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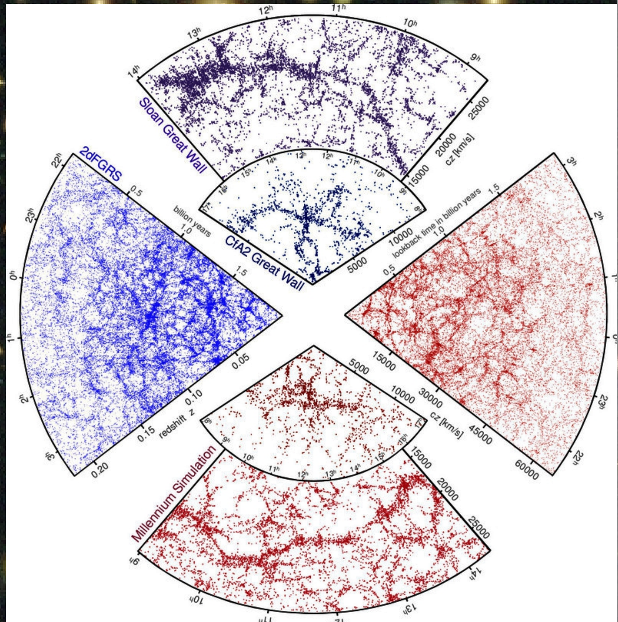
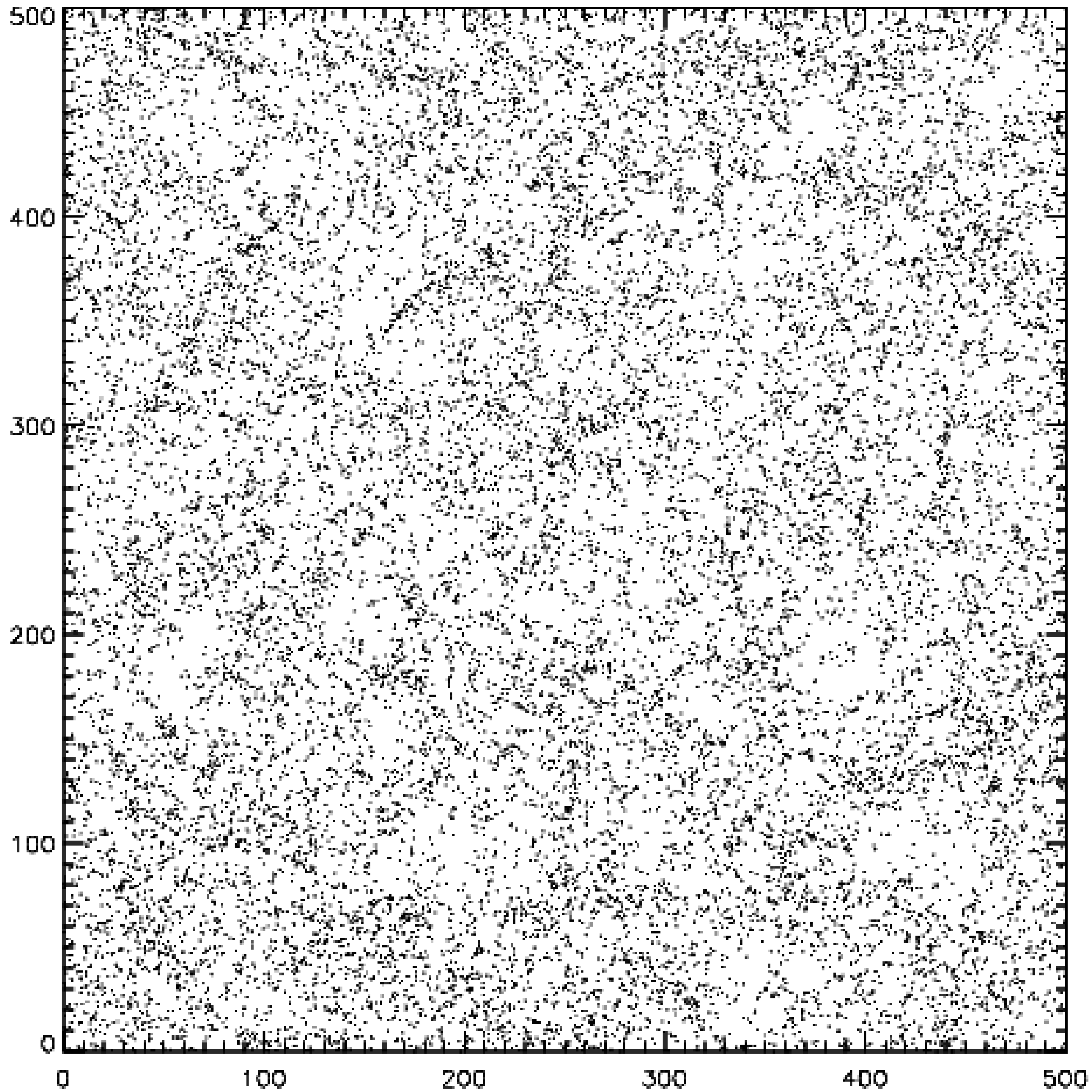
Assembly bias and splashback in galaxy clusters

Simon White and Philipp Busch
Max Planck Institute for Astrophysics



Halo clustering depends on formation history

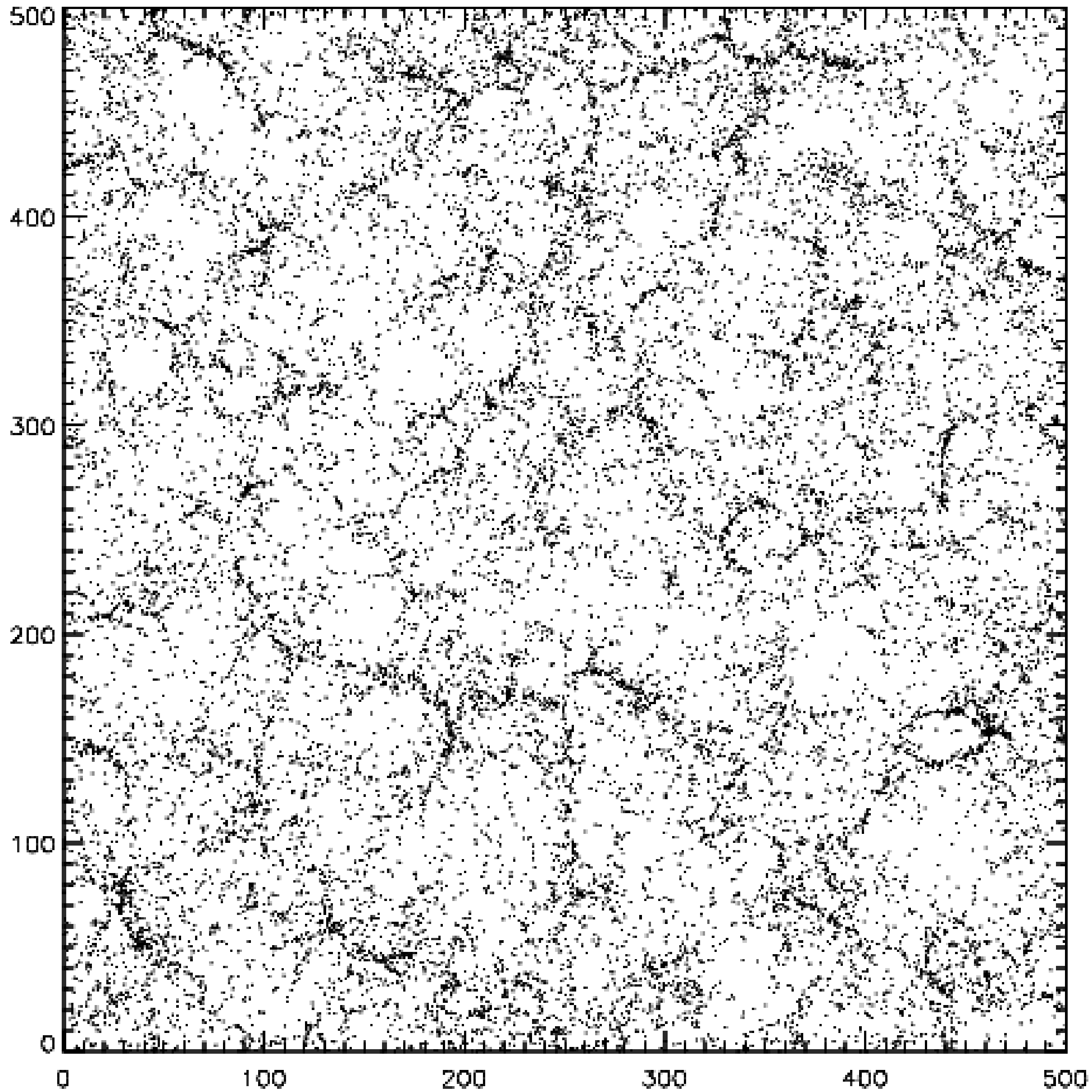


Gao, Springel & White 2005

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



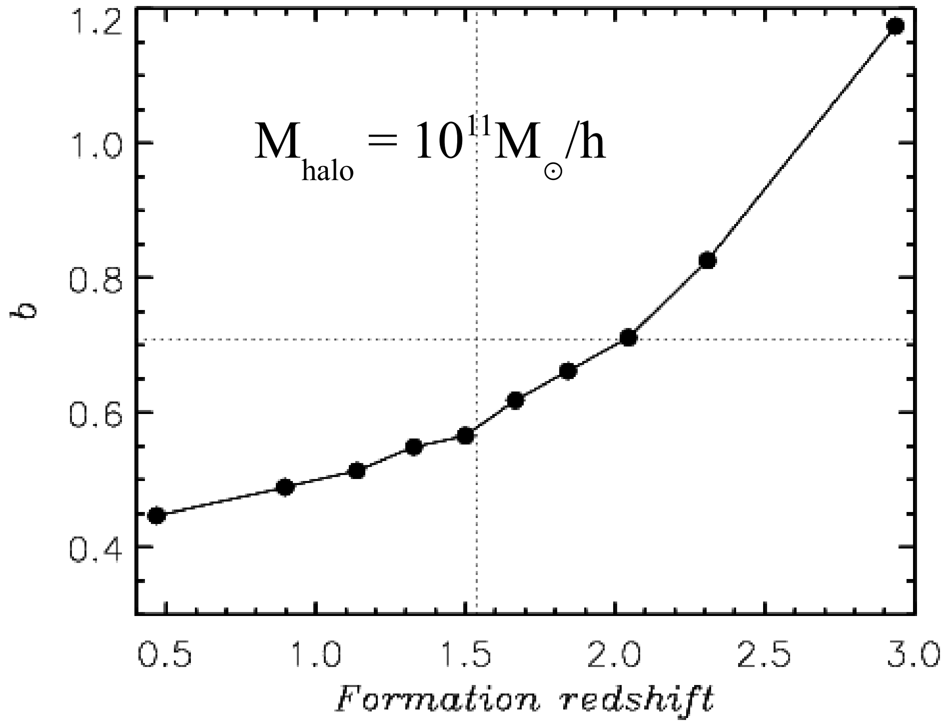
Gao, Springel & White 2005

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

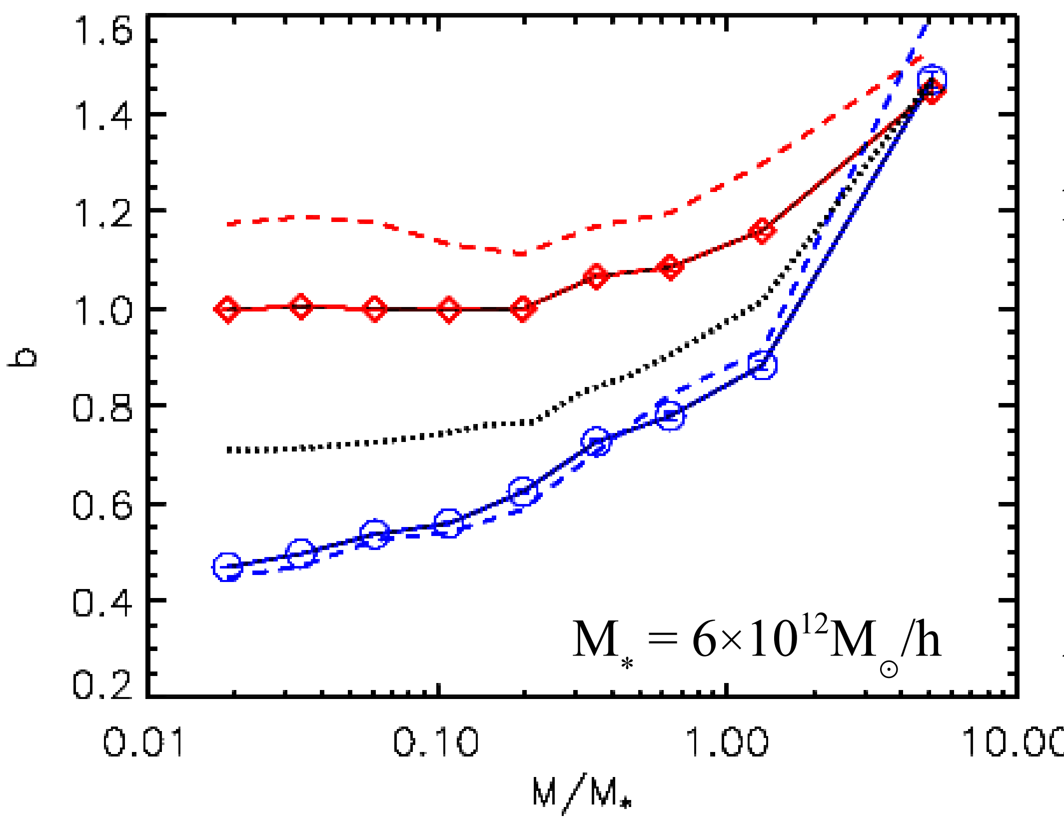
$$M_{halo} \sim 10^{11} M_{\odot}$$

Halo bias as a function of mass and formation time

Gao, Springel & White 2005



Bias increases smoothly with formation redshift

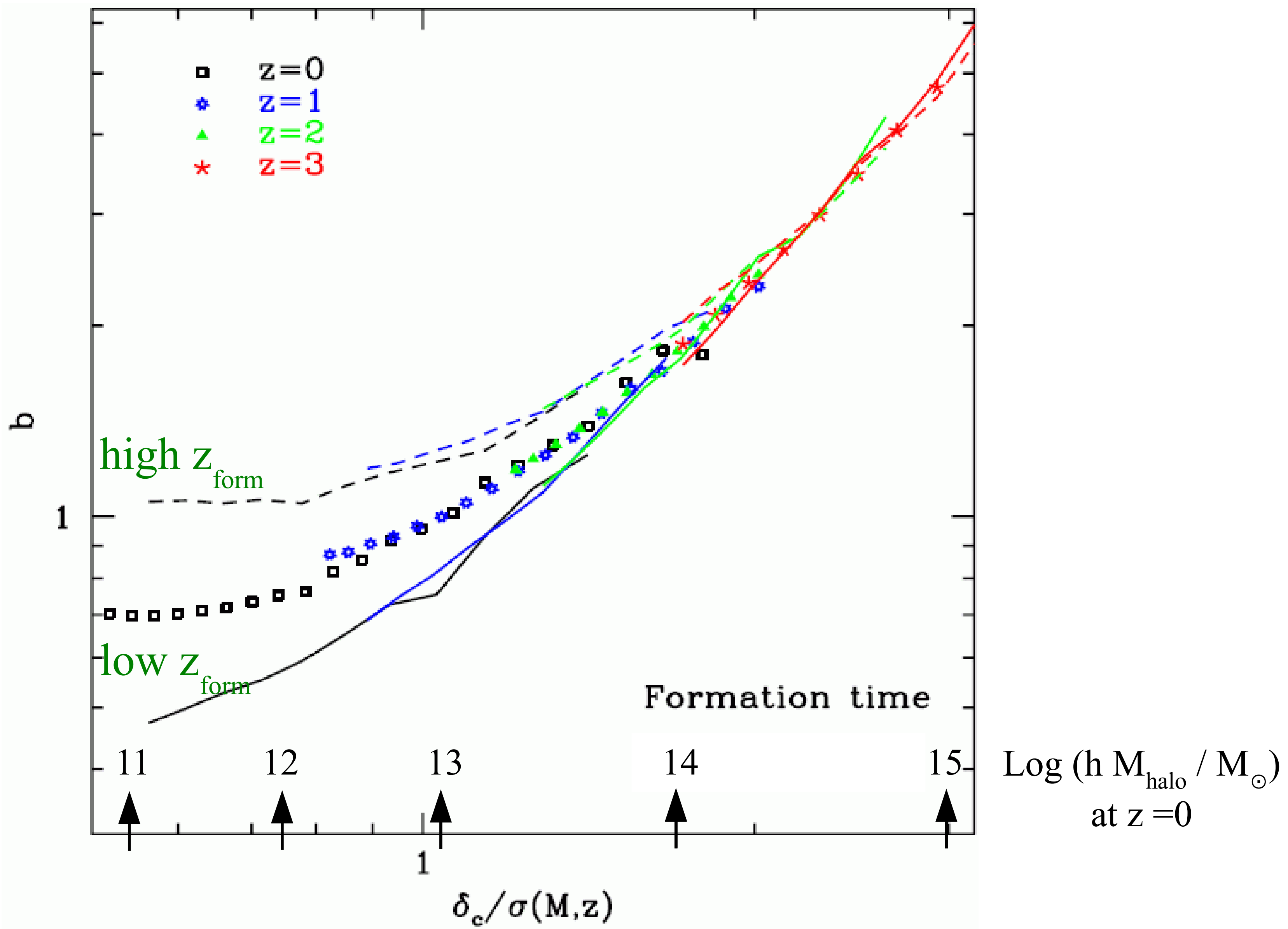


The dependence on formation redshift is strongest at low mass

Such **assembly bias** is not consistent with excursion set theory, with HOD models or with abundance matching models

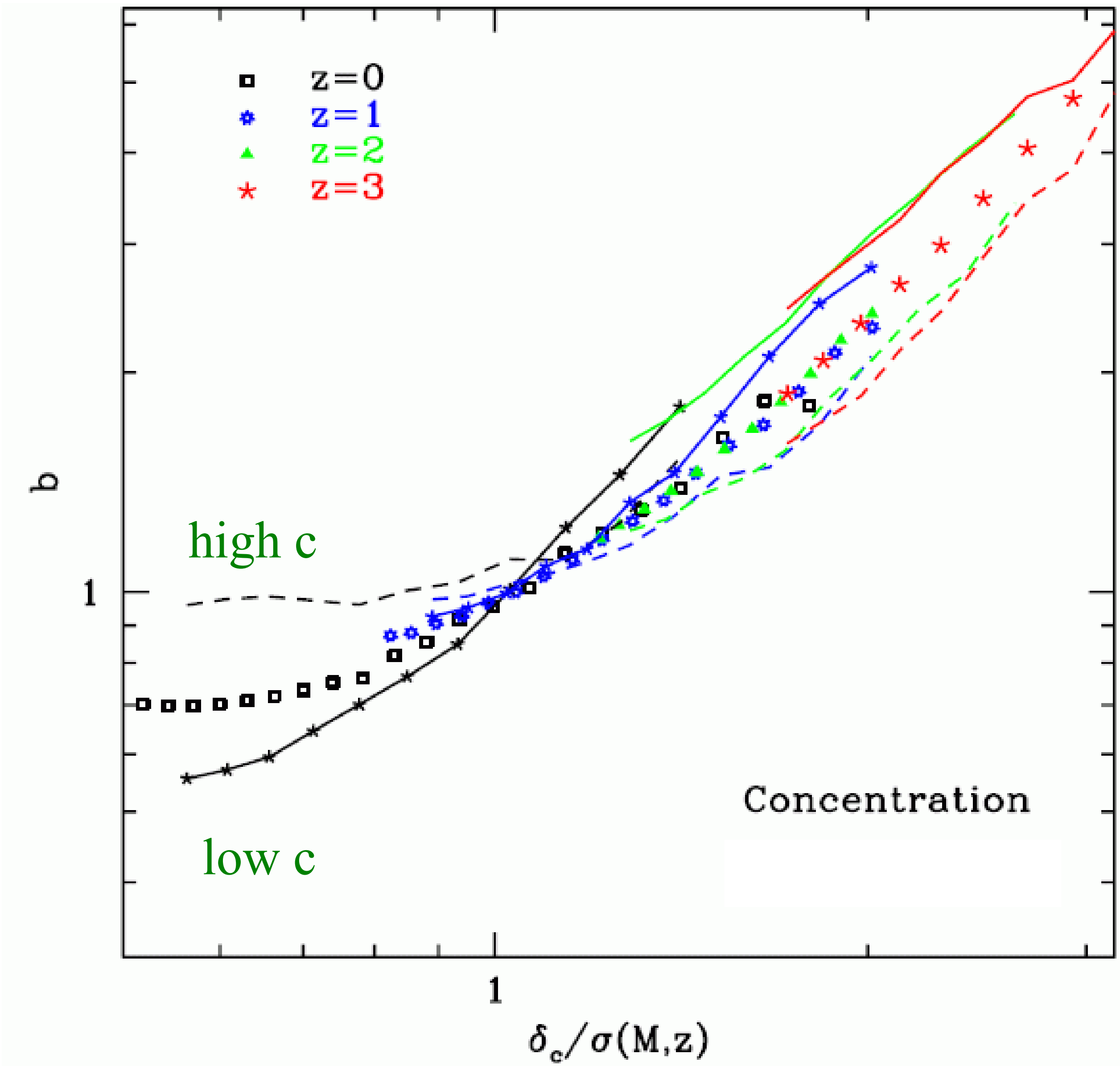
Bias as a function of ν and formation time

Gao & White 2007



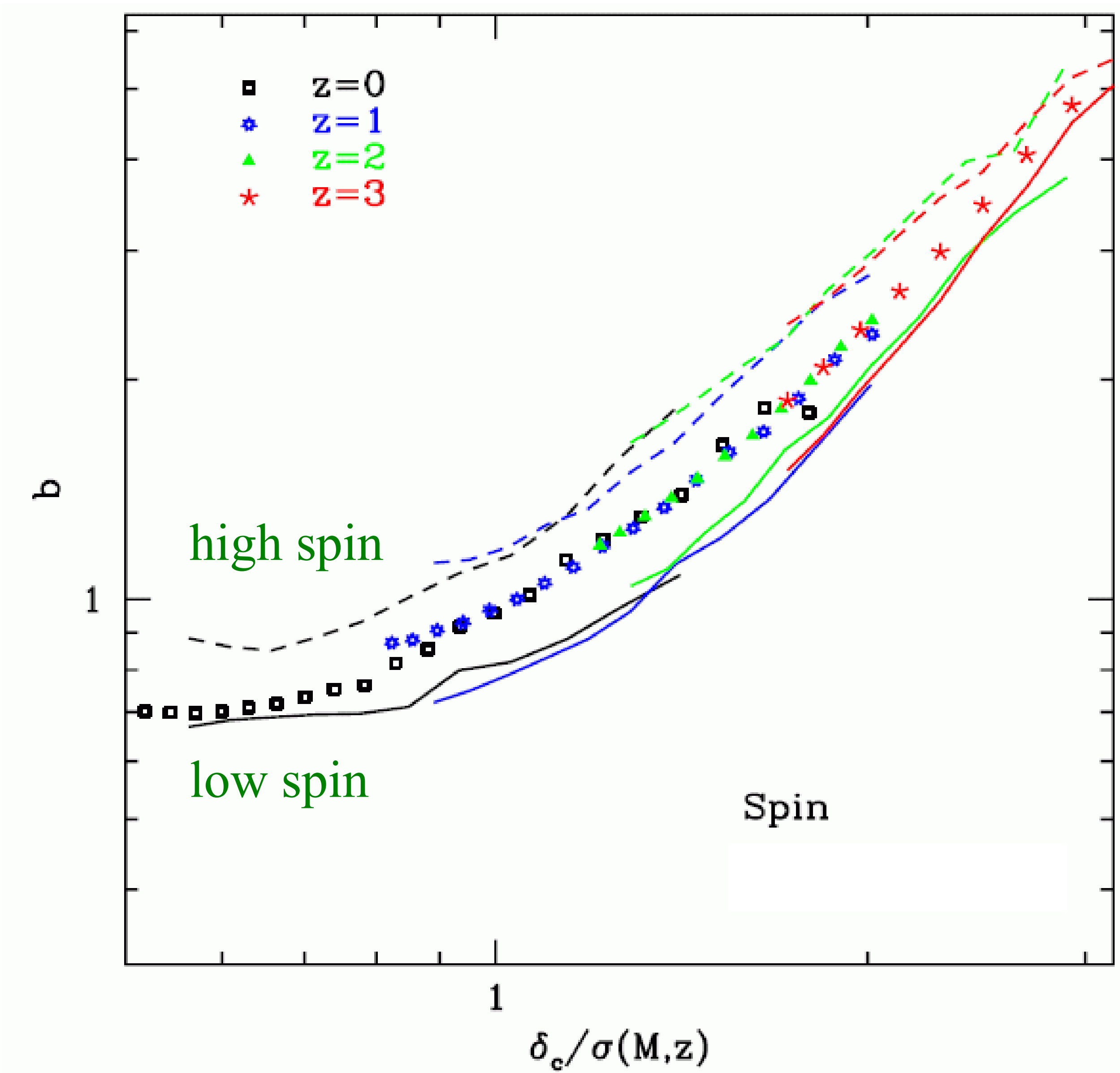
Bias as a function of ν and concentration

Gao & White 2007



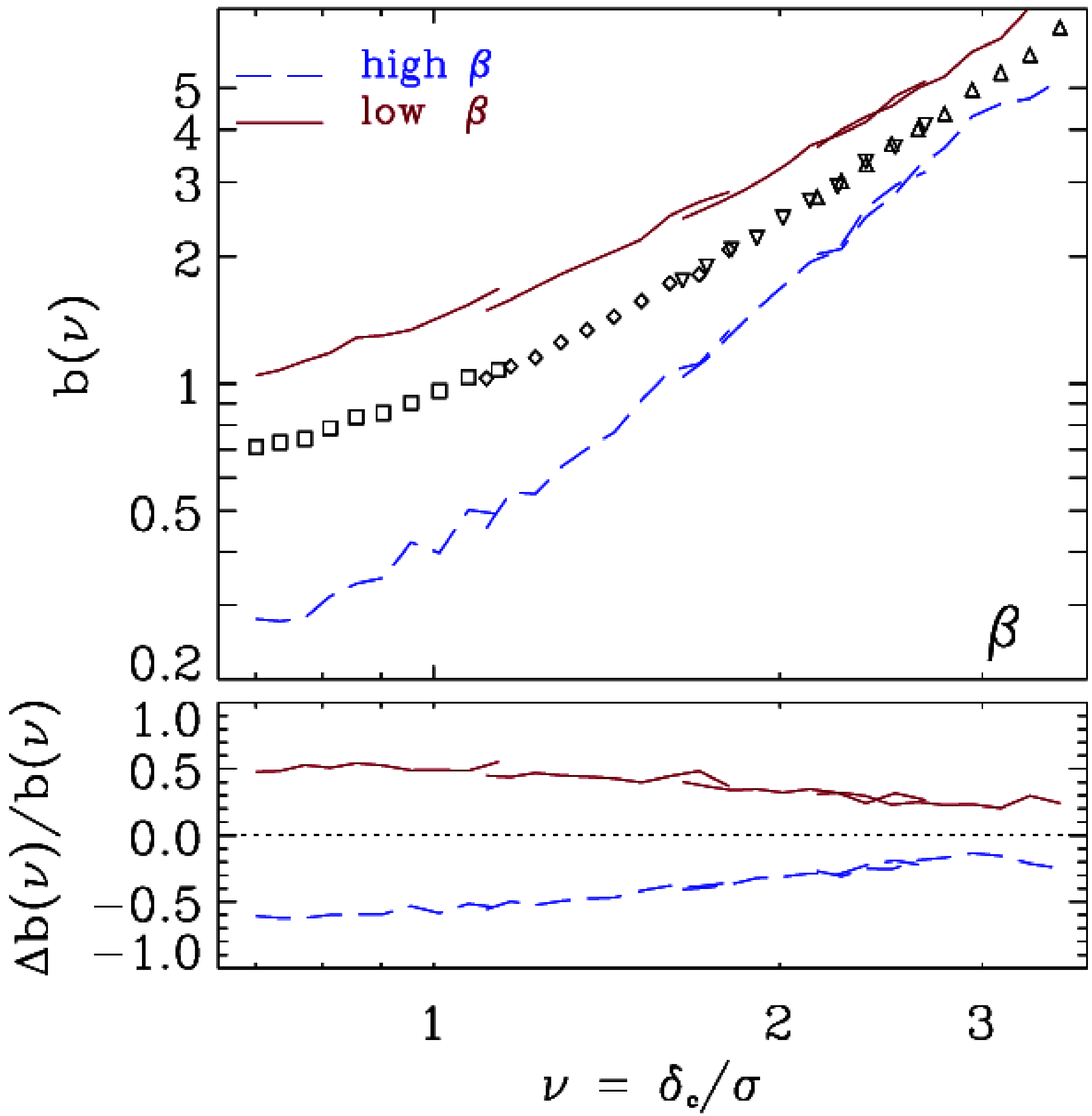
Bias as a function of ν and spin

Gao & White 2007



Bias as a function of ν and velocity anisotropy

Faltenbacher & White 2010



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

Halo assembly bias

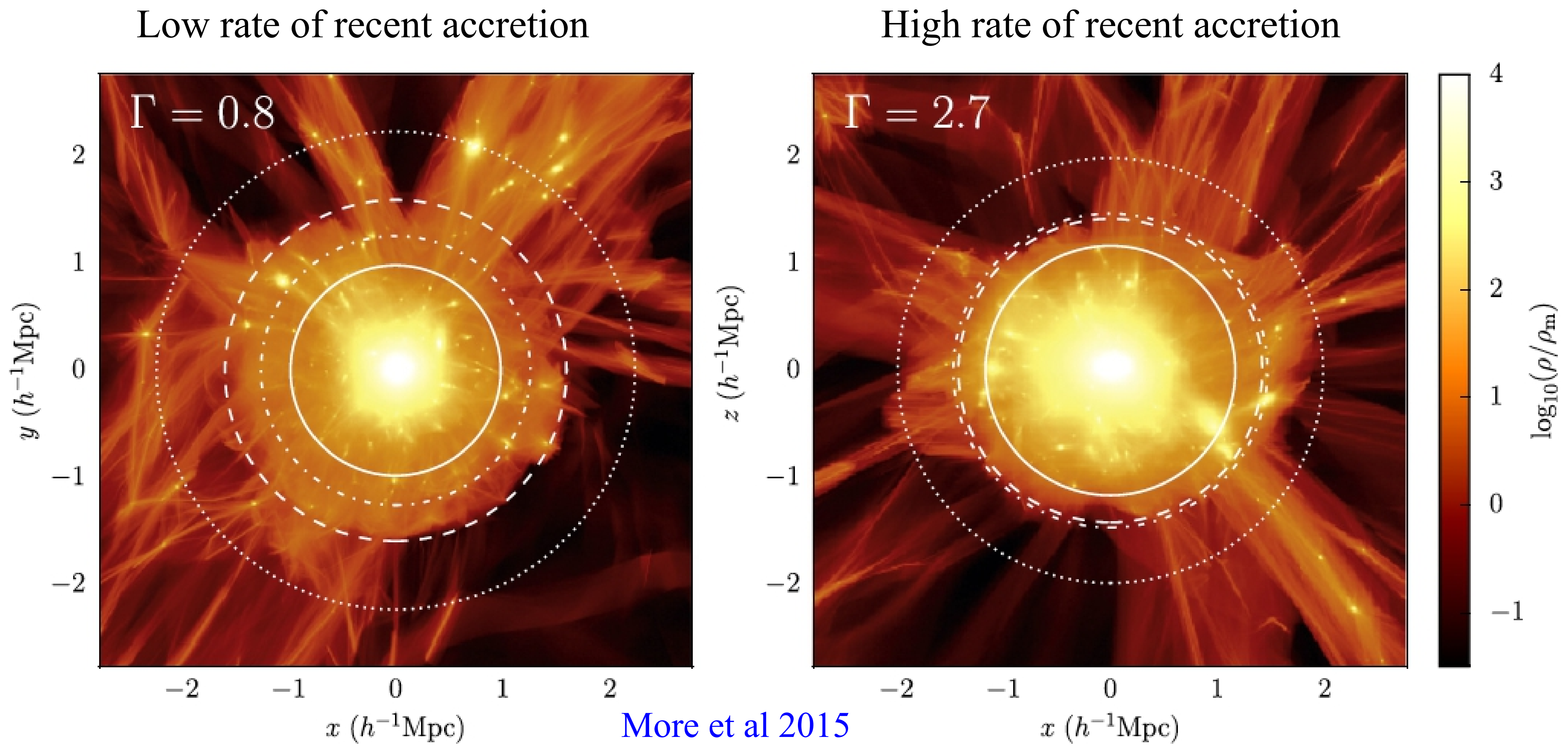
The large-scale bias of halo clustering depends not only on halo mass through $\nu = \delta_c / D(z)\, \sigma_o(M)$, but <u>also</u> on

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

The dependences on different assembly variables are different and <u>cannot</u> be derived from each other.

These dependences are likely to be reflected in <u>galaxy</u> bias, hence in the matter clustering inferred from observed galaxy clustering.

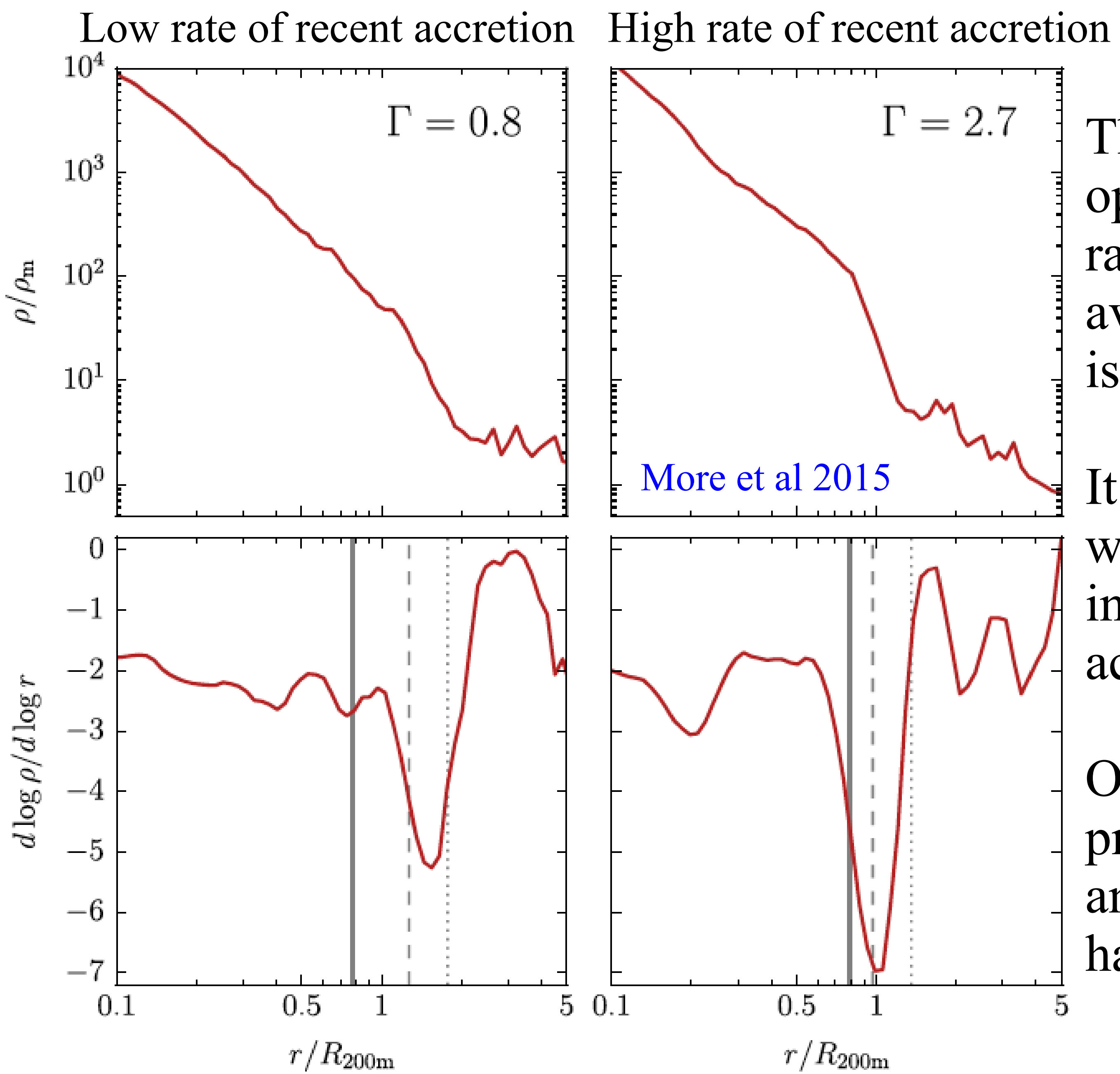
Halo splashback radius



More et al 2015

The splashback radius (- - -) marks the apocentre of the orbits of recently accreted material and corresponds to the outermost dark matter caustic. It is the best simple definition of the boundary of a halo

Halo splashback radius



The splashback radius can be operationally defined as the radius where the spherically averaged mass density profile is steepest.

It occurs at **smaller** radius with a **deeper** slope minimum in halos with larger recent accretion rates.

Observational detection can provide estimates of the mass and recent accretion rates of halos.

Assembly bias and splashback in SDSS 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

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

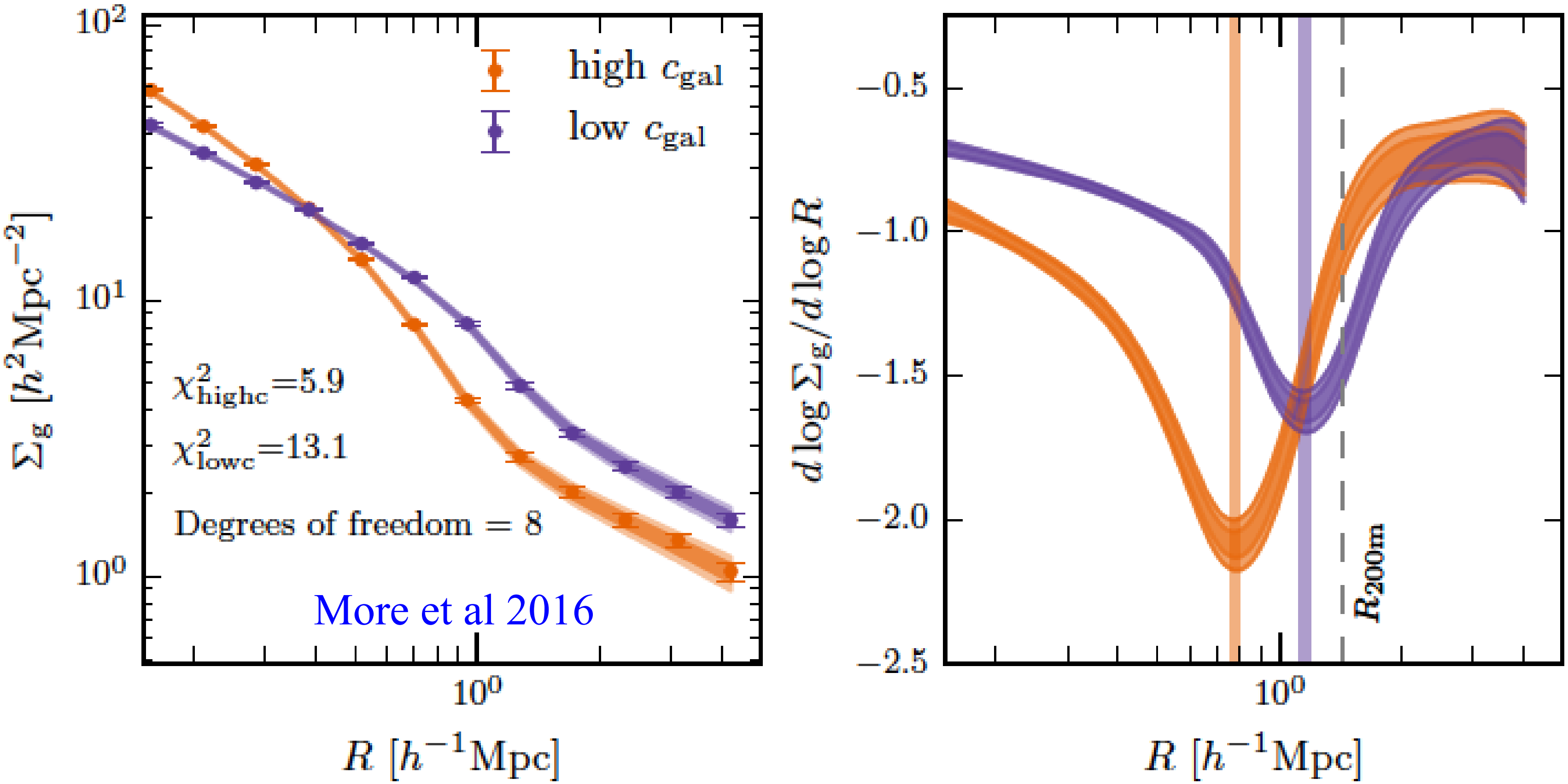
This sample is split into two equal subsamples according to whether

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

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 and splashback in SDSS clusters



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

(ii) Slope minimum is *deeper* and at *smaller* radii for more concentrated clusters

(iii) Strong assembly bias seen at $R > 2.0\ h^{-1}$ Mpc – $b_{low\ C} / b_{high\ C} \sim 1.5$

(iii) is confirmed by lensing results, but (ii) is *unexpected* given splashback theory

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

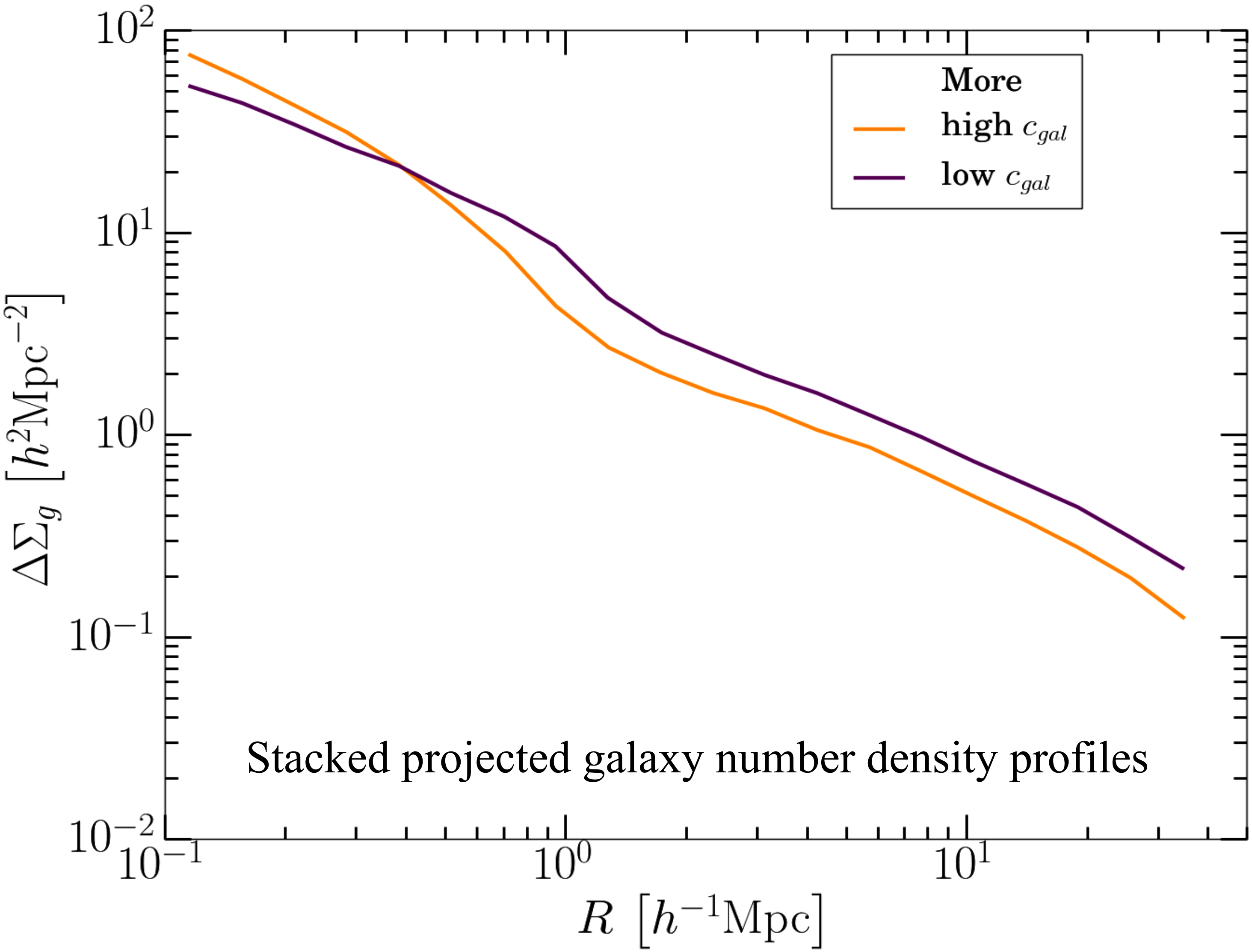
Project along three orthogonal directions $\longrightarrow$ 1/3 of SDSS/RedMaPPER volume

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 $20 < \lambda < 100$ $\longrightarrow$ 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



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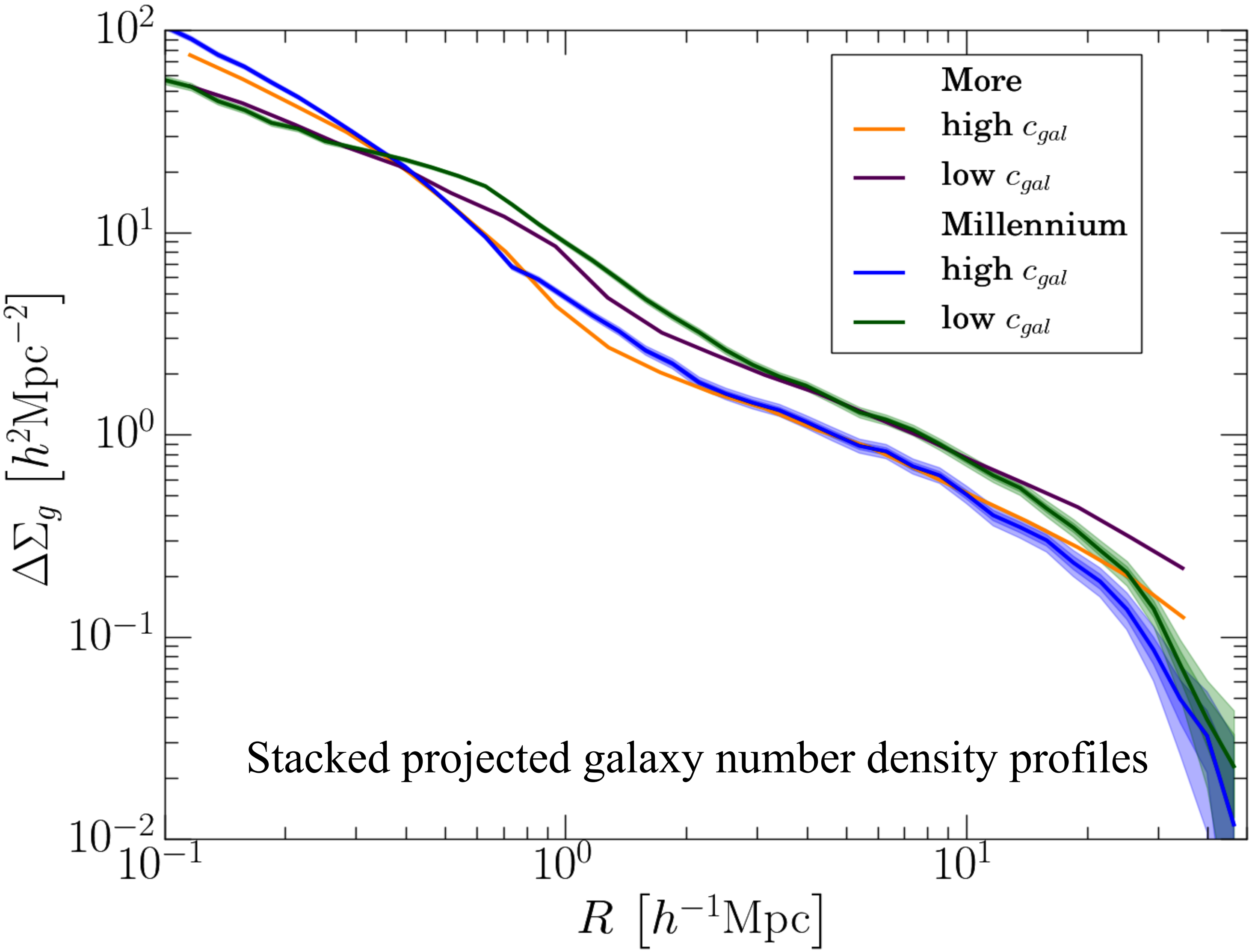
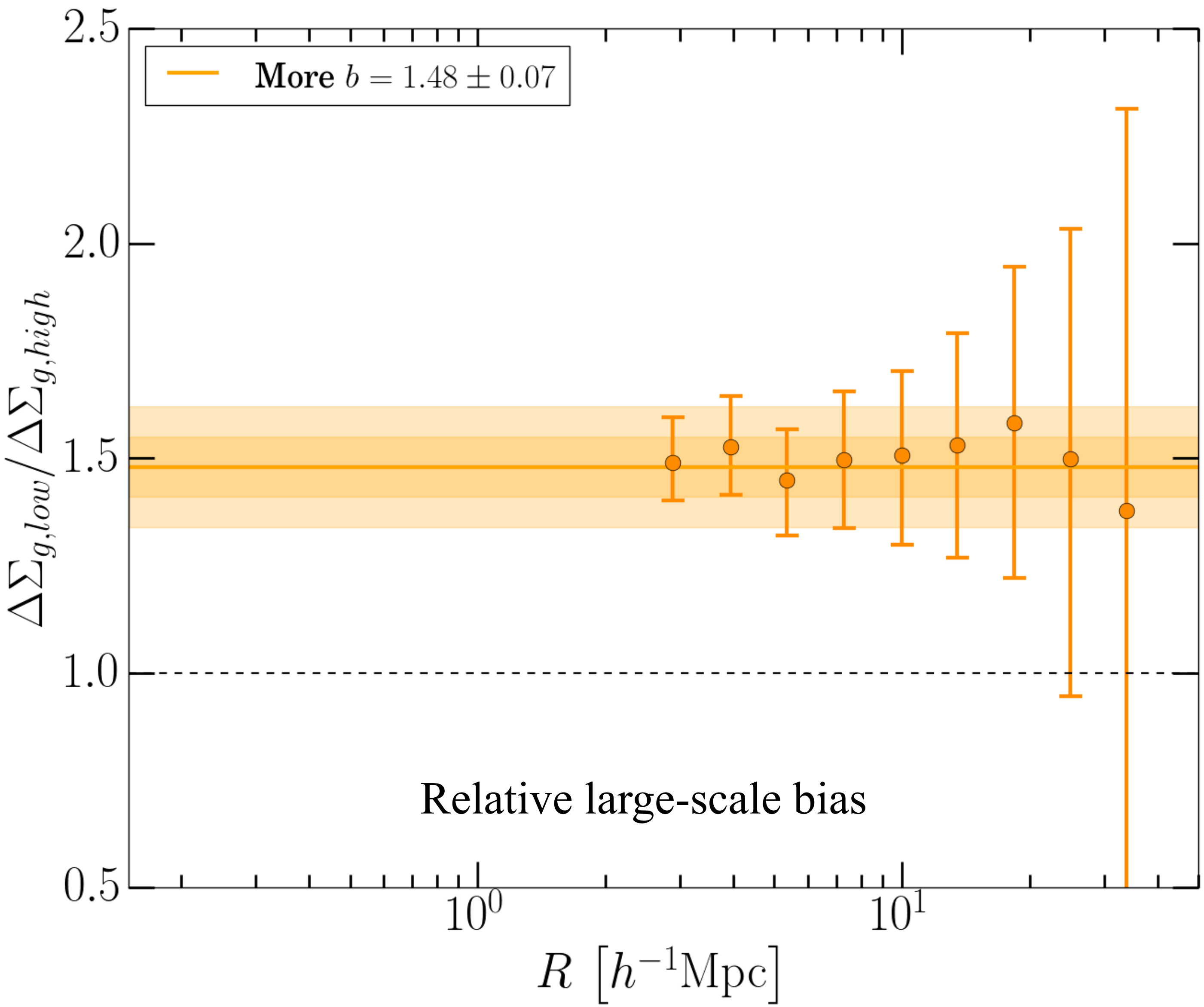


Millennium drop-off at large R due to finite box size, otherwise good agreement

Assembly bias and splashback in Millennium clusters



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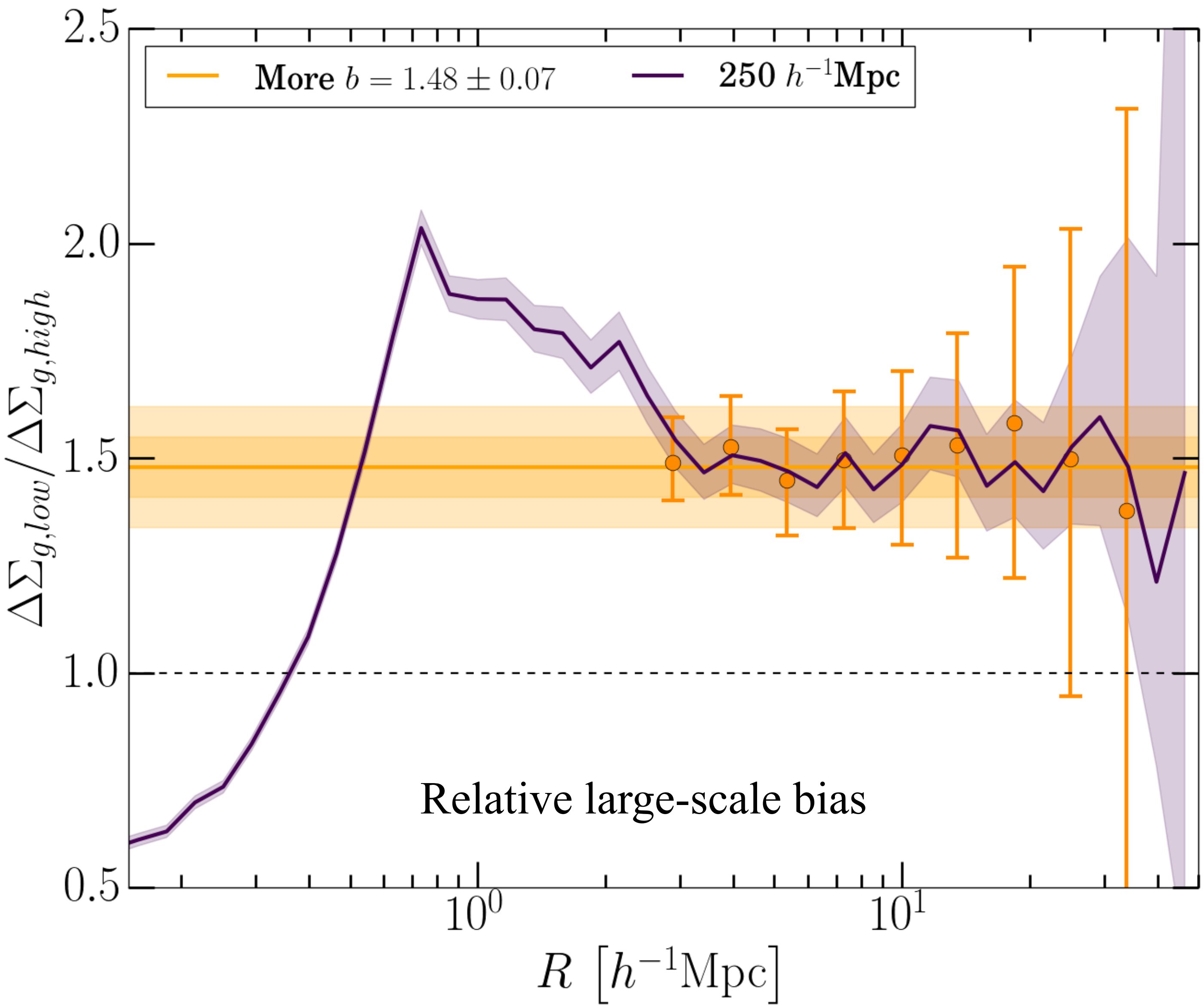
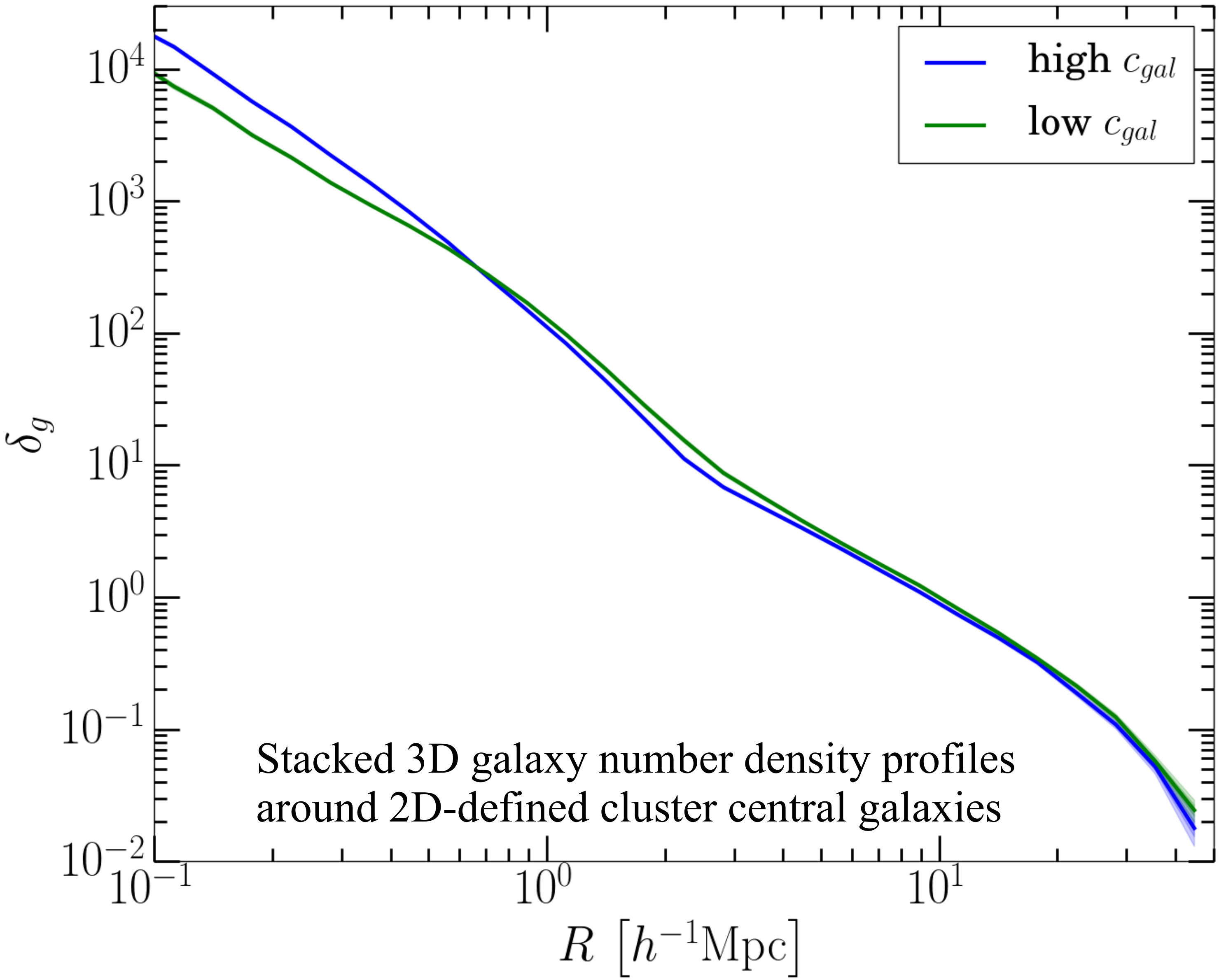


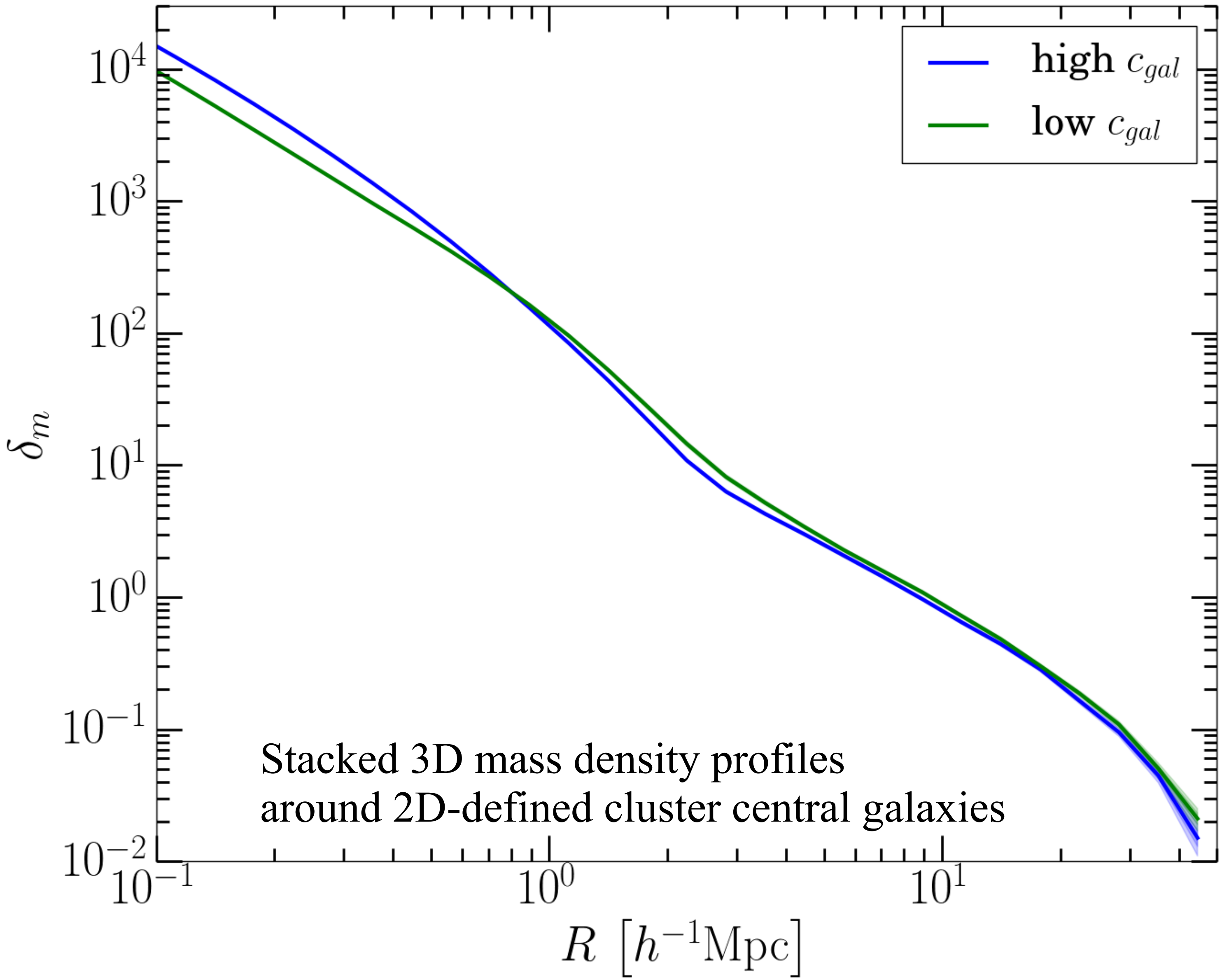
Good agreement on the relative assembly bias of the two subsamples

Assembly bias and splashback in Millennium clusters



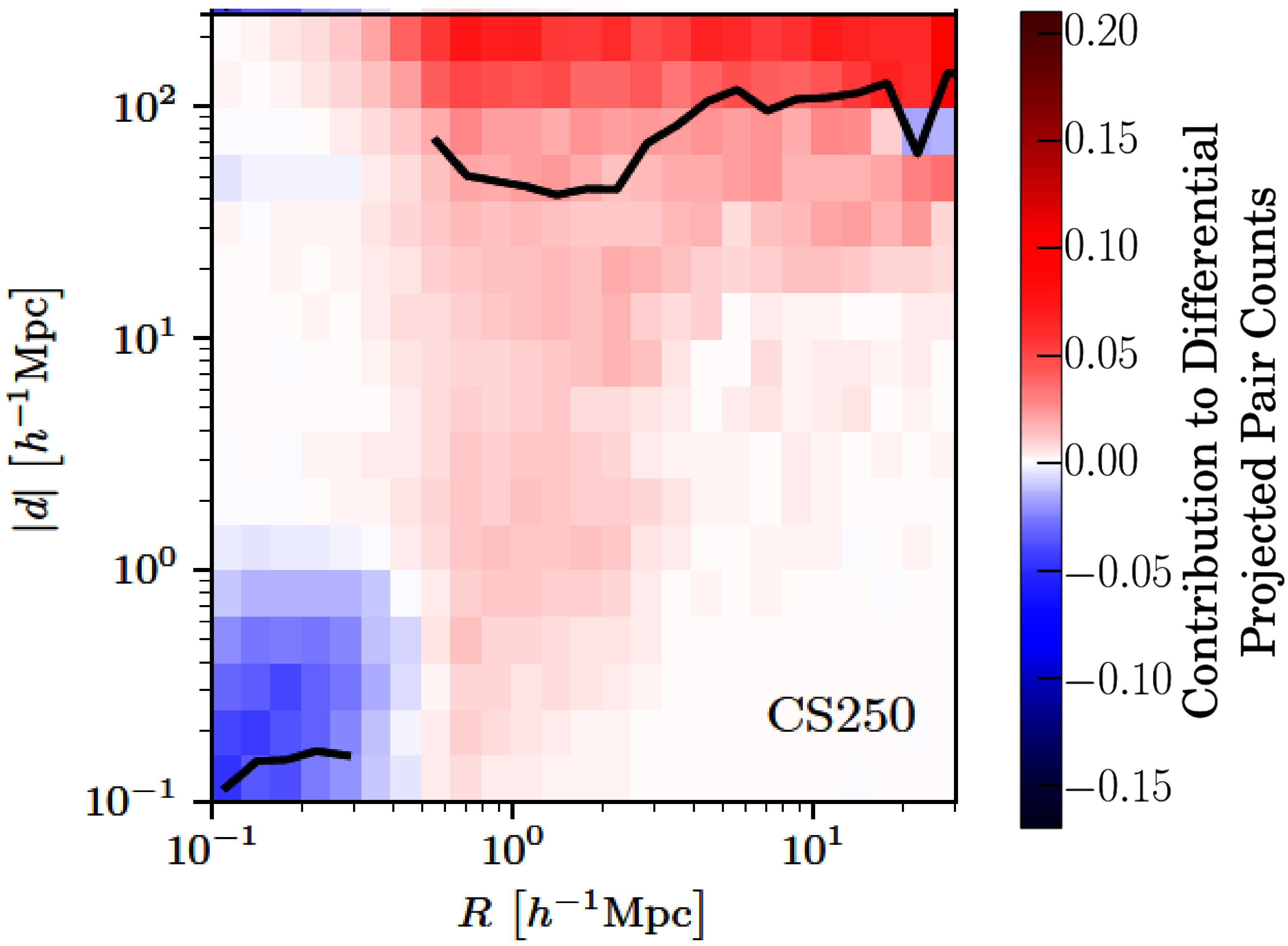
3D galaxy profiles show similar small-scale features but **smaller** assembly bias

Assembly bias and splashback in Millennium clusters



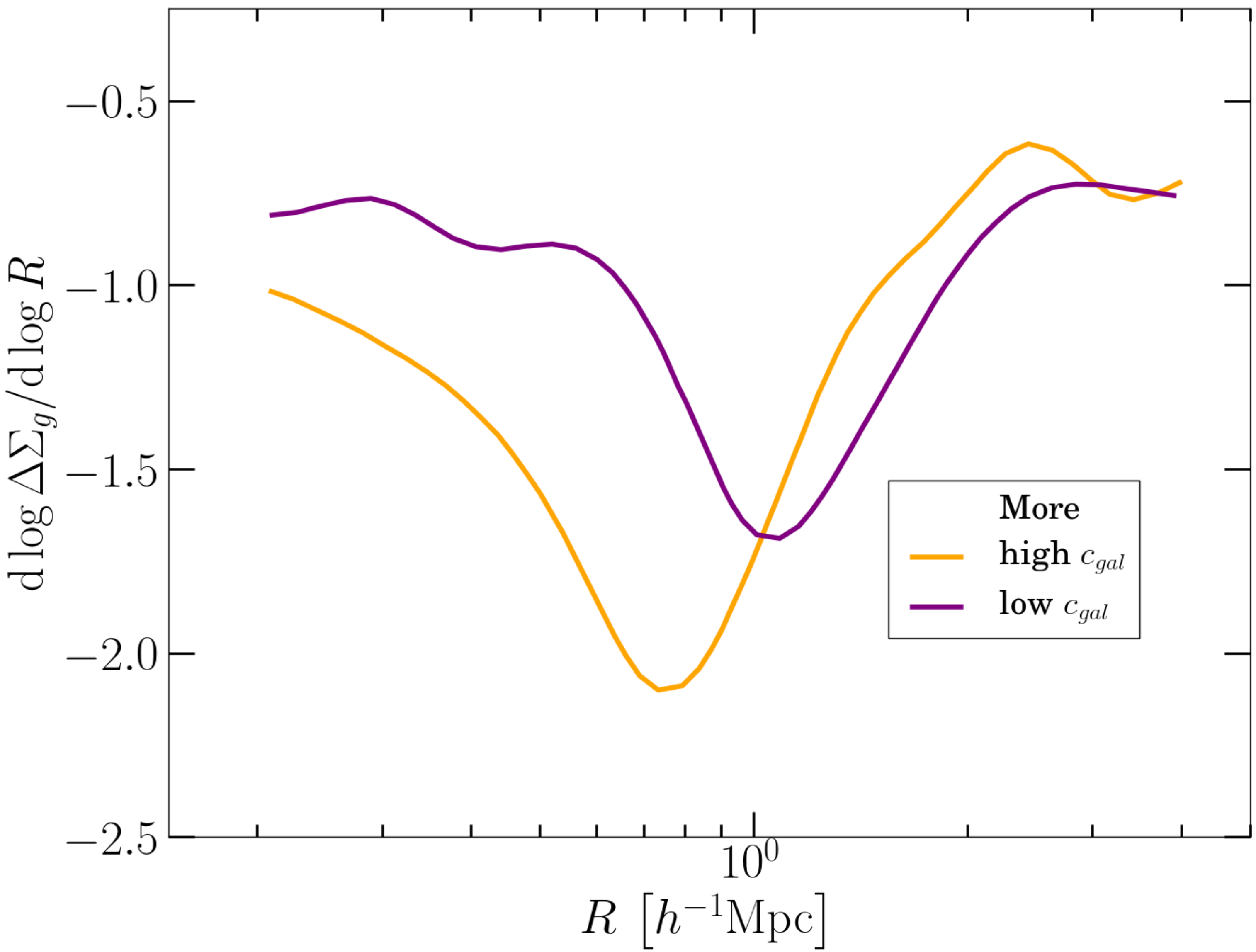
3D galaxy profiles show similar small-scale features but **smaller** assembly bias
The mass profiles in 3D are almost identical to the galaxy profiles

Assembly bias and splashback in Millennium clusters



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 100 to 200 h^{-1} kpc at R < 300 h^{-1} kpc (→ 2D cluster concentration)

Assembly bias and splashback in Millennium clusters



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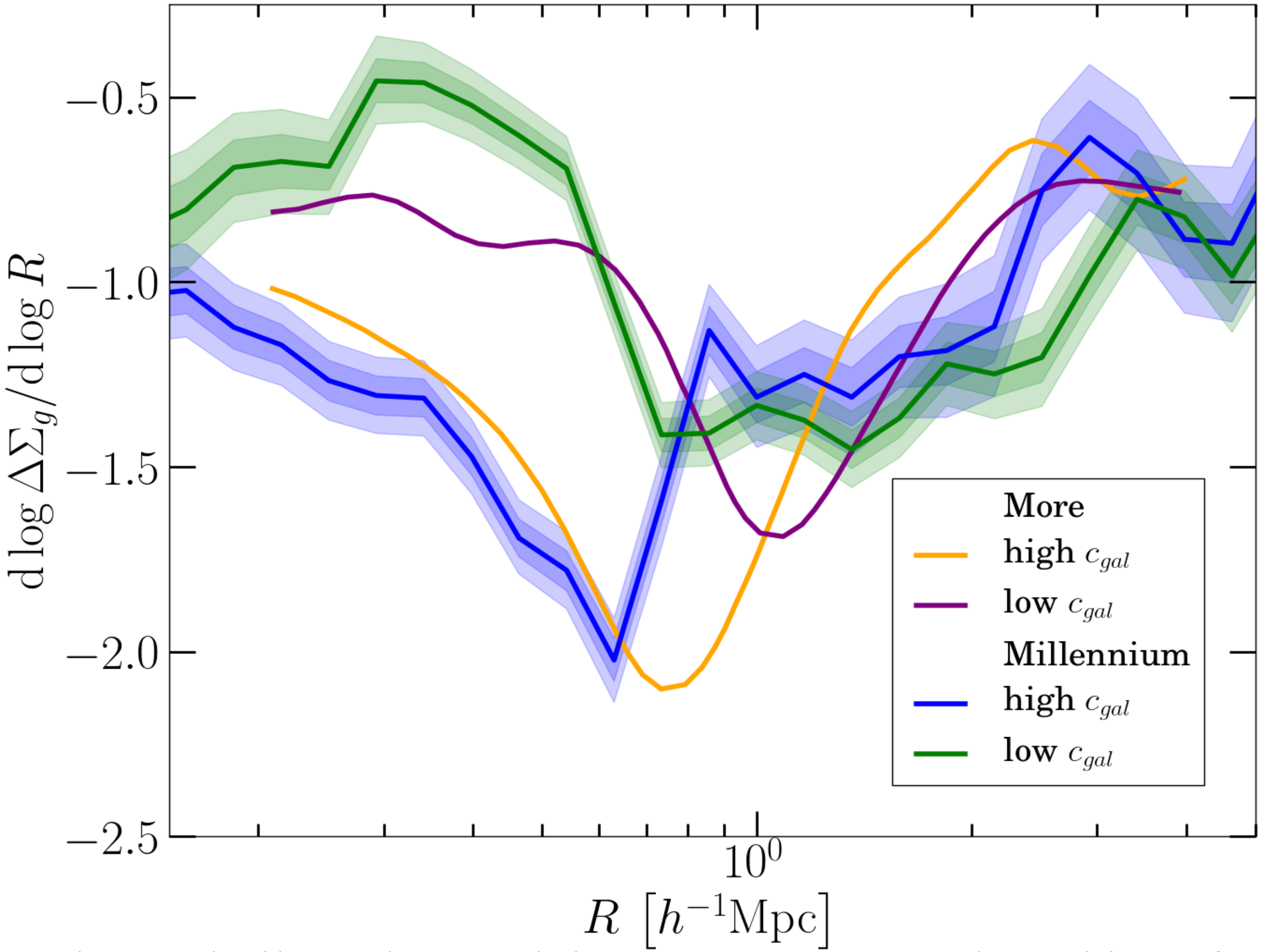
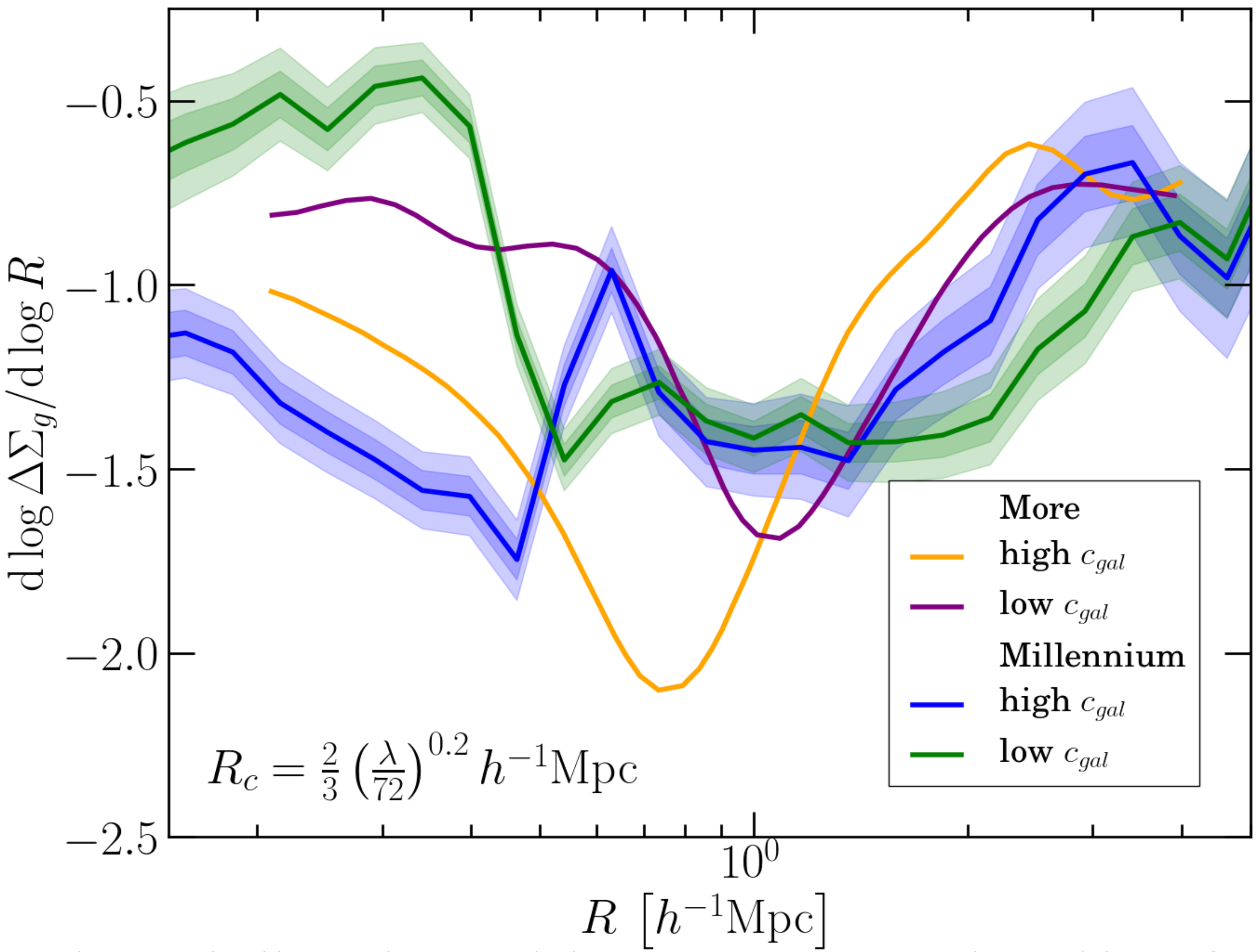


Simulation shows similar values and the same "unexpected" ranking of splashback radii as observed. The slopes at the splashback radius are also similar, but the shapes of the curves differ.

Assembly bias and splashback in Millennium clusters



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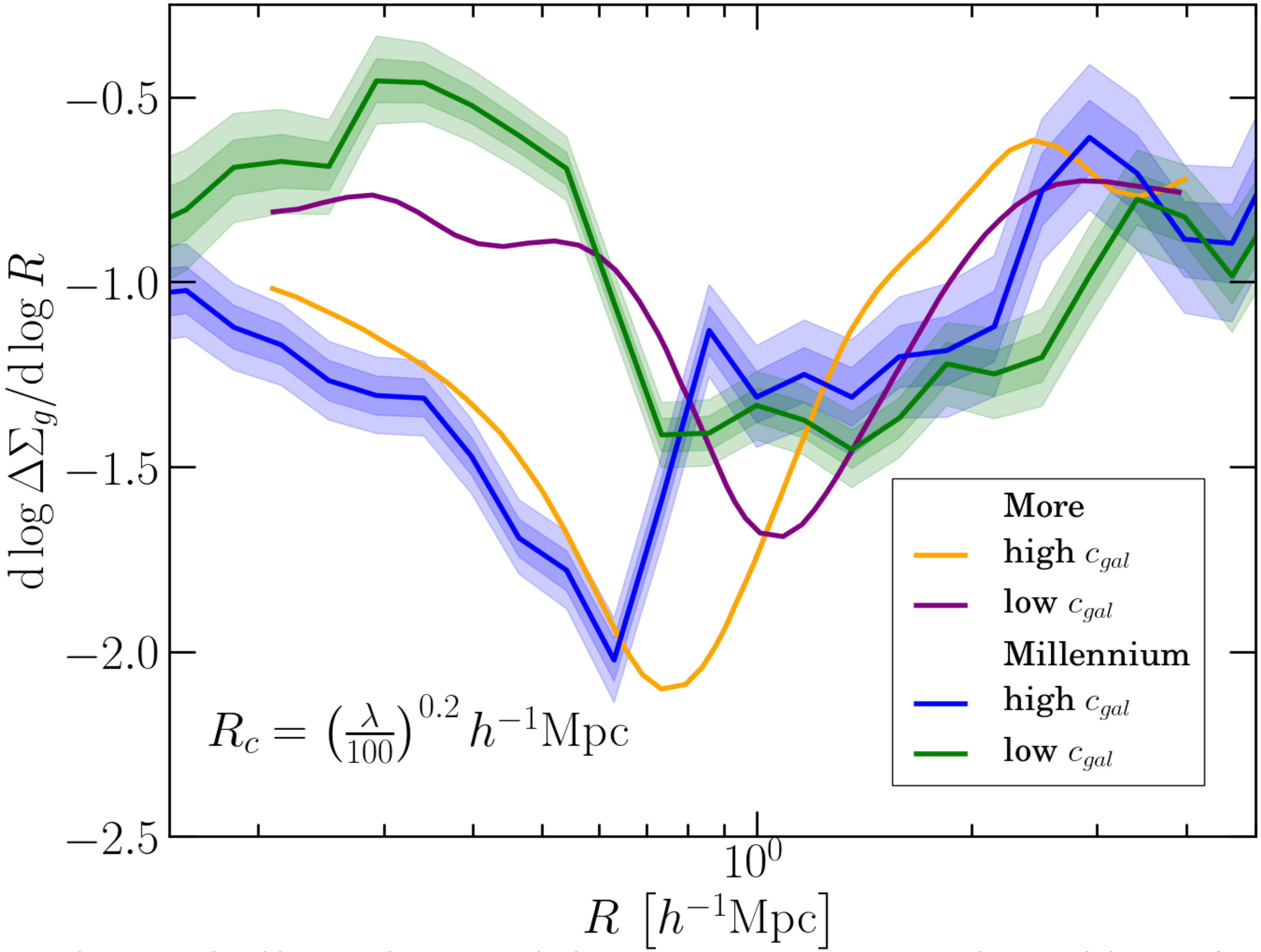

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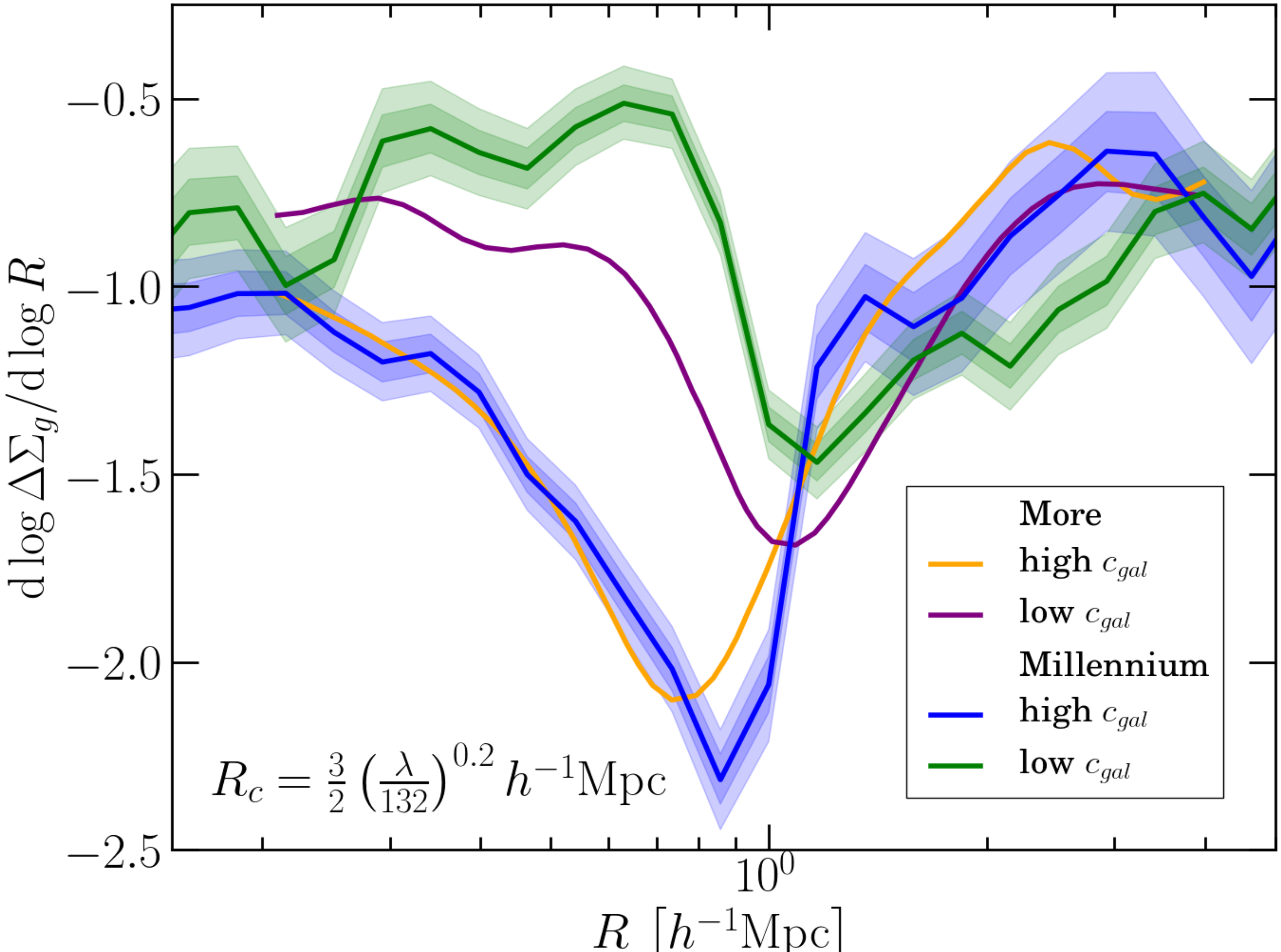

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Assembly bias and splashback in Millennium clusters

- When projected across the full Millennium box, the public Guo et al (2011) simulation reproduces the observed assembly bias signal.

- The 3D assembly bias signal around the cluster central galaxies is only about one third of that measured in 2D.

- Most of the 2D assembly bias signal at $R \sim 10\ h^{-1}$ Mpc comes from galaxies lying $\sim 100\ h^{-1}$ 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.