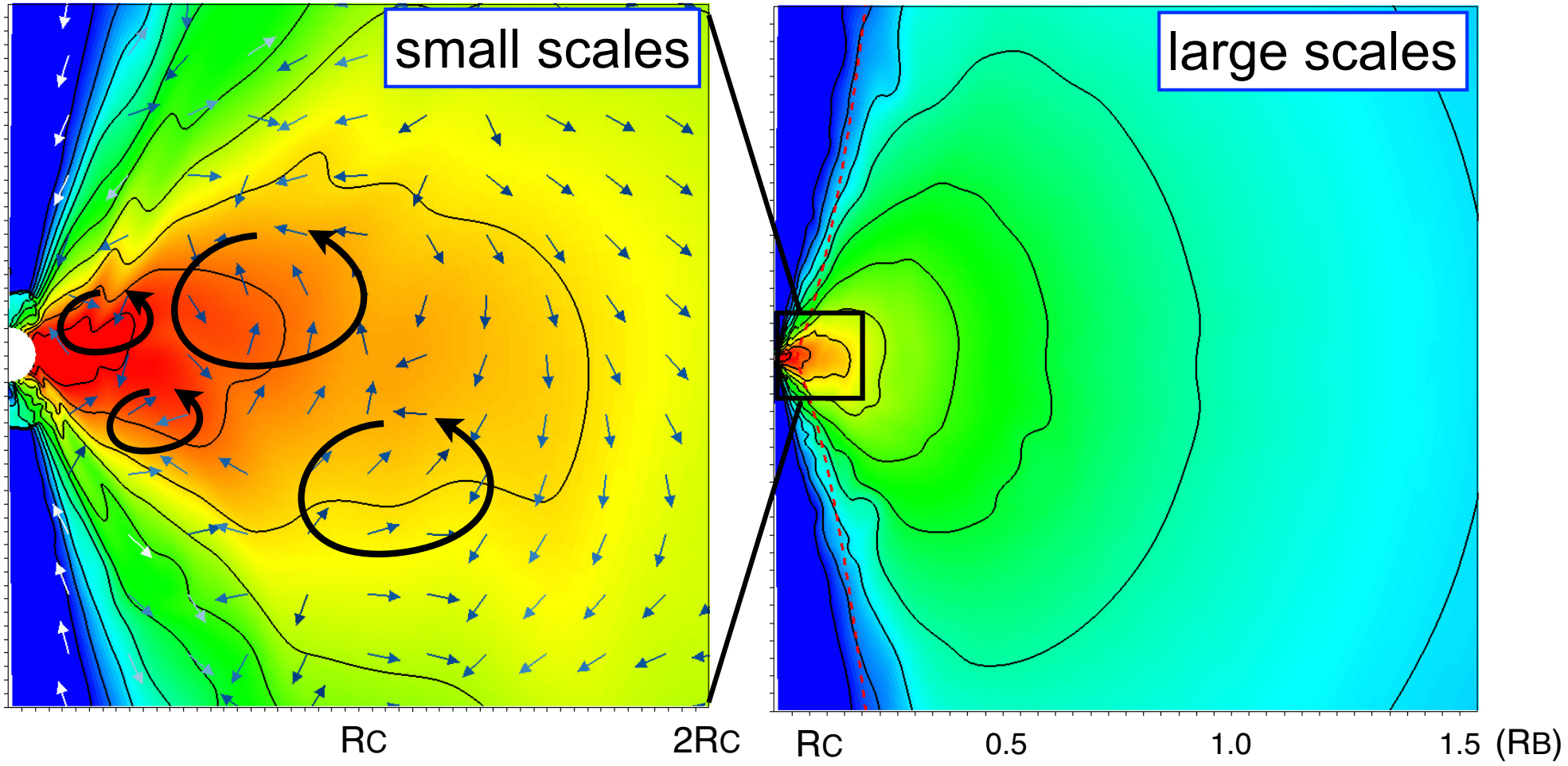
  alpha-viscosity: $\alpha=0.01$

- Radiation (optically thin)

  cooling (free-free)

  + Compton heating

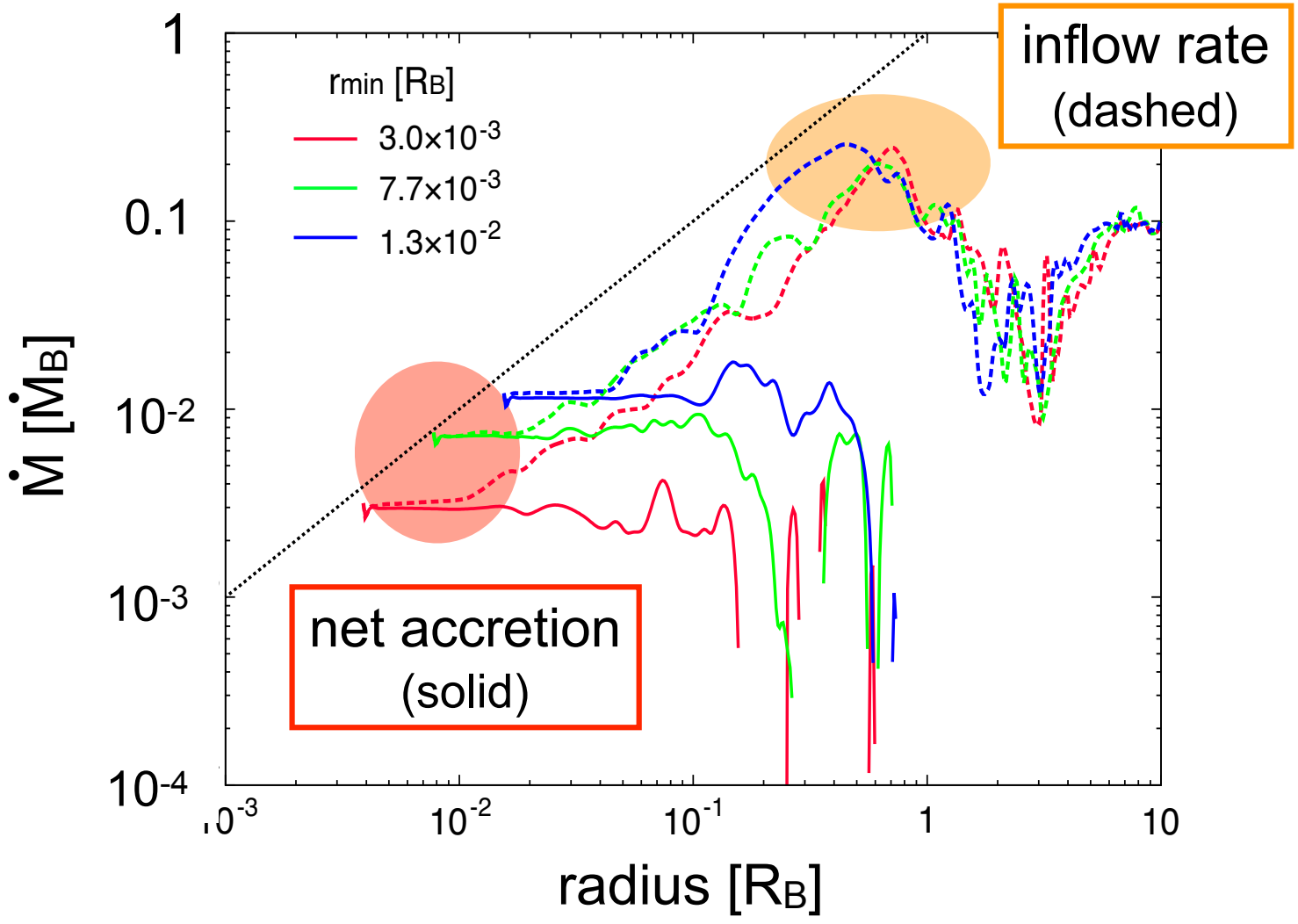
Density & velocity of the flow



rotating **convective** accretion flows

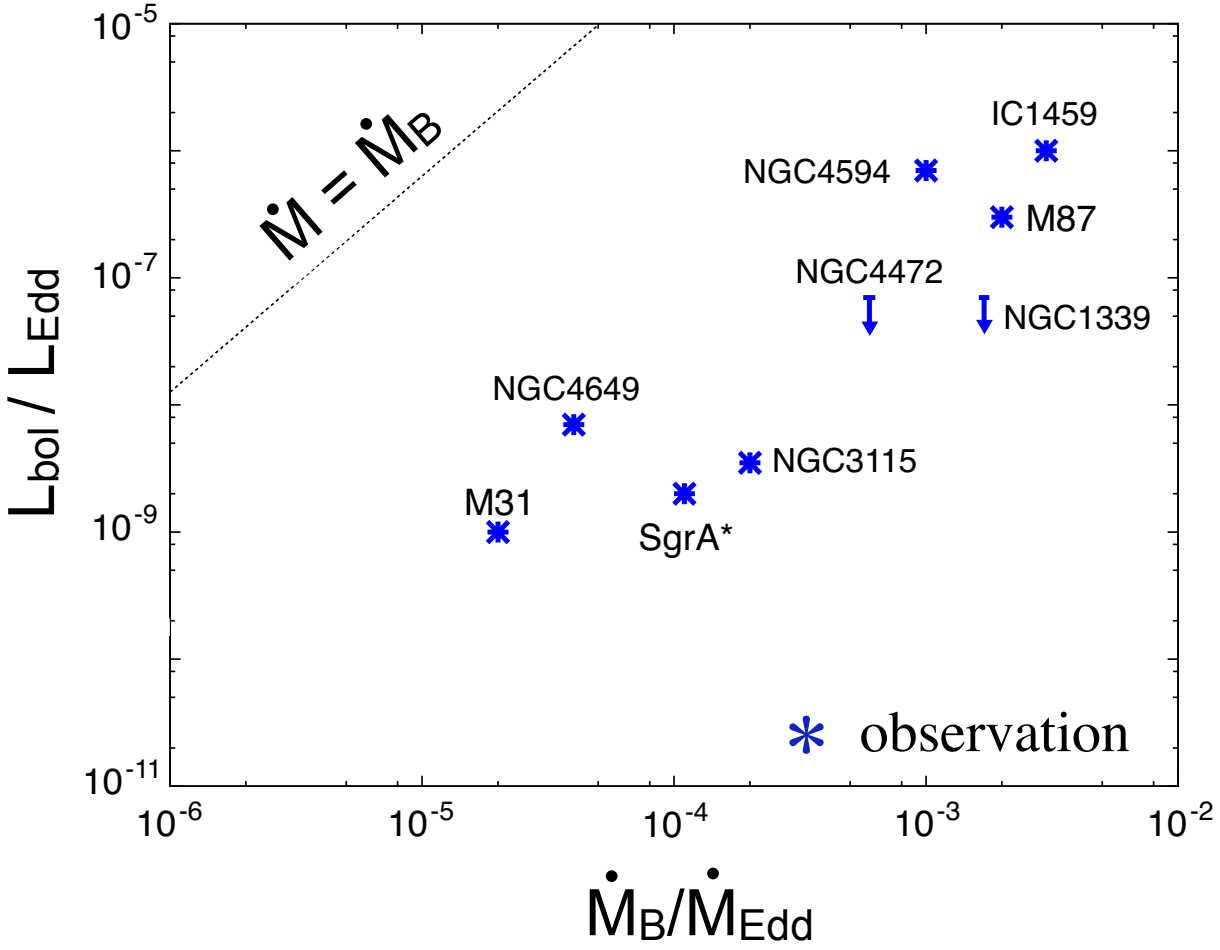
thick torus structure

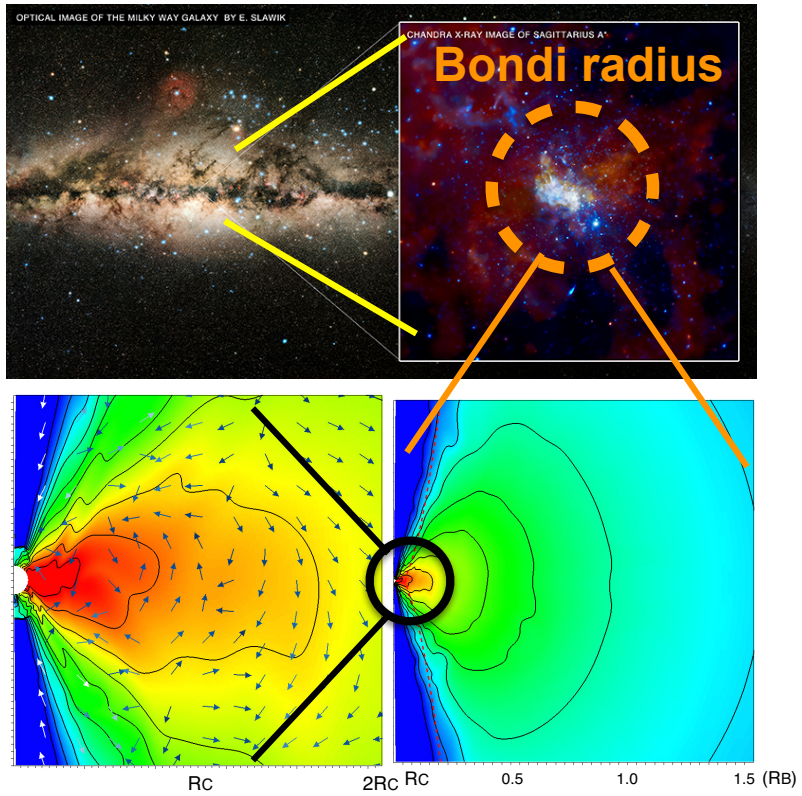
Suppression of inflows by convection



$\dot{M}_{\rm BH} \ll \dot{M}_{\rm in}$ ⇒ BH growth shuts off

Comparison to observations!

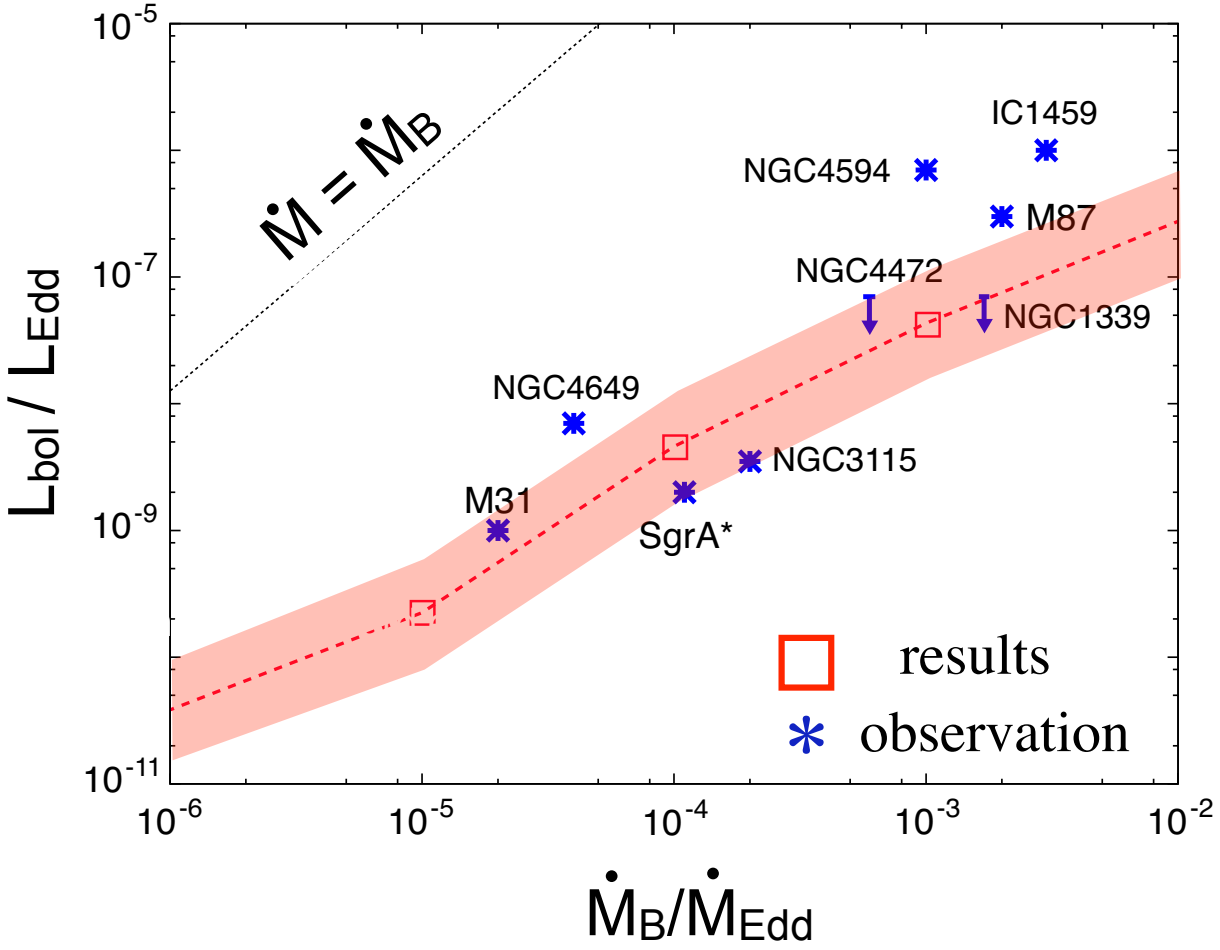


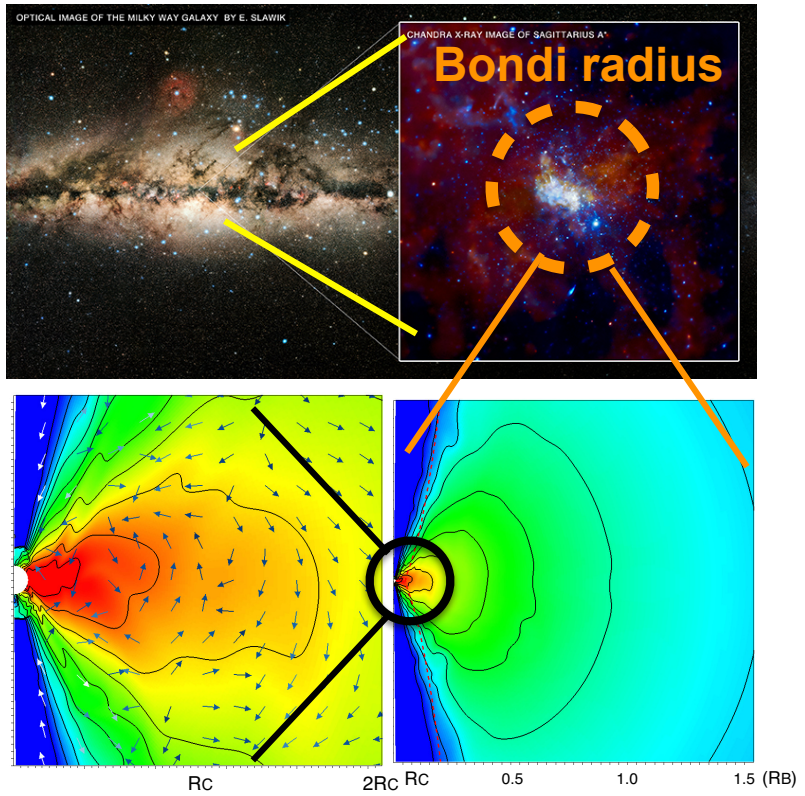


KI, Ostriker, Haiman & Kuiper (2018)

This simulation result naturally explain nearby low-luminosity SMBHs

Comparison to observations!





KI, Ostriker, Haiman & Kuiper (2018)

This simulation result naturally explain nearby low-luminosity SMBHs

Summary

- SMBHs have a maximum mass of $10^{10}M_{sun}$, which seems independent of redshift

- The gas inflow rate onto the nuclear region for a BH with $M>M_{max}$ can be 1% of the Eddington accretion rate

⇨ a radiatively inefficient AGN disk

- Such accretion flows flow from larger scales are so convectively unstable that further BH feeding / growth is strongly suppressed

$M_{max} \sim 10^{10}M_{sun}$

Thank you !

Appendix

Thompson + 2005

star formation vs. advection

$$\dot{M} \propto r^2 T^{2-\beta}$$

$$\propto r^{\frac{6+5\beta}{4+2\beta}} M_{\rm BH}^{\frac{2-\beta}{4+2\beta}} m^{\frac{\beta-2}{2+\beta}}$$

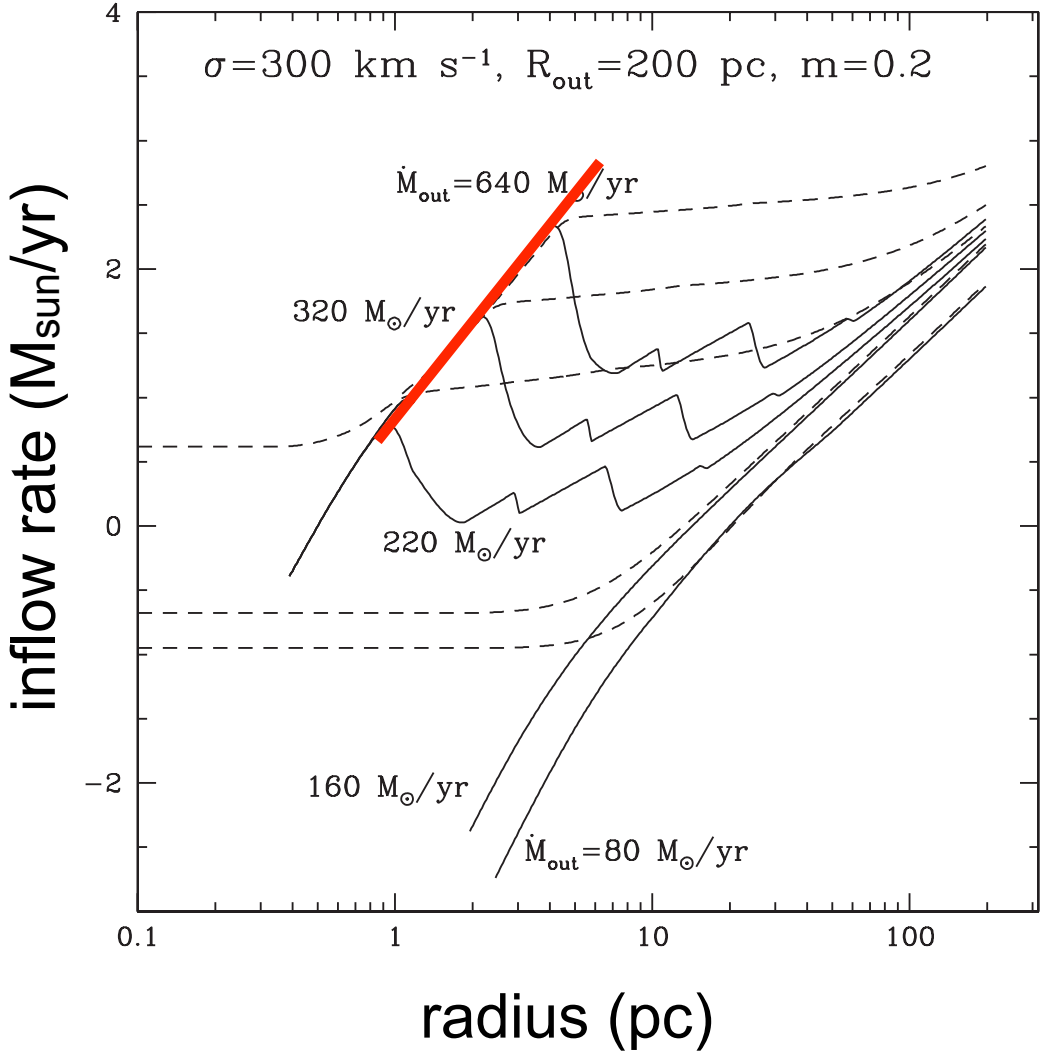
$$\longrightarrow \quad r^{5/2} M_{\rm BH}^{-1/2} m$$

$$\text{for } \beta \longrightarrow -\infty$$

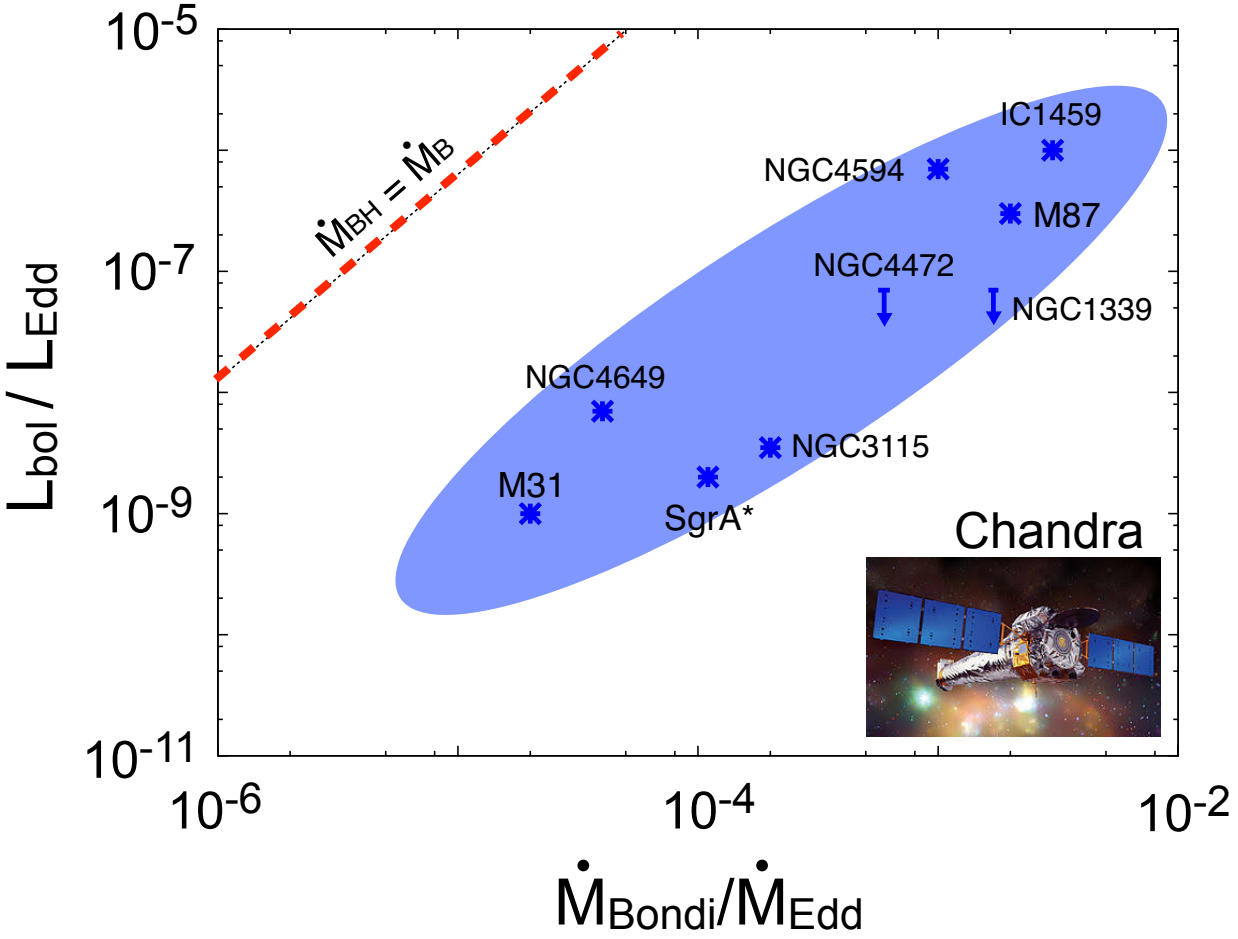
where

$$\kappa \propto T^{\beta} \text{ at } T \gtrsim T_{\rm dust,sub}$$

$$\beta < -20$$



Our neighbor SMBHs



- SgrA*, M87, M31
- X-ray observations

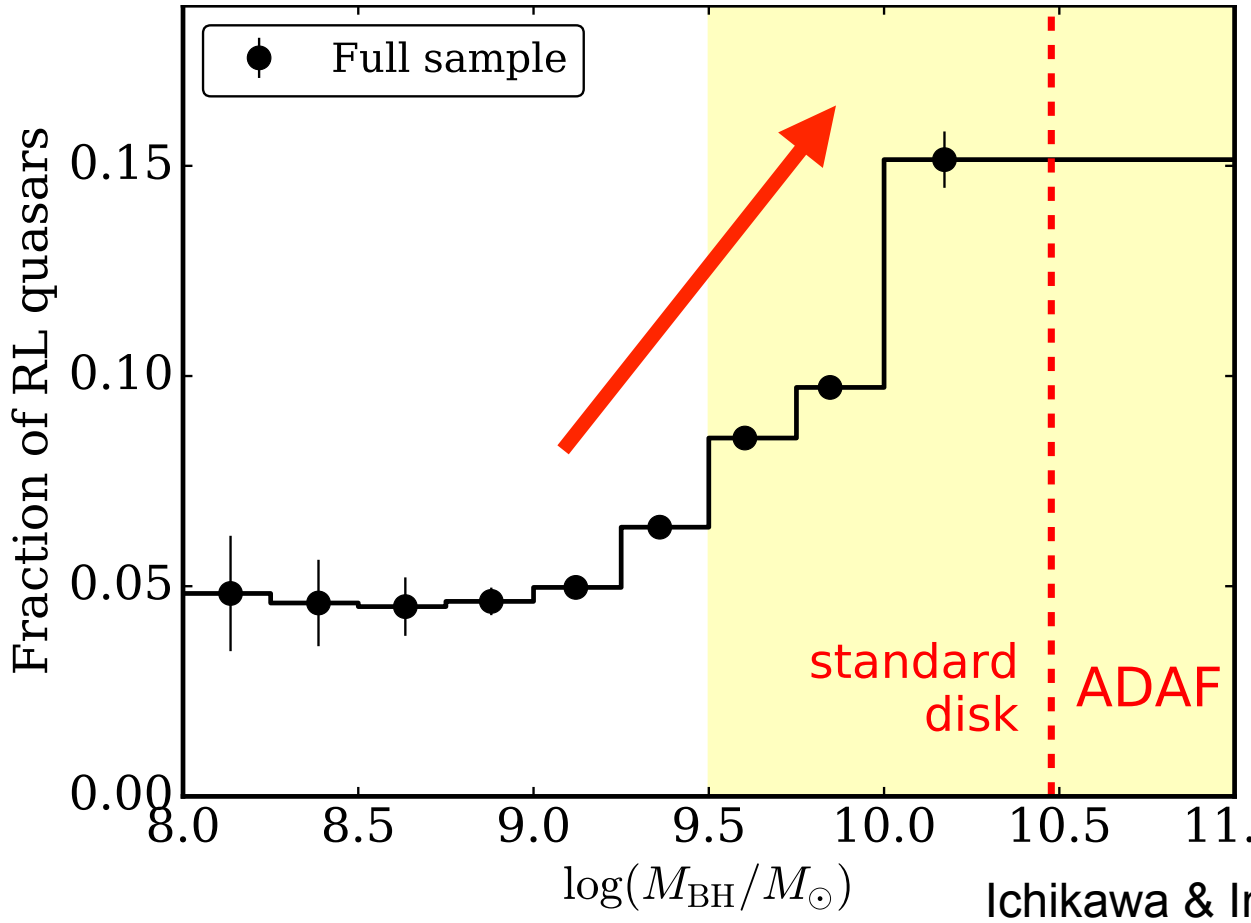
$\dot{M}_B$; Bondi rates
outer region

L_{bol}; luminosity
inner region

If $\dot{M} \sim \dot{M}_{\rm Bondi}$
BHs are **over-luminous**

$\Rightarrow$ $\dot{M} \ll \dot{M}_{\rm Bondi}$

Observational evidence



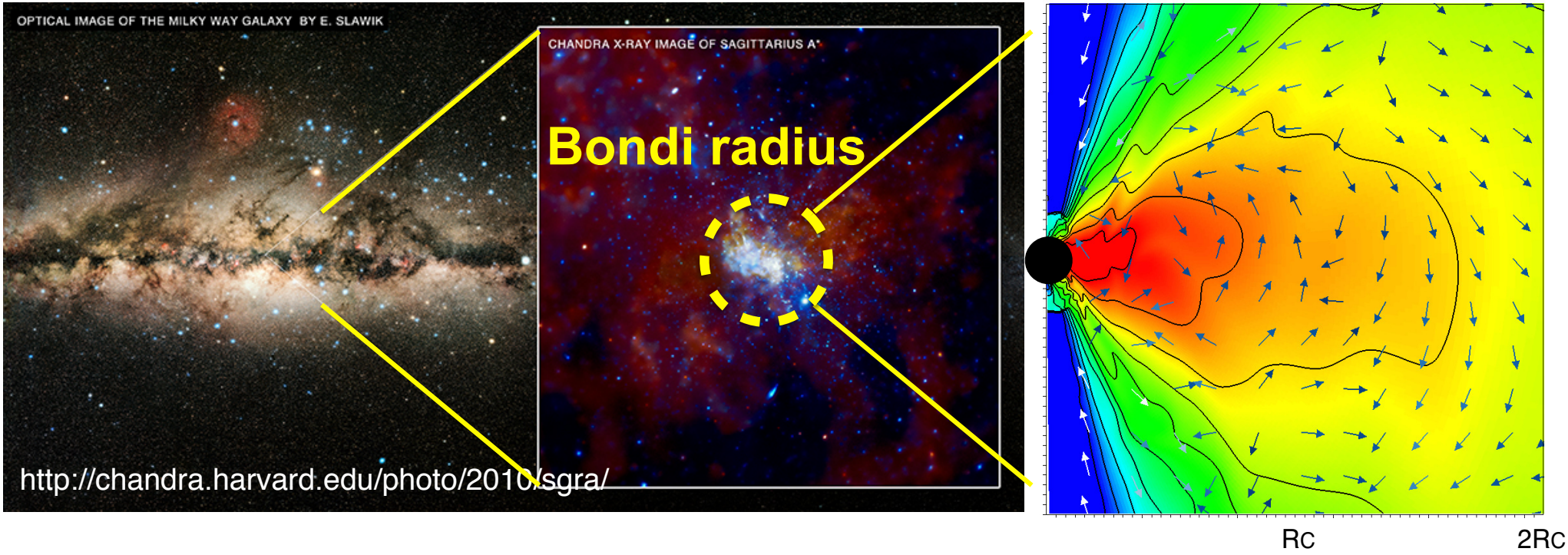
SDSS DR7
(Shen et al. 2011)

radio loudness parameter (RL)

Ichikawa & Inayoshi (submitted)

jets associated with ADAFs ≈ **RL fraction increases**

Important physical scales



galactic scales nuclear region BH

R_{bulge} ~ 1 kpc >> R_{Bondi} ~ 0.1 pc >> R_{Sch} ~ 10^{-6} pc

(M_{BH}~$10^7 M_{sun}$, T~keV)