Cosmological modeling of optically-selected clusters

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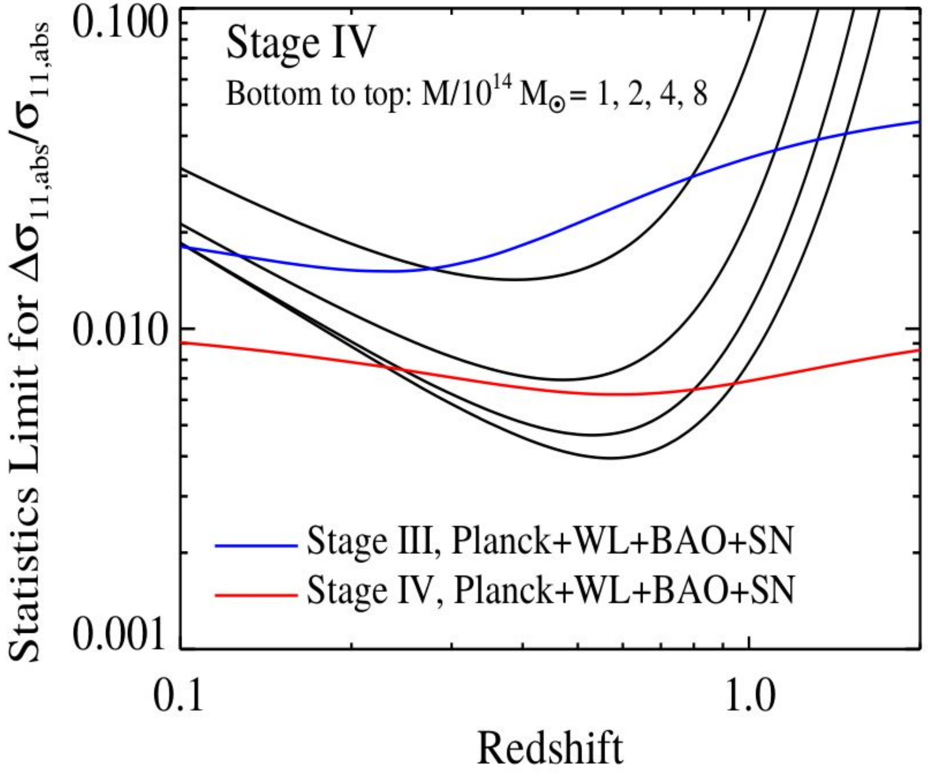
Dissecting cluster cosmology: toward a roadmap for forthcoming cluster surveys
Institute for Fundamental Physics of the Universe

THE UNIVERSITY OF ARIZONA

The cosmological potential of clusters

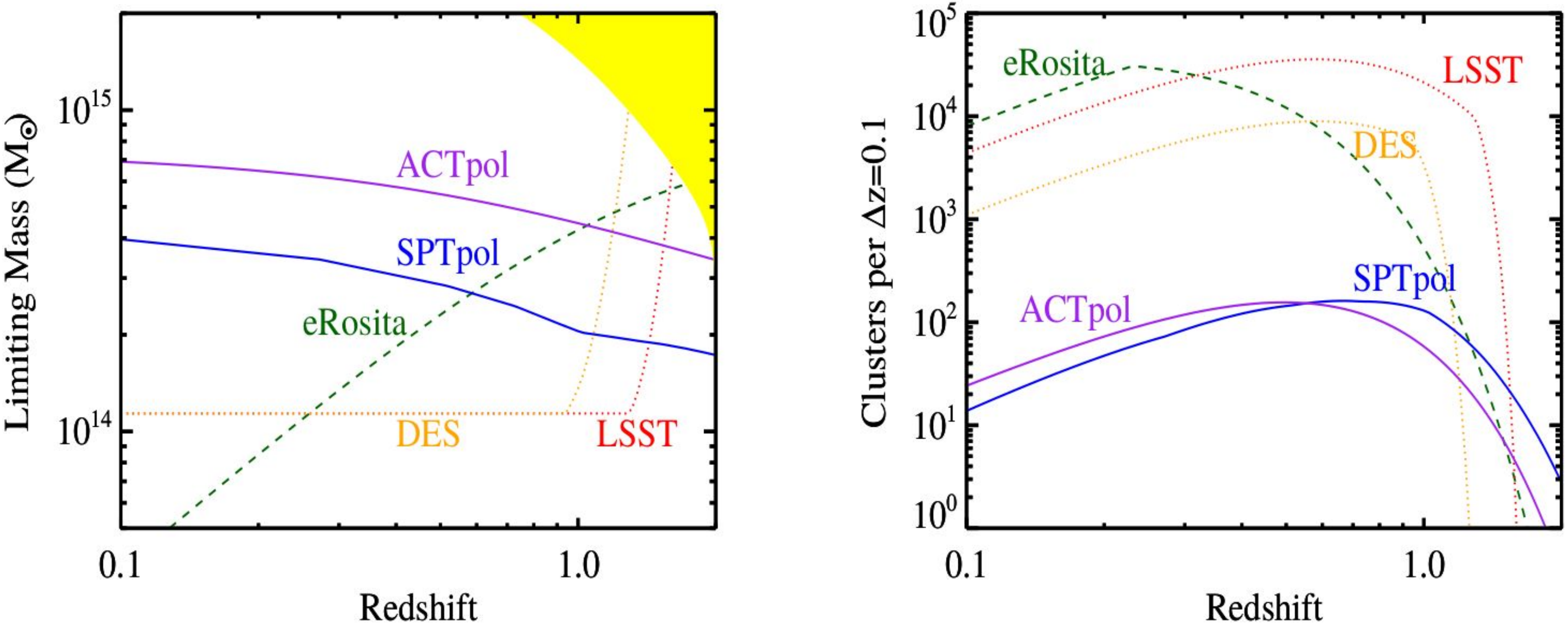


Assuming:

- Redshift bins of width $z \pm 0.05$.
- a 10^4 sq. deg. Survey
- Source density of 30 arcmin^{-2}
- Negligible uncertainty on Ω_m
- Systematics are controlled!

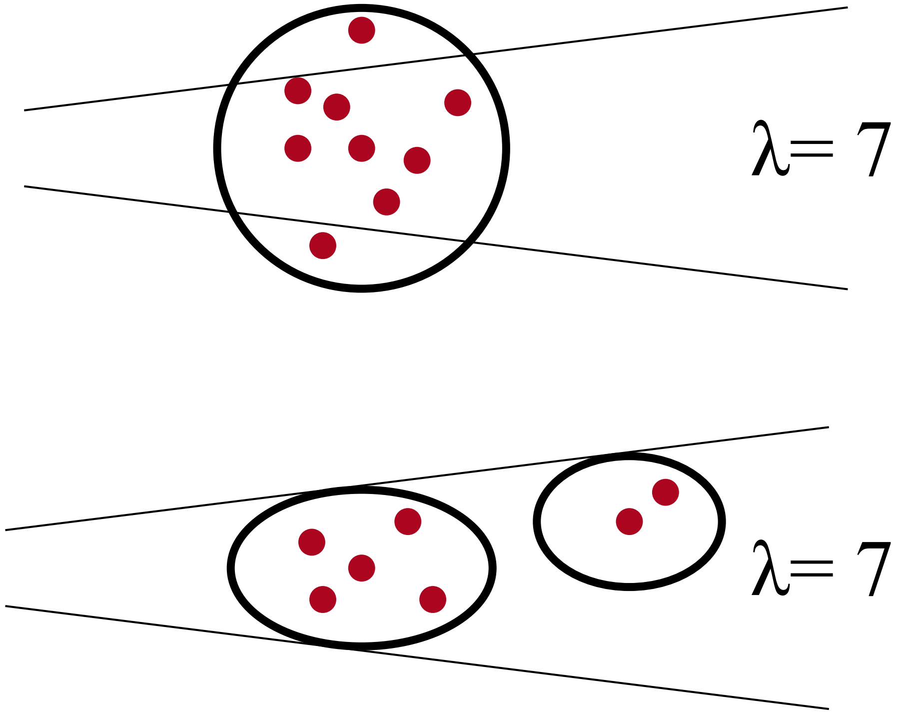
Weinberg et al. 2013

Optical vs. X-ray vs. CMB cluster selection



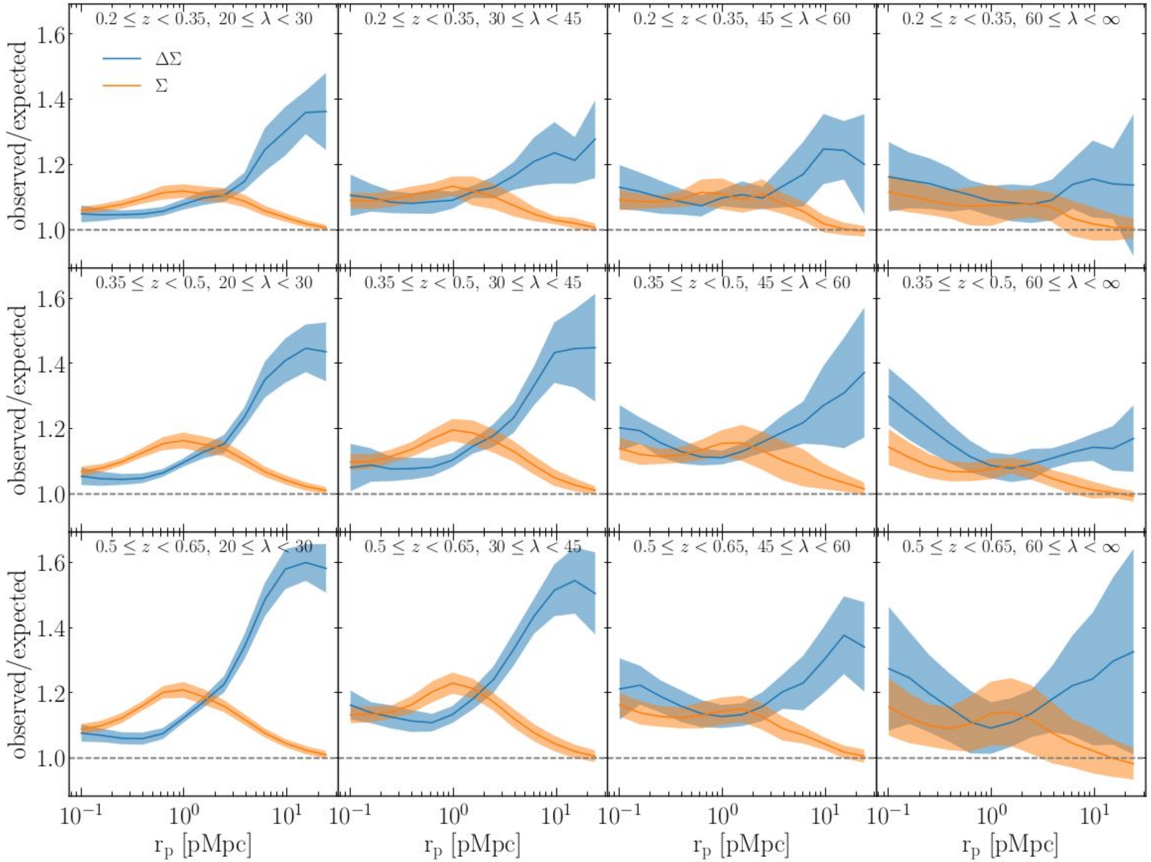
Weinberg et al. 2013

Selection effects in optical clusters



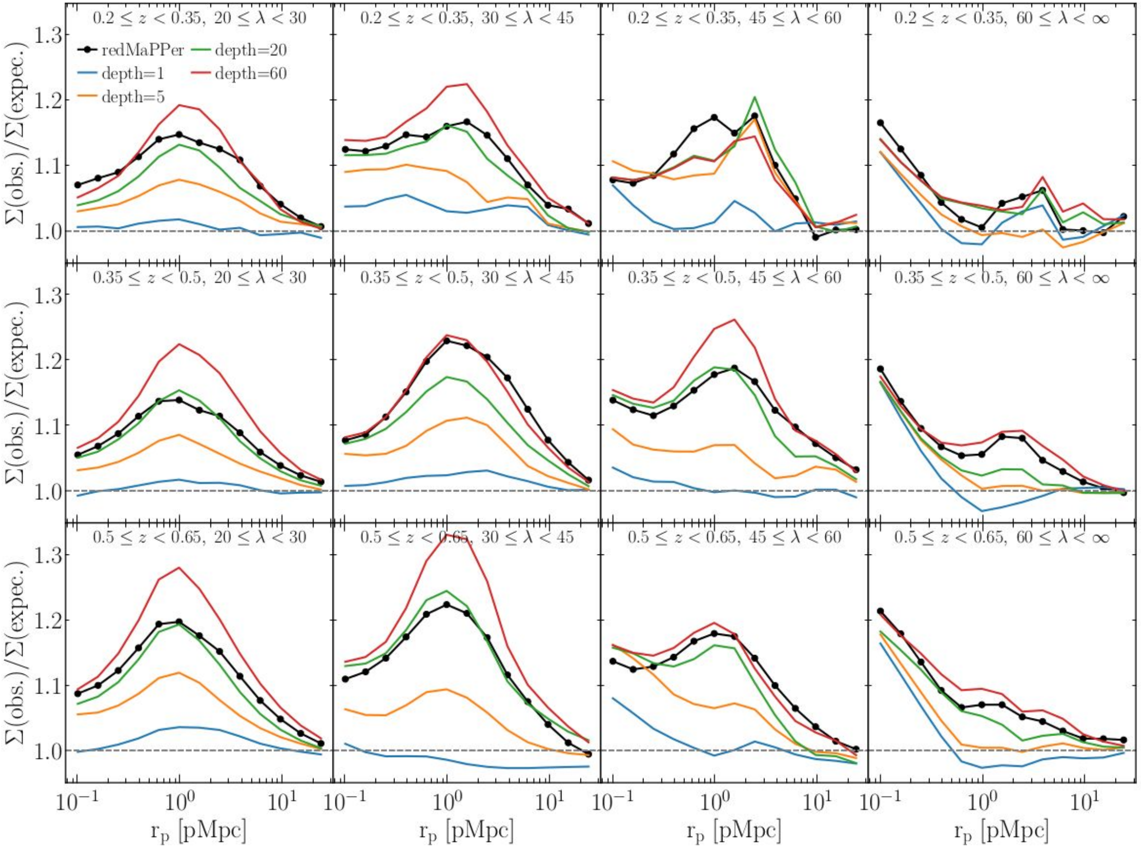
- Structure along the line of sight can spuriously enhance optical richness.
- Halo orientation with respect to line of sight can change the richness within selection aperture.
- Non-trivially breaks expected relation between cluster mass and 2-pt. observables.

Selection effect phenomenology: impact on lensing



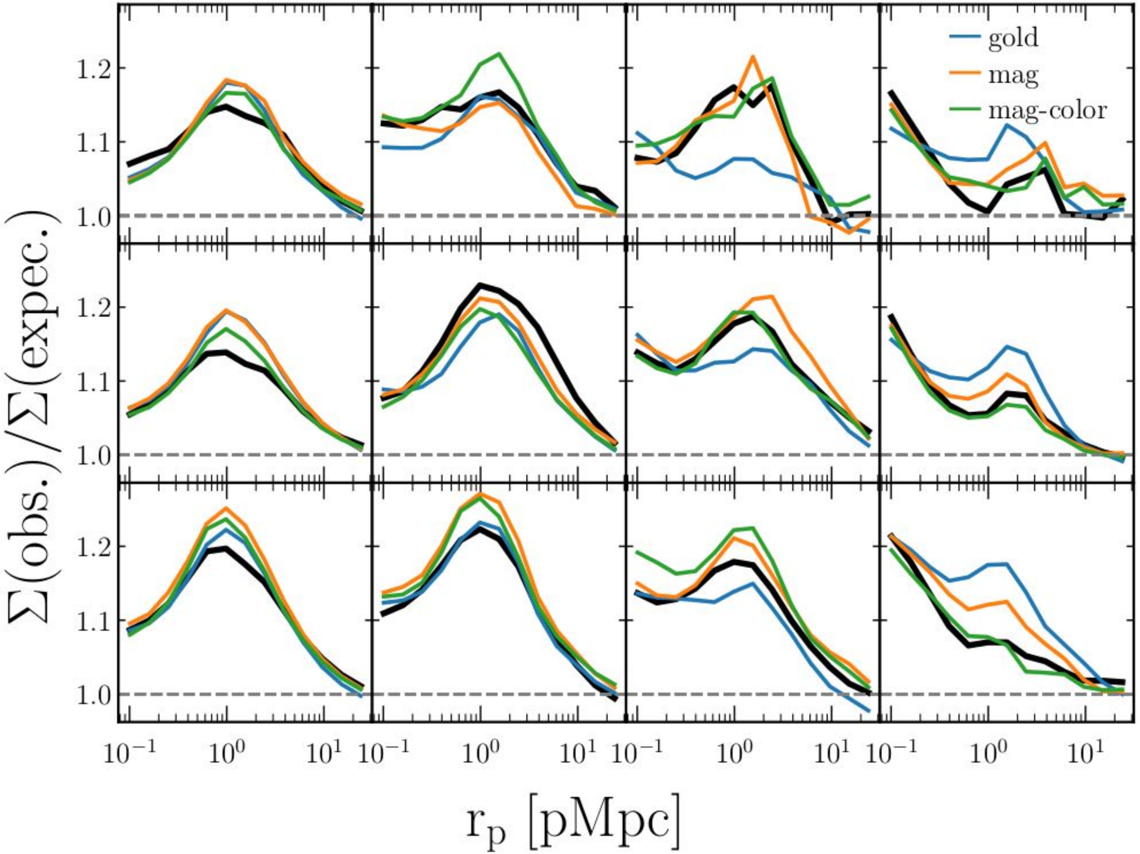
Wu et al. 2022

Selection effect phenomenology: comparison with cylinder selection



Wu et al. 2022

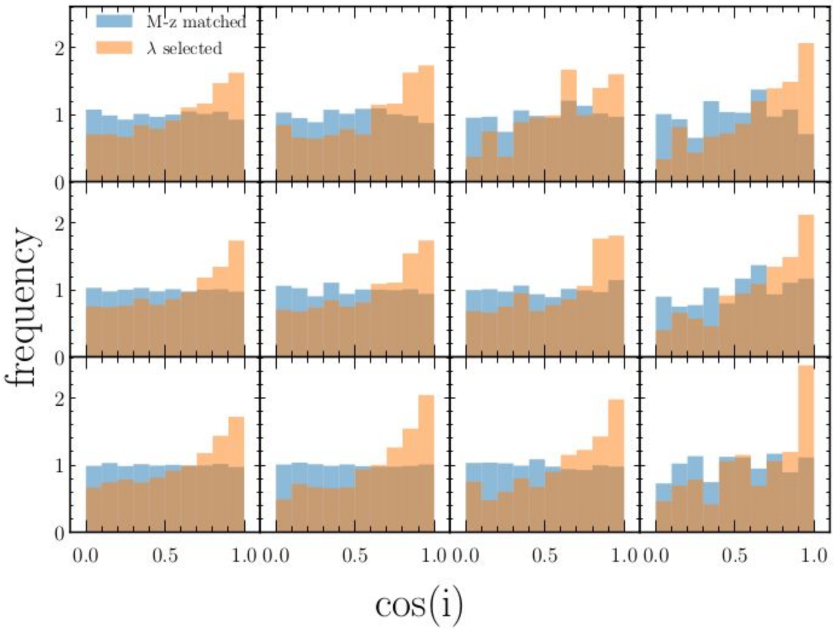
Selection effect phenomenology: dependence on “member” sample



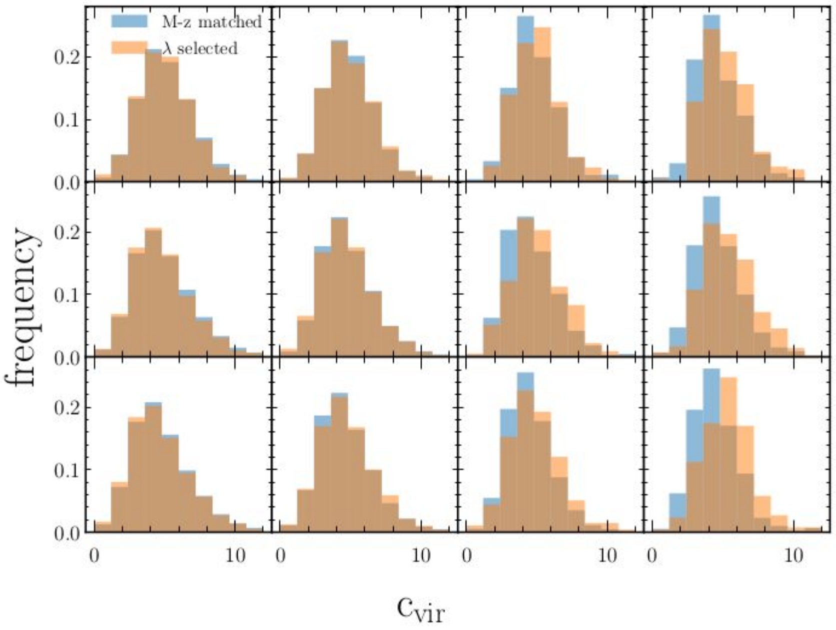
Wu et al. 2022

Selection effect phenomenology: concentration and orientation bias

orientation

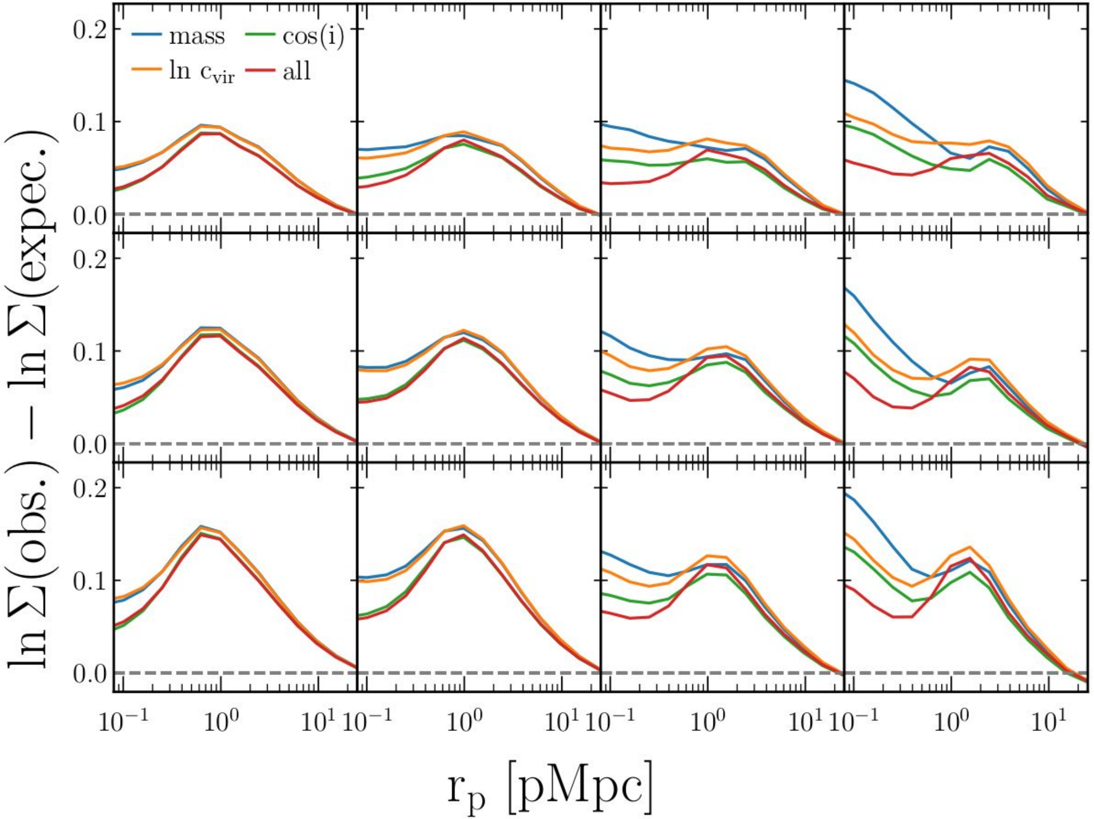


concentration



Wu et al. 2022

Selection effect phenomenology: importance of 1- vs. 2-halo effect



Wu et al. 2022

Selection effect mitigation strategies

- Remove problematic scales (e.g. To et al. 2021a, b, Zeng et al. 2023).
- Combine with overlapping multi-wavelength data (e.g. Rozo & Rykoff 2014, Saro et al. 2015, Farahi et al. 2019, Costanzi et al. 2021, Grandis et al. 2021a).
- Combine with cluster-clustering observables (e.g. Salcedo et al. 2020, Chiu et al. 2020, To et al. 2021a,b, Park et al. 2023, Zeng et al. 2023, Sunayama 2023).
- Combine with spectroscopic observations (e.g. Myles et al. 2021, Wetzell et al. 2021).
- Redefine cluster selection (e.g. Huang et al. 2022, Xhakaj et al. 2023).
- Apply a parametric correction (e.g. Sunayama et al. 2018, Park)
- Forward model optical cluster selection (e.g. Costanzi et al. 2019a, Salcedo et al. in prep).

Selection effect mitigation strategies

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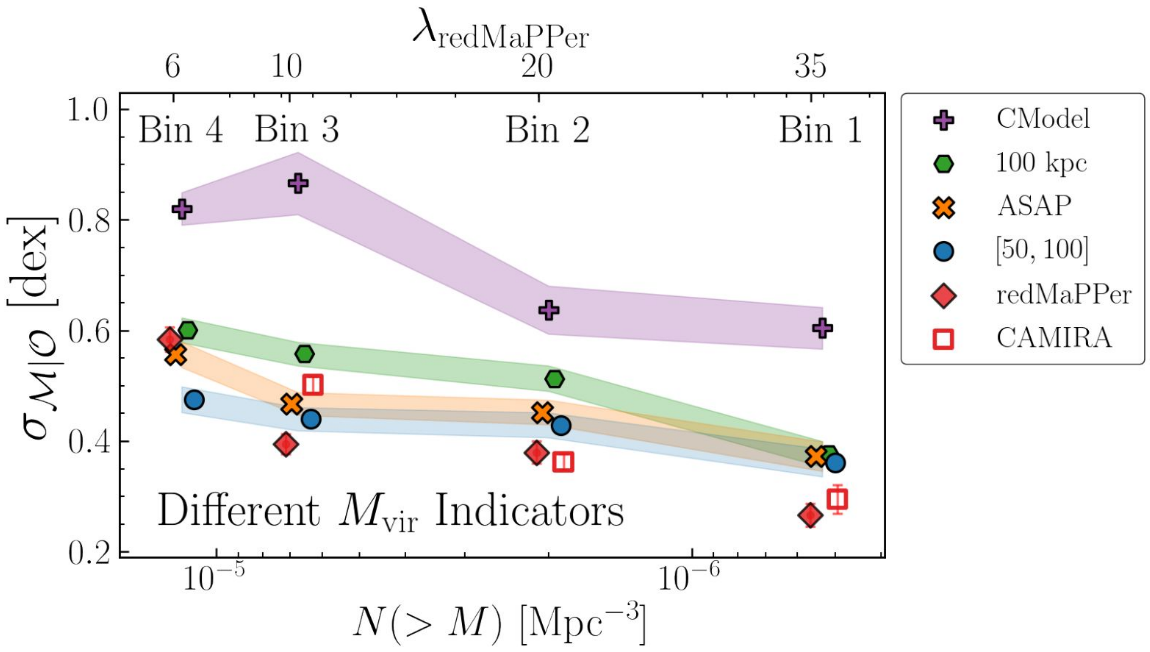
Optical cluster selection without projection effects?

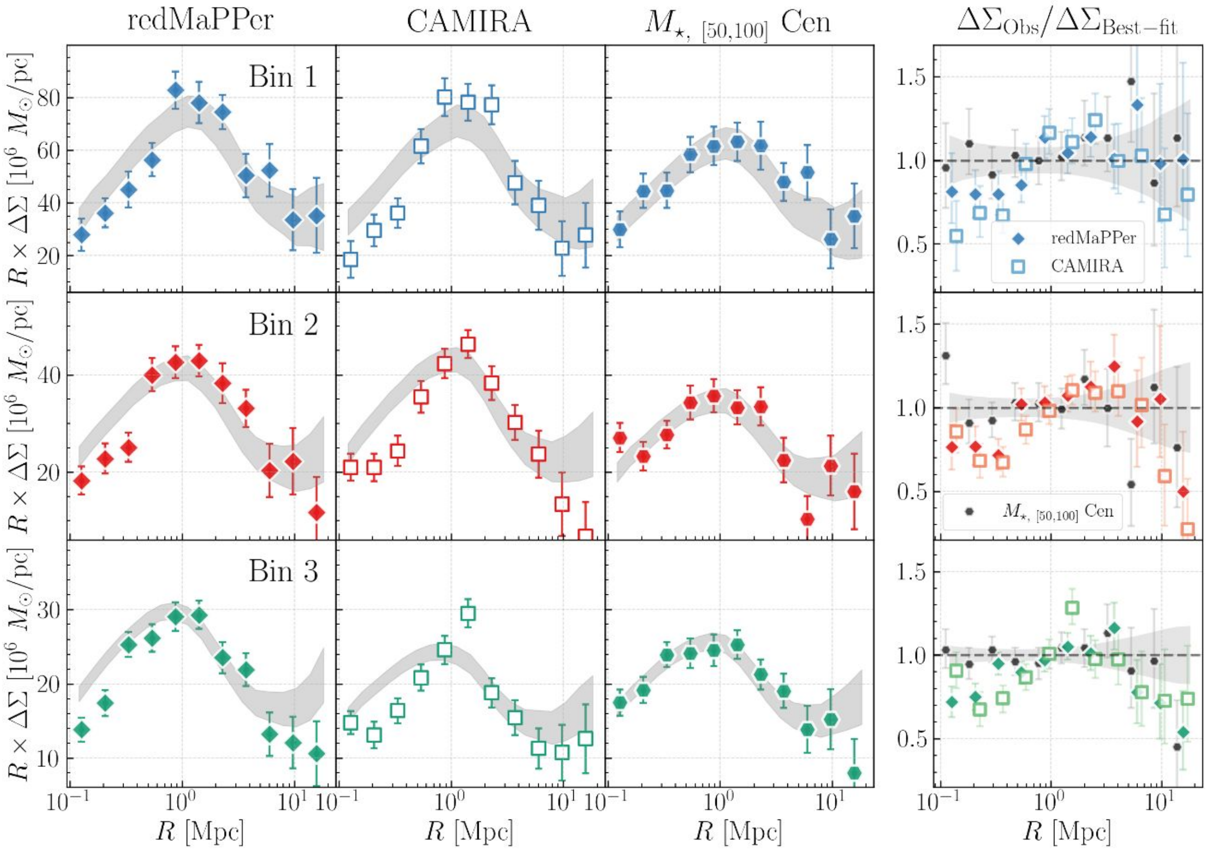
Huang et al. 2022: Outer stellar mass as halo mass proxy



- Scatter in mass-observable relation from HSC lensing for different mass-proxies.
- Inner-stellar mass (purple) is a bad proxy for halo mass.
- Outer-stellar mass (blue) is almost as good as richness, but…

Huang et al. 2022

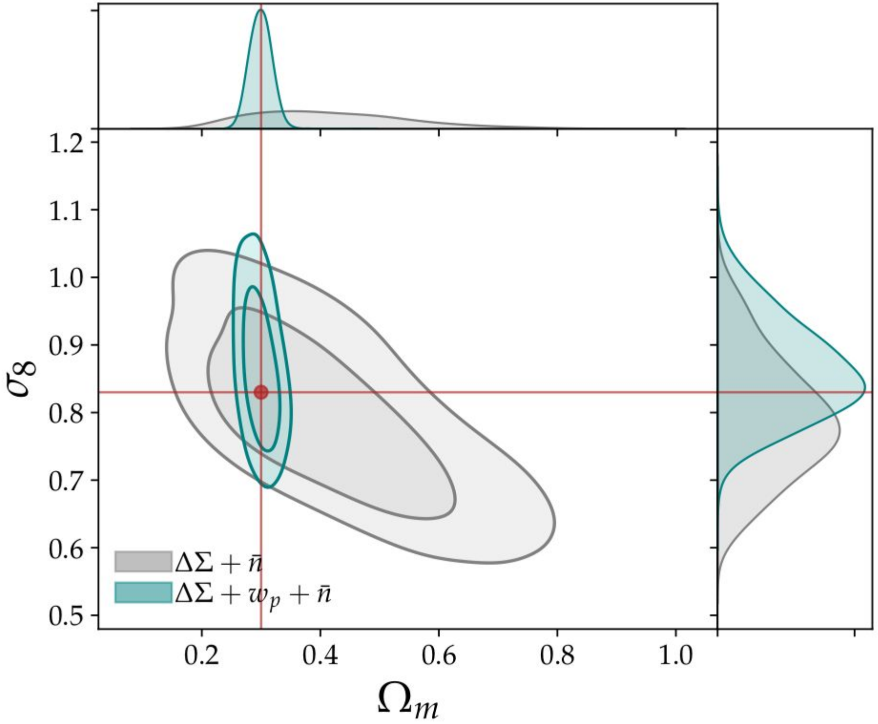
Huang et al. 2022: Is outer stellar mass free of projection effects?

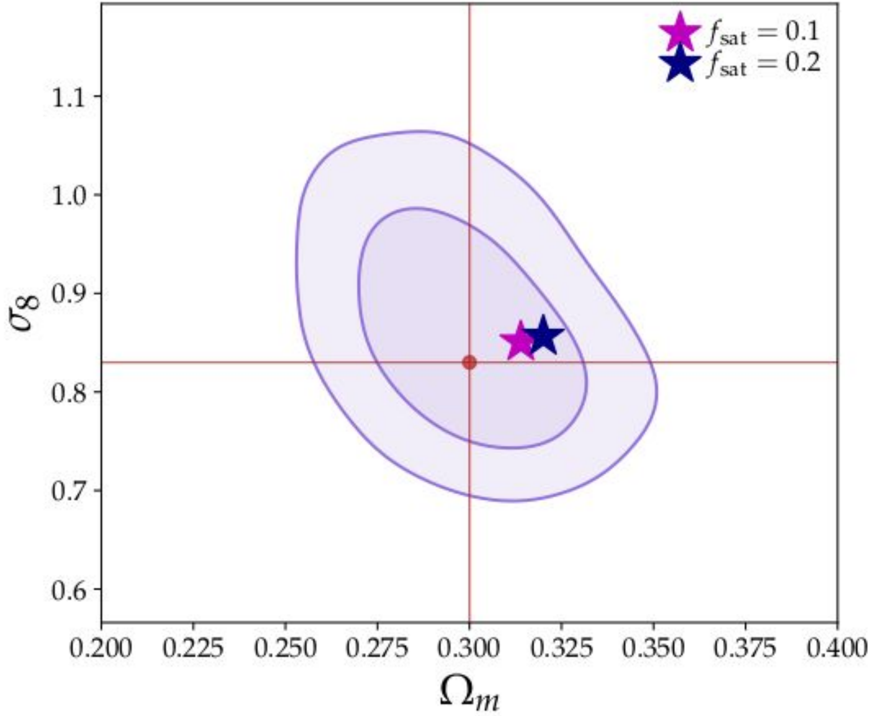


- Measurements of redMaPPer, CAMIRA, and outer-stellar mass selected cluster HSC lensing.
- Outer stellar mass sample includes satellite removal procedure.
- Comparison with best-fitting projection-less lensing model.

Huang et al. 2022

Xhakaj et al. 2023: Cluster cosmology without cluster finding

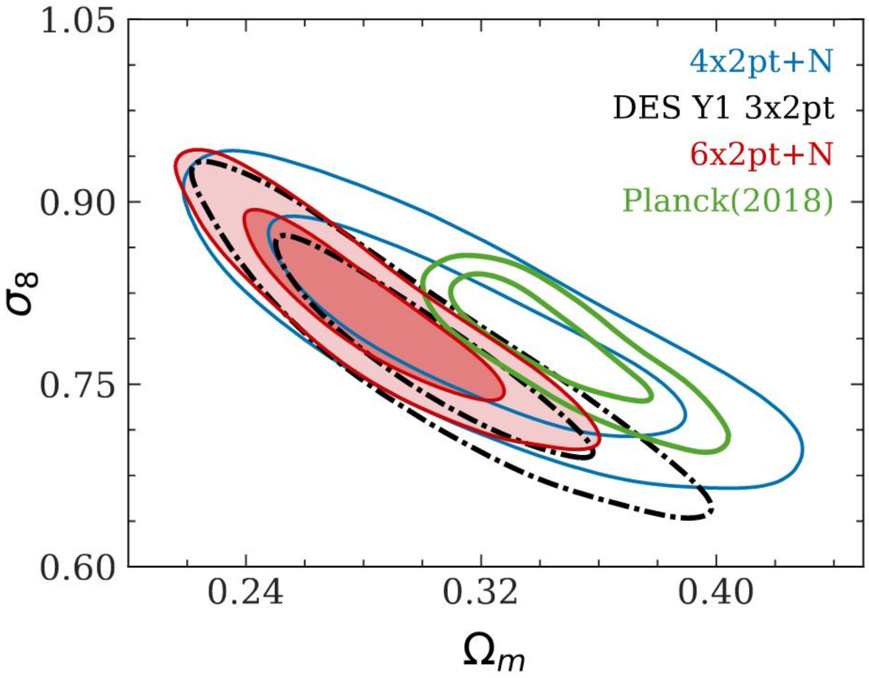




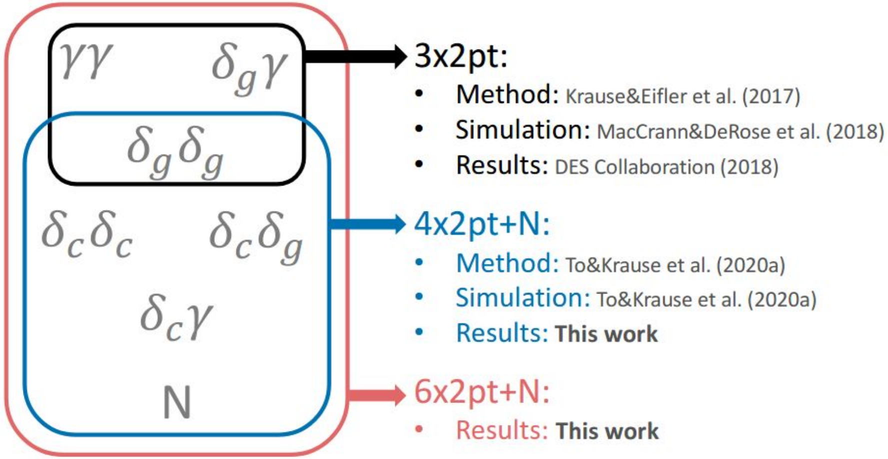
Xhakaj et al. 2022

Combining cluster lensing with cluster-clustering

To et al. 2021b: Multi-probe cluster cosmology at large scales

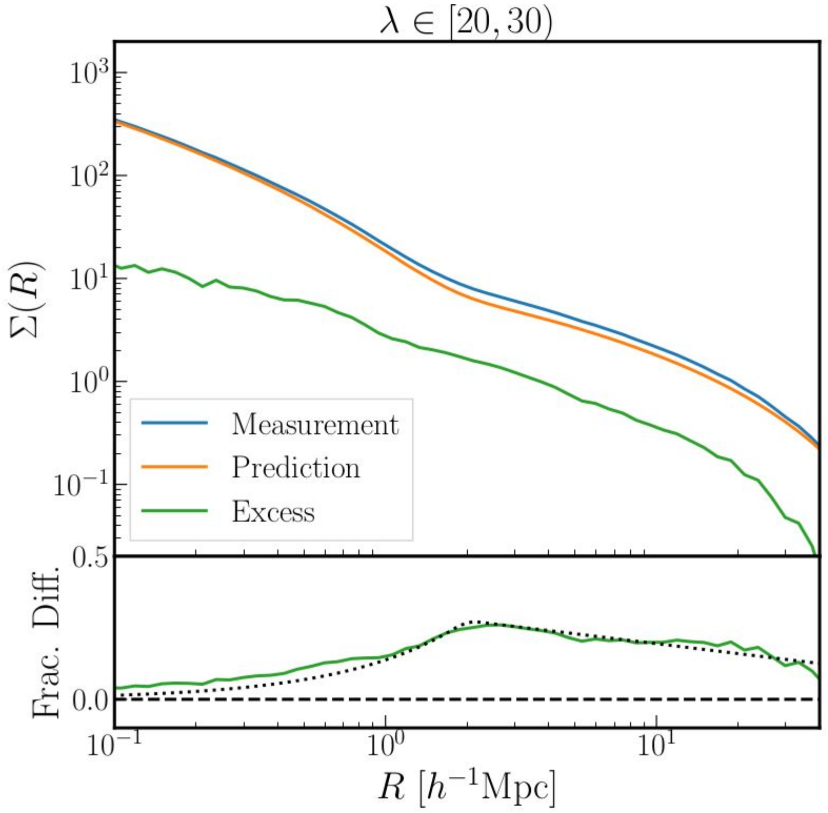


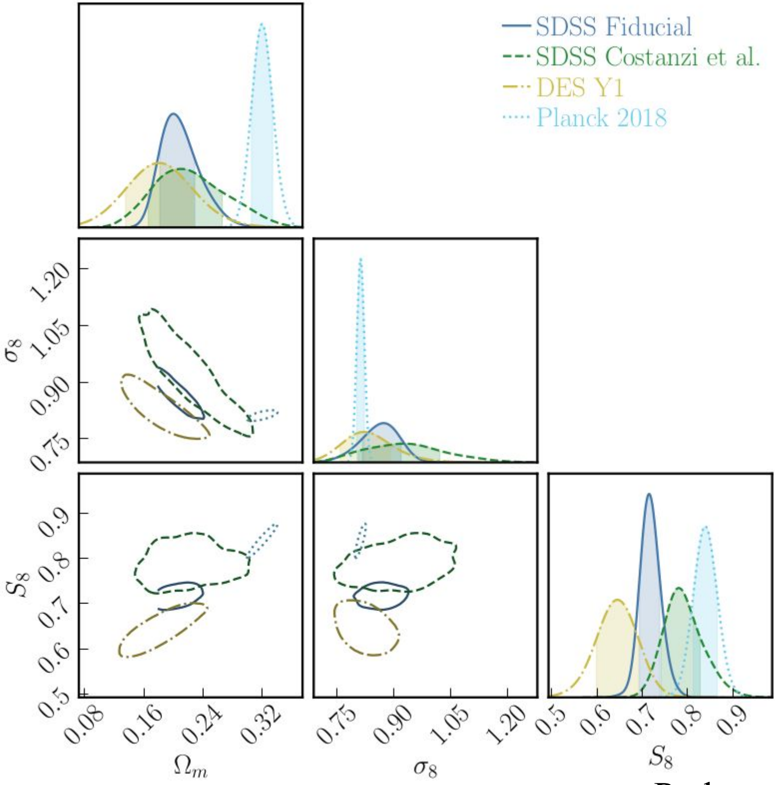
DES-Y1 clusters, galaxies and lensing; restricted to r_p > 8 Mpc/h



To et al. 2021b

Park et al. 2022: SDSS cluster lensing, abundances, and clustering

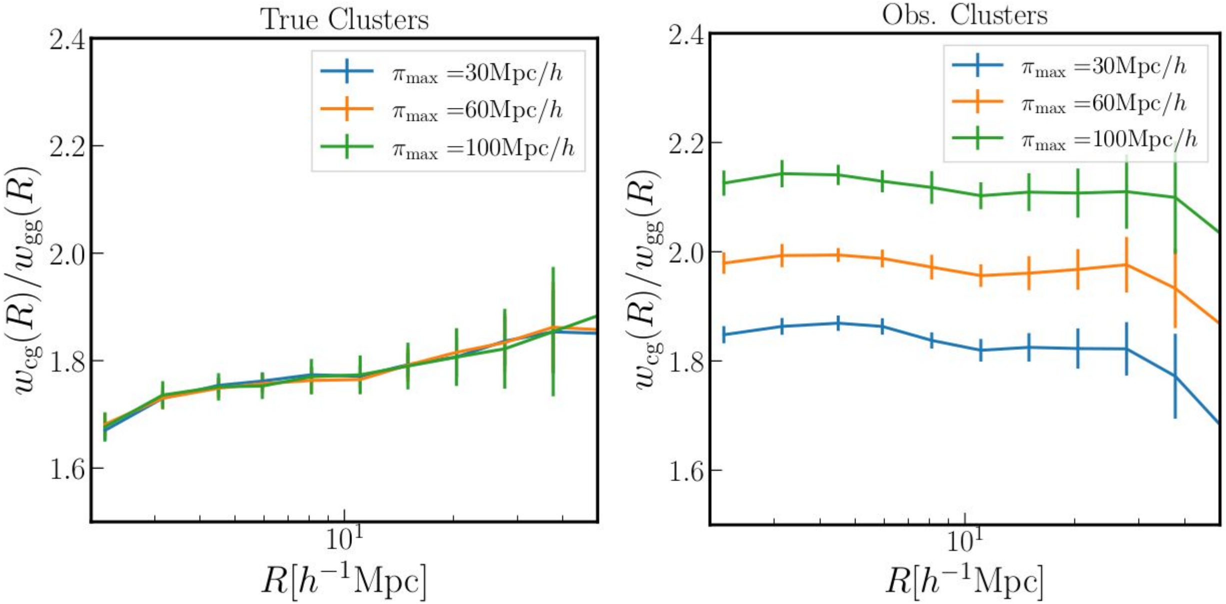




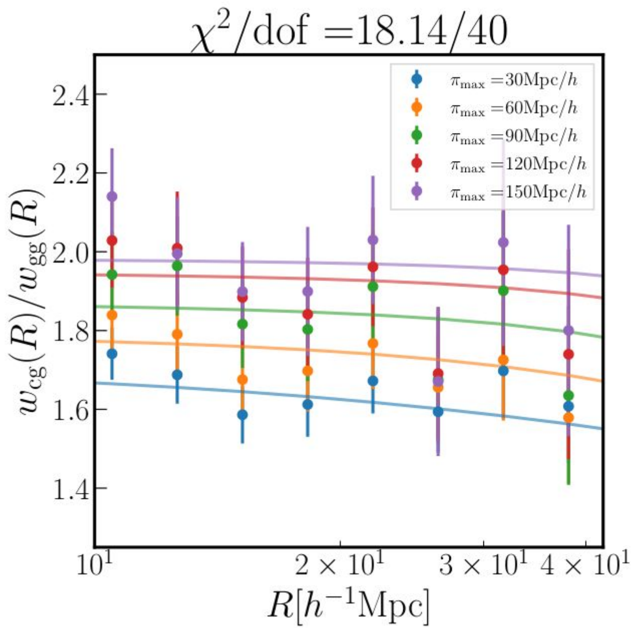
Park et al. 2022

Sunayama 2023: A novel method to constrain the projection depth

Simulation-based mock



SDSS redMaPPer observations



Sunayama 2023

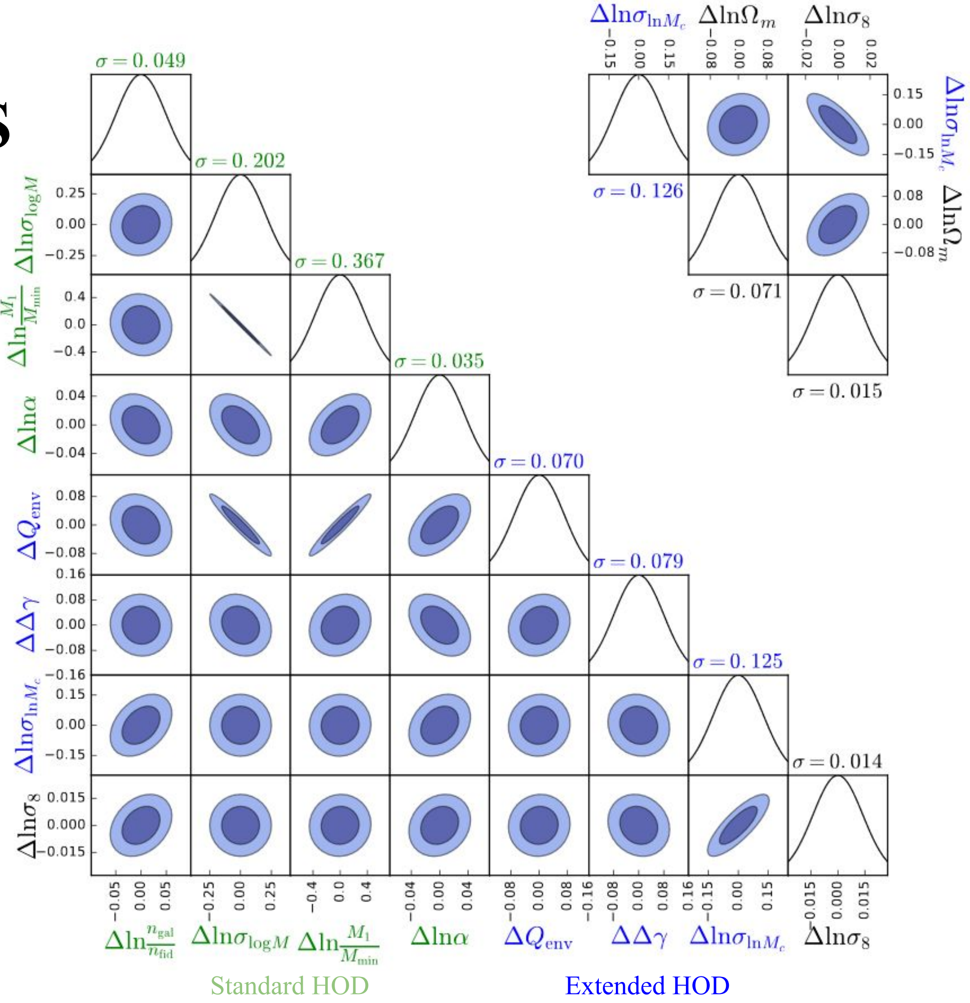
Forecasting small scale clustering and lensing in DES

Salcedo et al. 2020: Combining 1- and 2-halo scales of cluster lensing ΔΣ, $w_{p,cg}$, and $w_{p,gg}$ in DES-Y6 yields forecasted constraint of ~1.5% on σ_8

$$\Delta\Sigma \propto \xi_{cm} \propto b_c \sigma_8^2,$$

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

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



Salcedo et al. 2020

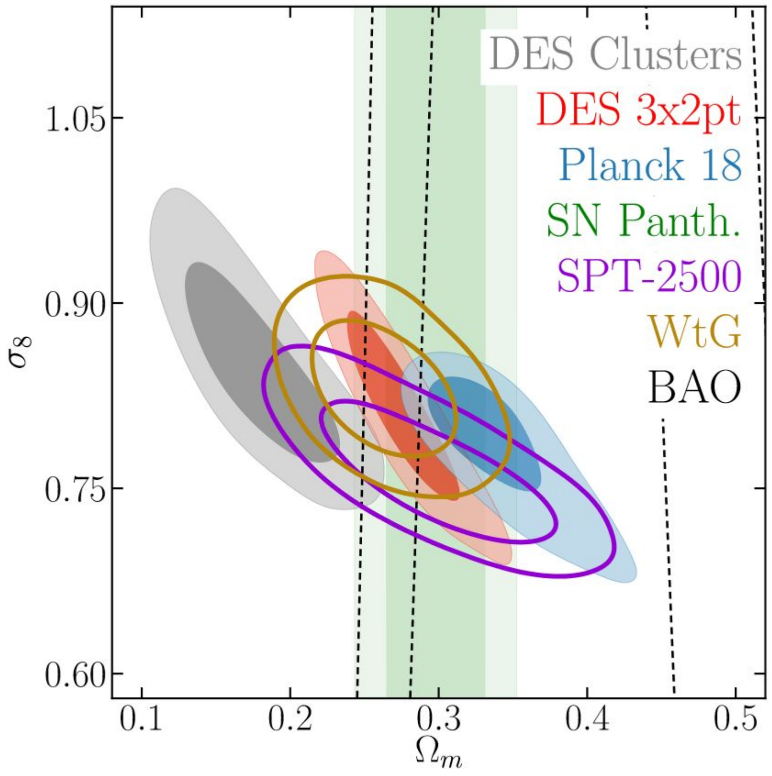
Forecasting small scale clustering and lensing in DES

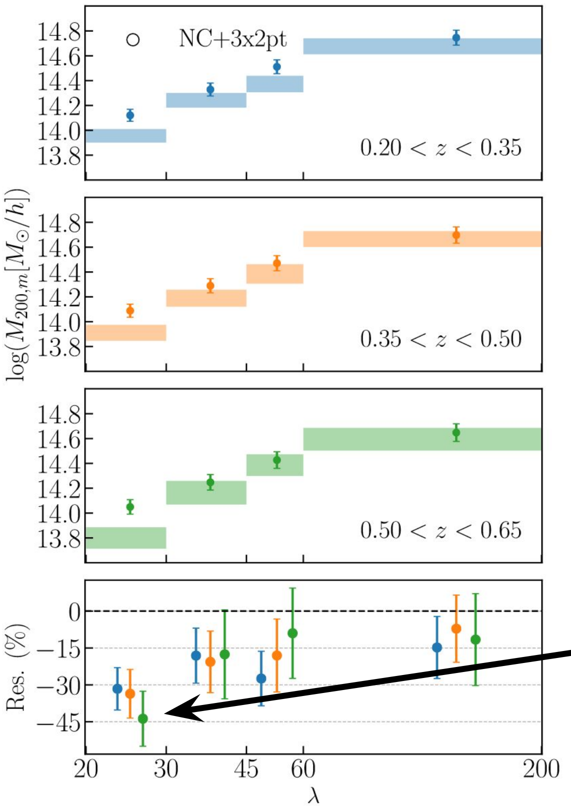
$\Delta\Sigma$	$w_{p,cg}$	$w_{p,gg}$	$\Delta \ln \frac{n_{\rm gal}}{n_{\rm fid}}$	$\Delta \ln \sigma_{\log M}$	$\Delta \ln \frac{M_1}{M_{\rm min}}$	$\Delta \ln \alpha$	ΔQ_{env}	$\Delta\Delta\gamma$	$\Delta \ln \sigma_{\ln M_c}$	$\Delta \ln \sigma_8$
all	all	all	0.049	0.202	0.367	0.035	0.070	0.079	0.125	0.014
all	-	-	.	.	.	.	.	.	0.926	0.083
-	all	-	0.050	3.257	4.531	0.734	0.293	0.162	5.818	0.152
-	-	all	0.050	0.387	0.694	0.087	0.124	0.366	.	0.116
-	all	all	0.049	0.202	0.373	0.038	0.071	0.097	0.126	0.063
all	-	all	0.050	0.382	0.694	0.078	0.124	0.366	0.755	0.068
all	all	-	0.050	0.800	1.616	0.458	0.189	0.150	0.813	0.073
large	large	large	0.050	1.504	7.422	3.024	0.139	9.512	0.422	0.037
large	large	all	0.050	0.356	0.629	0.073	0.113	0.359	0.283	0.026
small	small	small	0.050	0.328	0.601	0.050	0.119	0.081	0.169	0.018
small	small	all	0.050	0.249	0.455	0.039	0.085	0.080	0.143	0.015
small	all	all	0.049	0.202	0.367	0.035	0.070	0.079	0.125	0.014
all	small	all	0.050	0.249	0.455	0.039	0.085	0.080	0.143	0.015
all	all	small	0.050	0.242	0.441	0.038	0.083	0.080	0.130	0.014
large	all	all	0.049	0.202	0.367	0.035	0.070	0.080	0.125	0.018
all	large	all	0.050	0.356	0.629	0.073	0.113	0.359	0.283	0.026
all	all	large	0.050	0.427	0.978	0.306	0.118	0.134	0.312	0.029

Salcedo et al. 2020

Forward modeling optical selection

DES Y1 cluster lensing and abundance results



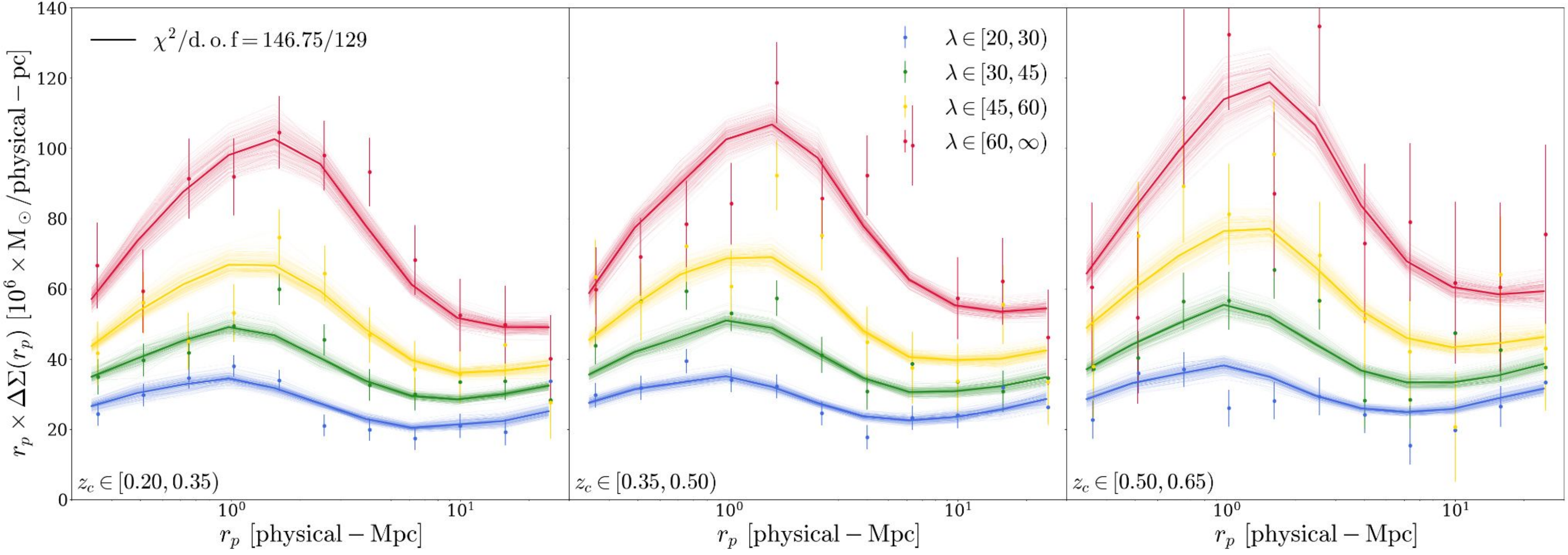


Fit abundances, predict lensing masses

Low richness lensing is low

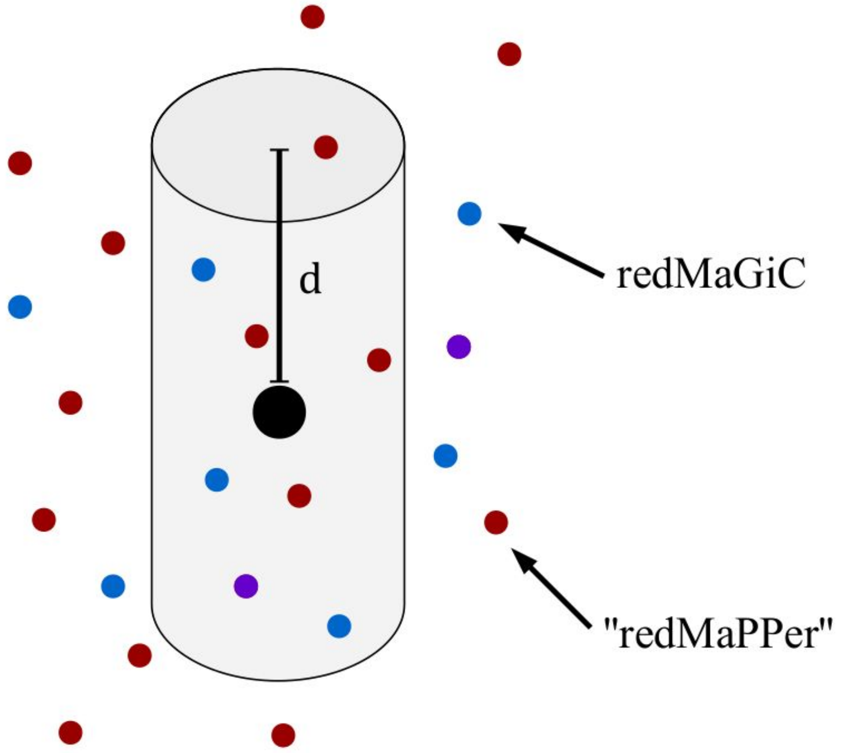
Abbott et al. 2020

DESY1-CL lensing and abundances are consistent with Planck cosmology



Cosmology fixed to Planck, Abundances fixed to DES-Y1 measurement

Generating mock redMaPPer catalogs in AbacusSummit



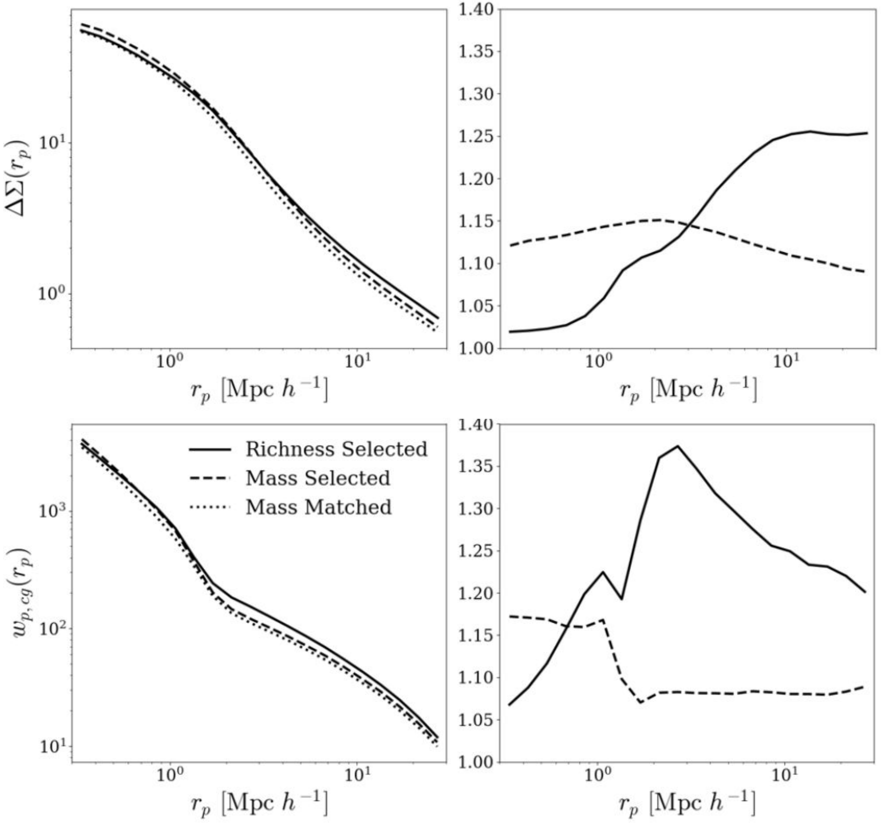
1. Two separate galaxy catalogs are generated to model redMaGiC and “redMaPPer” galaxies.

2. Richness assigned by (weighted) count of “redMaPPer” galaxies within cylinder centered on halo.

3. Catalog is selected by abundance matching based on assigned richness.

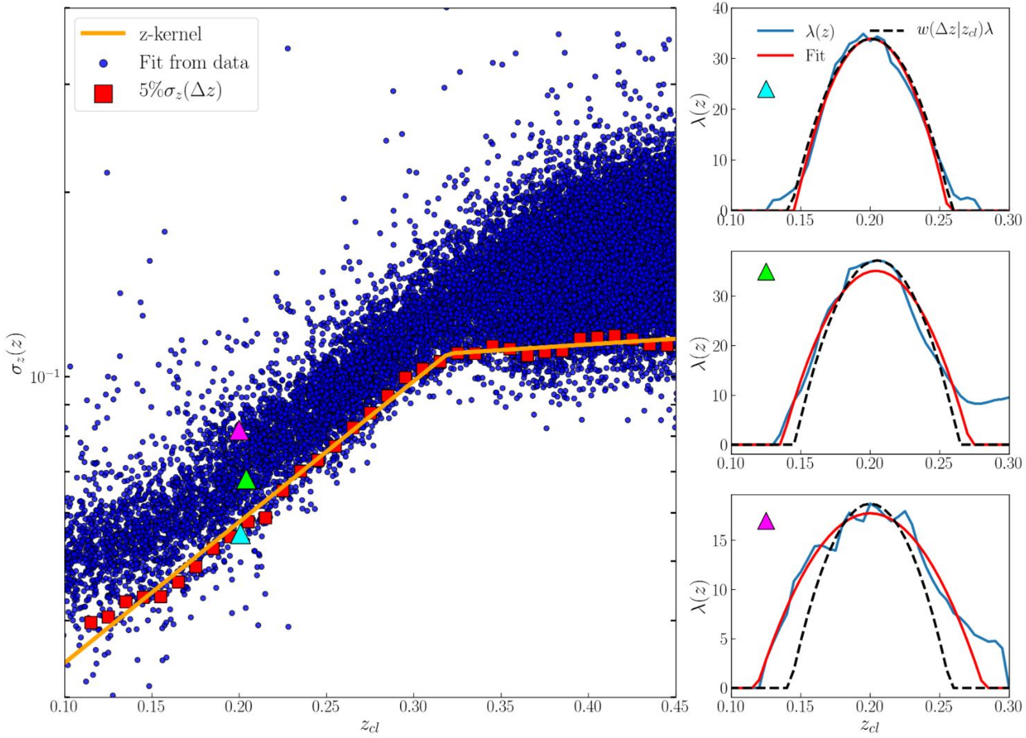
4. Cluster lensing and cluster-galaxy cross-correlation are computed using simulation particles and mock redMaGiC galaxies.

Projection effects in HOD-based cluster catalogs

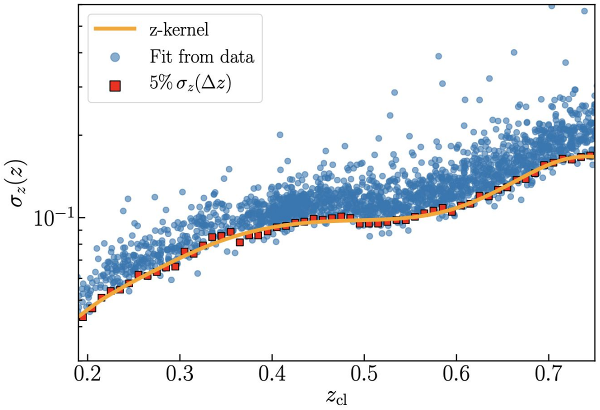


What can we say about the depth?

SDSS

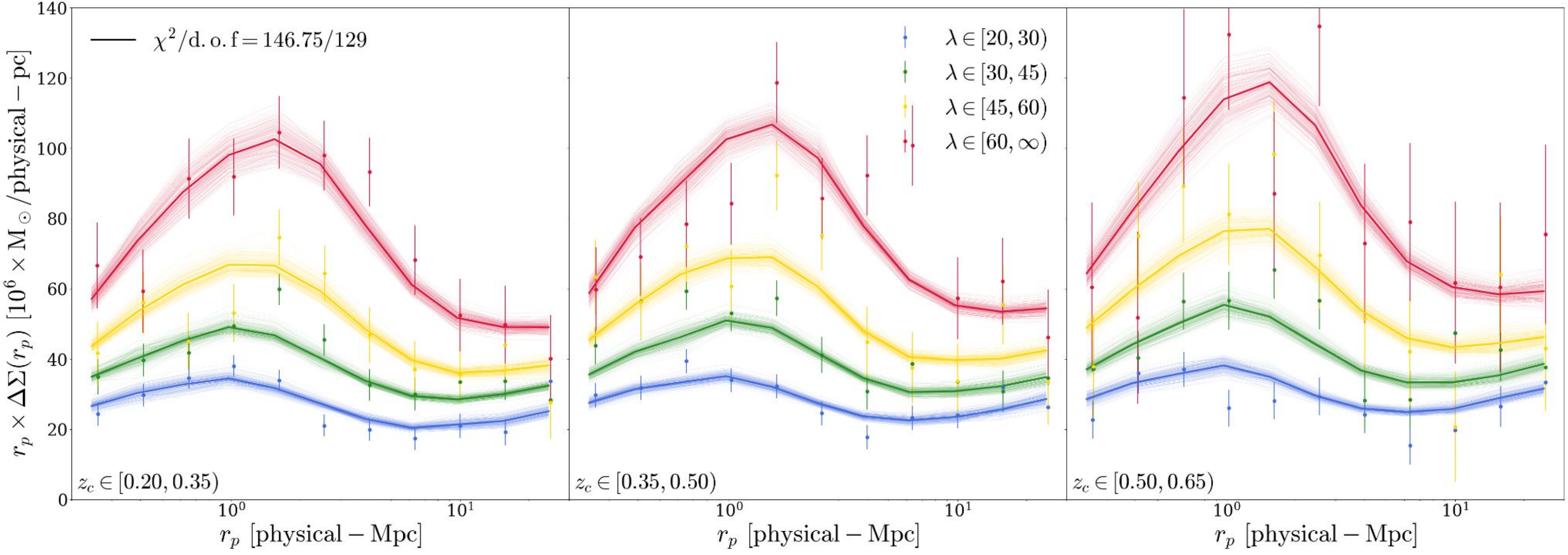


DES



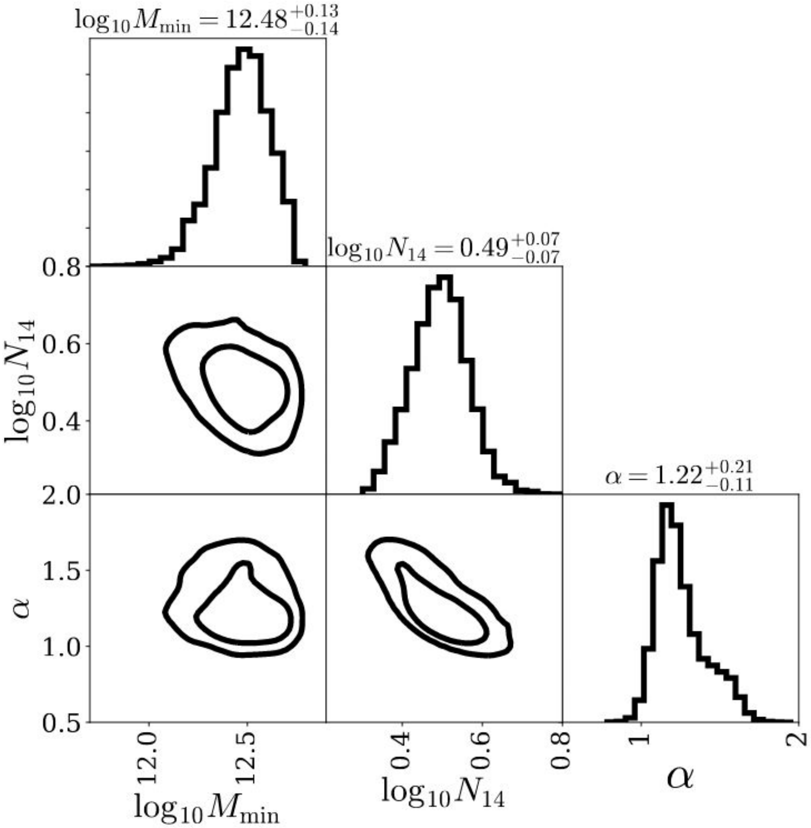
Costanzi et al. 2019, Abbott et al. 2020

DESY1-CL lensing and abundances are consistent with Planck cosmology



Cosmology fixed to Planck, Abundances fixed to DES-Y1 measurement

Fiducial cylinder+HOD posterior

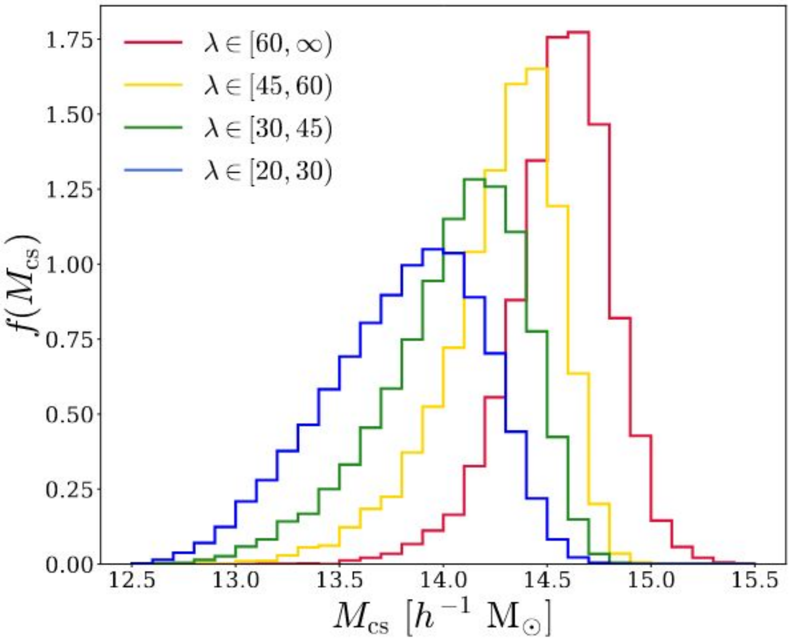


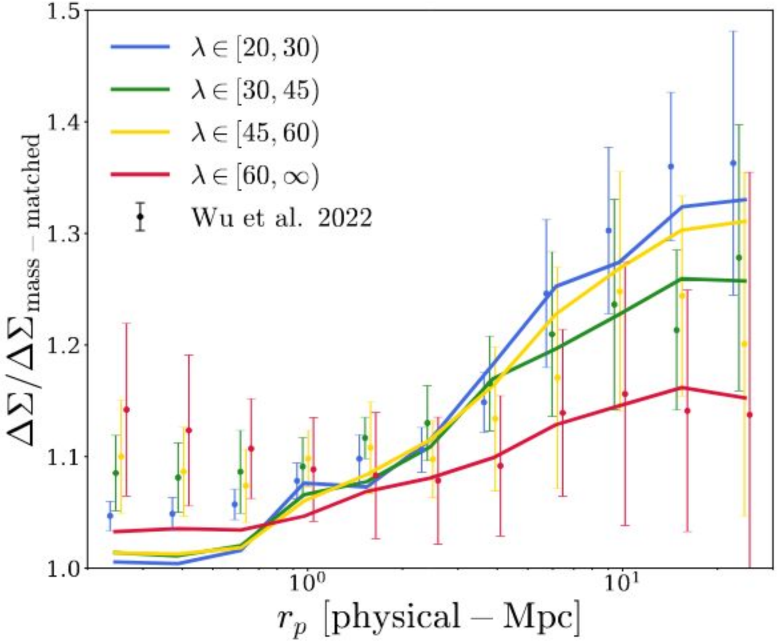
M_{min}: minimum halo mass to host central

N_{14}: occupation of log M = 14 halo

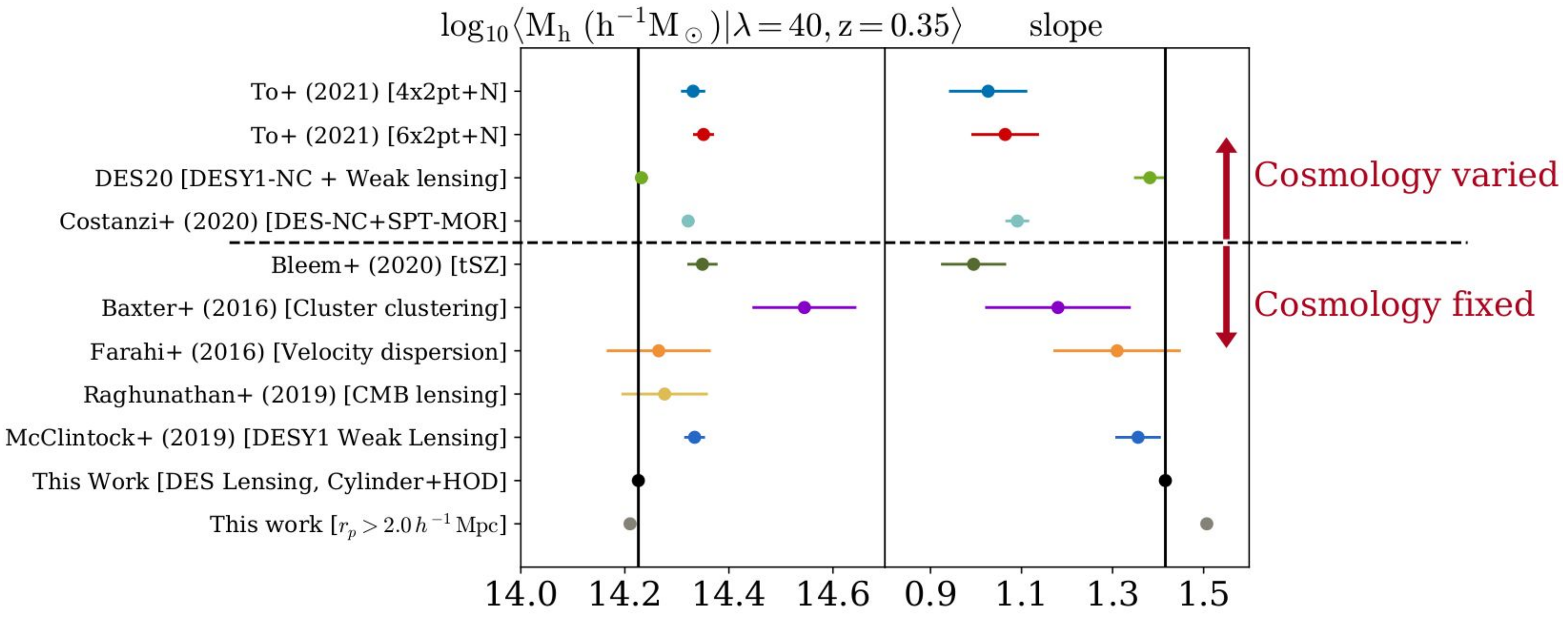
α: slope of satellite occupation power law

Predicted mass distributions and selection effects

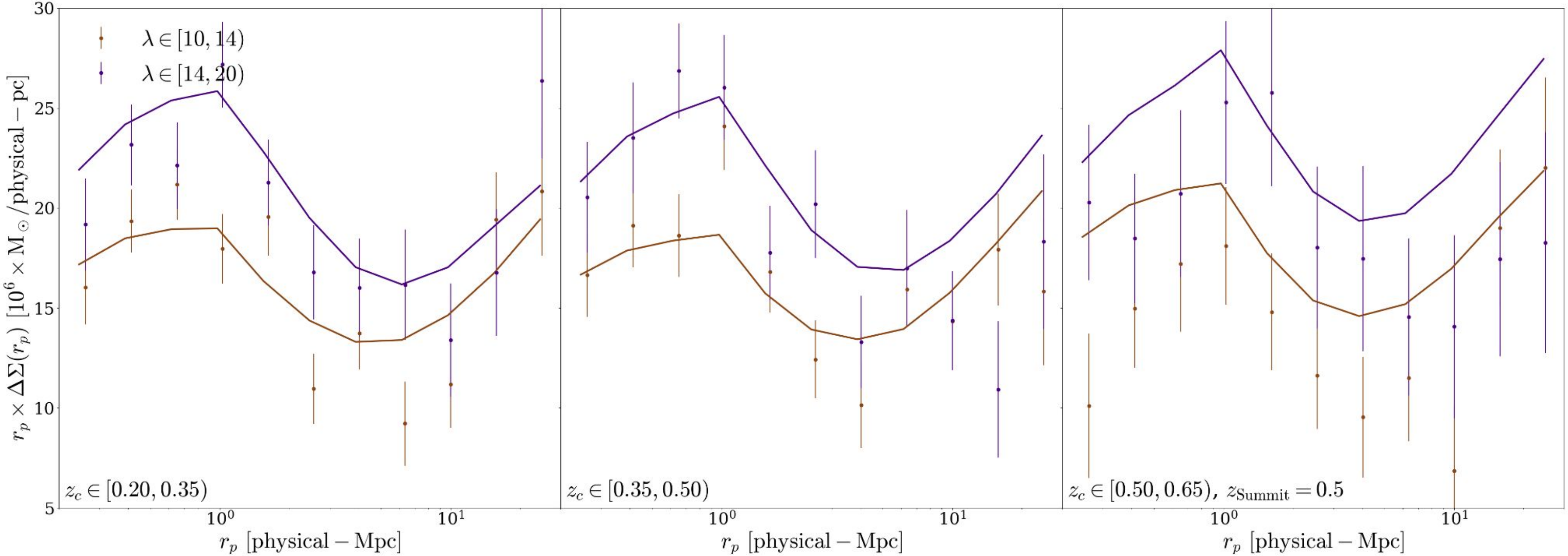




Predicted mass-observable relation



Pushing to lower richness



Summary

- Optical clusters have the potential to be among the most powerful cosmological probes *if* their systematics can be controlled.
- The most significant challenge currently is describing and calibrating the impact of selection on cluster abundances and 2-pt. Functions.
- A variety of promising strategies exist to address this challenge in the literature.
- We develop a novel framework to forward model the impact of optical cluster selection on cluster lensing, abundances and other two-point functions.
- This framework can consistently describe DES-Y1 lensing and abundances assuming Planck cosmology.