Exploring the AGN clustering using a semi-analytic model of galaxy formation

Galaxy evolution workshop

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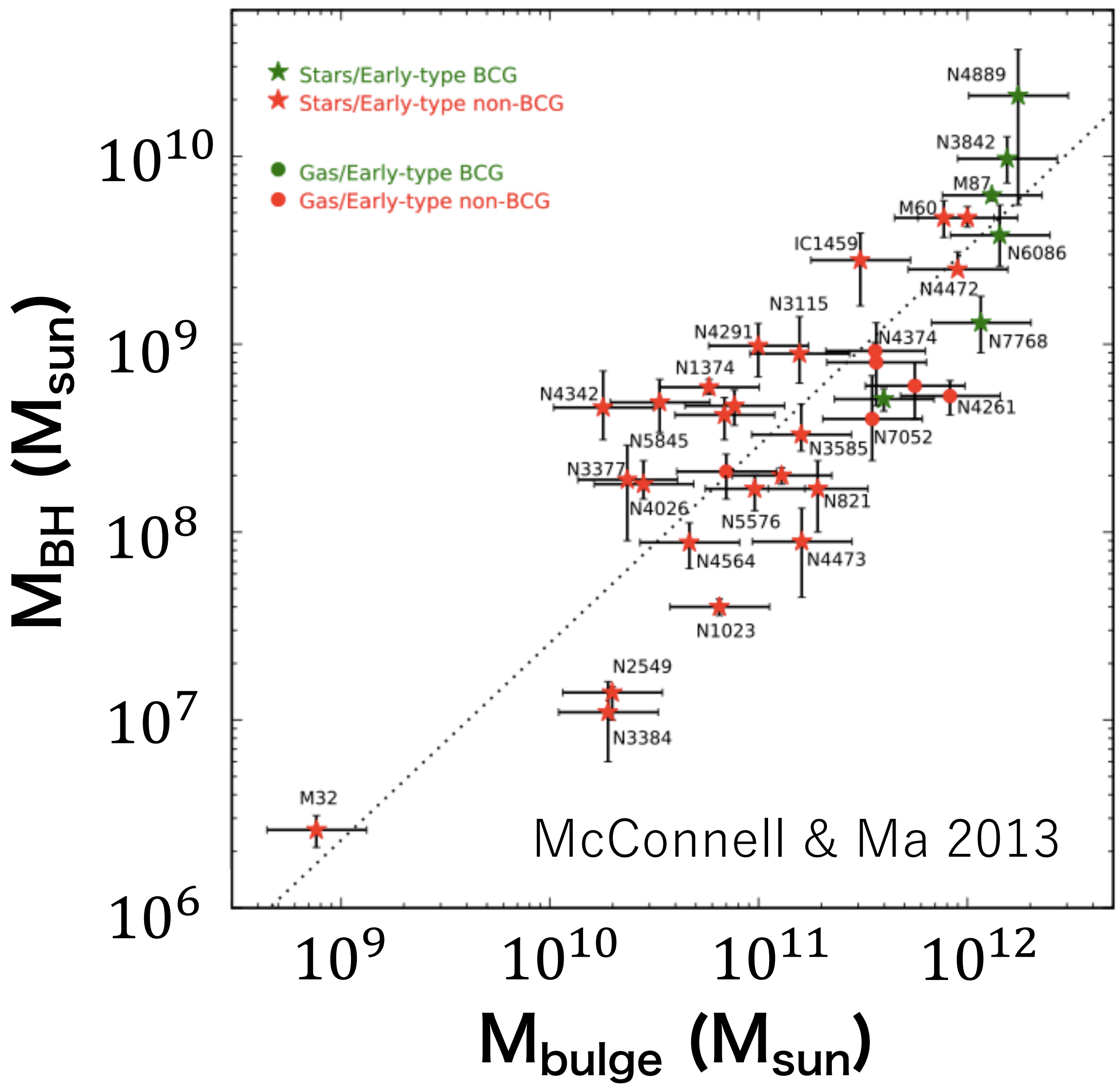
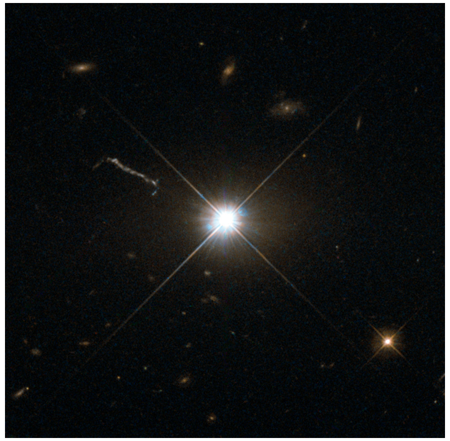
Outline

- Co-evolution of supermassive black holes and galaxies
- AGN host halo masses
- Previous work
- Model
  - AGN triggering mechanisms
- Results
  - Redshift evolution of AGN host halo masses
  - Two-point correlation functions of AGNs
  - AGN halo occupation distributions (HODs)

M_{BH}-M_{bulge} relation



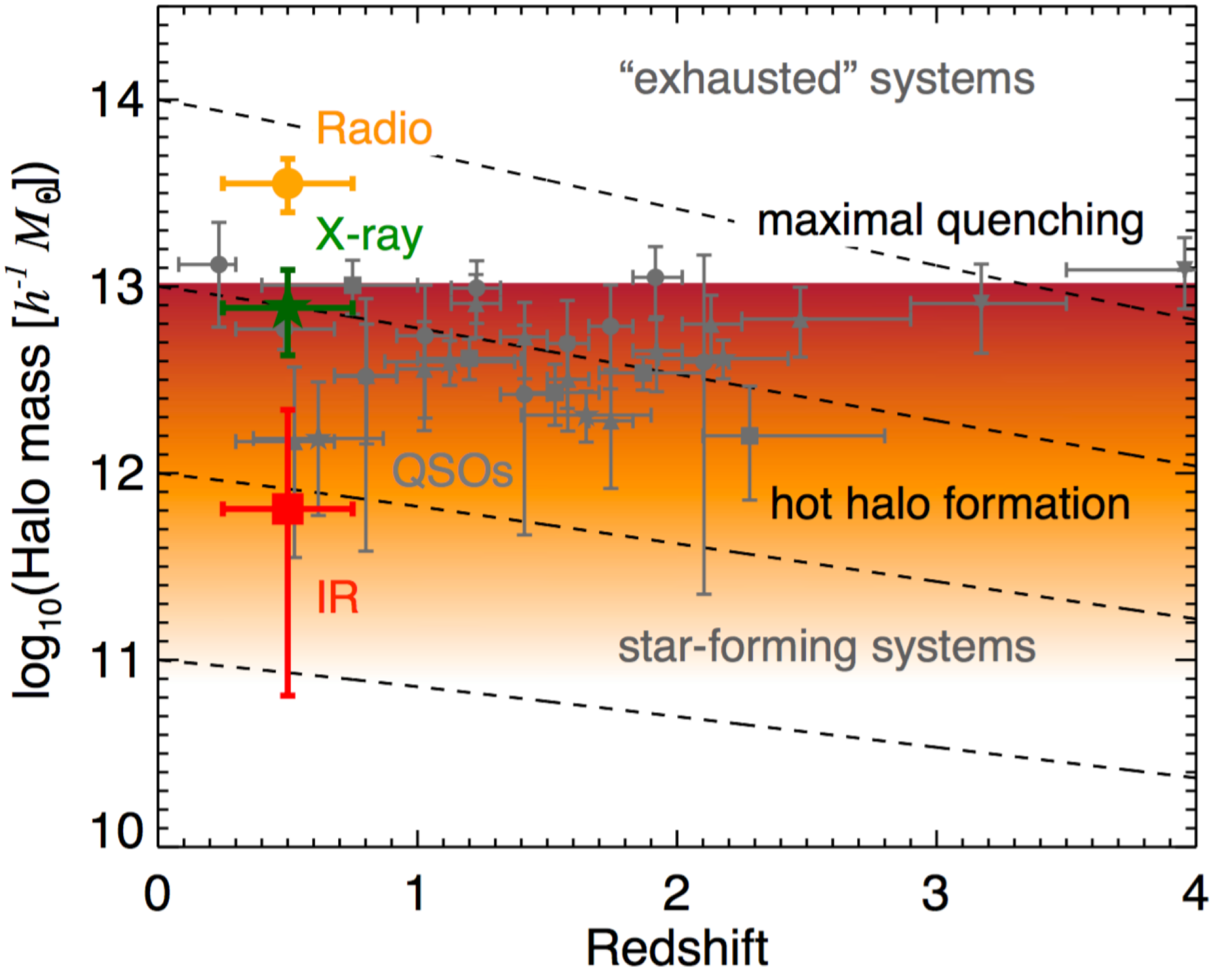


QSO 3C273
(ESA/Hubble & NASA)

- **Implication for the co-evolution of SMBHs and galaxies.**
- **Statistical properties of active galactic nuclei (AGNs) are important for understanding the co-evolution.**

AGN host dark matter (DM) halos

Redshift evolution of DM halo mass inferred from AGN clustering for AGN populations (Alexander & Hickox 2012)



AGN clustering and host halo mass can be constraints on the SMBH growth and AGN triggering mechanisms.

AGN host dark matter (DM) halos

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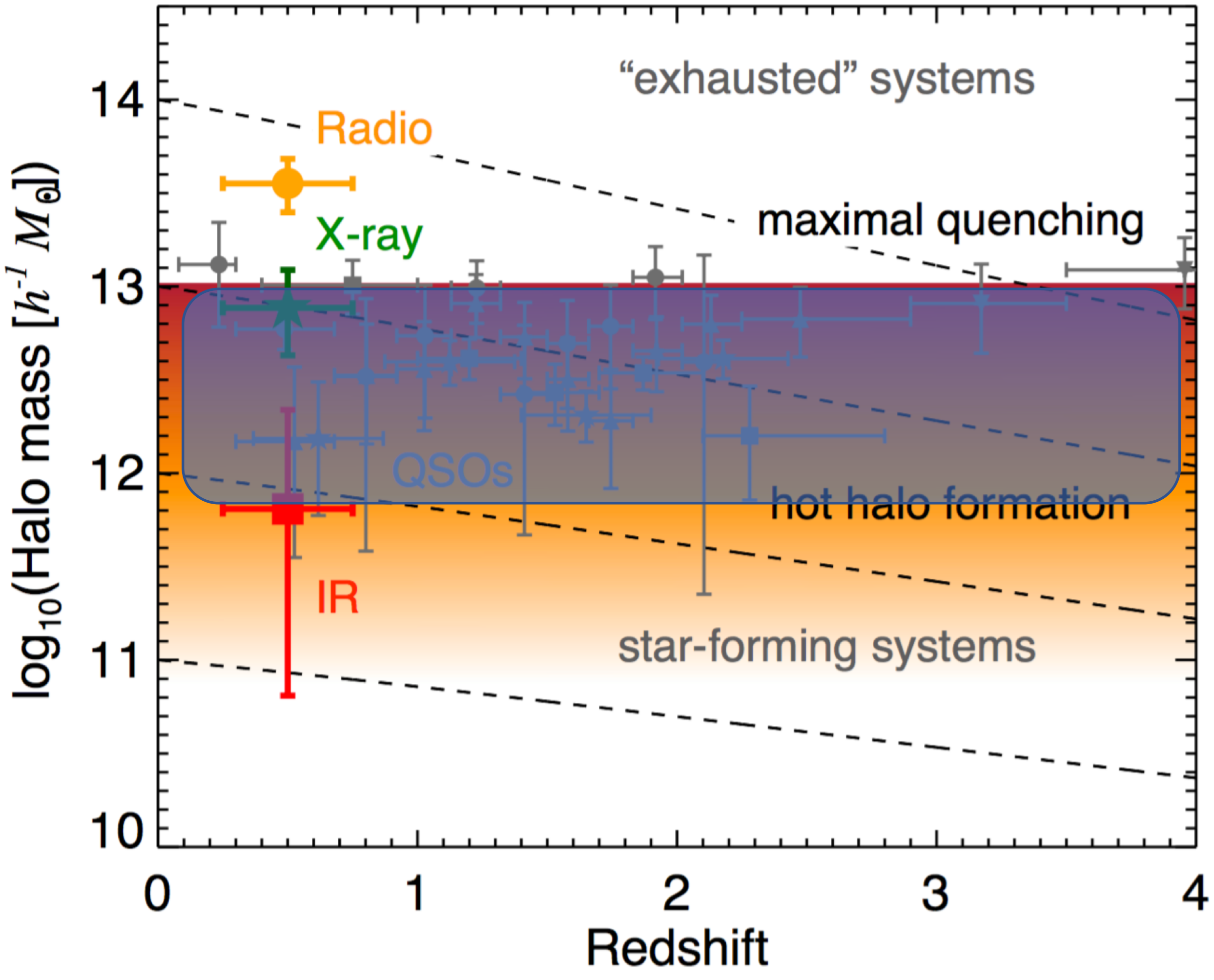
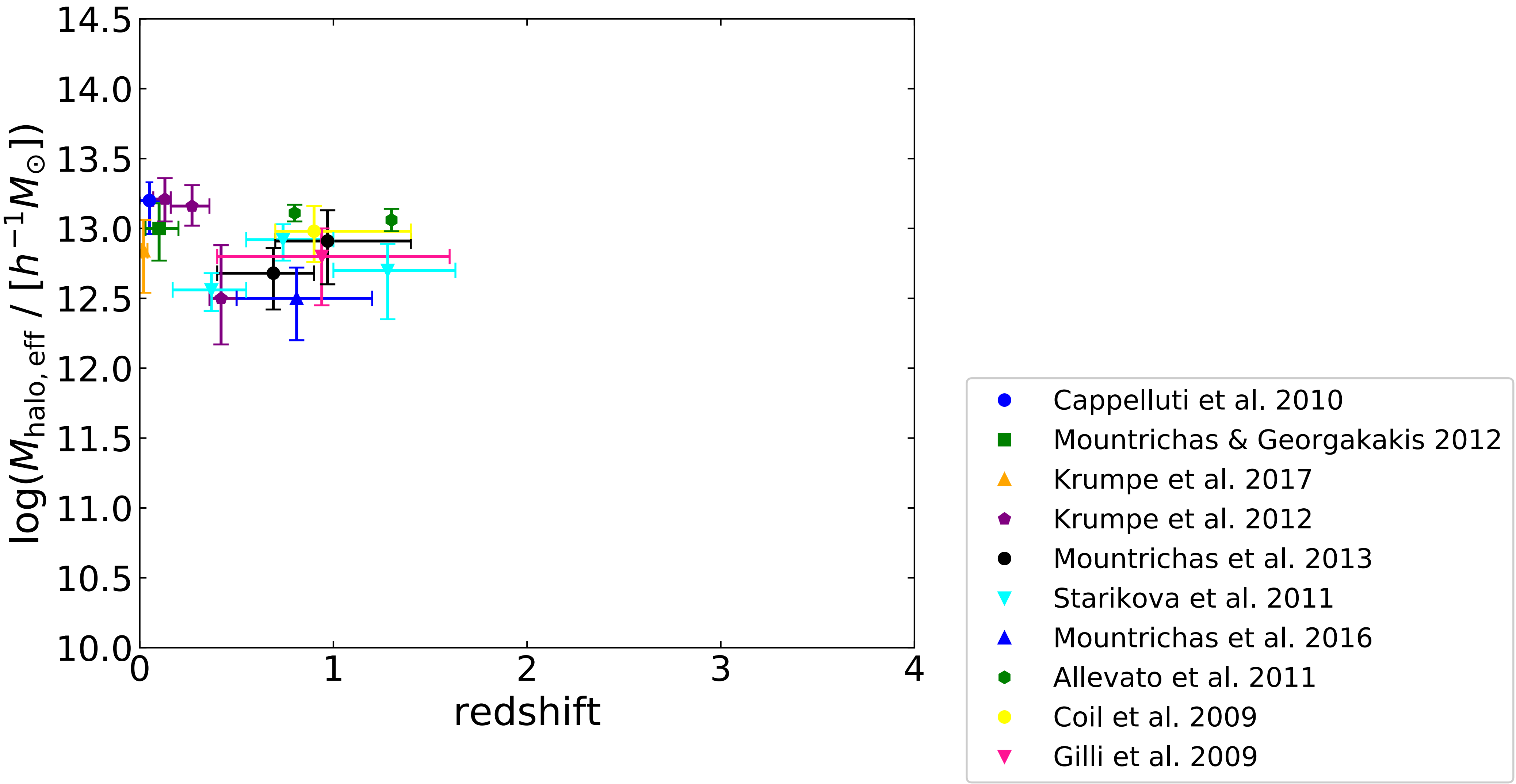


For optically luminous quasars, the host halo mass inferred from clustering is $2-3\times10^{12}h^{-1}M_{\odot}$.

DM halo mass of X-ray AGNs

Redshift evolution of DM halo mass for moderate luminosity (X-ray) AGNs (compilation by Georgakakis et al. 2019)



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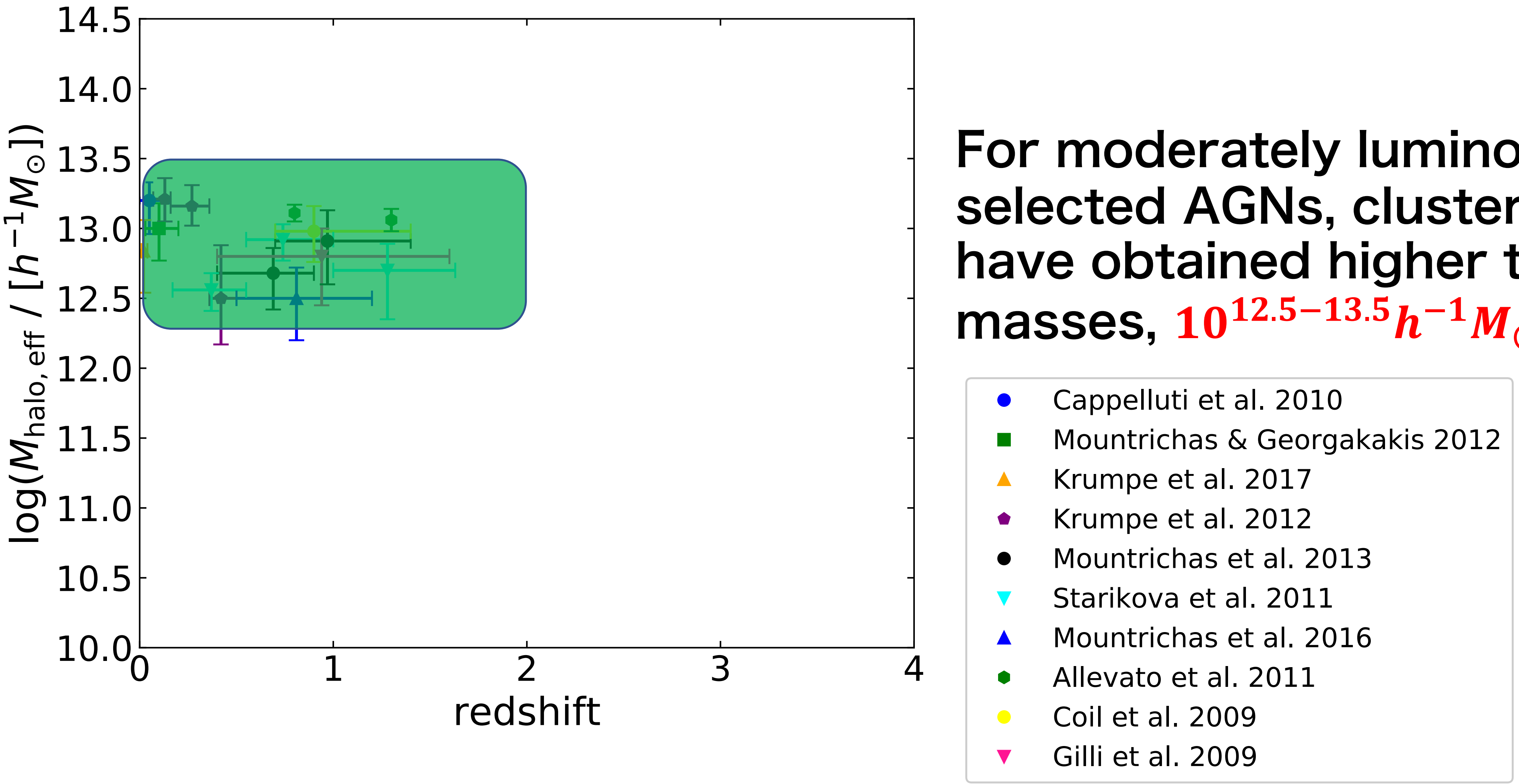

For moderately luminous X-ray-selected AGNs, clustering studies have obtained higher typical halo masses, $10^{12.5-13.5}h^{-1}M_{\odot}$.

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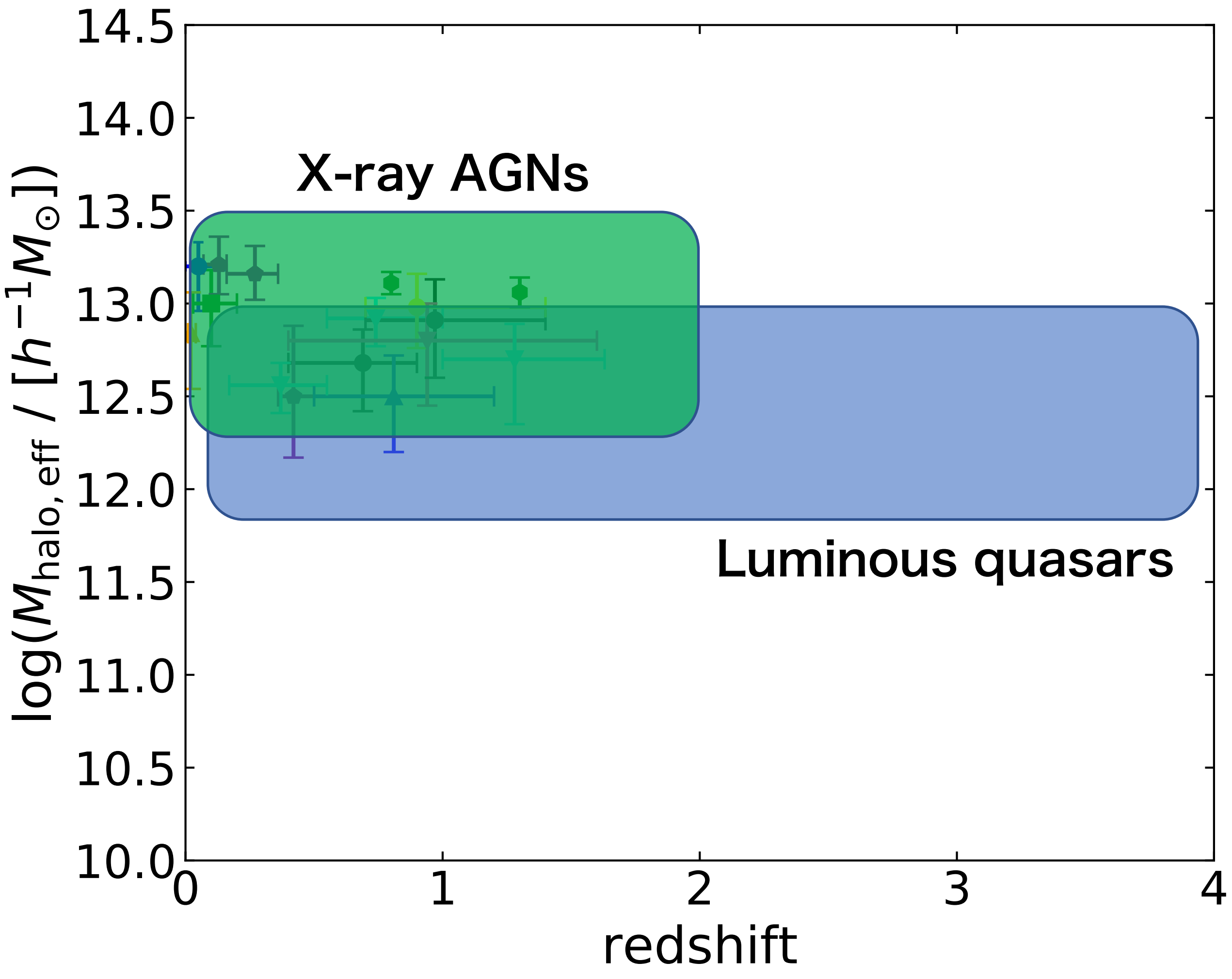

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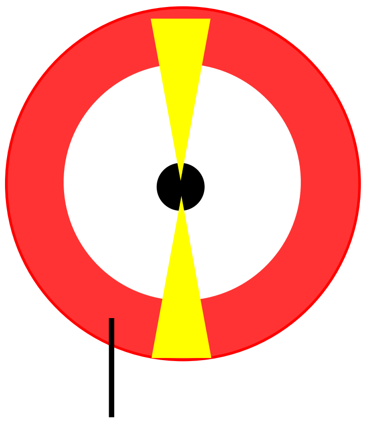
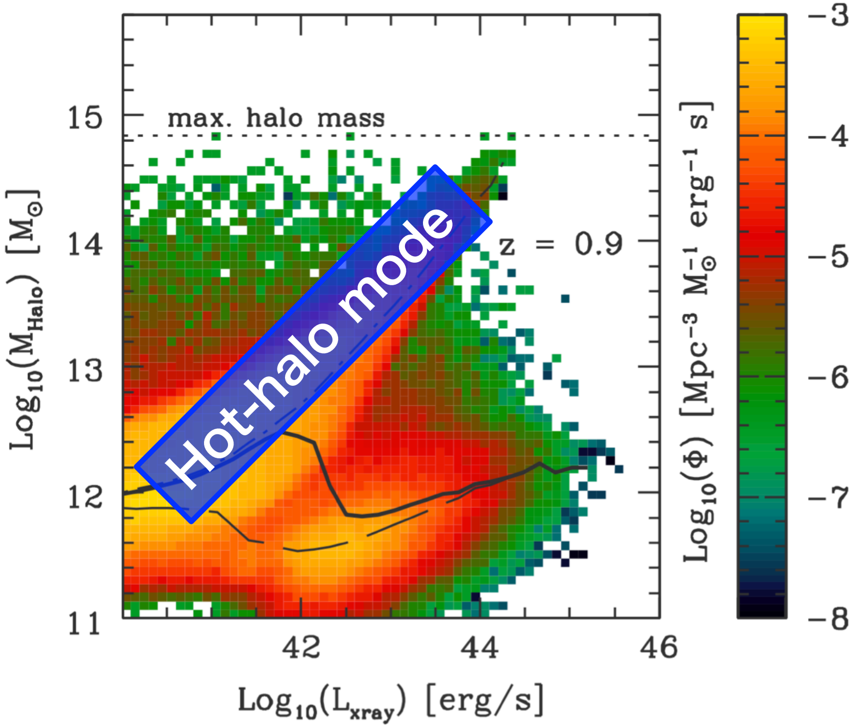
Previous work

- The DM halo mass of luminous quasars can be explained by models in which quasar activity is triggered by galaxy major mergers (at least $z \lesssim 2$).
- The X-ray AGN host halo can be explained by "hot-halo mode AGN" (Fanidakis et al. 2013).

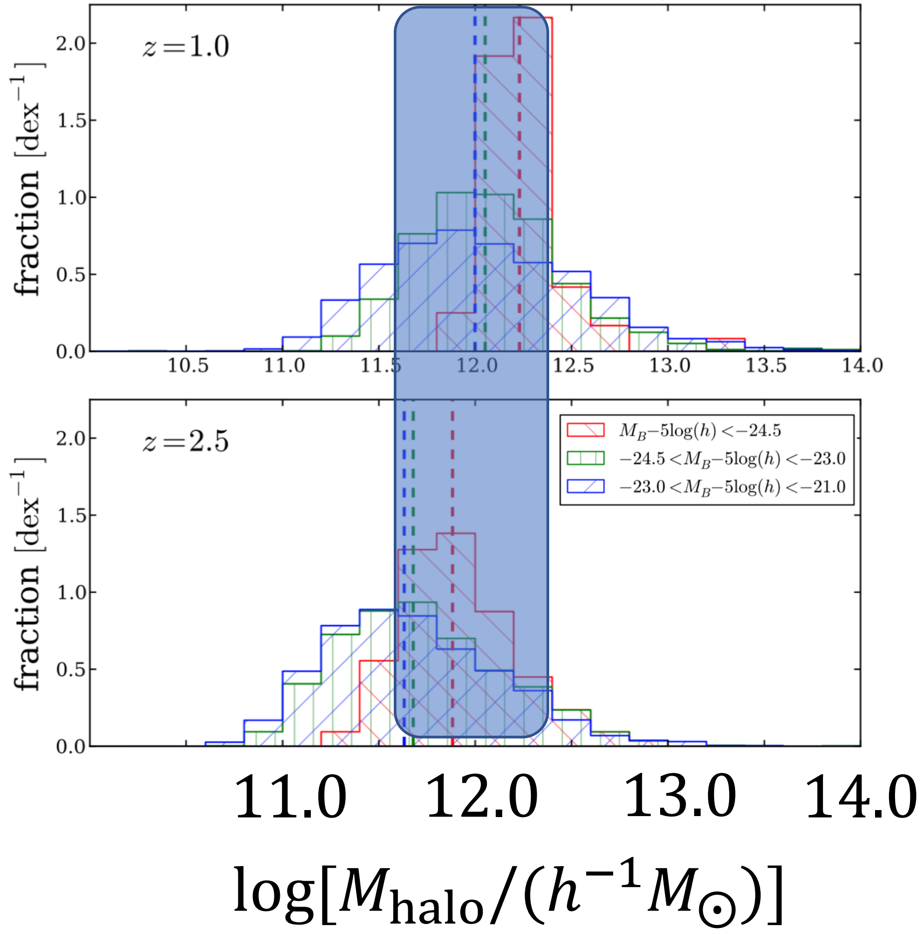




Fanidakis et al. 2013

DM halo mass distribution of quasars

$M_h \sim 10^{12} h^{-1} M_\odot$



Oogi et al. 2016

Aim of this study

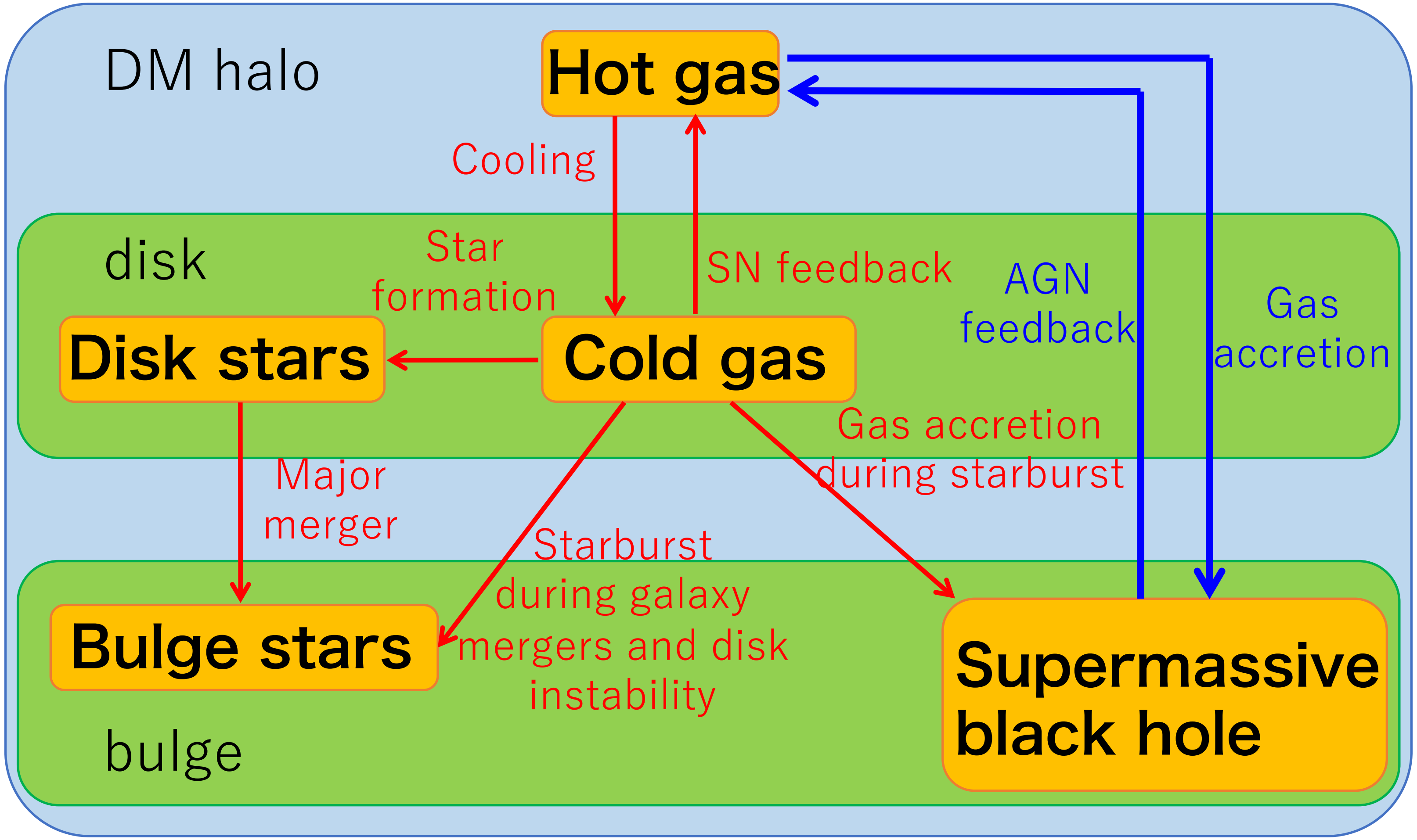
We explore whether the hot-halo mode AGN activity is necessary to explain the host halo mass of moderately-luminous AGNs or not.

We investigate this issue with our semi-analytic model of galaxy and AGN formation (Shirakata et al. 2019)

Semi-analytic model ν^2GC

1. Galaxy formation model

- Dark matter halo merger trees from cosmological simulations (Ishiyama et al. 2015)
- Baryon physics : gas cooling, star formation, and feedback through supernovae and AGNs (Shirakata et al. 2019)



Semi-analytic model ν^2GC

2. AGN triggering model

Assumption: a major/minor merger of galaxies and disk instability trigger cold gas accretion on to a SMBH and AGN activity.

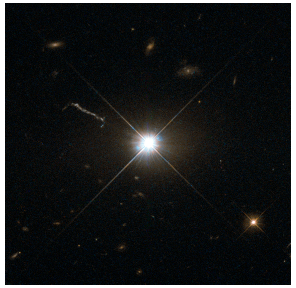
The mass accretion rate:

$$\dot{M}_{BH} = \frac{\Delta M_{acc}}{t_{acc}} \exp\left(\frac{t_{start} - t}{t_{acc}}\right)$$

$$t_{acc} = \alpha_{bulge} t_{dyn,bulge} + t_{\mathrm{loss}}$$

Galaxy mergers

Disk instability



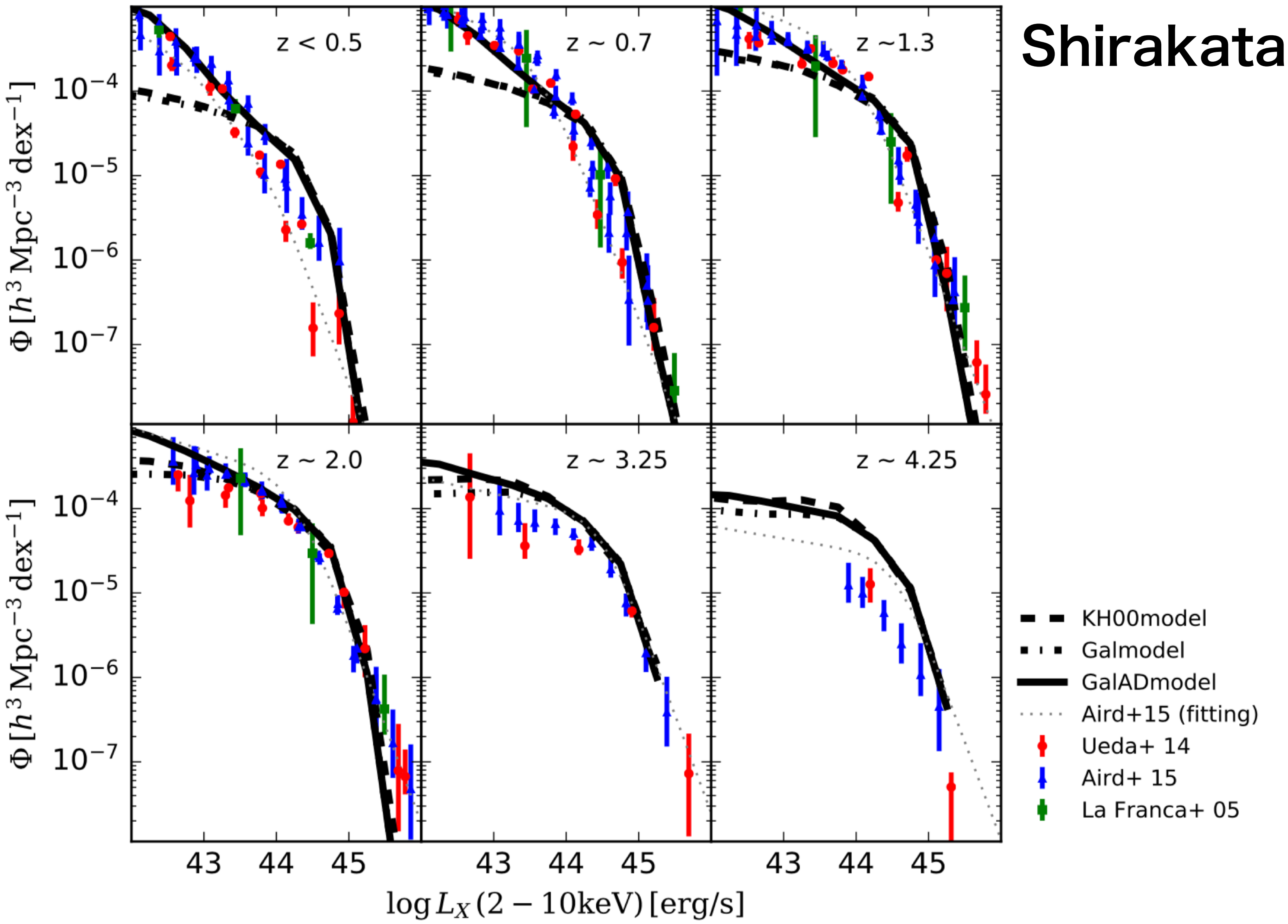
QSO 3C273
(ESA/Hubble
& NASA)

3. Gas accretion timescales onto black holes

Assumption: the timescale of BH growth, i.e. gas accretion, is controlled by the timescale of angular momentum loss at < 100 pc,
$t_{\mathrm{loss}} \propto M_{BH}^{3.5}\, \Delta M_{acc}^{-4}$,
where M_{BH} is the SMBH mass and ΔM_{acc} is the accreted gas mass.

AGN luminosity functions

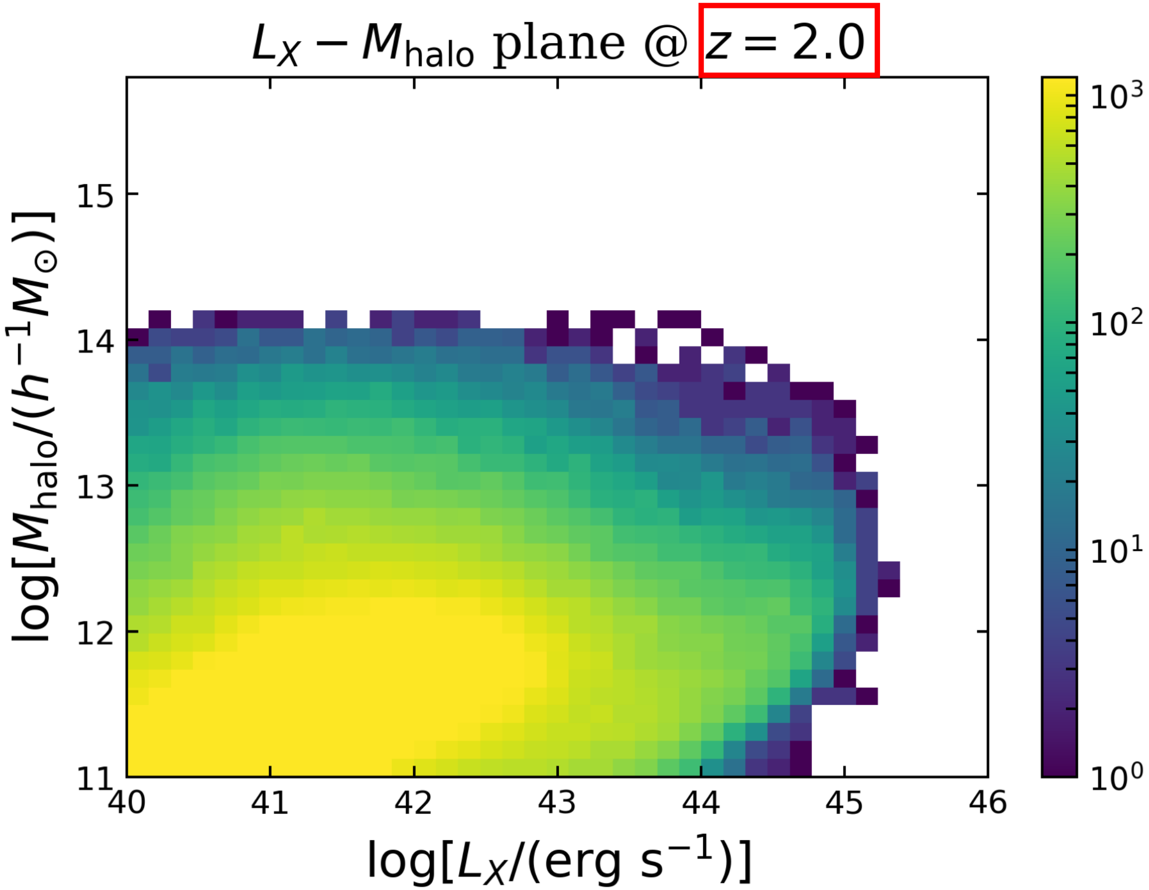
Shirakata et al. 2019

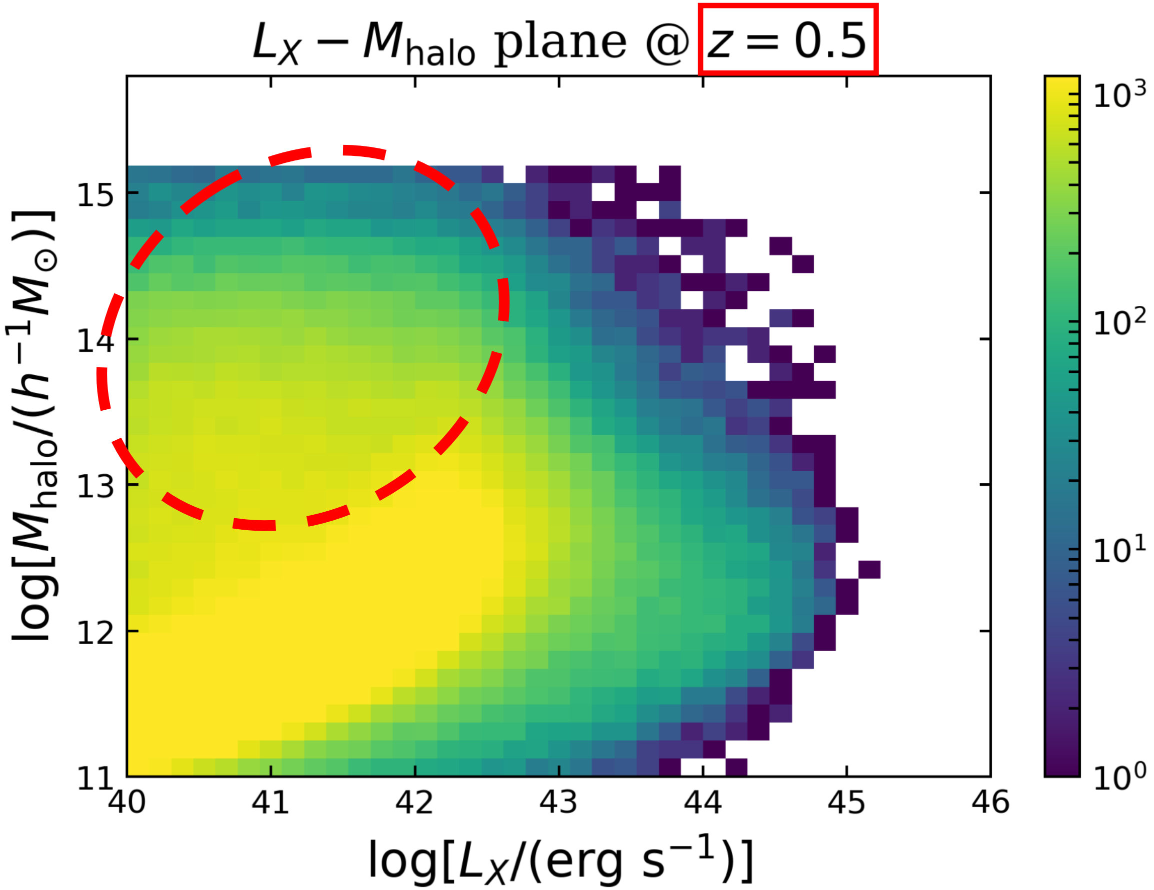


The model reproduces the observed AGN luminosity function at z<6.

Results

L_X-M_{halo} relation

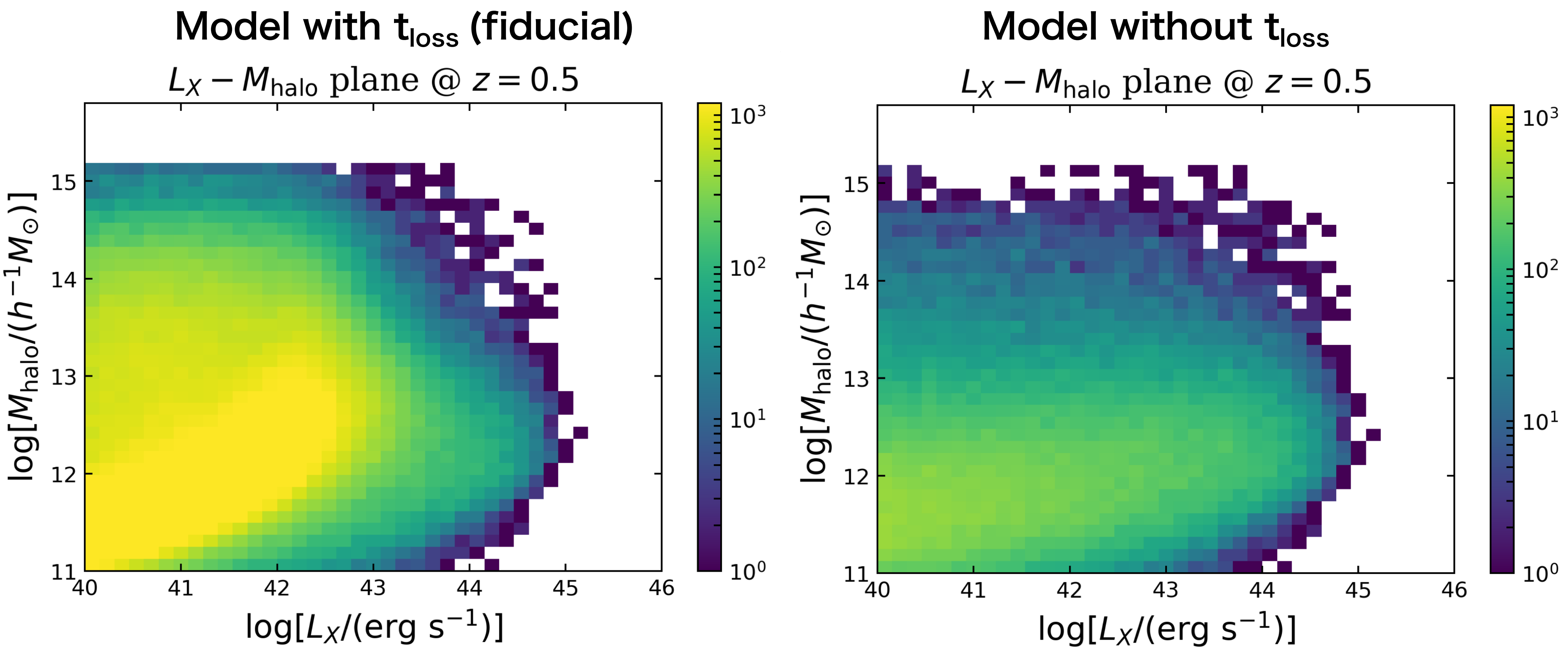




At high redshifts (z=2), the halo mass a weak dependence on AGN luminosity.

At low redshifts (z=0.5), there are many faint AGNs in high mass halos ($M_{halo} \gtrsim 10^{13} h^{-1} M_\odot$, dashed circle).
These AGNs have long gas accretion timescales.

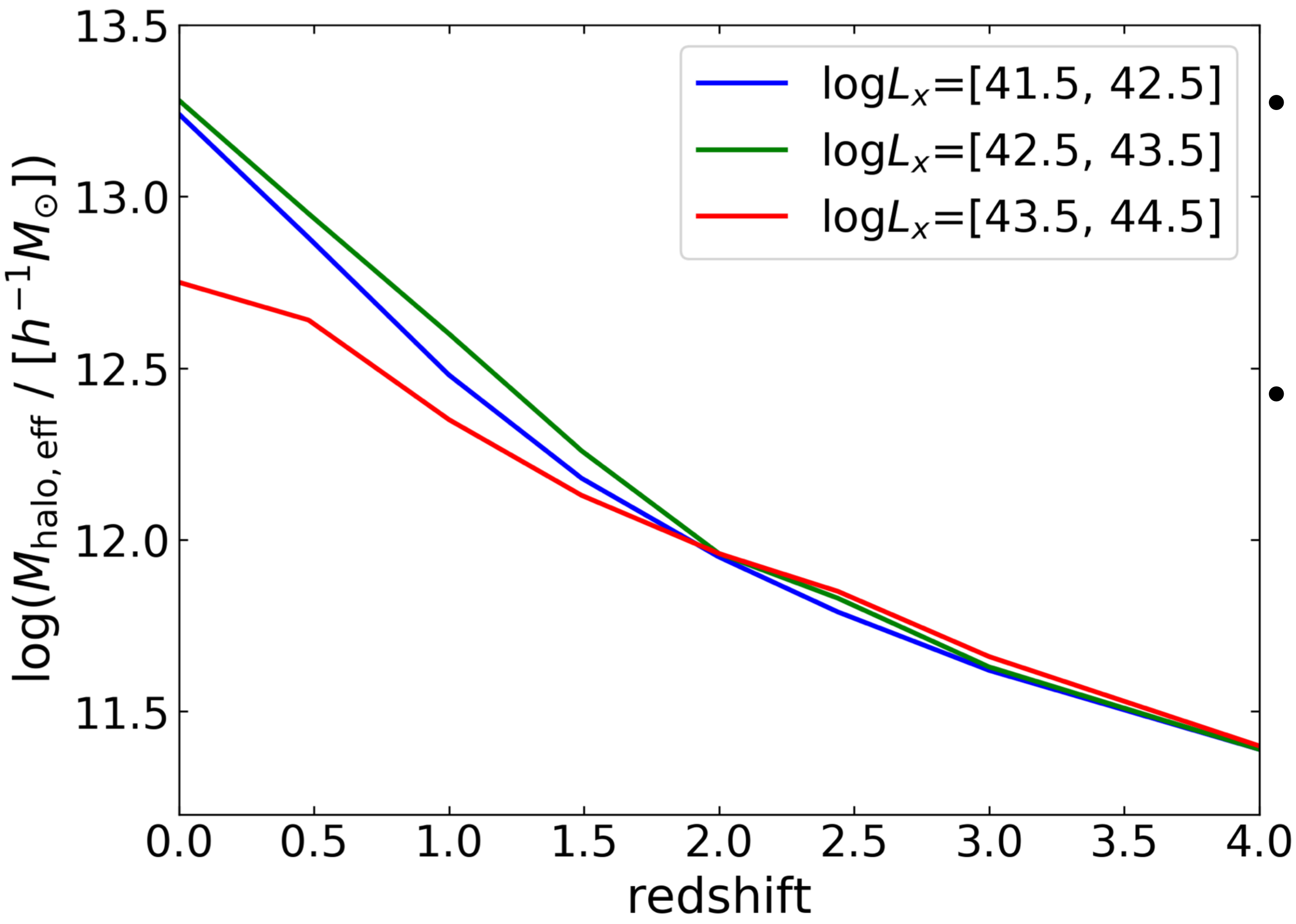
L_X-M_{halo} relation: model dependence



Relatively faint AGNs in massive halos with $M_{halo} \gtrsim 10^{13} h^{-1} M_\odot$ are an important feature of the fiducial model with t_{loss} .

Redshift evolution of AGN host halo mass: model

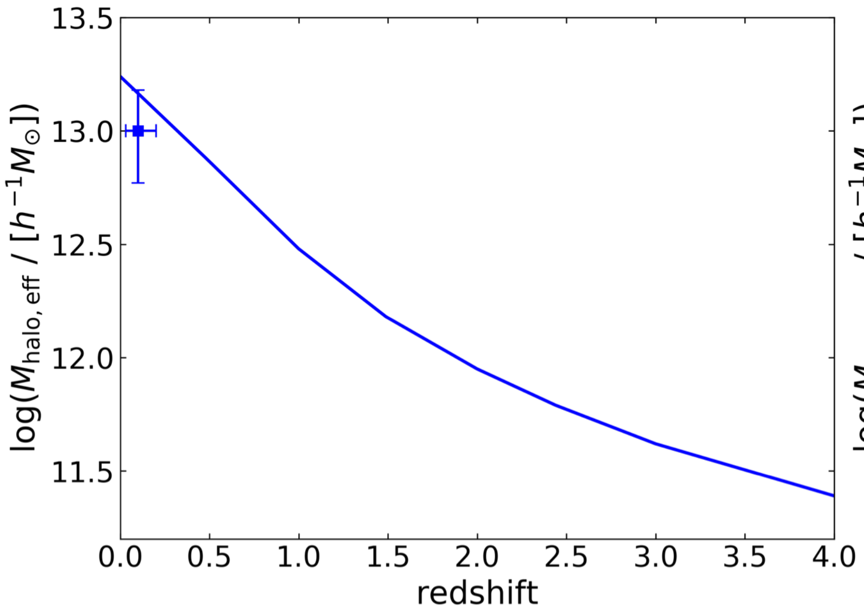
The effective halo mass is defined as the mass which satisfied $b(M_{eff}) = b_{AGN}$, where $b(M_h)$ is the halo bias of mass M_h (Tinker et al. 2010).



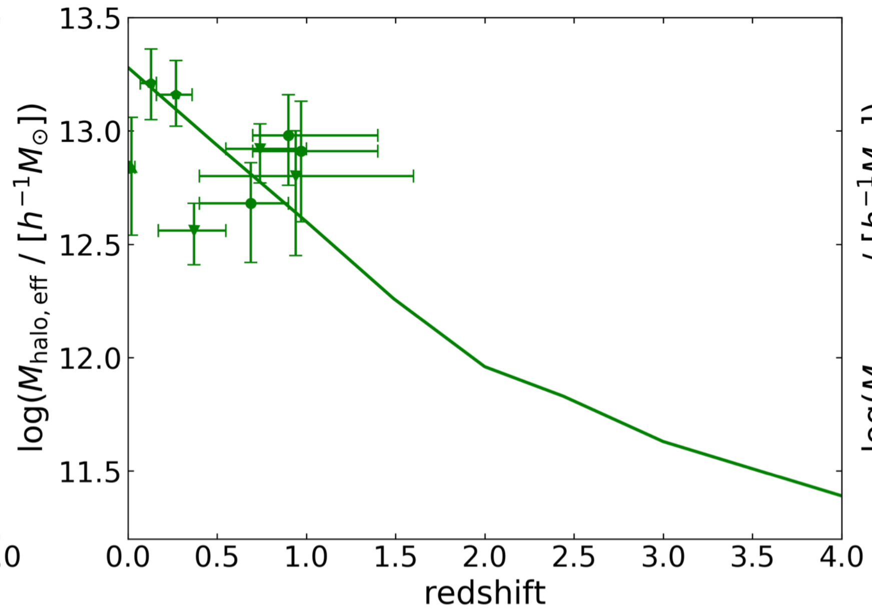
- The AGN host halo mass of low luminosity AGNs is higher than that of luminous AGNs at low-z.
- At high-z, there is no significant luminosity dependence.

Redshift evolution of host halo mass

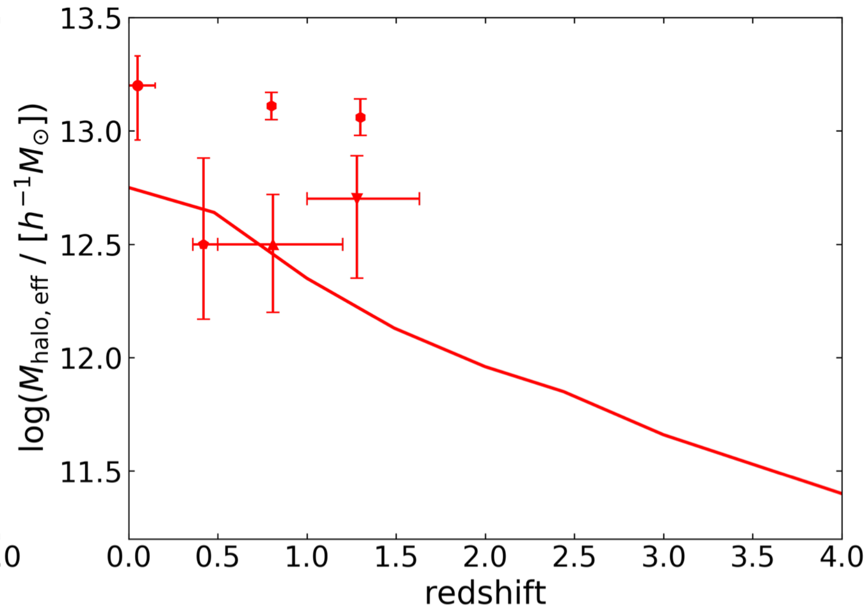
log (L_x / erg s^{-1}) = [41.5, 42.5]



log (L_x / erg s^{-1}) = [42.5, 43.5]



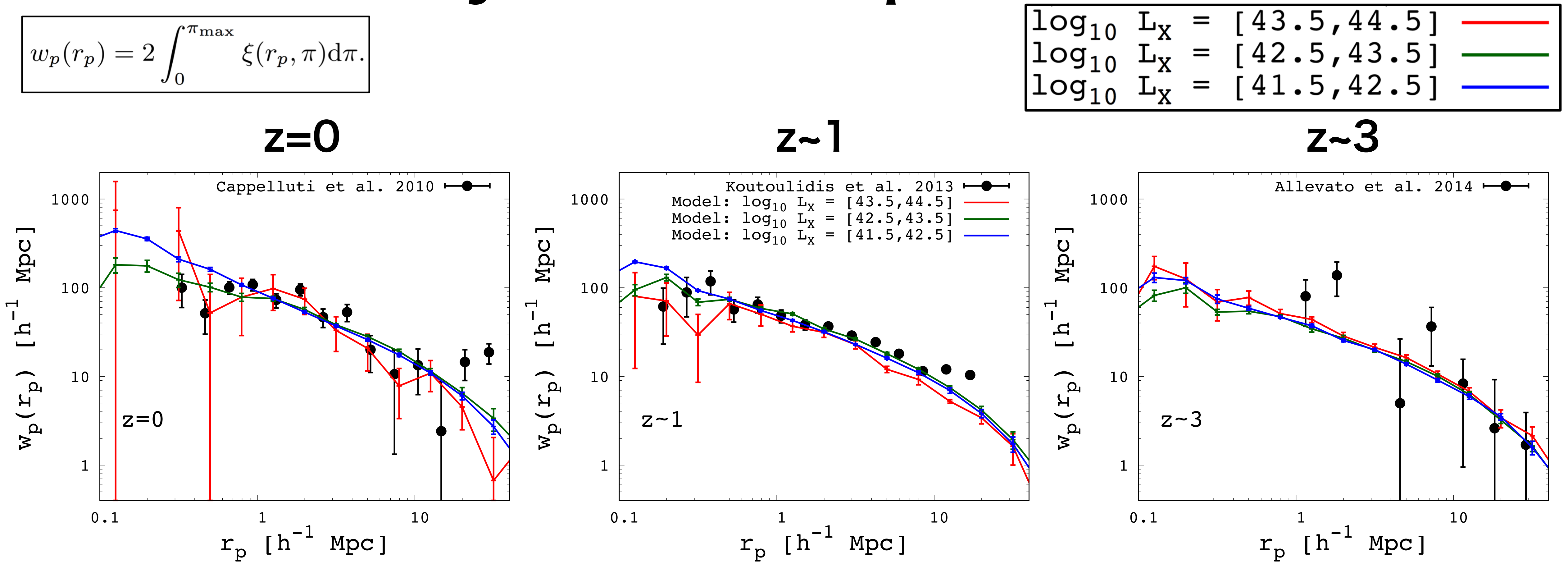
log (L_x / erg s^{-1}) = [43.5, 44.5]



- Overall, our model is consistent with the current measurements.
  - typical host halo mass, $10^{12.5-13.5}h^{-1}M_\odot$.
- There is a large scatter of the observationally estimated halo masses.
- Difficult to explain the massive host halo mass for luminous AGNs.

2PCF of X-ray AGN: comparison with Obs.

$$w_p(r_p) = 2\int_0^{\pi_{\max}} \xi(r_p,\pi)\mathrm{d}\pi.$$

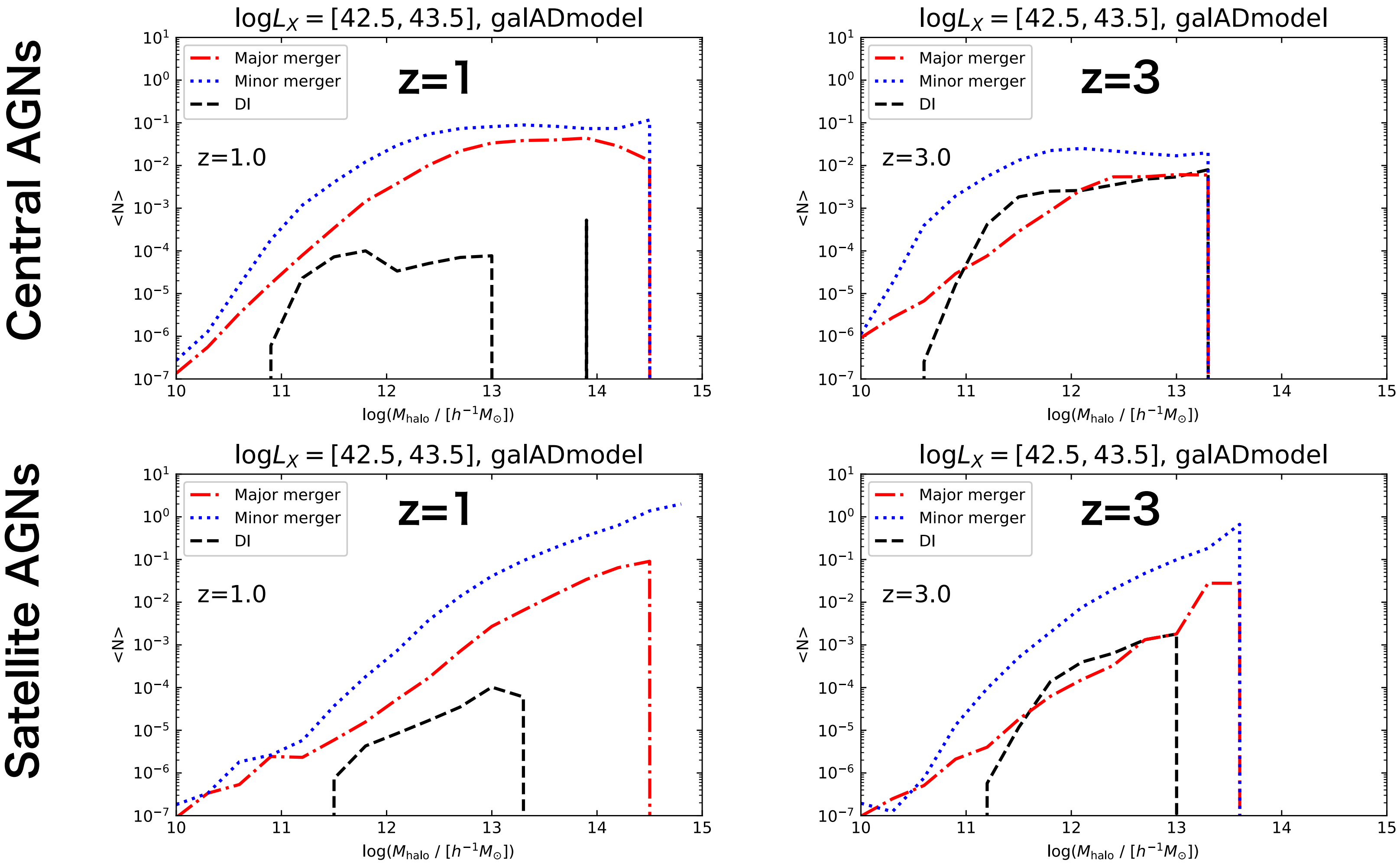


- Our model results are in agreement with observed AGN clustering.
- At low redshifts (z=0, 1), the clustering amplitude of less luminous AGNs is higher than luminous AGNs.

HOD for different triggering mechanisms

Major merger
Minor merger
Disk instability

X-ray AGNs with 42.5 < log (L_x / erg s^{-1}) < 43.5



- Minor mergers are the main triggering mechanism of AGN.
- Satellite AGNs contribute the HOD.

Summary

- We can predict the AGN host halo mass and clustering by using our latest semi-analytic model.
- Our model is consistent with the current observations.
  - Typical host halo mass, $10^{12.5-13.5} h^{-1} M_{\odot}$.
- Hot-halo mode AGNs is not necessary to explain the host halo mass of X-ray AGNs.
- Minor mergers are the main triggering mechanism of AGNs.
- Halo occupation distributions of AGNs can be an additional constraint.