AGN Duty Cycles in the Illustris Simulation

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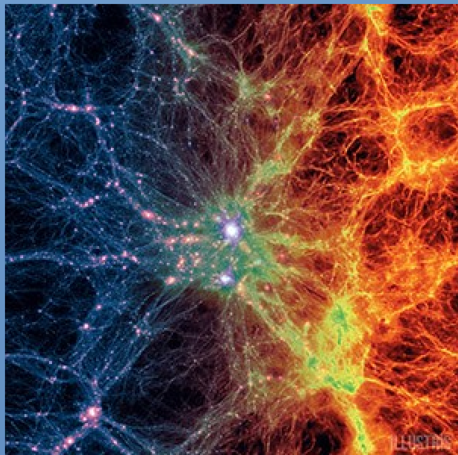
Outline

- Simulation background
- AGN duty cycle
  - Dependences on M_{BH}, L_{AGN}, z
- Clustering predicted duty cycle
  - Implications of host mass



Illustris Simulation

- Run with moving mesh code AREPO
- Volume: (106.5 Mpc)^3
- Minimum cell size: ~50pc
- Typical cell: m_{gas} ~$1.26*10^6$ M_{sun}
- SF+feedback, stellar evolution, gas recycling and enrichment, galactic outflows, time-dependent UV background

http://www.illustris-project.org/

BH implementation

- BH seeded to DM halos

M_{seed} ~10^5 h^{-1} M_{sun}, $M_{h,threshold}$ ~$5*10^{10}$ h^{-1} M_{sun}

- Bondi-like accretion

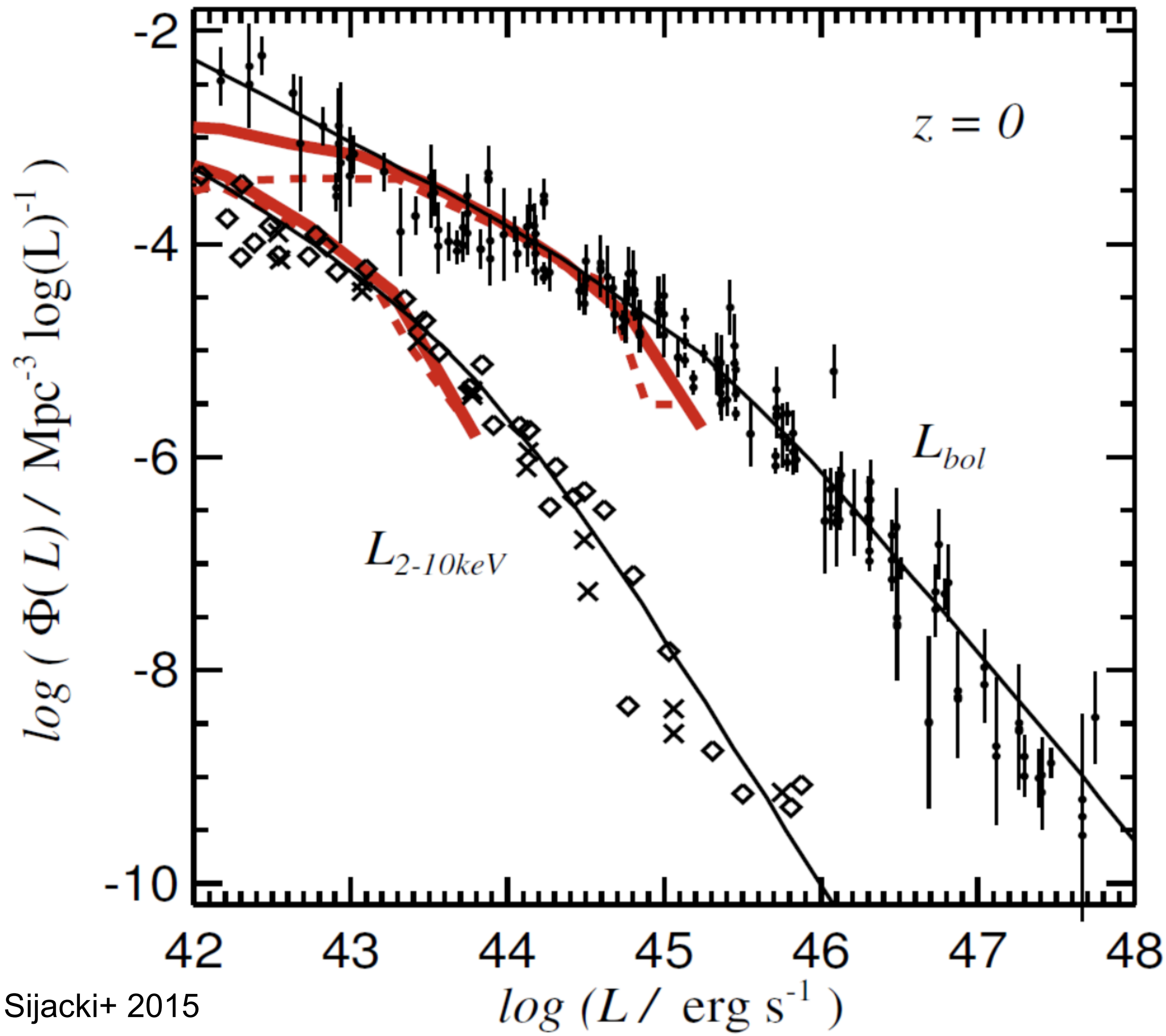
  with Eddington limit and pressure criterion

$$\dot{M} = \frac{4\pi\alpha G^2 M_{BH}^2 \rho}{c_s^3}$$

- 3-component feedback model

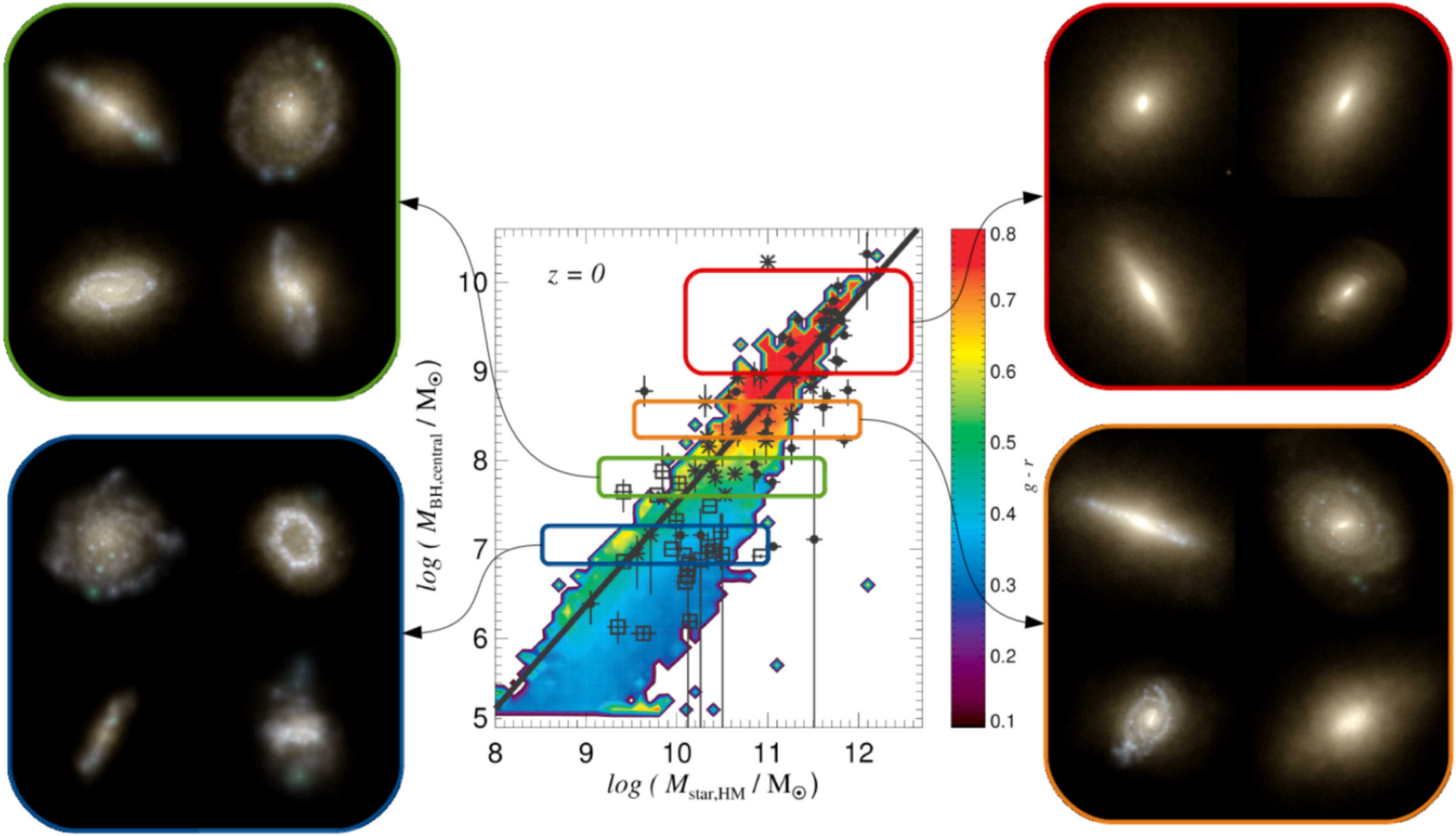
  Quasar Mode: Efficient accretion; thermal feedback
  Radio Mode: Inefficient accretion; energy inserted as radio bubbles
  Radiative feedback: Modified photo-ionization and photo-heating rates near BH

Quasar Luminosity Function



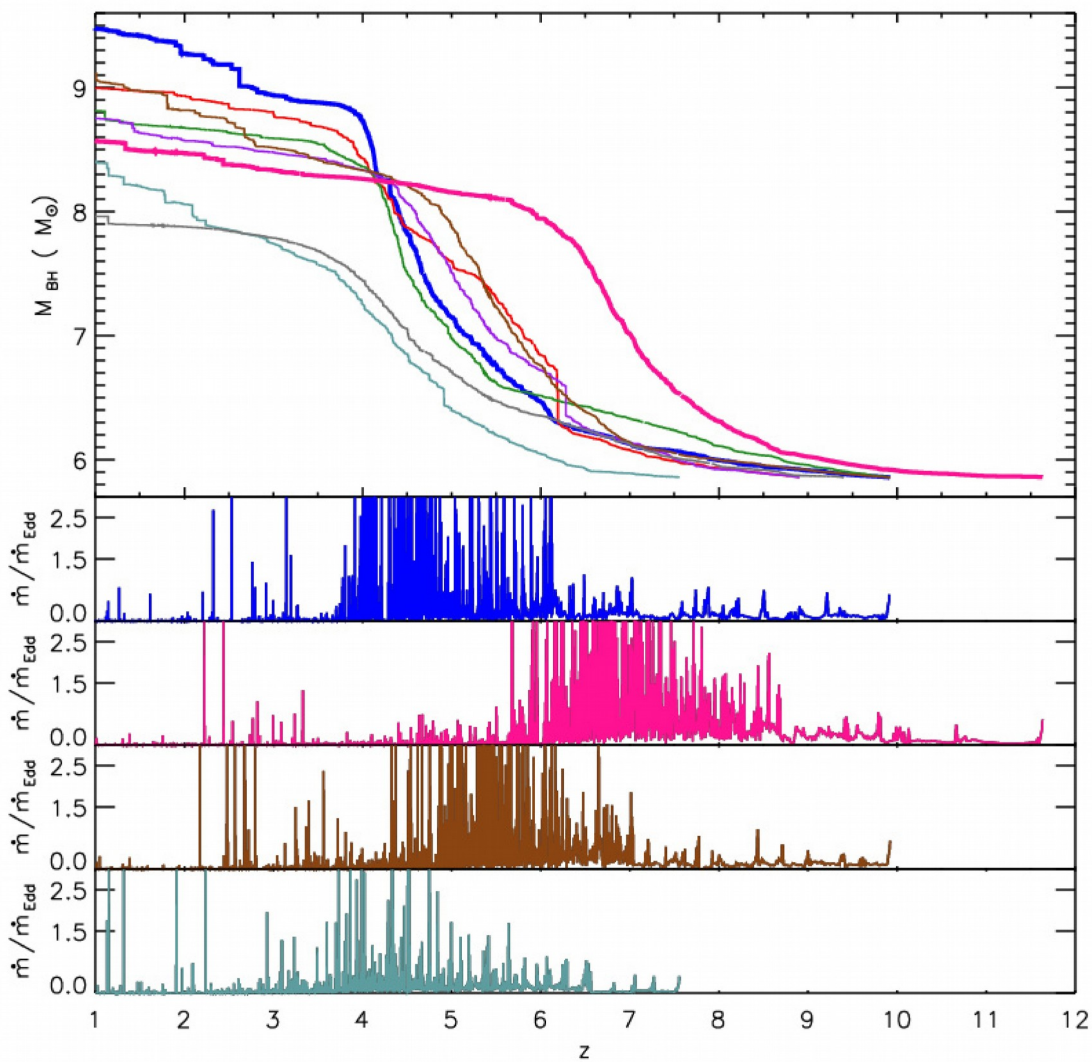
Sijacki+ 2015

- Reproduces observed luminosity function



Sijacki+ 2015

Typical BH Growth

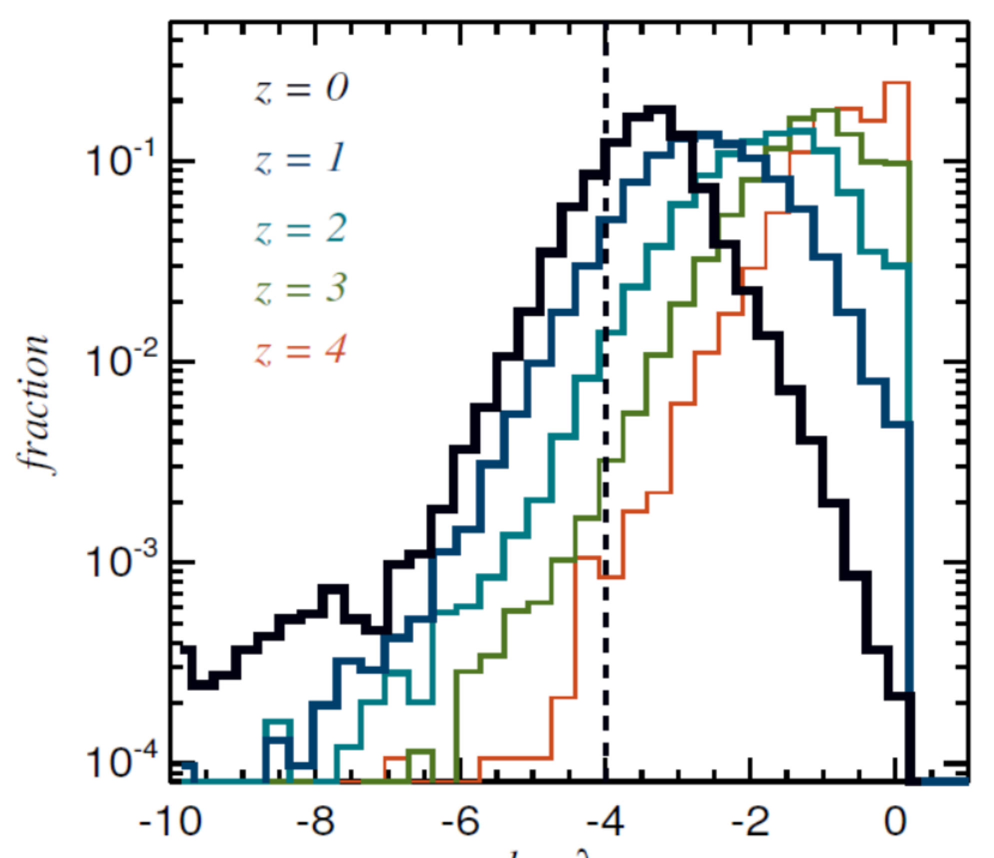


Di Matteo+ 2008

- Sample growth histories using Bondi-like accretion
- Significant variation in accretion rate/luminosity
- Final mass constrained by self-regulation

Eddington Fraction Distribution

- High-z distribution peaks at higher λ_{Edd}
    - Sharper Eddington ratio peak → less scatter in L_{BH}-M_{host} relation



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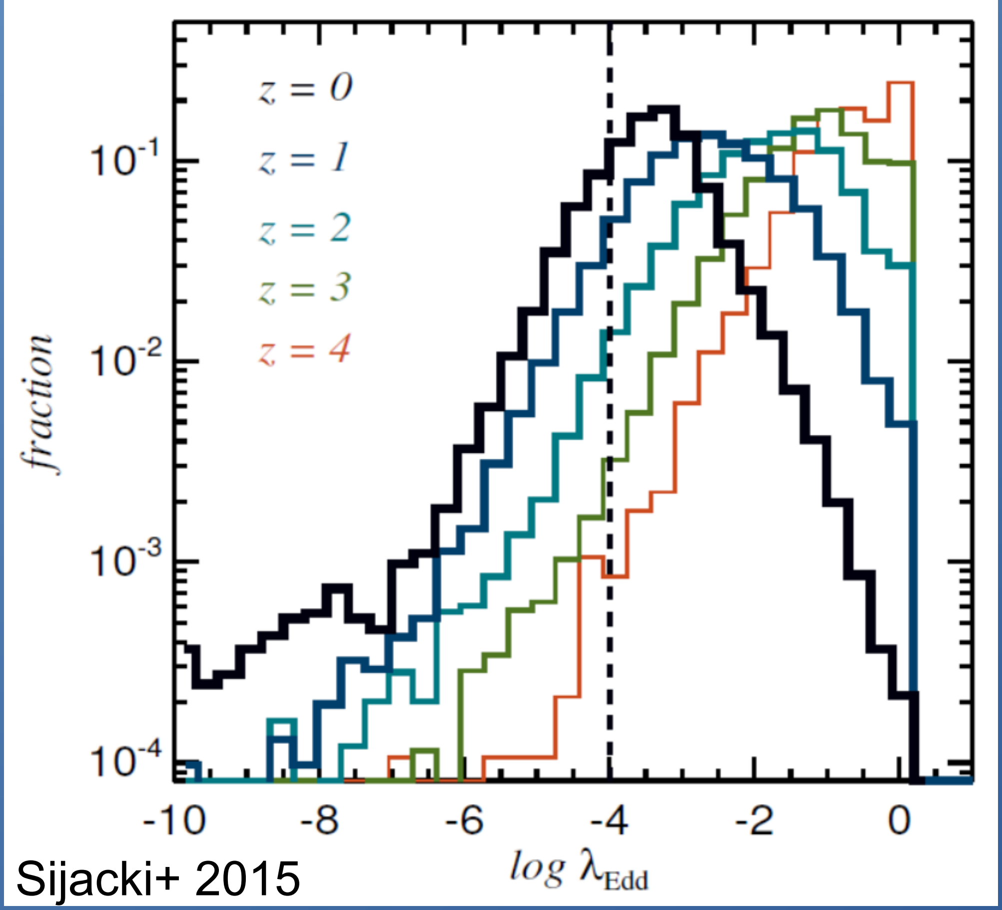
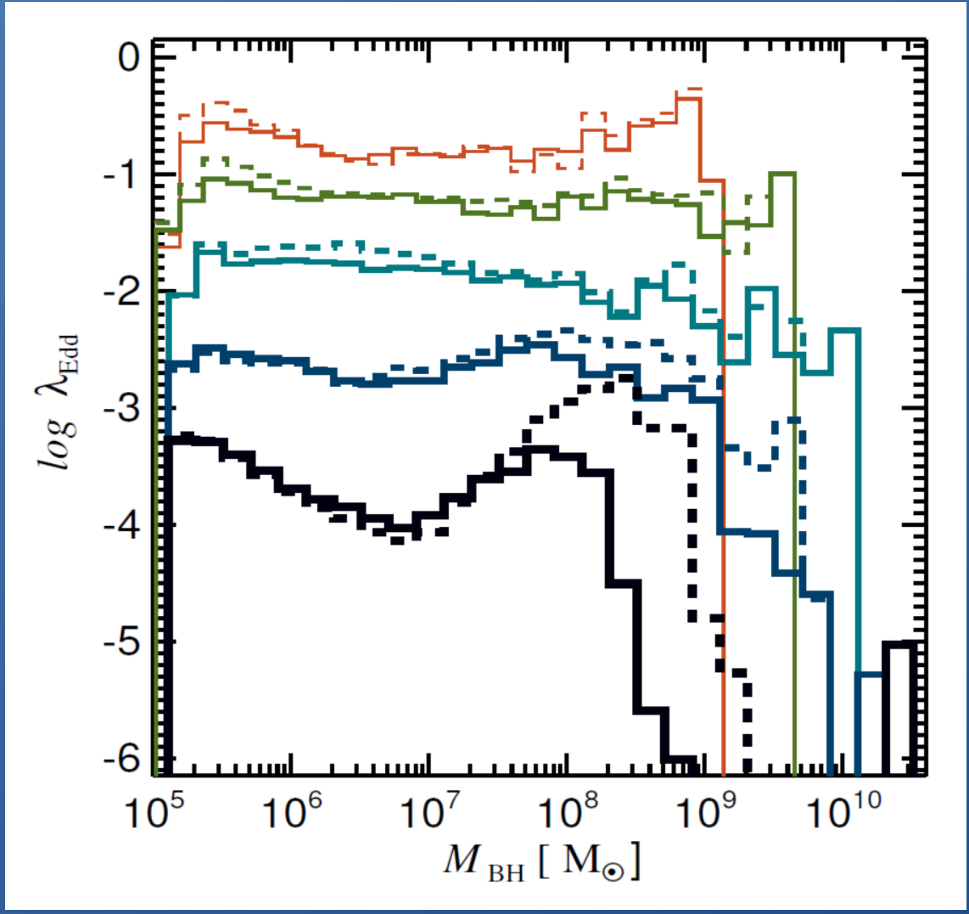
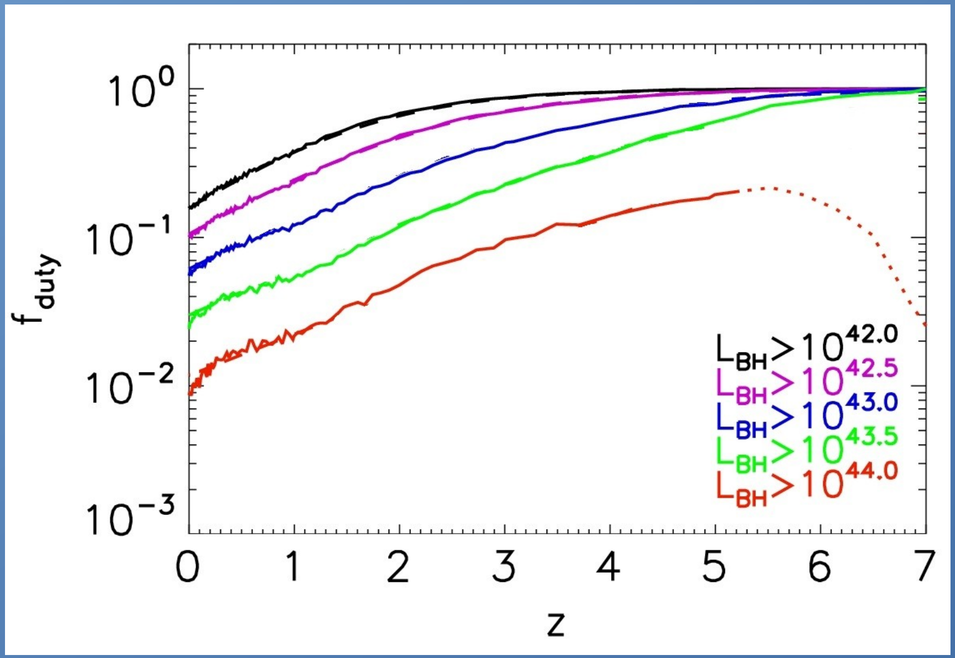




$$f_{duty} = \frac{N_{BH,active}}{N_{BH}}$$

Duty Cycle Evolution



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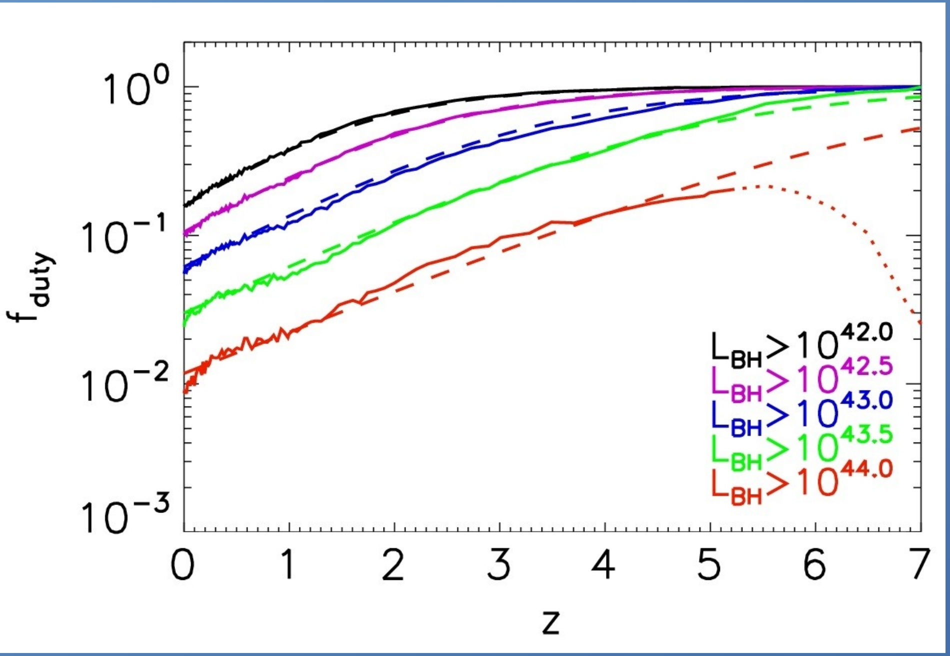

- Well fit by single logistic function

$$f_{duty} = \frac{1}{1 + e^{-k(z - z_0)}}$$

$$k = 0.87 \left(\frac{L_{BH,min}}{10^{43}\, erg/s} \right)^{-1.27}$$

$$z_0 = 3.13 \left(\frac{L_{BH,min}}{10^{43}\, erg/s} \right)^{0.338}$$

- Fitted for 0<z<4, but extends to higher-z
- f_{duty} drops for brightest objects
    - Due to limits on Eddington limit

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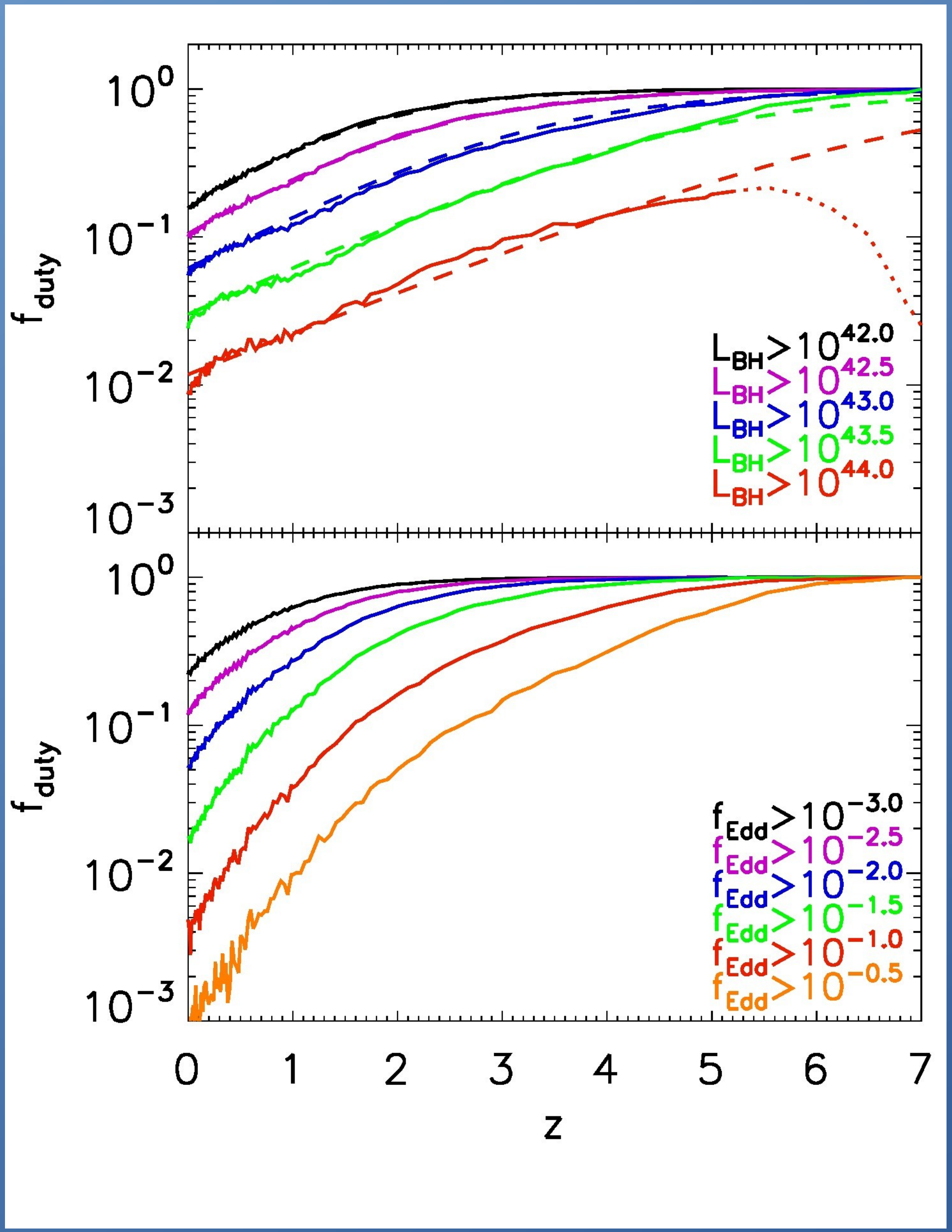

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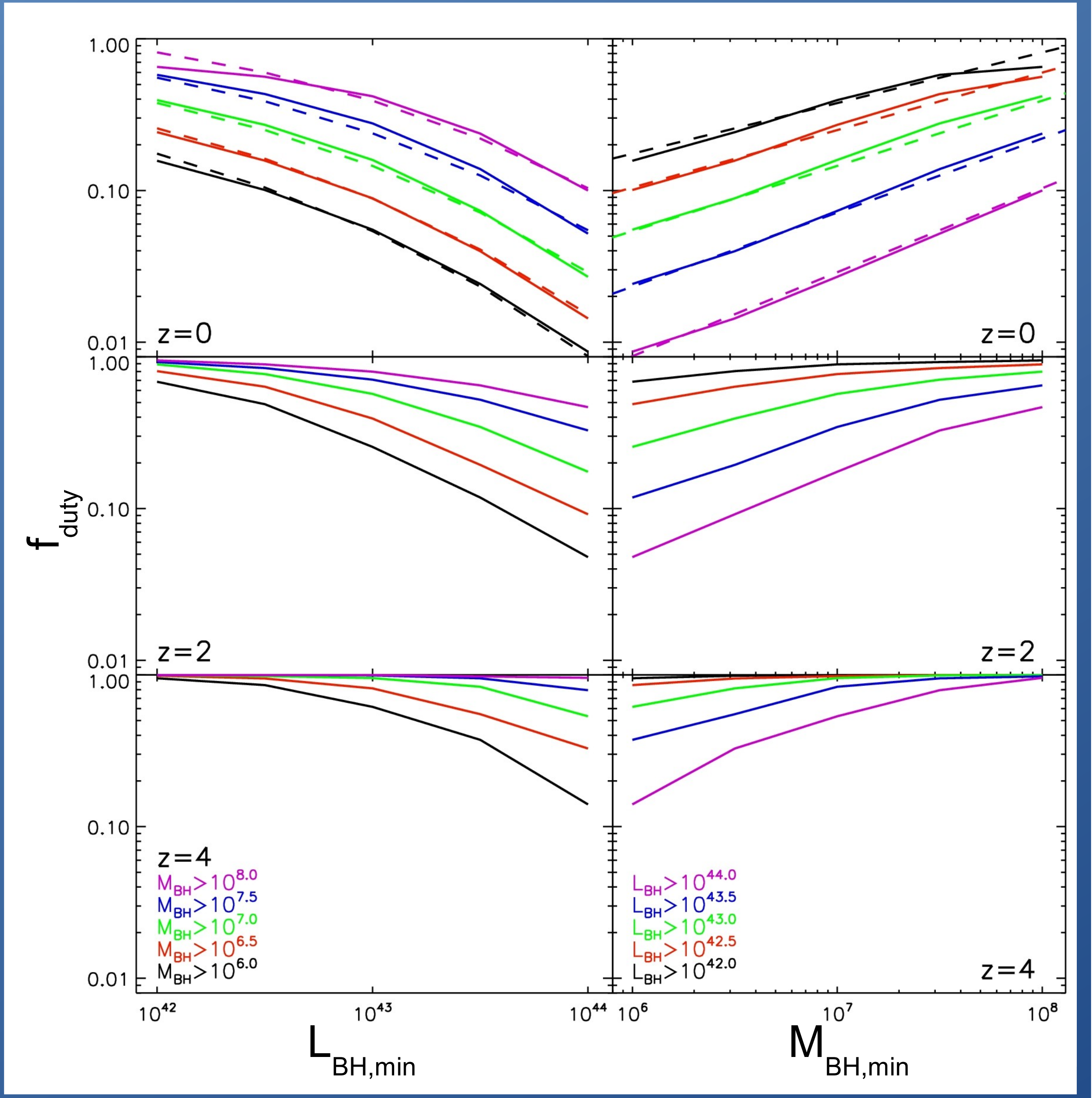
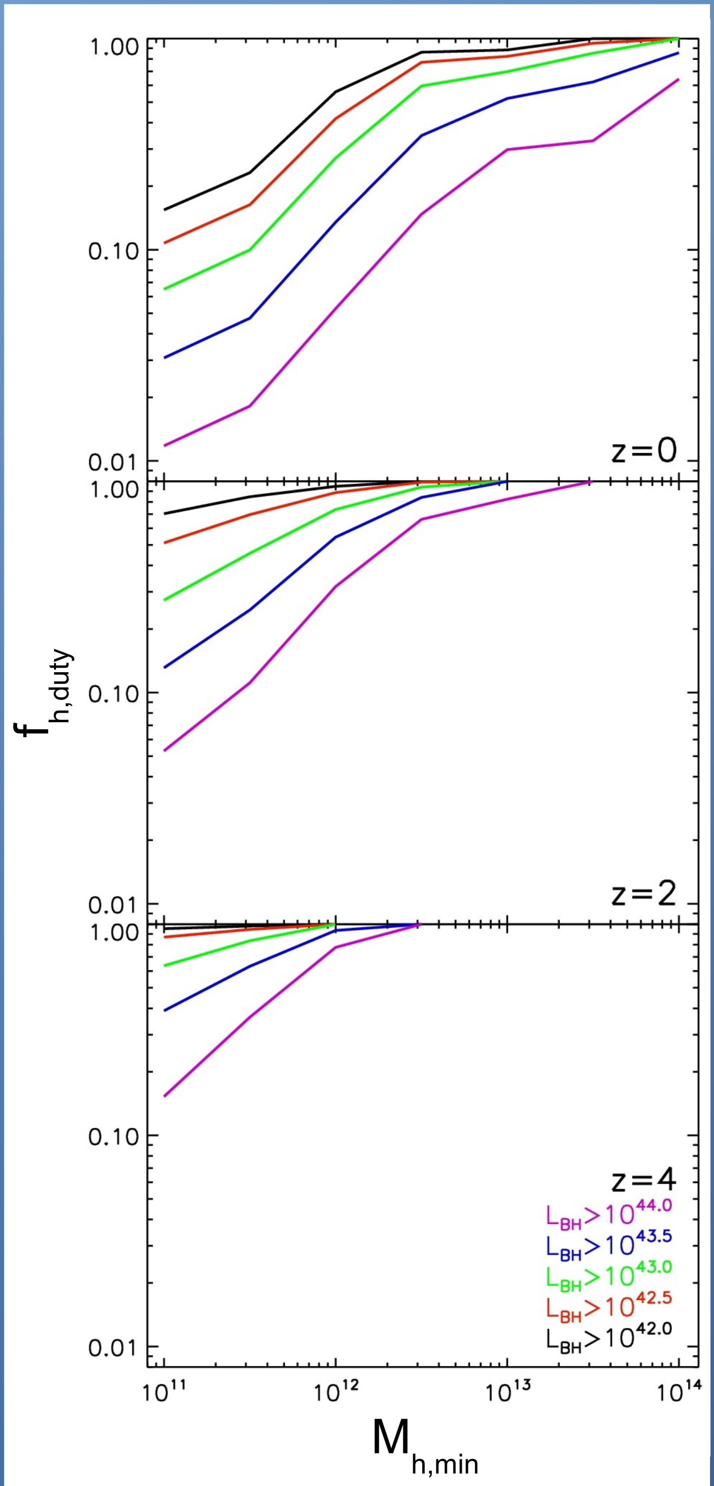
- Fitted for 0<z<4, but extends to higher-z
- f_{duty} drops for brightest objects
  - Due to limits on Eddington limit
  - Not seen when selected by Eddington fraction instead

Duty Cycle Dependencies

- Lower duty cycle for higher L_{AGN} and lower M_{BH}
- Smooth dependencies
- Dependencies are weaker at higher-z
  - Generally higher Eddington ratios



Halo Duty Cycles

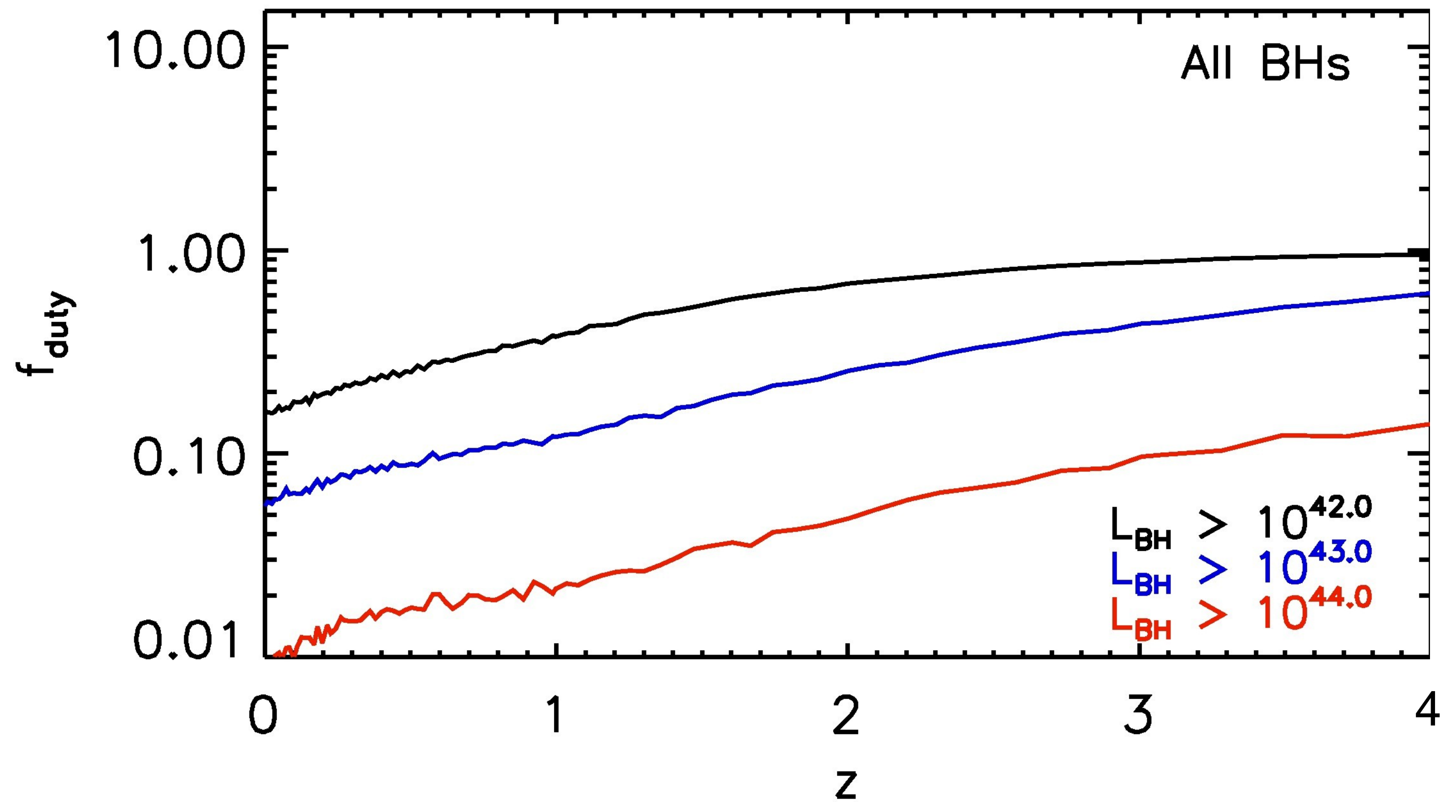


- Defined as: $$f_{h,duty} = \frac{N_h(>L_{BH,min})}{N_h(M_h > M_{h,min})}$$

- Distinct from BH duty cycle, as halos may host multiple BHs

Duty Cycle Evolution

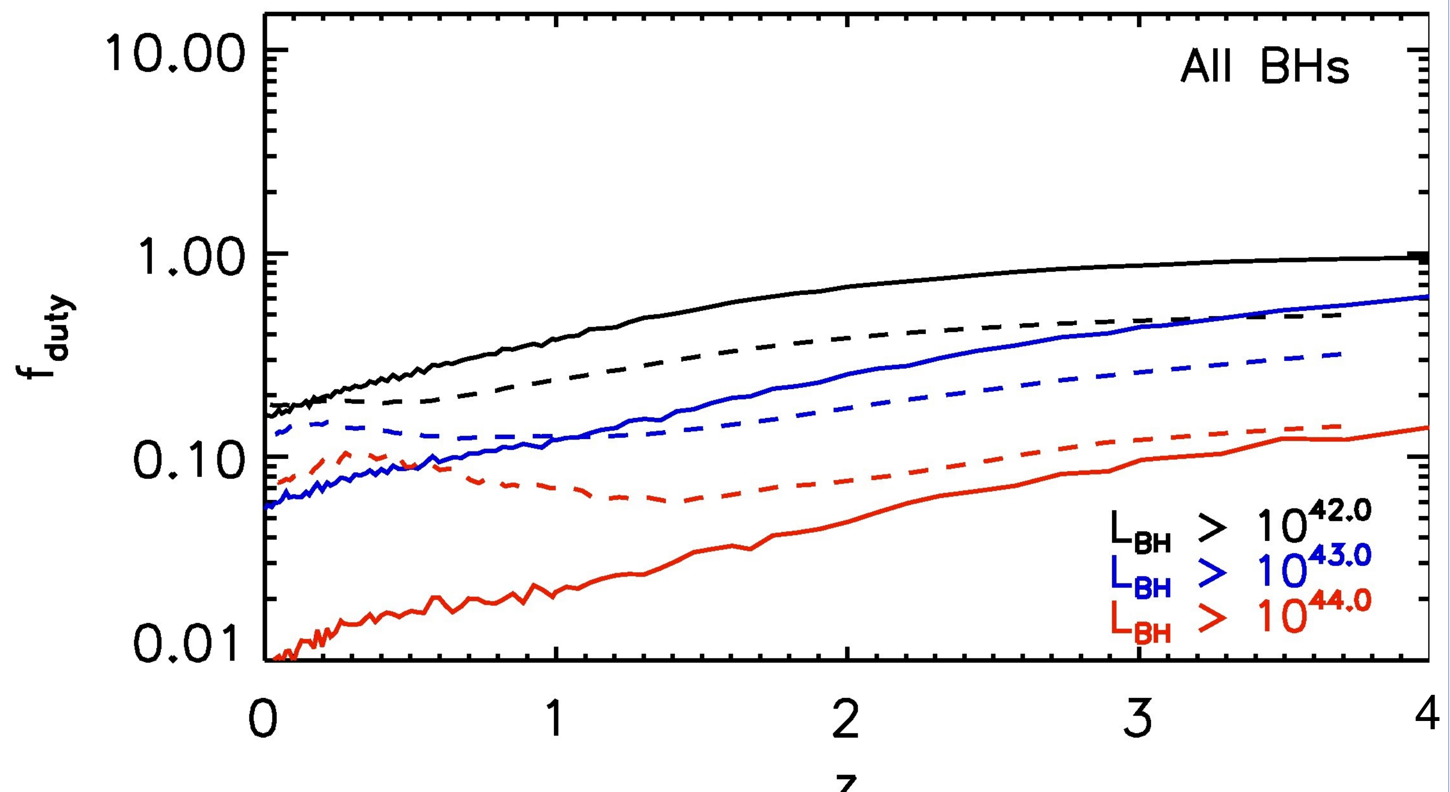
- Slow decrease in f_{duty} with time



— $\frac{N_{BH,active}}{N_{BH}}$

Duty Cycle Evolution

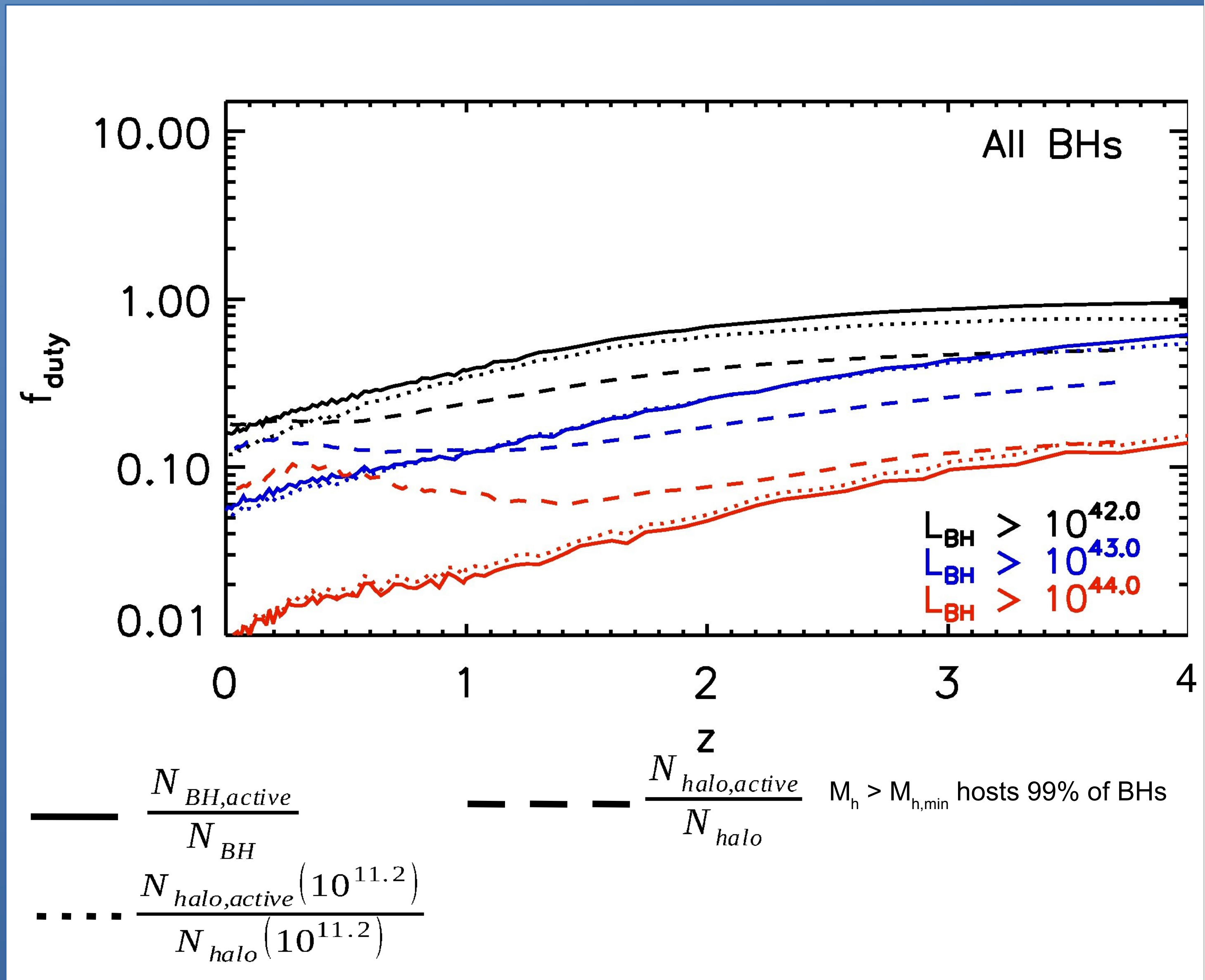
- Slow decrease in f_{duty} with time
- Halo duty cycle matches only at high-z



$\frac{N_{BH,active}}{N_{BH}}$ $\frac{N_{halo,active}}{N_{halo}}$ $M_h > M_{h,min}$ hosts 99% of BHs

Duty Cycle Evolution

- Slow decrease in f_{duty} with time
- Halo duty cycle matches only at high-z
- Fixed-mass halo duty cycle well matches at all z



Clustering-predicted Duty Cycle

$$f_{duty} = \frac{N_{BH}(>L_{BH,min})}{N_h(M_h > M_{h,min})} = \frac{\int_{L_{BH,min}}^{\infty} \Phi(L)\, dL}{\int_{M_{h,min}}^{\infty} \frac{dn}{dM}\, dM}$$

- N_{BH} (> $L_{BH,min}$): Observed count
- N_h (> $M_{h,min}$): From halo mass function
- $M_{h,min}$:Minimum host halo mass, based on clustering amplitude

$$b_{BH}(>L_{BH,min}) = \frac{\int_{M_{h,min}}^{\infty} b(M) \frac{dn}{dM}}{\int_{M_{h,min}}^{\infty} \frac{dn}{dM}\, dM}$$

Duty Cycle Evolution

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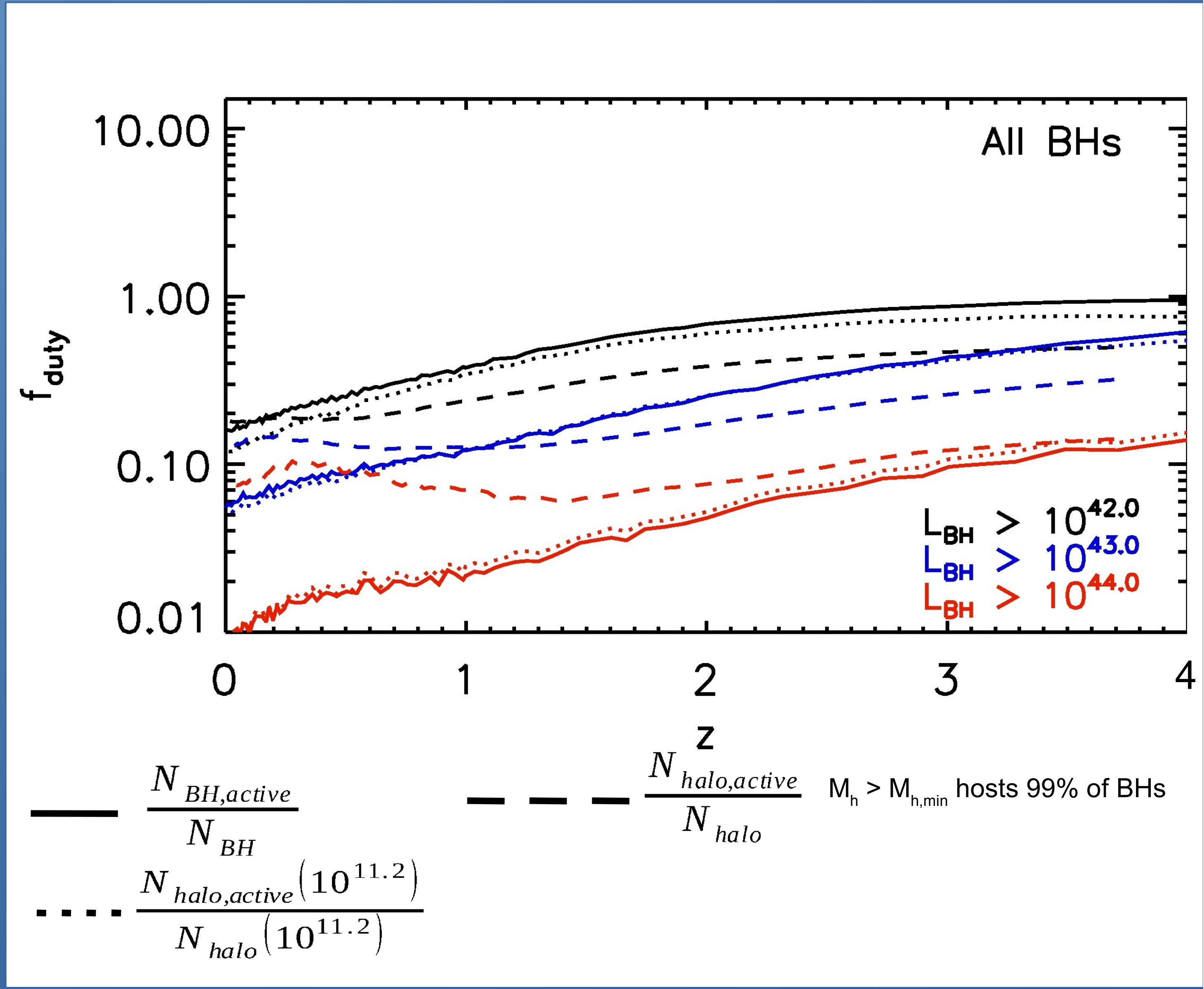
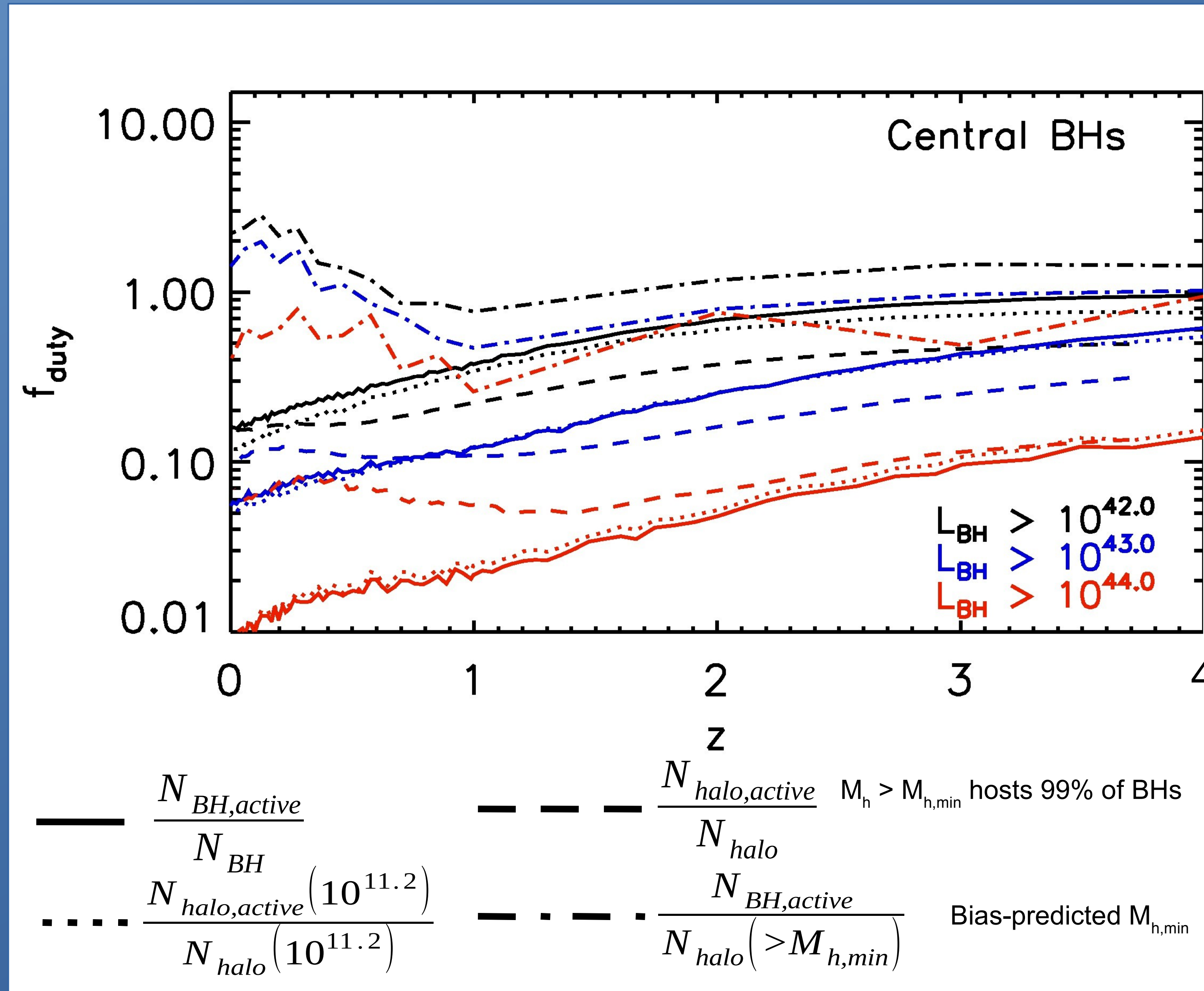


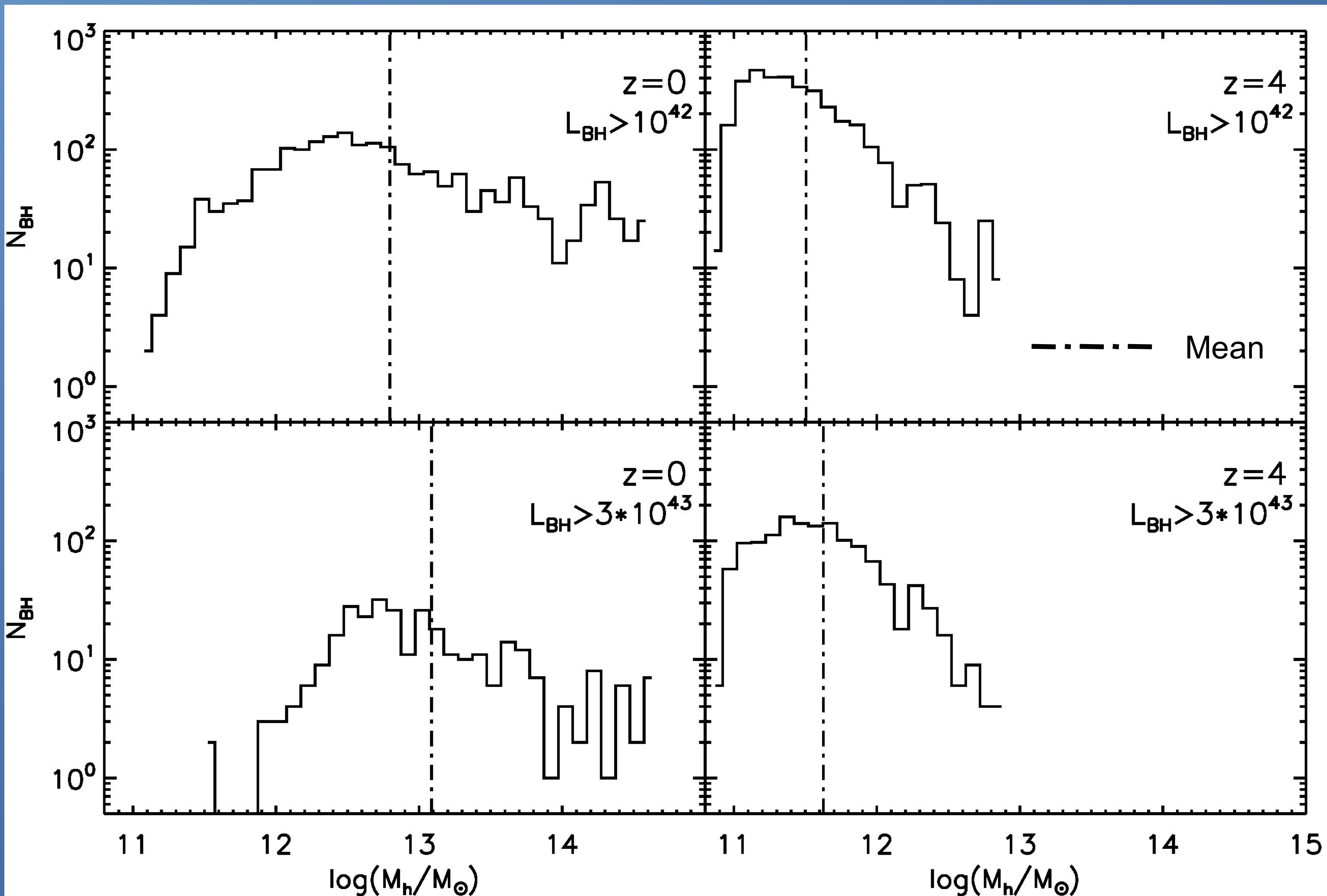
Duty Cycle Evolution

- Discrepancy caused by overestimate of halo mass + steep halo mass function

$$f_{duty} = \frac{\int_{L_{BH,min}}^{\infty} \Phi(L)\, dL}{\int_{M_{h,min}}^{\infty} \frac{dn}{dM}\, dM}$$



Host mass distribution



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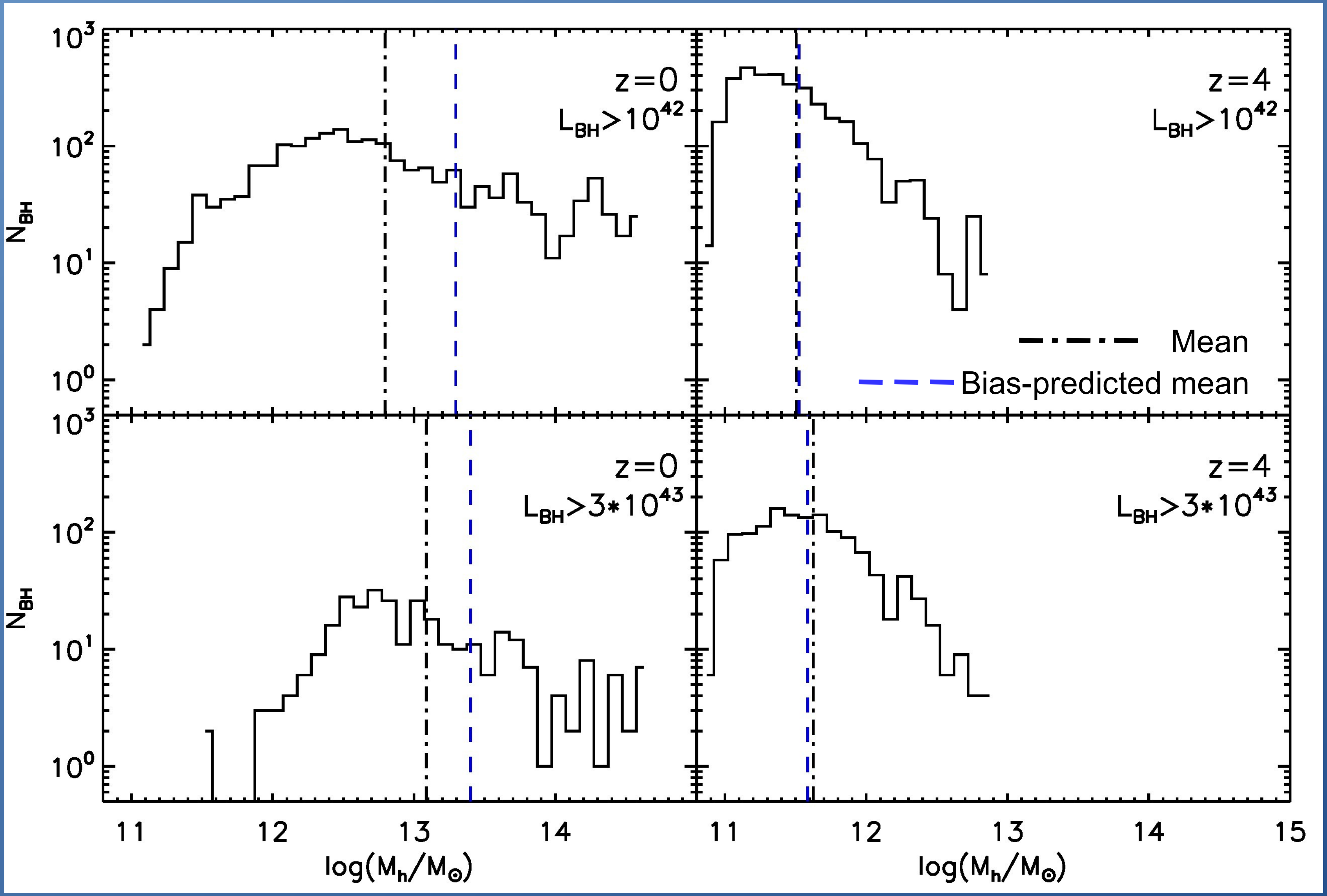

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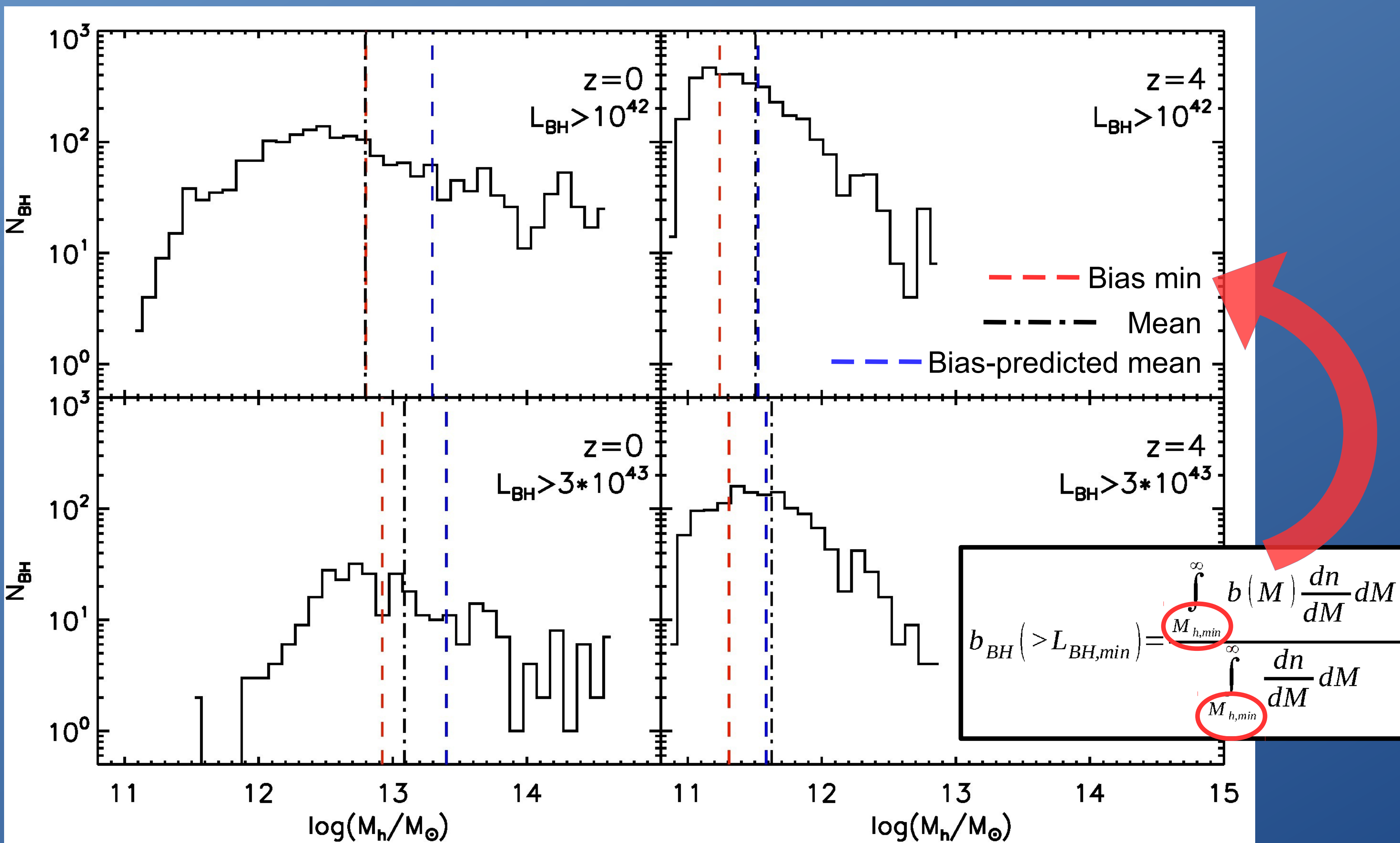
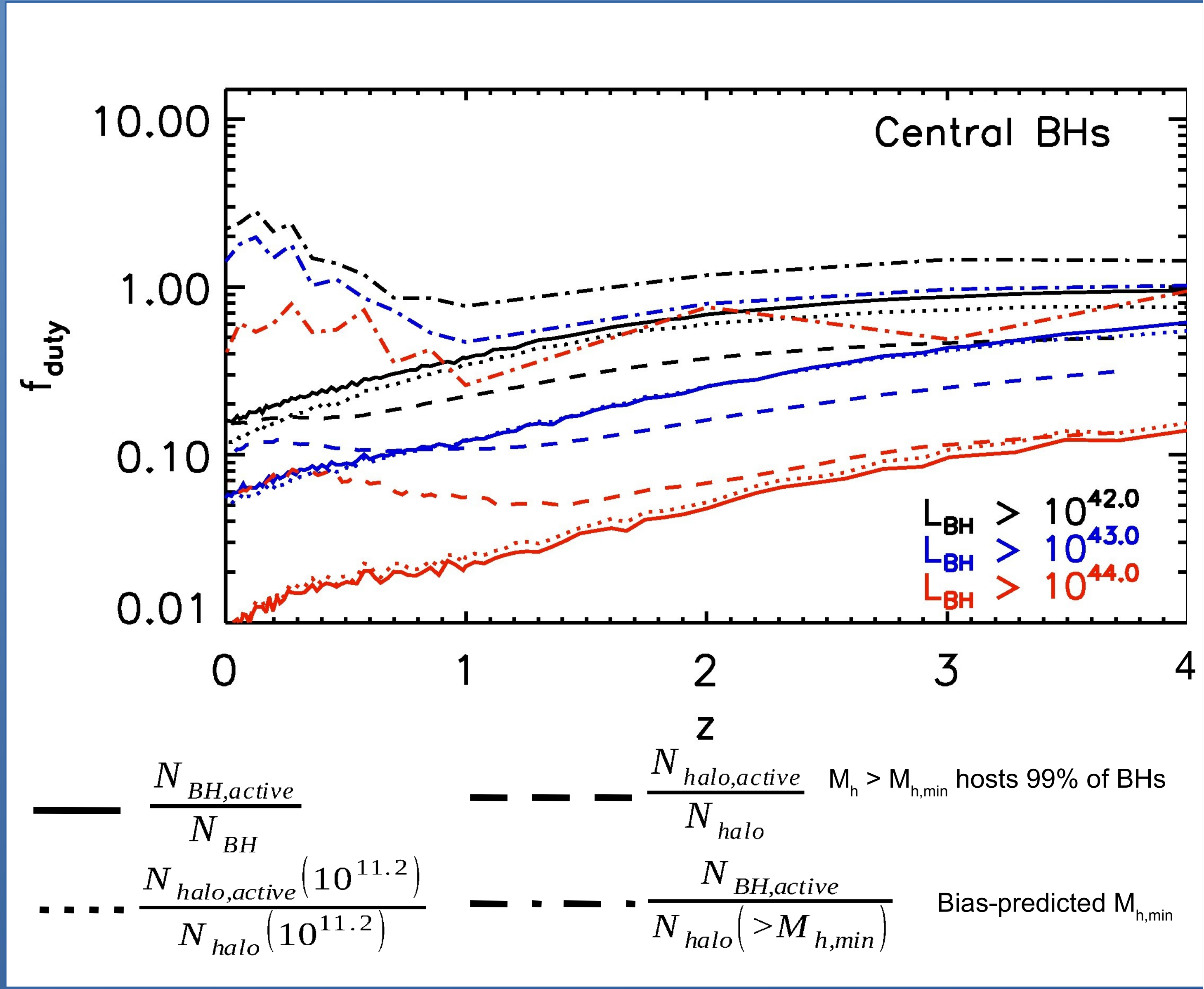


Duty Cycle Evolution

- Clustering-estimated f_{duty} is poor at low-z
- Discrepancy between AGN clustering and host halos
- Extended tail of host halo masses



Conclusions

- Duty cycle evolves smoothly with z, M_{BH}, L_{cut}
- BH duty cycle matches halo duty cycle for fixed host mass
- Clustering $\rightarrow$ duty cycle predictions only valid at high-z
  - Clustering predicted masses inaccurate at low-z