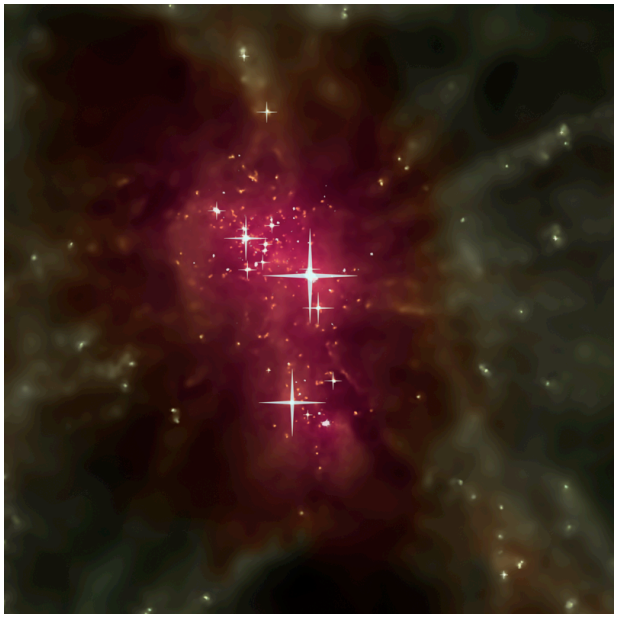
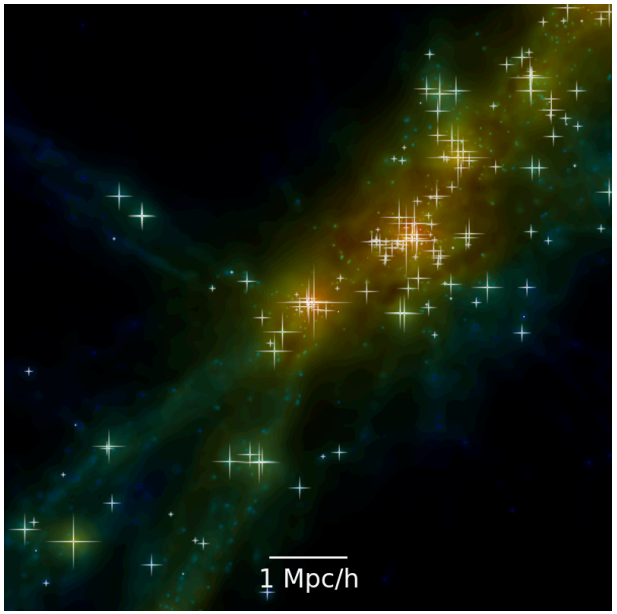
Supermassive Black Hole Growth in Hydrodynamic Simulations



Colin DeGraf
Racah Institute of Physics
Hebrew University of Jerusalem



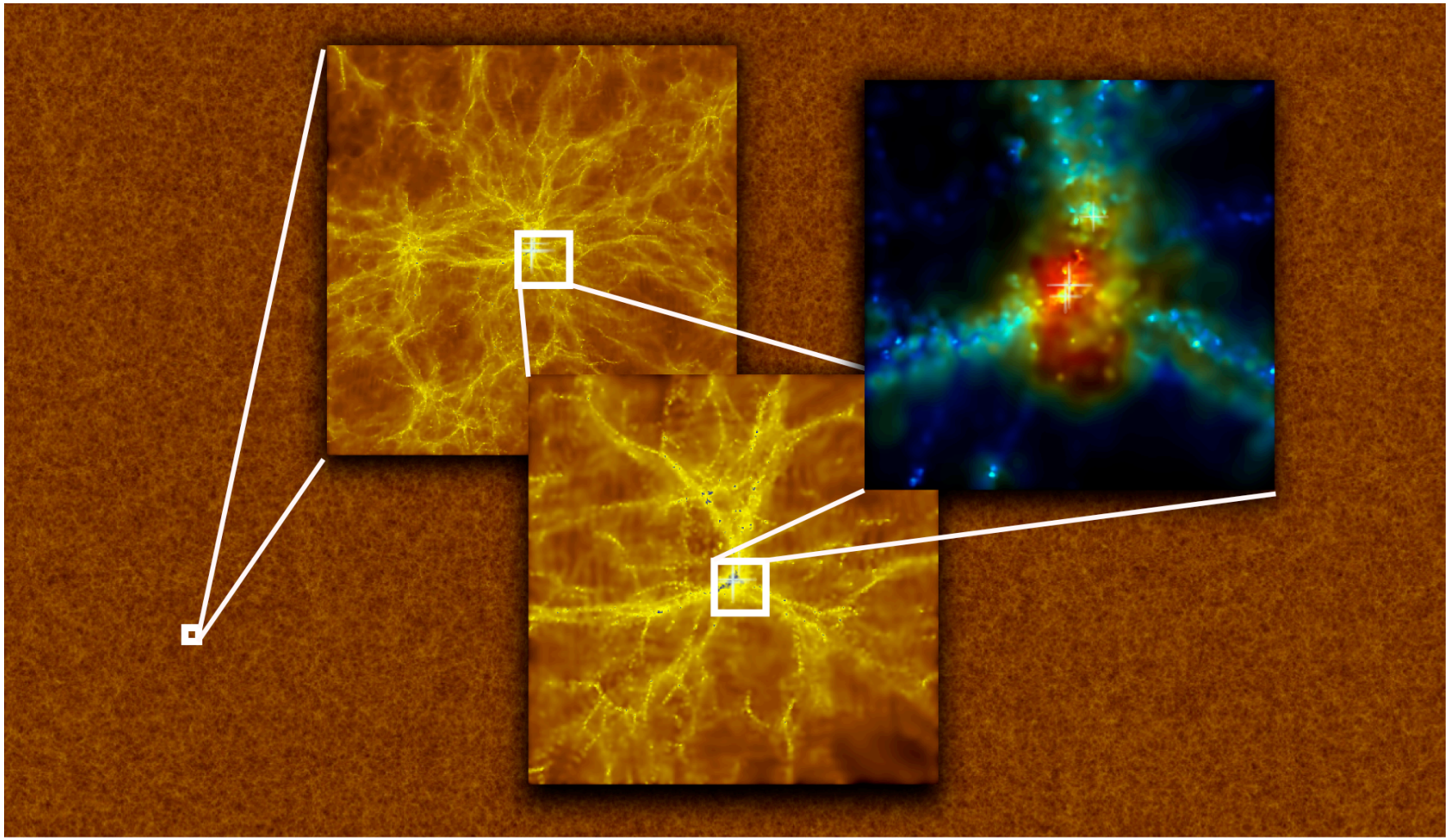
UCSC Galaxy Workshop/
AGORA Workshop
August 16, 2013

Outline

- Numerical Implementation
- Quasar Populations
- Black Hole Growth
- Scaling Relations

Collaborators: T. Di Matteo, N. Khandai,
Y. Feng, R. Croft
A. Dekel, J. Gabor, F. Bournaud

Simulation



(Image by Y. Feng)

Simulation - *MassiveBlack*

- Code: PetaGADGET
  - SPH, cooling, SF, feedback, BHs
- Particle Number: $2*3200^3$ ~ 64 billion
- Box Size: 533 h^{-1} Mpc
- Resolution:
  - 5 h^{-1} kpc
  - $m_{dm} = 2.8*10^8\ M_\odot$, $m_{gas} = 5.6*10^7\ M_\odot$
- Run on ~ 100K compute cores on Kraken at NICS

Simulation team: N. Khandai, T. Di Matteo, C. DeGraf, Y. Feng, R. Croft, V. Springel

Simulation - BH implementation

- FoF-based seeding: $5*10^5$ $M_\odot$ BH seeded into $5*10^{10}$ $M_\odot$ halo

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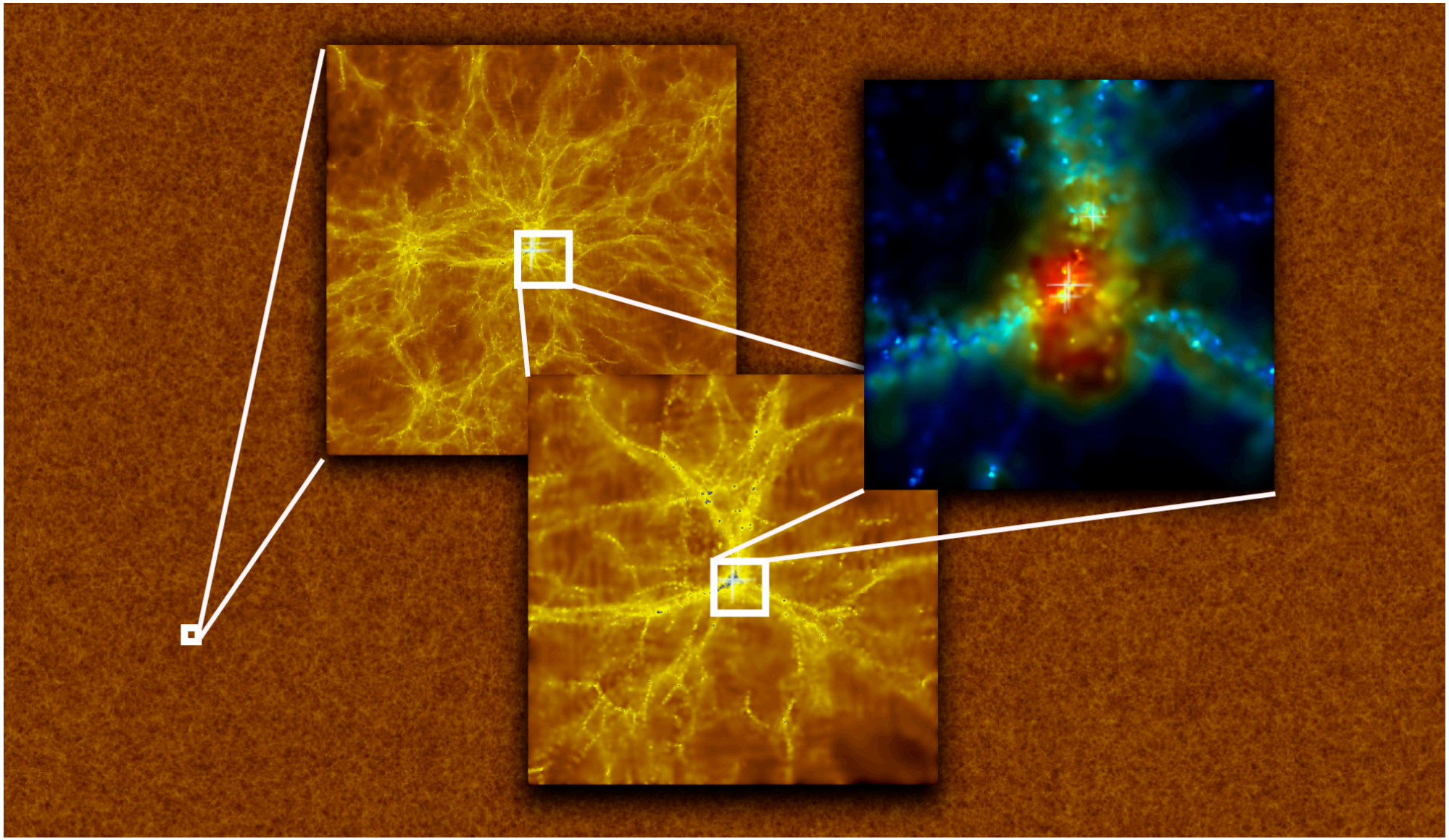
- BH feedback via thermal coupling:
  - $E_{feedback} = f(\eta Mc^2)$
    - f=5%, η=10%



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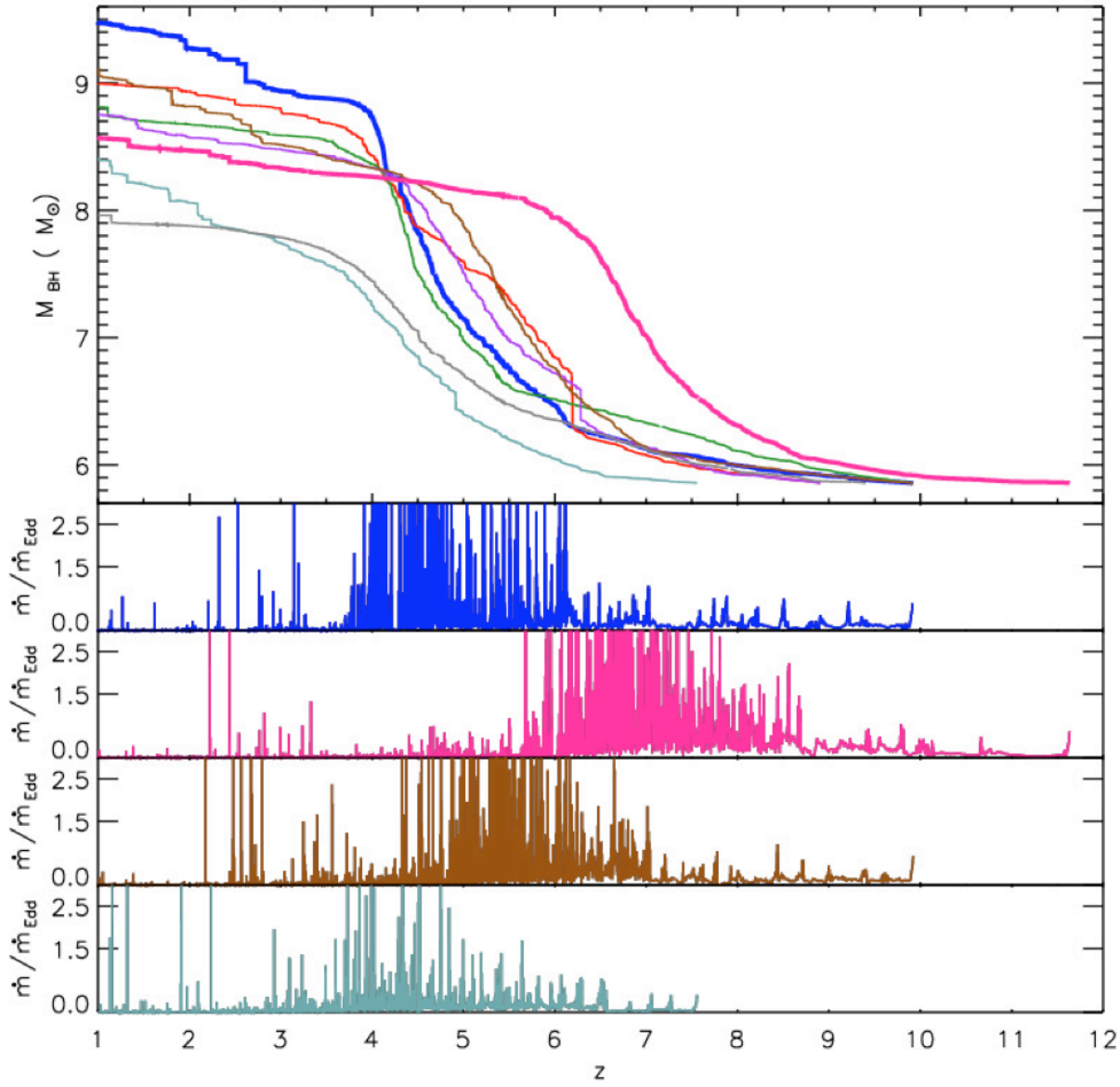
Sample accretion histories



(Di Matteo+ 2008)

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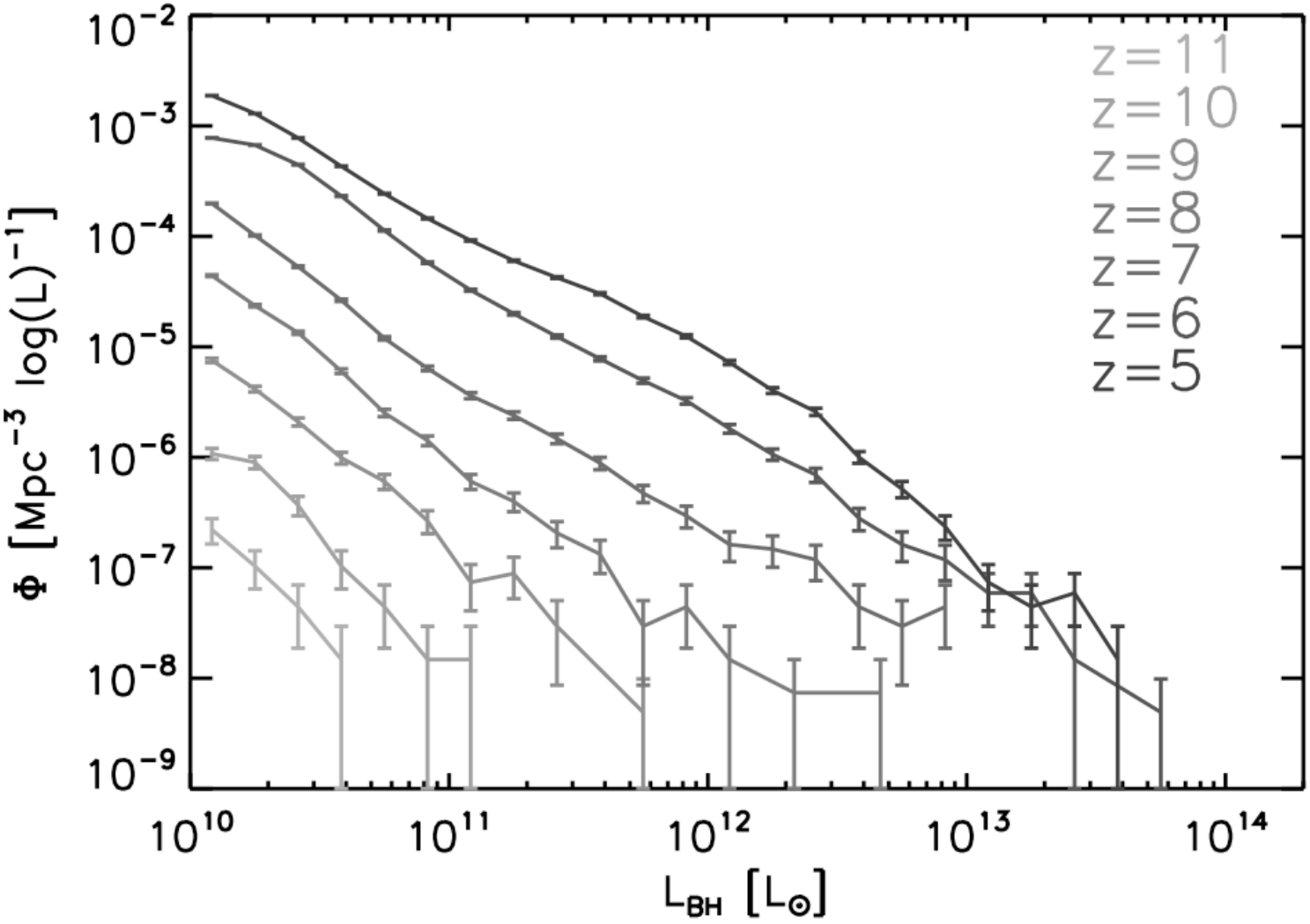
Quasar Luminosity Function



(DeGraf+ 2012)

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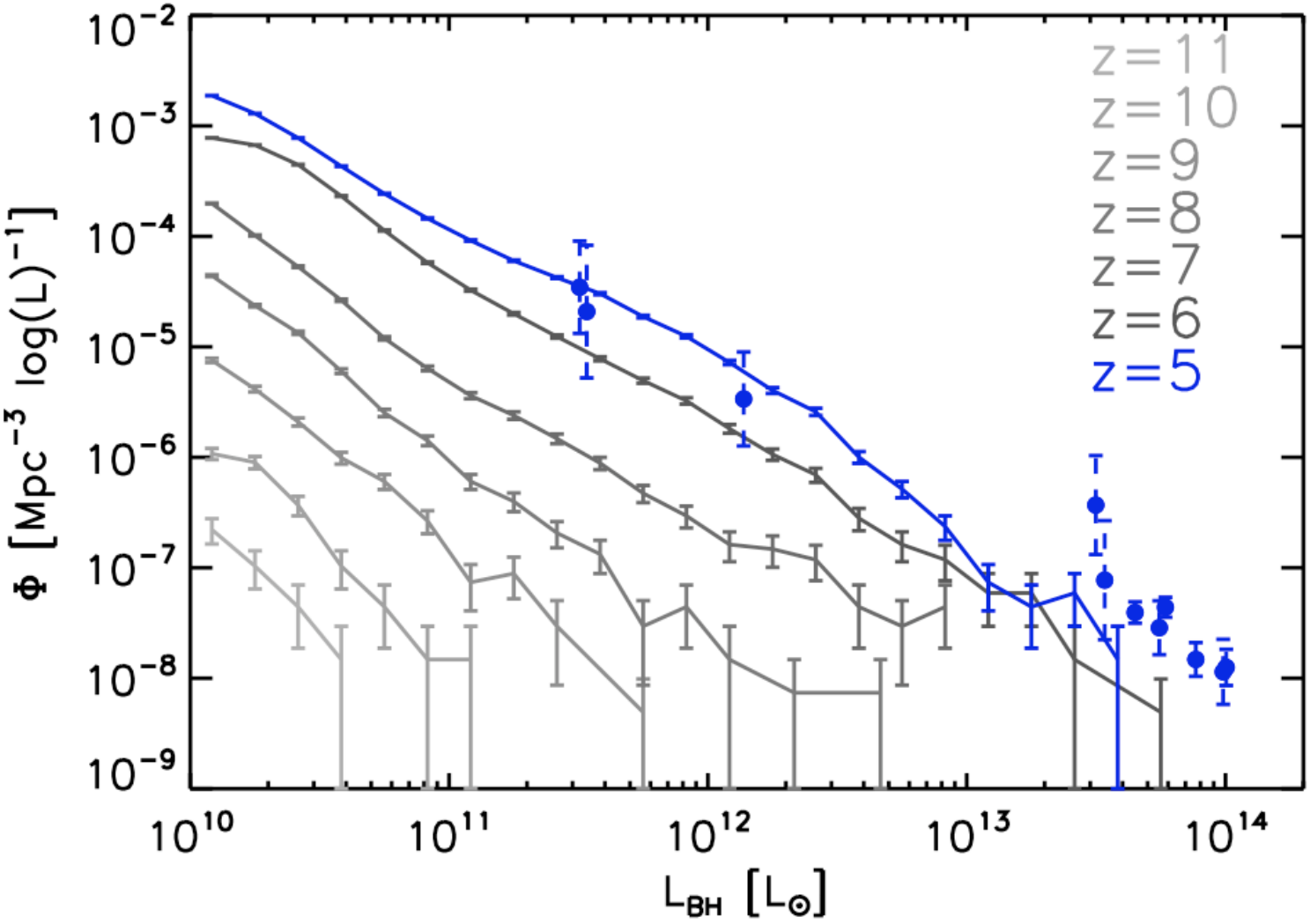

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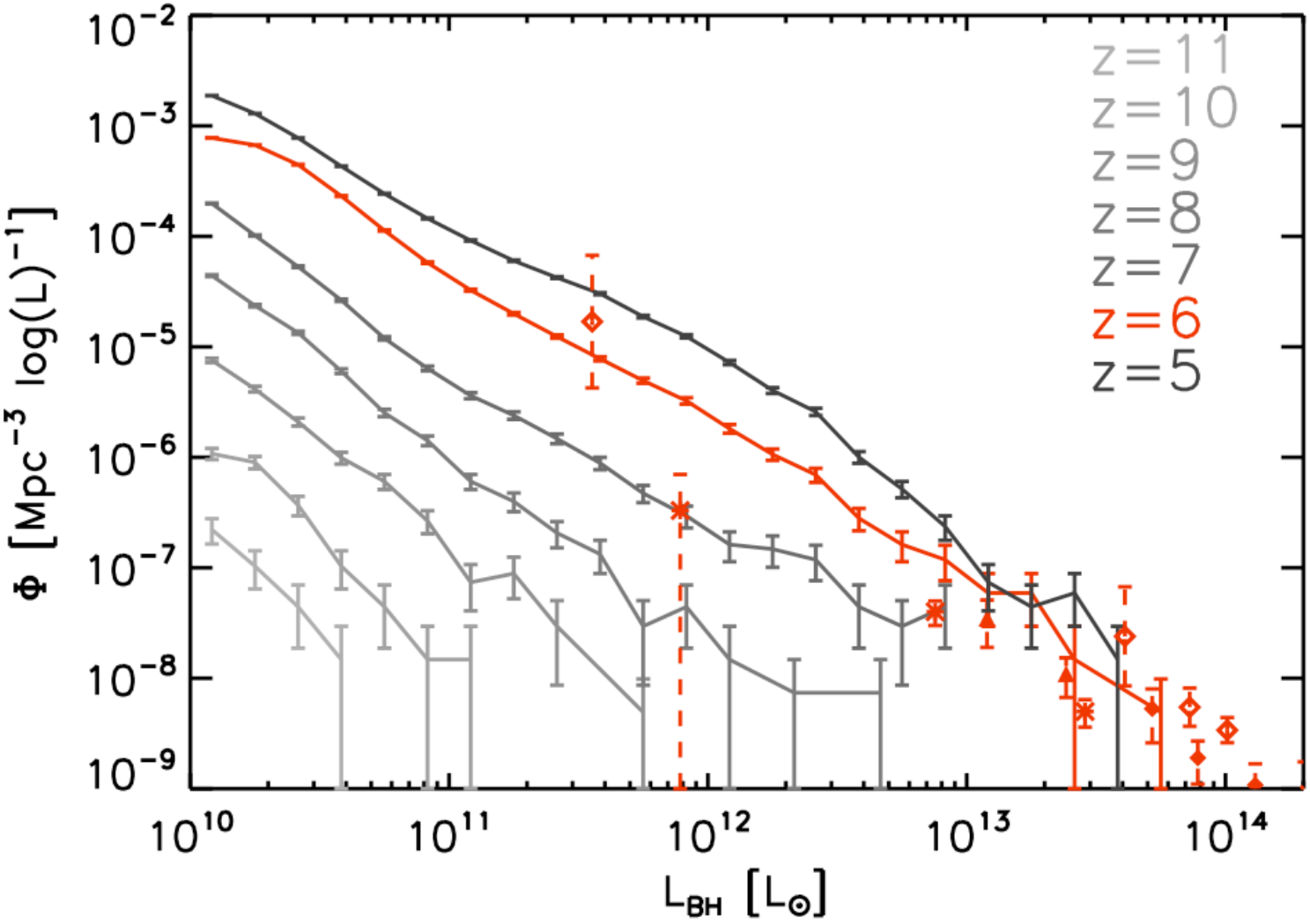

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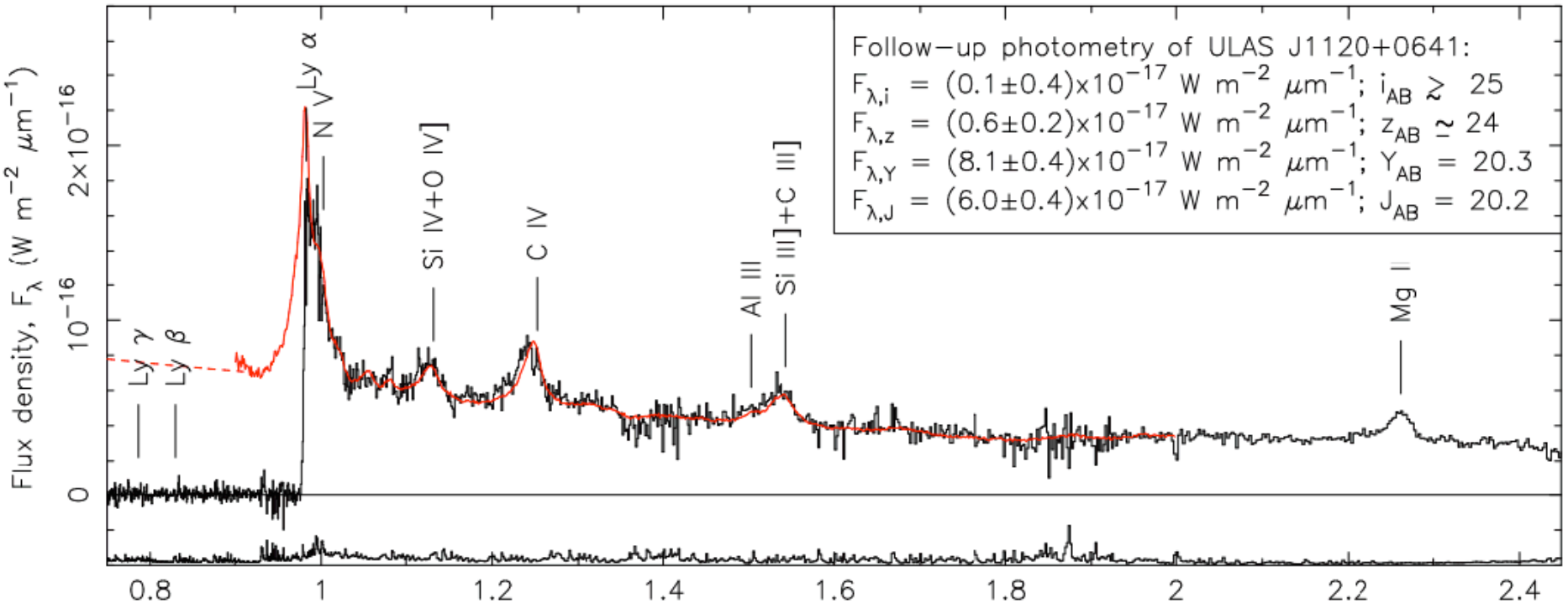
How do BHs get so large?

- Observations find BHs at 10^9 M_{sun} by z~7



Mortlock+ 2011

M_{BH} ~ 2*10^9 M_{sun} at z=7.085

How do BHs get so large?

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  - Even with exponential growth, this is challenging to explain

$$M_{BH} = M_{seed} e^{t/t_{edd}}$$

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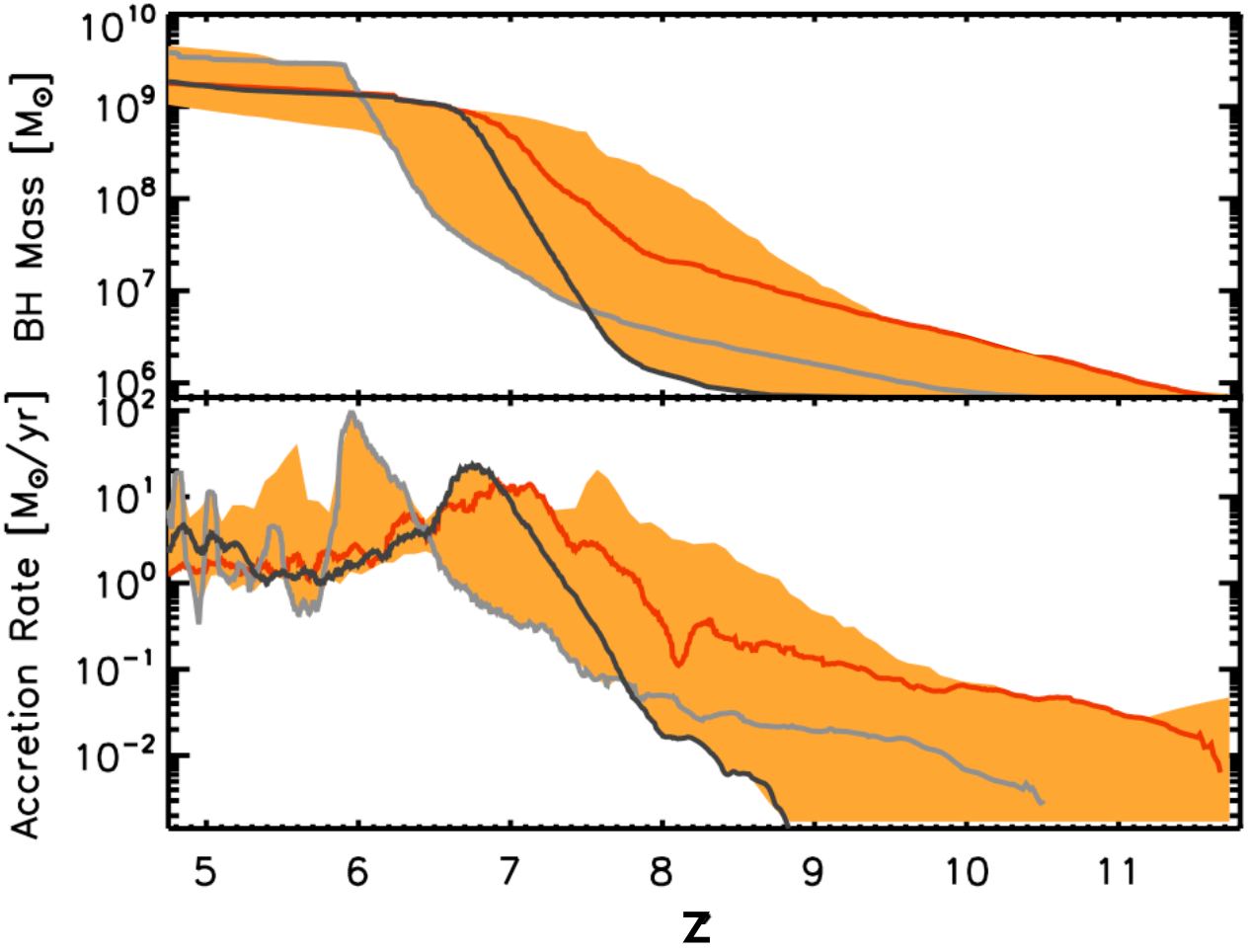
$$t_{edd} \approx 50\ Myr$$

- M_{seed} = 100-10^5 M_{sun}

  → 10-16 e-foldings to 10^9 M_{sun}

  → 0.5-0.8 Gyr

Black Hole Growth



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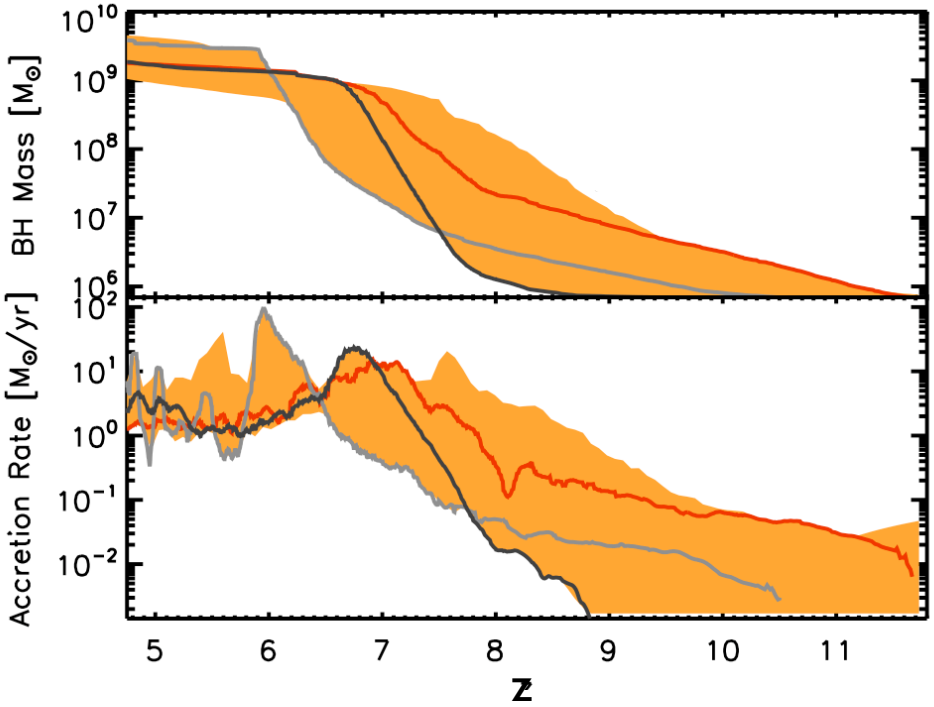

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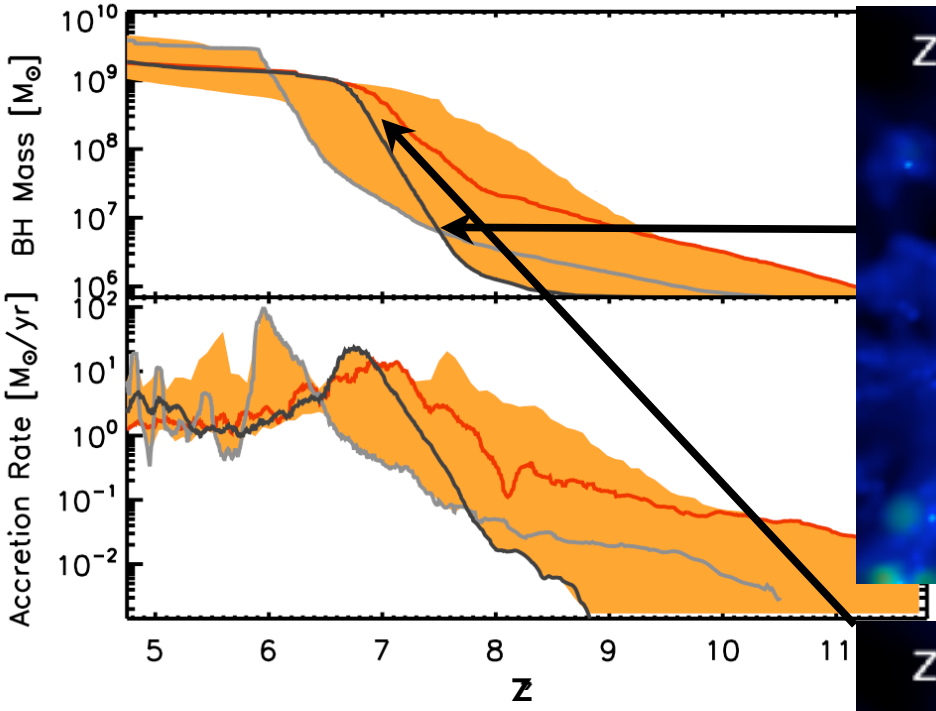

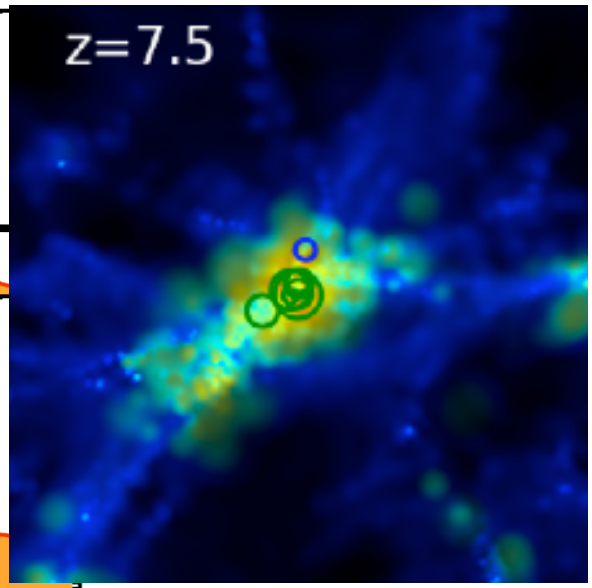

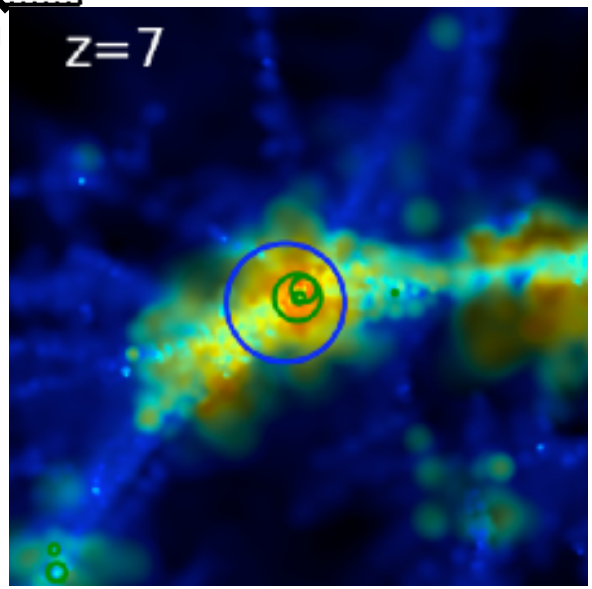

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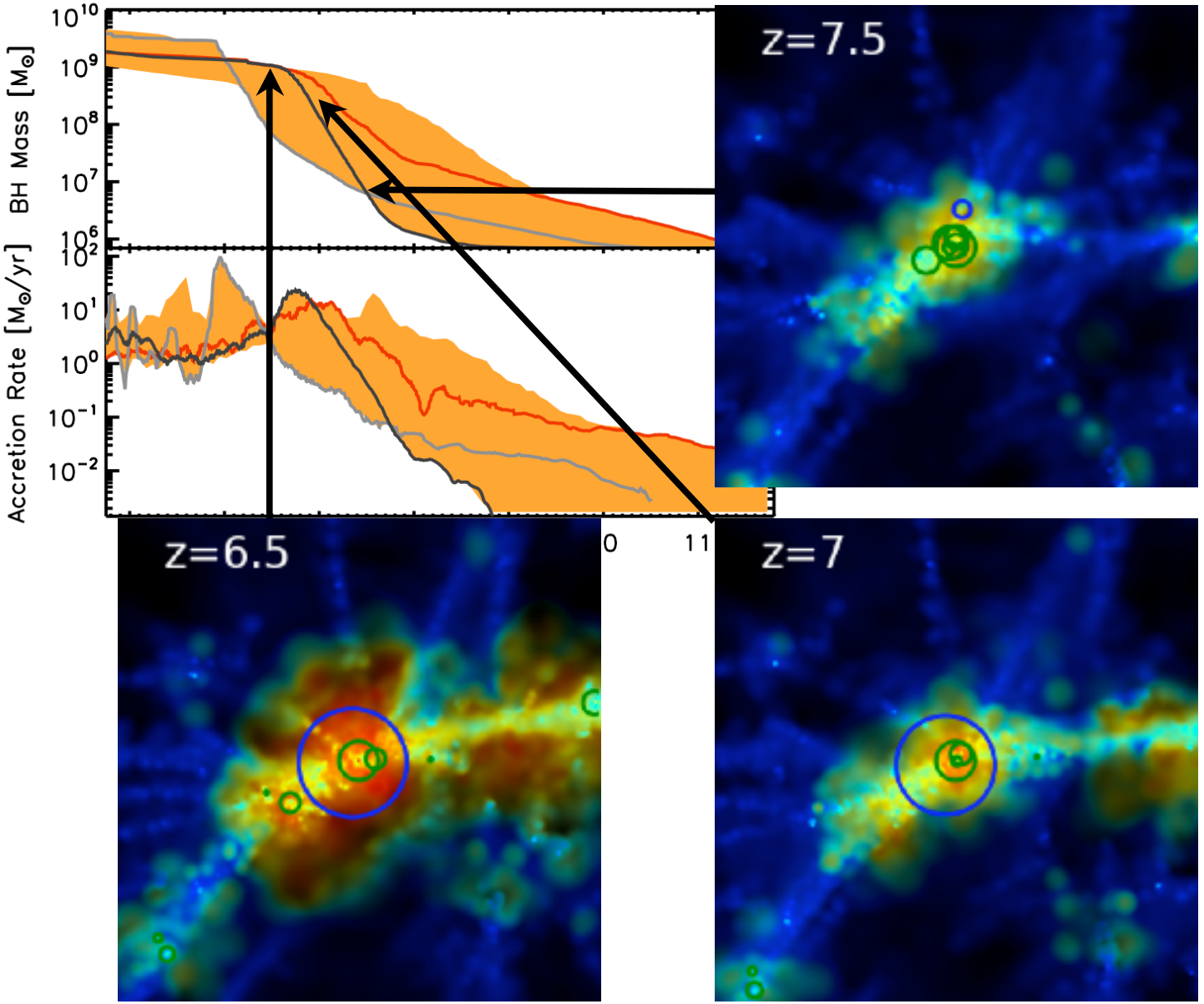

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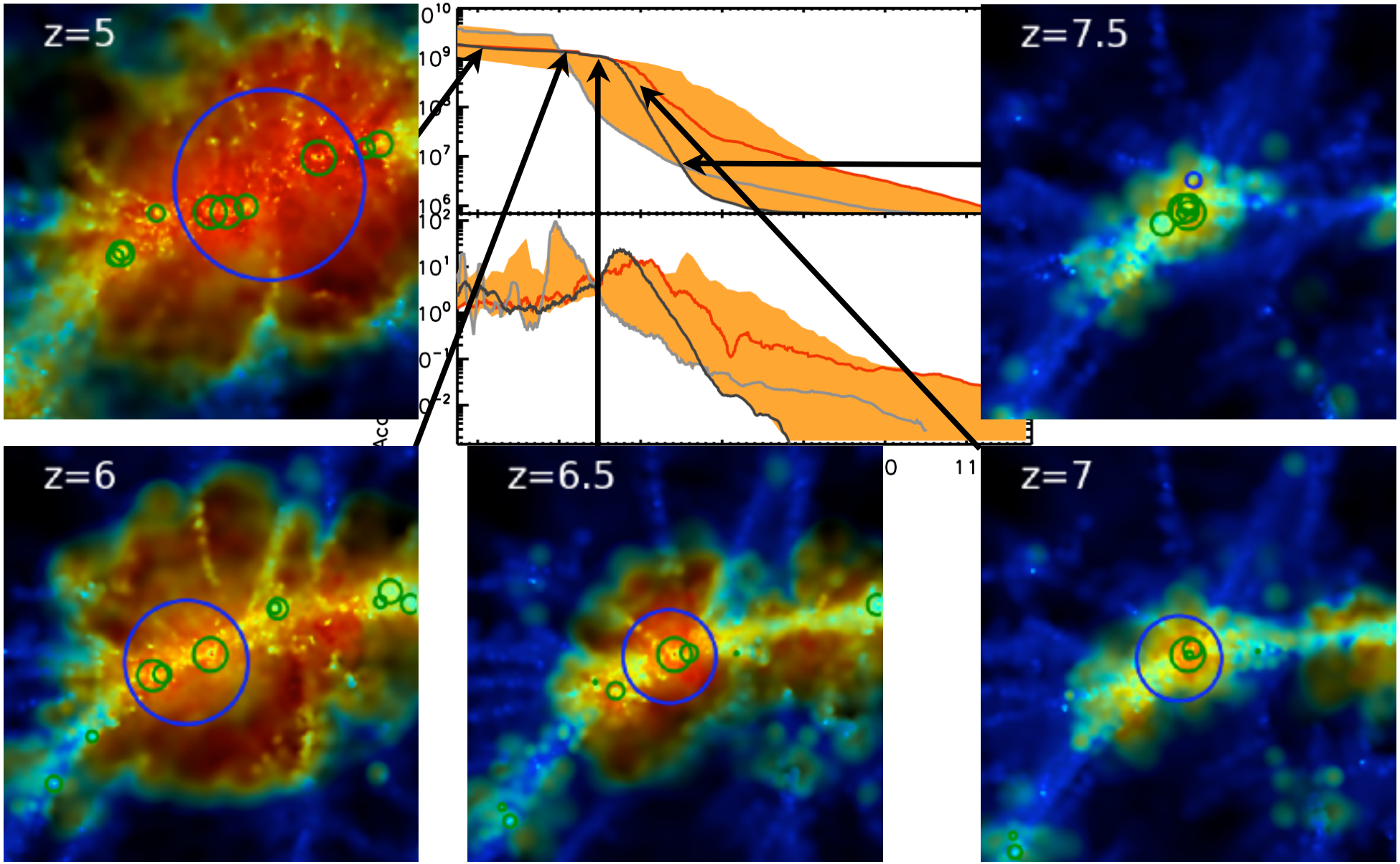
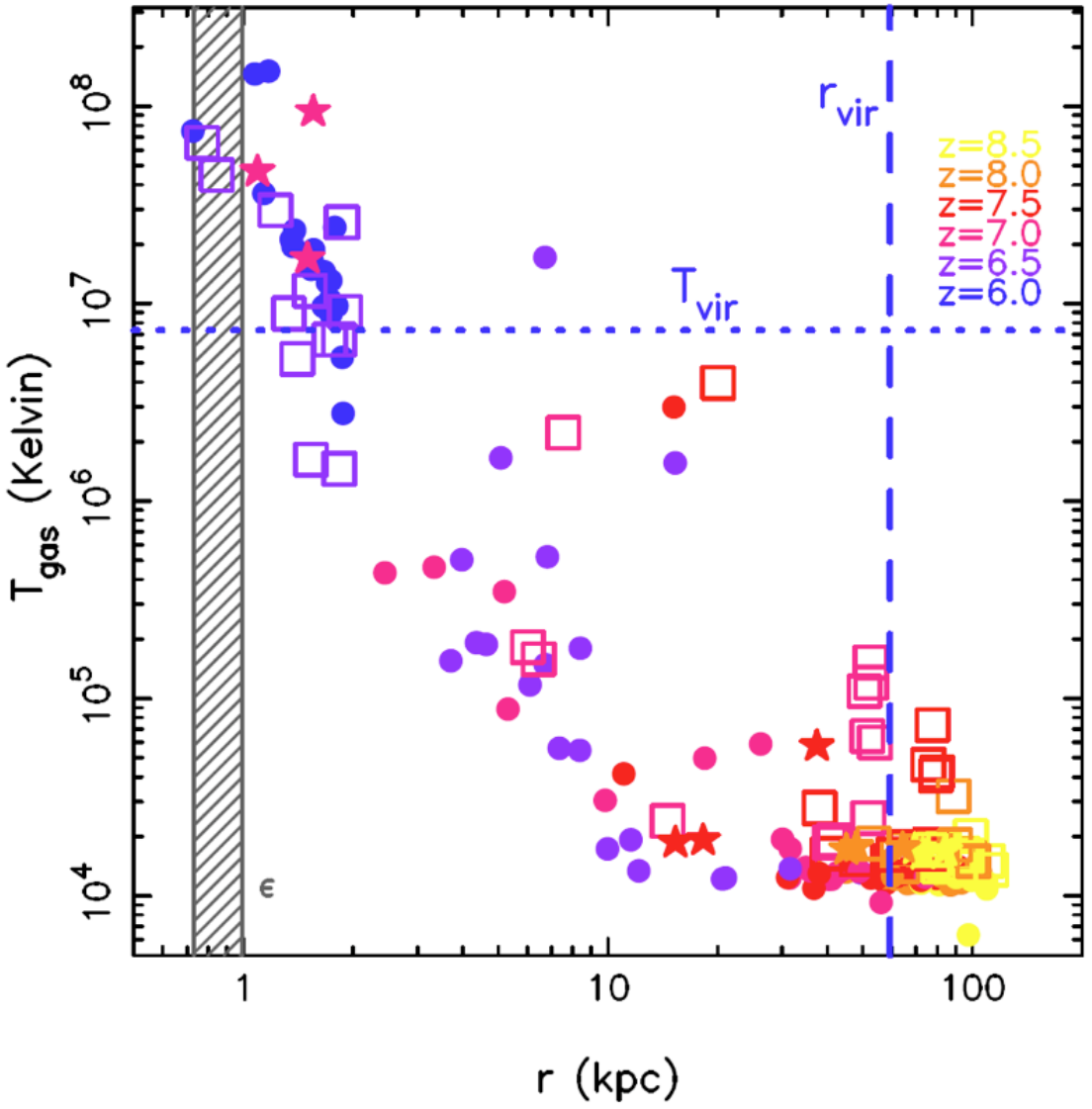


Black Hole Growth

- Temperature history of accreting gas particles
  - Fall in cold
  - Heated once within 10 kpc



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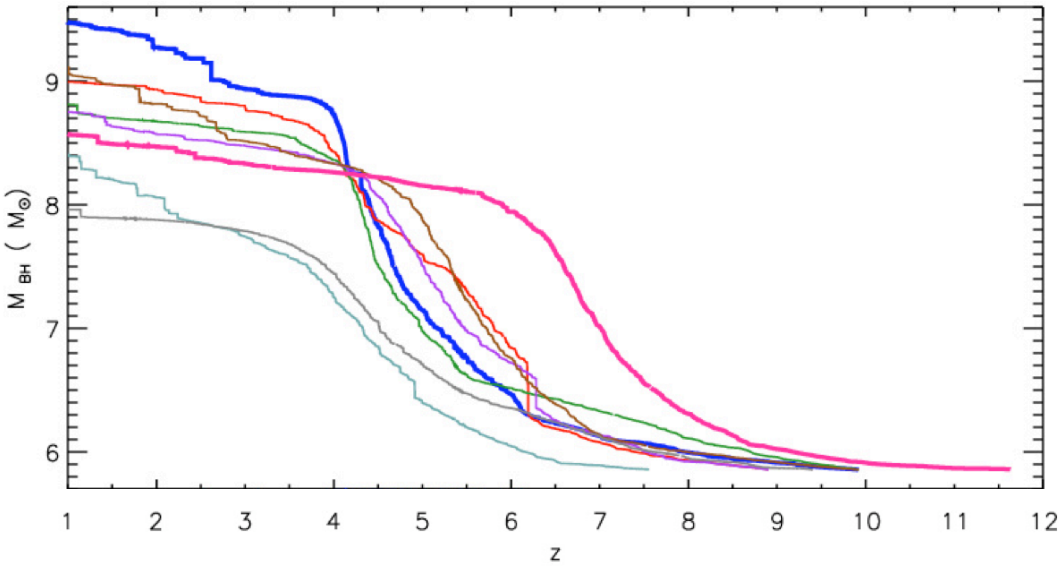

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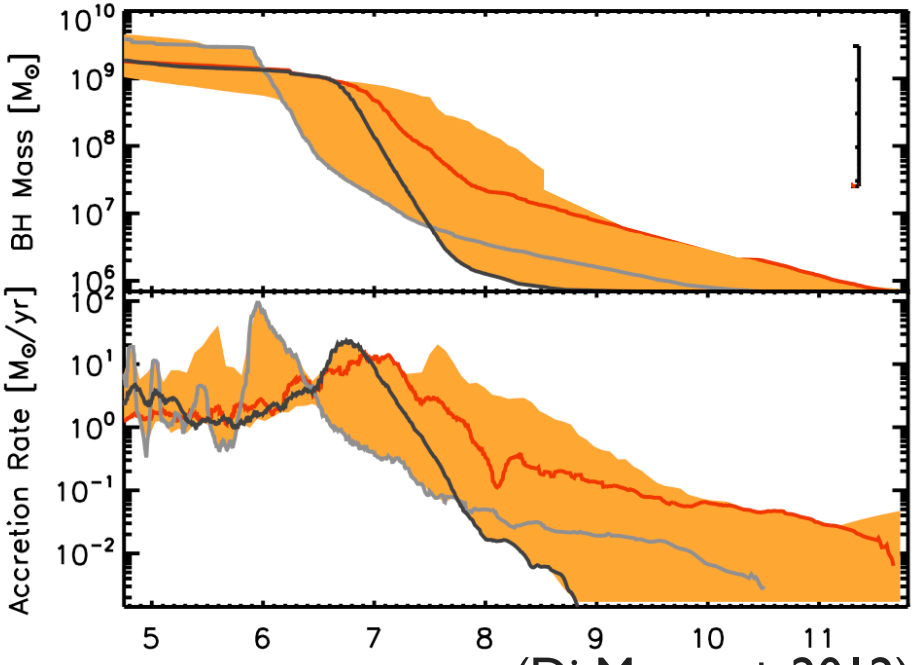

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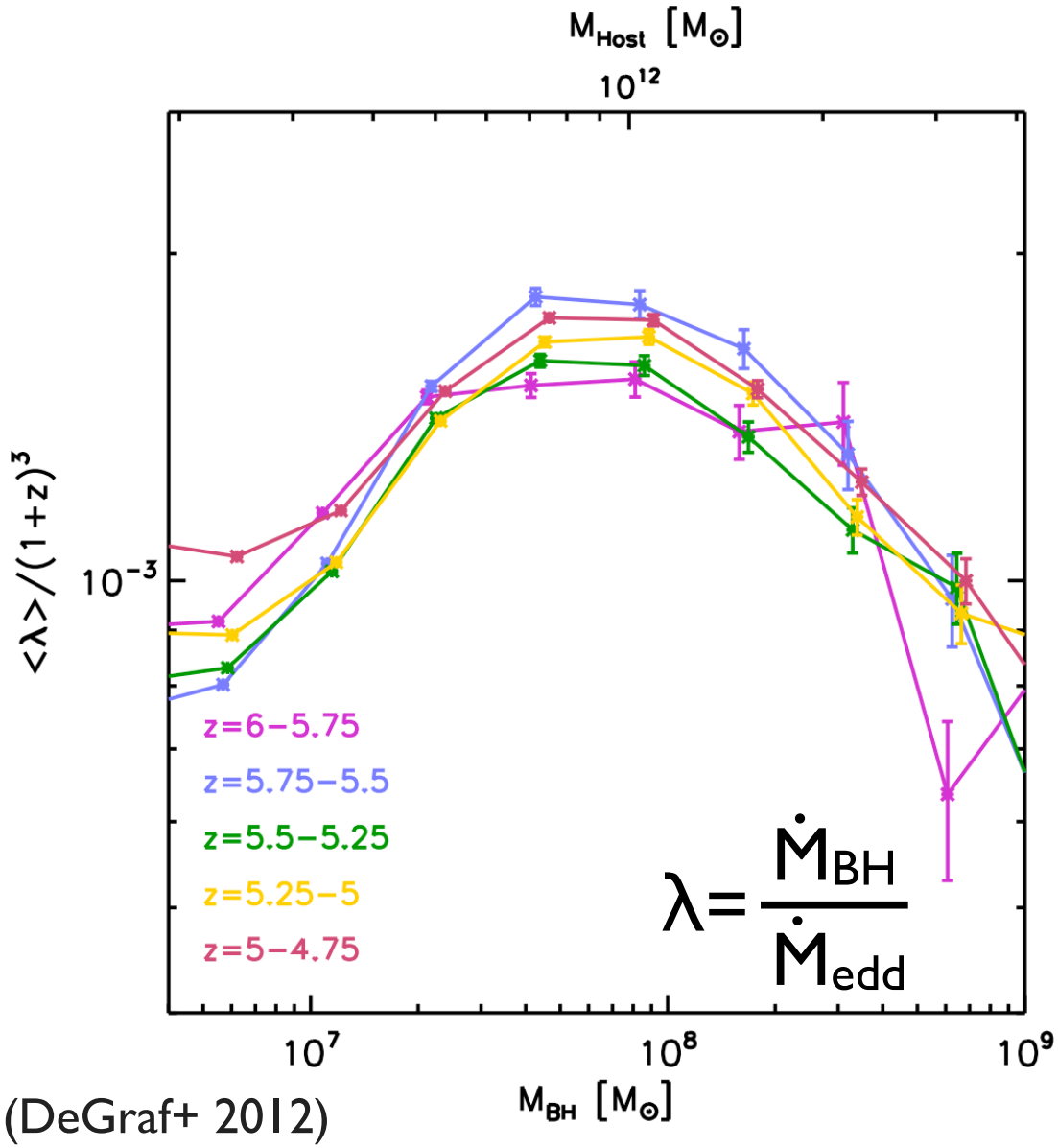
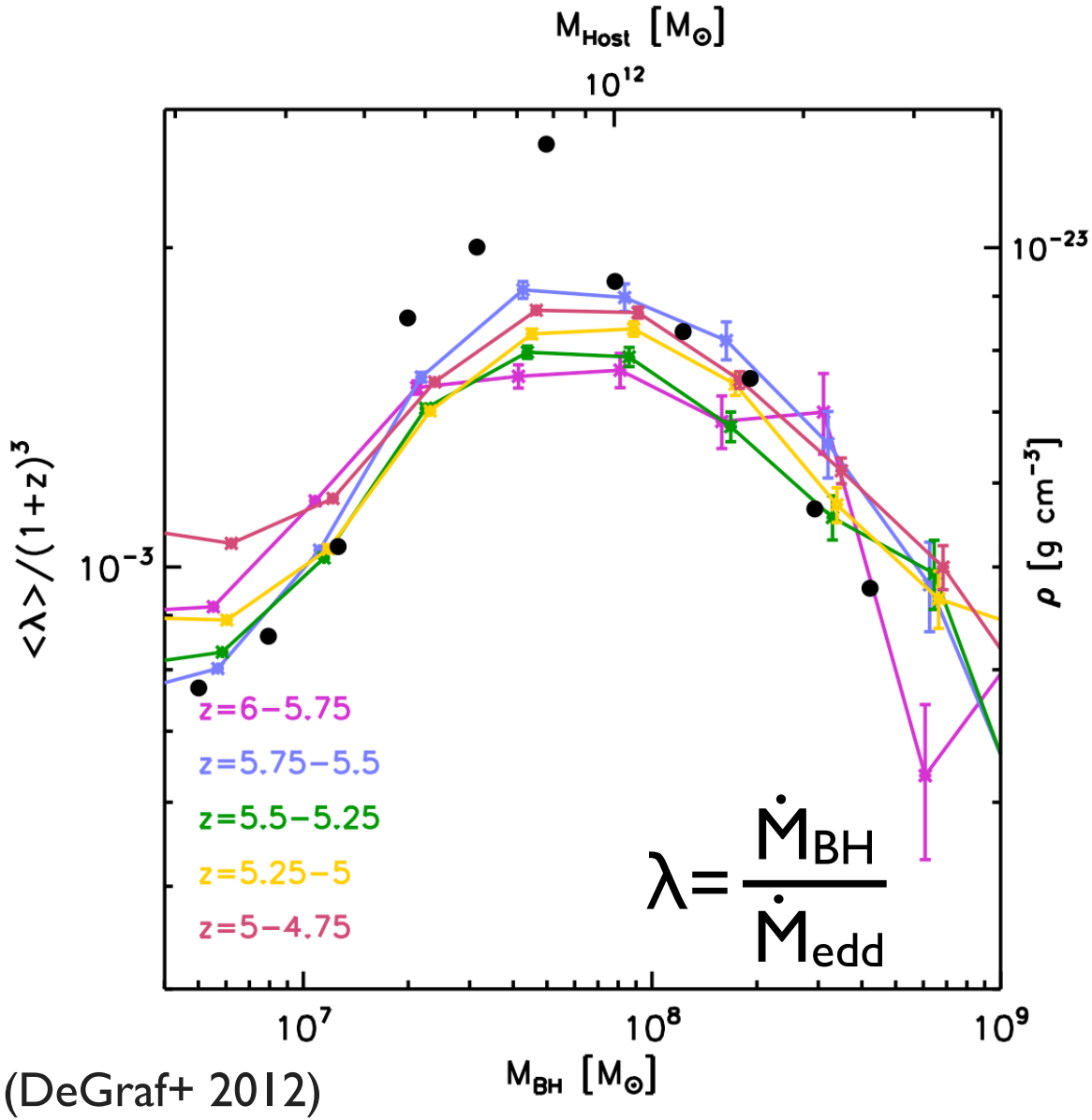


(DeGraf+ 2012)

- Clear peak in growth rate

Black Hole Growth



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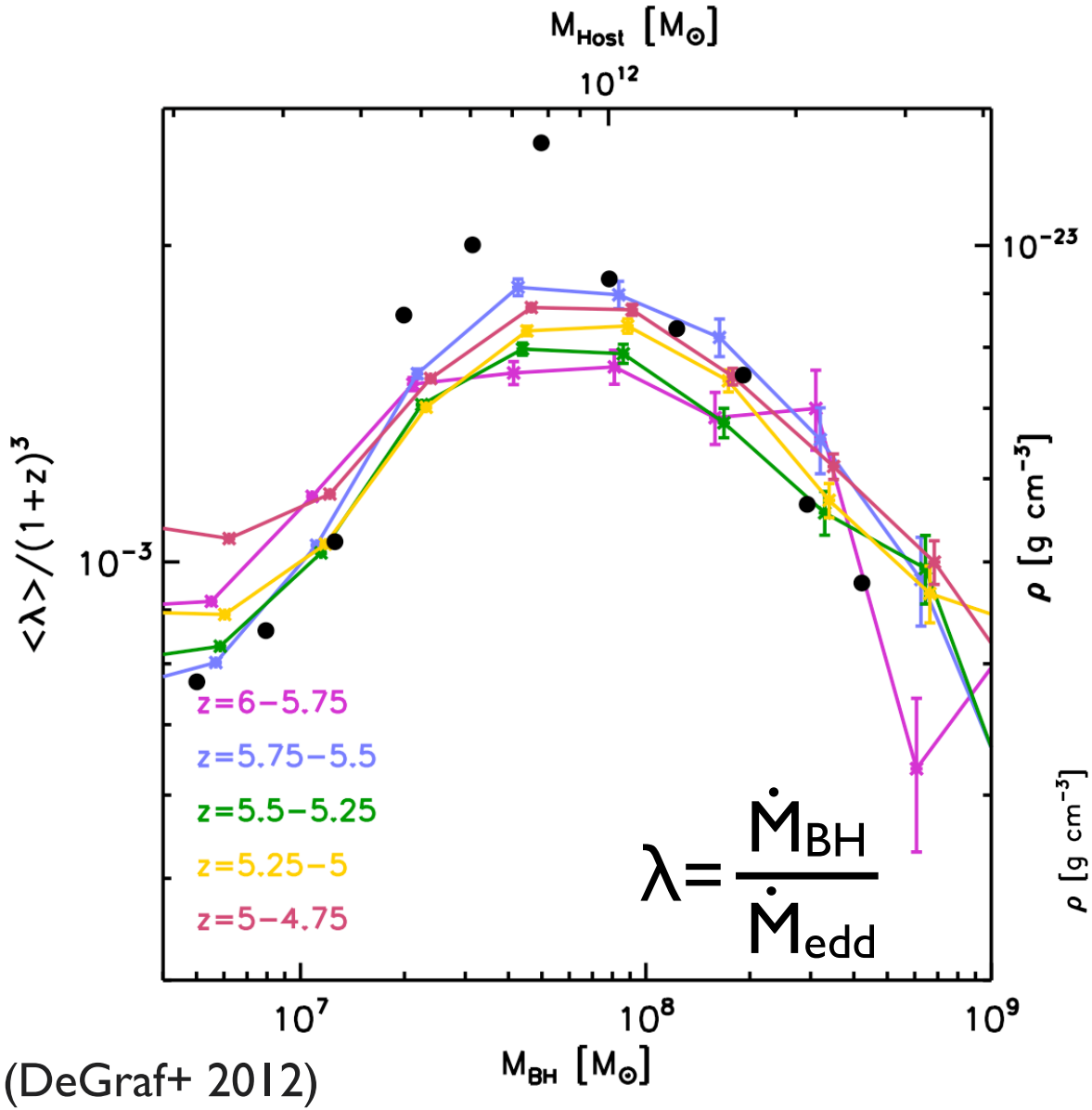

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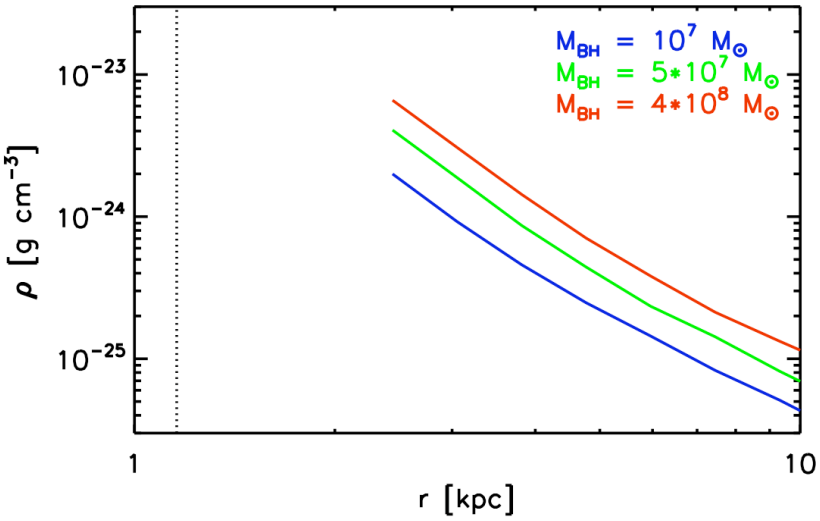

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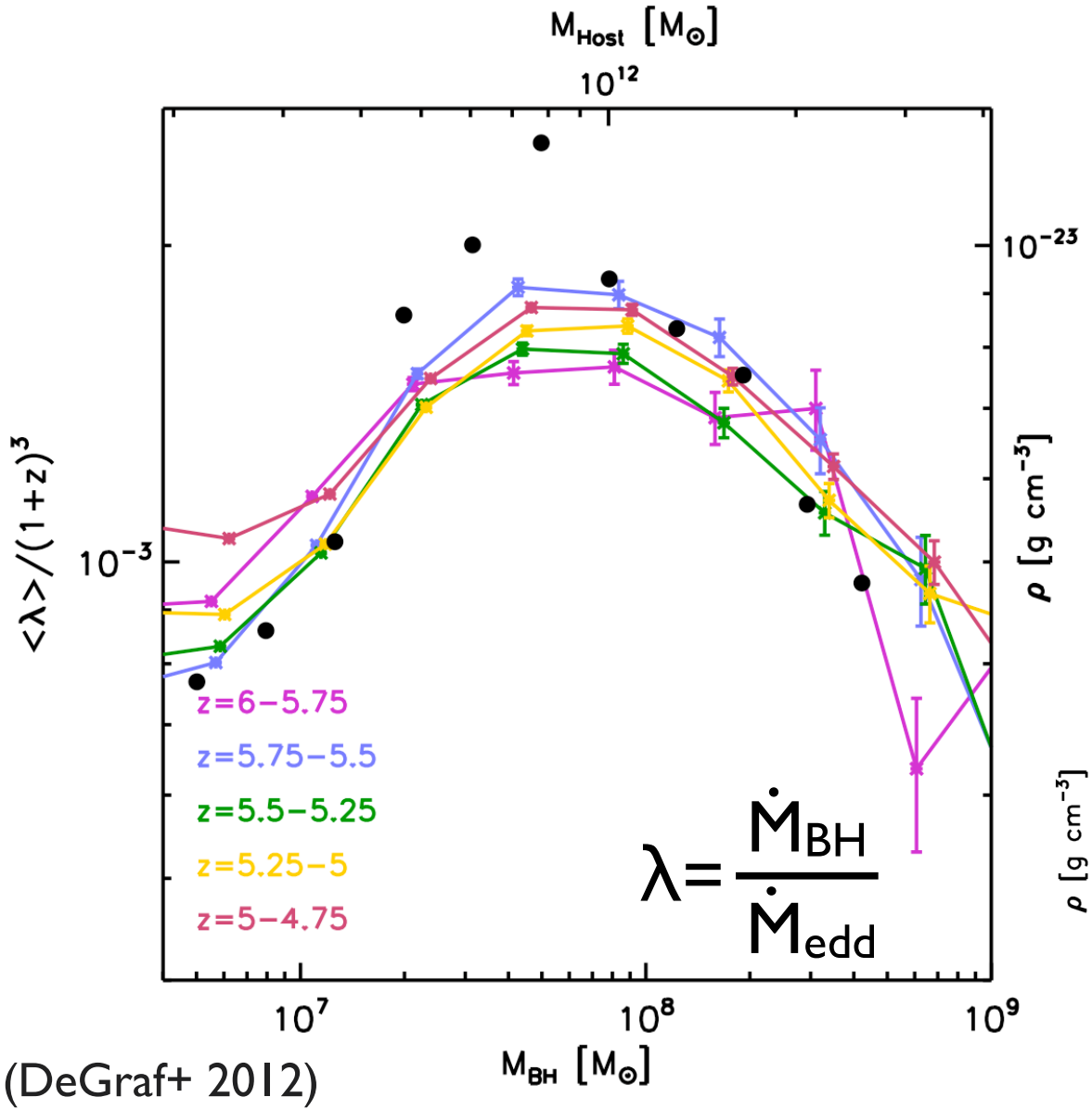

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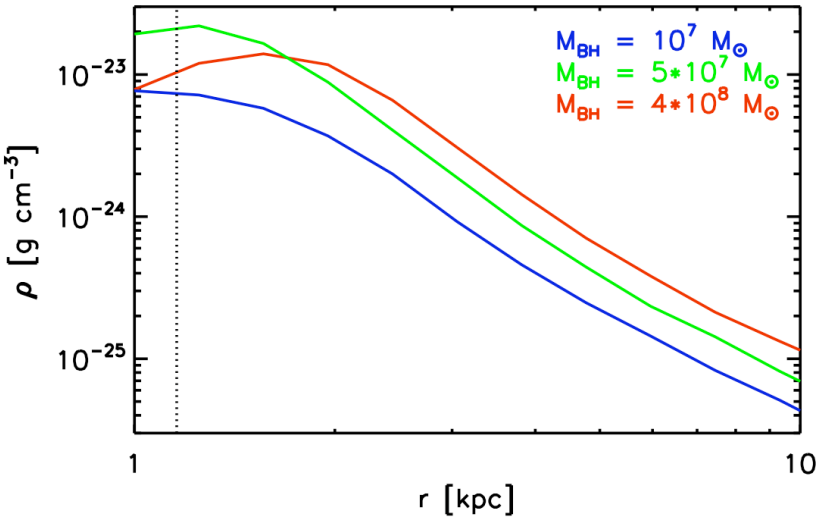

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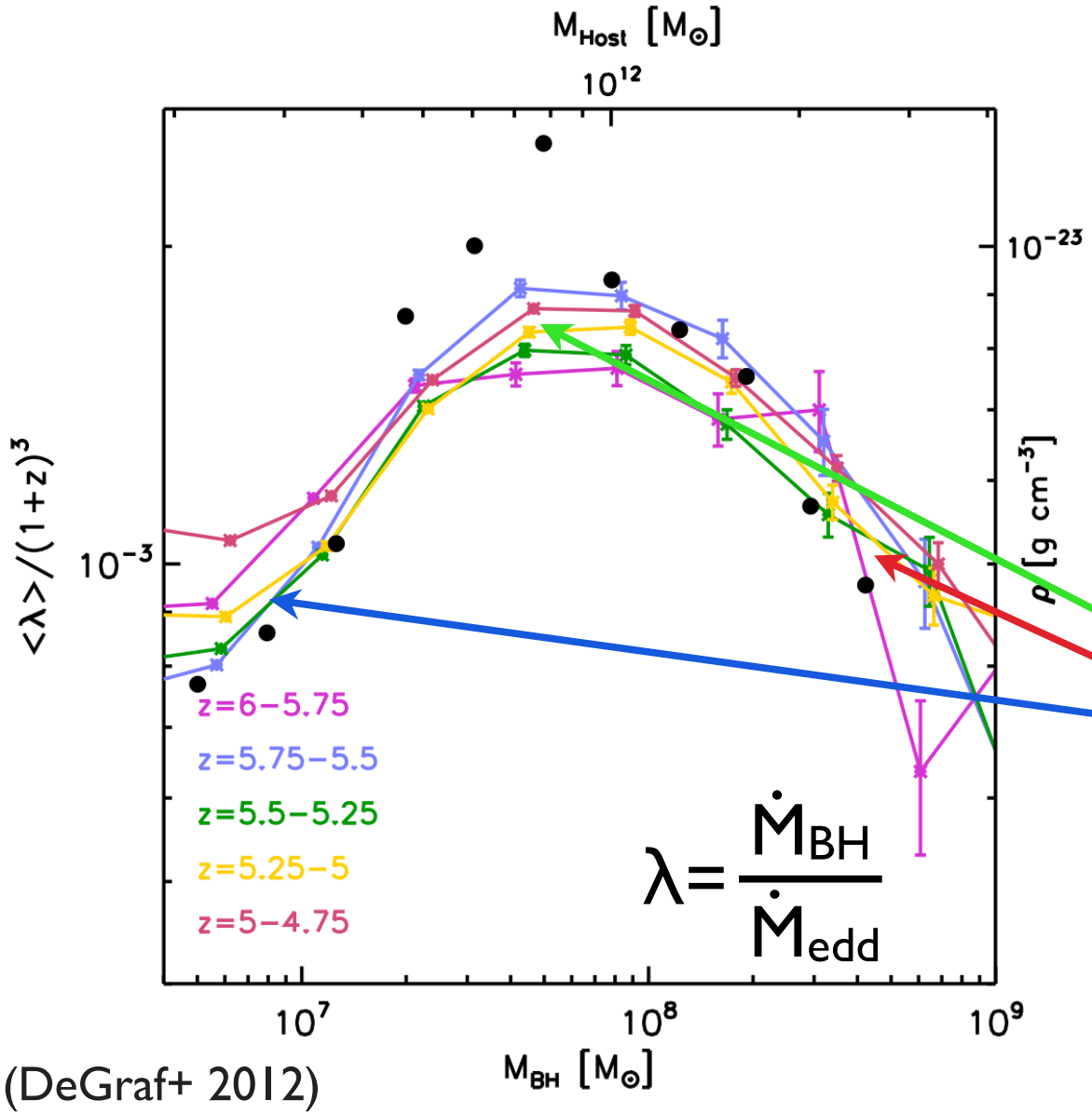

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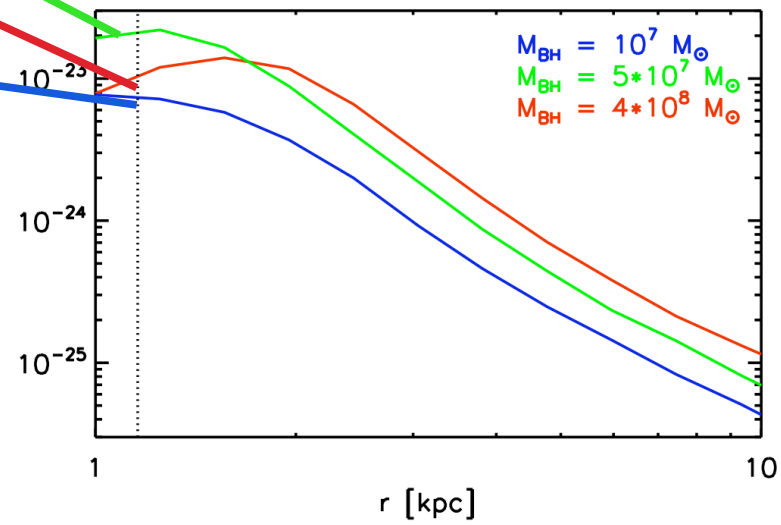

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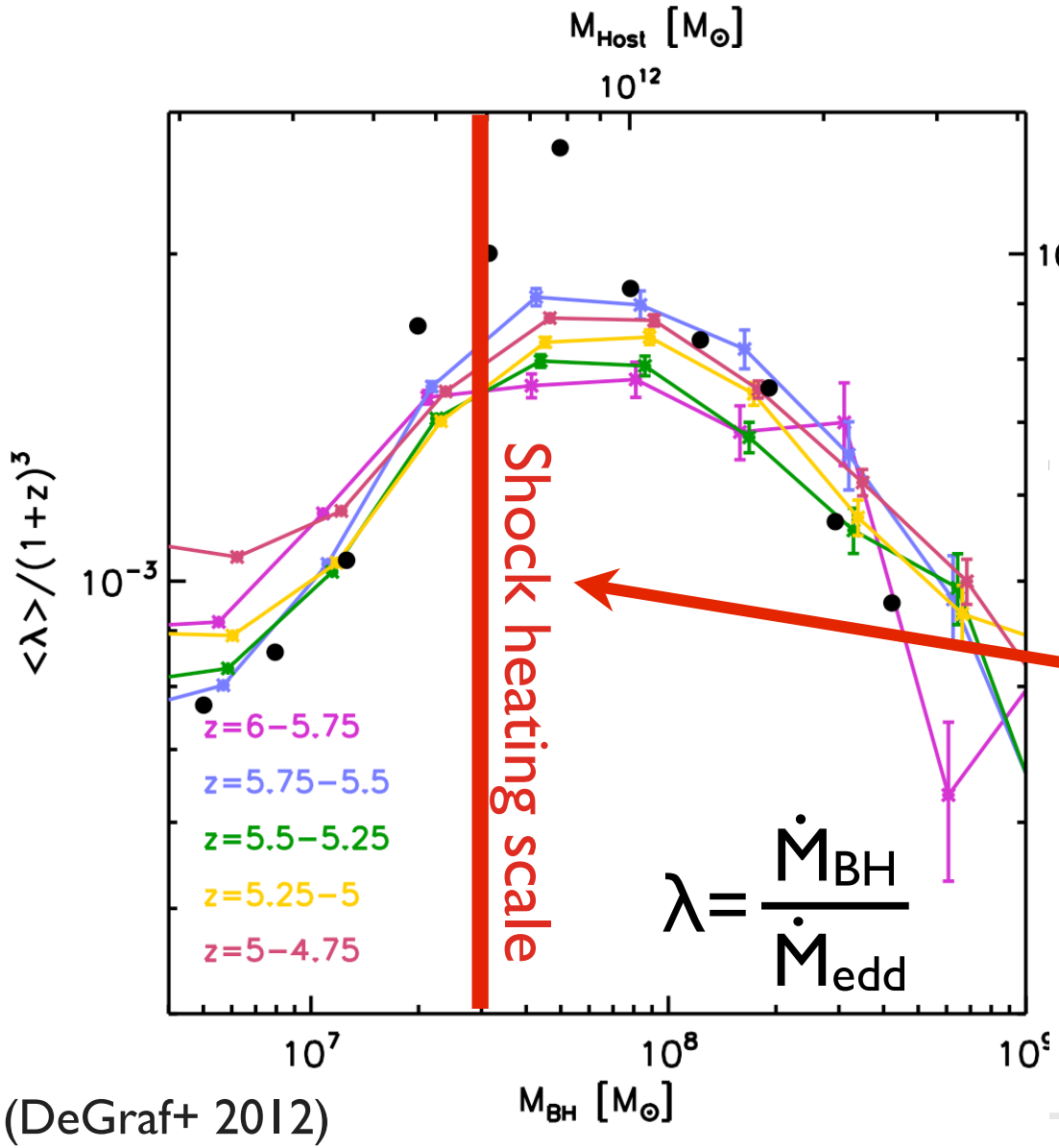

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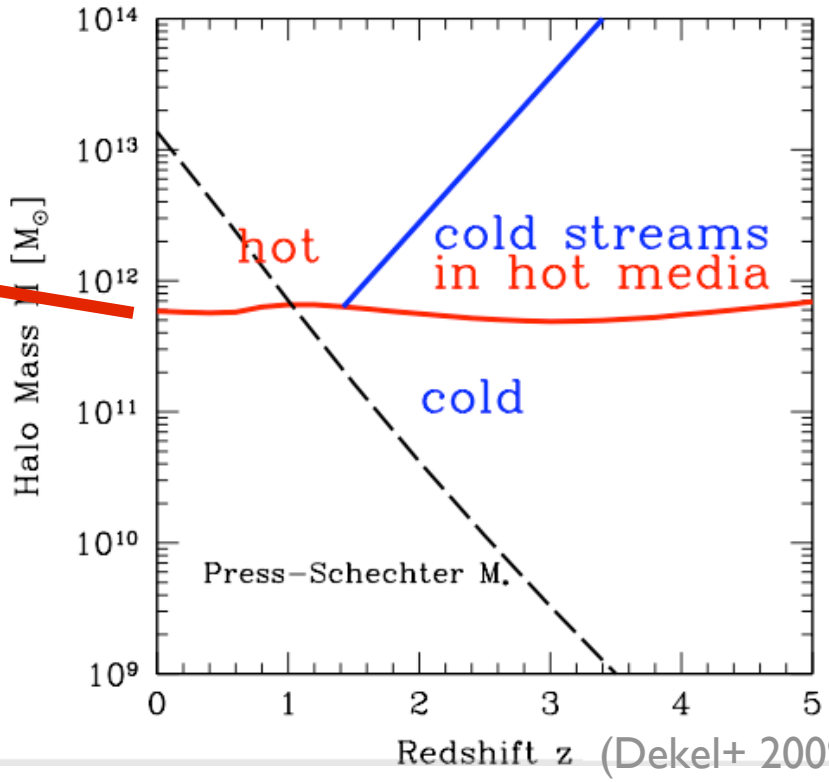
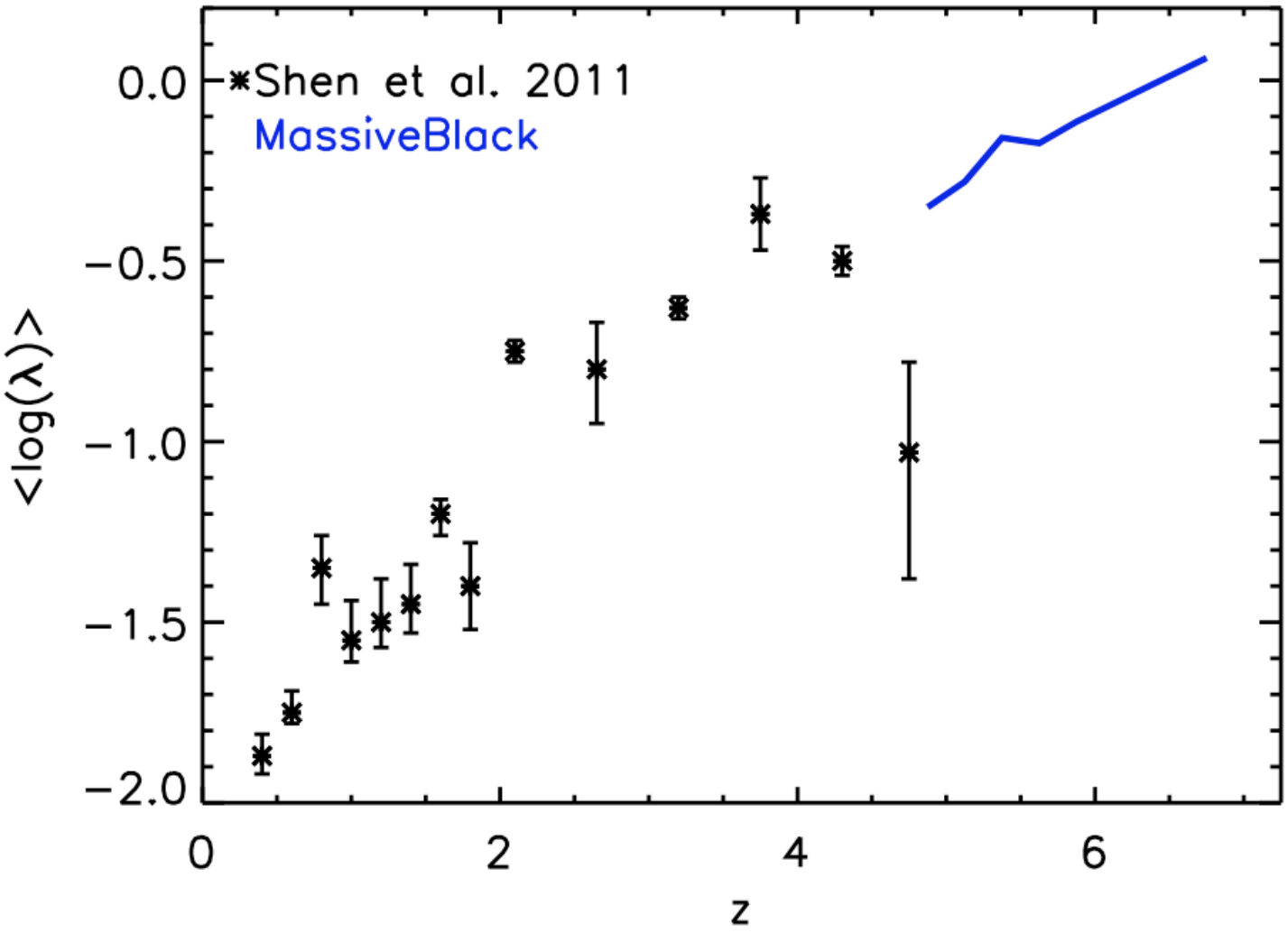


(Dekel+ 2009)

Evolution of Growth Rate



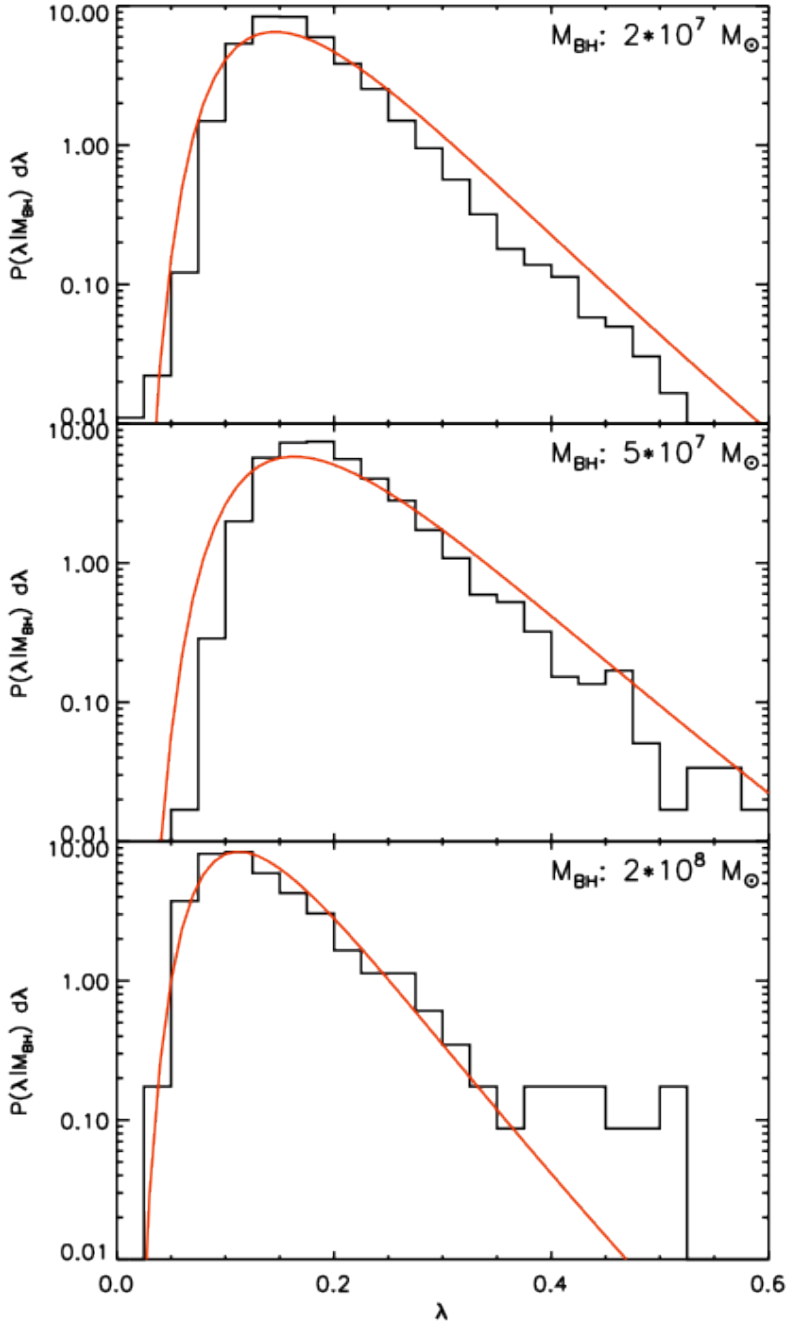
(DeGraf+ 2012)

Eddington Ratio Distribution

- Eddington ratio follows log-normal distribution
  - σ = 0.39

$$P(\lambda|M_{BH}, z) = \frac{1}{\lambda \sigma_m \sqrt{2\pi}} e^{\frac{-(\ln(\lambda)-\mu_m)^2}{2\sigma_m^2}}$$

(DeGraf+ 2012)



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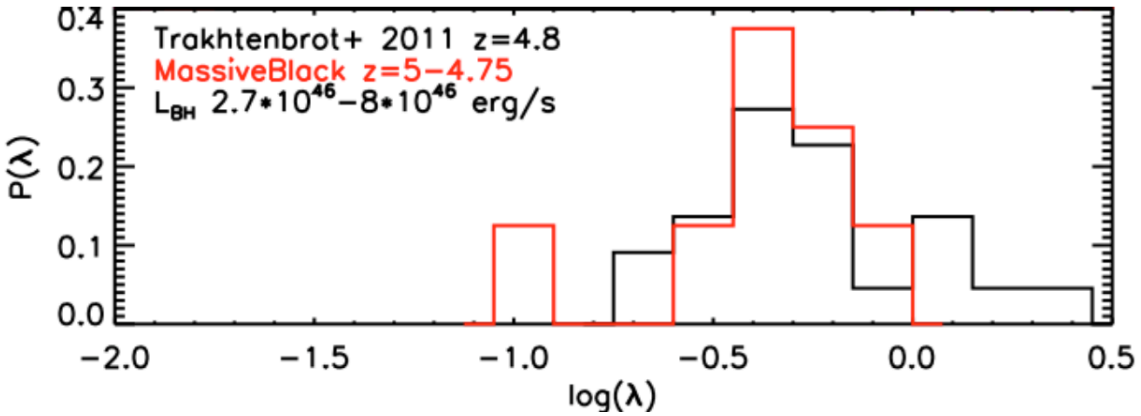

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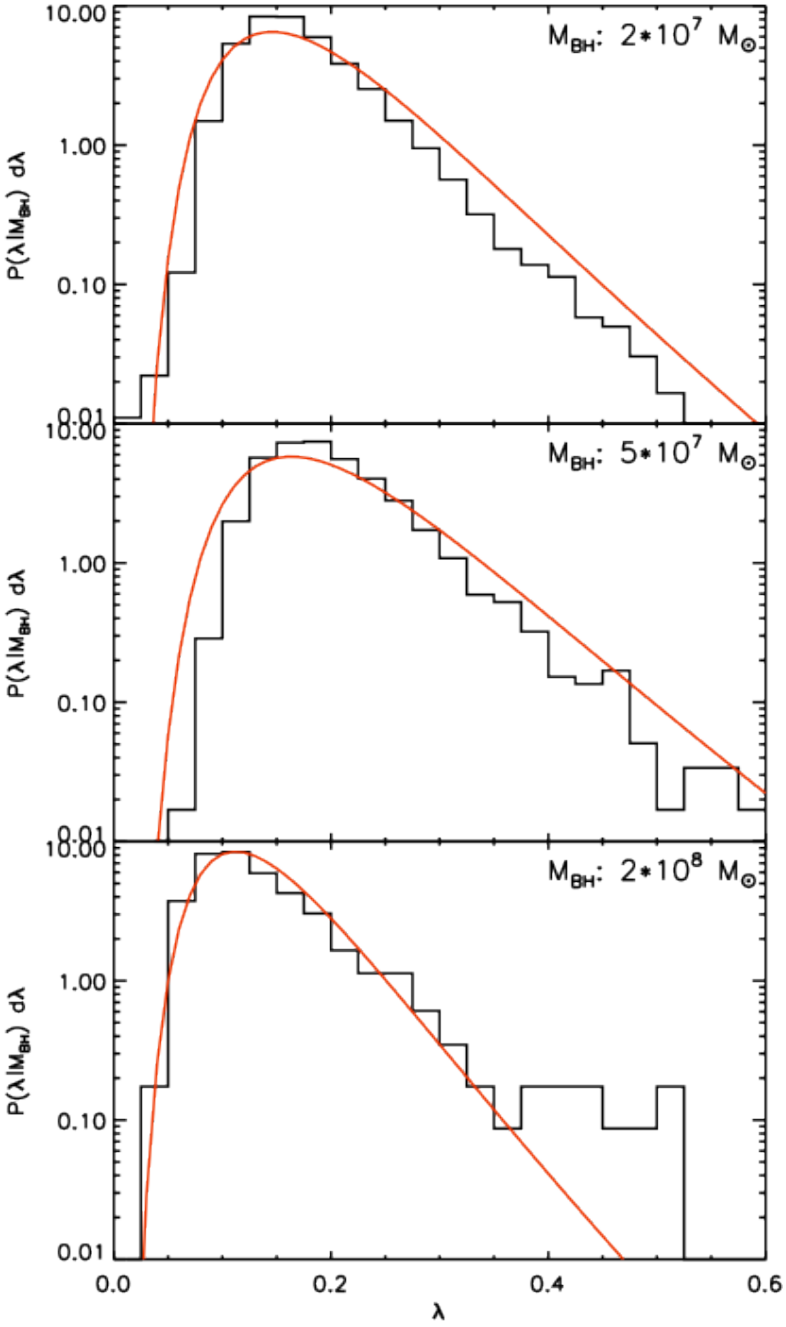

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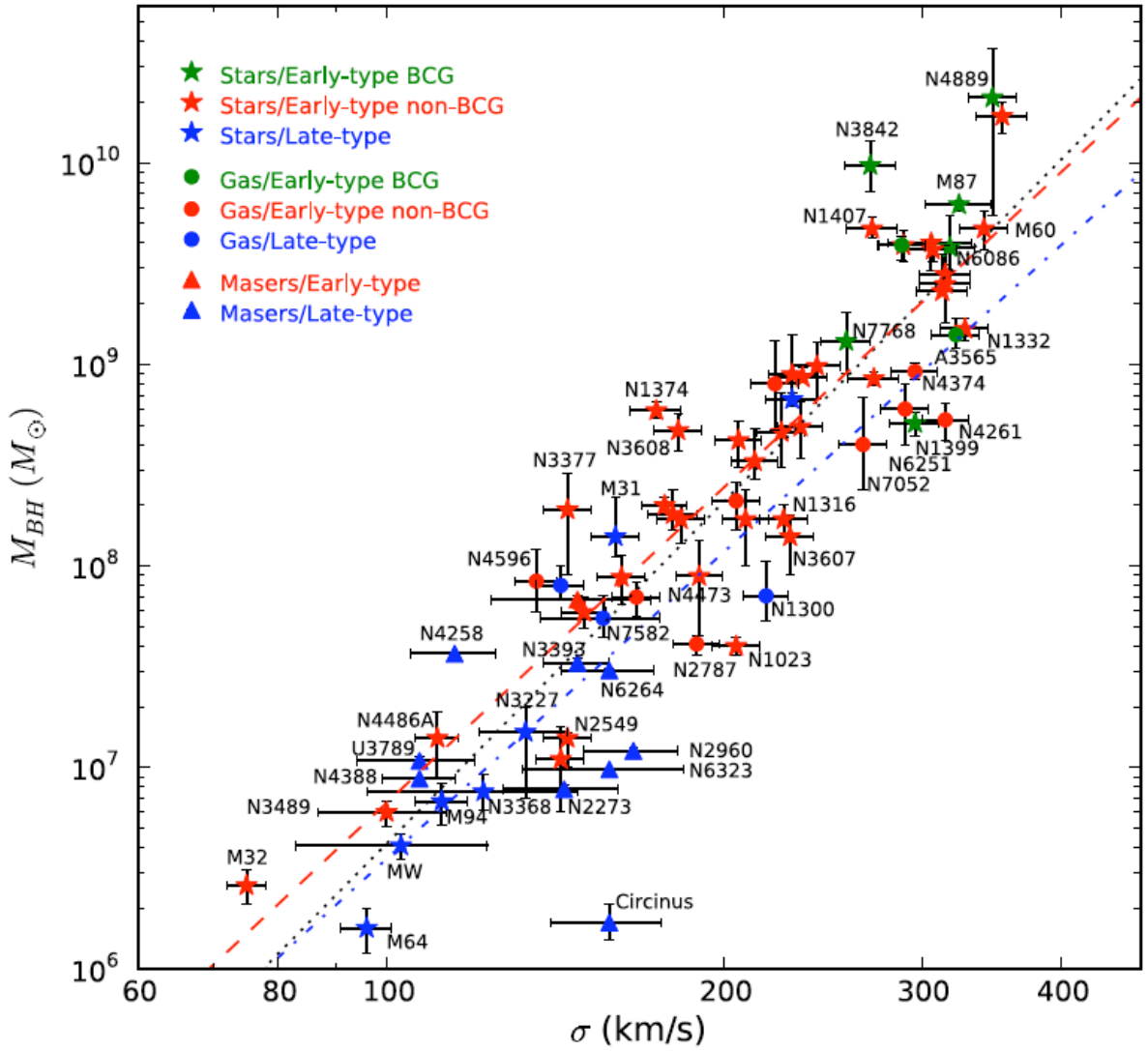
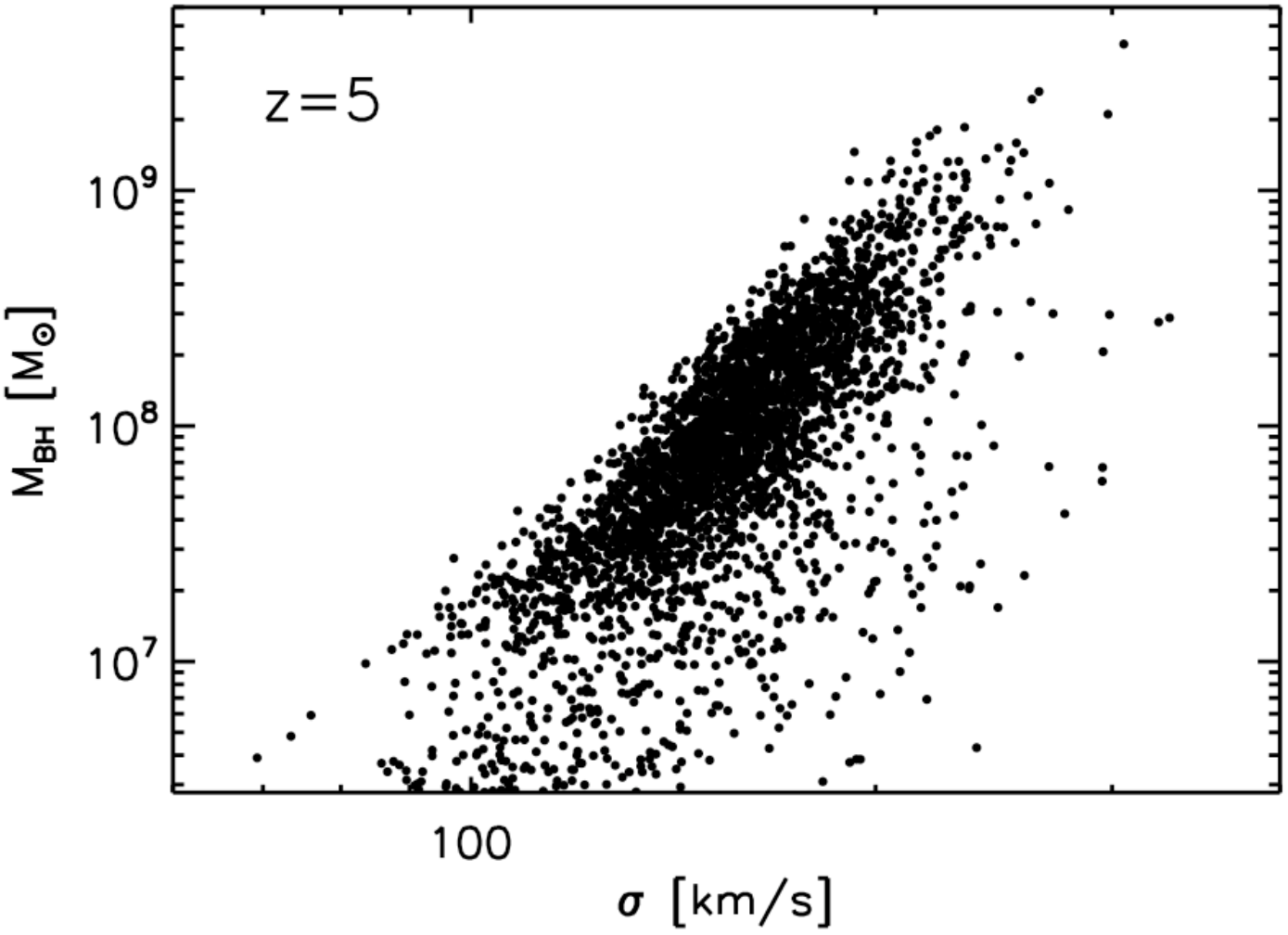
M-σ Relation



(McConnell & Ma 2013)

High-z M-σ Relation



(DeGraf+ in prep)

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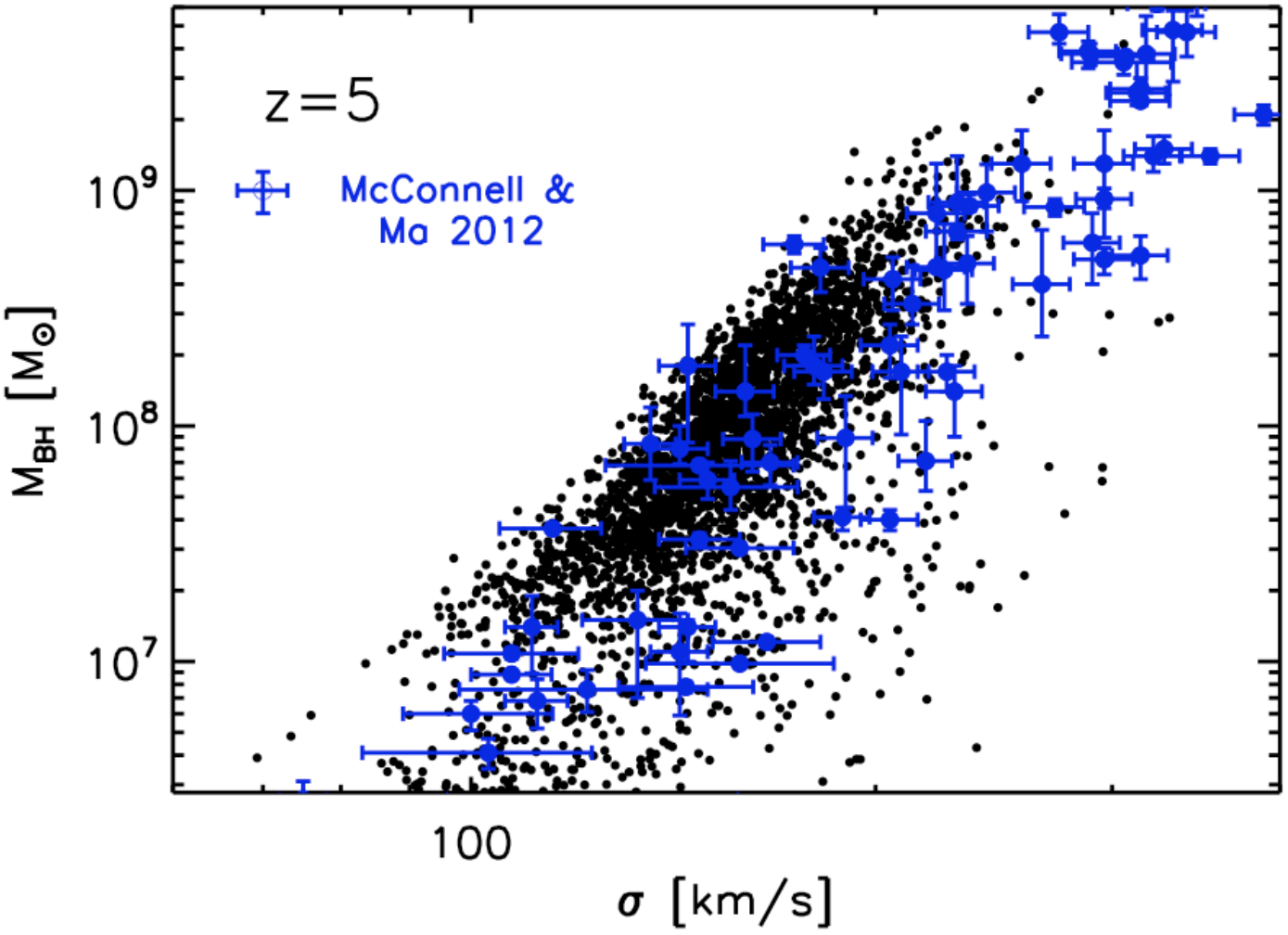

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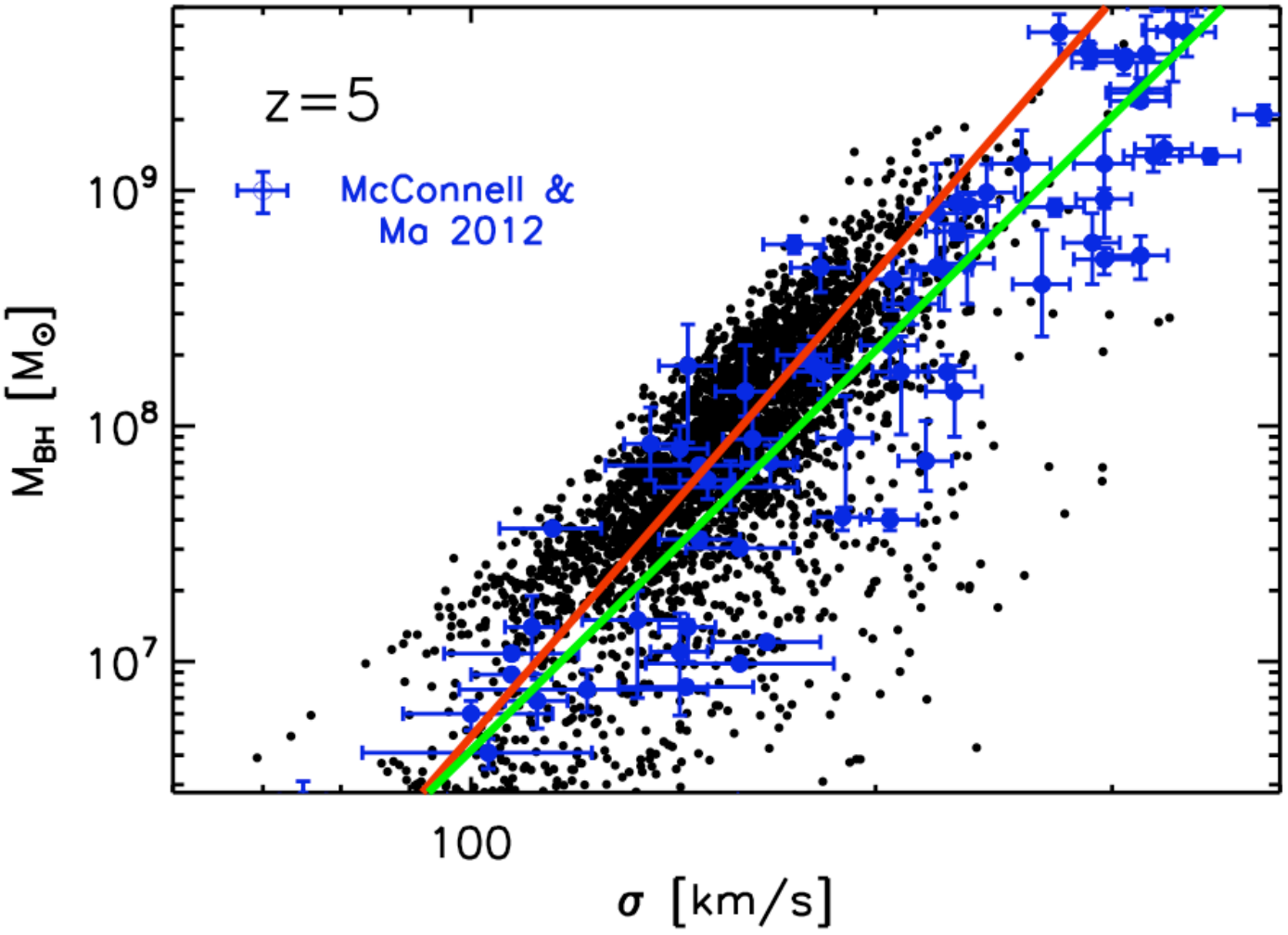

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M-σ: Luminosity Dependence

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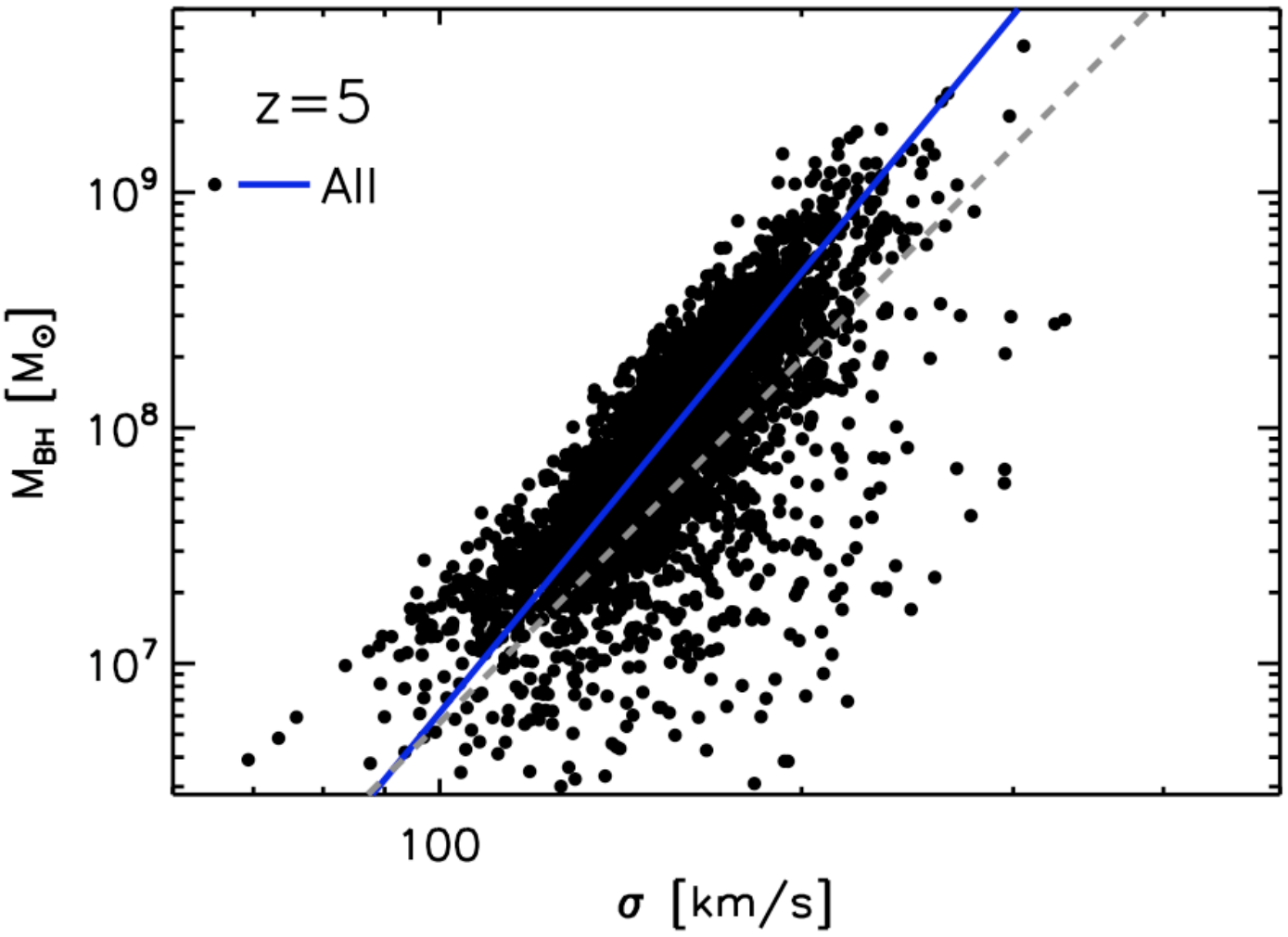

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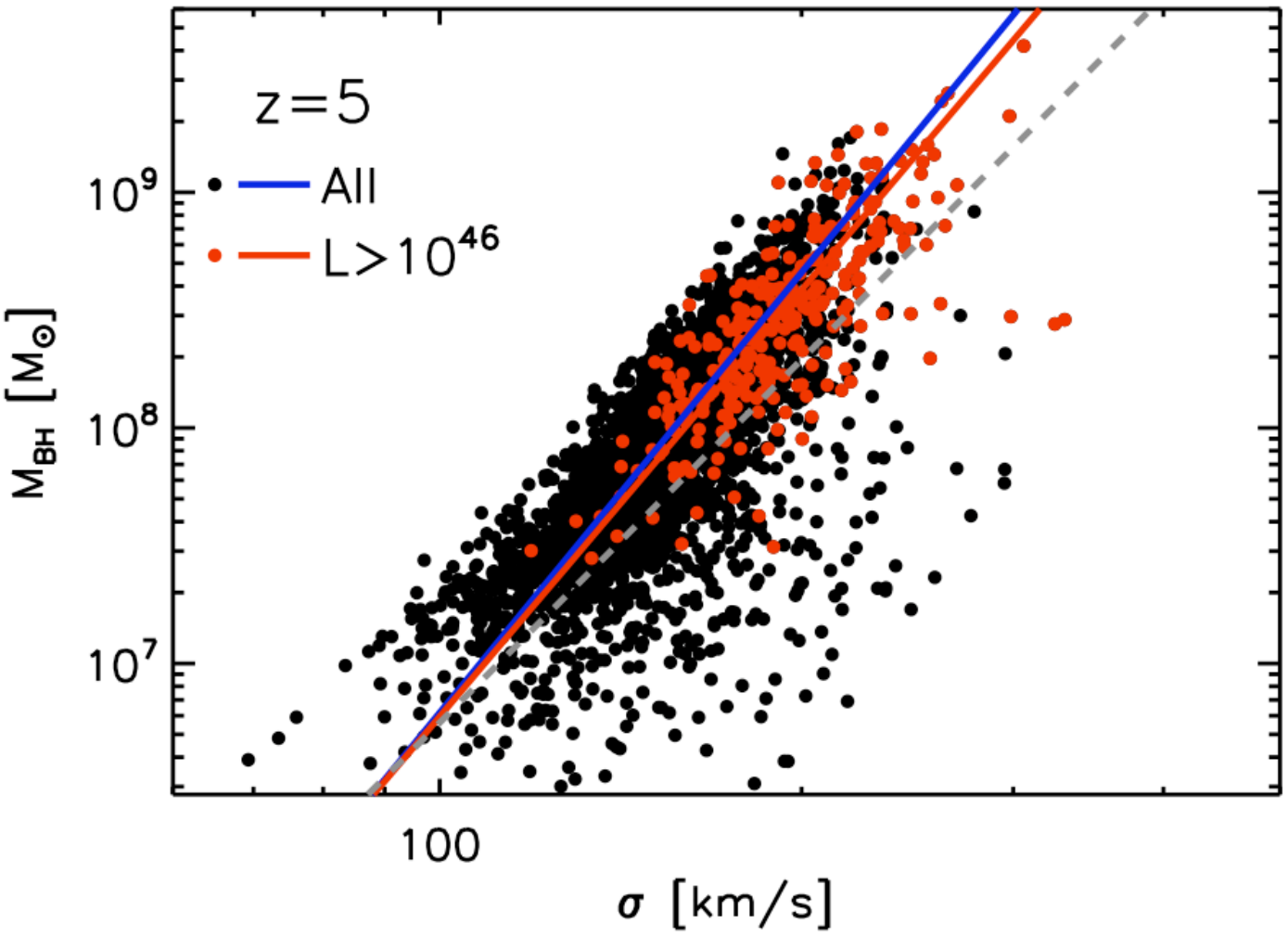

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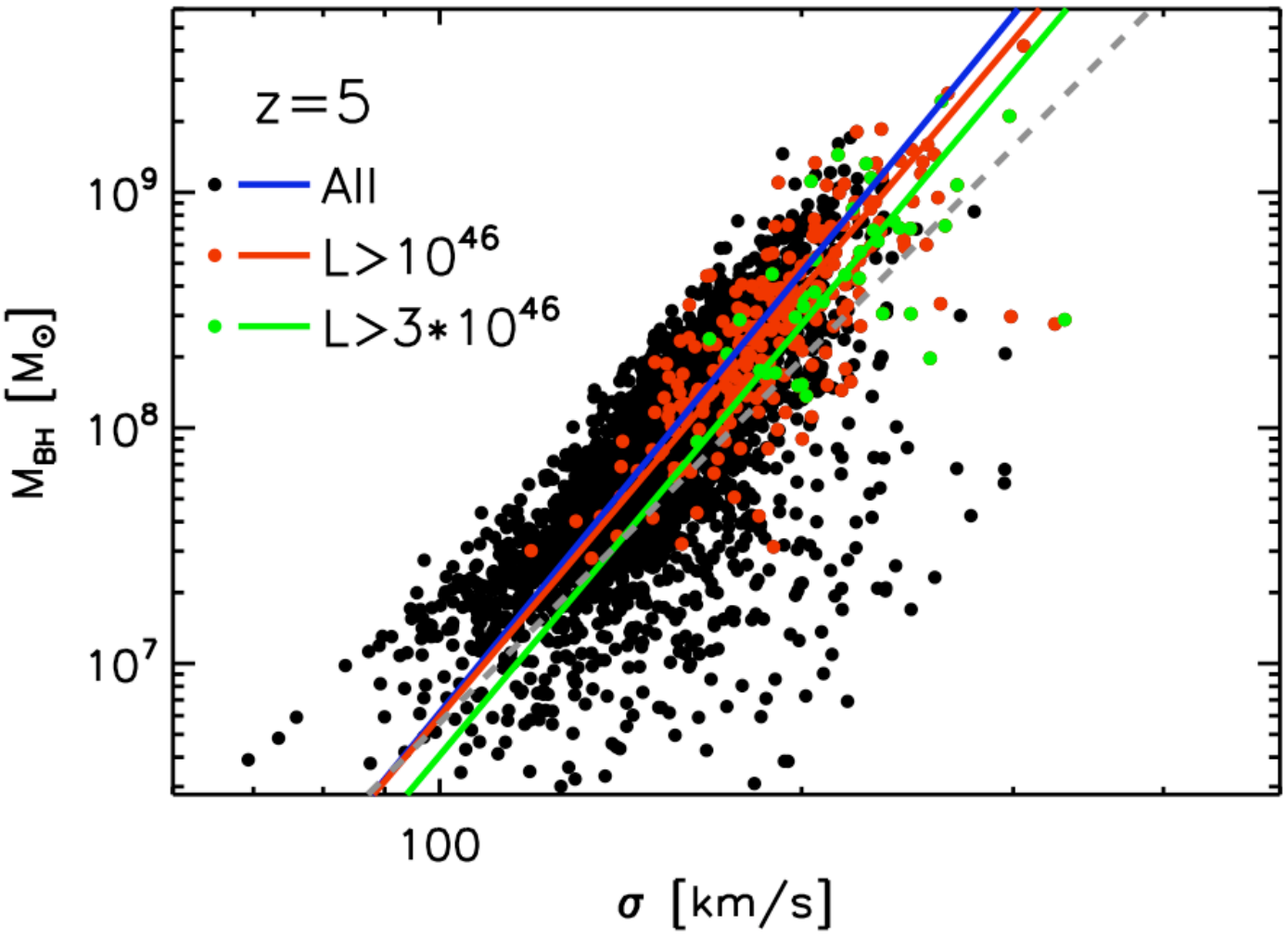

(DeGraf+ in prep)

M-σ: Impact of galaxy mergers

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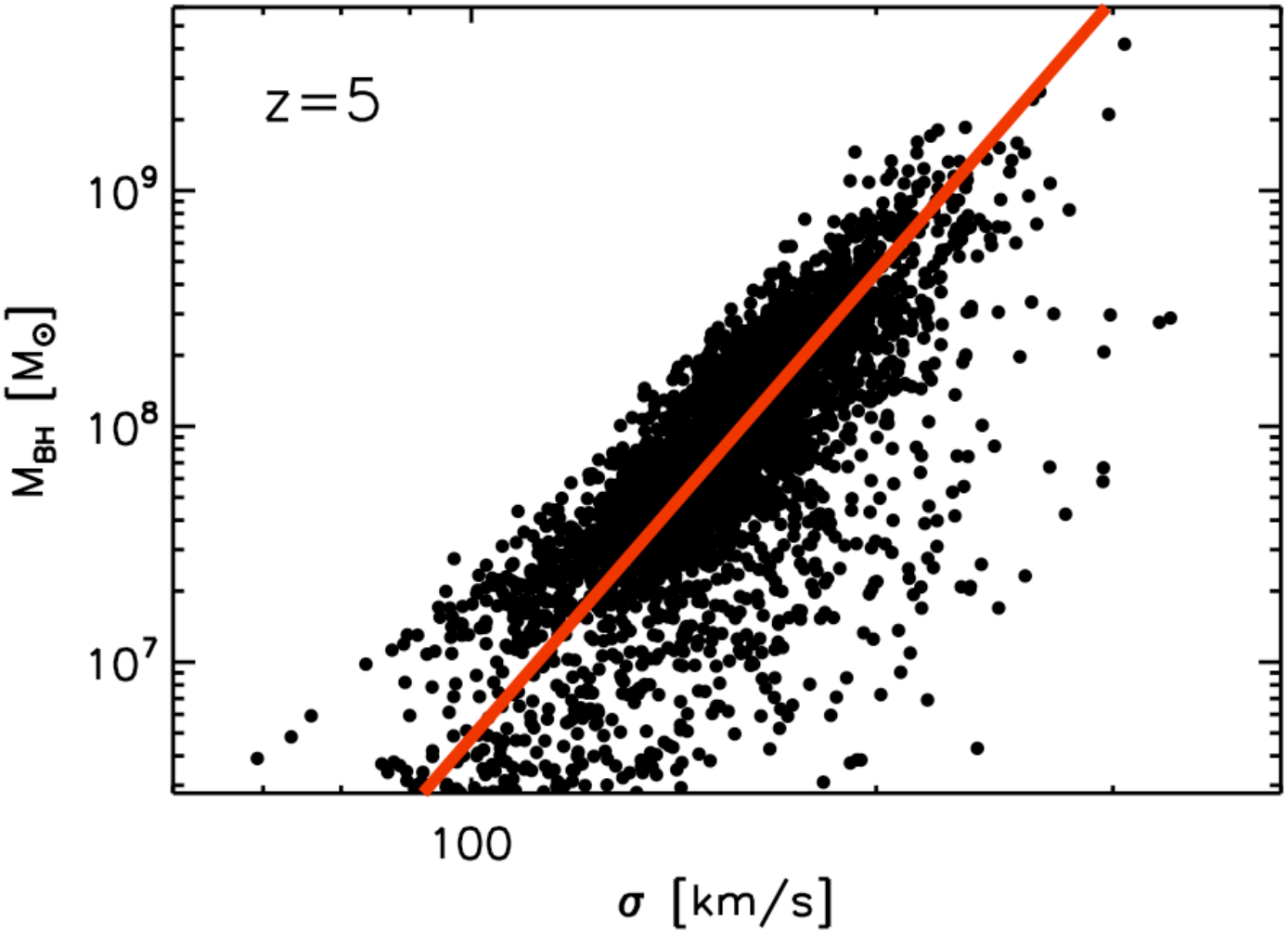

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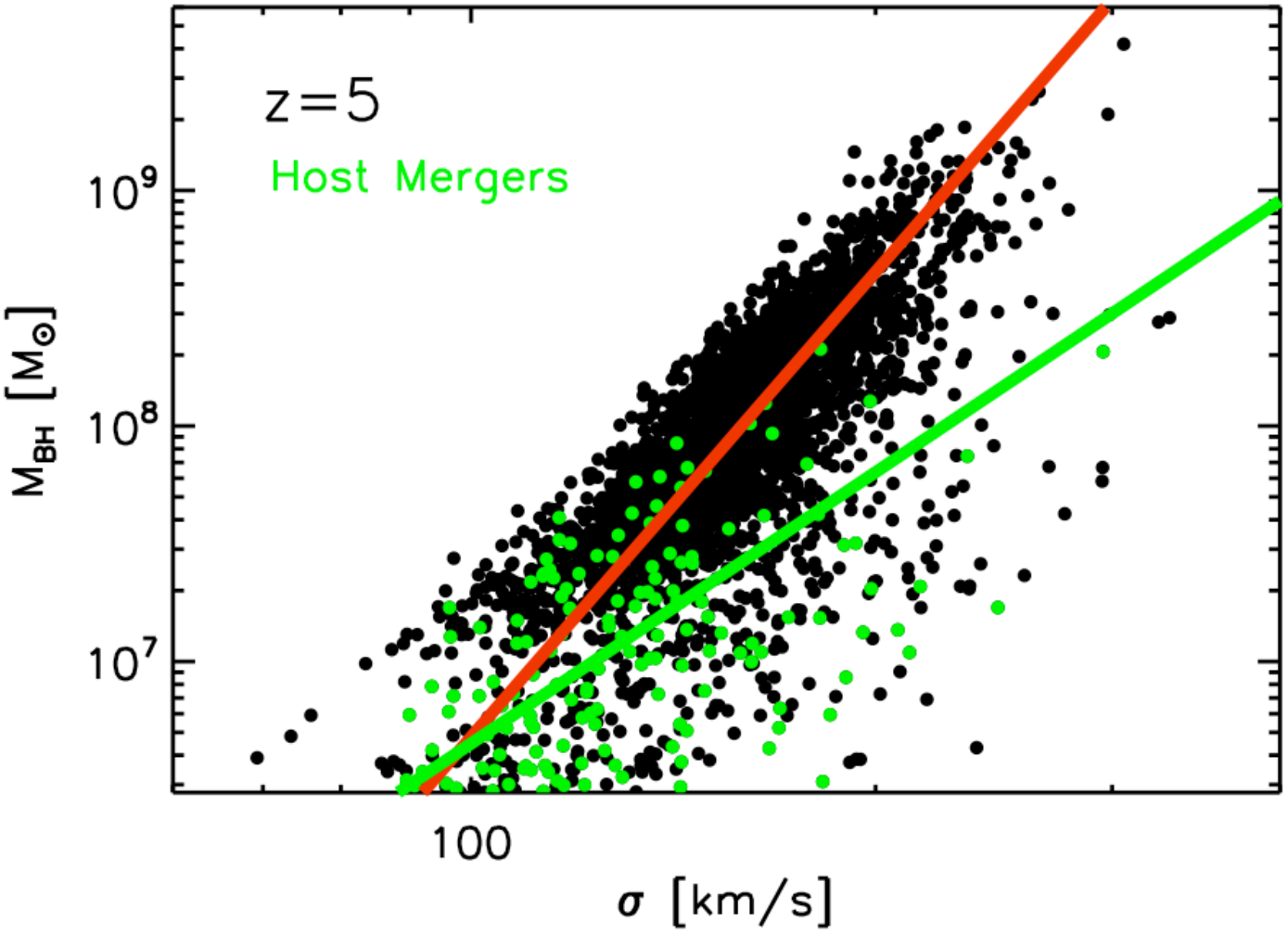
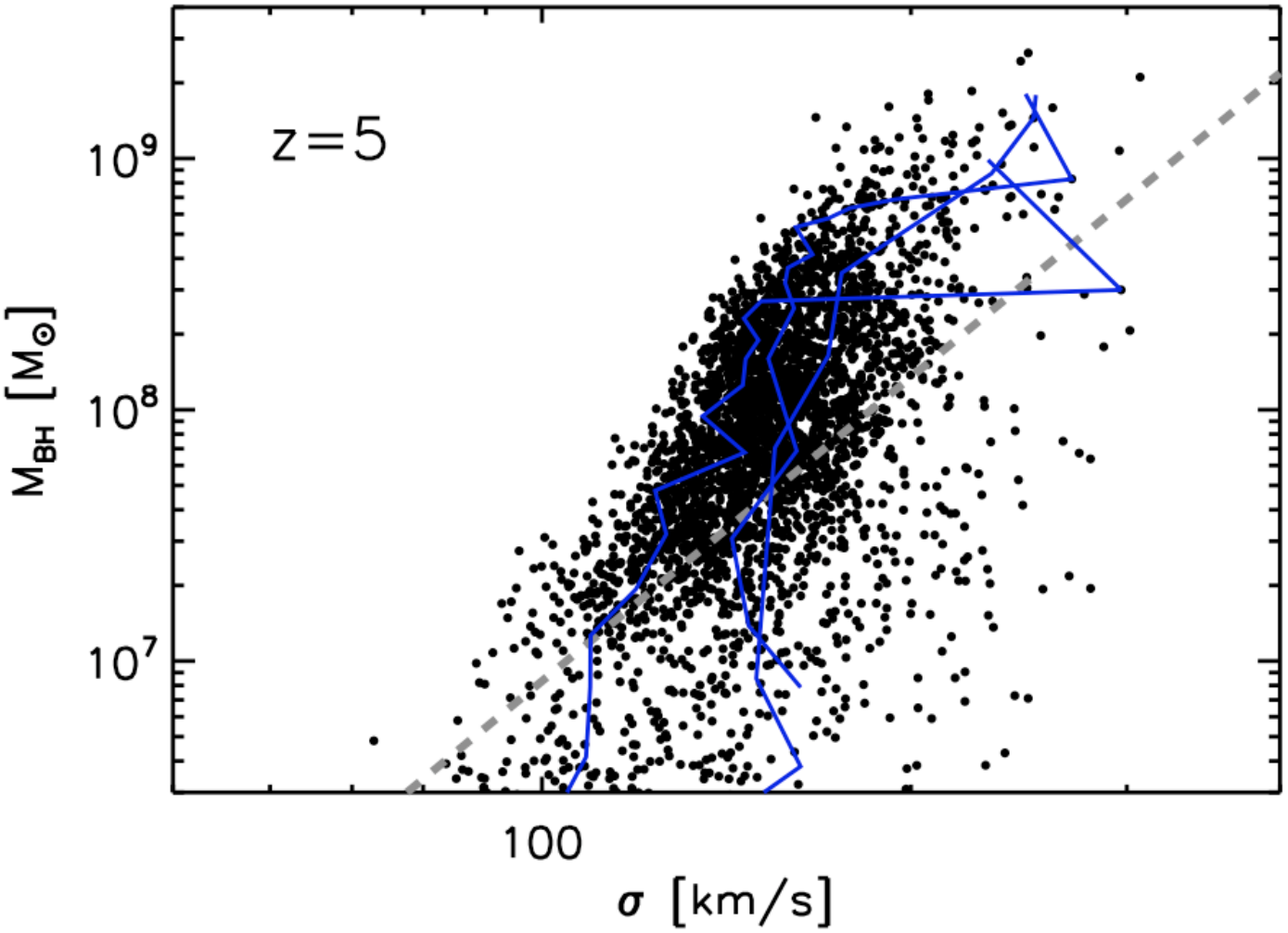


Population undergoing major mergers

(DeGraf+ in prep)

M-σ: Impact of galaxy mergers



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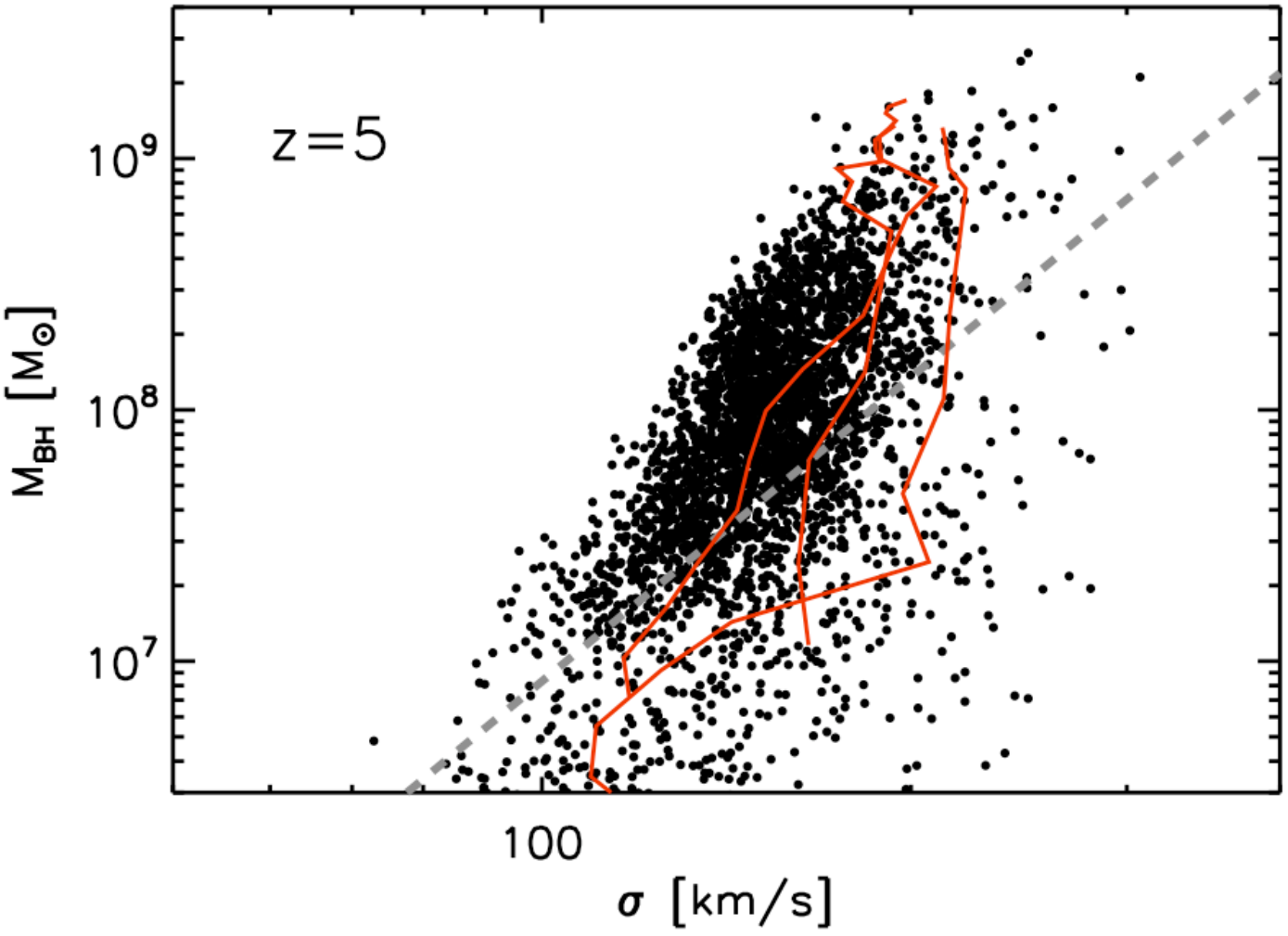
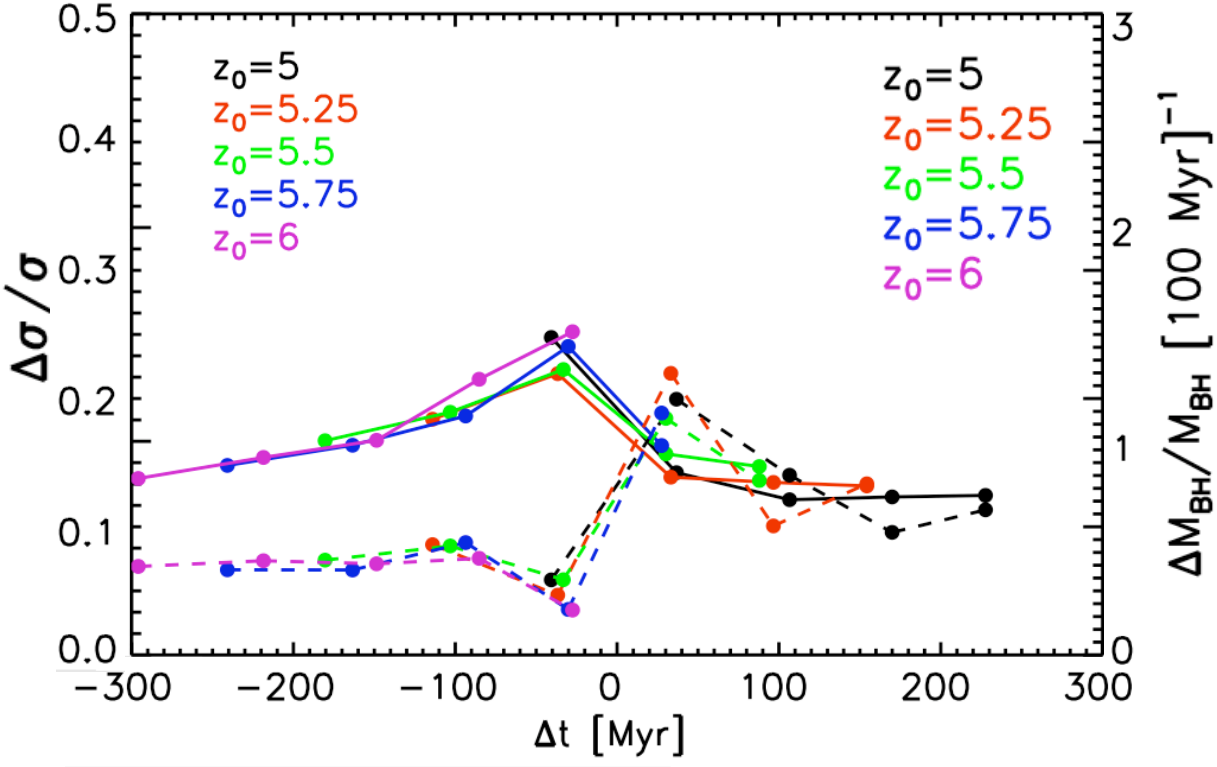
M-σ: Impact of galaxy mergers



(DeGraf+ in prep)

M-σ: Impact of galaxy mergers

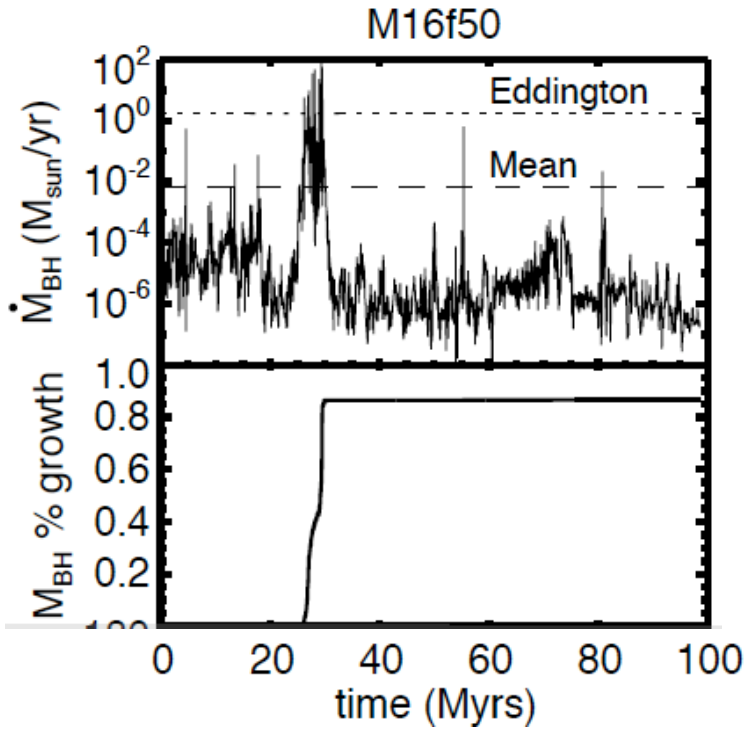
- Galaxy merger causes jump in σ
- BH undergoes rapid growth, delayed ~100 Myr relative to jump in σ

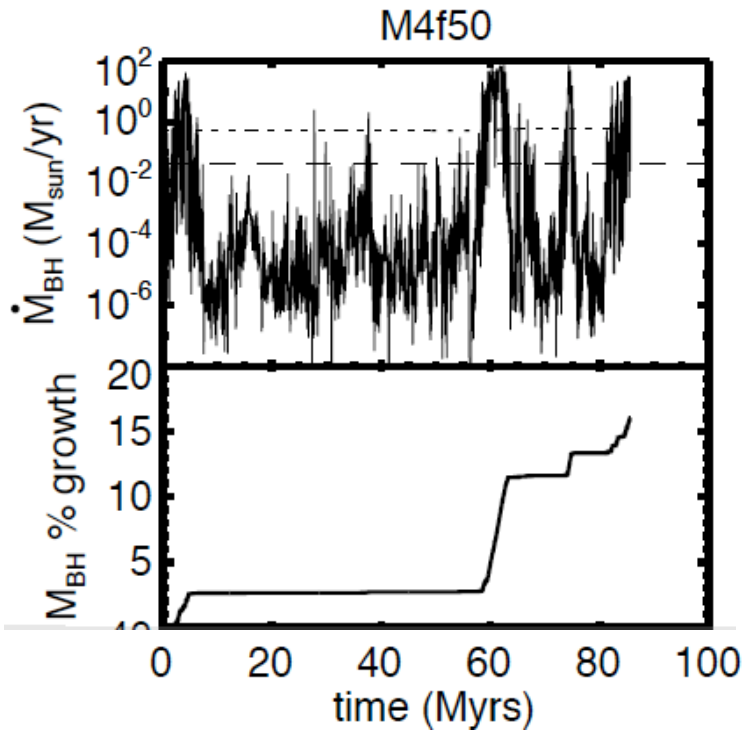


(DeGraf+ in prep)

Future Directions

High-resolution galaxies

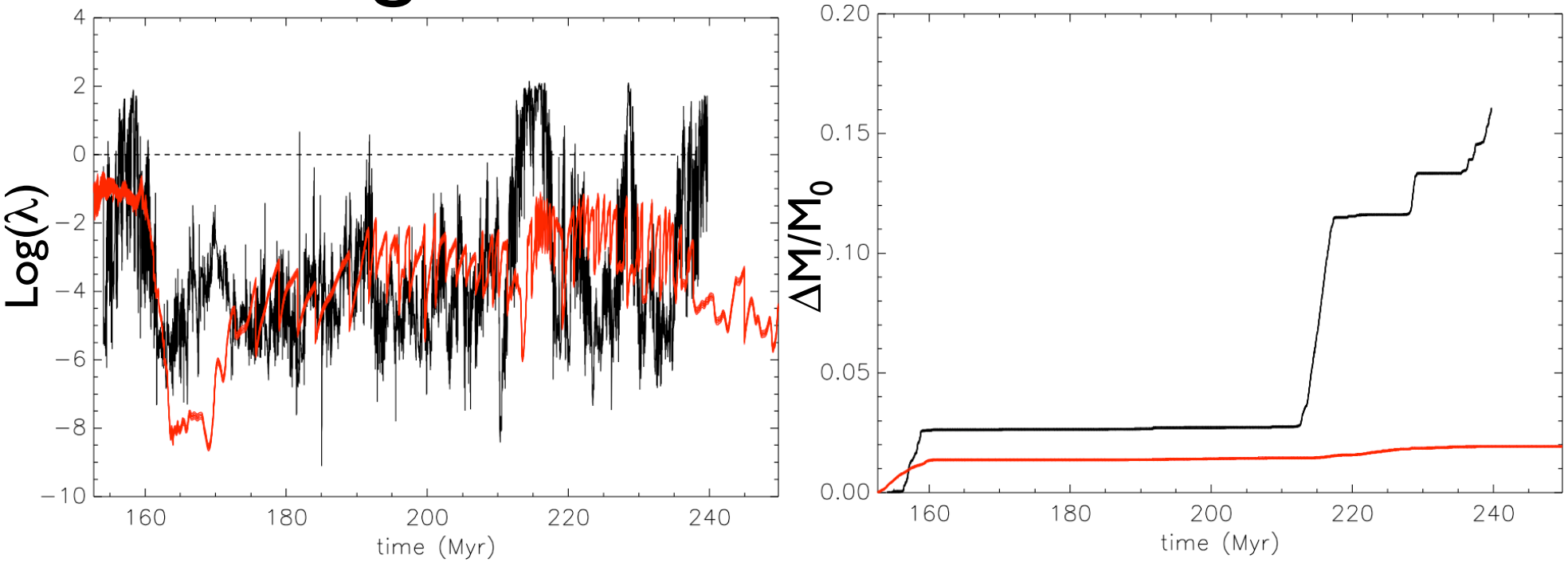




- Growth dominated by small, dense gas clouds

Gabor & Bournaud 2013

High-resolution Accretion



- Lower-resolution runs miss bursts of rapid accretion
- Must be addressed in cosmological simulations

Conclusions

- Direct incorporation of BHs well-reproduces quasar populations
- BH growth evolves as local gas density
- BH growth well-described by M_{BH}-dependent gaussian distribution
  - Suppressed above a characteristic mass scale
- High-z M-σ slightly steeper than local relation - generally L_{BH}-independent