# Measuring the growth of matter fluctuations with third order galaxy correlations

Hoffmann, Bel, Gaztañaga

INSTITUT D'ESTUDIS ESPACIALS DE CATALUNYA
IEEC
CSIC
INSTITUTO DE CIENCIAS DEL ESPACIO
ICE
Generalitat de Catalunya
OSSERVATORIO ASTRONOMICO DI BRERA

# cosmology with large scale structure

matter fluctuations:

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

linear growth (R > 40 Mpc/h):

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

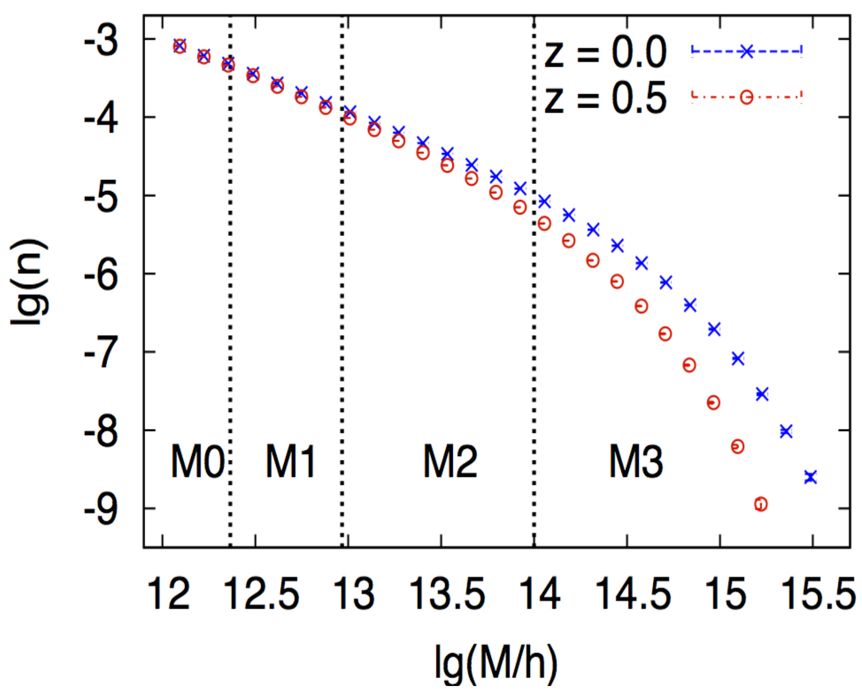
growth depends on cosmology

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

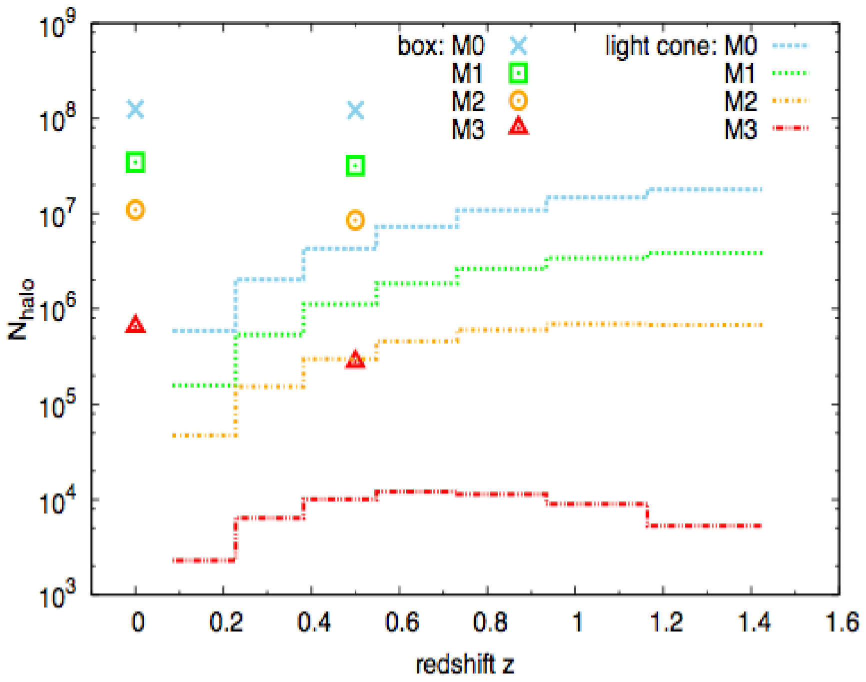
# MICE Grand Challenge simulation

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:

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

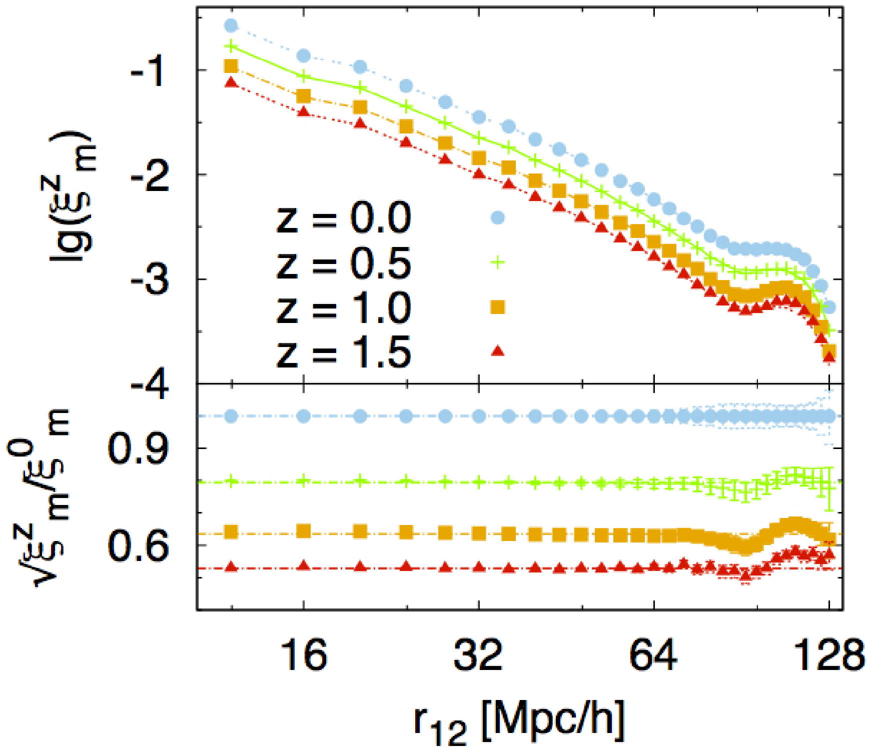
# measuring growth with two-point correlations

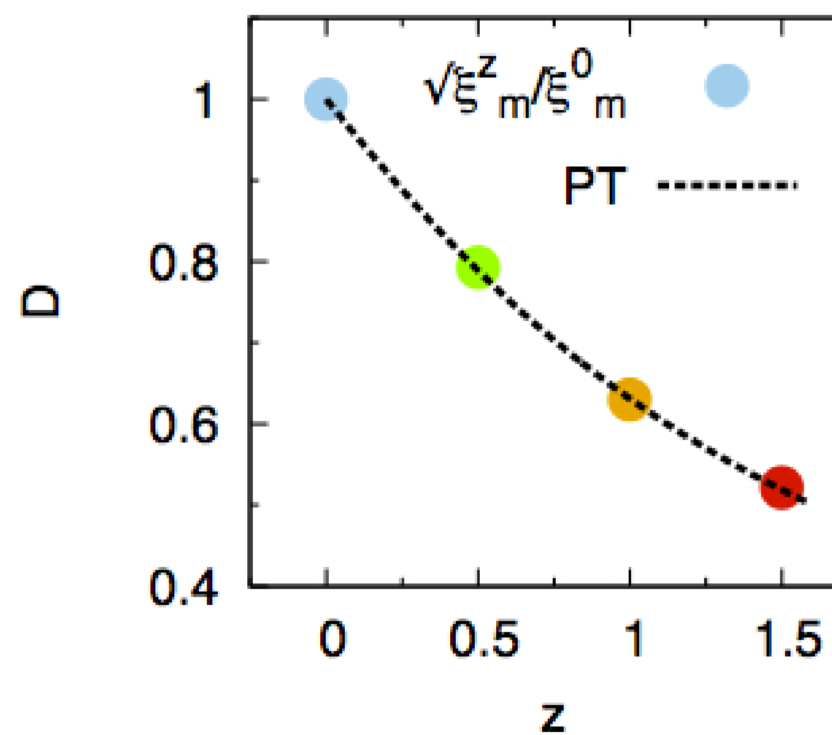
two point correlation:

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

large scale growth:

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



# galaxy bias

quadratic model for local bias:

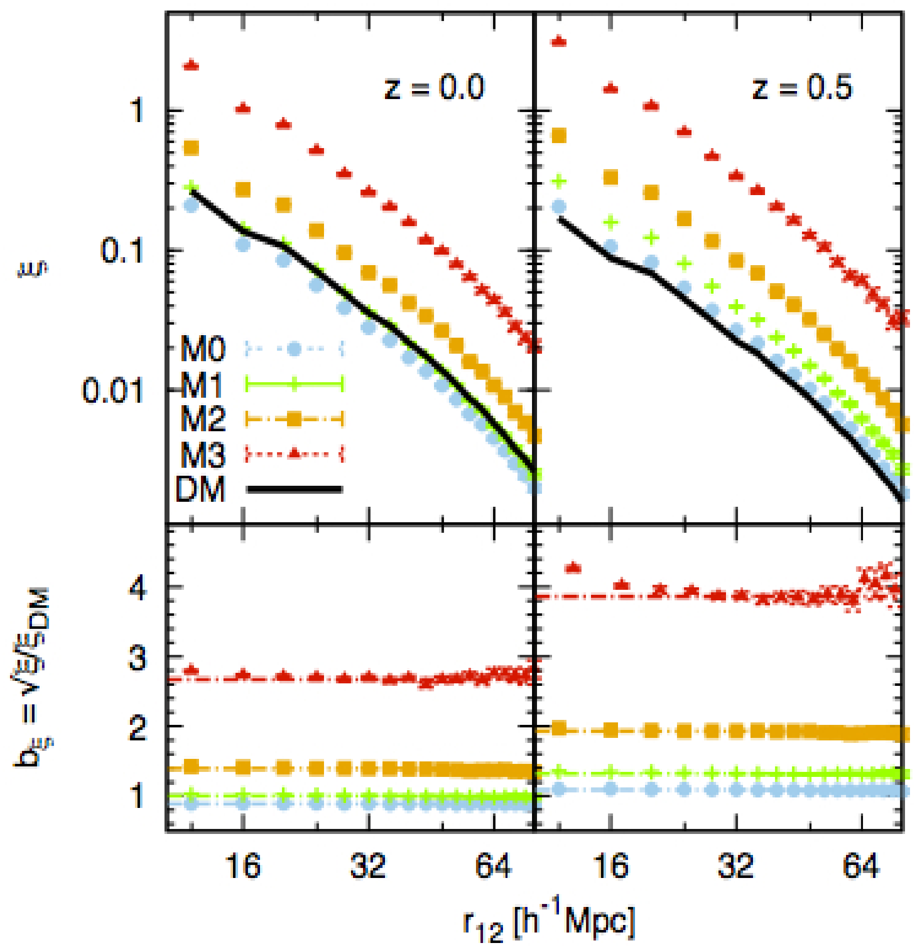
$$\delta_g \simeq b_1 \delta_m + (b_2/2)(\delta_m^2 - \langle \delta_m^2 \rangle)$$

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

degeneracy with growth:

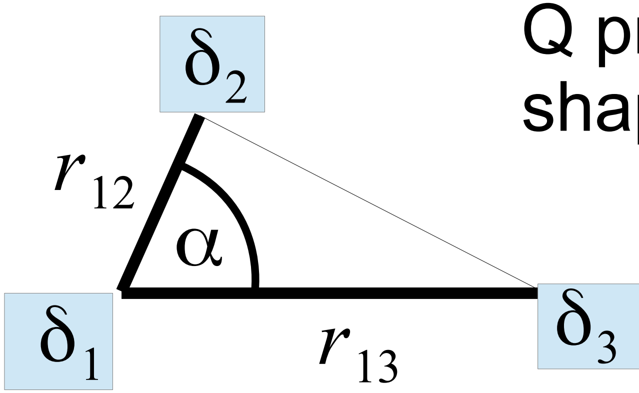
$$D(z) = \sqrt{\frac{\xi_m(z)}{\xi_m(0)}} = \frac{b(0)}{b(z)} \sqrt{\frac{\xi_g(z)}{\xi_g(0)}}$$

can be broken with third order correlations



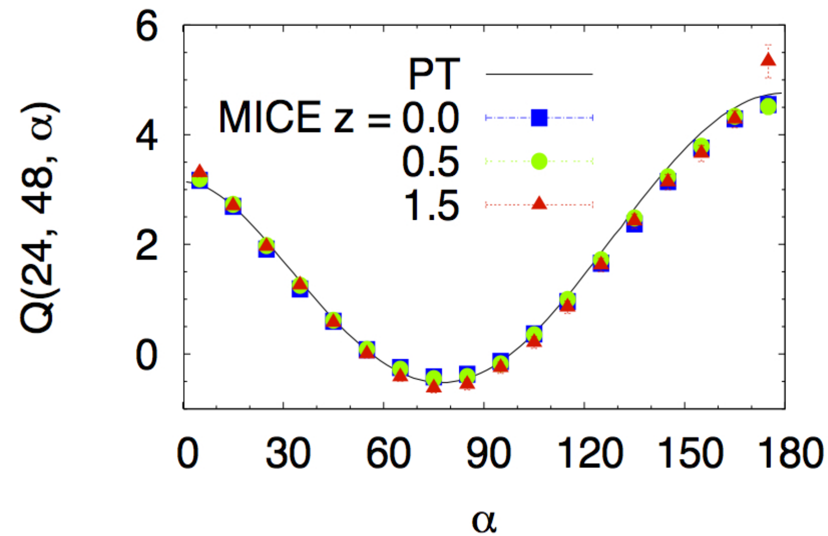
# three-point correlation

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




Q probes shape of LSS

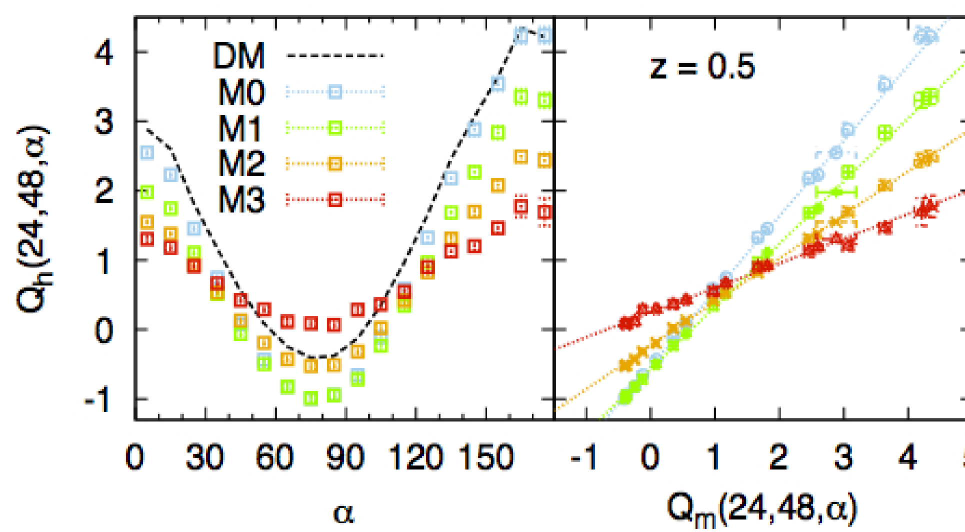
Q independent of redshift




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

independent of growth

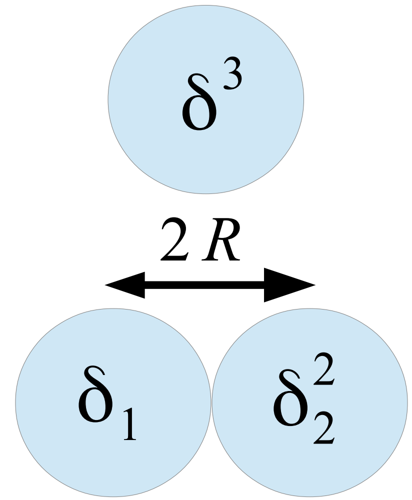
Q dependent on bias



# third-order moments

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

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

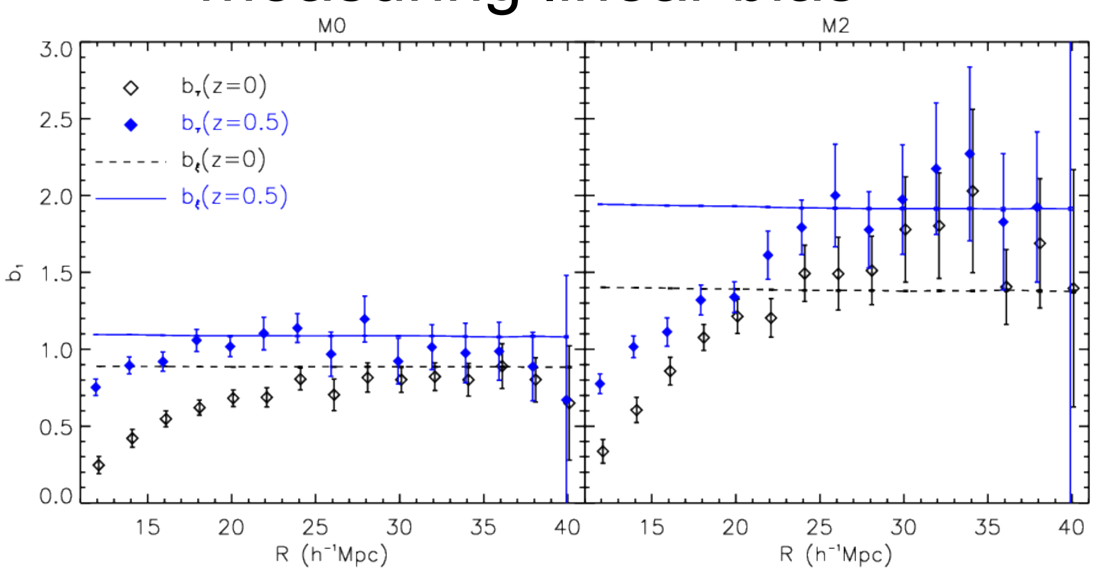



**linear bias:**

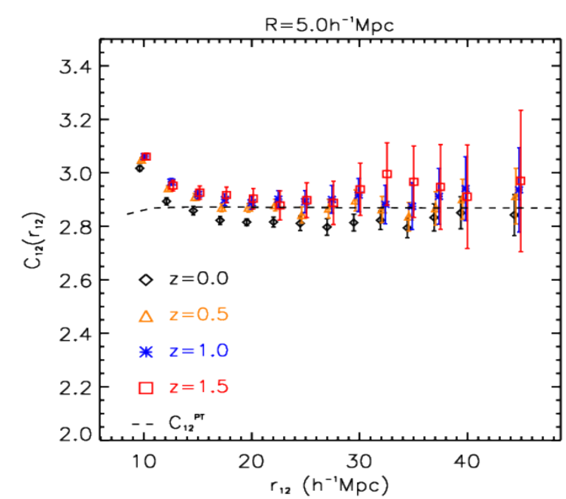
$$b_\tau \equiv \frac{3\,C_{12}^m - 2\,S_3^m}{3\,C_{12}^g - 2\,S_3^g}$$

Bel & Marinoni, 2012, MNRAS, 424, 971

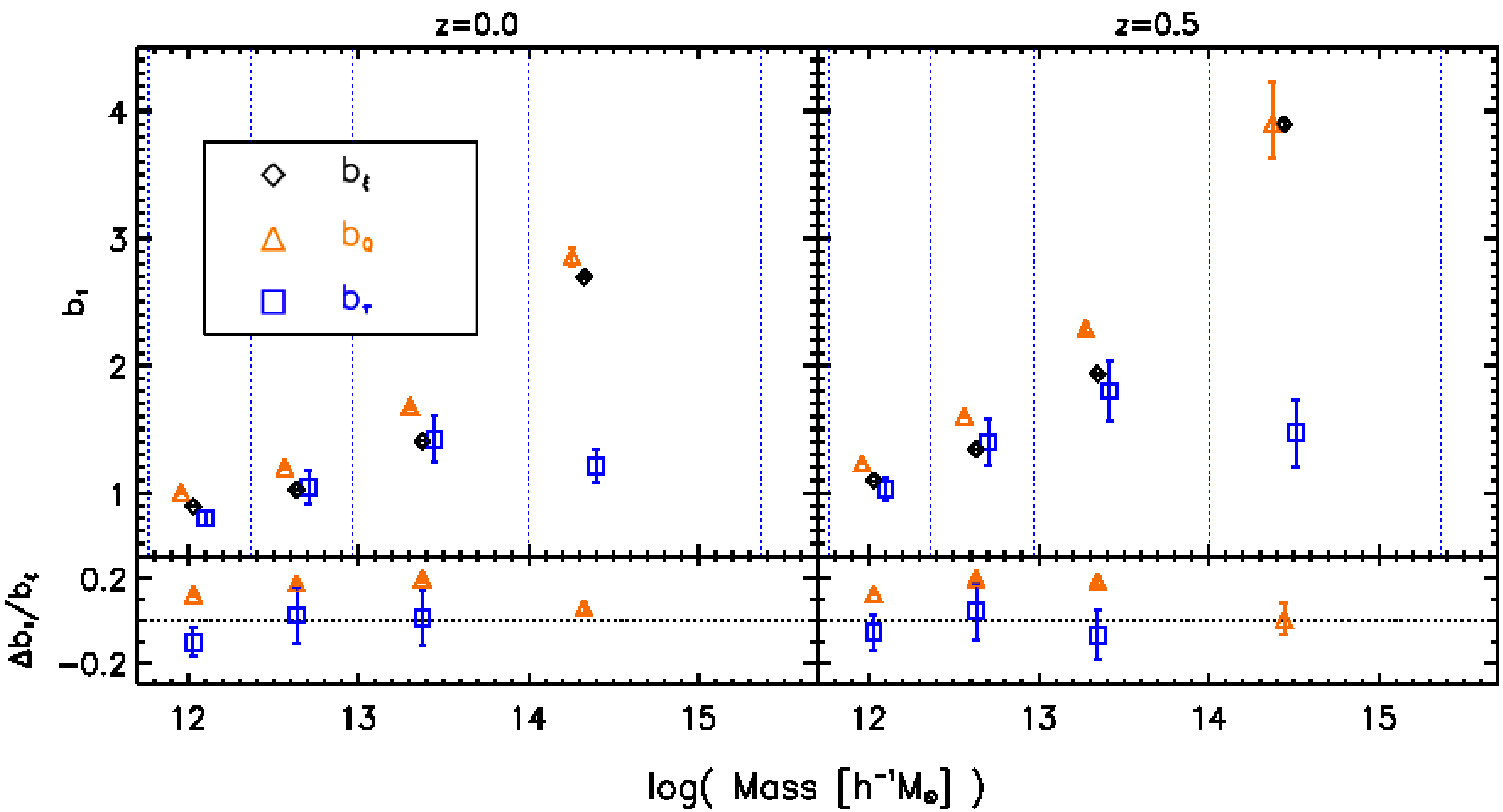
## measuring linear bias




## C12 independent of redshift



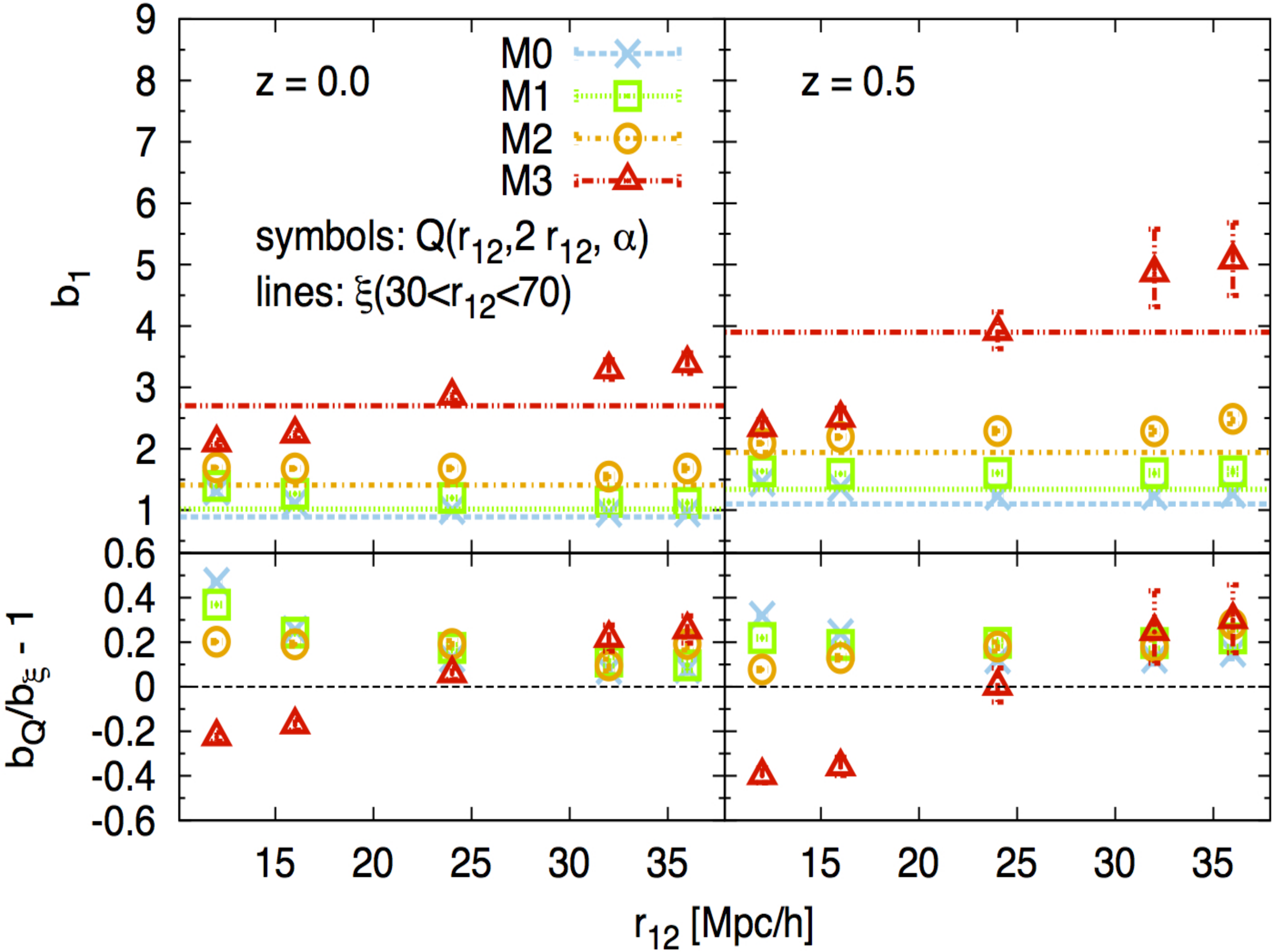
# comparing bias from $\xi$, Q, $C_{12}$



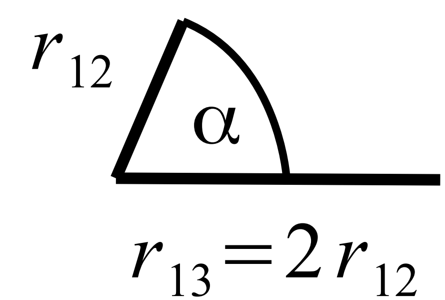

Differences can be caused by

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

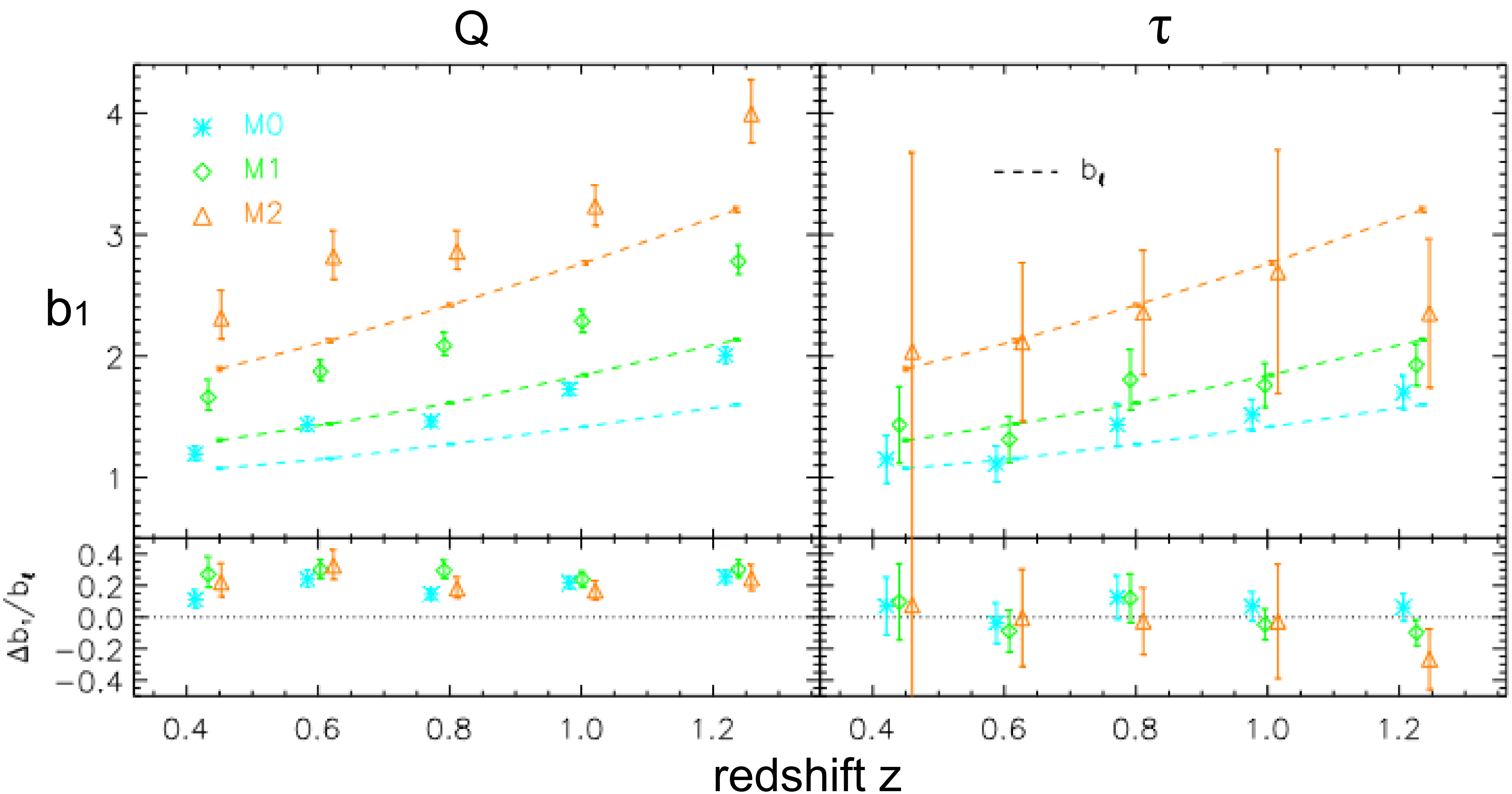
# comparing bias from $\xi$ & Q at different triangle scales ($r_{12}$)




triangle configuration:



# comparing bias from $\xi$, Q & $\tau$ at different redshifts




**problem**: bias measurements from Q & $\tau$ depend on dark matter models

# measuring growth without dark matter

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

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

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

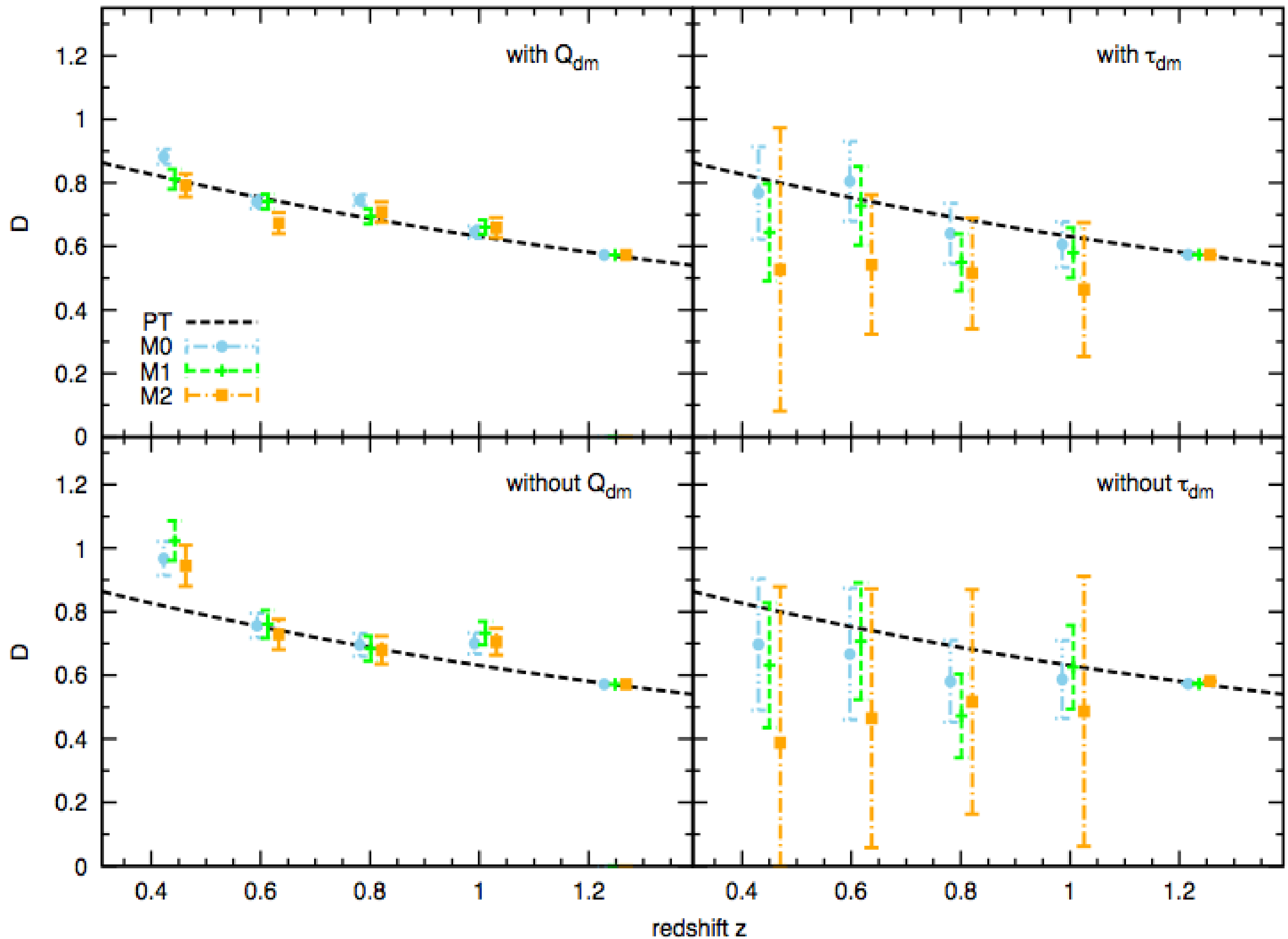
$$Q_g(z) \simeq \frac{1}{b_Q(z)}\left(Q_m + c_Q(z)\right)$$

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

=> 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

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

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

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

# 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 $\xi$, but in detail they seem systematically away

- growth measurement using 3rd order bias agrees qualitatively with growth from $\xi_m$ and PT

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

thanks!