Constraining the early Universe with the large-scale structure

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Dark Side of the Universe

2017-07-13, IBS

Cosmology Group at
Korea Astronomy and Space Science Institute

Outline

1. Introduction
2. Models and simulations
3. Results
4. Summary

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Concordance model of cosmology

Hypotheses

- Gravity described by General Relativity
- Isotropy and homogeneity
- Inflation in the early Universe, power-law primordial power spectrum

The concordance ΛCDM model

- Solution of the Einstein equations: FLRW metric
- The Universe is flat
- Universe dominated by dark energy (Λ) and cold dark matter (CDM)
- Big bang theory observationally supported:
  - Cosmological Microwave Background
  - Expansion of the Universe
  - Abundance of light elements
  - Large-scale structures

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Planck 2015 cosmology

Table 5. Constraints on 1-parameter extensions to the base ΛCDM model for combinations of *Planck* power spectra, *Planck* lensing, and external data (BAO+JLA+H_0, denoted "ext").

Parameter	TT	TT+lensing	TT+lensing+ext	TT, TE, EE	TT, TE, EE+lensing	TT, TE, EE+lensing+ext
Ω_K	$-0.052^{+0.049}_{-0.055}$	$-0.005^{+0.016}_{-0.017}$	$-0.0001^{+0.0054}_{-0.0052}$	$-0.040^{+0.038}_{-0.041}$	$-0.004^{+0.015}_{-0.015}$	$0.0008^{+0.0040}_{-0.0039}$

Table 4. Parameter 68% confidence limits for the base ΛCDM model from *Planck* CMB power spectra, in combination with lensing reconstruction ("lensing") and external data ("ext", BAO+JLA+H_0).

Parameter	TT+lowP 68% limits	TT+lowP+lensing 68% limits	TT+lowP+lensing+ext 68% limits	TT,TE,EE+lowP 68% limits	TT,TE,EE+lowP+lensing 68% limits	TT,TE,EE+lowP+lensing+ext 68% limits
$\Omega_b h^2$	0.02222 ± 0.00023	0.02226 ± 0.00023	0.02227 ± 0.00020	0.02225 ± 0.00016	0.02226 ± 0.00016	0.02230 ± 0.00014
$\Omega_c h^2$	0.1197 ± 0.0022	0.1186 ± 0.0020	0.1184 ± 0.0012	0.1198 ± 0.0015	0.1193 ± 0.0014	0.1188 ± 0.0010
$100\theta_{MC}$	1.04085 ± 0.00047	1.04103 ± 0.00046	1.04106 ± 0.00041	1.04077 ± 0.00032	1.04087 ± 0.00032	1.04093 ± 0.00030
τ	0.078 ± 0.019	0.066 ± 0.016	0.067 ± 0.013	0.079 ± 0.017	0.063 ± 0.014	0.066 ± 0.012
$\ln(10^{10}A_s)$	3.089 ± 0.036	3.062 ± 0.029	3.064 ± 0.024	3.094 ± 0.034	3.059 ± 0.025	3.064 ± 0.023
n_s	0.9655 ± 0.0062	0.9677 ± 0.0060	0.9681 ± 0.0044	0.9645 ± 0.0049	0.9653 ± 0.0048	0.9667 ± 0.0040
H_0	67.31 ± 0.96	67.81 ± 0.92	67.90 ± 0.55	67.27 ± 0.66	67.51 ± 0.64	67.74 ± 0.46
Ω_Λ	0.685 ± 0.013	0.692 ± 0.012	0.6935 ± 0.0072	0.6844 ± 0.0091	0.6879 ± 0.0087	0.6911 ± 0.0062
Ω_m	0.315 ± 0.013	0.308 ± 0.012	0.3065 ± 0.0072	0.3156 ± 0.0091	0.3121 ± 0.0087	0.3089 ± 0.0062
r_{drag}	147.33 ± 0.49	147.60 ± 0.43	147.63 ± 0.32	147.27 ± 0.31	147.41 ± 0.30	147.50 ± 0.24

- Precision cosmology

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- Precision cosmology
- *But this is model-dependent*: What if the primordial power spectrum is *not* a power law?

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1. Introduction
2. Models and simulations
   - Models
   - The Simulations
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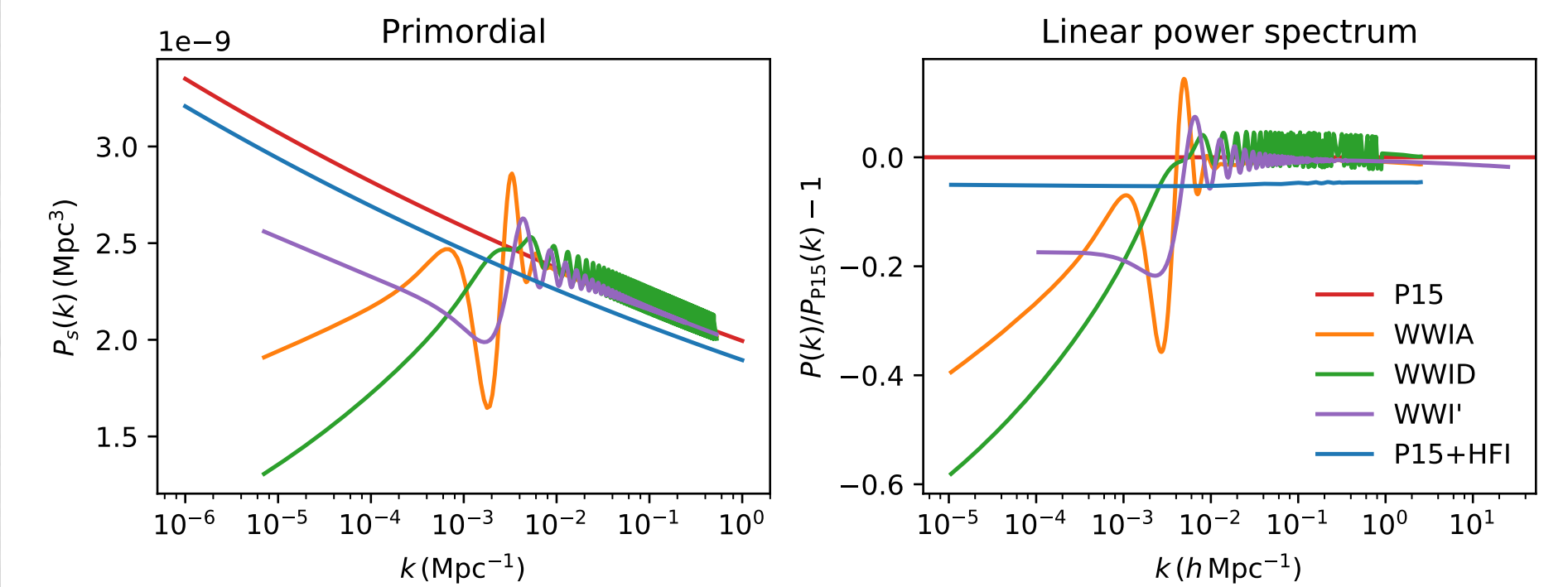
Primordial power spectrum



- Reference model: Planck 2015 TTTEEE (P15)
- Wiggly-whipped inflation (Hazra et al. 2014ab, 2016): WWIA, WWID, WWI'
- Planck 2015 TTTEEE+HFI (P15+HFI)
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- Can we use the LSS to distinguish these models?

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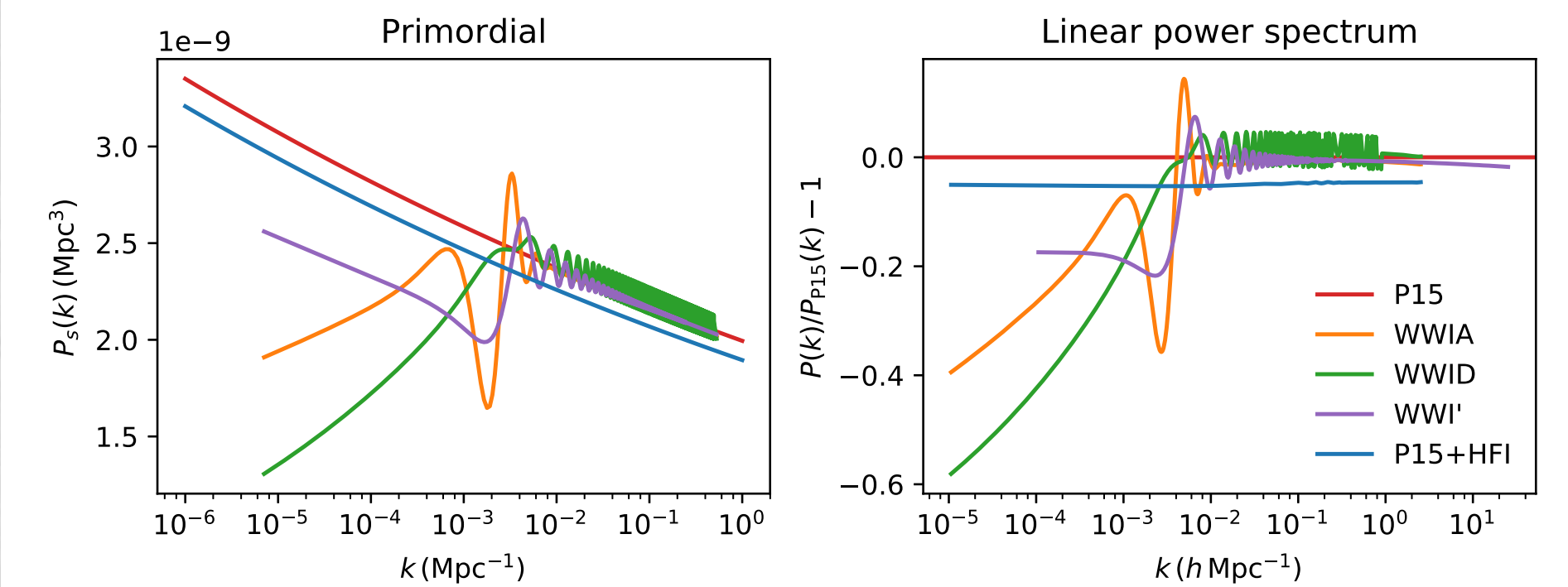

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The simulations

- N-body simulations with GADGET-2 Springel 2005
- 5 models $\times$ 15 random realizations
- Volume: $L = 1.89\,h^{-1}\mathrm{Gpc}$, $N = 1024^3$ (DESI survey)

Model	Ω_m	H_0 (km s^{-1} Mpc^{-1})	σ_8	n_s
P15	0.317	67.05	0.836	0.9625
WWIA	0.320	66.86	0.834	-
WWID	0.318	67.01	0.842	-
WWI'	0.317	67.04	0.842	-
P15+HFI	0.319	66.93	0.816	0.9619

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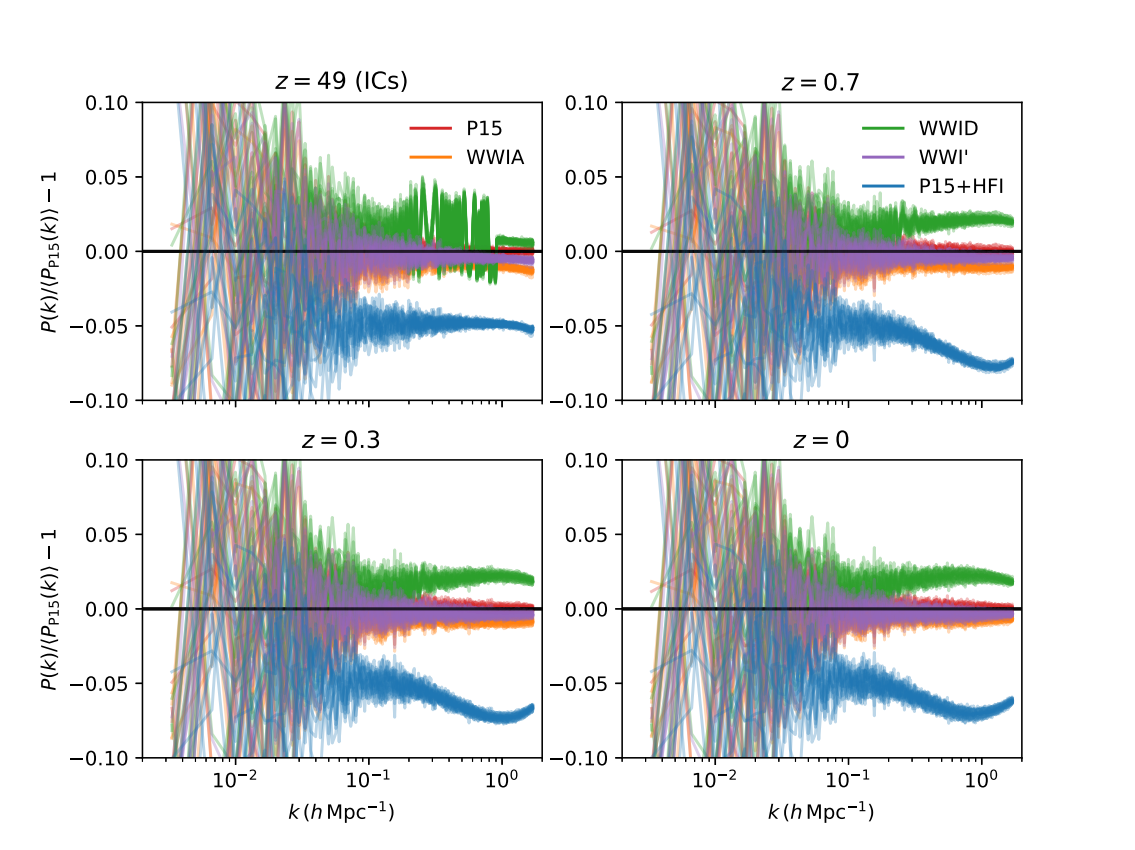
Matter power spectrum

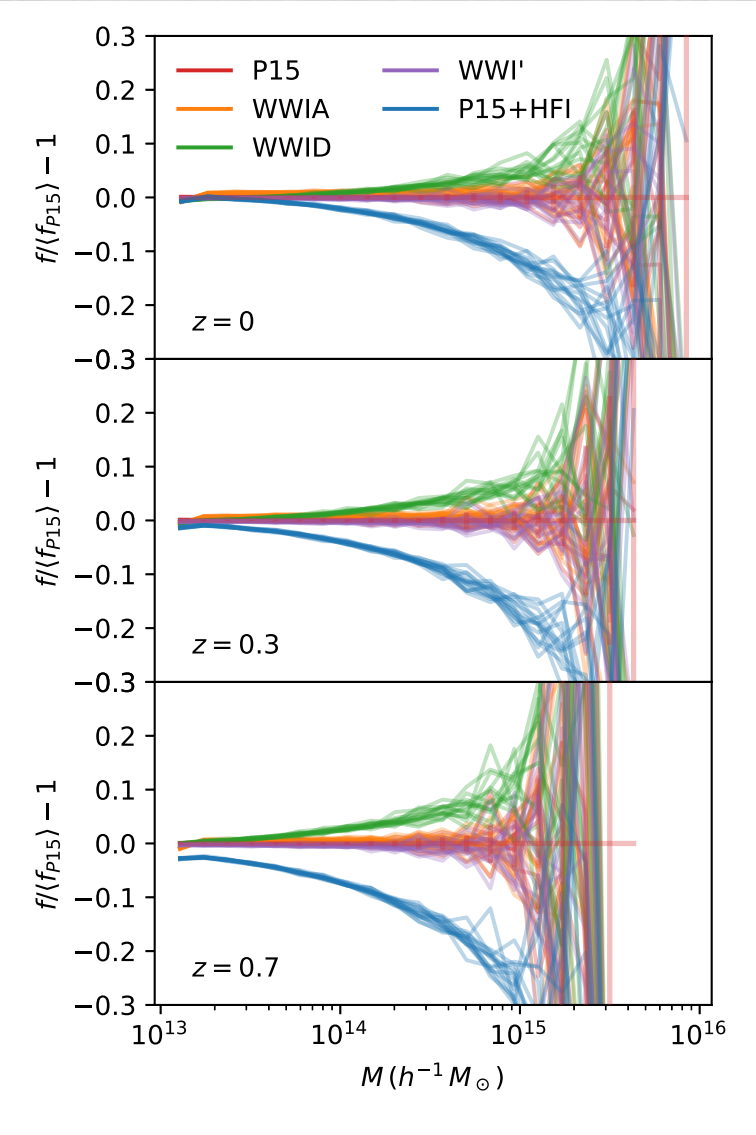
L'Huillier et al. (2017, in prep.)

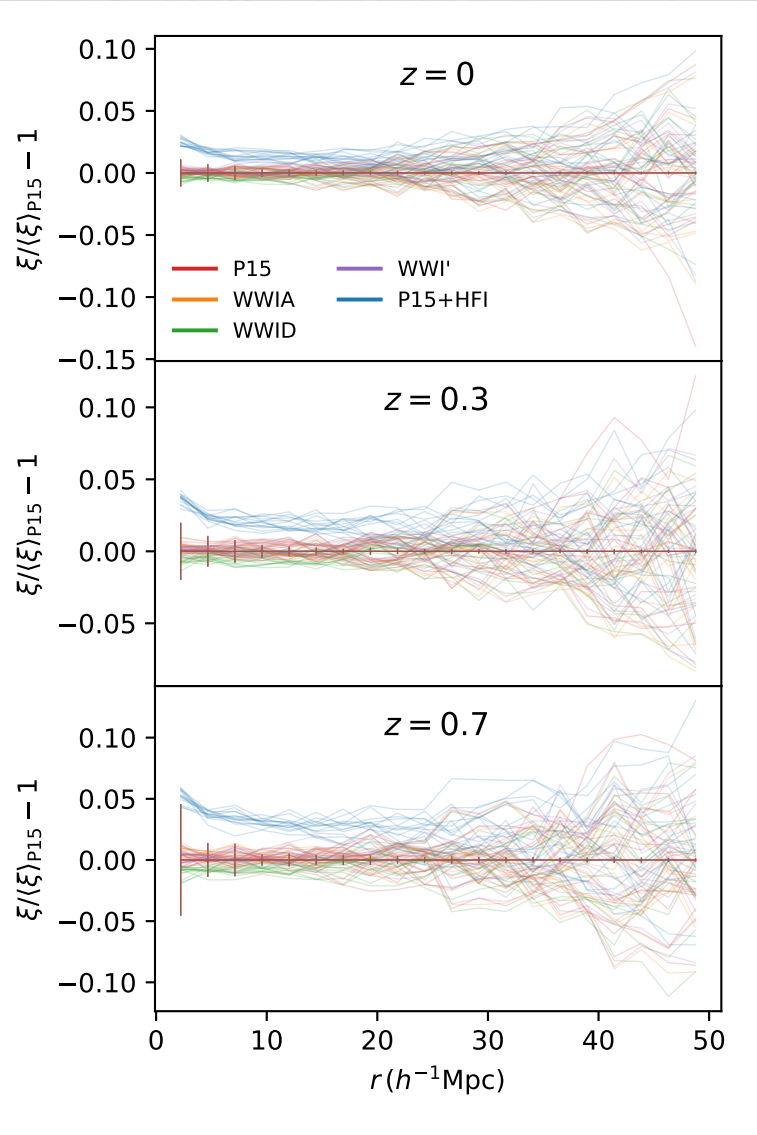


Relative difference $P(k)/\langle P_{\mathrm{P15}}(k)\rangle - 1$

- Power spectrum calulated by ComputePk (L'Huillier 2014)
- TSC assignment, $N_c = 1024^3$
- WWID and P15+HFI can be distinguished, but not WWIA, WWID and P15

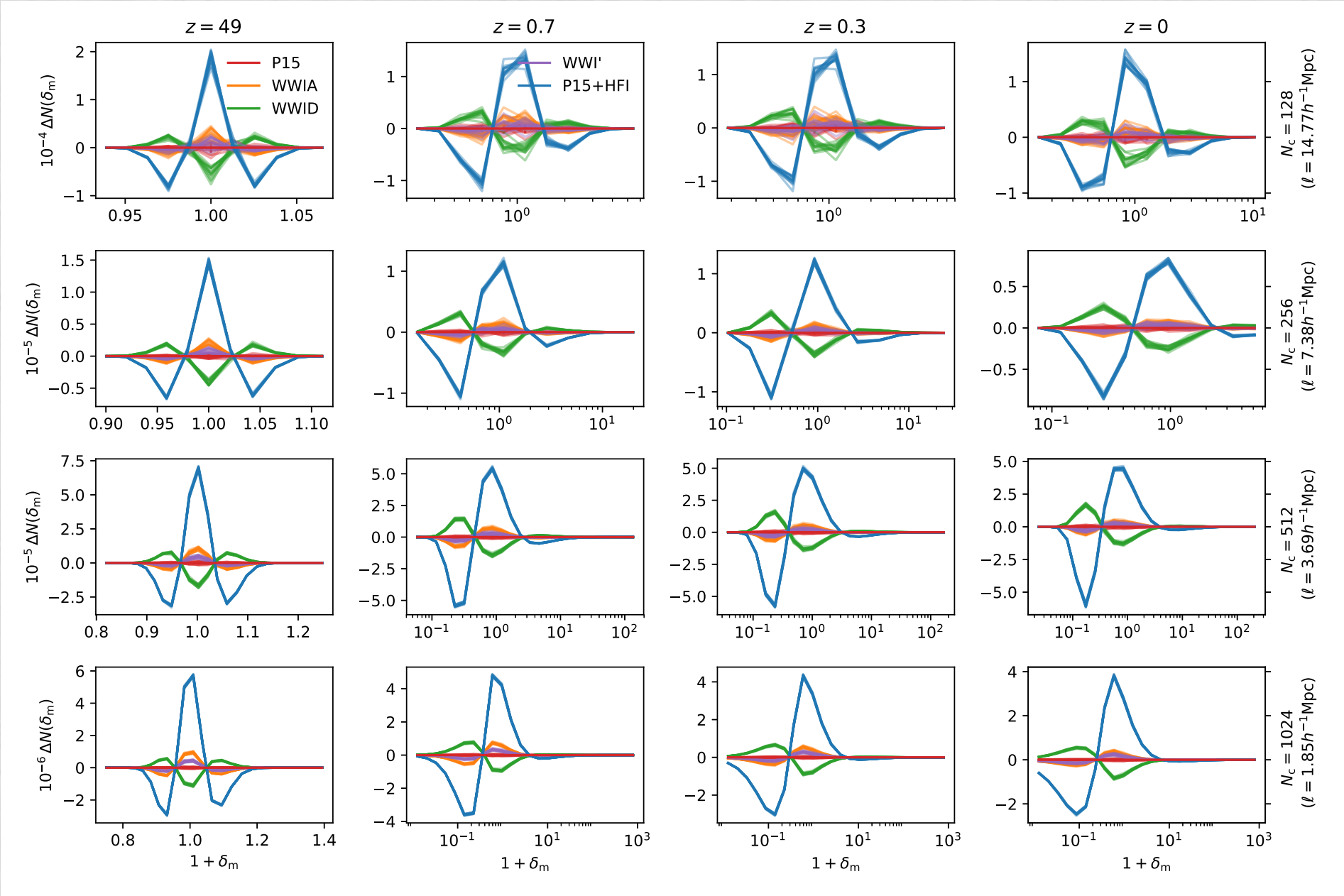
Haloes: mass and correlation functions



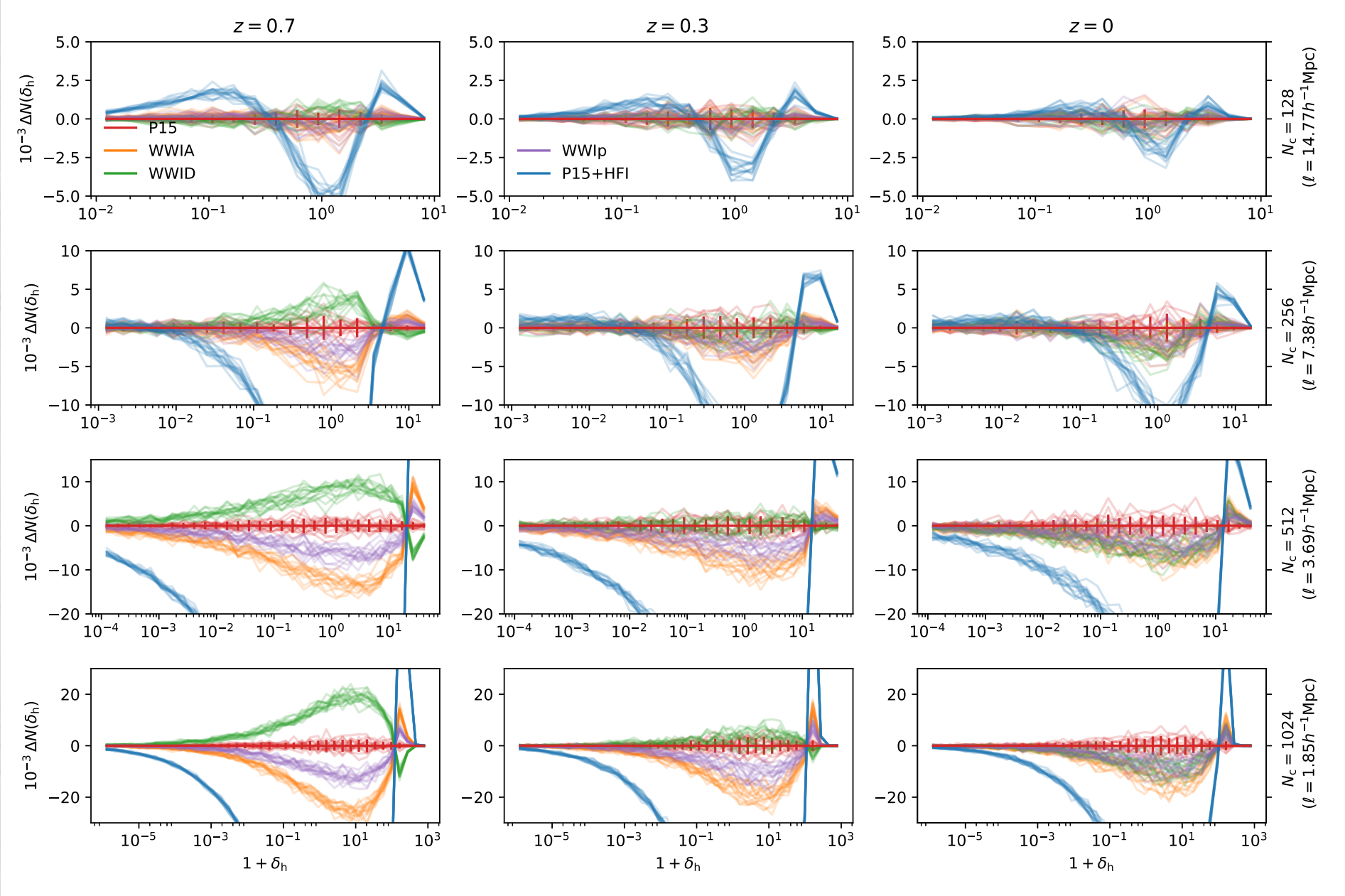


No extra information

Matter density



Halo mass density



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- Yes!
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  - Halo mass and correlation functions: not helpful
  - Count-in-cell: large number of pixels show the difference in the density PDF
  - Still holds for biased tracers at $z \simeq 0.7$
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감사합니다!