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Une nouvelle sonde cosmologique le *galaxy clustering ratio*

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J. Bel & CM 2012 MNRAS, 424,971

J. Bel & CM 2013 A&A in press arXiv:1310.2365

J. Bel, CM, the VIPERS team, 2013 A&A in press arXiv:1310.3380

Cosmology after Planck

Next Generation of Spectroscopic surveys of the large scale structure ([DESpec](#), [HETDEX](#), [VISTA/spec](#), [EUCLID](#), [WFIRST](#), [SKA](#)) will provide a sensitive probe of the dark matter and dark energy characteristics

What is the nature of dark energy?
(dynamical? Inhomogeneous? new gravitational degrees of freedom?)

How dark matter drives the growth of large scale structures?
(role of biasing, massive neutrinos, non-standard gravitational instability....)

Ideal laboratory for measuring high order clustering statistics

Can we see growth of structure directly from galaxies?

Can we extract structural parameters of $P(K)$ $n_s, \Omega_m, m_\nu \dots$
without modelling galaxy bias and redshift distortions?

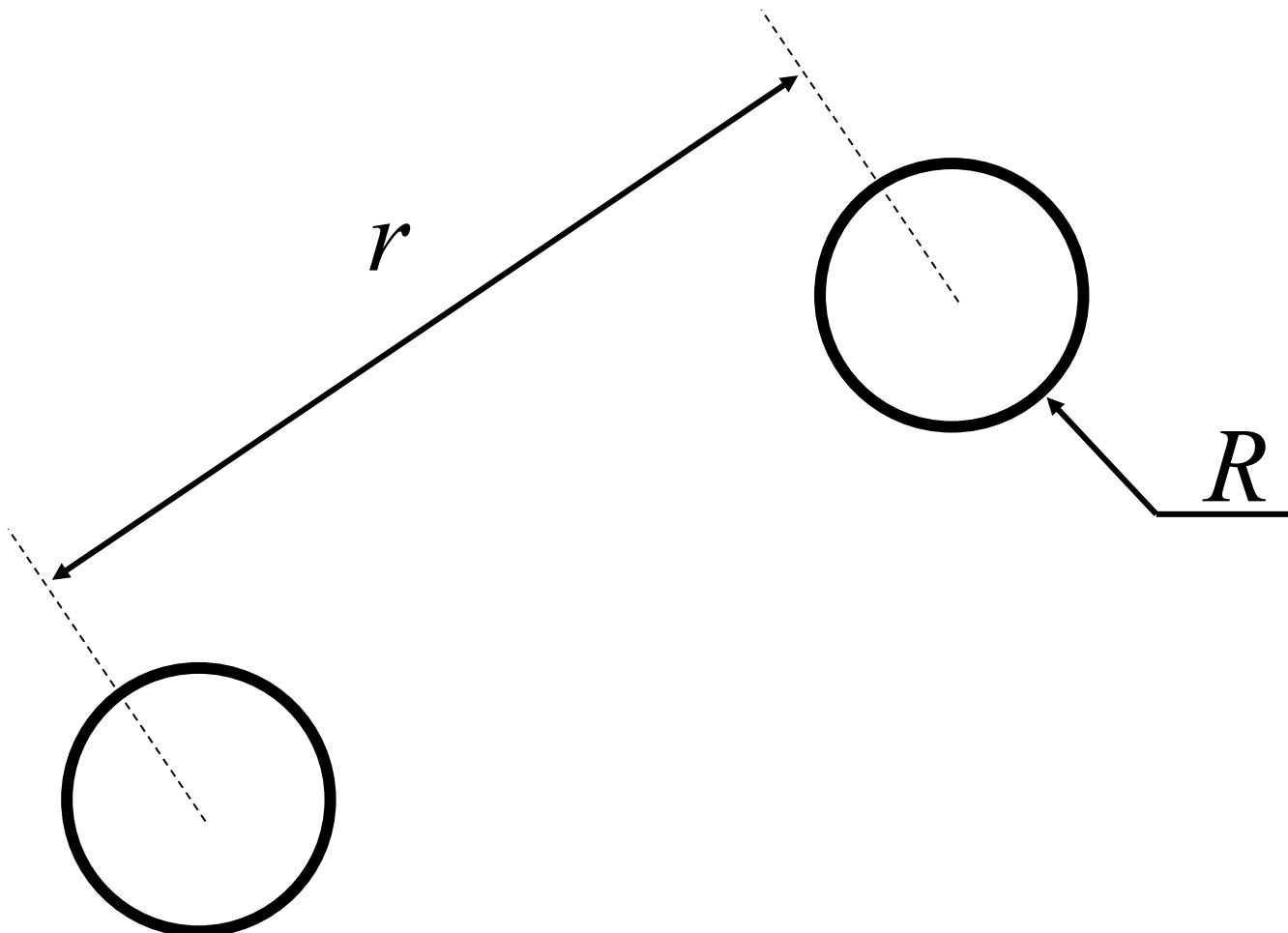
Two points correlators of order (n,m)

Two point correlators of order n,m: $k_{nm,R}(r) \equiv \left\langle \delta_R^n(\vec{x}) \delta_R^m(\vec{x} + \vec{r}) \right\rangle_c$

Two points correlators of order (n,m)

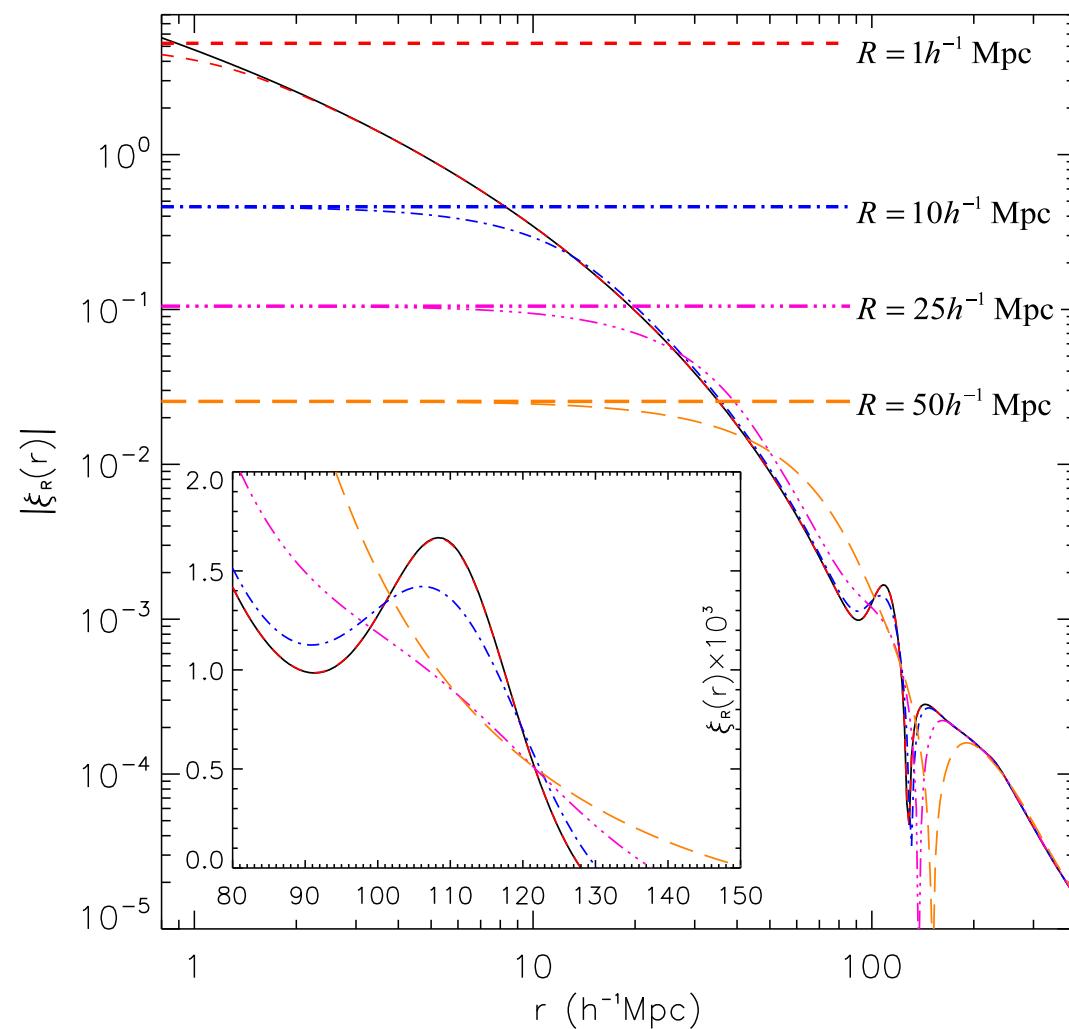
Two point correlators of order n,m:

$$k_{nm,R}(r) = \frac{1}{V_R^{n+m}} \int_{V_R(x_1)} dy_1 \dots dy_n \int_{V_R(x_1+r)} dy_{n+1} \dots dy_{n+m} \xi_{n+m}(y_1 \dots y_{n+m})$$



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 The two point correlation function of the smoothed overdensity density field: $\xi_R(r) \equiv \langle \delta_R(\vec{x}) \delta_R(\vec{x} + \vec{r}) \rangle_c$



Two points correlators

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The two point correlation function of the smoothed overdensity density field:

$$\xi_R(r) \equiv \langle \delta_R(\vec{x}) \delta_R(\vec{x} + \vec{r}) \rangle_c$$

Hierarchical scaling

$$\langle \delta^n(\vec{x}) \delta^m(\vec{x} + \vec{r}) \rangle_c = C_{n,m} \langle \delta(\vec{x}) \delta(\vec{x} + \vec{r}) \rangle_c \langle \delta^2(\vec{x}) \rangle_c^{n+m-2}$$

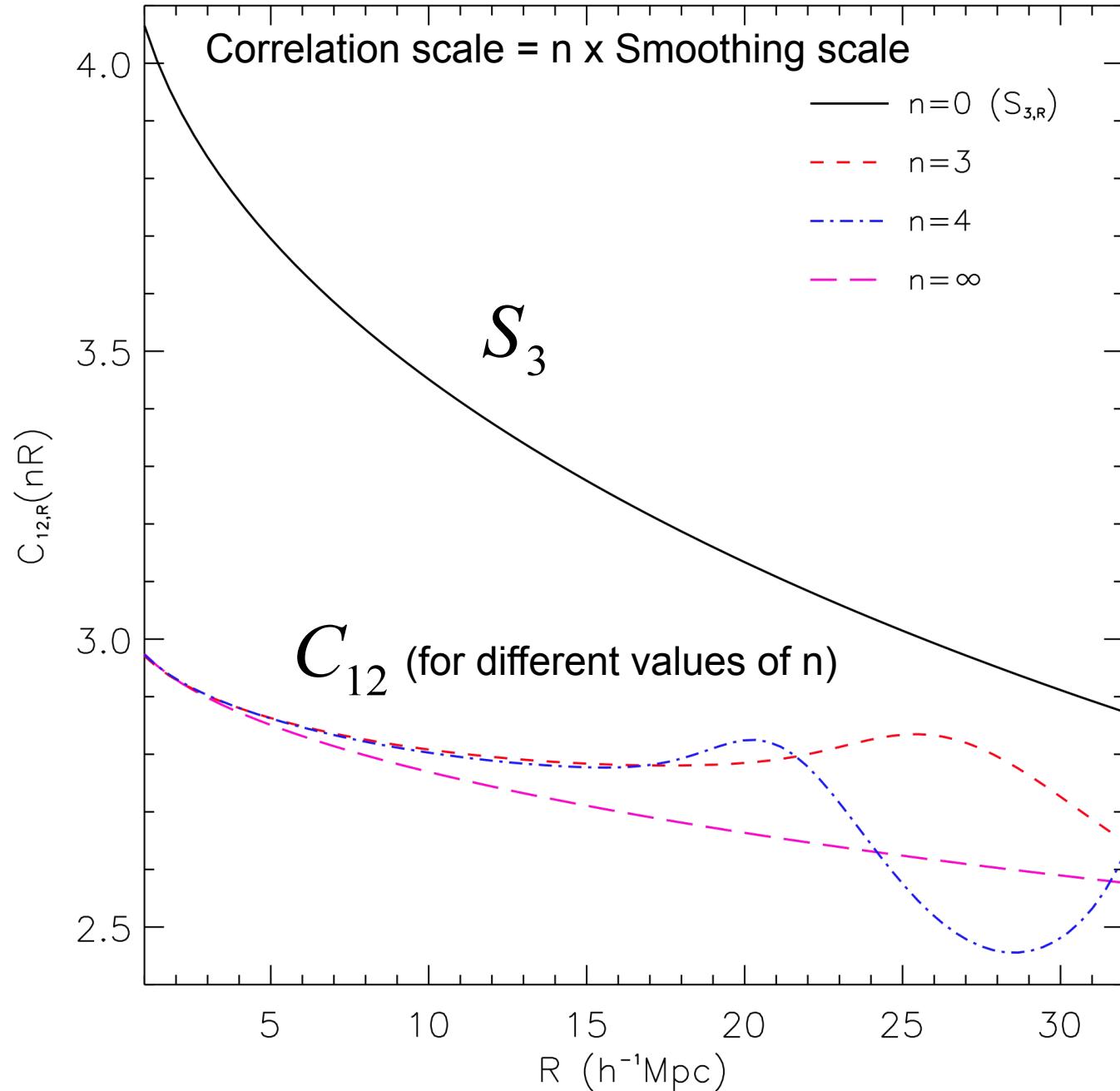
Szapudi & Szalay 1992

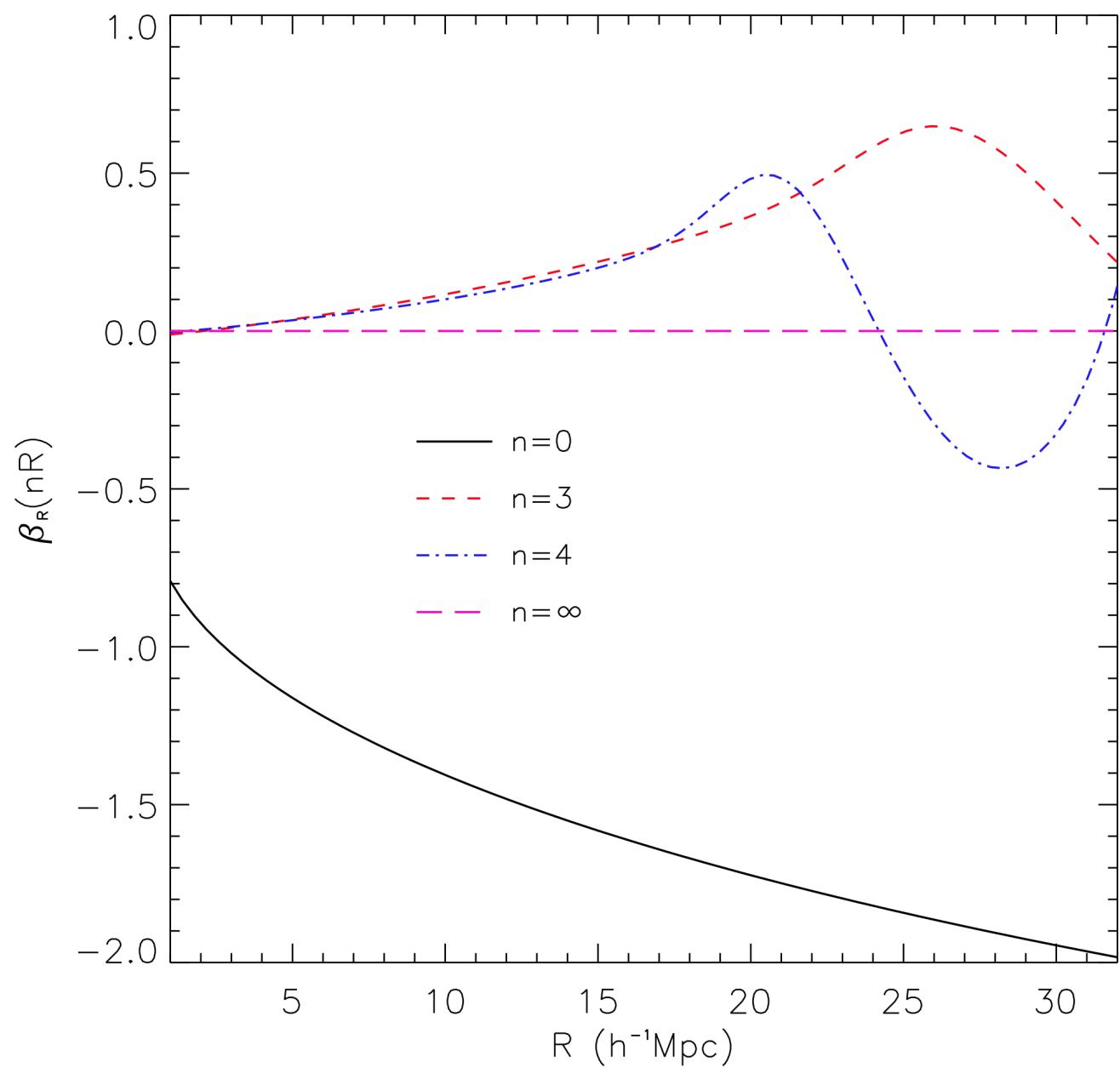
The amplitude of the $\langle \delta^{n+m}(\vec{x}) \rangle_c$ is controlled by the WNLPT
Fry 1984

$$C_{12,R}(r) = \frac{68}{21} + \frac{\beta_R(r) + \gamma_R}{3} \quad \text{Bernardeau 1998}$$

$$\beta_R(r) = \frac{d \ln \xi_R(r)}{d \ln R}$$

$$\gamma_R = \frac{d \ln \sigma_R(r)}{d \ln R}$$





Galaxy Correlators

Bias function: $\delta_{g,R}(\vec{x}) = \sum_{i=0}^N \frac{b_i}{i!} \delta_R^i(\vec{x})$

$$S_{3,g} = b_1^{-1} (S_3 + 3c_2)$$

$$c_i = \frac{b_i}{b_1}$$

Fry & Gaztañaga (1993)

$$S_{4,g} = b_1^{-2} (4c_3 + 12c_2S_3 + S_4 + 12c_2^2)$$

$$S_{5,g} = b_1^{-3} (S_5 + 5c_4 + 20c_2S_4 + 60c_2c_3 + 60c_2^3 + 120c_2^2S_3 + 30c_3S_3 + 15c_2S_3^2)$$

.....

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.....

The transformation preserves the hierarchical properties of matter correlators

$$k_{nm,g} = C_{nm,g} k_{11,g} k_{2,g}^{n+m-2}$$

$$C_{12,g} = b_1^{-1} (C_{12} + 2c_2)$$

$$C_{22,g} = b_1^{-2} (4c_2C_{12} + 4c_2^2 + C_{22}) \quad \text{Bel \& CM (2012)}$$

$$C_{13,g} = b_1^{-2} (6c_2^2 + C_{13} + 3c_2S_3 + 3c_3 + 6c_2C_{12})$$

$$C_{23,g} = b_1^{-3} (C_{23} + 2c_2C_{13} + 6c_2C_{22} + 6c_2^2S_3 + 3c_3C_{12} + 18c_2^2C_{12} + 6c_3c_2 + 3c_2C_{12}S_3 + 12c_2^3)$$

.....

Bias Coefficients

Bias function: $\delta_{g,R}(\vec{x}) = \sum_{i=0}^N \frac{b_i}{i!} \delta_R^i(\vec{x})$

Bias coefficients in real space

$$b_1 = \frac{3C_{12} - 2S_3}{3C_{12,g} - 2S_{3,g}} \quad \text{Szapudi 1996} \quad (33)$$

$$b_2 = \frac{(C_{12}S_{3,g} - S_3C_{12,g})(3C_{12} - 2S_3)}{(3C_{12,g} - 2S_{3,g})^2} \quad (34)$$

$$b_3 = \frac{(9S_{4,g}C_{12}^2 - 12S_{4,g}C_{12}S_3 + 4S_{4,g}S_3^2 - 12S_3S_{3,g}C_{12}C_{12,g} + 24S_3S_{3,g}^2C_{12} - 24S_3^2S_{3,g}C_{12,g} + 24S_3^2C_{12,g}^2 - 9S_4C_{12,g}^2 + 12S_4C_{12,g}S_{3,g} - 4S_4S_{3,g}^2 - 12S_{3,g}^2C_{12}^2)(3C_{12} - 2S_3)}{4(3C_{12,g} - 2S_{3,g})^3} \quad (35)$$

Bel & CM, 2012 MNRAS

$$\tau_g^z(r) \equiv 3C_{12,g}^z - 2S_{3,g}^z$$

$$\alpha_g^z(r) \equiv \frac{d \log k_{11,g}^z}{d \log R} - \frac{d \log k_{2,g}^z}{d \log R}$$

$$b_1 = \frac{\alpha_g^z}{\tau_g^z}$$

Estimating the amplitude of mass fluctuations σ_R

$$\hat{\sigma}_R = \sigma_{g,R}^z \times \left[\left(\frac{\alpha_g^z}{\tau_g^z} \right)^2 + \frac{2\alpha_g^z}{3\tau_g^z} f + \frac{1}{5} f^2 \right]^{-1/2}$$

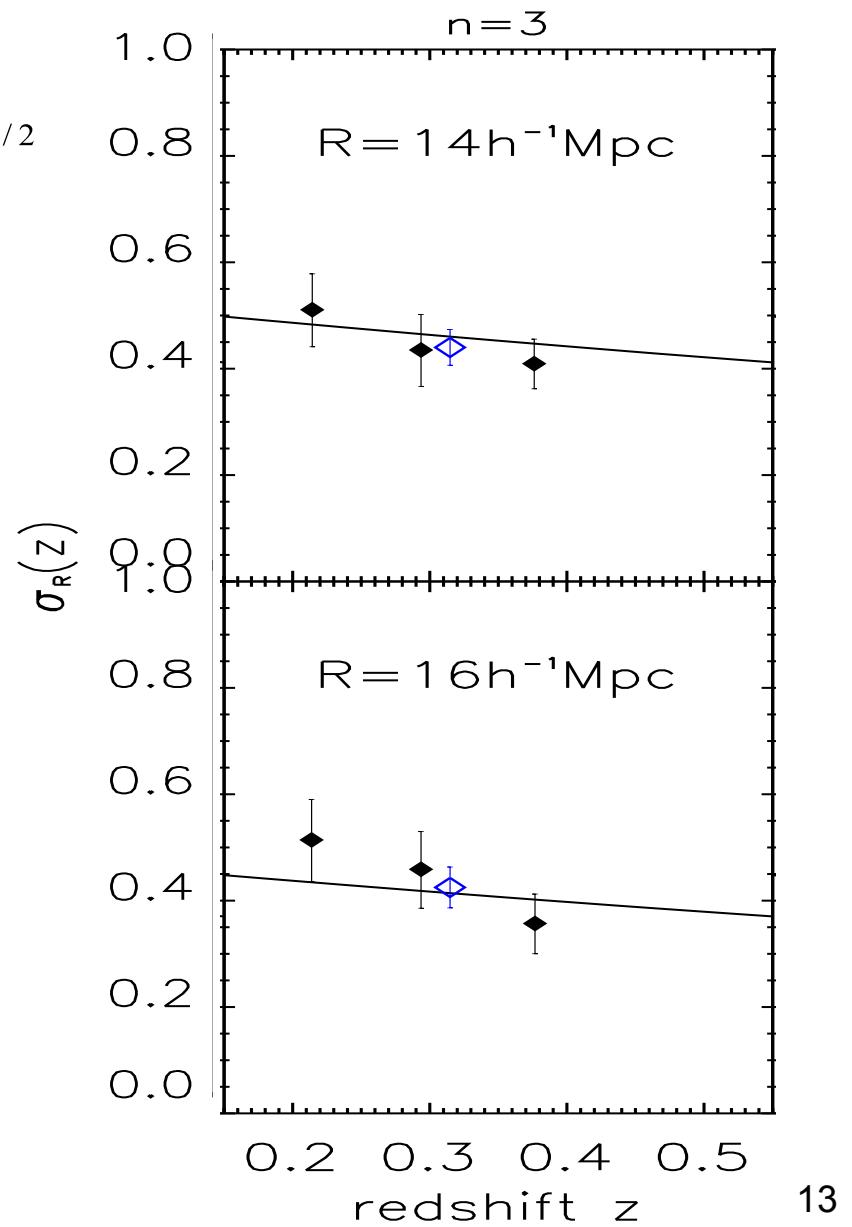
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Blind test using the
Las Damas simulation

McBride et al, 2011

$0.2 < z < 0.5$
 $V \approx 1 h^{-3} \text{Gpc}^3$
 $N \approx 10^5$ LRG
 $\rho \approx 10^{-4} h^3 \text{ gal/Mpc}^3$



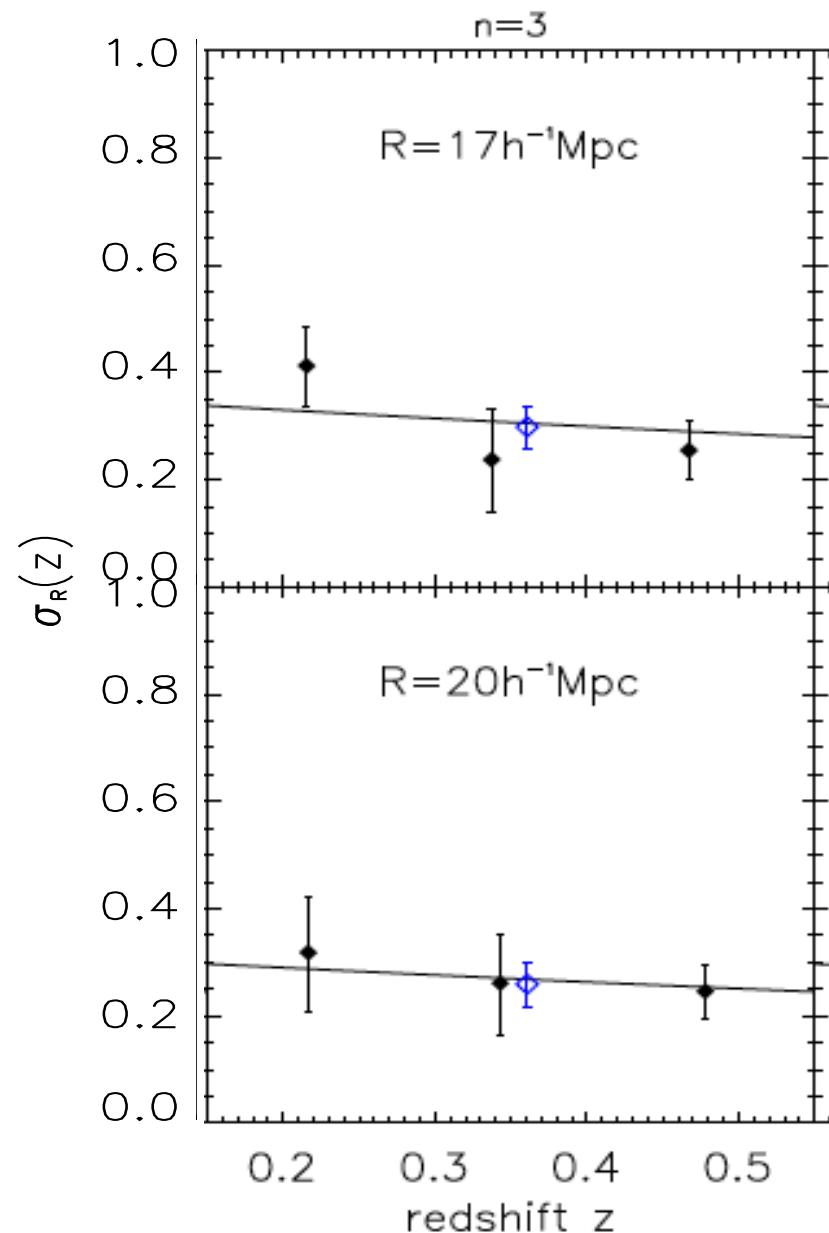
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Blind test using the
Horizon simulation

Kim et al 2009

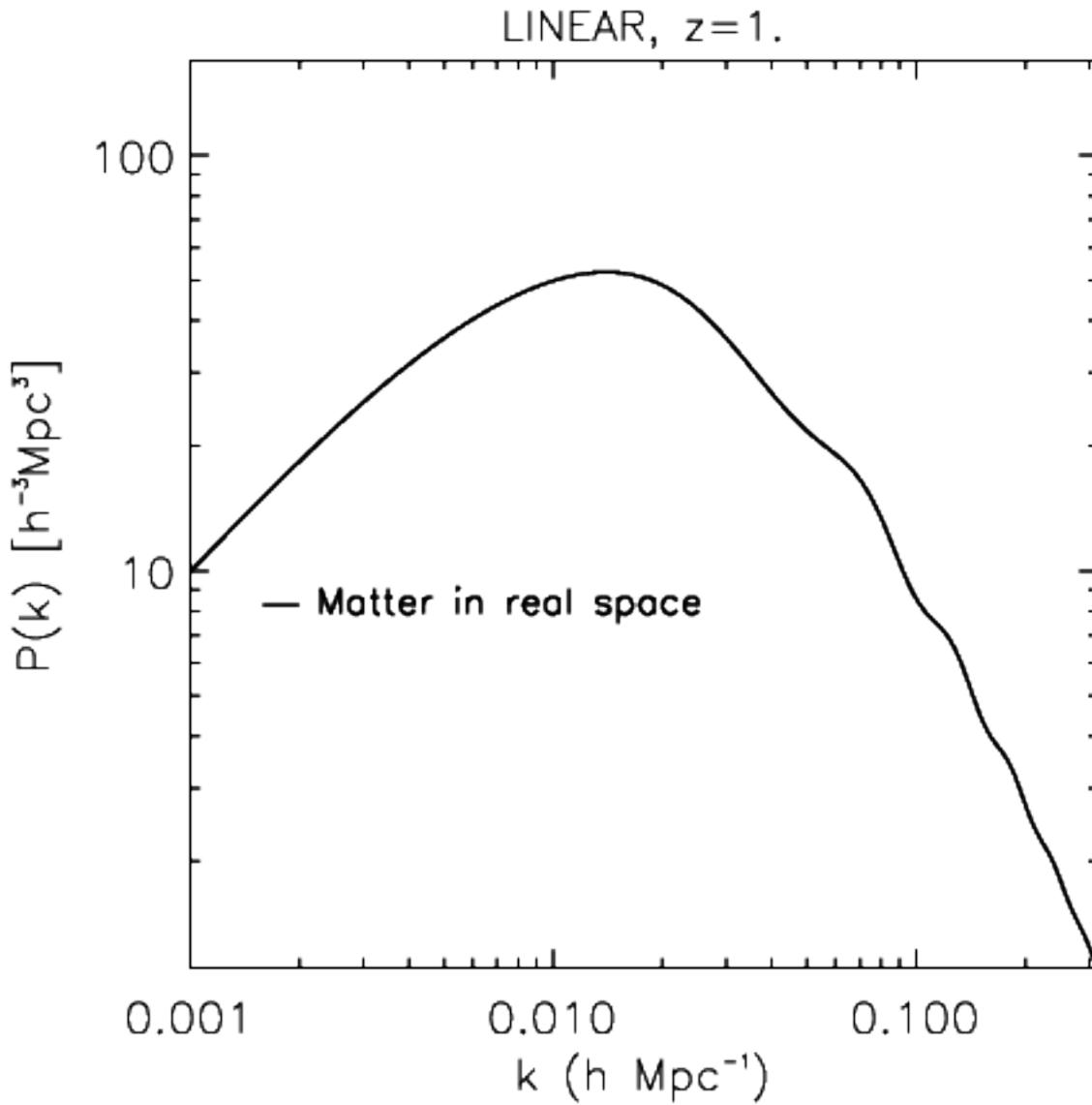
$0.15 < z < 0.55$
 $V \approx 10 h^{-3} \text{Gpc}^3$
 $N \approx 4 \cdot 10^6$ LRG
 $\rho \approx 4 \cdot 10^{-4} h^3 \text{ gal/Mpc}^3$



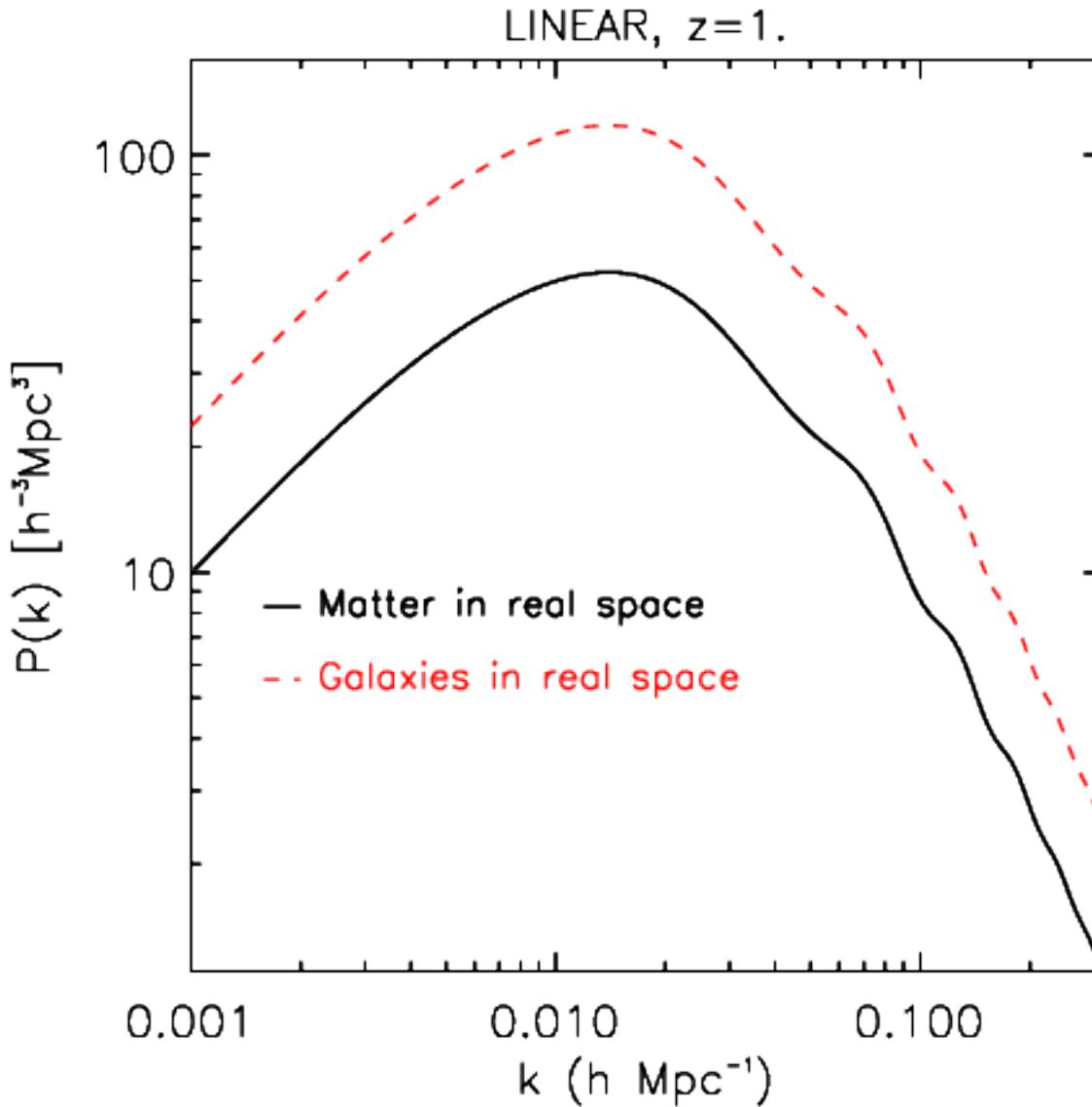
Future directions

- Test/extend the WNLPT prediction for C_{nm} using matter simulations!
- Apply the method to EUCLID-like simulations and forecast the precision with which the growth index γ or Ω can be constrained

Can we extract structural parameters of $P(K)$ $n_s, \Omega_m, m_v \dots$
without modelling galaxy bias and redshift distortions?



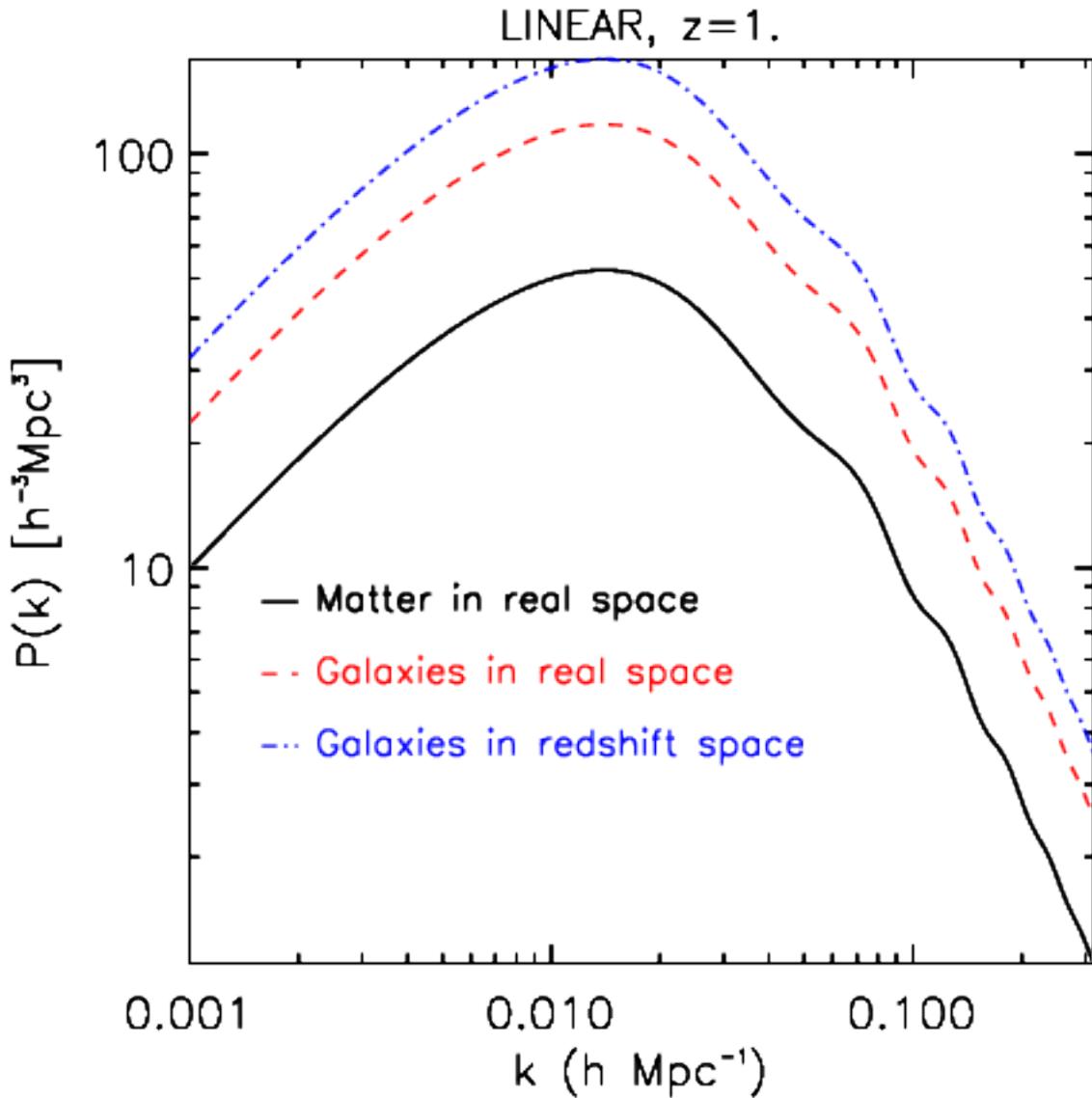
Can we extract structural parameters of $P(K)$
without modelling galaxy bias and redshift distortions?



$$\delta_{g,R} = \sum_{i=0}^N \frac{b_i}{i!} \delta_R^i$$

Fry & Gaztañaga (1993)

Can we extract structural parameters of $P(k)$
without modelling galaxy bias and redshift distortions?



$$\delta_{g,R} = \sum_{i=0}^N \frac{b_i}{i!} \delta_R^i$$

Fry & Gaztañaga (1993)

$$\delta_{g,R}^z = \delta_{g,R} + \mu_k^2 f^2 \delta_R$$

Kaiser (1987)

The clustering ratio

The galaxy clustering ratio:

$$\eta_{g,R}^z(r) \equiv \frac{\xi_{g,R}(r)}{\sigma_{g,R}^2}$$

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$$F_R = \frac{\int_0^{+\infty} \Delta_k W_{TH}^2(kR) d \ln k}{\int_0^{+\infty} \Delta_k W_{TH}^2(kr_8) d \ln k} \quad \text{and} \quad G_R(r) = \frac{\int_0^{+\infty} \Delta_k(z) W_{TH}^2(kR) j_0(kr) d \ln k}{\int_0^{+\infty} \Delta_k(z) W_{TH}^2(kr_8) d \ln k}$$

where $\Delta_k = 4\pi k^3 P(k)$ is the dimensionless power spectrum

and $W_{TH}(kR) = \frac{3}{(kR)^3} [\sin(kR) - kR \cos(kR)]$

The clustering ratio

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$$\eta_R(r) = \frac{\int_0^{+\infty} \Delta(k) W_{TH}^2(kR) j_0(kr) d\ln k}{\int_0^{+\infty} \Delta(k) W_{TH}^2(kR) d\ln k} \stackrel{r > R}{\approx} \frac{\Delta(k_j)}{\Delta(k_w)}$$

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The clustering ratio

$$\eta_{g,R}^z(r) =$$

In the

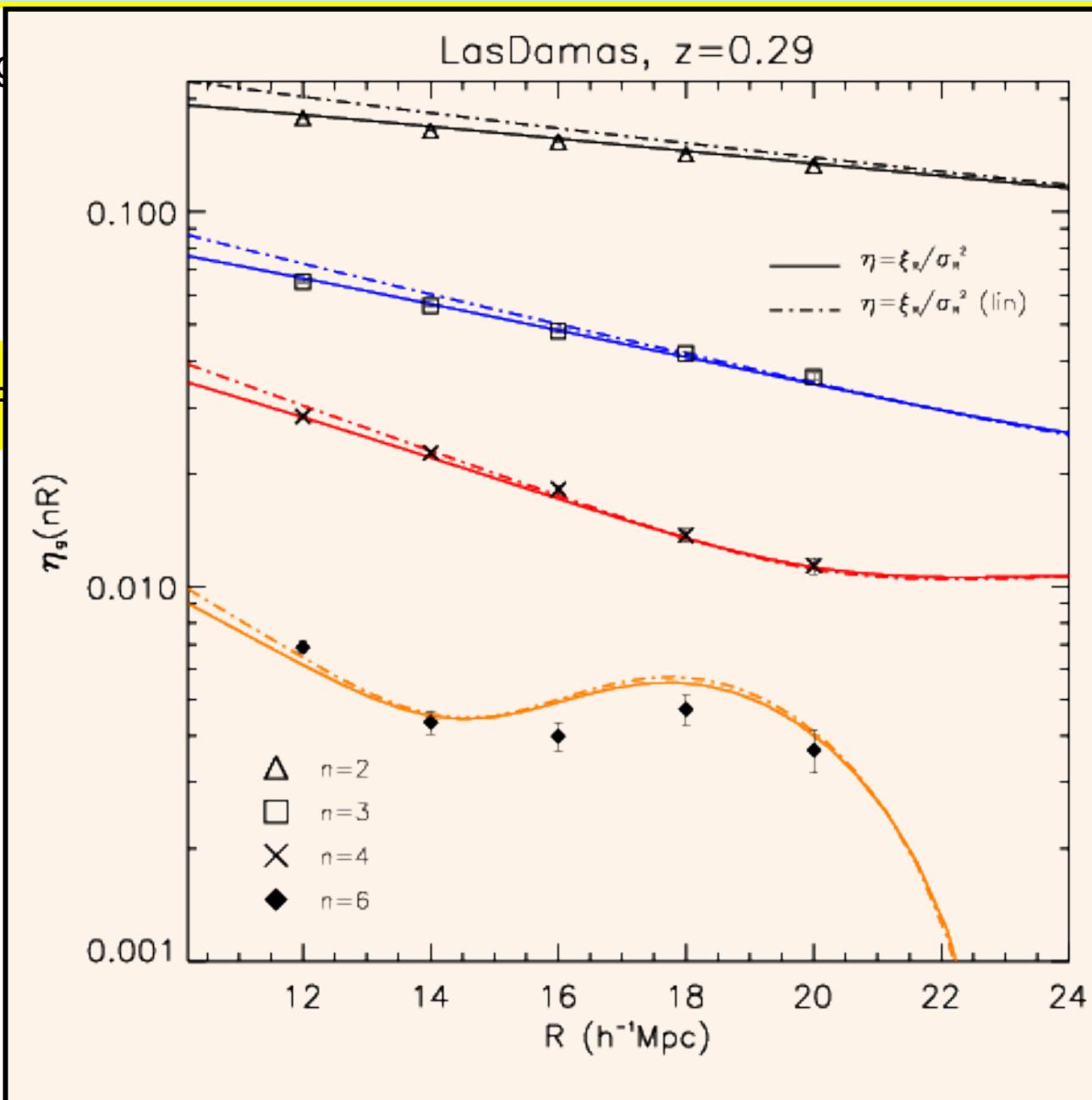
The g

ratio:

$$(r)$$

R

$$_R(r)\xi_R^z(r)$$



The clustering ratio

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$$\eta_{g,R}^z(r) = \eta_R(r) - \left\{ \left(S_{3,R}^z - C_{12,R}^z \right) c_2 + 1/2 c_2^2 \right\} \xi_R^z(r) + 1/2 c_2^2 \eta_R(r) \xi_R^z(r)$$

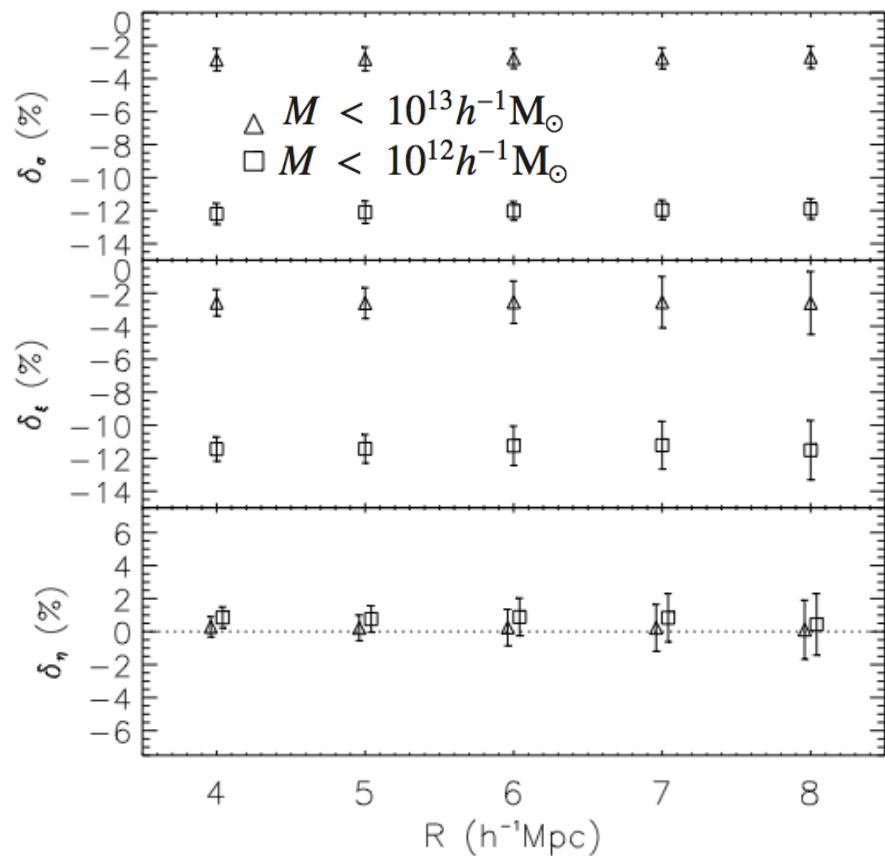
In the large separation limit ($\xi_R(r) \ll \sigma_R^2$) it reduces to:

$$\boxed{\eta_{g,R}^z(r) = \eta_R(r)}$$

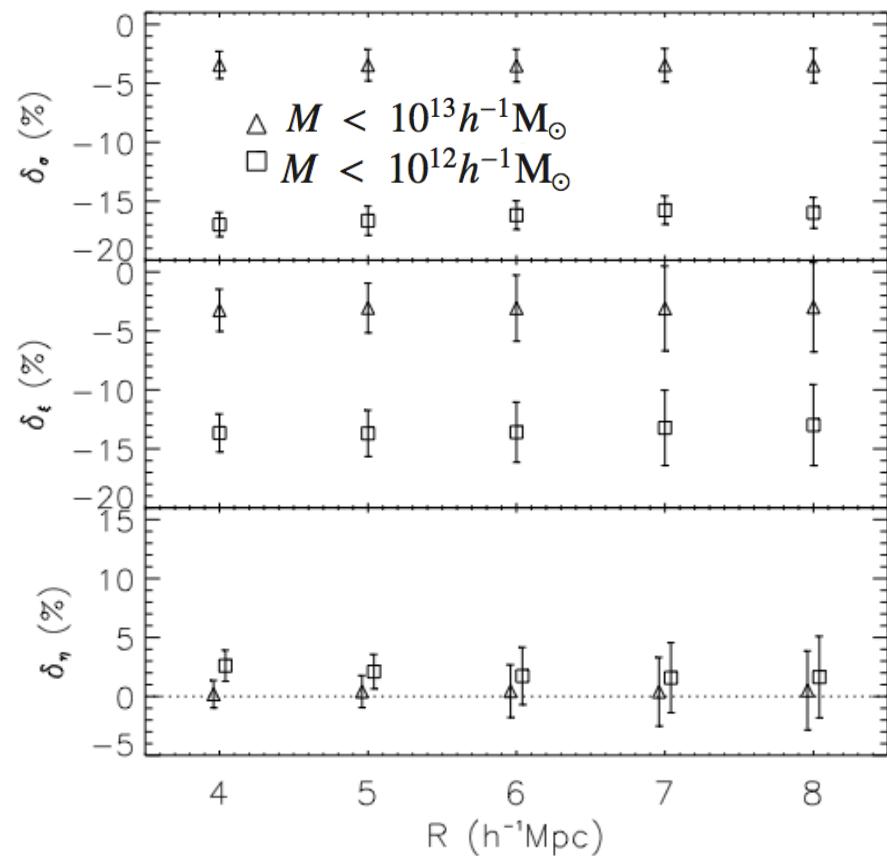
What you see (clustering of galaxies) is what you get (clustering of matter)

The clustering ratio Vs Halo bias

Real space (comoving output):



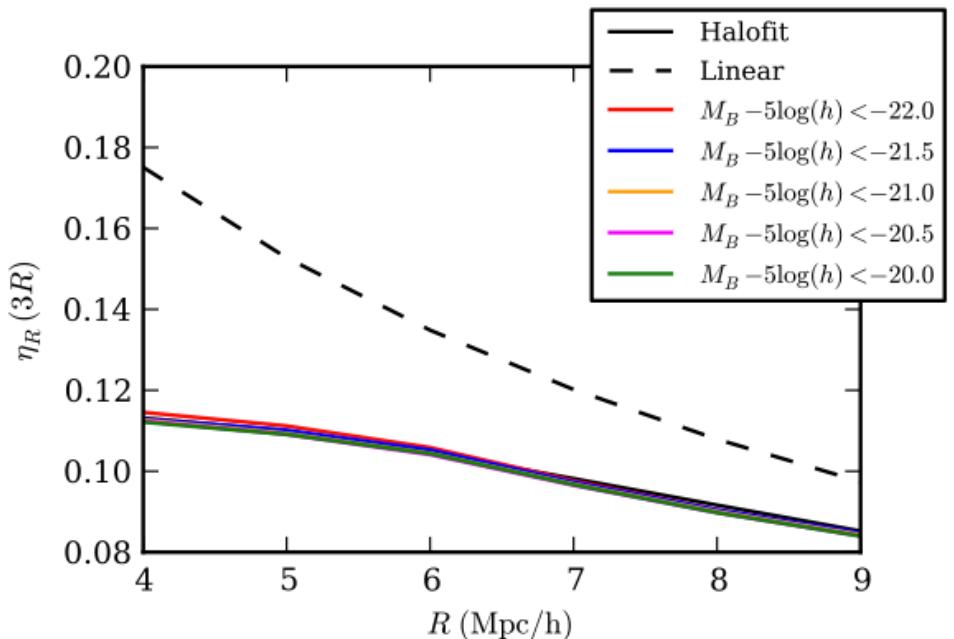
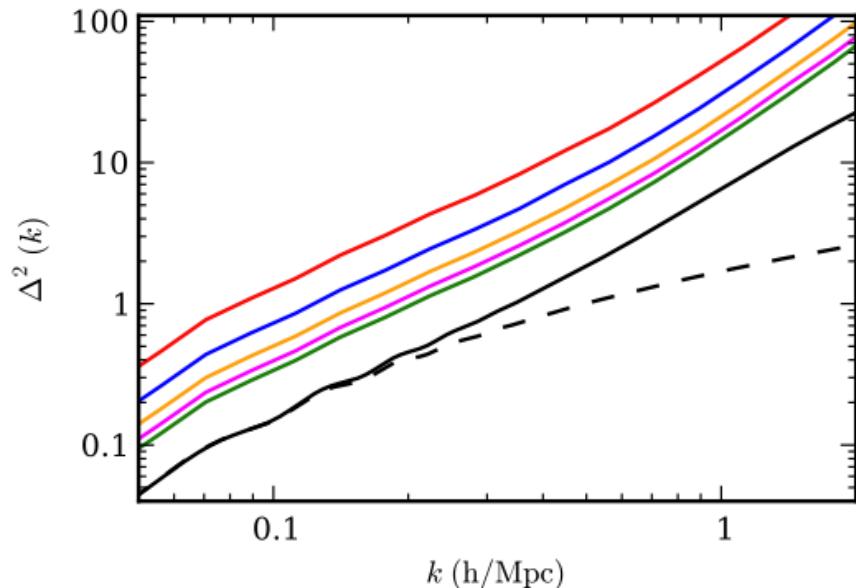
Redshift space (light cone):



$$n = \frac{r}{R} = 3$$

The clustering ratio Vs Galaxy bias

Impact of scale dependent bias:



Analysis performed on HOD galaxy mock catalogues described in
de la Torre, Peacock, Guzzo et al. (2013)

The clustering ratio

The galaxy clustering ratio:

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The matter clustering ratio:

$$\eta_R(r) = \frac{\xi_R(r)}{\sigma_R^2} = \frac{G_R(r)}{F_R}$$

$$\eta_{g,R}^z(r) = \eta_R(r) - \left\{ \left(S_{3,R}^z - C_{12,R}^z \right) c_2 + 1/2 c_2^2 \right\} \xi_R^z(r) + 1/2 c_2^2 \eta_R(r) \xi_R^z(r)$$

In the large separation limit ($\xi_R(r) \ll \sigma_R^2$) it reduces to:

$$\boxed{\eta_{g,R}^z(r) = \eta_R(r)}$$

What you see (clustering of galaxies) is what you get (clustering of matter)

Amplitude independent from galaxy bias, redshift distortions, time evolution

The clustering ratio

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Powerful Cosmic Probe

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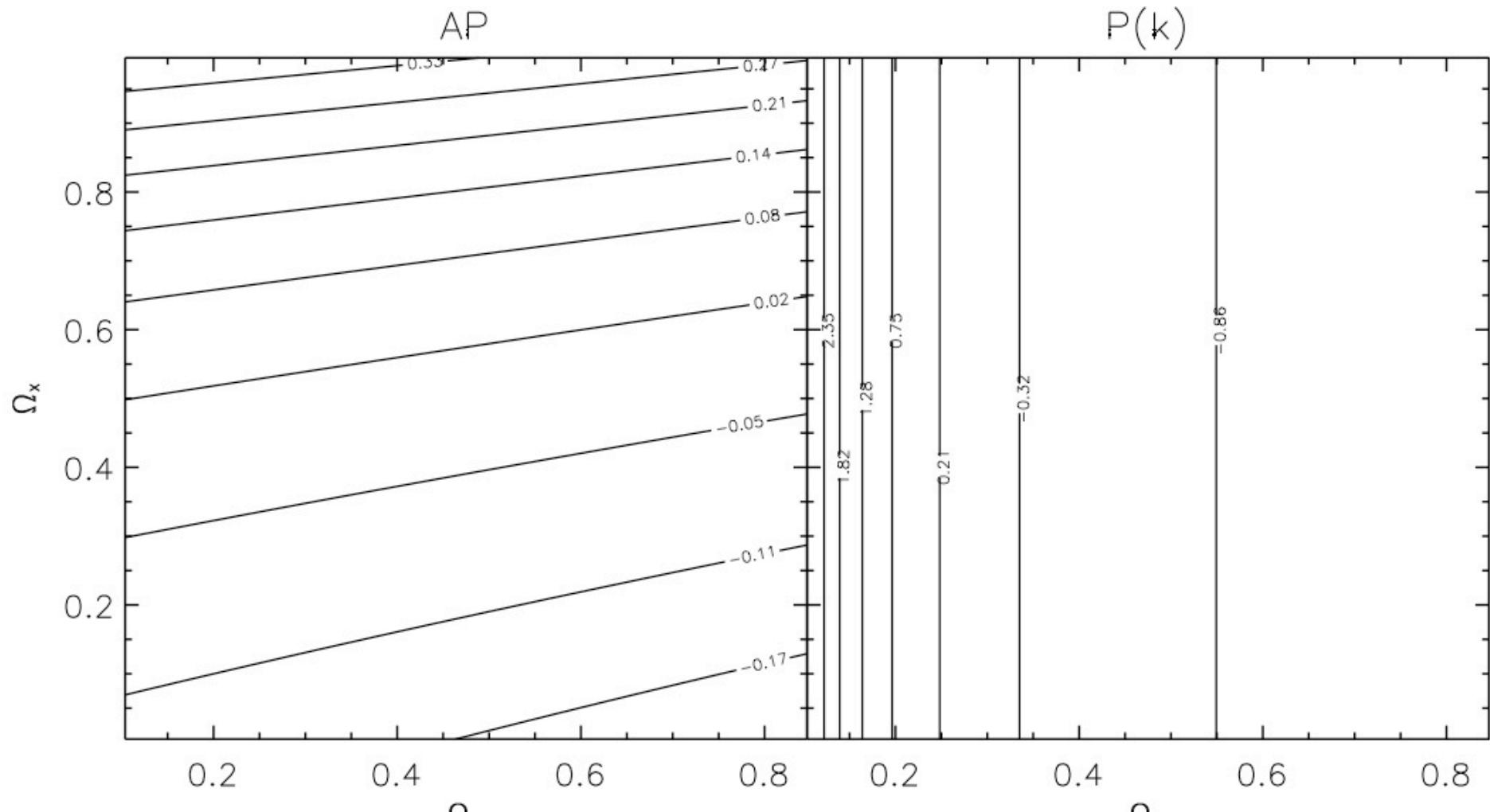
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$$\boxed{\eta_{g,R}^z(r) = \eta_R(r)}$$

Alcock-Paczynski

Power spectrum

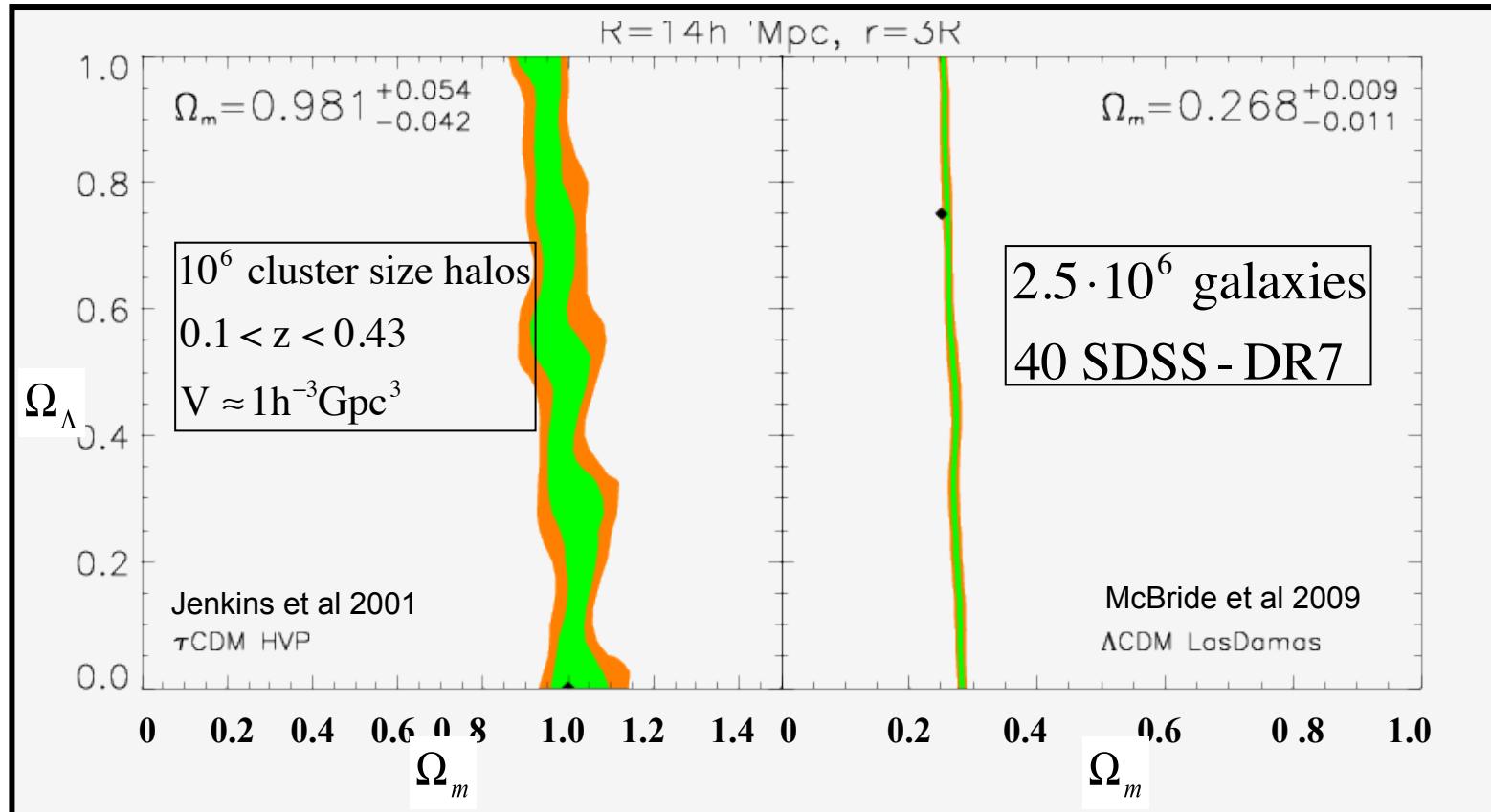
The clustering ratio: dependence on cosmological parameters



$$\eta_{g,R}^z(r, \vec{\Omega}) / \eta_{g,R}^z(r, \vec{\Omega}_{true}) - 1$$

$$\eta_R(r, \vec{\Omega}) / \eta_R(r, \vec{\Omega}_{true}) - 1$$

“Blind test” of N-body simulations: Retrieving the hidden cosmology

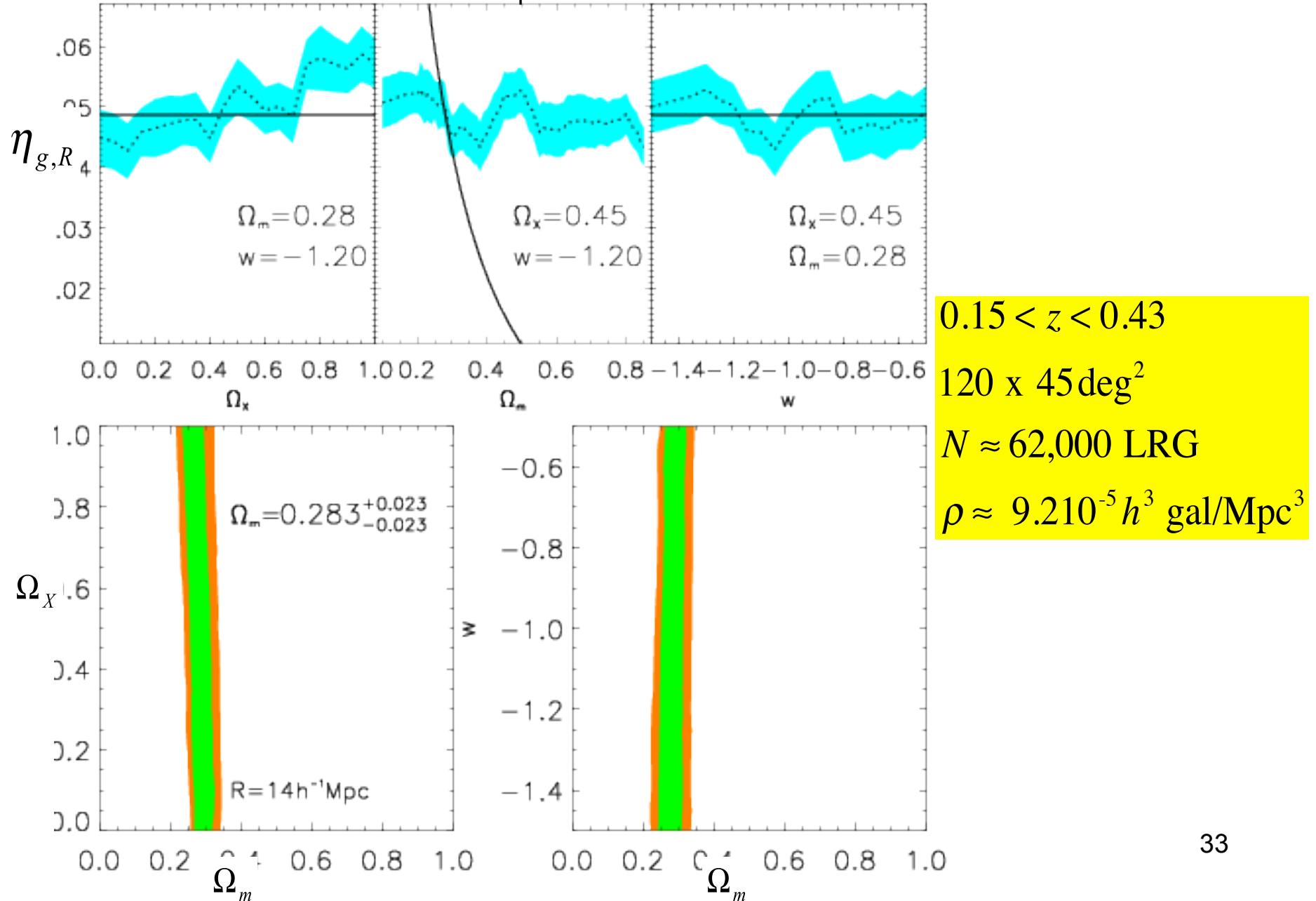


$$\begin{cases} h = 0.21 \\ \Omega_\Lambda = 0 \\ \Omega_m = 1 \\ \Omega_b = 0 \end{cases}$$

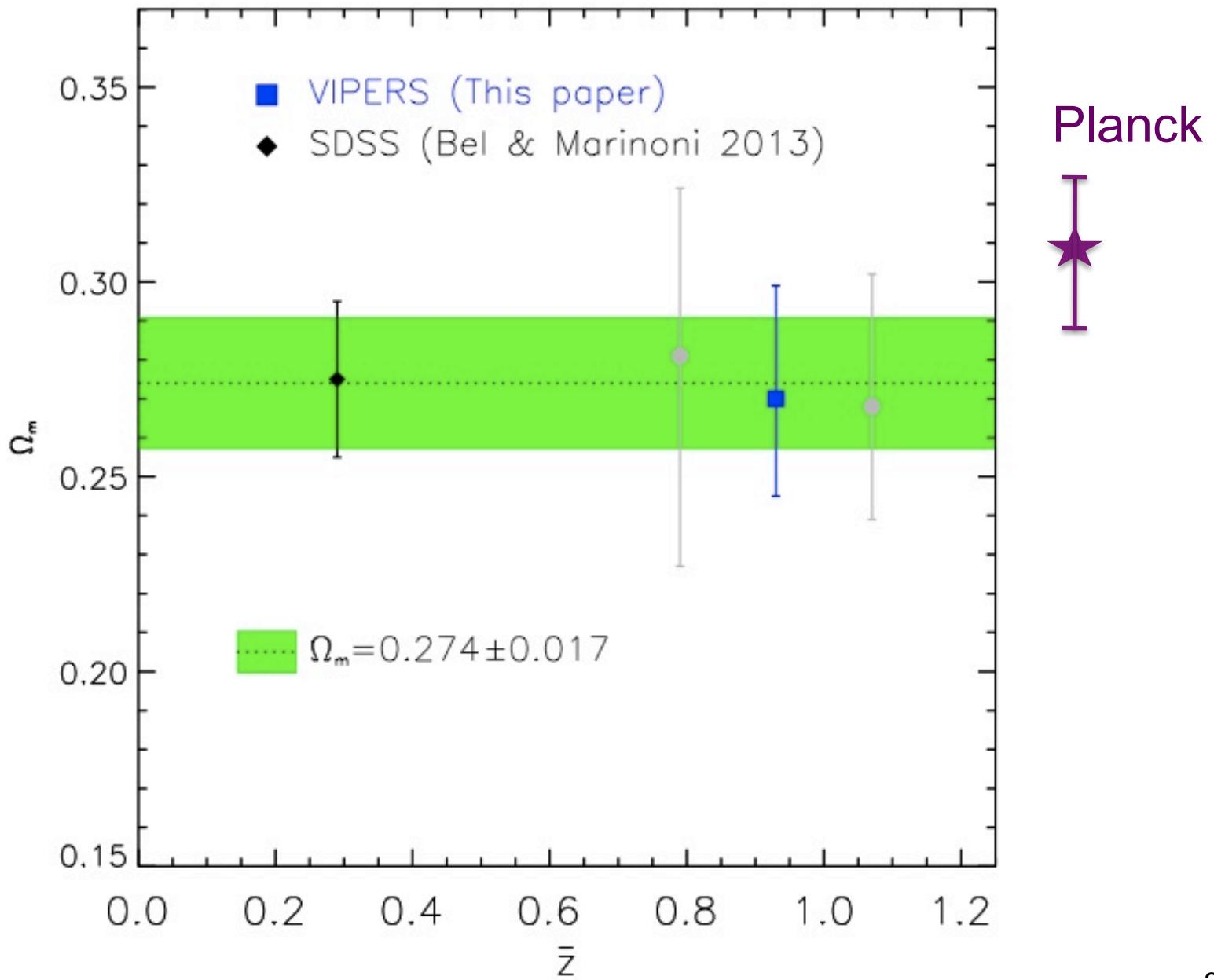
$$\begin{cases} h = 0.70 \\ \Omega_\Lambda = 0.75 \\ \Omega_m = 0.25 \\ \Omega_b = 0.04 \end{cases}$$

Cosmological constraints from the SDSS DR7 Abazajian et al. 2009

J. Bel & CM 2013 A&A in press arXiv:1310.2365



SDSS DR7 + VIPERS PDR1



Conclusions

- A new clustering statistic, **the galaxy clustering ratio**, $\eta_R = \frac{\xi_R}{\sigma_R^2}$

Universal amplitude:

- same whatever is the galaxy type, mass, color, sample
- same for galaxies and matter (on linear scales)
- same at any cosmic epoch
- insensitive to linear redshift distortions

Simple Cosmological probe

- no need of computing covariance matrix (single scale analysis)
- no need to frame the likelihood analysis in any fiducial cosmology
- no nuisance parameter in the likelihood analysis (bias, redshift distortions)

Competitive constraints (6%) on Ω_m from combining VIPERS and SDSS measurements

Future directions

- constraints on the mass of neutrinos
- combine with Planck results
- apply to photo-z data