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Study on the mapping of dark matter clustering from real space to redshift space

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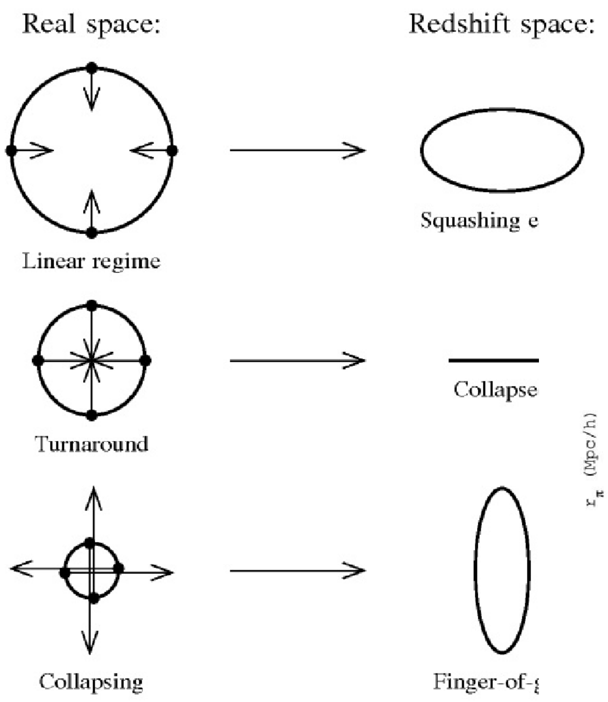
Yi Zheng, Yong-Seon Song, arXiv:1603.00101

RSD Introduction

Redshift space distortion

In observation, galaxy distance is determined by "redshift"

Peculiar velocity of galaxies cause them to appear displaced along the line of sight in redshift space



A. J. S. Hamilton, astro-ph/970810

SDSS DR9, CMASS, 2D correlation function

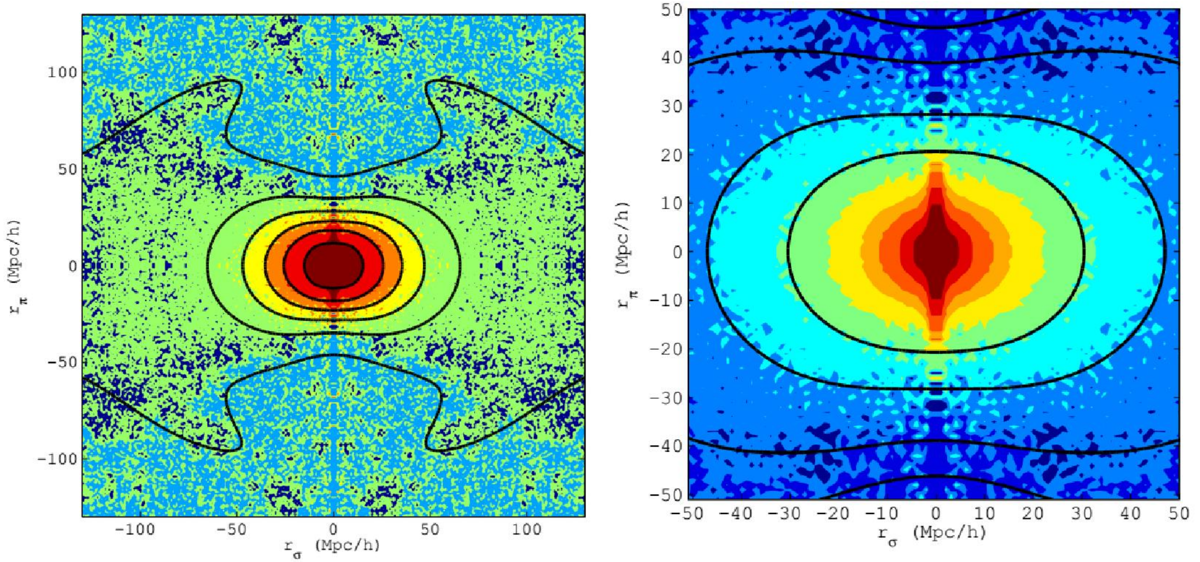
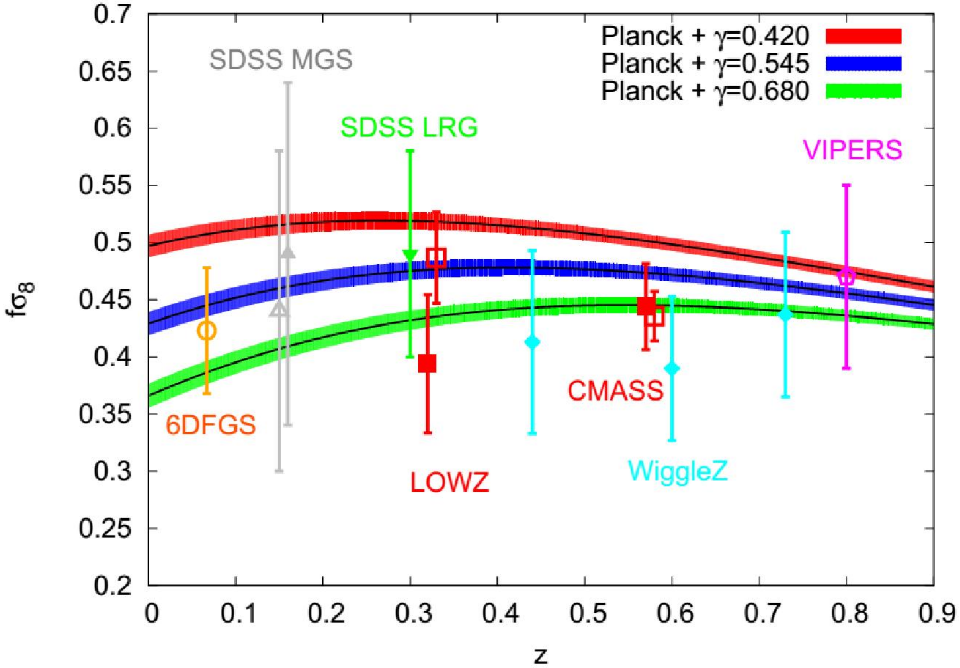


Figure 3. *Left panel*: Two-dimensional correlation function of CMASS galaxies (color) compared with the best fit model described in Section 6.1 (black lines). Contours of equal ξ are shown at [0.6, 0.2, 0.1, 0.05, 0.02, 0]. *Right panel*: Smaller-scale two-dimensional clustering. We show model contours at [0.14, 0.05, 0.01, 0]. The value of ξ_0 at the minimum separation bin in our analysis is shown as the innermost contour. The $\mu \approx 1$ "finger-of-god" effects are small on the scales we use in this analysis.

Reid et al. 1203.6641

RSD Introduction

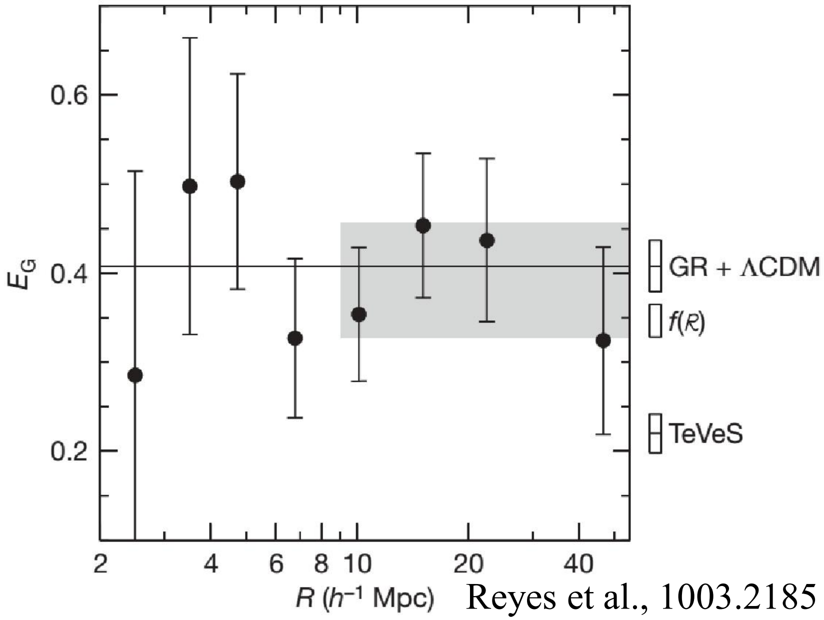
$$f = \frac{d\ln D}{d\ln a} = \Omega_m(z)^\gamma$$ Eric Linder, astro-ph/0507263



Gil-Marin et al. 1509.06386

$$\langle \hat{E}_G \rangle = \left[\frac{\nabla^2(\psi - \phi)}{-3H_0^2 a^{-1}\theta}\right]_{k=l/\bar{\chi},\bar{z}} = \left[\frac{\nabla^2(\psi - \phi)}{3H_0^2 a^{-1}\beta\delta}\right]_{k=l/\bar{\chi},\bar{z}} \equiv E_G.$$

Zhang et al., 0704.1932



Reyes et al., 1003.2185

RSD correlation function

Streaming model:

$$1 + \xi_S(s_\perp, s_\parallel) = \int dr_\parallel \, [1 + \xi_R(r)] \, \mathcal{P}(r_\parallel - s_\parallel | \mathbf{r})$$

Pairwise velocity probability distribution function

Improving the modelling of redshift-space distortions: I. A bivariate Gaussian description for the galaxy pairwise velocity distributions

arXiv:1407.4753v2

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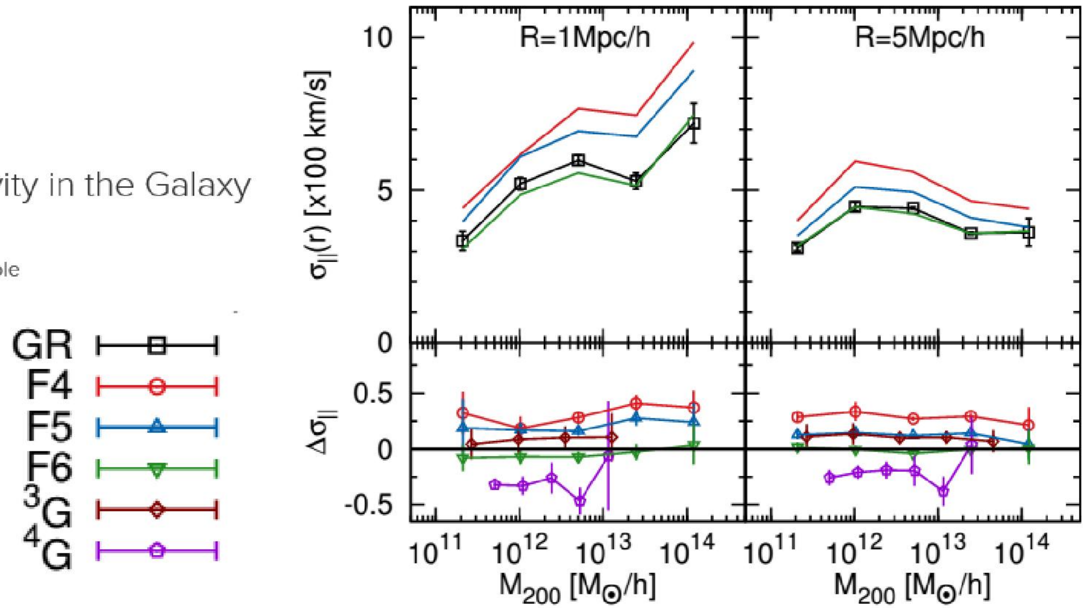
Clear and Measurable Signature of Modified Gravity in the Galaxy Velocity Field

Wojciech A. Hellwing, Alexandre Barreira, Carlos S. Frenk, Baojiu Li, and Shaun Cole

Phys. Rev. Lett. **112**, 221102 – Published 5 June 2014



Power spectrum modelling: 1. mapping; 2. PT

We follow the derivation of TNS paper, Taruya et al. 1006.0699

The redshift position **s**: $\boldsymbol{s} = \boldsymbol{x} + v_z/(aH)\,\hat{\boldsymbol{z}}$

From mass conservation: $\left(1 + \delta^s(\boldsymbol{s})\right) d^3 s =$

Taylor expansion and trunction

The redshift space power spectrum:

$$P^{(S)}(\boldsymbol{k}) = \int d^3\boldsymbol{x} e^{i\boldsymbol{k}\cdot\boldsymbol{x}} \langle e^{-ik\mu f \Delta u_z} \{\delta(\boldsymbol{r}) + f\nabla_z u_z(\boldsymbol{r})\} \times \{\delta(\boldsymbol{r}') + f\nabla_z u_z(\boldsymbol{r}')\}\rangle,$$

$$u_z(\boldsymbol{r}) = -v_z(\boldsymbol{r})/(aHf)$$

RSD modelling

$$P^{(\mathrm{S})}(\boldsymbol{k}) = \int d^3\boldsymbol{x}\, e^{i\boldsymbol{k}\cdot\boldsymbol{x}} \langle e^{-ik\mu f \Delta u_z}\{\delta(\boldsymbol{r}) + f\nabla_z u_z(\boldsymbol{r})\} \times \{\delta(\boldsymbol{r}') + f\nabla_z u_z(\boldsymbol{r}')\}\rangle,$$

Definition:

$$j_1 = -ik\mu f, \qquad A_1 = u_z(\boldsymbol{r}) - u_z(\boldsymbol{r}'),$$
$$A_2 = \delta(\boldsymbol{r}) + f\nabla_z u_z(\boldsymbol{r}), \qquad A_3 = \delta(\boldsymbol{r}') + f\nabla_z u_z(\boldsymbol{r}').$$

$$P^{(\mathrm{S})}(k,\mu) = \int d^3\boldsymbol{x}\, e^{i\boldsymbol{k}\cdot\boldsymbol{x}} \langle e^{j_1 A_1} A_2 A_3\rangle,$$

$$\langle e^{j_1 A_1} A_2 A_3\rangle = \exp\{\langle e^{j_1 A_1}\rangle_c\}[\langle e^{j_1 A_1} A_2 A_3\rangle_c + \langle e^{j_1 A_1} A_2\rangle_c \langle e^{j_1 A_1} A_3\rangle_c].$$

Important for separation of FoG

$$P^{(\mathrm{S})}(k,\mu) = \int d^3\boldsymbol{x}\, e^{i\boldsymbol{k}\cdot\boldsymbol{x}} \exp\{\langle e^{j_1 A_1}\rangle_c\}[\langle e^{j_1 A_1} A_2 A_3\rangle_c + \langle e^{j_1 A_1} A_2\rangle_c \langle e^{j_1 A_1} A_3\rangle_c].$$

Scale dependent part+scale independent part

$$\langle e^{j_1 A_1} A_2 A_3\rangle_c + \langle e^{j_1 A_1} A_2\rangle_c \langle e^{j_1 A_1} A_3\rangle_c \simeq \langle A_2 A_3\rangle + j_1\langle A_1 A_2 A_3\rangle_c + j_1^2\{\tfrac{1}{2}\langle A_1^2 A_2 A_3\rangle_c + \langle A_1 A_2\rangle_c \langle A_1 A_3\rangle_c\} + \mathcal{O}(j_1^3).$$

Final model

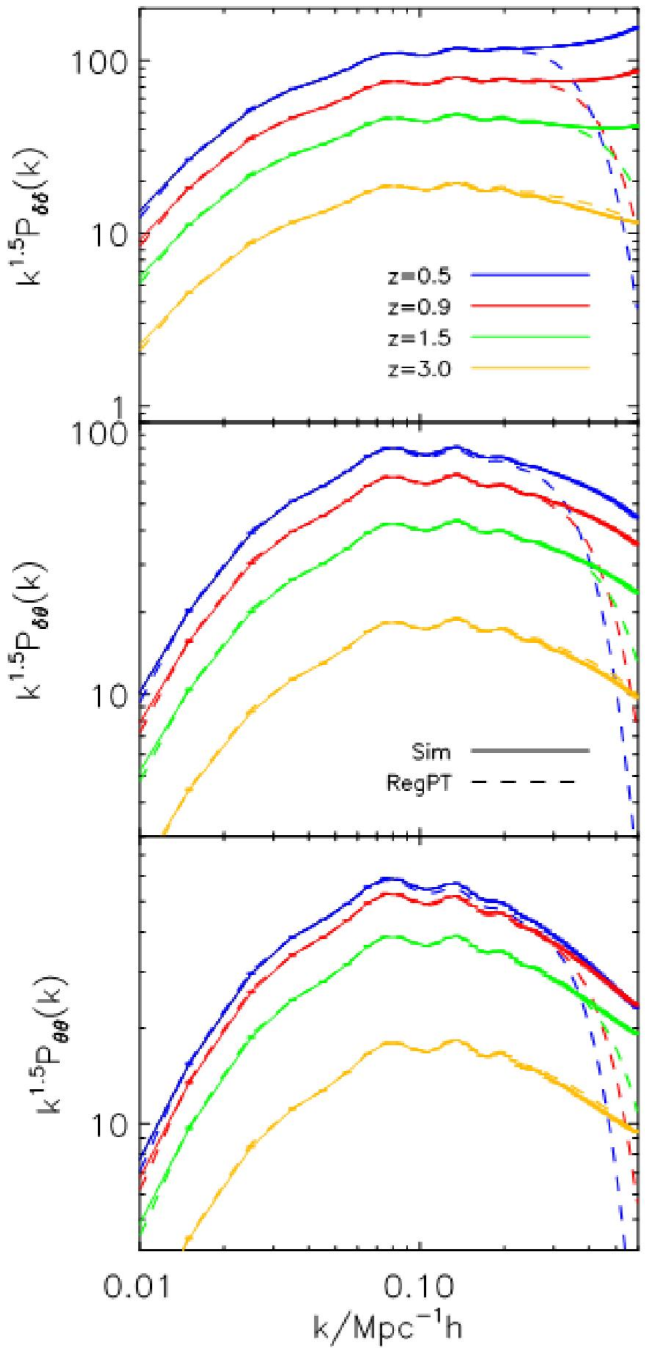
1006.0699 & 1603.00101

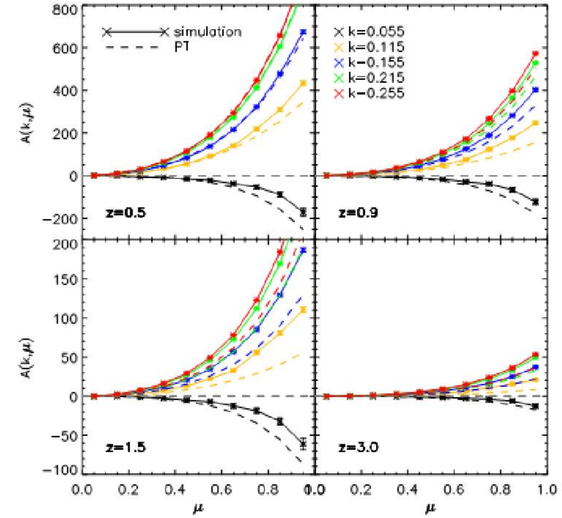
Taylor expansion in terms of $j_1 = -ik\mu$

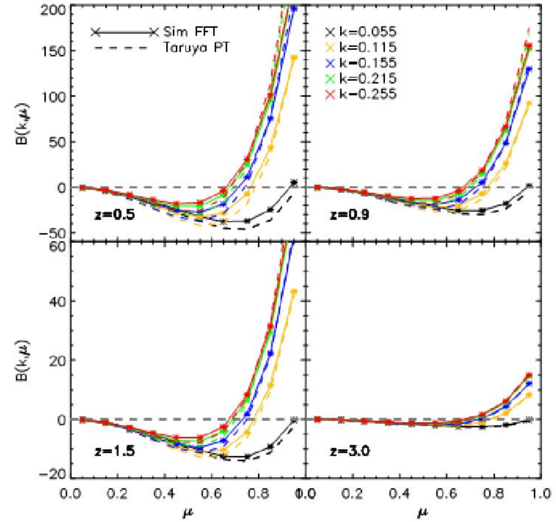
$$
\begin{aligned}
&D^{\rm FoG}_{\rm local}(k\mu, \boldsymbol{x}) \left[\langle e^{j_1 A_1} A_2 A_3\rangle_c + \langle e^{j_1 A_1} A_2\rangle_c \langle e^{j_1 A_1} A_3\rangle_c\right] \\
&\simeq j_1^0 \langle A_2 A_3\rangle_c + j_1^1 \langle A_1 A_2 A_3\rangle_c \\
&+ j_1^2 \left\{ \langle A_1 A_2\rangle_c \langle A_1 A_3\rangle_c + \frac{1}{2} \langle A_1^2 A_2 A_3\rangle_c - \langle u_z u_z'\rangle_c \langle A_2 A_3\rangle_c \right\} \\
&+ \mathcal{O}(j_1^3) \,, \qquad (14)
\end{aligned}
$$

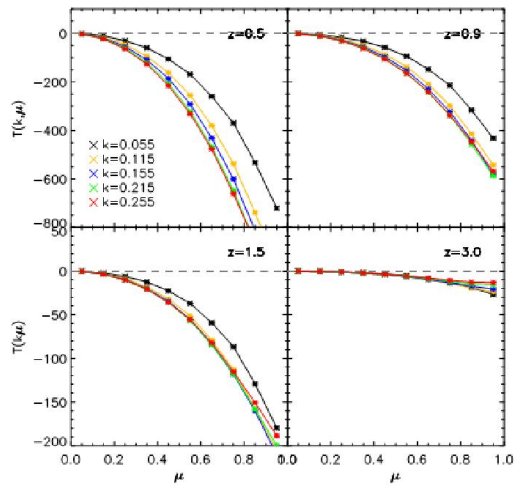
$$
\begin{aligned}
P^{(\rm S)}(k,\mu) &= D^{\rm FoG}(k\mu\sigma_z) P_{\rm perturbed}(k,\mu) \\
&= D^{\rm FoG}(k\mu\sigma_z)[P_{\delta\delta} + 2\mu^2 P_{\delta\Theta} + \mu^4 P_{\Theta\Theta} \quad (15) \\
&\quad + A(k,\mu) + B(k,\mu) + T(k,\mu) + F(k,\mu)].
\end{aligned}
$$

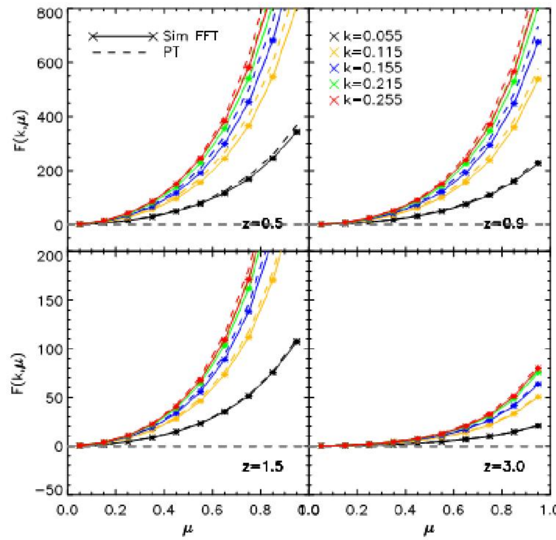
parameter	physical meaning	value
Ω_m	present fractional matter density	0.3132
Ω_Λ	$1 - \Omega_m$	0.6868
Ω_b	present fractional baryon density	0.049
h	$H_0/(100\ \mathrm{km\ s^{-1} Mpc^{-1}})$	0.6731
n_s	primordial power spectral index	0.9655
σ_8	r.m.s. linear density fluctuation	0.829
$L_{\rm box}$	simulation box size	$1890\ h^{-1}\mathrm{Mpc}$
$N_{\rm p}$	simulation particle number	1024^3
$m_{\rm p}$	simulation particle mass	$5.46 \times 10^{10} h^{-1} M_\odot$











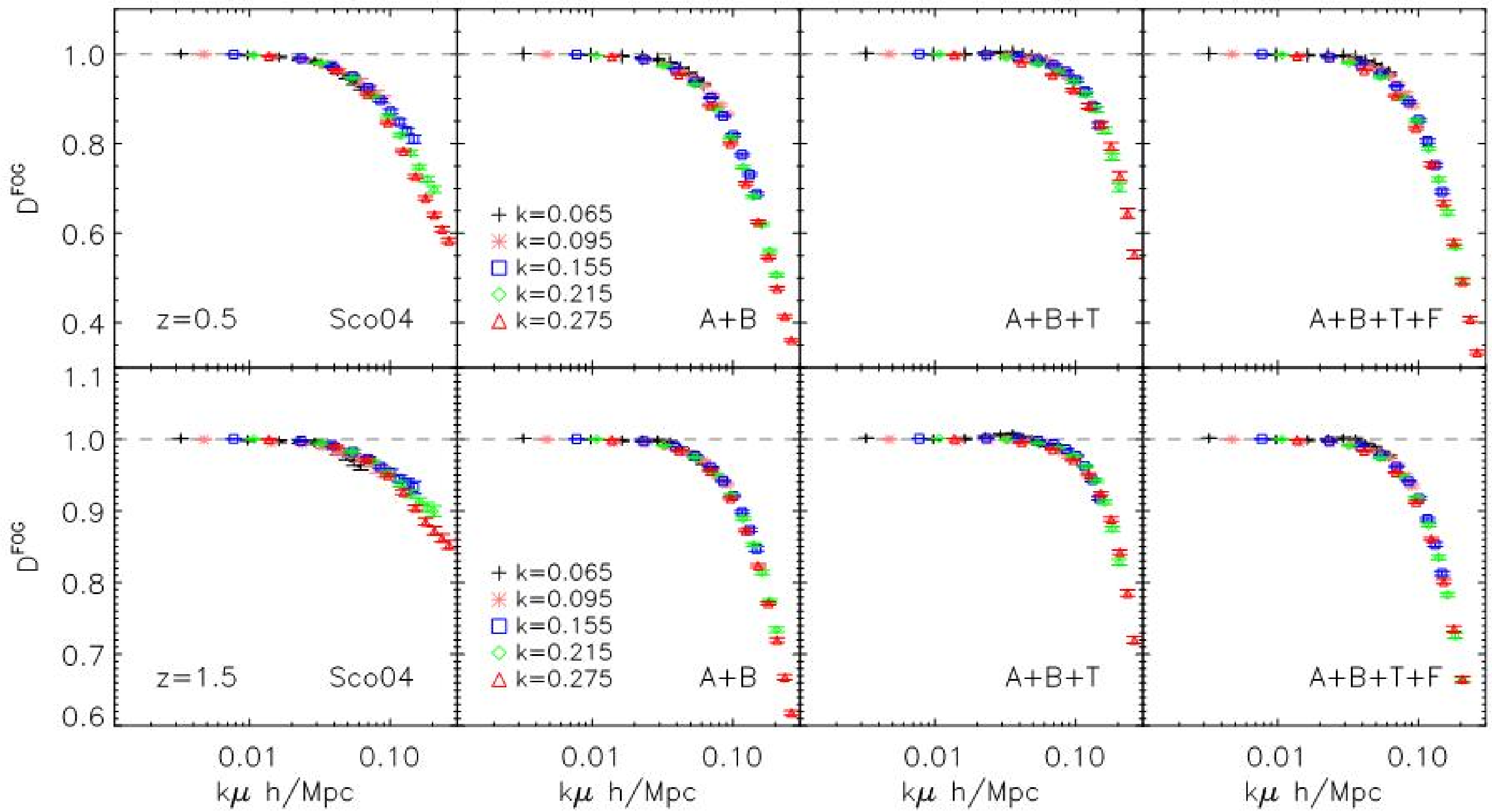
Finding 1: All higher order terms are important!

1. FoG test

$$P^{(S)}(k,\mu) = D^{\rm FoG}(k\mu\sigma_z)P_{\rm perturbed}(k,\mu)$$
$$= D^{\rm FoG}(k\mu\sigma_z)[P_{\delta\delta} + 2\mu^2 P_{\delta\Theta} + \mu^4 P_{\Theta\Theta} \quad (15)$$
$$+A(k,\mu) + B(k,\mu) + T(k,\mu) + F(k,\mu)].$$

$$D^{\rm FoG} = \frac{P^{(S)}_{\rm sim}(k,\mu)}{P_{\rm perturbed}(k,\mu)},$$

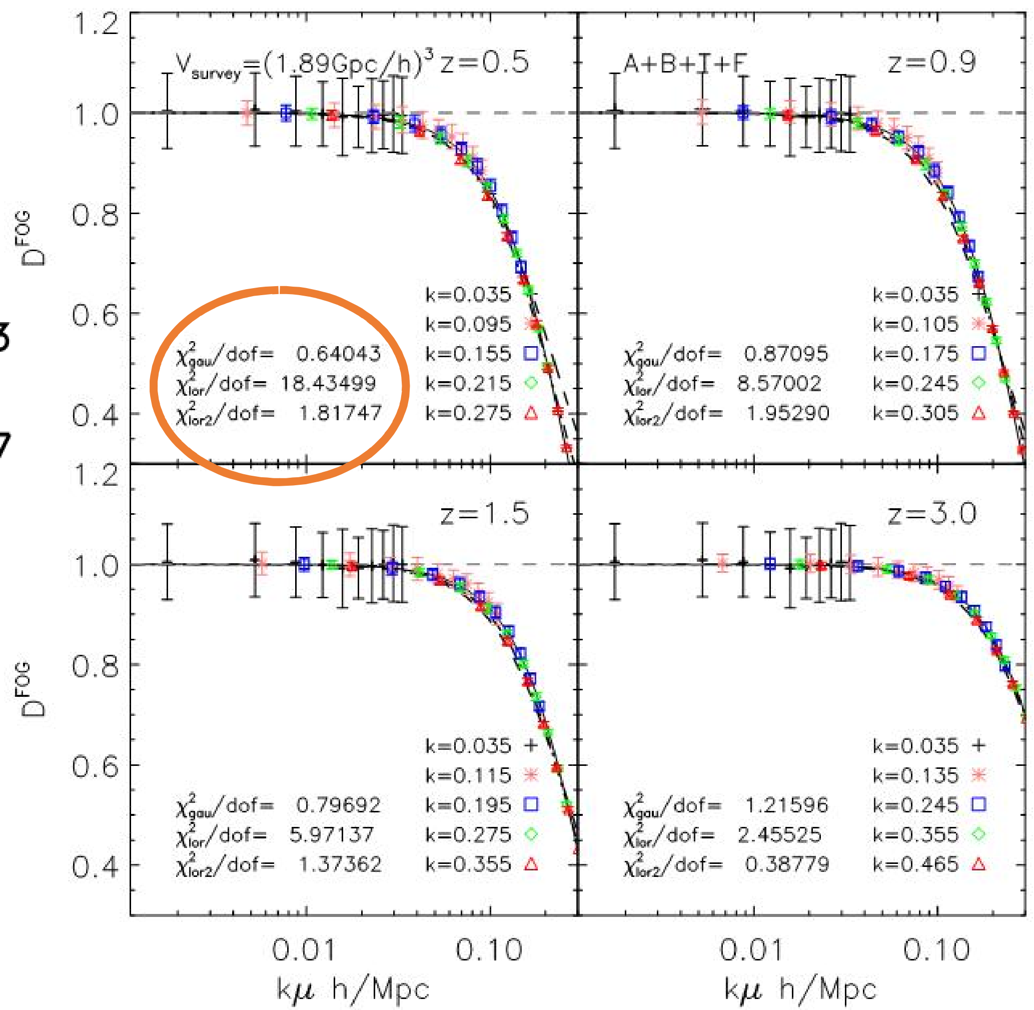
One 'standard' for good RSD model: if FoG term is a simple function of $k\mu\sigma_z$



Finding 2: A+B+F+T works best, also in order to be complete at j_1^2 order, we will consider A+B+F+T model hereafter.

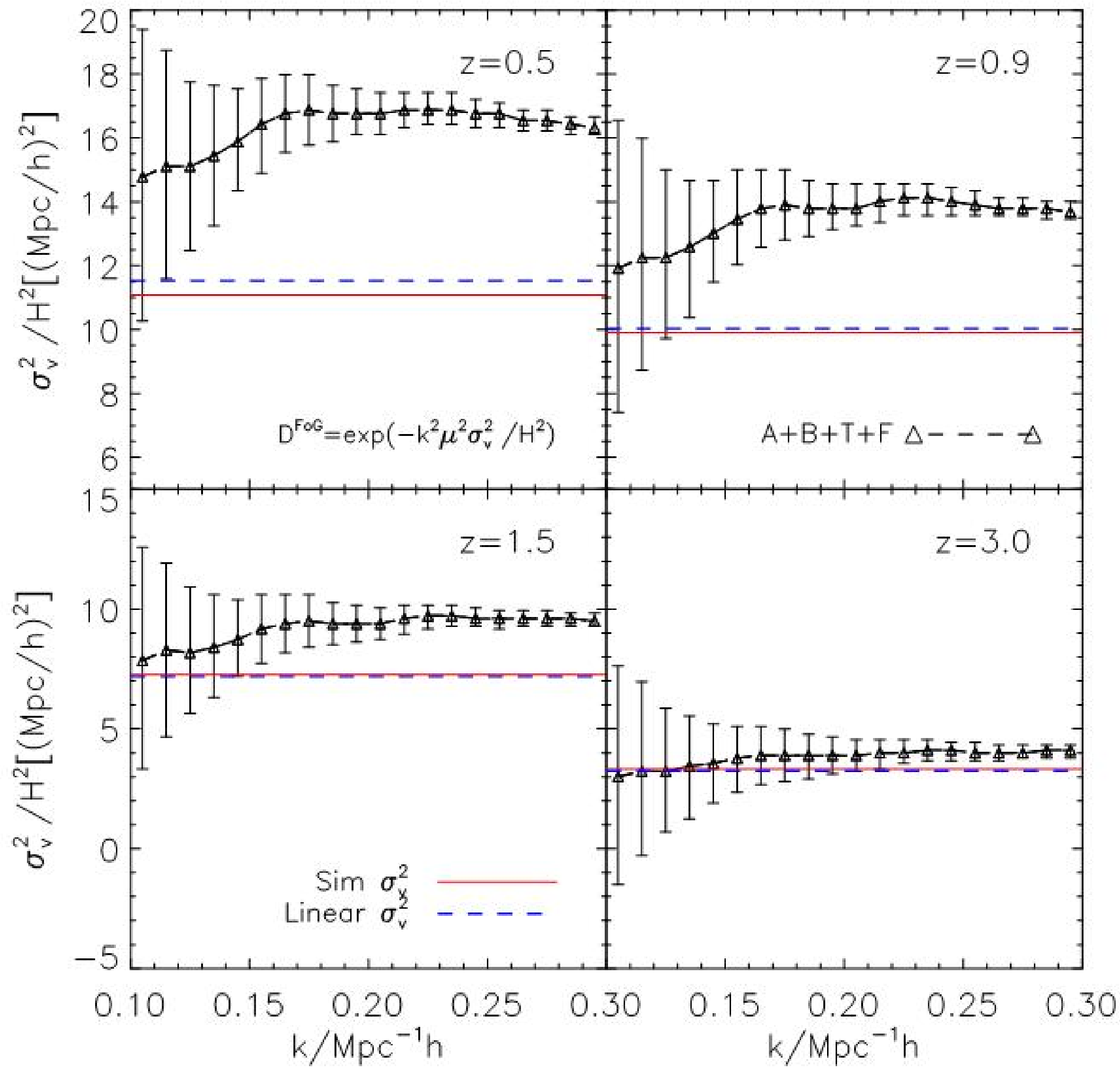
$$D^{\mathrm{FoG}}(k\mu\sigma_z) = \begin{cases} e^{-k^2\mu^2\sigma_z^2/2} & \text{Gaussian,} \\ \left(1+k^2\mu^2\sigma_z^2/2\right)^{-1} & \text{Lorentzian,} \\ \left(1+k^2\mu^2\sigma_z^2/2\right)^{-2} & \text{squared Lorentzian,} \end{cases}$$

χ^2_{gau}/dof= 0.64043
χ^2_{lor}/dof= 18.43499
χ^2_{lor2}/dof= 1.81747



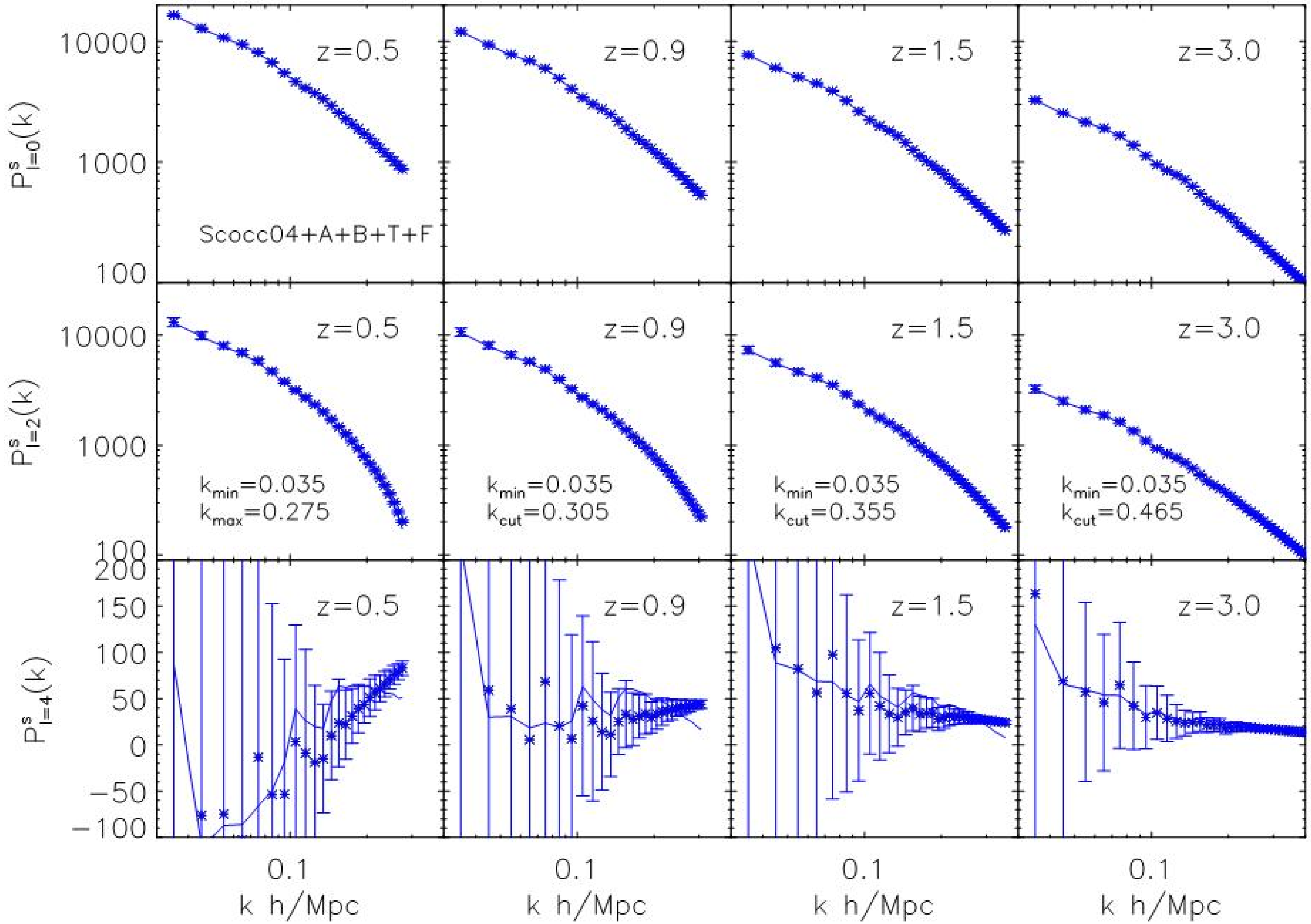
Finding 3: Gaussian model is best FoG model for A+B+F+T case

Check if σ_z is a constant over scales:

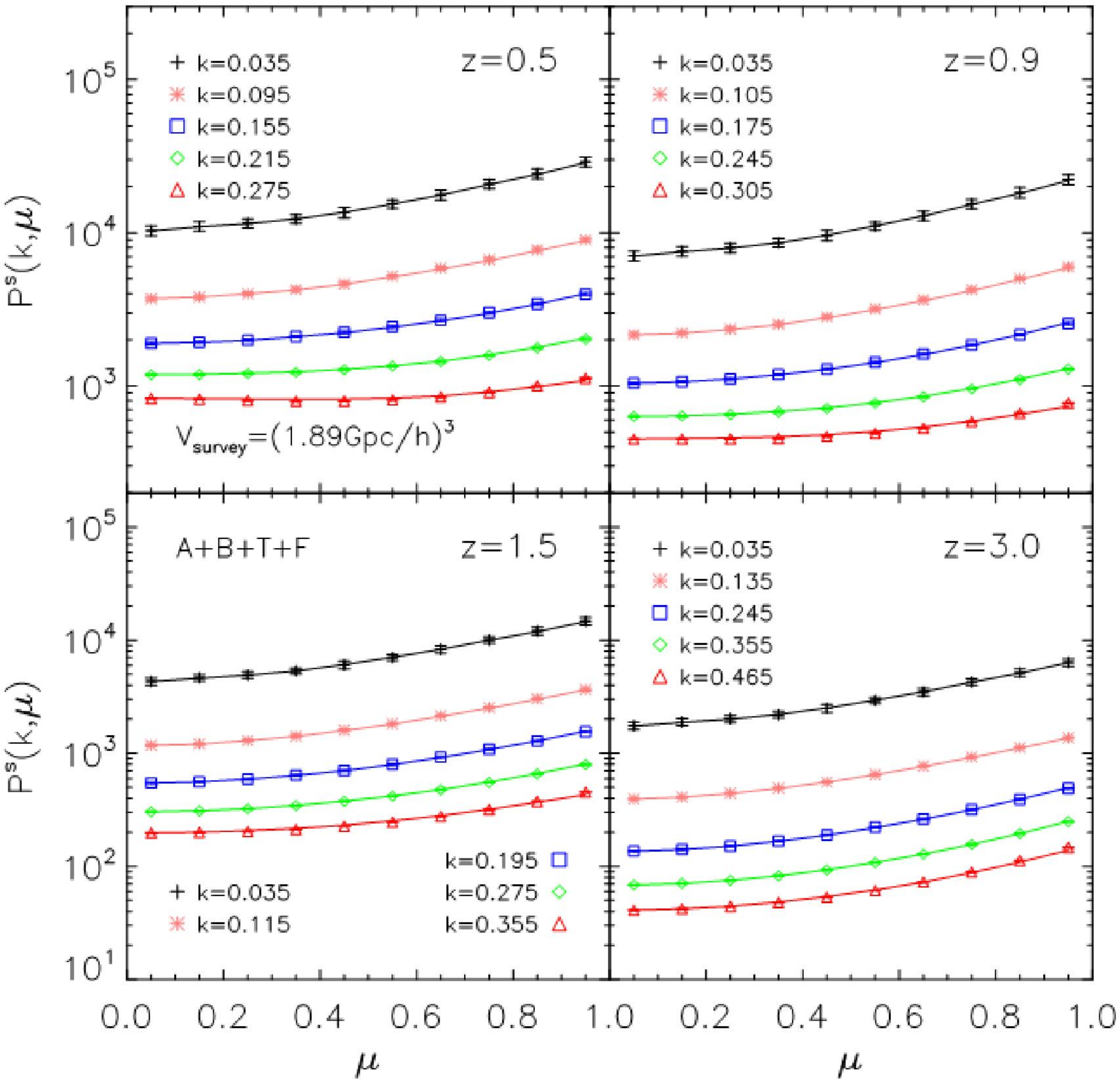


2. Multipole test:

$$P_\ell^{(S)}(k) = \frac{2\ell + 1}{2} \int_{-1}^{1} d\mu P^{(S)}(k, \mu) \mathcal{P}_\ell(\mu),$$

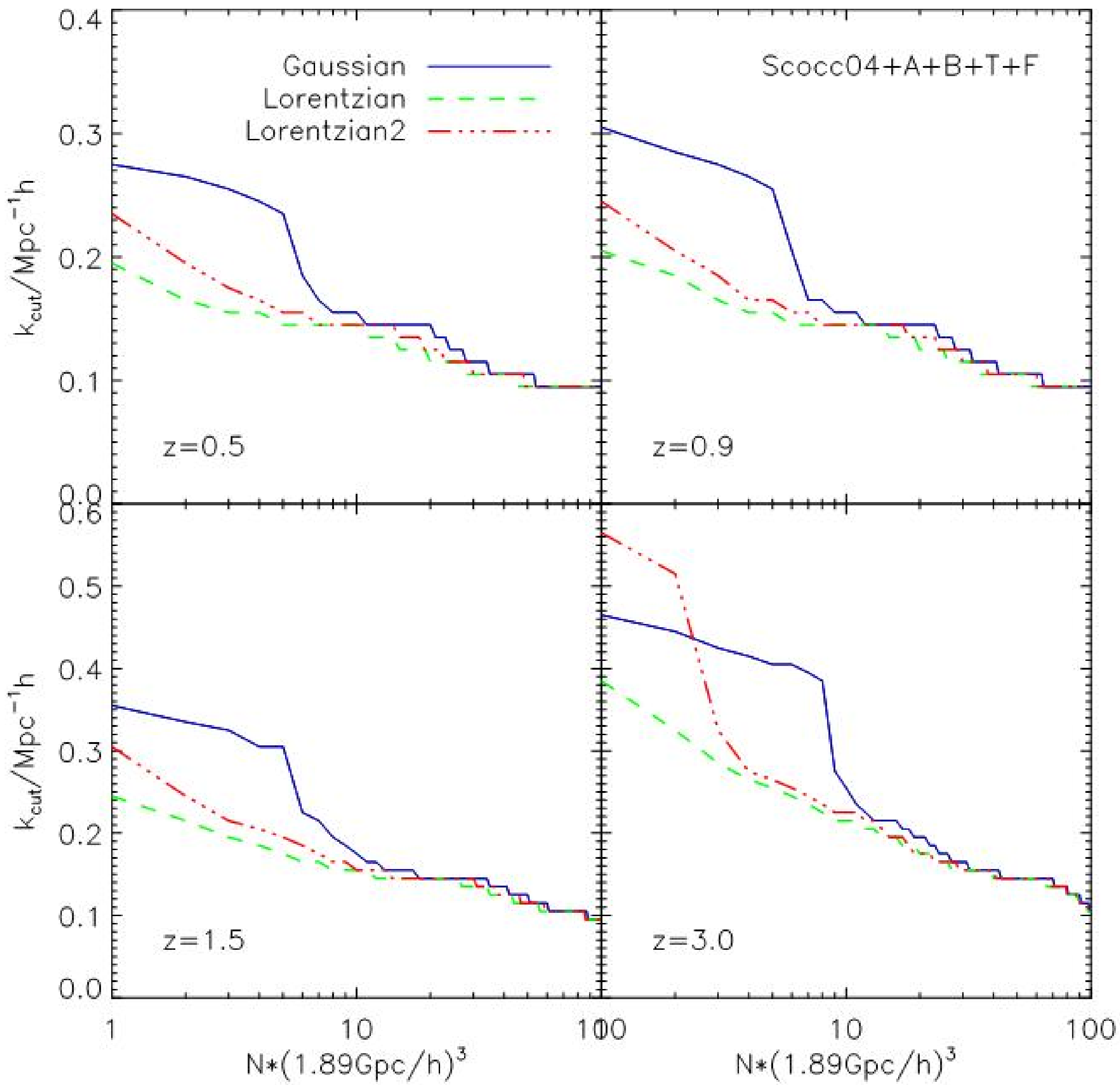


3. 2D power spectrum test:



4. k_cut test:

The scale up to which systemic error = statistical error



Future work

- Test the mapping for halo case and galaxy case
- Develop robust halo/galaxy bias scheme, so combine the bias model with dark matter template measured from simulations, we could do the cosmological constrain from data.
- …