Measuring the growth of matter fluctuations with third order galaxy correlations

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cosmology with large scale structure

matter fluctuations:

$$\delta_R = (\rho_R - \overline{\rho_R}) / \overline{\rho_R}$$

linear growth (R > 40 Mpc/h):

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

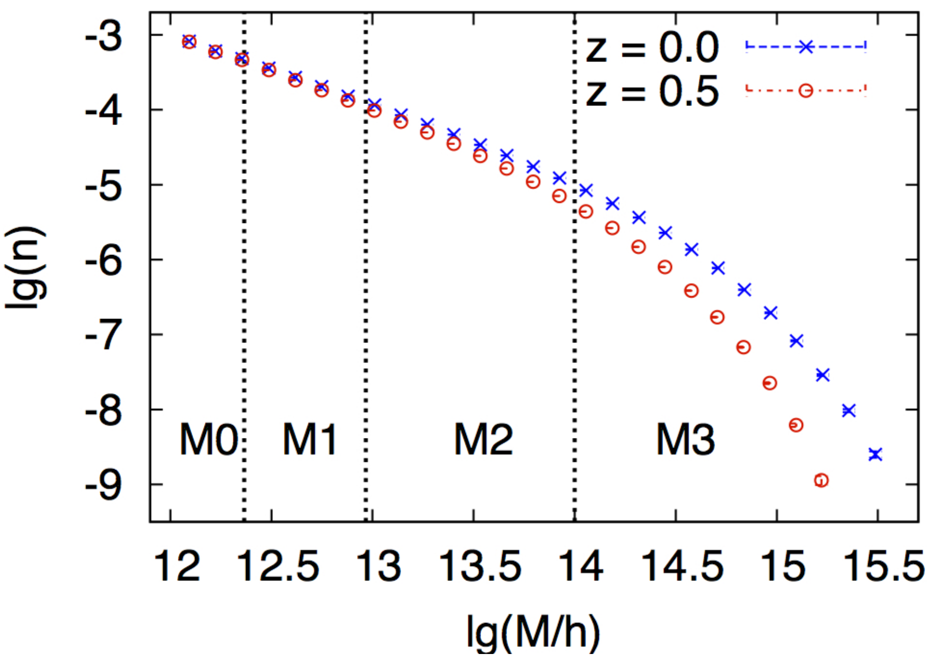
growth depends on cosmology

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

MICE Grand Challenge simulation

3 Gpc/h box, 4000^3 particles

halo mass samples:



ΛCDM cosmology:

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

redshifts:

box: z = 0, 0.5

light cone: 0 < z < 1.2

halos are FoF-groups ("galaxies")

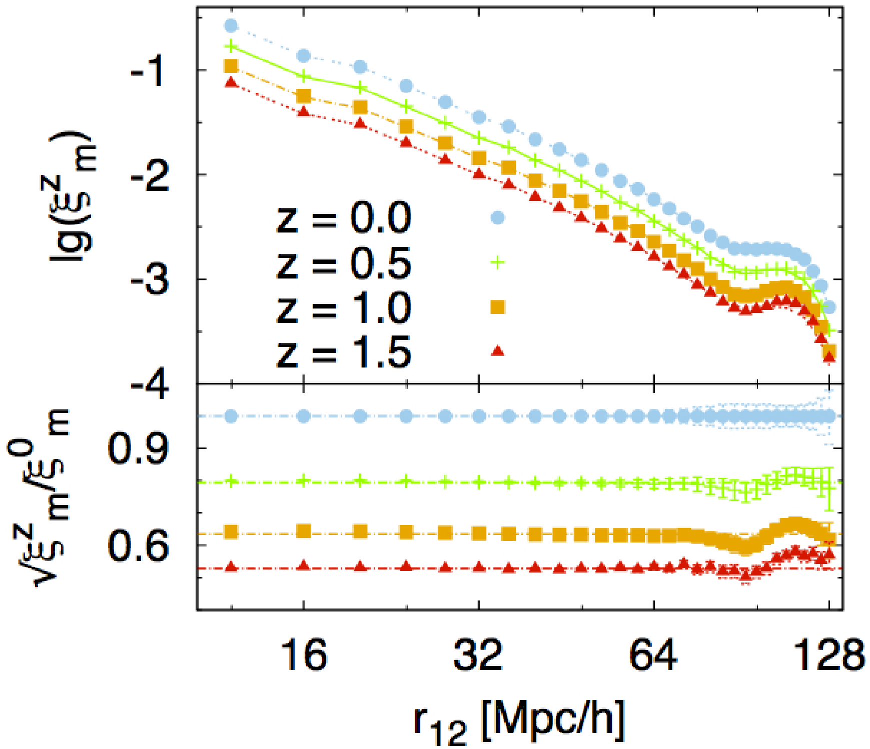
measuring growth with two-point correlations

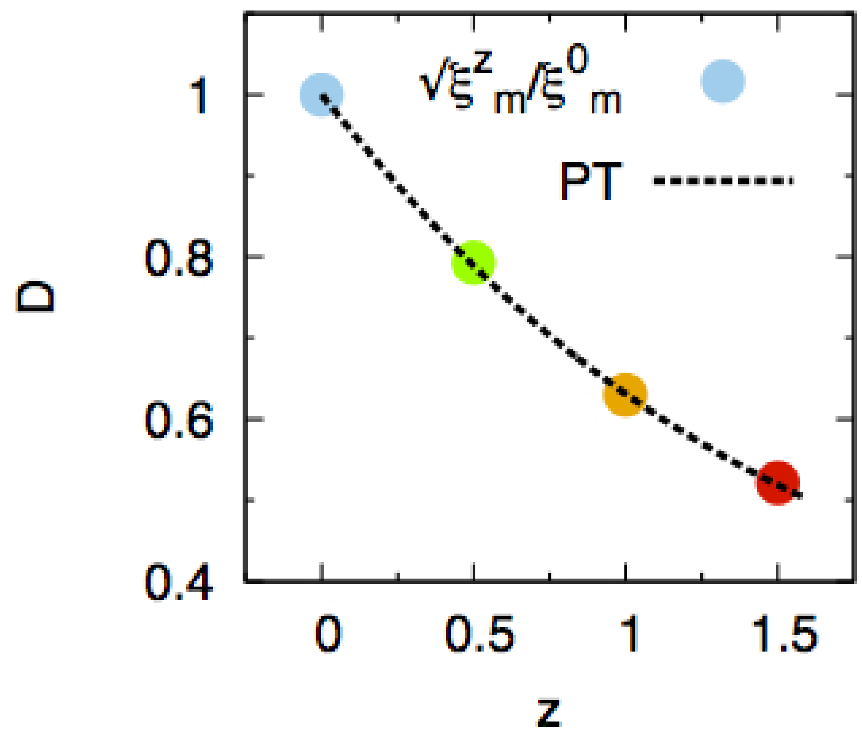
two-point correlation:

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

large scale growth:

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





galaxy bias

quadratic model for local bias:

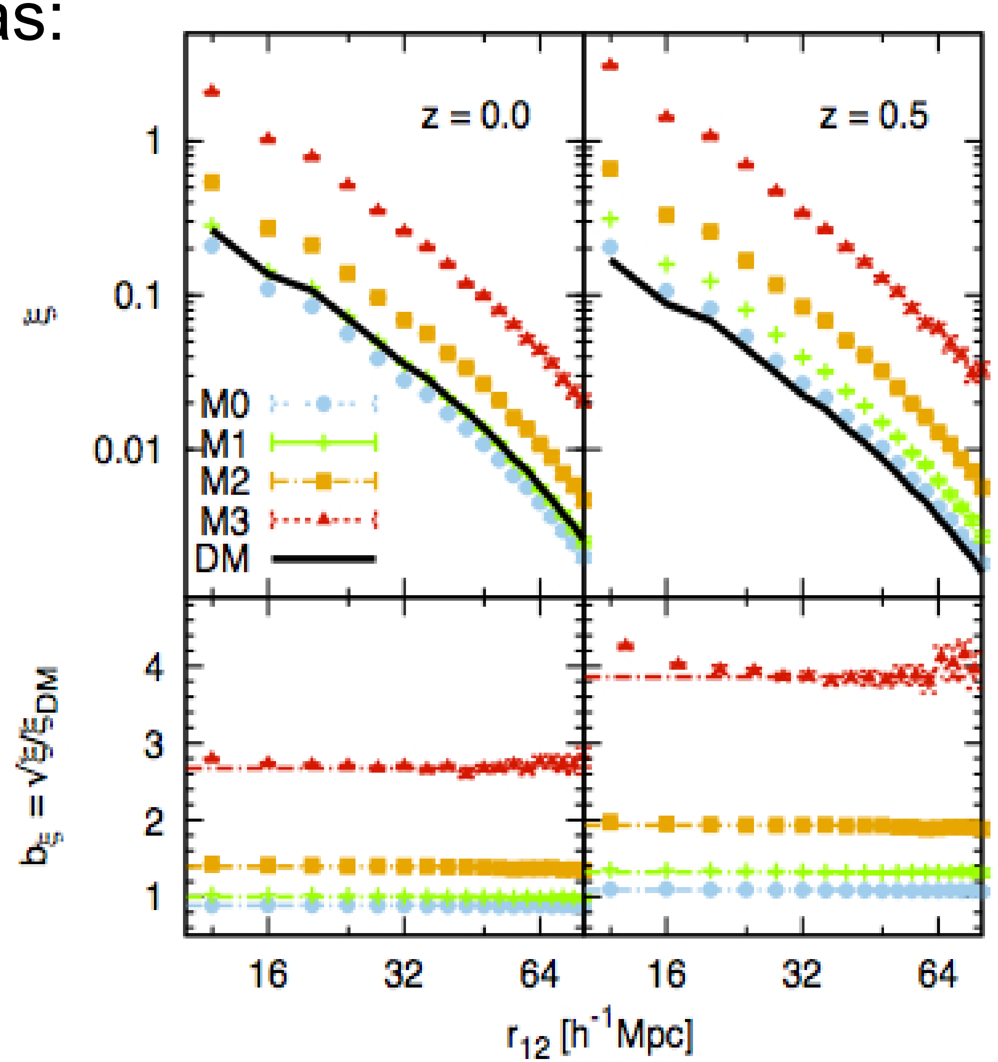
$$\delta_g \simeq b_1 \delta_m + (b_2/2)(\delta_m^2 - \langle \delta_m^2 \rangle)$$

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

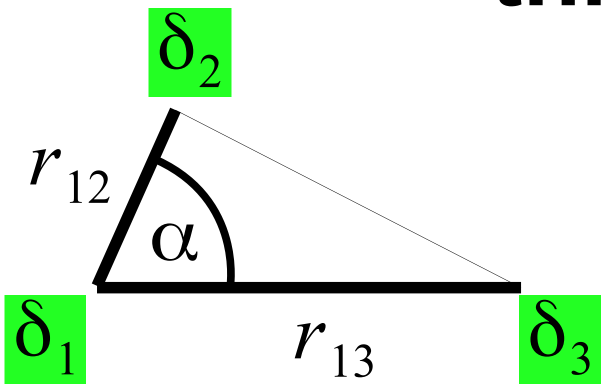
growth – bias degeneracy:

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

can be broken with third order correlations



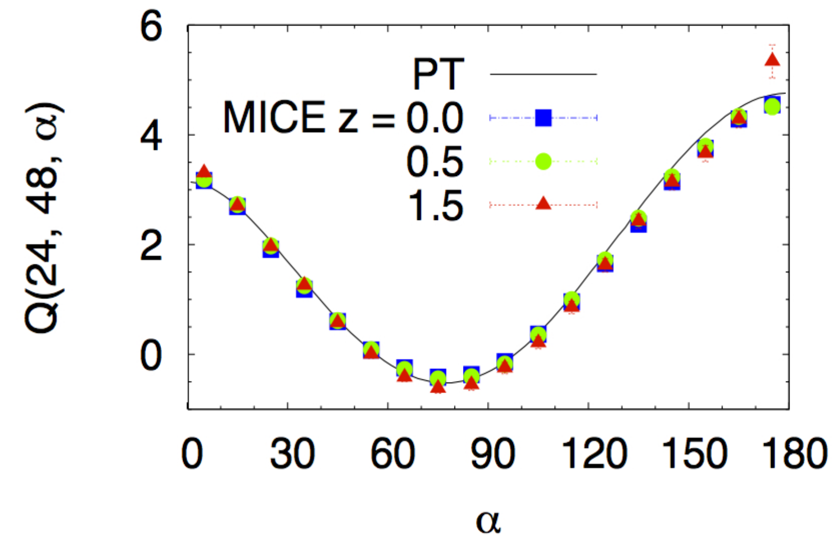
three-point correlation



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

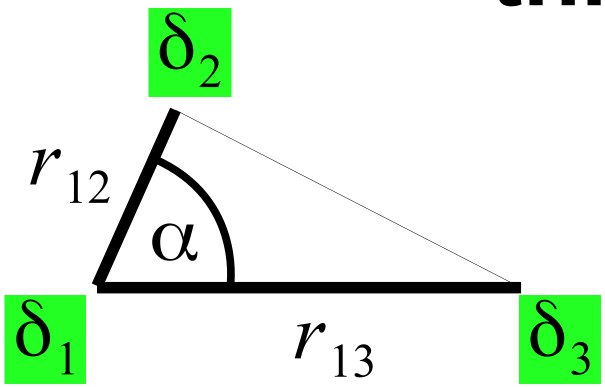
probes shape of LSS

Q independent of redshift



Q dependent on bias

three-point correlation



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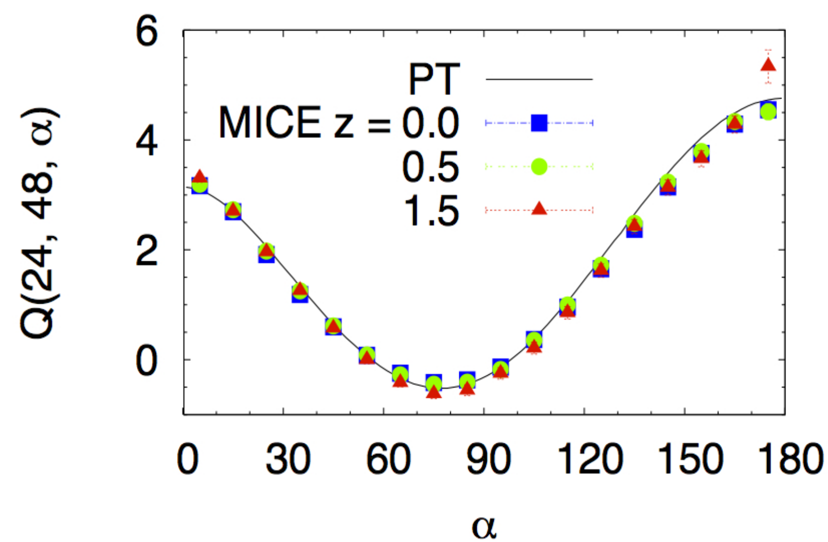

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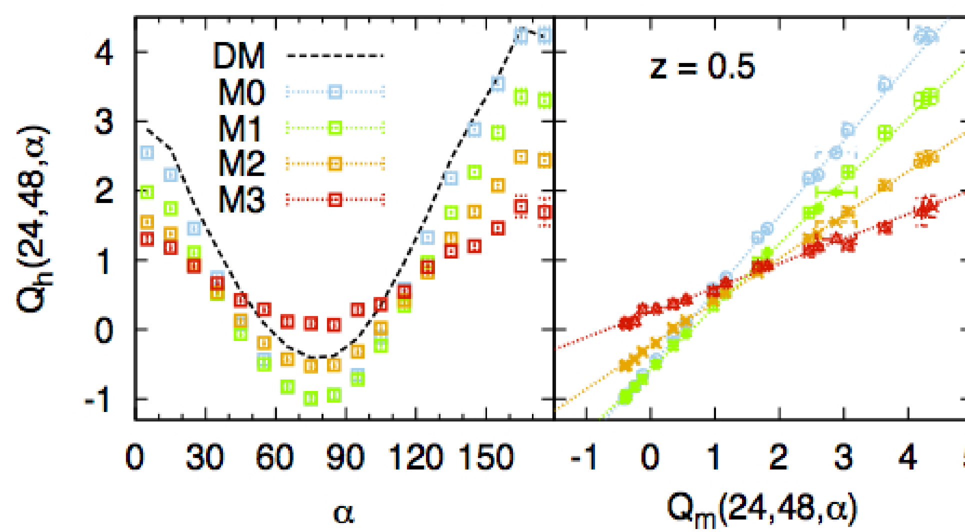


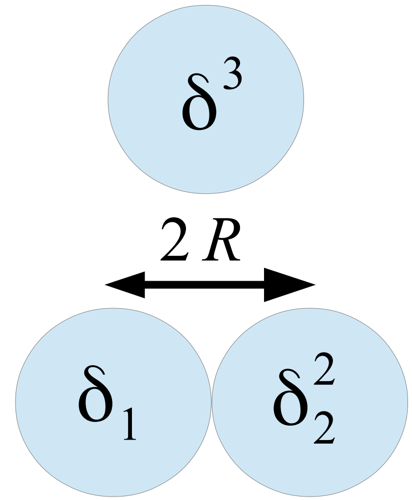
bias: $$Q_g \simeq \frac{1}{b_Q}(Q_m + c_Q)$$

b,c measured independent of growth

third-order moments

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

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

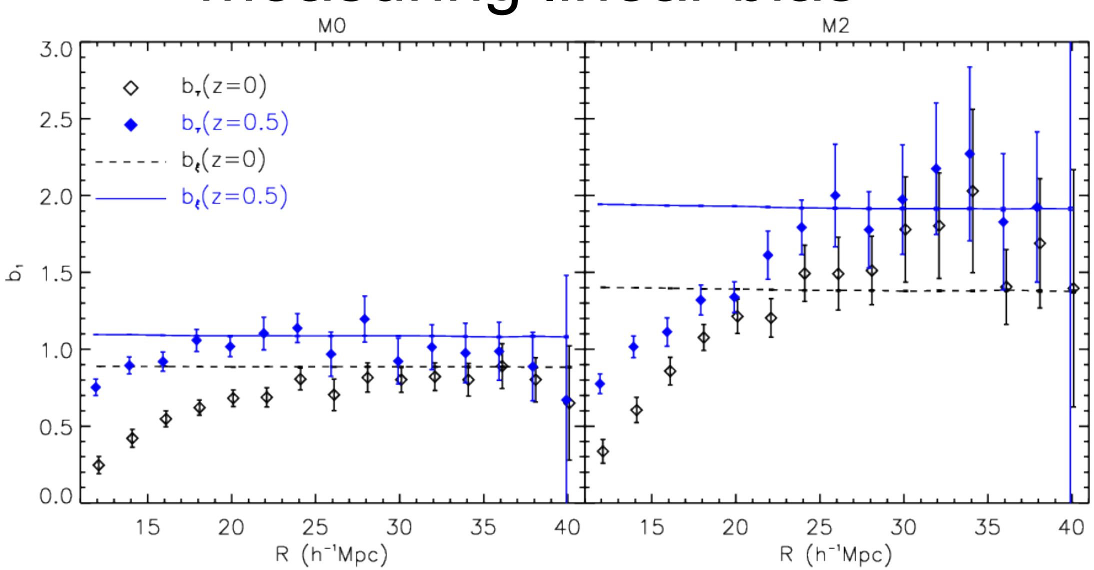


linear bias:

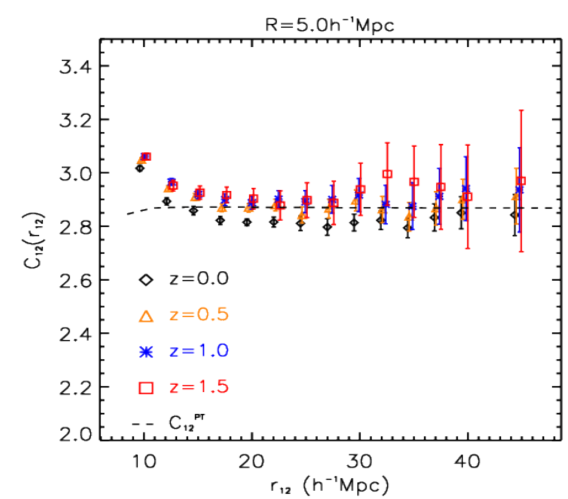
$$b_\tau \equiv \frac{3\,C_{12}^m - 2\,S_3^m}{3\,C_{12}^g - 2\,S_3^g}$$

Bel & Marinoni, 2012, MNRAS, 424, 971

measuring linear bias

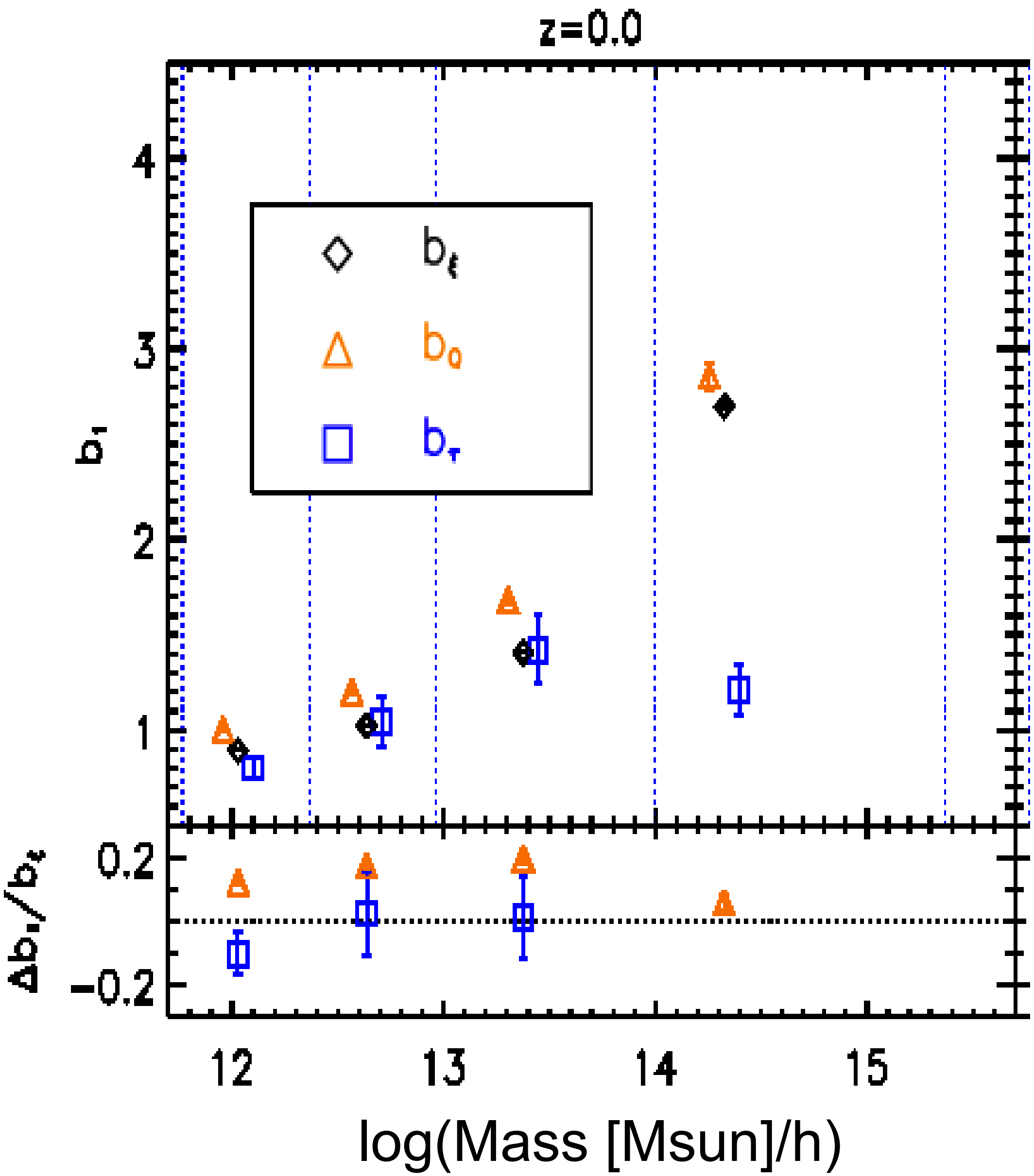


C12 independent of redshift



Results

comparing linear bias from ξ , Q, τ



ξ: two- point correlation
Q: tree-point correlation
τ: skewness & cumulants

Differences can be caused by

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

non-local bias from Q auto+cross

Q auto: galaxy-galaxy-galaxy

$$Q_g \simeq \frac{1}{b}\left(Q_m + [c + g_2 Q_{nloc}]\right)$$

non-local term

non-local bias from Q auto+cross

Q auto: galaxy-galaxy-galaxy

$$Q_g \simeq \frac{1}{b}\left(Q_m + \left[c + g_2 Q_{nloc}\right]\right)$$

non-local term

Q cross: galaxy-matter-matter

$$Q_{gm} \simeq \frac{1}{b}\left(Q_m + \frac{1}{3}\left[c + g_2 Q_{nloc}\right]\right)$$

non-local bias from Q auto+cross

Q auto: galaxy-galaxy-galaxy

$$Q_g \simeq \frac{1}{b}(Q_m + [c + g_2 Q_{nloc}])$$

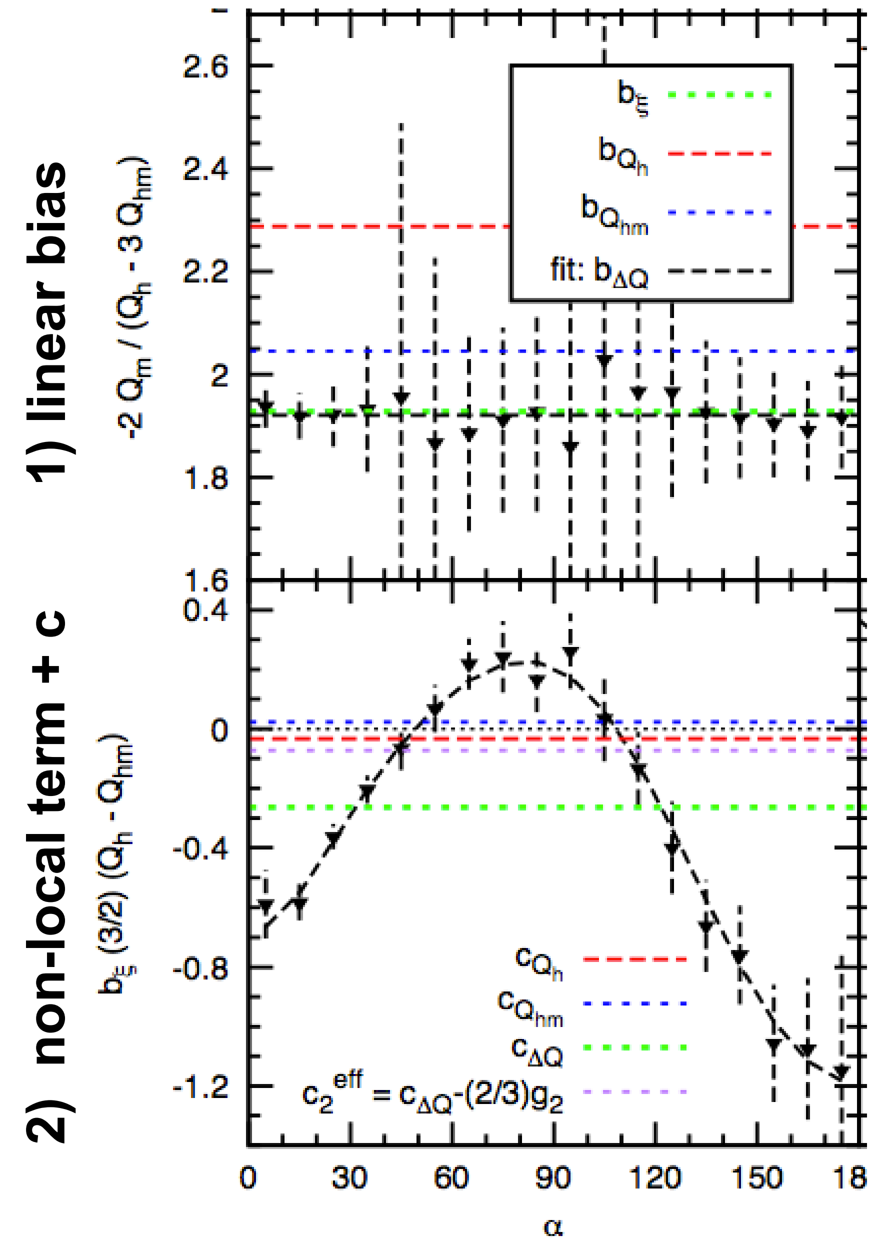
non-local term

Q cross: galaxy-matter-matter

$$Q_{gm} \simeq \frac{1}{b}(Q_m + \frac{1}{3}[c + g_2 Q_{nloc}])$$

1) Q auto – 3 Q cross:

$$Q_g - 3 Q_{gm} = -2 \frac{Q_m}{b}$$



triangle opening angle

non-local bias from Q auto+cross

Q auto: galaxy-galaxy-galaxy

$$Q_g \simeq \frac{1}{b}(Q_m + [c + g_2 Q_{nloc}])$$

non-local term

Q cross: galaxy-matter-matter

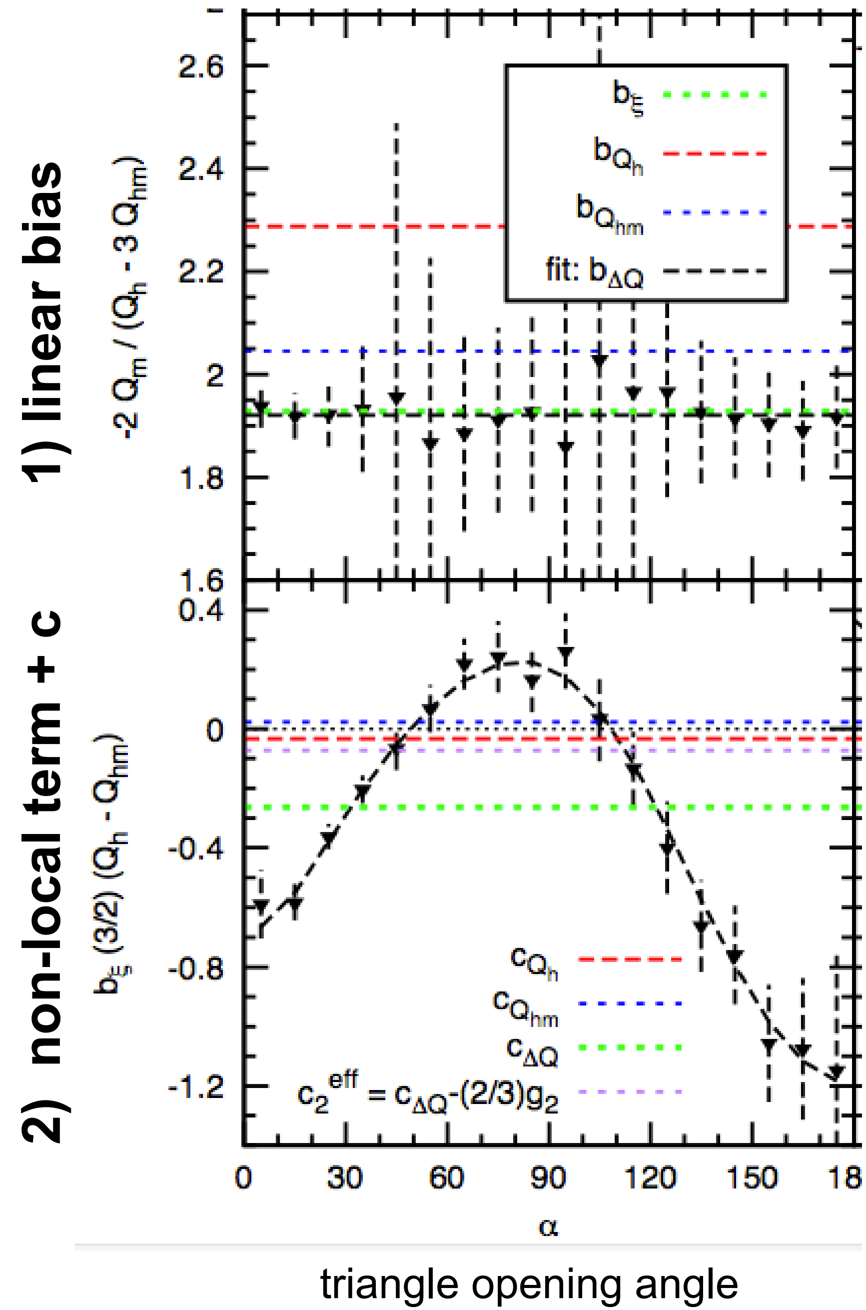
$$Q_{gm} \simeq \frac{1}{b}(Q_m + \frac{1}{3}[c + g_2 Q_{nloc}])$$

1) Q auto – 3 Q cross:

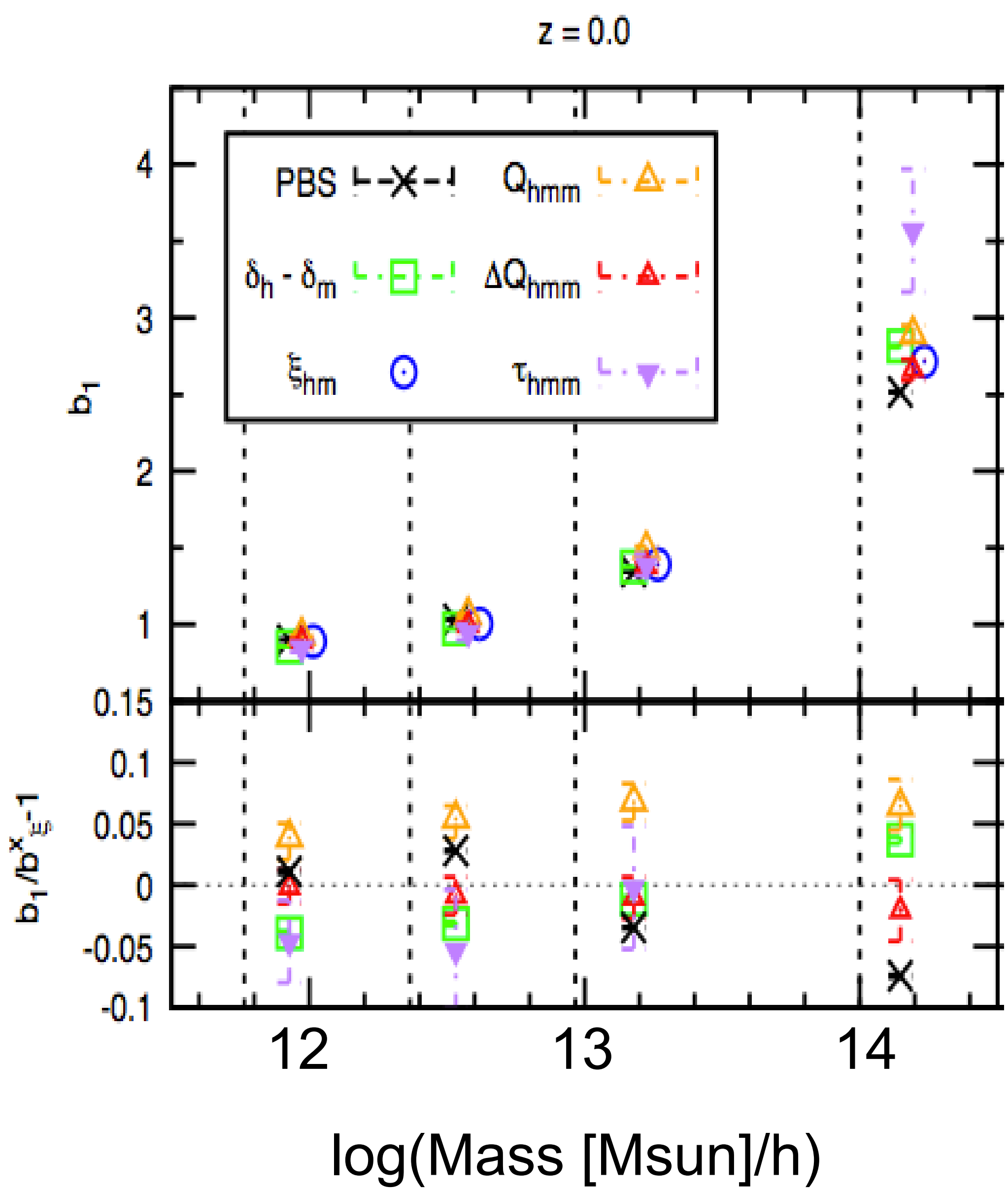
$$Q_g - 3 Q_{gm} = -2 \frac{Q_m}{b}$$

2) Q auto – Q cross:

$$Q_g - Q_{gm} = \frac{2}{3}\frac{1}{b_\xi}(c + g_2 Q_{nloc})$$



comparing linear bias from different approaches



ξ: two- point cross-correlation

Q: tree-point cross-correlation

ΔQ: tree-point auto&cross correlation

τ: cross skewness & cumulants

PBS: peak background split

δh-δm:
fit to halo vs matter fluctuations

measuring growth without dark matter

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

only bias ratio $\hat{b}\equiv\frac{b(z)}{b(0)}$ needs to be known for measuring D(z)

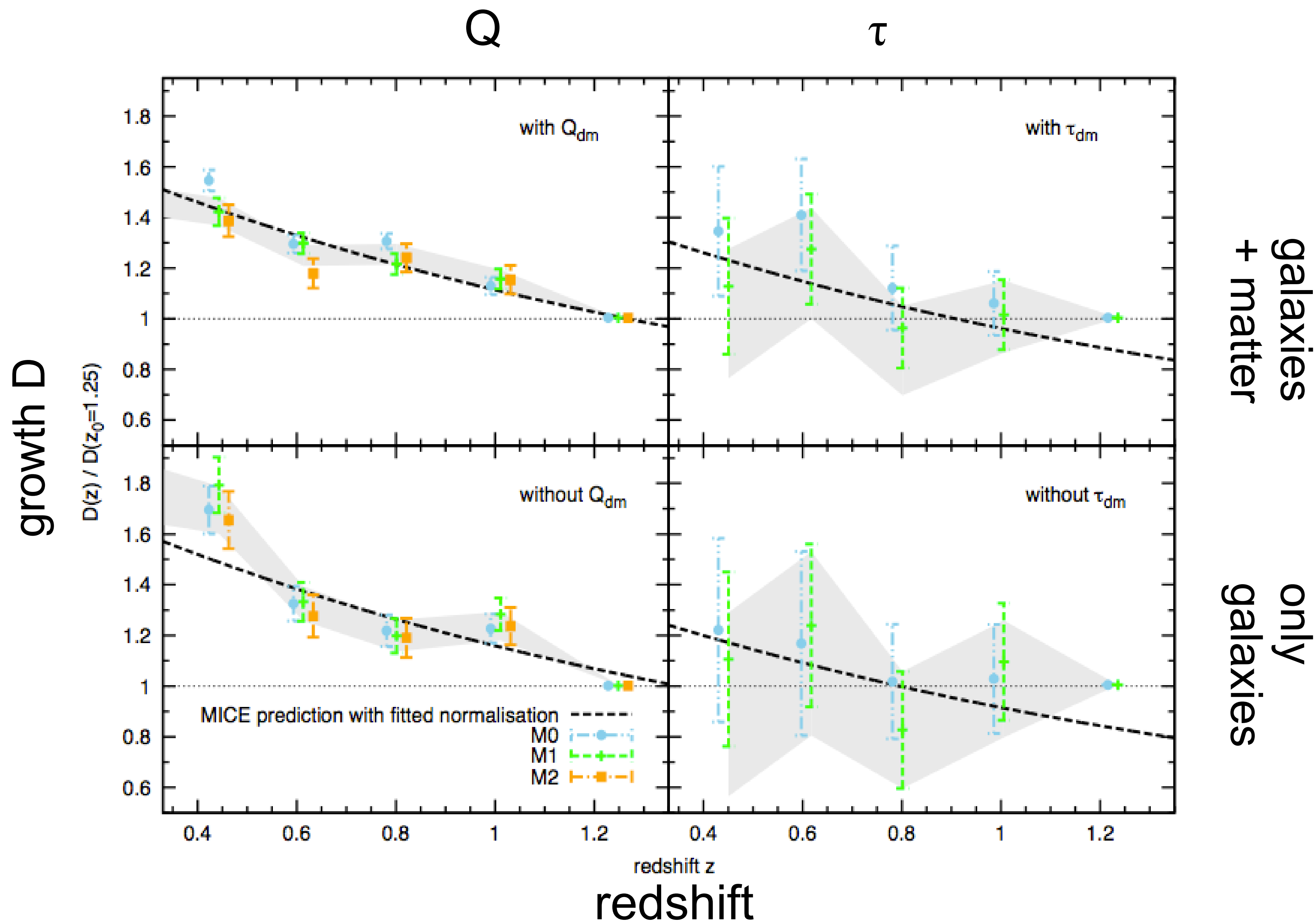
$$Q_g(z)\simeq\frac{1}{b_Q(z)}\left(Q_m+c_Q(z)\right)$$

$$Q_m(z)=Q_m(0)$$

$$Q_g(z)\simeq\frac{1}{\hat{b}_Q}\left(Q_g(0)+\hat{c}_Q(0)\right)$$

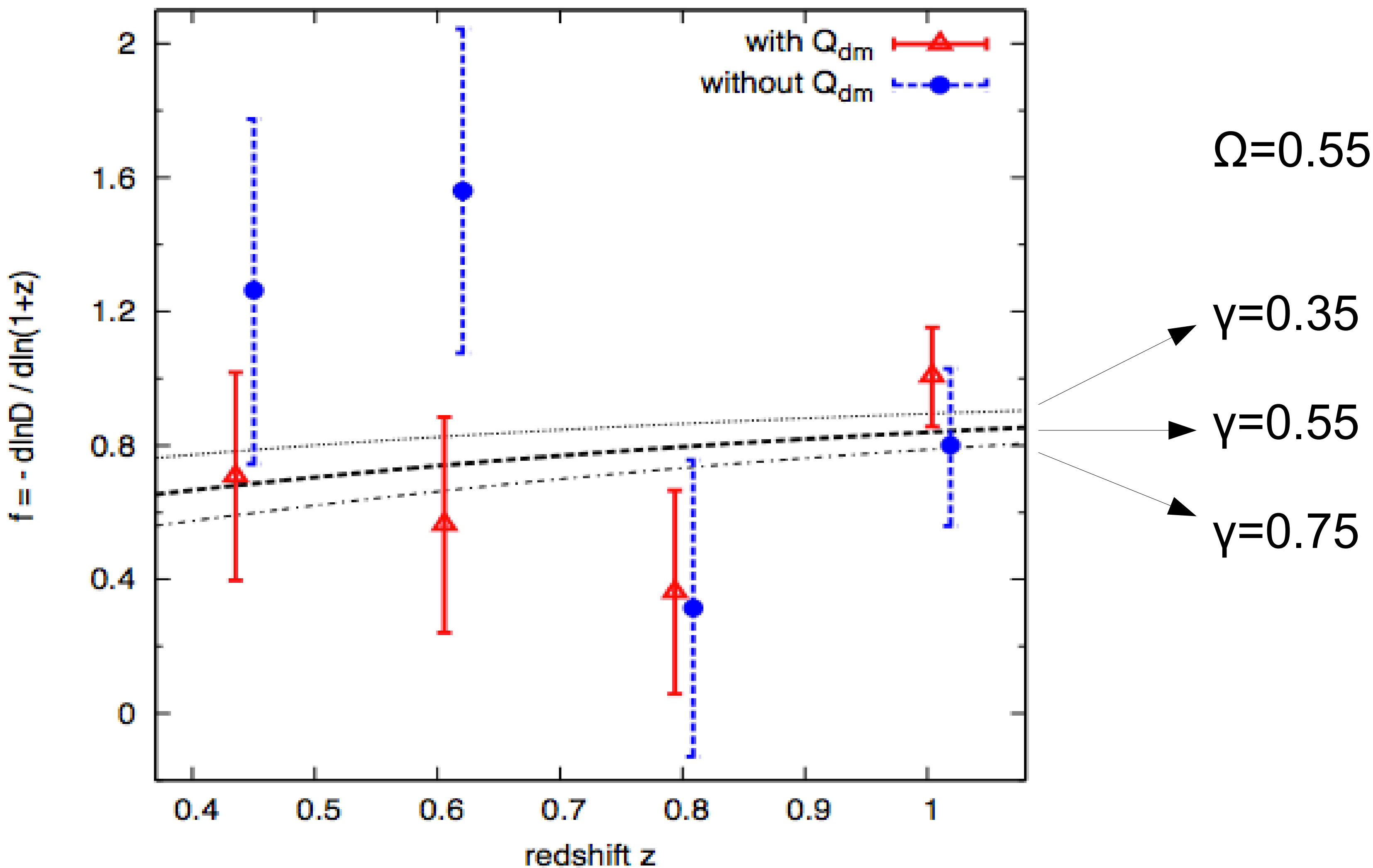
=> D(z) can be measured without modeling Q_m

growth in MICE light cone



growth rate in MICE light cone from Q

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



Summary

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

- 3^{rd} order methods give good qualitative measurement of bias from ξ

- deviations between bias from 3^{rd} order methods and ξ might come from non-local terms in bias function

- growth measurement using 3^{rd} order bias agrees qualitatively with true growth in simulation

- combining 3^{rd} order correlations at different redshifts allows growth measurement without modeling dm correlation

thanks!