# Cosmology with Cluster-Galaxy Cross-Correlations and Topics in Assembly Bias

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# My research

1. **Cluster Cosmology** (Salcedo et al. 2020, Wu et al. 2020)

2. **Halo Assembly Bias** (Salcedo et al. 2018)

3. **Galaxy Assembly Bias in SDSS** (Salcedo et al. in prep)

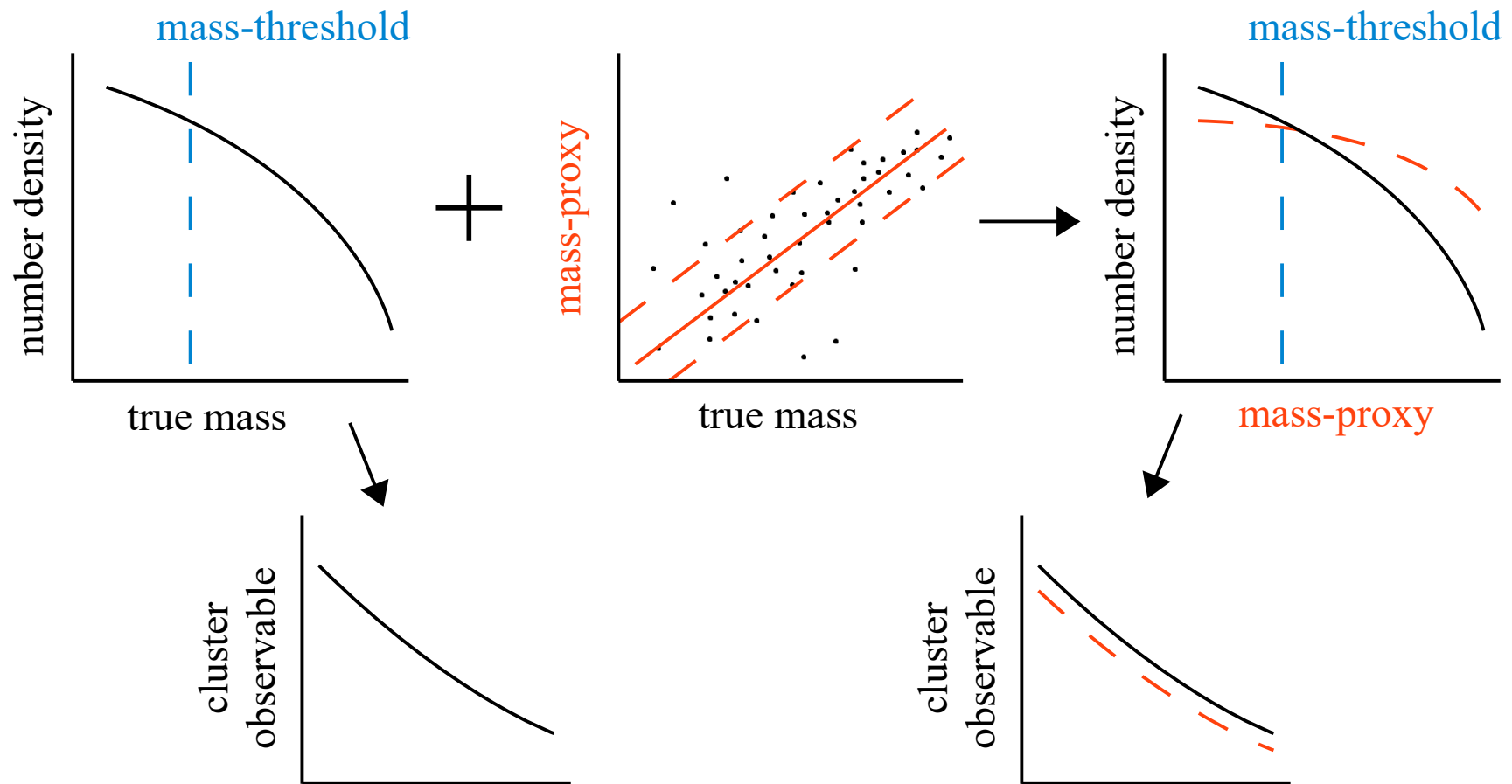4. **Galaxy-Galaxy Lensing and Galaxy Clustering** (Wibking et al 2019, 2020, Salcedo et al. in prep)

# Cluster cosmology from a novel three observable datavector
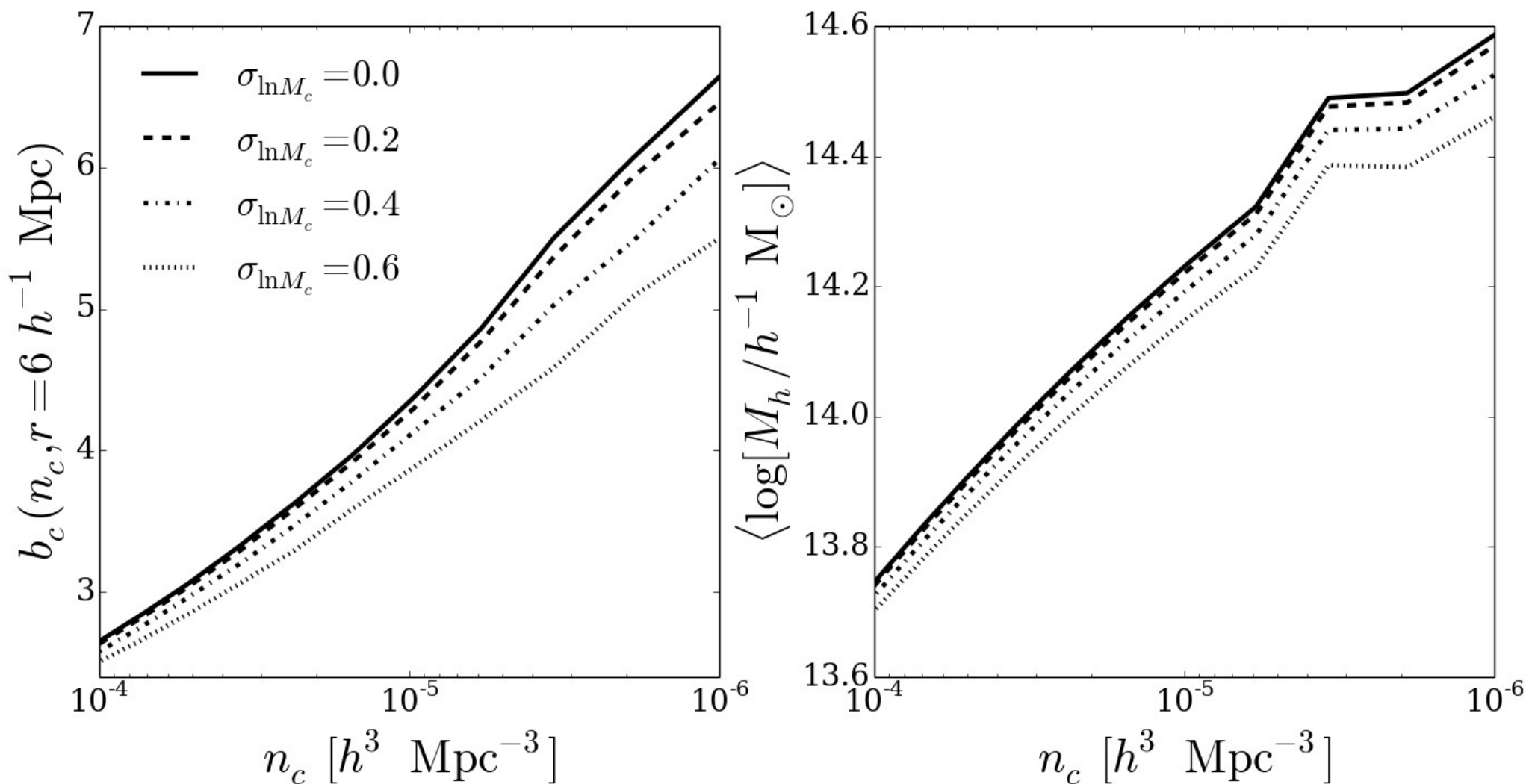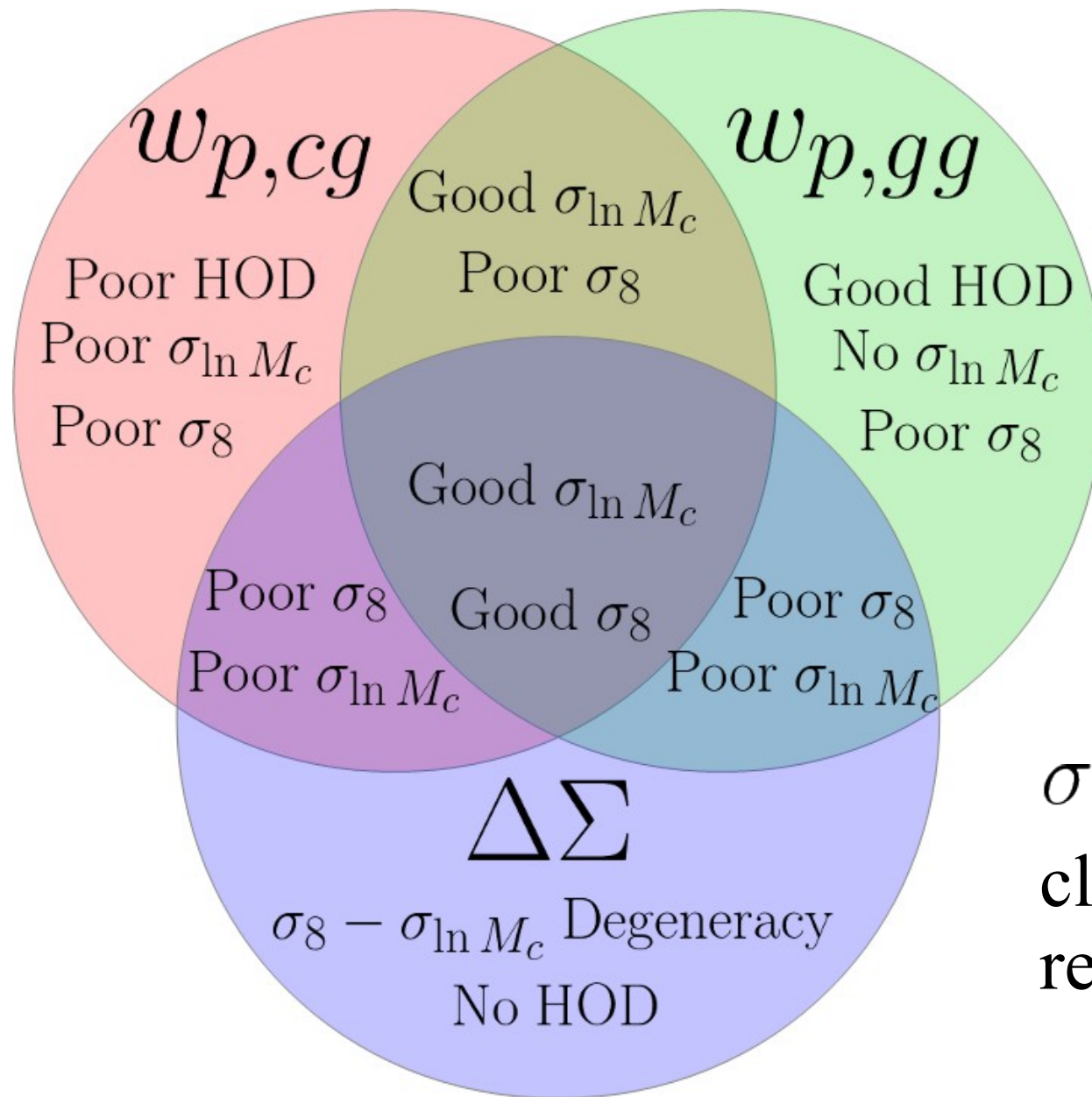
# Cluster mass-observable relation

# Cluster mass-observable relation

# Effects of scatter in the cluster mass-observable relation
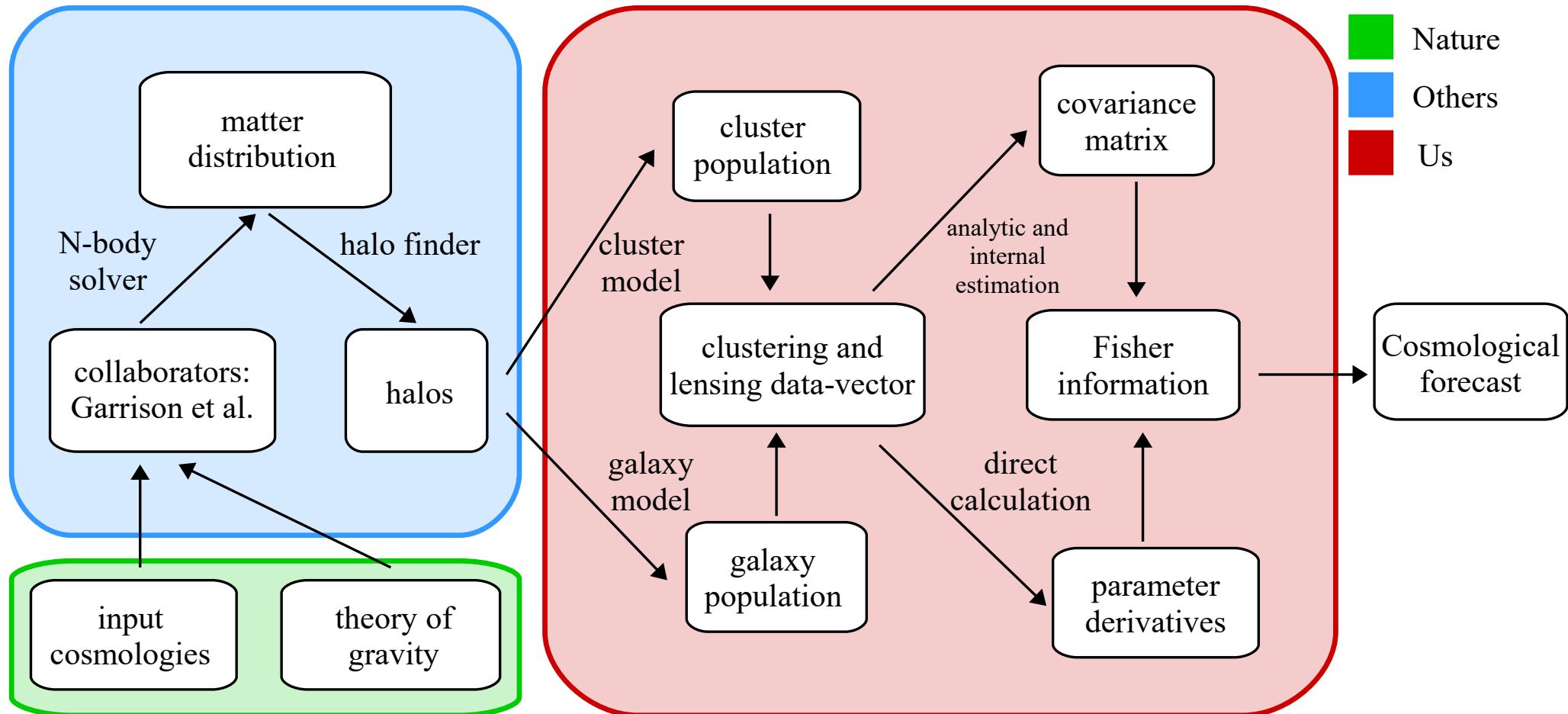
# Three observables, three unknowns



$$\Delta\Sigma \propto b_c \sigma_8^2,$$

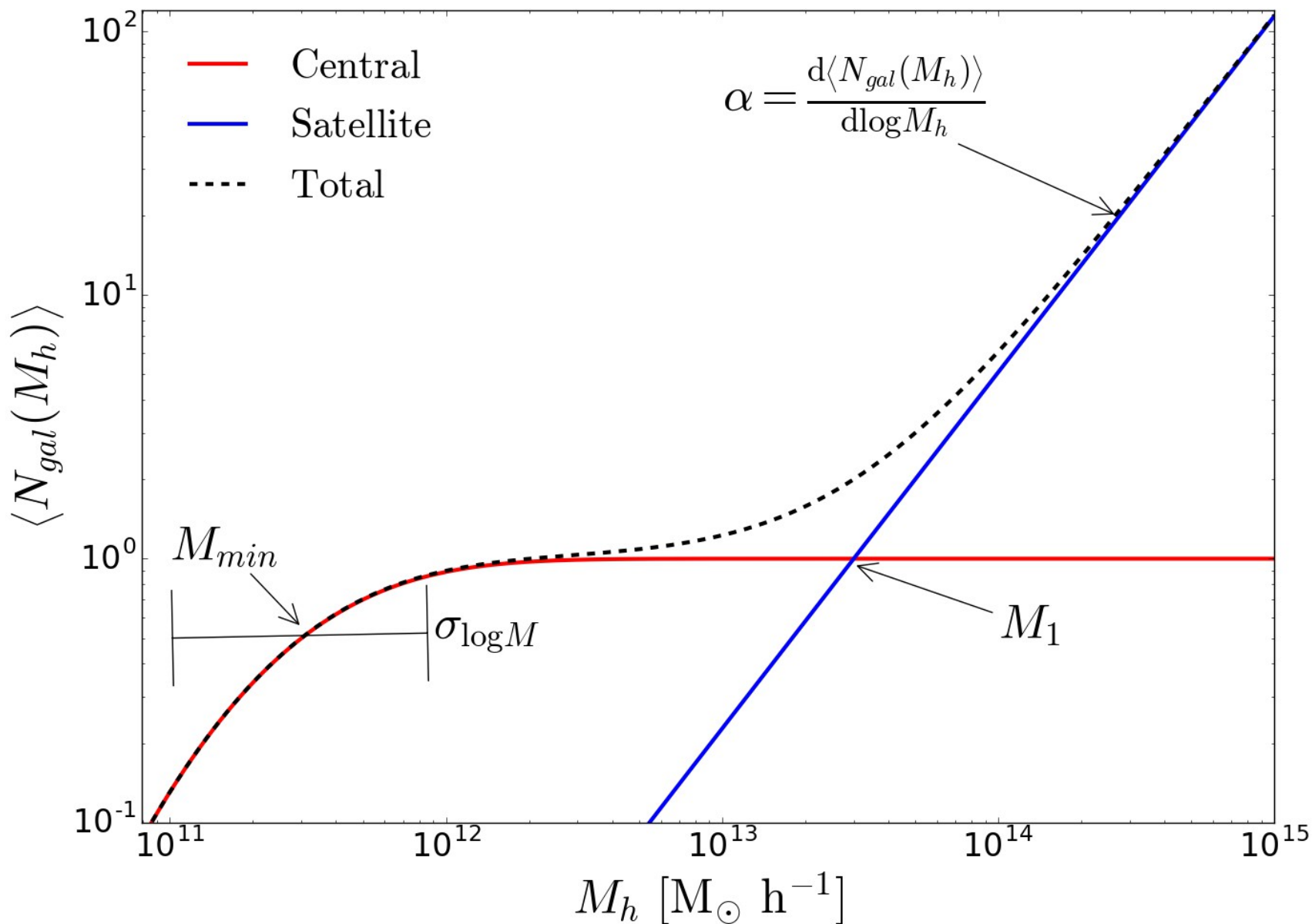$$w_{p,cg} \propto b_c b_g \sigma_8^2,$$

$$w_{p,gg} \propto b_g^2 \sigma_8^2,$$

$\sigma_{\ln M_c}$ -scatter in the cluster mass-observable relation
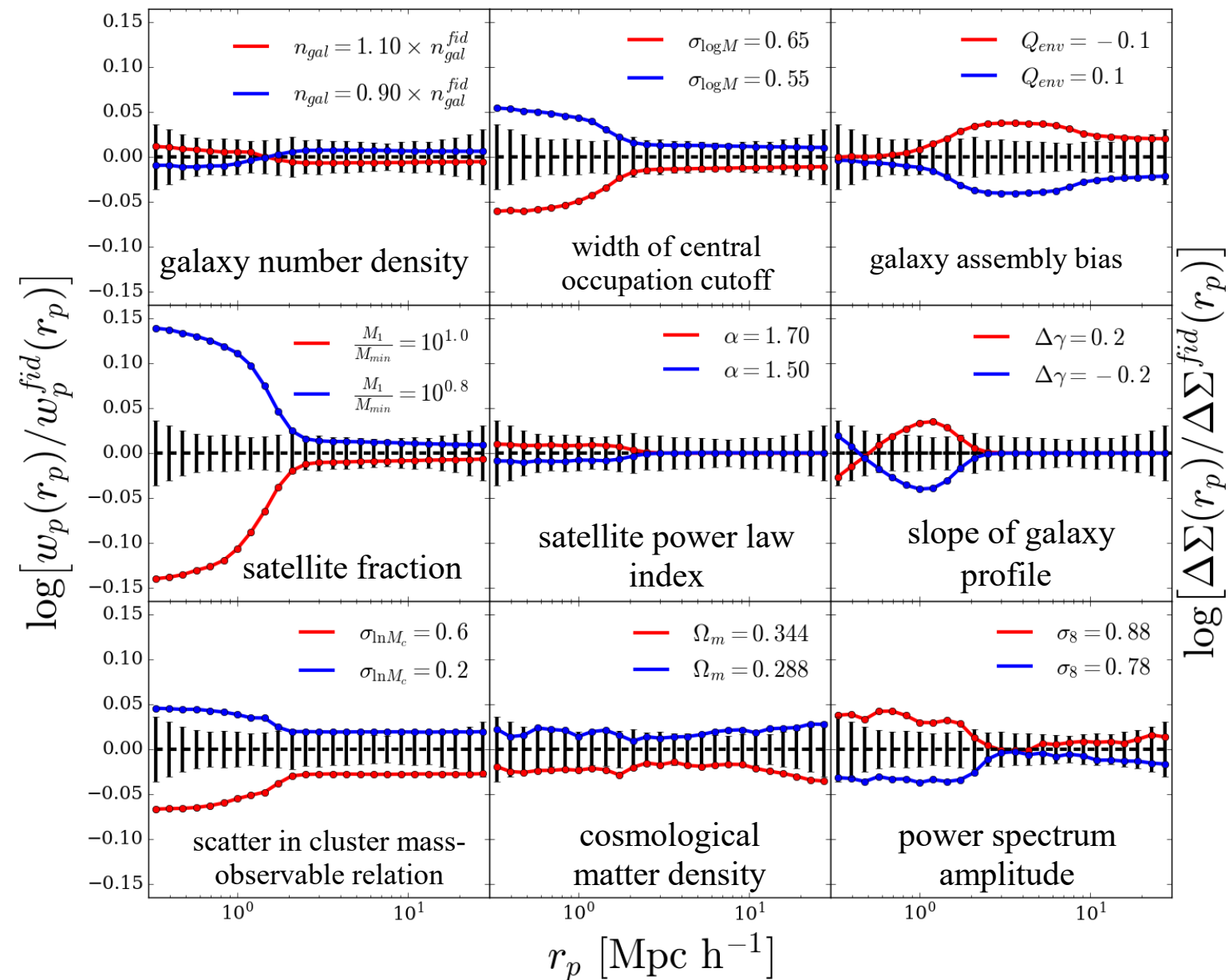
# Analysis workflow

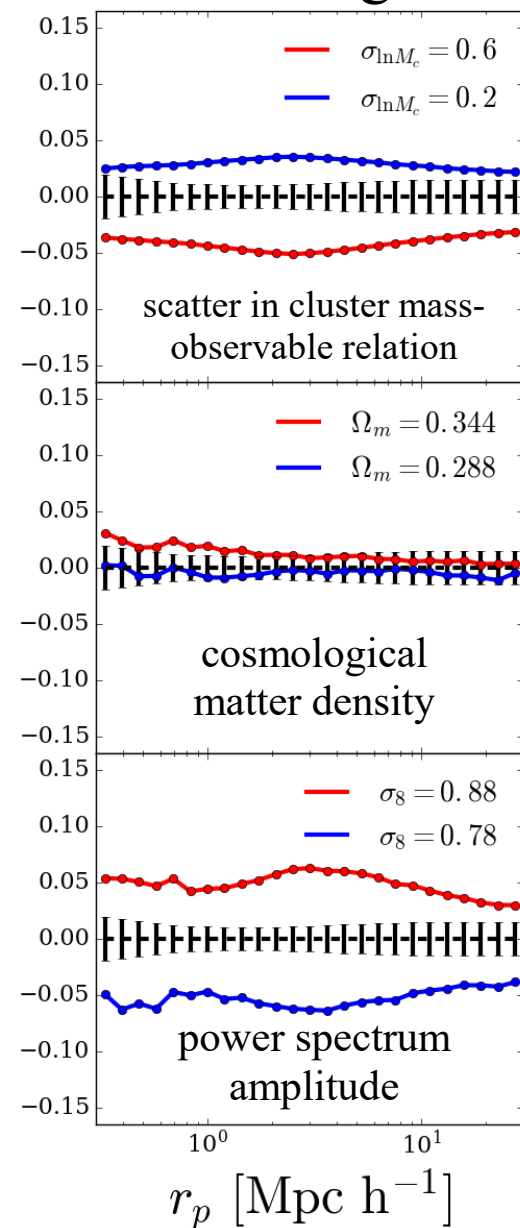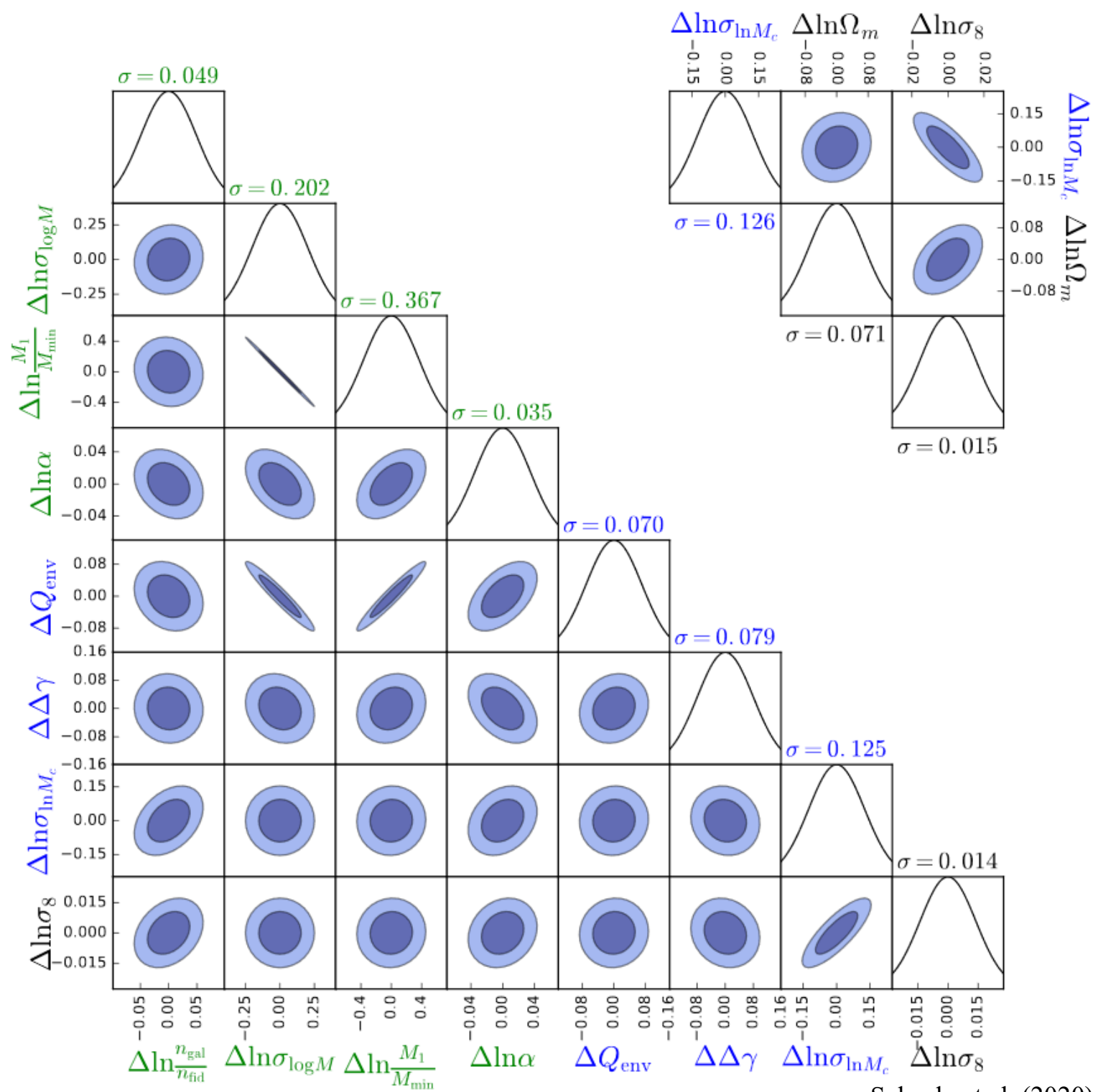# Halo occupation distribution modeling

# Parameter variations

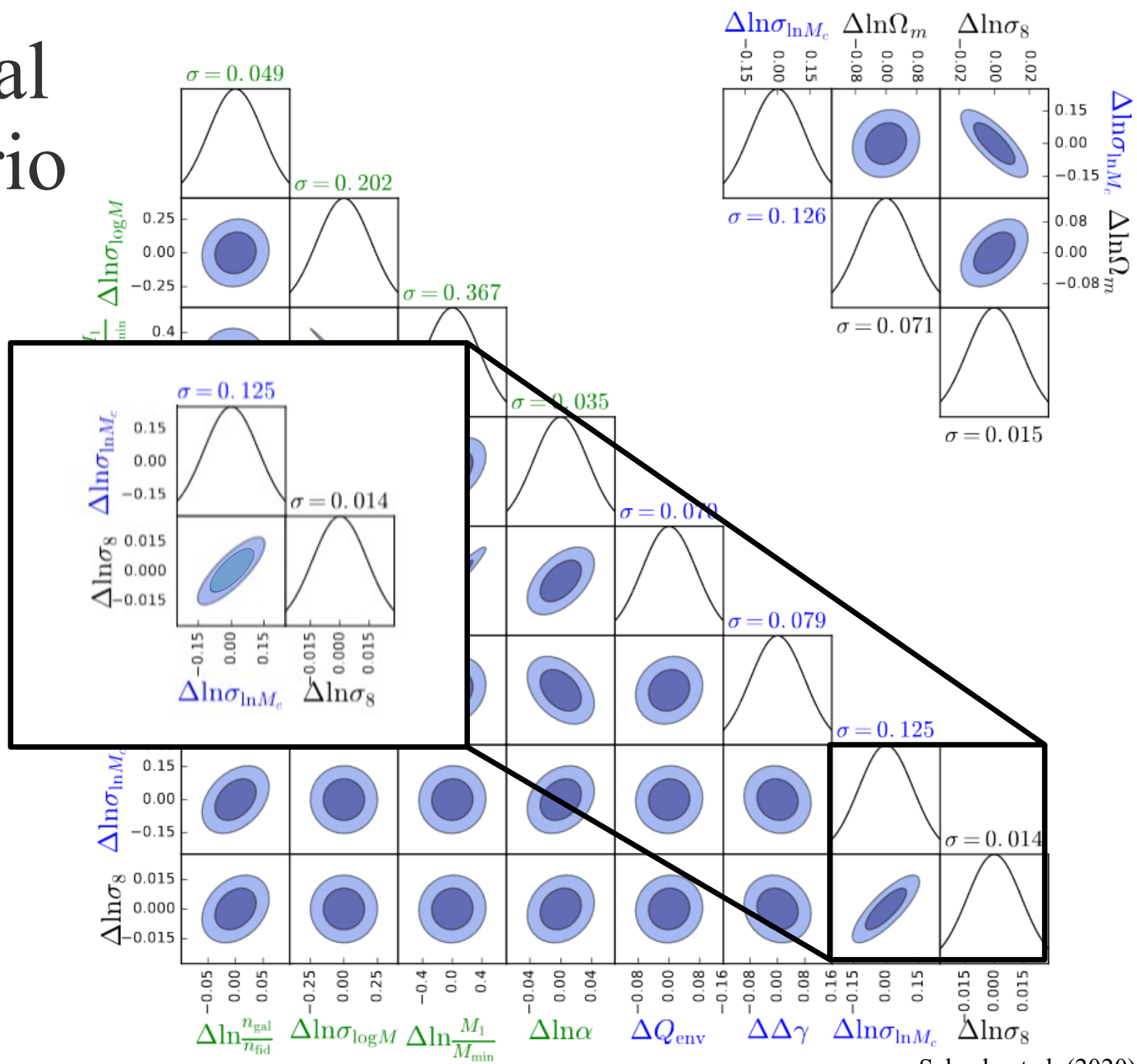## cluster-galaxy cross-correlation

## cluster weak lensing



Salcedo et al. (2020)
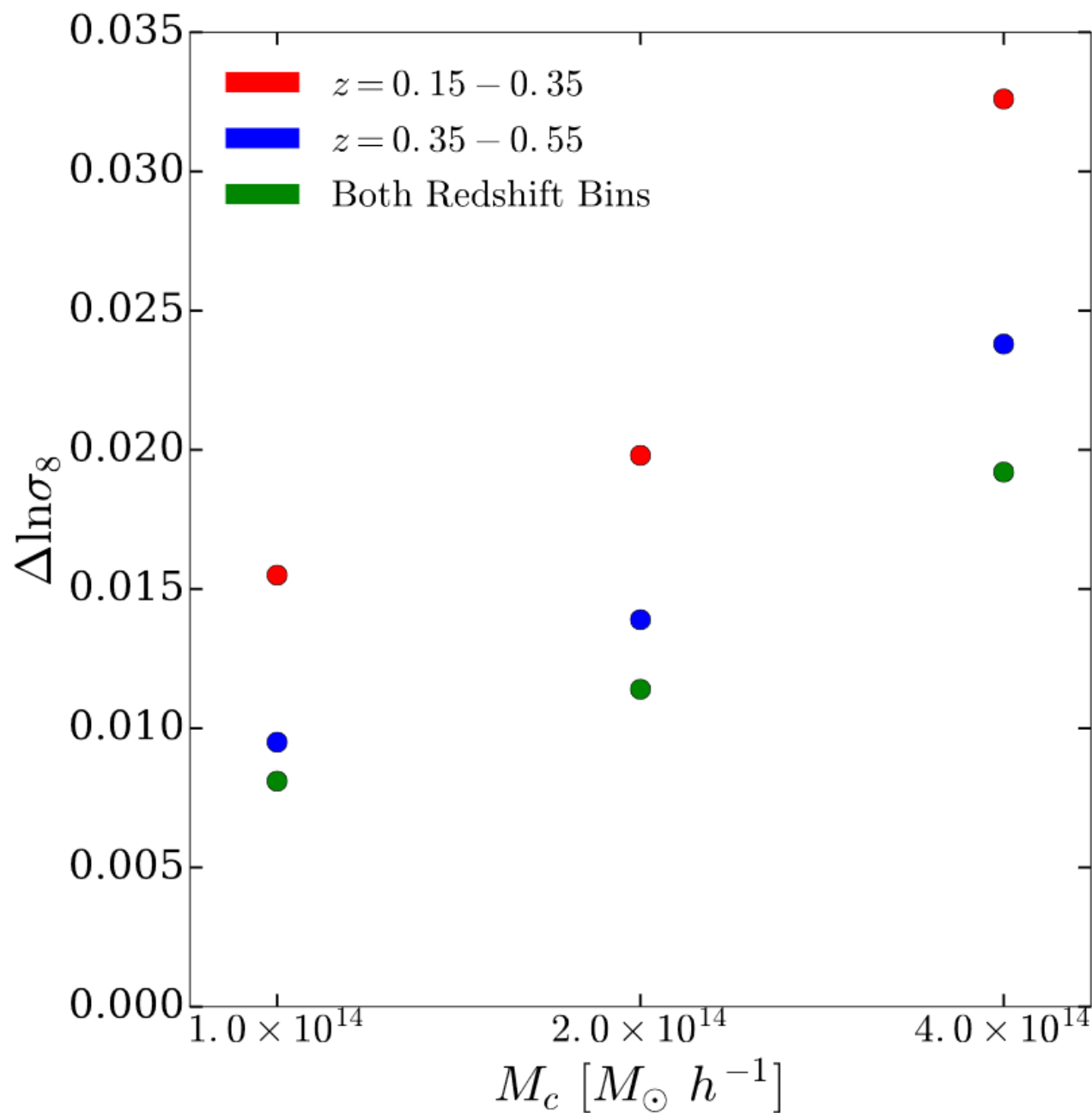
# Fiducial Scenario



Salcedo et al. (2020)

# Fiducial Scenario

Salcedo et al. (2020)

# Varying cluster definition and combining redshift bins



Salcedo et al. (2020)

# Other Scenarios

| $\Delta\Sigma$ | $w_{p,cg}$ | $w_{p,gg}$ | $\Delta\ln\sigma_{\ln M_c}$ | $\Delta\ln\sigma_8$ |
|---|---|---|---|---|
| all | all | all | 0.125 | 0.014 |
| all | - | - | 0.926 | 0.083 |
| - | all | all | 0.126 | 0.063 |
| all | - | all | 0.755 | 0.068 |
| all | all | - | 0.813 | 0.073 |
| small | all | all | 0.125 | 0.014 |
| large | all | all | 0.125 | 0.018 |

Salcedo et al. (2020)

# Emulation: observables
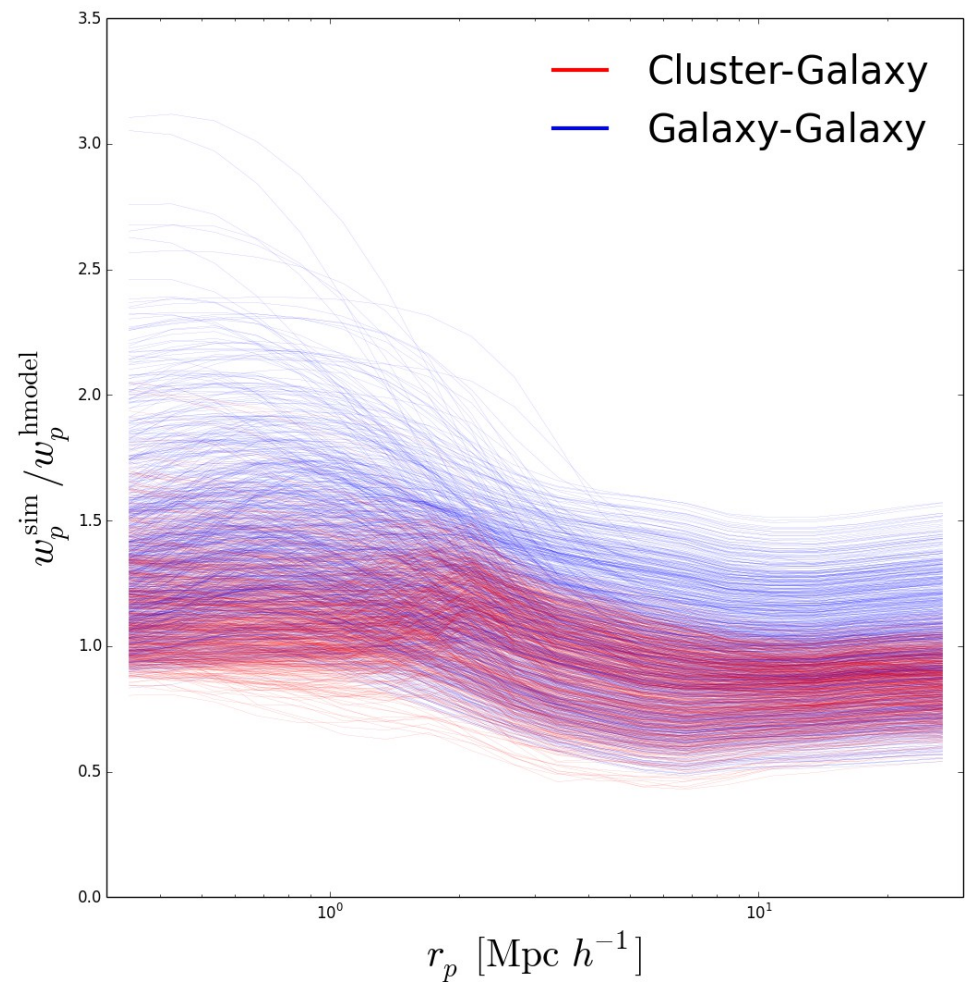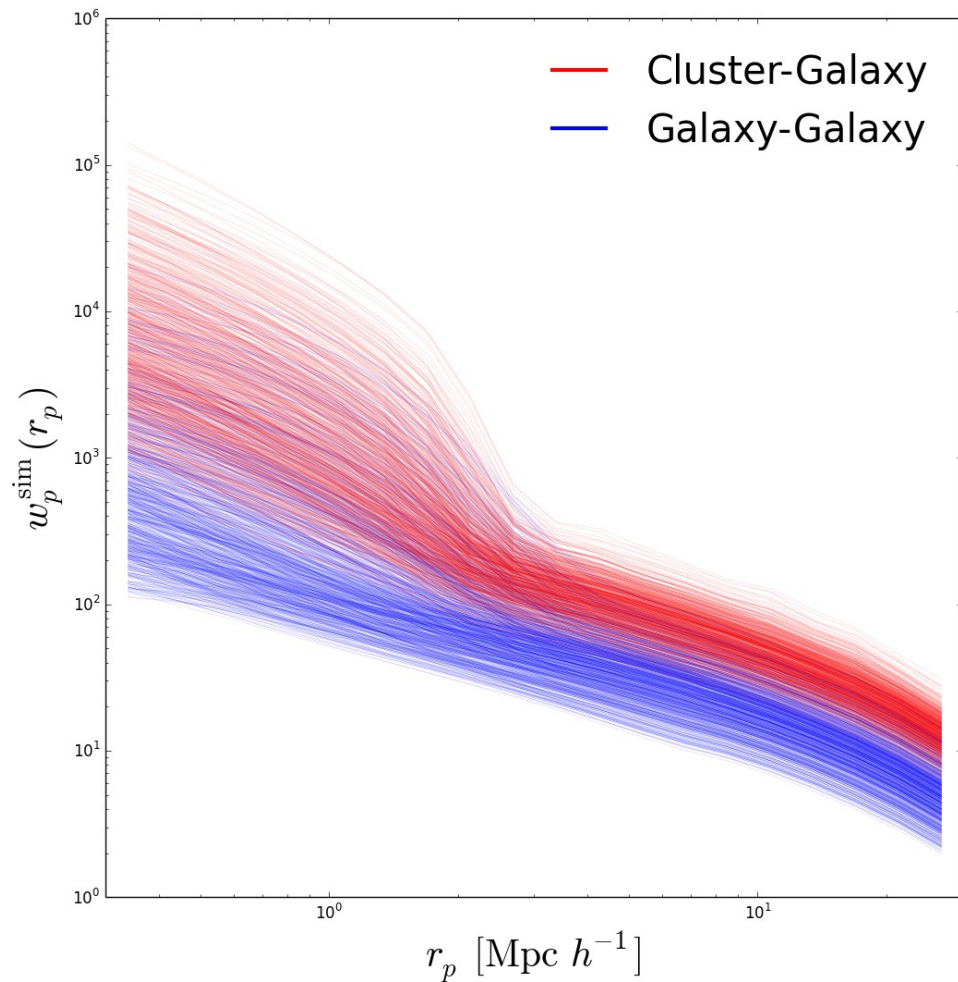
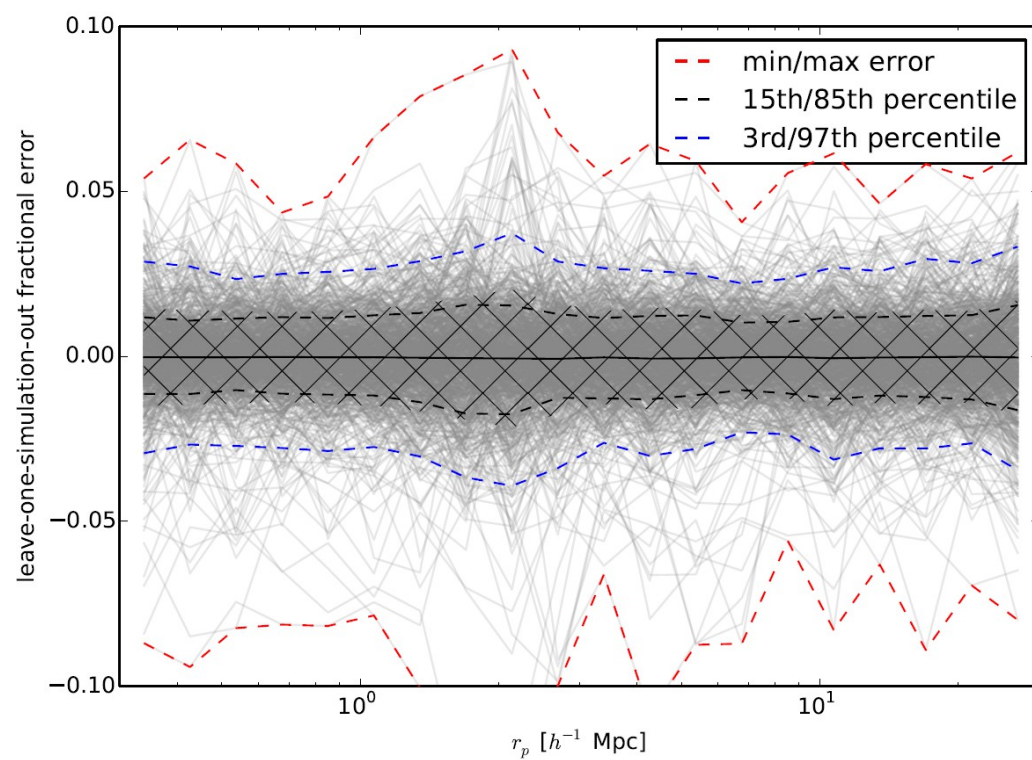# Emulation: leave-one-out accuracy
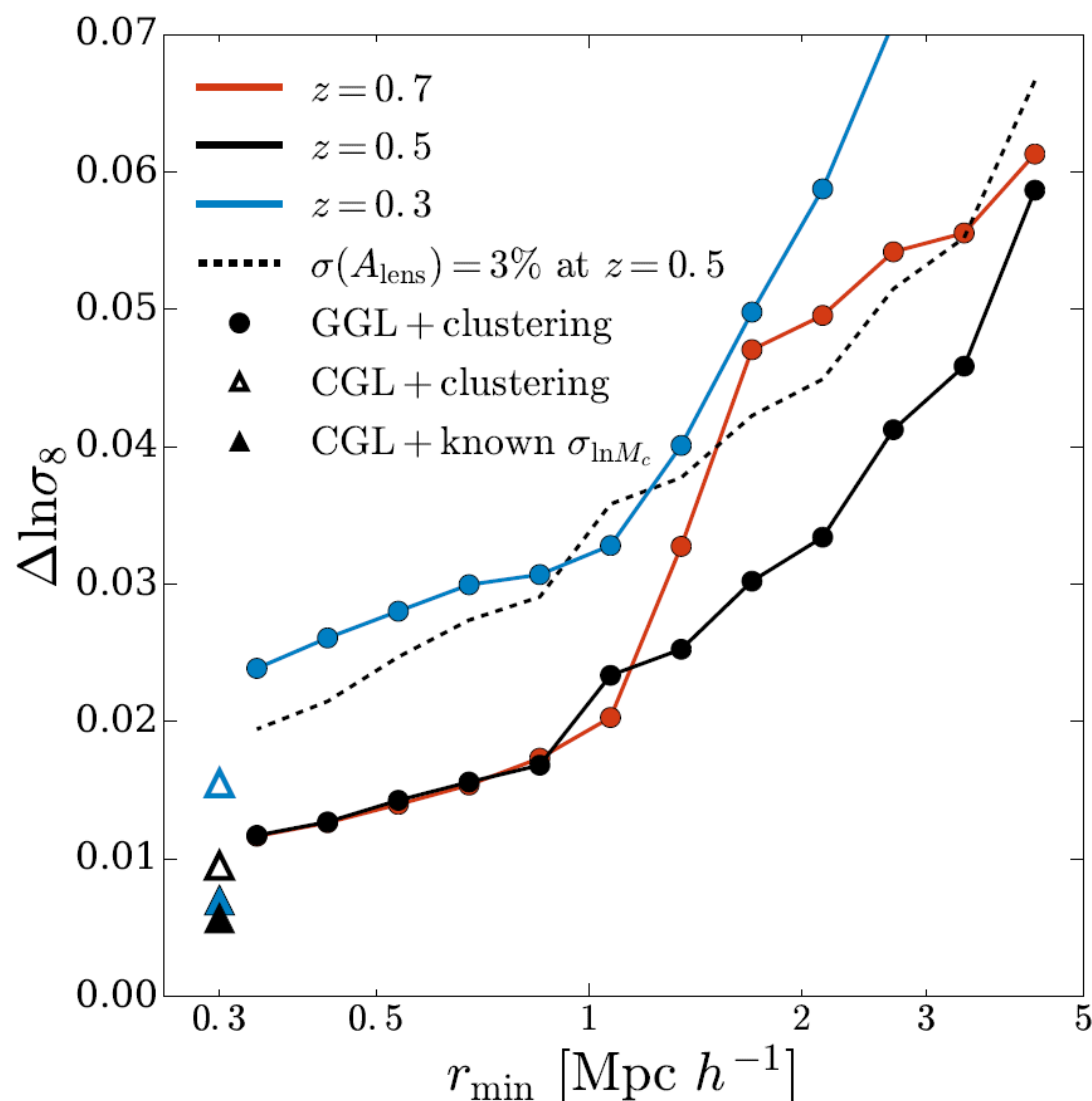


galaxy-galaxy auto-correlation
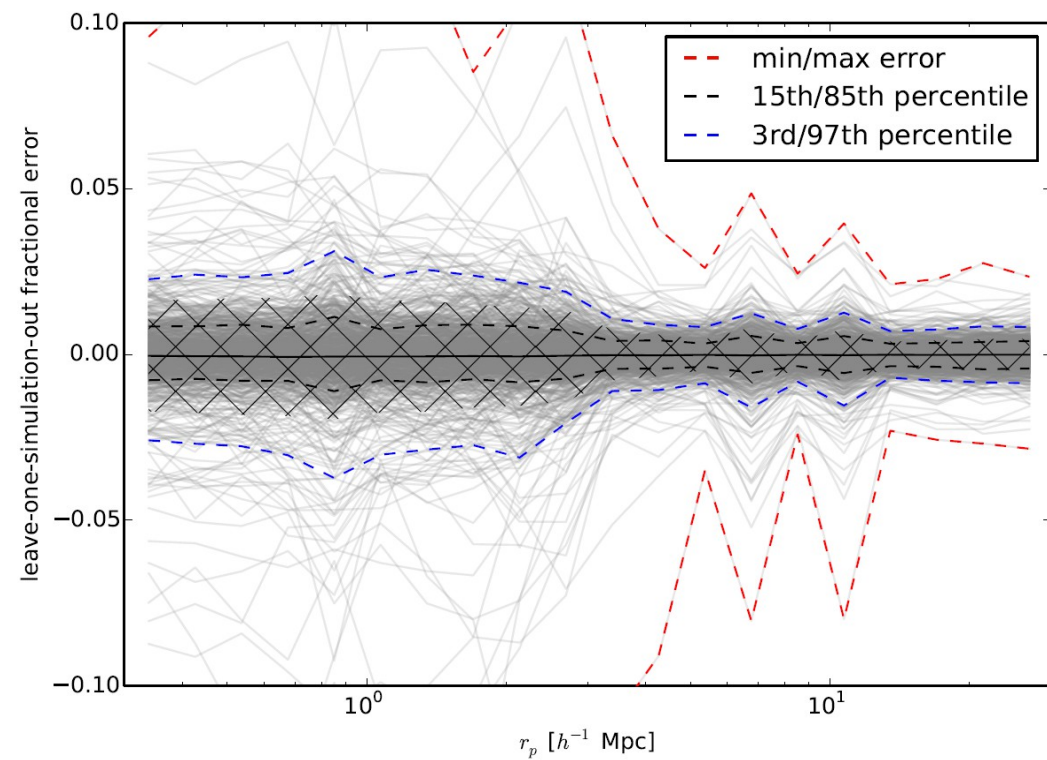
cluster-galaxy cross-correlation

# What's next?

- Forecasting non-linear GGL+clustering in DES with emphasis on breaking degeneracies with scale independent weak lensing systematics.

- Measuring w$_{p,cg}$ in DES to constrain the cluster mass-richness relation.

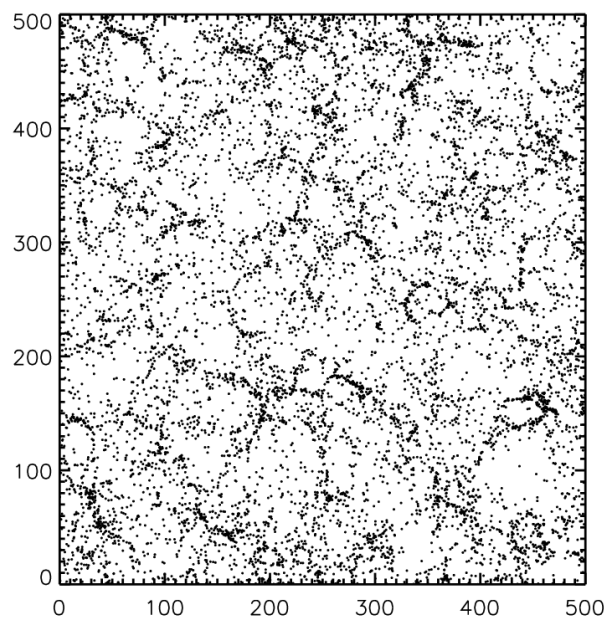- Apply the 3-observable framework to produce constraints on S$_8$ and $\sigma_8$.

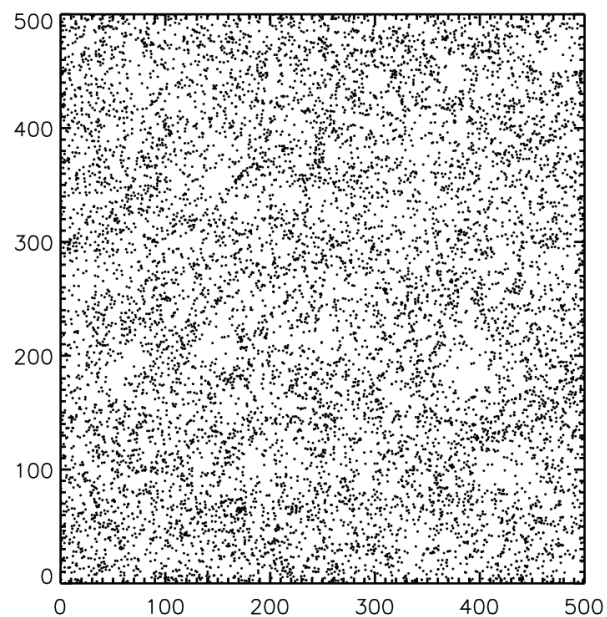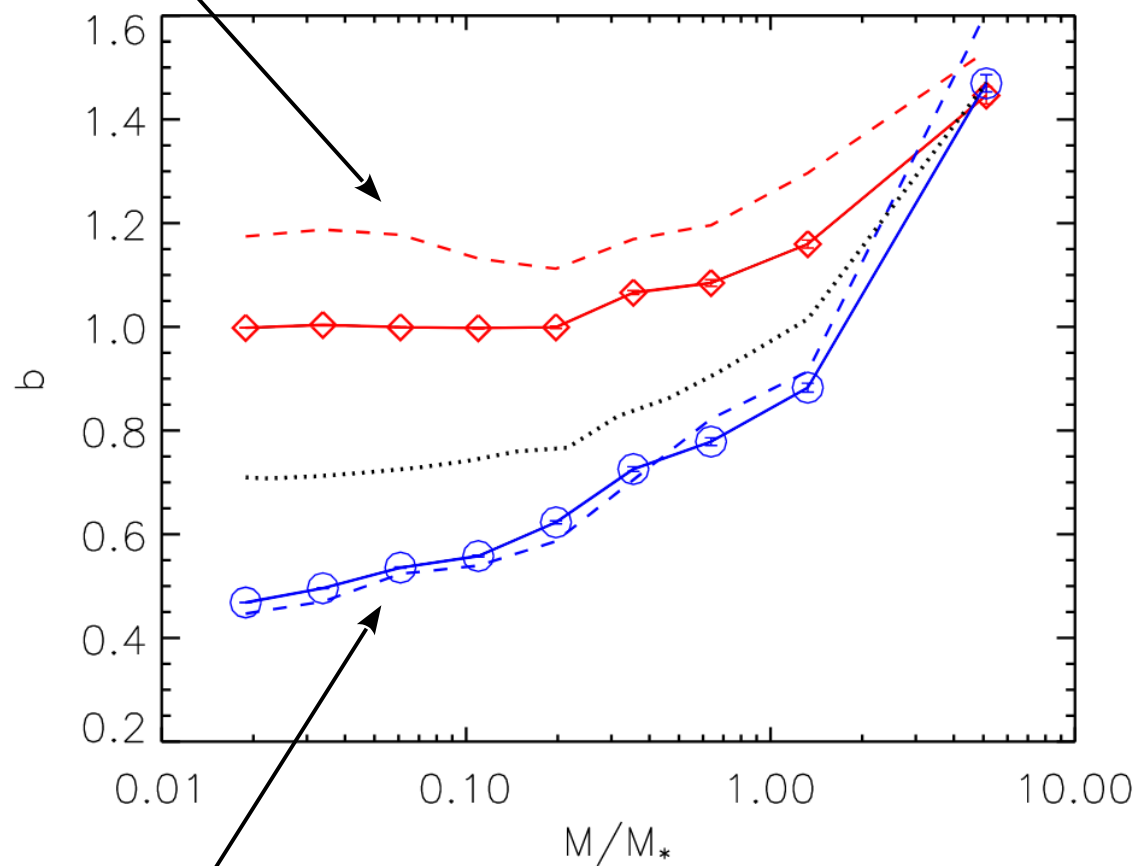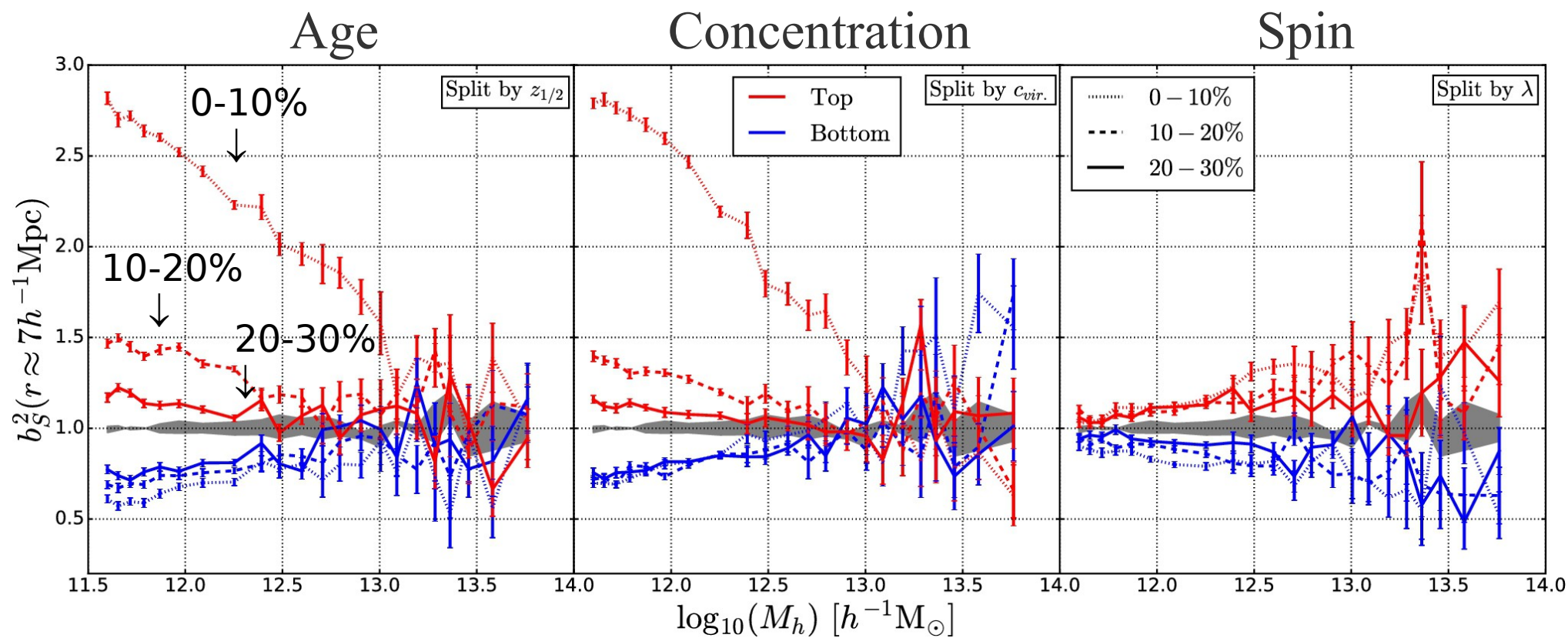# Secondary and neighbour halo bias

# What is halo assembly bias?



←10% oldest

←10% youngest

Gao, Springel, and White (2005)

# Halo assembly bias



Salcedo et al. (2018)

# Secondary bias



Salcedo et al. (2018)
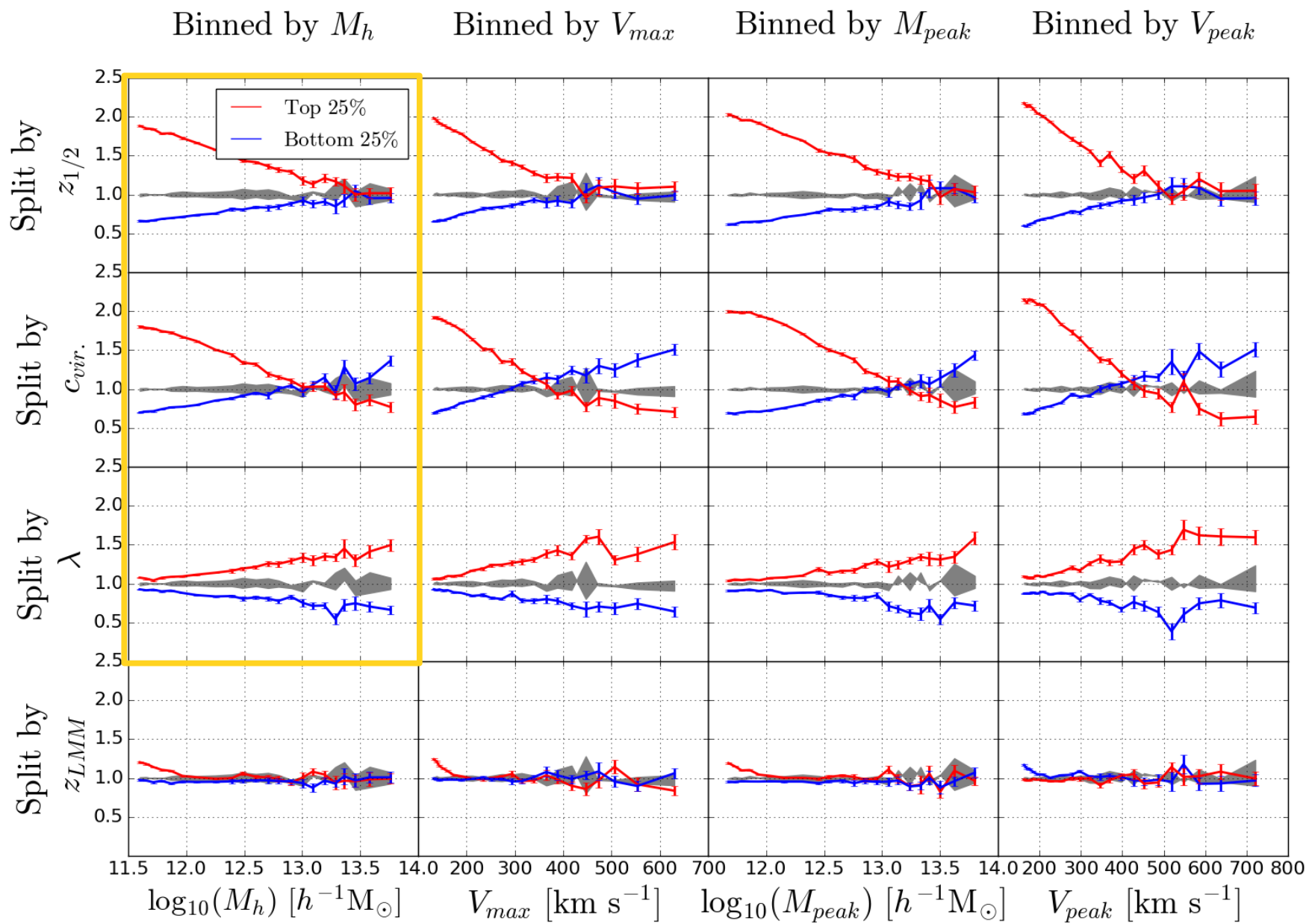
# Dependence of halo properties on normalized neighbor distance



Age — Concentration — Spin

$$D_n = \frac{D}{R_{\mathrm{vir},n}}$$

Legend:
- $M_c = 1 - 3 \times M_h$
- $M_c > 3 \times M_h$
- $M_c > 10 \times M_h$
- $M_c > 30 \times M_h$
- $M_c > 100 \times M_h$
- $M_c > 300 \times M_h$

Salcedo et al. (2018)
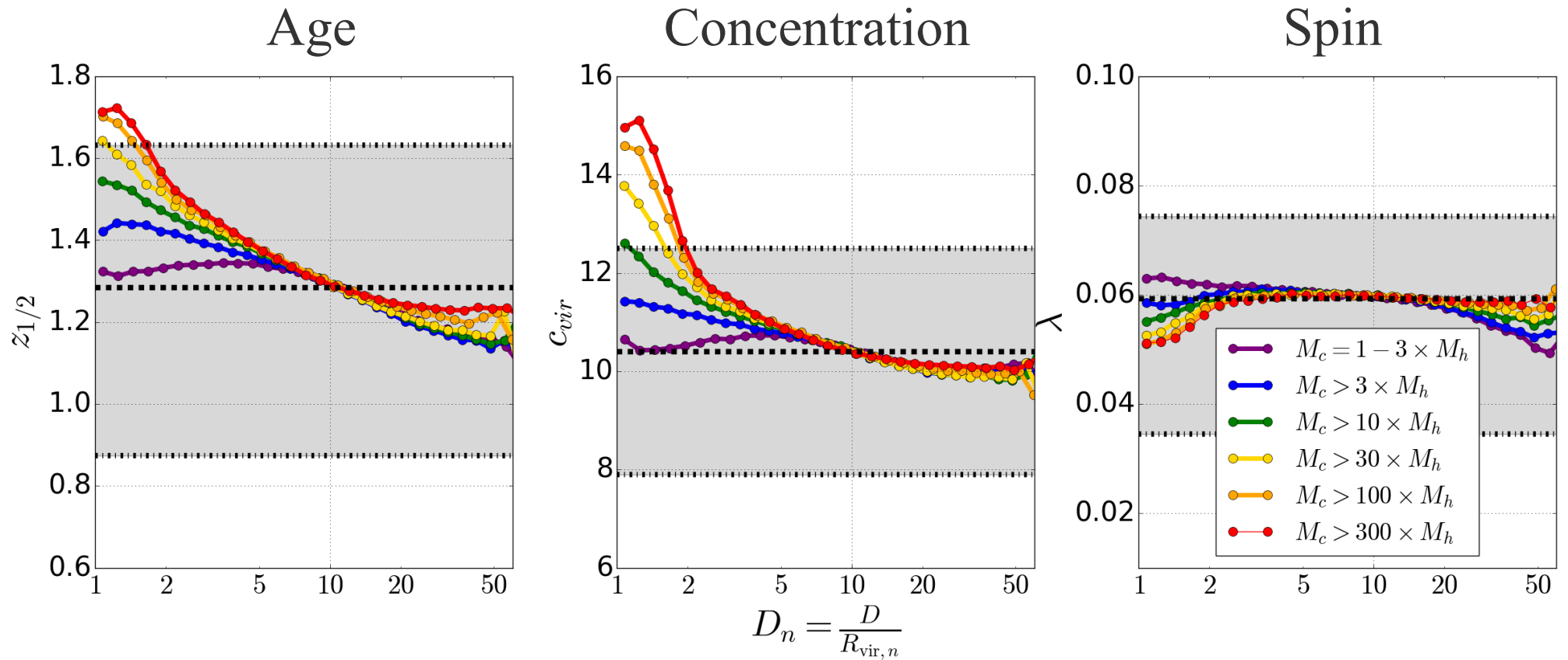
# Neighbor normalization and bias, bins of mass



Salcedo et al. (2018)
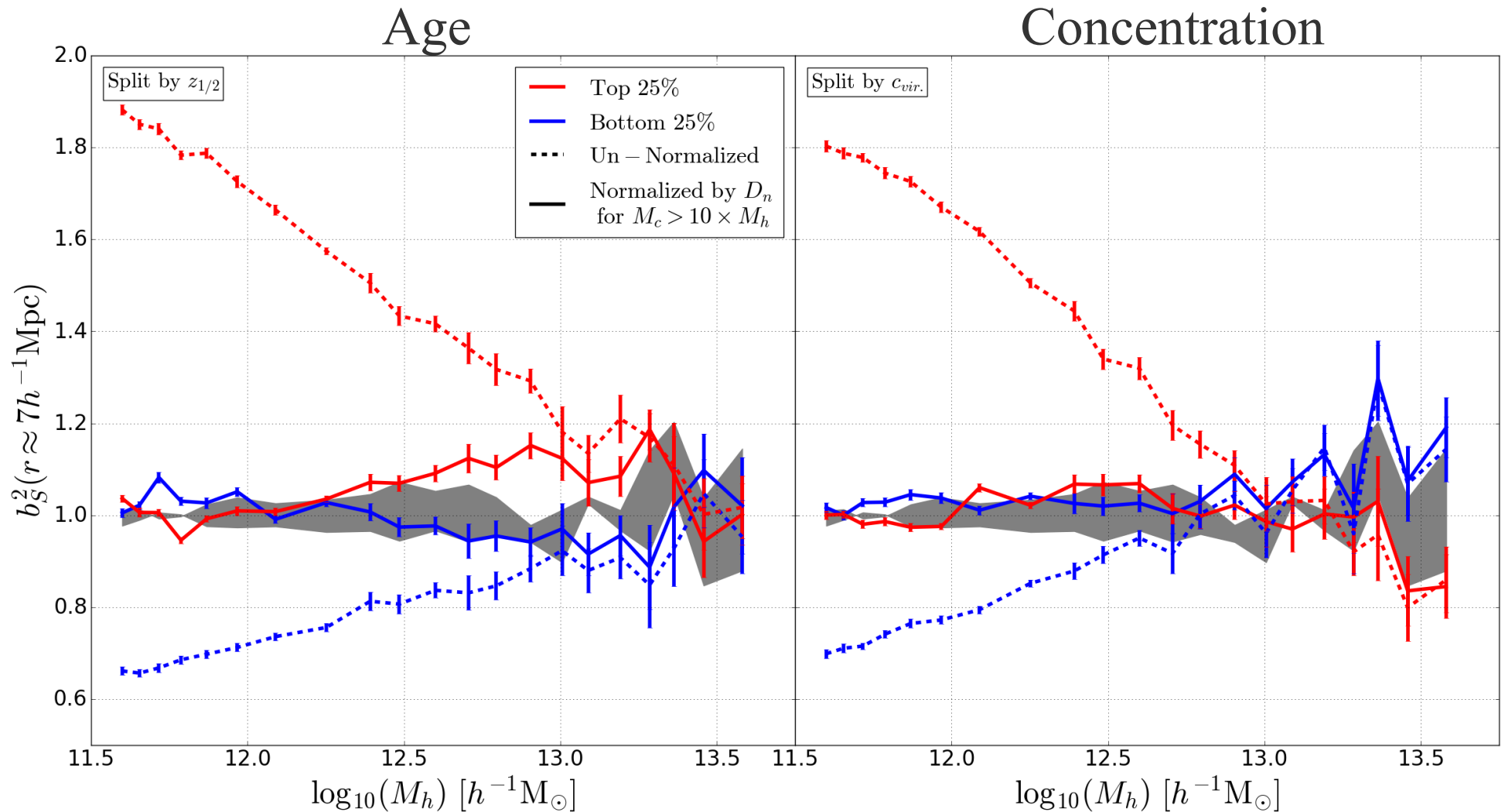
# Galaxy assembly bias in SDSS

# The ELUCID constrained simulation



points are galaxies, colored by value of local galaxy overdensity

# Modifications to the HOD

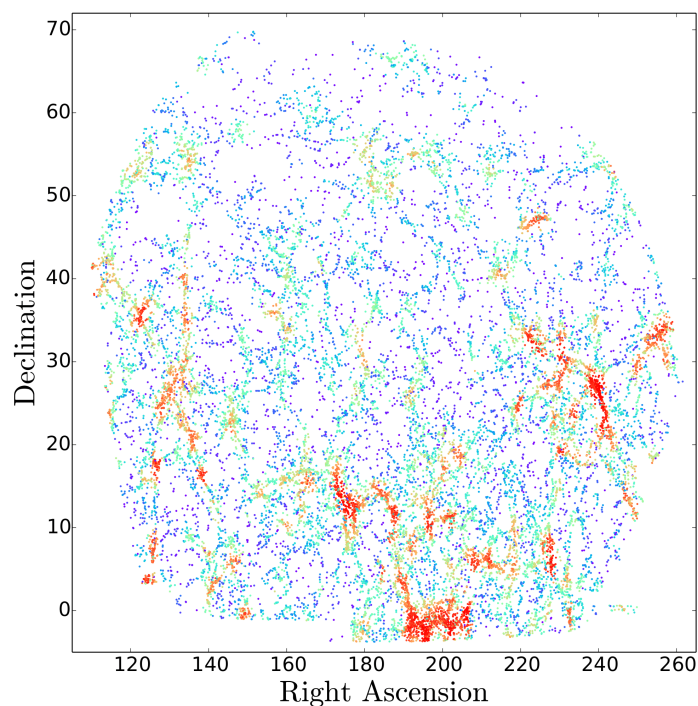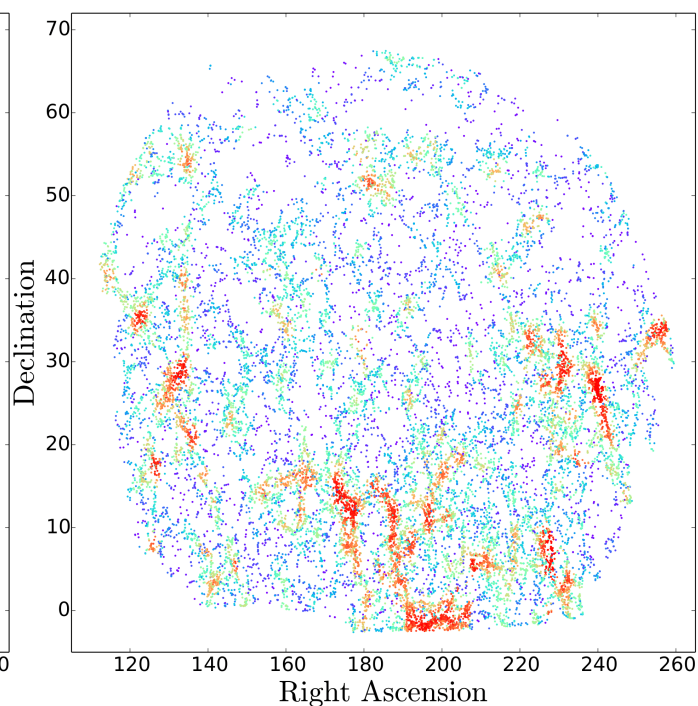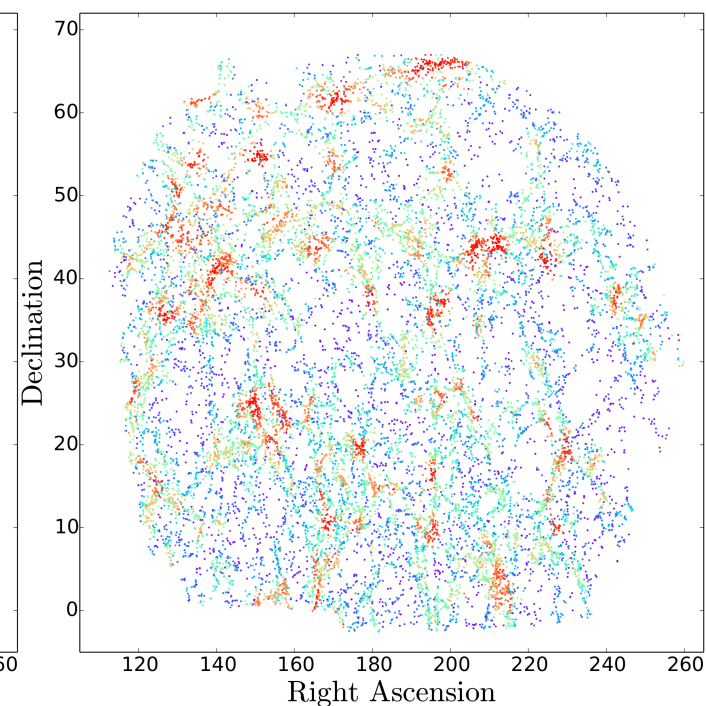$Q_{\text{cen/sat}}$ – central/satellite assembly bias parameter



Salcedo et al. in prep

# Cosmic variance



Salcedo et al. in prep
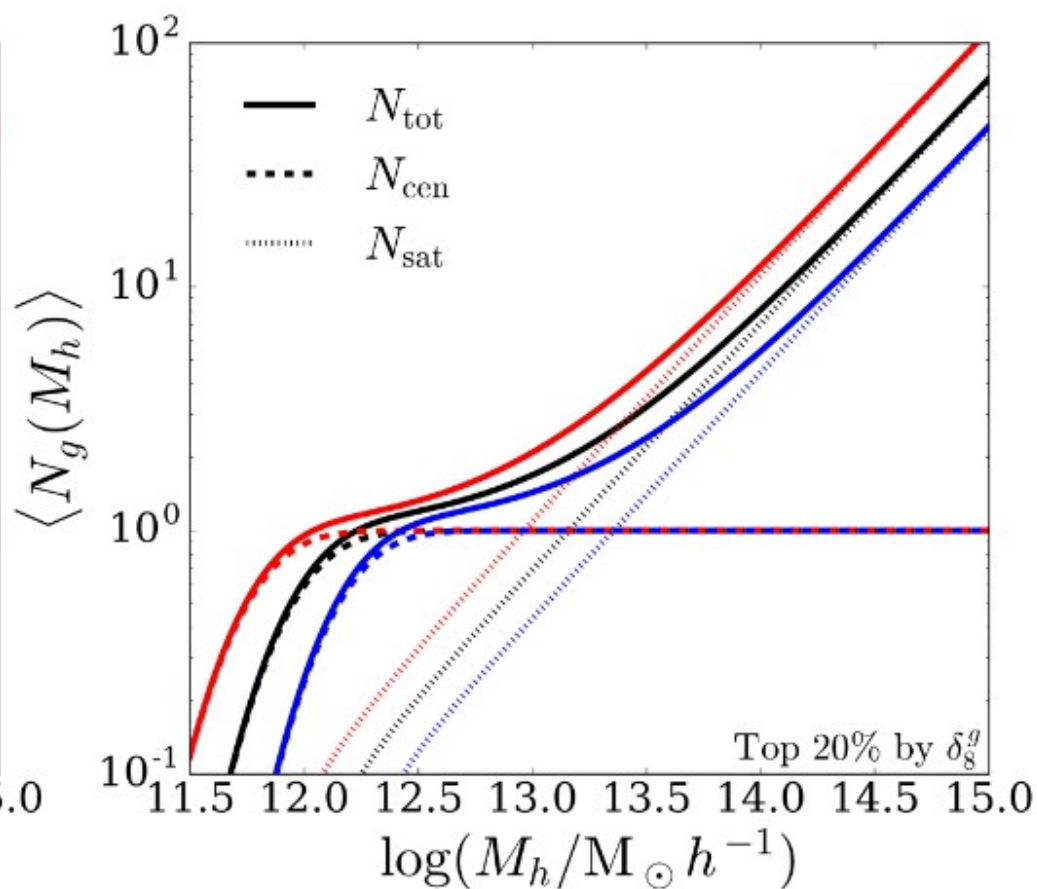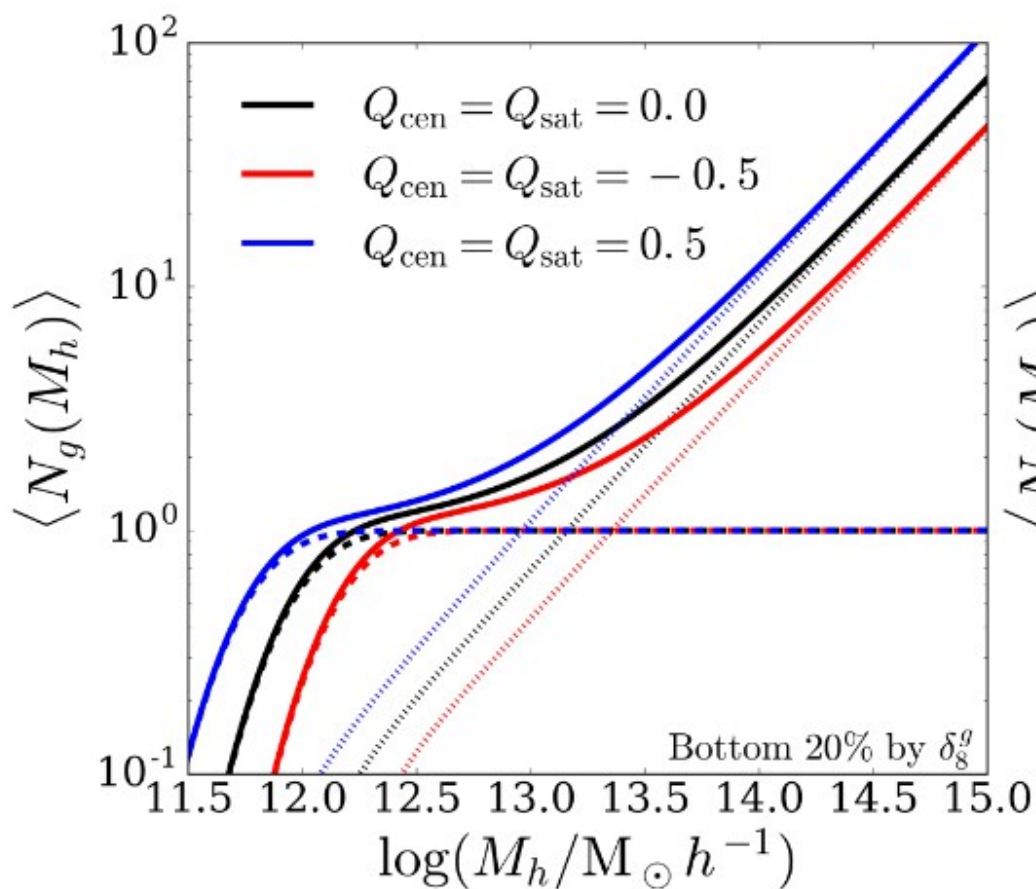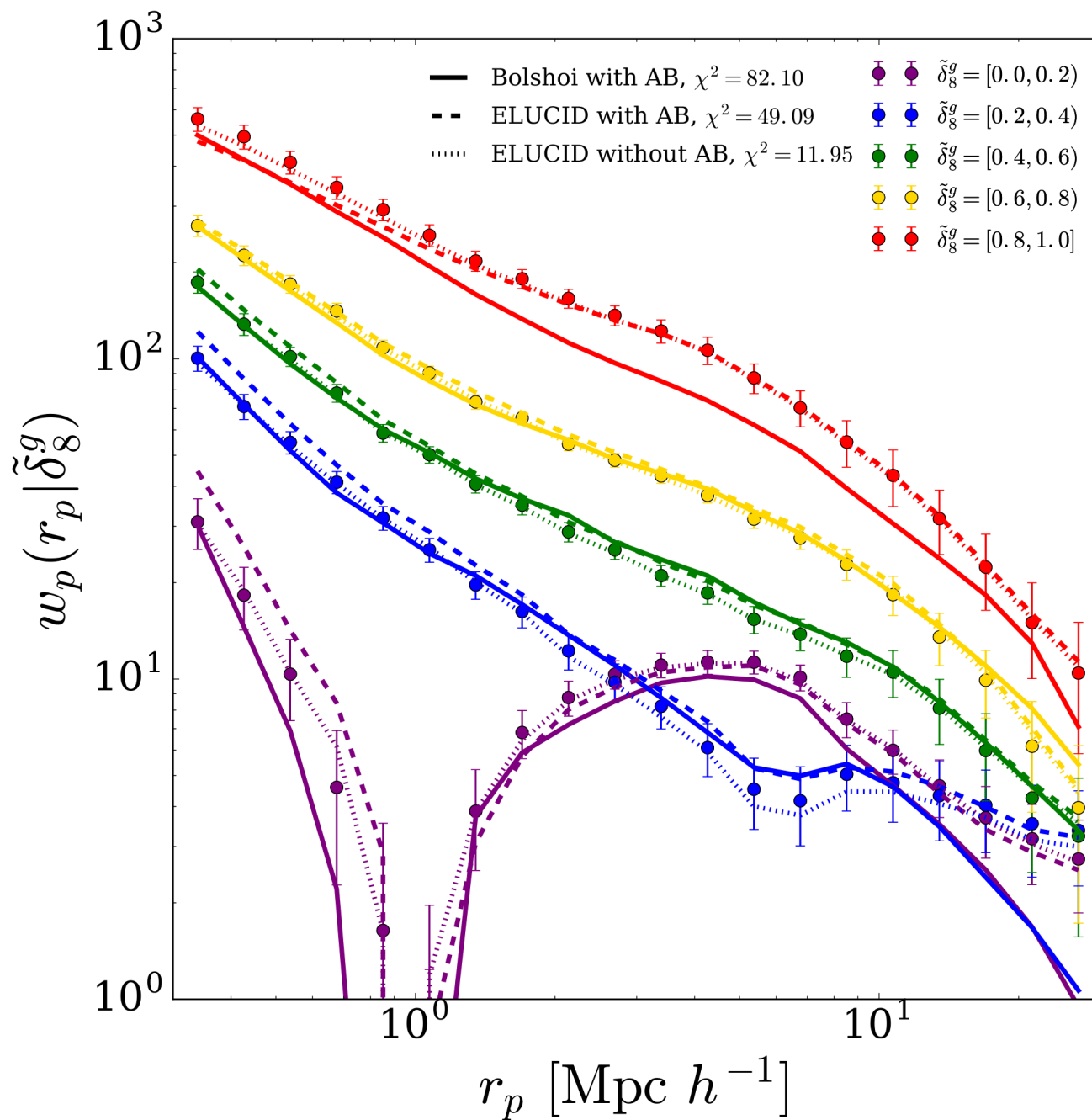
# Mock tests, ELUCID vs. Bolshoi



Mock with ELUCID

Mock with Bolshoi

$\{w_p(r_p), n_g\}$

$\{w_p(r_p), f(\delta_8^g), n_g\}$

$\{w_p(r_p|\tilde{\delta}_8^{g,i})|_{i=1-5}, n_g\}$

$\{w_p(r_p|\tilde{\delta}_8^{g,i})|_{i=1-5}, f(\delta_8^g), n_g\}$

$Q_{\mathrm{sat}}$

$Q_{\mathrm{cen}}$

Salcedo et al. in prep

# Fits to SDSS data



Salcedo et al. in prep
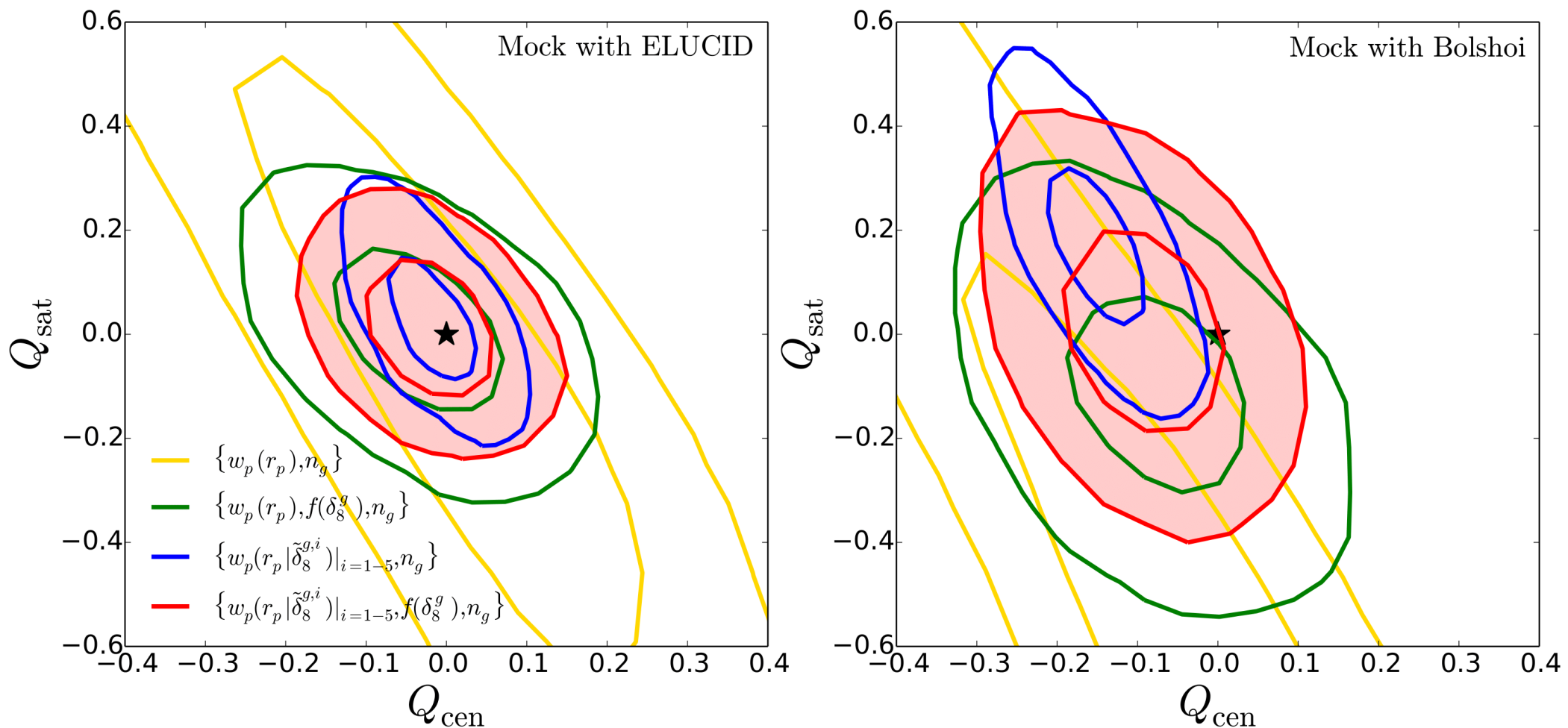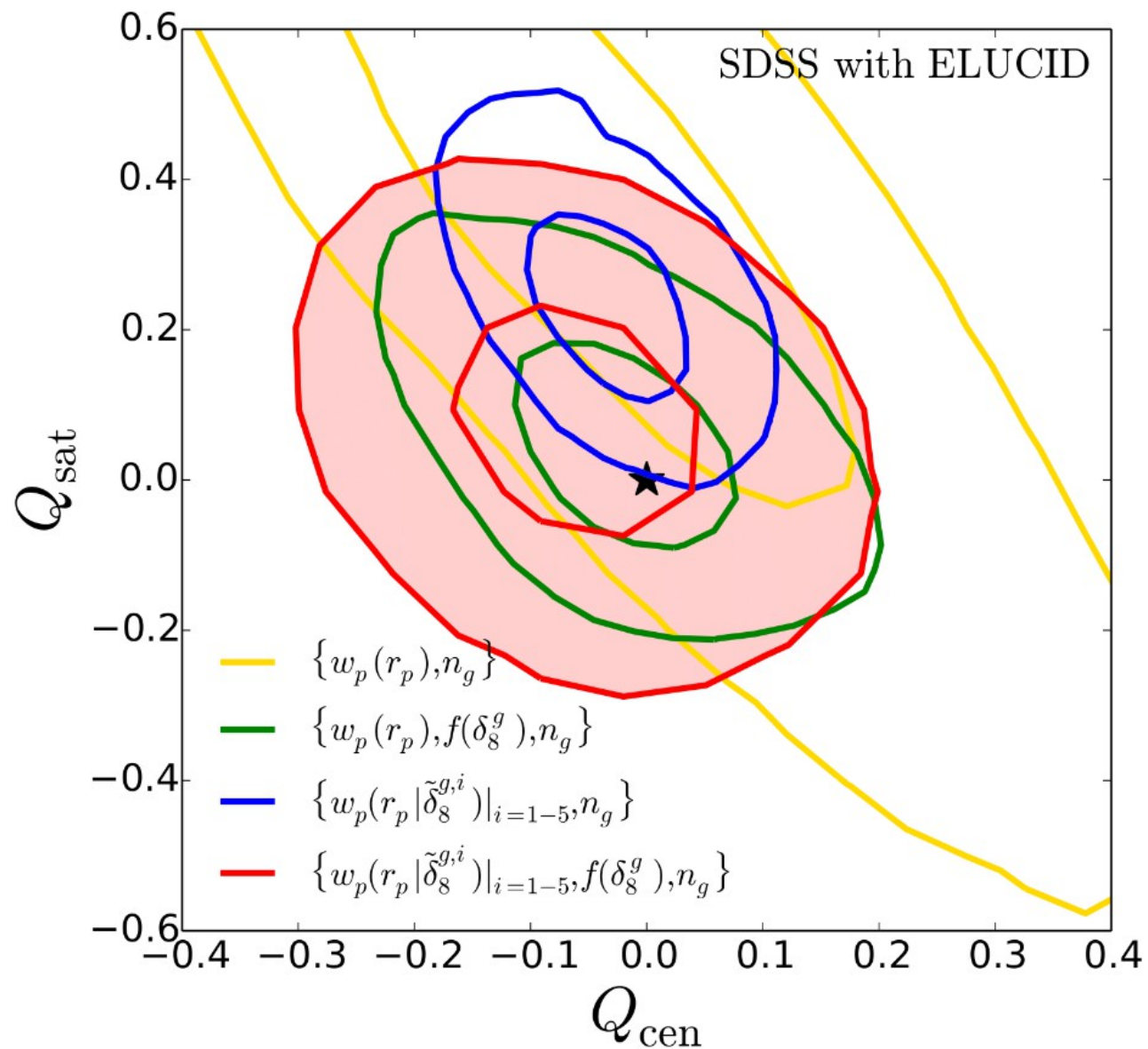
# Fiducial fit

# Summary

- Using a combination of cluster weak-lensing, cluster-galaxy cross-correlations, and galaxy-galaxy auto-correlations we forecast 1% level constraints on $\sigma 8$ from a DES-like survey.

- Halo assembly/secondary bias is a ubiquitous feature of halo clustering. We find that the relationship between halo properties and proximity to a massive neigbour introduces a neighbour bias that can explain assembly bias in many cases.

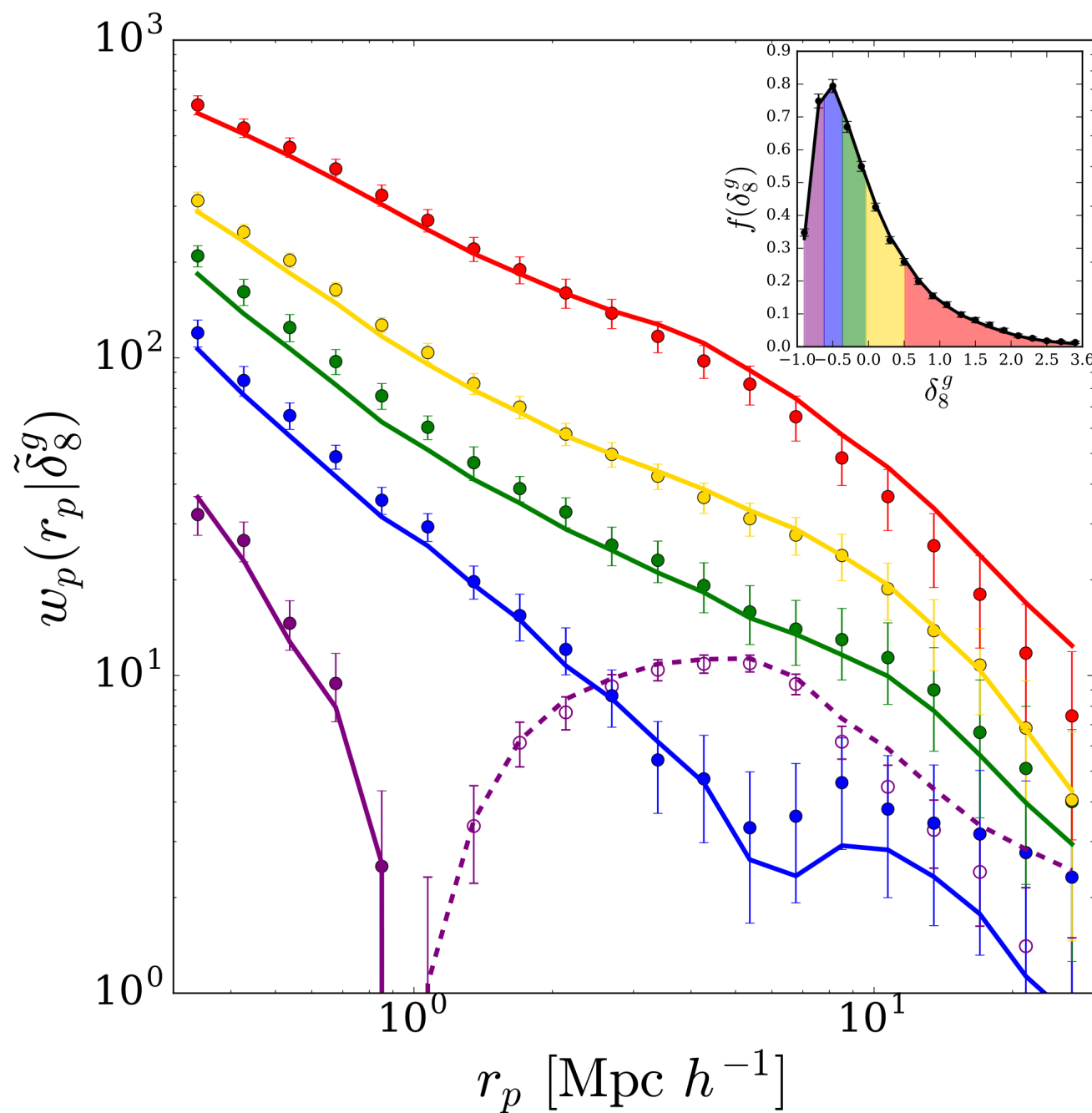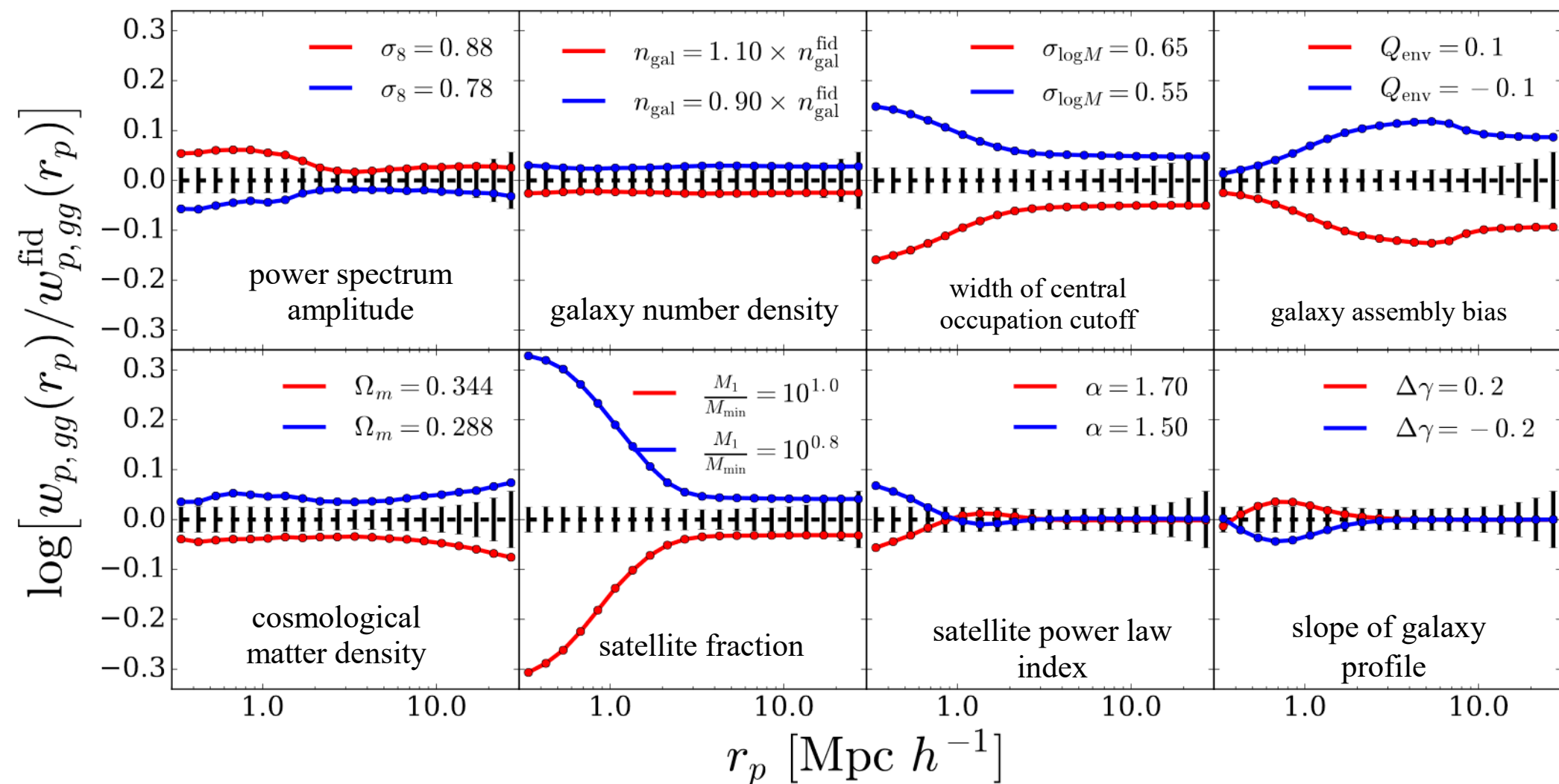- We constrain the level of galaxy assembly bias in SDSS using the ELUCID constrained simulation and a variety of 1 and 2 point galaxy statistics. We also investigate the effects of cosmic variance on these constraints by comparing results from ELUCID to those from Bolshoi.

# Extra Slides

# Parameter variations (galaxy-galaxy)



galaxy-galaxy auto-correlation

Salcedo et al. (2020)

# Other Scenarios



Salcedo et al. (2020)
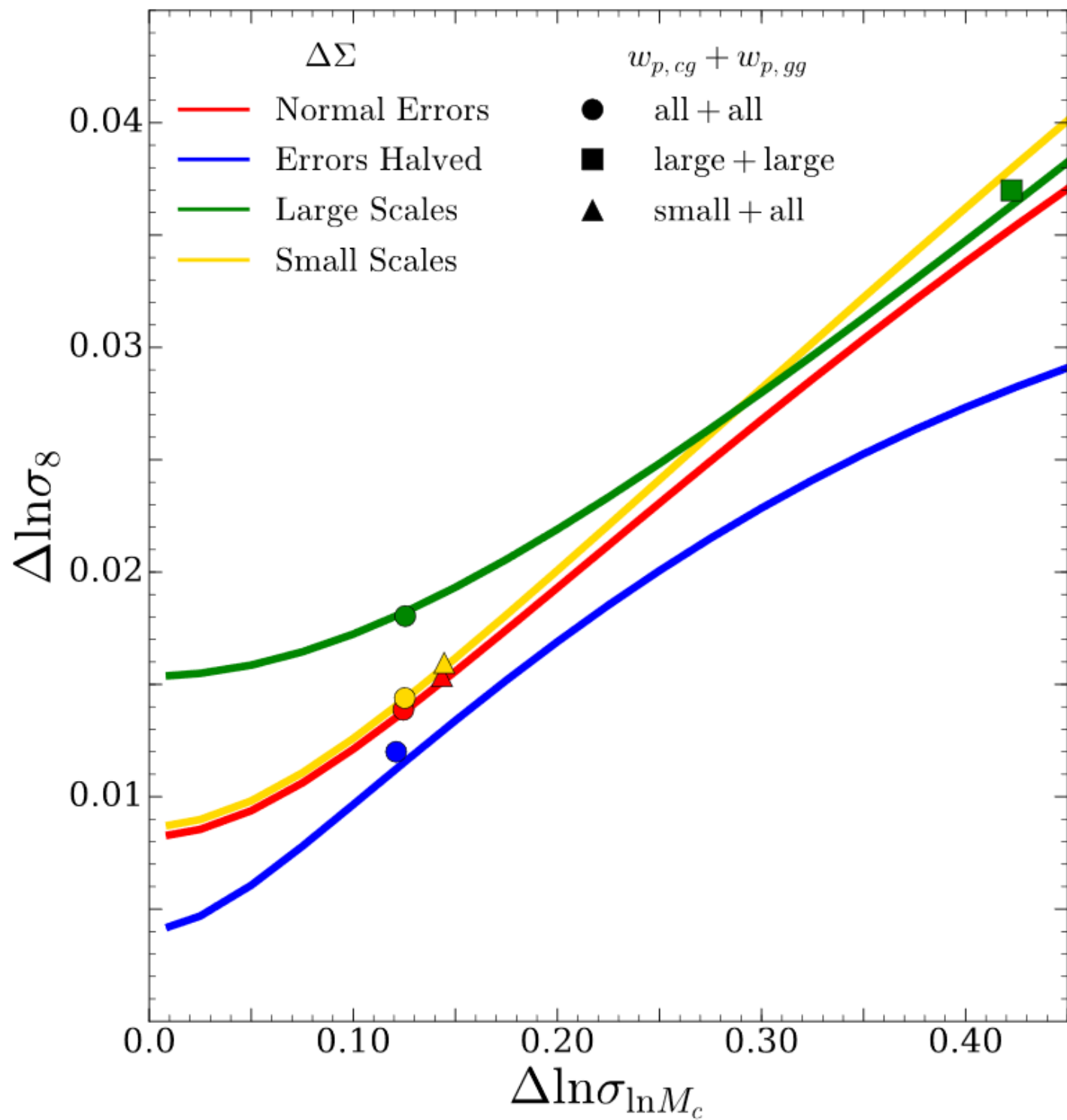
# Combining cluster samples



Salcedo et al. (2020)
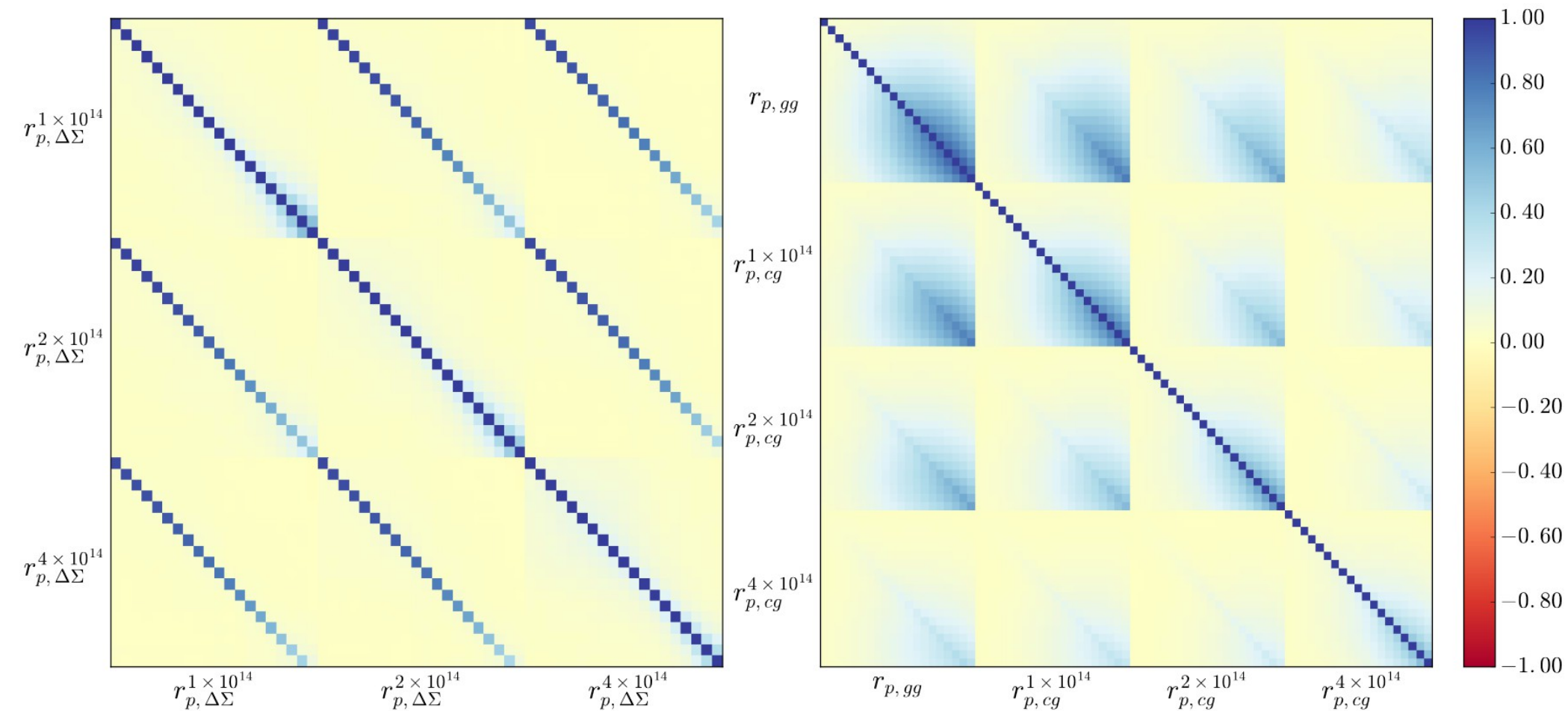
# Uncertainties in cluster number density



Salcedo et al. (2020)
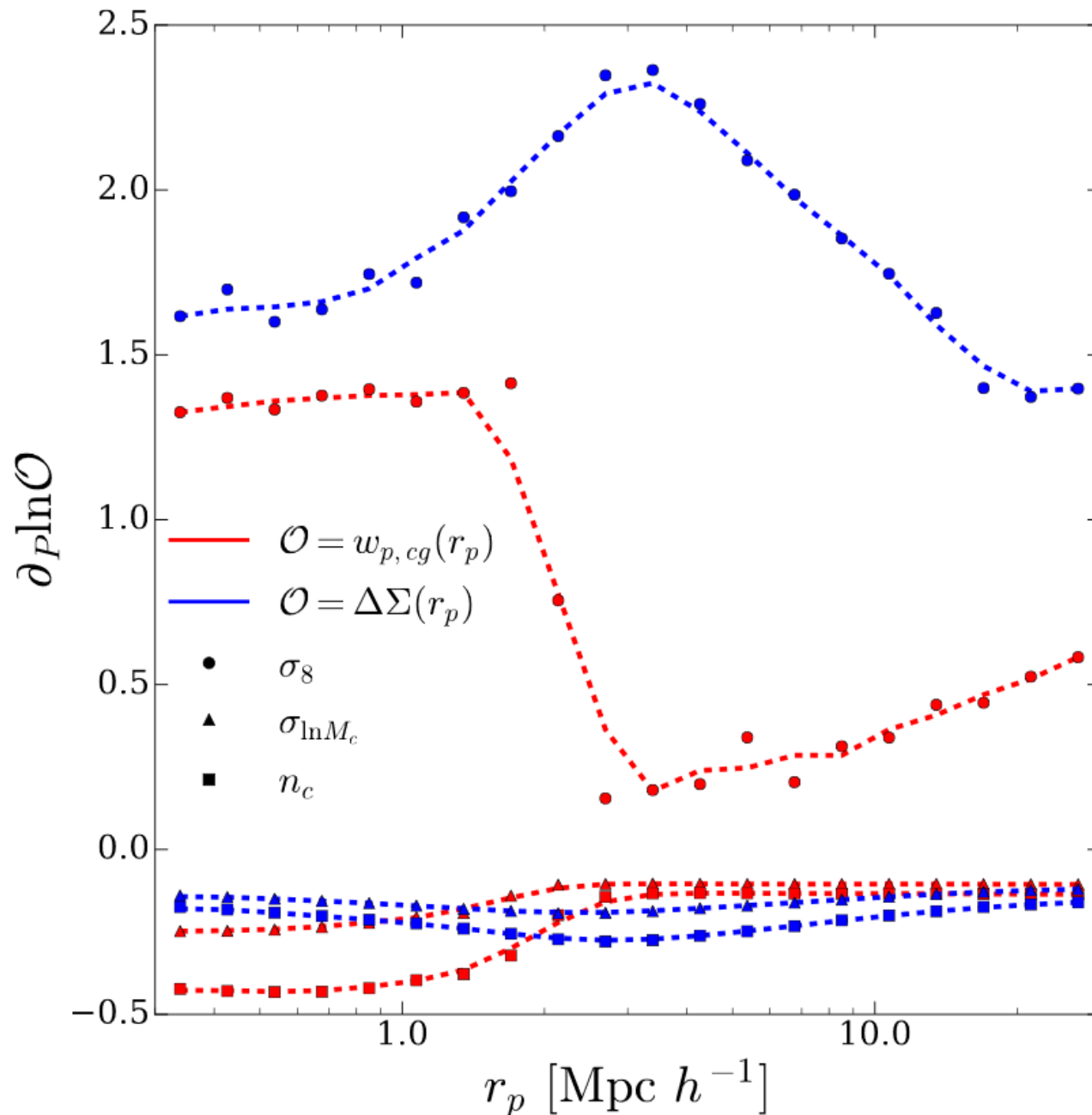
# Gaussian process emulation



Salcedo et al. in prep
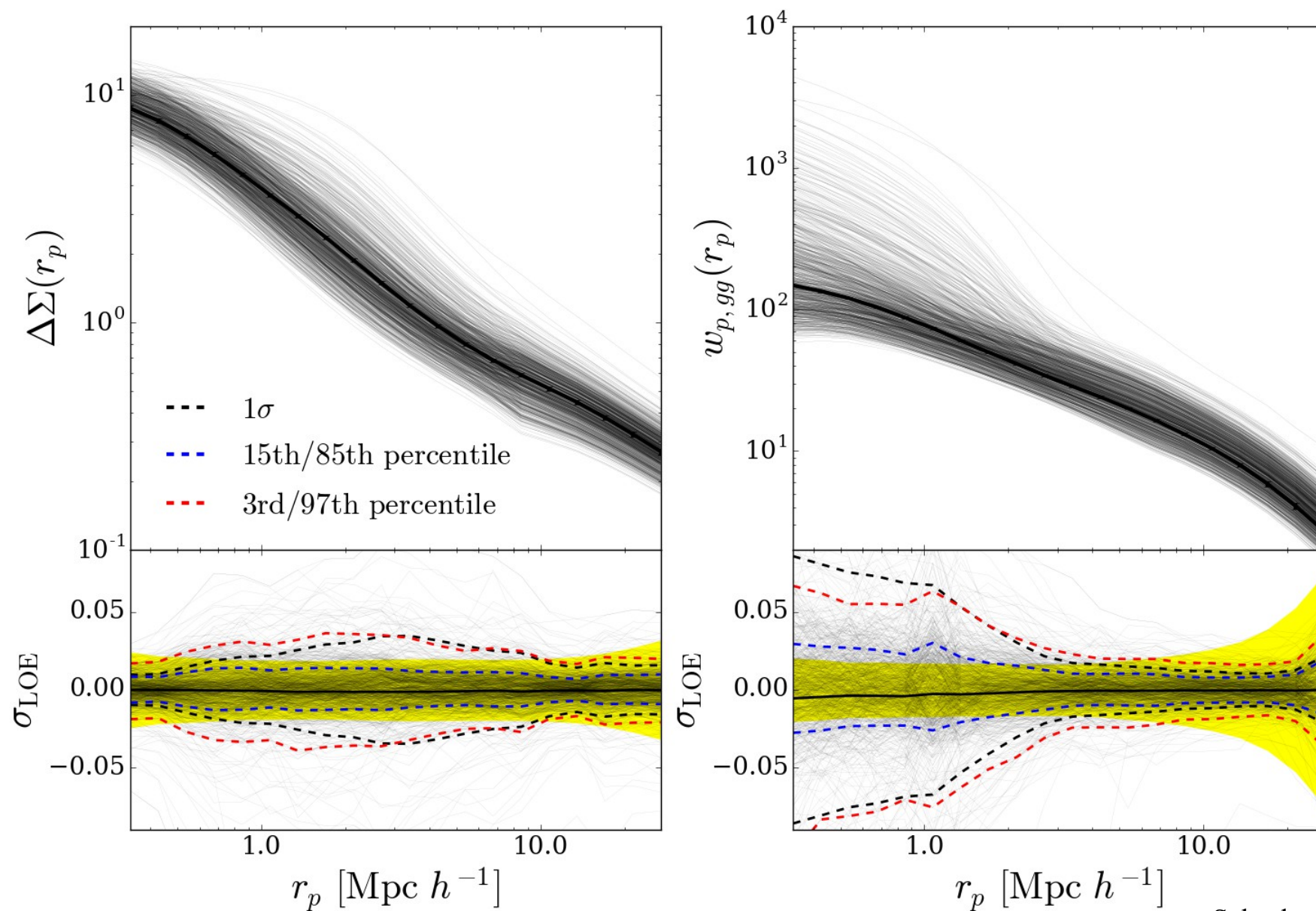
# Constraints from clustering+ggl



Salcedo et al. in prep
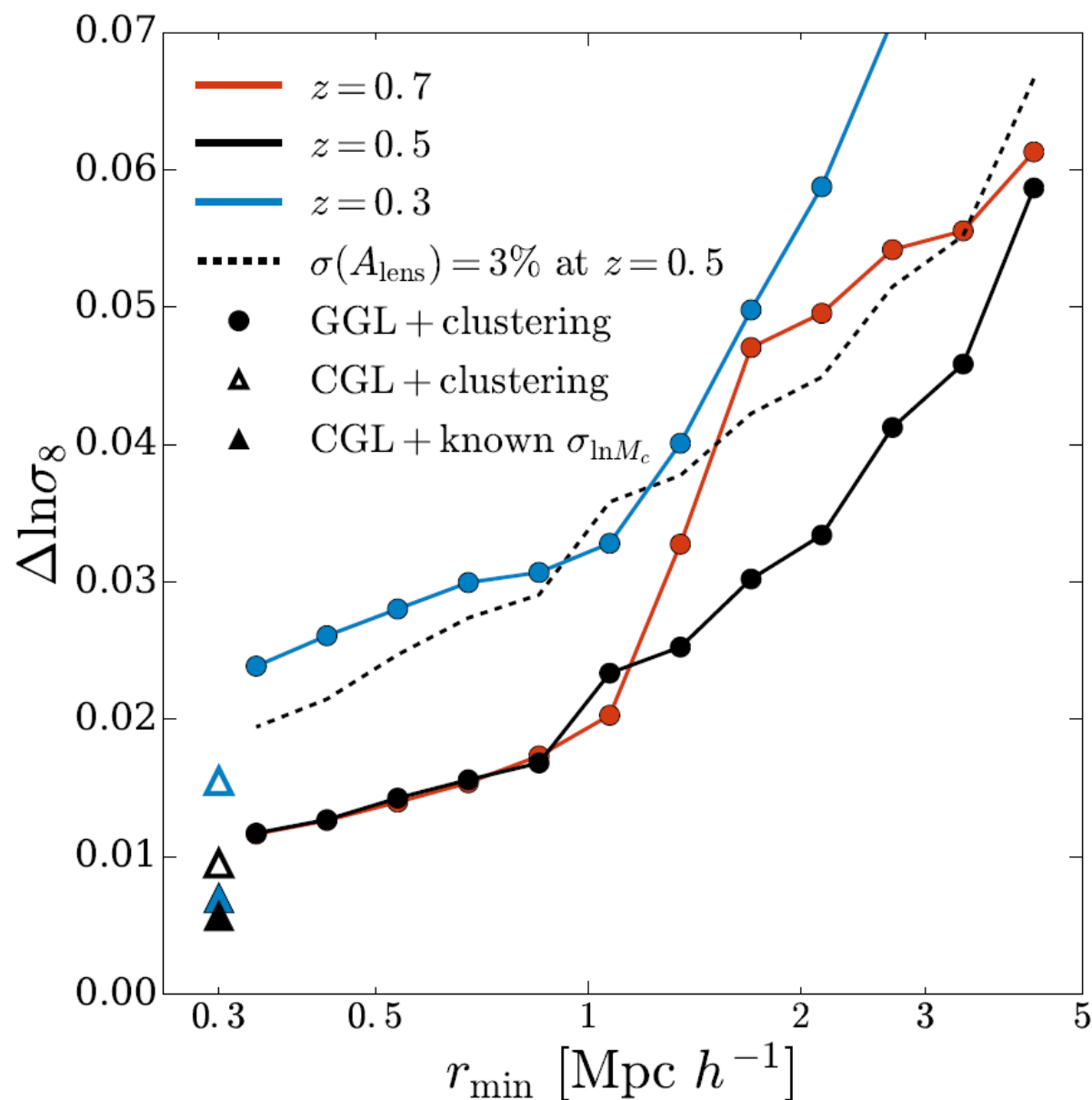
# Galaxy assembly bias modifications
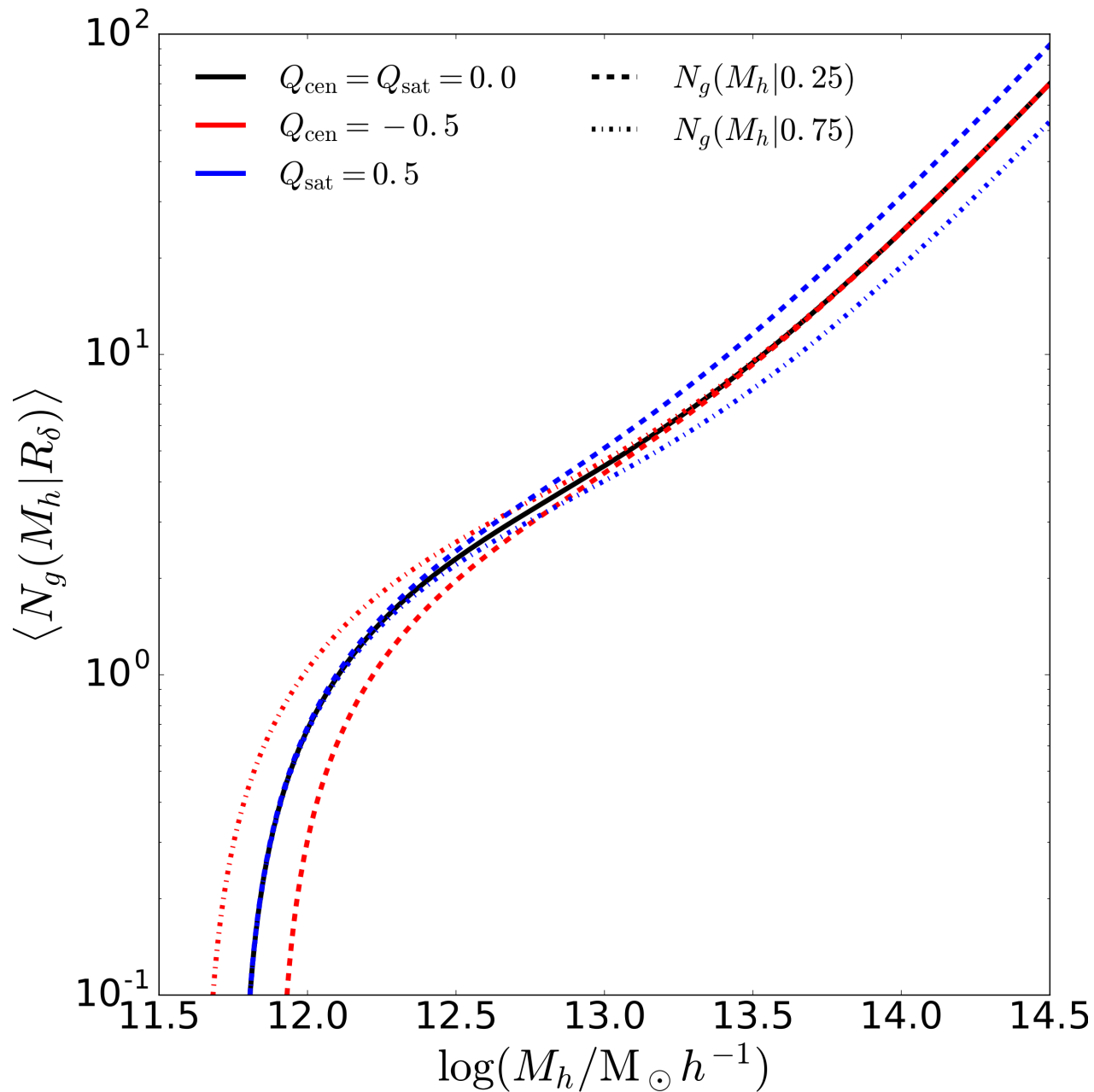
# More observable mock tests



$\sigma_{\log M} = 0.17^{+0.09}_{-0.09}$
$\sigma_{\log M} = 0.20^{+0.10}_{-0.11}$

$\log M_{\min} = 11.94^{+0.03}_{-0.03}$
$\log M_{\min} = 11.94^{+0.04}_{-0.03}$

$\log M_1 = 13.14^{+0.06}_{-0.05}$
$\log M_1 = 13.01^{+0.08}_{-0.08}$

$\alpha = 0.98^{+0.05}_{-0.05}$
$\alpha = 0.89^{+0.04}_{-0.05}$

$Q_{\mathrm{cen}} = -0.02^{+0.06}_{-0.05}$
$Q_{\mathrm{cen}} = -0.15^{+0.06}_{-0.06}$

$Q_{\mathrm{sat}} = 0.03^{+0.12}_{-0.10}$
$Q_{\mathrm{sat}} = 0.18^{+0.17}_{-0.16}$

$A_{\mathrm{con}} = 0.83^{+0.10}_{-0.11}$
$A_{\mathrm{con}} = 0.79^{+0.11}_{-0.13}$

Bolshoi

ELUCID
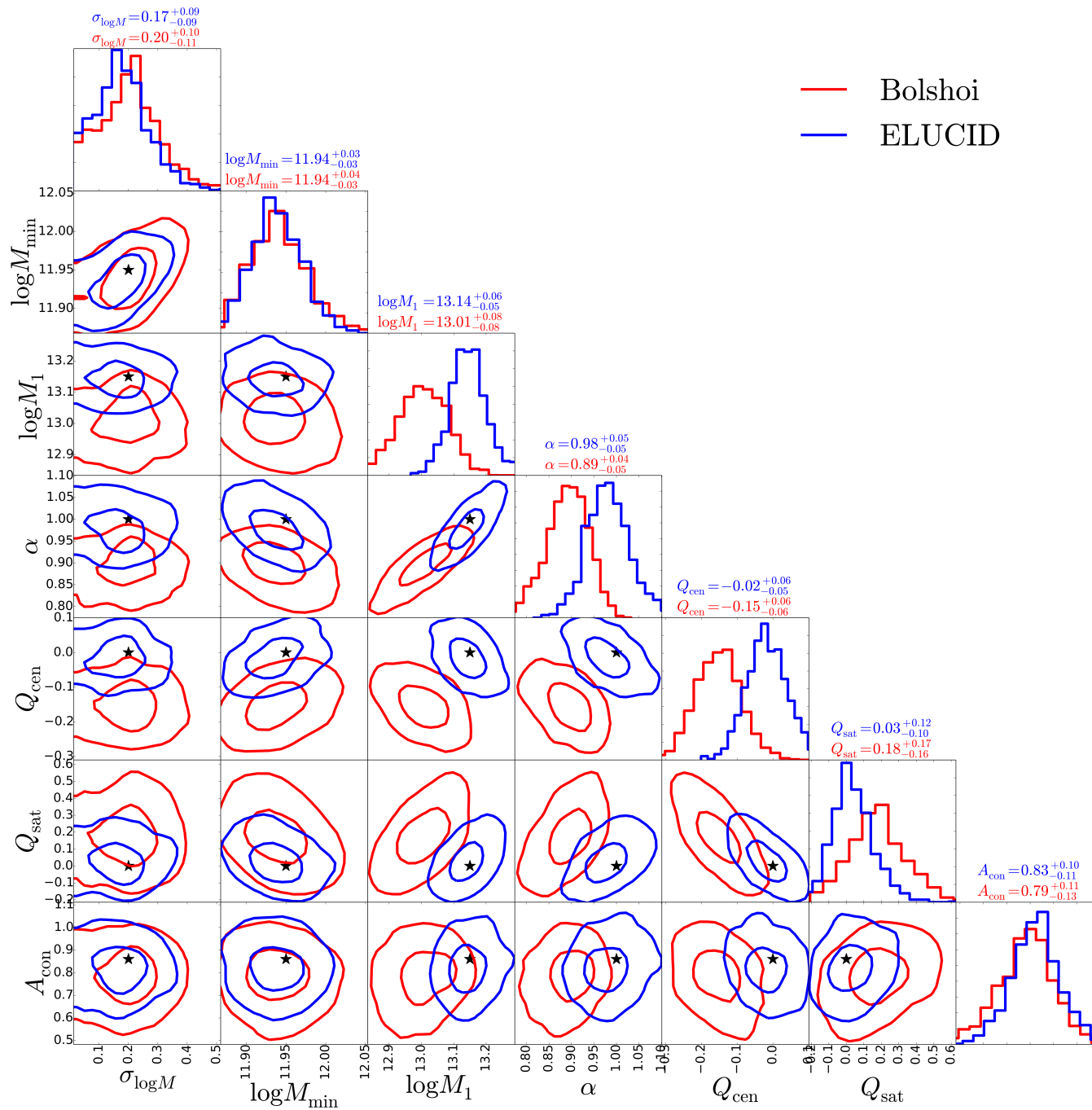
# Fits to SDSS data

# Secondary bias of mass-like properties



Binned by $M_h$ — Binned by $V_{max}$ — Binned by $M_{peak}$ — Binned by $V_{peak}$

Split by $M_h$ / Split by $V_{max}$ / Split by $M_{peak}$ / Split by $V_{peak}$

Top 25%
Bottom 25%

$\log_{10}(M_h)$ [$h^{-1}M_\odot$] — $V_{max}$ [km s$^{-1}$] — $\log_{10}(M_{peak})$ [$h^{-1}M_\odot$] — $V_{peak}$ [km s$^{-1}$]

Salcedo et al. (2018)
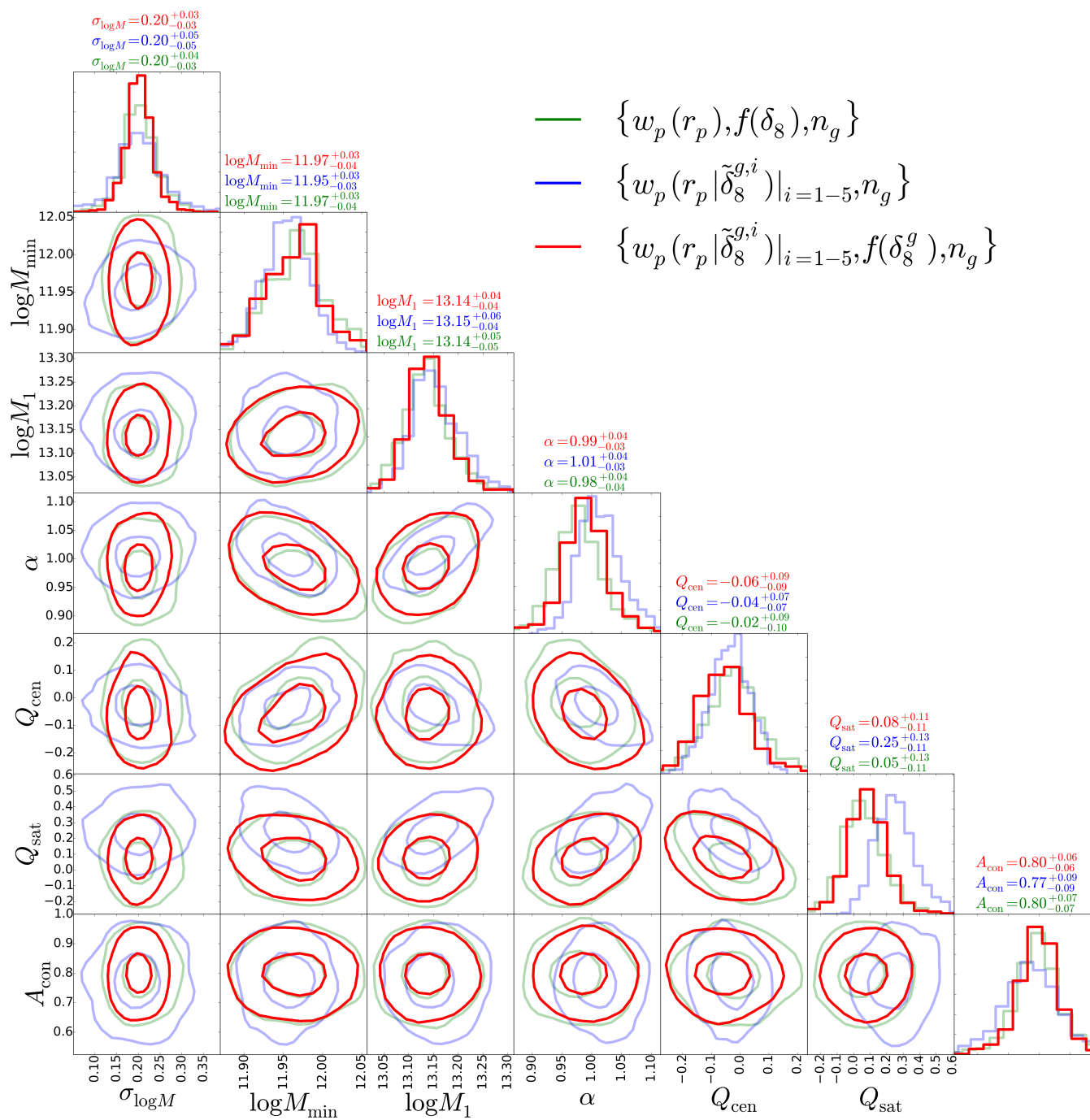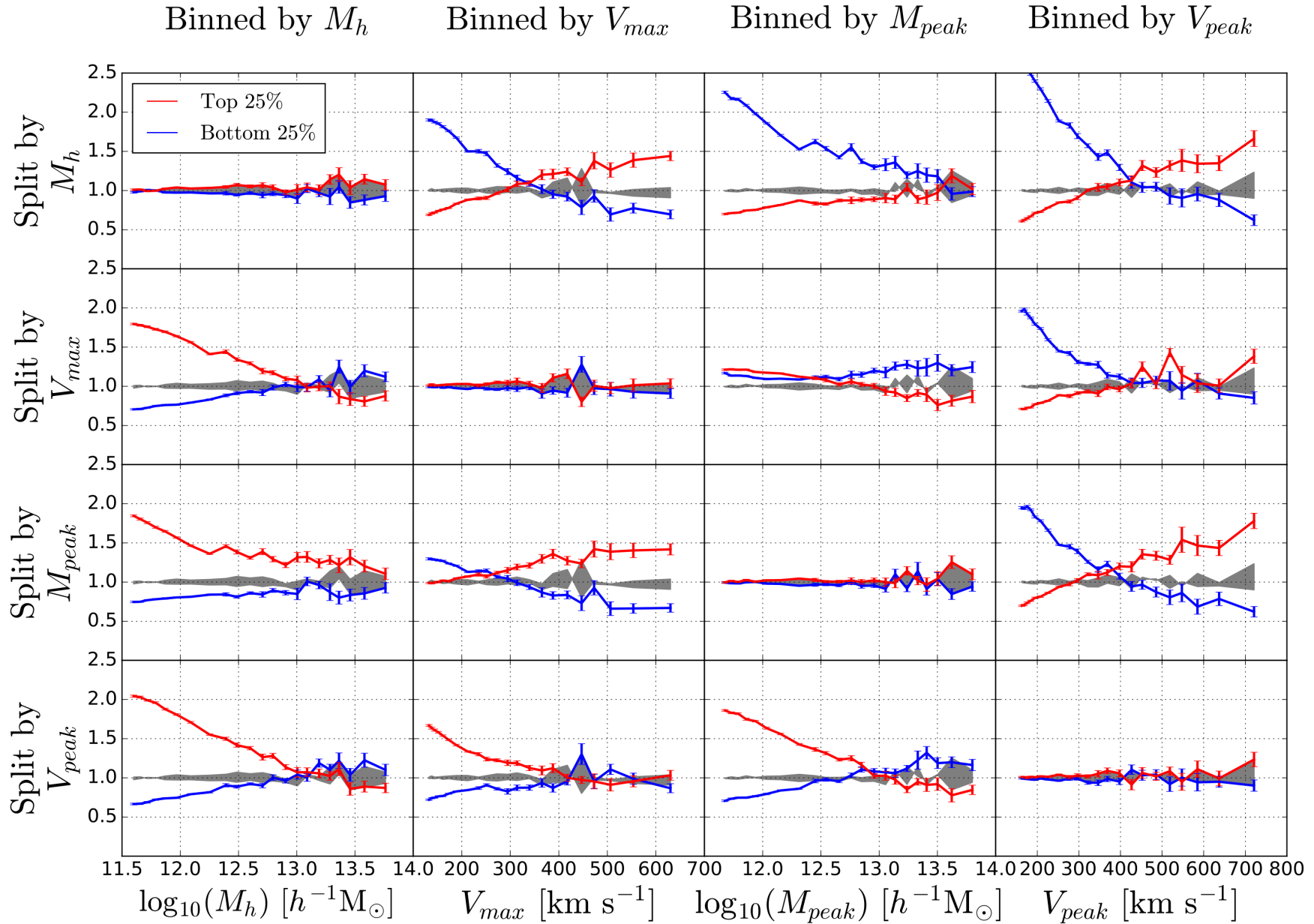
# Secondary bias of mass-like properties
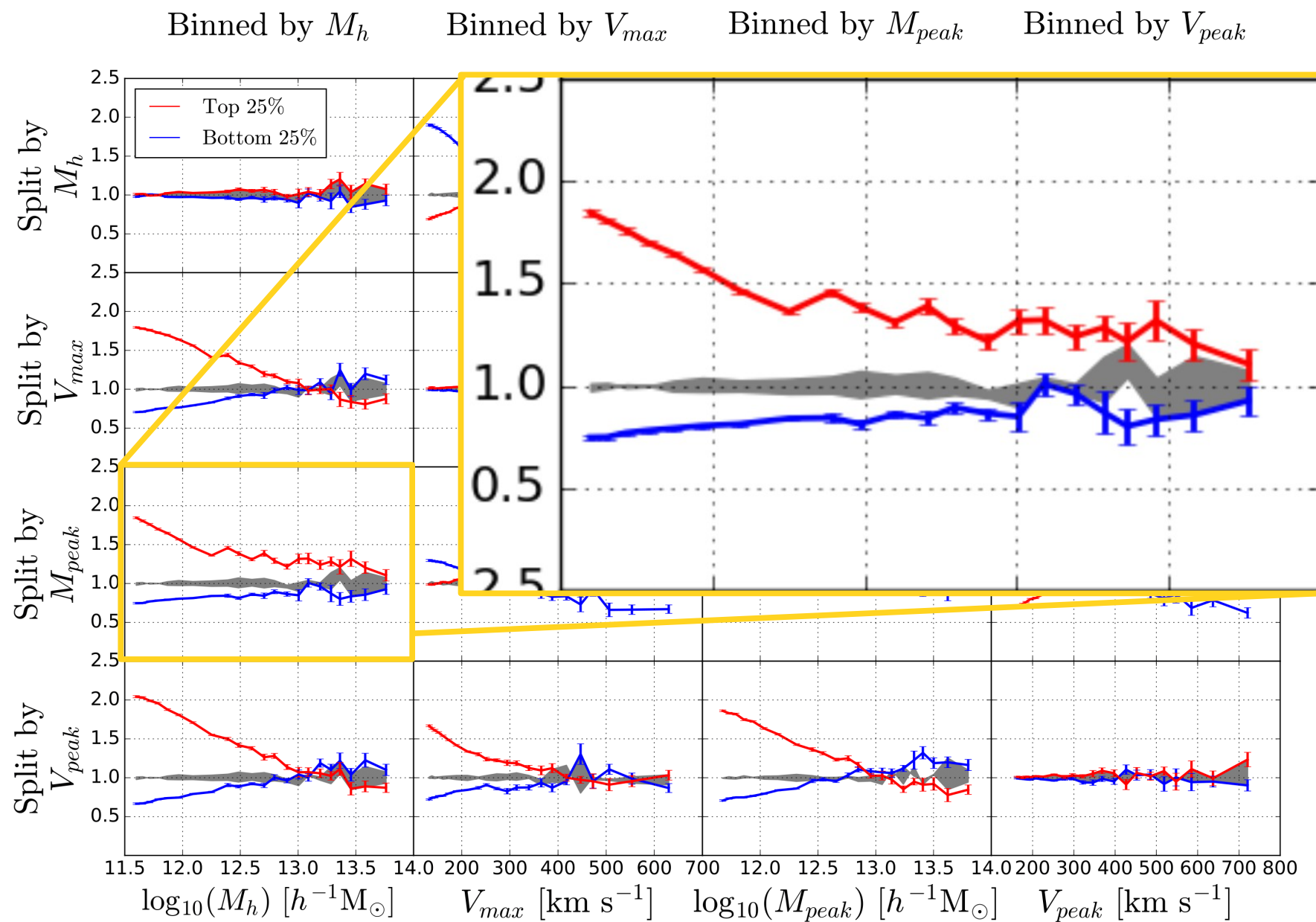
# Neighbor normalization and bias, bins of v-max



Salcedo et al. (2018)
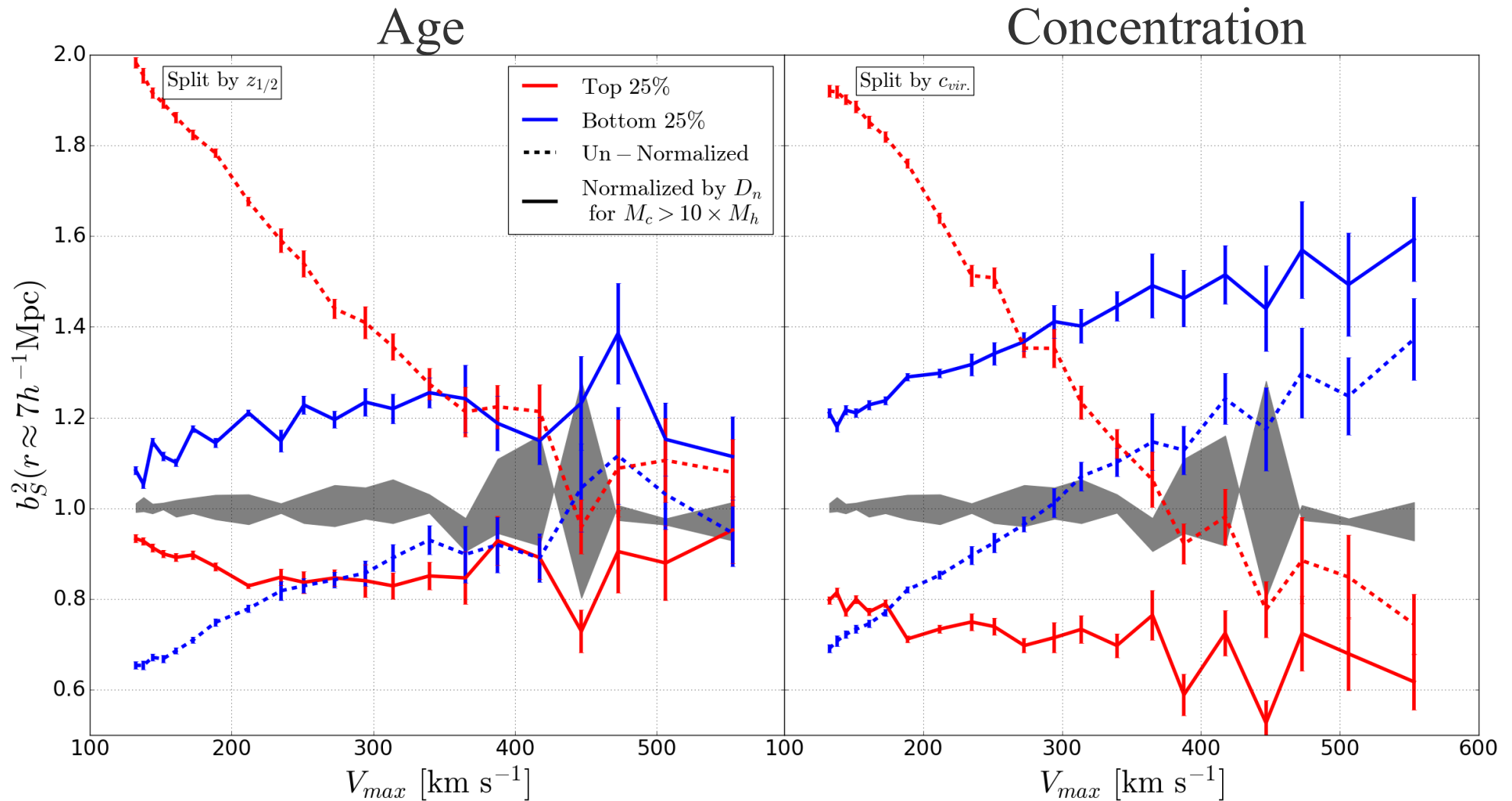
# Analytic vs. numerical covariances



Salcedo et al. (2020)
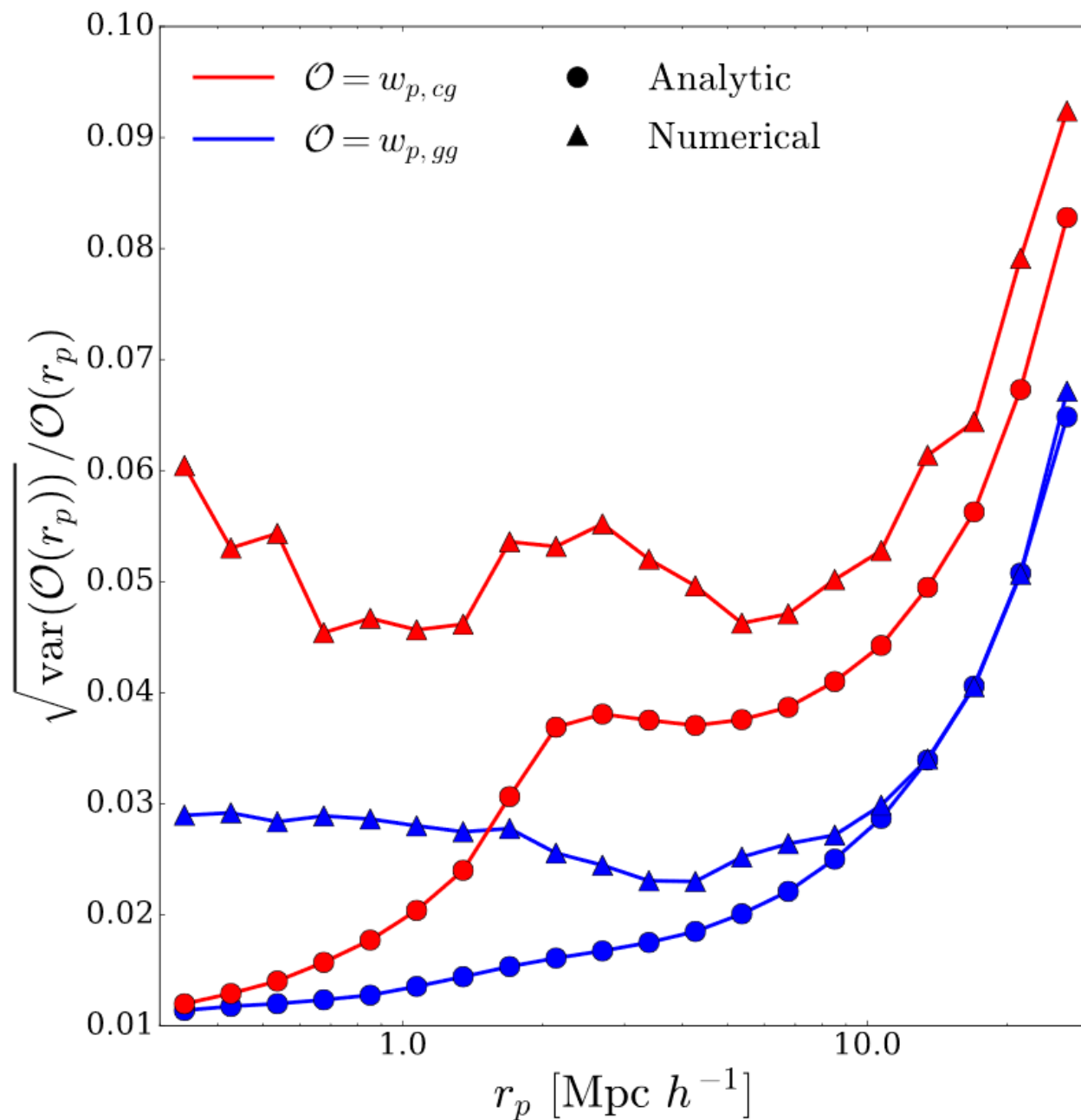
# Clustering Covariance



Numerical

Analytic

$r^{\mathrm{N}}_{p,cg}$

$r^{\mathrm{N}}_{p,gg}$

$r^{\mathrm{N}}_{p,cg}$

$r^{\mathrm{N}}_{p,gg}$

$r^{\mathrm{A}}_{p,cg}$

$r^{\mathrm{A}}_{p,gg}$

$r^{\mathrm{A}}_{p,cg}$

$r^{\mathrm{A}}_{p,gg}$

Salcedo et al. (2020)
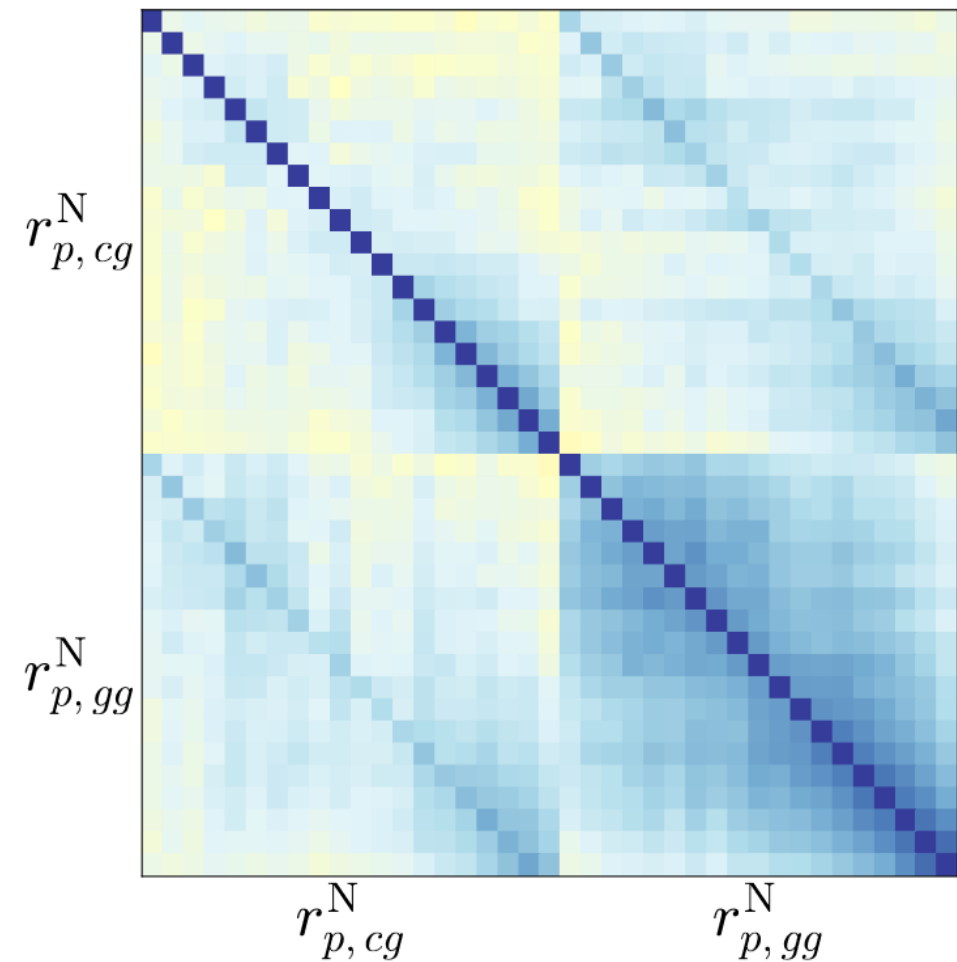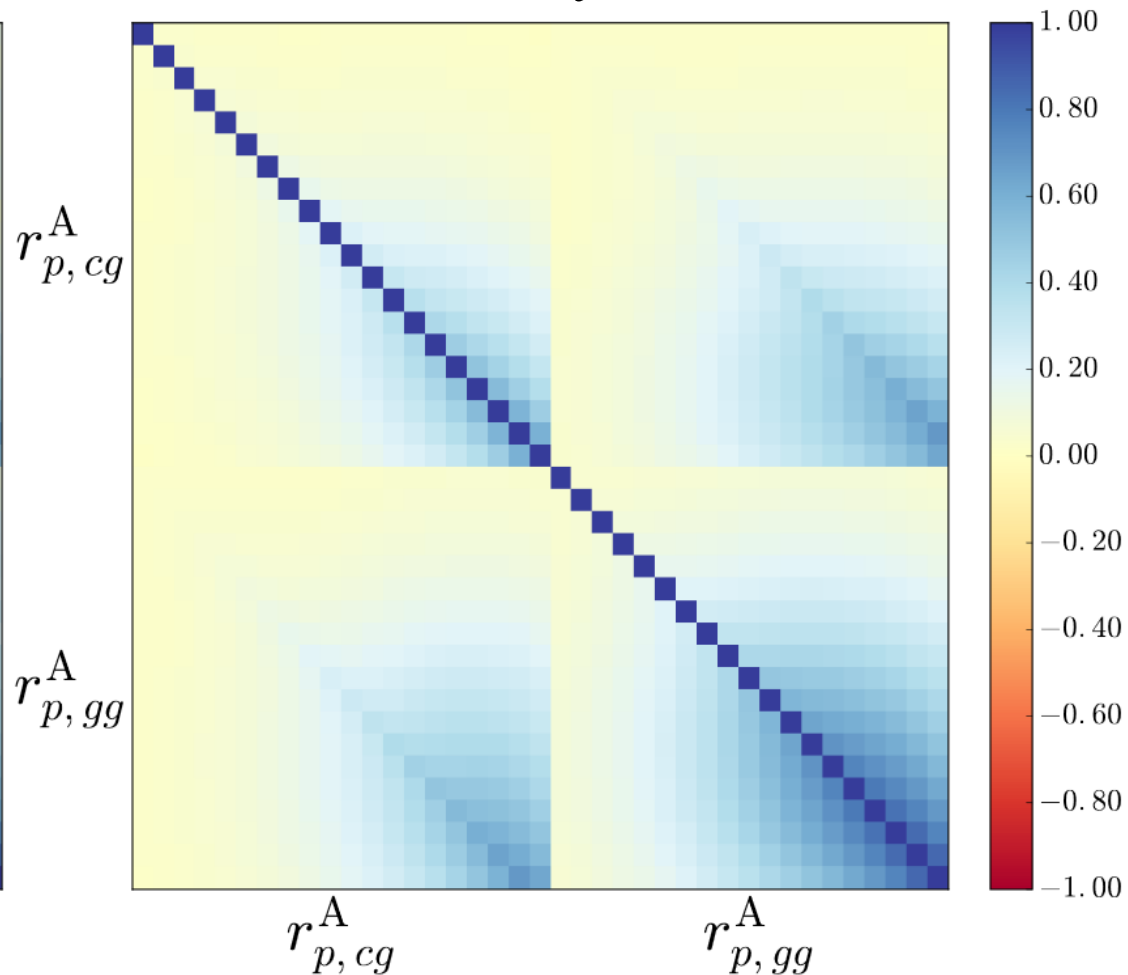
# Lensing Covariance
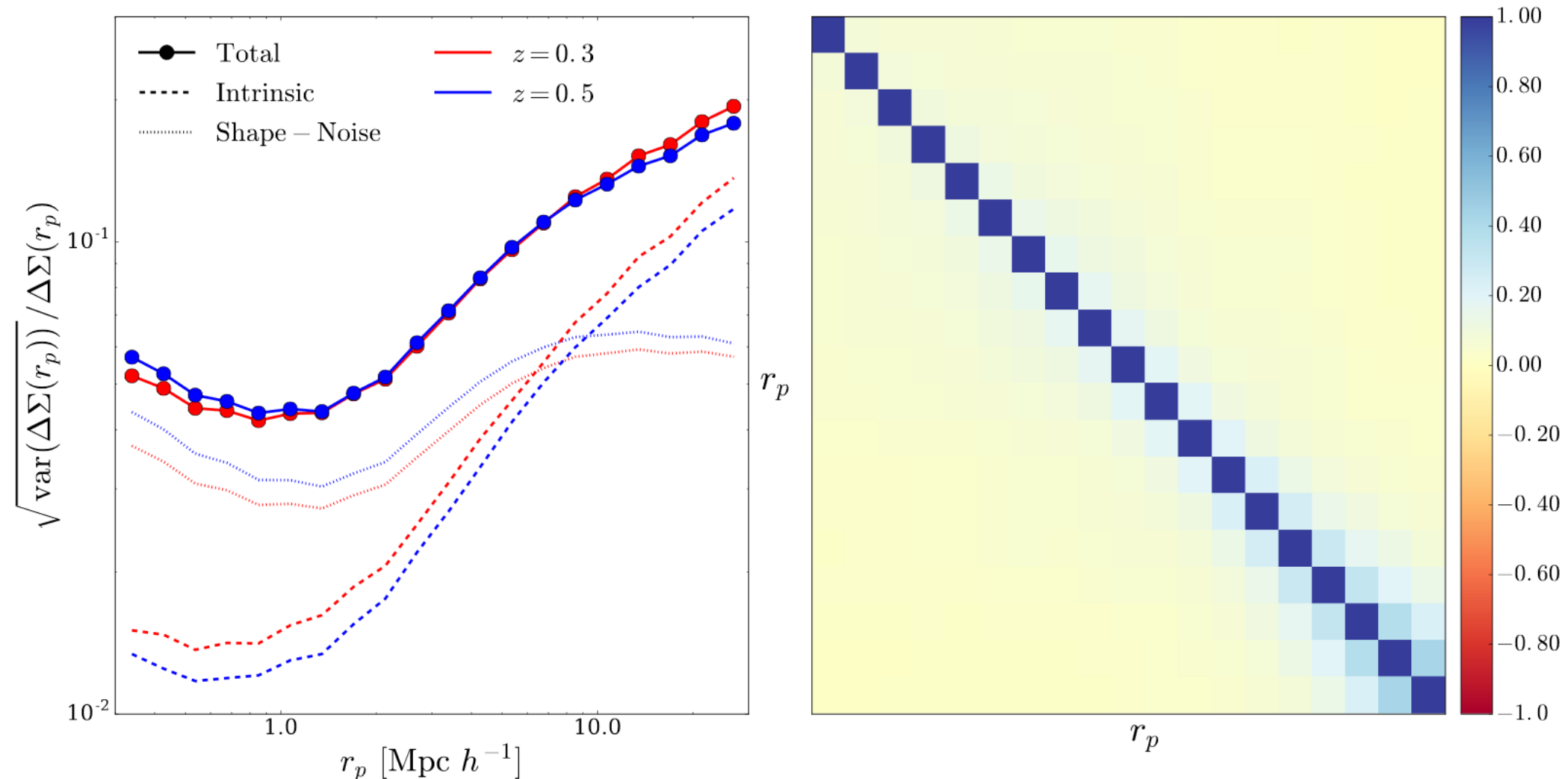


For more details see Wu et al. 2019

Salcedo et al. (2020)

# Novel galaxy observables



Salcedo et al. in prep