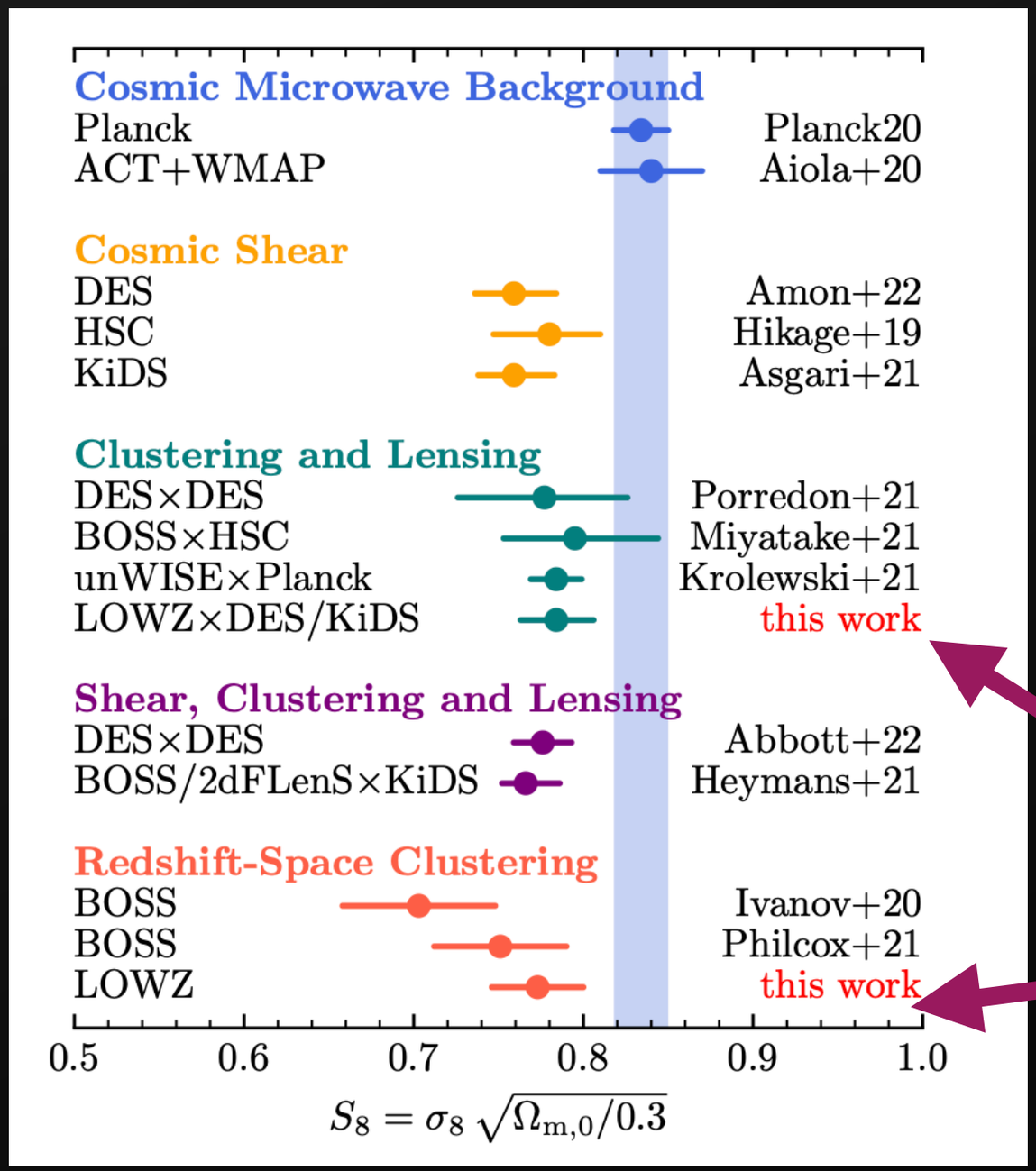
Galaxy-Halo Connection for Cosmology

A brief review

Alexie Leauthaud
UCSC

Motivation



Lange et al. 2022 in prep (preliminary)

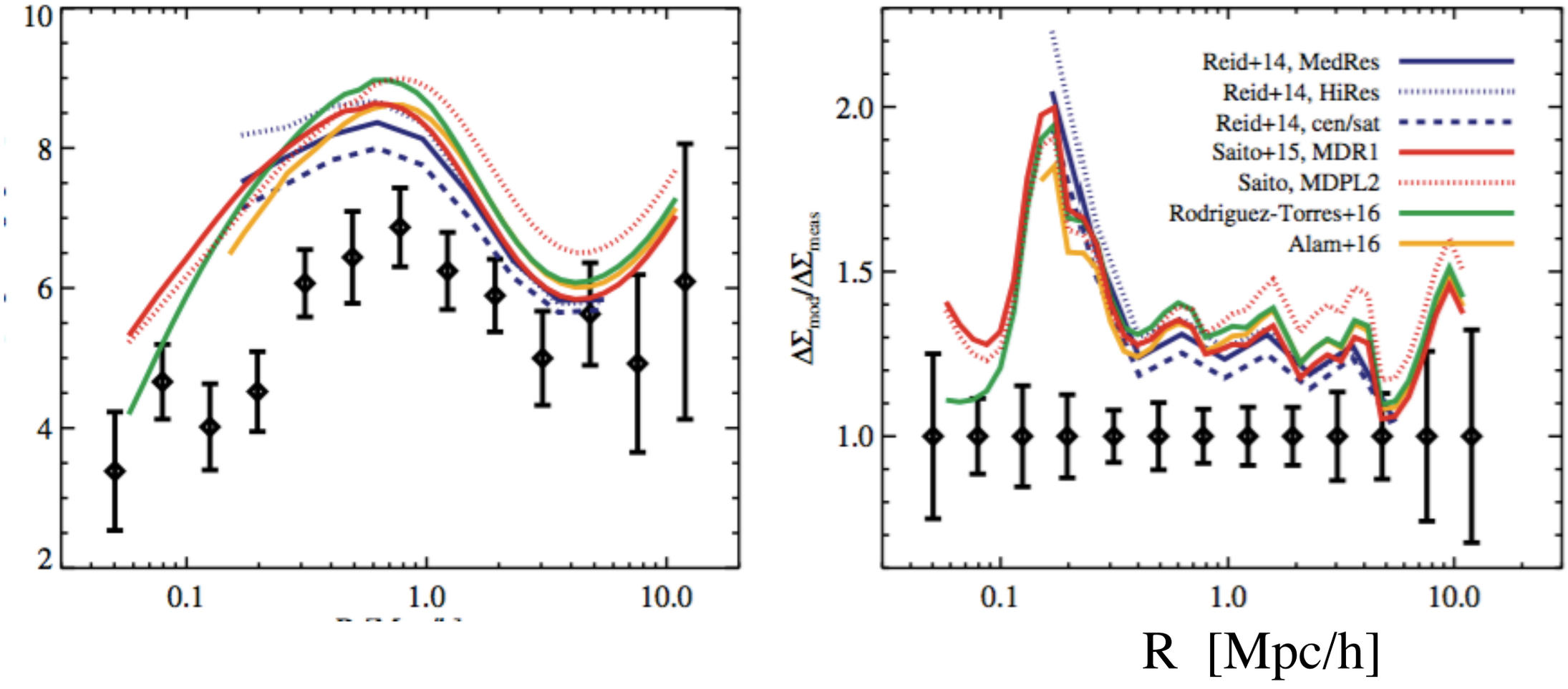
Constraints on the growth of structure from:

1) clustering, RSD, and lensing

2) cluster counts

Full scale joint fit to lensing, wp, and RSD

“Lensing is low” phenomenon



- Standard galaxy-halo models make robust prediction for lensing
- Standard galaxy-halo models constrained by clustering predict a lensing signal that is **20-40% higher than observed**

Also see Cacciato et al. 2013, Singh et al 2018, Wibking et al. 2019, Lange 2020, 2021, Troster et al 2020, Amon et al. 2022

How can we constrain the link between galaxies and dark matter halos in order to constrain cosmology better?

What are the degeneracies between cosmological and astrophysical parameters?

1. Potential for Improved Tracers of Halo Mass
2. Small Scales, Large Scales, Full Scales
3. Galaxy Halo Models and Assembly bias
4. Baryonic Effects
5. Emulators and the DESI Emulator mock challenge

Potential for Improved Tracers of Halo Mass

In the context of cosmology with the HMF, we want:

1. Halo mass proxies (M*, λ) with low scatter
2. Halo mass proxies with simple (well understood) selection effects
3. Halo mass proxy with no (or well understood) assembly bias

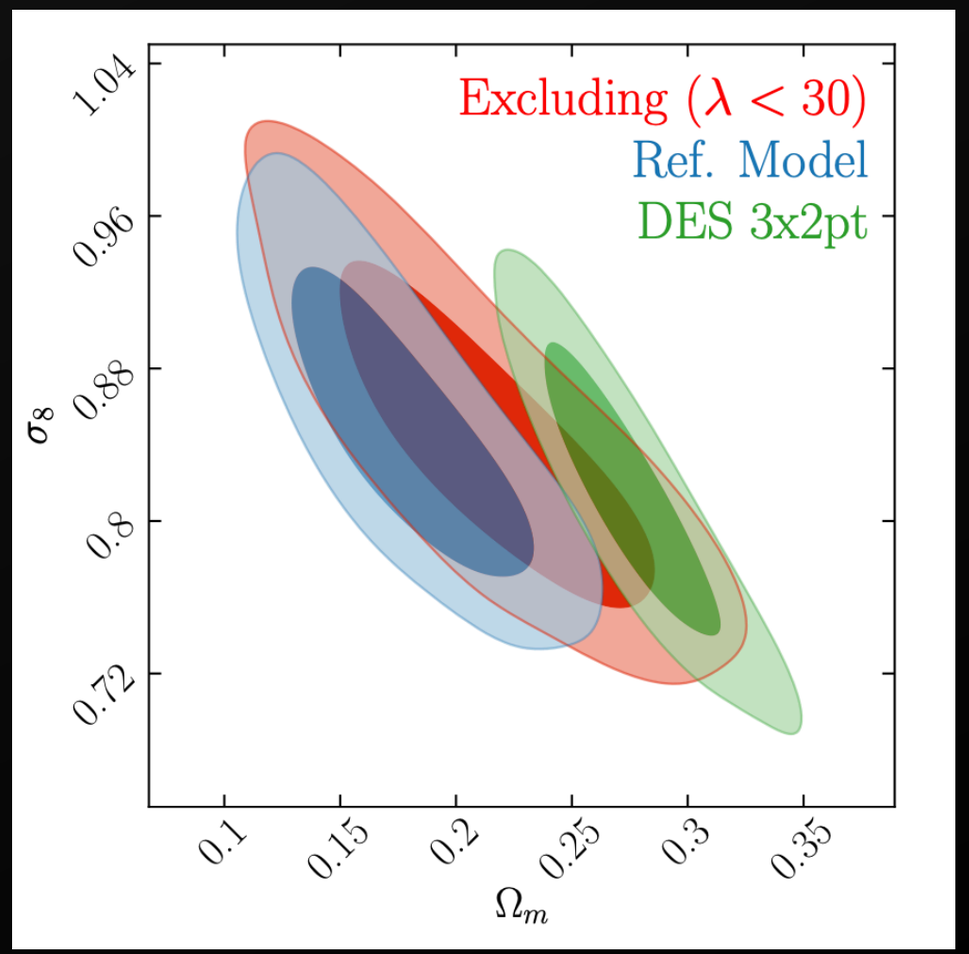
DES collaboration 2020

$$S_8 = \sigma_8(\Omega_m/0.3)^{0.5} = 0.65 \pm 0.04,$$

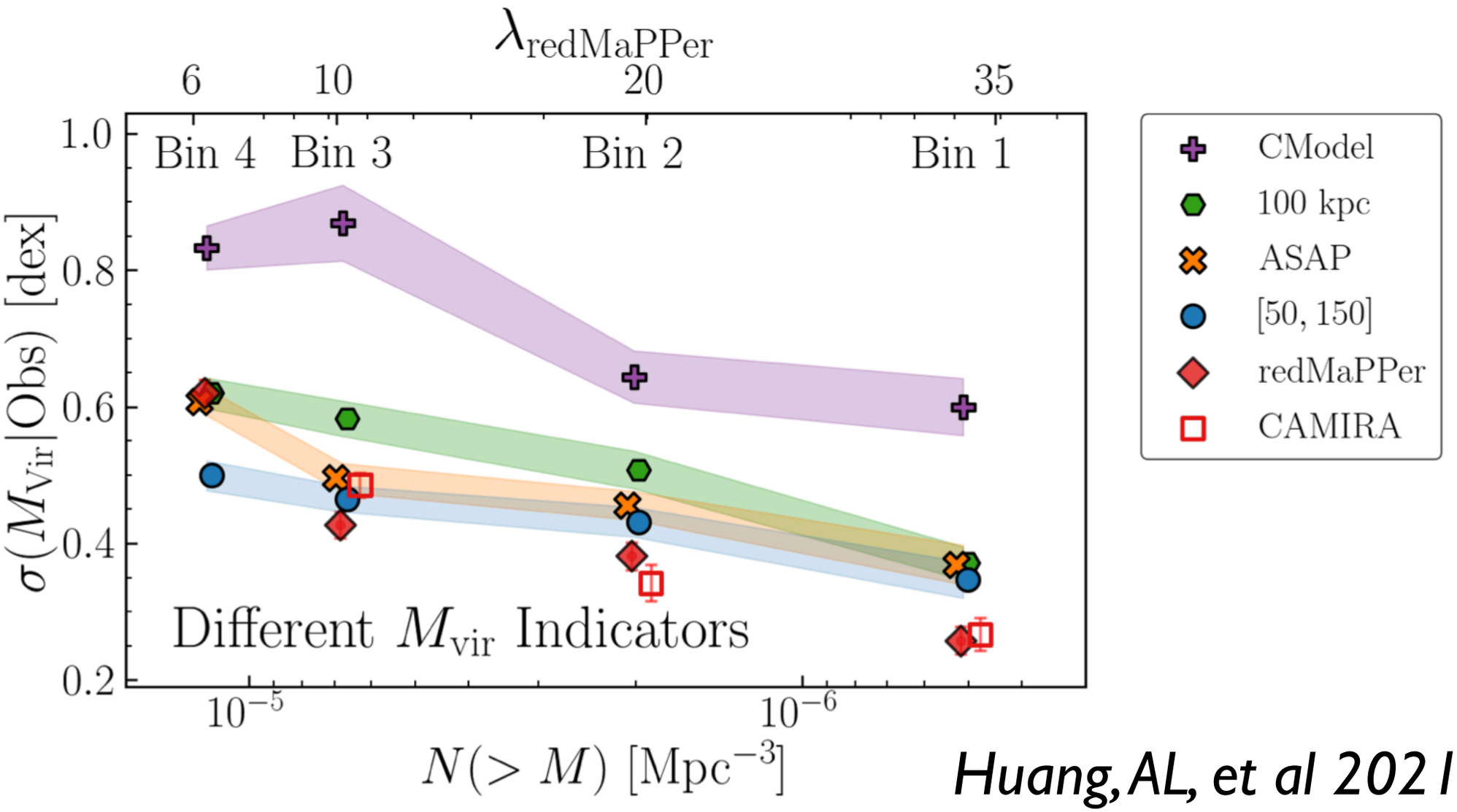
A lot of effort going into improving richness based estimators

Large potential for improvements using multi wavelength tracers

Potential for improvements in galaxy based estimators

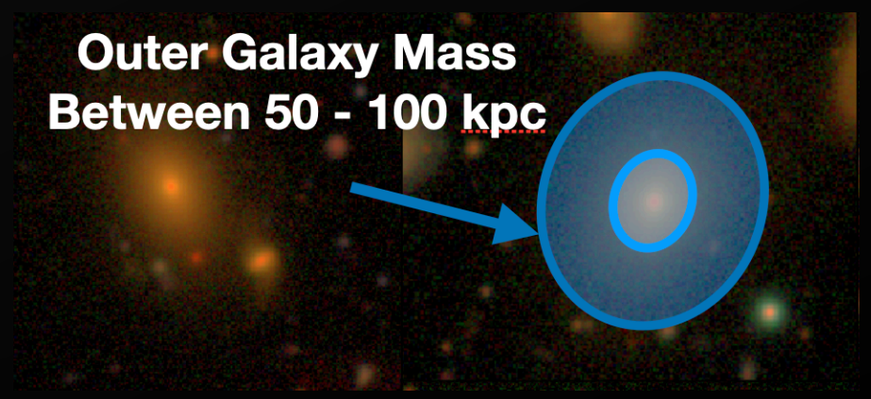


A New Potential Halo Mass Tracer!

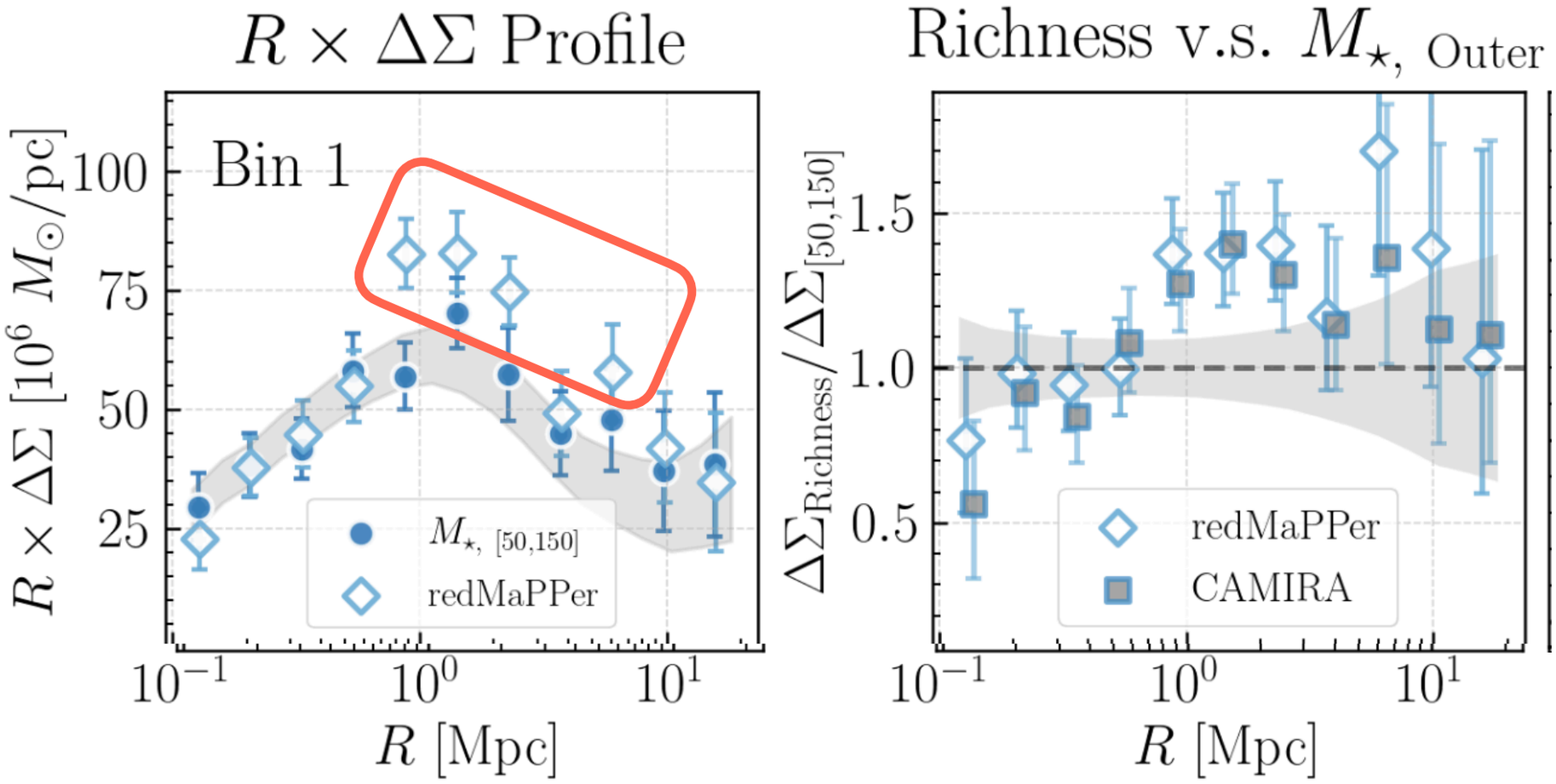


Huang, AL, et al 2021

Stellar envelope (galaxy outer mass) has scatter comparable to state of the art optical cluster finders!

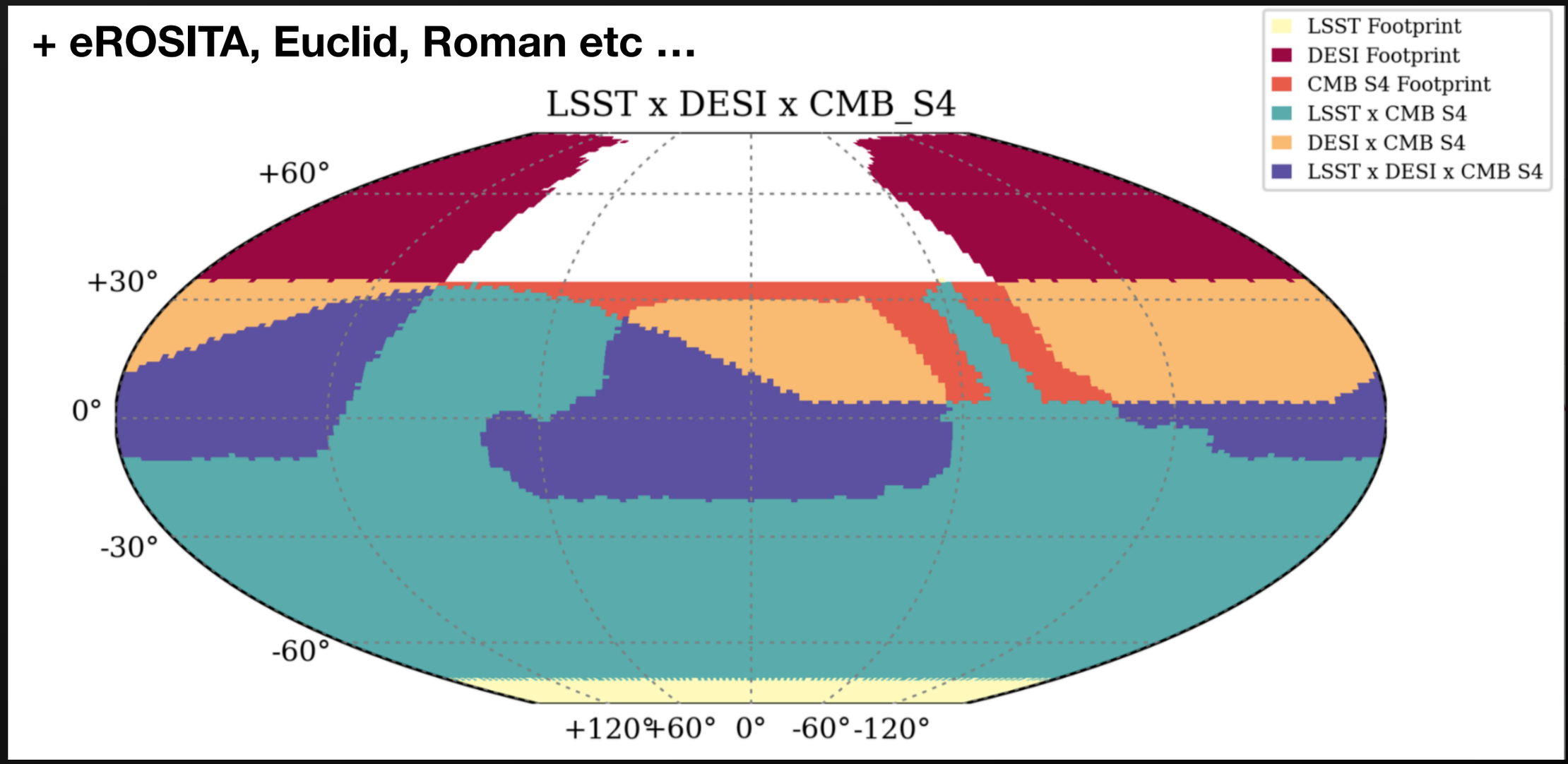


Reduced projection effects



Shape of lensing profile appears to indicate less projection effects compared to richness based cluster finders.

Multiwavelength Era is Here!



More sophisticated modeling of all components (gas, dark matter, stars) will be possible e.g., Farahi et al. 2022

1. Potential for Improved Tracers of Halo Mass
2. **Small Scales, Large Scales, Full Scales**
3. The Question of Assembly Bias
4. Baryonic Effects
5. Galaxy Halo Models
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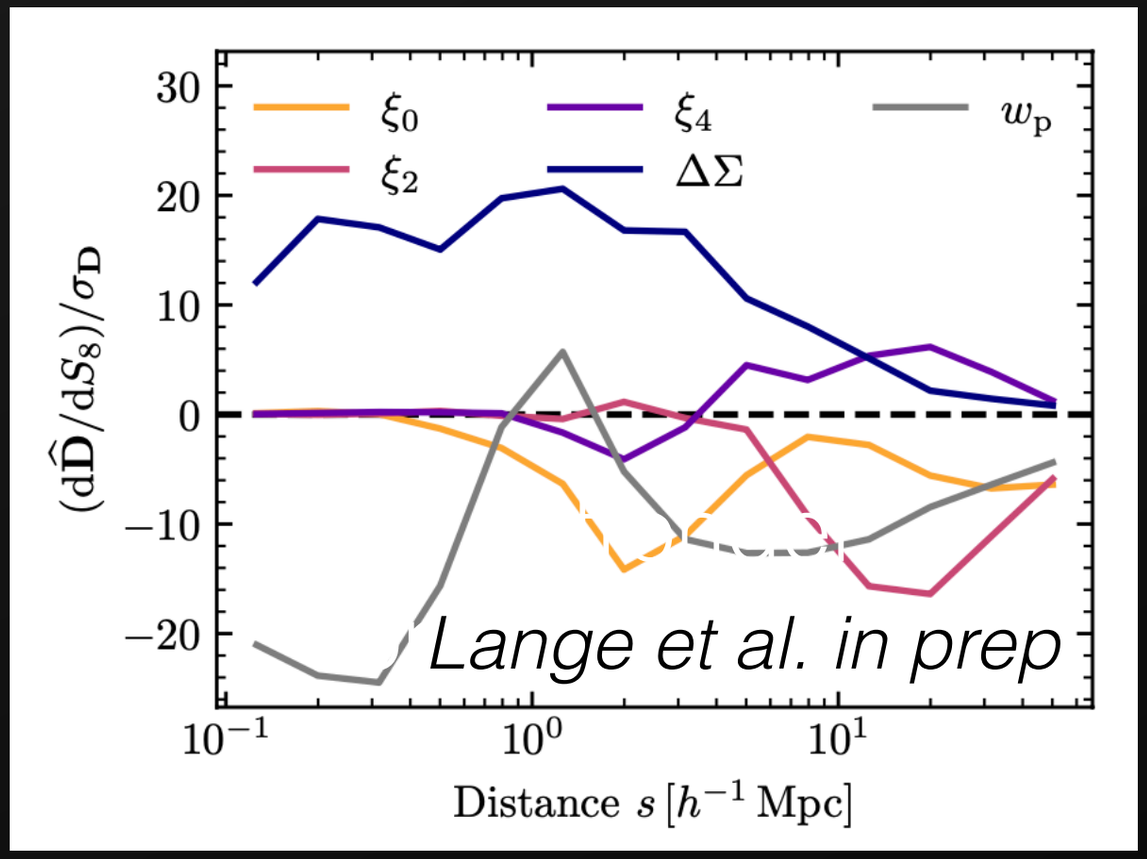
Scale Dependance of Cosmological Constraints

Which scales to use?



Small scales Large scales

Small scales

Large scales

Full scale

Small scales

Stronger constraints. Modeling: galaxy-halo connection, assembly bias, baryonic effects

Large scales

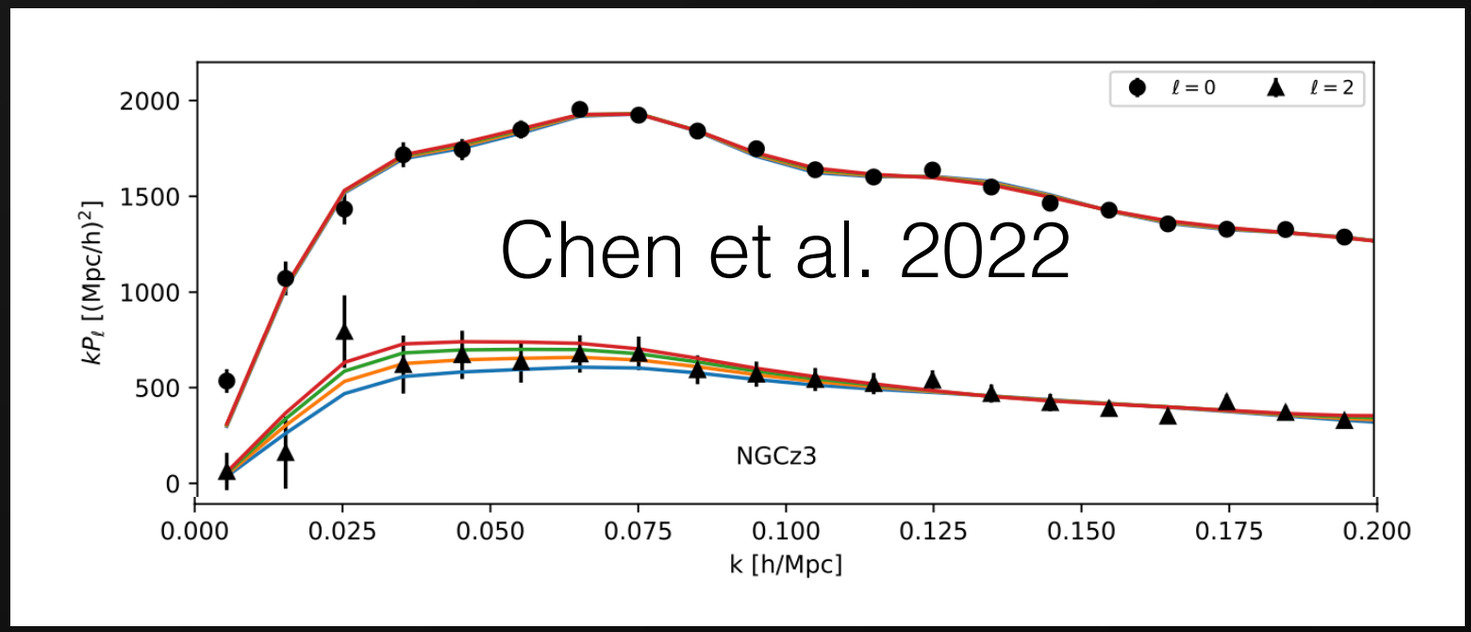
Weaker constraints. Modeling is more simple (perturbation theory)

Modified gravity:

Interesting to model range of scales, halo mass, and z

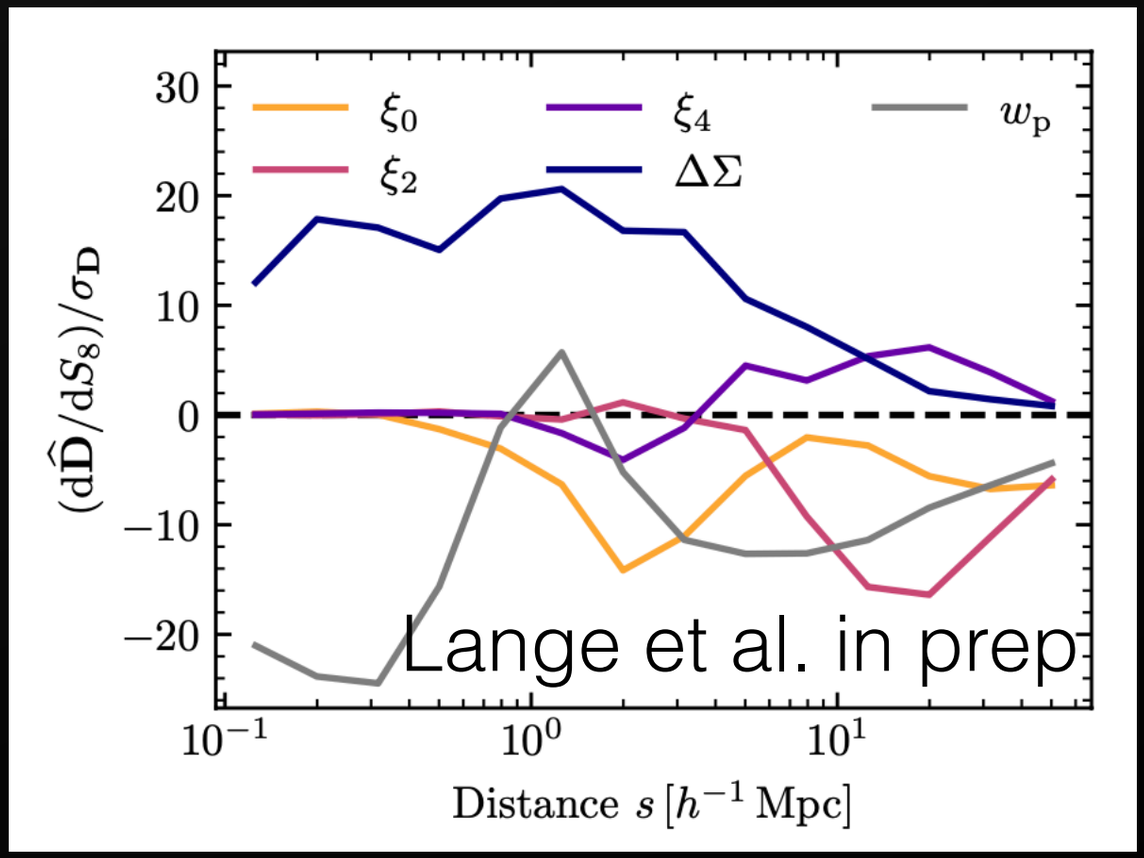
Do Smaller Scales Add Information?

Chen et al 2022. Perturbation based approach. Small scales do not add information (RSD only)



Simulation based modeling approaches. Adding in smaller scales improves constraints (~ factor of 2)

e.g., Lange et al. 2022, Lange et al. in prep, Wibking et al. 2019, Zhai et al. 2018, Reid et al. 2014



Do Smaller Scales Add Information?

Lange et al. 2022 (RSD)

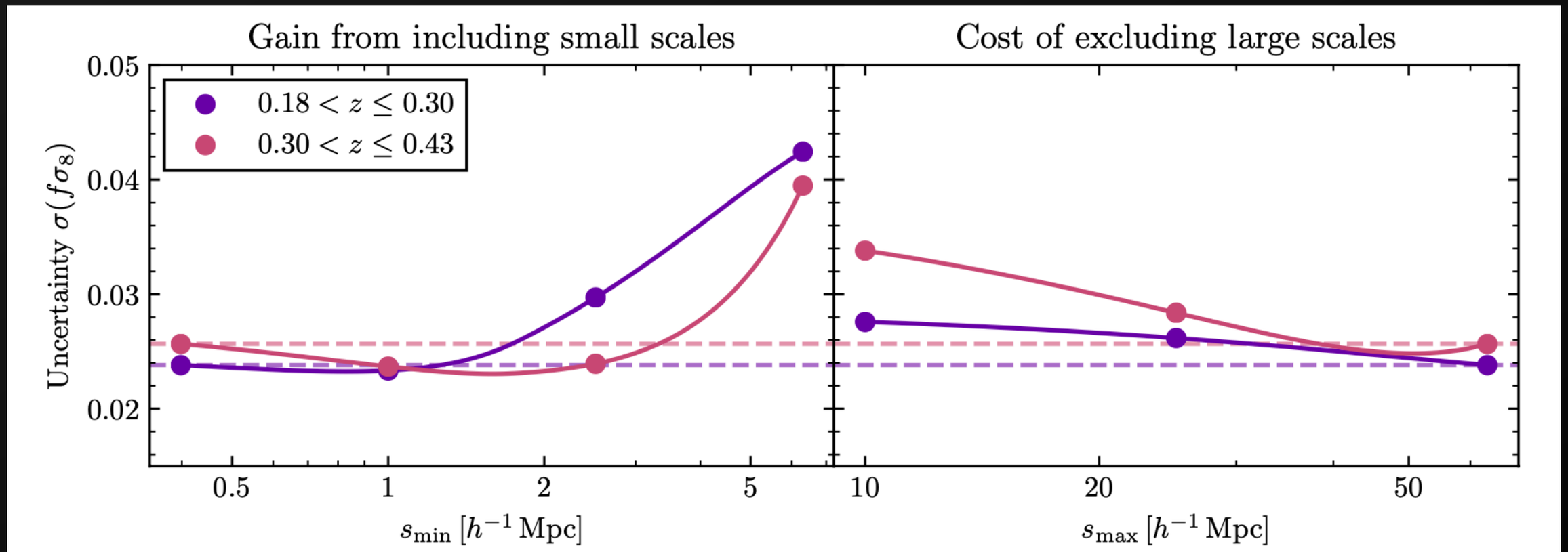


Figure 15. Similar to Figure 10 but showing how the constraints on $f\sigma_8$ depend on scale cuts. In the left panel, we show the dependence when the small-scale cut is increased compared to its default value of $s_{\rm min} = 400\,h^{-1}$ kpc. Similarly, the right panel shows the change in constraining power if the large-scale cut is reduced to values lower than $s_{\rm max} = 63\,h^{-1}$ Mpc.

Lange et al. in prep

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Galaxy Halo Models

Traditionally adopted models (not much recent innovation here)

1. Standard HOD
2. Abundance matching
3. Conditional mass/ luminosity functions

More innovation possible! Lightweight SAMs. And see Hearin et al. 2021, 2022

Extensions (more recent innovation). Extensions to account for secondary halo bias:

1. Central velocity bias
2. Satellite velocity bias
3. Radial satellite profile
4. Central concentration assembly bias
5. Satellite concentration assembly bias
6. Environment based assembly bias

List from Yuan et al. 2022 (but non exhaustive list of what is possible)

Assembly bias

Degeneracy between cosmological constraints and assembly bias?
No single simple answer for the following reasons:

1. Multiples types of secondary bias possible (halo mass, spin, formation time, e.g., Shi & Sheth 2018, Xhakaj et al. 2022)

2. Multiple definitions of assembly bias (e.g., Hadzhiyska et al. 2020, Delgado et al. 2021)

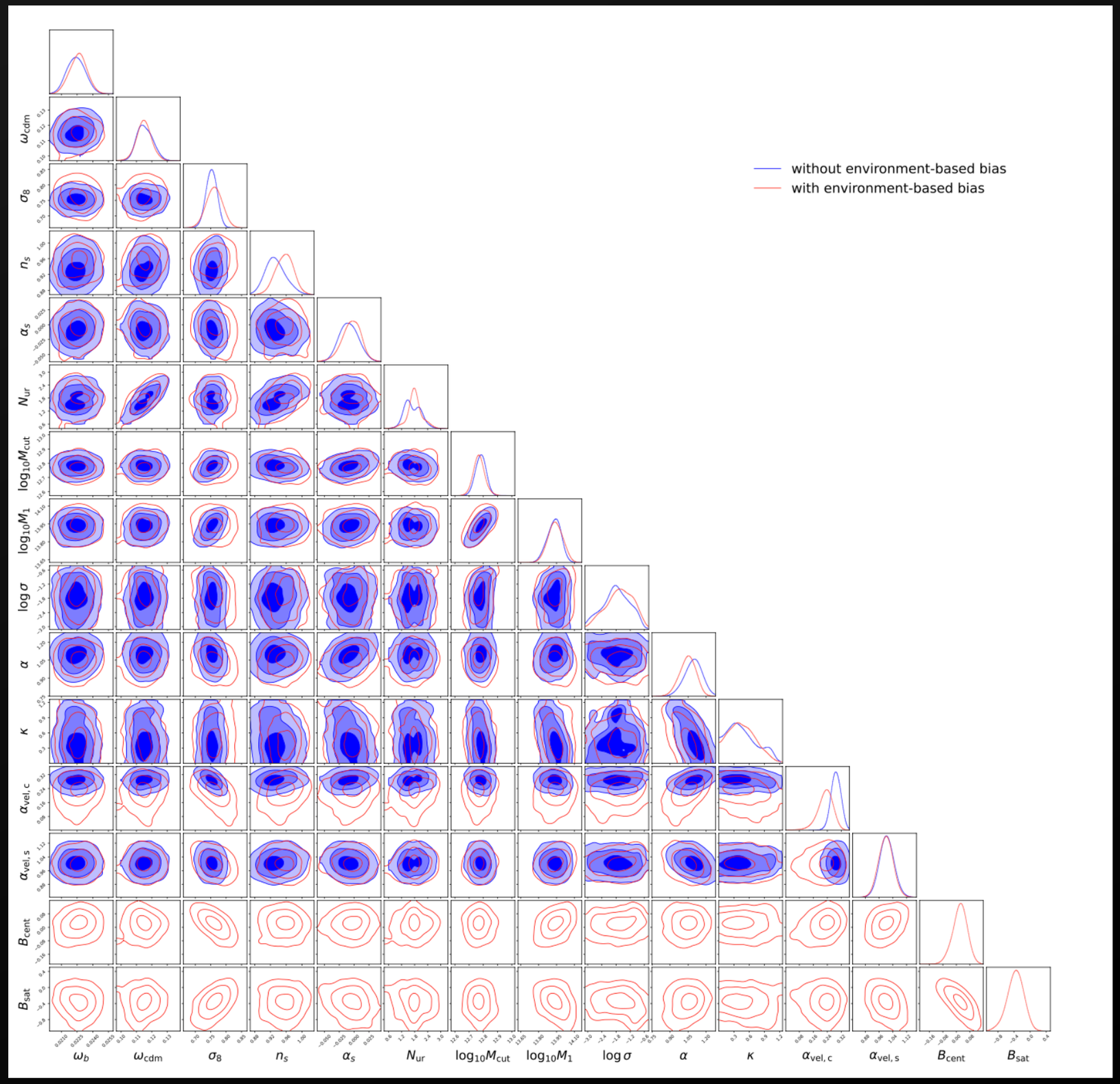
3. Will depend on scales analyzed

4. Will depend on galaxy samples

Assembly bias in BOSS

Yuan et al. 2022

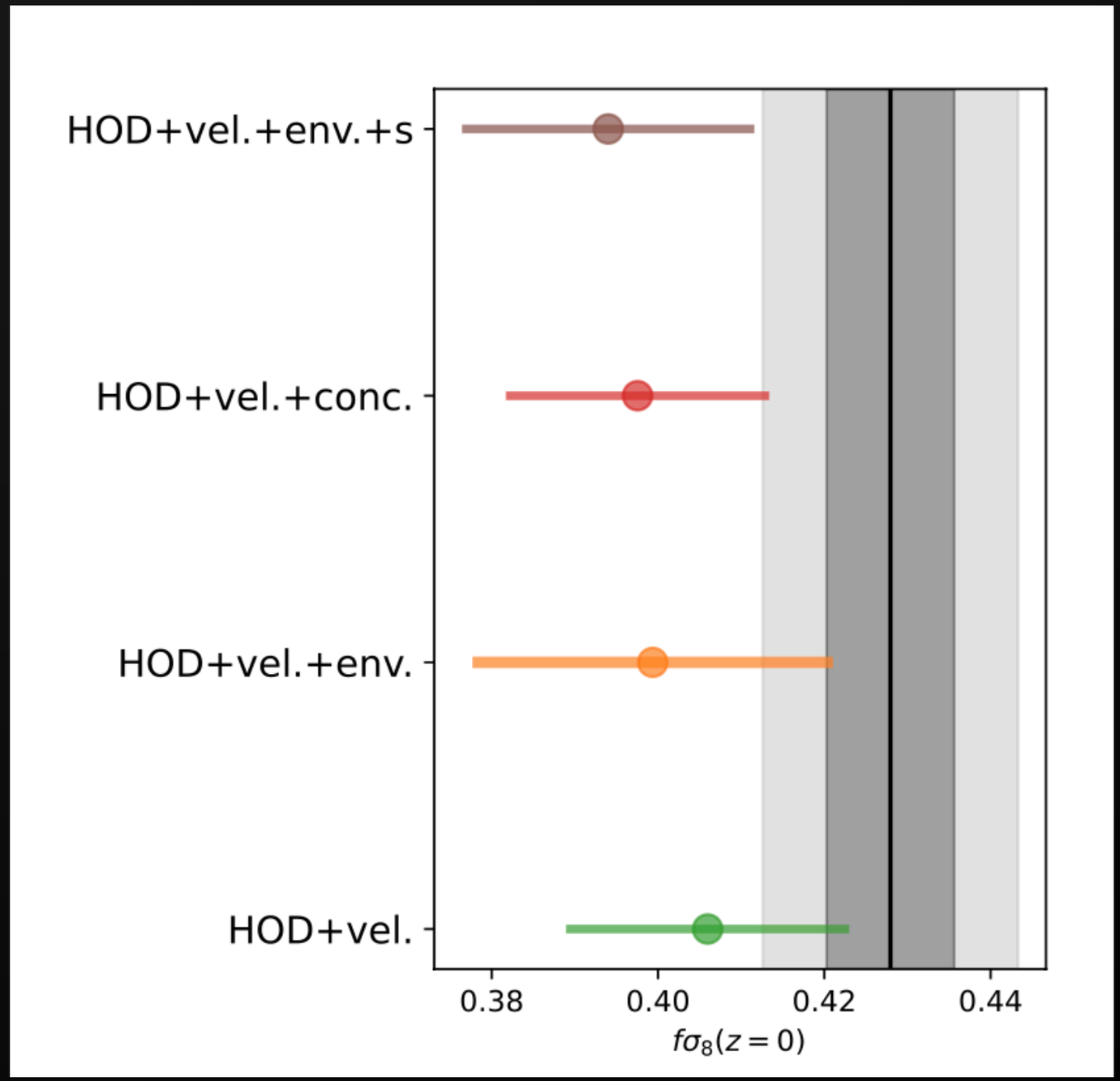
- Simulation based modeling
- Small scales clustering
- Tests a number of assembly bias models



Assembly bias in BOSS

Yuan et al. 2022

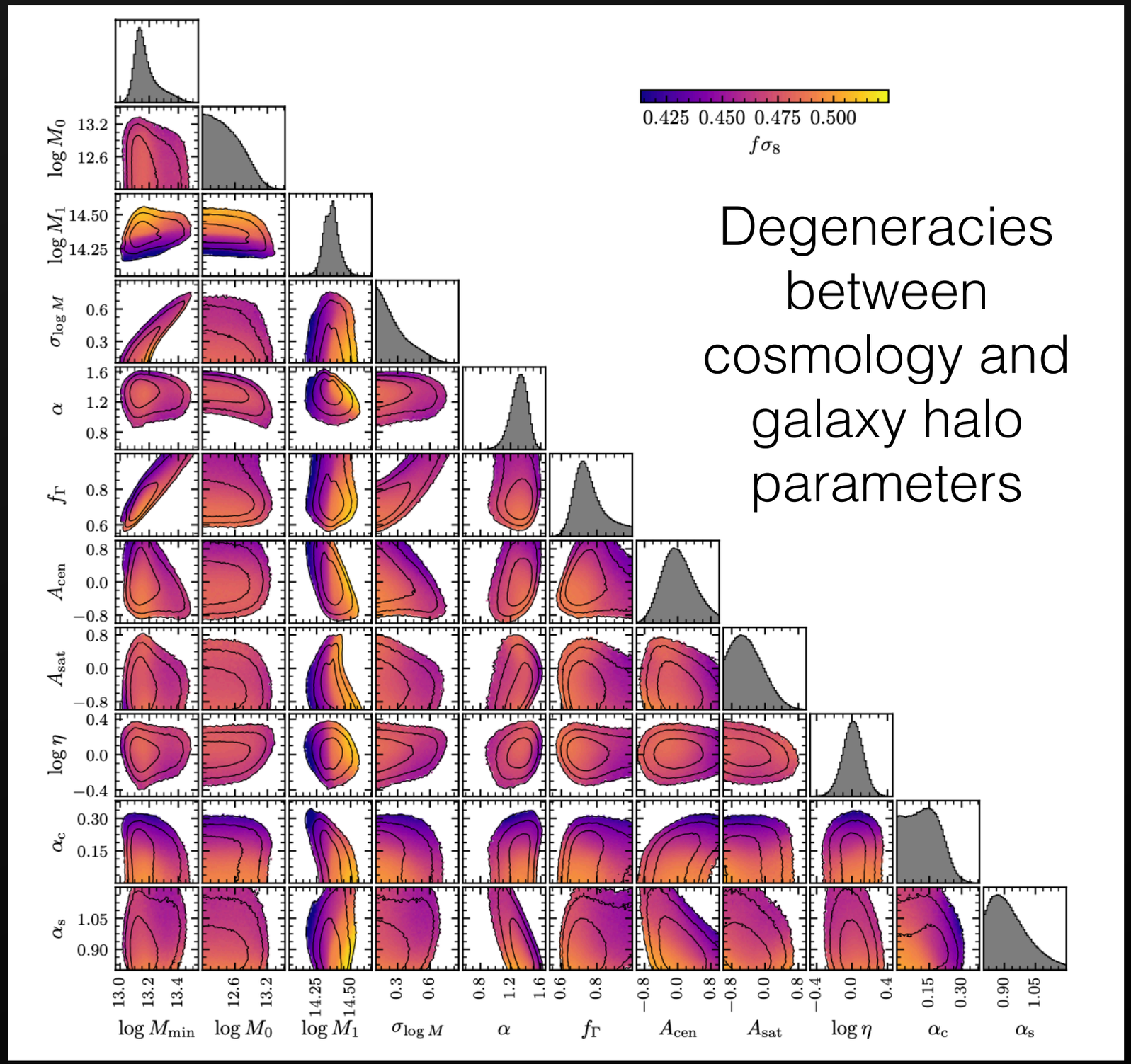
- Testing robustness against HOD model assumptions and extensions to HOD
- Assembly bias alone seems unlikely to explain emerging S8 tension (also see Leauthaud et al. 2017, Lange et al. 2019, 2022)



Assembly bias in BOSS

Lange et al 2020

- Decorated HOD for assembly bias (Hearin et al. 2017)
- No strong evidence for assembly bias
- Hint at central velocity bias
- No satellite velocity bias



Degeneracies between cosmology and galaxy halo parameters

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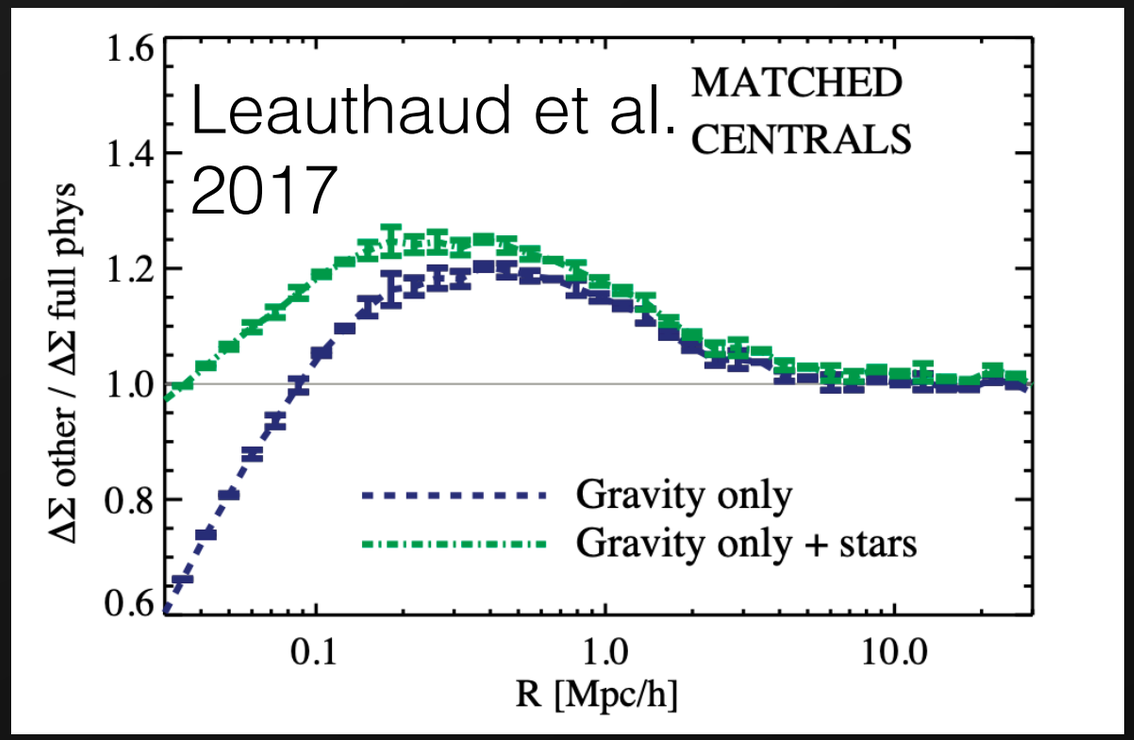
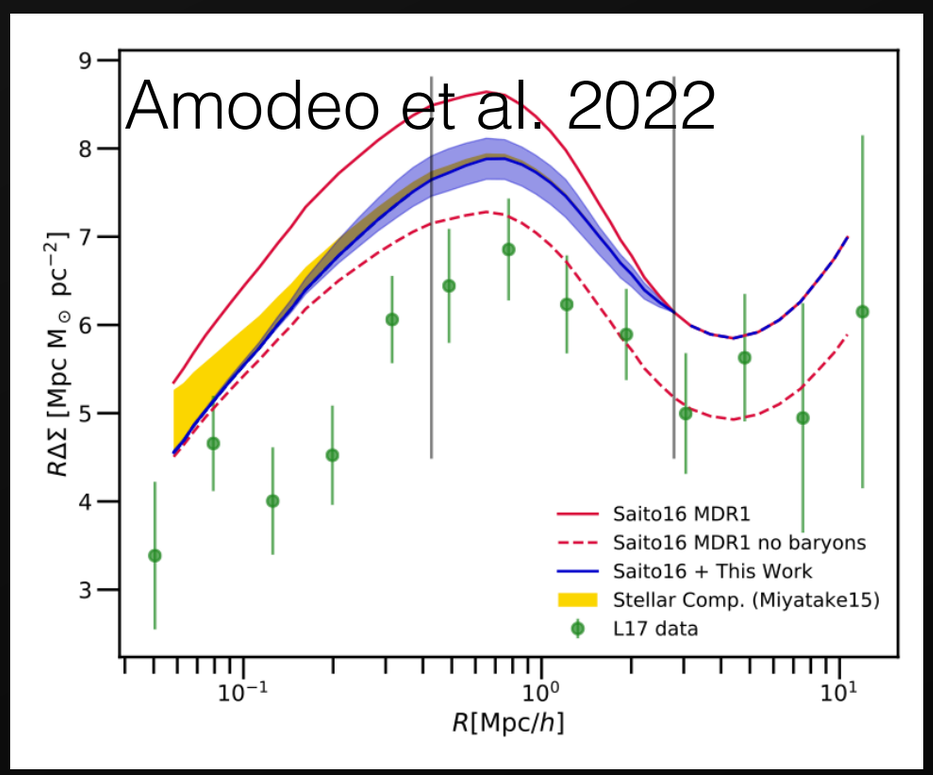
Impact of Baryons





Baryonic feedback expected to change observables on scales below a few kpc - perhaps as much as 20% (e.g., Leauthaud et al. 2017, Lange et al. 2019, Amon et al. 2022).
See Hellwing et al. 2016 for RSD

New multi wavelength data has potential to constrain this effect (e.g., Schaan et al 2021, Amodeo et al. 2021)

Next frontier: joint modeling of assembly bias and baryons

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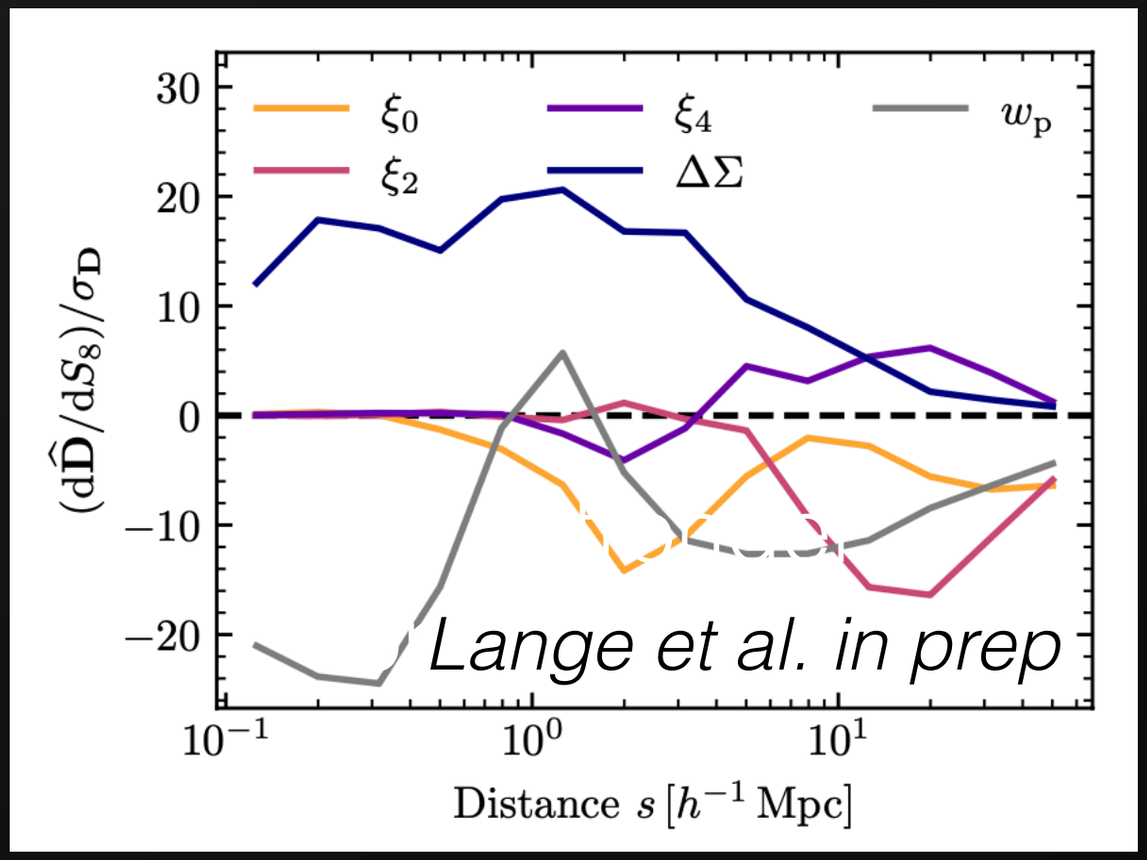
Simulation based modeling



Small scales

Large scales

Full scale

Full scales analysis Requires the use of “emulators” or “simulation based modeling”

Aemulus (deRose 2018)

Abacus (Garrison et al. 2017)

DESI emulator mock challenge

CMASS effective volume => 5 Gpc^3
DESI LRG effective volume => 40 Gpc^3 (e.g., Chuang et al. 2019)

Yuan et al. 2022 ABACUS analysis - for full DESI sample, emulator errors ~ DESI sample variance

Plus a number of outstanding questions: halo finding, galaxy halo models, assembly bias, baryons….

The DESI emulator mock challenge aims to tackle these questions in preparation for DESI!
DESI lensing working group

The End

Merci !