The quasar clustering and its evolution in a semi-analytic model based on ultra high-resolution N-body simulations

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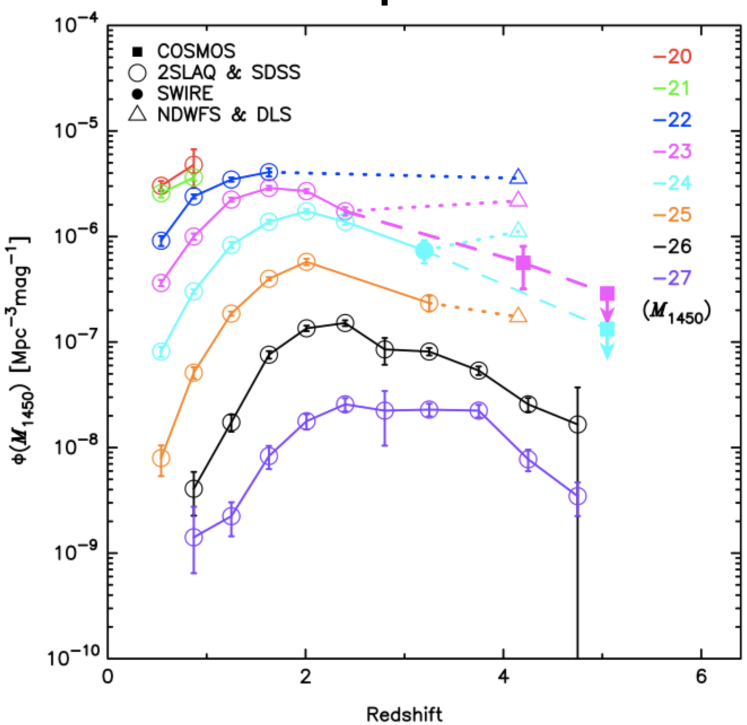
Introduction
Observed properties of QSO/AGN

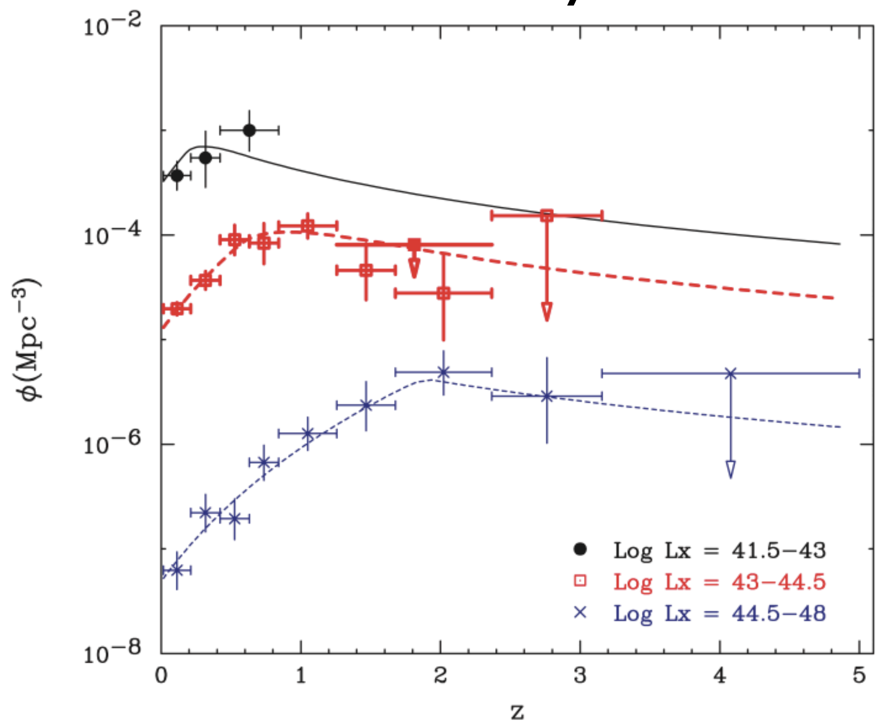
- AGN downsizing : the space densities of fainter AGNs peak at lower redshifts than those of brighter AGNs.

Optical



Ikeda et al. (2012)

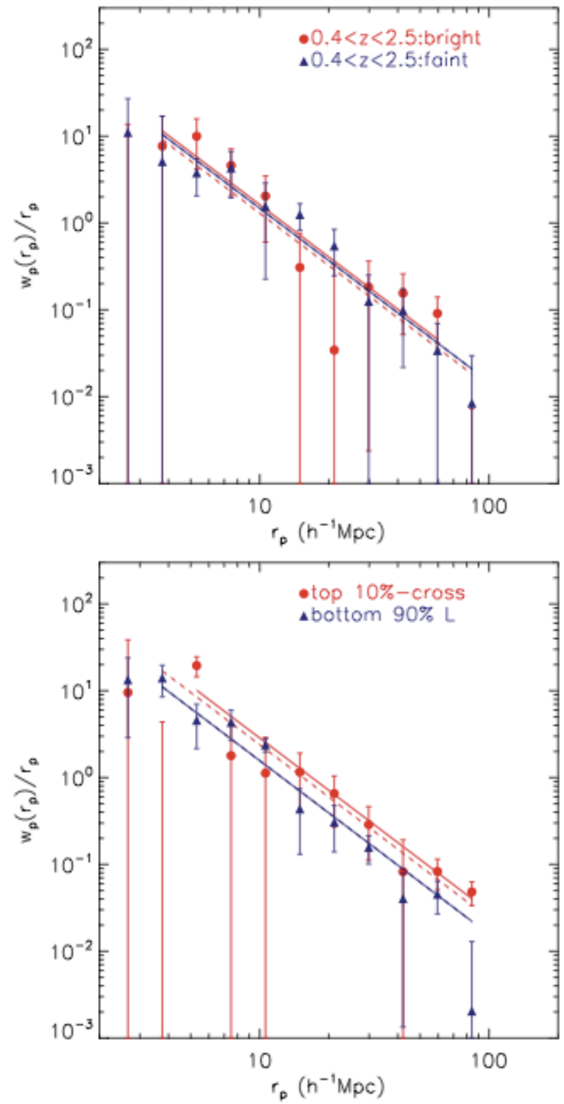
X-ray



Ueda et al. (2003)

Introduction
Observed properties of QSO/AGN

- QSO clustering
  - Shen et al. (2009) : 10 per cent brightest quasars of their sample are clustered stronger than the fainter quasars
  - Other studies (for usually observed luminosity ranges): the clustering strength does not depend significantly on quasar luminosity.



Shen et al. (2009)

Theoretical studies

- Bonoli et al. 2009
  - Black hole accretion and quasar activity are triggered by galaxy mergers.
  - The masses of host dark matter haloes are ~10^{12} M_{sun}/h and are almost independent of redshift and quasar luminosity.
- Fanidakis et al. 2013
  - Other accretion modes : disc instabilities, hot-halo mode
  - The masses of host dark matter haloes of X-ray AGN are greater than ~$10^{12.5}$ M_{sun}.

Motivation

- In this study, we investigate whether the observed trends of QSO clustering can be explained using our semi-analytic model, ν GC, of galaxy and SMBH/QSO formation based on a hierarchical clustering scenario.
- We present the large-scale QSO clustering and its evolution from z=4 to z=0.5 for a wide luminosity range.

Numerical Galaxy Catalog (ν GC)

Our semi-analytic model :

- Large box size *N*-body simulation
  - Box size : 400 Mpc
  - Number of particles : 2048^3
  - Minimum DM halo mass : 8.79×10^9 M_{sun}/h
  - Planck cosmology $\Omega_0 = 0.31, \Omega_\Lambda = 0.69, h = 0.68$
- Galaxy formation model (Nagashima et al. 2005)
  - Gas cooling, star formation, supernova feedback, galaxy mergers
  - Our model reproduce various observations including galaxy luminosity functions, galaxy number counts, the cosmic star formation history.
- SMBH/QSO formation model (Enoki et al. 2003)

SMBH formation model (Enoki et al. 2003)

Assumptions

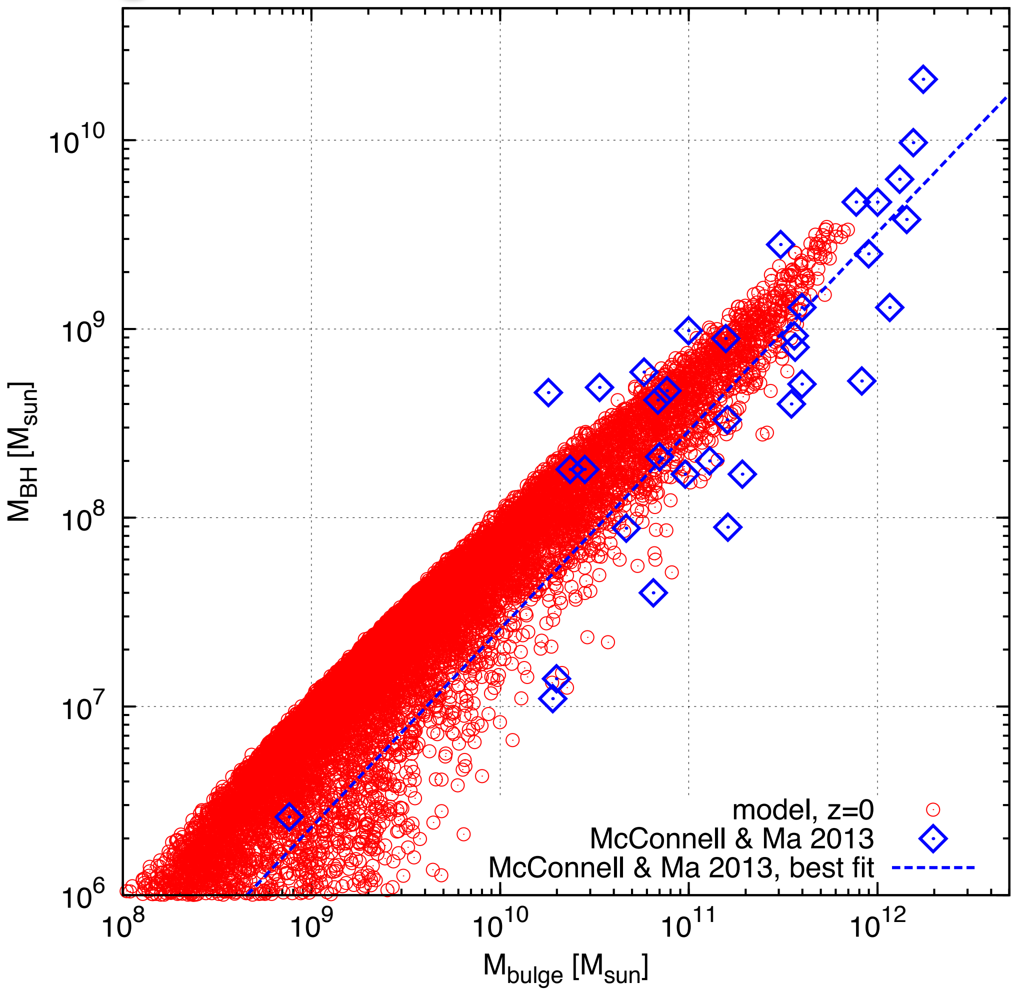
1. When host galaxies merge, the pre-existing SMBHs in the progenitors immediately coalesce.
2. During a major merger of galaxies, a certain fraction of the cold gas that is proportional to the total mass of newly formed stars at starburst accretes onto the SMBH.

$$M_{\rm acc} = f_{\rm BH} M_{*,\rm burst}$$

is fixed by matching the observed $M_{\rm bulge} - M_{\rm BH}$ relation

We adopted $f_{\rm BH} = 0.0067$

Constraint
M_{BH}-M_{bulge} relation



QSO/AGN light curve model

QSO B-band luminosity

$$L_B(t) = \frac{\varepsilon_B M_{\rm acc} c^2}{t_{\rm life}} \exp\left(-\frac{t}{t_{\rm life}}\right)$$

ε_B : the radiative efficiency in the B-band

$t_{\rm life}$: QSO lifetime scale

$t_{\rm life}$ scales with the dynamical time scale of the host galaxy,

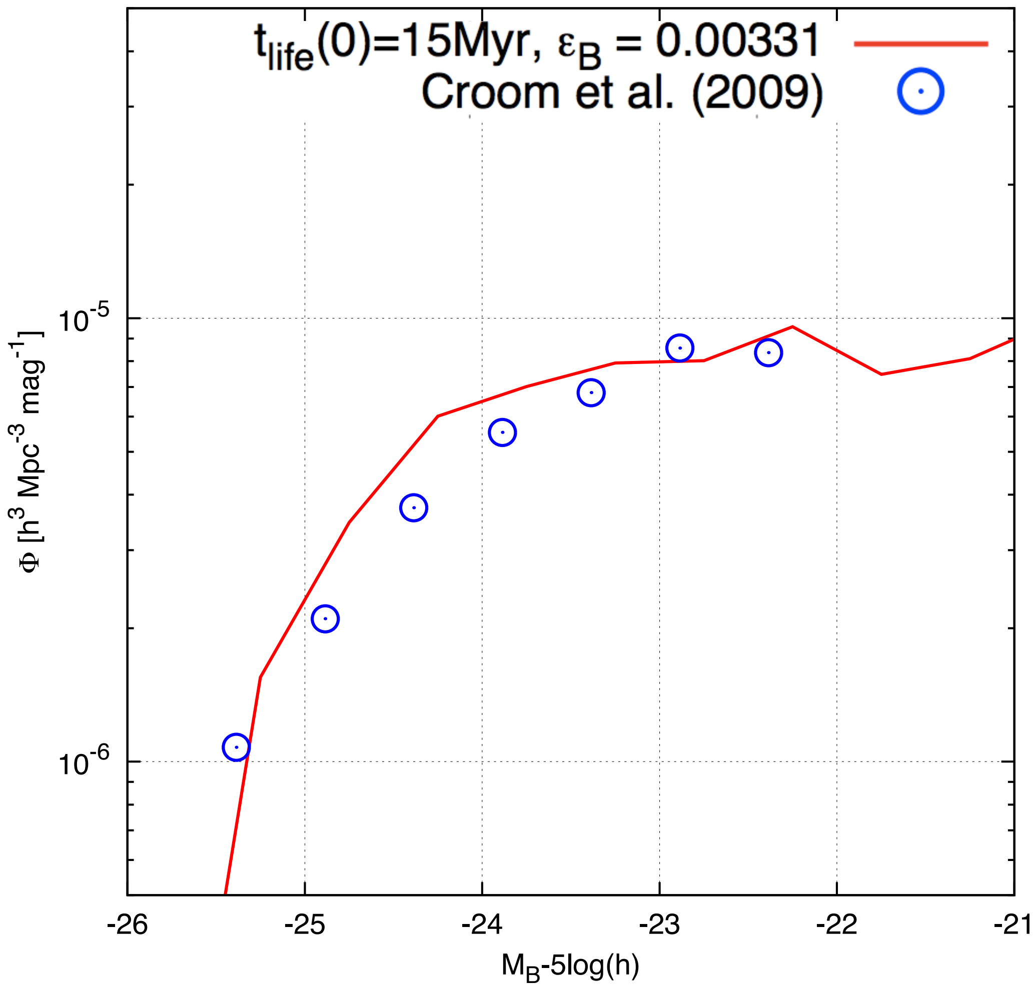
$$t_{\rm life}(z) \propto t_{\rm dyn} \propto 1/\rho_{\rm vir}$$

$\varepsilon_B, t_{\rm life}(z=0)$ are fixed by matching the observed B-band Luminosity function of QSO at z=2.

$$\varepsilon_B = 0.00331$$

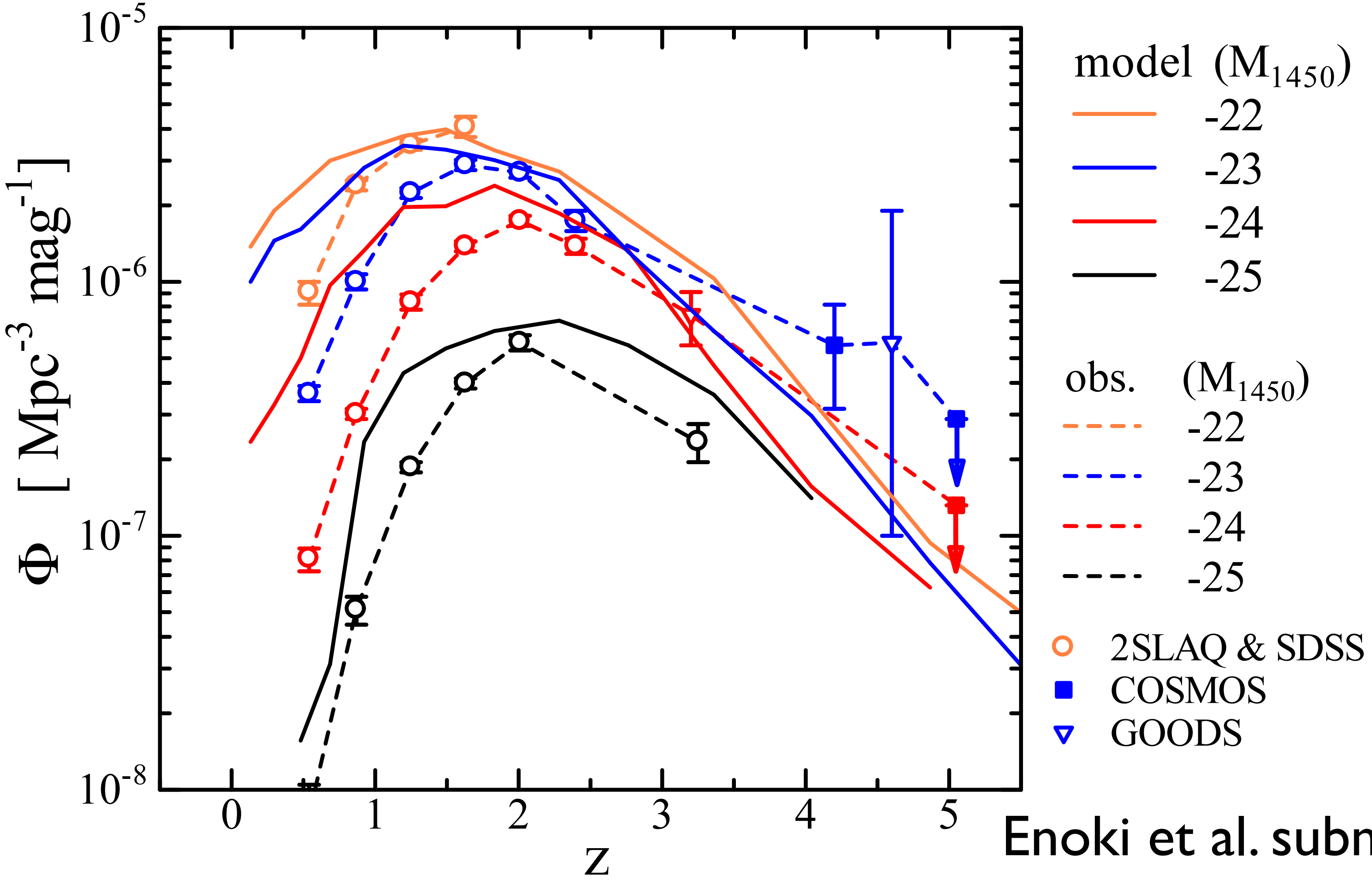
$$t_{\rm life}(z=0) = 15\text{Myr}$$

Constraint
QSO luminosity function at z=2



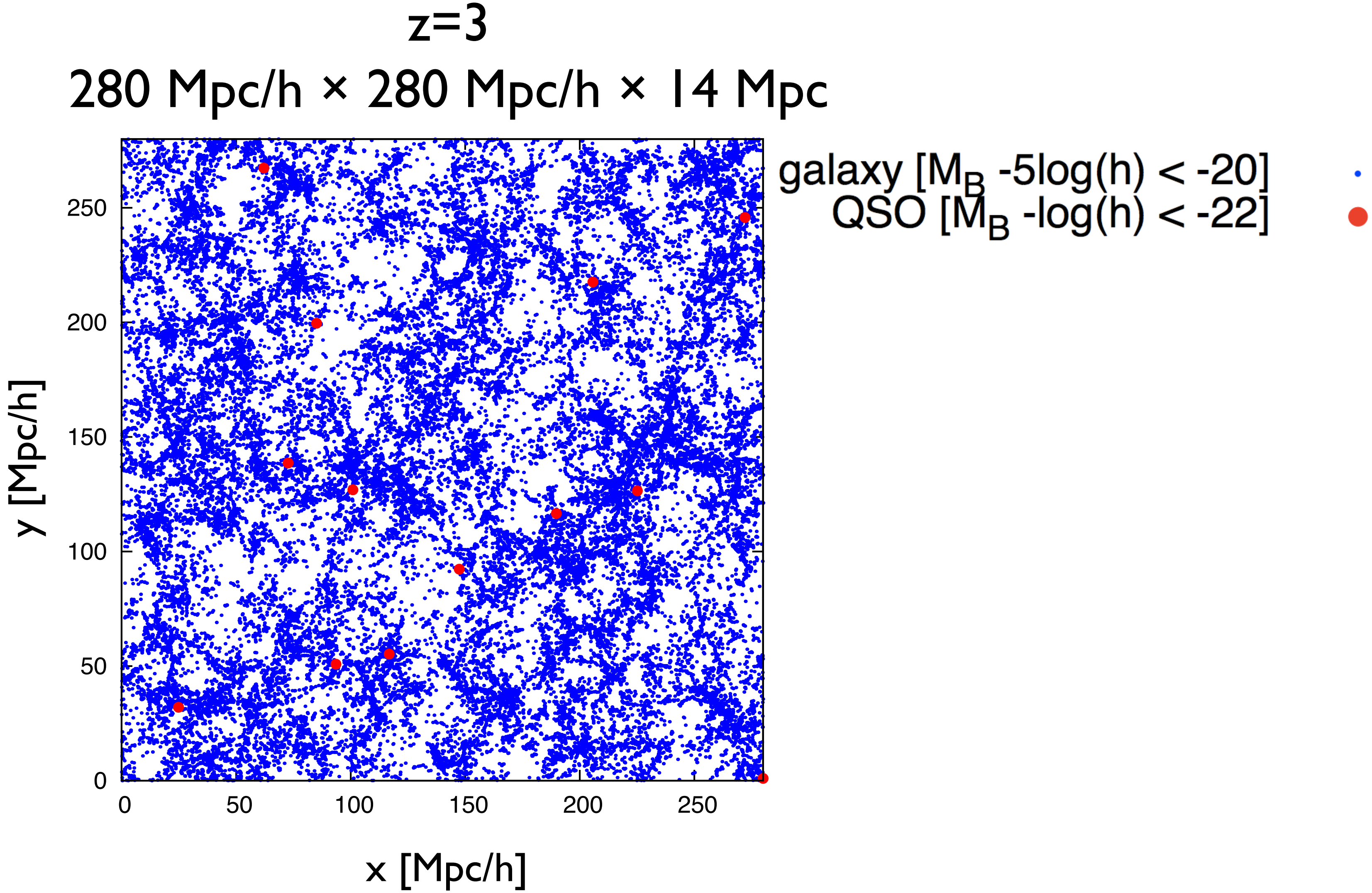
QSO number density evolution, "downsizing"

- Our model naturally reproduces the observed trend of the downsizing.



Enoki et al. submitted

Spatial distribution of galaxies and quasars



Estimators of correlation functions

- Galaxy auto-correlation function

$$\xi(r) = \frac{\langle DD(r) \rangle}{\langle DR(r) \rangle} - 1$$

D: Galaxies, R: Random data
<DD(r)>: the average number of galaxies around a galaxy as a function of distance r
<DR(r)>: the average number of random objects around a galaxy as a function of distance r

  - e.g. Davis & Peebles 1983

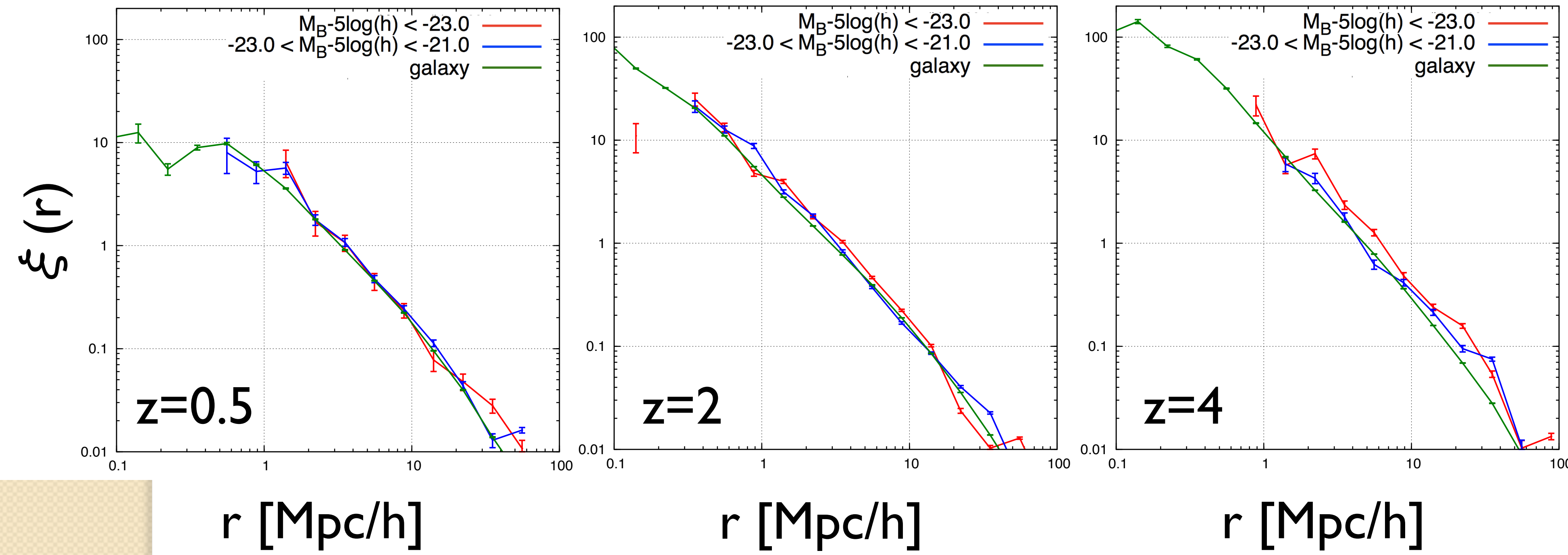
- QSO-galaxy cross-correlation function
  - The estimator in Coil et al. 2007

$$\xi(r) = \frac{QG}{QR} - 1$$

Q: QSOs, G: Galaxies
R: Random data
QG: the average number of galaxies around a quasar as a function of distance r
QR: the average number of random galaxies around a quasar as a function of distance r

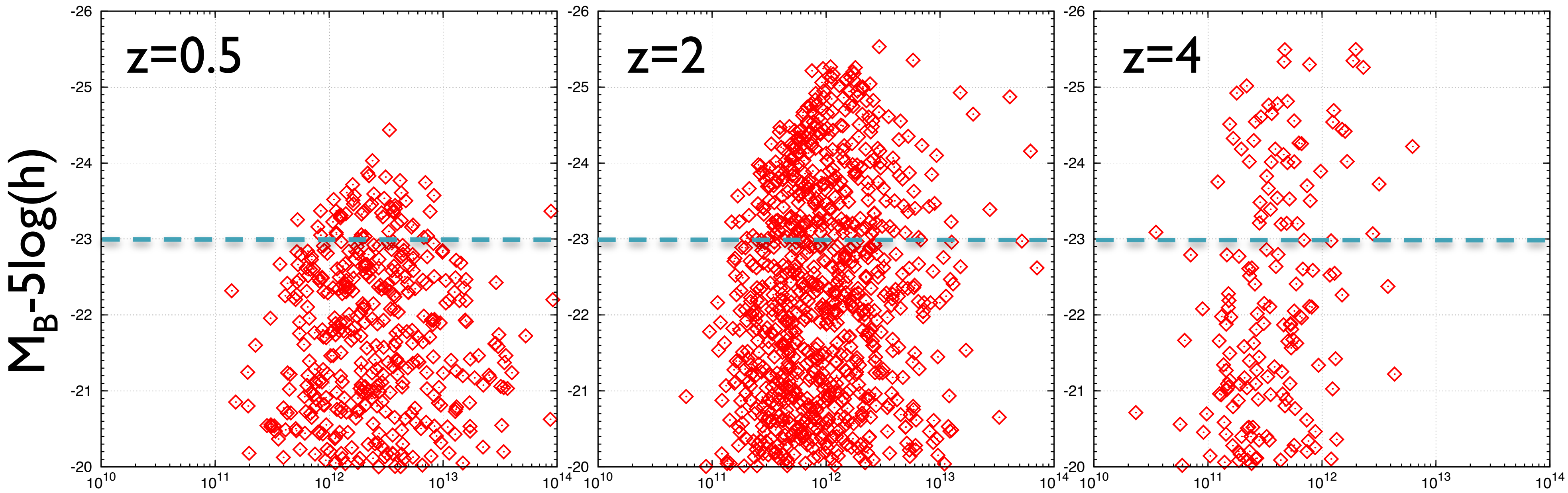
QSO-galaxy cross correlation function

Galaxy sample: M_B-5log(h)<-20



- Quasar-galaxy cross-correlation functions do not have significant dependence on quasar luminosity.
- This result is consistent with observations and Bonoli et al. (2009).

DM halo mass – M_B relation



M_{DM} [M_{sun}] $\sim 10^{12} - 10^{13} M_{sun}$

M_{DM} [M_{sun}] $\sim 5 \times 10^{11} - 5 \times 10^{12} M_{sun}$

M_{DM} [M_{sun}] $\sim 10^{11} - 10^{12} M_{sun}$

- In our model, quasar activity is triggered by galaxy mergers.
- Galaxy merger rate peaks in galaxy group scale haloes.

→ Host dark matter halo masses are up to $\sim 10^{13}$ M_{sun}.

QSO linear bias

$$b_Q = \sqrt{\frac{\xi_Q(r)}{\xi_{DM}(r)}}$$

Assuming a linear bias,

$$\xi_{QG} = \sqrt{\xi_Q \xi_G}$$

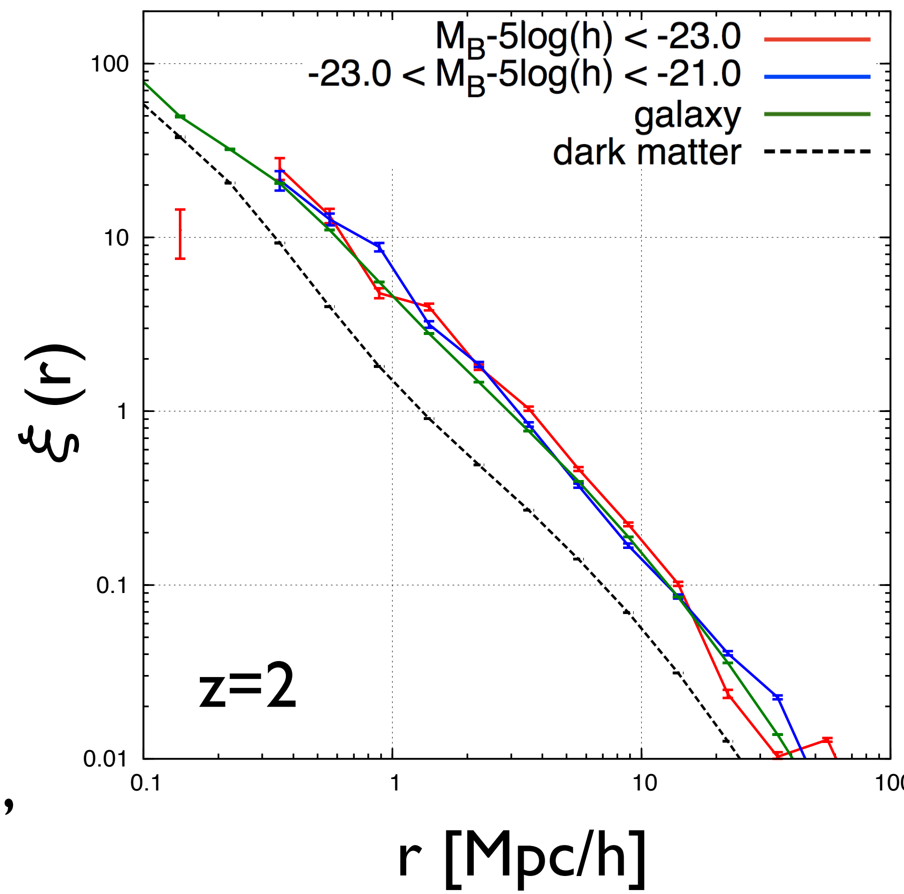
i.e. $$b_{QG}^2 = \sqrt{b_Q b_G}$$

where b_G : galaxy linear bias,

$$b_{QG} = \sqrt{\frac{\xi_{QG}(r)}{\xi_{DM}(r)}}$$

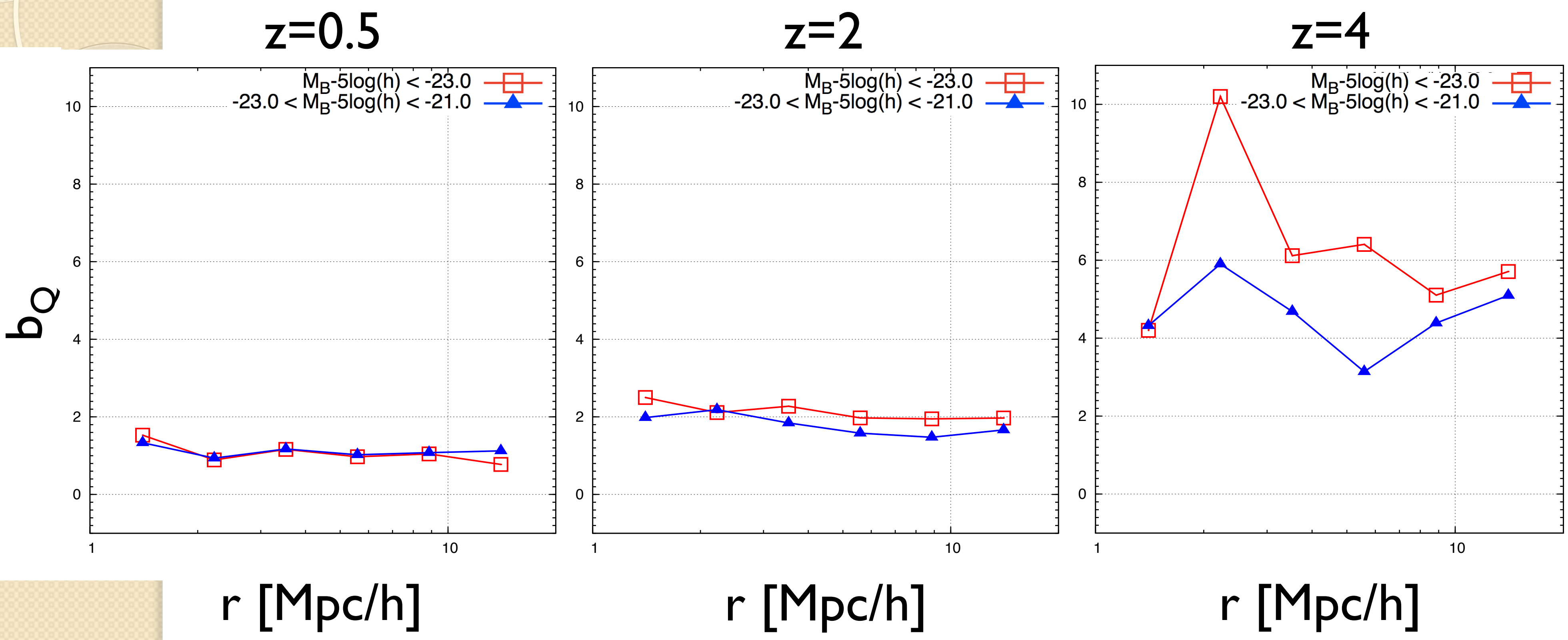
Then,

$$b_Q = \frac{b_{QG}^2}{b_G}$$



We calculate the bias of the QSOs as a function of distance r.

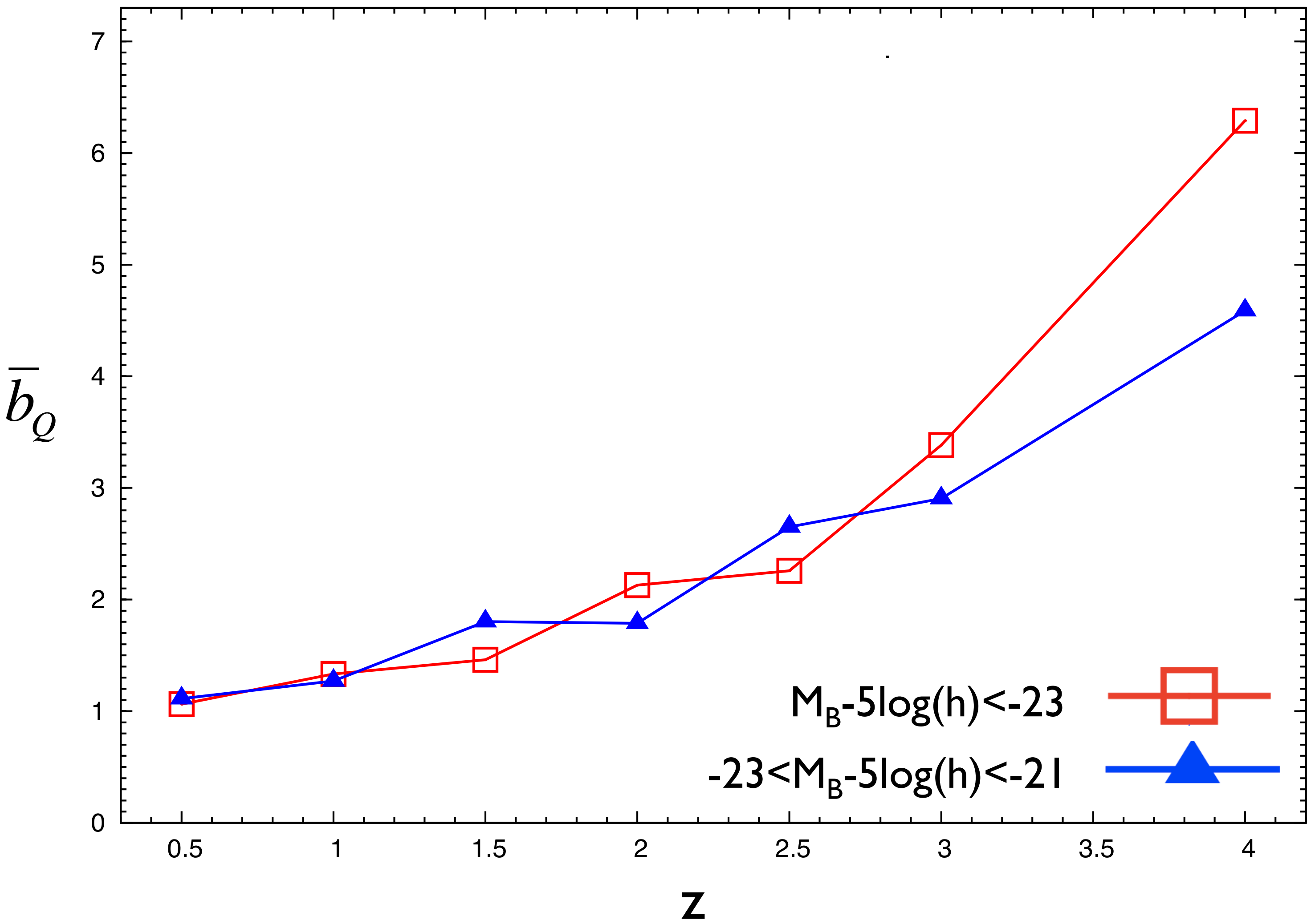
QSO linear bias



- z<~2 : almost independent on radius
- z=4 : highly dependent on radius

We simply average the quasar biases over all radial bins.

Redshift evolution of the QSO bias



- The quasar bias is an increasing function of redshift.
- At z=4, the brighter sample has a bias higher than the fainter sample.

Summary and future study

- We have explored the clustering properties of quasars using our updated semi-analytic model.
- For a wide luminosity range (-20 > M_B-5log(h) > -25), host dark matter haloes have similar mass at each redshift.
  - -> similar clustering
- Our results are consistent with observations.
- Our results are also consistent with Bonoli et al. (2009).
  - Luminosity independence of quasar clustering seems to be a generic prediction of galaxy merger triggered models.
- At z=4, the brighter sample has a bias higher than the fainter sample.
- Our model also explain AGN downsizing qualitatively.
- We prepare a cosmological *N*-body simulation with
  - Box size : 800 Mpc
  - Number of particles : 4096^3
  - -> We will derive QSO auto-correlation function.