Black hole mass and cluster mass relation in cosmological hydro-dynamical simulations

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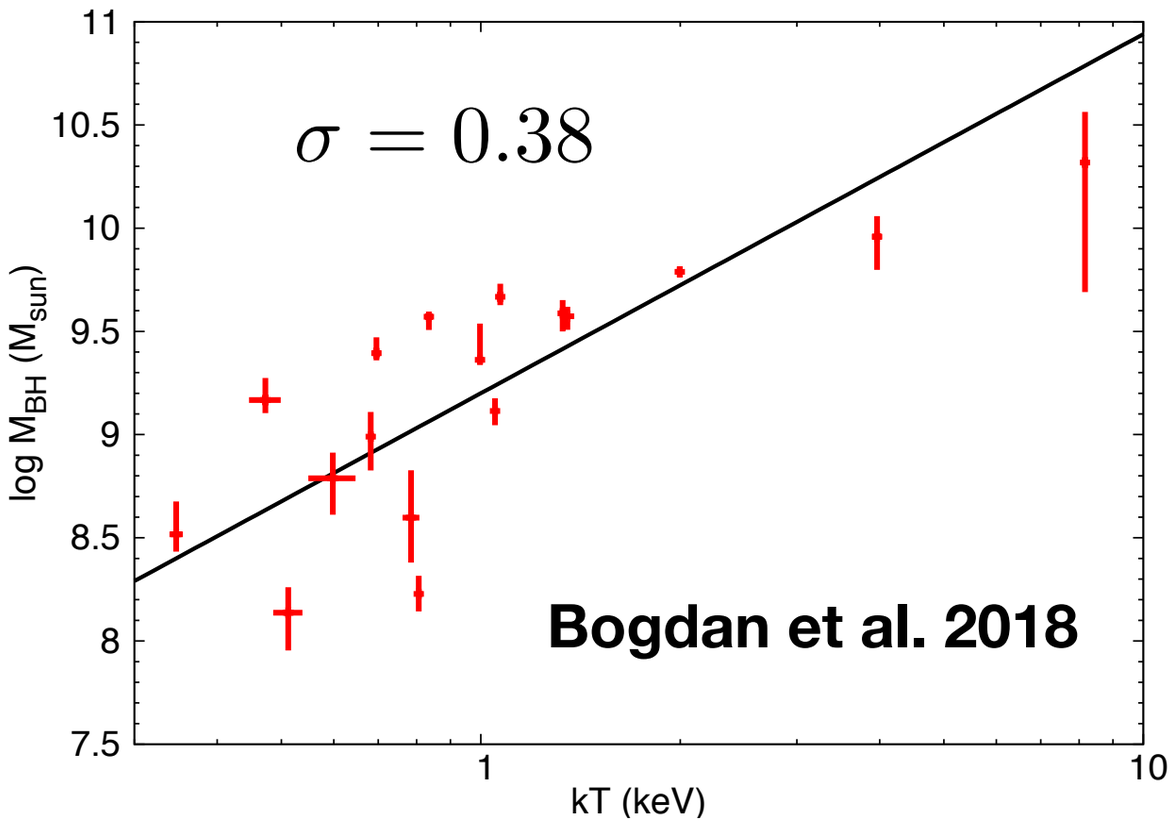
Goals of our work:

- ***Do we reproduce the observed*** $M_{\rm BH} - M_{500}$ ***relation?***
- ***How the*** $M_{\rm BH} - M_{500}$ ***correlation forms?***
- ***Through which channel do SMBHs grow in time?***
- ***Is*** M_{500} ***as appropriate as BCG mass as proxy for*** $M_{\rm BH}$ ***?***

SMBH mass-Galaxy Cluster properties correlations

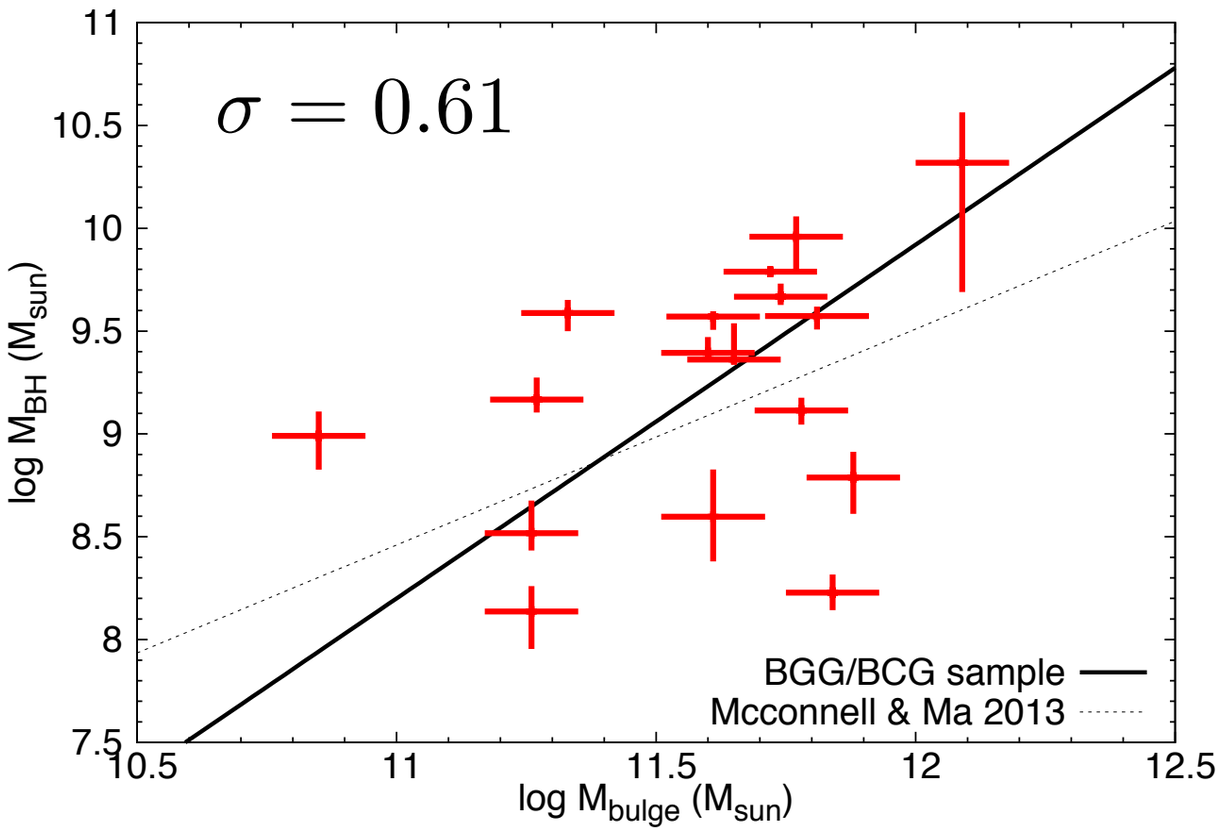


BH masses dynamically measured

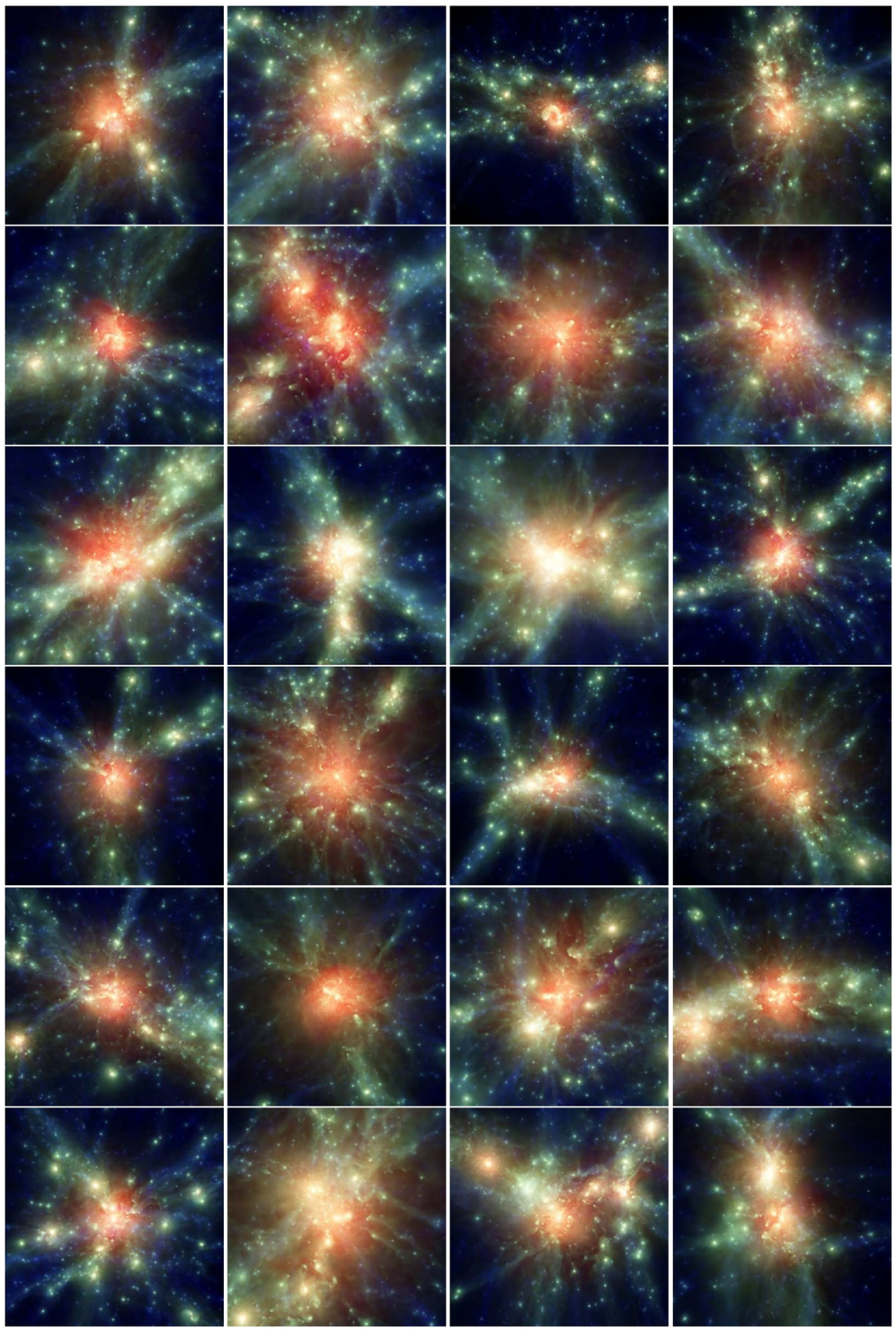
Temperature obtained from Xray observations

Bulge masses given by Kormendy & Ho 2013 (compilation of different sources)

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



Numerical set-up and sample selection (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:

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

Numerical set-up and sample selection (AGN feedback)

$$\dot{M}_{\mathrm{bondi},\alpha} = \alpha \frac{4\pi G^2 M_{\mathrm{BH}}^2 \rho}{(c_s^2 + v_{\mathrm{BH}}^2)^{3/2}}$$

$\alpha = 100$ for $T < 5 \times 10^5 K$

$\alpha = 10$ for $T > 5 \times 10^5 K$

Fraction thermally coupled

Radiated fraction

$$\dot{E}_{\mathrm{th}} = \epsilon_f \epsilon_r \dot{M}_{\mathrm{bondi},\alpha} c^2$$

$\dot{M}_{\mathrm{bondi},\alpha}/\dot{M}_{\mathrm{edd}} > 0.01$

$\epsilon_r = 0.07$

$\epsilon_f = 0.1$

quasar mode

$\dot{M}_{\mathrm{bondi},\alpha}/\dot{M}_{\mathrm{edd}} < 0.01$

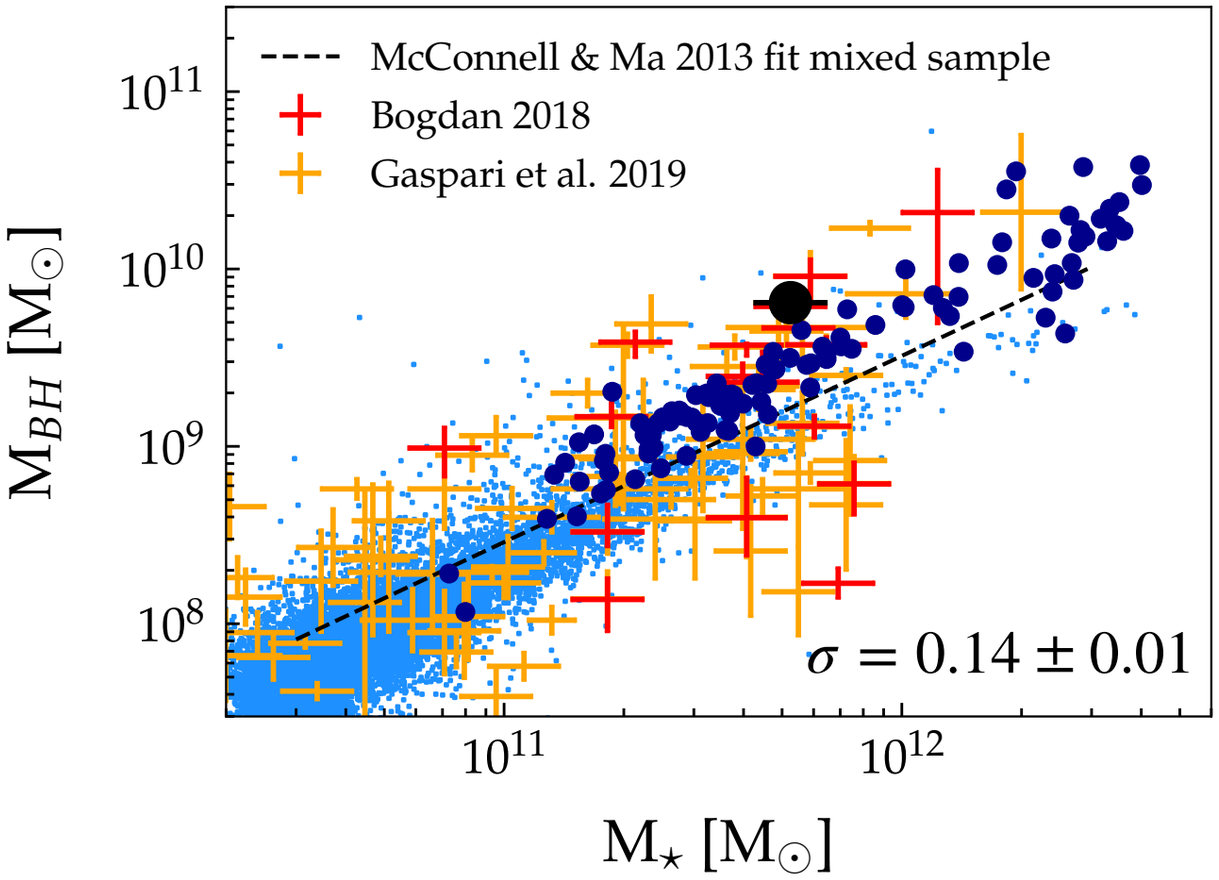
$\epsilon_r = 0.07$

$\epsilon_f = 0.7$

radio mode

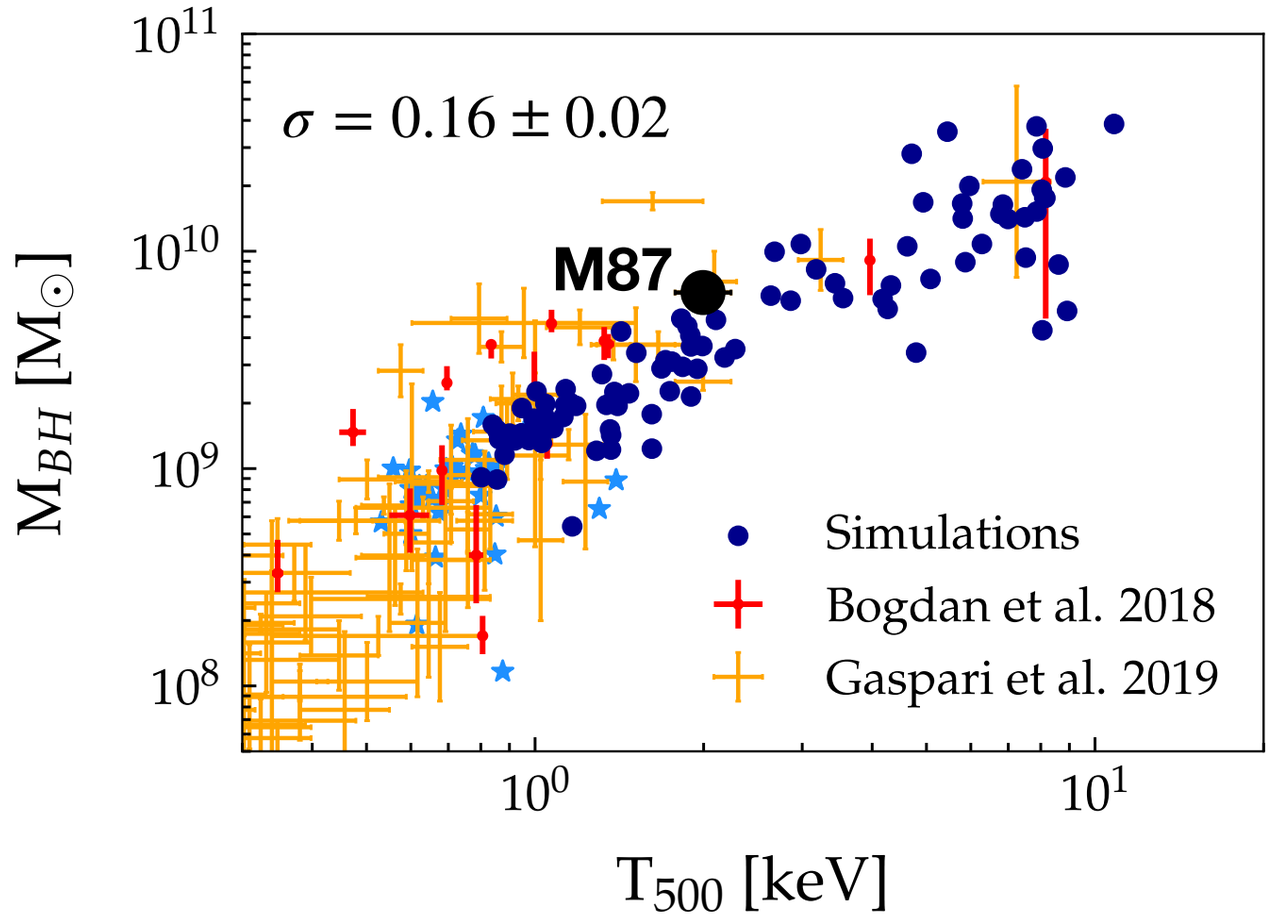
BHs seeded with initial mass of $4.4 \times 10^5 M_\odot$ **in halos of mass**

Calibration of AGN feedback



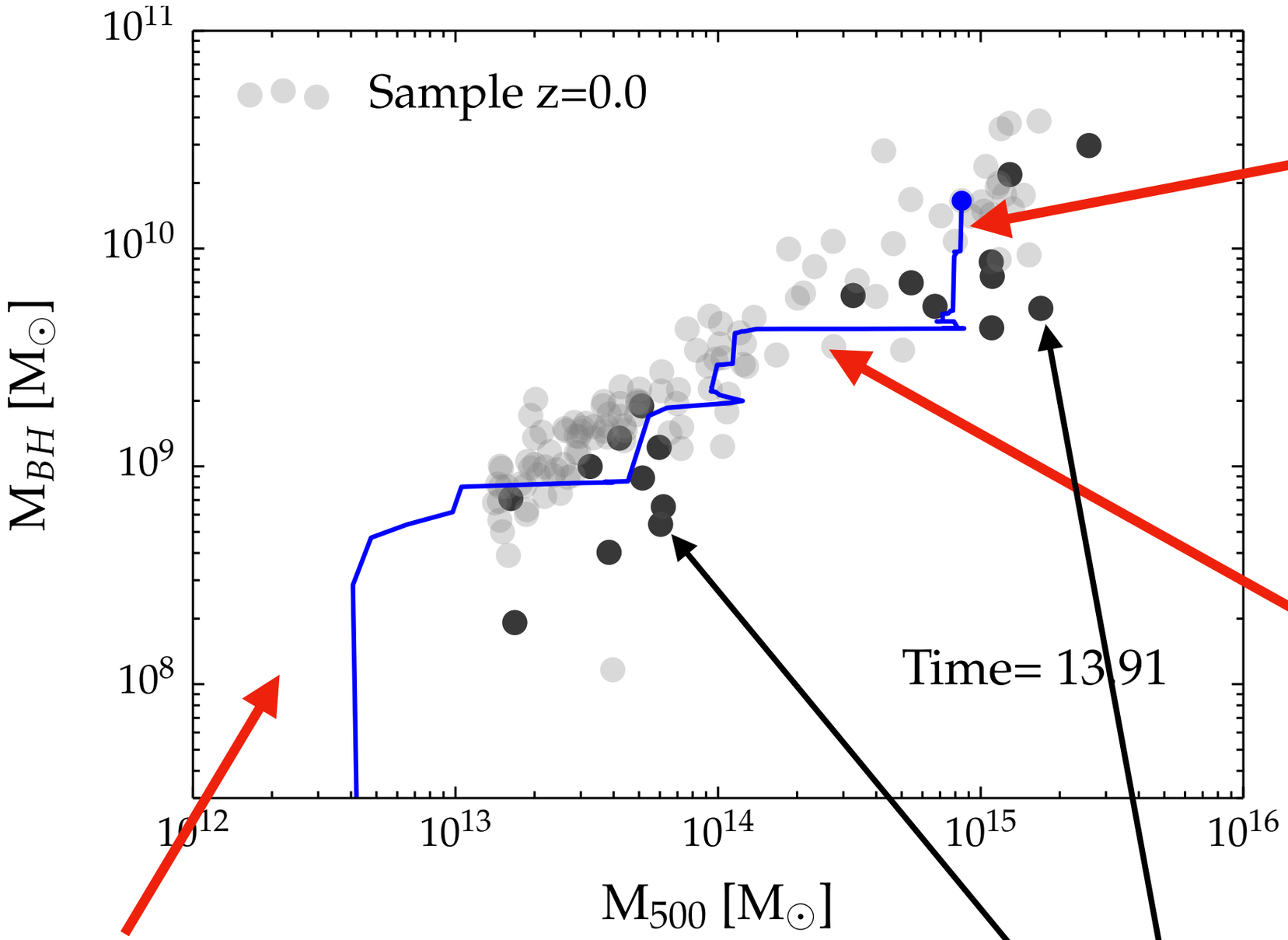
Scatter around $M_{\rm BH} - M_{\rm BCG}$ relation lower in numerical simulations

Comparison between numerical results and observations



Numerical results in agreement with observations on the $M_{\rm BH} - T_{500}$ plane

Establishment of $M_{\rm BH} - M_{500}$ ***correlation***



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

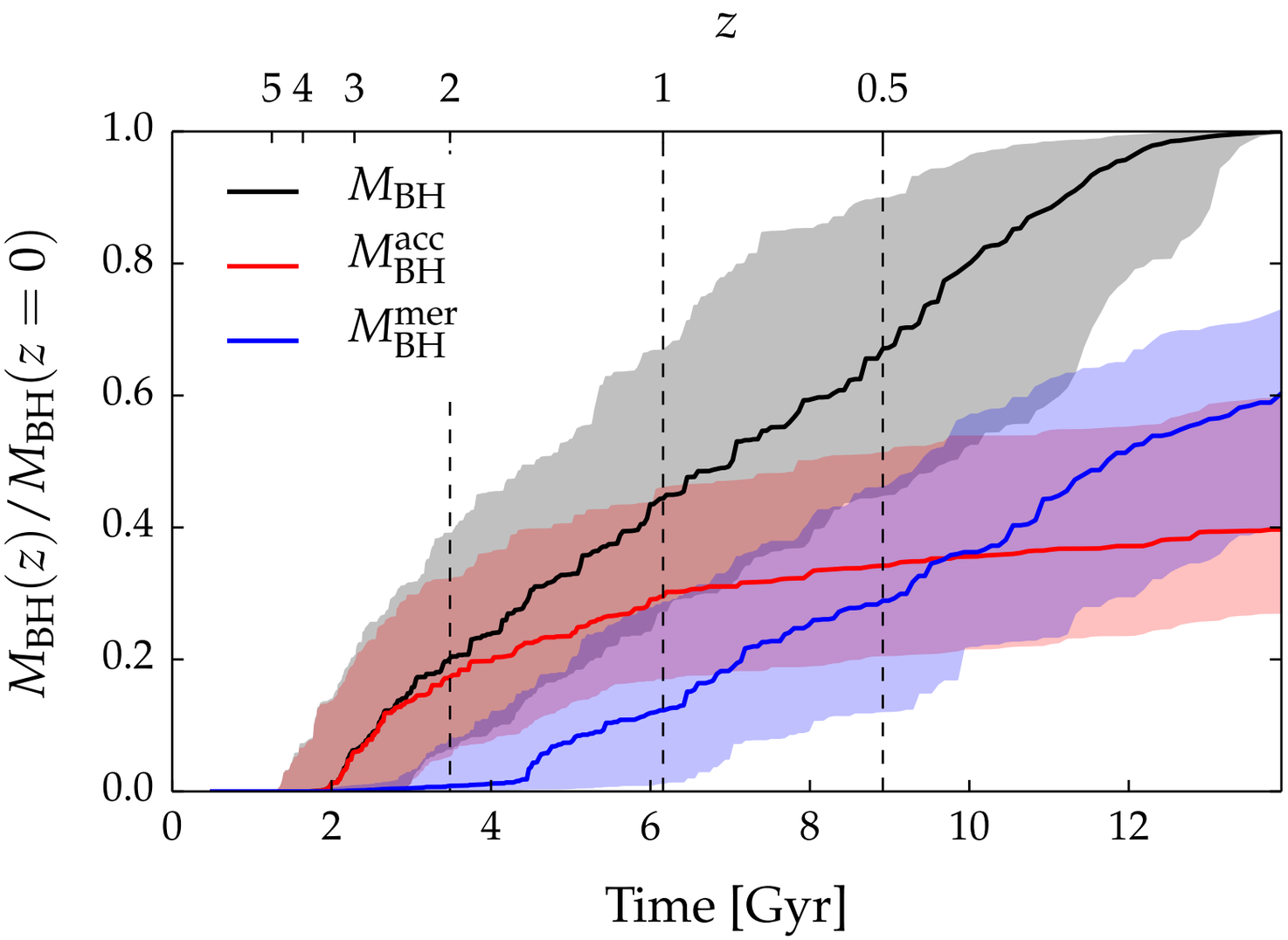
(2) Structures enter R500 (M500 grows for mergers)

(1) Rapid growth for gas accretion

Systems right after a cluster merger

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

SMBHs mass evolution during cosmic time



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

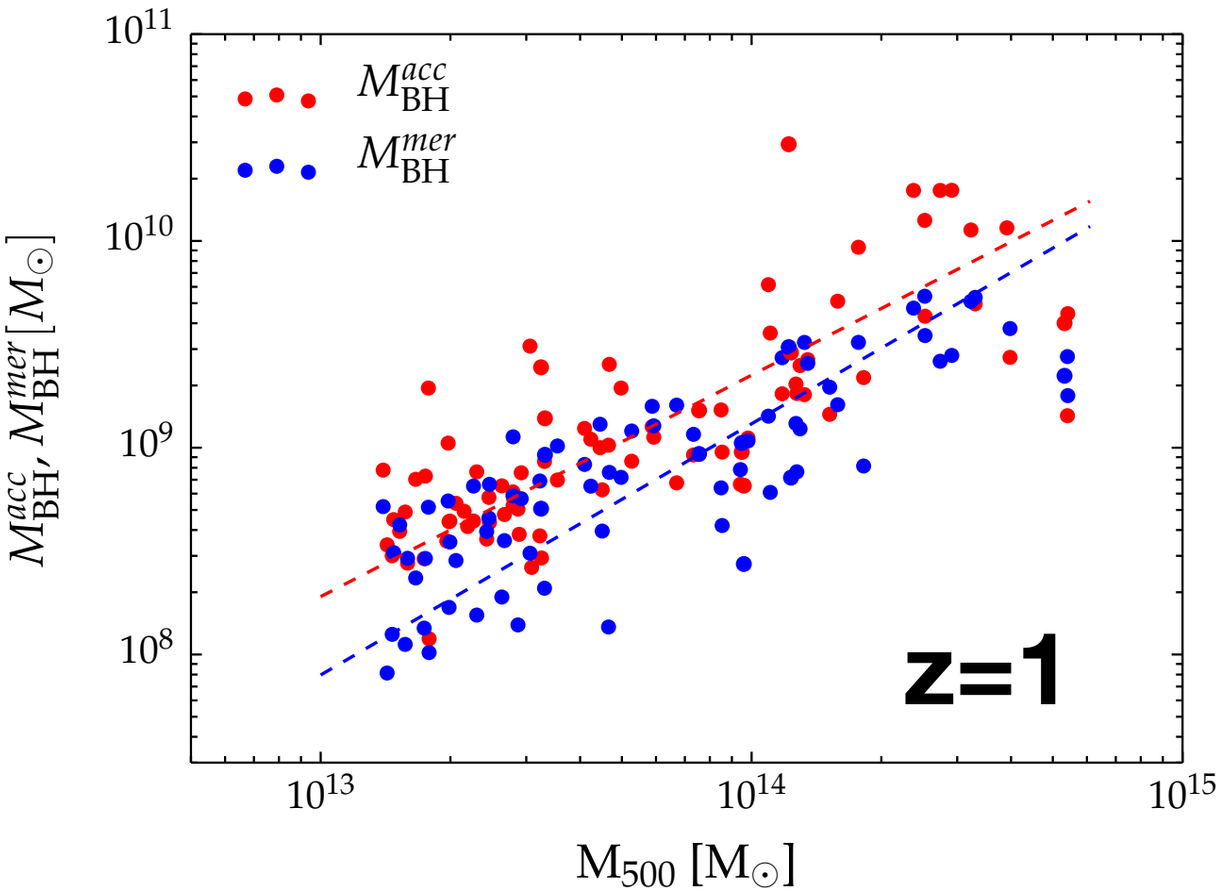
At z<2 gas accretion slows down with an accretion rate which is a fraction of the Eddington limit;

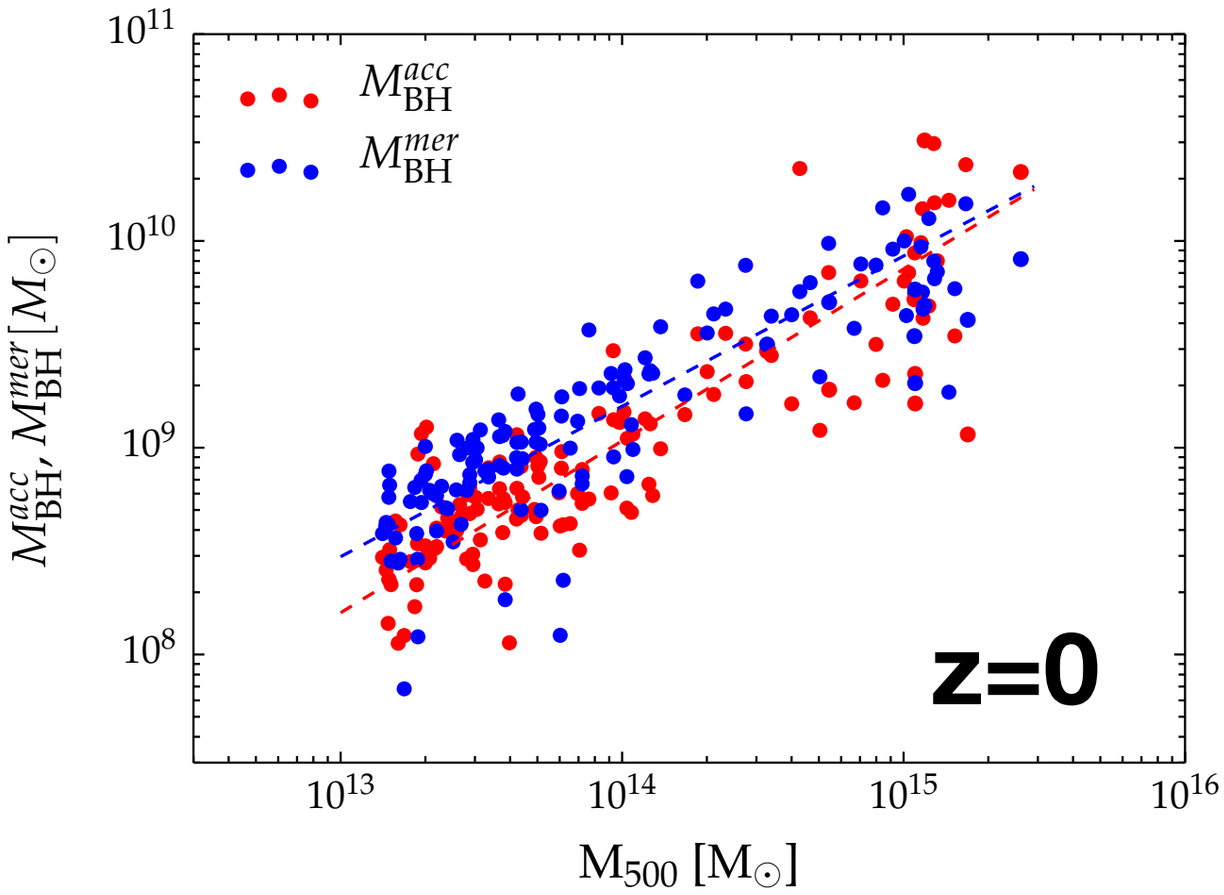
At z<1 BH-BH mergers are the main channel for SMBH mass growth;

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

SMBHs mass evolution during cosmic time

$M_{\rm BH}^{acc}$ $M_{\rm BH}^{mer}$





$$M_{\rm BH}^{acc} > M_{\rm BH}^{mer}$$

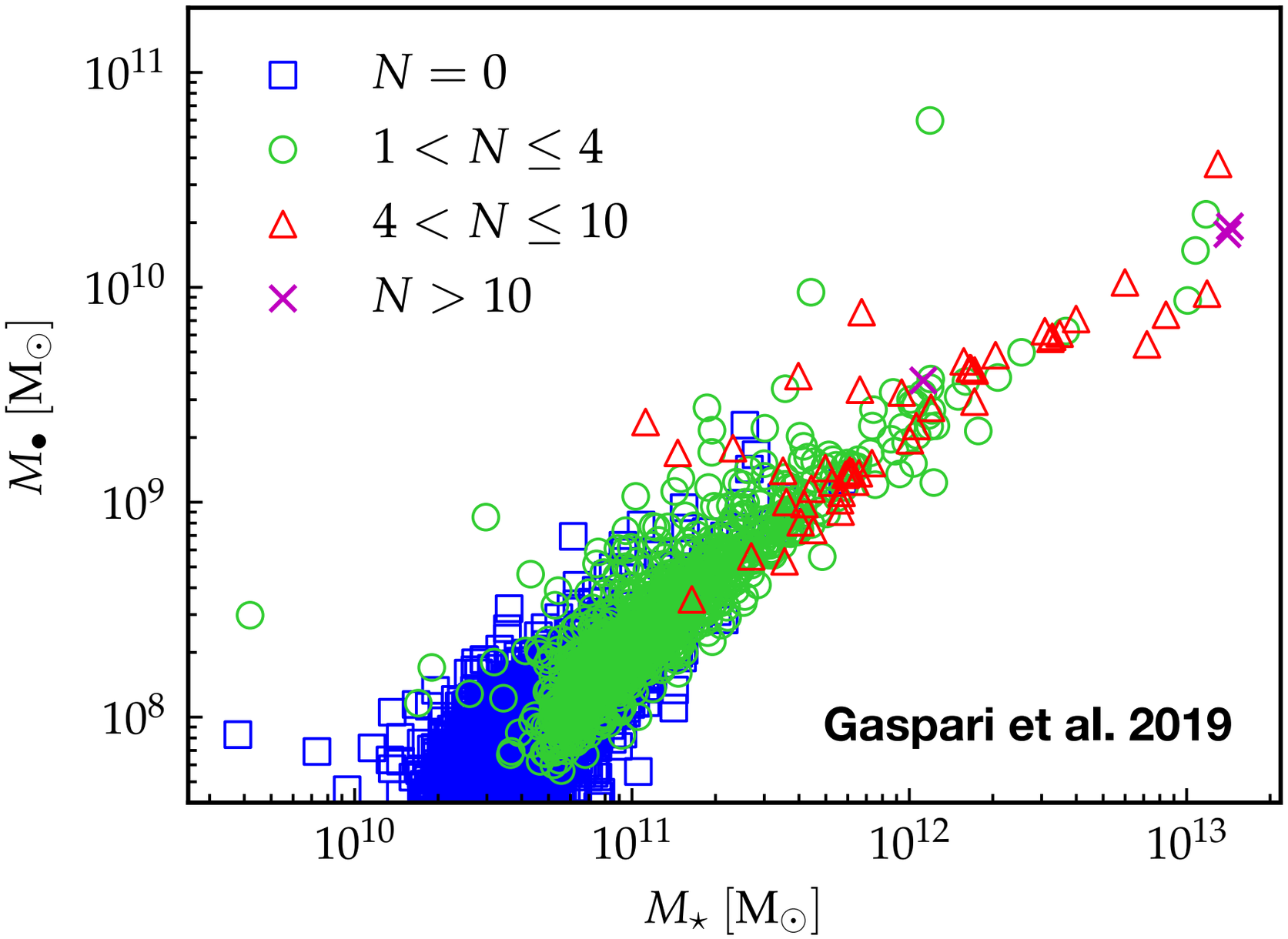
$$M_{\rm BH}^{mer} \sim 33\,\%$$

$$M_{\rm BH}^{mer} > M_{\rm BH}^{acc}$$

$$M_{\rm BH}^{mer} \sim 60\,\%$$

SMBHs mass evolution during cosmic time

N number of mergers with $M_1 : M_2 > 0.25$



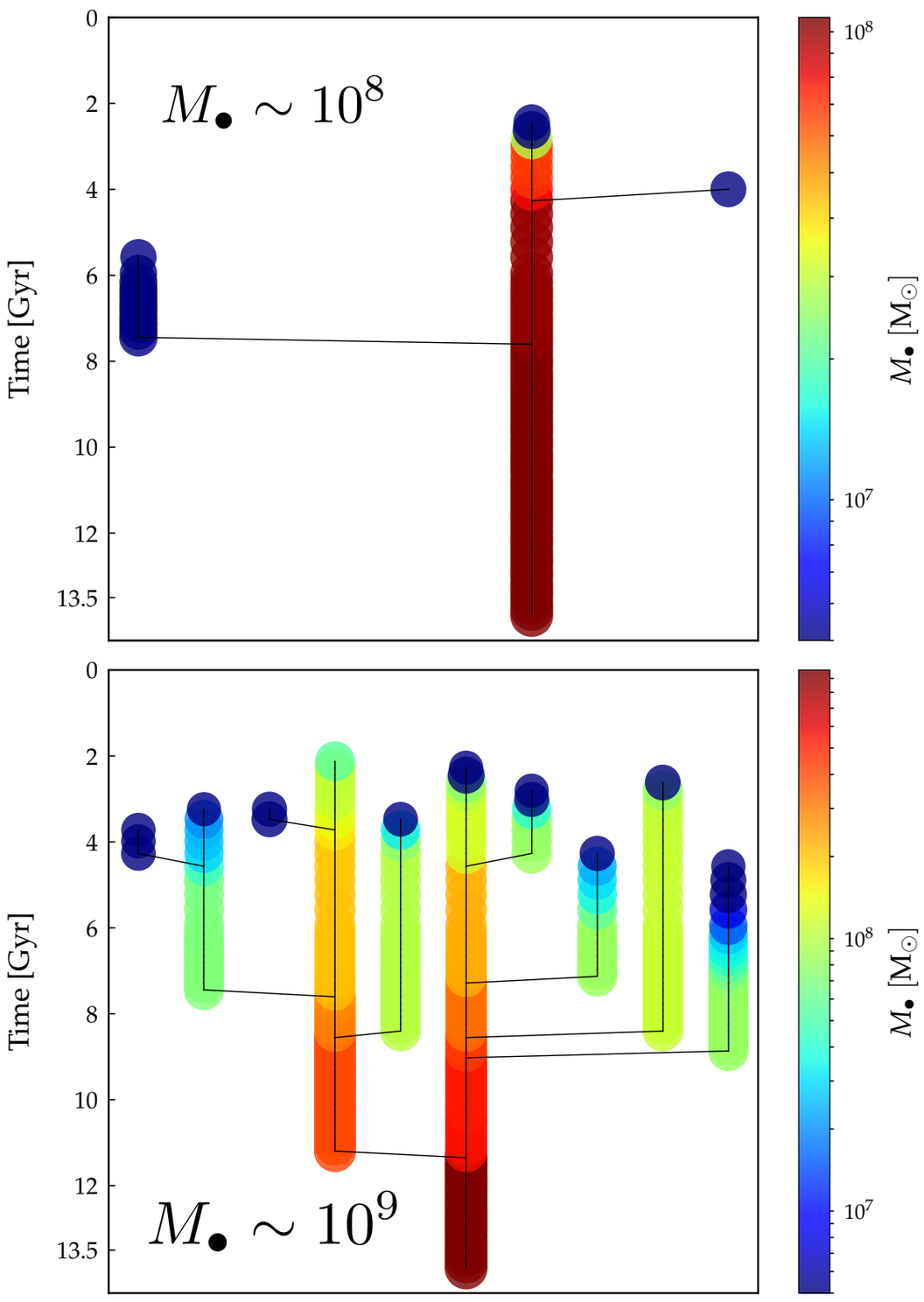
Mergers important for the most massive objects

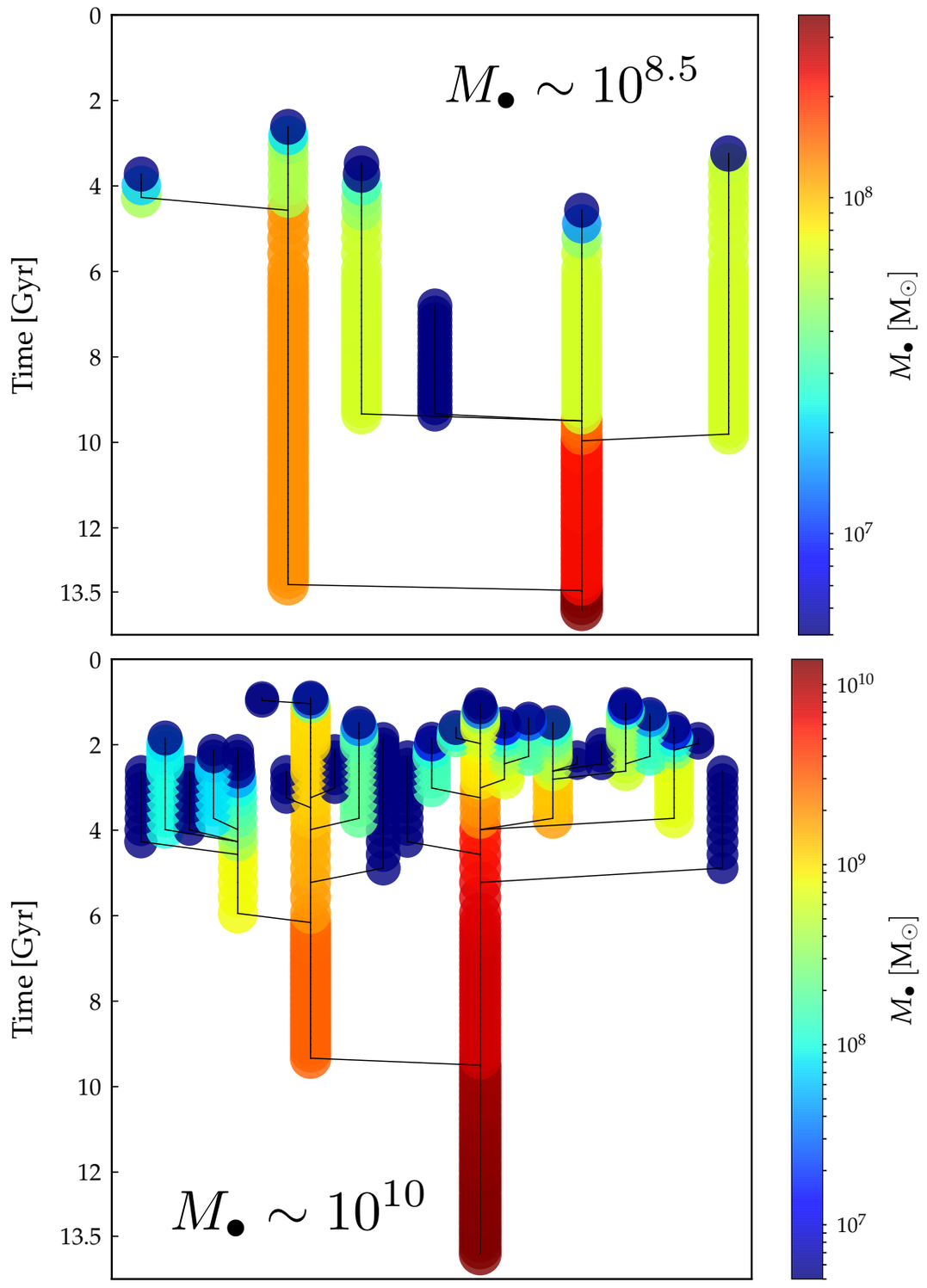
$M_\bullet \sim 5 \times 10^7\ M_\odot : < N > = 0$

$M_\bullet \sim 5 \times 10^8\ M_\odot : < N > = 2$

$M_\bullet \sim 5 \times 10^9\ M_\odot : < N > = 4$

SMBHs mass evolution during cosmic time





Conclusions

- ***Simulations reproduce the observed relation between MBH and T500 (M500);***

- ***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*** R_{500} ***→*** M_{500} ***grows move towards the center→*** $M_{\rm BH}$ ***grows via 2 channels)***

- $M_{\rm BH} - M_{500}$ ***is as reliable as*** $M_{\rm BH} - M_{\rm BCG}$ ***for*** $M_{\rm BH}$ ***mass estimate (the scatter of the 2 relations are comparable)***

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