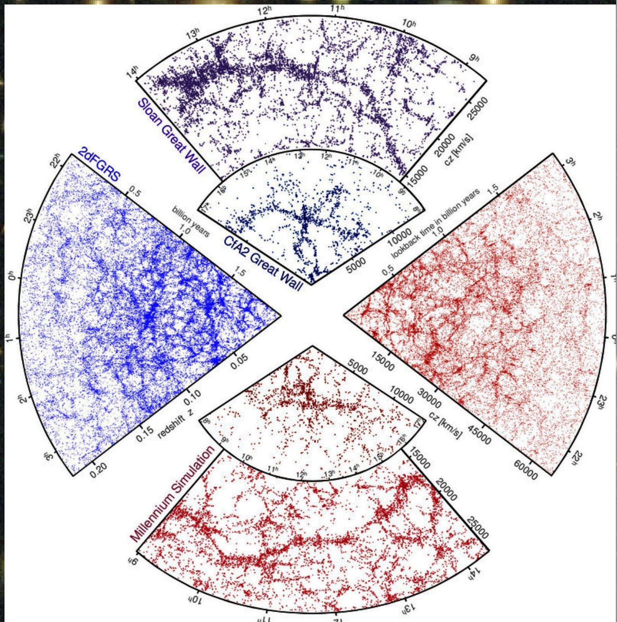
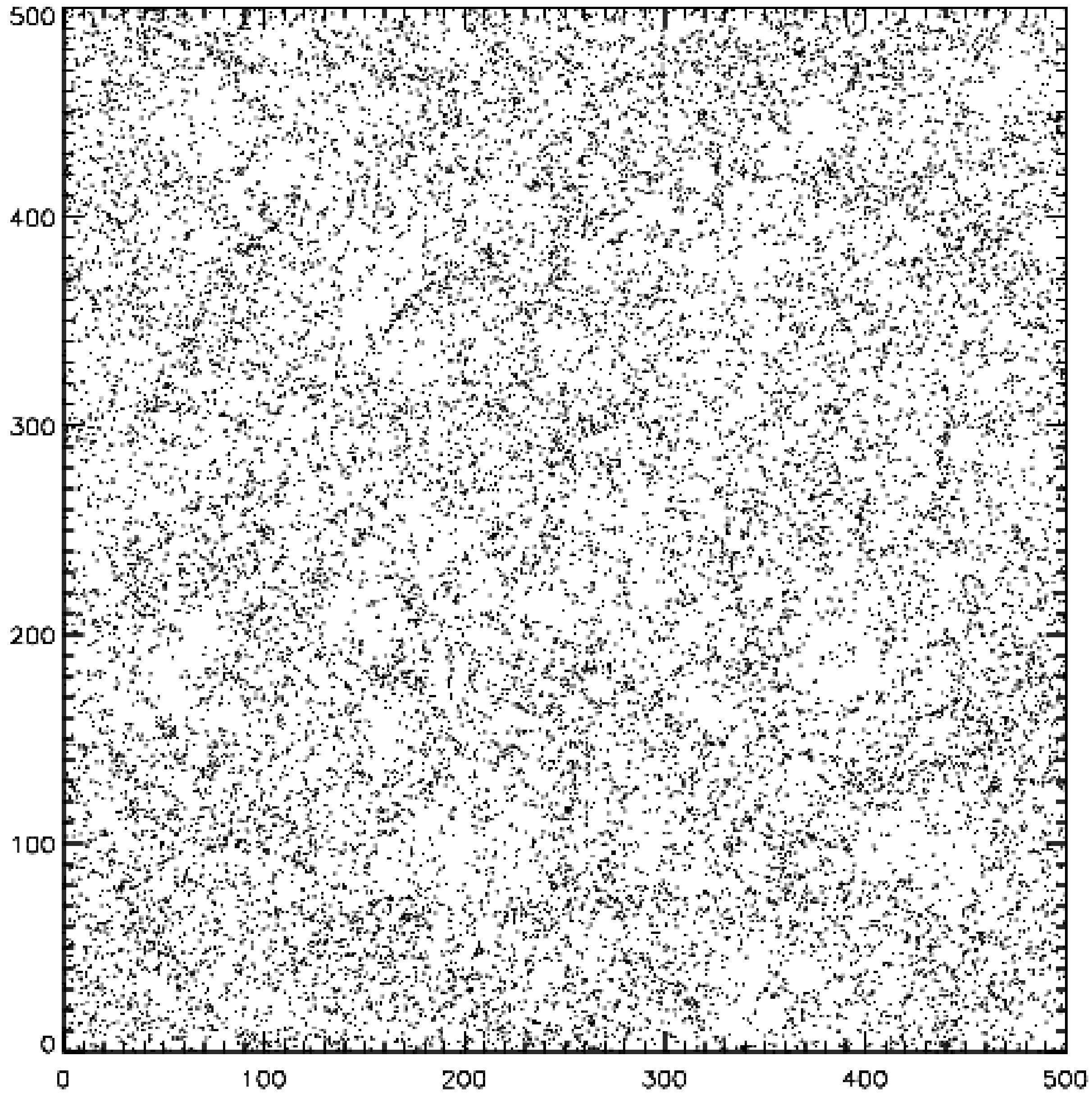
Cambridge, December 2016`

Assembly bias, splashback, and subhalo disruption in RedMaPPer and Millennium clusters



Simon White and Philipp Busch
Max Planck Institute for Astrophysics

Halo clustering depends on formation history

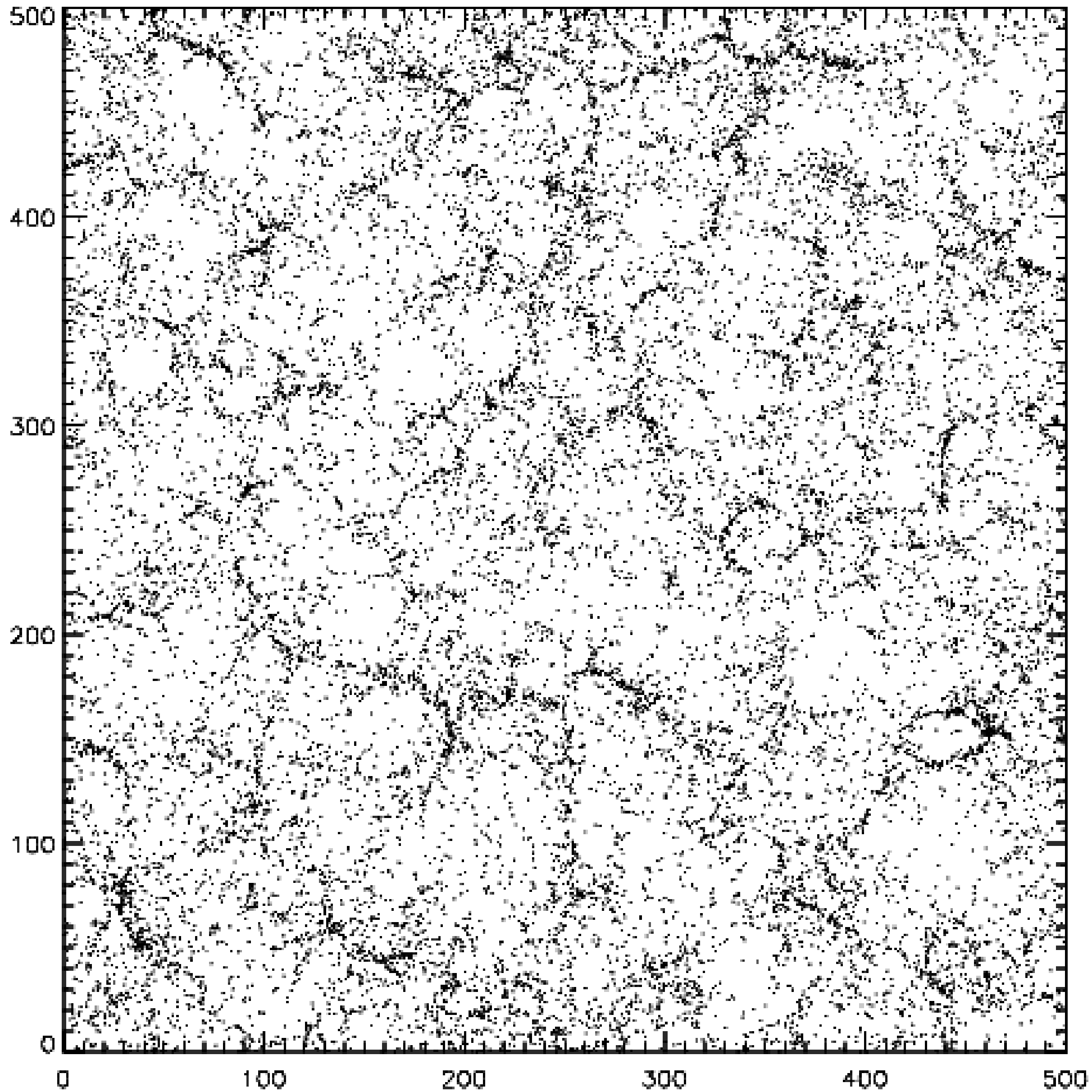


Gao, Springel & White 2005

The 20% of halos with the *latest* half-mass assembly redshifts in a 30 Mpc/h thick slice

$M_{halo} \sim 10^{11} M_{\odot}$

Halo clustering depends on formation history

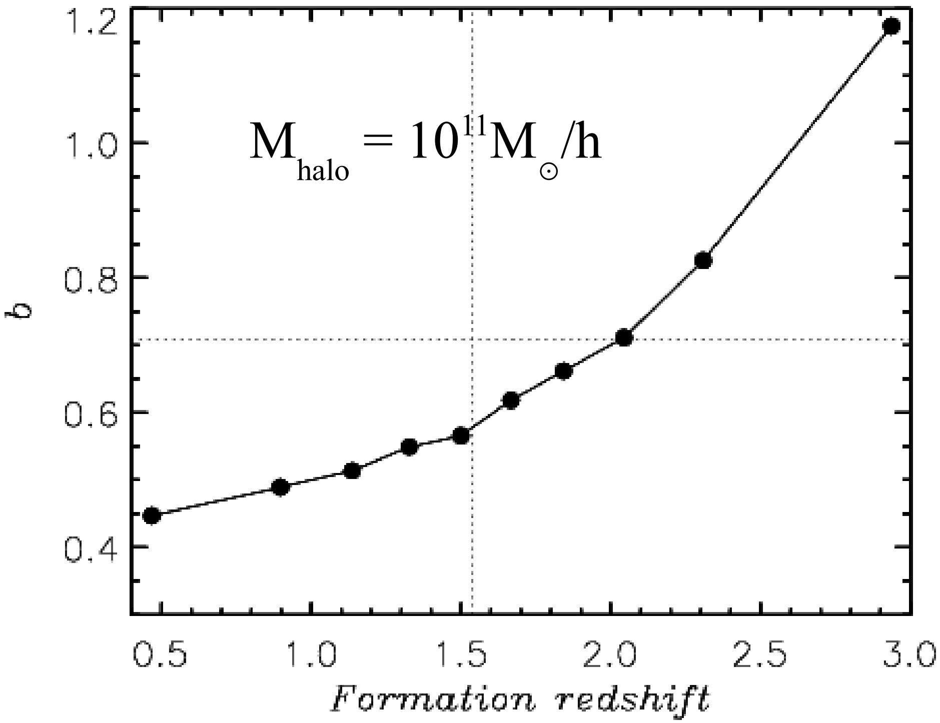


Gao, Springel & White 2005

The 20% of halos with the *earliest* half-mass assembly redshifts in a 30 Mpc/h thick slice

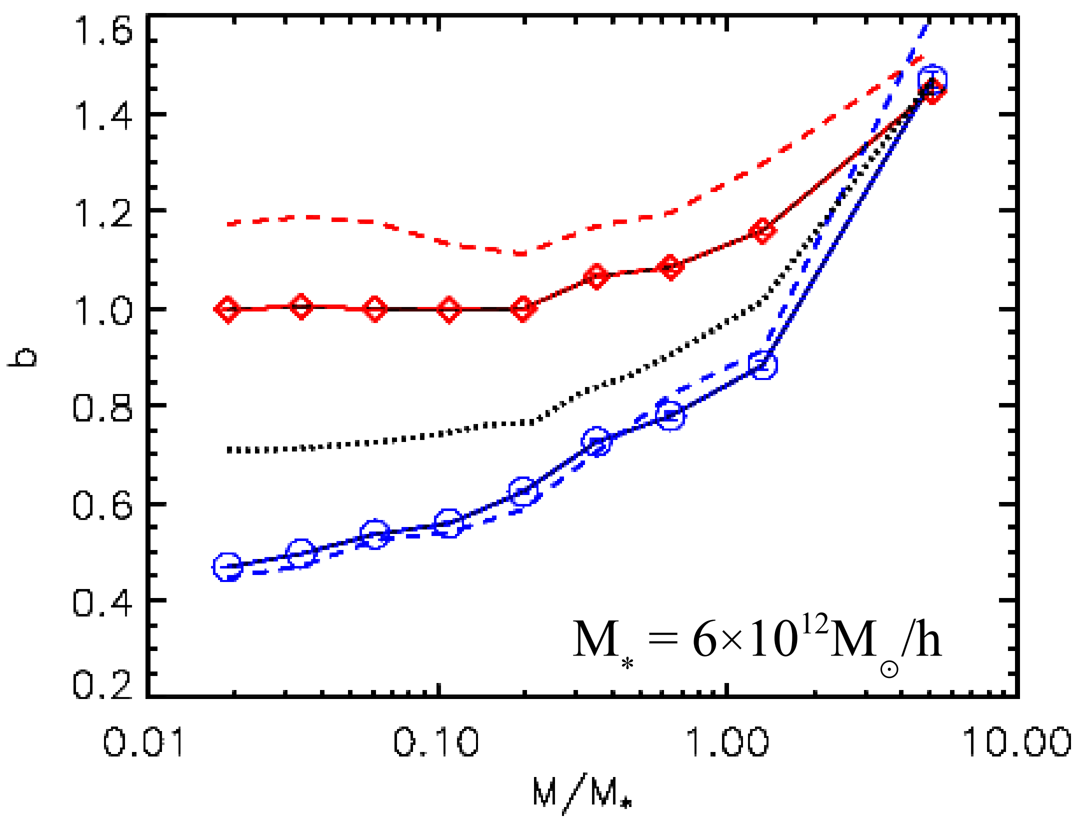
$$M_{halo} \sim 10^{11} M_{\odot}$$

Halo bias as a function of mass and formation time



Gao, Springel & White 2005

Bias increases smoothly with formation redshift

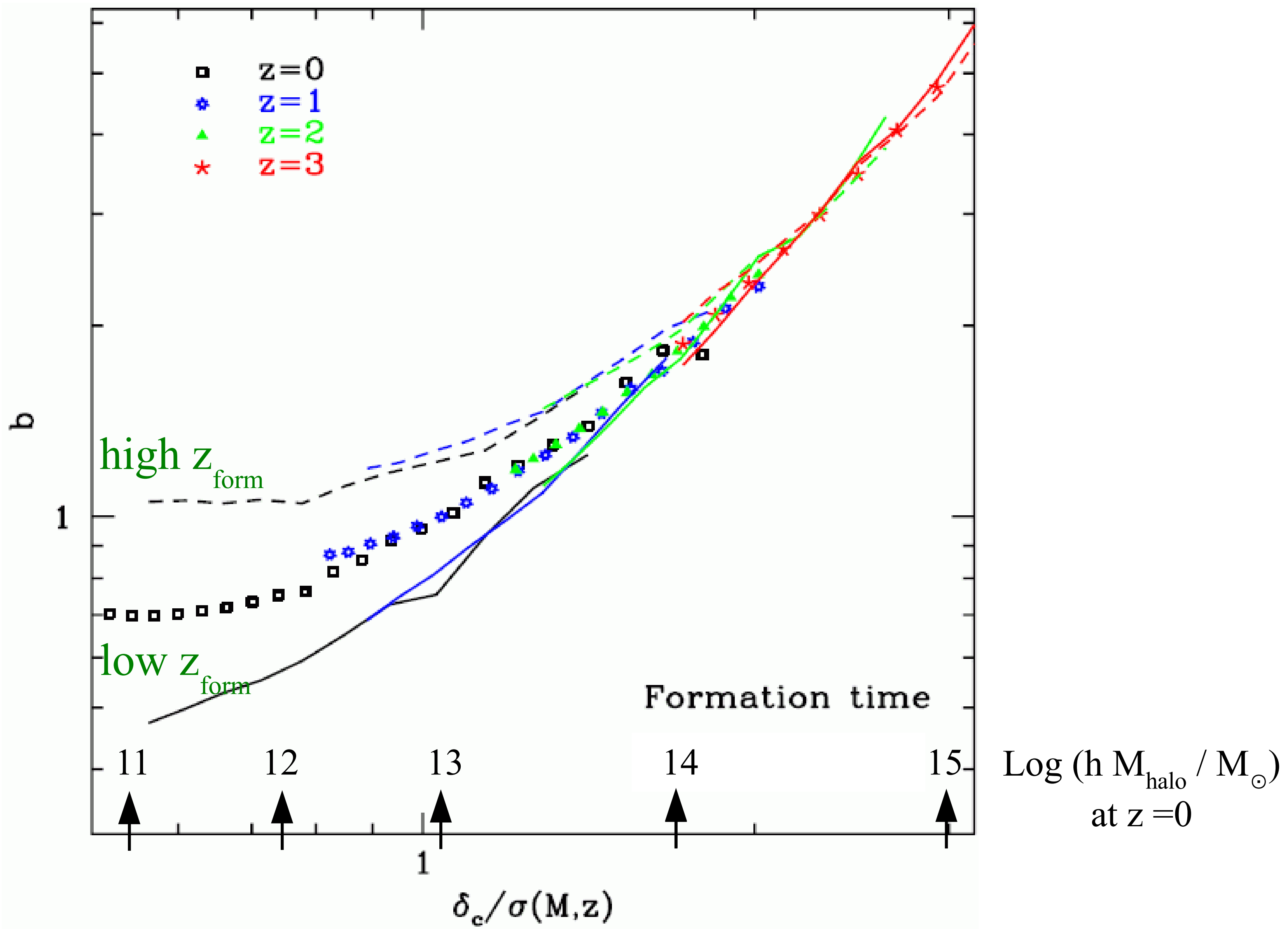


The dependence on formation redshift is strongest at low mass

This behaviour is inconsistent with standard excursion set theory, HOD models and abundance matching models

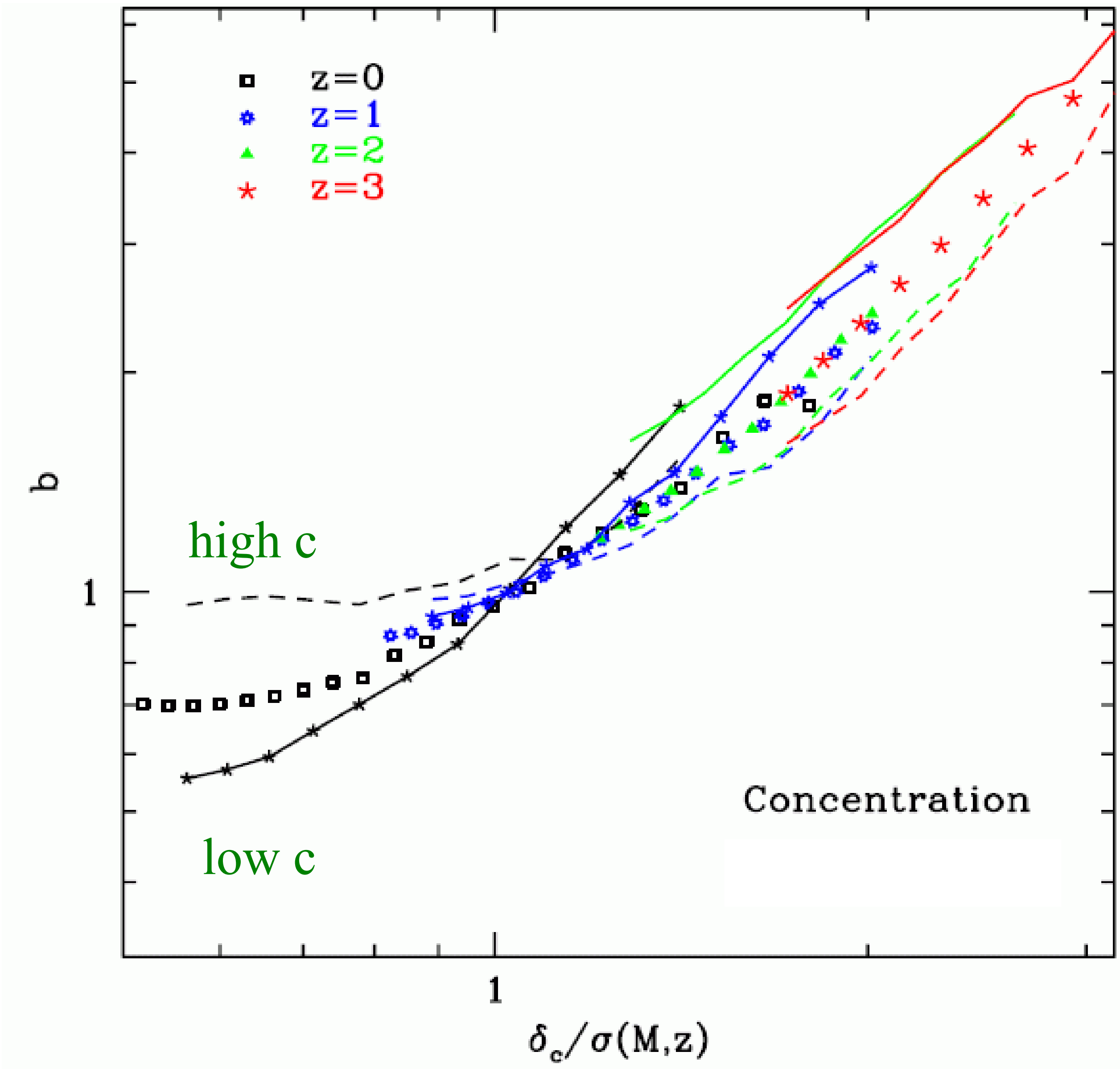
Bias as a function of ν and formation time

Gao & White 2007



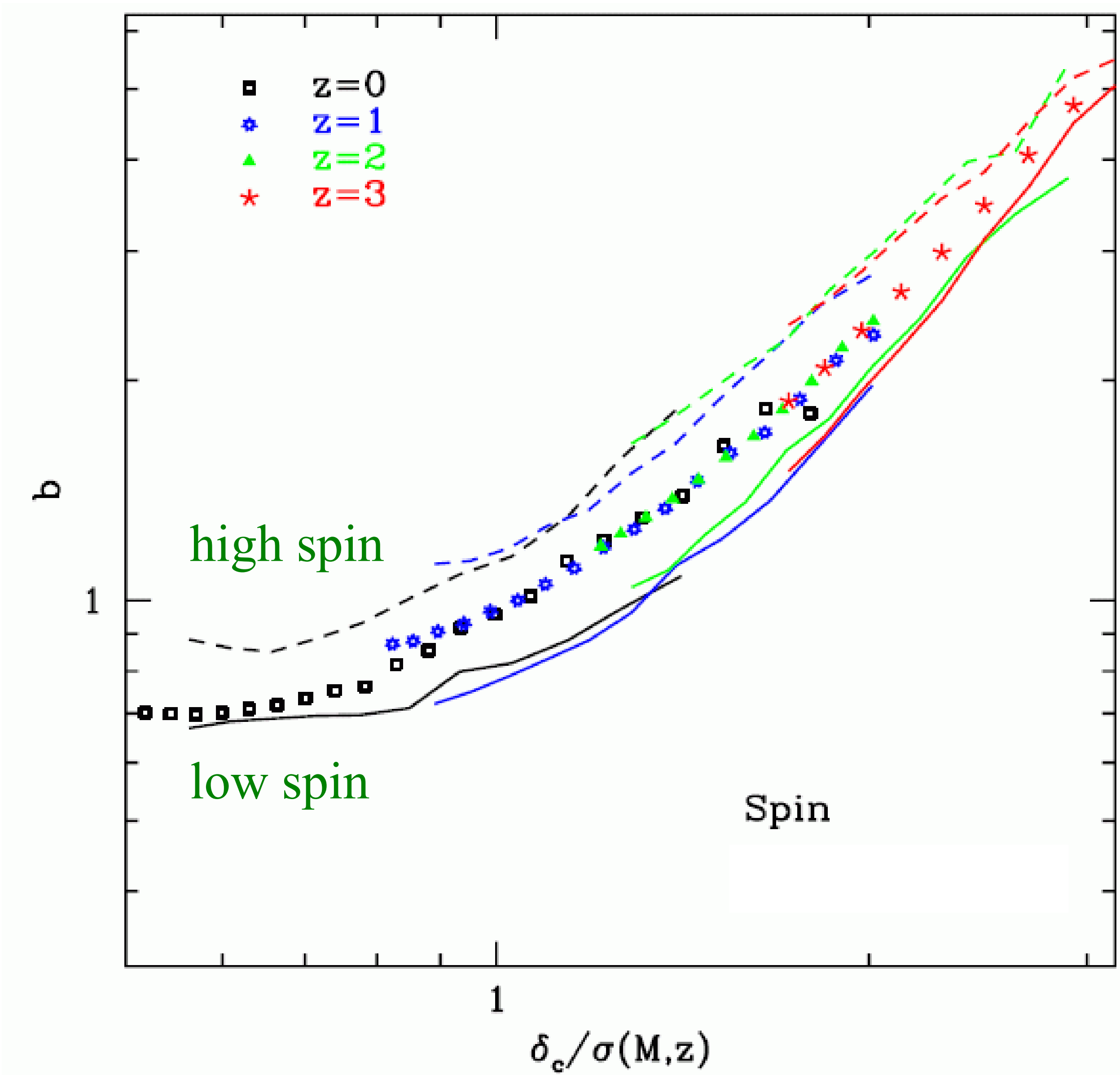
Bias as a function of ν and concentration

Gao & White 2007



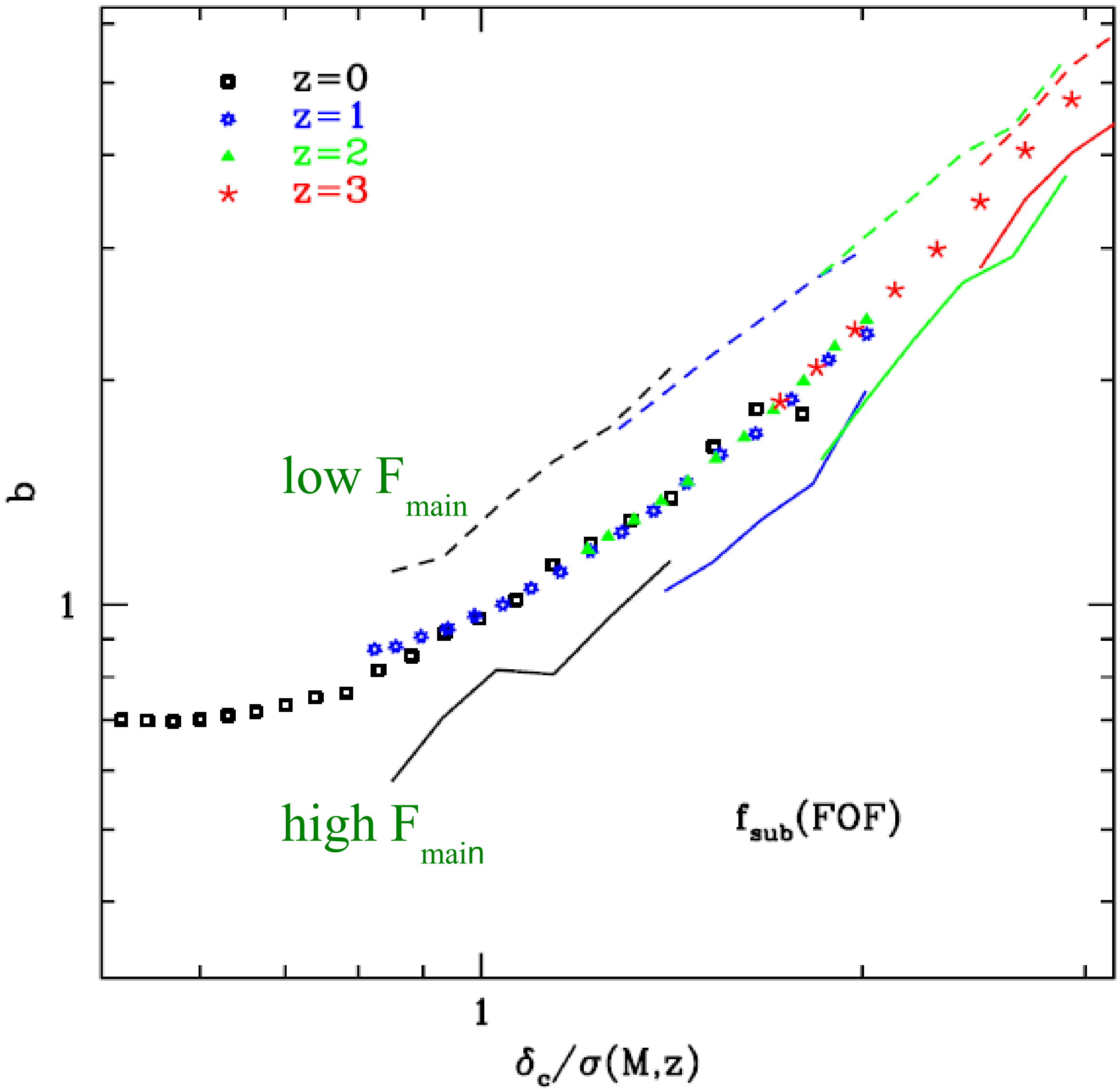
Bias as a function of ν and spin

Gao & White 2007



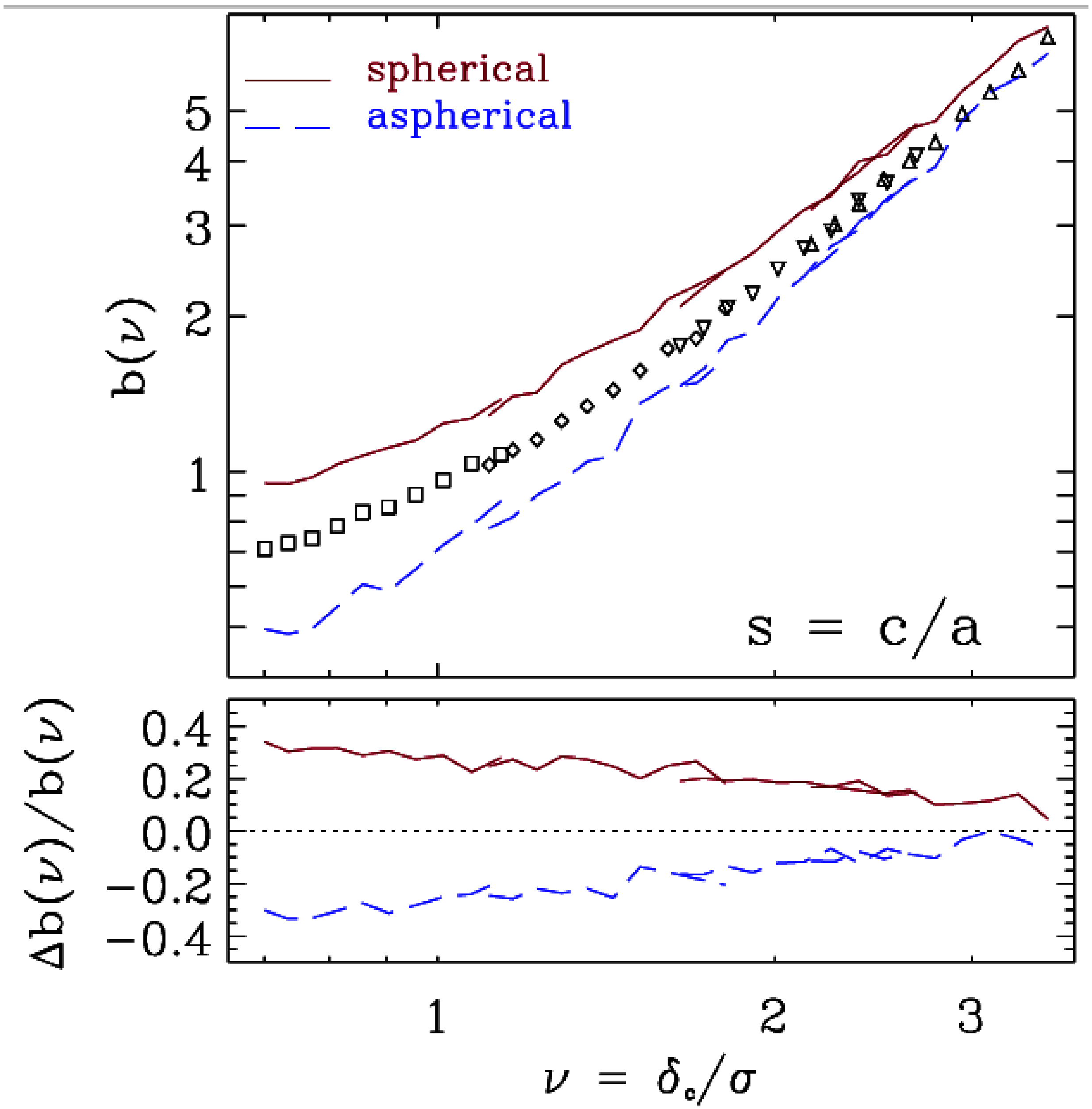
Bias as a function of ν and main subhalo mass fraction

Gao & White 2007



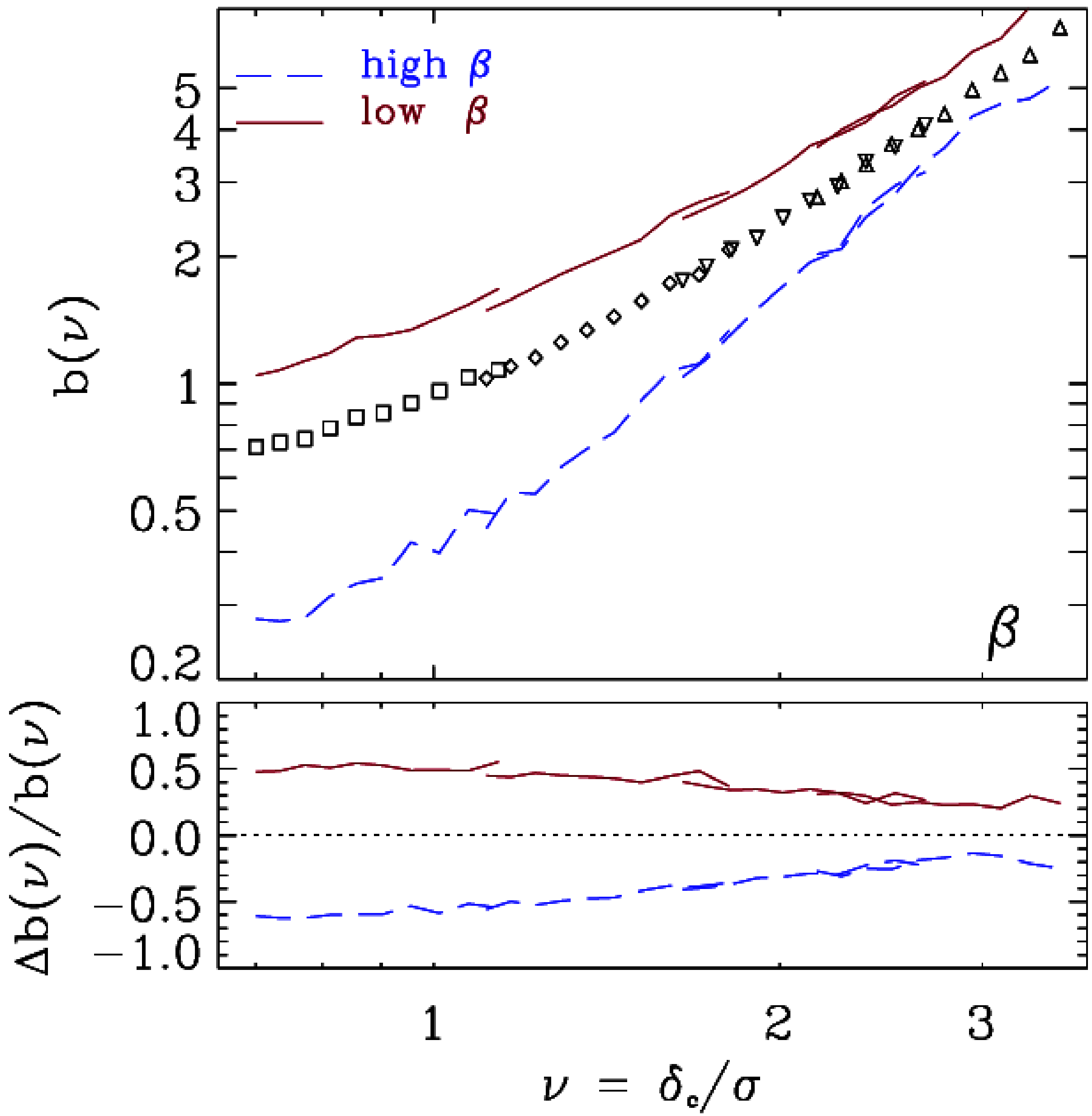
Bias as a function of ν and main subhalo shape

Faltenbacher & White 2010



Bias as a function of ν and velocity anisotropy

Faltenbacher & White 2010



β increases with the fraction of the K.E. of the main subhalo which is in radial motions

Halo assembly bias: conclusions

The large-scale bias of halo clustering depends not only on halo mass through $\nu = \delta_c / D(z)\, \sigma_o(M)$, but also on

- formation time
- concentration
- substructure content
- spin
- shape
- velocity anisotropy

The dependences on different assembly variables are different and cannot be derived from each other.

These dependences are likely to be reflected in galaxy bias

Assembly bias in SDSS/RedMaPPer clusters

Miyatake et al. 2016PhRvL.116d1301M, Evidence of Halo Assembly Bias in Massive Clusters
More et al. 2016ApJ...825...39M, Detection of the Splashback Radius and Halo Assembly Bias of Massive Galaxy Clusters

SDSS/DR8 5-band photometric catalogues analysed with RedMaPPer

→ 8,648 clusters with $0.1 < z_{phot} < 0.33$ and $20 < \lambda < 100$

where λ is a richness, the estimated number of red sequence members with

$$M_i < -19.43 - 5 \log h; \quad R < R_c \equiv 1.0 \, (\lambda / 100)^{0.2} \, h^{-1} \, \mathrm{Mpc}$$

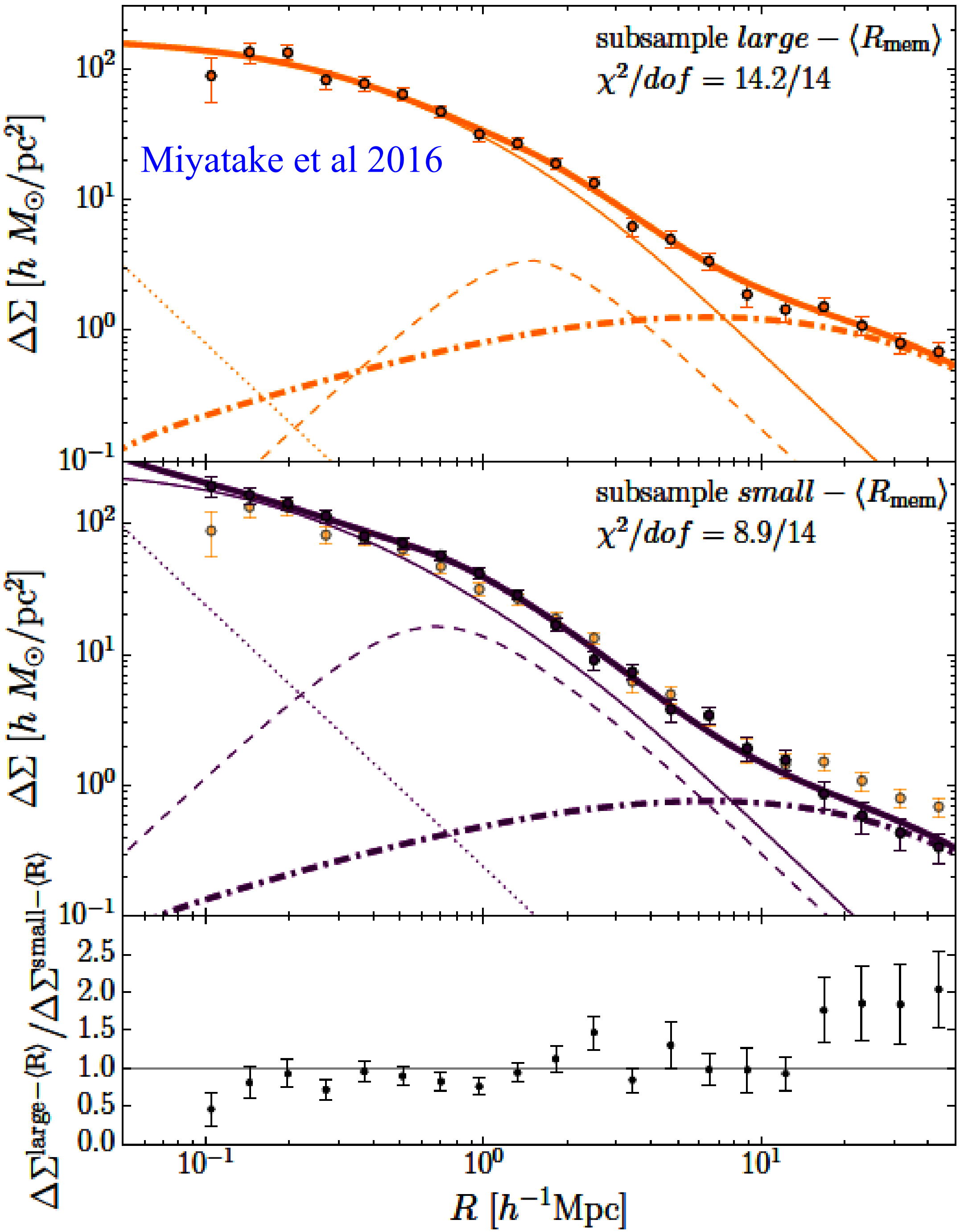
This sample is split into two equal subsamples according to whether

$$\langle R_{mem} \rangle \equiv \sum R \, p_{mem} \quad \text{for red sequence members}$$

lies above or below the median at each cluster's z_{phot} and λ

A set of comparison galaxies has $M_i < -19.43 - 5 \log h$ (no colour cuts)

Assembly bias in SDSS/RedMaPPer clusters



Stacked lensing mass surface densities for the two subsamples compared with an HOD model.

At $R < 2.0\ h^{-1}$ Mpc the mean profiles of the two samples are very similar

A tendency for the clusters with large $\langle R_{mem} \rangle$ to have less concentrated mass

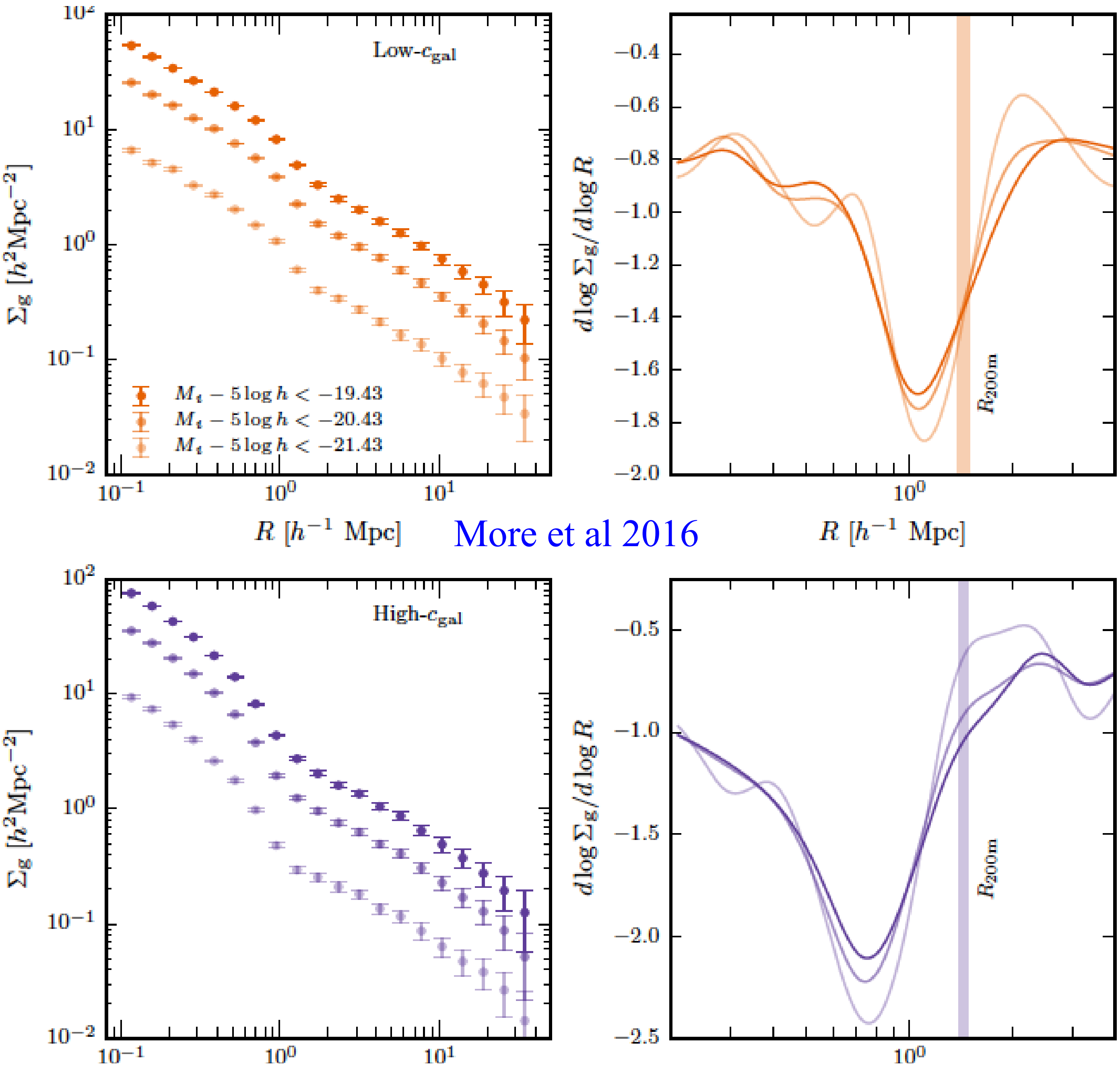
The **same** mean mass (M_{200m}) for the two samples to within 20%

Different large-scale clustering bias by a factor of

$$b^{large} / b^{small} = 1.64 \pm 0.28$$

→ Cluster assembly bias

Assembly bias in SDSS/RedMaPPer clusters



More et al 2016

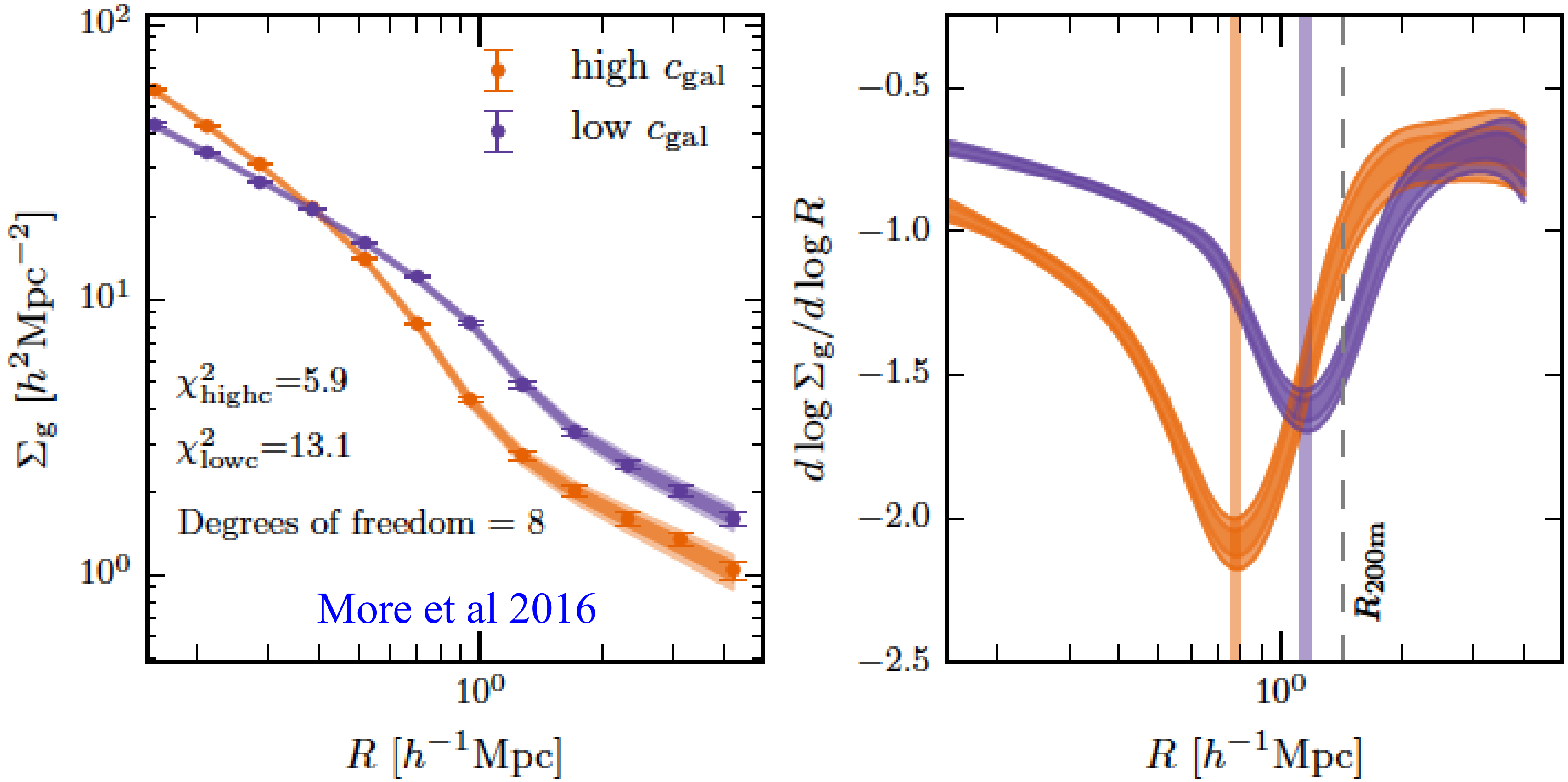
Stacked projected galaxy surface density profiles for the two subsamples

Profiles have very small statistical errors

They are not affected by the luminosity limit of the comparison galaxy sample

Changes in slope are well measured and appear to indicate a high significance detection of splashback

Assembly bias in SDSS/RedMaPPer clusters



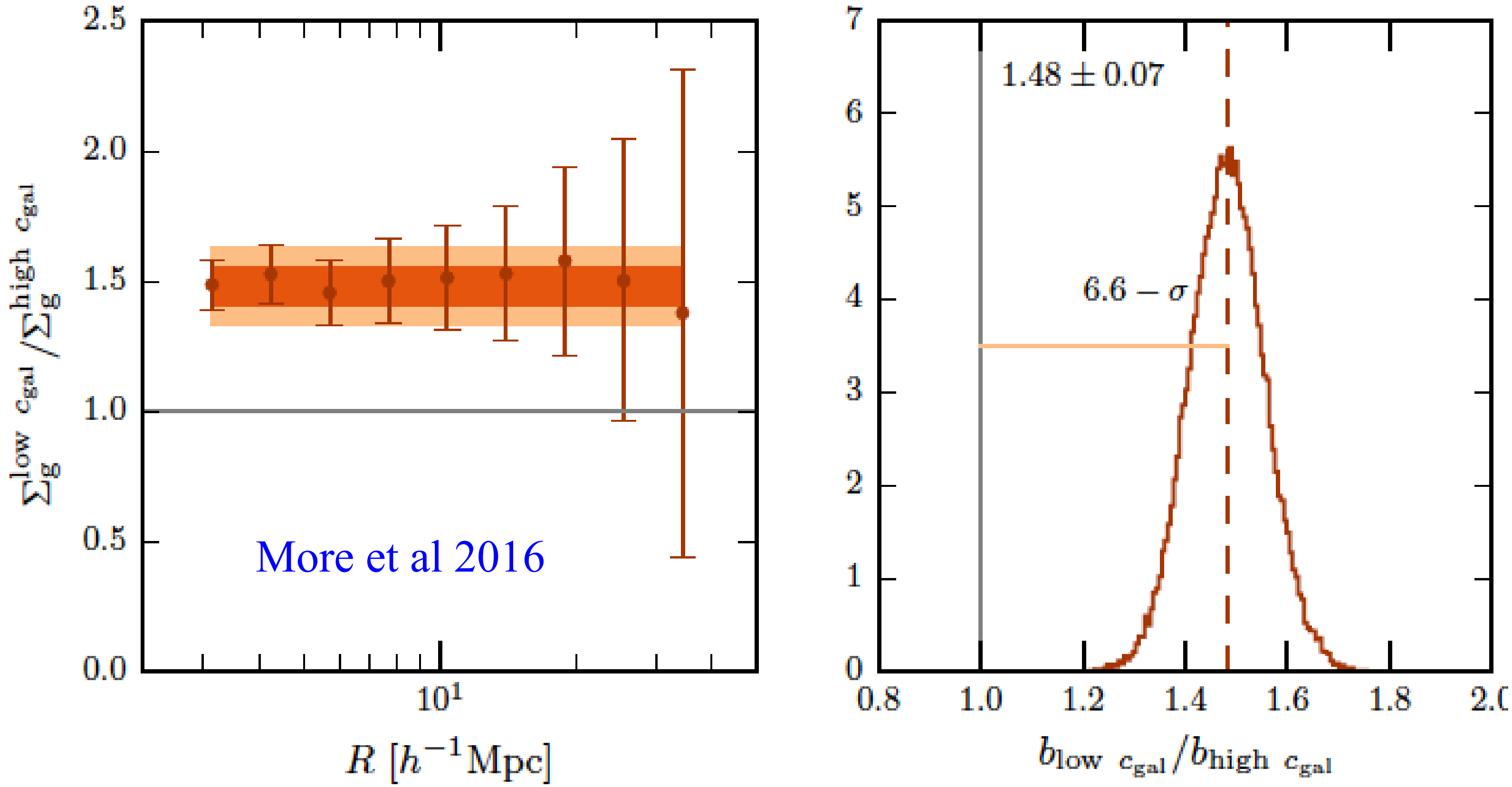
(i) Profiles differ at $R < 1.0\ h^{-1}$ Mpc because of separation of clusters by $\langle R_{mem} \rangle$

(ii) Maximum slope → R_{splash} which is *smaller* for more concentrated clusters

(iii) Strong assembly bias is confirmed at $R > 2.0\ h^{-1}$ Mpc

(iii) is expected from lensing results, but (ii) is *unexpected* given splashback theory

Assembly bias in SDSS/RedMaPPer clusters



Assembly bias is detected and appears constant over a decade in radius

The overall detection significance is 6.6σ

The relative value $b^{large} / b^{small} = 1.48 \pm 0.07$ agrees with the lensing result

Assembly bias and splashback in Millennium clusters

Galaxies from the Guo et al (2011) Millennium-based galaxy formation simulation, taking all properties from the z = 0.24 output file on the **public** data archive

2,239,661 galaxies with $M_i < -19.43 - 5 \log h$, with 897,604 on red sequence

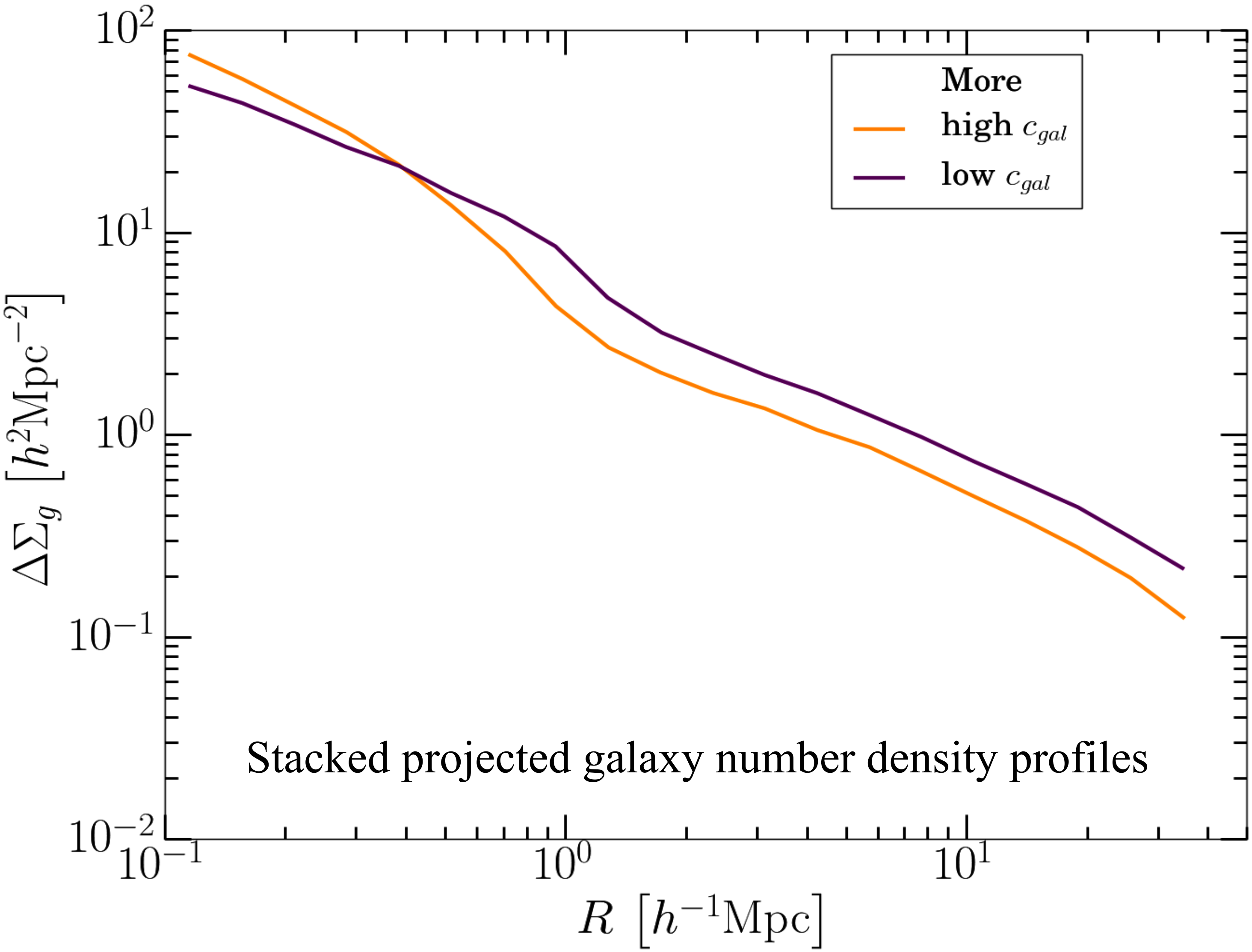
Project along three orthogonal directions → 1/3 of SDSS/RedMaPPER volume

Clusters are centred on their most massive galaxy and contain λ red sequence galaxies in excess of background within projected $R_c \equiv 1.0\, (\lambda / 100)^{0.2}\, h^{-1}$ Mpc

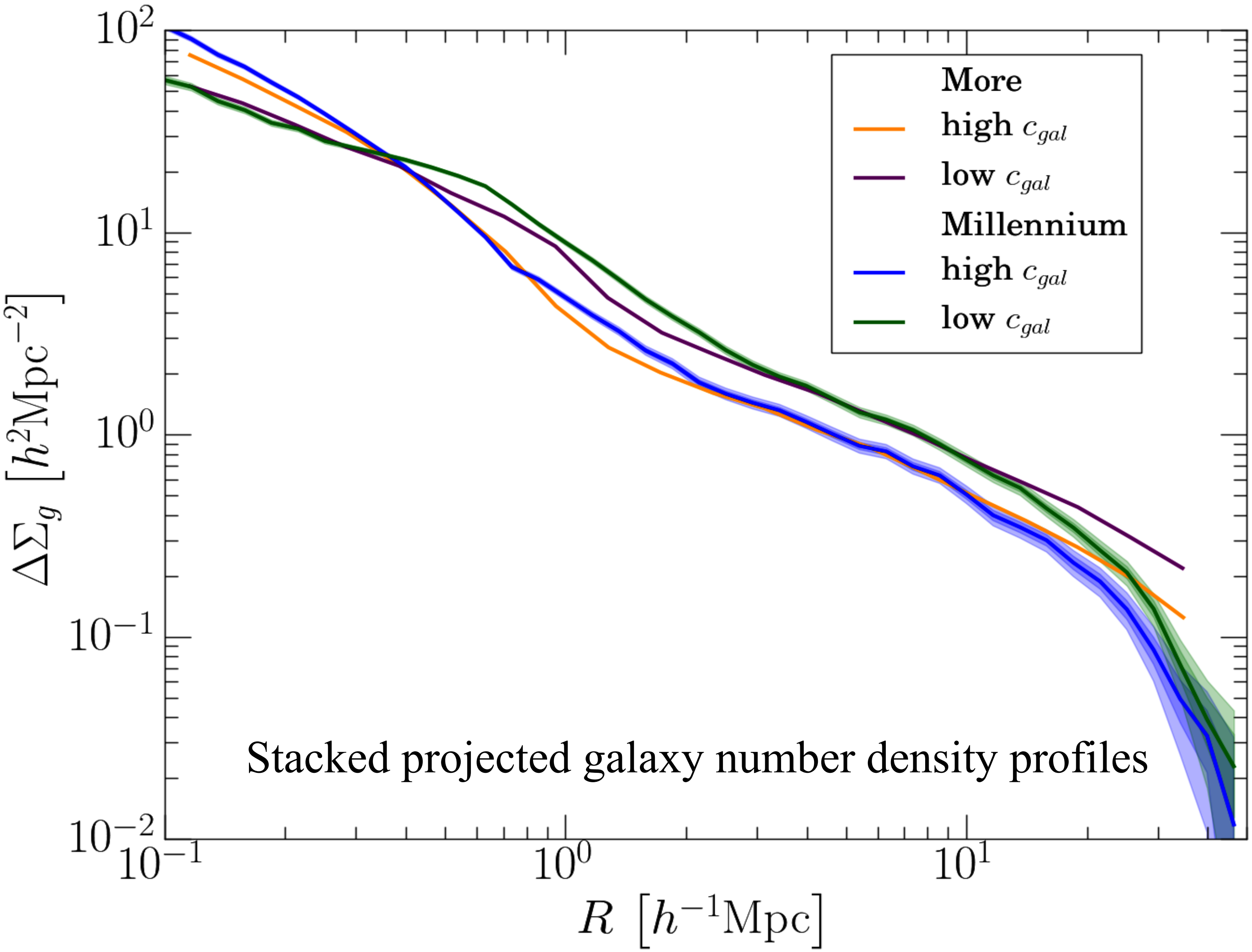
Choose objects with $20 < \lambda < 100$ → a sample of 8,220 clusters

Split into two equal subsamples according to whether $\langle R_{mem} \rangle$ lies above or below the median at each cluster's value of λ

Assembly bias and splashback in Millennium clusters

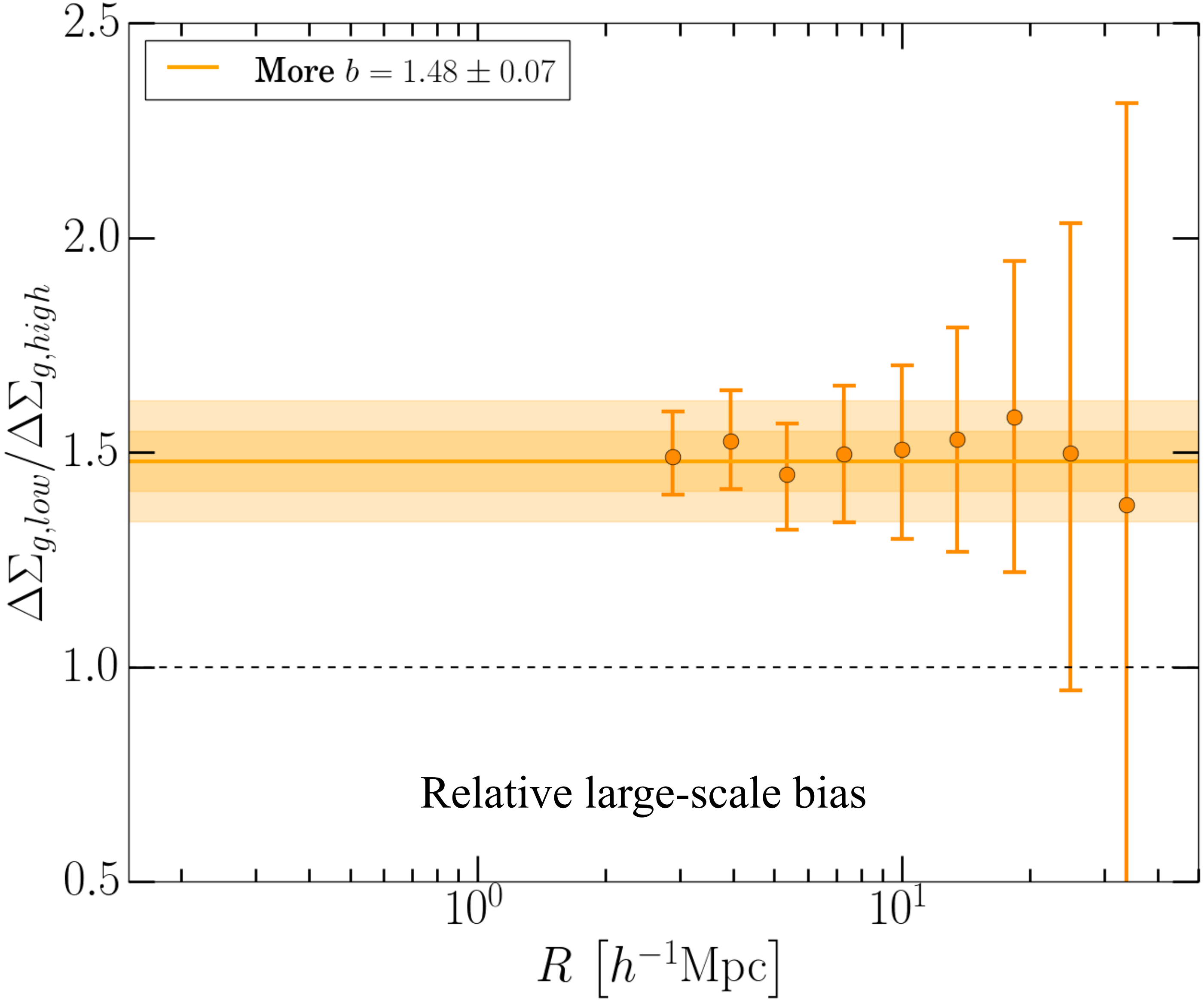


Assembly bias and splashback in Millennium clusters

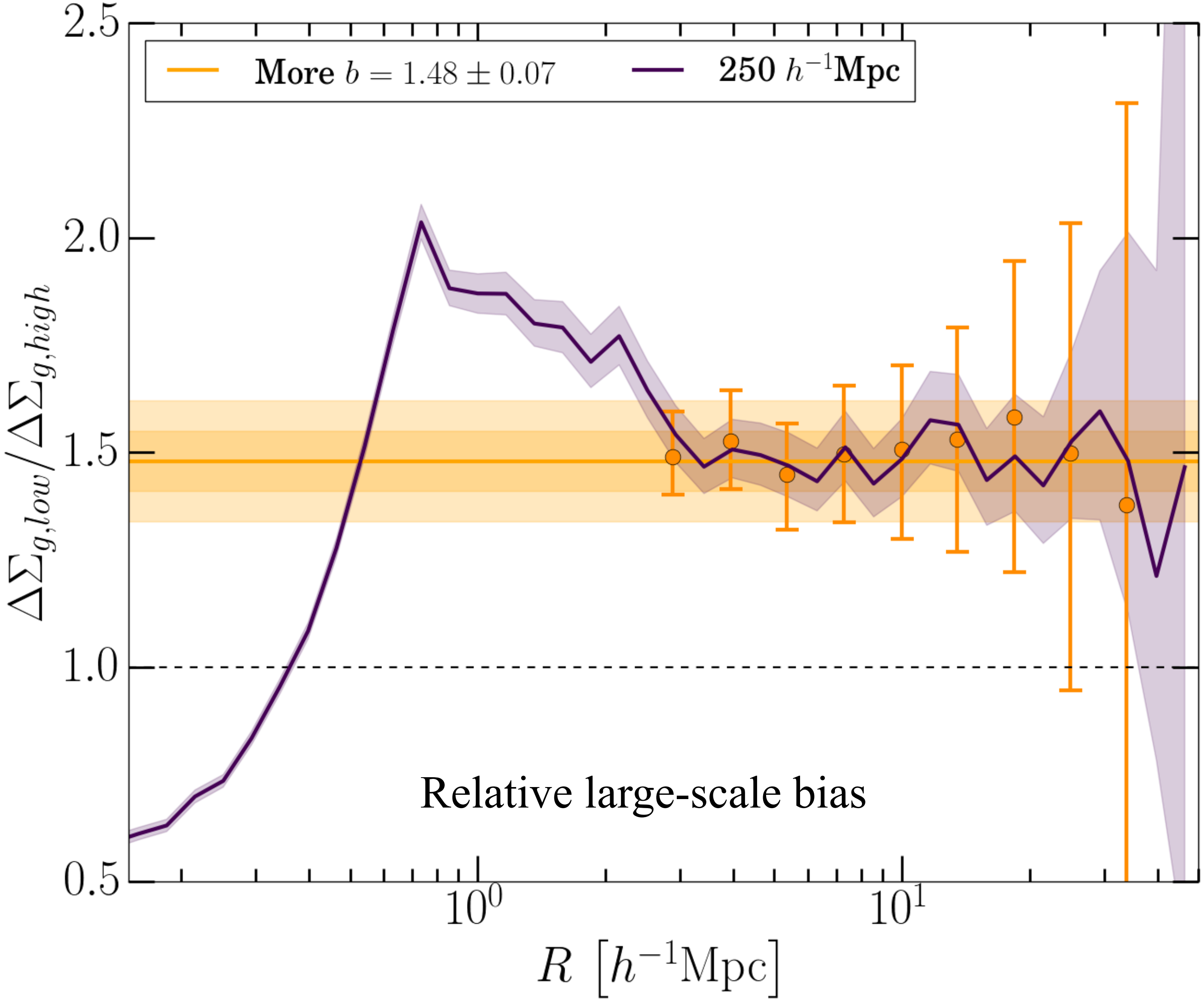


Millennium drop-off at large R due to finite box size, otherwise good agreement

Assembly bias and splashback in Millennium clusters

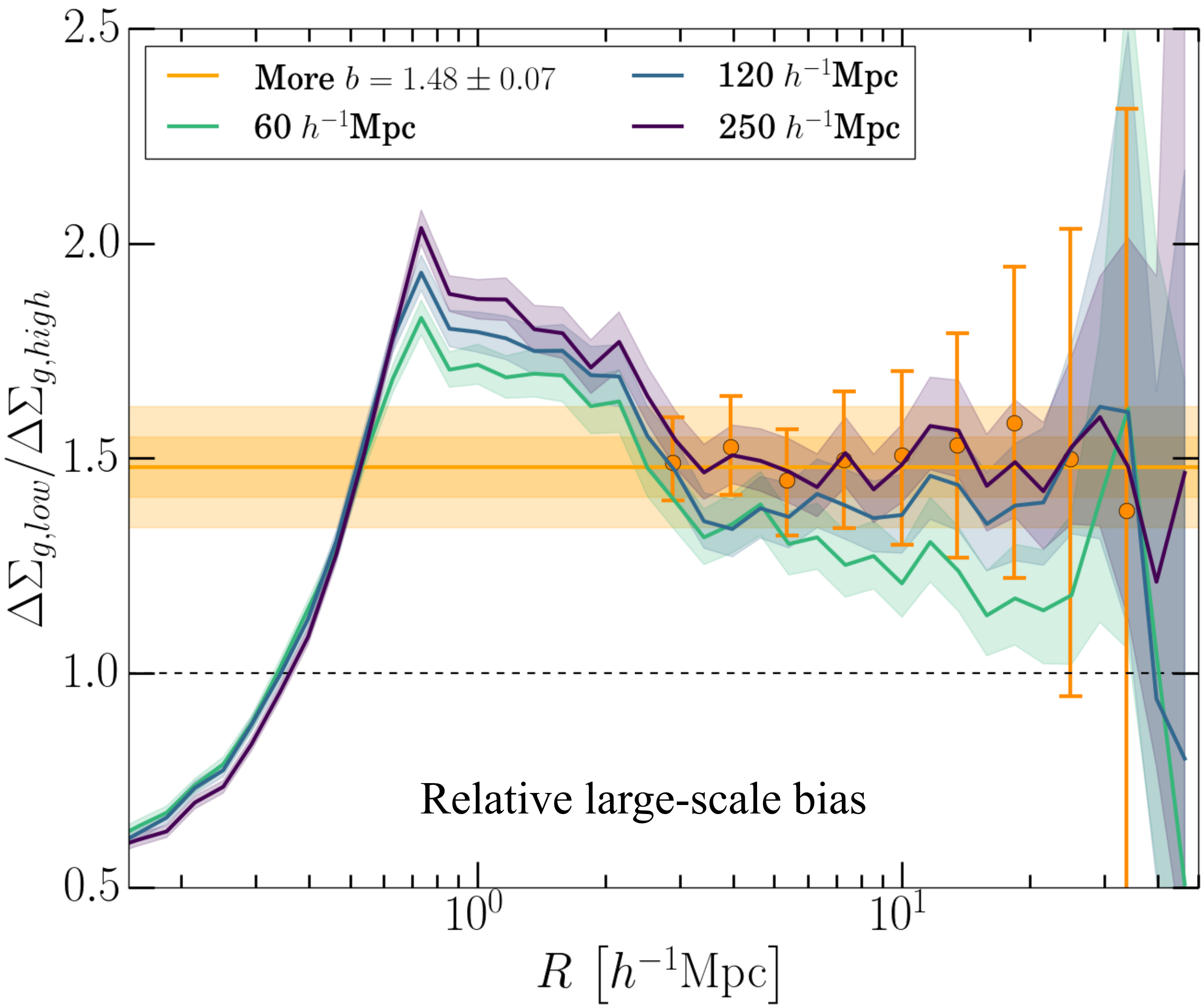


Assembly bias and splashback in Millennium clusters



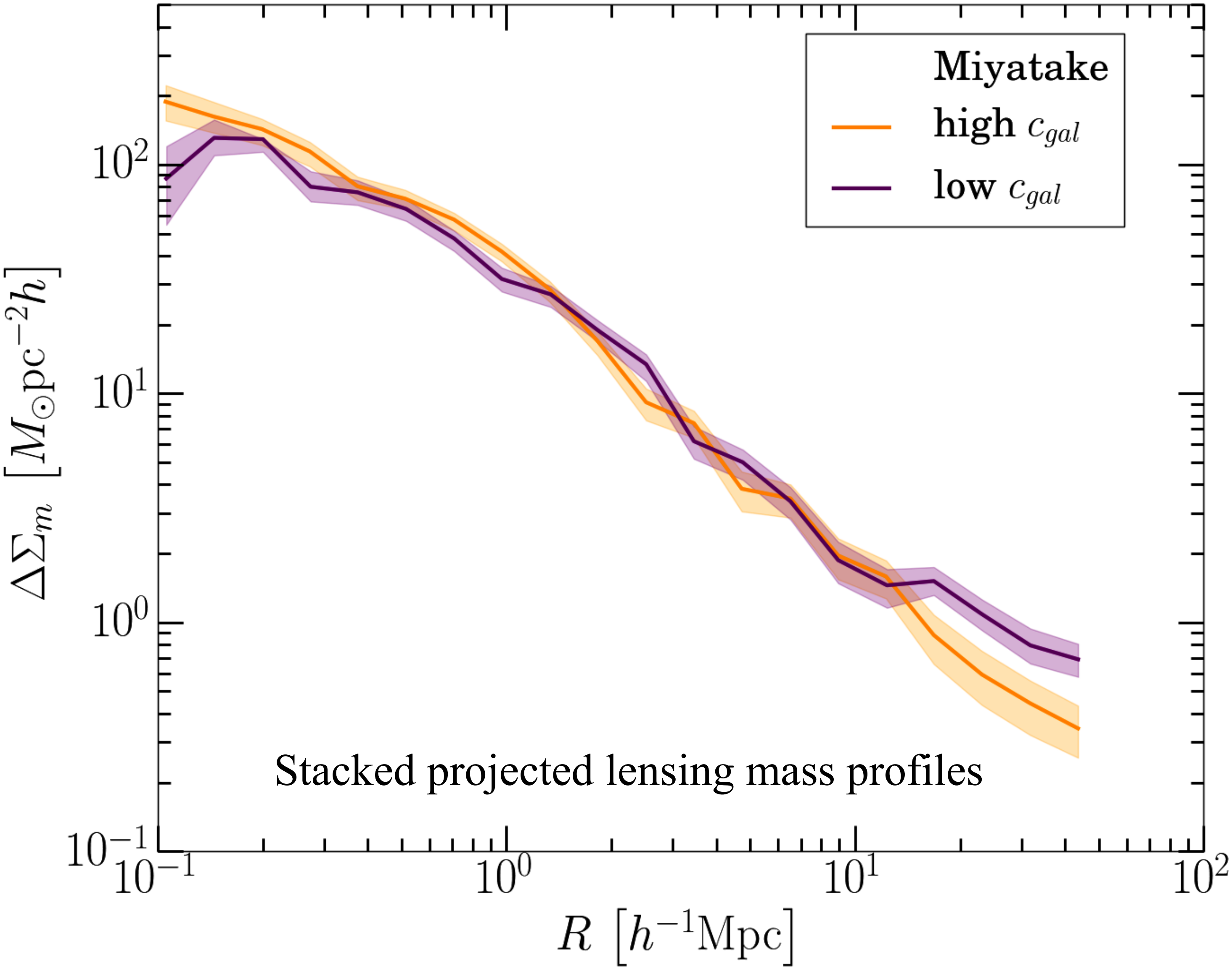
Good agreement on the relative assembly bias of the two subsamples

Assembly bias and splashback in Millennium clusters



Good agreement on the relative assembly bias of the two subsamples
But only for projection though the full Millennium simulation

Assembly bias and splashback in Millennium clusters



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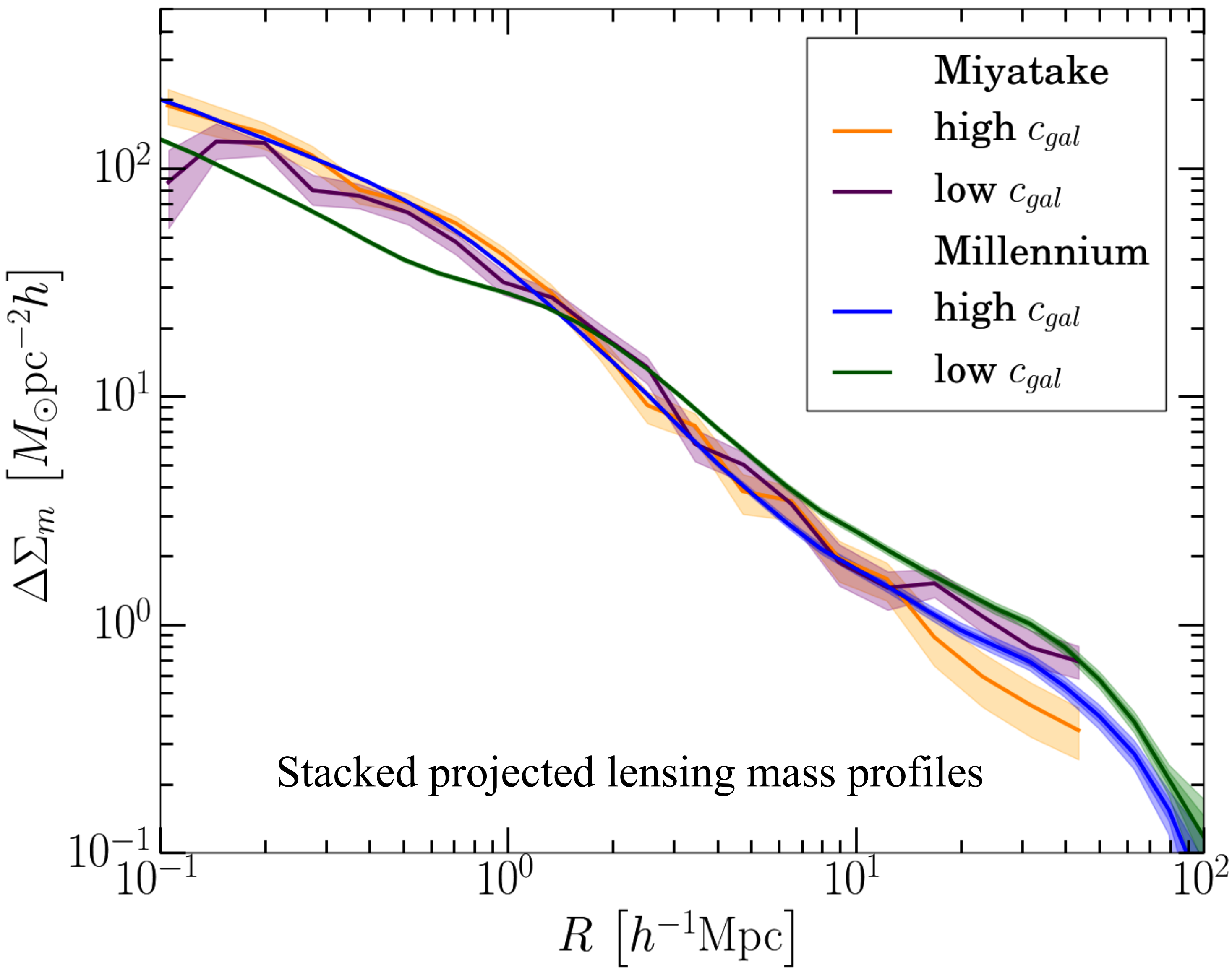
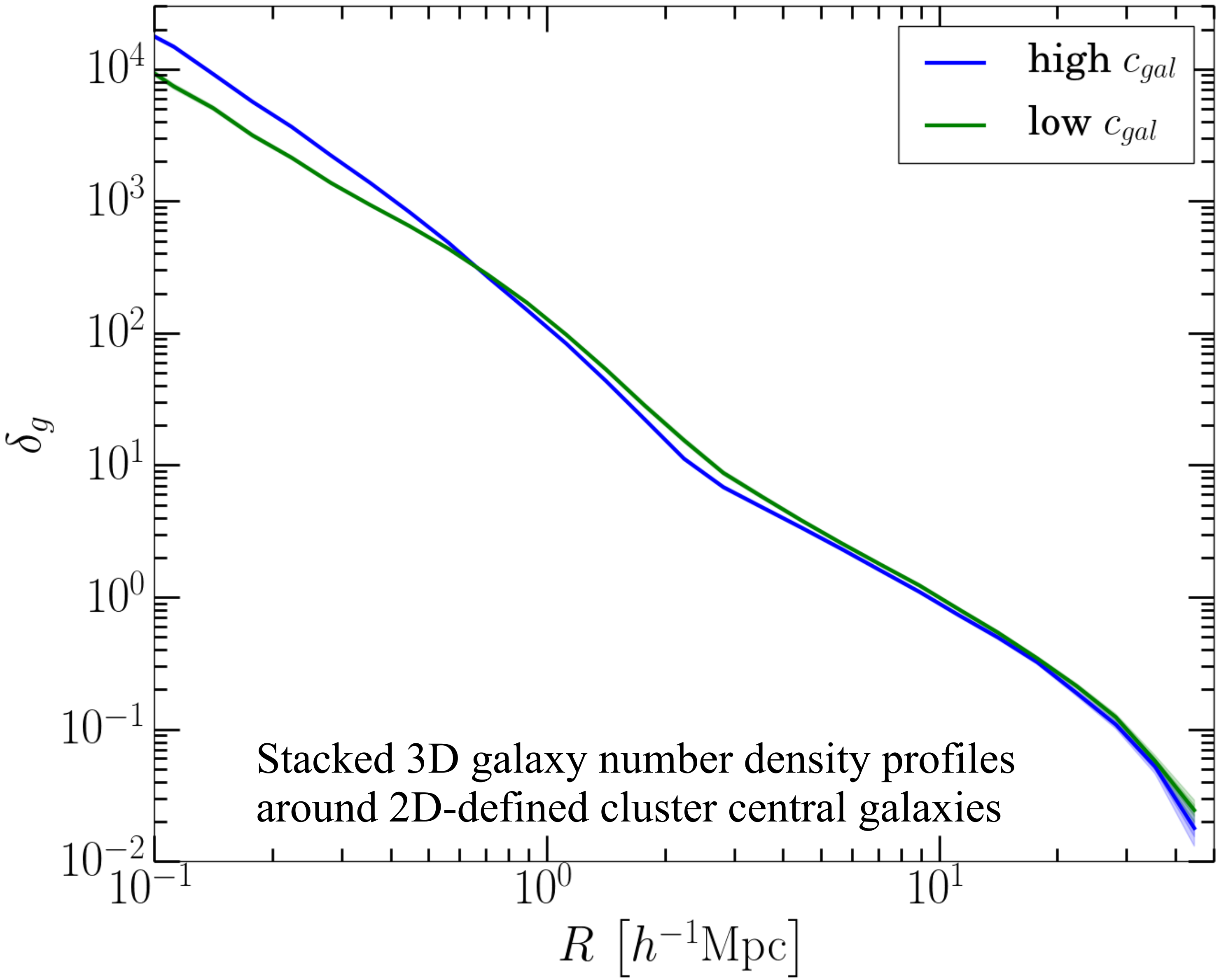


At R < 10.0 h^{-1} Mpc, MS agrees with SDSS for high c but not for low c

At R > 10.0 h^{-1} Mpc, the reverse is true

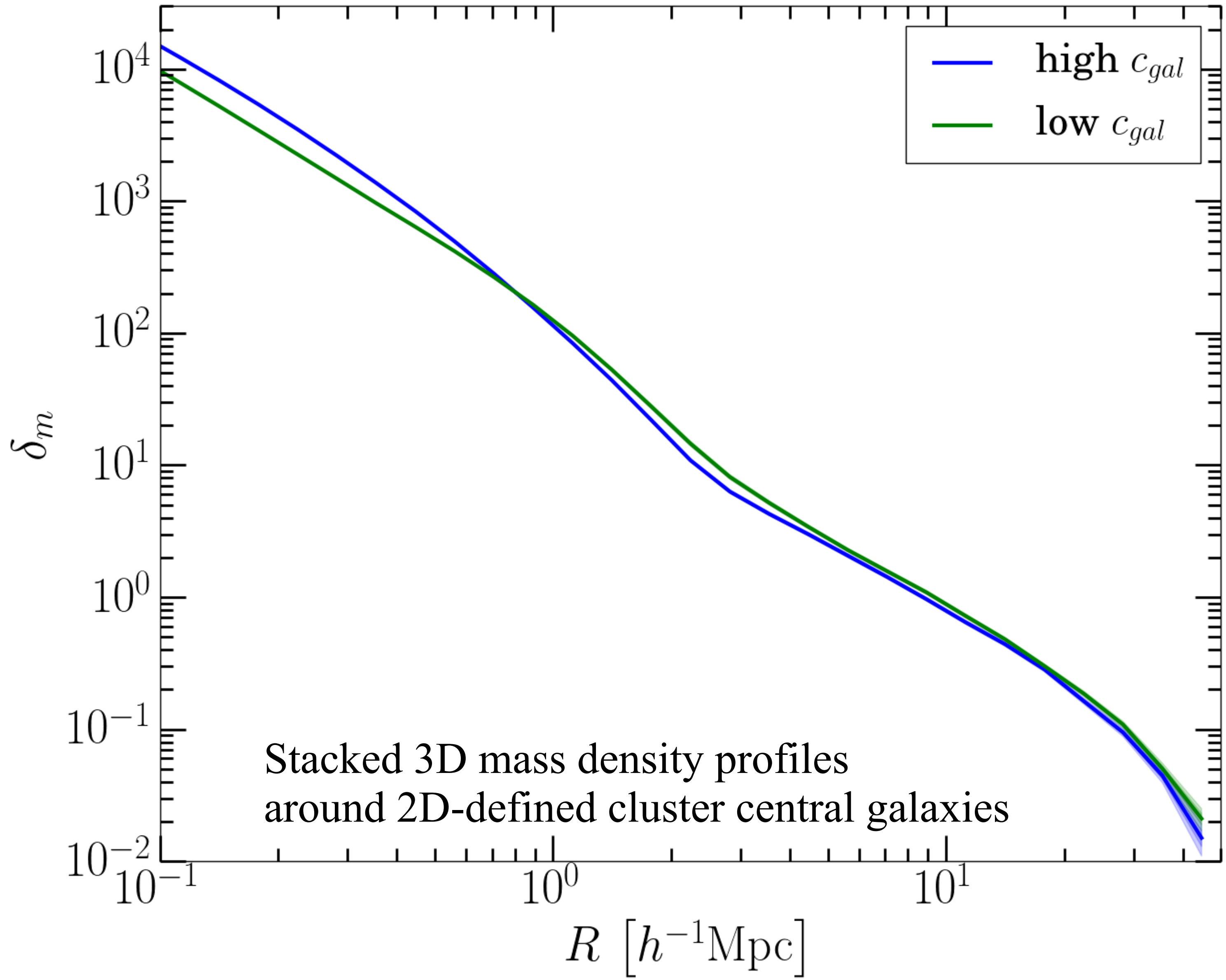
In the simulation, the bias ratio in mass agrees with that in galaxies

Assembly bias and splashback in Millennium clusters



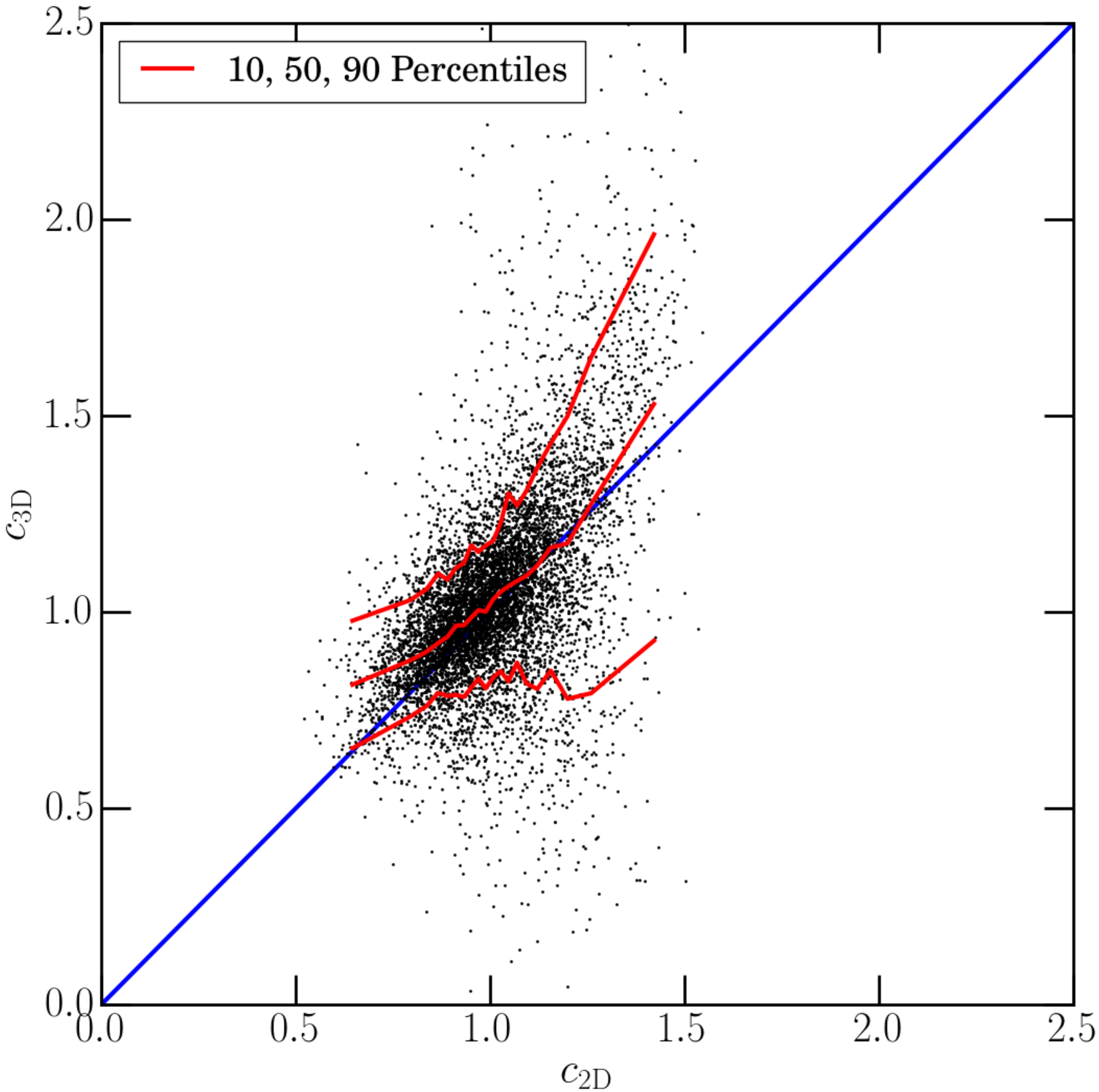
3D galaxy profiles show similar small-scale features but smaller assembly bias

Assembly bias and splashback in Millennium clusters



3D galaxy profiles show similar small-scale features but smaller assembly bias
The mass profiles in 3D are almost identical to the galaxy profiles

Assembly bias and splashback in Millennium clusters



Define the observable cluster property

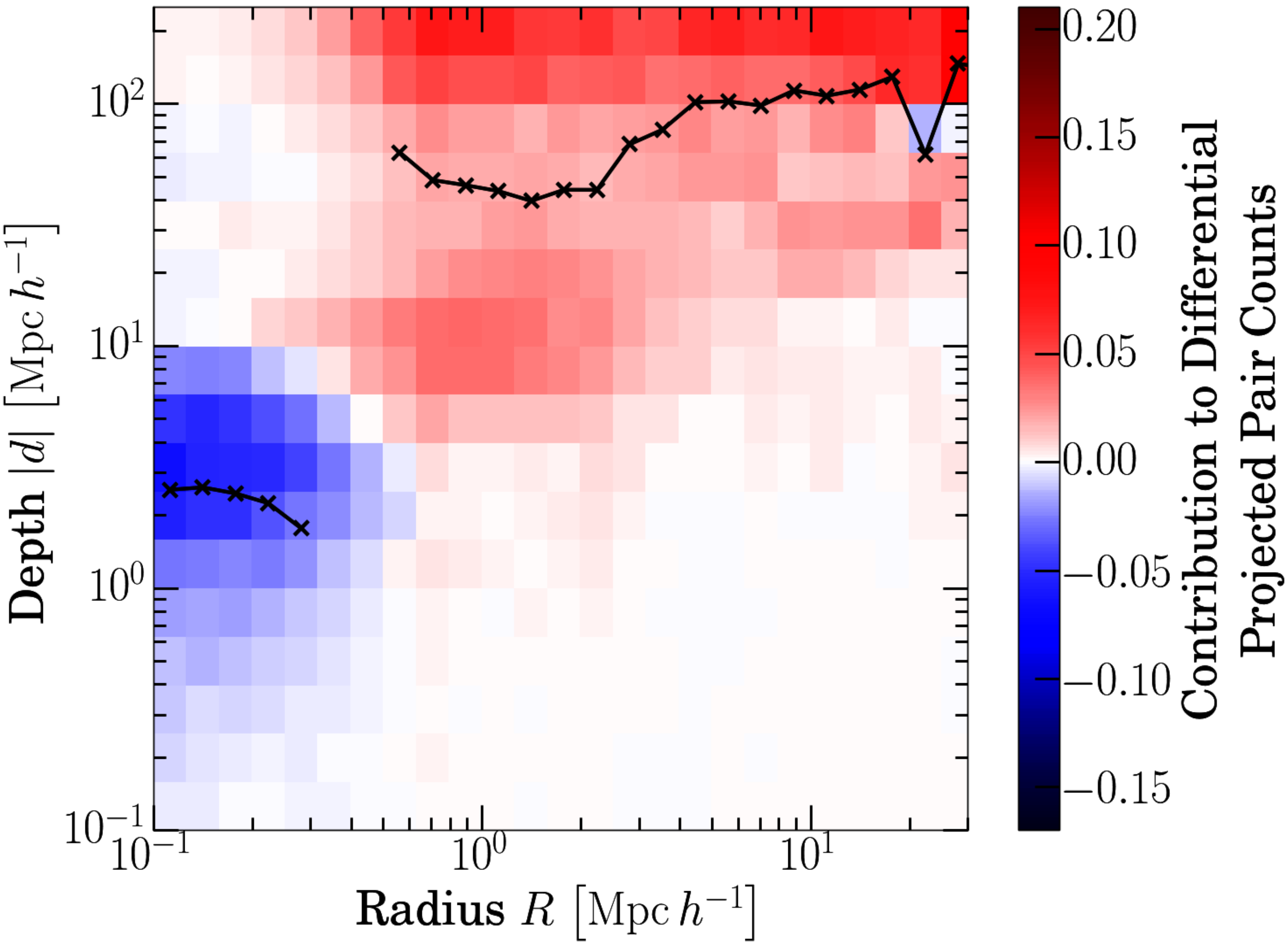
$$c_{2D} \equiv \langle R_{mem} \rangle / \mathrm{median}_{\lambda,z}\{\langle R_{mem} \rangle\}$$

and define a similar quantity averaged over all red sequence galaxies within R_c in 3D as c_{3D}.

Note that these measures increase with decreasing concentration.

The relation between the observable 2D structure and the actual 3D structure is quite weak, particularly at low concentration

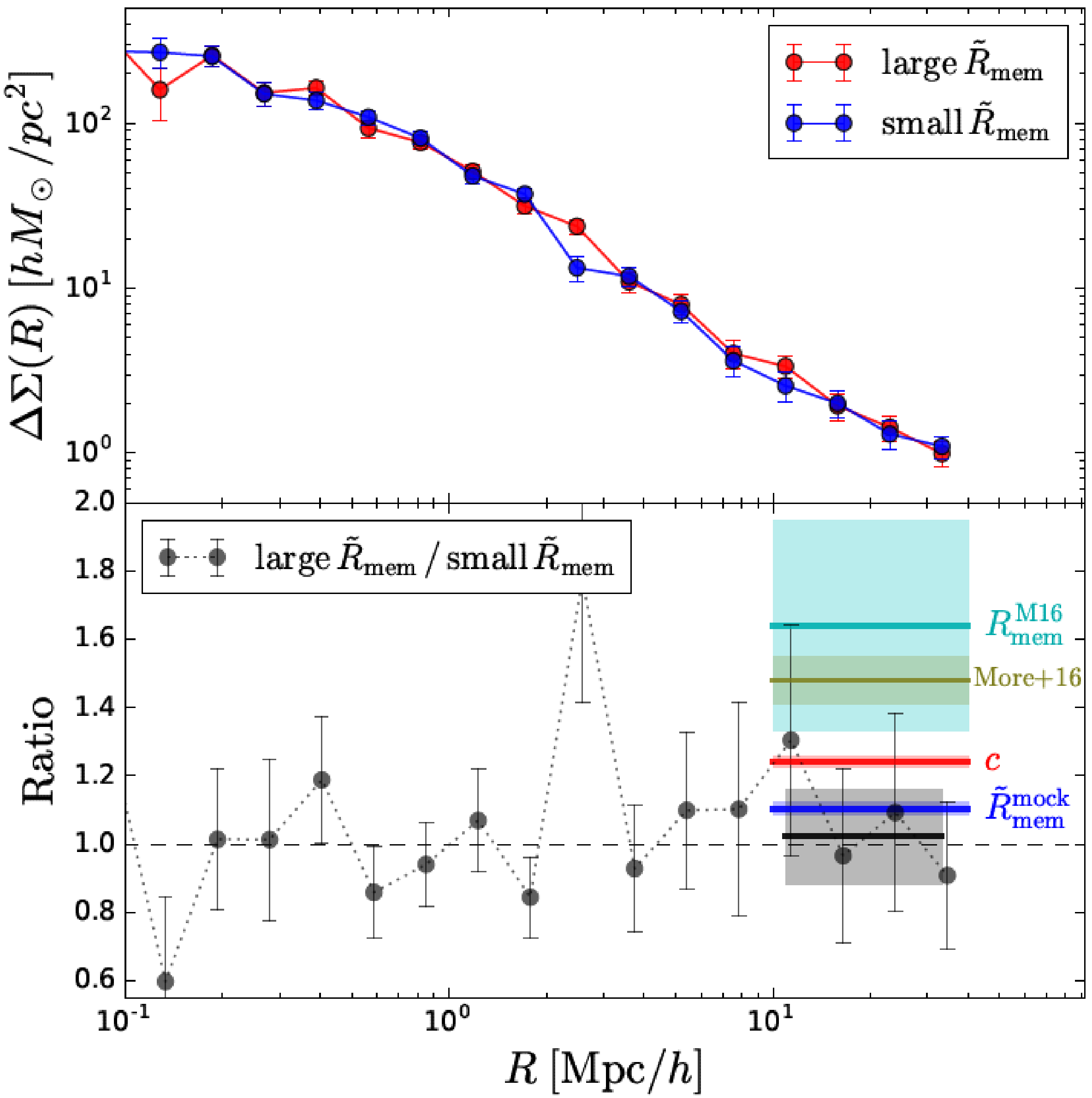
Assembly bias and splashback in Millennium clusters



The galaxies which produce higher projected surface densities are typically at differential depths of 10's to 100's of Mpc at R > 1.0 h^{-1} Mpc (→ the assembly bias signal) and of a few Mpc at R < 300 h^{-1} kpc (→ 2D cluster concentration)

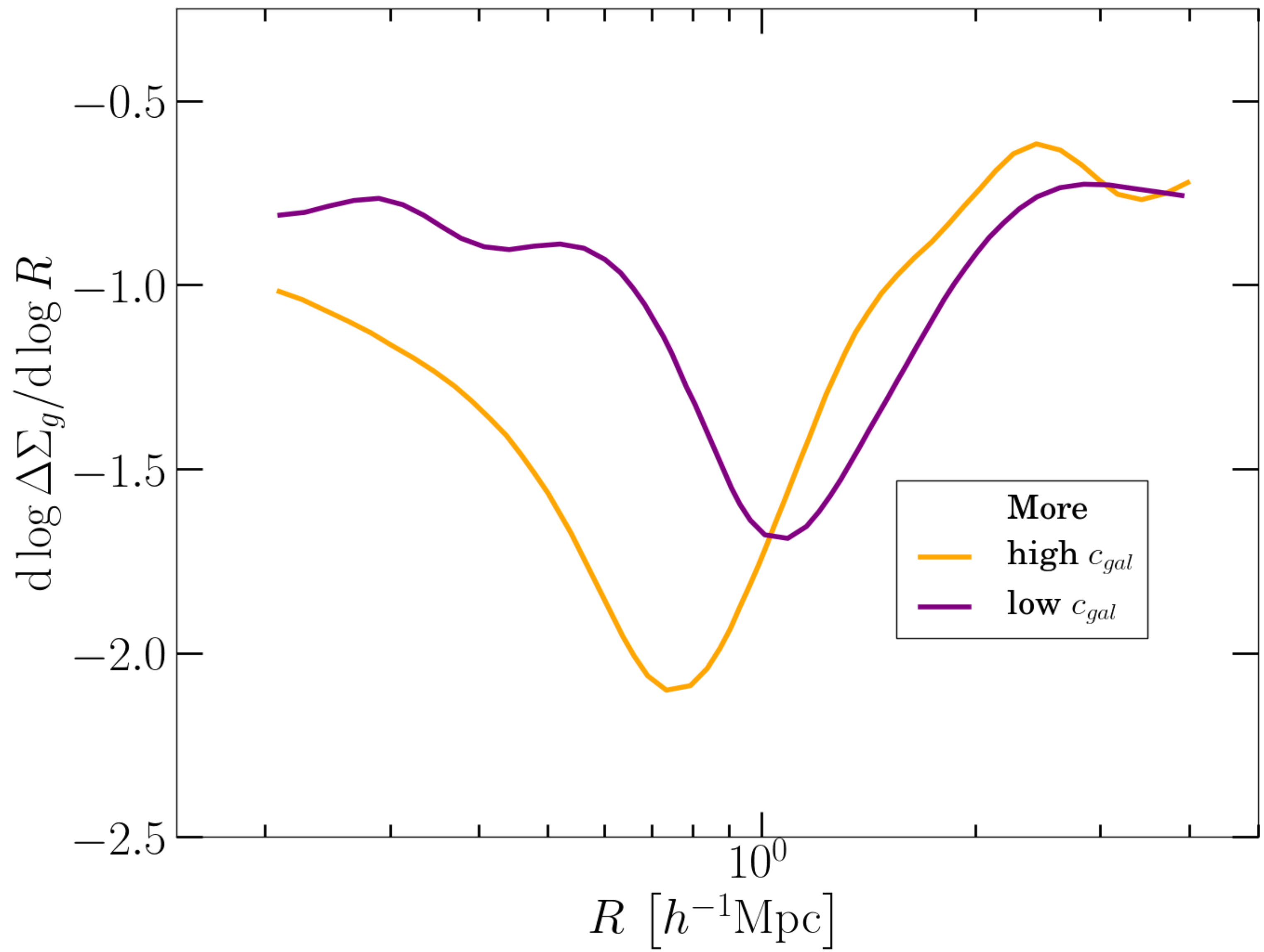
Assembly bias sensitivity to cluster definition in SDSS

Zu et al arXiv:1611.00366



The large-scale bias measured from lensing is eliminated if clusters are defined counting as members only those galaxies for which $p_{mem} > 0.8$

Assembly bias and splashback in Millennium clusters



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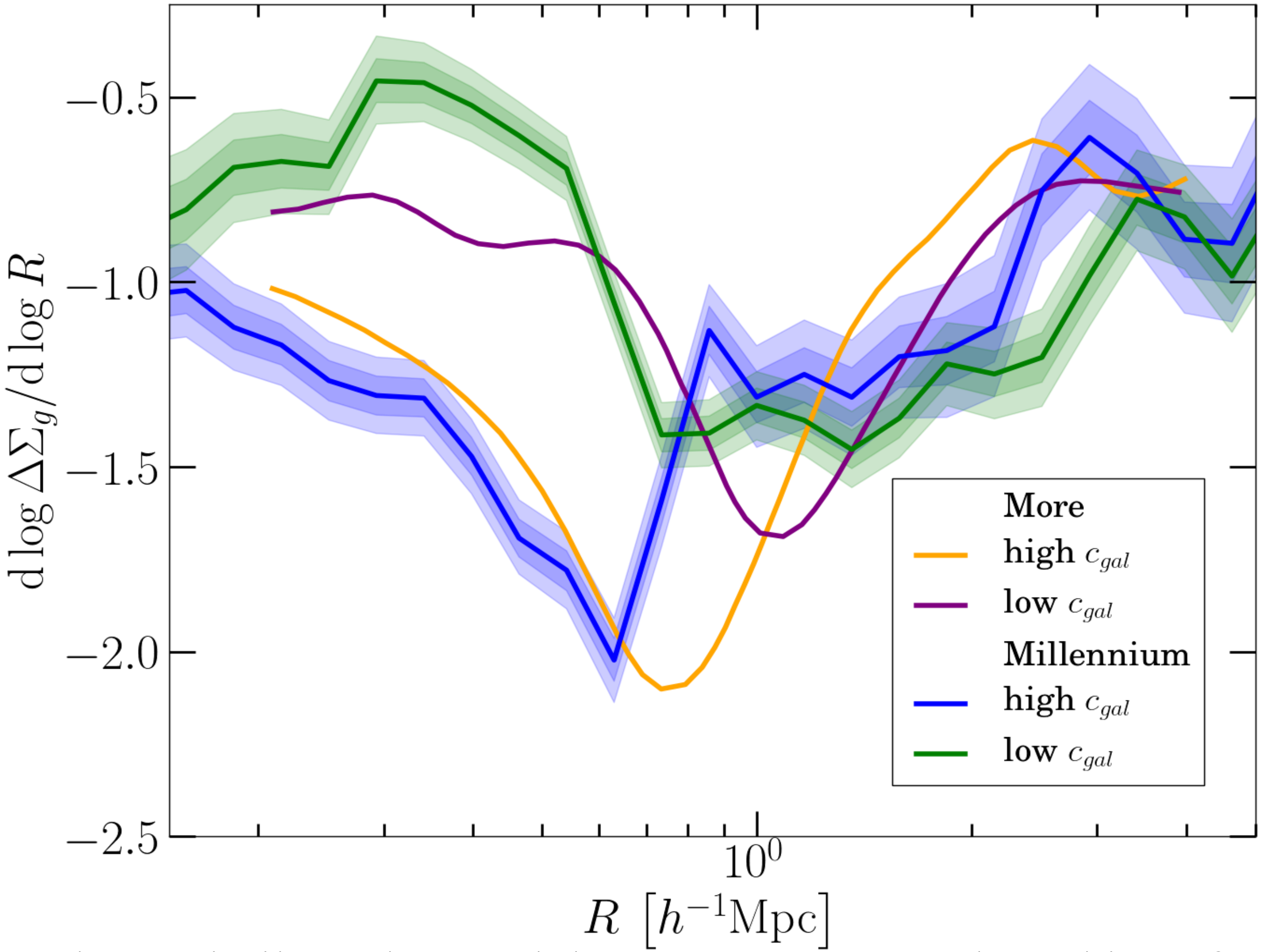
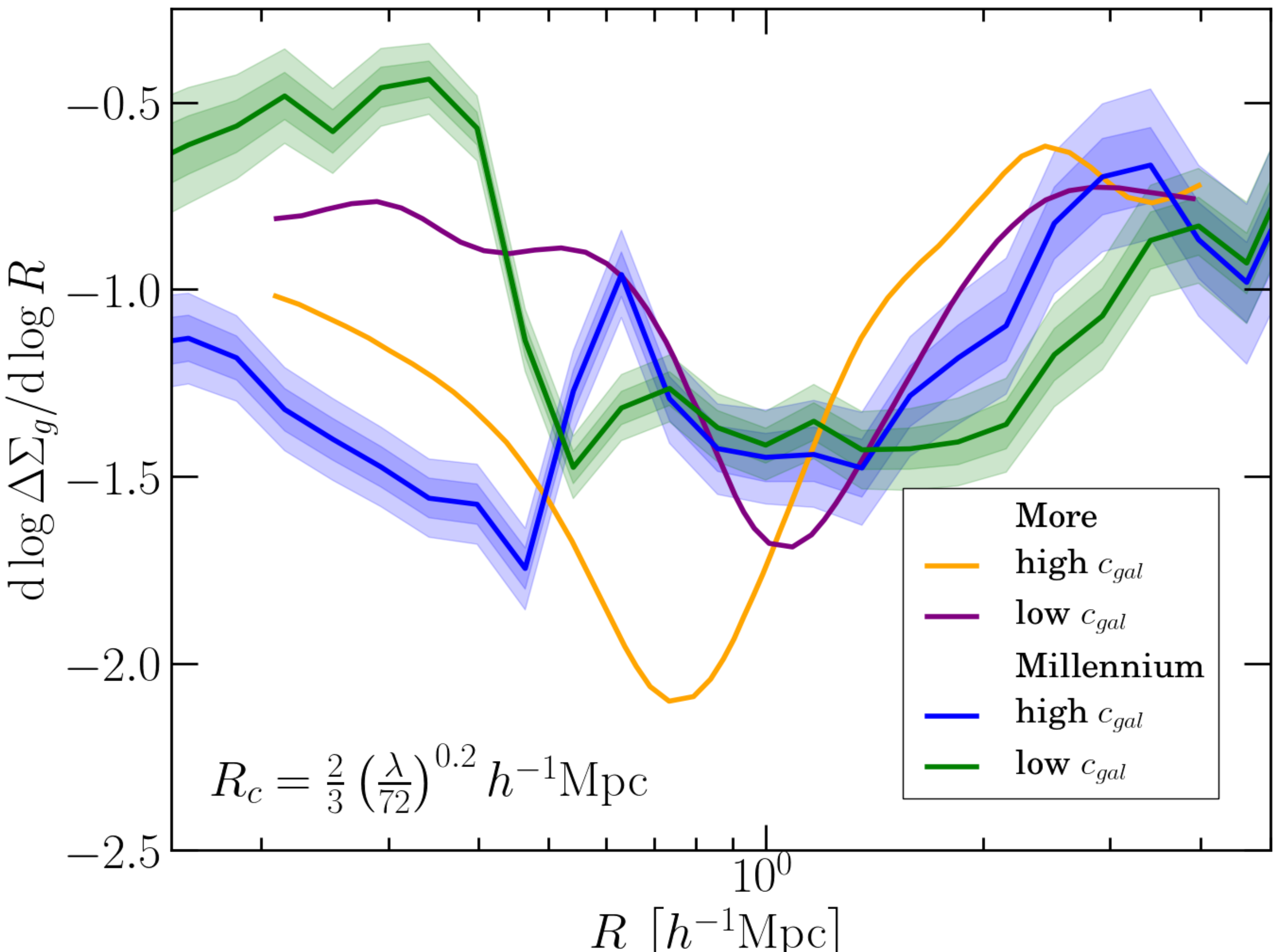


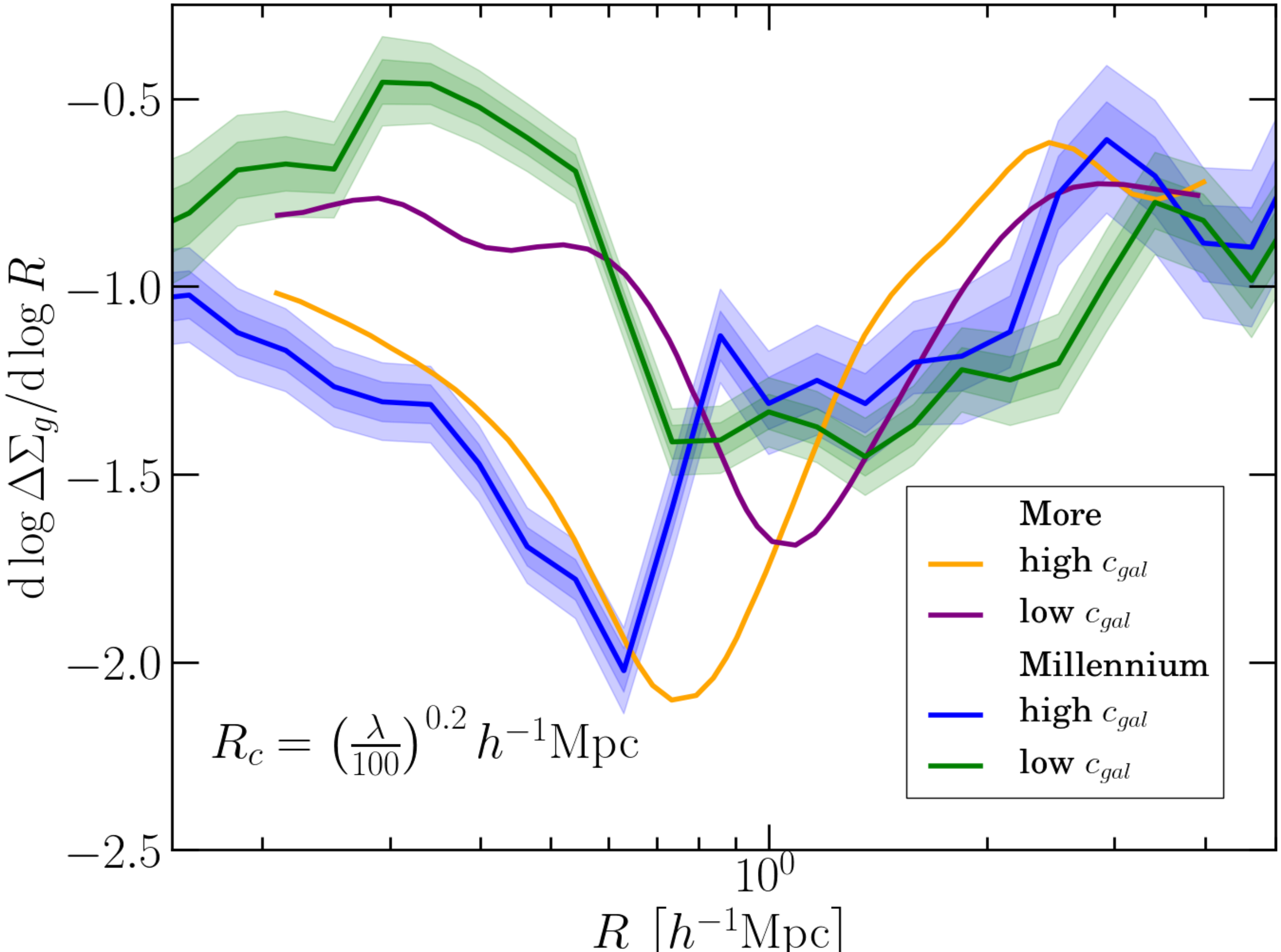
Simulation shows similar values and the same “unexpected” ranking of splashback radii as observed. The slopes at the splashback radius are also similar, but the shapes of the curves differ.

Assembly bias and splashback in Millennium clusters



Simulation shows similar values and the same "unexpected" ranking of splashback radii as observed. The slopes at the splashback radius are also similar, but the shapes of the curves differ. These depend on the value of R_c defining clusters.

Assembly bias and splashback in Millennium clusters



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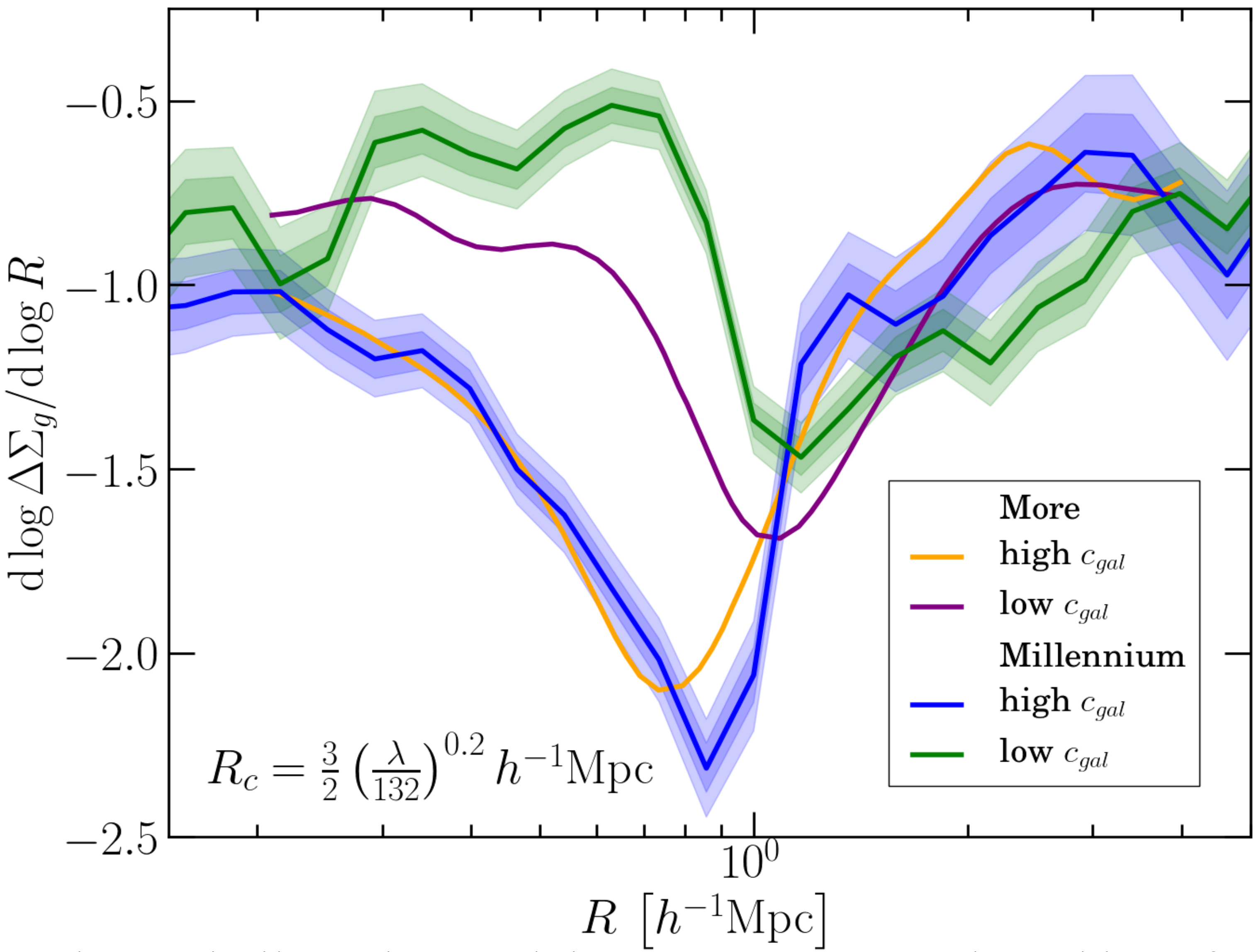

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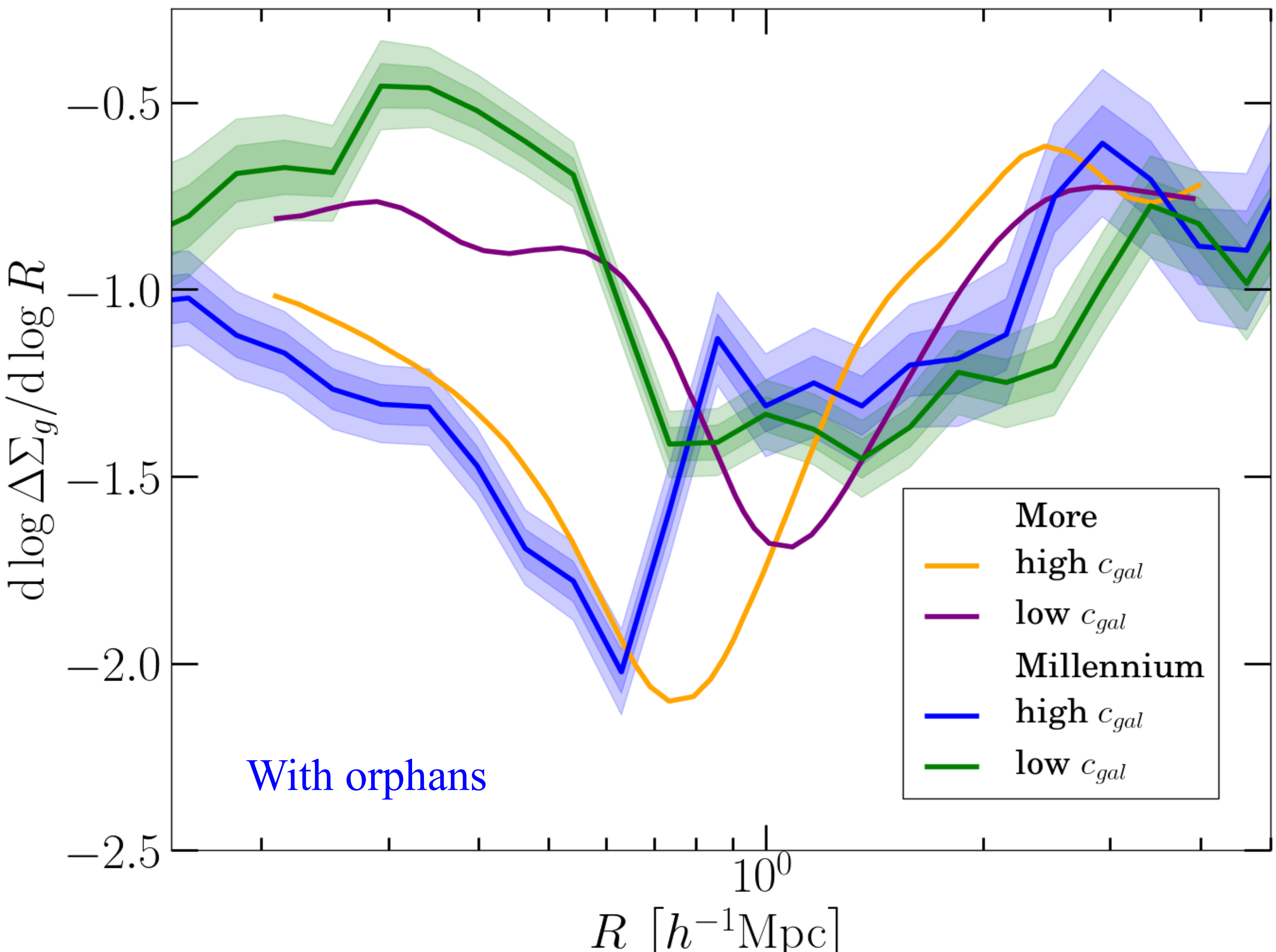

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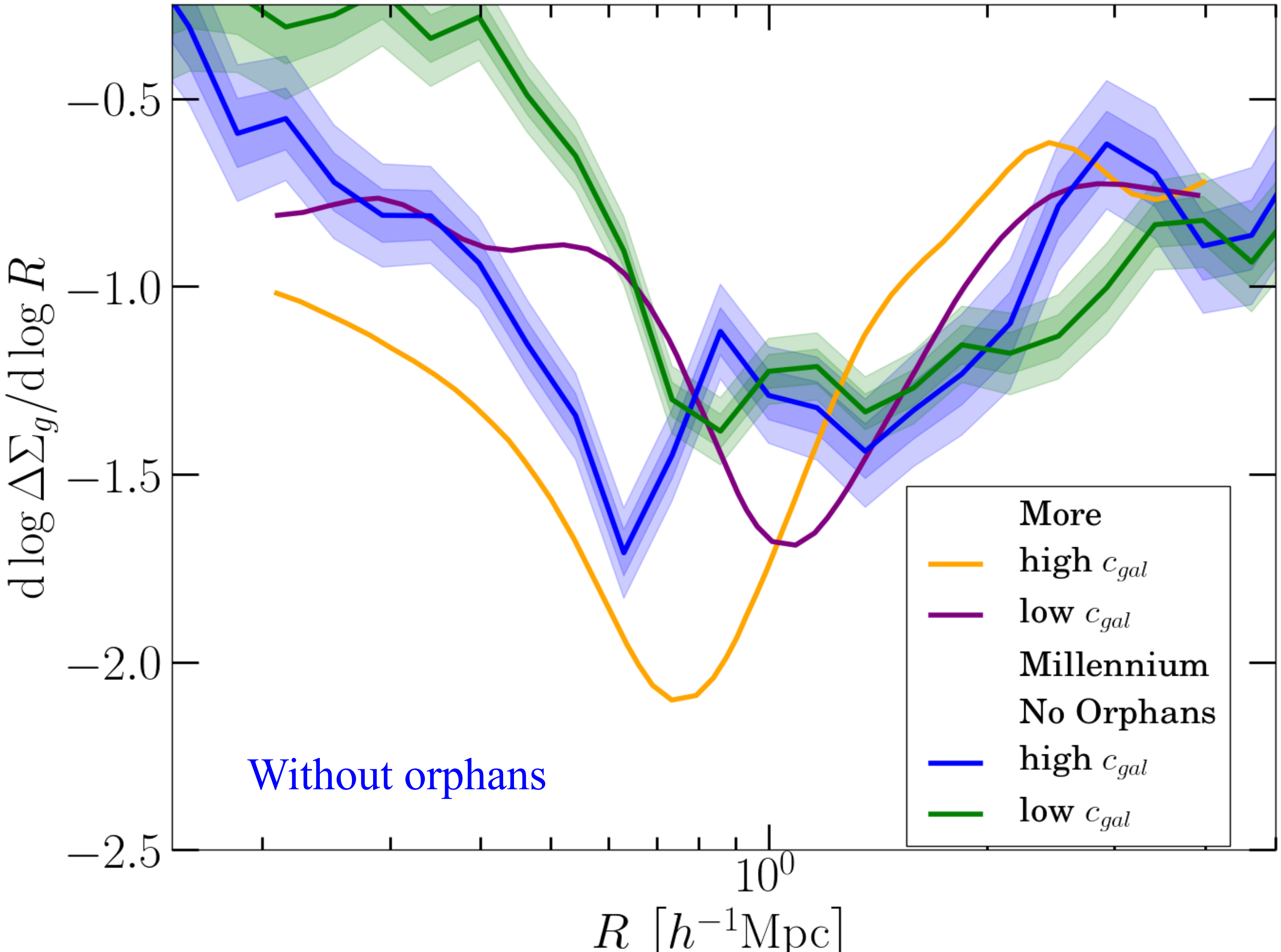
Assembly bias and splashback in Millennium clusters



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Assembly bias and splashback in Millennium clusters

- When projected across the full Millennium box, the public Guo et al (2011) simulation reproduces the observed assembly bias signal.
- The signal is slightly reduced for a projection depth of $\pm$ 120 h^{-1} Mpc, and is significantly reduced for $\pm$ 60 h^{-1} Mpc.
- The 3D assembly bias signal around the cluster central galaxies is only about one quarter of that measured in 2D.
- Most of the 2D assembly bias signal at $R \sim 10$ h^{-1} Mpc comes from galaxies lying ~ 100 h^{-1} Mpc in front of/behind the "associated" cluster.
- Stacked projected galaxy number profiles of clusters show features which reflect their operational definition and can confuse splashback detection.
- There is only a weak cluster-to-cluster correlation between structural properties defined in 2D (e.g. concentration) and their 3D analogues.