Hybrid Small-scale Two-point Modeling with HZPT

Jamie Sullivan
(work w/ Uroš Seljak & Sukhdeep Singh arXiv:2104.10676)

Goals

I. Demonstrate potential of analytic **hybrid** models for modern two-point analysis
II. Explain how Halo Zeldovich Perturbation Theory accurately models small-scale effects of:
    - Halo profiles and baryons
    - Halo exclusion
    - Satellite galaxies

In configuration **and** Fourier space!

Overview

Introduce HZPT

Matter and Baryons

Halos and Exclusion

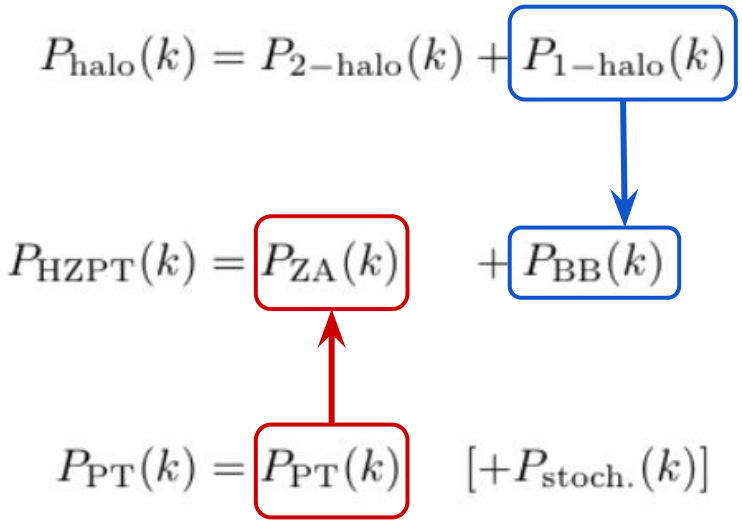
HOD Mock Galaxies

Future Directions

HZPT Outline

Halo-Zeldovich Perturbation Theory - a compromise between the halo model and perturbation theory

PT instead of standard 2-halo term, generalize 1-halo term



Model Components

Model parameters (for matter) are all in BB:

Mohammed & Seljak - r^{2n} moments of (unknown) profile:

$$P_{1h}(k) = A_0(1 - \widetilde{R}_1^2 k^2 + \widetilde{R}_2^4 k^4 + ...)$$

Seljak & Vlah - blows up at high-k so use Padé approximant instead, add compensation

$$P_{BB}(k) = A_0 F(k) \frac{\sum_{m=0}^{m=n_{\rm max}-1} (kR_m)^{2m}}{\sum_{n=0}^{n=n_{\rm max}} (kR_{nh})^{2n}} \qquad F(k) = \left(1 - \frac{1}{1 + k^2 R^2}\right)$$

Model Components

Zeldovich

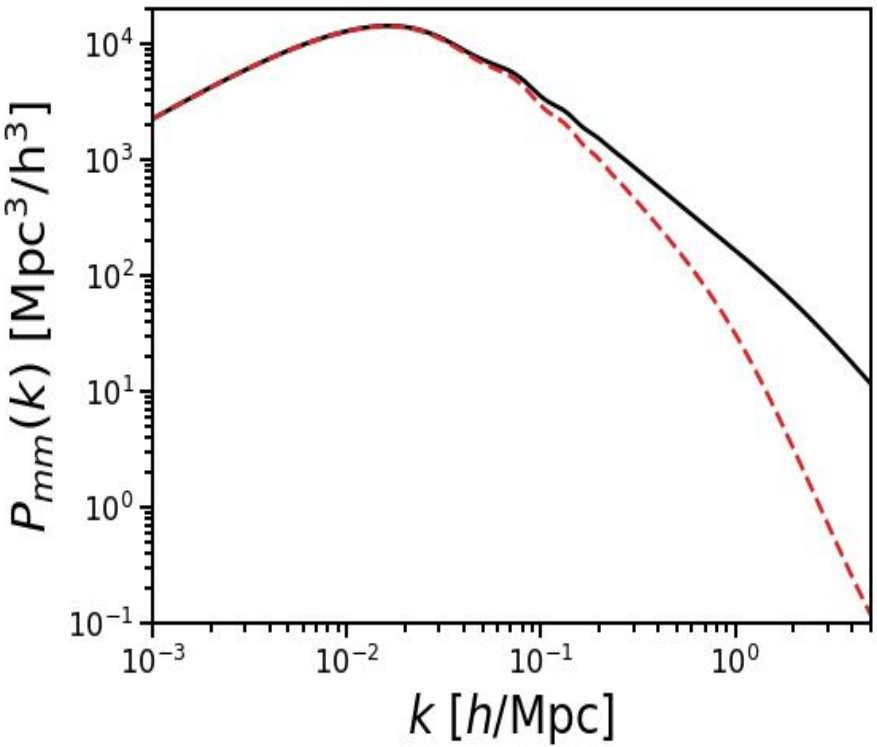
Replace standard 2-halo with ZA - get bulk flows

Broadband Beyond Zeldovich (BB)

Reprocess k^2 expansion of halo profile through Padé

Compensation

Suppress mass conservation violating white noise



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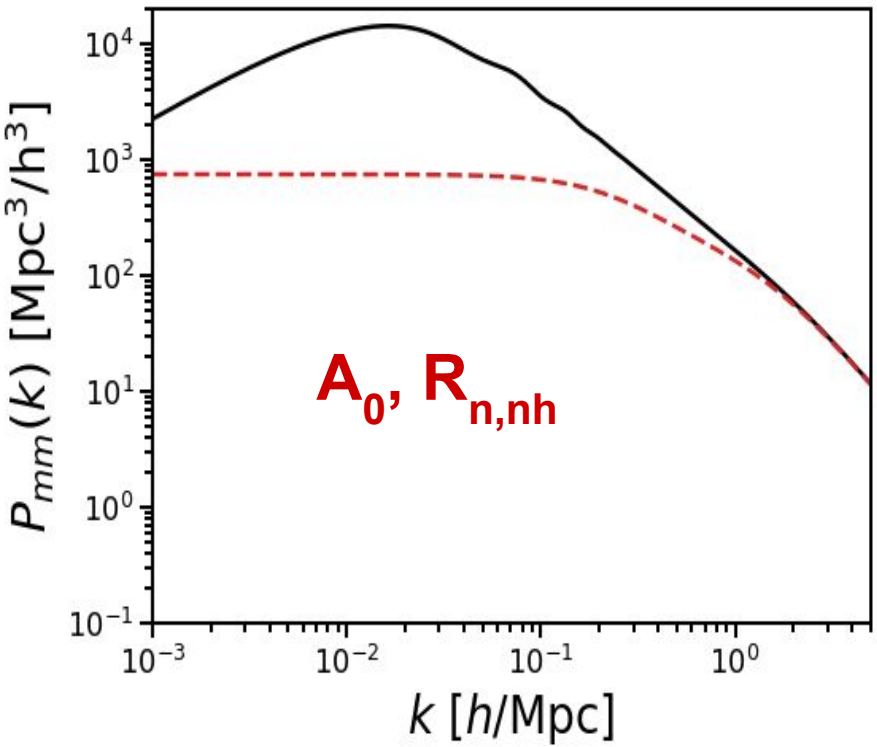

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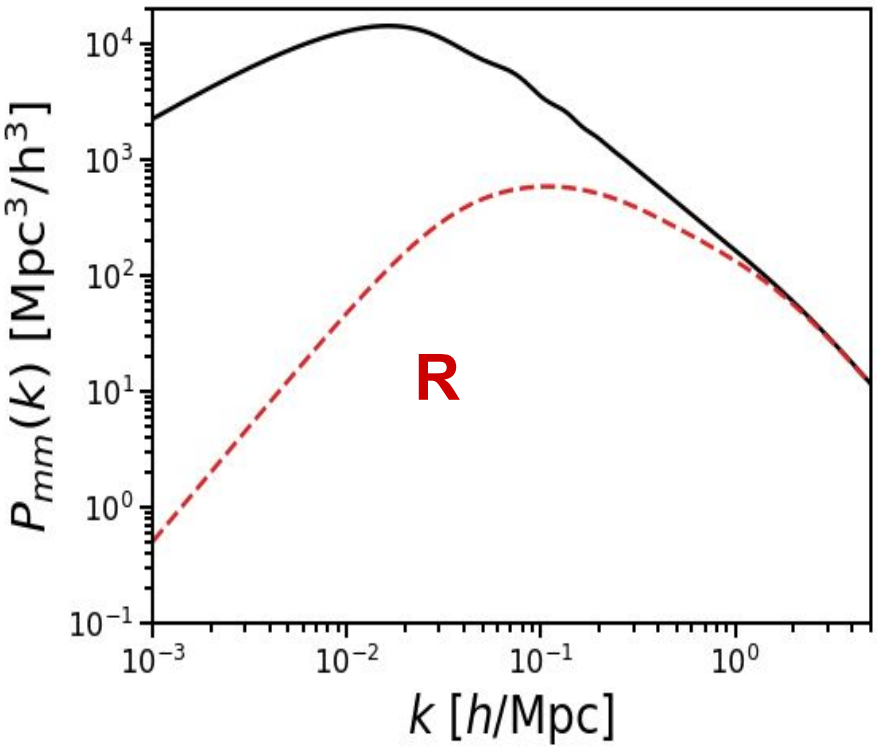


Bracketing Baryonic Effects

Baryonic effects impact small-scale matter distribution

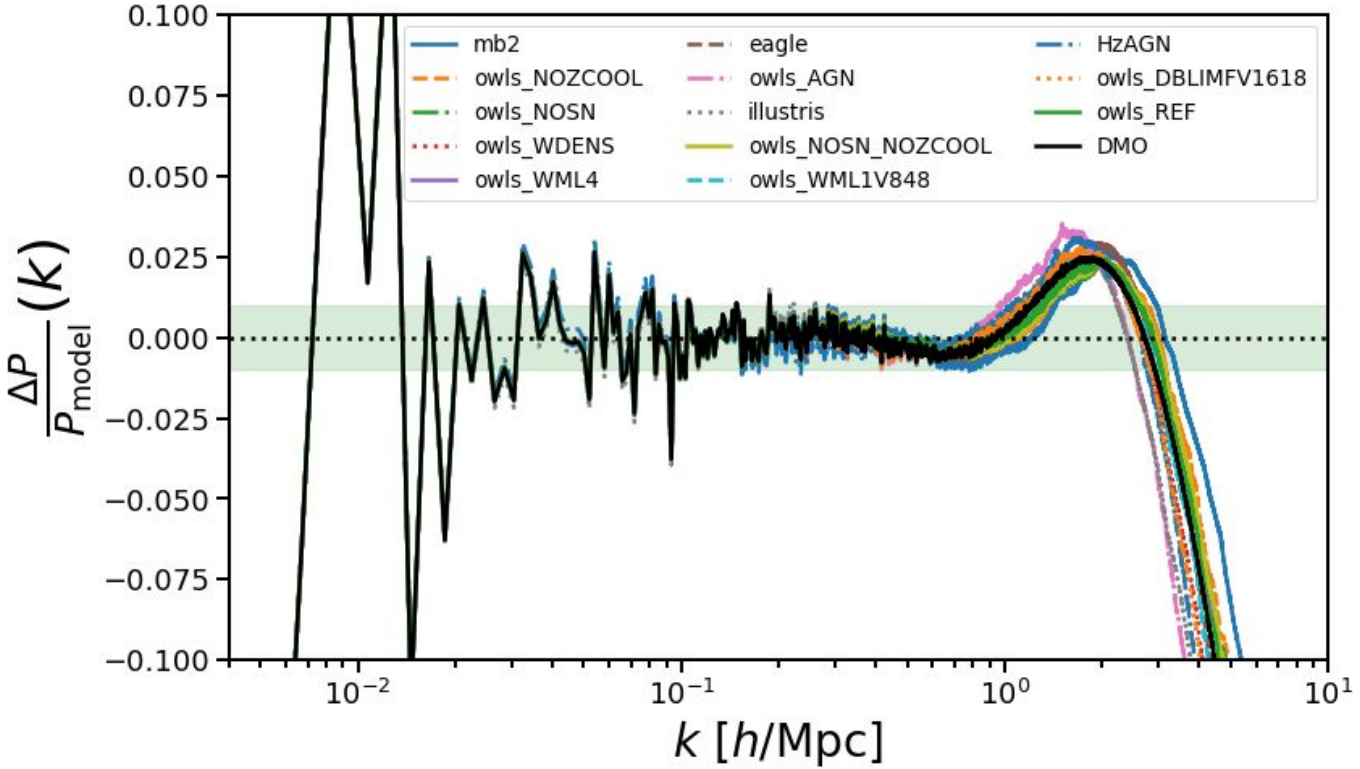
Can be understood through impact on halo profiles

Test HZPT using power spectrum ratios from hydrodynamical simulations

(OWLS, EAGLE, Massive-Black 2, Illustris, Horizon-AGN) as used in Huang et al. 2019

Bracketing Baryonic Effects

Base model 1% accurate at k < 1 h/Mpc



Extended Matter Models

1-halo extension: Add extra Padé term ($n_{max} = 3$)

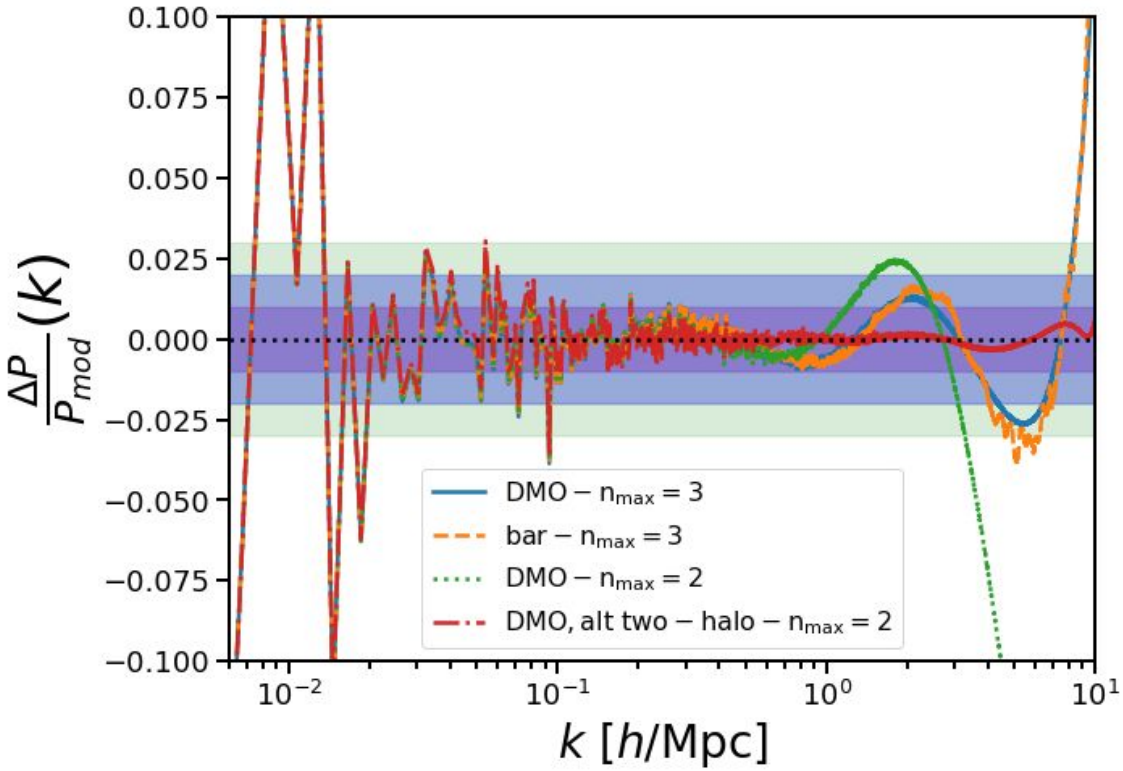
2-halo extension: Use alternative to ZA or k^{2n} transfer function

$$P_{\mathrm{alt,HZPT}}(k) = \left(1 + \alpha k^2 + \beta k^4\right) P_{\mathrm{alt}}(k) + P_{BB}(k)$$

Extended Matter Models

Can extend to k of 7-10 h/Mpc

Also captures strongest baryonic effects (Illustris)



Dark Matter - Cosmology Dependence

Limited comparison at z = 0 using Ω_{cb} & σ_8

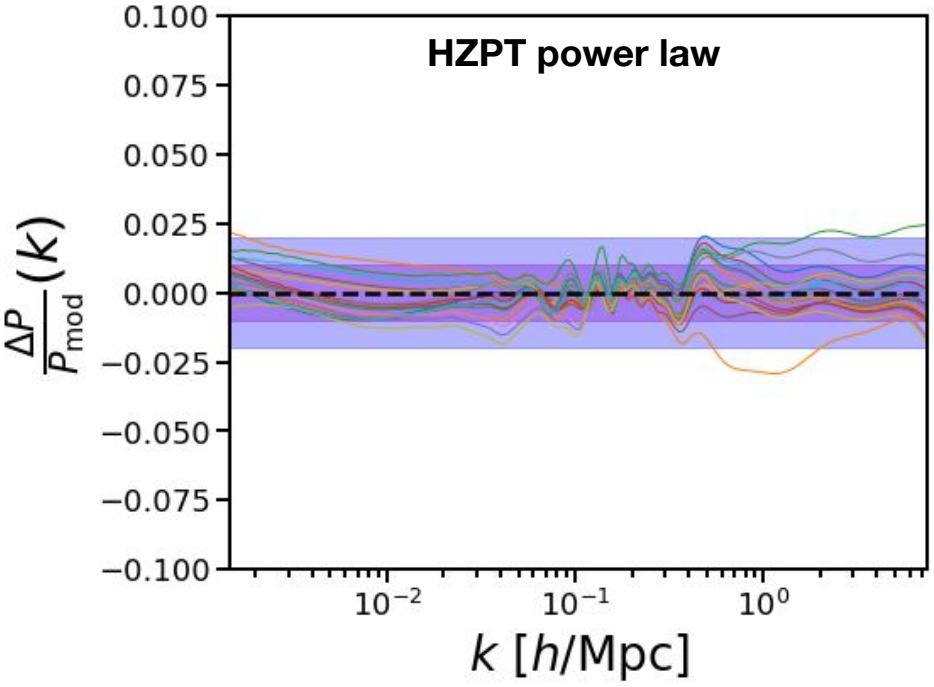
Sample from MiraTitan CosmicEmu (Lawrence++2017)

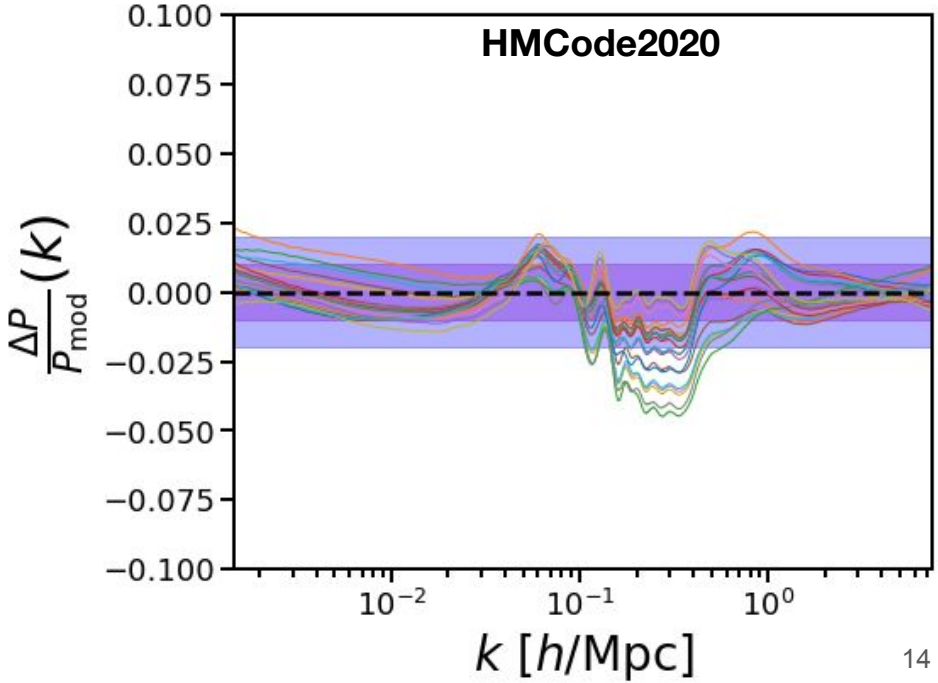
$\Omega_{cb} \in [.26,.34]$, $\sigma_8 \in [.7,.9]$

Fit simple power laws of HZPT parameters in cosmology

Dark Matter - Cosmology Dependence

Power law cosmology fits on par with HMCode2020

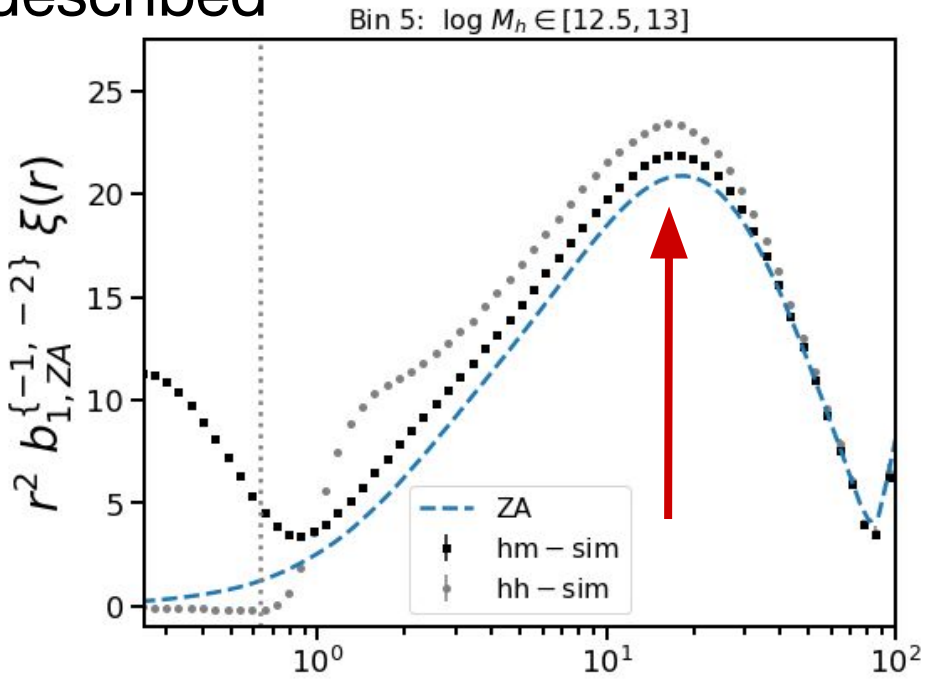




Halos - Correlation Functions

Halo correlation functions well-described by three scales

1. **Large-scale enhancement** over ZA
2. Small-scale enhancement over ZA
3. Halo exclusion scale



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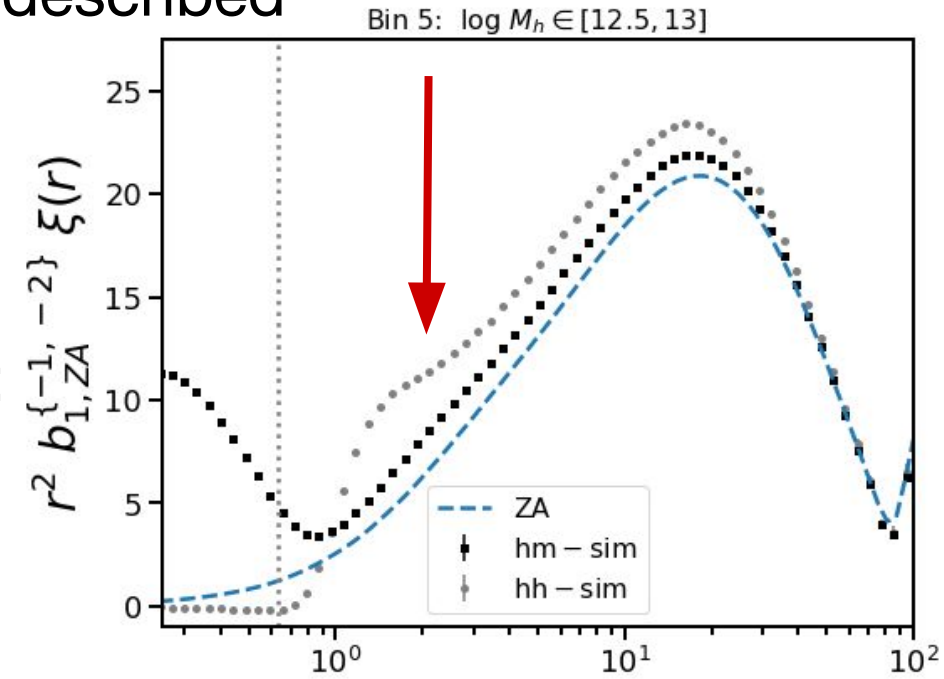

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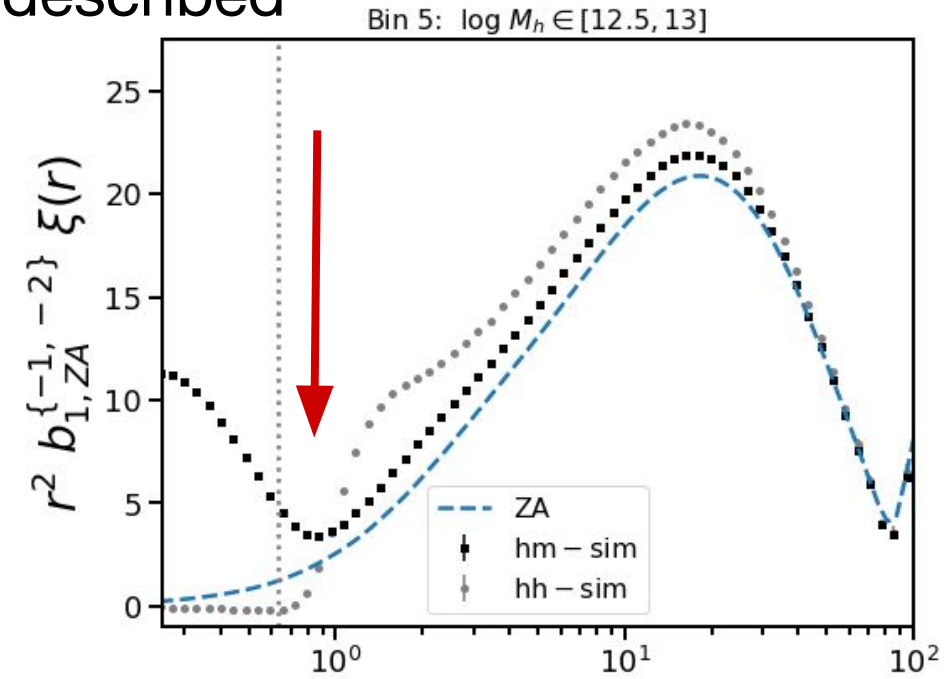
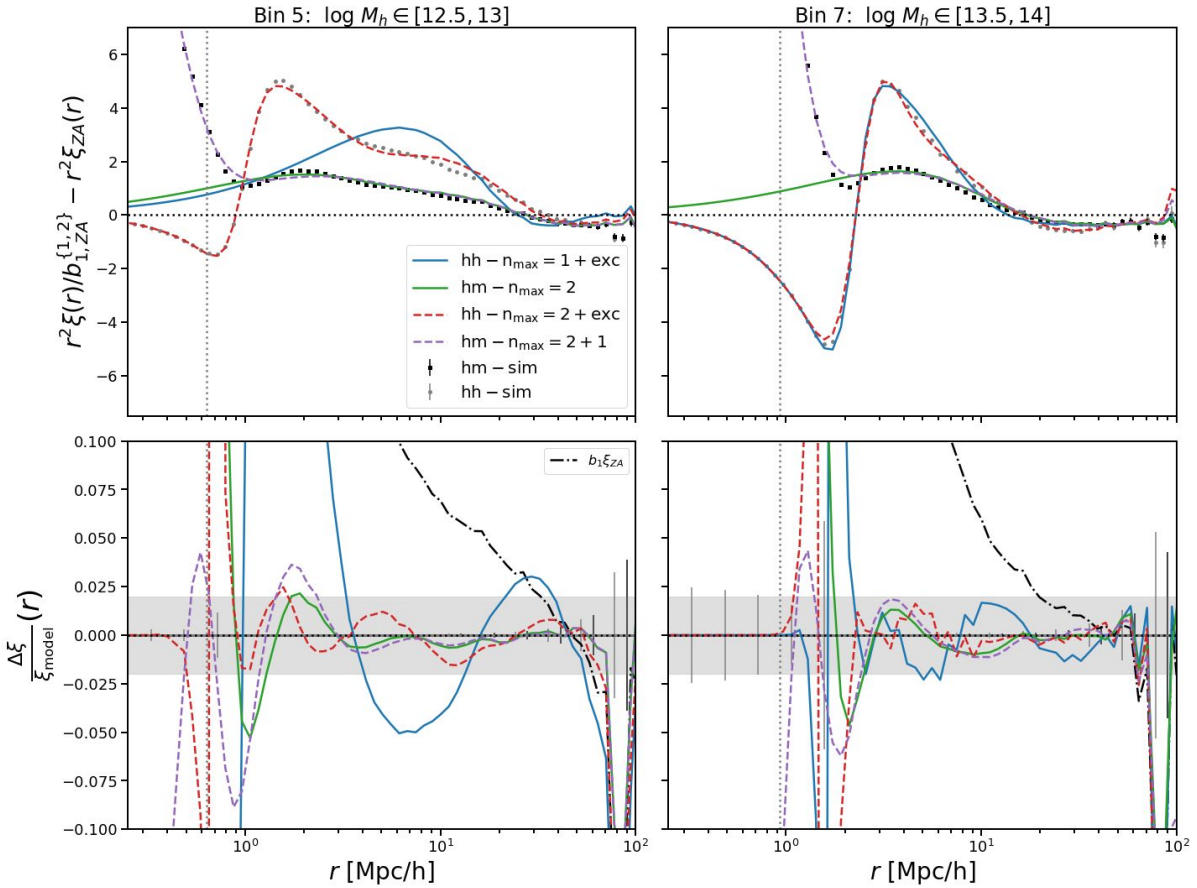


Halos - Correlation Functions

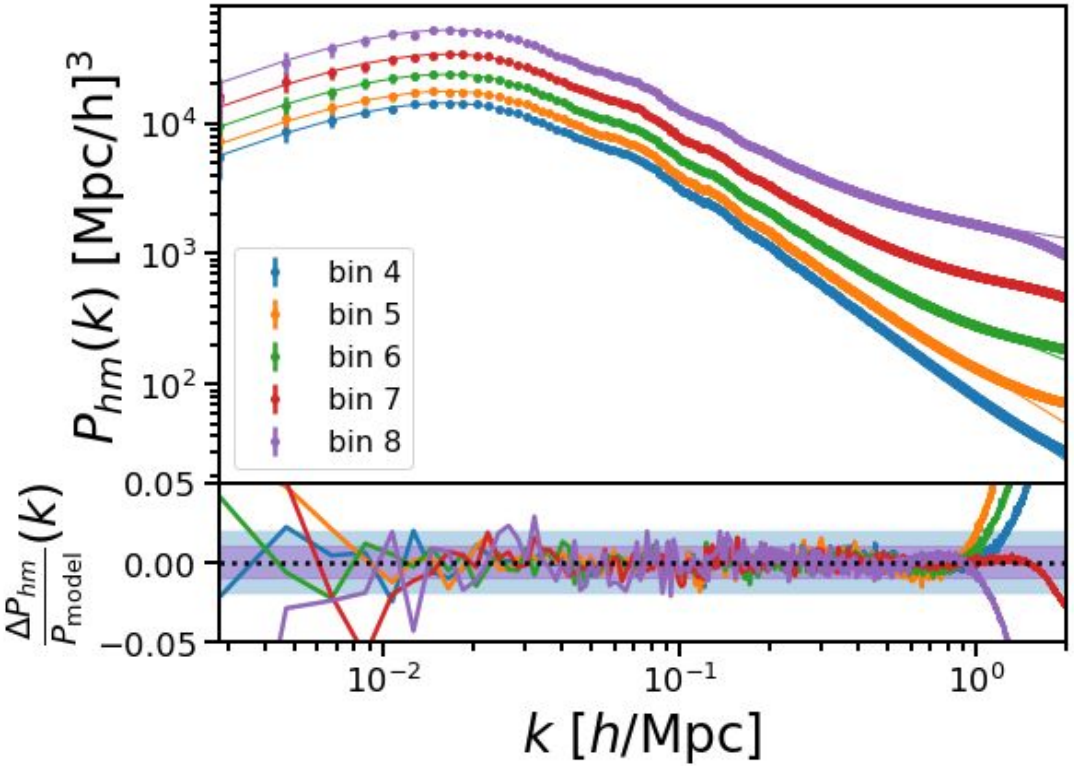
HZPT fits well down to exclusion scale

Scales change with mass bin



Halos - Power spectra

Base model for halo matter with linear bias good to 1 h/Mpc



Halos - Power spectra

Model exclusion in halo-halo power spectrum

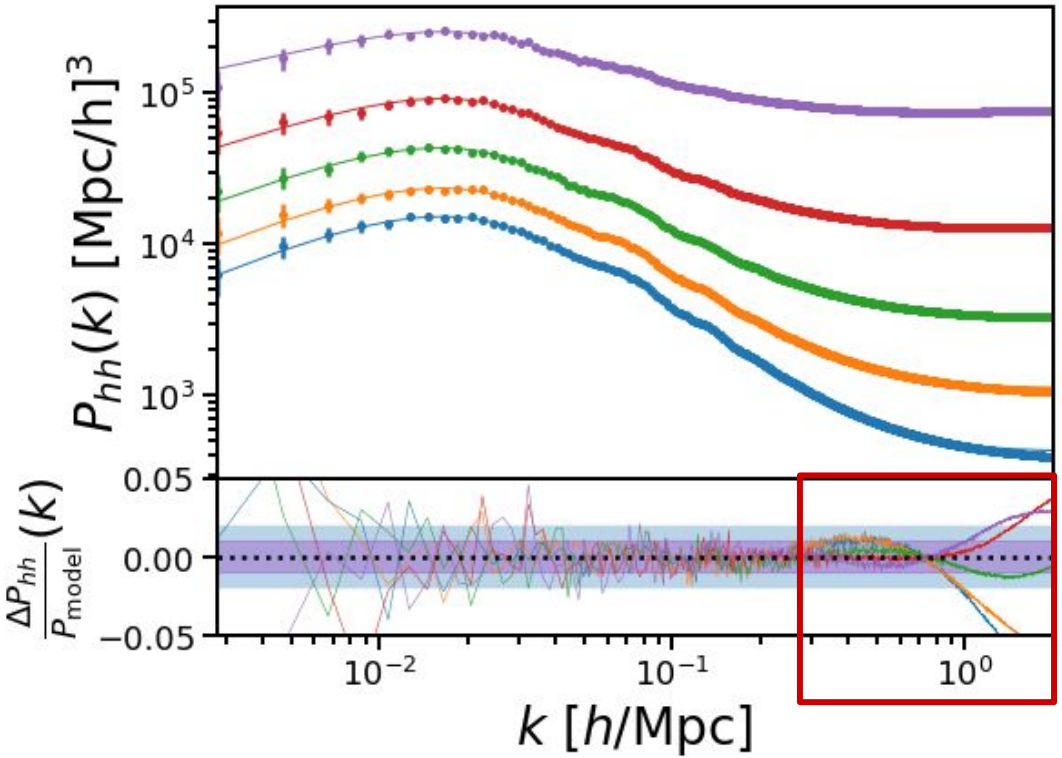
PT bias style free scale-independent shot noise model with n_{max}=1 works but struggles at high k

Exclusion improves this with **no** additional parameters

$$P_{hh}^{(d)}(k) = \frac{1}{\bar{n}} + P_{hh}^{(c)}(k) - V_{\rm excl}\left(W_R(k) + \left[W_R * P_{hh}^{(c)}\right](k)\right)$$

Halos - Power spectra

Exclusion (& small/large-scale enhancements) matter in Phh!



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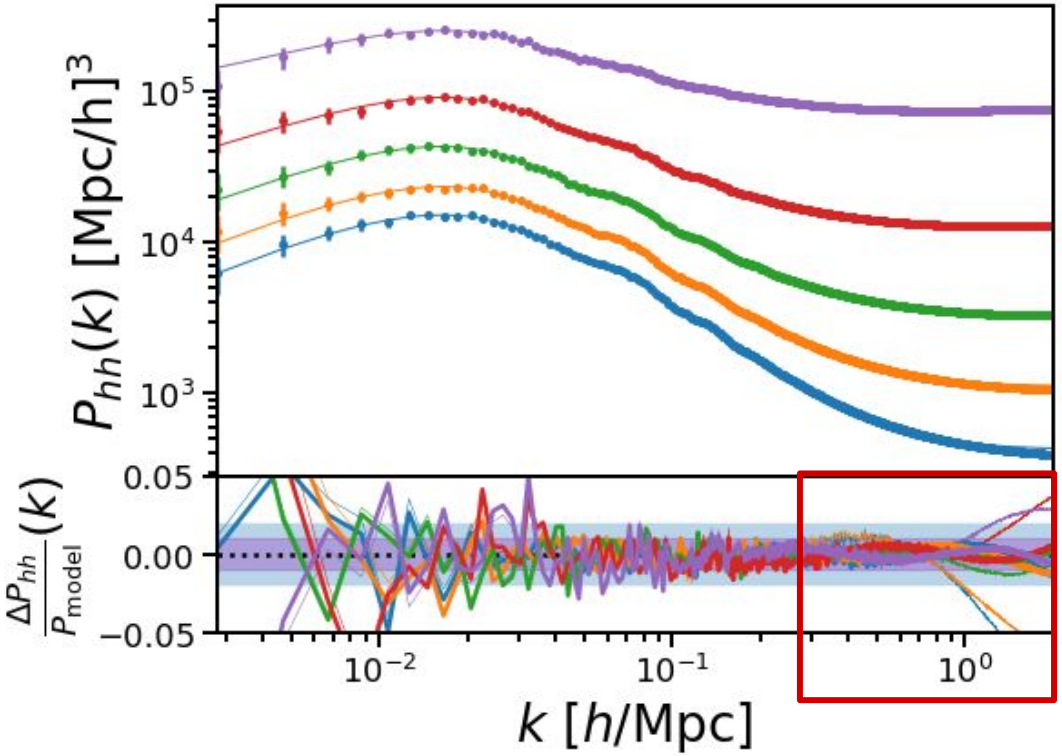


Galaxies

Galaxy two-point statistics are more complicated than halos

Take a pragmatic minimal model approach

HZPT as an effective model for all contributions

Need to add satellites on small scales

Two HOD samples

Simple Zheng++07 HOD

Wide hypercube design

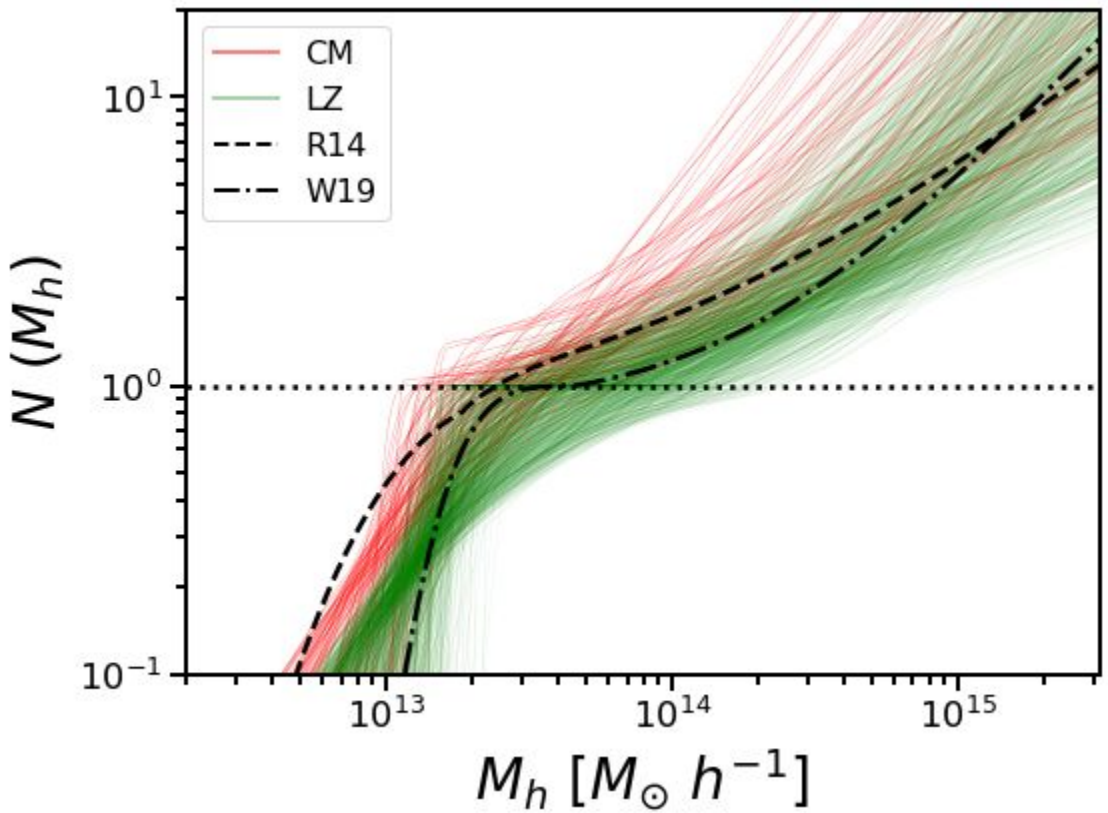
CMASS-like sample

(Approx Reid++14)

LOWZ-like sample

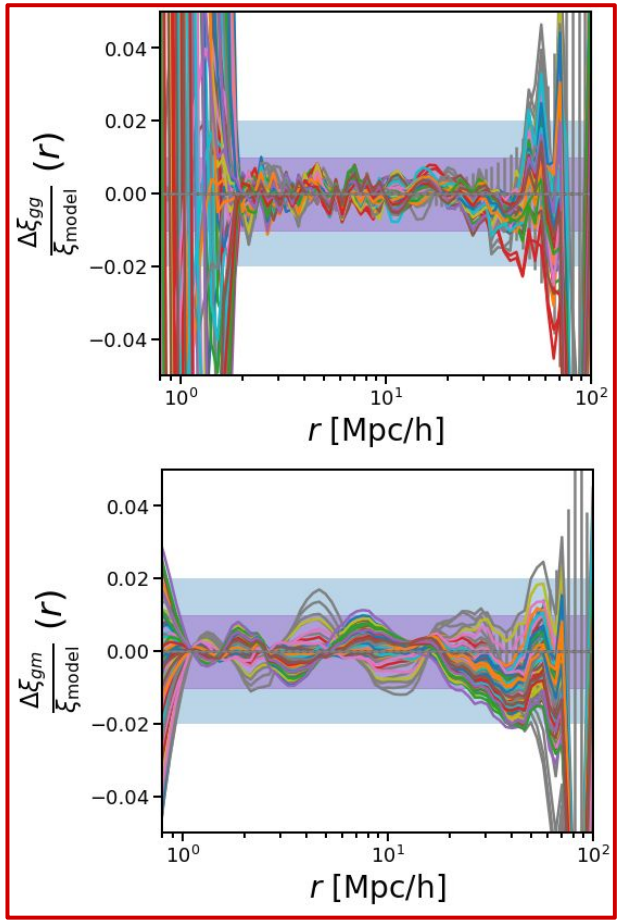
(Close to Wibking++19)

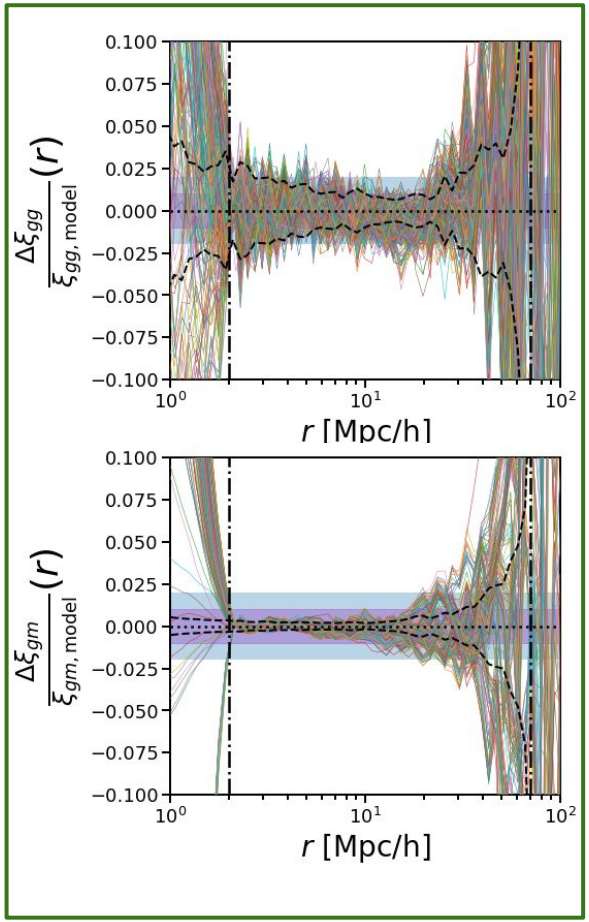
(w/ cosmology)



HOD Galaxies - 2PCF accuracy

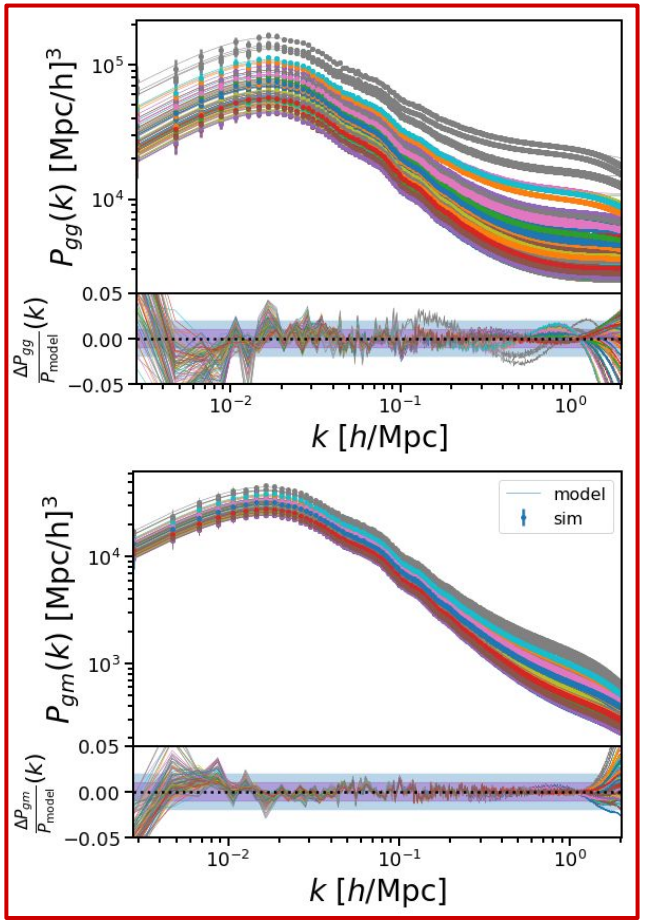
Correlation functions are accurate to 1-2% to r of 1-2 Mpc/h for both sets of HOD

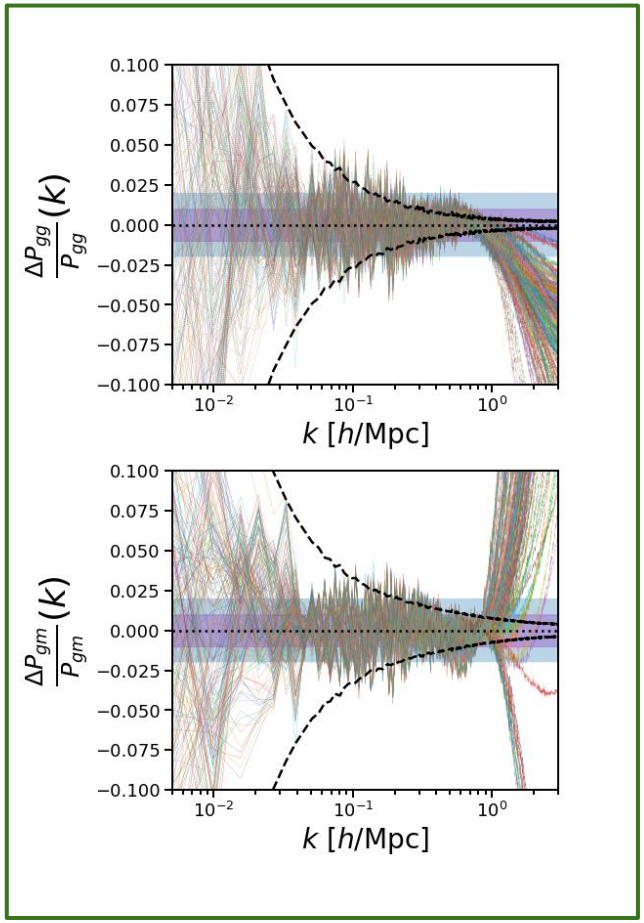




HOD Galaxies - Power spectrum accuracy

Power spectra are accurate to 1-2% to k of 1 h/Mpc for both sets of HOD as well

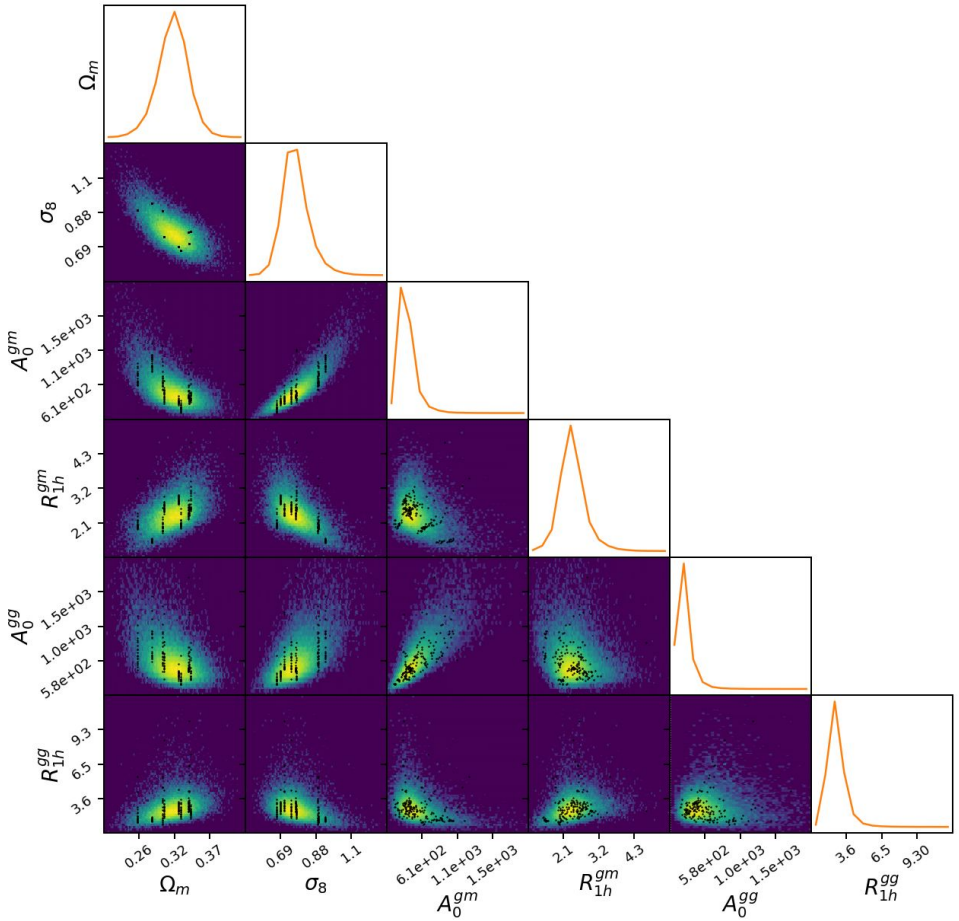




Galaxies - Density estimation

Train on 10 Aemulus cosmologies, 200 HOD (LOWZ-like)

Use normalizing flow (Dai+Seljak 20)



Future and Extensions

Realistic application to projected statistics

Quantify effect of priors on posterior

Potential increased range by balancing augmented ZA

2-halo with BB for tracers (especially cross-correlation)

Conclusions

- ZA plus Padé-style term is a good ansatz for 2-point correlators in configuration AND Fourier space down to small scales
- Baryons can be modeled in Padé-style term through profile parameters
- Halo-halo correlators require exclusion modeling, which eliminates free shot noise, and is a complete description on all scales in HZPT
- Analytic hybrid modeling of galaxy correlators can capture GHC as modeled by broad HOD parameter space to profile-dominated scales
- Parameters in terms of scales, fast evaluation, gradients available

arXiv:2104.10676