Measuring the growth of matter fluctuations with third order galaxy correlations

Hoffmann, Bel, Gaztañaga

cosmology with large scale structure

matter fluctuations:

$$\delta_R = (\rho_R - \bar{\rho}) / \bar{\rho}$$

linear growth (R > 40 Mpc/h):

$$D(z) \simeq \delta_m(z) / \delta_m(0)$$

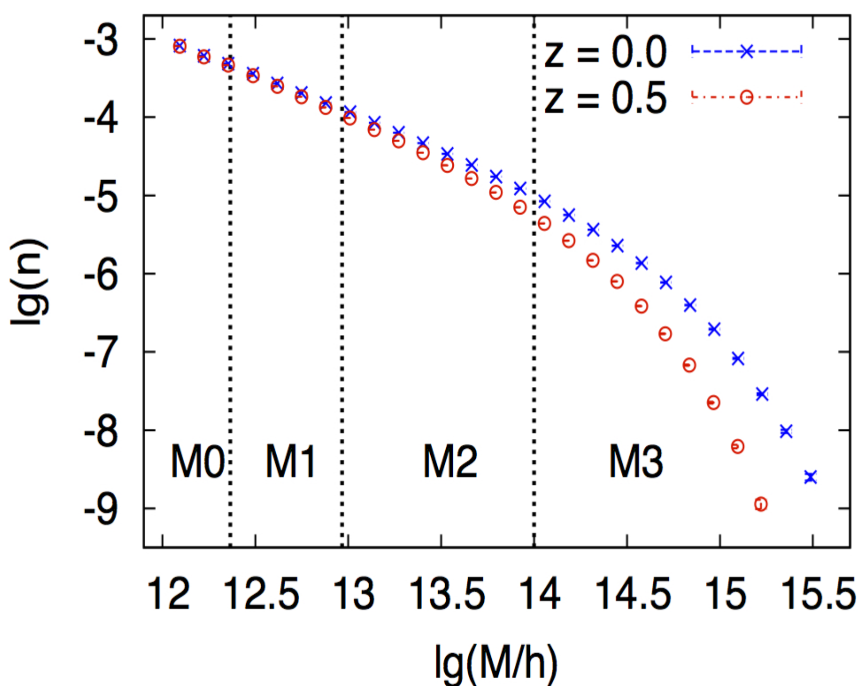
growth depends on cosmology

$$D(a) \propto \frac{H(t)}{H(0)} \int_0^a \frac{da'}{\left[\Omega_m / a' + \Omega_\Lambda a' - (\Omega_m + \Omega_\Lambda - 1)\right]^{3/2}} \qquad a = \frac{1}{1+z}$$

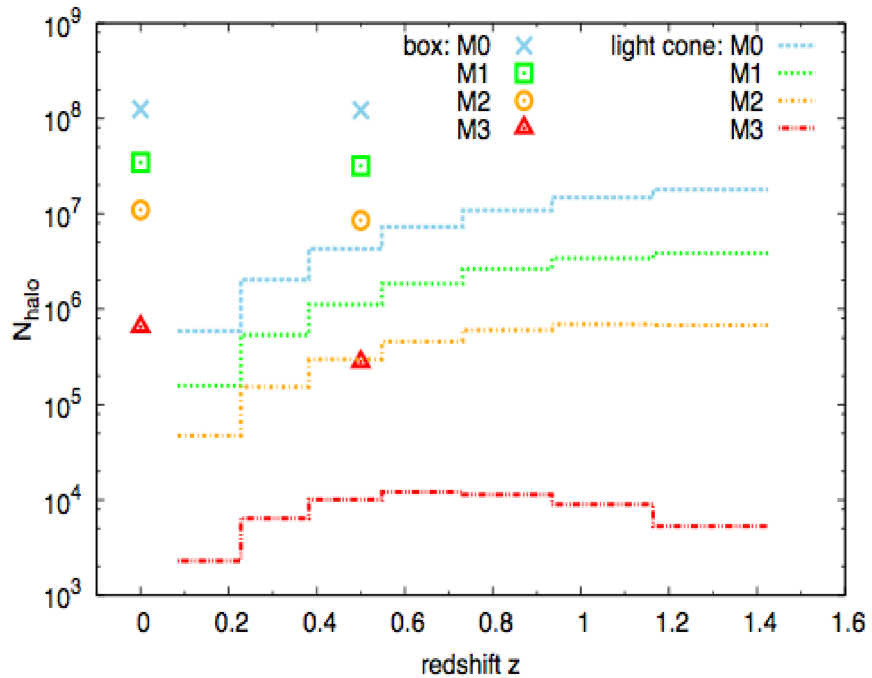
MICE Grand Challenge simulation

3072 Mpc/h box, 4096^3 particles, $m_p=2.9\ 10^{10} M_{sun}/h$
halos are FoF-groups

halo mass samples:



$N_h(z)$ in light cone and box:



ΛCDM cosmology:

$$\Omega_m = \Omega_{DM} + \Omega_b = 0.25, \Omega_\Lambda = 0.75, \Omega_b = 0.044, \sigma_8(z=0) = 0.8, n_s = 0.95, h = 0.7$$

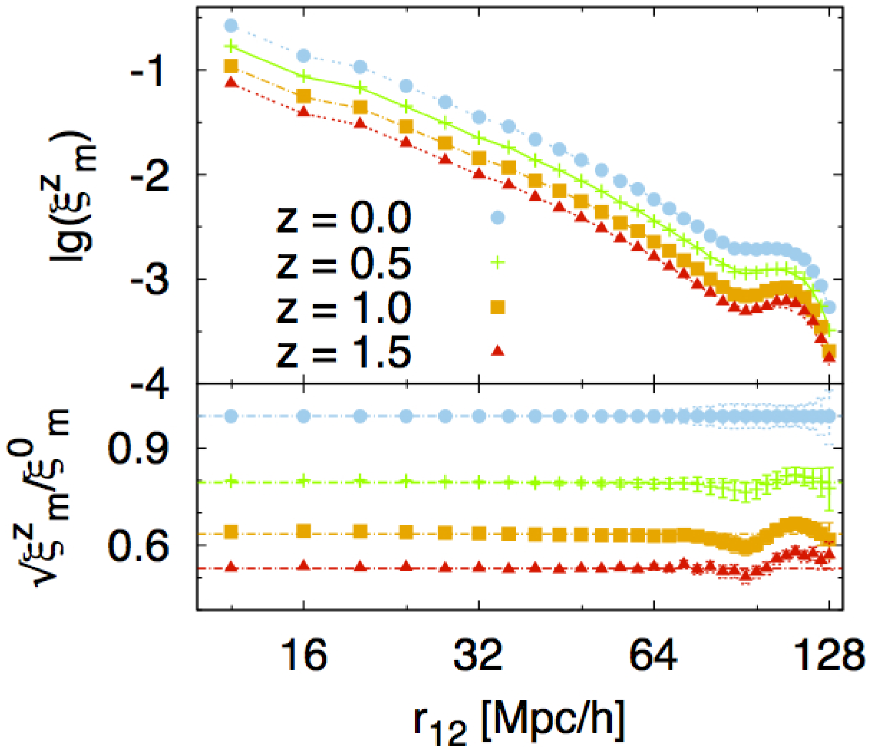
measuring growth with two-point correlations

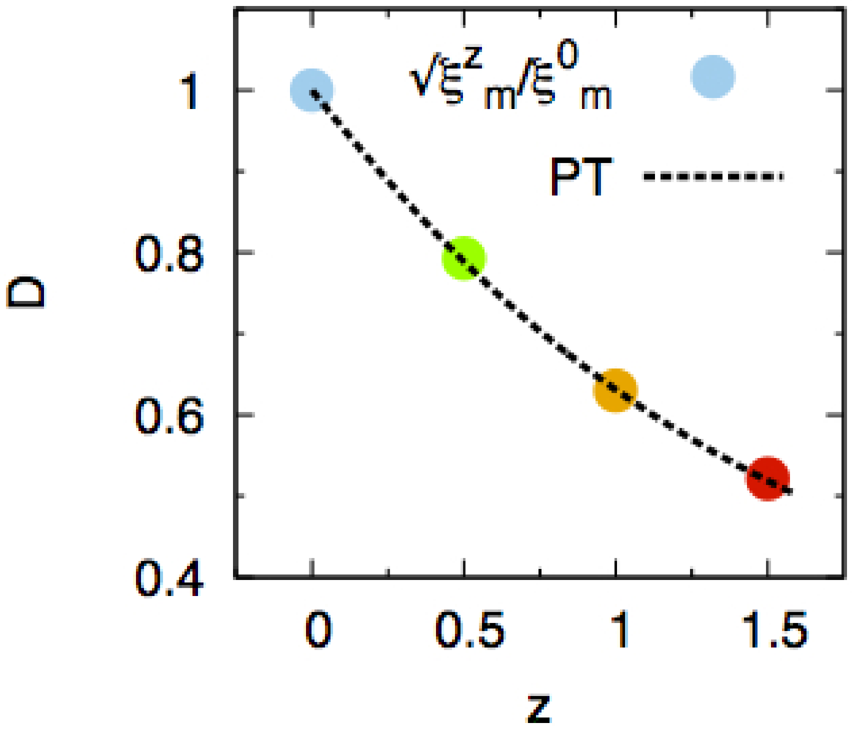
two point correlation:

$$\xi(r_{12}) \equiv \langle \delta_1 \delta_2 \rangle (r_{12})$$

large scale growth:

$$\xi_m(z) = D^2(z)\,\xi_m(0)$$





galaxy bias

quadratic model for local bias:

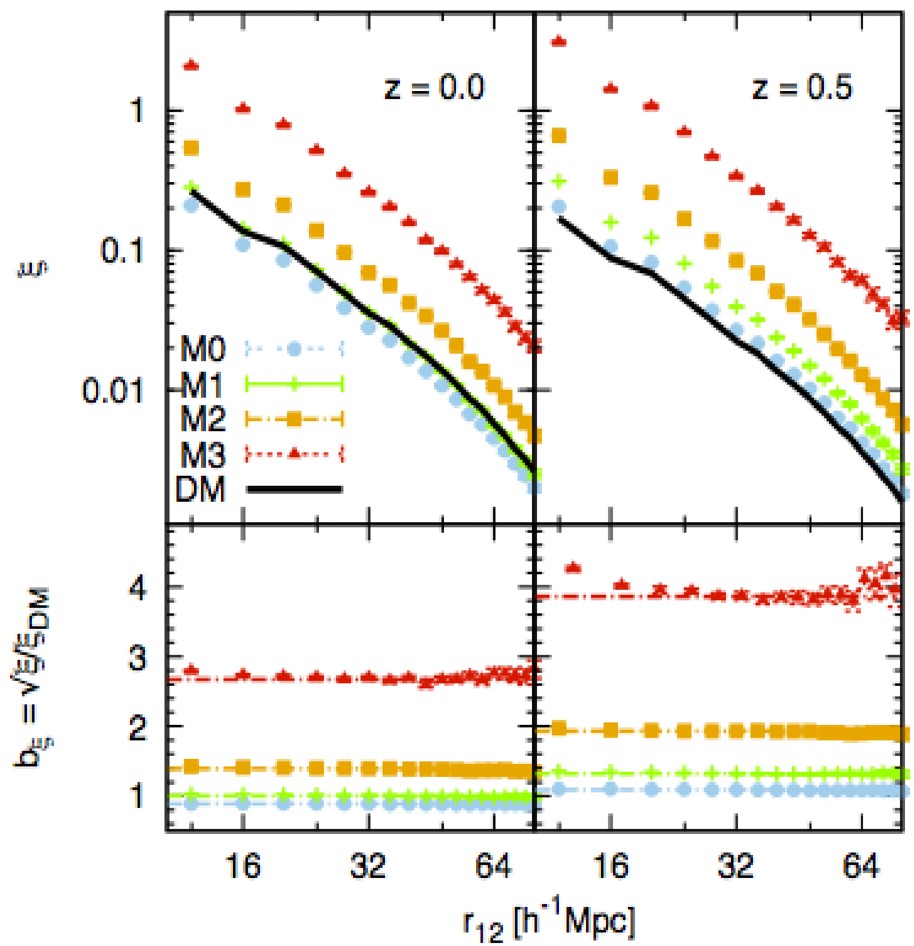
$$\delta_g \simeq b_1 \delta_m + (b_2/2)(\delta_m^2 - \langle \delta_m^2 \rangle)$$

large scales: $\xi_g \simeq b_\xi^2 \xi_m$

degeneracy with growth:

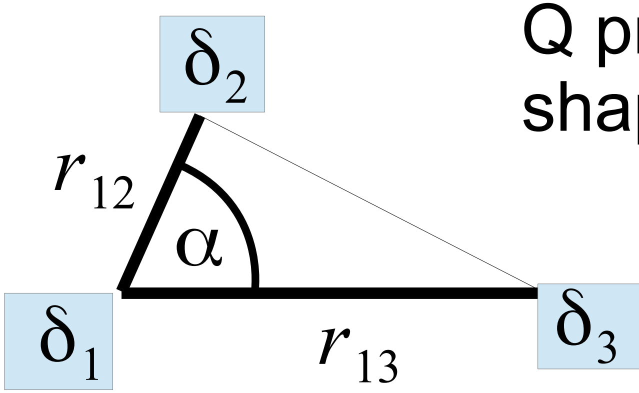
$$D(z) = \sqrt{\frac{\xi_m(z)}{\xi_m(0)}} = \frac{b(0)}{b(z)} \sqrt{\frac{\xi_g(z)}{\xi_g(0)}}$$

can be broken with third order correlations



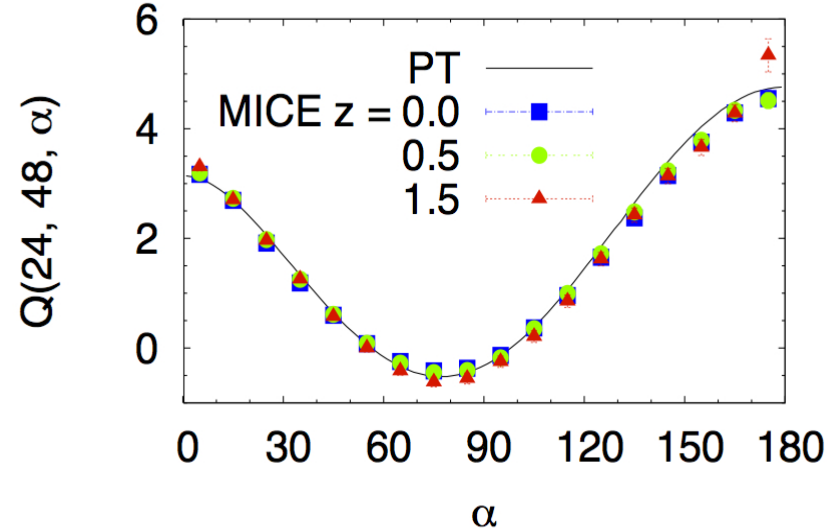
three-point correlation

$$Q \equiv \frac{\langle \delta_1 \delta_2 \delta_3 \rangle (r_{12}, r_{13}, \alpha)}{\langle \delta_1 \delta_2 \rangle \langle \delta_1 \delta_3 \rangle + 2\, perm.}$$

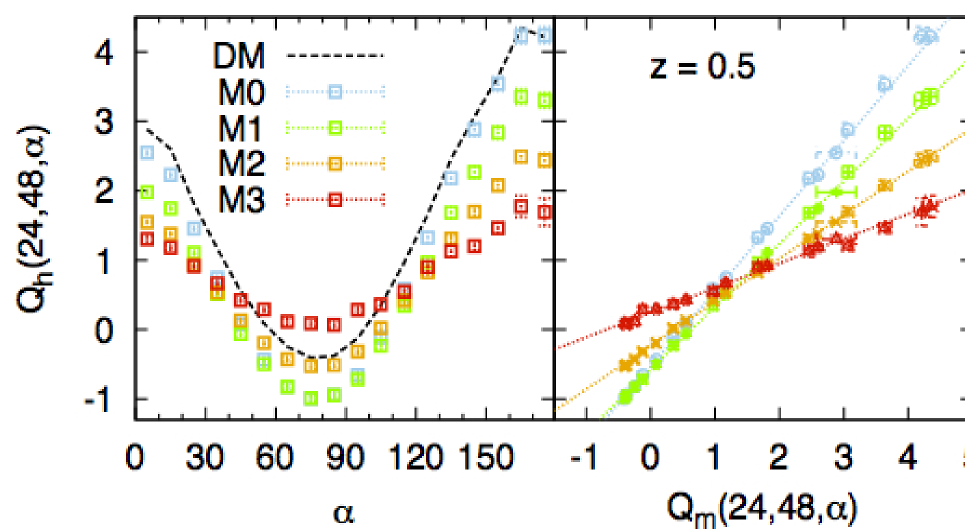


Q probes shape of LSS

Q independent of redshift



Q dependent on bias



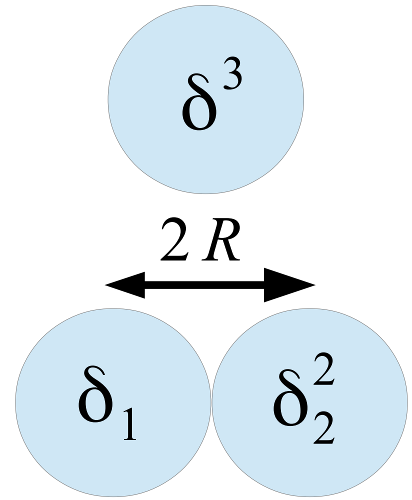
bias: $Q_g \simeq \frac{1}{b_Q}(Q_m + c_Q)$

independent of growth

third-order moments

skewness: $S_3 \equiv \dfrac{\langle \delta^3 \rangle}{\langle \delta^2 \rangle^2}$

cumulants: $C_{12} \equiv \dfrac{\langle \delta_1 \delta_2^2 \rangle}{\langle \delta_1 \delta_2 \rangle \langle \delta^2 \rangle}$

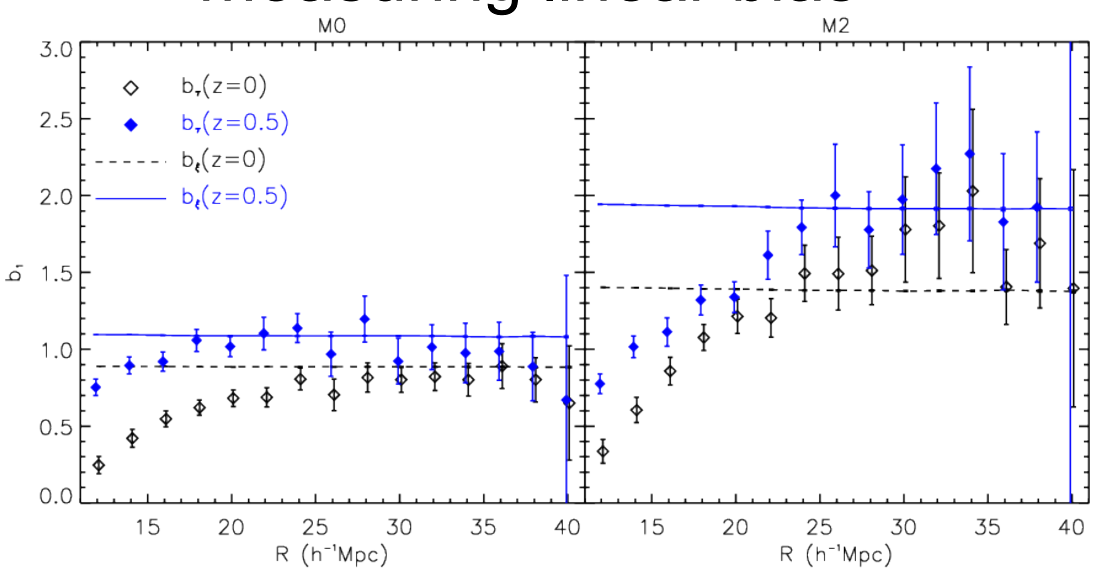


linear bias:

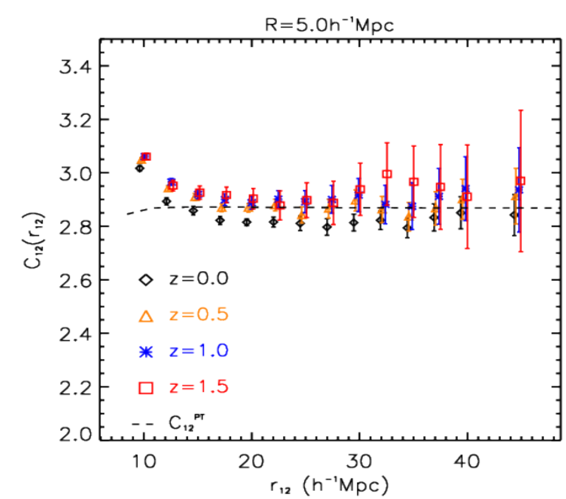
$$b_\tau \equiv \frac{3\,C_{12}^m - 2\,S_3^m}{3\,C_{12}^g - 2\,S_3^g}$$

Bel & Marinoni, 2012, MNRAS, 424, 971

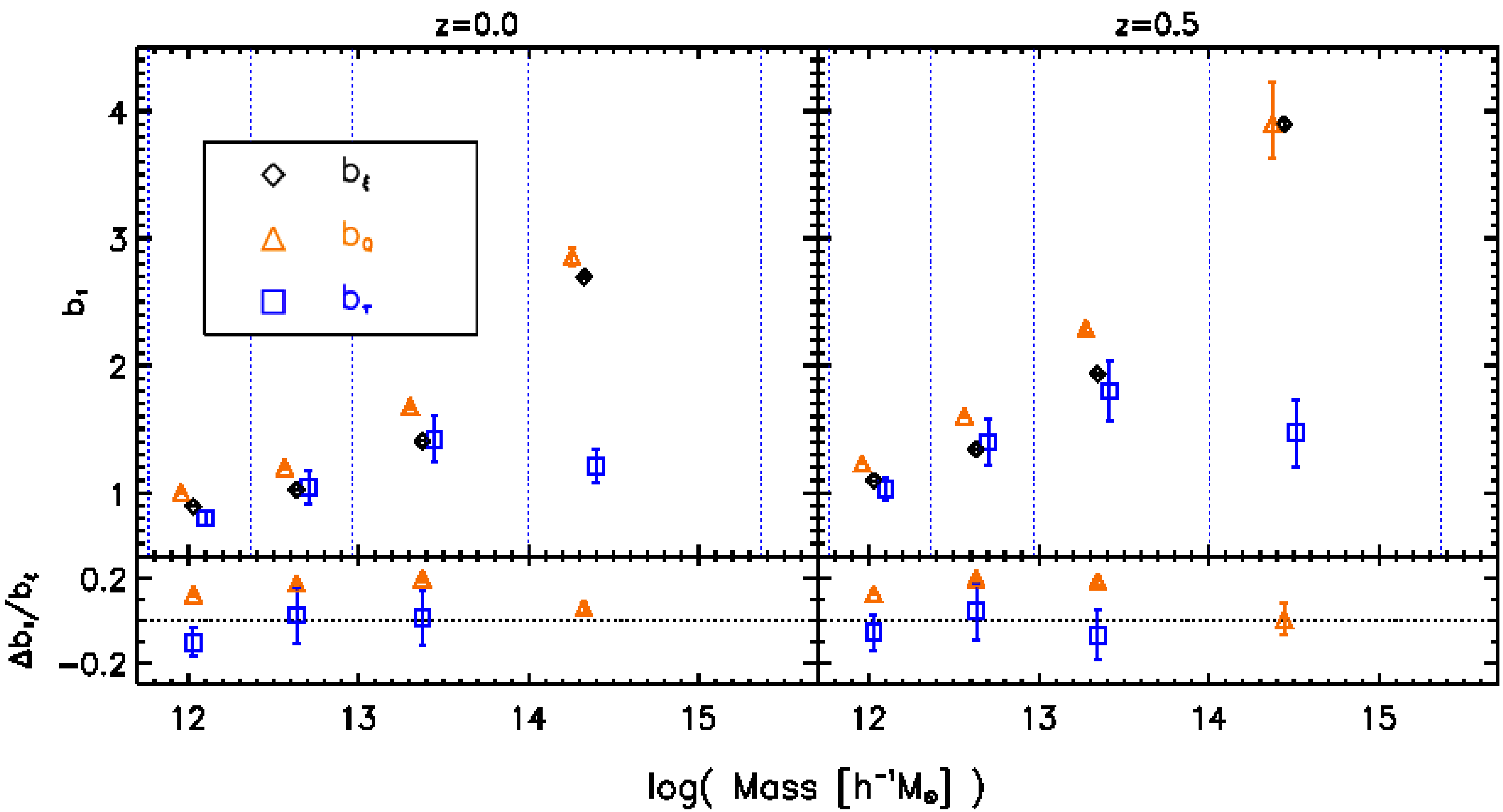
measuring linear bias



C12 independent of redshift



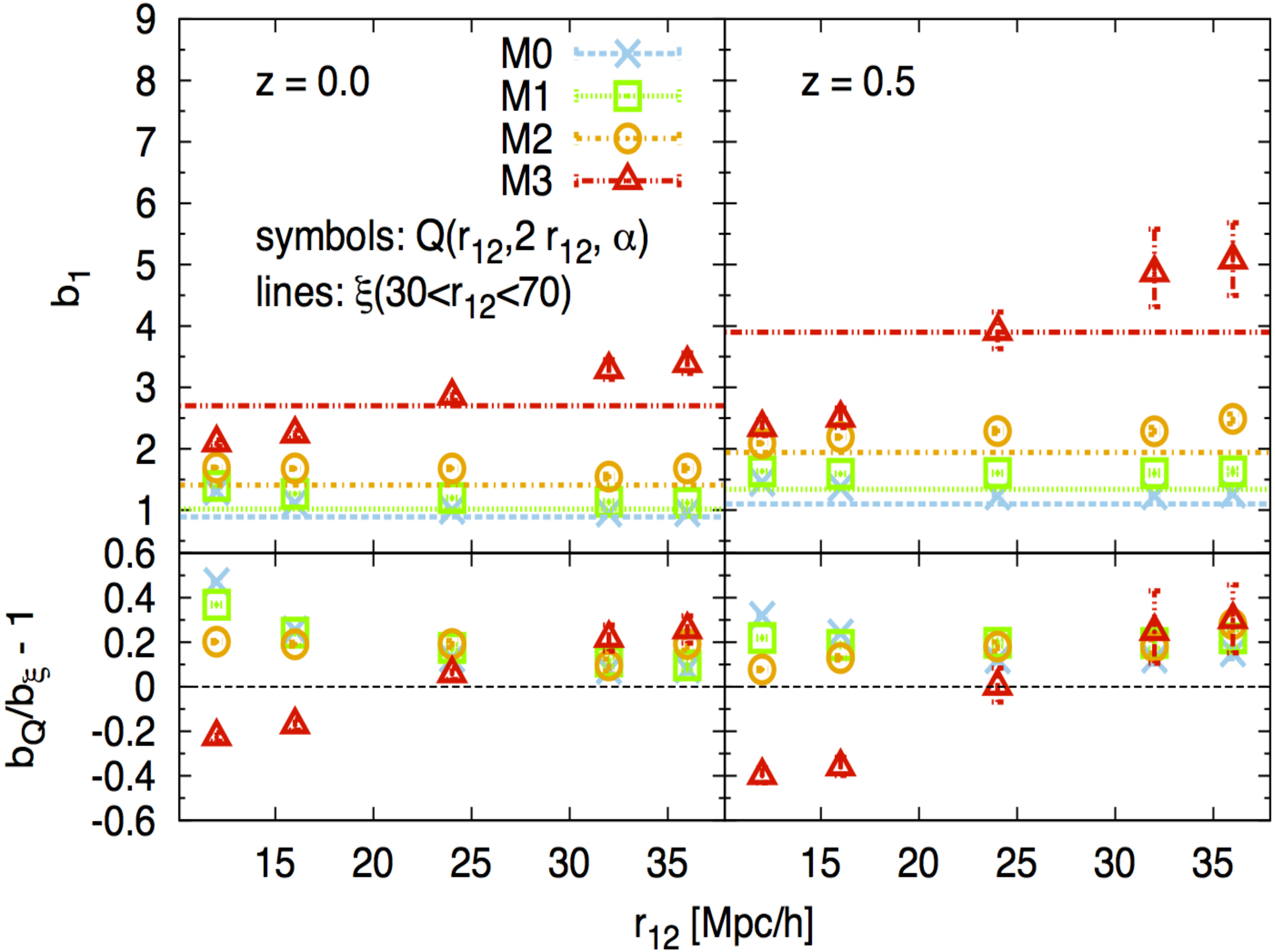
comparing bias from ξ, Q, C_{12}



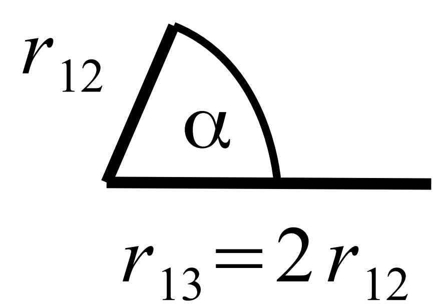
Differences can be caused by

- large scale approximations
- higher order terms in bias function
- shot noise
- non-local bias (Chan et al., 2012)

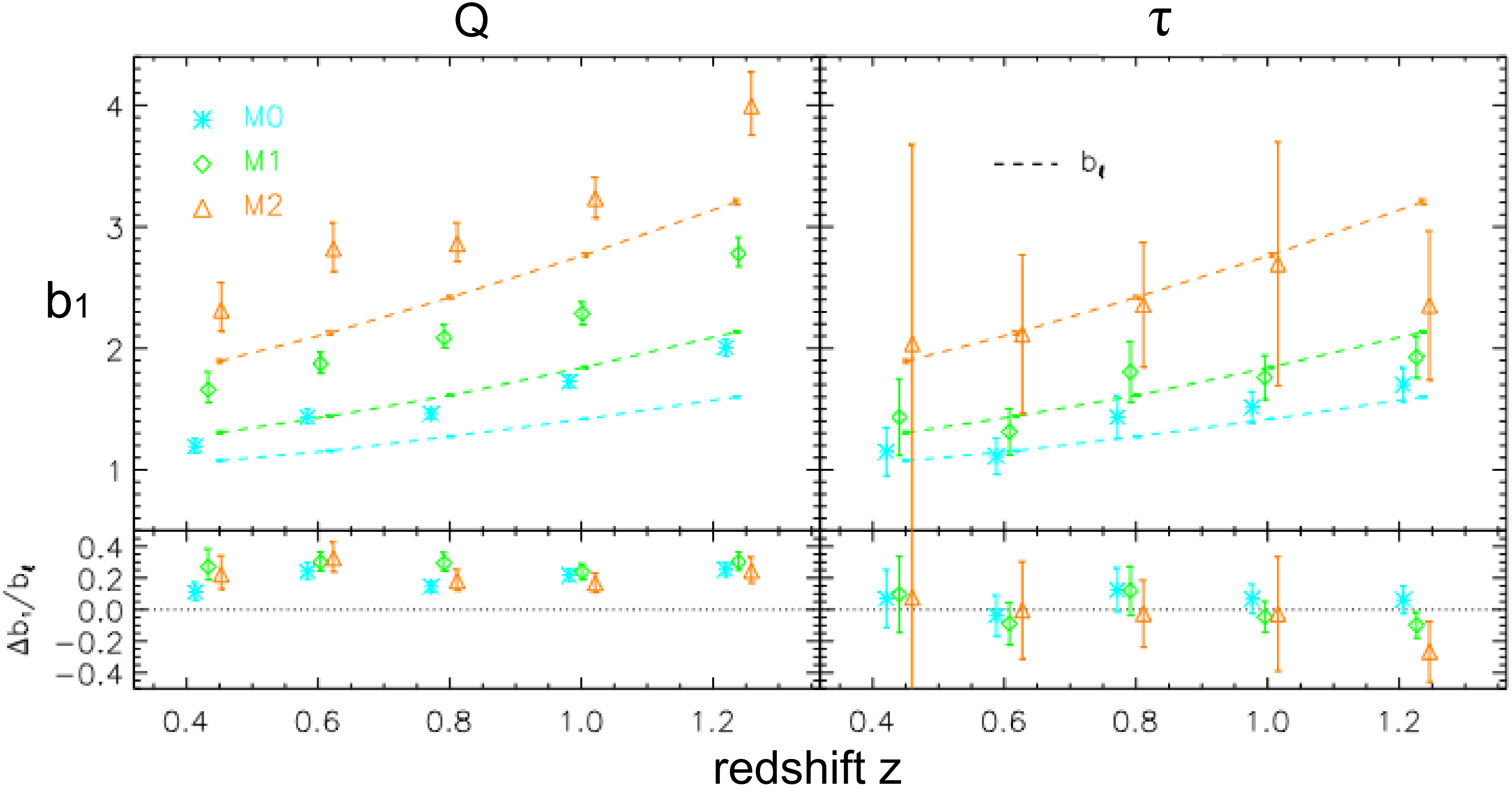
comparing bias from ξ & Q at different triangle scales (r_{12})



triangle configuration:



comparing bias from ξ, Q & τ at different redshifts



problem: bias measurements from Q & τ depend on dark matter models

measuring growth without dark matter

$$D(z)=\frac{b(0)}{b(z)}\sqrt{\frac{\xi_g(z)}{\xi_g(0)}}$$

$$\hat{b}\equiv\frac{b(z)}{b(0)}$$

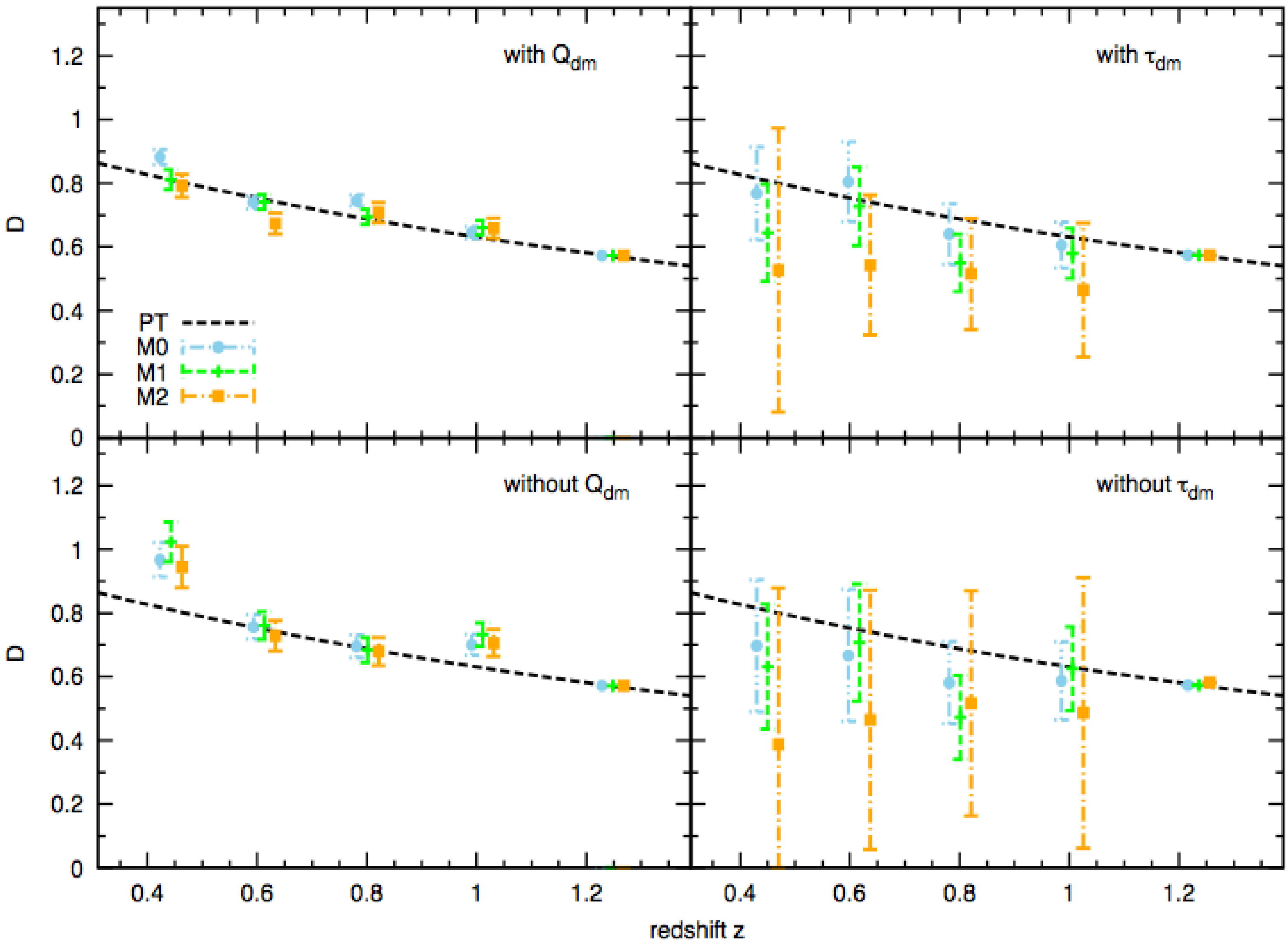
only bias ratio needs to be known for measuring D(z)

$$\left.\begin{aligned} Q_m(z)&=Q_m(0)\\ Q_g(z)&\simeq\frac{1}{b_Q(z)}\left(Q_m+c_Q(z)\right)\end{aligned}\right\} \quad Q_g(z)\simeq\frac{1}{\hat{b}_Q}\left(Q_g(0)+\hat{c}_Q(0)\right)$$

=> bias ratio can be measured using only Q_g

=> D(z) can be measured without assumptions on Q_m

growth measured in MICE light cone using galaxy bias from Q



Q_g&Q_m
(b_z, b_0)

only Q_g
(b_z/b_0)

$$f \equiv \frac{d\ln D}{d\ln a}$$

growth rate measurements

$$f \equiv \frac{dln\, D}{dln\, a} \simeq \frac{a}{\Delta a} \frac{\Delta D}{D} = \Omega^{\gamma} \qquad a = \frac{1}{1+z}$$

$$\frac{\Delta D}{D} = \frac{1}{2}\left(\hat{D}_{i+1,i} - \hat{D}_{i-1,i}\right)$$

$$\hat{D}_{i,j} = \frac{D_i}{D_j} = \hat{b}_{i,j} \sqrt{\frac{\xi_i^g}{\xi_j^g}} \qquad \hat{b} \equiv \frac{b(z)}{b(0)}$$

Summary

- growth-bias degeneracy broken with 3rd order correlations:
  i) three-point correlations (Q)
  ii) combining two- and one point statistic (S_3&C_{12})

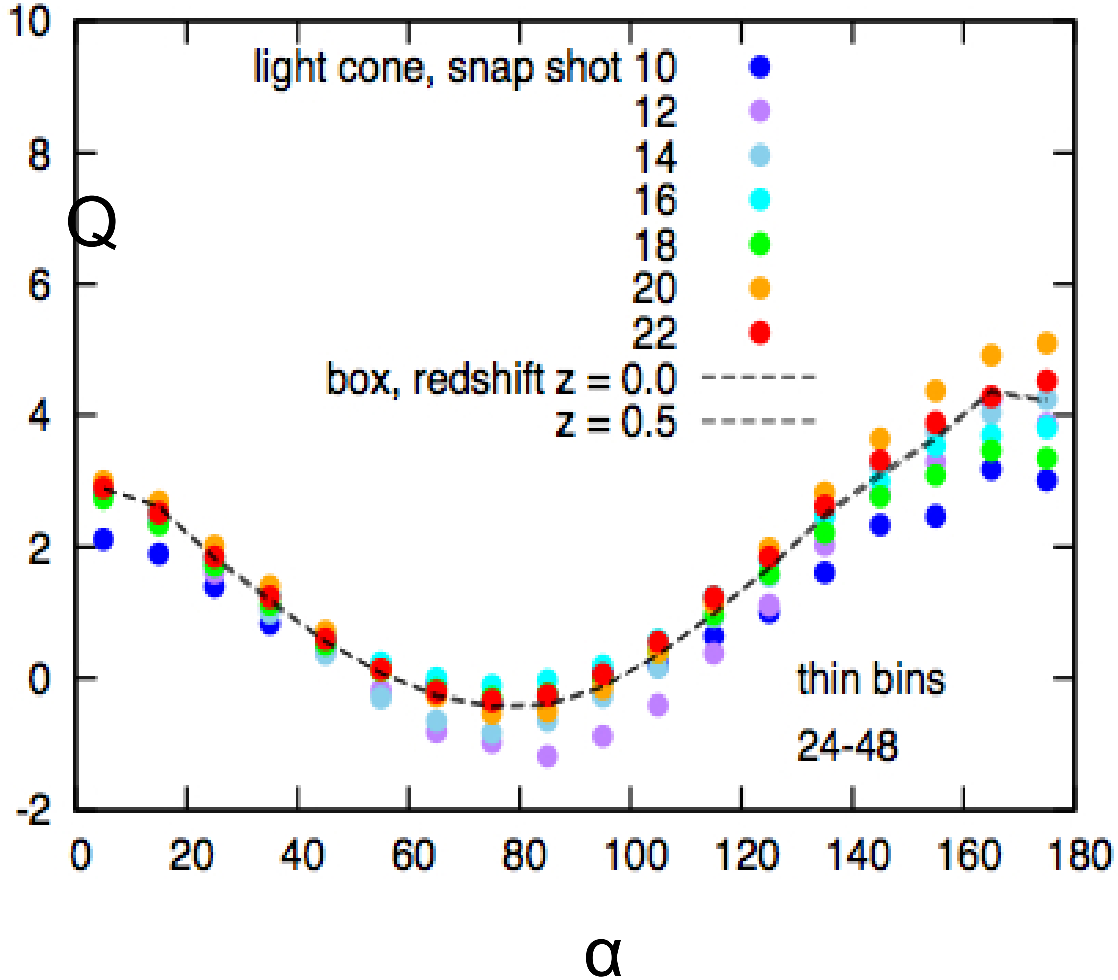
- 3rd order methods give good qualitative measurement of bias from ξ, but in detail they seem systematically away

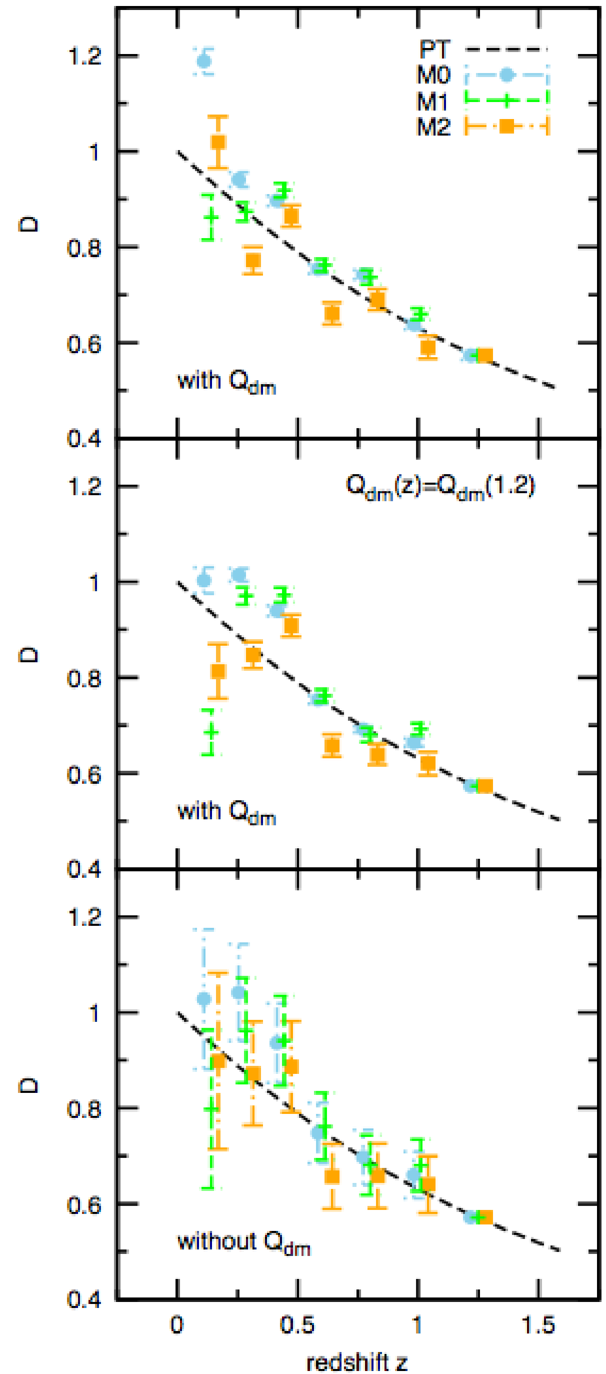
- growth measurement using 3rd order bias agrees qualitatively with growth from ξ_m and PT

- combining 3rd order correlations at different redshifts allows growth measurement without assumption on dm correlation

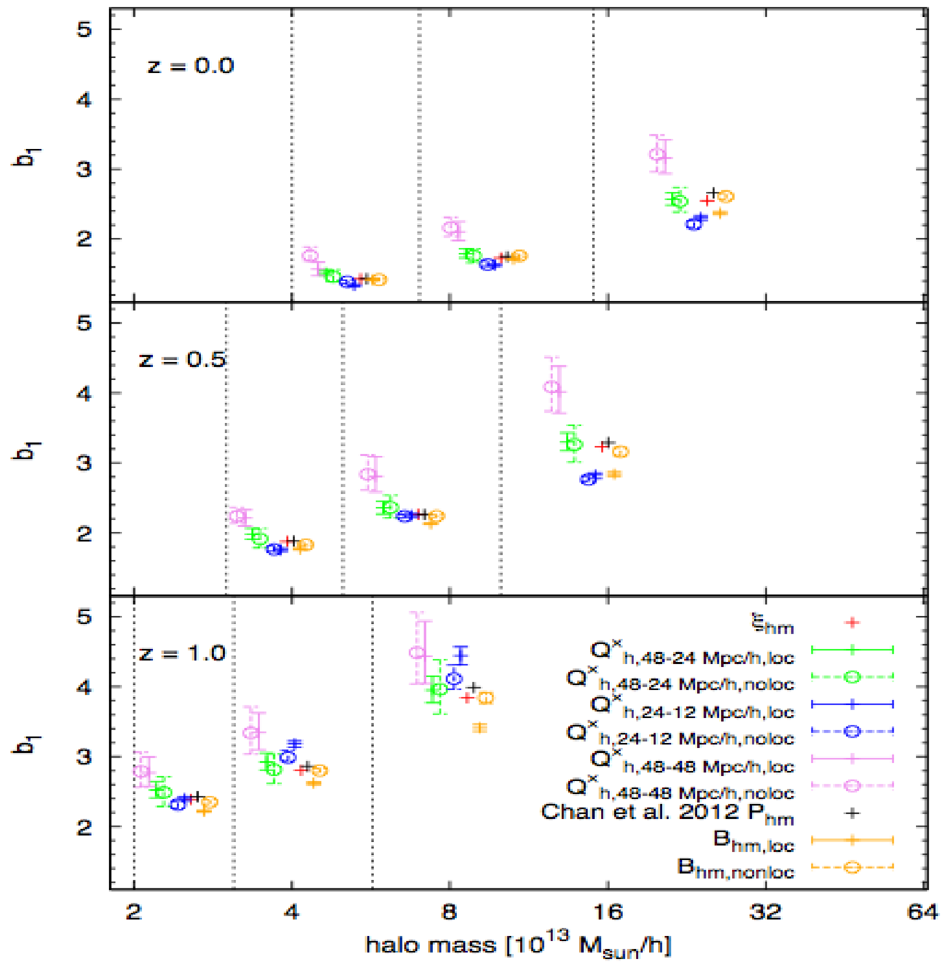
thanks!

effect of sampling variance on Q

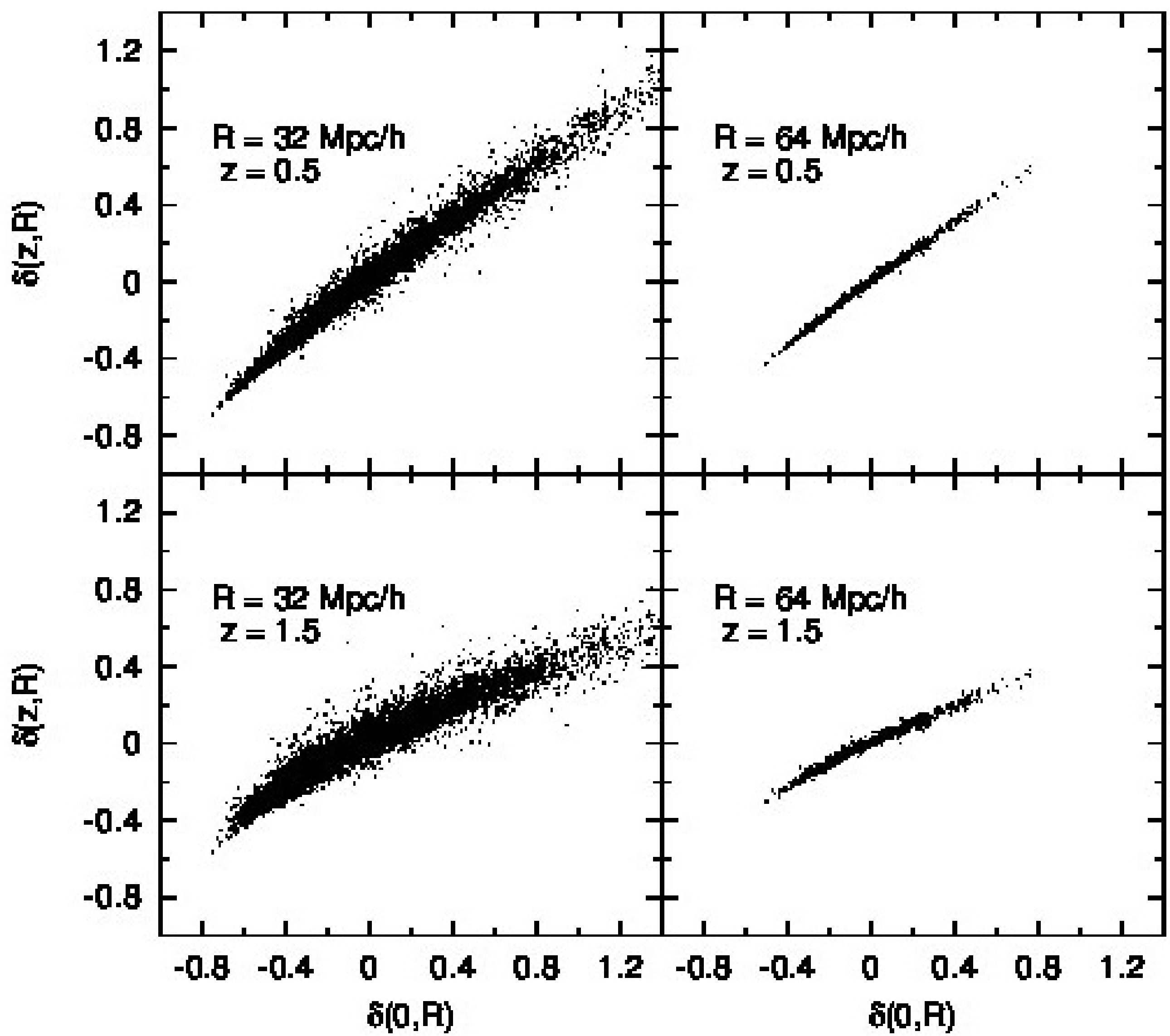




linear bias fitted with non-local contribution



Data We use the same set of 50 ΛCDM N-body simulations as Chan et al. (2012) with $\Omega_m = 0.27$, $\Omega_\Lambda = 0.73$, $\Omega_b = 0.046$, $h = 0.72$, $\sigma_8 = 0.7$, $n_s = 1$, $N_{part} = 640^3$, $L_{box} = 1200$ Mpc/h.


R = 32 Mpc/h
z = 0.5
R = 64 Mpc/h
z = 0.5
R = 32 Mpc/h
z = 1.5
R = 64 Mpc/h
z = 1.5
δ(z,R)
δ(z,R)
δ(0,R)
δ(0,R)
1.2
0.8
0.4
0
-0.4
-0.8
-0.8
-0.4
0
0.4
0.8
1.2

Baugh, Gaztanaga & Efstathiou 1995

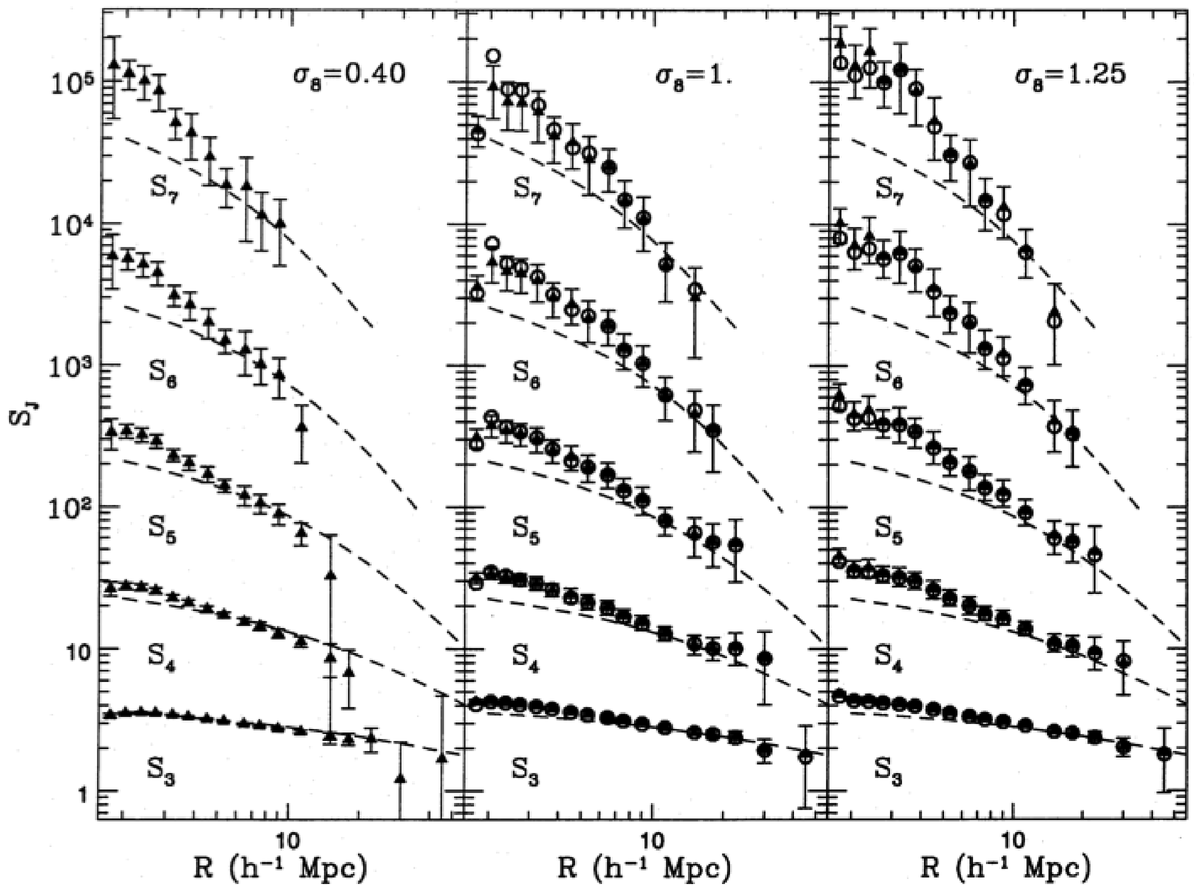


Figure 14. The hierarchical amplitudes $S_J = \overline{\xi}_J/\overline{\xi}_2^{J-1}$ in the $L_B = 180\ h^{-1}$ Mpc, $N = 64^3$ simulations for different output times: $\sigma_8 = 0.40, 1.0, 1.25$. The dashed line shows the PT approximation. Triangles correspond to the values averaged over 10 different realizations of the initial displacements from a grid (the error bars are the dispersion around the mean). Circles correspond to the average over 10 different realizations of the displacements from a glass.