Relation between SMBH and gas properties in simulations and observations

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Bassini et al. 2019, Arxiv: 1903.03142
Gaspari et al. 2019, Arxiv: 1904.10972

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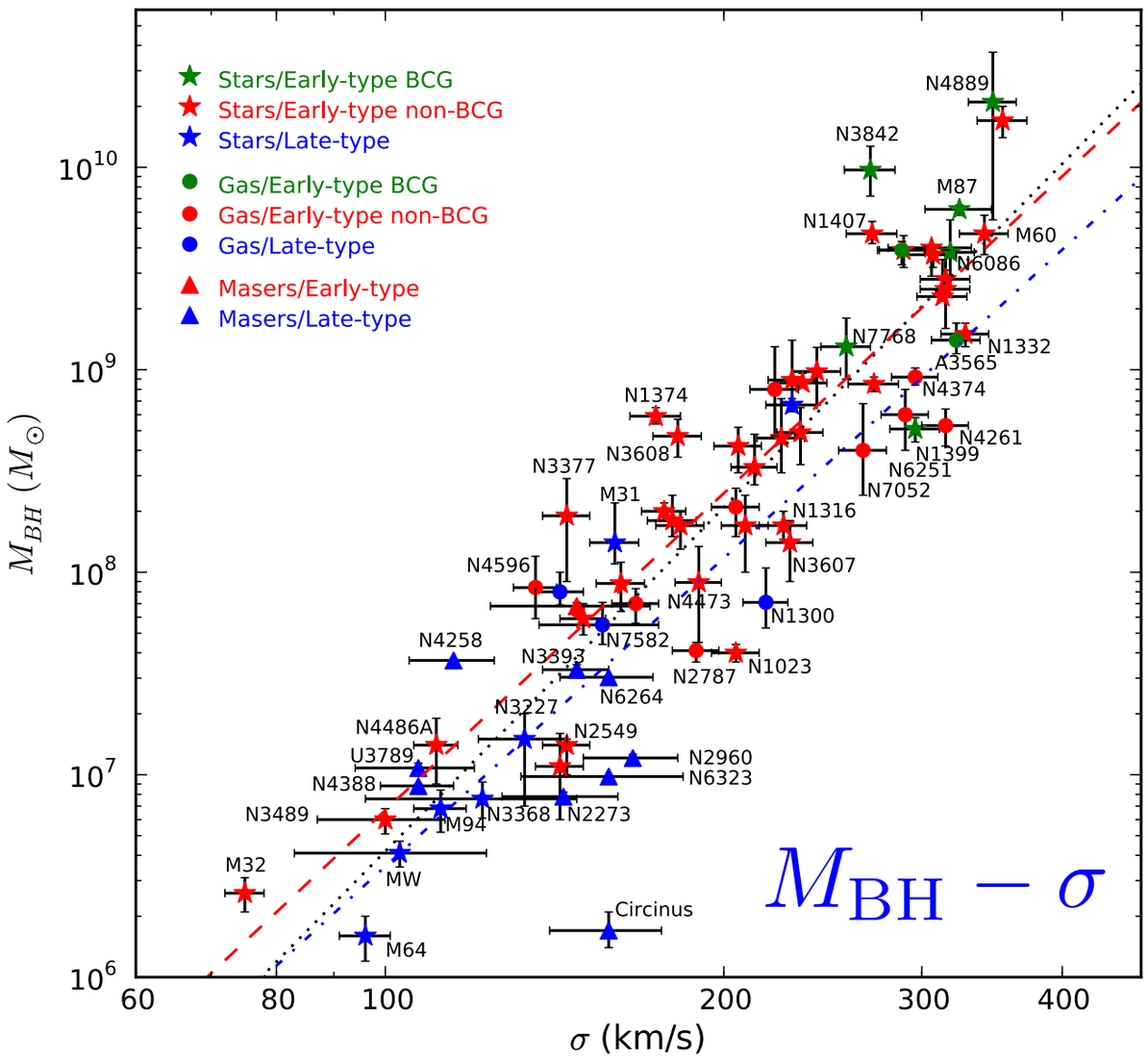
DI TRIESTE

BH mass and hosting Galaxy:



McConnel & Ma 2013

$$M_{\rm BH} - M_{\rm bulge}$$

Magorrian et al. 1998;

Marconi & Hunt 2003; Häring & Rix 2004;

Hu 2009; Sani et al. 2011; Beifiori et al. 2012;

$$M_{\rm BH} - \sigma$$

Ferrarese & Merritt 2000; Gebhardt et al. 2000;

Merritt & Ferrarese 2001; Tremaine et al. 2002;

Wyithe 2006a,b; Hu 2008; Gültekin et al. 2009;

McConnell et al. 2011; Schulze & Gebhardt 2011;

Graham et al. 2011; Beifiori et al. 2012;

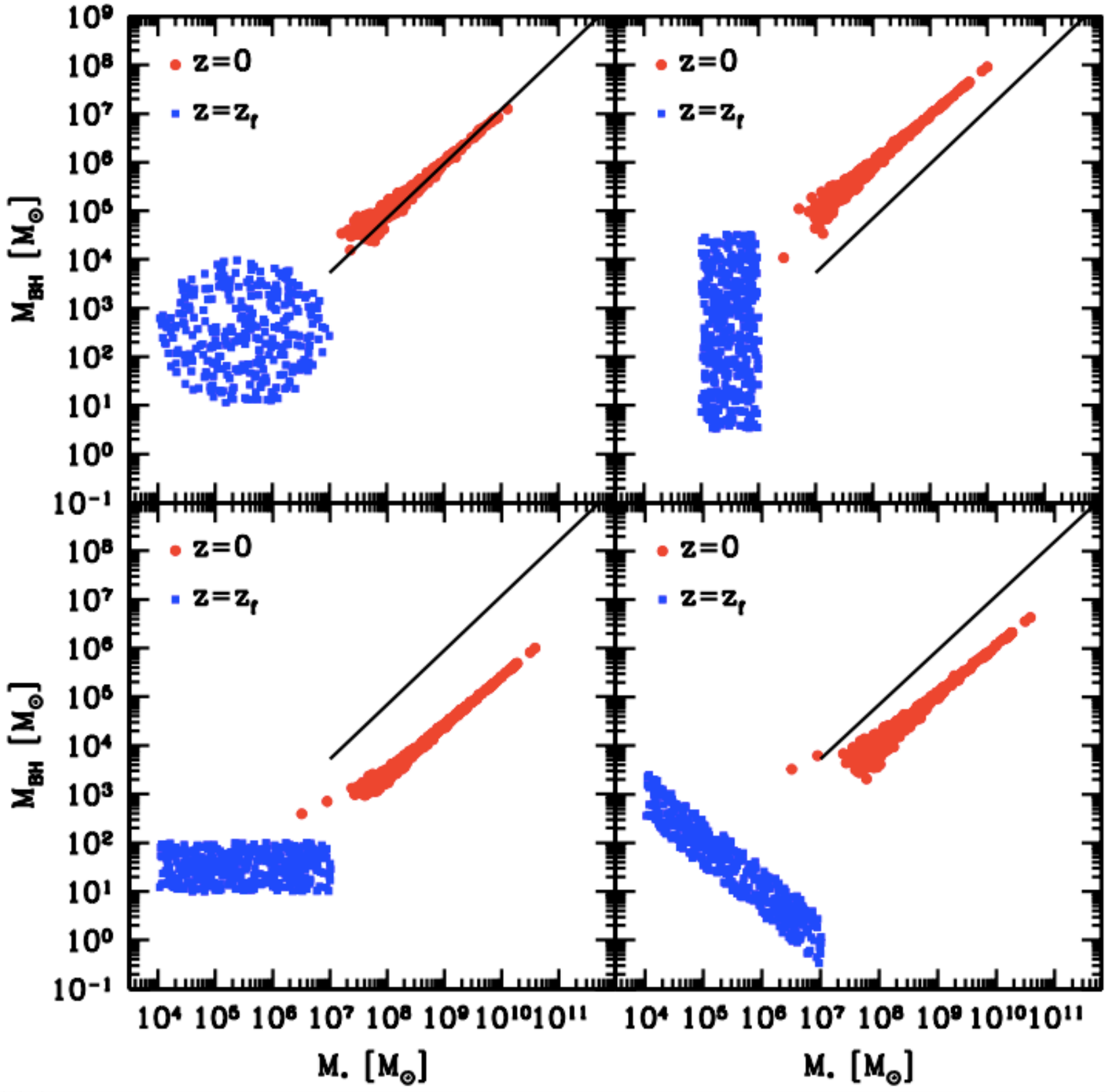
$$M_{\rm BH} - L$$

Kormendy & Gebhardt et al. 2000;

Gültekin et al. 2009; Schulze & Gebhardt 2011;

McConnell et al. 2011;

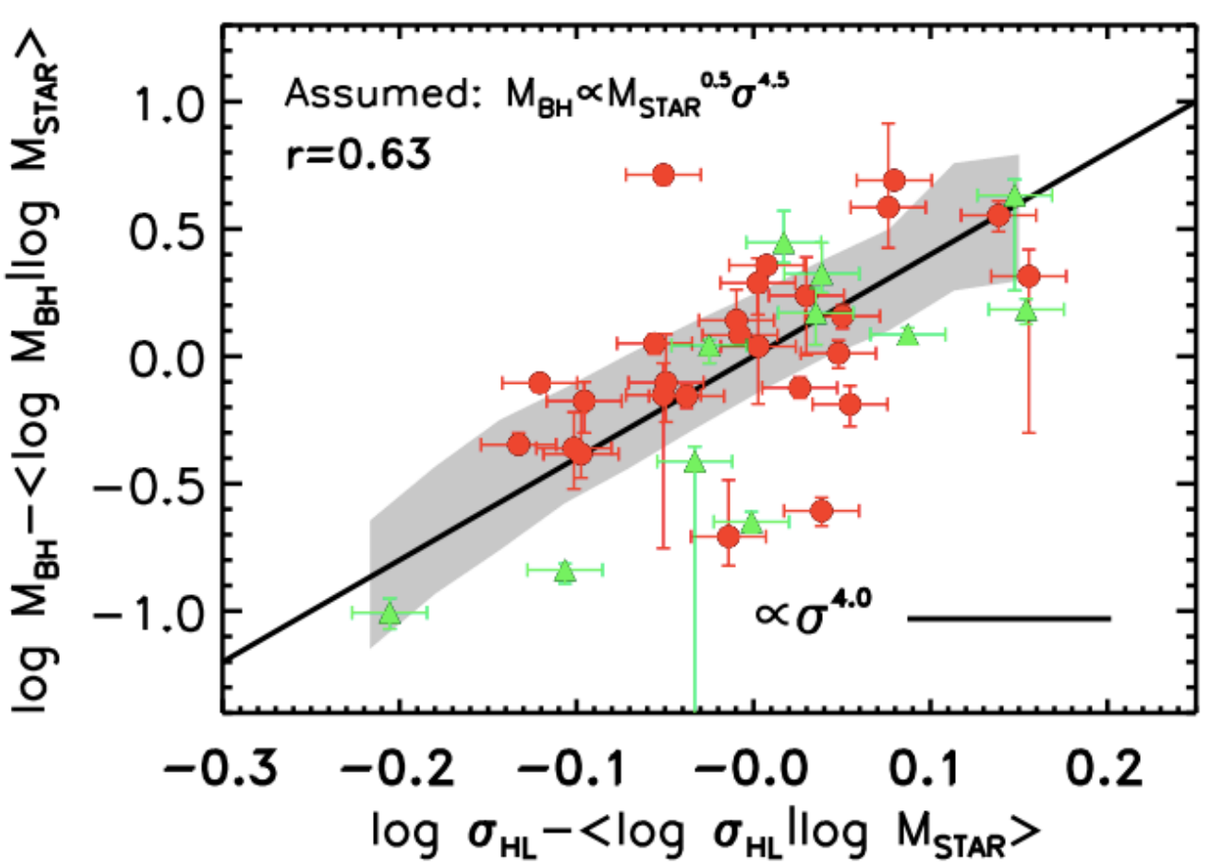
Correlation does not imply causation

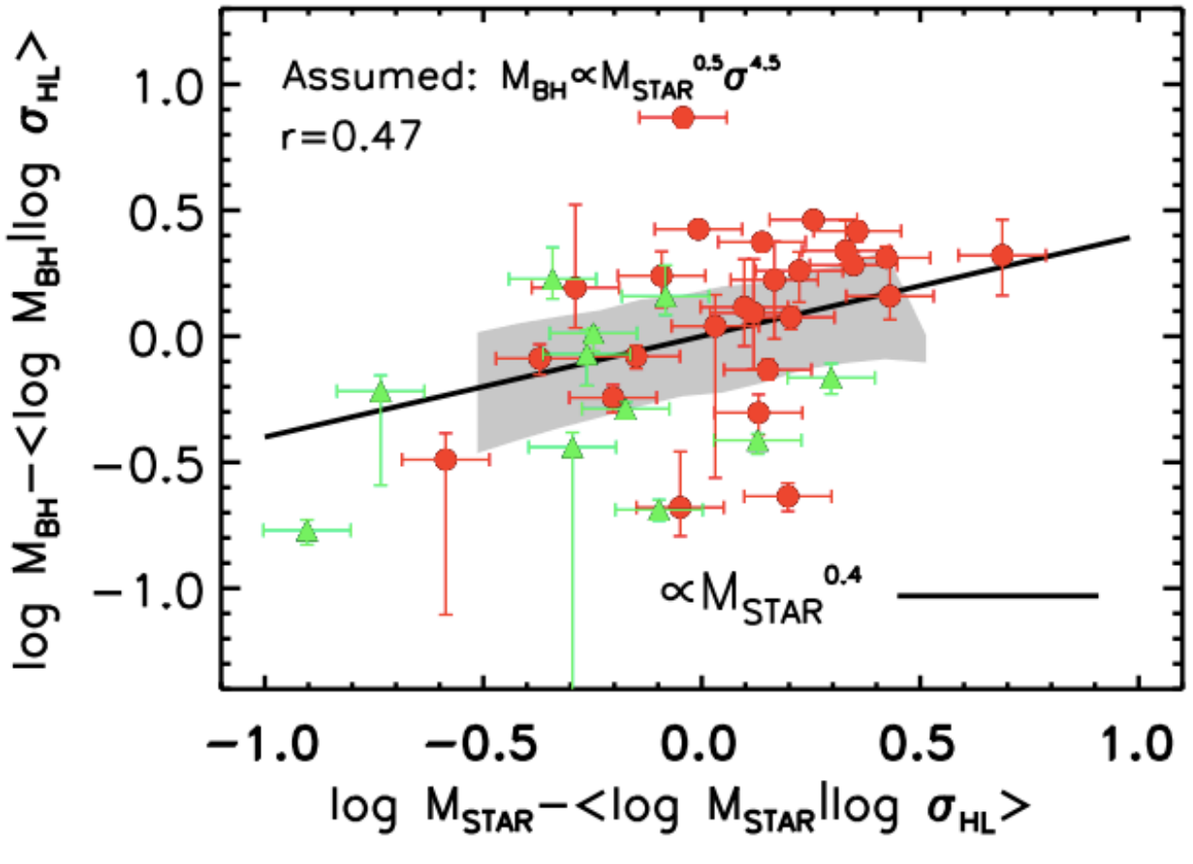


Jahnke & Macciò 2011

(see also Peng et. al 2007)

Which one is the most fundamental variable?



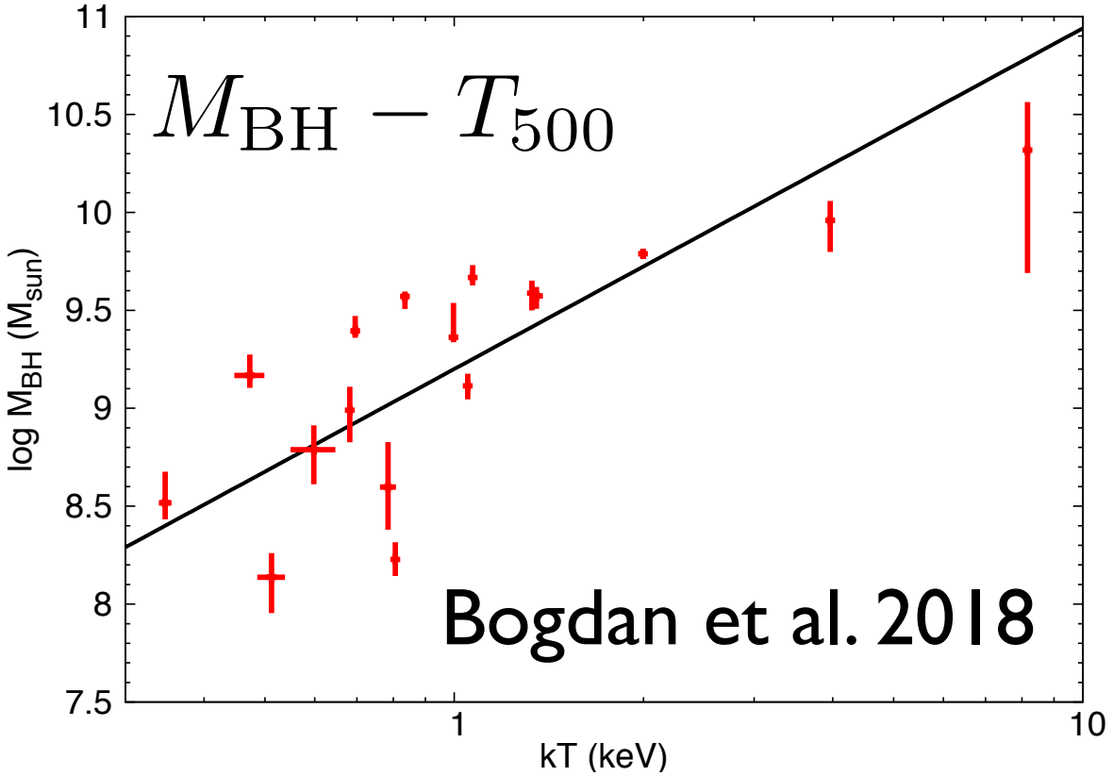


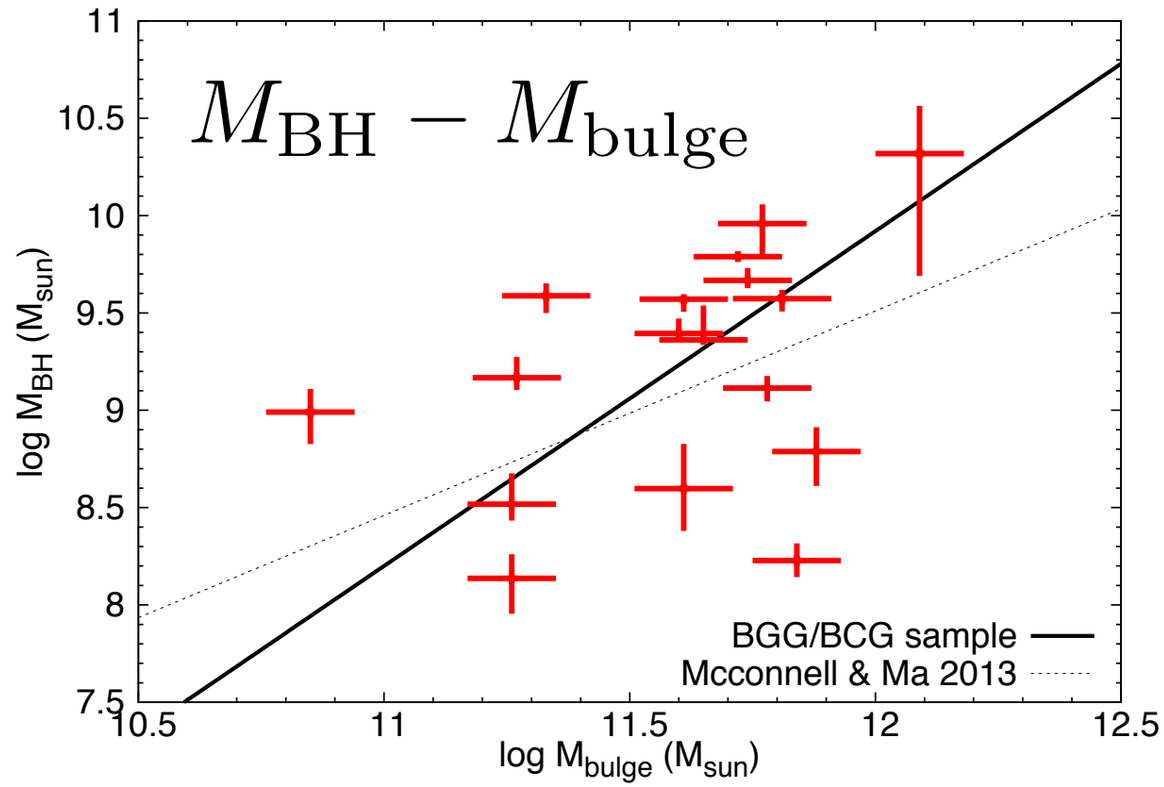
Shankar et al. 2016

residuals

More recently:

Correlation between BH mass of BCGs/BGGs and large scale properties of hosting Cluster





Scatter around Mbh-T500 lower than in Mbh-Mbulge!

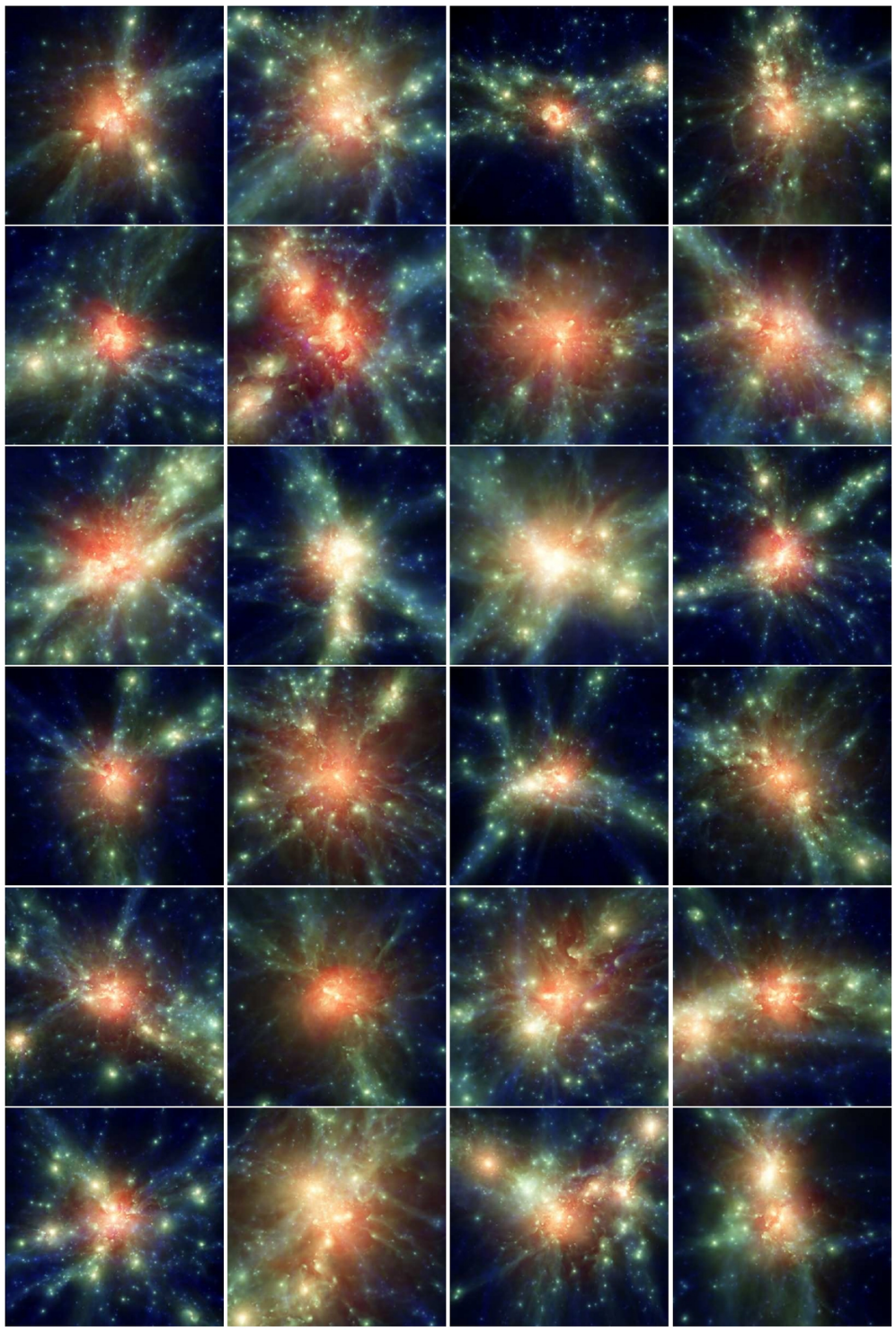
(See also Phipps et al. 2019 and Gaspari et al. 2019)

Goals of our work:

- **Employ numerical simulations to understand how $M_{\rm BH} - M_{500}$ relation sets up;**
- **How evolves with redshift;**
- **How BH mass grows.**

Bassini et al. 2019, Arxiv: 1903.03142

Numerical set up (Dianoga set)



29 Cosmological hydrodynamical zoom-in simulations extracted from a parent N-body simulation of 1.4 Gpc side

Simulations performed with the Lagrangian GADGET-3 SPH code (see Beck et al. 2016)

Subgrid models: radiative cooling, star formation and associated feedback, metal enrichment and chemical evolution, BH accretion and AGN feedback.

mass resolution:

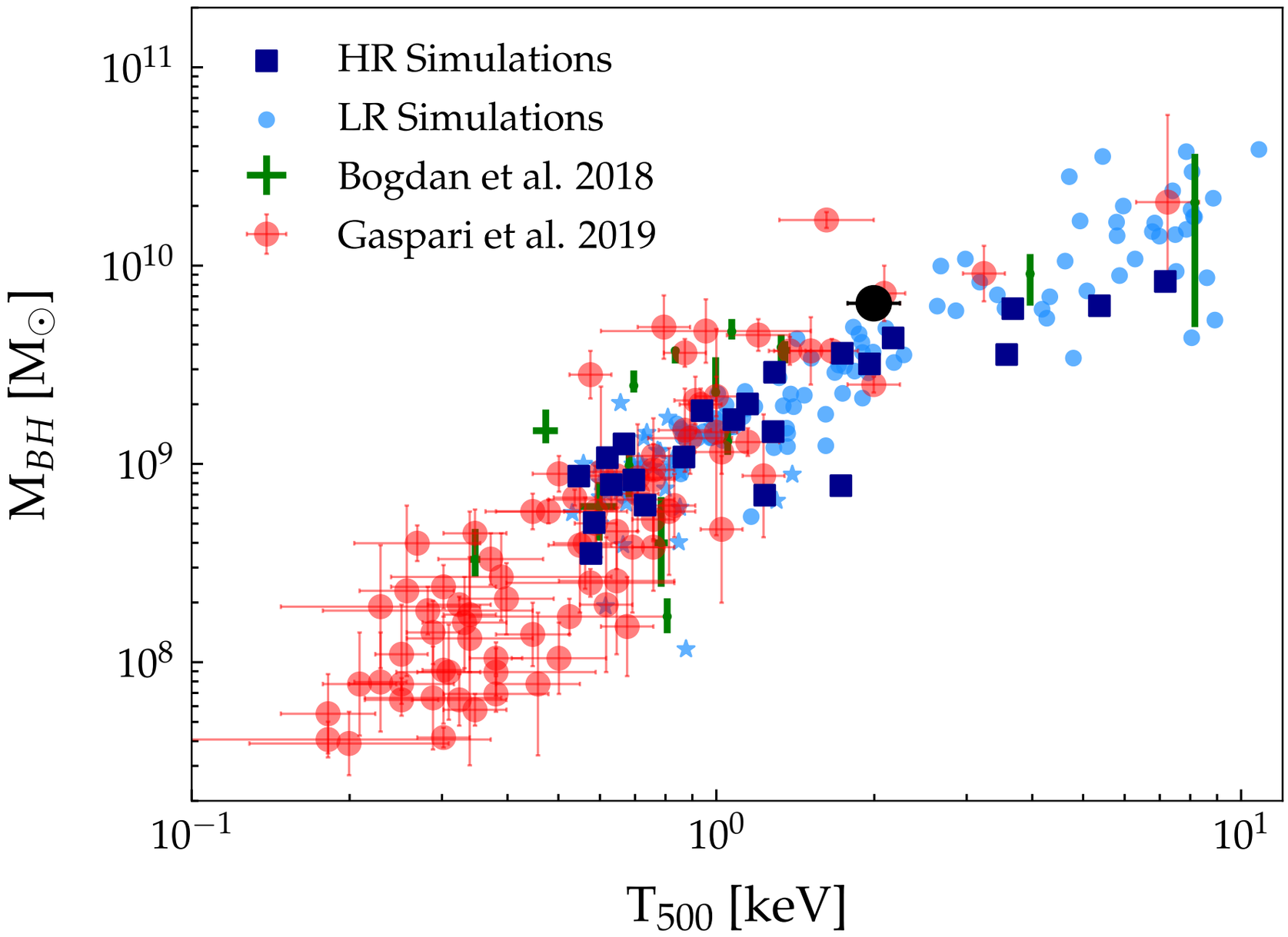
$$m_{\rm DM} = 8.47 \times 10^8 h^{-1} M_\odot$$

$$m_{\rm gas} = 1.53 \times 10^8 h^{-1} M_\odot$$

At z=0 we consider all 135 clusters with:

$$M_{500} > 1.4 \times 10^{13} M_\odot$$

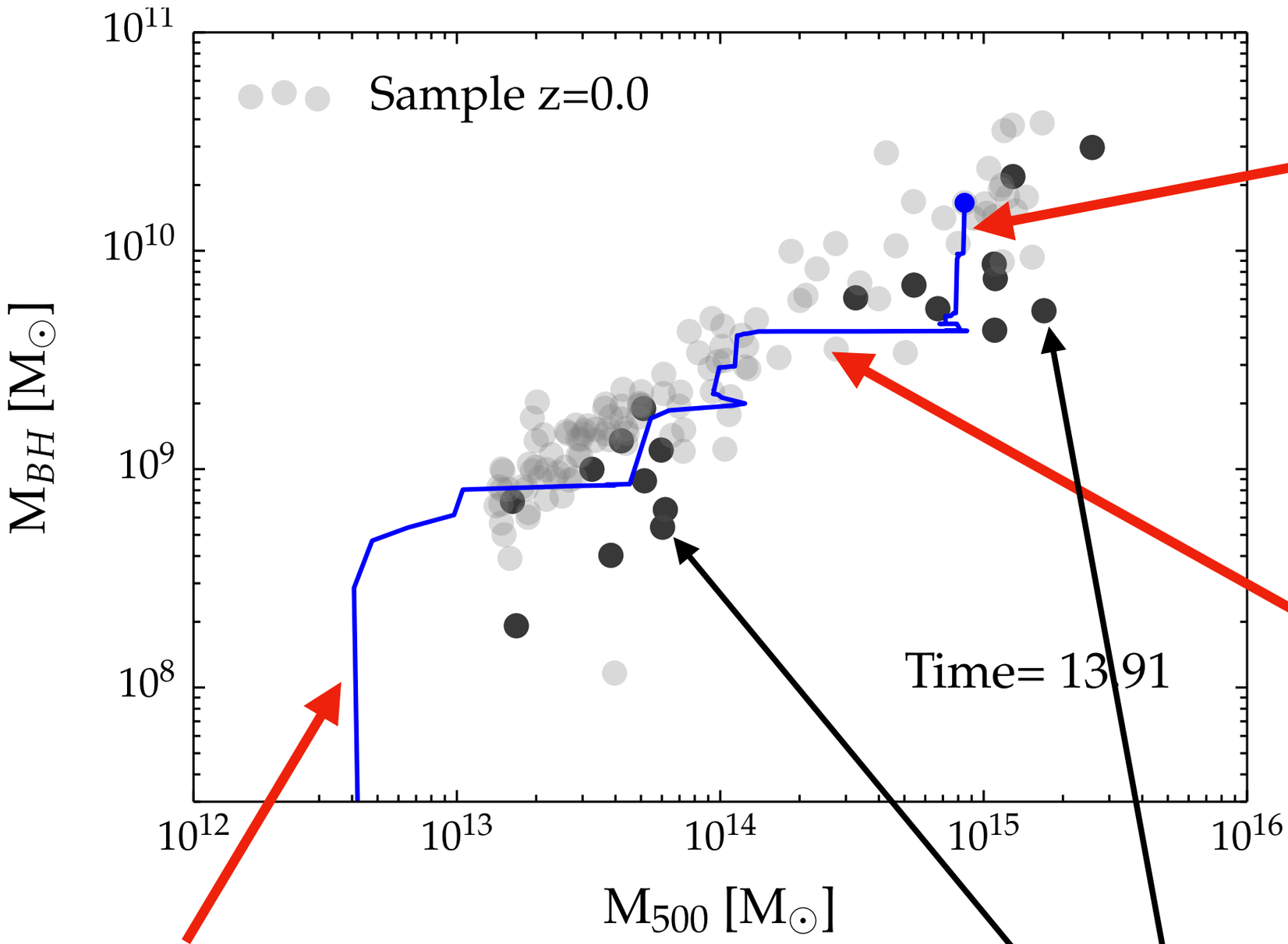
Simulation vs Observations $M_{\rm BH} \propto T_{500}^{\alpha}$



In numerical simulations, scatter comparable with the scatter around the Magorrian relation

Numerical results in agreement with Xray observations

Purpose: understand how the relation sets up



(3) Structures reach the center (BH grows for gas accretion and merger)

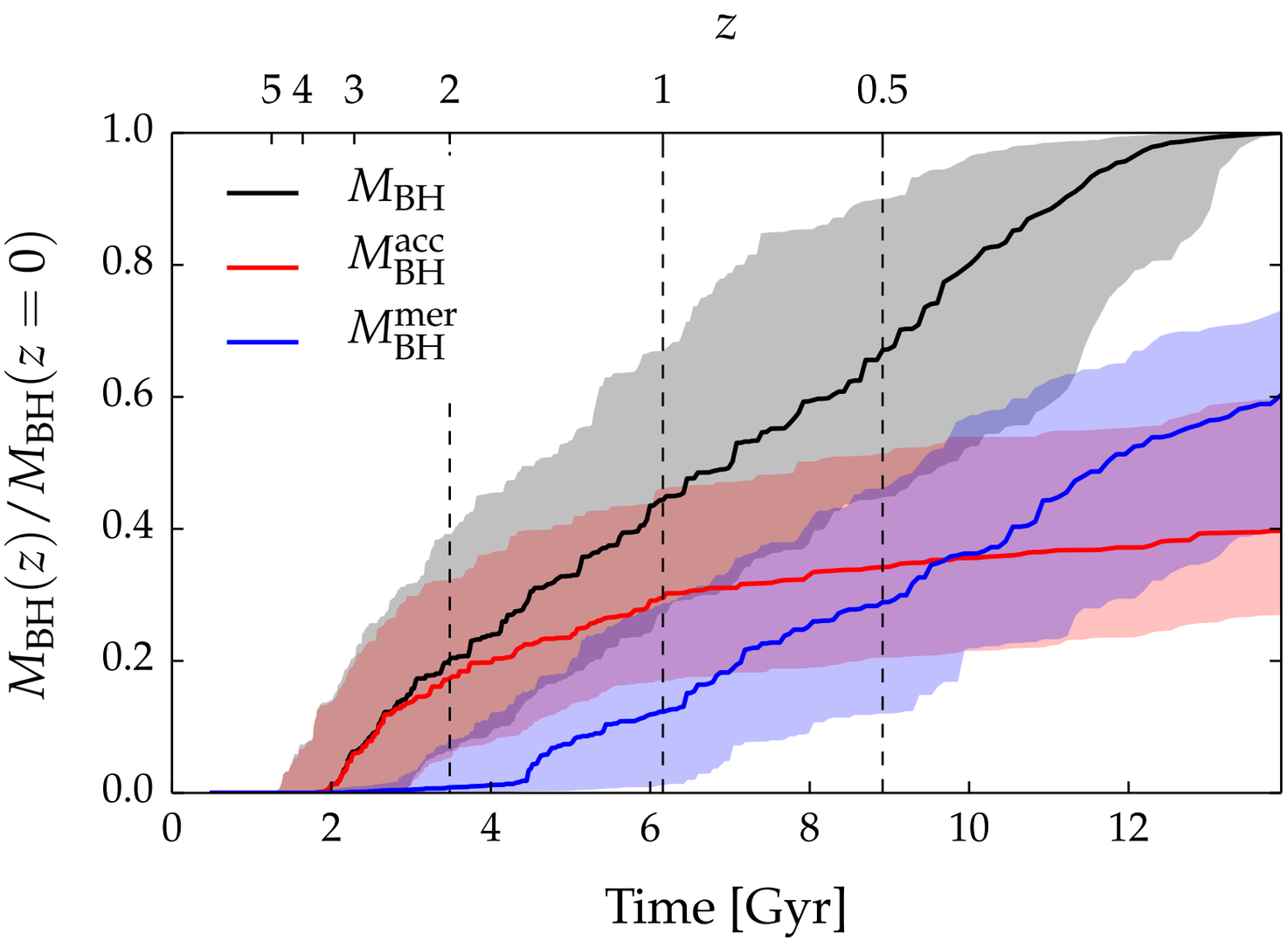
(2) Structures enter R500 (M500 grows for mergers)

(1) Rapid growth for gas accretion

Systems right after a cluster merger

(M500 grew by more than 40% in the last Gyr)

SMBHs growth:



At z>2 BHs gain mass via gas accretion. Gas is accreted at the Eddington limit;

At z<2 gas accretion slows down with an accretion rate which is a fraction of the Eddington limit;

At z<1 BH-BH mergers are the main channel for SMBH mass growth;

At z=0 the two component equally contribute to the total mass of SMBHs

Conclusions for $M_{\rm BH} - M_{500}$ relation :

- At z>2 BH mass grows by rapid gas accretion and systems set on the relation;

- Once on the relation, systems evolve as a stairway (structures enter R500 → M500 grows move towards the center → MBH grows via 2 channels)

- Massive cluster gain more mass wrt central BH → relation becomes shallower with time;

- Both masses (gas accreted & BH-BH merger) correlate with M500

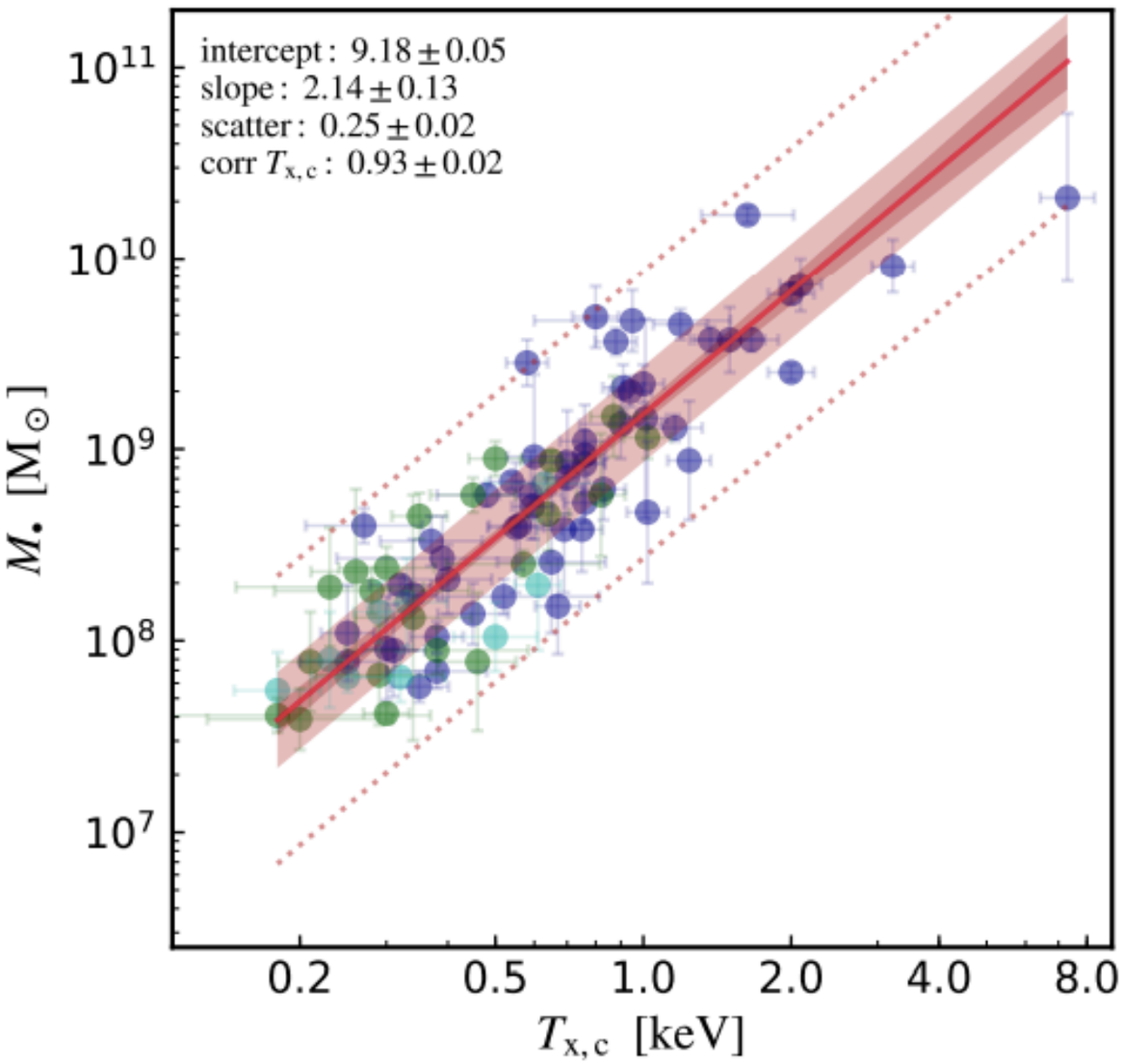
- Gas accretion dominate BH mass growth at z>2
  BH-BH mergers dominate BH mass growth at z<1

X-RAY HALO SCALING RELATIONS OF SUPERMASSIVE BLACK HOLES

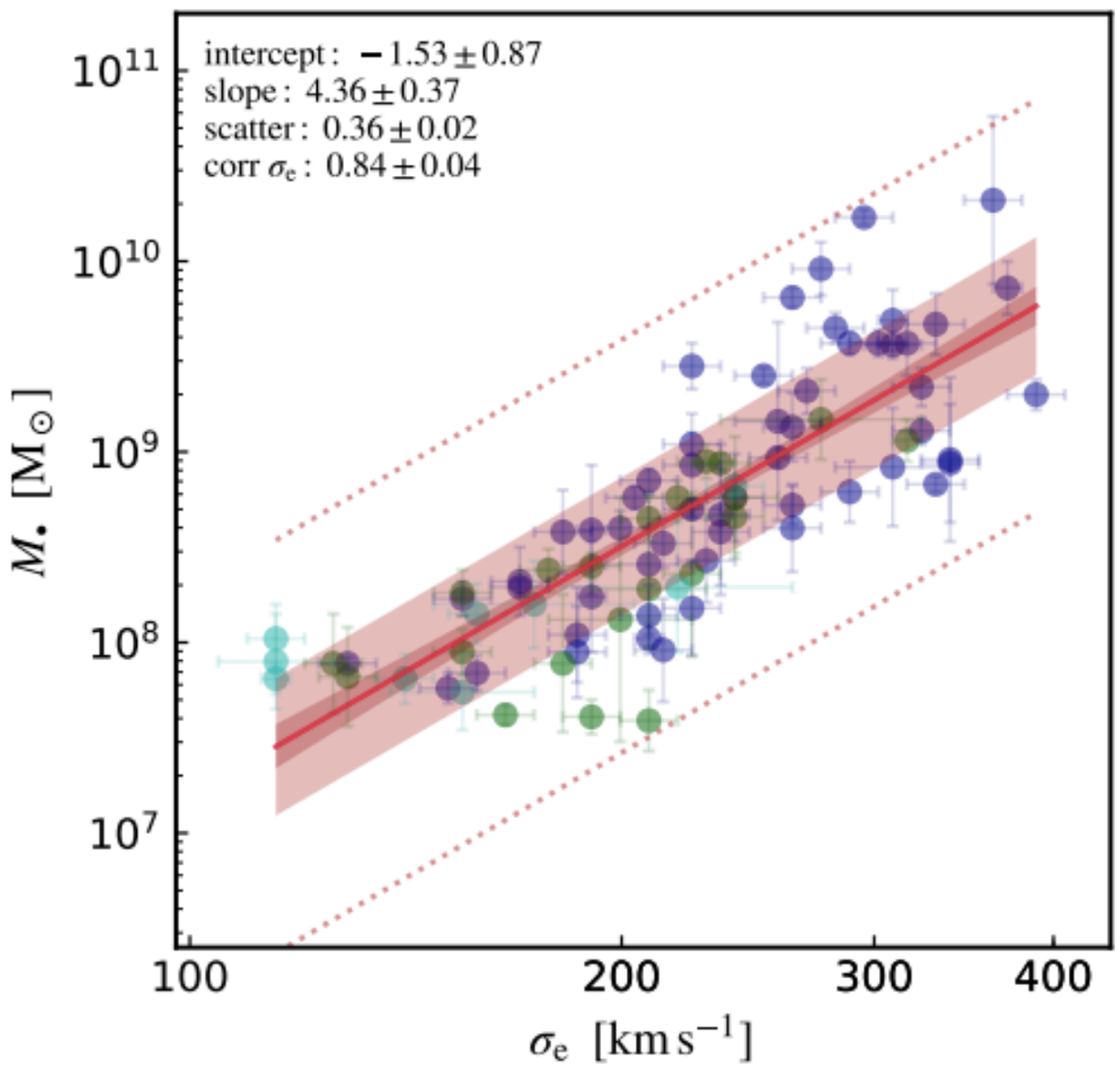
Comprehensive study of the correlations between the (direct) masses of supermassive black holes (SMBHs) and X-ray hot halo properties, by using both a Bayesian analysis of archival datasets and physics-driven theoretical models.

Gaspari et al. 2019, Arxiv: 1904.10972

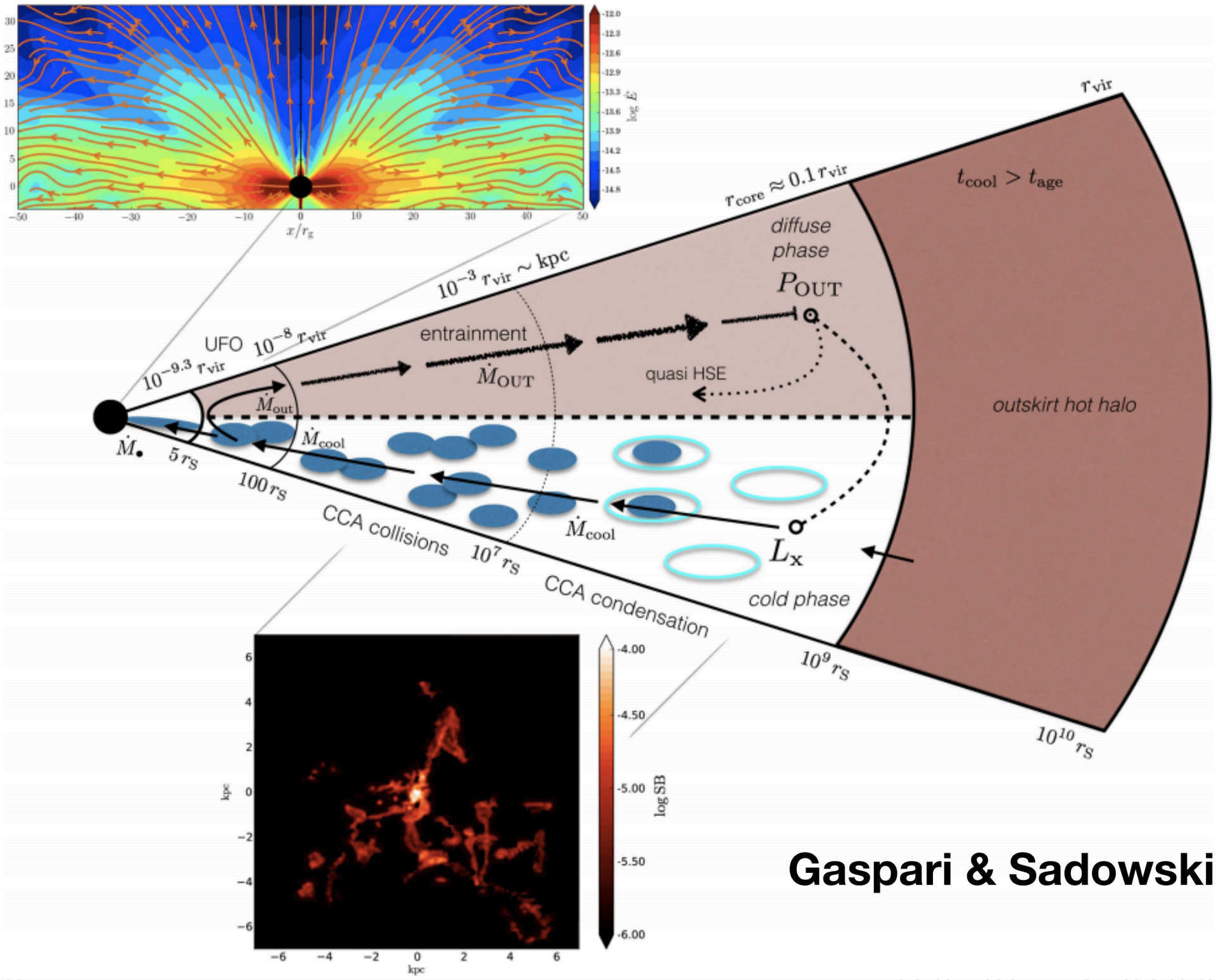
$$M_\bullet \propto T_X^{\alpha}$$



$$M_\bullet \propto \sigma_e^{\beta}$$

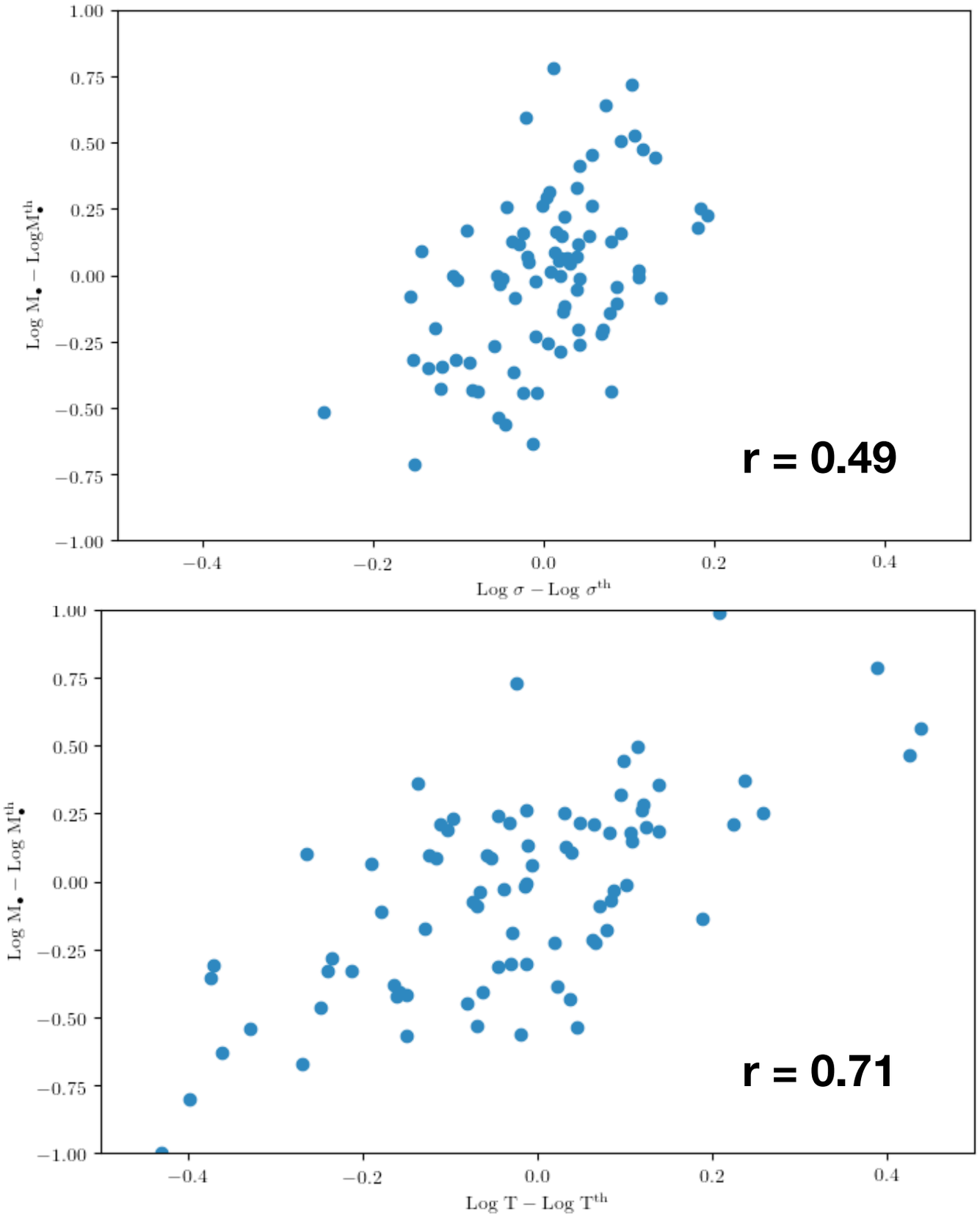


Theoretical model: Chaotic Cold Accretion (CCA)



Gaspari & Sadowski 2017

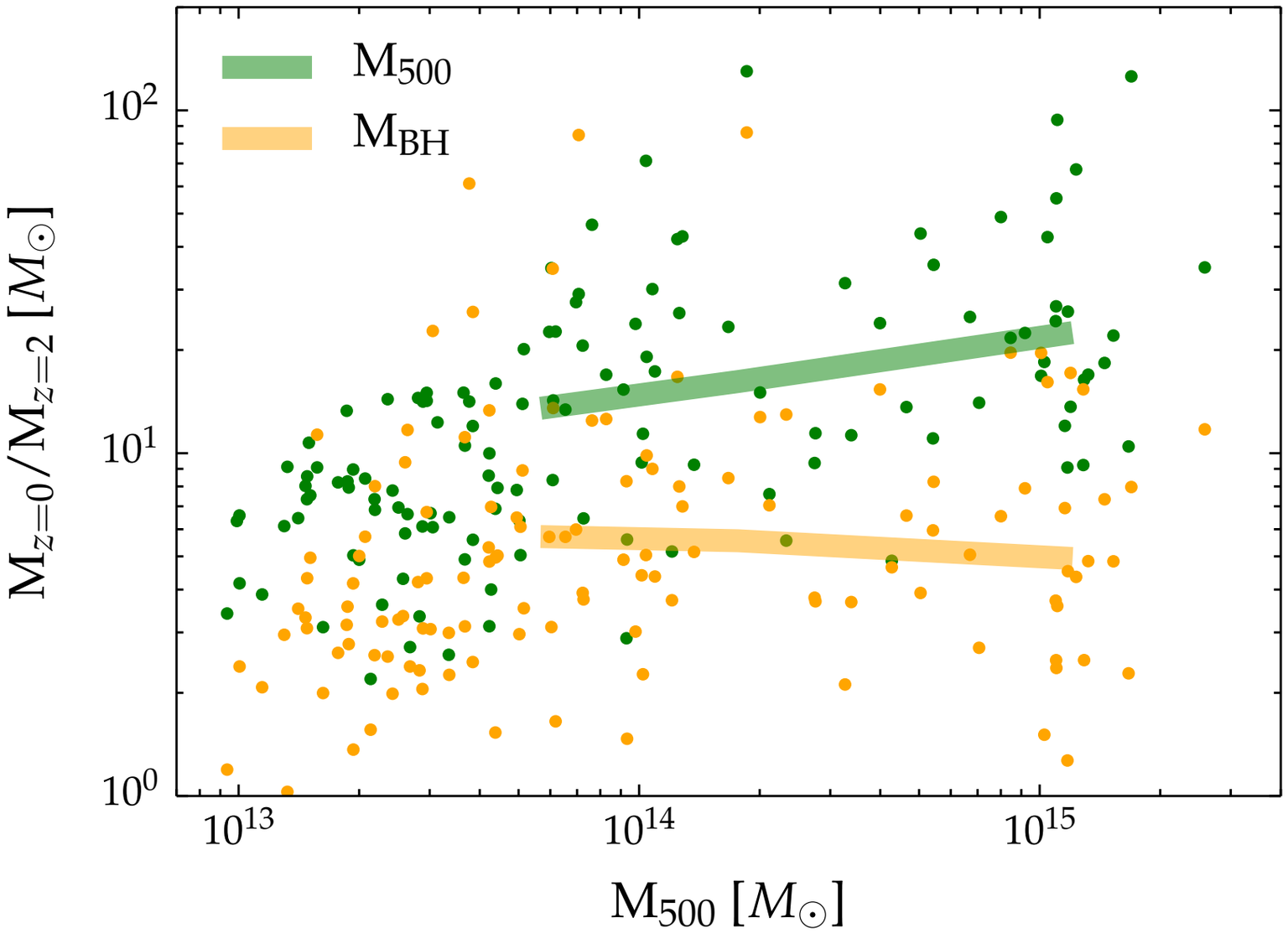
What about residuals?



At fixed temperature

At fixed sigma

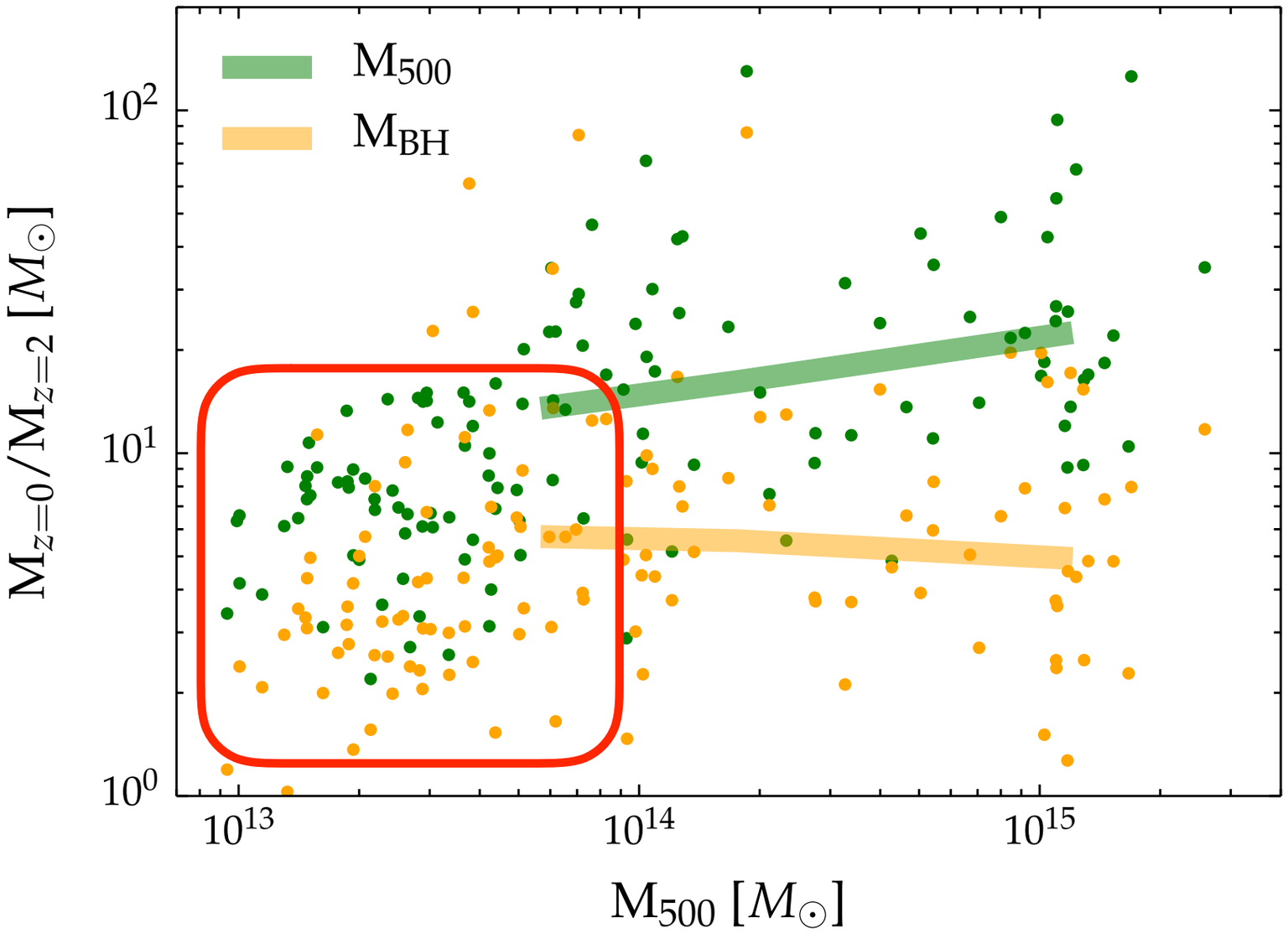
Evolution of M500 and BH mass



Ratio between M500 at z=0 and M500 at z=2 vs m500 at z=0

Ratio between BH mass at z=0 and BH mass at z=2 vs M500 at z=0

Evolution of M500 and BH mass



Ratio between M500 at z=0 and M500 at z=2 vs m500 at z=0

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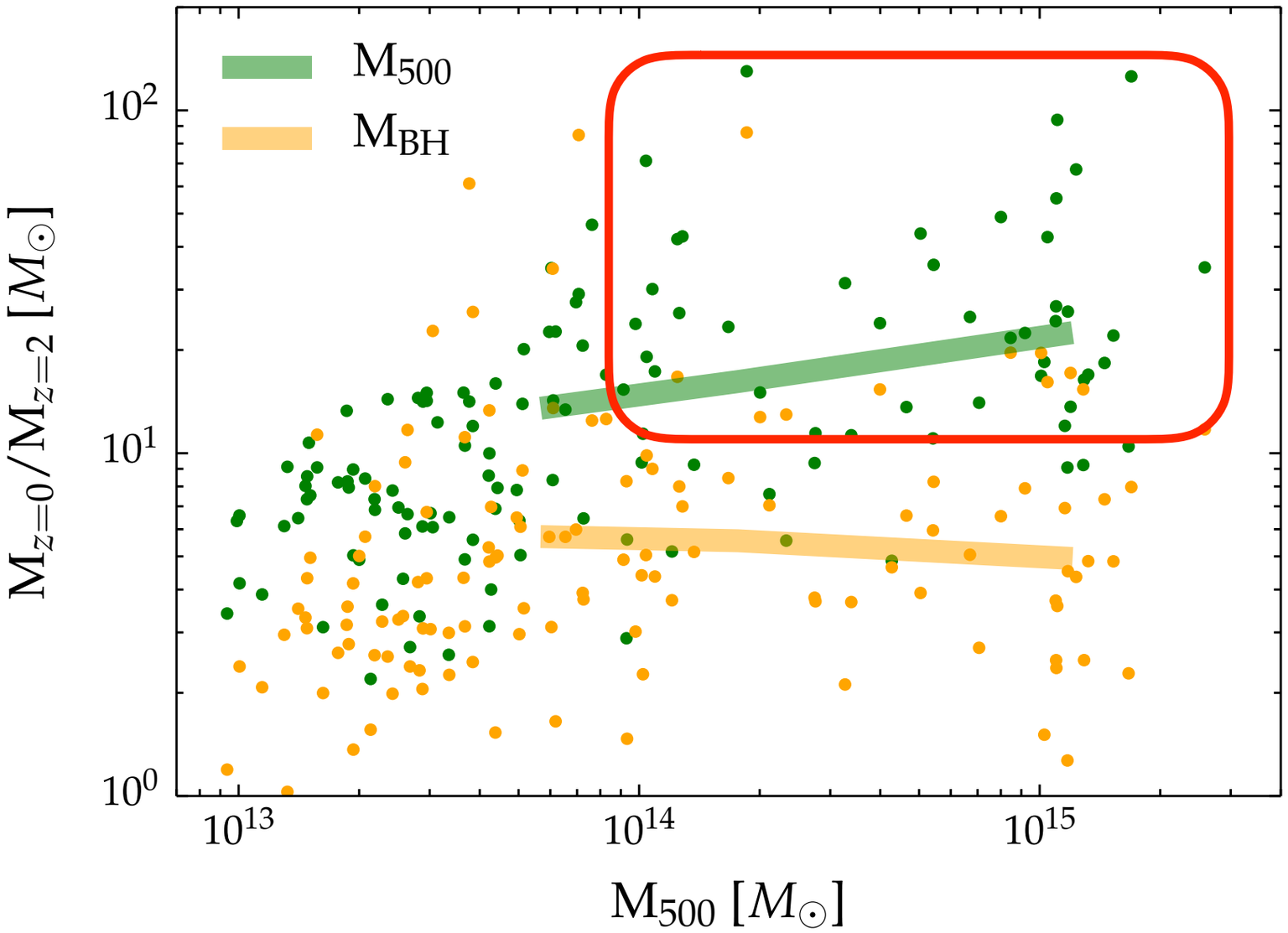
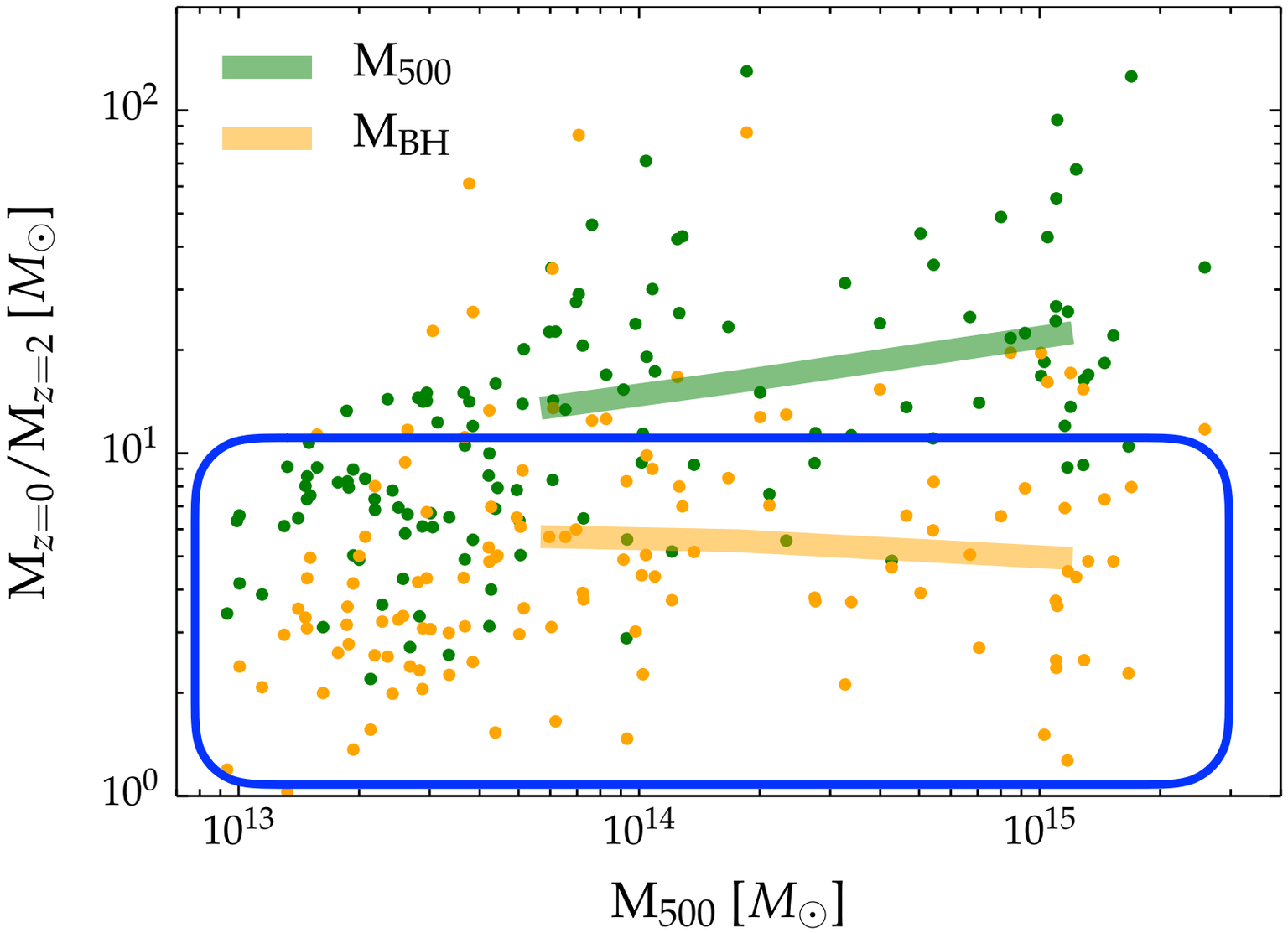
Evolution of M500 and BH mass



Ratio between M500 at z=0 and M500 at z=2 vs m500 at z=0

Ratio between BH mass at z=0 and BH mass at z=2 vs M500 at z=0

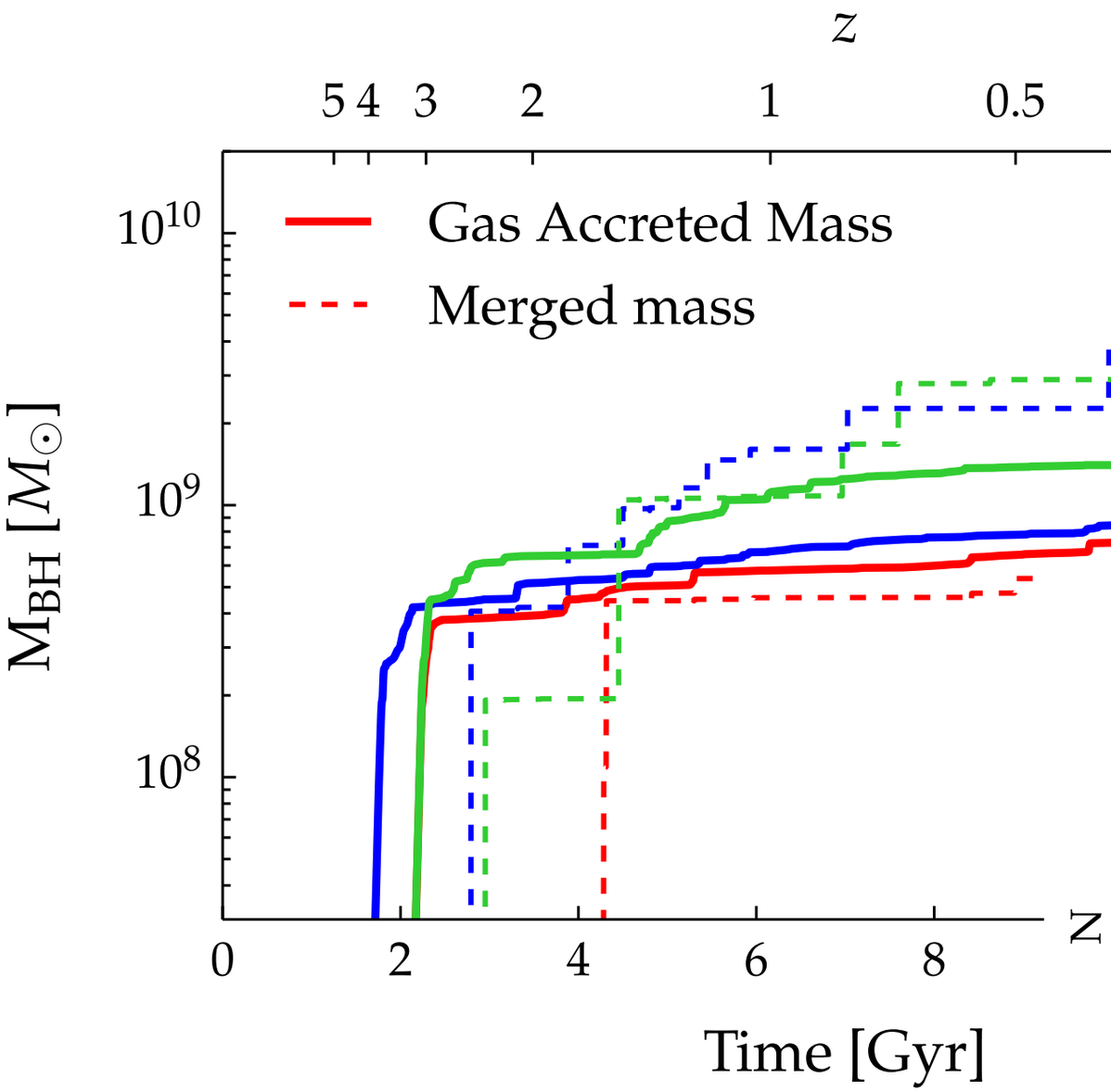
Evolution of M500 and BH mass



Ratio between M500 at z=0 and M500 at z=2 vs m500 at z=0

Ratio between BH mass at z=0 and BH mass at z=2 vs M500 at z=0

BH Mass evolution

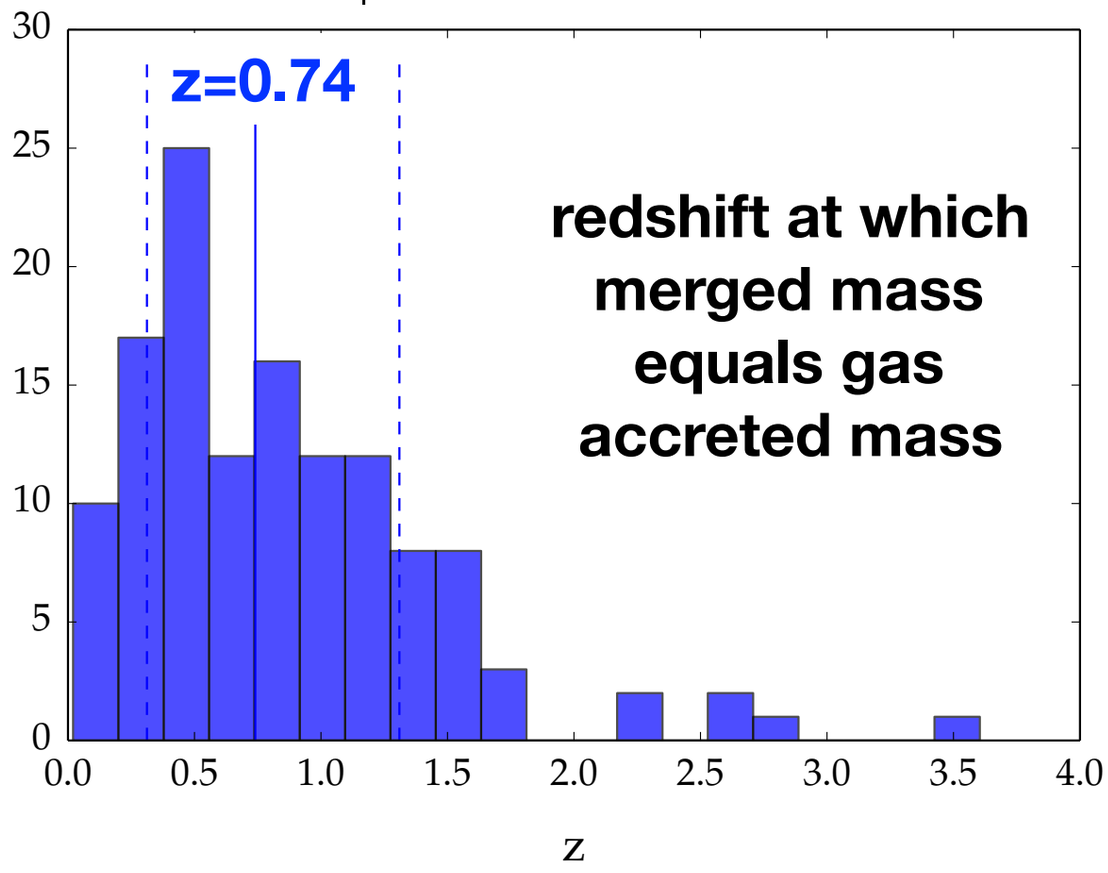


BH mass evolution of three BHs divided into two channels:

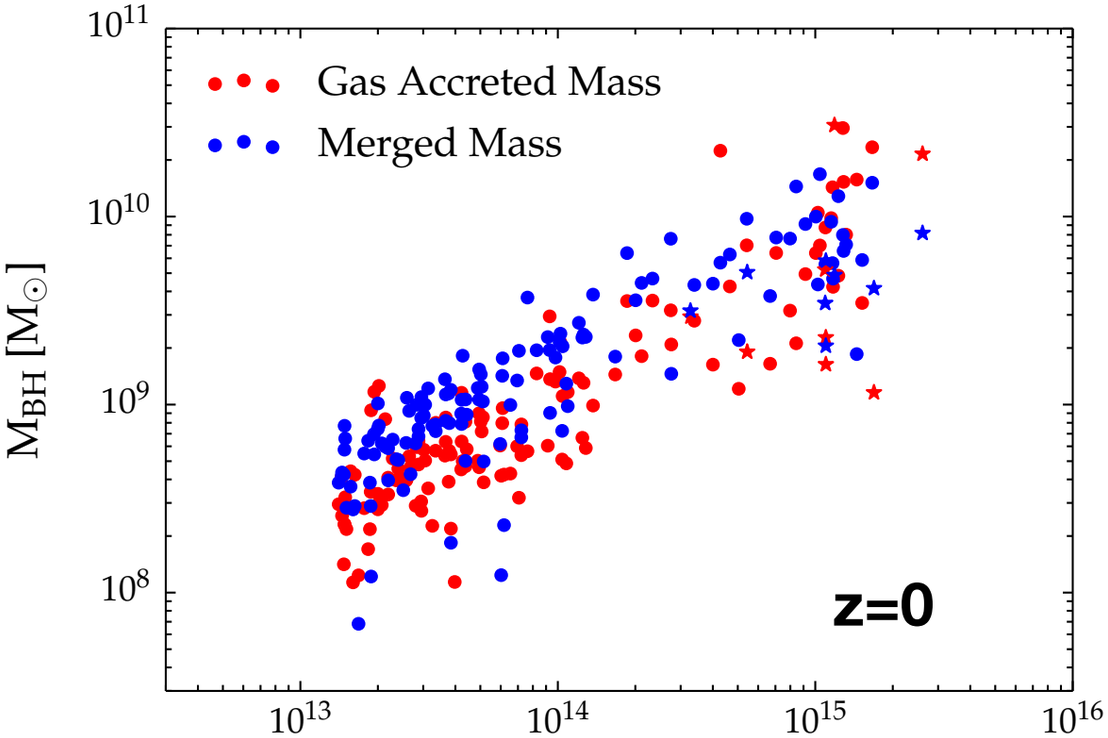
Gas accretion

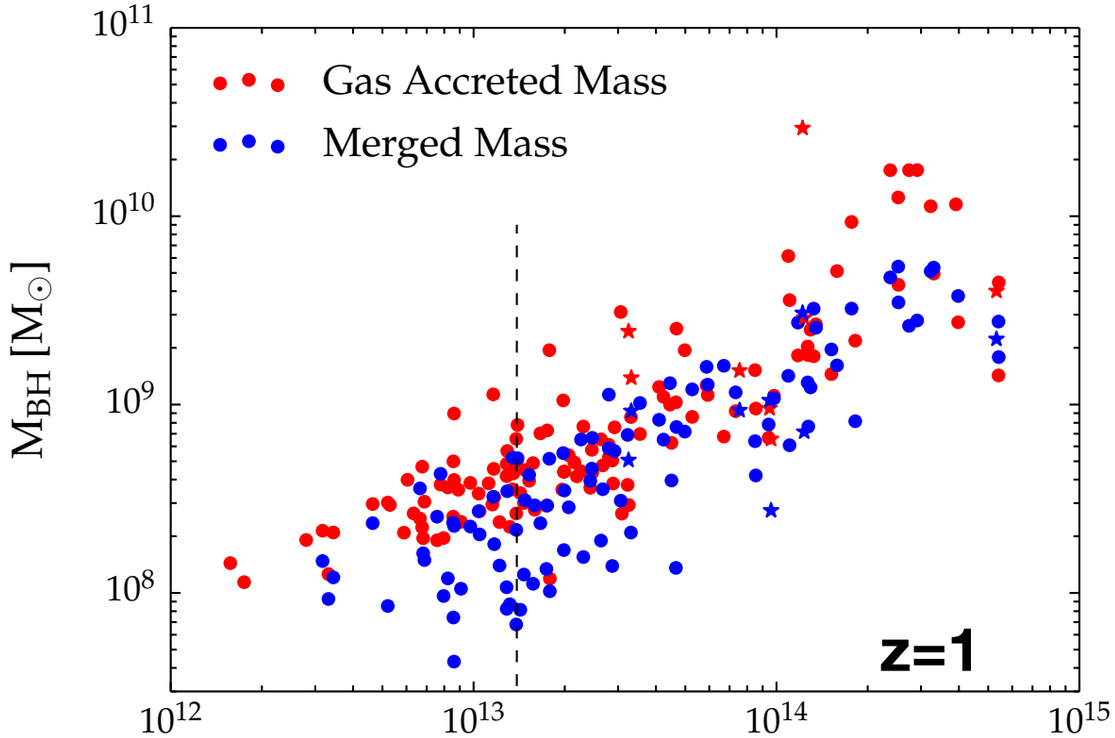
and

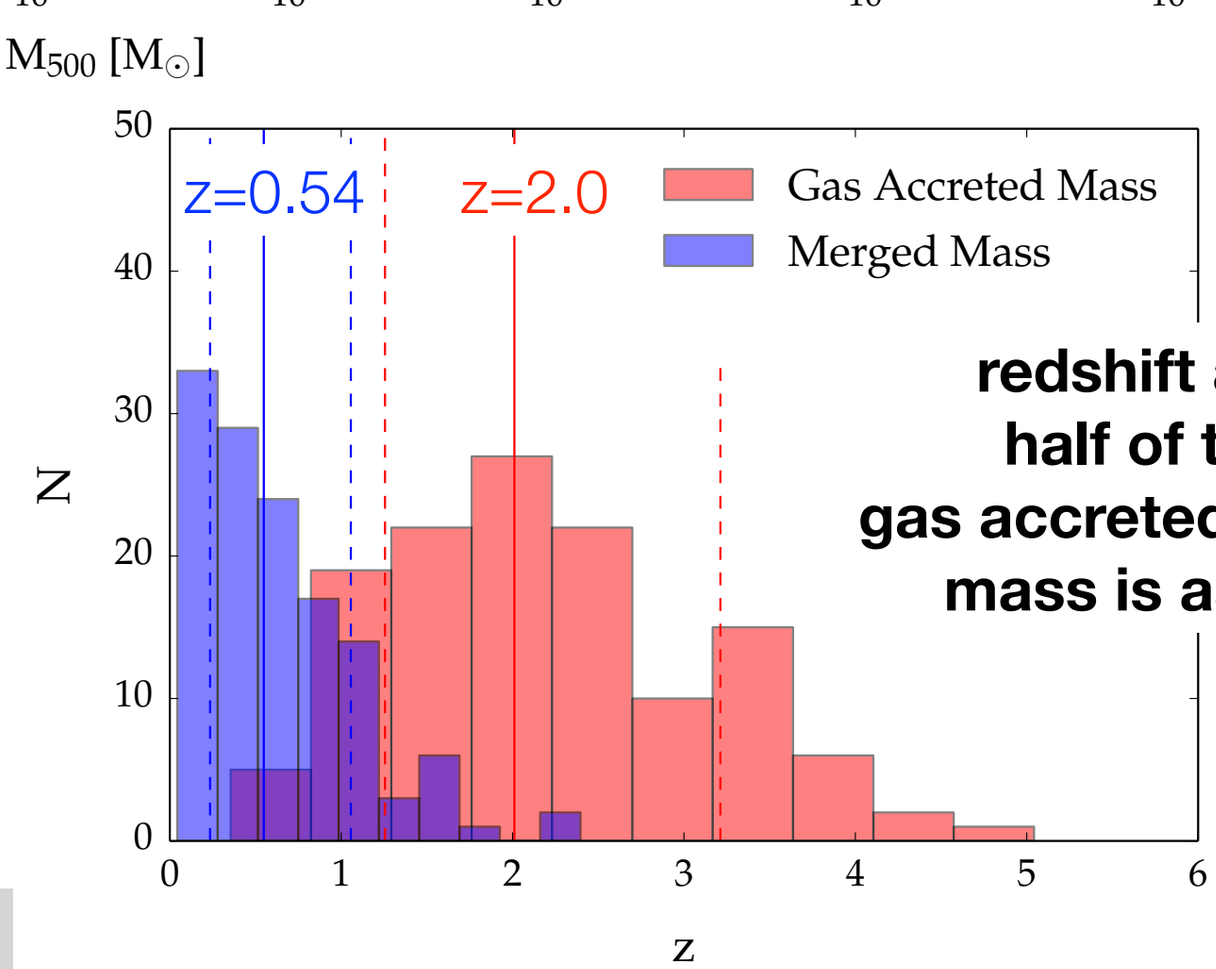
Merger



Relation between BH mass components and M500







redshift at which half of the final gas accreted/merged BH mass is assembled

T

$M_\star$

M_{BH}

M_{BH}^{gas}

M_{BH}^{mer}

z=1

z=0

Questions addressed:

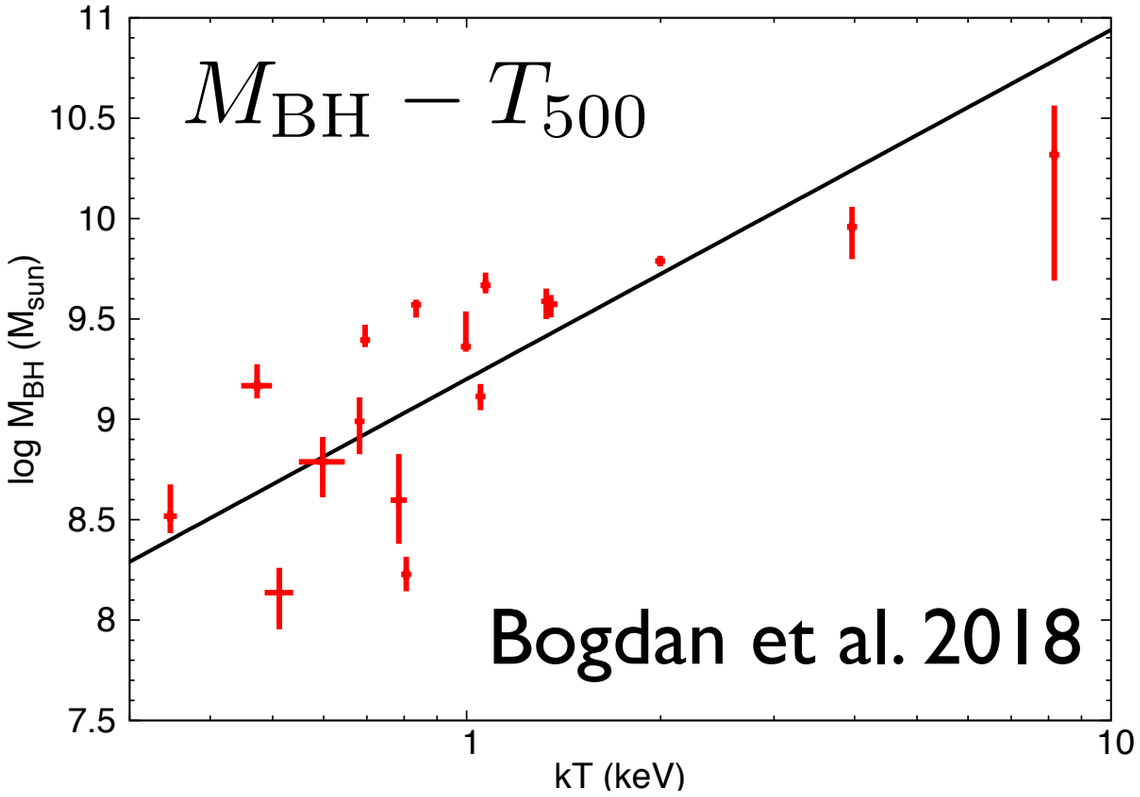
- Does SMBHs in BCGs correlate with global properties of hosting cluster?
- Does this relation evolve with redshift?
- How does the relation set up?
- Is the scatter around this relation lower than in $M_{\rm BH} - M_{\star}$

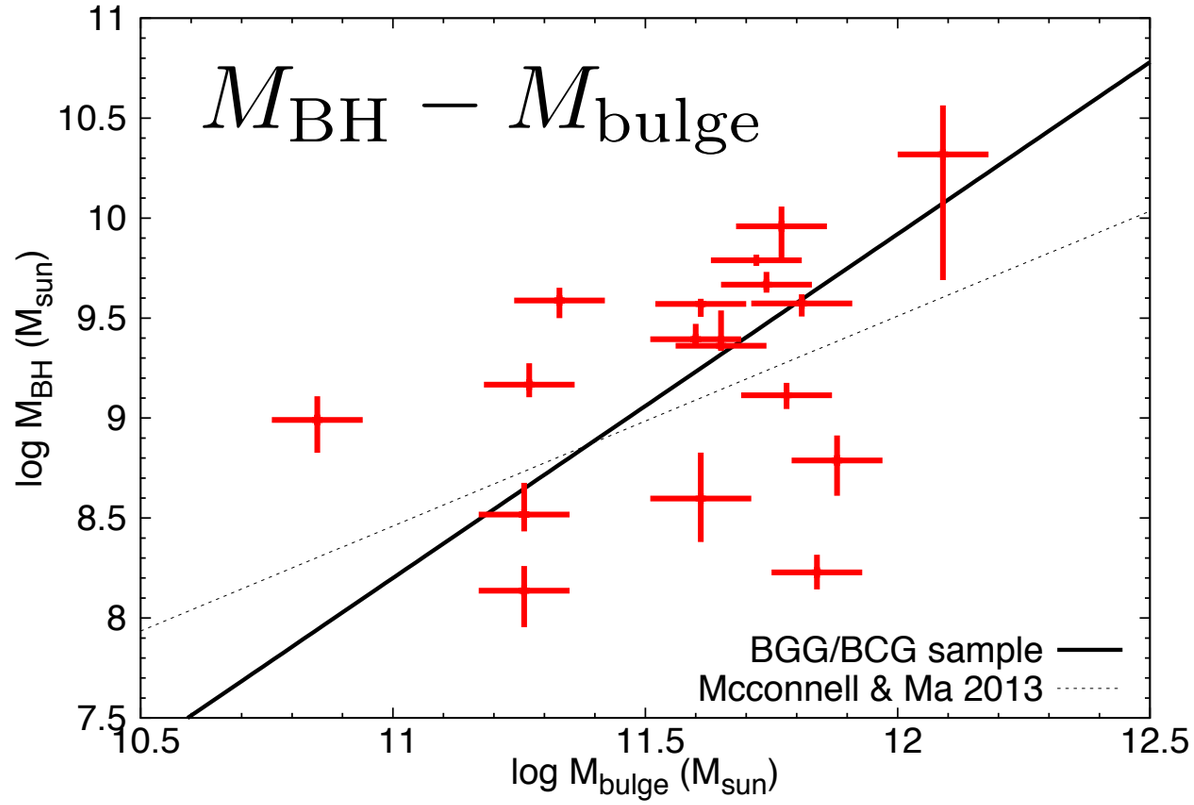
How:

- 29 zoom-in cosmological hydrodynamical simulations

More recently:

Correlation between BH mass of BCGs/BGGs and large scale properties of hosting Cluster



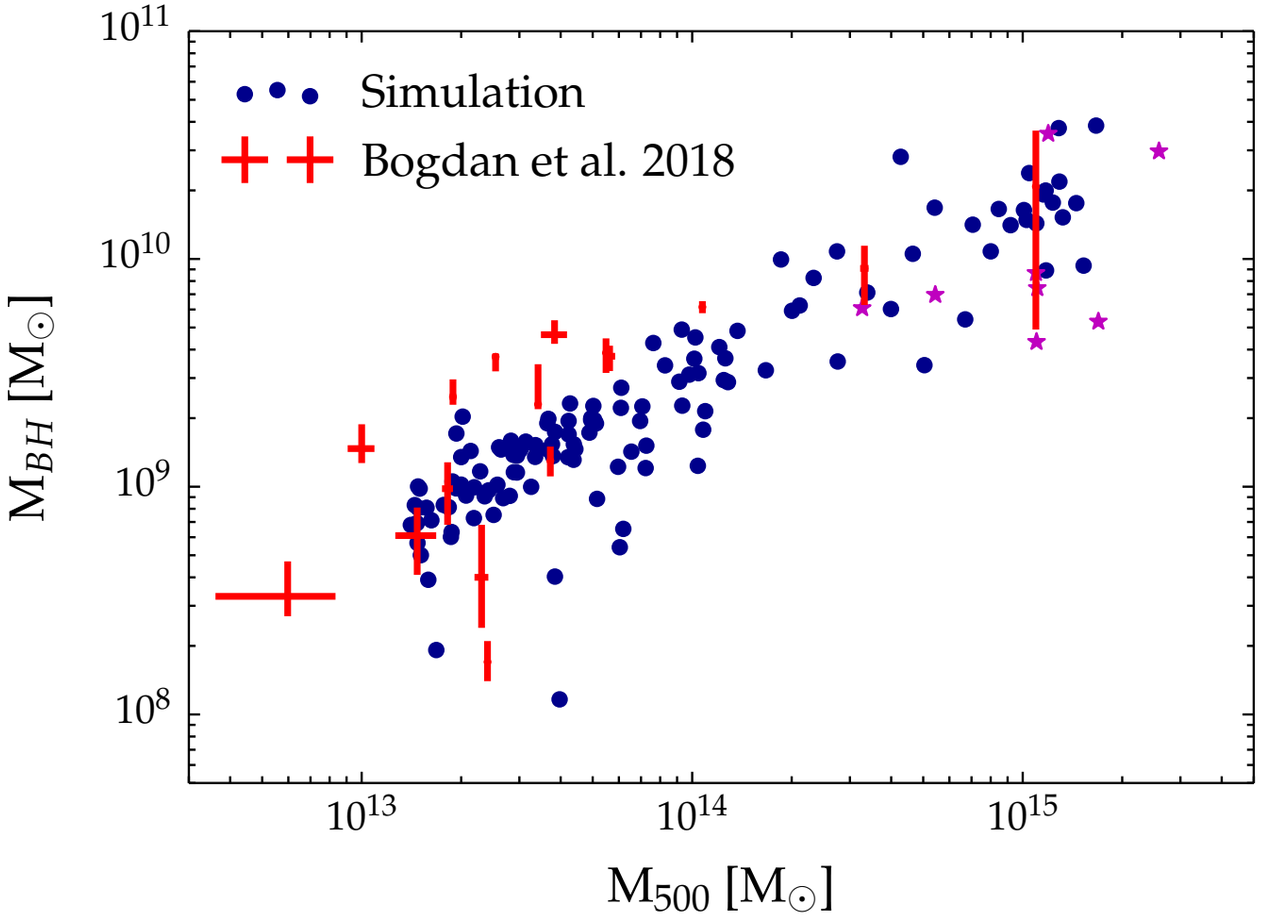


Mbh-T500 in this work has smaller scatter than Mbh-Mbulge

WARNING: **Mbulge data taken from literature, with different techniques for different authors**

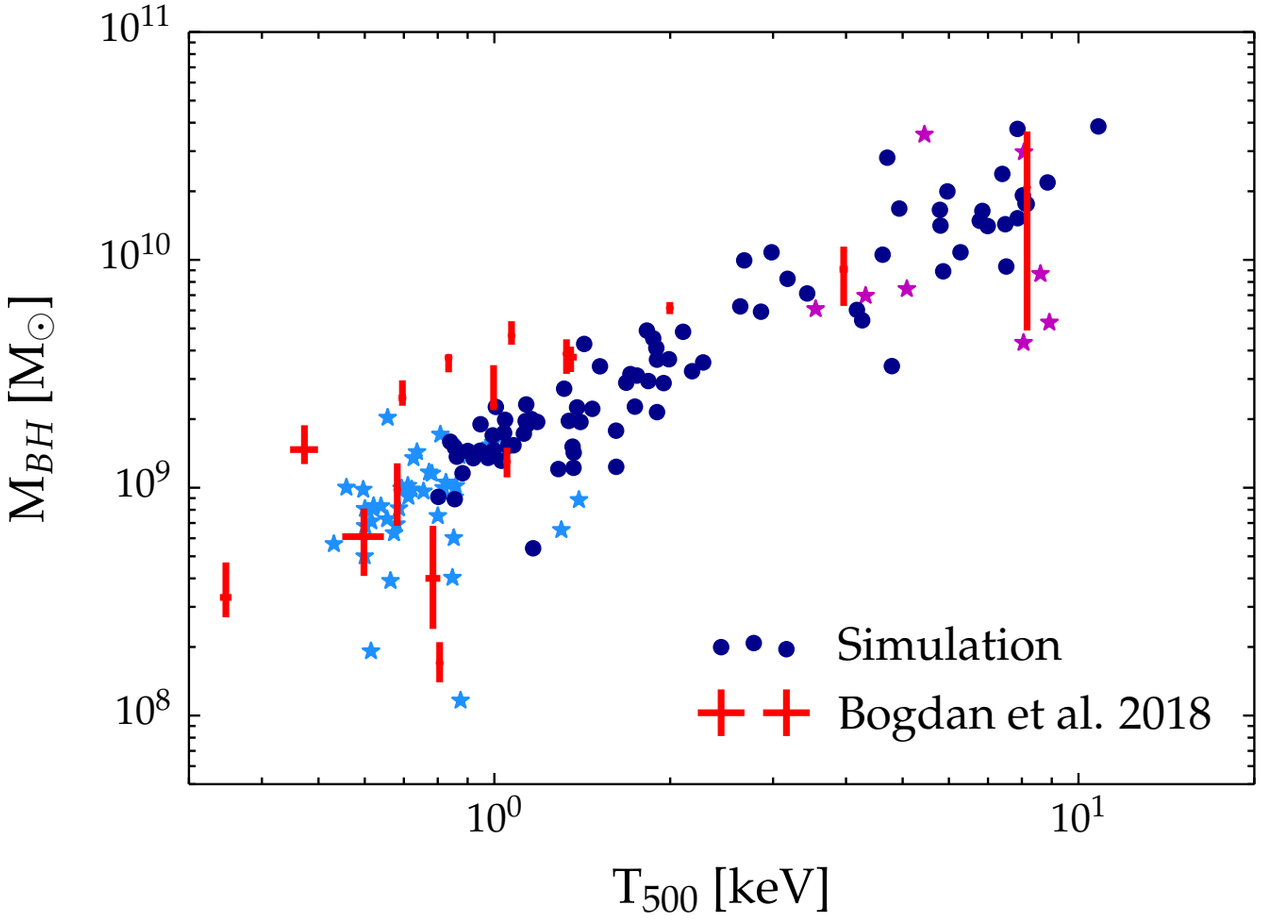
Scaling relations:

$$M_{\rm BH} \propto M_{500}^{\beta}$$

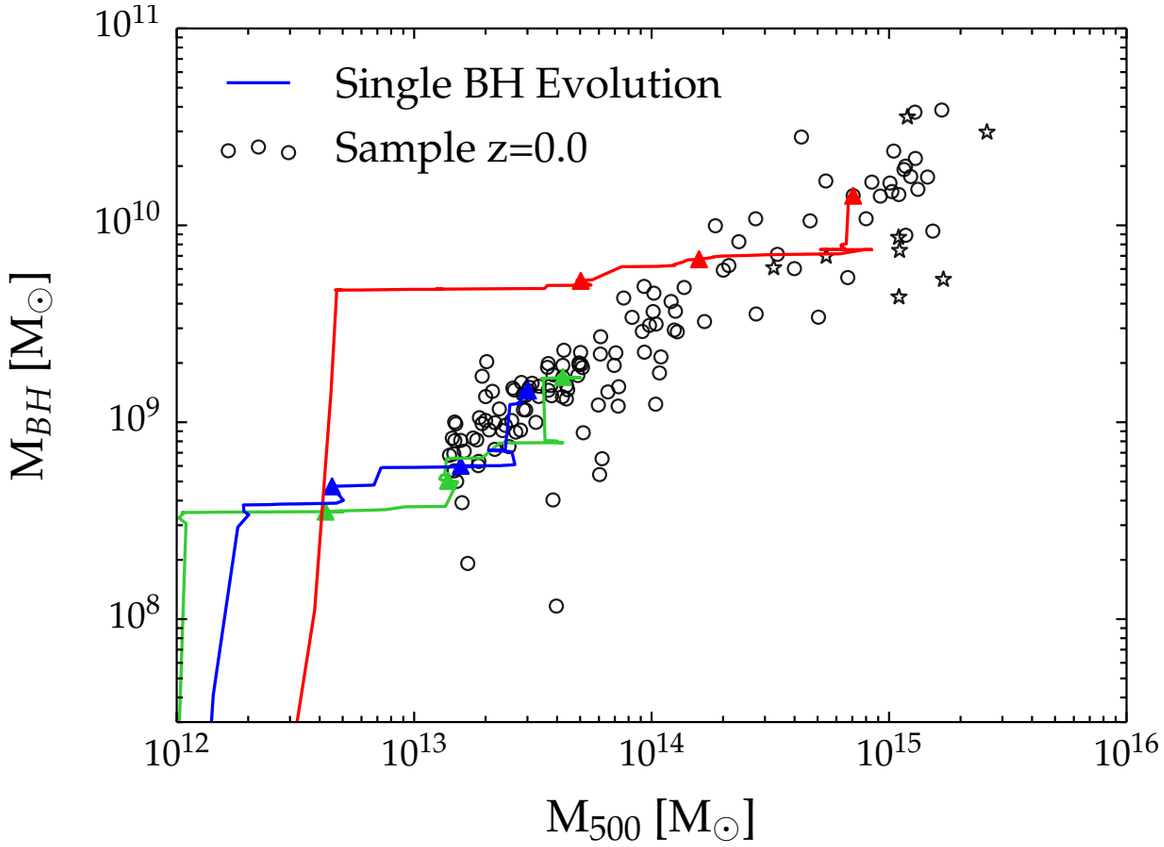


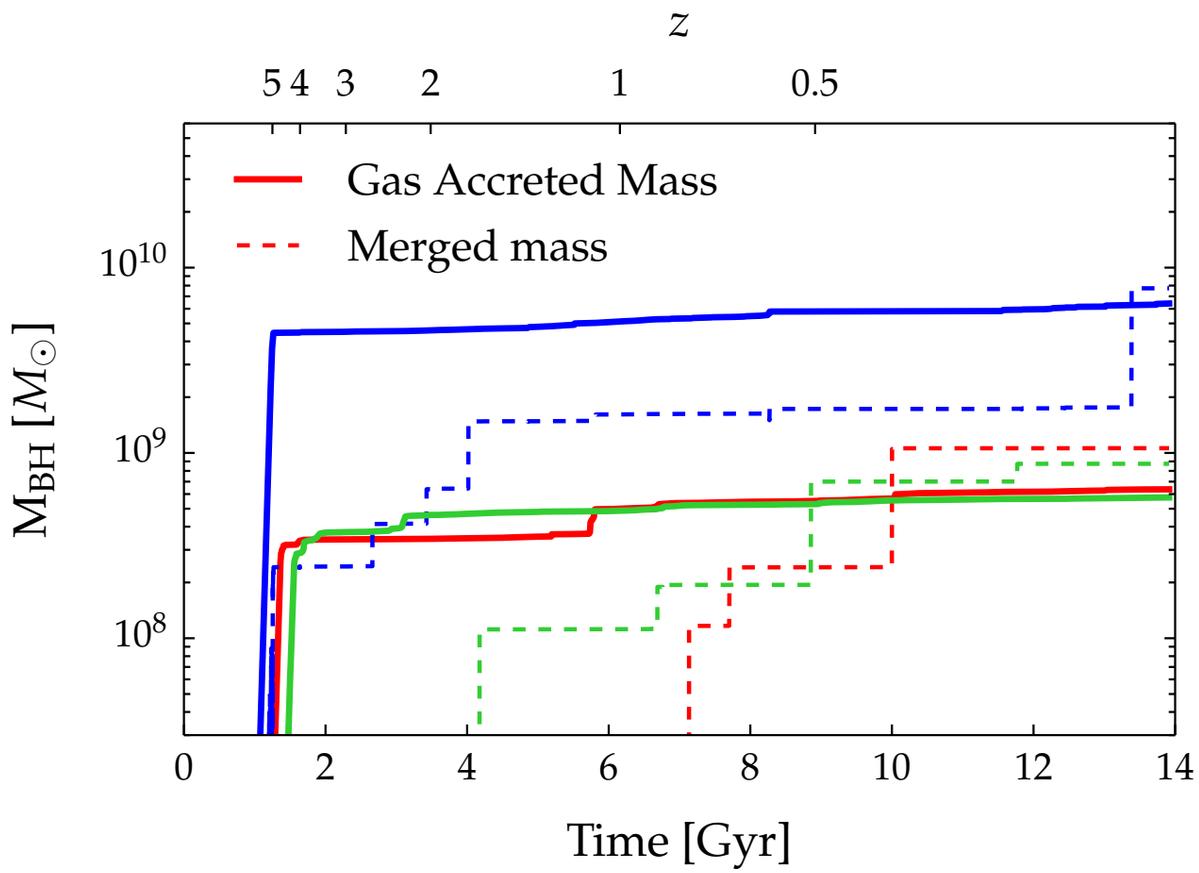
$$\sigma = 0.217 \pm 0.023$$

$$M_{\rm BH} \propto T_{500}^{\alpha}$$

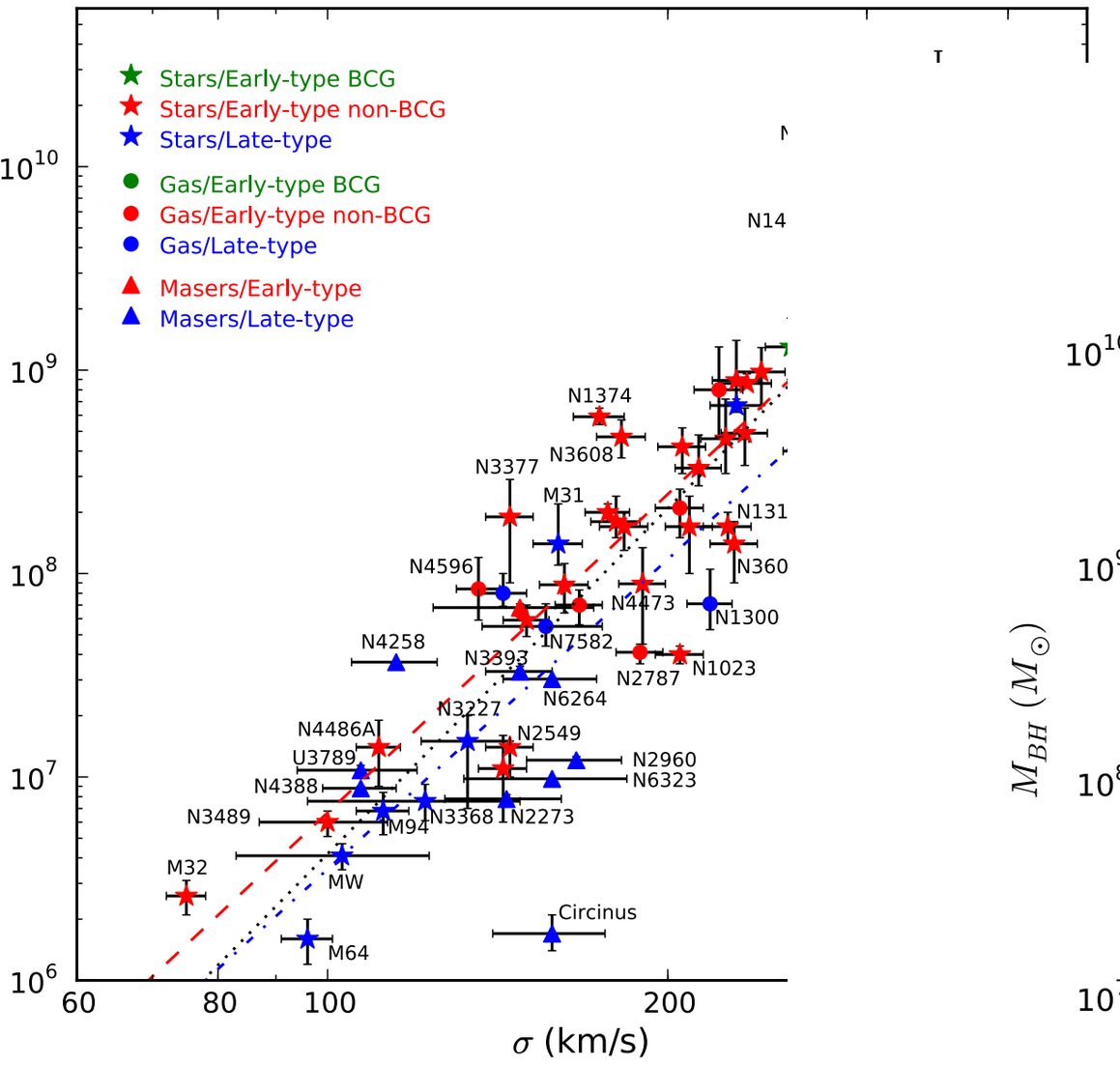


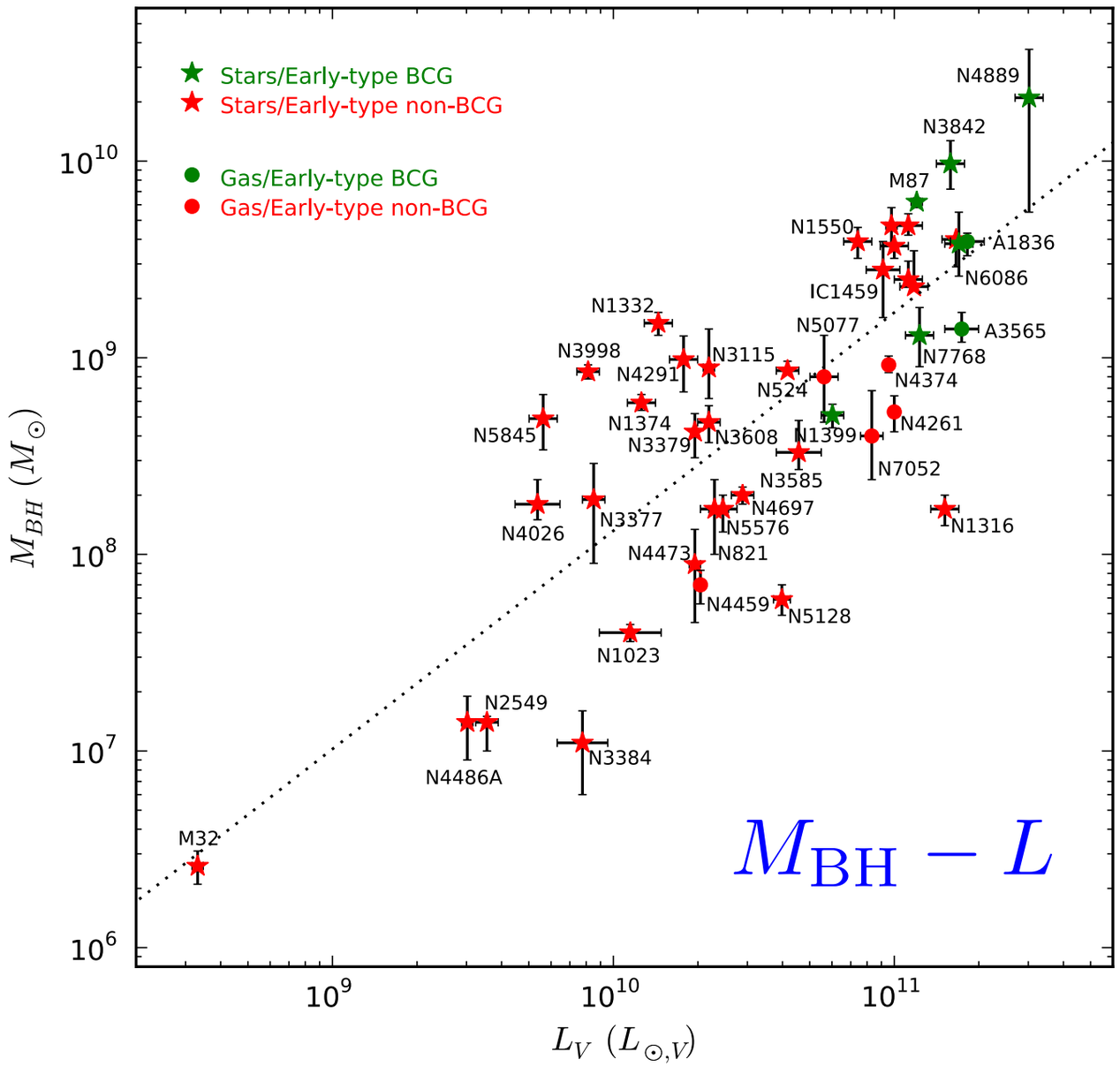
$$\sigma = 0.191 \pm 0.022$$


Single BH Evolution
Sample z=0.0
M_{BH} [$M_\odot$]
M_{500} [$M_\odot$]
10^{11}
10^{10}
10^{9}
10^{8}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}

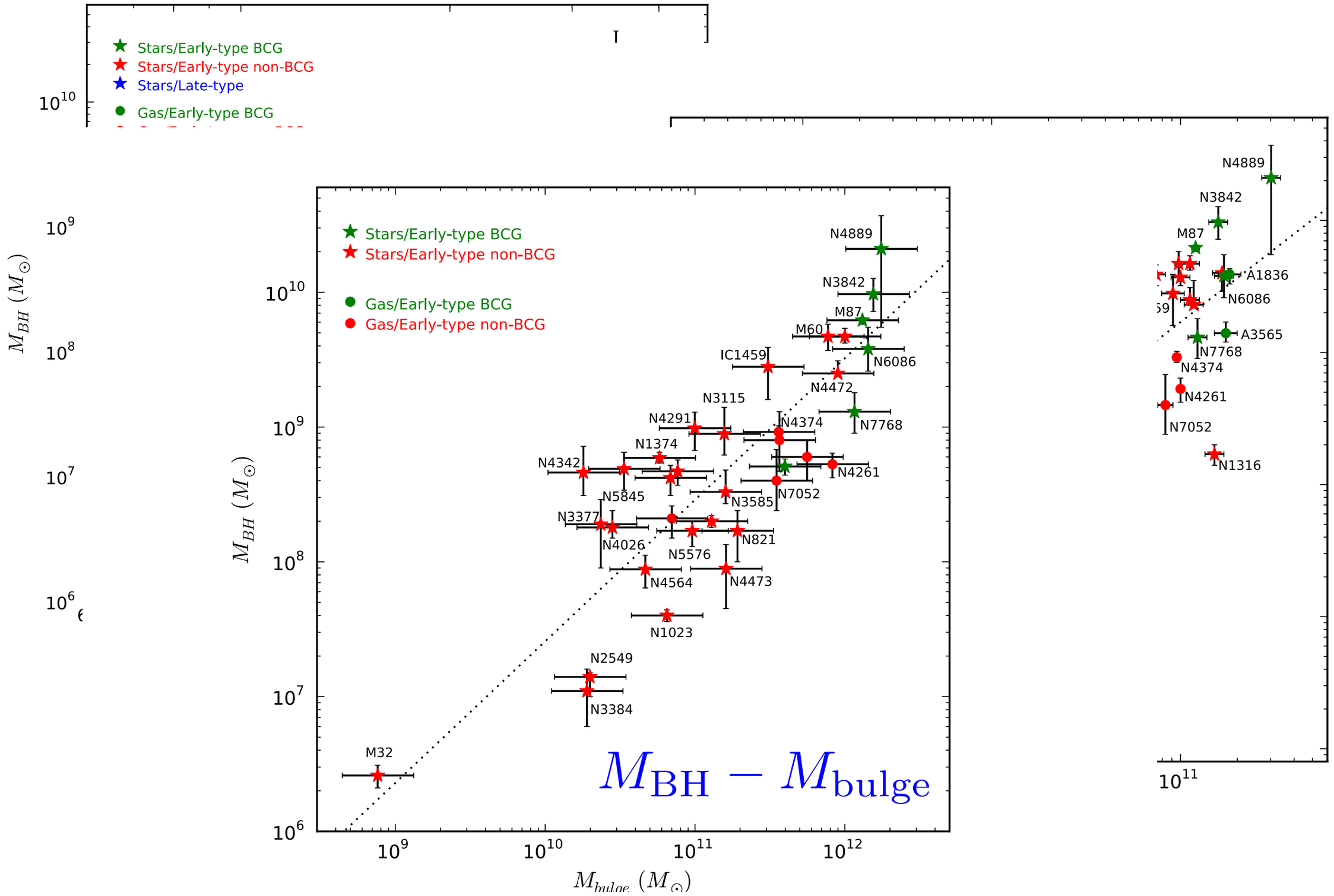

z
5 4 3 2 1 0.5
Gas Accreted Mass
Merged mass
M_{BH} [$M_\odot$]
10^{10}
10^{9}
10^{8}
0 2 4 6 8 10 12 14
Time [Gyr]

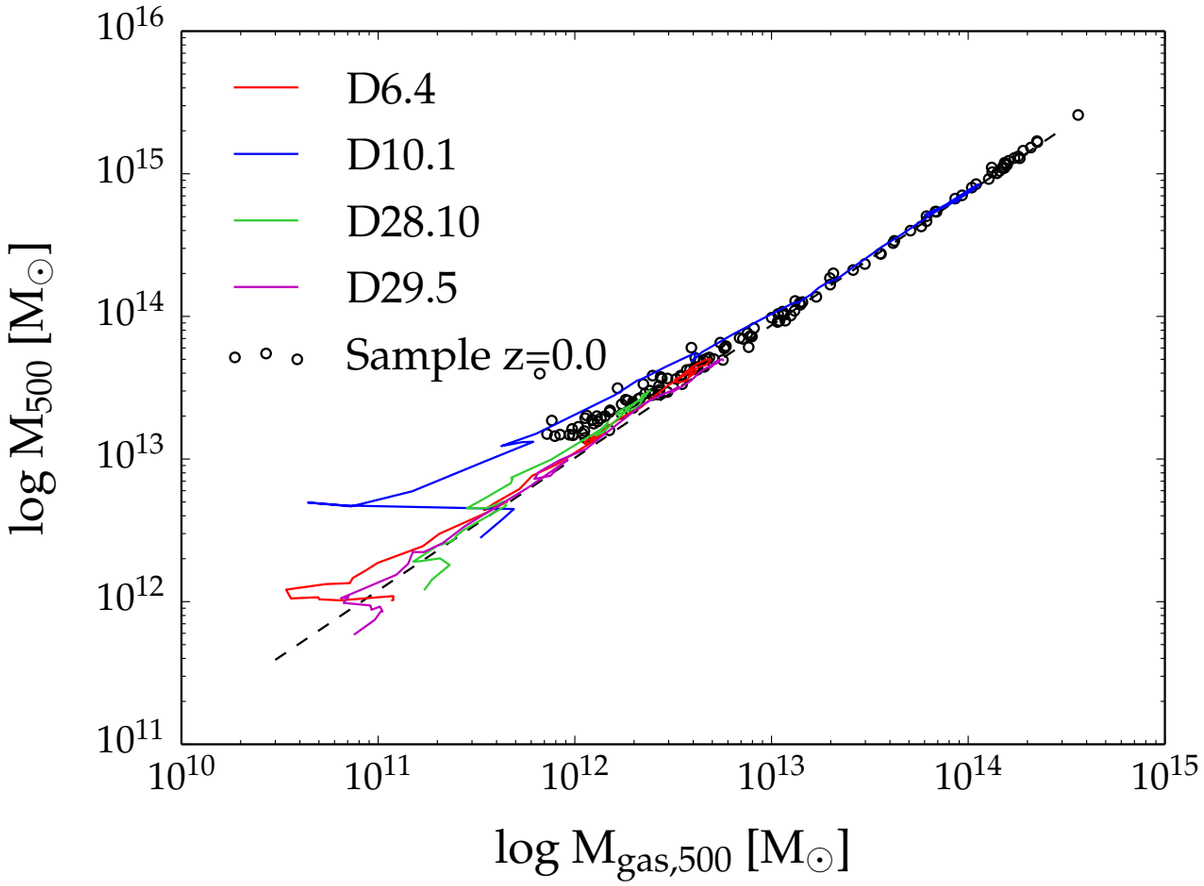
BH mass and hosting Galaxy:

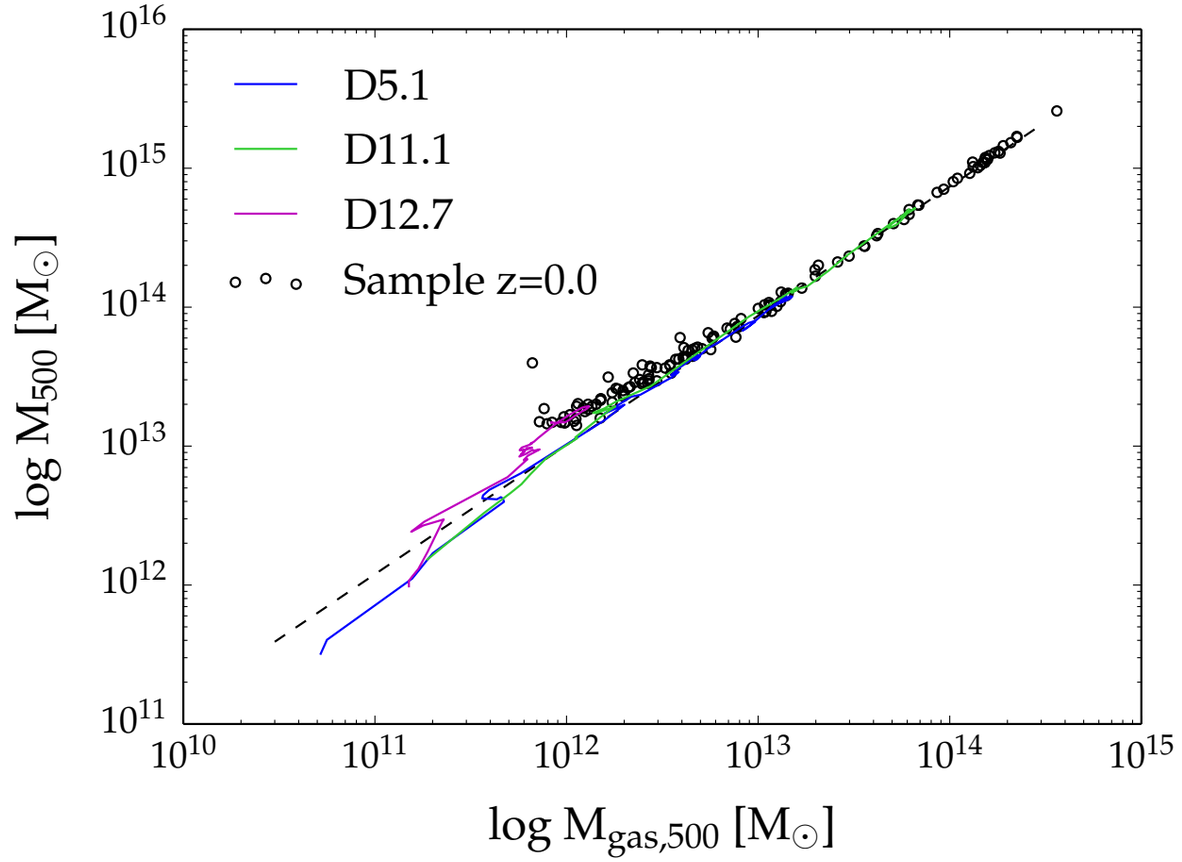




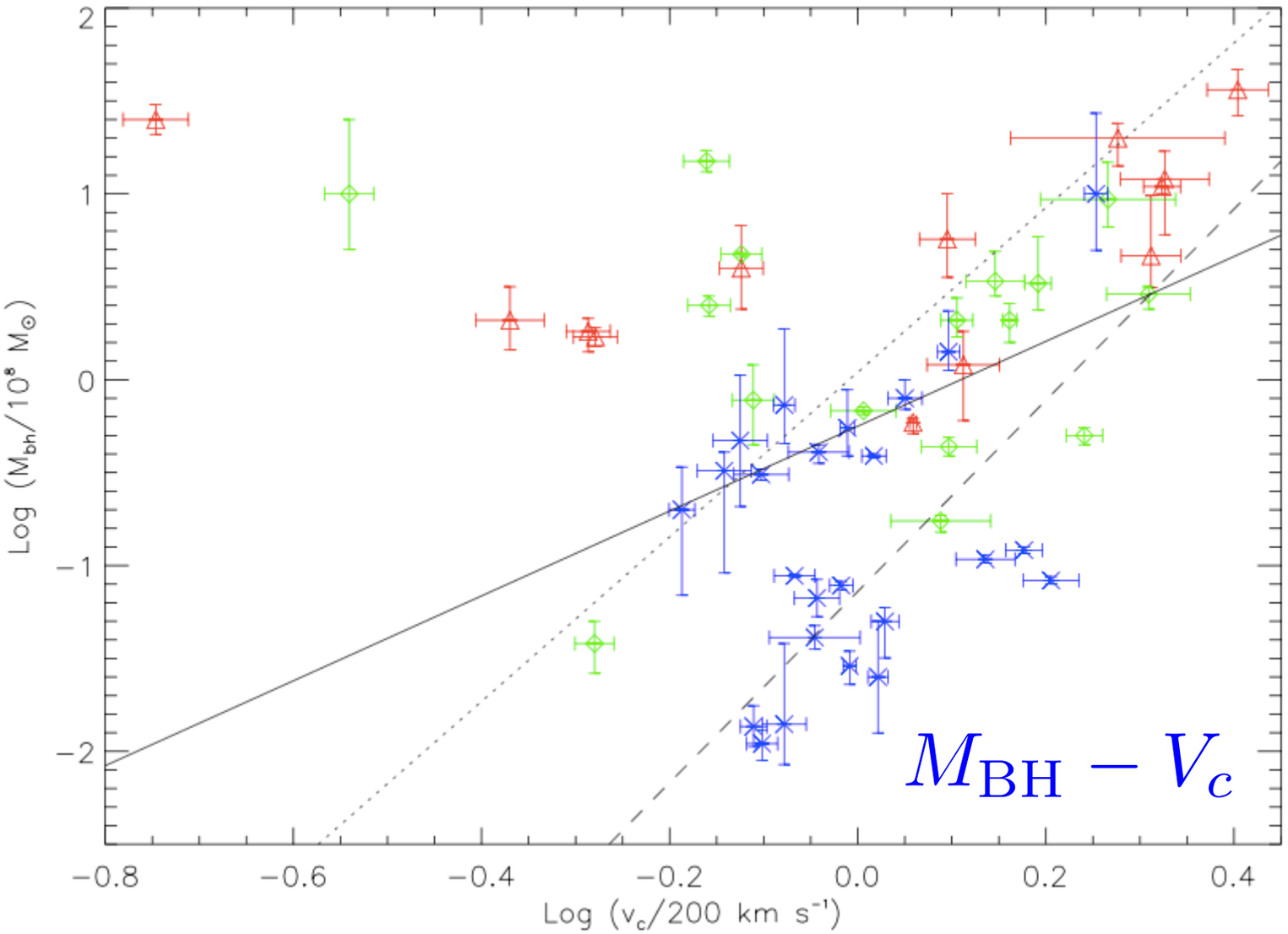
BH mass and hosting Galaxy:




D6.4
D10.1
D28.10
D29.5
Sample z=0.0
log M500 [M⊙]
log Mgas,500 [M⊙]


D5.1
D11.1
D12.7
Sample z=0.0
log M500 [M⊙]
log Mgas,500 [M⊙]

BH mass and dark matter halo:



Sabra et al. 2015

Ferrarese 2002;

Bandara et al. 2009;

Booth & Schaye 2010;

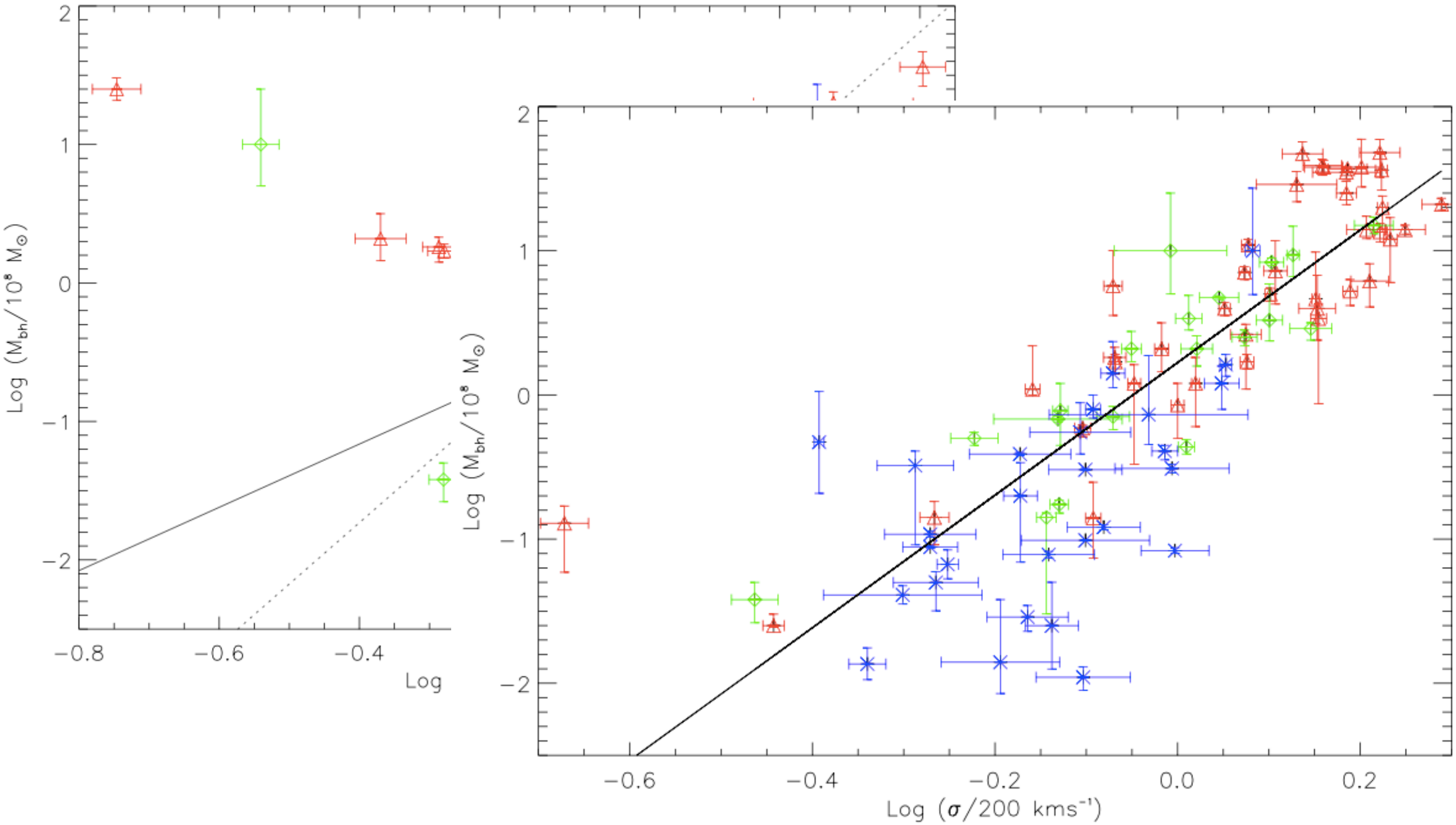
Bogdan et al. 2012;

Kormendy & Bender 2011;

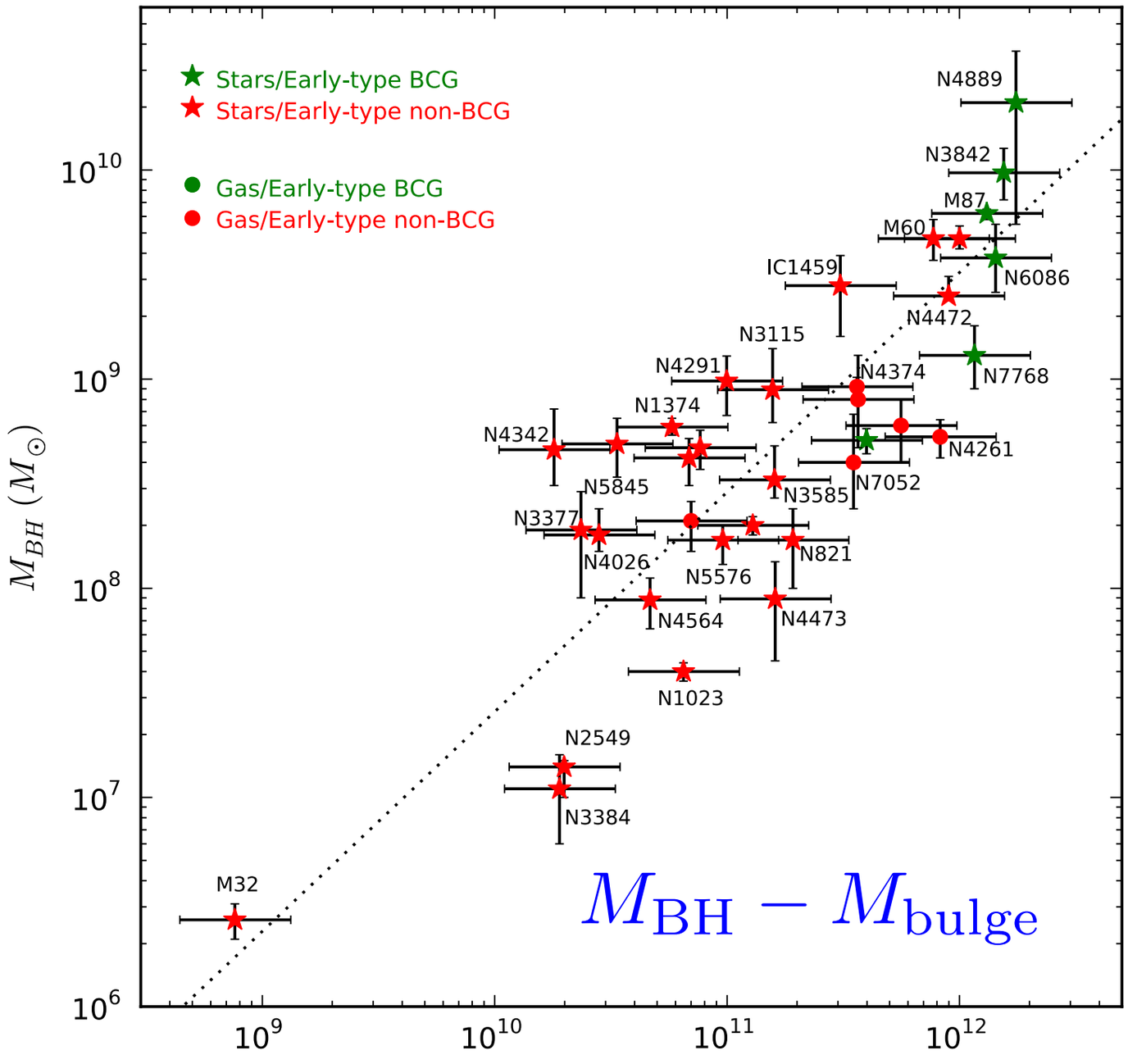
Volonteri et al. 2011;

Sun et al. 2013;

BH mass and dark matter halo:



BH mass and hosting Galaxy:



McConnel & Ma 2013

$M_{\rm BH} - M_{\rm bulge}$

Magorrian et al. 1998;

Marconi & Hunt 2003;

Häring & Rix 2004;

Hu 2009;

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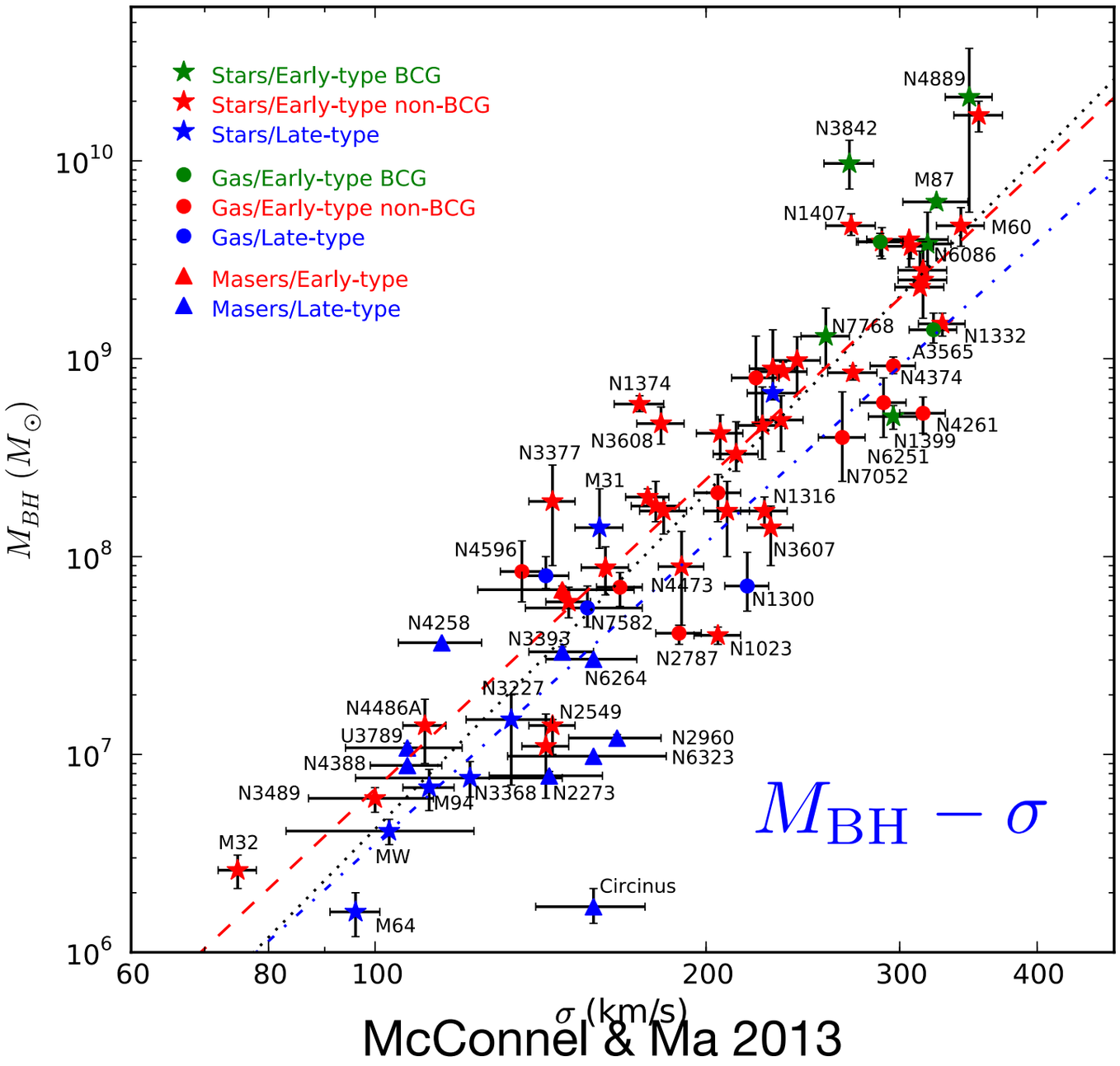


McConnel & Ma 2013

$M_{\rm BH} - \sigma$

Ferrarese & Merritt 2000;

Gebhardt et al. 2000;

Merritt & Ferrarese 2001;

Tremaine et al. 2002;

Wyithe 2006a,b;

Hu 2008;

Gültekin et al. 2009;

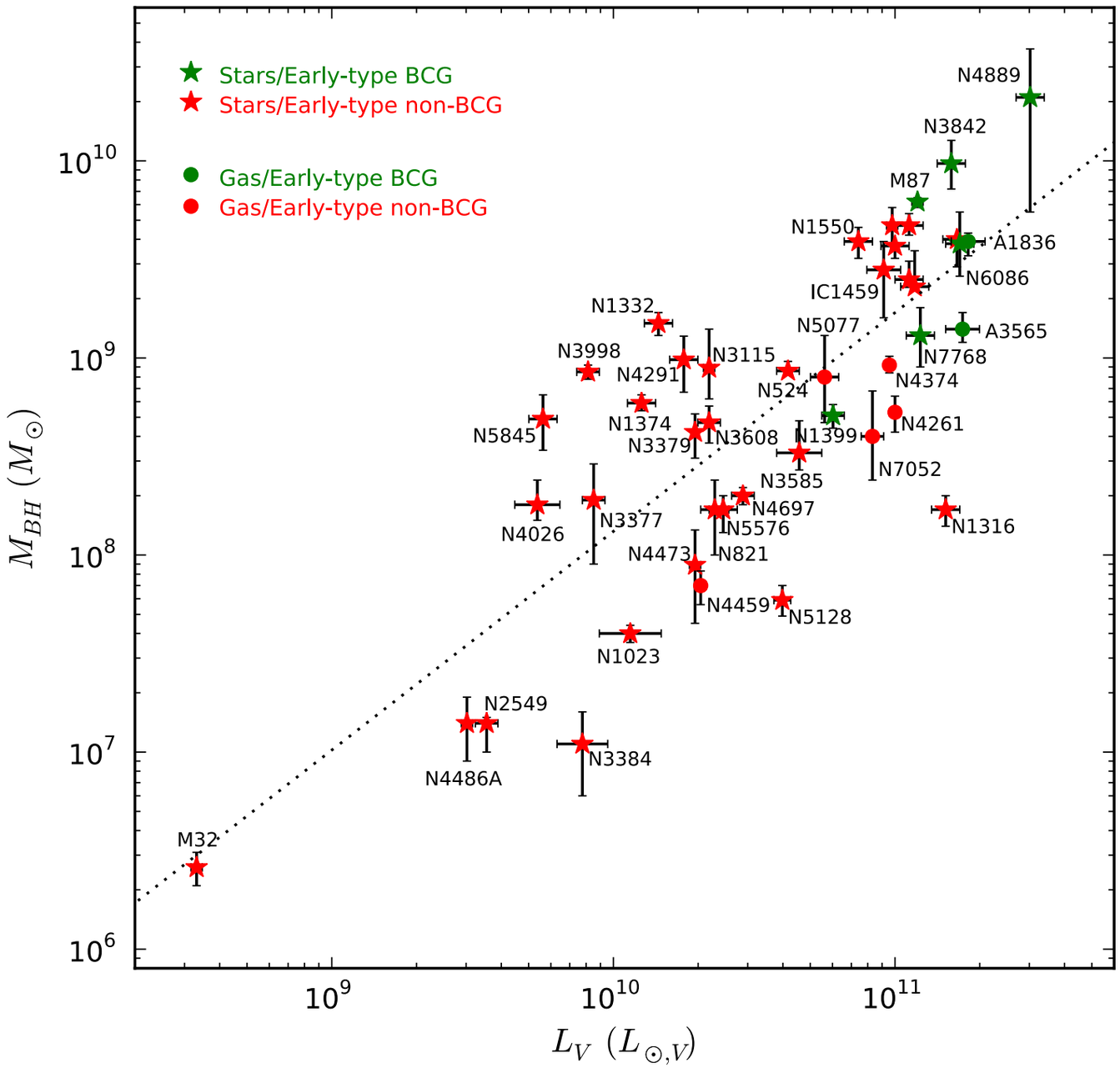
McConnell et al. 2011;

Schulze & Gebhardt 2011;

Graham et al. 2011;

Beifiori et al. 2012;

BH mass and hosting Galaxy:



McConnel & Ma 2013

$$M_{\rm BH} - L$$

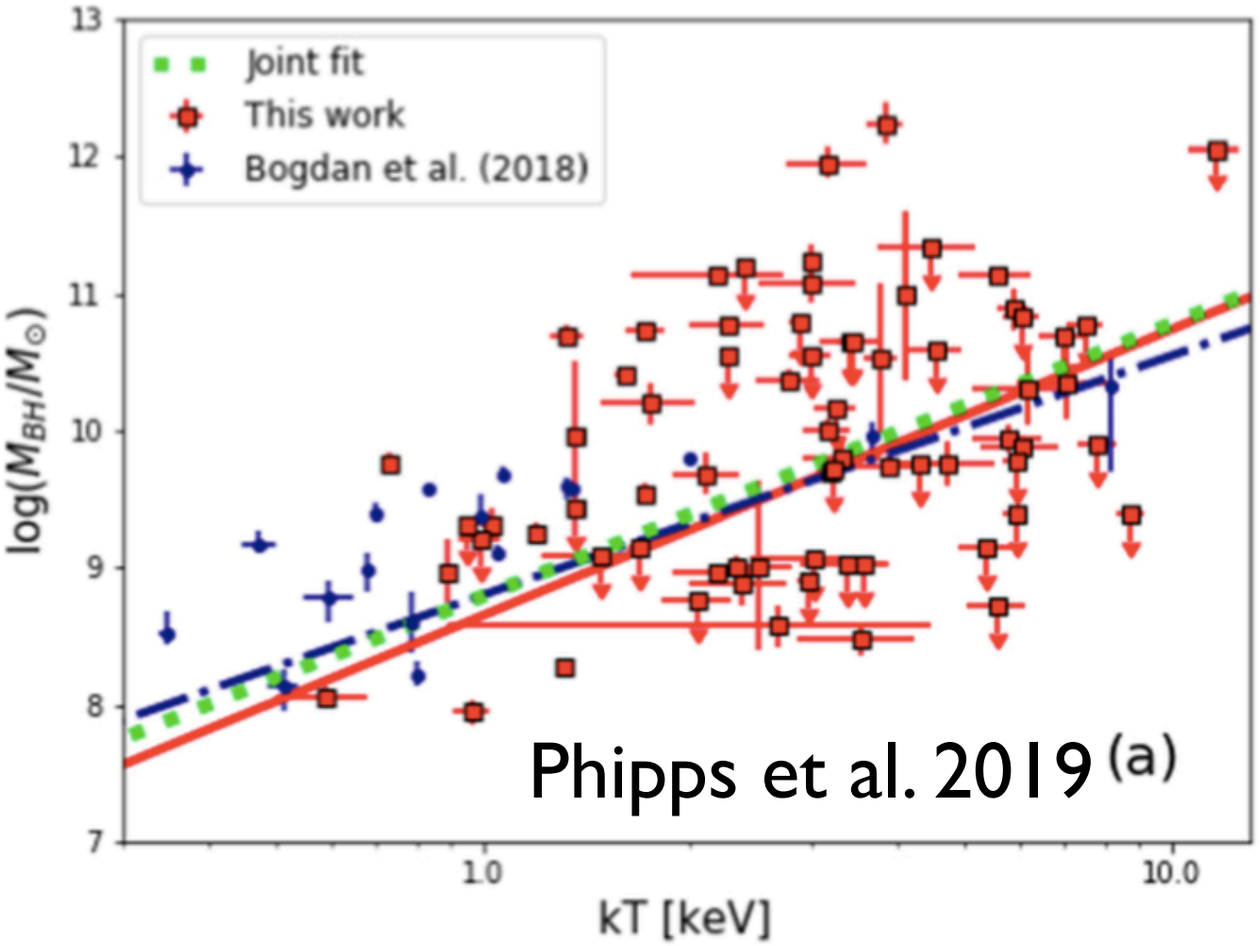
Kormendy & Gebhardt et al. 2000;

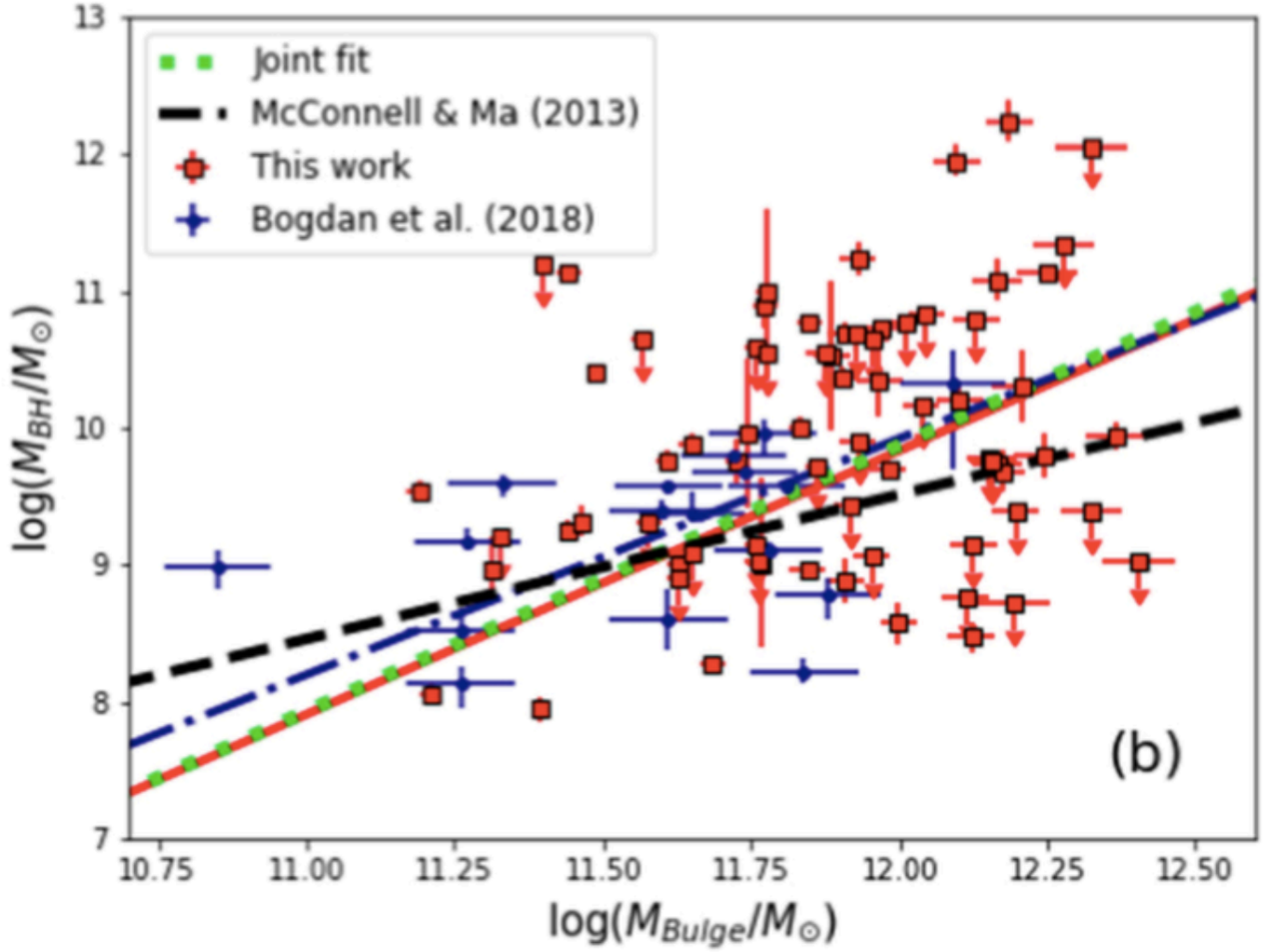
Gültekin et al. 2009;

Schulze & Gebhardt 2011;

McConnell et al. 2011;

Other works followed:





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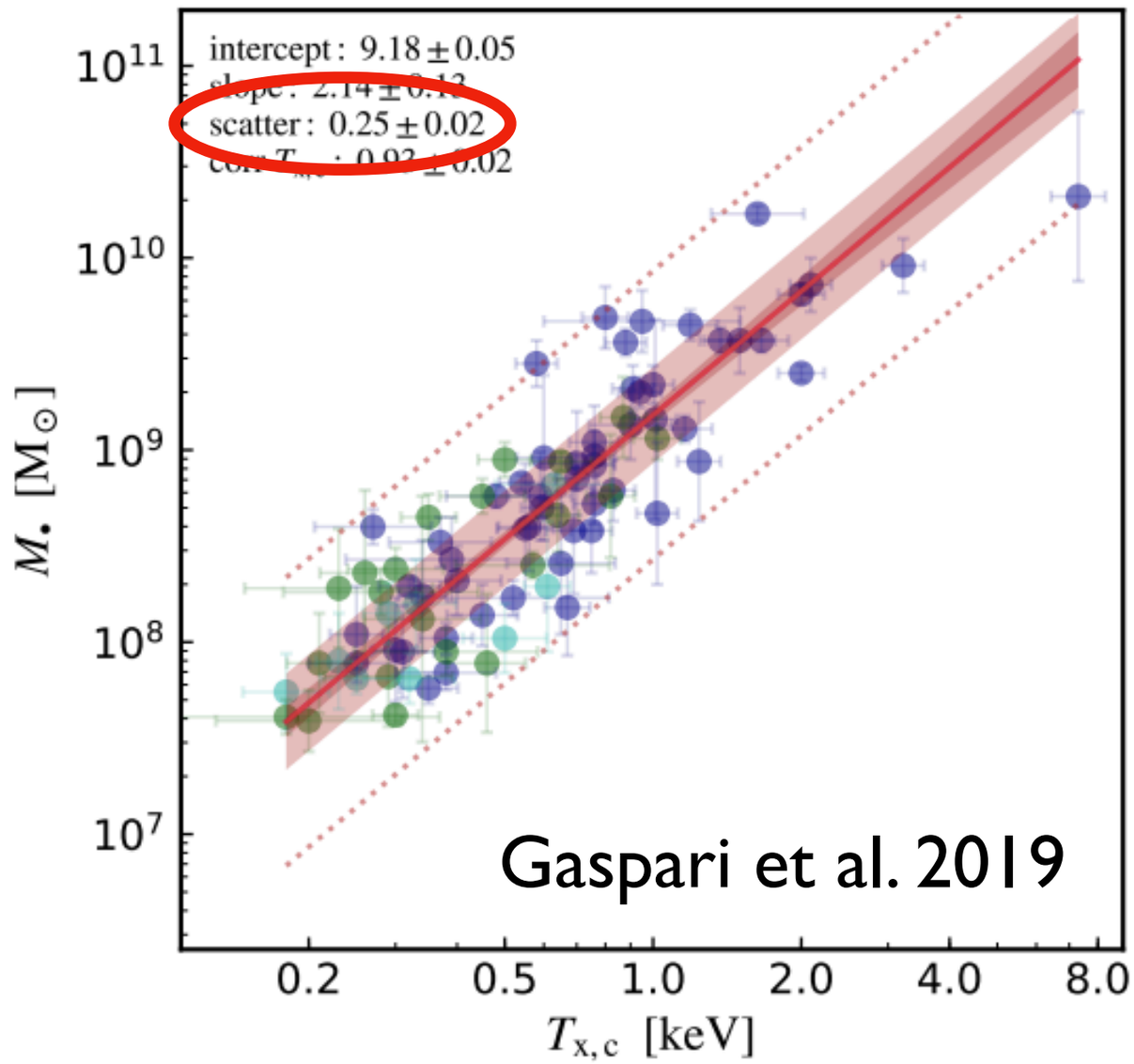

Gaspari et al. 2019