EAYAM 2017 at Ishigaki, Japan on Nov 14, 2017

Is there a maximum mass for supermassive black holes (SMBHs) ?

See *Ichikawa & Inayoshi (2017b), ApJL, 840, L9*

COLUMBIA UNIVERSITY

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A: Yes. And the value is ~$10^{10}M_{sun}$

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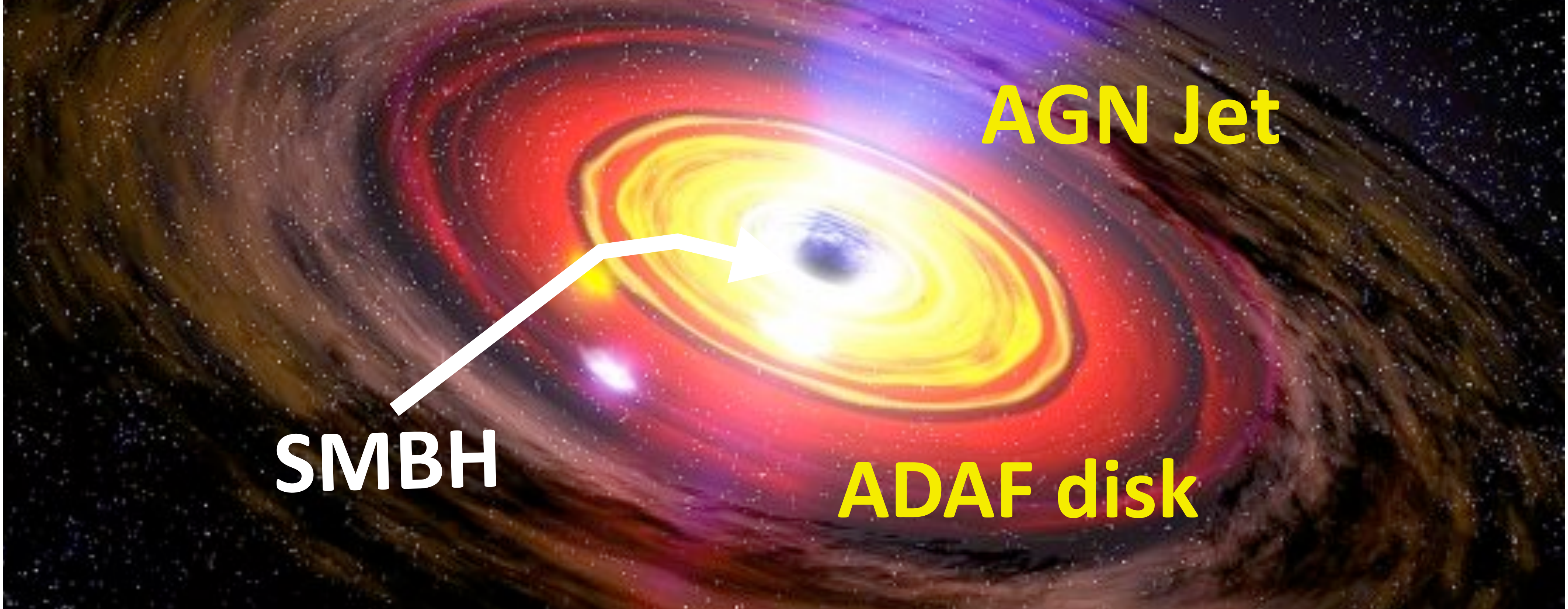

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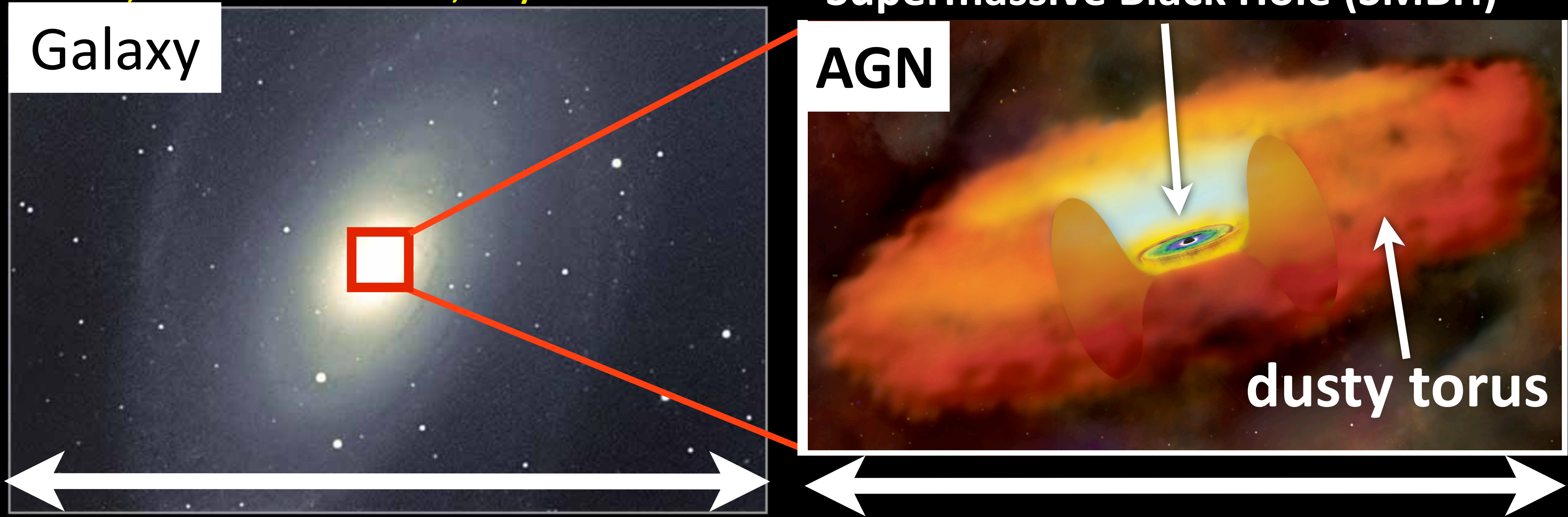
Active Galactic Nuclei (AGN)

Rees 84;Antonucci & Miller 85; Urry & Padovani95

Supermassive Black Hole (SMBH)



<10 kpc

<10 pc

(see Ichikawa+15, Burtscher+13)

Why do we observe AGN for SMBH studies?

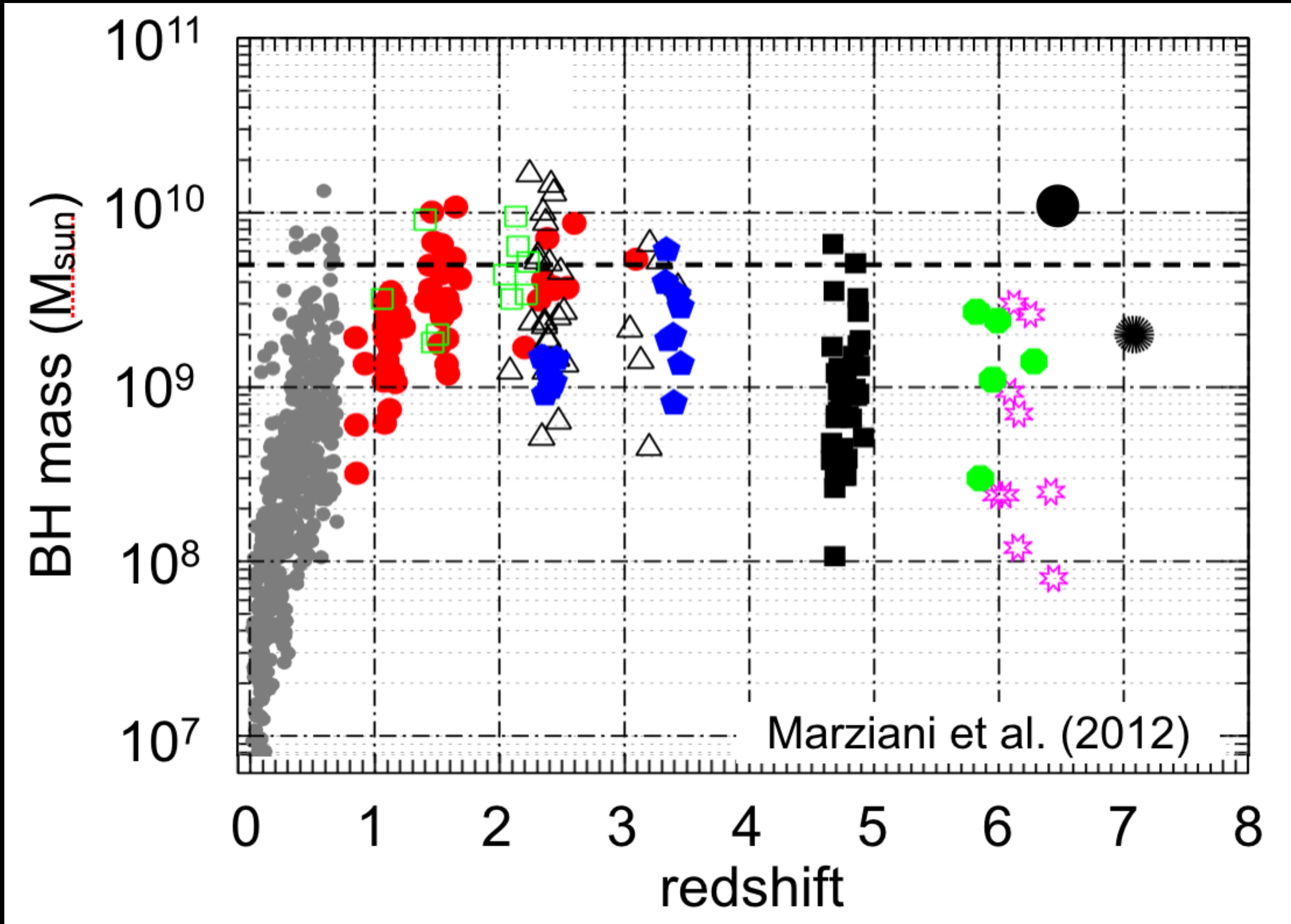
☑ AGN is a growing phase of SMBH

☑ easy to estimate BH mass (e.g., single-epoch method; Kaspi+00,05)

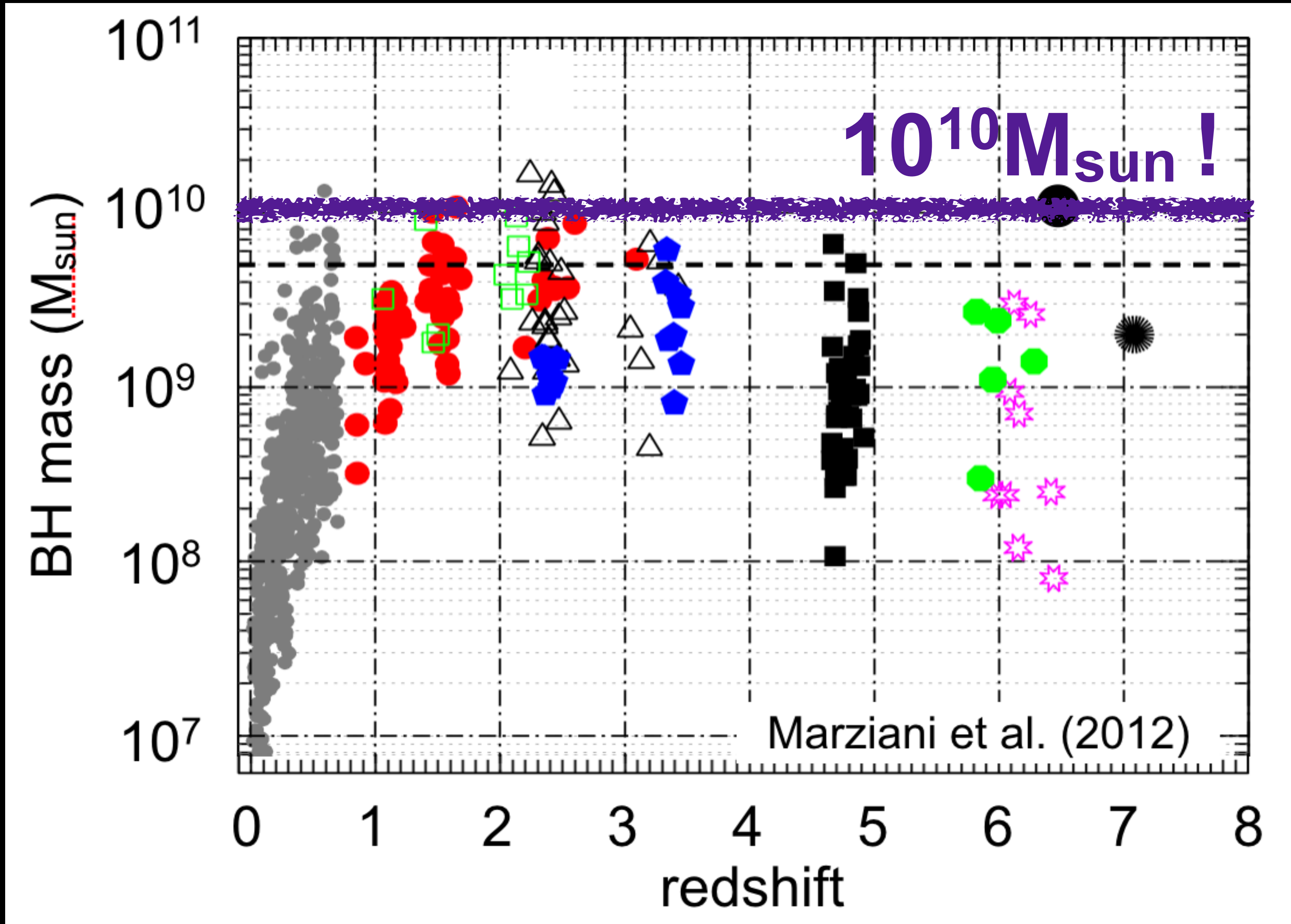
☑ Very, very bright in optical/UV (and also X-ray, IR!)

L_{bol} >= 10^{47} erg/s; which can be observable up to z~7!

Maximum mass of SMBHs



Maximum mass of SMBHs

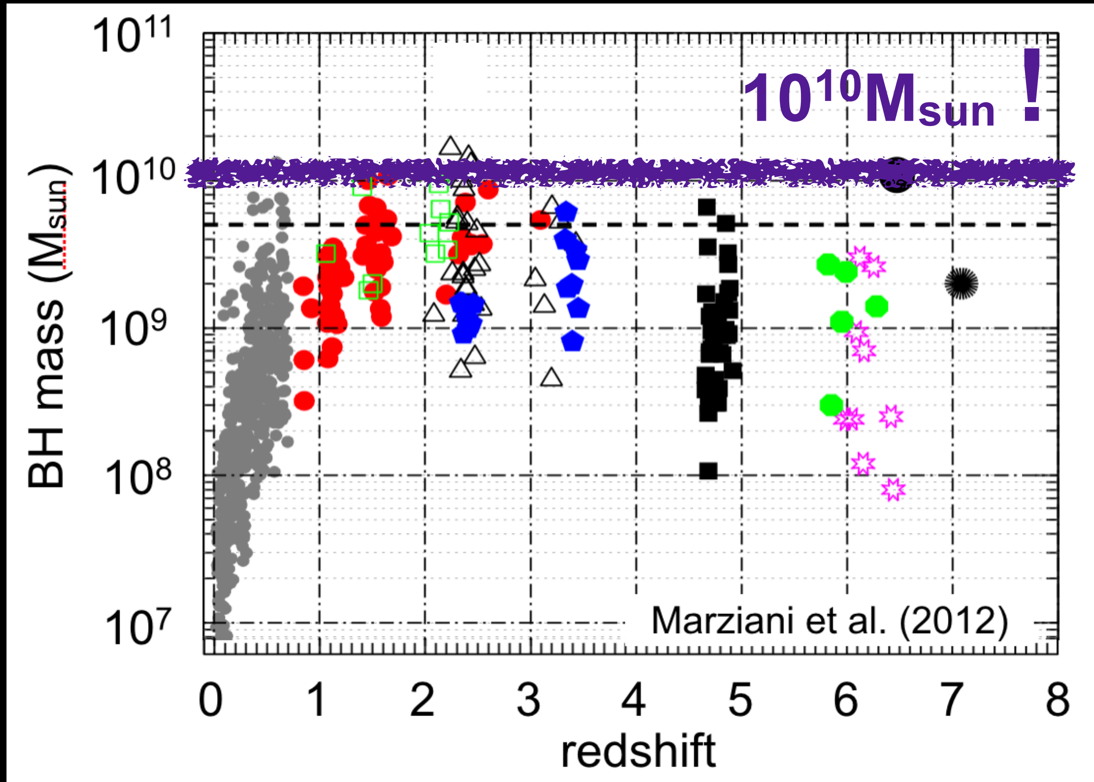


☑ Maximum mass of SMBHs: M_{max} ~ $10^{10\text{-}11}$ M_{sun} ?

☑ M_{max} seems independent of redshift

See McConnell+11; Kormandy & Ho '13 for the local SMBHs, and see Netzer+03; Trakhtenbrot'14; Wu +15 for high-z sources

What mass limit of SMBHs tells us?



☑ e-folding time: only 40 Myr

☑ Max M_{BH} exists already at z~6

But no ultra-massive M_{BH} w/ $10^{12\text{-}13}$ M_{sun} at z<6 !

Something regulates SMBH growth at 10^{10} M_{sun} (and, it seems to be z-independent)

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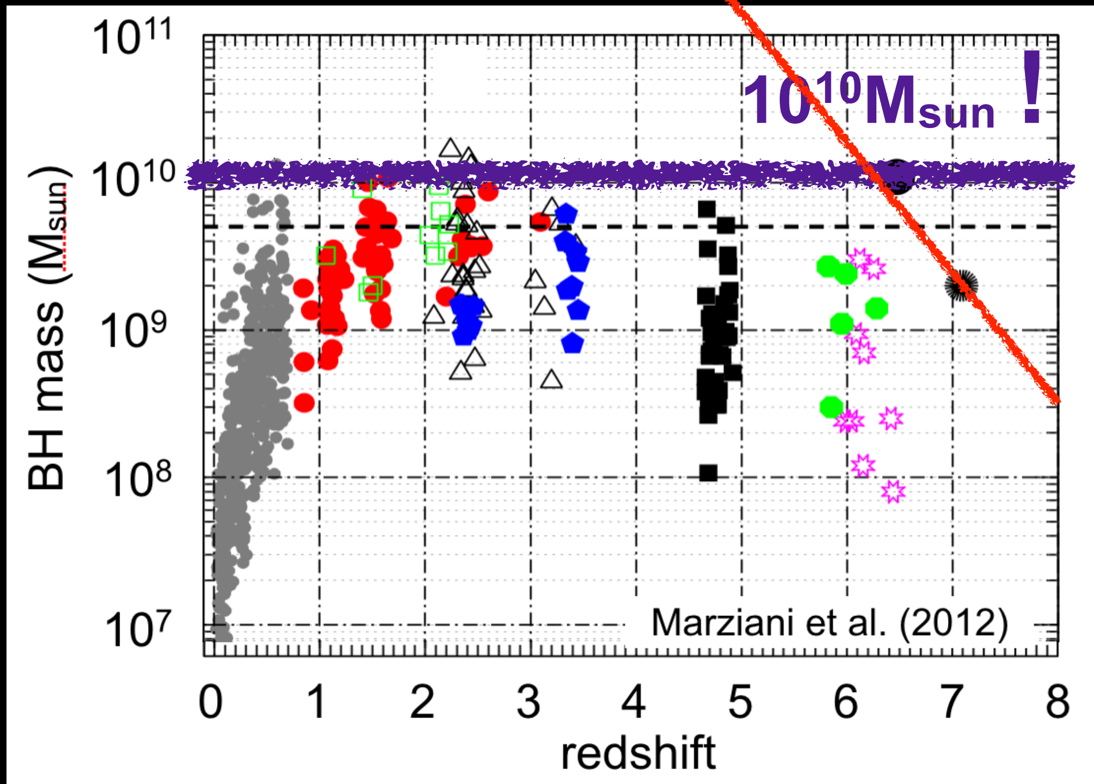

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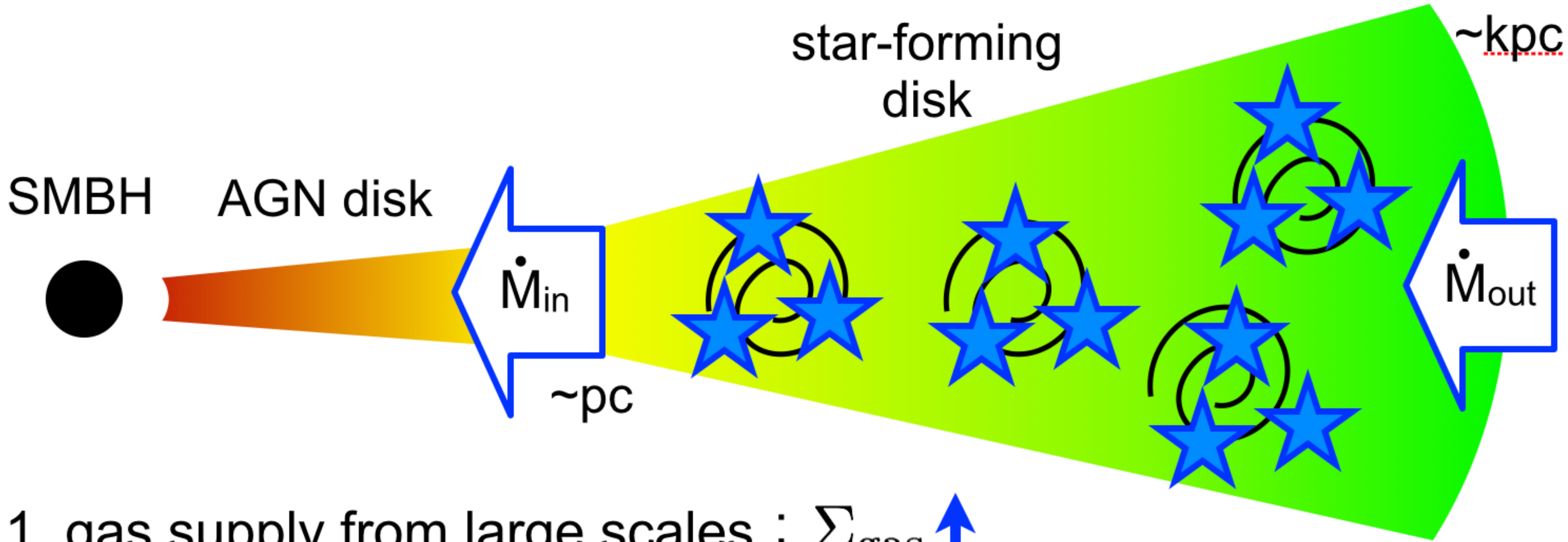
Theory: Let's calculate the mass accretion rate



Thompson et al. (2005)

1. gas supply from large scales : Σ_{gas} ↑
2. gravitationally unstable: $Q = \dfrac{c_s \Omega}{\pi G \Sigma_{gas}}$ < 1
3. star formation
   - gas consumption Σ_{gas} ↓
   - rad. pressure on dusts $p_{rad} \propto \tau_d \dot{\Sigma}_*$ ↑

self-gravitating / star-forming disk

$$Q \simeq 1$$

Inayoshi & Haiman '16

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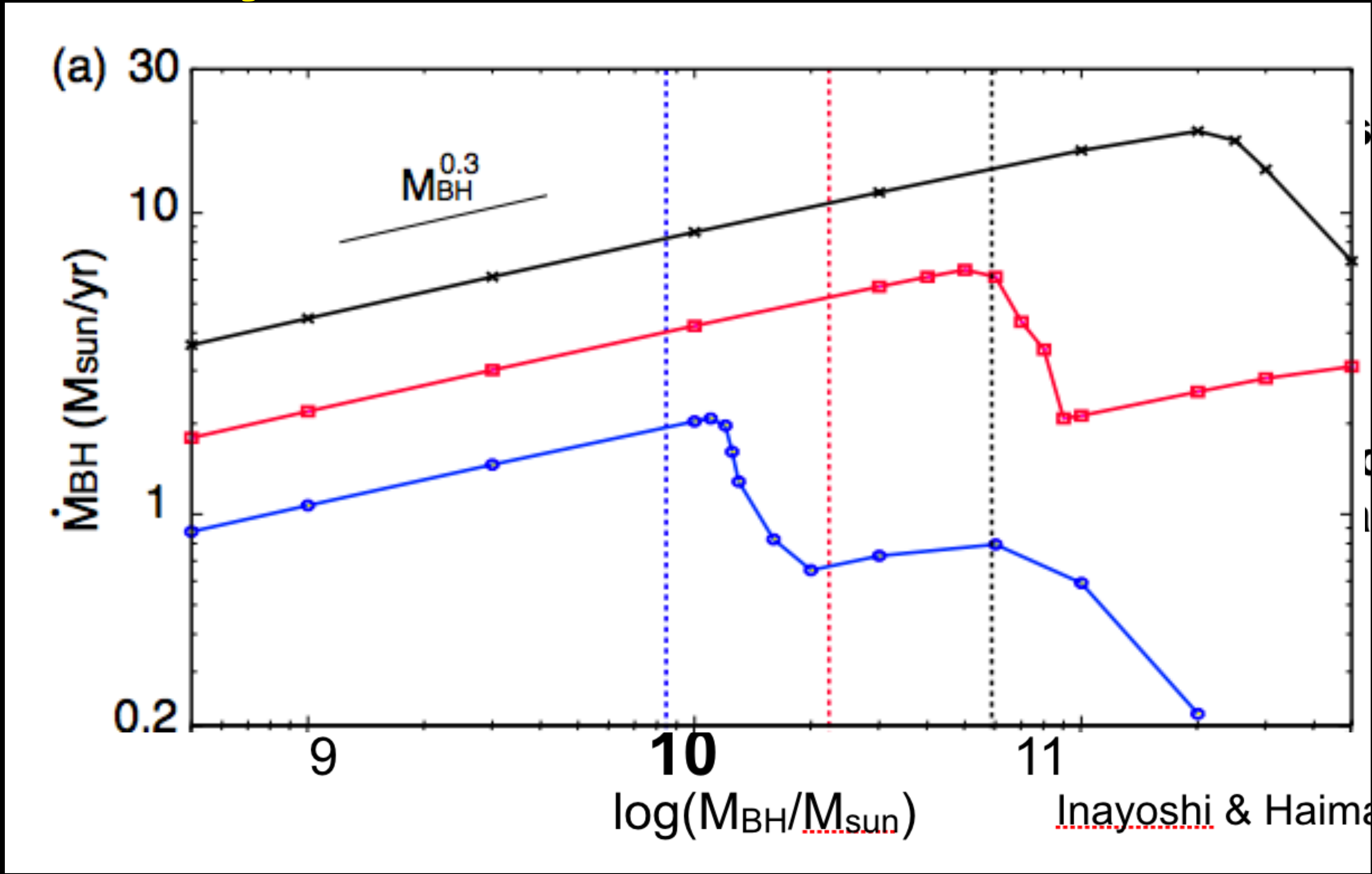
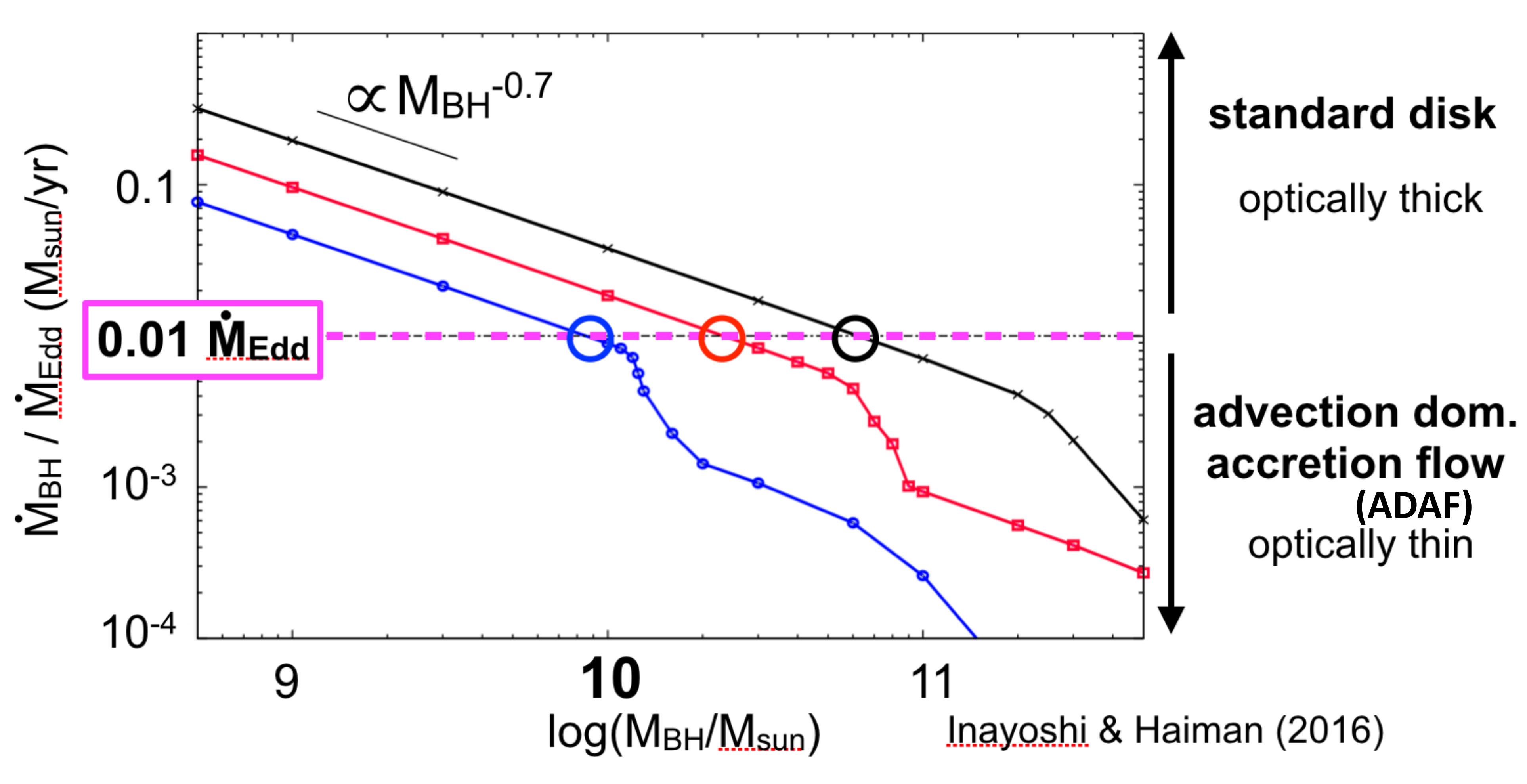


Inayoshi & Haiman '16

☑ $\dot{M}_{\rm acc} \propto M_{\rm BH}^{0.3}$

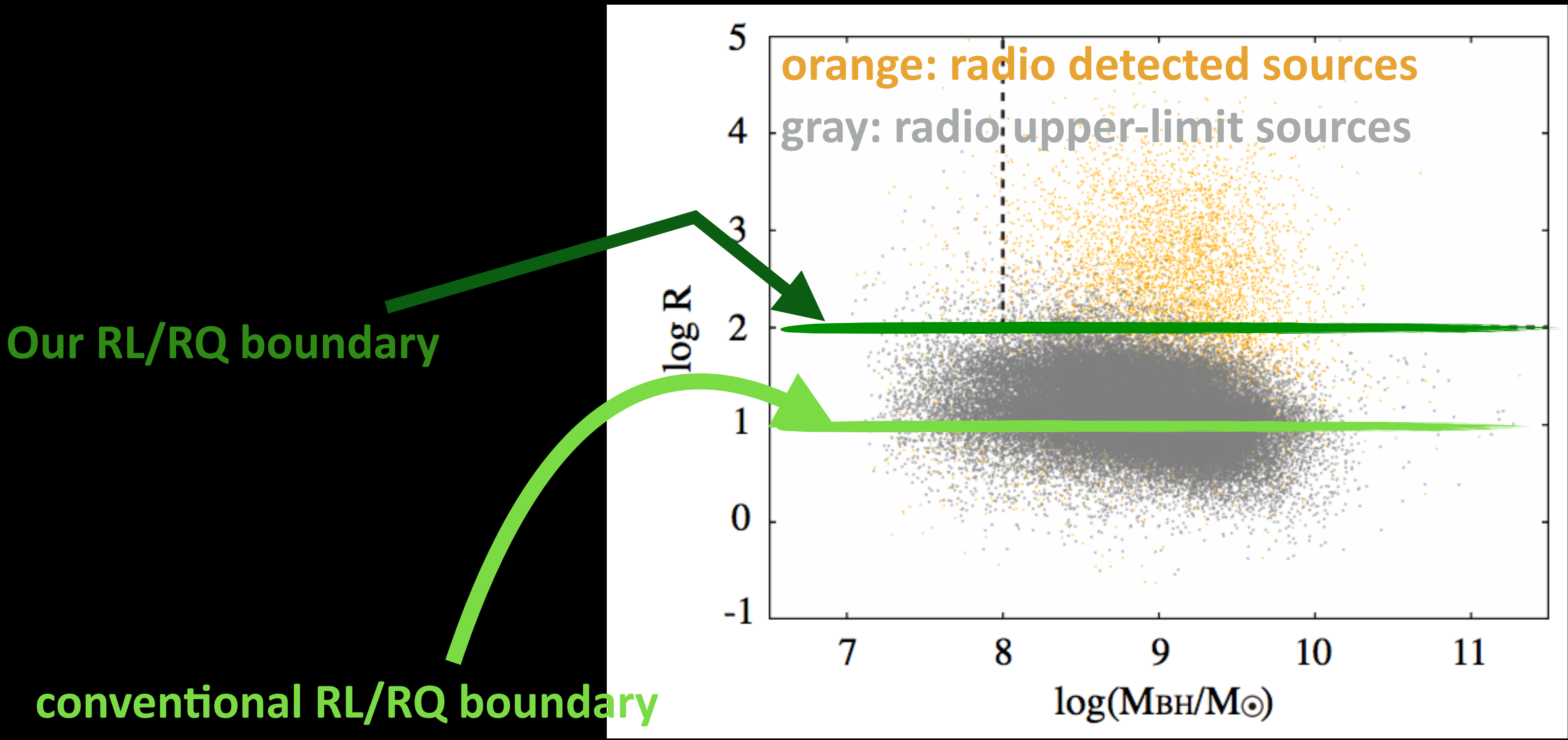
Theory: Let's calculate the mass accretion rate



- ☑ $\dot{M}_{\rm acc} \propto M_{\rm BH}^{0.3}$ **and** $\dot{M}_{\rm Edd} \propto M_{\rm BH}^{1.0}$ **=>** $\dot{M}_{\rm acc}/\dot{M}_{\rm Edd} \propto M_{\rm BH}^{-0.7}$
- ☑ **All accretion disks become ADAF at M_{BH} ~ $10^{10\text{-}11}$ M_{sun}**
- ☑ **most of the mass is expelled as jet/outflows**

=> Let's check radio-loud AGN fraction as a function of M_{BH}

Observations: SDSS AGN/Quasars (QSOs)



SDSS DR7 QSO catalog contains 76,000 QSOs at z<2

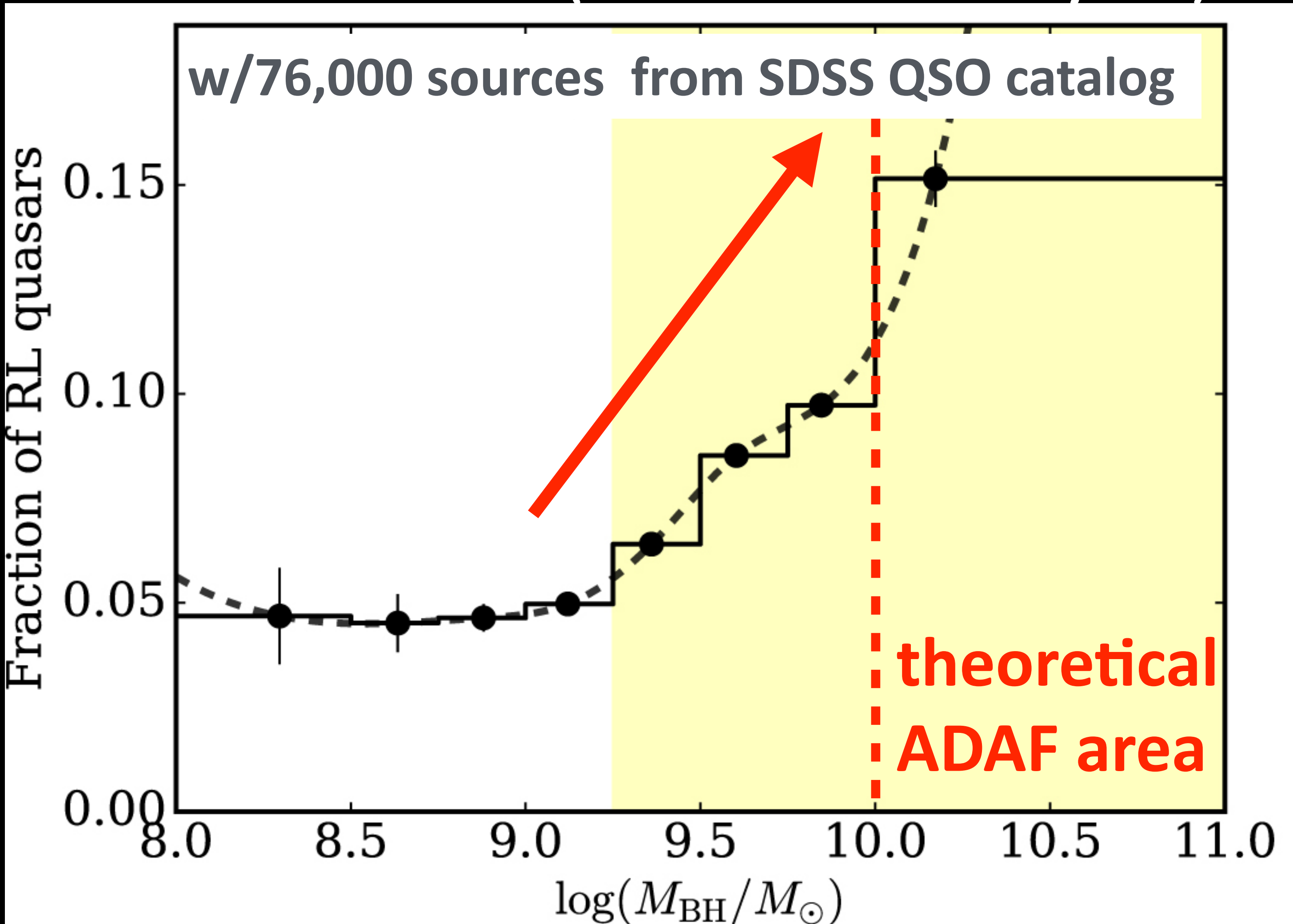
☑ M_{BH}, radio-loudness $R=f_{1.5GHz}/f_{2500Å}$, (R>10; radio-loud QSO)

☑ we used the conservative value of R>100 for RL QSOs

Radio Loud (RL) fraction vs. M_{BH}

Jets should be associated with ADAFs ≈ RL fraction increase

KI[2] (K. Ichikawa & K. Inayoshi) '17



☑ RL fraction starts to increase at M_{BH} ~ 2×10^9 M_{sun}

☑ RL fraction = $t_{jet}/(t_{jet} + t_{acc})$

What does the RL fraction tell us?

☑ RL fraction = $t_{jet}/(t_{jet} + t_{acc})$ <=> $t_{jet} \simeq t_{acc} f_{RL}/(1 - f_{RL})$

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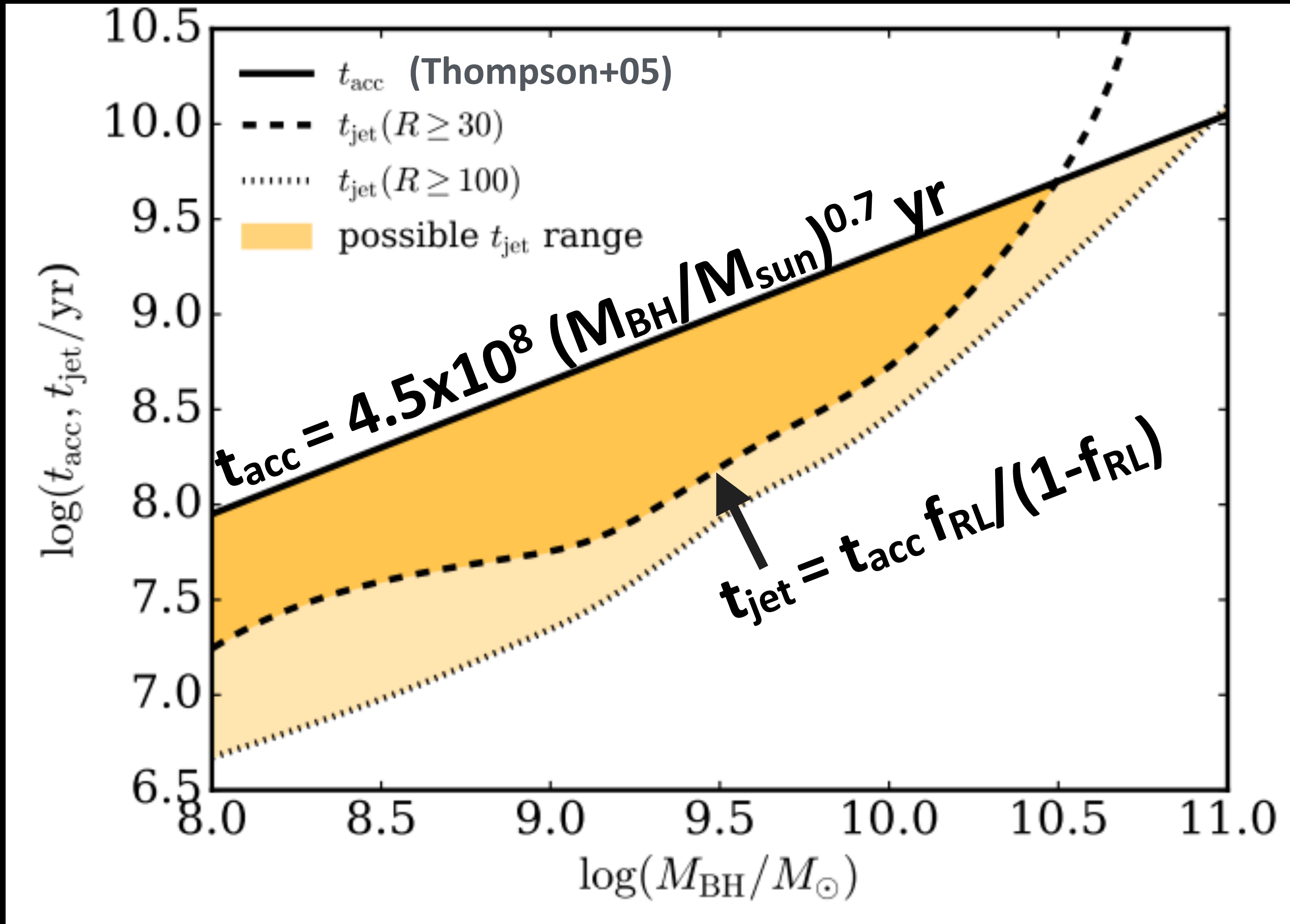

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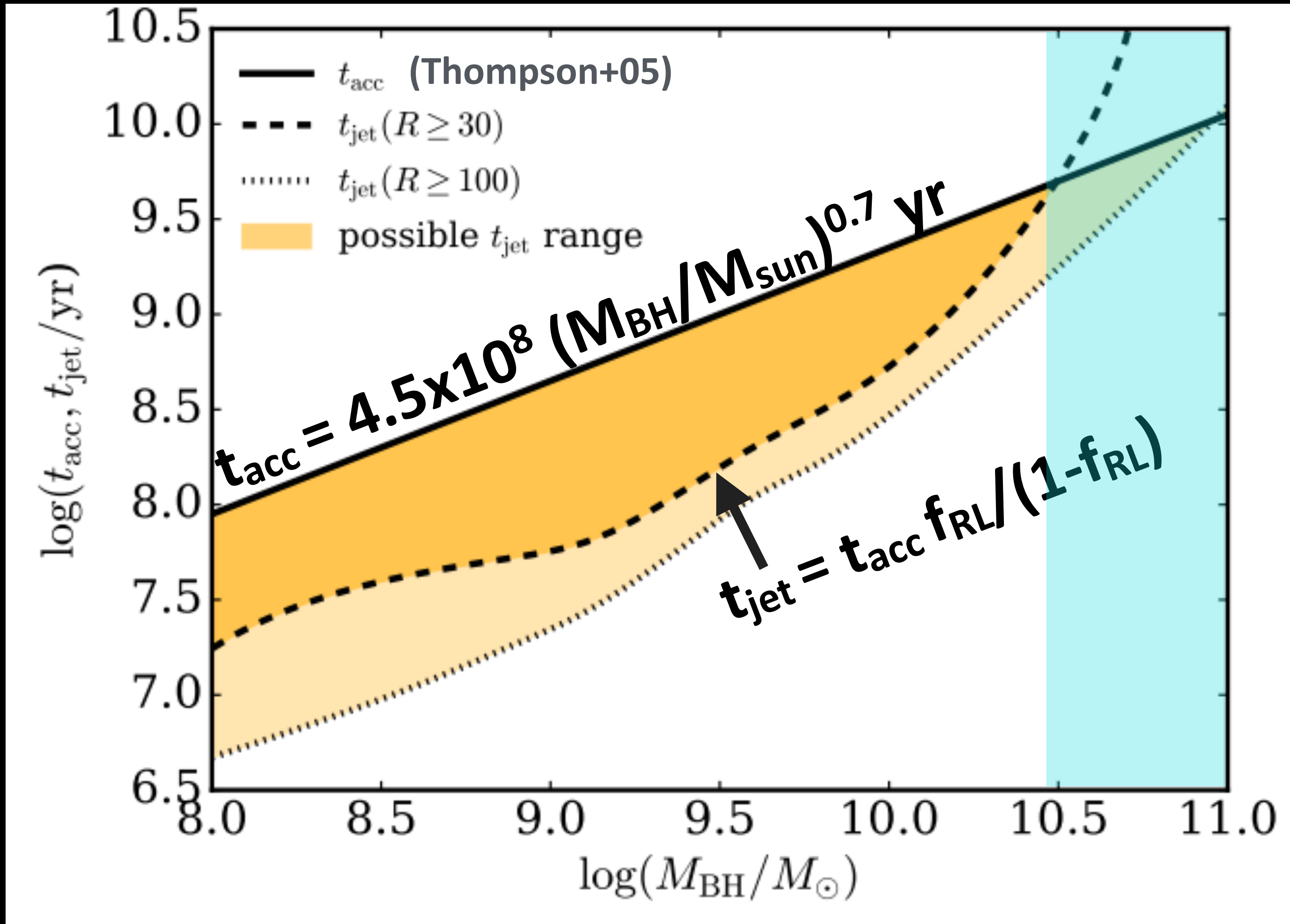


☑ t_{jet} >= t_{acc} at log (M_{BH}/M_{sun}) > 10.3

SMBH cannot get the mass at log (M_{BH}/M_{sun}) > 10.3

Summary & Conclusion

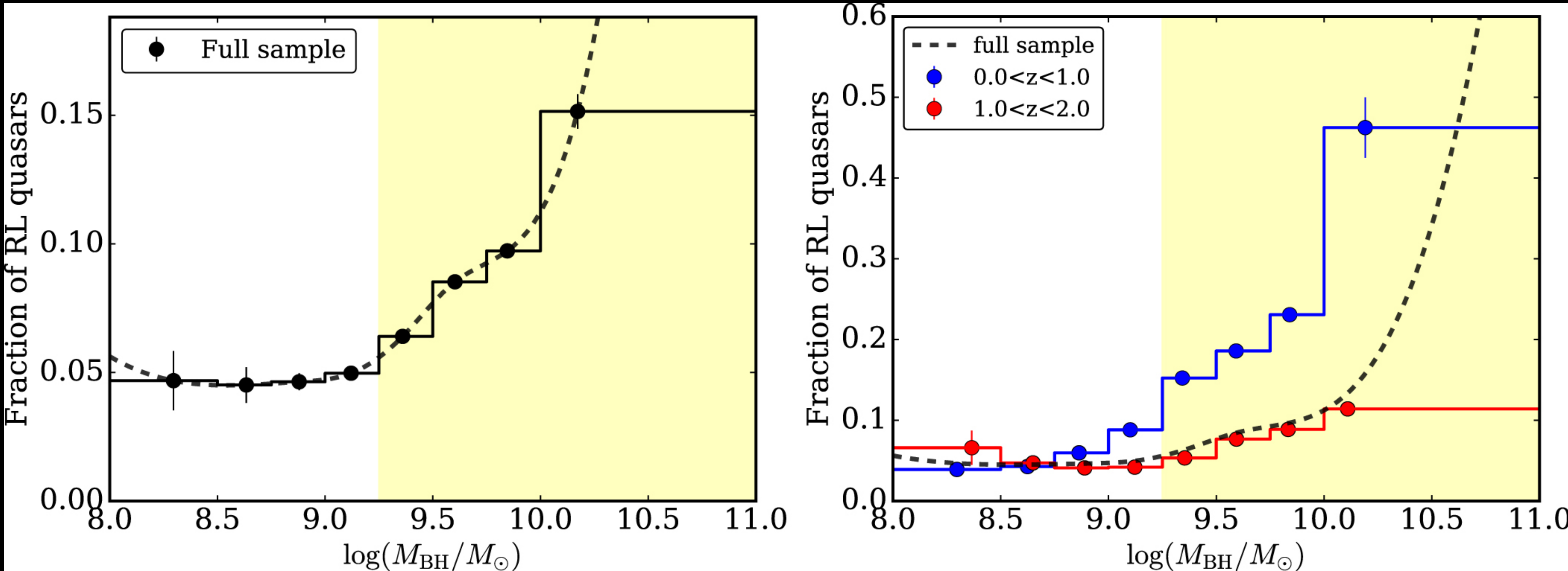
- ✓ **SMBHs seem to have mass limit to $10^{10\text{-}11}$ M_{sun} and z independent**
  - ✓ This suggests SMBHs have self regulation system at the max mass
- ✓ **Theory suggests all AGN fall in ADAF state at the max mass end**
  - ✓ mainly done by Inayoshi & Haiman '16
  - ✓ Observationally, the outflow/**jets are expected at the mass mass**
- ✓ **Radio-loud QSO increases at M_{BH} ~ 2×10^9 M_{sun} (Ichikawa & Inayoshi '17)**
  - ✓ Using 76,000 SDSS DR7 QSOs w/ conservative RL criterion of R>100
  - ✓ RL fraction = $t_{jet}/(t_{jet} + t_{acc})$ <=> $t_{jet} \simeq t_{acc} f_{RL}/(1 - f_{RL})$
  - ✓ t_{jet} >= t_{acc} at log (M_{BH}/M_{sun}) > 10.3

SMBH cannot get the mass at log (M_{BH}/M_{sun}) > 10.3

Auto-quenching of SMBH growth occurs at log (M_{BH}/M_{sun}) > 10.3

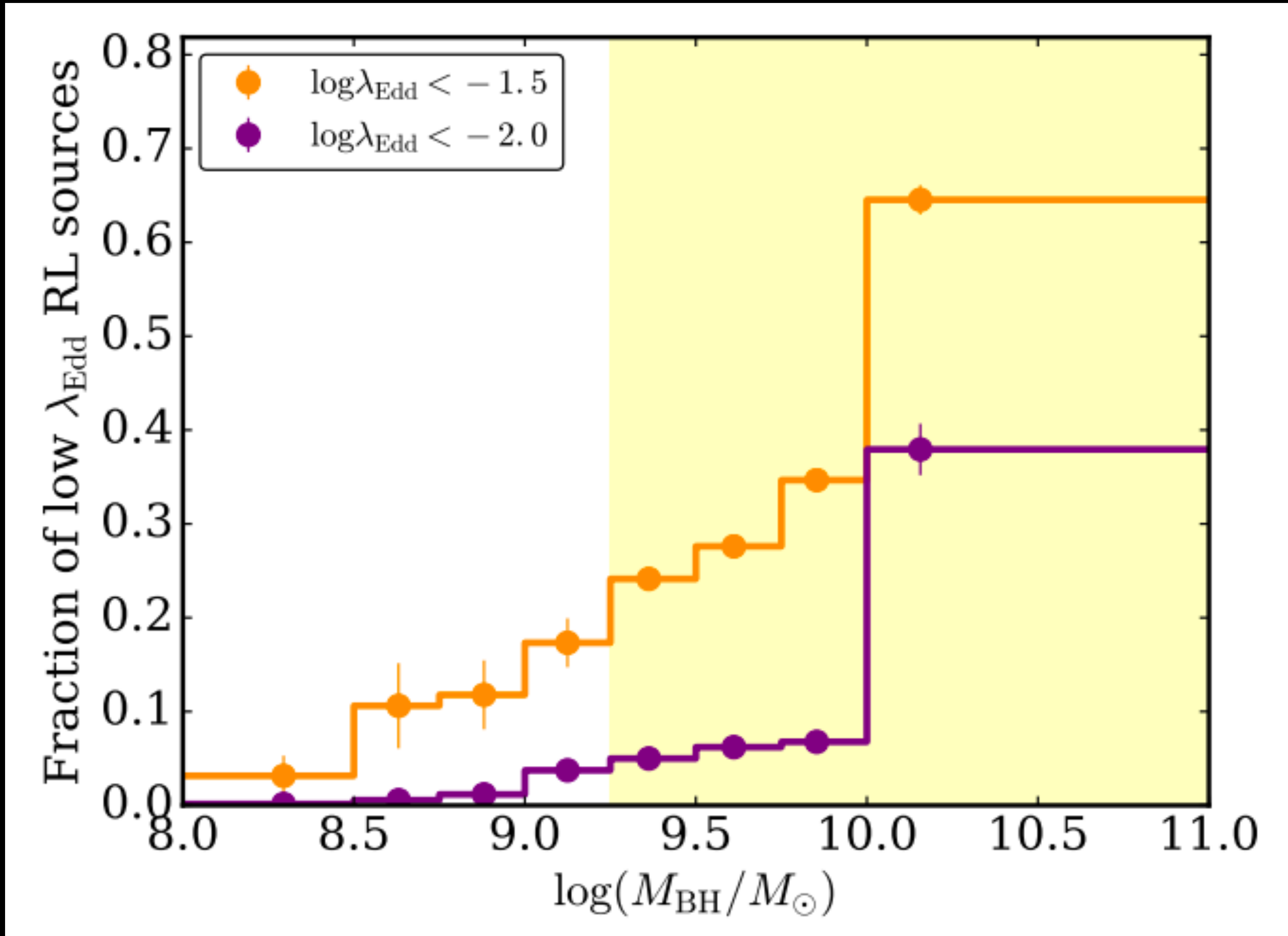
Appendix

z dependence of RL fraction



KI & KI 2017

Eddington ratio vs. M_{BH}



☑ λ_{Edd} increases at M_{BH} ~ 2×10^9 M_{sun}

M_{BH} vs. z

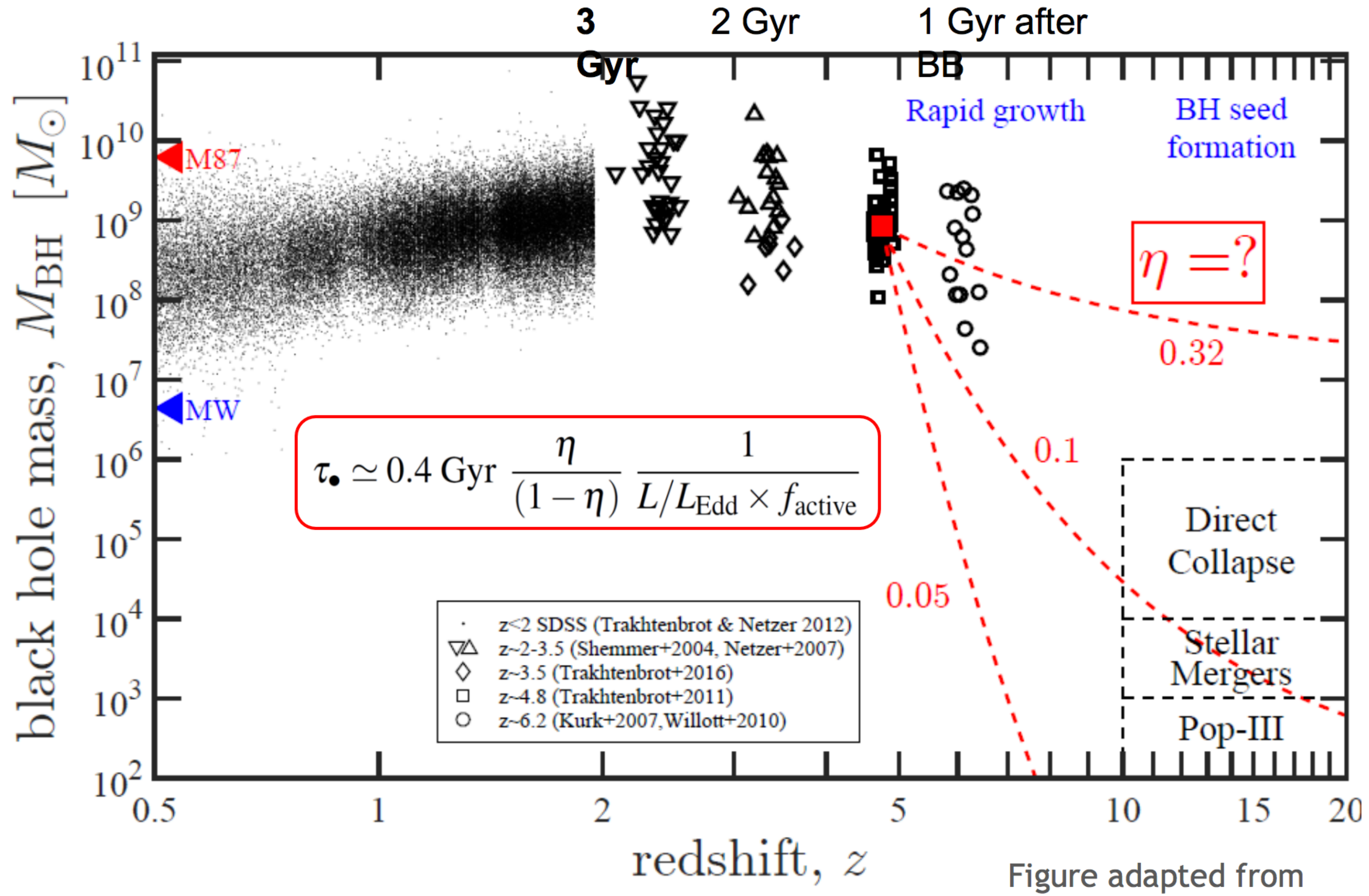


Figure adapted from Trakhtenbrot & Netzer 12

Estimation of BH mass

$$M_{\rm BH}({\rm H}\beta) = 1.05 \times 10^{8} \left(\frac{L_{5100}}{10^{46}\,{\rm erg\,s^{-1}}} \right)^{0.65} \left[\frac{{\rm FWHM(H}\beta)}{10^{3}\,{\rm km\,s^{-1}}} \right]^{2} {\rm M_{\odot}}.$$