Observational Cosmology Journal Club

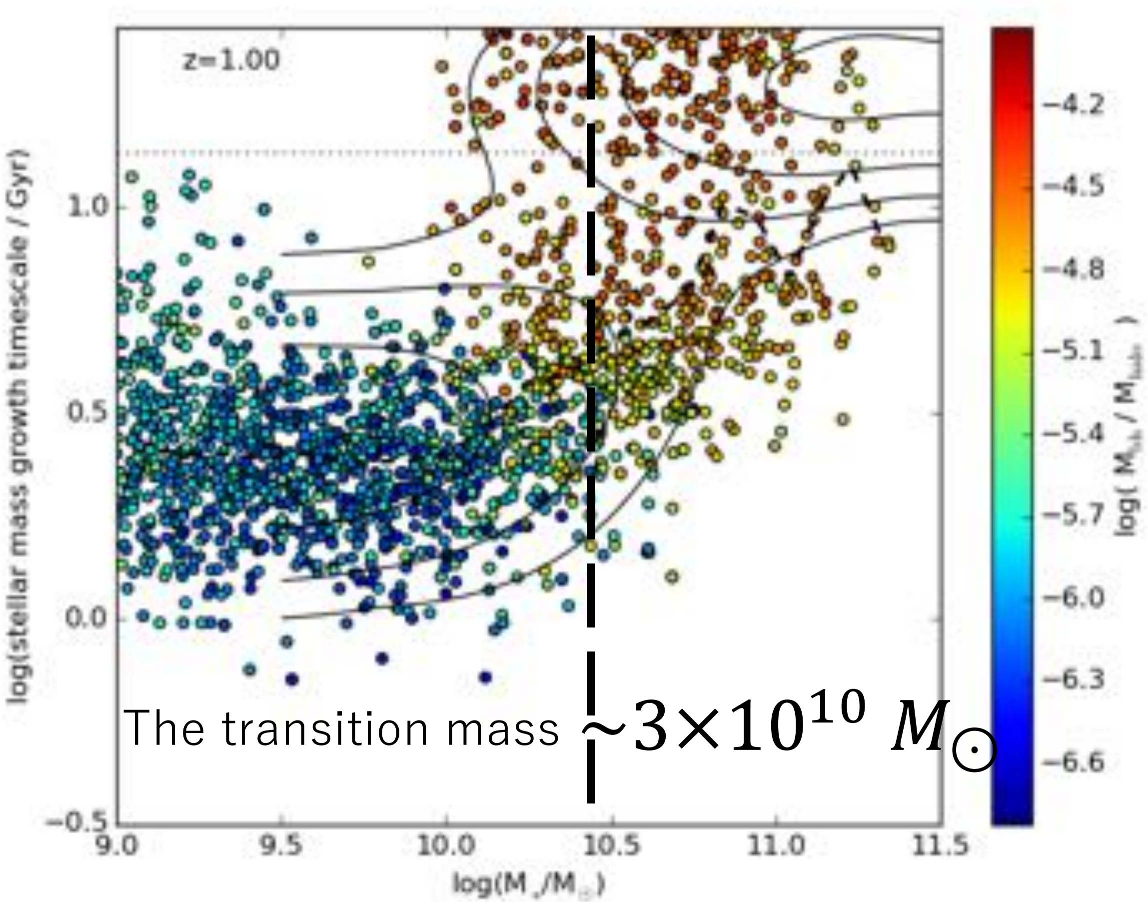
Oct. 17, 2016, Taira Oogi

[1] The dark nemesis of galaxy formation: why hot haloes trigger black hole growth and bring star formation to the end
Richard G. Bower, Joop Schaye, Carlos S. Frenk et al.; arXiv:1607.07445

[2] Satellite quenching timescales in clusters from projected phase space measurements matched to simulated orbits
Kyle A. Oman, Michael J. Hudson; arXiv:1607.07934

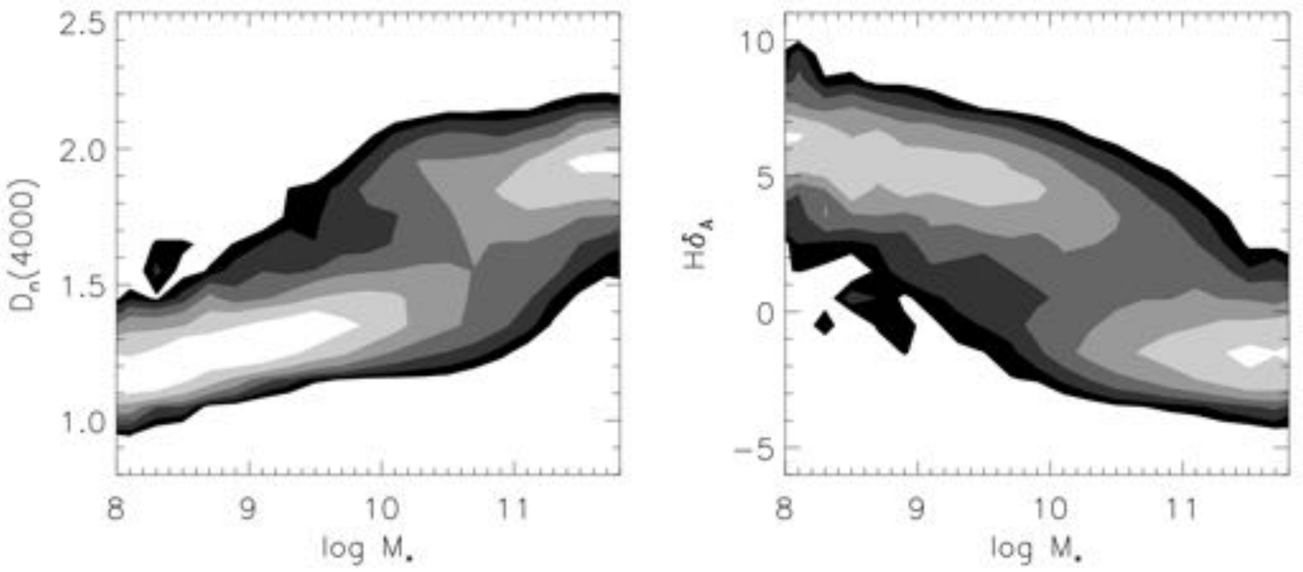
[3] Black hole clustering and duty cycle in the Illustris simulation
C. DeGraf, D. Sijacki; arXiv:1609.06727

[1] The dark nemesis of galaxy formation: Background
Two distinct galaxy types



The transition mass $\sim 3\times10^{10}\ M_{\odot}$

Kauffmann et al. 2003



These sequences are created by a competition between star formation-driven outflows and gas accretion on to the supermassive black hole at the galaxy’s center.

[1] The dark nemesis of galaxy formation

The buoyancy of the outflow is determined by the difference between its 'adiabat' (or entropy), $K = k_B T(\rho/\mu m_H)^{-2/3}$, and that of the galaxy's diffuse corona.

Outflow

$$K_{crit} \approx 8 \left(\frac{n_H^0}{0.1cm^{-3}}\right)^{-2/3} \left(\frac{M_{halo}}{10^{12}M_\odot}\right)^{-2/9} \Delta_z{}^{-4/3} \text{ keV cm}^2$$

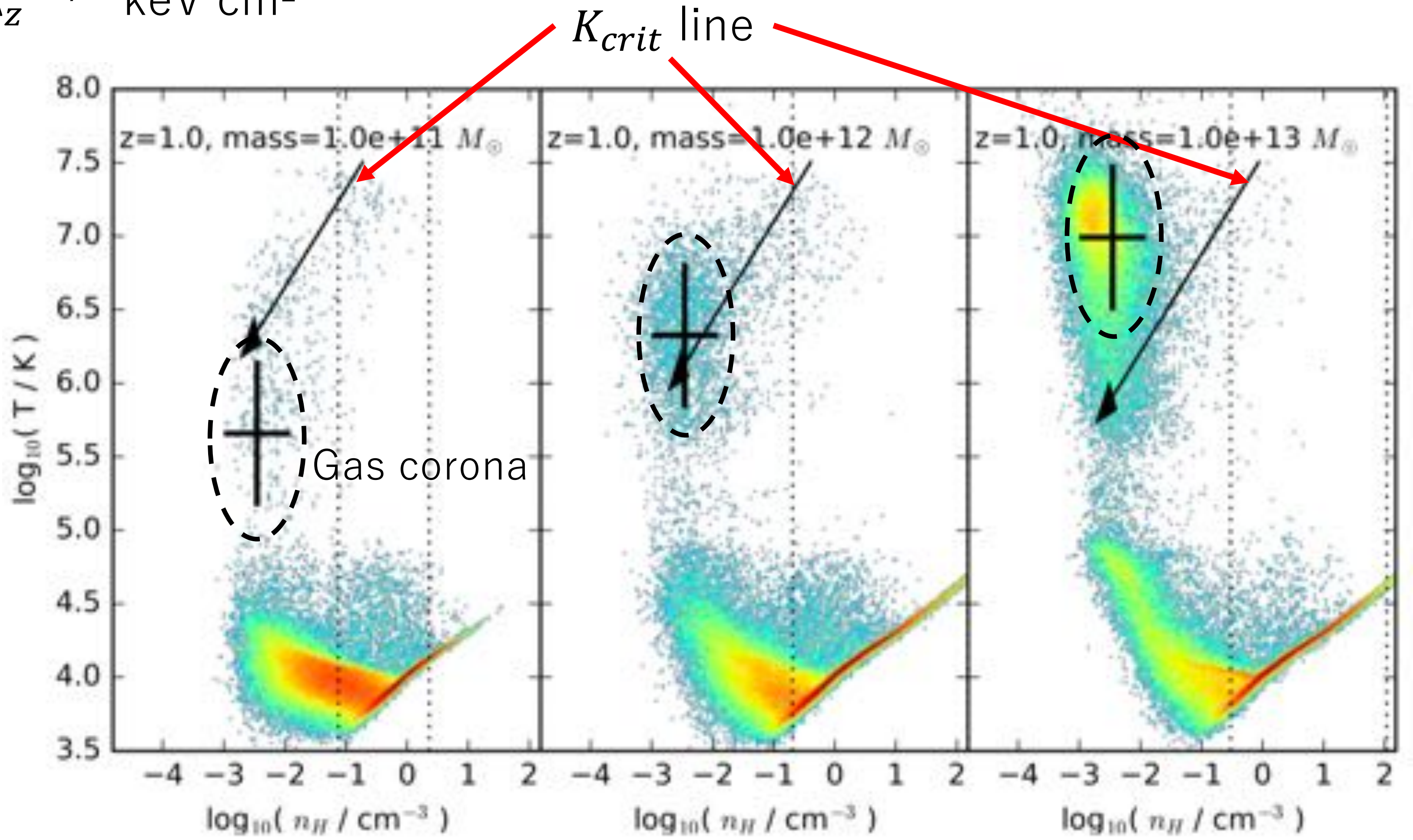
Gas corona

$$T \approx 1.4\times10^6 \left(\frac{M_{halo}}{10^{12}M_\odot}\right)^{2/3} \Delta_z \text{ K}$$

$$K_{halo} \approx 7 \left(\frac{M_{halo}}{10^{12}M_\odot}\right)^{2/3} \Delta_z{}^{-1} \text{ keV cm}^2$$

$$K_{outflow} \approx K_{halo}$$

$$\longrightarrow M_{crit} \approx 10^{12}\,\Delta_z{}^{-3/8}\,M_\odot$$



[1] The dark nemesis of galaxy formation

The gas density around the black hole,

$$n_{\rm bh} = n^0_{\rm bh} \left(\frac{M_{\rm halo}}{M_{\rm crit}}\right)^{8/9} \left(\frac{M_{\rm halo}}{10^{12}\,{\rm M}_\odot}\right)^{1/3} \Delta_z^2$$

$$\sim n^0_{\rm bh} \left(\frac{M_{\rm halo}}{10^{12}\,{\rm M}_\odot}\right)^{4/3} \Delta_z^{5/2}.$$

The black hole accretion disk is fed at a rate (Bondi 1952):

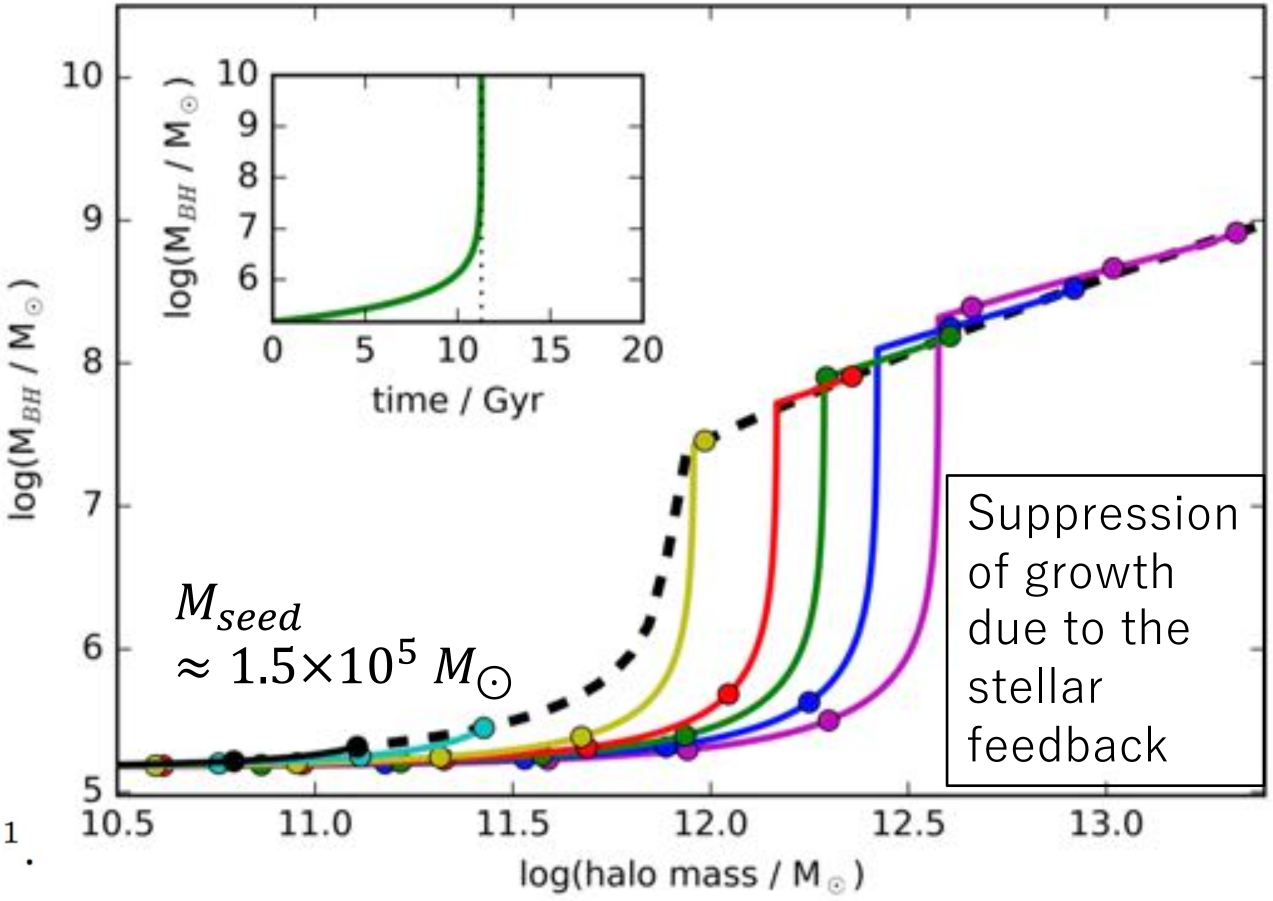
$$\dot{M}_{\rm bh} = 4\pi {\rm G}^2 f_{\rm sup} \frac{M_{\rm bh}^2 \rho_{\rm bh}}{c_s^3}.$$

The halo growth rate (Correa et al. 2015):

$$\dot{M}_{\rm halo} = 7\times 10^{10} \left(\frac{M_{\rm halo}}{10^{12}\,{\rm M}_\odot}\right) (0.51 + 0.75z) \Delta_z^{3/2}\,{\rm M}_\odot\,{\rm Gyr}^{-1}.$$

Above the mass scale, $M_{crit} \approx 10^{12}\,\Delta_z{}^{-3/8}\,M_\odot$, the mass of the black hole is limited to a fraction of the halo binding energy.

The black hole growth in this model



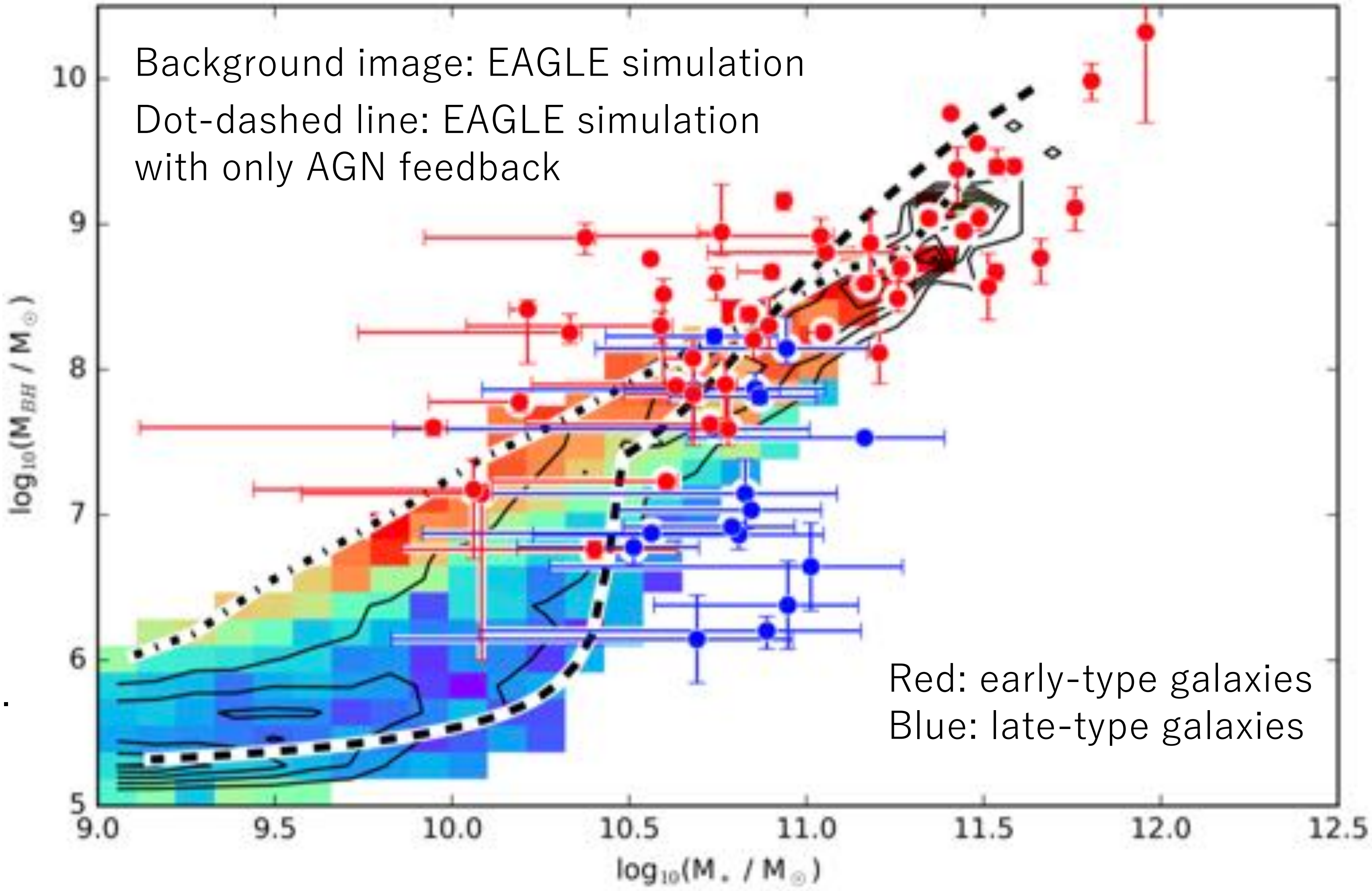
Colors show the seed formation time, 0.4 to 2 Gyr (purple to cyan).

[1] The dark nemesis of galaxy formation

In the absence of star formation driven outflows, black holes are always able to accrete efficiently and grow along a power-law relation.

The model predicts that the black holes present in isolated low-mass galaxies will be small, $M_{BH} < 10^6 M_{\odot}$.

Black hole mass – stellar mass relation



[2] Satellite quenching timescales in clusters: Motivation

1. Environmental quenching

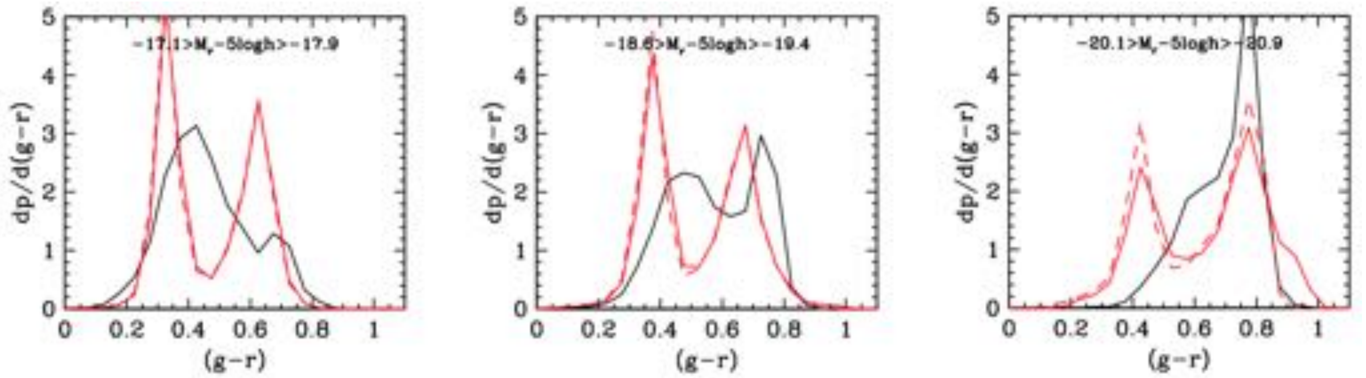
- Red galaxies in cluster galaxies
- Physical mechanism: ram pressure stripping of disc gas and/or halo gass

2. Issues

- The quenching timescale is uncertain
- In semi-analytic models, too many red satellite galaxies are produced.

3. New approach: the orbital library method

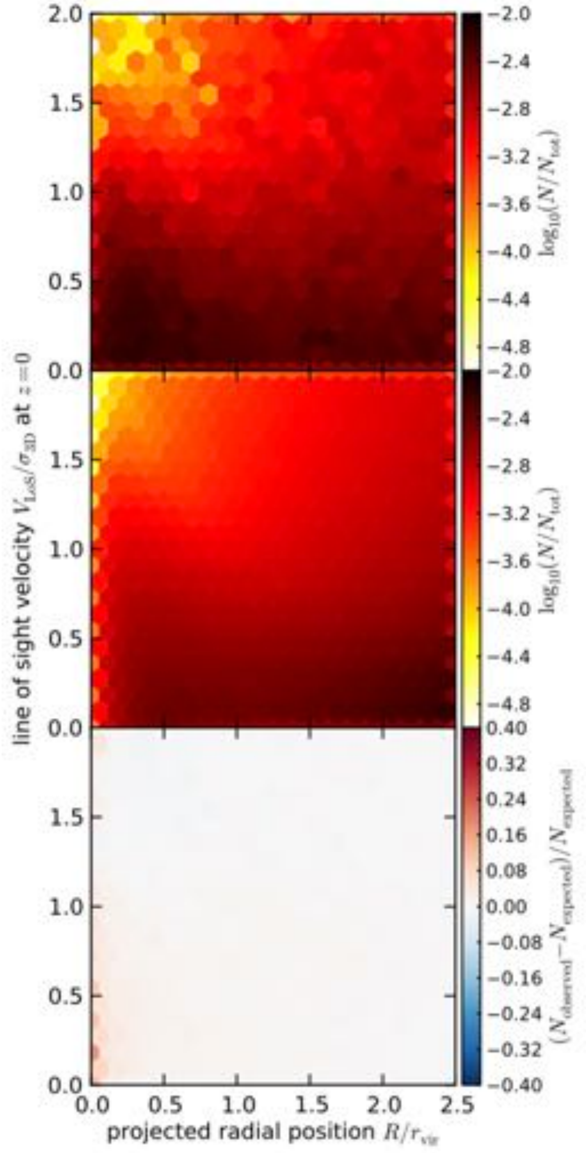
- Cosmological N-body simulation
- A simple quenching model



Galaxy g-r colors at z=0. The red lines show model predictions (Lacey et al. 2016). The black lines show the SDSS results.

[2] Satellite quenching timescales in clusters: Method

Comparison of observed and simulated samples



Quenching model

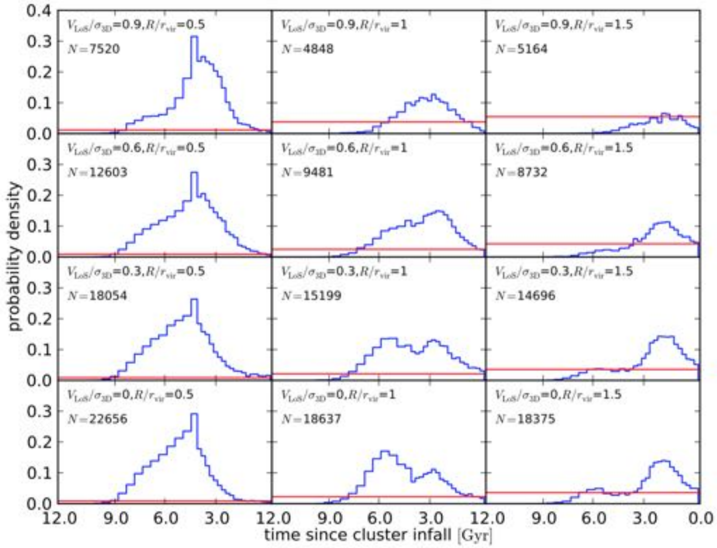
The probability that the galaxy is passive

$$p_{\text{passive},i} = f_{\text{passive,out}} + p_{q,i}\,\Delta f_{\text{passive}},$$

The probability that the cluster has quenched the galaxy

$$p_{q,i} = \int_{t=0}^{t_f} p_q(t)\,p_{\text{infall},i}(R_i, V_i, t)\,\mathrm{d}t,$$

$$p_q(t) = \begin{cases} 0, & t \le \Delta t \\ 1 - \mathrm{e}^{-(t-\Delta t)/\tau} & t > \Delta t \end{cases}.$$



Parameters:

$f_{\text{passive, out}}$: the passive fraction outside the cluster

$\Delta f_{\text{passive}}$: the increase of the passive fraction

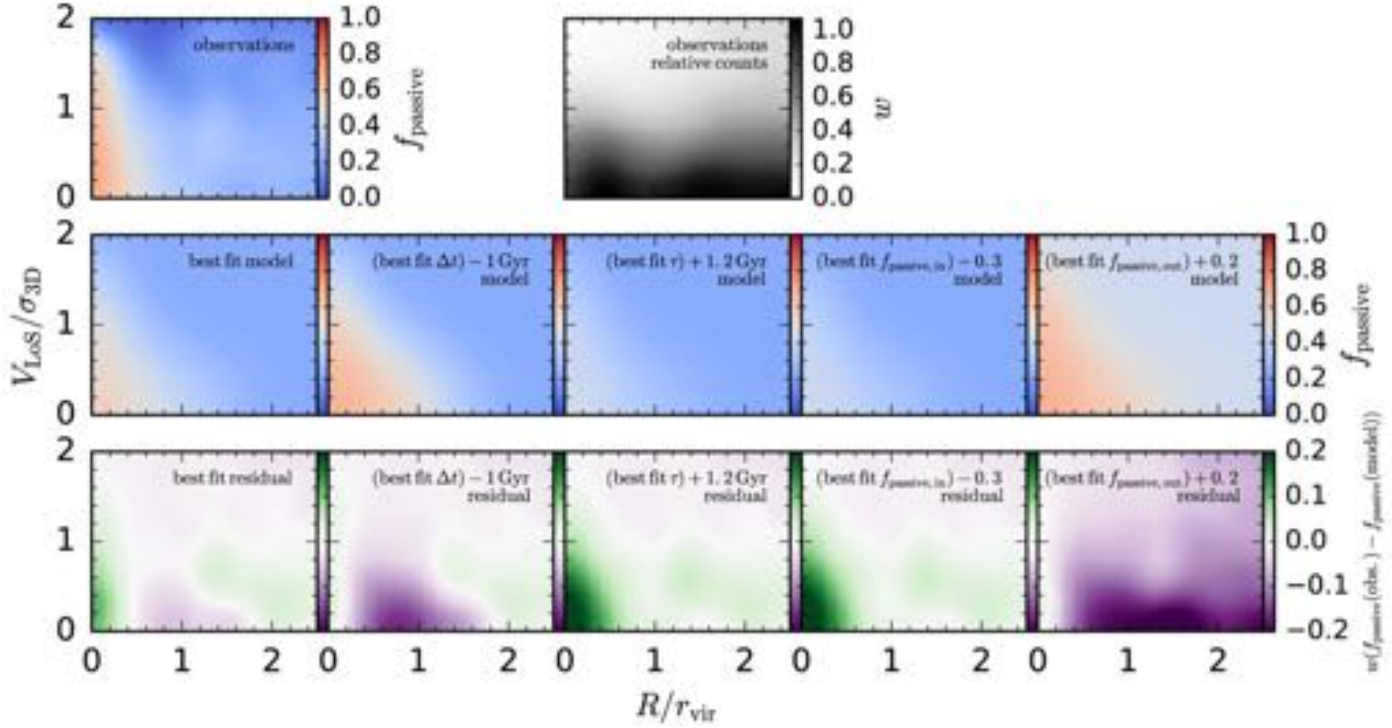
Δt: Δt has elapsed after infall, the probability of quenching increases.

τ : quenching timescale

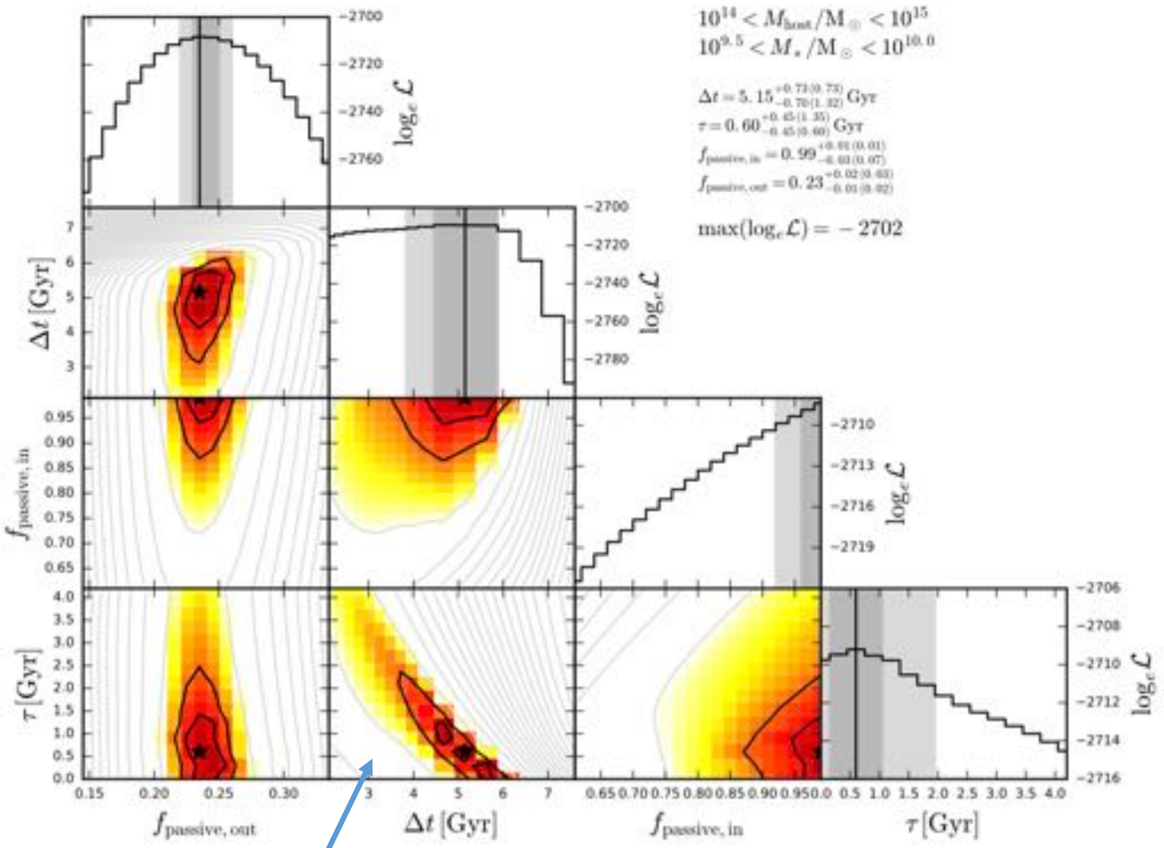
[2] Satellite quenching timescales in clusters: Results

Sample clusters: $14 < \log_{10}(M_{\mathrm{host}}/M_{\odot}) < 15$ and $9.5 < \log_{10}(M_{*}/M_{\odot}) < 10$

The passive fraction as a function of phase space coordinates



Marginalized likelihood distributions



The degeneracy between Δt and τ

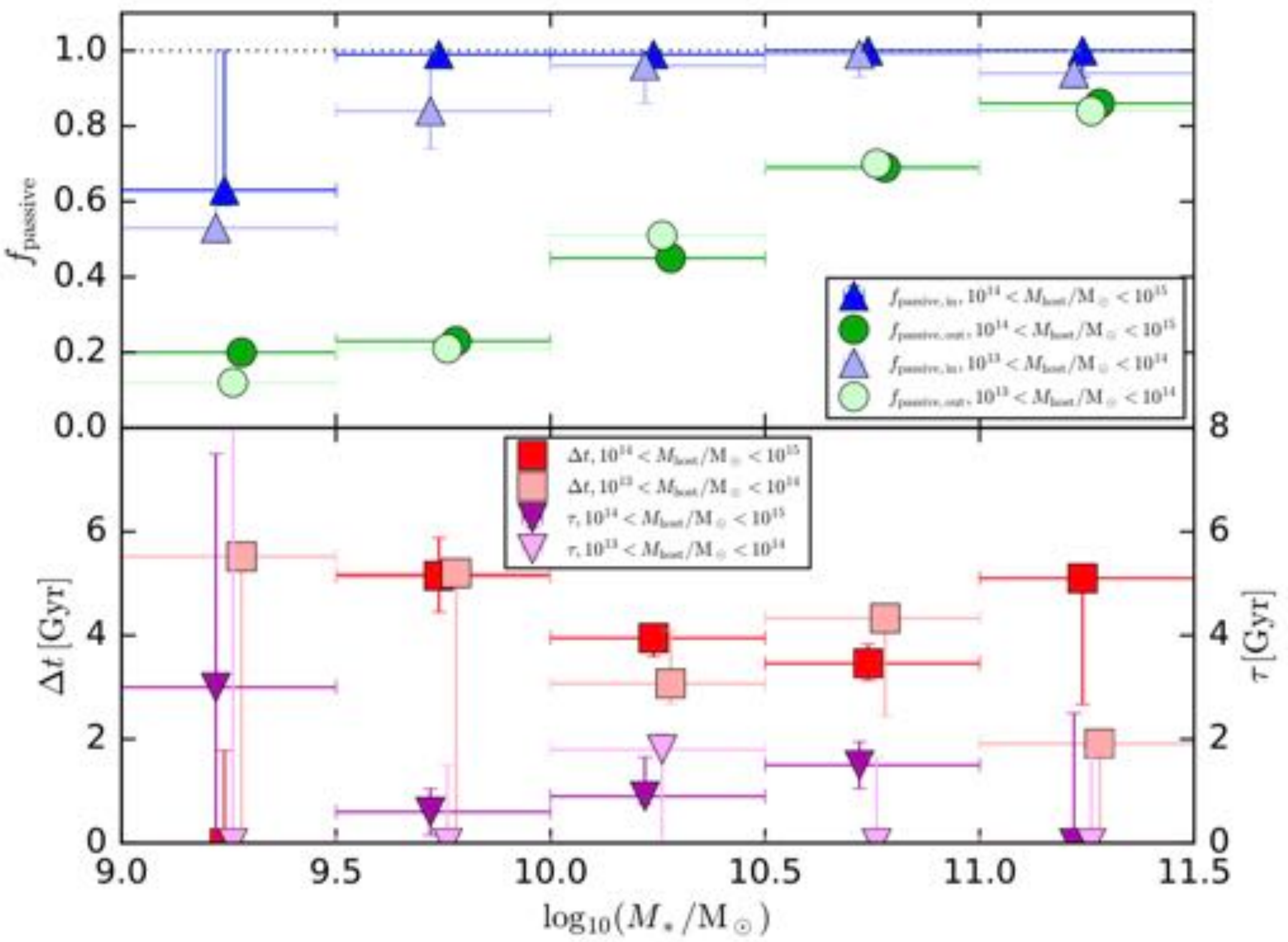
[2] Satellite quenching timescales in clusters

Finding:

- Quenching of satellite galaxies of all stellar masses in our sample by massive cluster is essentially 100 per cent efficient.
- All galaxies quench on their first infall, approximately at or within a Gyr of their first pericentric passage.

The results are in agreement with previous work (Wetzel et al. 2013), which suggest a ‘delayed-then-rapid’ quenching scenario.

Maximum likelihood model parameters



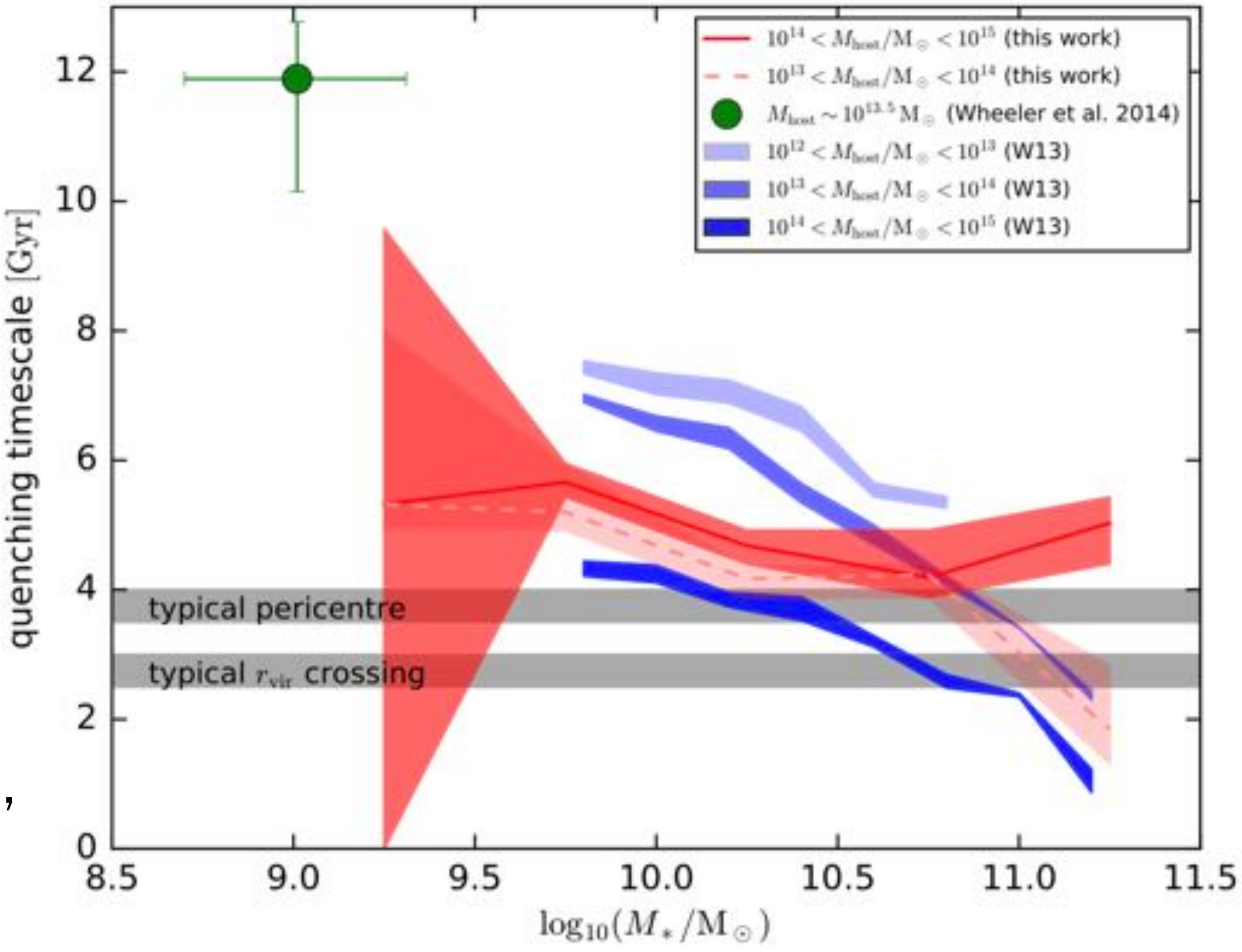
[2] Satellite quenching timescales in clusters

The same trend:
A decreasing quenching timescale with increasing M_*

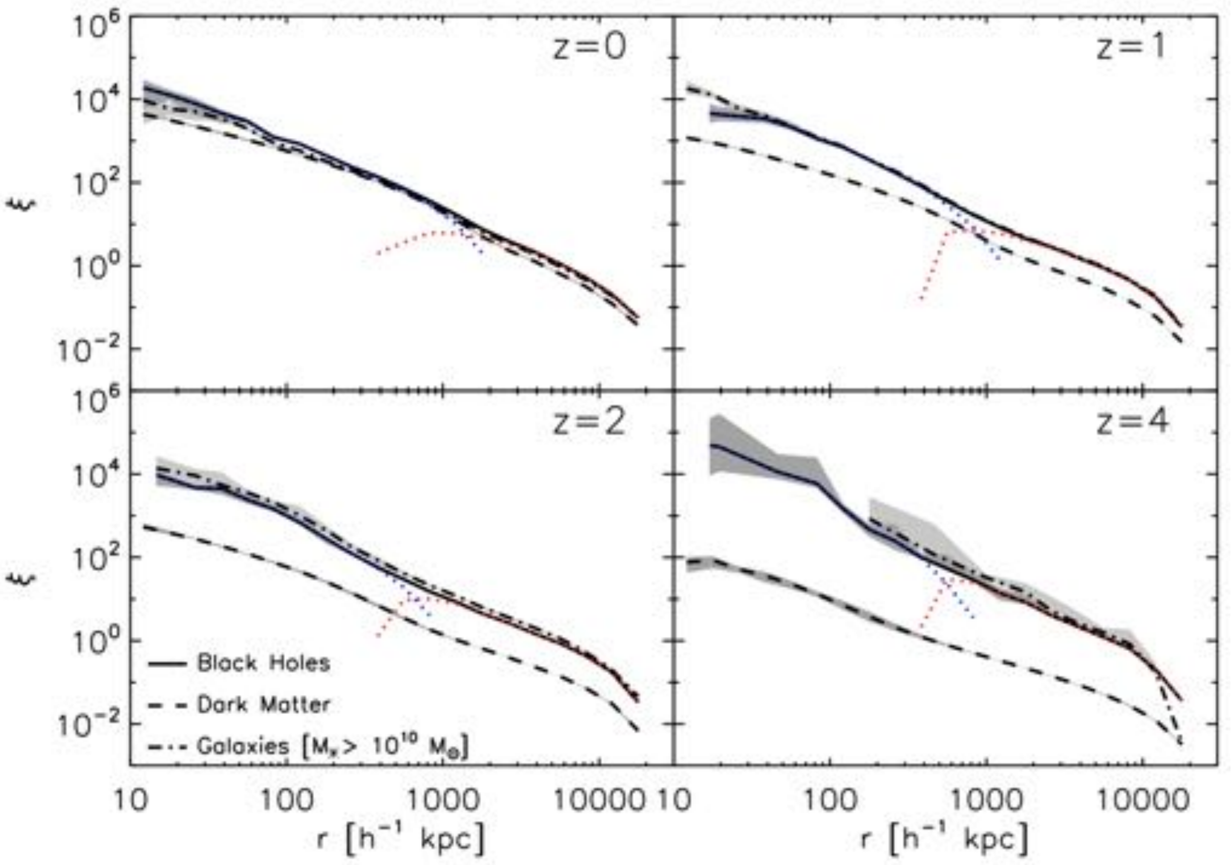
A different trend:
A much weaker (or no) trend with M_{host} in this work

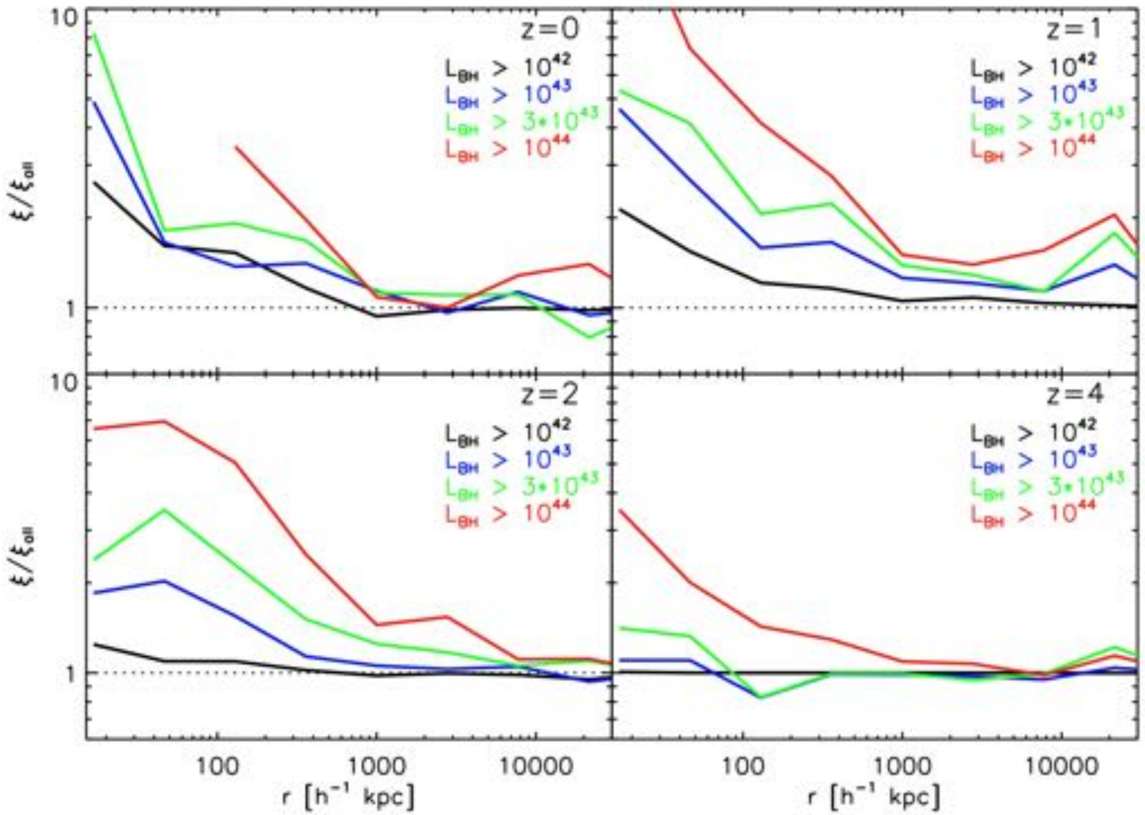
At high M_{host} end, the quenching of W13 includes pre-processing in another (previous) group or cluster. This work, however, includes this effect as the parameter $f_{\mathbf{passive,\,out}}$, and isolates the effect of the final host halo.

Comparison with other works



[3] Black hole clustering and duty cycle in the Illustris simulation





Ratio between autocorrelation functions using luminosity-selected population ξ and full population ξ_{all}.

Black hole clustering is strongly luminosity-dependent on small, 1-halo scales.

[3] Black hole clustering and duty cycle in the Illustris simulation

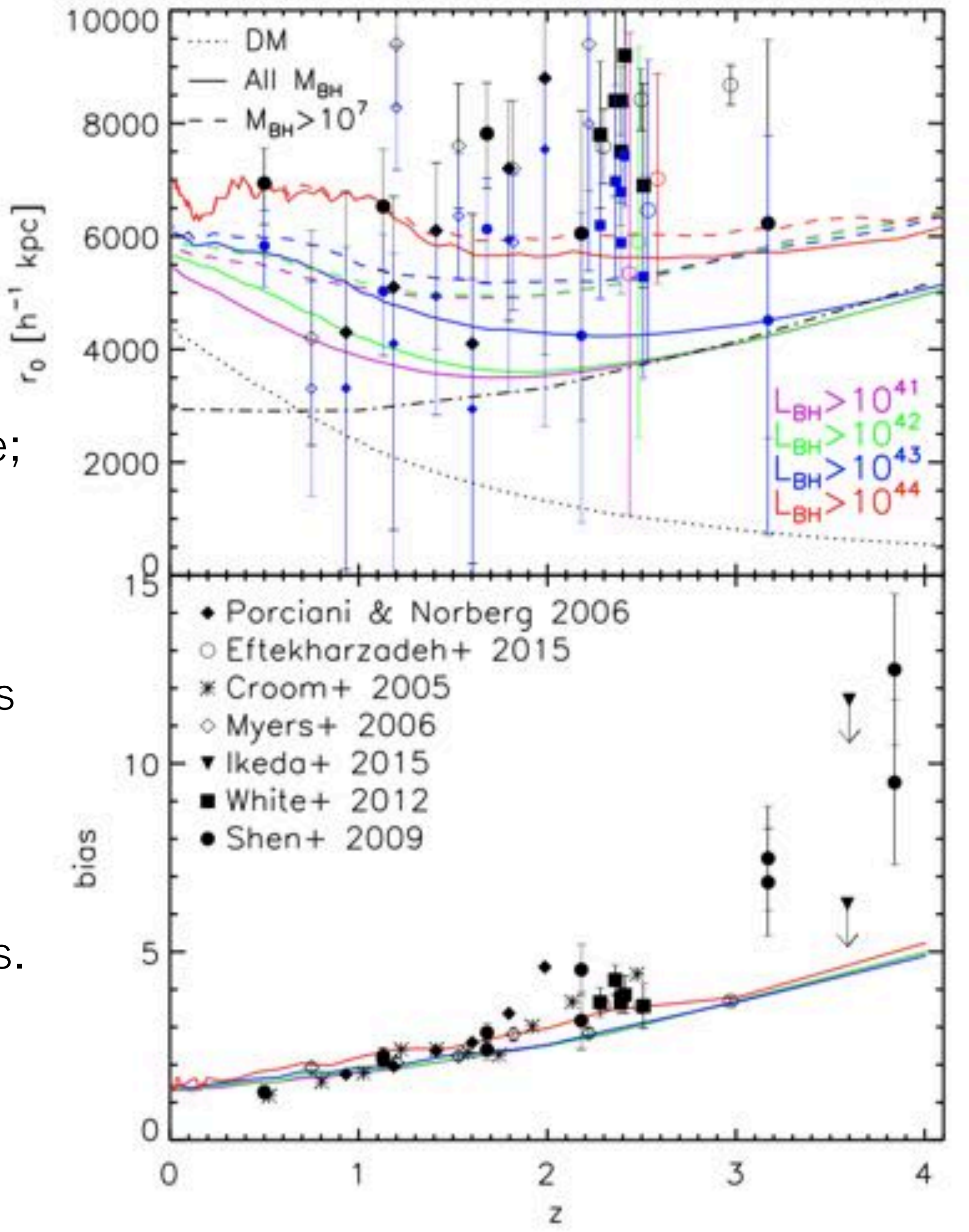
Dot-dashed line: halo correlation length

The typical host halo mass of low-luminosity black holes is roughly constant at z>2.

While r_0 of the dark matter increases with cosmic time; that of the BH has weaker evolution.

Their r_0 values are slightly lower than the observations partly because of their volume limited sample.

At below z~2, their bias is agreement with observations. At higher redshift, they underestimate the bias.



[3] Black hole clustering and duty cycle in the Illustris simulation

Halo bias (Tinker et al. 2010)

$$b(\nu) = 1 + \frac{1}{\sqrt{a}\delta_c}\left[\sqrt{a}(a\nu^2) + \sqrt{a}b(a\nu^2)^{1-c} - \frac{(a\nu^2)^c}{(a\nu^2)^c + b(1-c)(1-c/2)}\right],$$

$$\nu = \delta_c/\sigma(M)$$

Table 2
Parameters of Bias Equation (6) as a Function of Δ

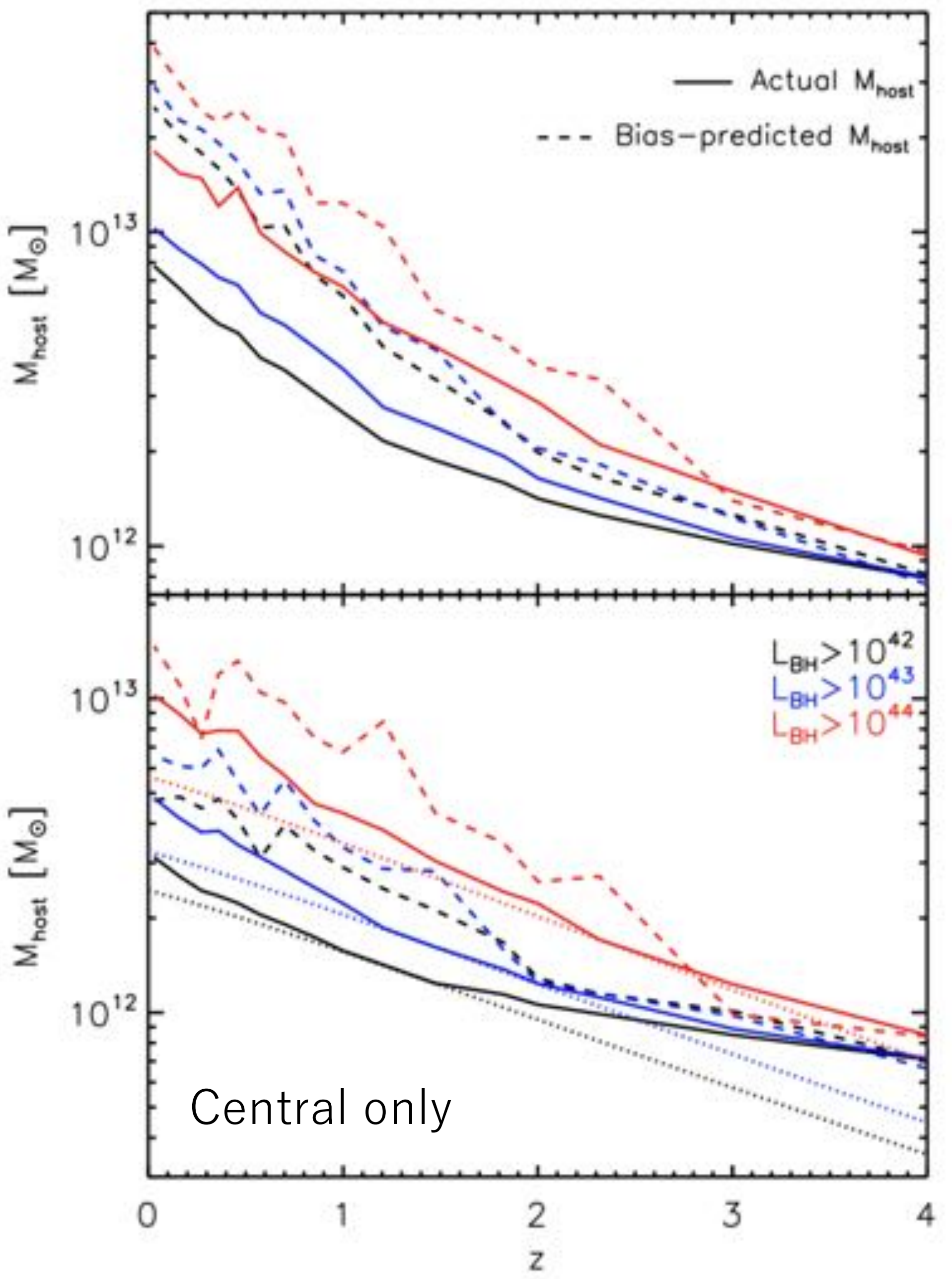
Parameter	$f(\Delta)$
A	$1.0 + 0.24y\exp[-(4/y)^4]$
a	$0.44y - 0.88$
B	0.183
b	1.5
C	$0.019 + 0.107y + 0.19\exp[-(4/y)^4]$
c	2.4

Note. $y \equiv \log_{10}\Delta$.

For z<2, the bias-predicted mass overestimates the typical host mass by a factor of 2.

At least part of this is due to halos hosting multiple black holes: larger halos tend to host larger numbers of satellite black holes, which biases ξ toward the clustering of the larger halos.

This suggests that observational estimates for typical host halo masses may overestimates by a factor of ~2, especially at z <~ 1.5.

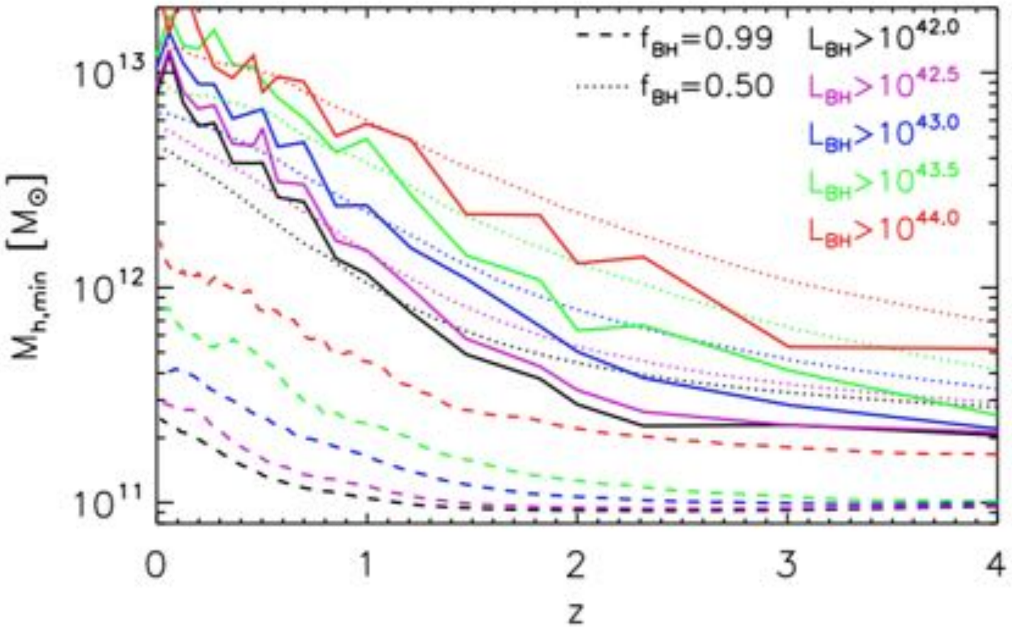


[3] Black hole clustering and duty cycle in the Illustris simulation

Minimum halo mass

Estimation:

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



Duty cycle

Estimation:

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