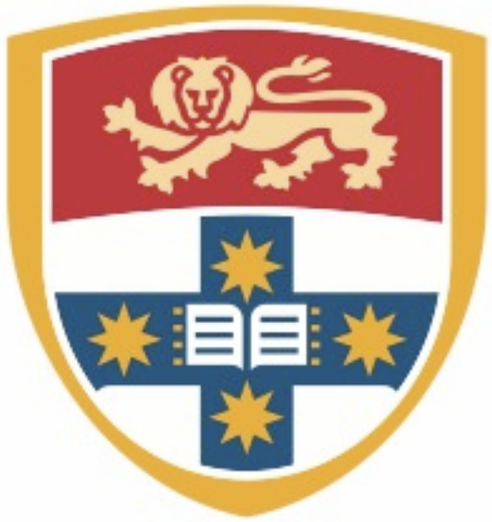


THE UNIVERSITY OF SYDNEY

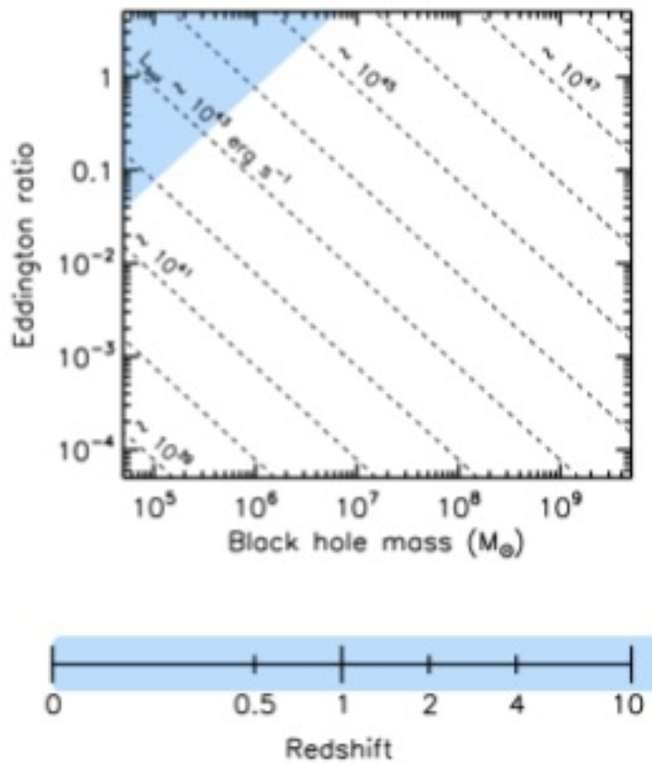
Sydney Institute for Astronomy

Miroslav Micic

Modeling the Growth of SMBH at the center of Milky Way

with

Kelly Holley-Bockelmann - Vanderbilt University
Steinn Sigurdsson - Pennsylvania State University



Growth of Massive Black Holes

1. Current Model: Springel et al. 2005, Croton et al. 2006, Sijacki et al. 2007, Di Matteo 2008, Somerville et al. 2008

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   - FPL works for M - σ SMBHs at the centers of massive stellar systems.

   - What about various types of spiral and dwarf galaxies?
     - M33 : spiral, no bulge, no SMBH!!! Merritt et al. 2001, Gebhardt et al. 2001.
     - NGC 205: dwarf elliptical, no SMBH!!! Valluri et al. 2005.

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     - Competitive Feedback , Nayakshin et al. 2009.

       Who gets the gas? Black holes or stars?
       - If σ > 150 km/s: BH beats NC => M - σ SMBH forms.
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     - Gravitational Wave Recoil (Kicks), Baker et al. 2007, Campanelli et al. 2008.
       - Escape velocities in high redshift dwarfs <100km/s.
       - Gravitational wave recoil <1000km/s.

What you will see next is ...

- Implement gravitational wave recoil (kicks) in FPL.

- Apply FPL to Local Group represented by via lactea 2 simulation.

- FPL works, scatter in M - σ due to kicks.

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1. AGN feedback bundled with stellar feedbacks (star formation, SNe...)
2. Combined feedbacks control gas accretion, not the "black hole fundamental plane".
3. Black hole growth not limited by the "black hole fundamental plane".
4. Both "quasar" mode and "radio" mode motivated by galaxy mergers:

mass ratio ↑	accretion efficiency ↑	accretion time scale ↓	→	quasar mode
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FPL

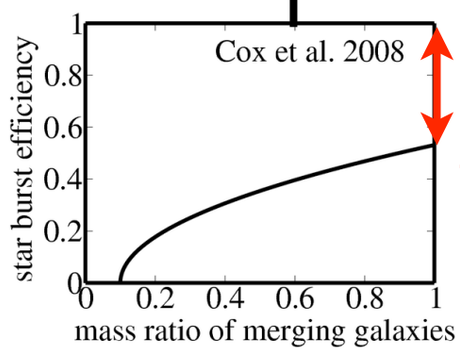
AGN feedback

"black hole fundamental plane"

proceed at close to / or Eddington rate

total mass in stars in bulge/spheroid

trigger gas accretion onto the black hole.



stars related feedbacks

major mergers (>0.1)

star burst efficiency = amount of gas available for star formation

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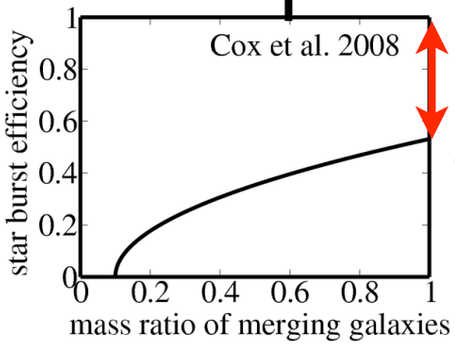

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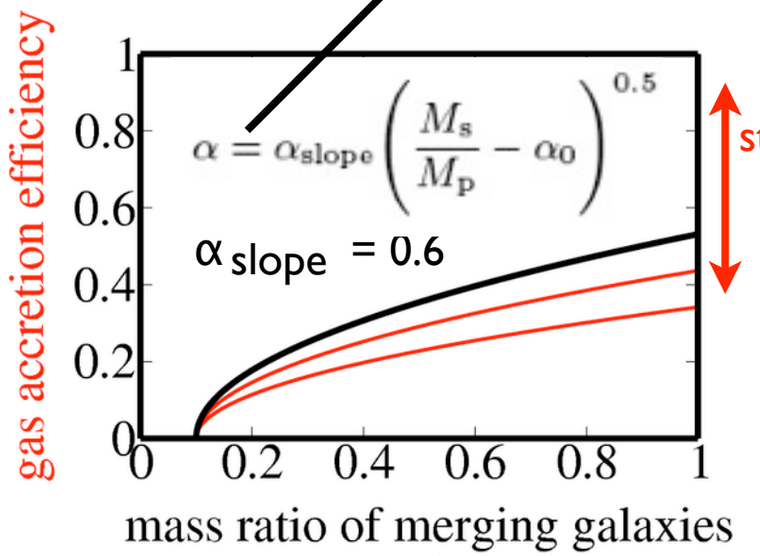
$M_{\rm acc} = M_{\rm BH,0}(e^{\frac{\alpha t_{\rm acc}}{t_{\rm sal}}} - 1)$



α slope = 0.6

α0 = 0.1

stars related feedbacks + AGN feedback

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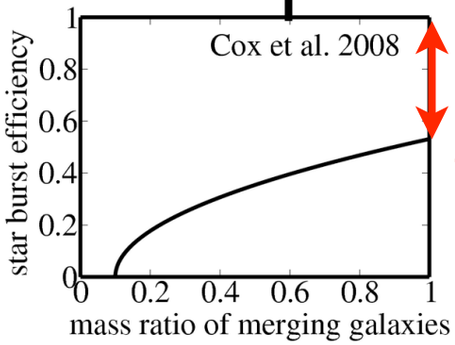

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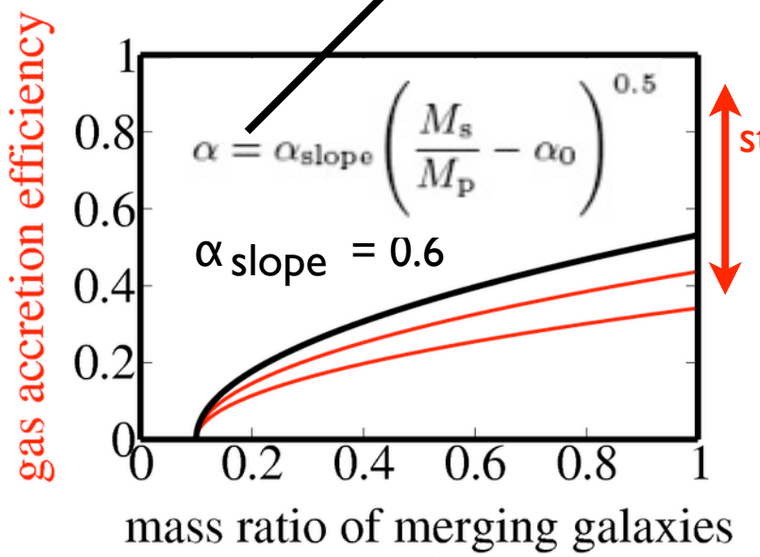

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- We need new model that will allow for implementation of small scale AGN simulations.

DETAILS

- via lactea 2 (VL-2): cosmological N-body simulation of Milky Way formation, over one billion dark matter particles with mass 4,100 solar masses each. Diemand et al. 2007, 2008

- make via lactea merger tree to create a numerical dark matter frame onto which we semi-analytically paint baryons (gas, stars, galaxies).

Via Lactea does not necessarily represent Milky Way merger history. It represents one of the possible merger histories!

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goal is to produce
4.2 million solar mass BH

FPL

- Bondi - Hoyle accretion rate during radio mode.

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- bundle all feedbacks into gas accretion efficiency.

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  - distribution with random BH spin (K1).
    1,000 merger trees
  - distribution with BH spin aligned with orbital angular momentum (K2).
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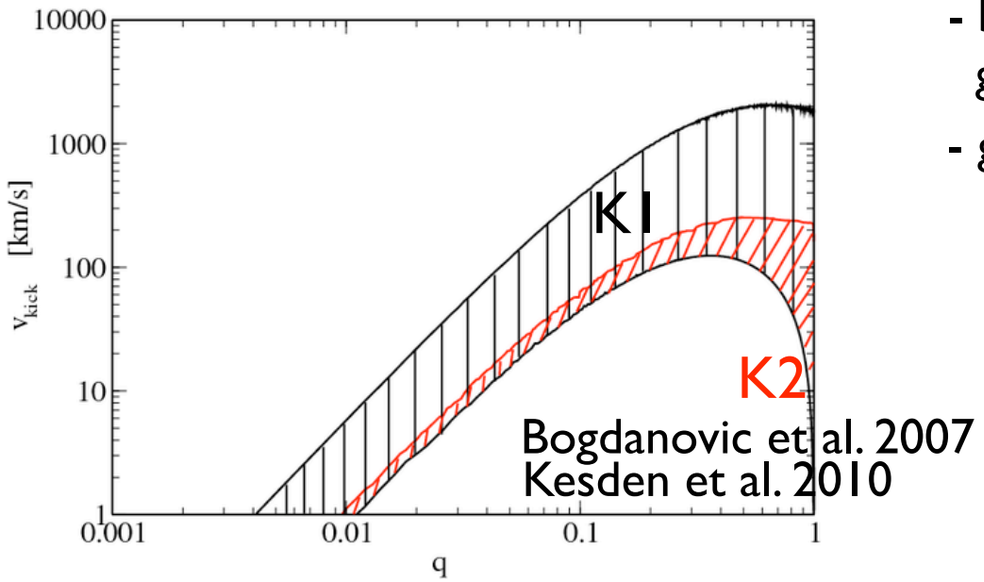

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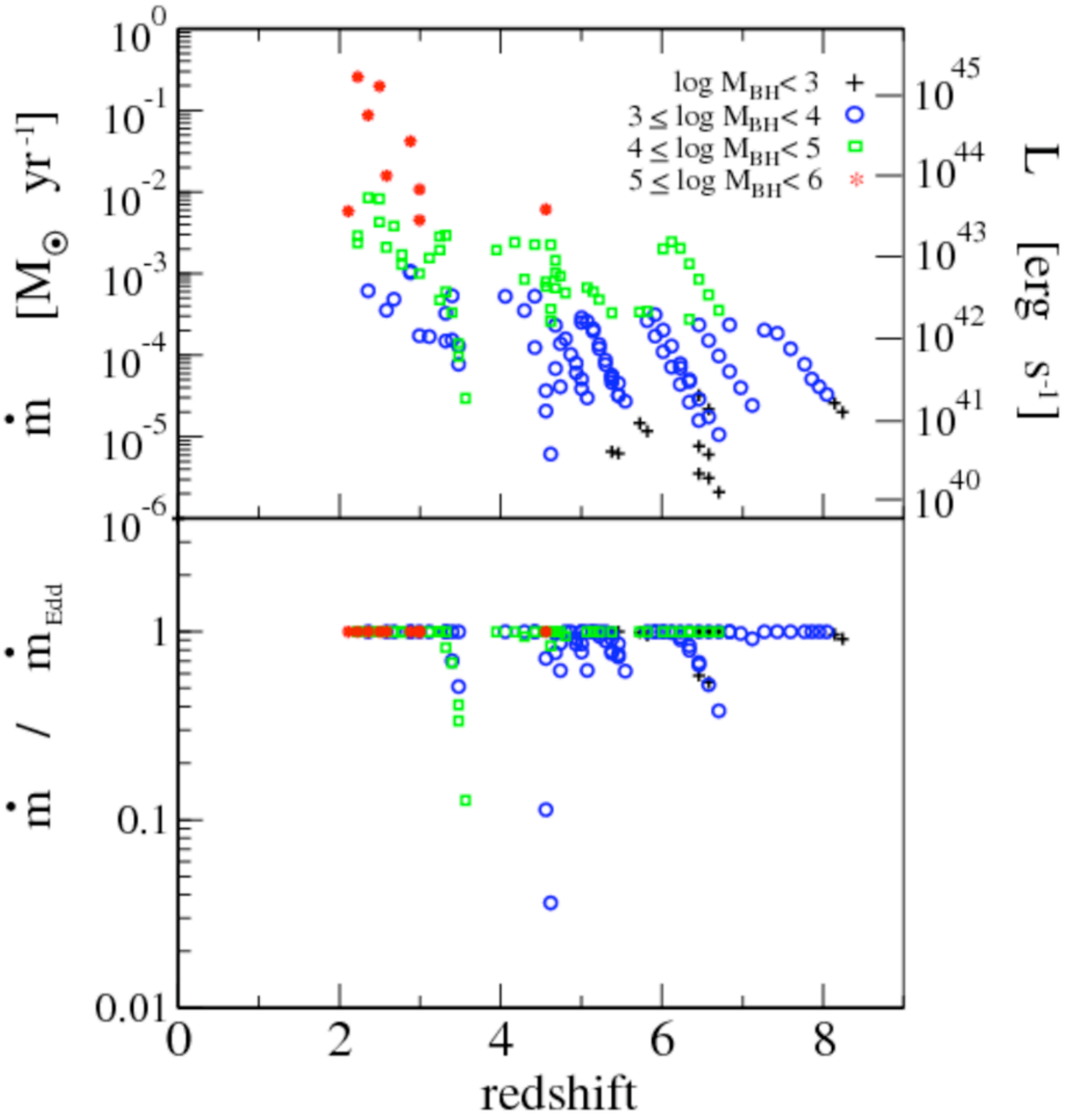
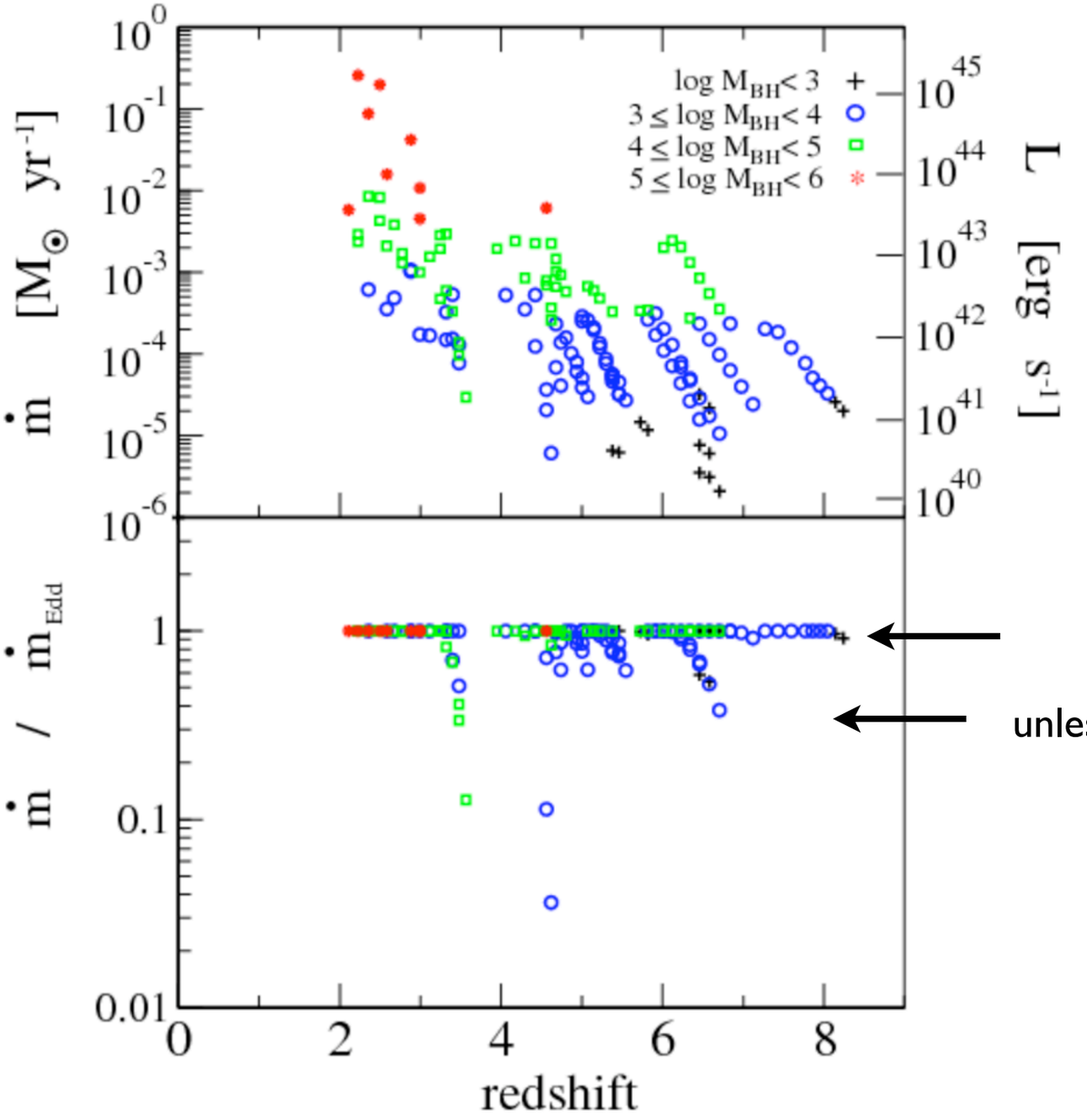

log M_BH< 3
3 ≤ log M_BH< 4
4 ≤ log M_BH< 5
5 ≤ log M_BH< 6
ṁ [M⊙ yr⁻¹]
L [erg s⁻¹]
ṁ / ṁ_Edd
redshift
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^45
10^44
10^43
10^42
10^41
10^40
1
0.1
0.01
0
2
4
6
8

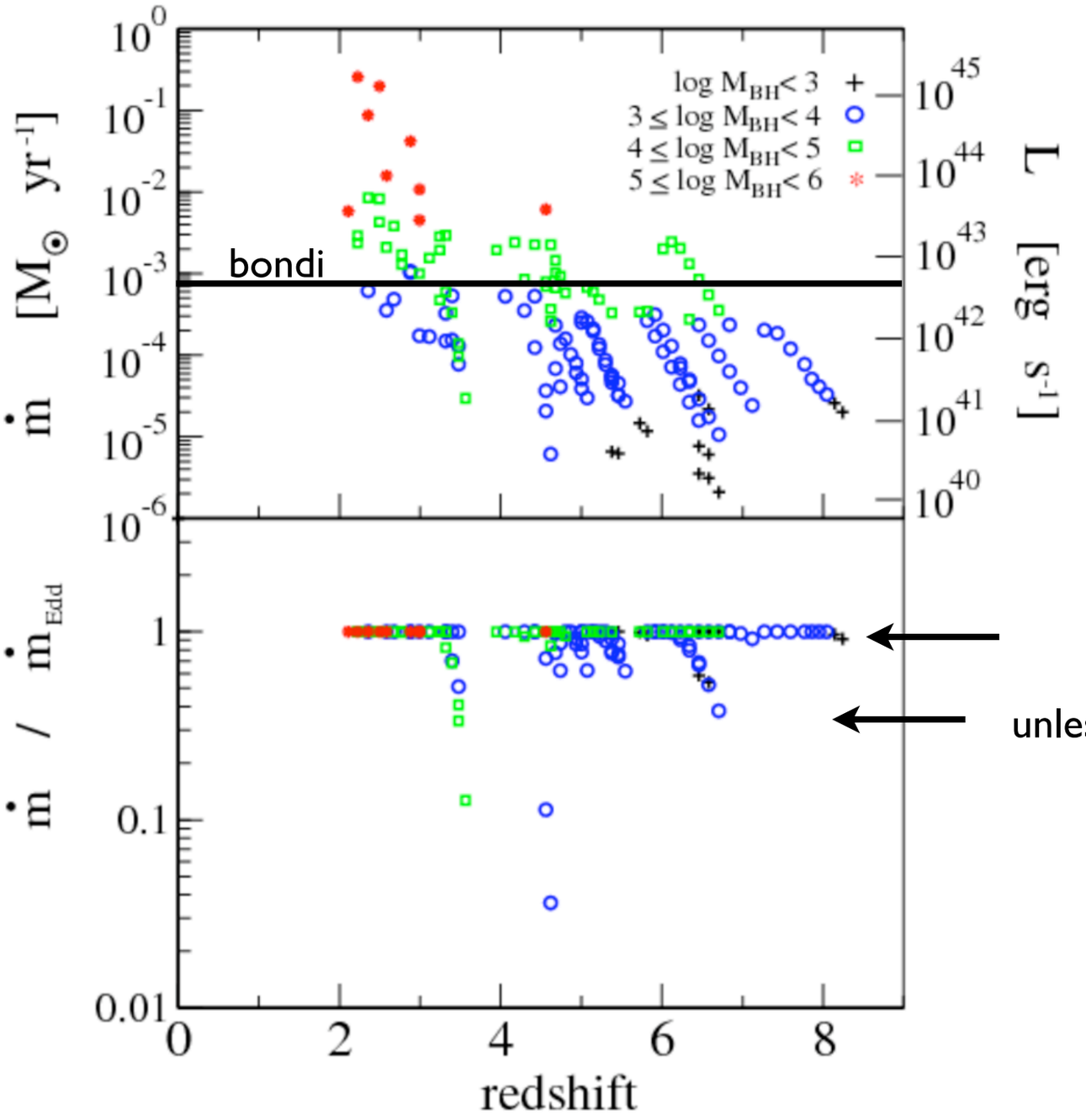
FPL



most of the black holes accrete at Eddington rate.

unless "black hole fundamental plane" stops them before they reach Eddington rate.

FPL



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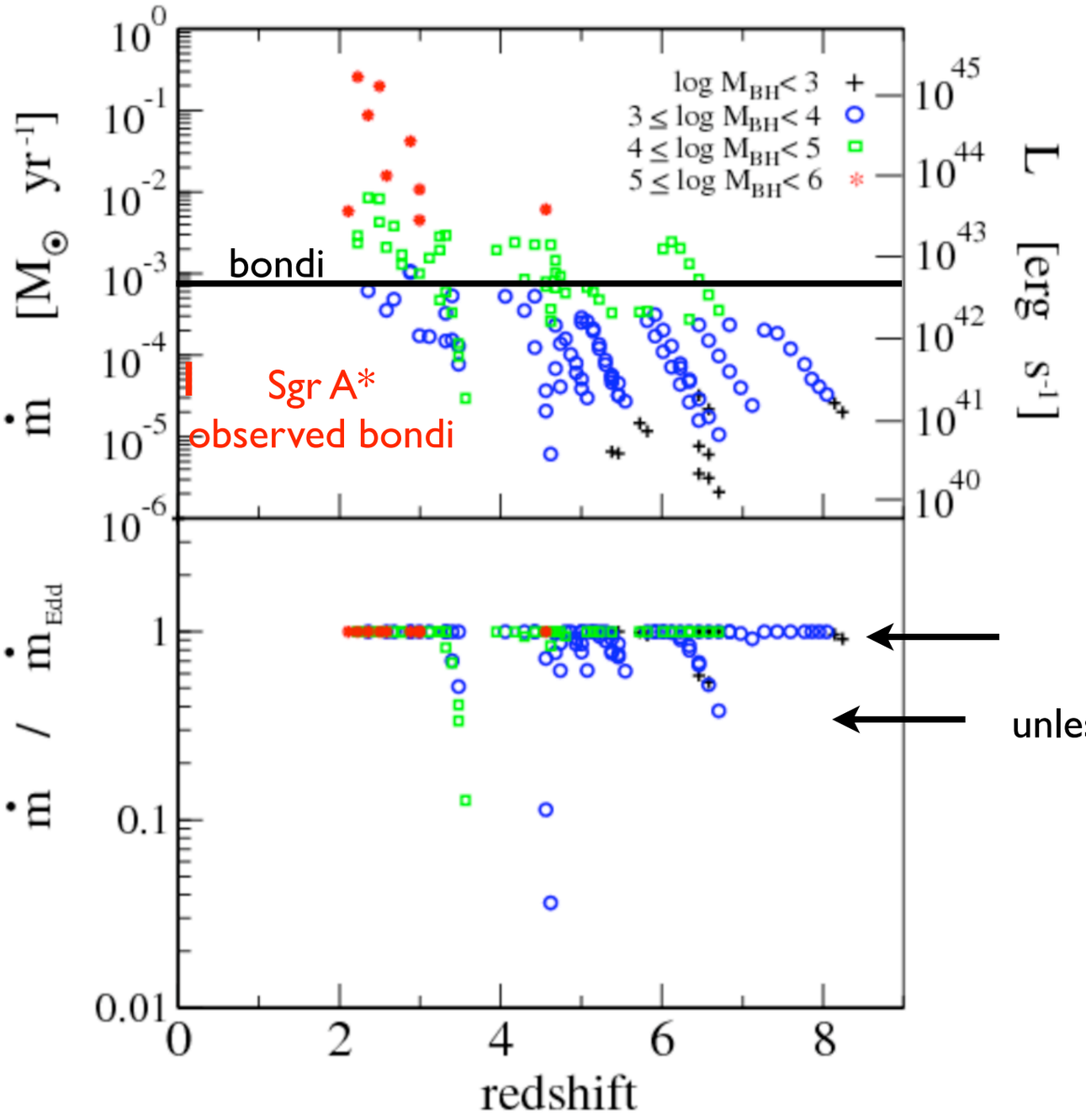

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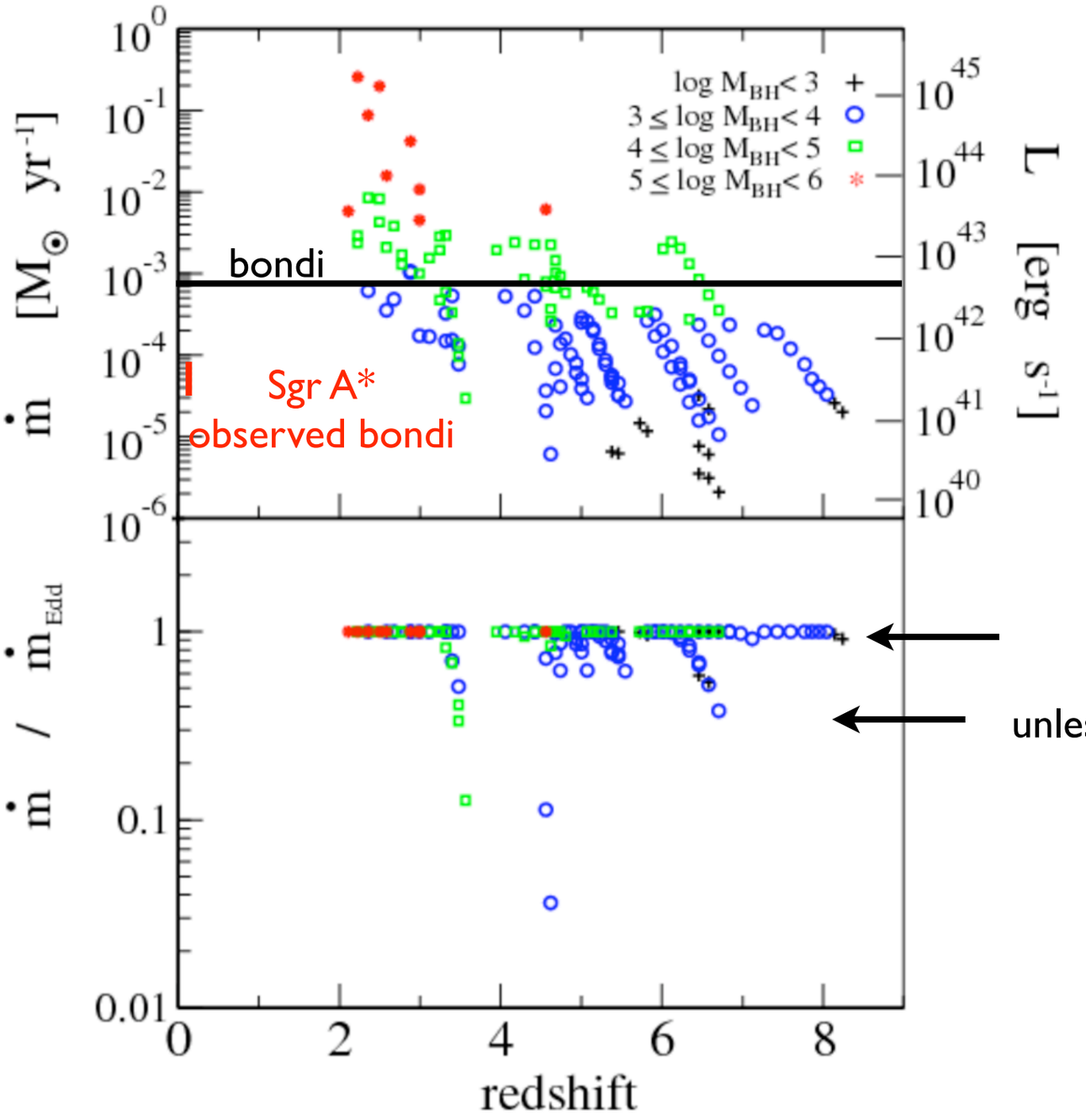

- consistent with the accretion rates in low mass AGNs in Local Universe.

- Milky Way progenitor was a low mass AGN.

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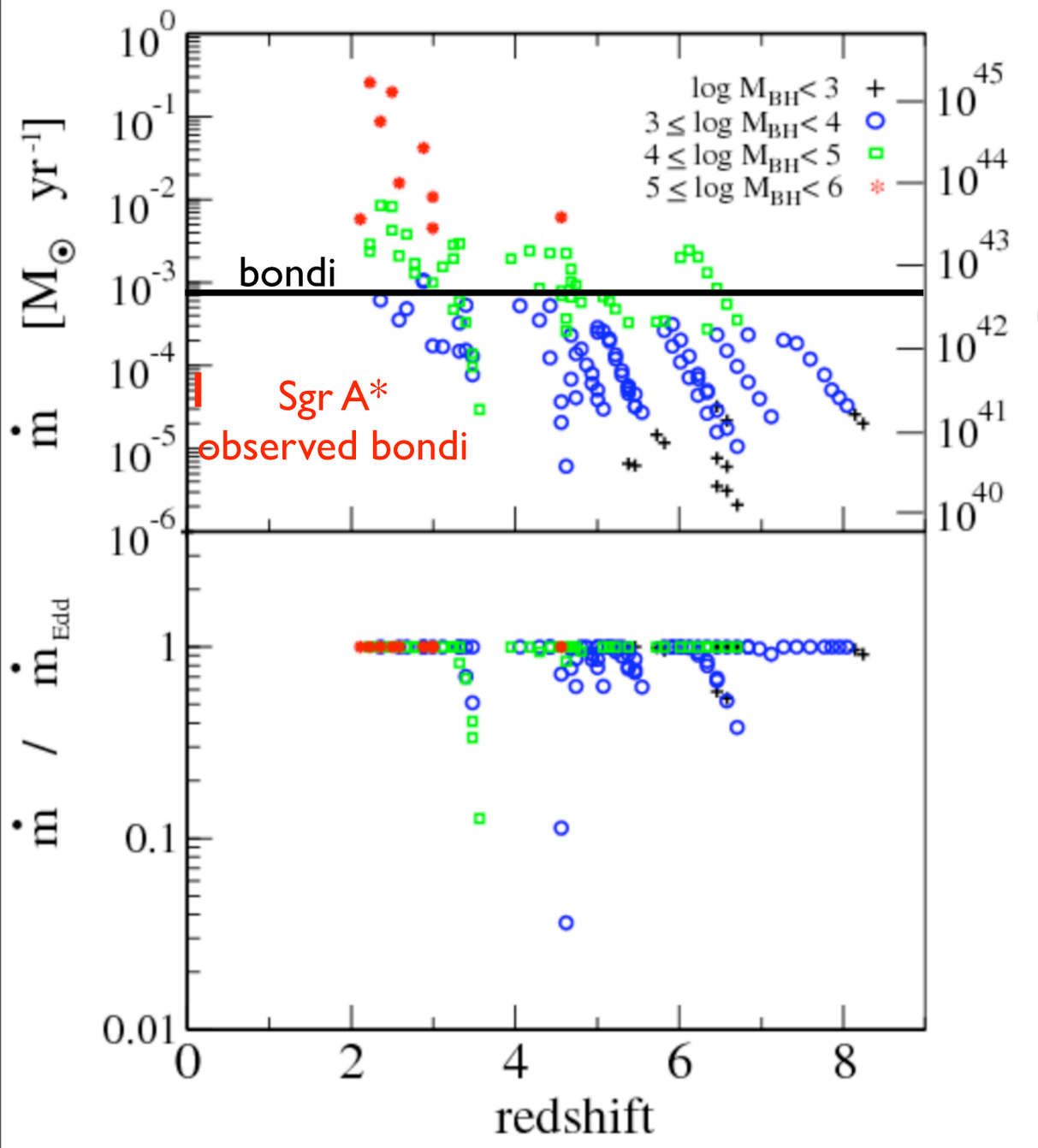

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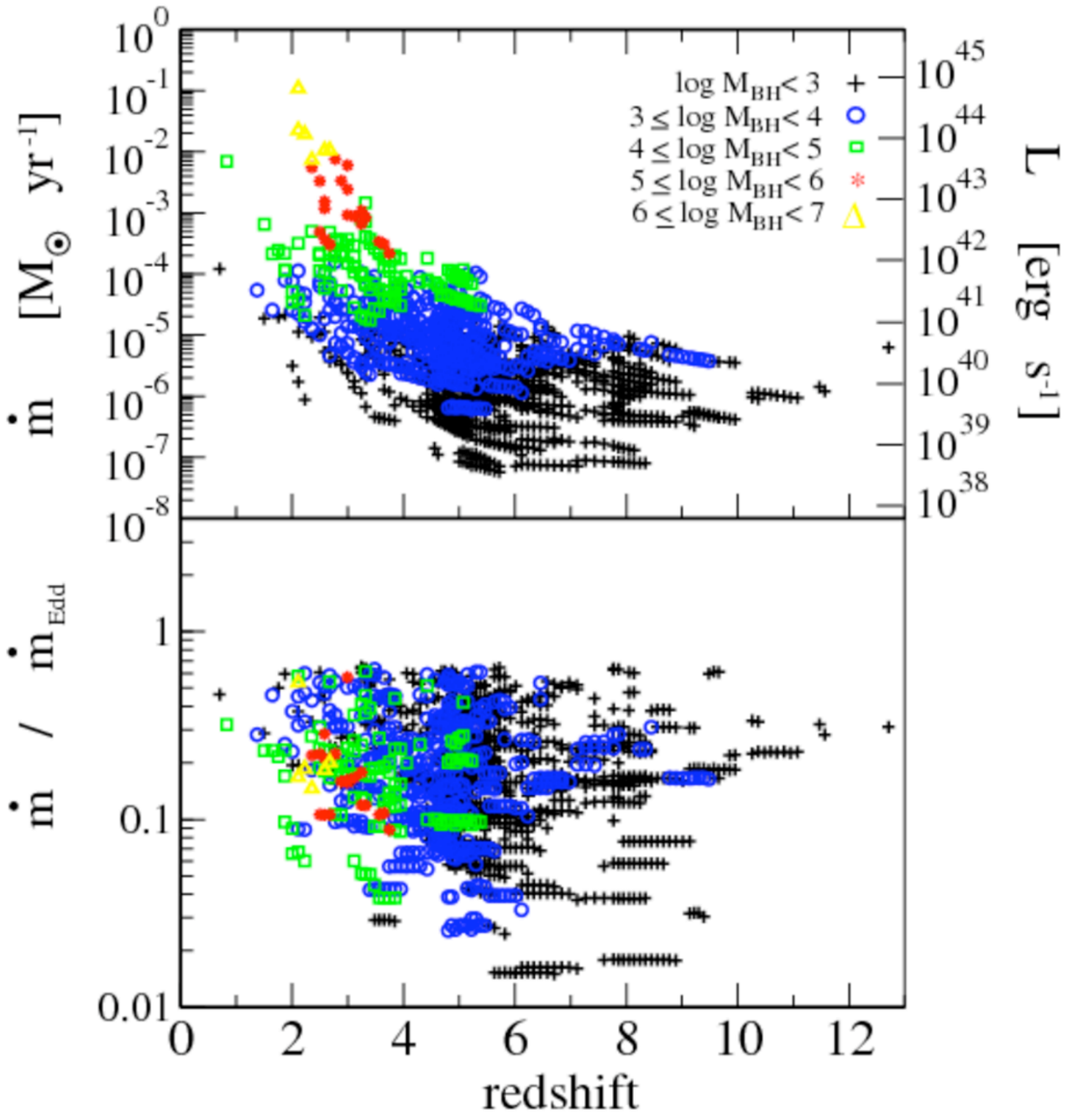


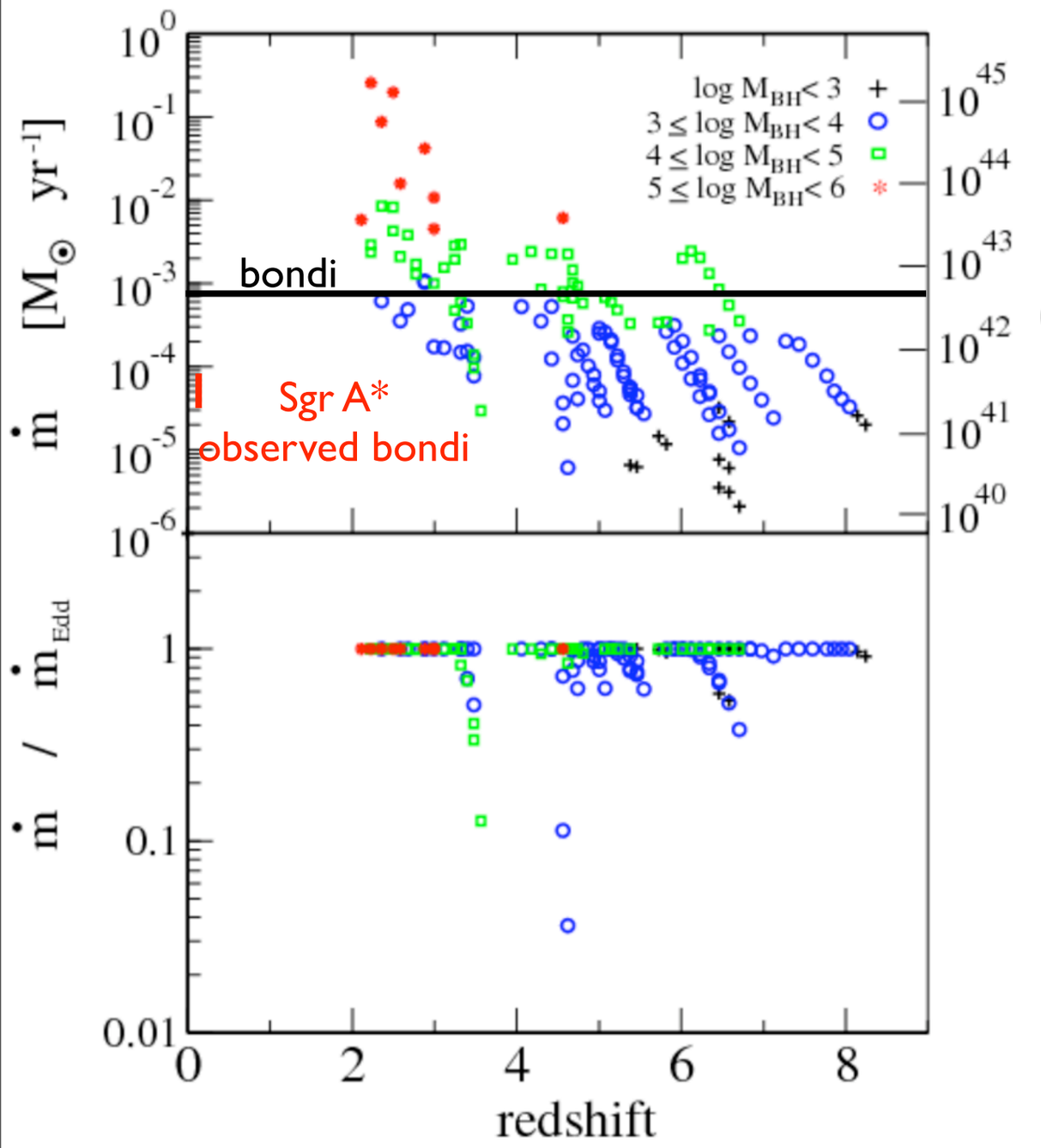
- order of magnitude less black holes in FPL due to the "black hole fundamental plane".

  10^8- 10^9 $M_\odot$ DMH has at least a million $M_\odot$ of gas available for accretion

  but "black hole fundamental plane" allows a black hole < 1,000 $M_\odot$

- no such limit in MD model.

FPL



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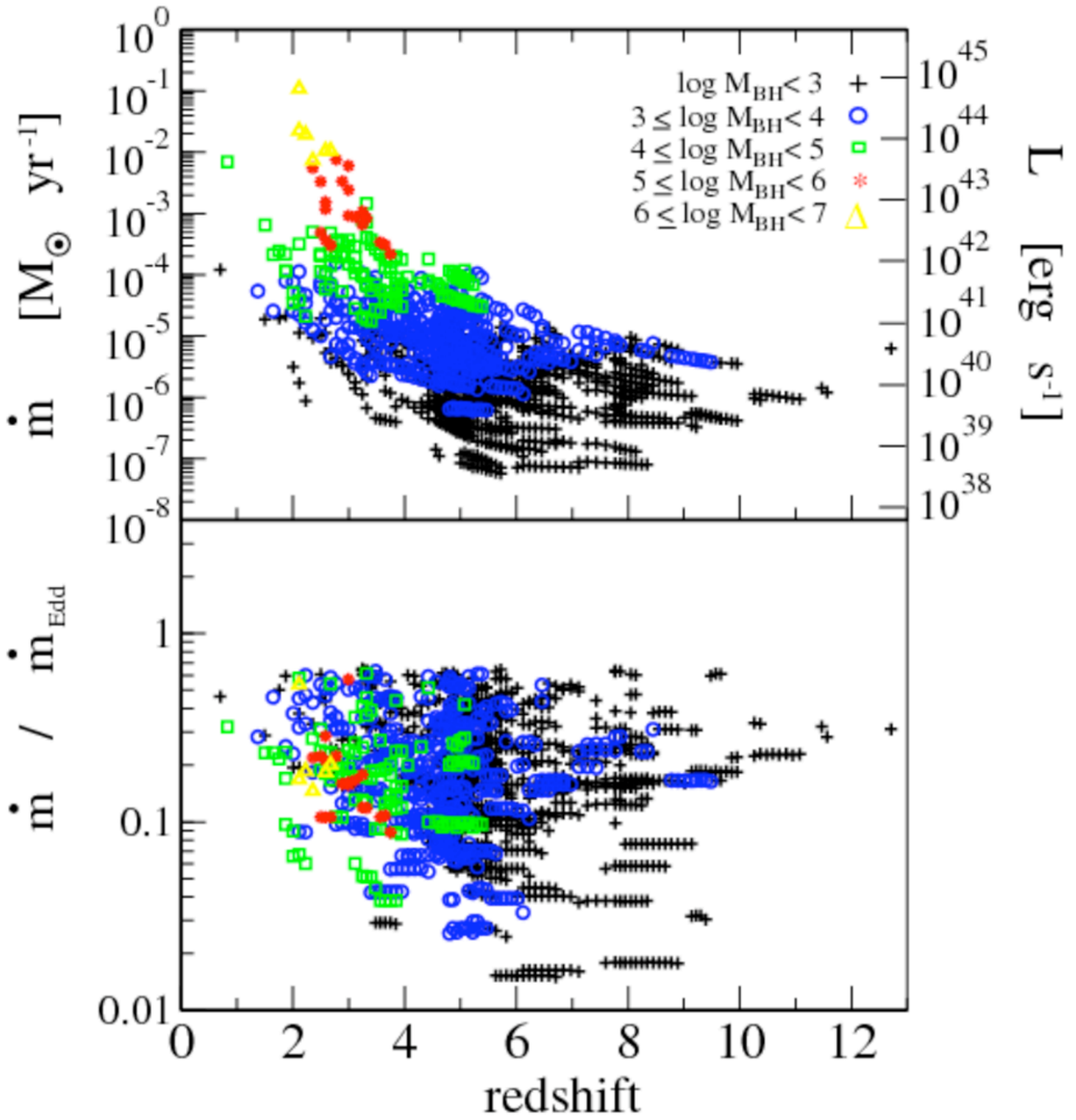

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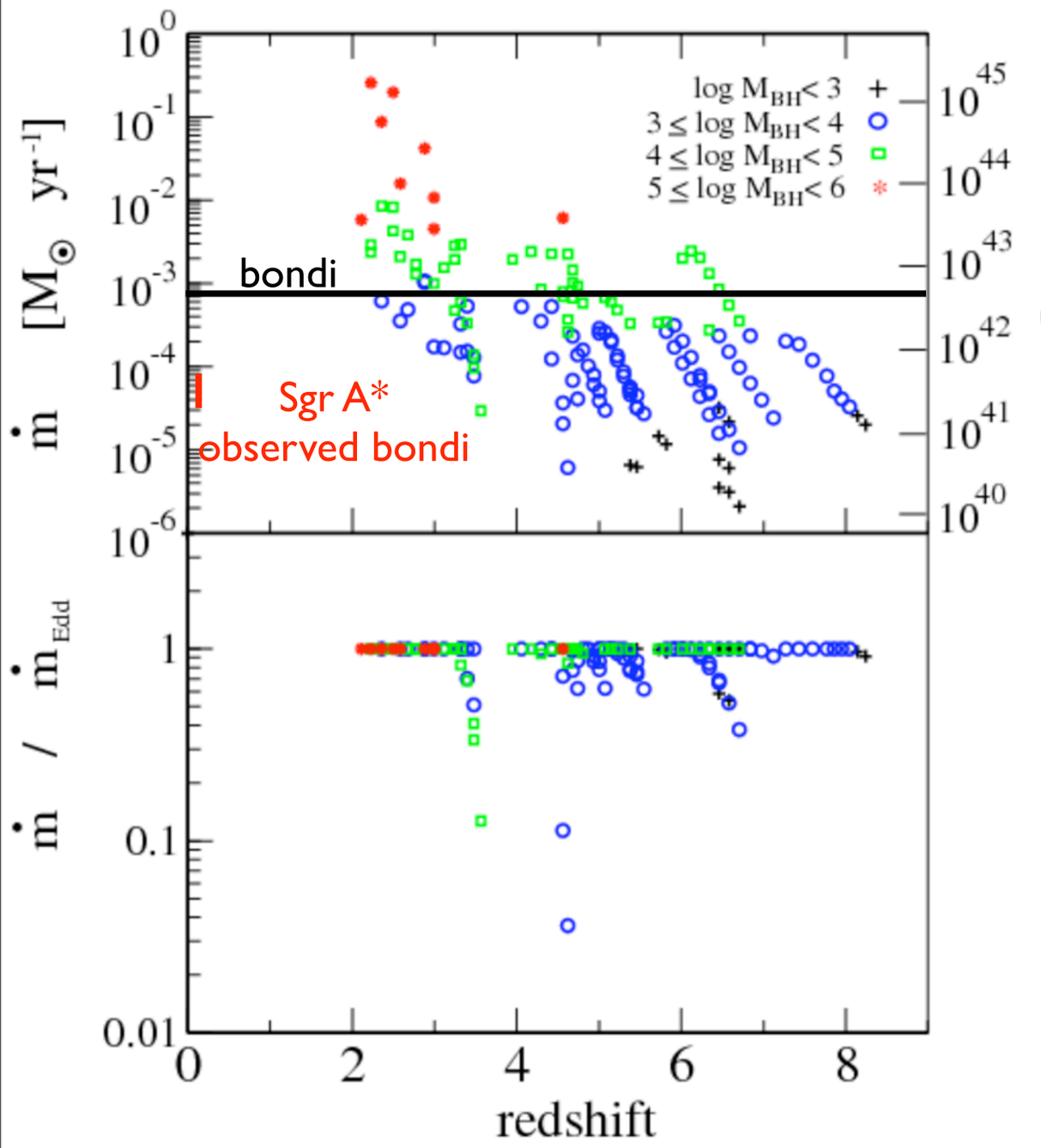

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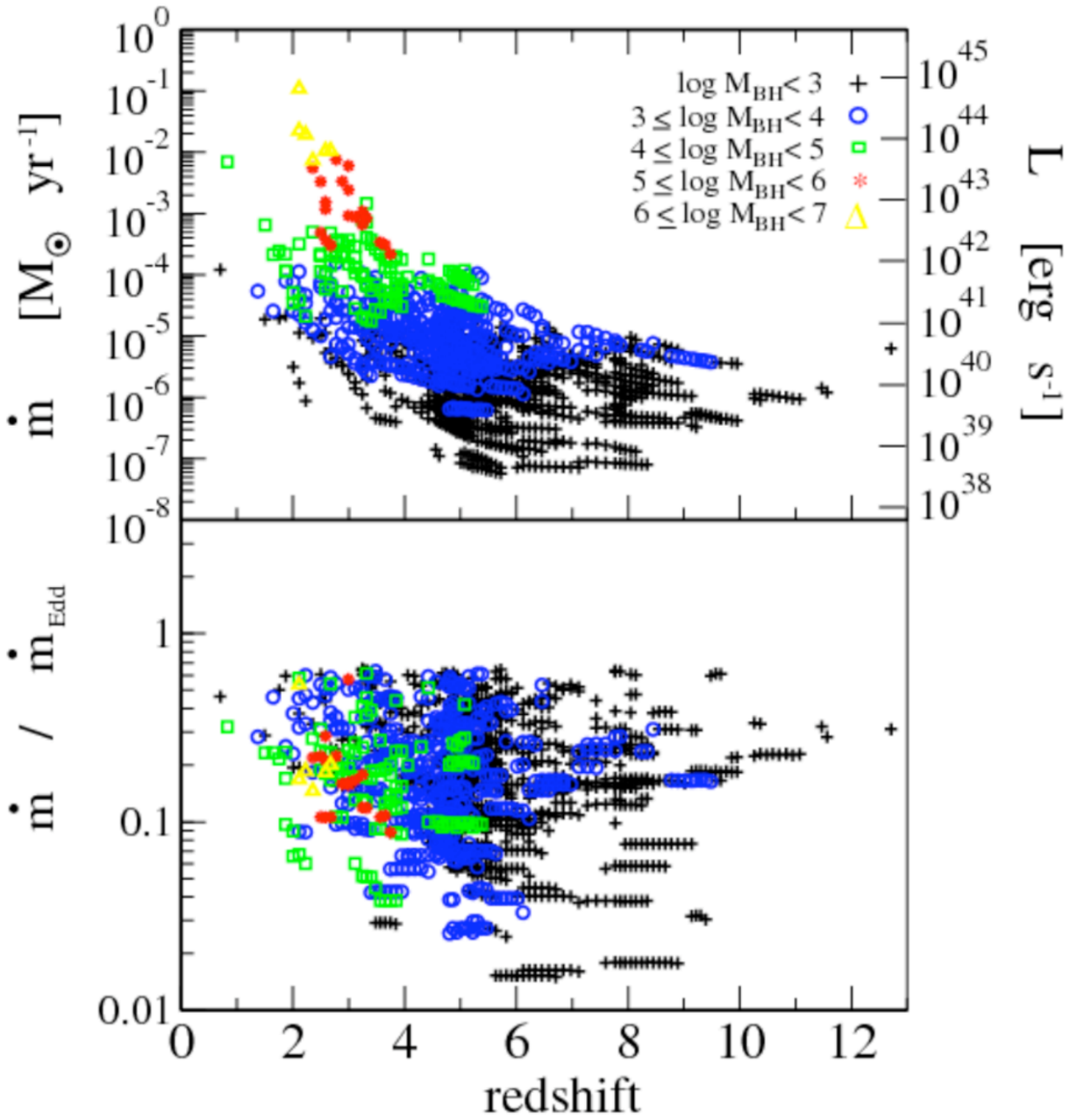

- order of magnitude less black holes in FPL due to the "black hole fundamental plane".
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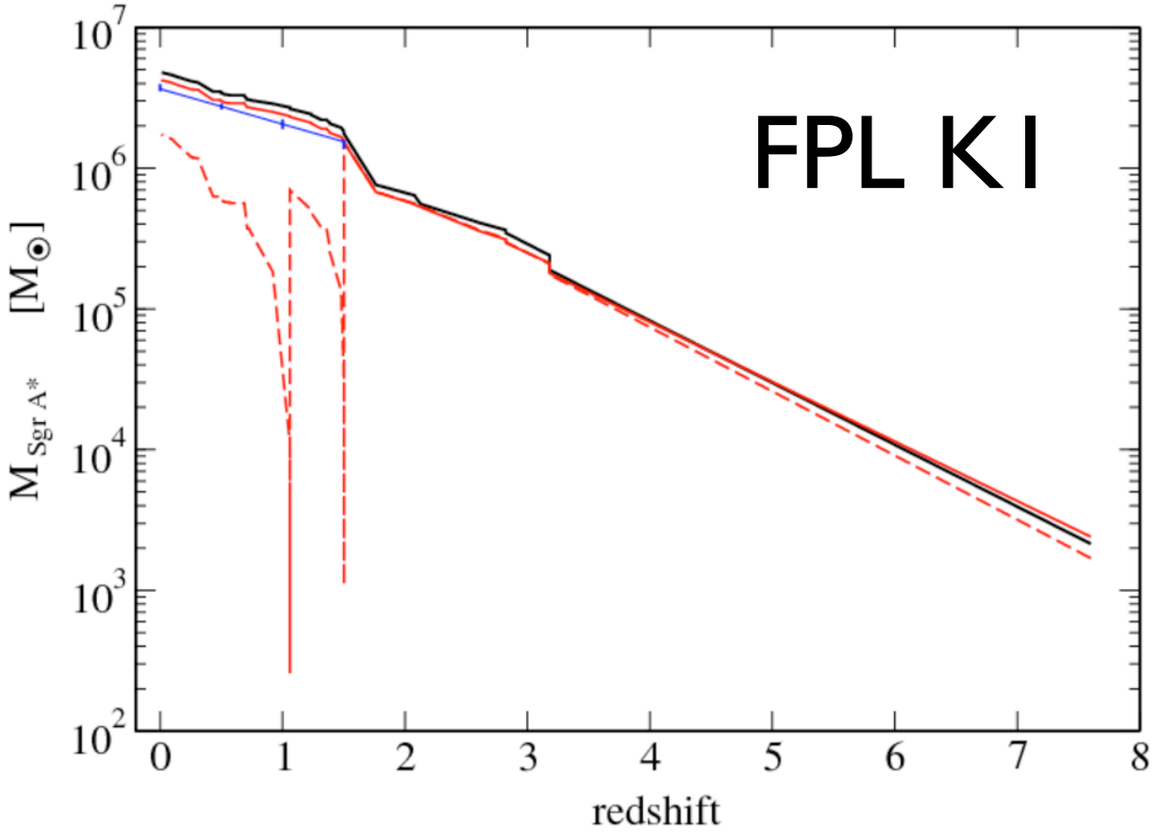
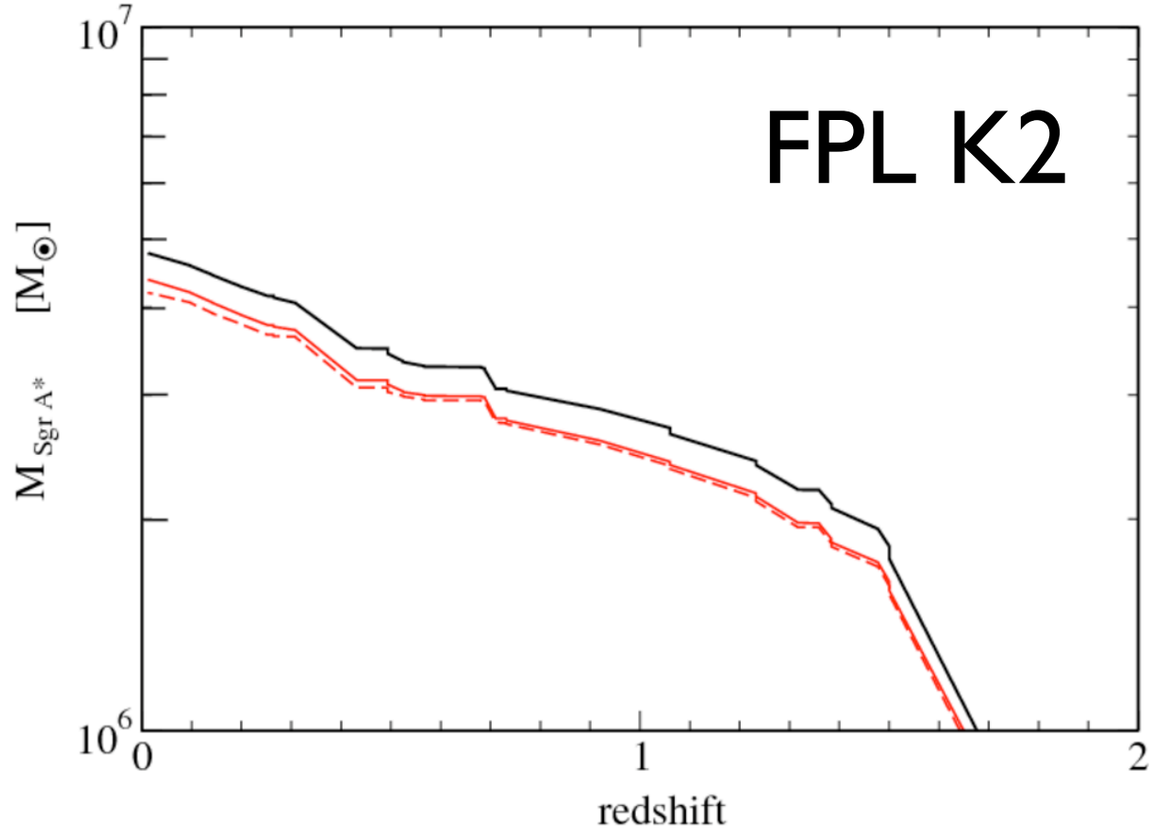
- hints of "downsizing" in MD?

Sgr A* Growth





merger tree with no kicks.

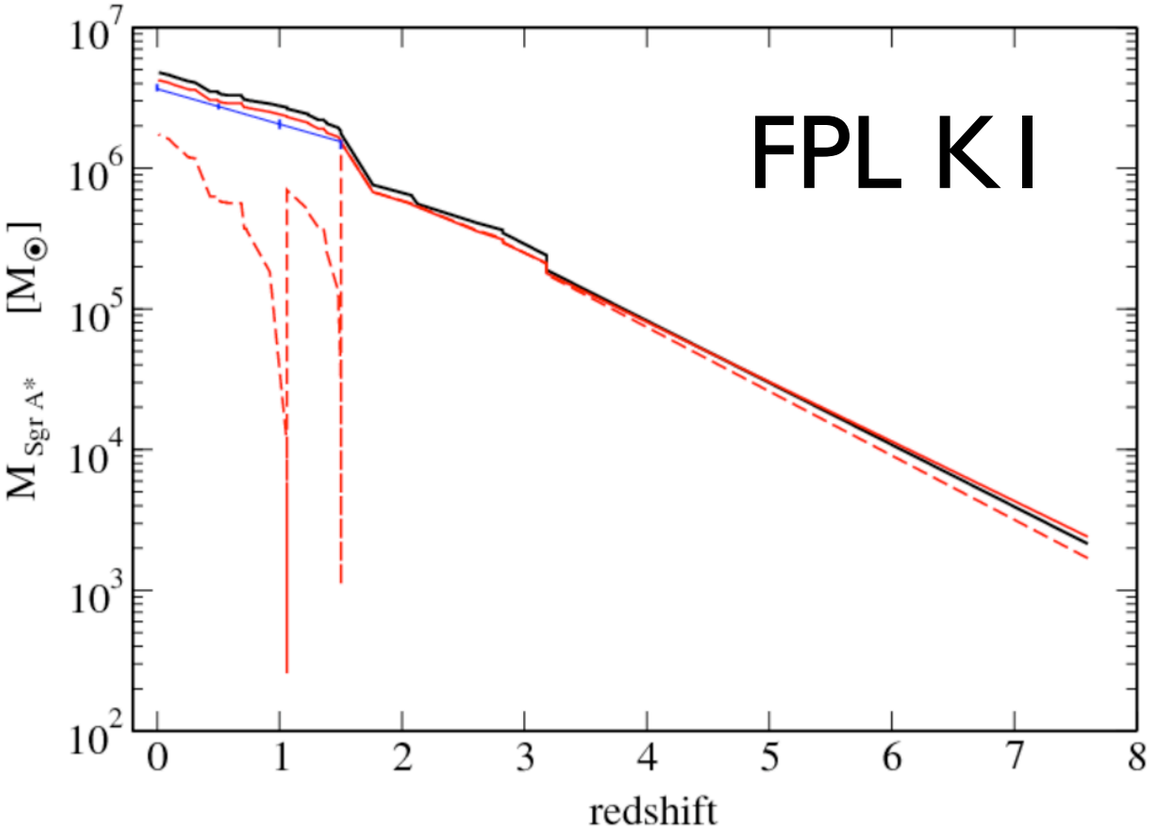
kick realization with largest final SMBH

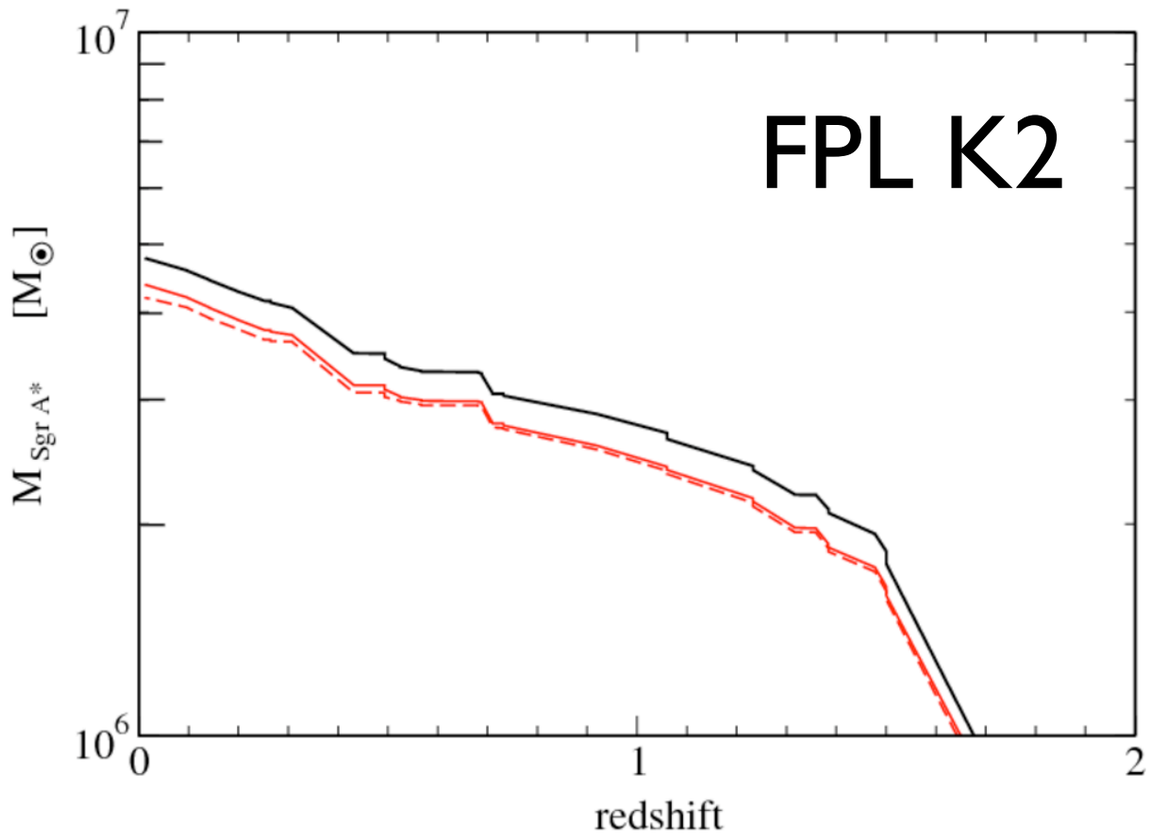
kick realization with most common final SMBH.

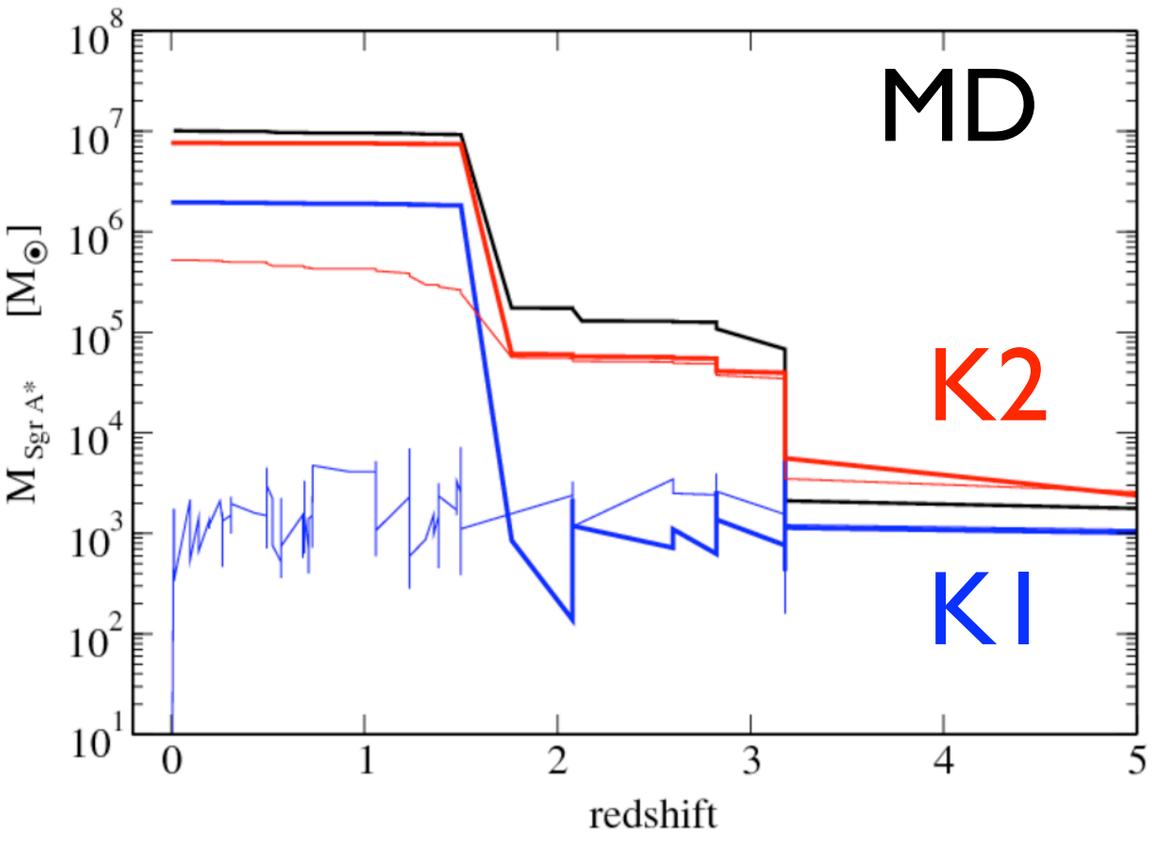
kick realization with smallest final SMBH.

- even when black hole is ejected, replacement has time to grow to SMBH range because of the Eddington rate gas accretion.

Sgr A* Growth







- lower accretion rates => larger range of final SMBH masses

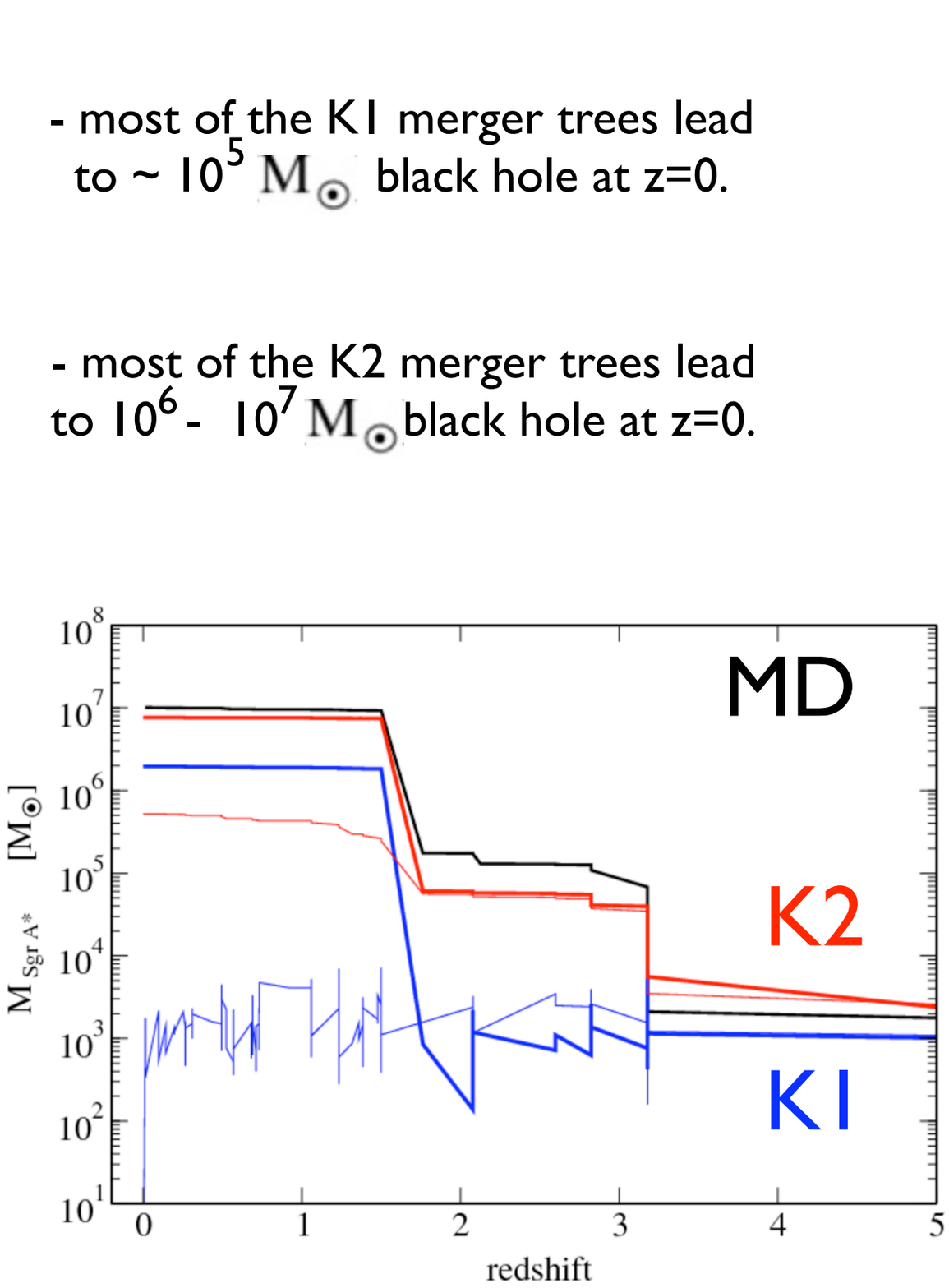
- kicks important in MD model

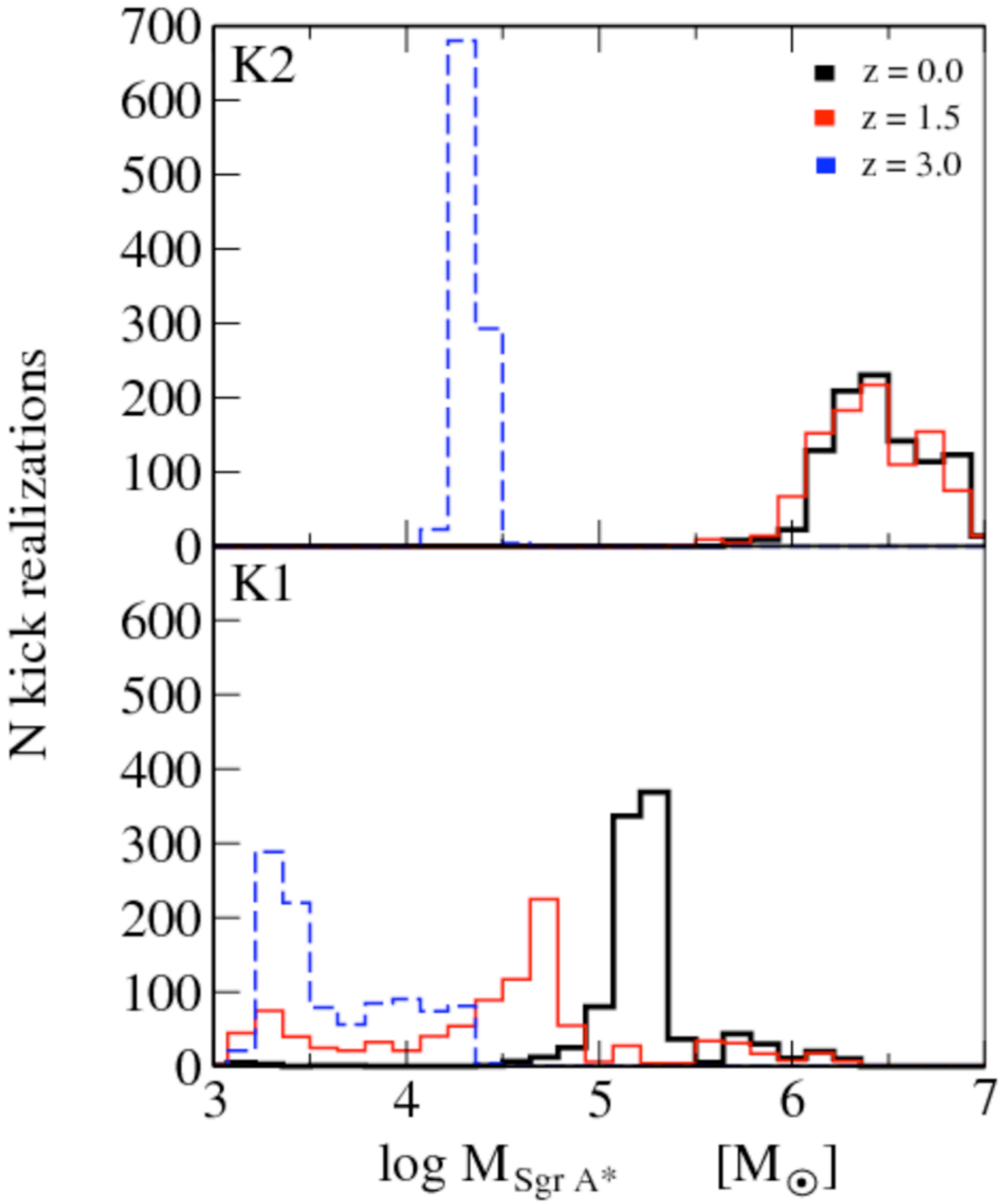
- but these are just extreme cases

Sgr A* Growth

- most of the K1 merger trees lead to ~ 10^5 $M_\odot$ black hole at z=0.

- most of the K2 merger trees lead to 10^6 - 10^7 $M_\odot$ black hole at z=0.





Conclusions

- FPL works fine for spiral and dwarf galaxies.

- It can even grow non M - σ BHs thanks to kicks.

- Whatever the seed IMF might be, it better be "flat"
otherwise kicks will be too efficient.

- MD model reproduces FPL results successfully for Sgr A*,
Local Dwarfs, rogue black holes, and ejected black holes.

  - 35 local dwarf galaxies in VL-2. Half of them with massive black holes.

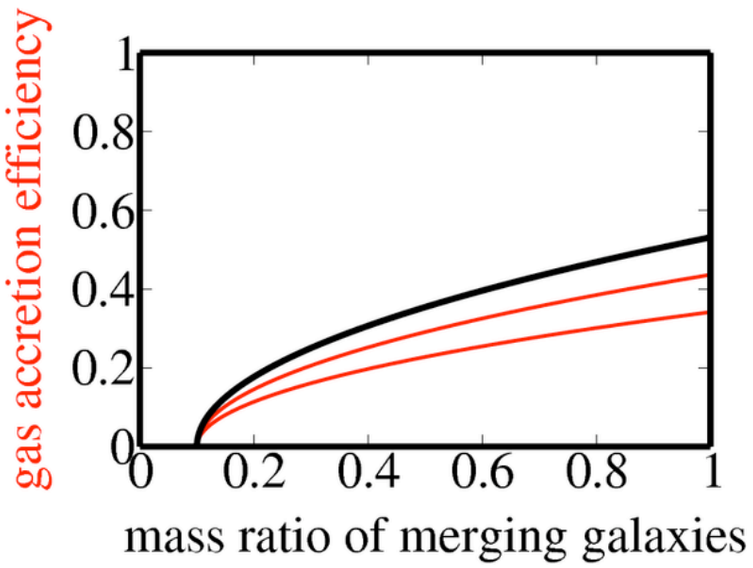
  - 149 rogue massive black holes in Milky Way halo. Most massive one is at 225 kpc distance, 227,643 solar masses, and 3,834 solar luminosities.

  - Hundreds of ejected massive black holes.

- Combining all feedbacks into gas accretion efficiency lowers the accretion rate and provides mechanism for switch from "quasar" to "radio" mode.

- Next: Spins of Massive Black Holes

What we need is:



- to reproduce this plot for a wide range of black hole masses, mass ratios of merging galaxies, and all feedbacks, following the work of Cox et al. 2008 and Younger et al. 2008.

- to run a cosmological simulation which will resolve hundreds of Local Groups. Via Lactea represents one of the possible Local Groups, probably not the correct one so the problem has to be approached statistically.

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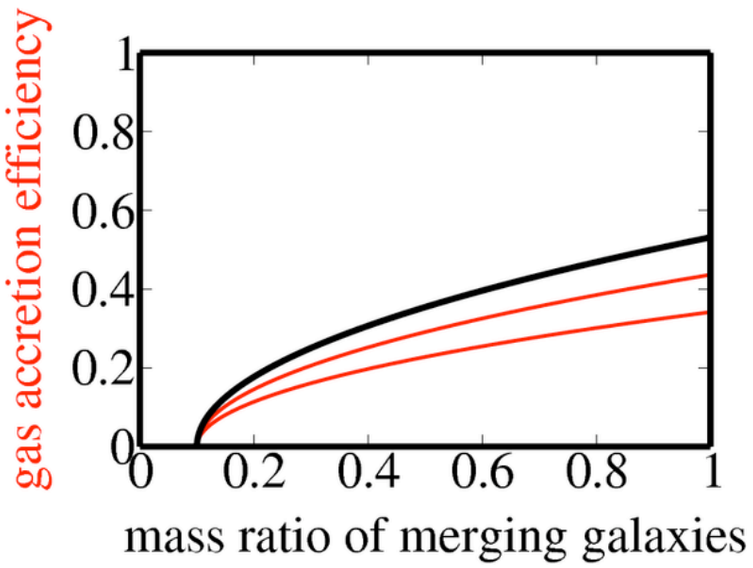

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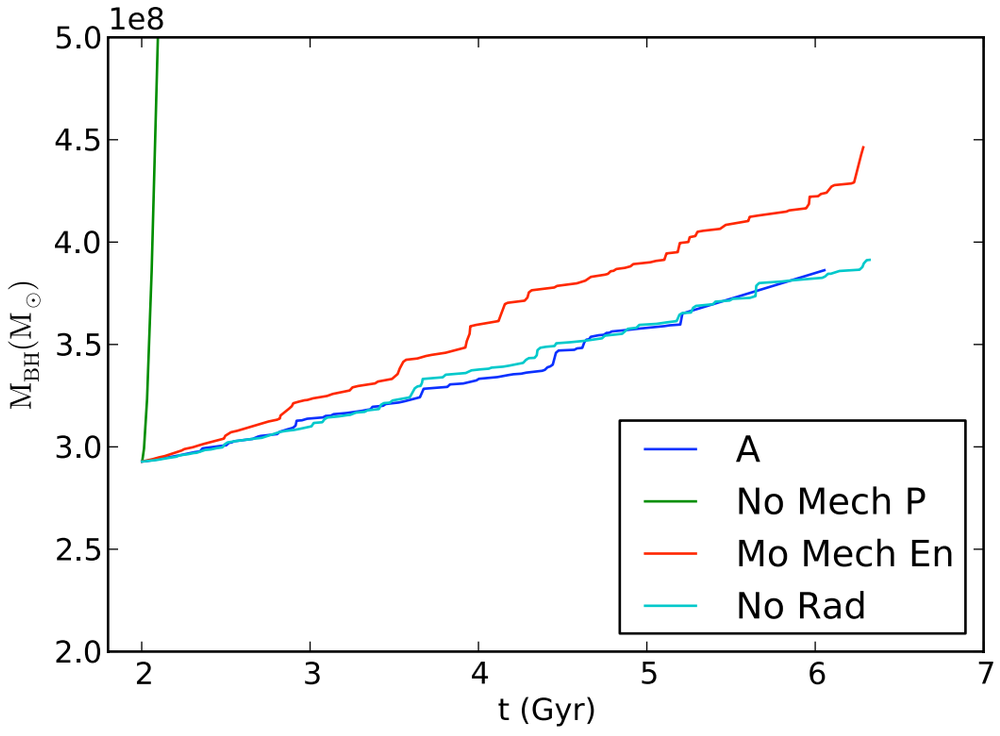
Very Disturbing!!!



Ostriker et al. 2010