Theoretical challenges for high-precision measurement of dark energy

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Ref.

Okumura, Jing, Li, 2009

Okumura, Jing 2009

Okumura, Jing, 2010

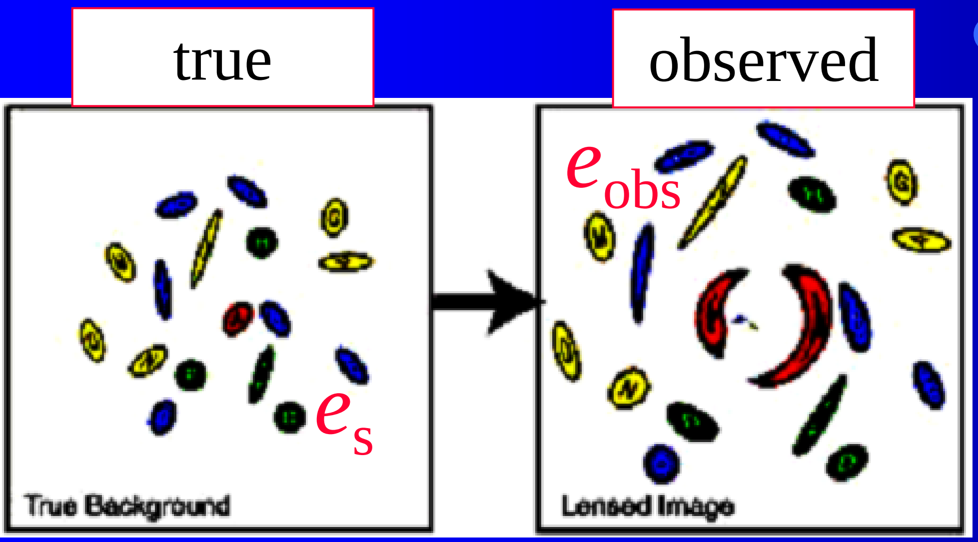
Observational Probes

- Supernovae M(z)
- Baryonic Acoustic Oscillations (BAO)
- Abundance of rich clusters
- Weak Lensing
- Redshift distortion

c.f. Takada, Taruya, Guzzo, Song et al in the meeting

Intrinsic alignment systematics for weak lensing

- Weak gravitational lensing by large-scale structure
  - Directly probe the matter distribution, thus dark matter and dark energy (such as KDUST and LSST)



- Observable
  - Ellipticity of galaxies e_{obs}
  - $e_{obs} = \gamma + e_s$

Tidal field, …

$$\langle e_{obs} e_{obs} \rangle = \langle \gamma\gamma \rangle + \langle e_s e_s \rangle + \langle \gamma e_s \rangle + \langle e_s \gamma \rangle$$

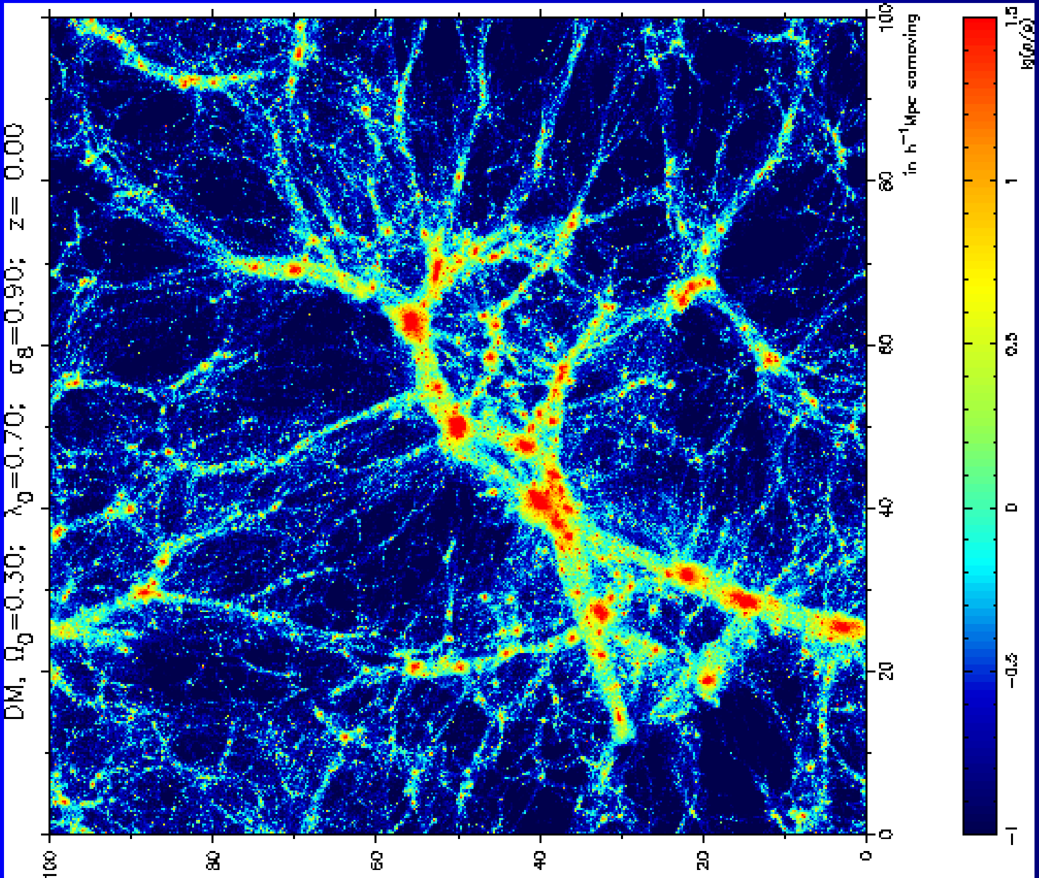
shear

II

Shear+I (GI term)

Intrinsic ellipticity – ellipticity (II) correlation

- It is known for dark matter halos;



Measuring the II correlation

- Definitions
  - Ellipticity of galaxies

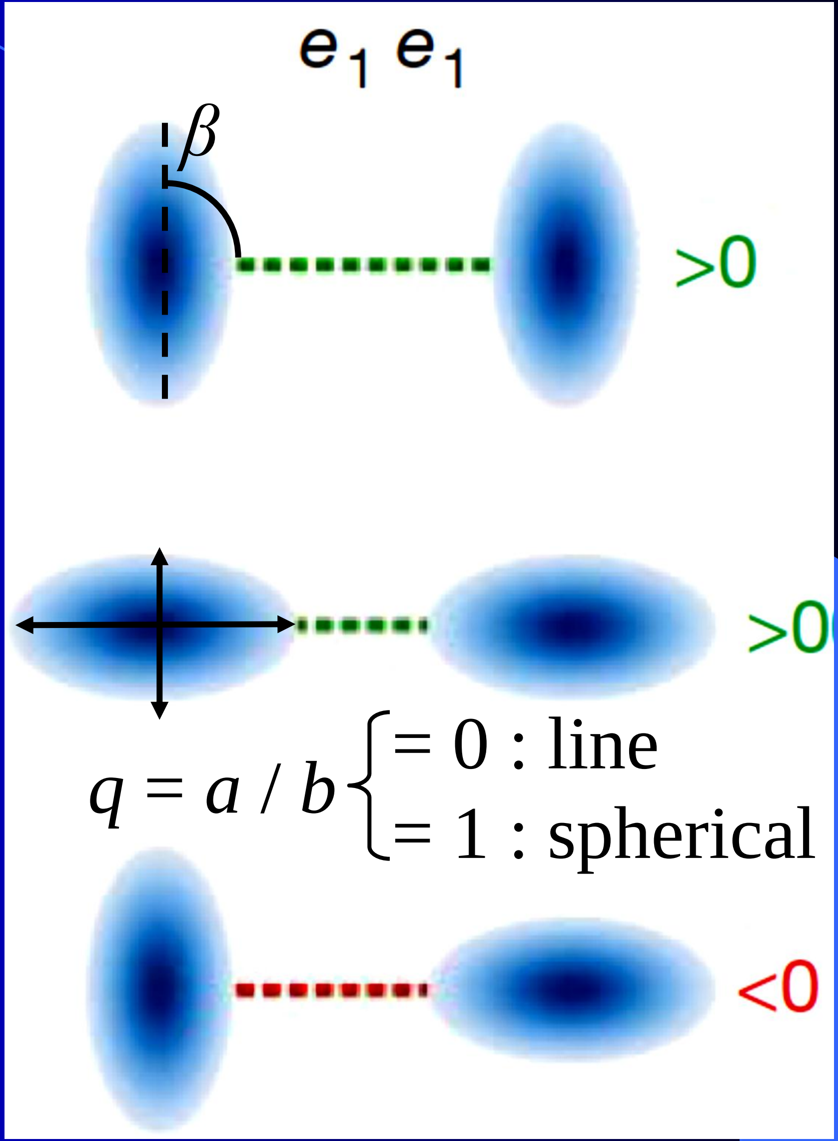
$$\begin{pmatrix} e_1 \\ e_2 \end{pmatrix} = \frac{1-q^2}{1+q^2} \begin{pmatrix} \cos 2\beta \\ \sin 2\beta \end{pmatrix}$$

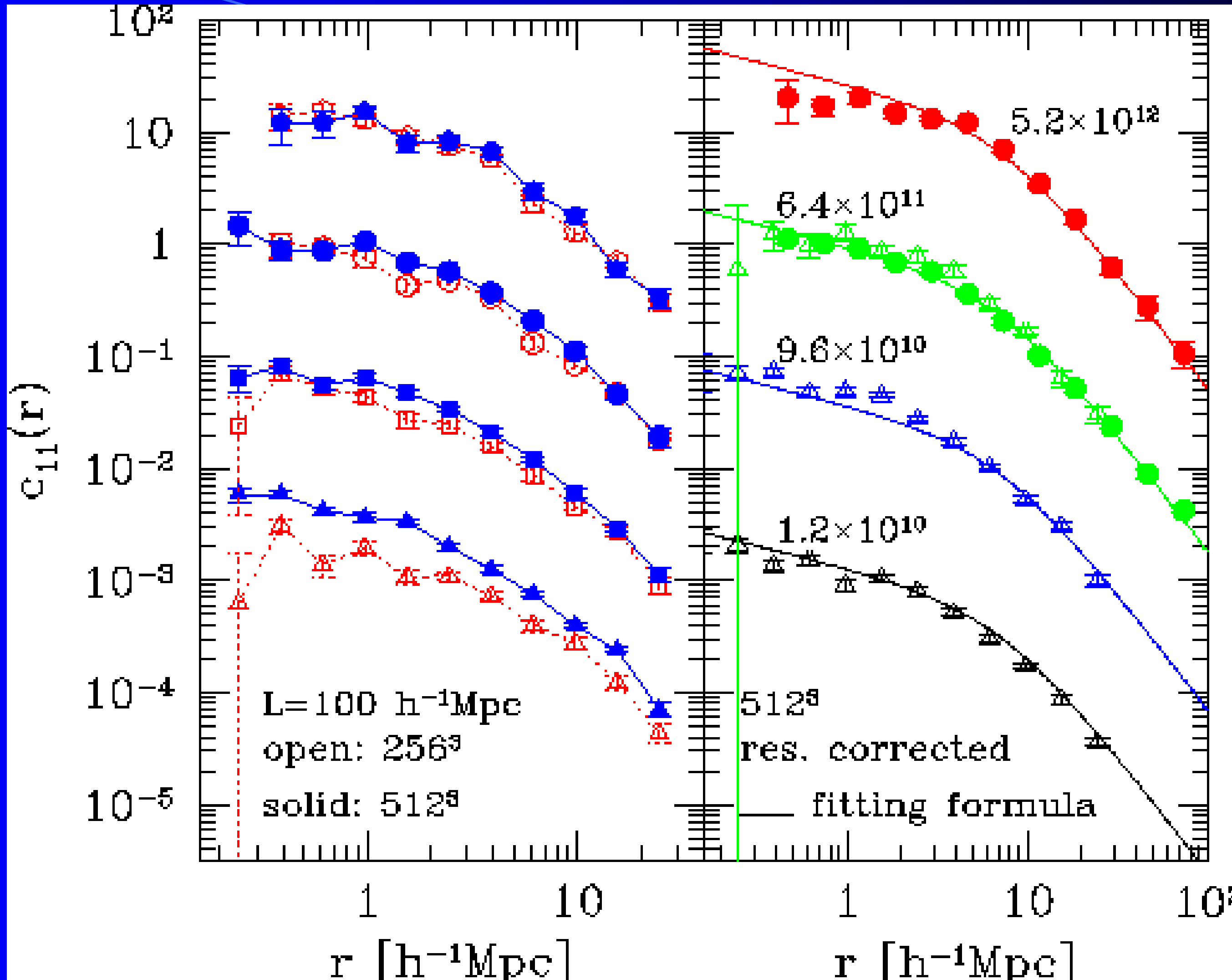
axis ratio | orientation

  - II correlation function

$$c_{11}(r) = \langle e_1(\mathbf{x}) e_1(\mathbf{x}+\mathbf{r}) \rangle$$

  - c_{22} is calculated in the same way and cross-correlations, c_{12} and c_{21}, should vanish on all scales.





The ellipticity correlat

$$c_{11}(r; \geqslant M_h) = \frac{3.6\times10^{-2}\left(\frac{M_h}{10^{10}\,h^{-1}\,\mathrm{M}_\odot}\right)^{0.5}}{r^{0.4}(7.5^{1.7}+r^{1.7})},$$

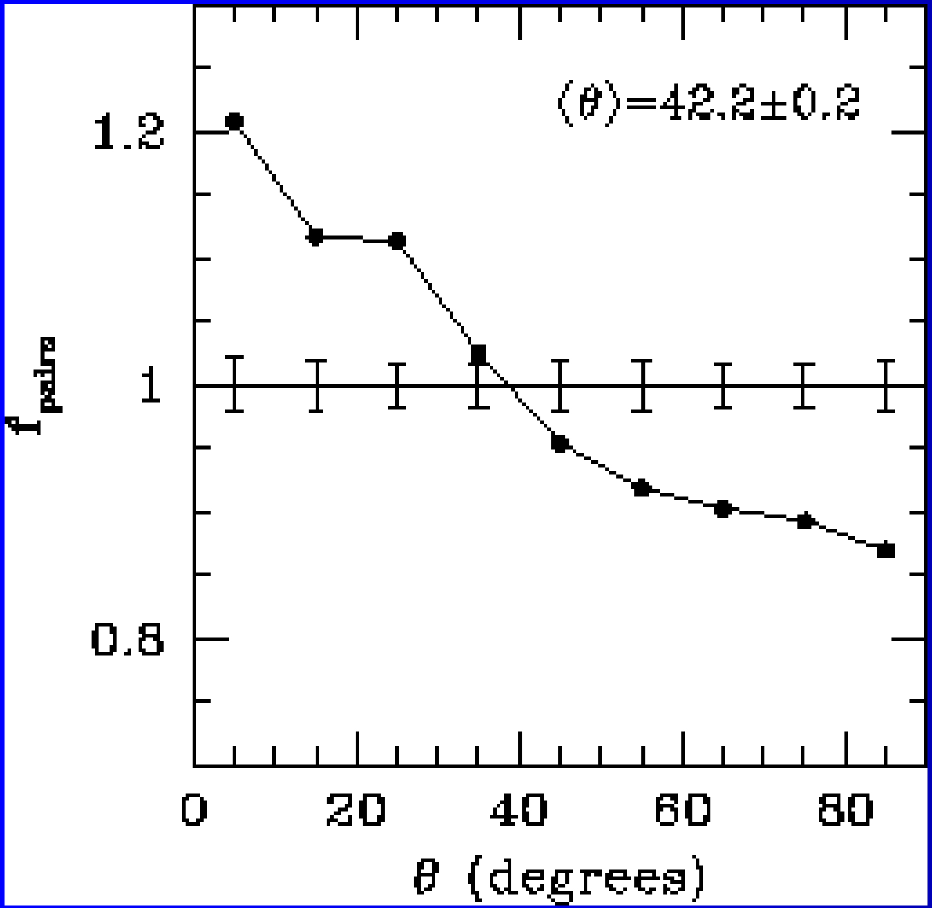
Jing, 2002, MNRAS

Intrinsic ellipticity – ellipticity (II) correlation

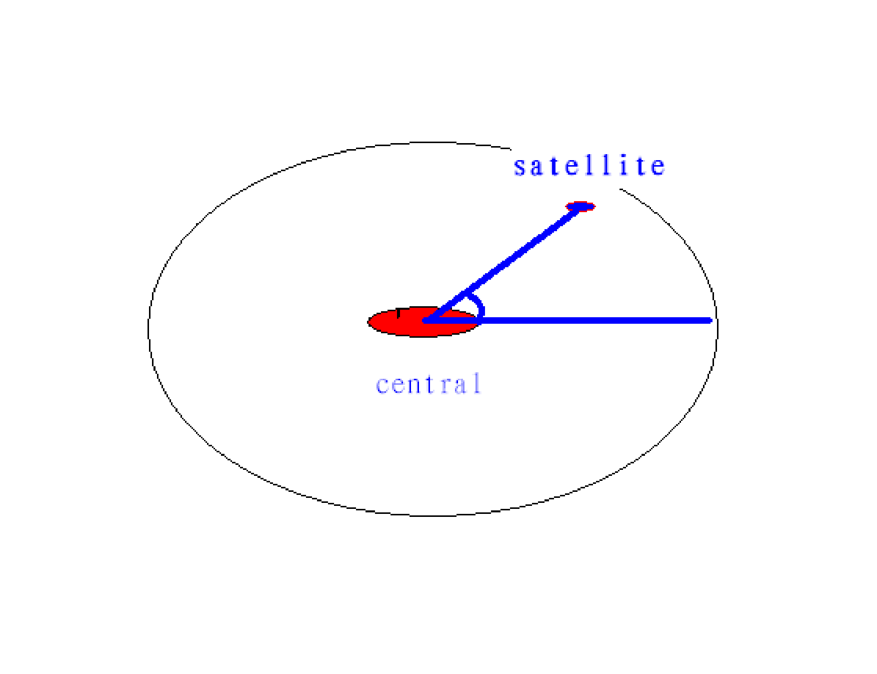
- It is known for dark matter halos;
- It is expected for galaxies, since galaxies, at least elliptical (red) ones, are aligned with host halo to a certain degree;

Alignment for the SDSS sample

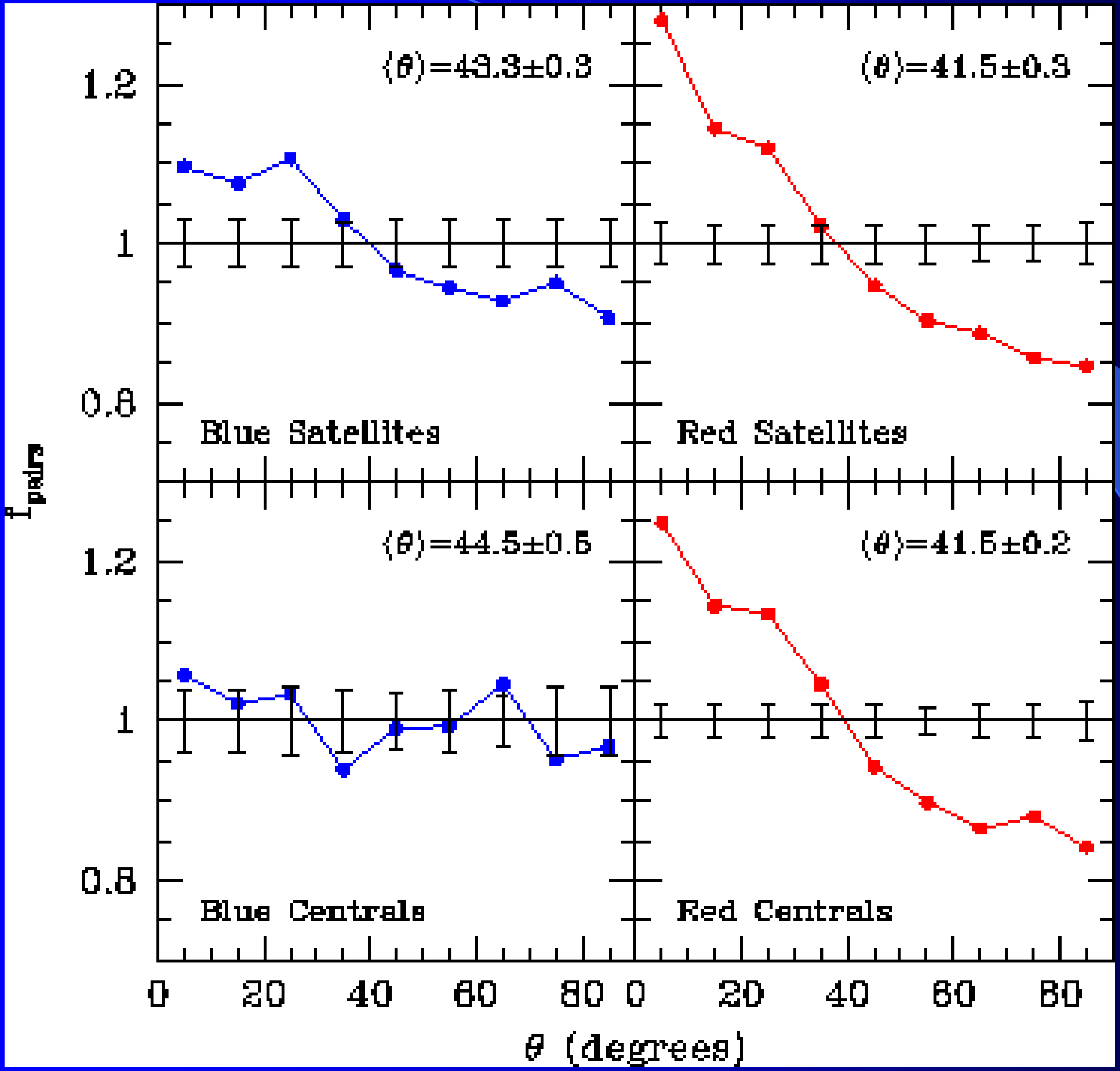
Yang, et al. 2006



- f= N(θ) /N_ran(θ)
- 24,728 pairs

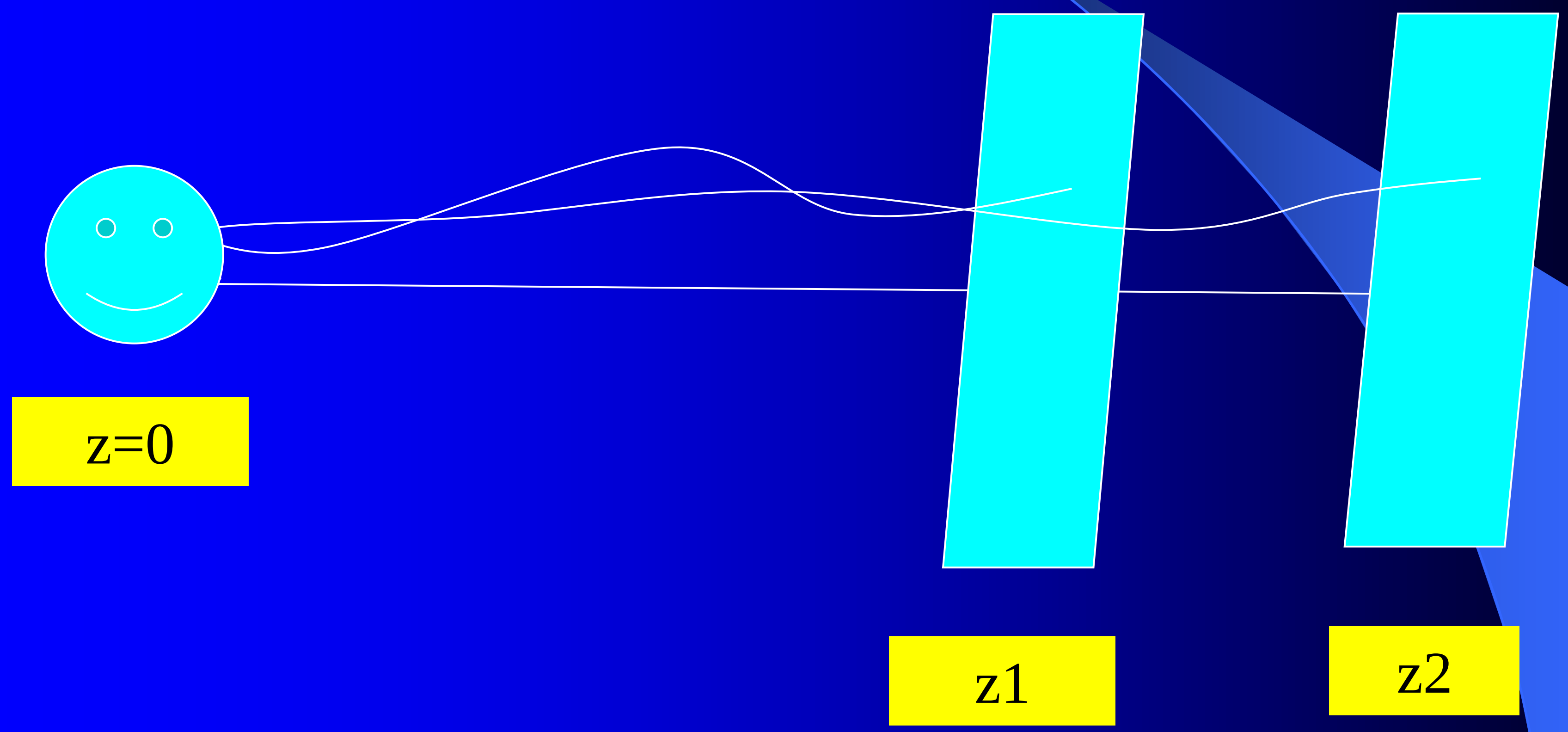


Dependences on the color



Intrinsic ellipticity – ellipticity (II) correlation

- It is known for dark matter halos;
- It is expected for galaxies, since galaxies, at least elliptical (red) ones, are aligned with host halo to a certain degree;
- Believed that the contamination can be EASILY corrected in weak lensing observations, if galaxies at well separated distance (redshift) are cross-correlated to get the shear correlation. But needs very good photo z !



z=0
z1
z2

Intrinsic ellipticity – ellipticity (II) correlation

- It is known for dark matter halos;
- It is expected for galaxies, since galaxies, at least elliptical (red) ones, are aligned with host halo to a certain degree;
- Believed that the contamination can be EASILY corrected in weak lensing observations, if galaxies at well separated distance (redshift) are cross-correlated to get the shear correlation.
- We want to understand it observationally and theoretically

Another contamination; Gravitational shear – intrinsic ellipticity correlation

- Observables
  - Ellipticity of galaxies

$$e_{obs} = \gamma + e_s$$

$$\langle e_{obs} e_{obs} \rangle = \langle \gamma\gamma \rangle + \langle e_s e_s \rangle$$

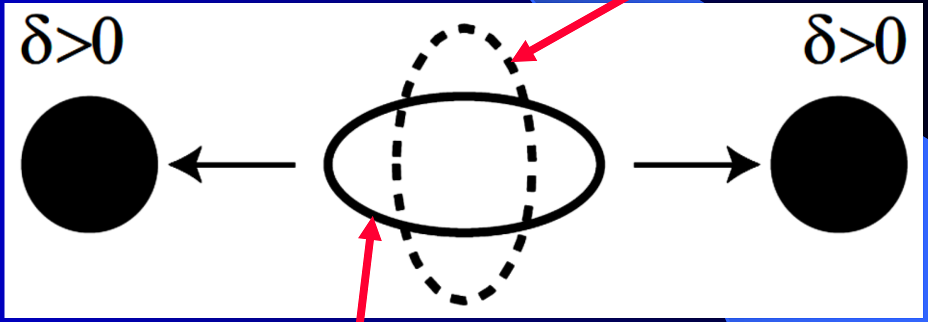
shear II

$$+ \langle \gamma e_s \rangle + \langle e_s \gamma \rangle$$

GI terms

Hirata & Seljak (2004),

Distant source (G)



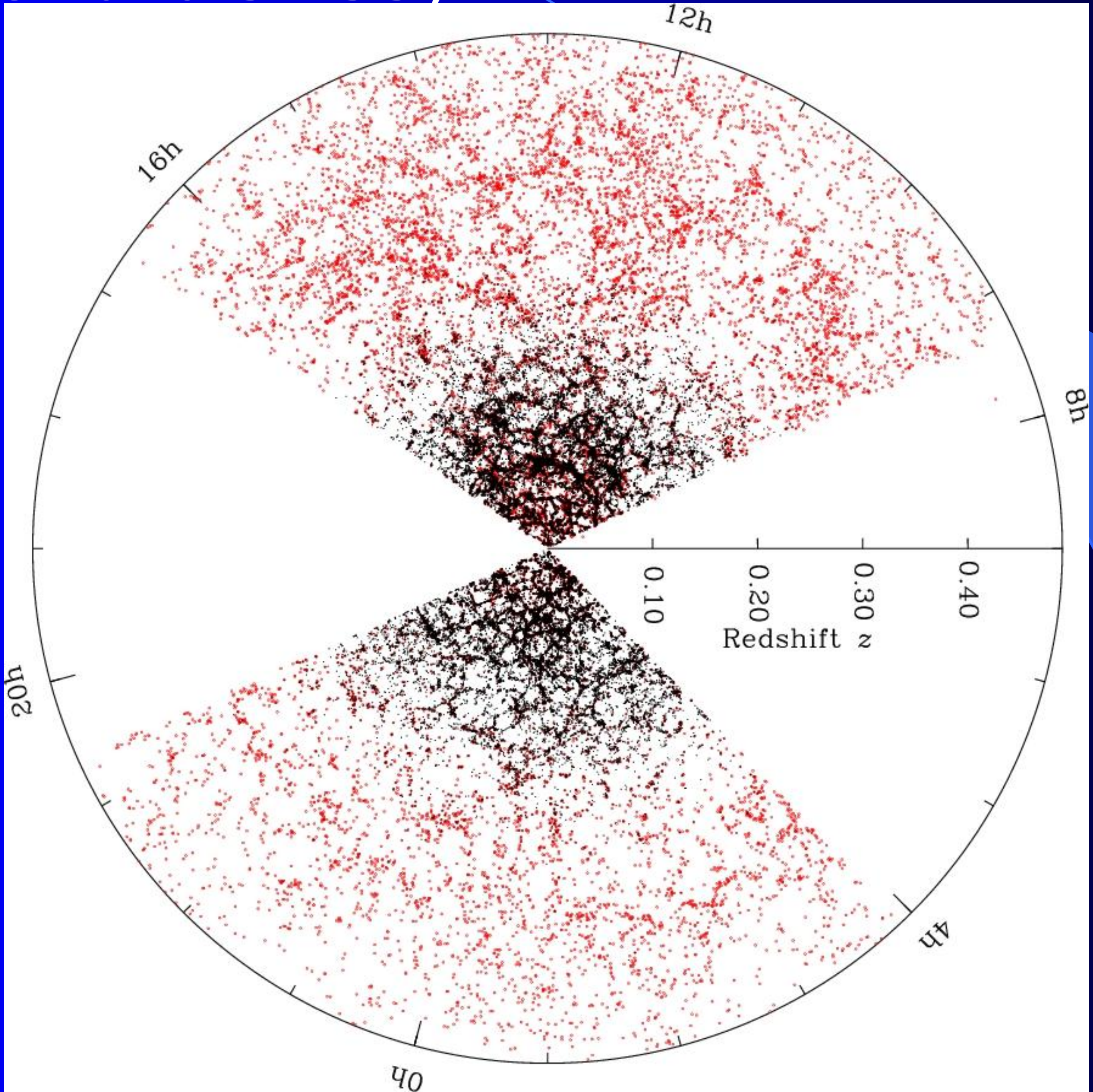
Nearby source (I)

- Unlike II correlation, GI correlation can exist between galaxies at very different redshifts. (see Joachimi &Schneider 2008; P.J. Zhang, 2008 for methods to eliminate it observationally)

SDSS luminous red galaxies (LRG)

- Properties of LRGs
  - Giant ellipticals (not contaminated by spirals)
  - Almost all the LRGs are central galaxies (~ 95%), and we keep central galaxies only
  - LRGs preferentially reside in massive halos which have stronger ellipticity correlation (Jing2002).
- We use 83,773 LRGs at $0.16 < z < 0.47$ and $-23.2 < M_g < -21.2$ from the SDSS DR6 sample.

Distribution of luminous red galaxies (Blanton and SDSS)



Measuring the II correlation

- Definitions
  - Ellipticity of galaxies

$$\begin{pmatrix} e_1 \\ e_2 \end{pmatrix} = \frac{1-q^2}{1+q^2} \begin{pmatrix} \cos 2\beta \\ \sin 2\beta \end{pmatrix}$$

axis ratio | orientation

  - II correlation function

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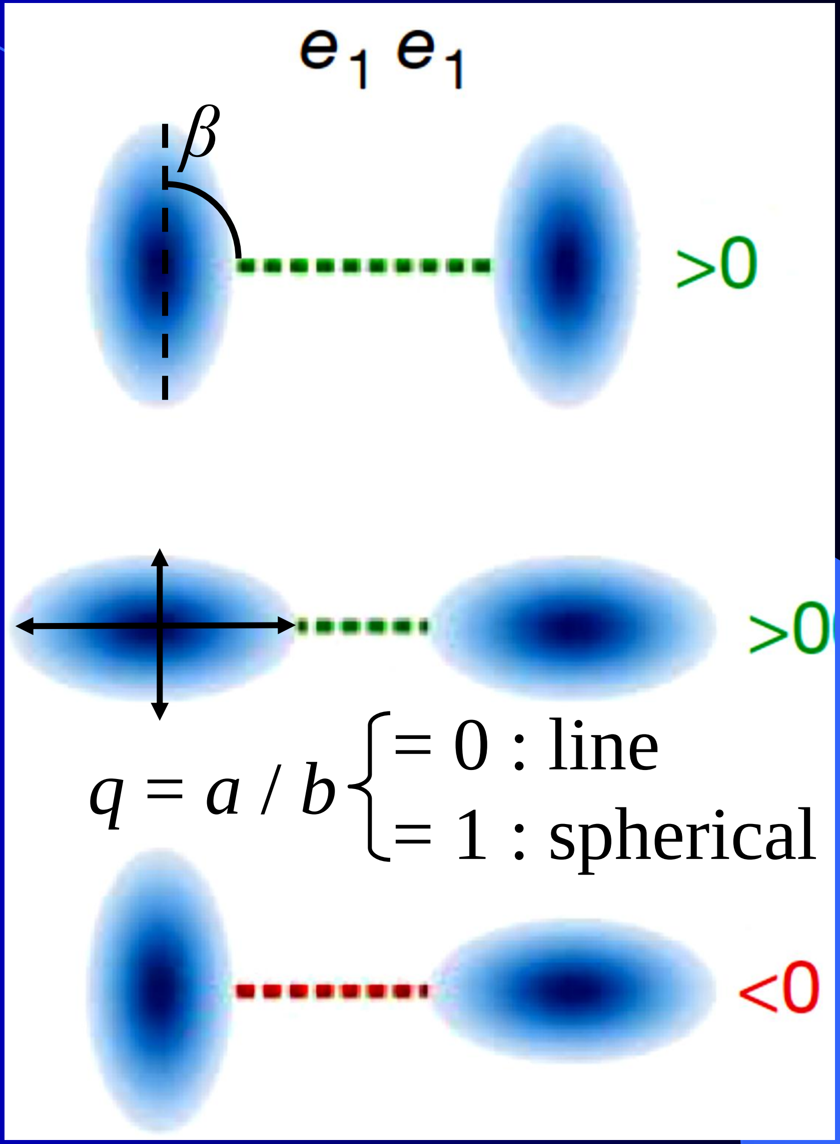
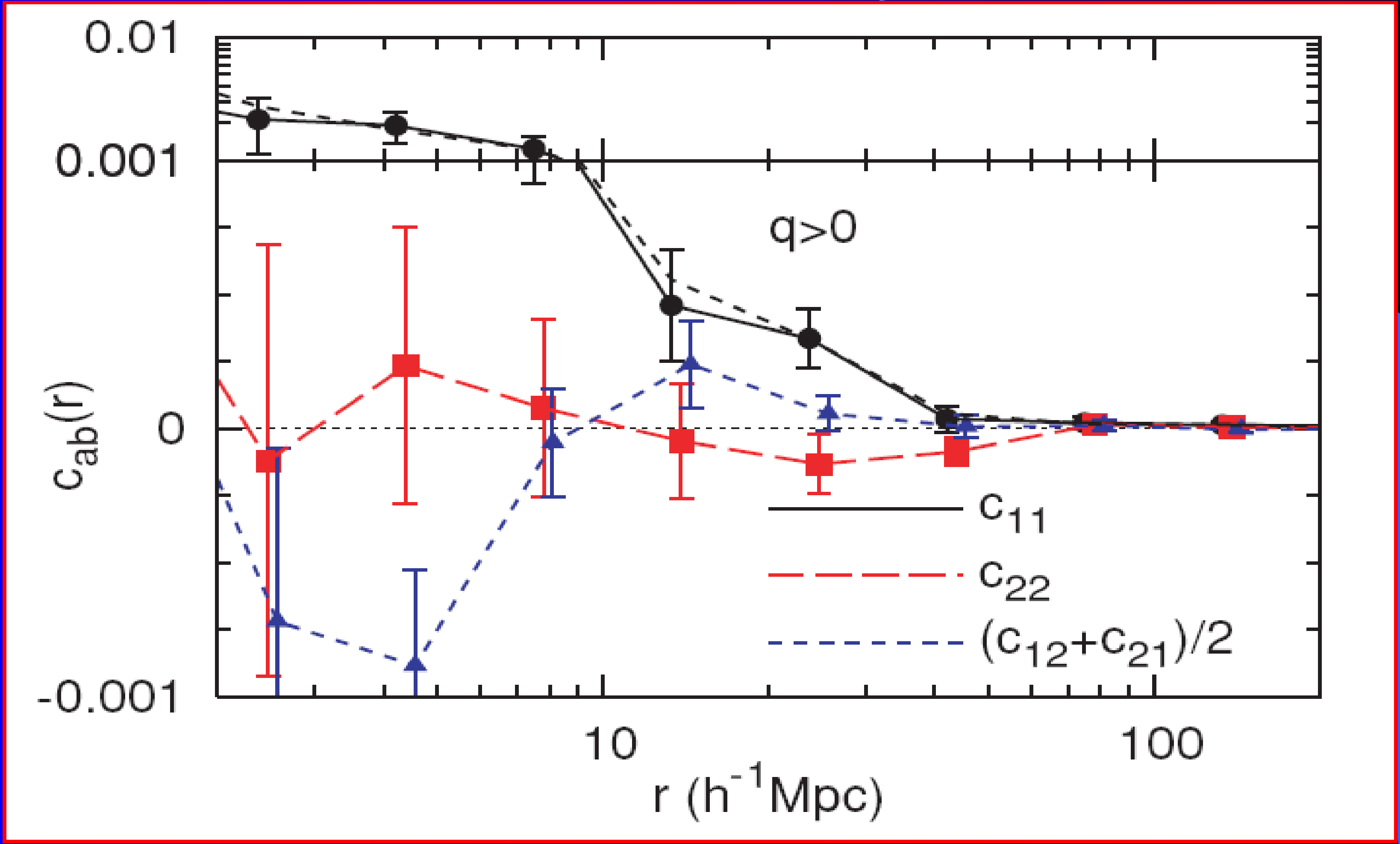
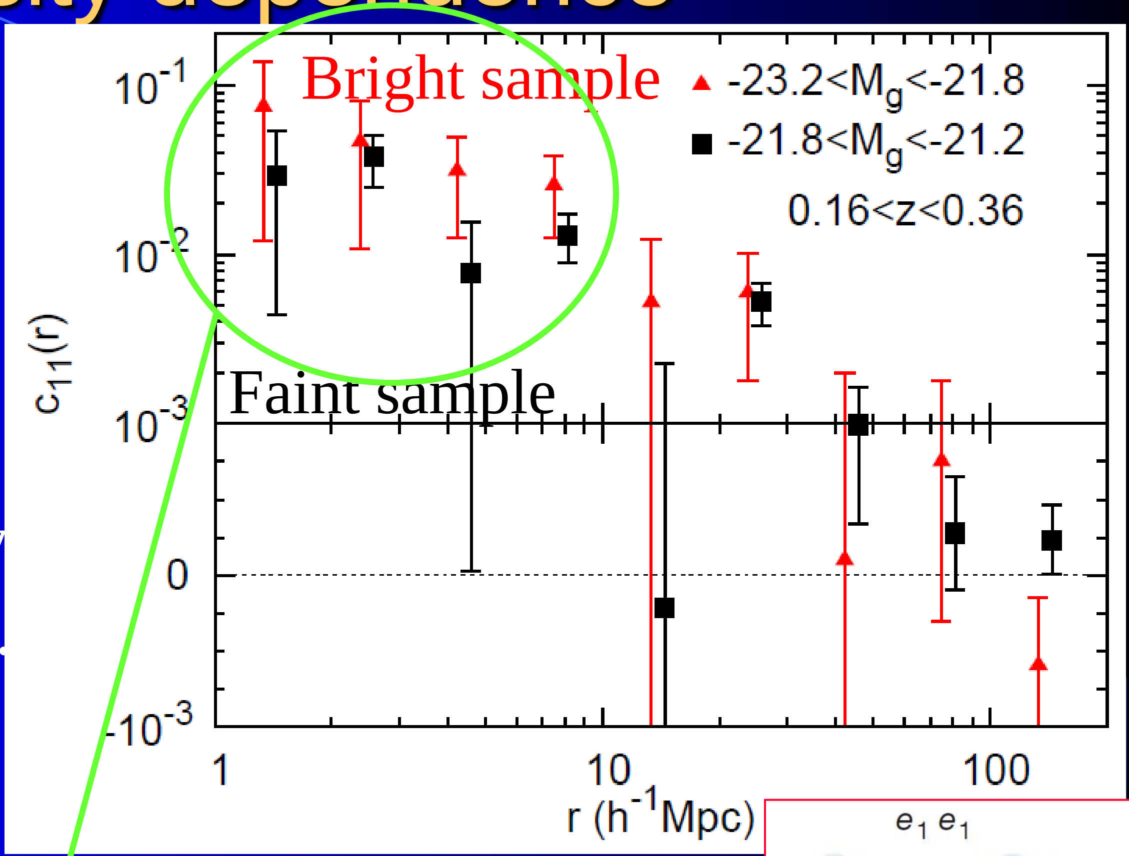


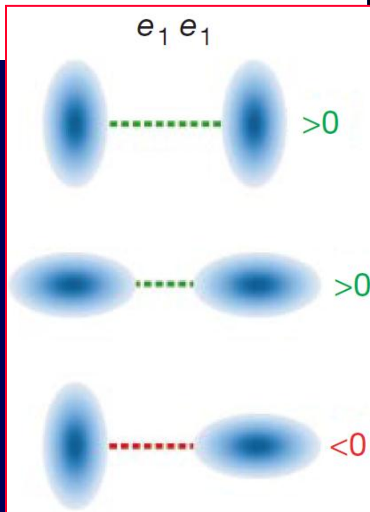
The II correlation function of LRGs in SDSS observation



Luminosity dependence

- Brighter LRGs tend to reside in more massive halos
- More massive halos have stronger ellipticity correlations (Jing2002).





- Stronger correlations can be seen in the brighter sample although the error bars are large.

Modeling the II correlation in theory—Lambda CDM model

- Mock halo catalog from *N*-body simulation (Jing et al. 2007); ellipticity is computed for halos by tracing all the particles in the halo.
- Then select halos that host the LRGs

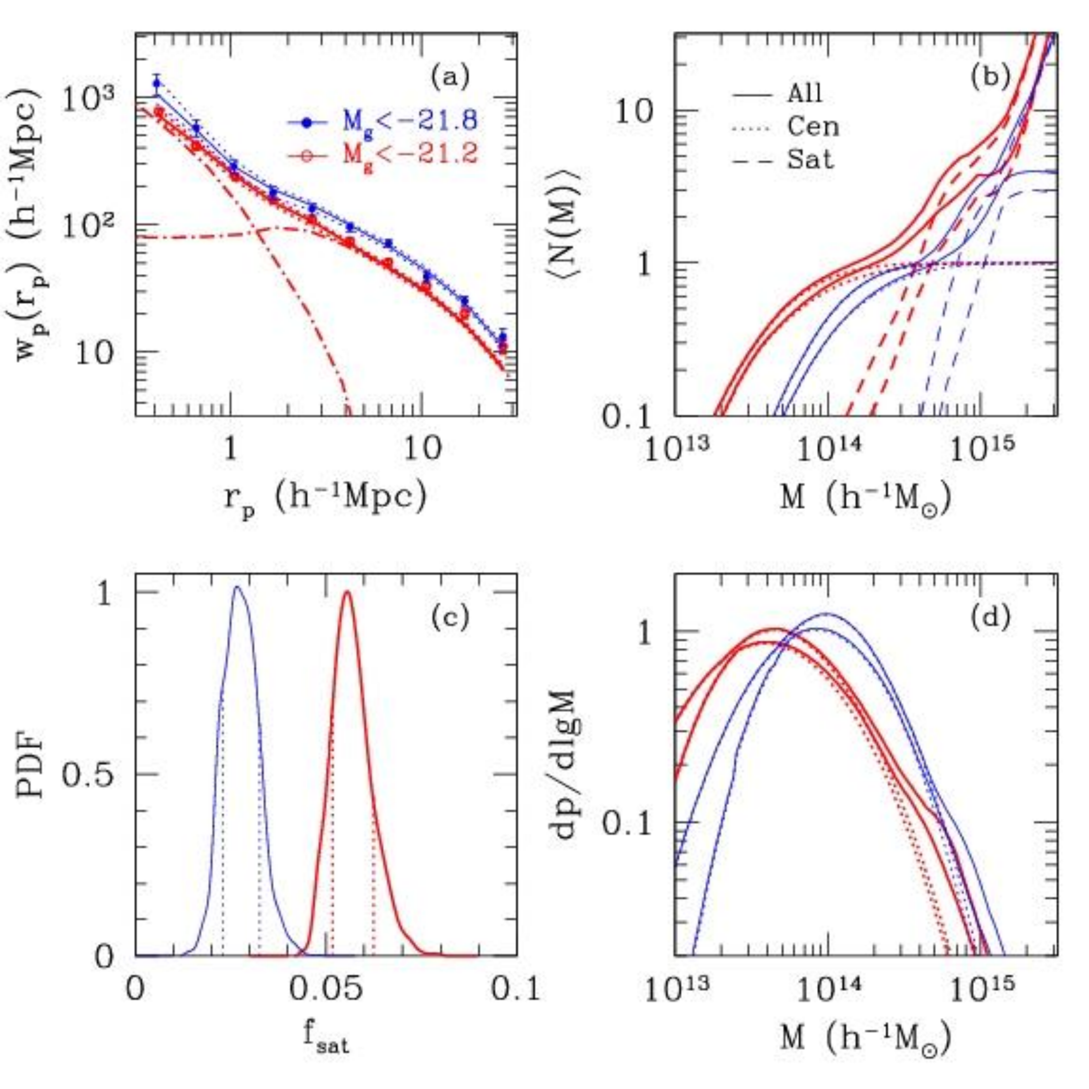
Galaxies assigned

Halo occupation distribution for LRGs (Seo+2008, Zheng+2009)

$$N(M)=N_{\rm cen}(M)+N_{\rm sat}(M)$$

- Mock LRG catalog
  - Then modeled ellipticity correlation functions can calculated.

Jing & Suto (2000)



（a）Projected CF of LRGs

（b）The average number of LRGs in a halo of mass M

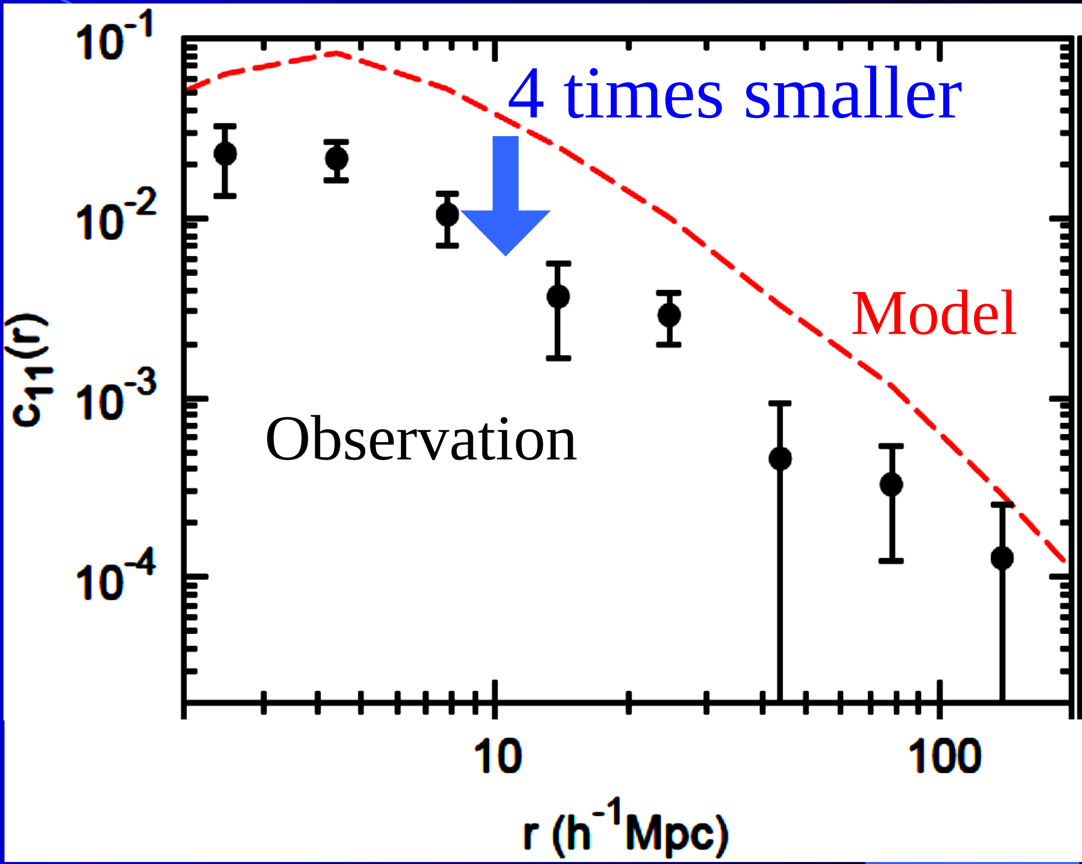
（c）fraction of satellites in halos

Projected two-point auto-correlation functions and best-fit HODs for the two luminosity-threshold LRG samples.

Zheng Zheng , et al., ApJ, 2009

Comparison of observation with model

- First we assume that all central LRGs are completely aligned with their host halos.
- The shape of the CF is good;
- but there are significant discrepancies in the amplitude between observation and model.

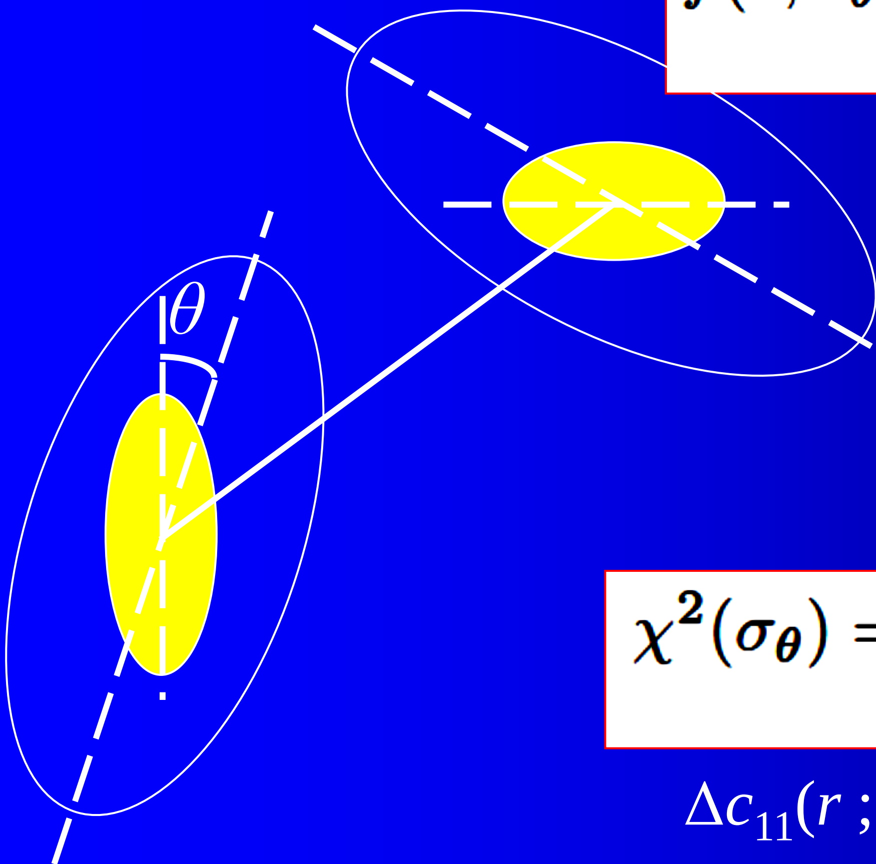


- We will model the II correlation by considering the misalignment of central LRGs with their host halos.

Misalignment between central LRGs and their host halos

- Misalignment angle parameter σ_θ
  - Assumption that the PDF of the misalignment angle θ follows Gaussian,

$$f(\theta;\sigma_\theta)d\theta = \frac{1}{\sqrt{2\pi}\sigma_\theta}\exp\left[-\frac{1}{2}\left(\frac{\theta}{\sigma_\theta}\right)^2\right]d\theta$$

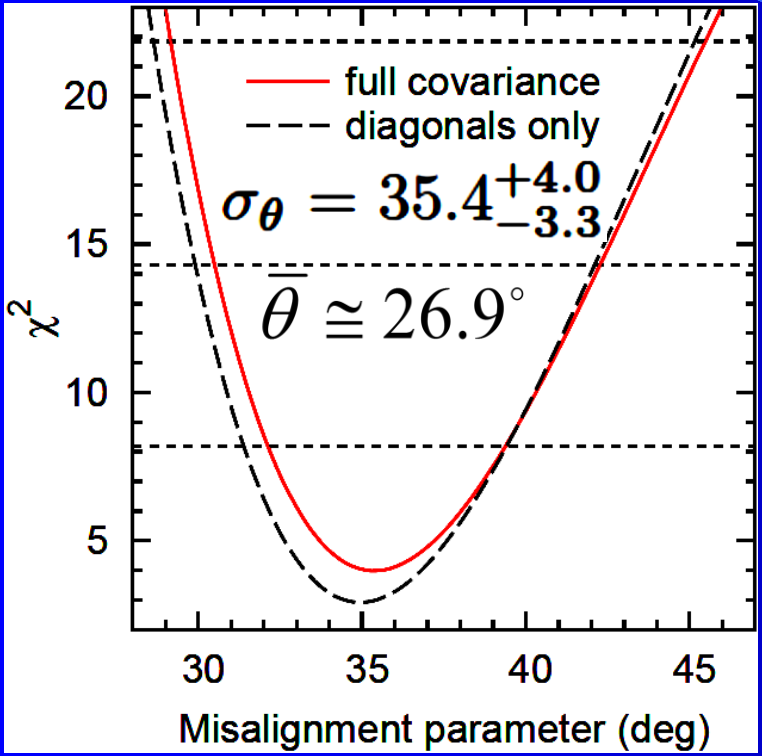


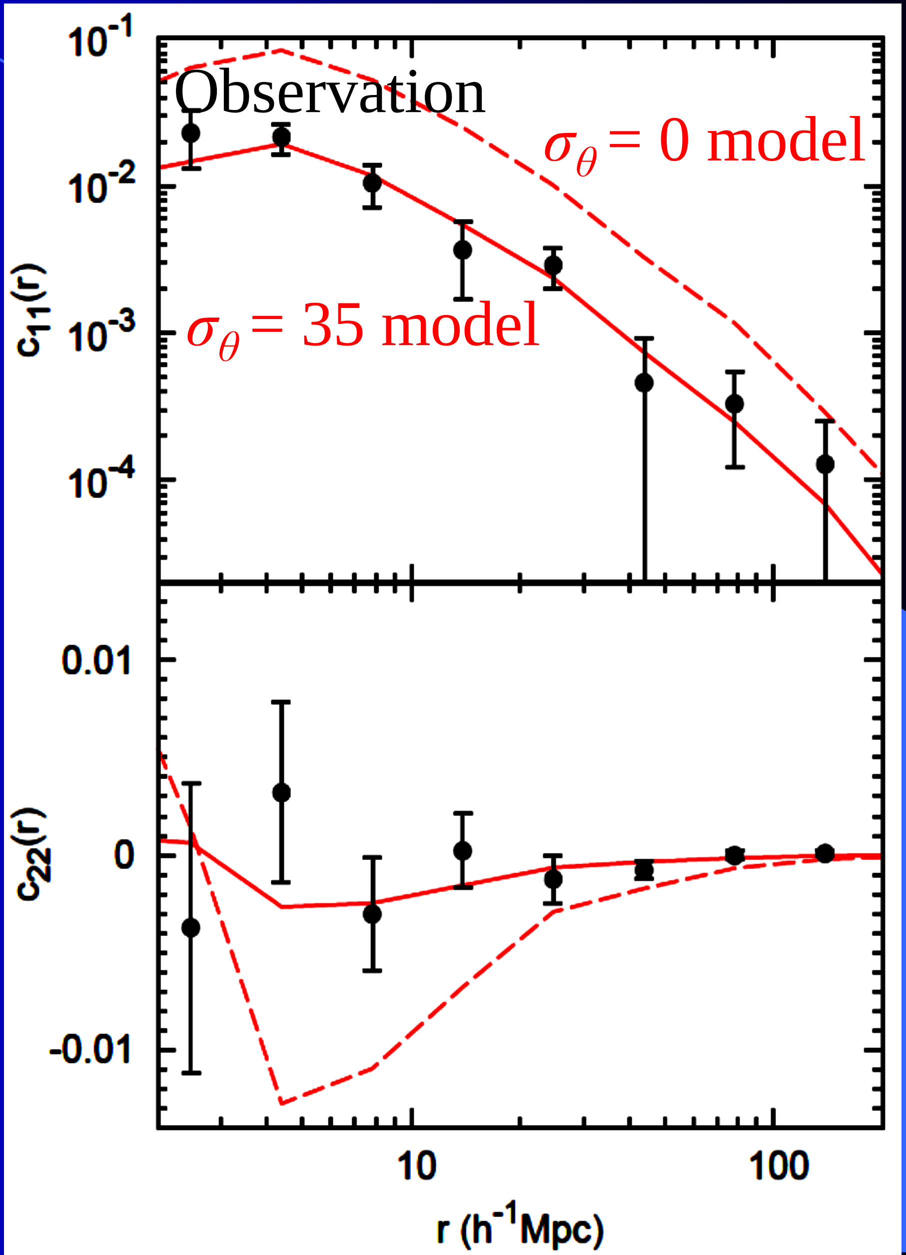
Calculation of model $c_{11}(r;\sigma_\theta)$ for LRGs

$$\chi^2(\sigma_\theta) = \sum_{i,j}\Delta c_{11}(r_i;\sigma_\theta)C_{ij}^{-1}\Delta c_{11}(r_j;\sigma_\theta)$$

$$\Delta c_{11}(r;\sigma_\theta) = c_{11}^{\mathrm{model}}(r;\sigma_\theta) - c_{11}^{\mathrm{obs}}(r)$$

Constraints on misalignment





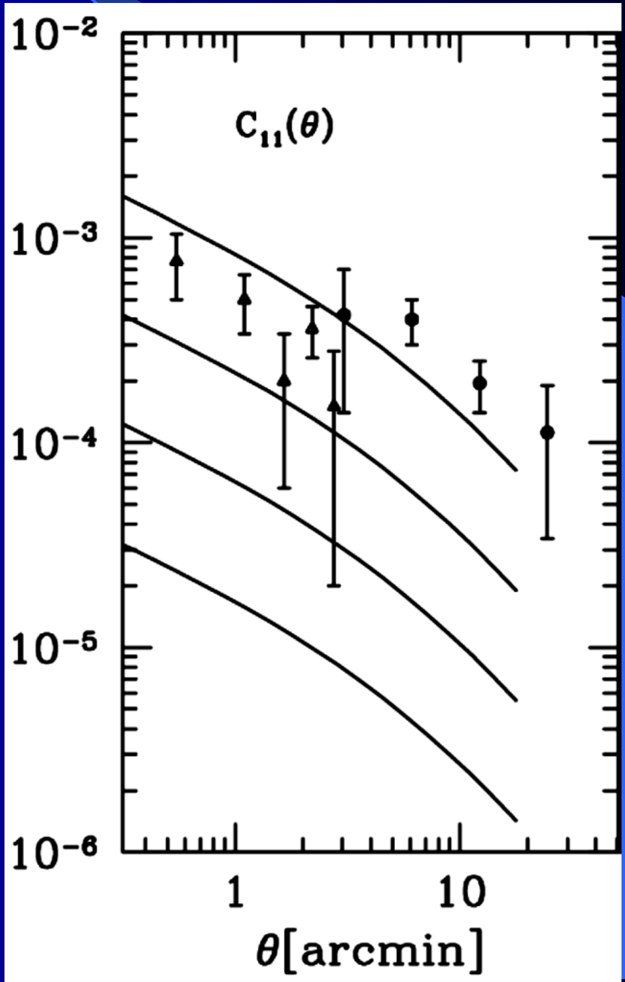
- A model in which the central galaxies and their host halos are completely aligned is strongly rejected by our analysis.

Implications for weak lensing surveys

- An example
  - CFHTLS weak lensing survey (z_s ~ 1 and R_{AB}=24.5). (Fu+)
  - Central galaxies in the DEEP2 are in dark halos ~ $4 \times 10^{11} h^{-1}$ M_{sun} (Zheng+)

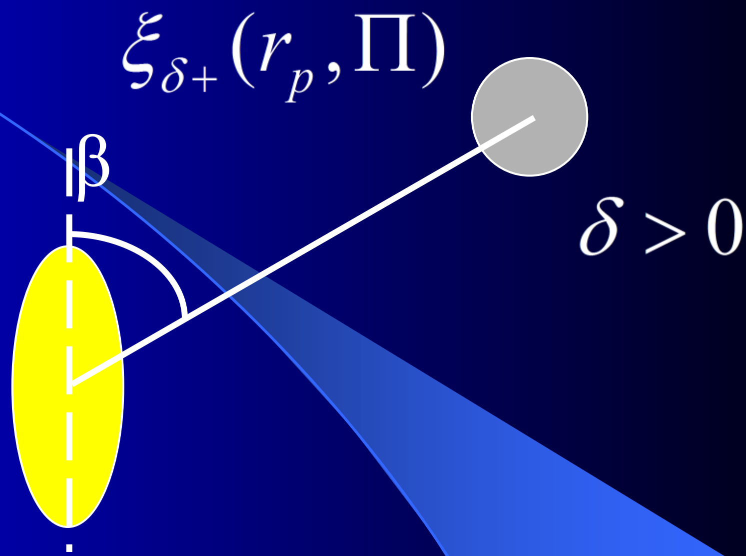
- If these central galaxies have the same misalignment distribution as the SDSS LRGs, the II correlation can contribute by 5 – 10% to the shear correlation.

Dependence of II correlation on halo mass (Jing 2002)



Measuring the GI correlations

- Definitions
  - Ellipticity of galaxies
    - $$e_+ = \frac{1-q^2}{1+q^2}\cos 2\beta$$



  - Projected GI correlation function

$$w_{\delta+}(r_p) = \int \xi_{\delta+}(r_p, \Pi)\, d\Pi$$

→ Directly related to the GI term of the shear power spectrum.

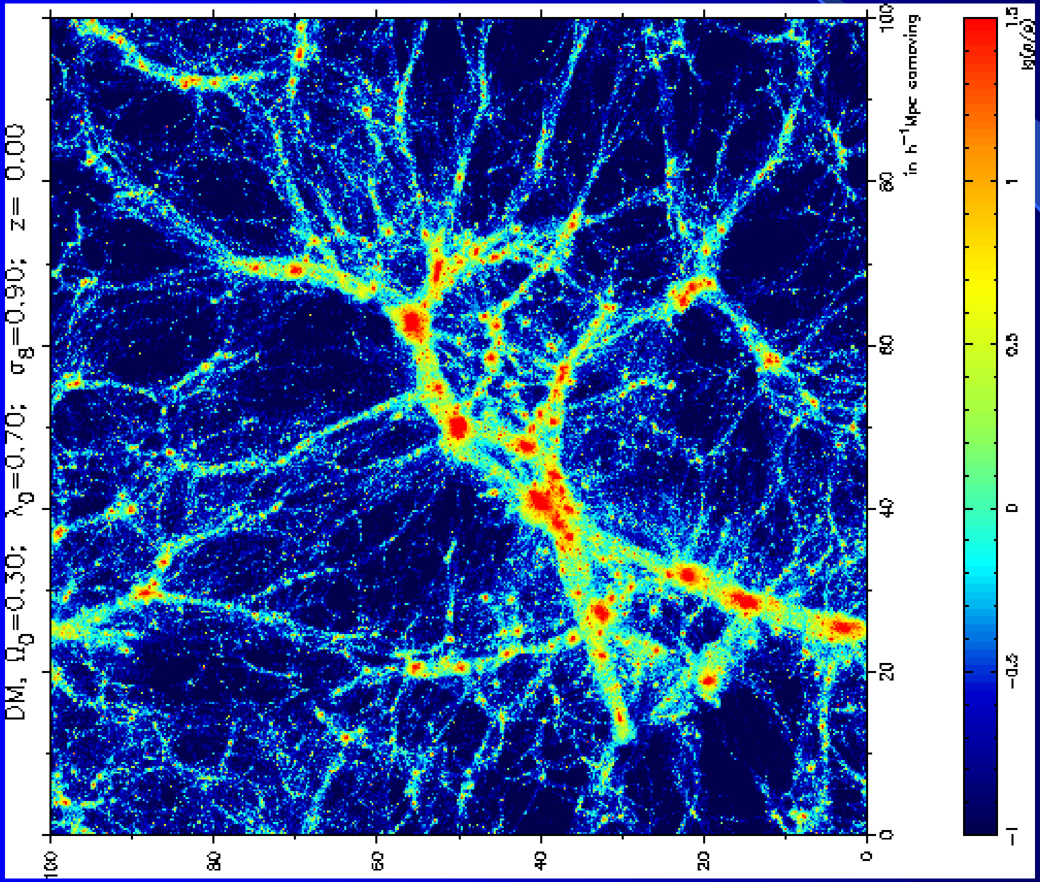
  - In observation

$$w_{g+}(r_p) = b_g w_{\delta+}(r_p)$$

Galaxy biasing
~2 for LRGs

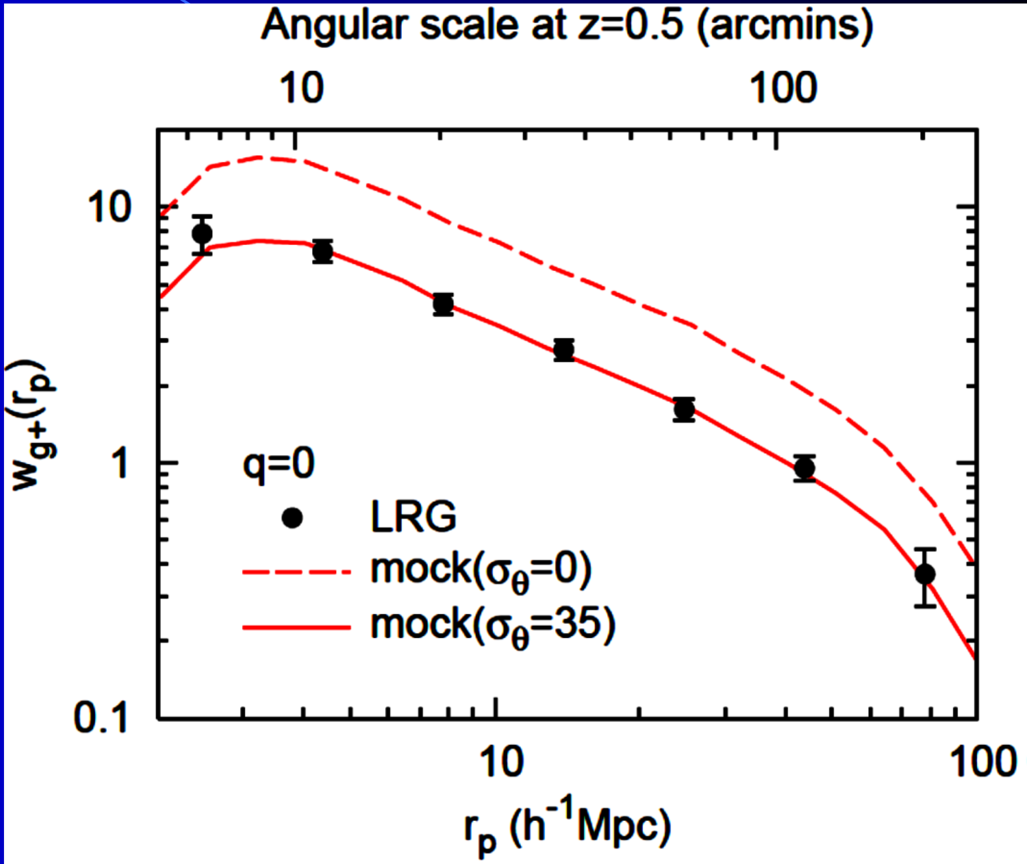
This relation is indeed valid on large scales.

Intrinsic ellipticity – density correlation



The GI correlation functions of LRGs in observation and in LCDM model

- The GI correlation is better determined than the II correlation in observation.
- The GI correlation can be well modeled in the current LCDM model if the misalignment angle parameter follows $\sigma_\theta = 34.9^{+1.9}_{-2.1}$



Correlation of the LRG shape and orientation

- Normalized GI correlation function

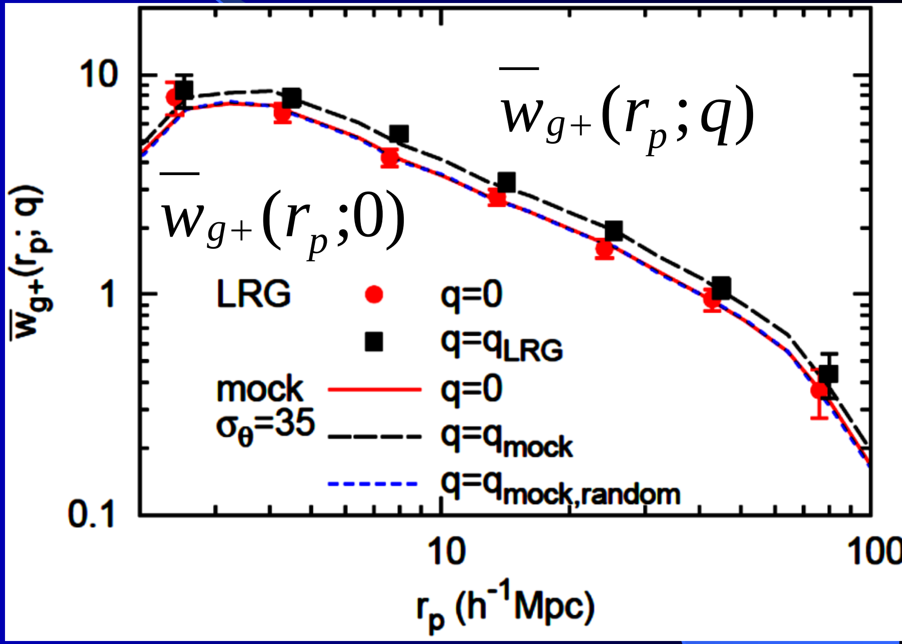
$$\bar{w}_{g+}(r_p;q) = \left\langle \frac{1-q^2}{1+q^2} \right\rangle^{-1} w_{g+}(r_p;q)$$

$$\propto \left\langle \frac{1-q^2}{1+q^2} \right\rangle^{-1} \sum_i^{N_{\rm pair}} \frac{1-q_i^2}{1+q_i^2} \cos 2\beta_i$$

axis ratio — orientation

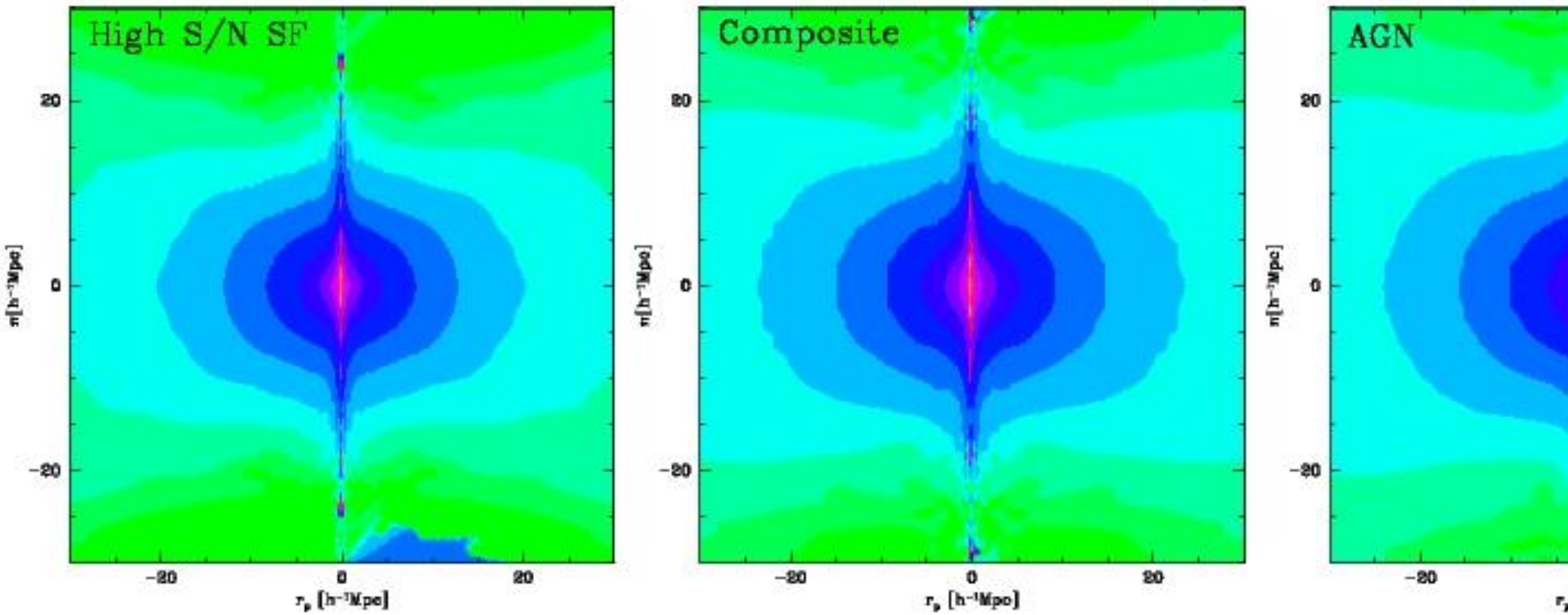
  – If there is no correlation between q and β, we expect

$$\overline{w}_{g+}(r_p;q) = \overline{w}_{g+}(r_p;0)$$



- This correlation increases the amplitude by ~15%.

Systematics for measuring the growth factor from redshift distortion



Guzzo's talk on redshift distortion

Mon. Not. R. Astron. Soc. **000**, 000–000 (0000) Printed 18 June 2010 (MN LaTeX style file v2.2)

Designing a space-based galaxy redshift survey to probe dark energy

Yun Wang[1⋆], Will Percival[2], Andrea Cimatti[3], Pia Mukherjee[4], I

- We also consider the dependence on the information used: the full galaxy power spectrum P(k), P(k) marginalized over its shape, or just the Baryon Acoustic Oscillations (BAO). We find that the inclusion of growth rate information (extracted using redshift space distortion and galaxy clustering amplitude measurements) leads to a factor of 3 improvement in the FoM, assuming general relativity is not modified. This inclusion partially compensates for the loss of information when only the BAO are used to give geometrical constraints, rather t

$$
P_{obs}(k_\perp^{ref}, k_\parallel^{ref}) = \frac{\left[D_A(z)^{ref}\right]^2 H(z)}{\left[D_A(z)\right]^2 H(z)^{ref}} \, b^2 \left(1+\beta\,\mu^2\right)^2 \cdot \cdot \left[\frac{G(z)}{G(0)}\right]^2 P_{matter}(k)_{z=0} + P_{shot}, \quad (1)
$$

Basics for redshift P(k)

$$P^{(s)}(k,\mu_{\mathbf{k}}) = P_0(k)L_0(\mu_{\mathbf{k}}) + P_2(k)L_2(\mu_{\mathbf{k}}) + P_4(k)L_4(\mu_{\mathbf{k}}),$$

$$P_l(k) = \frac{2l+1}{2}\int_{-1}^{+1} P^{(s)}(k,\mu_{\mathbf{k}})L_l(\mu_{\mathbf{k}})d\mu_{\mathbf{k}}.$$

$$\beta = f/b$$

$$f(z) = \Omega_m^{\gamma}(z)$$

$$P^{(0/r)}(k) \equiv \frac{P_0(k)}{P^{(r)}(k)} = 1 + \frac{2}{3}\beta + \frac{1}{5}\beta^2,$$

Not observable

$$P^{(2/0)}(k) \equiv \frac{P_2(k)}{P_0(k)} = \frac{\frac{4}{3}\beta + \frac{4}{7}\beta^2}{1 + \frac{2}{3}\beta + \frac{1}{5}\beta^2}.$$

Observable

Simulations

TABLE 1
SIMULATION PARAMETERS

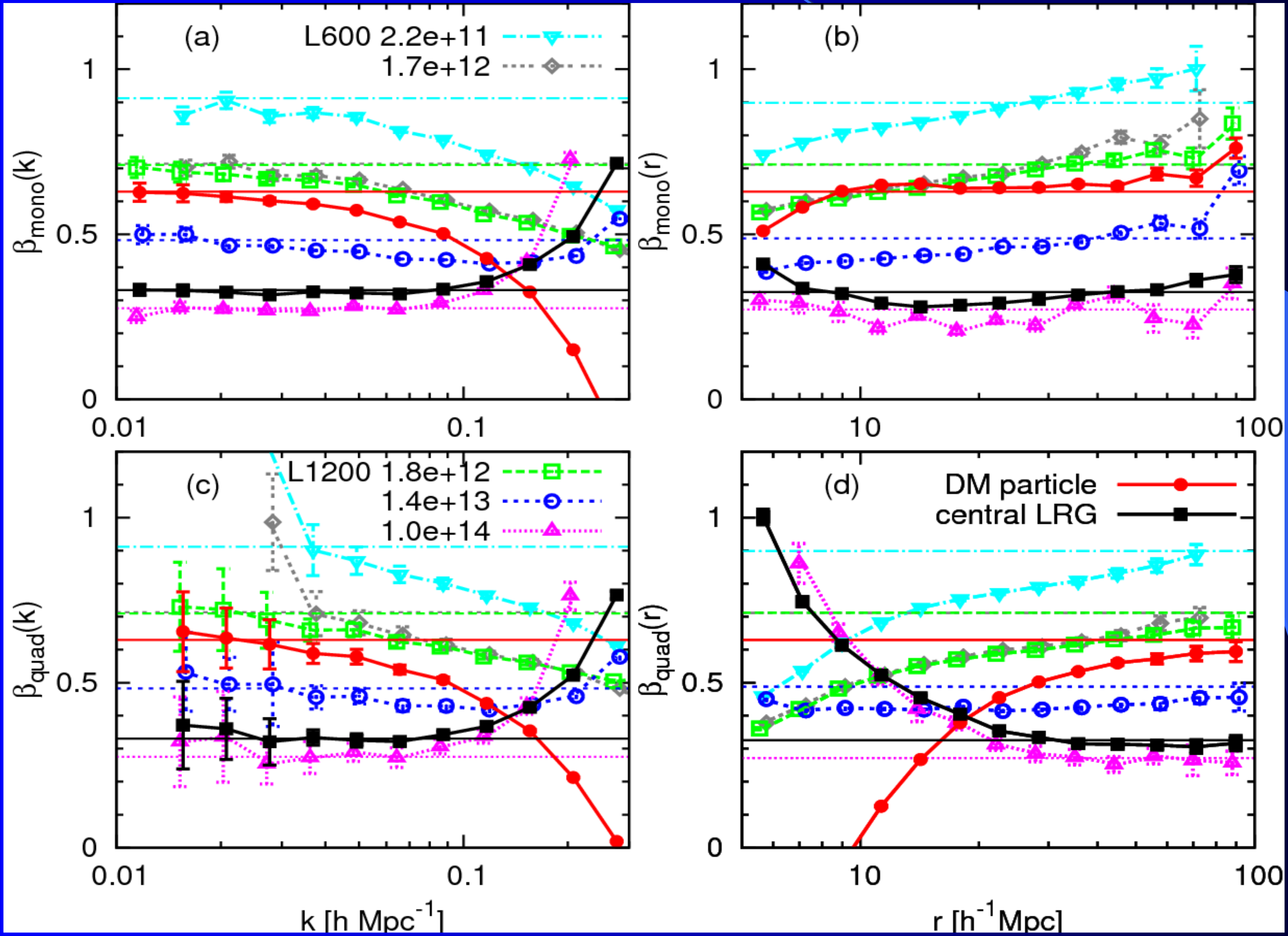
boxsize	particles	realizations	$m_p (h^{-1} M_\odot)$	z_{out}
600	1024^3	15	1.5×10^{10}	0.295
1200	1024^3	4	1.2×10^{11}	0.274

NOTE. — m_p in column 4 is the particle mass.

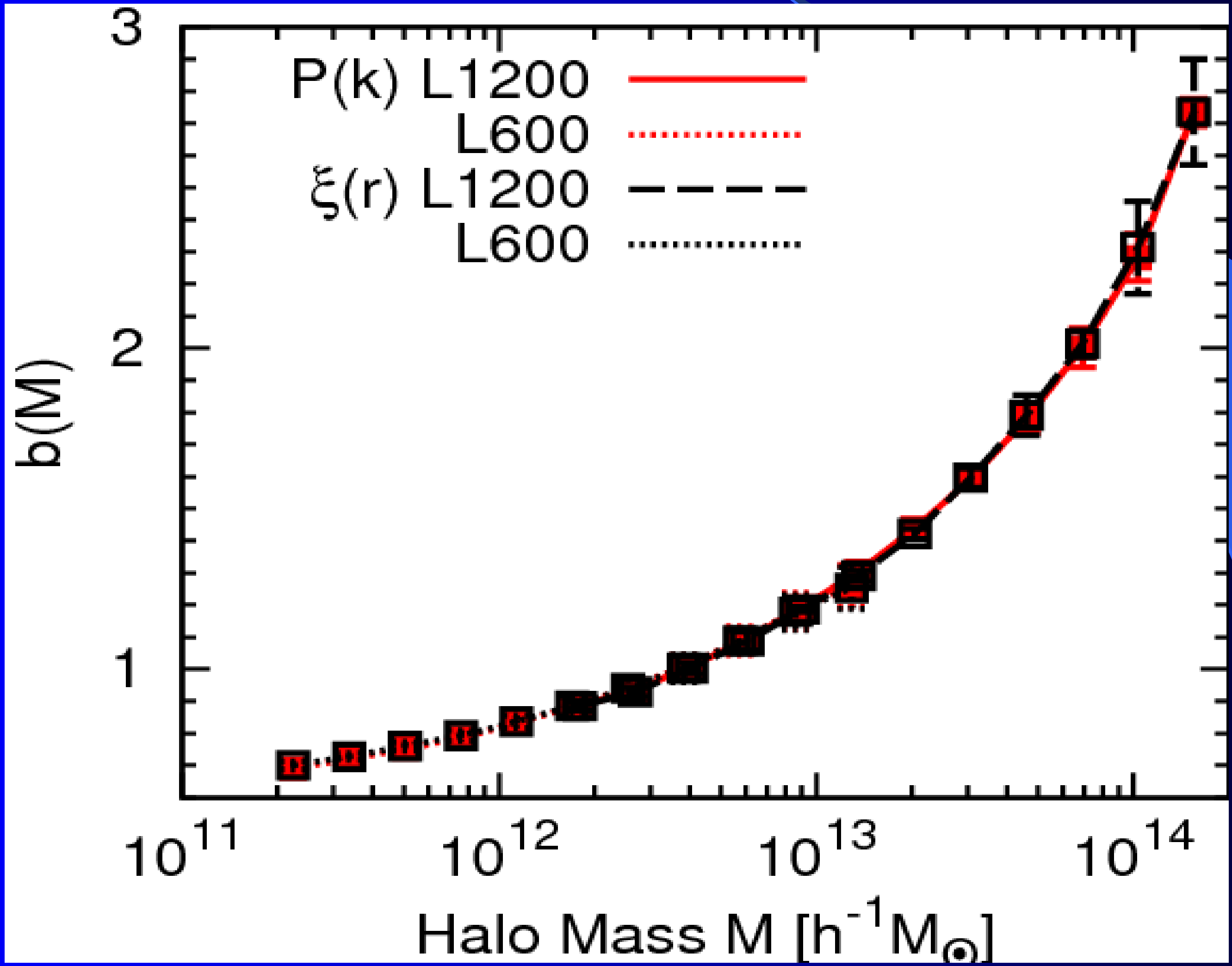
TABLE 2
PROPERTIES OF SIMULATED HALOS AND GALAXIES

box	$M (h^{-1} M_\odot)$	n_p	N_{halo}	$b(k)$	$b(r)$
L600	2.2×10^{11}	$13 \leq n_p \leq 18$	1.3×10^6	0.69	0.70
	1.7×10^{12}	$92 \leq n_p \leq 136$	1.9×10^5	0.88	0.89
L1200	1.8×10^{12}	$12 \leq n_p \leq 17$	1.7×10^6	0.89	0.88
	1.4×10^{13}	$92 \leq n_p \leq 136$	2.2×10^5	1.30	1.30
	1.0×10^{14}	$692 \leq n_p \leq 1037$	2.2×10^4	2.28	2.31
	LRG	$12 \leq n_p \lesssim 25000$	1.4×10^5	1.90	1.94

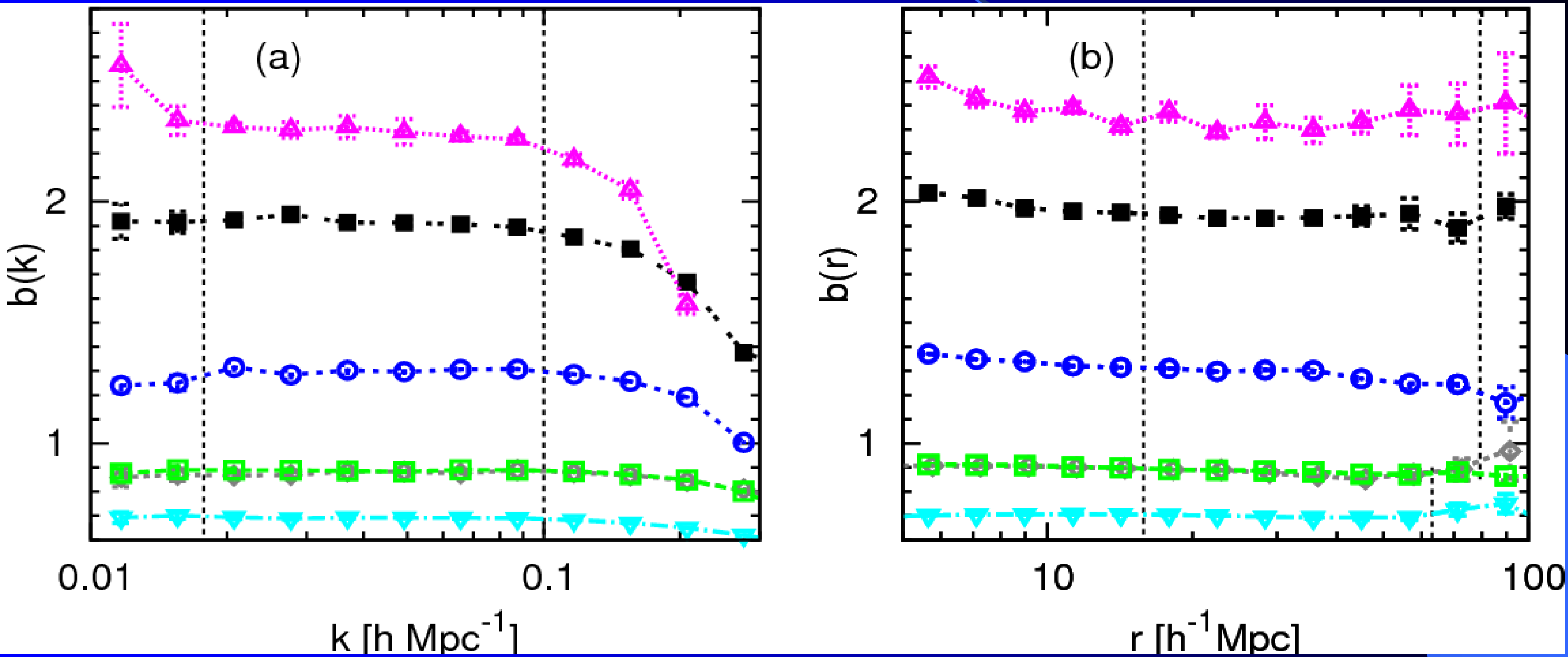
Beta from P(k) or xi(r)



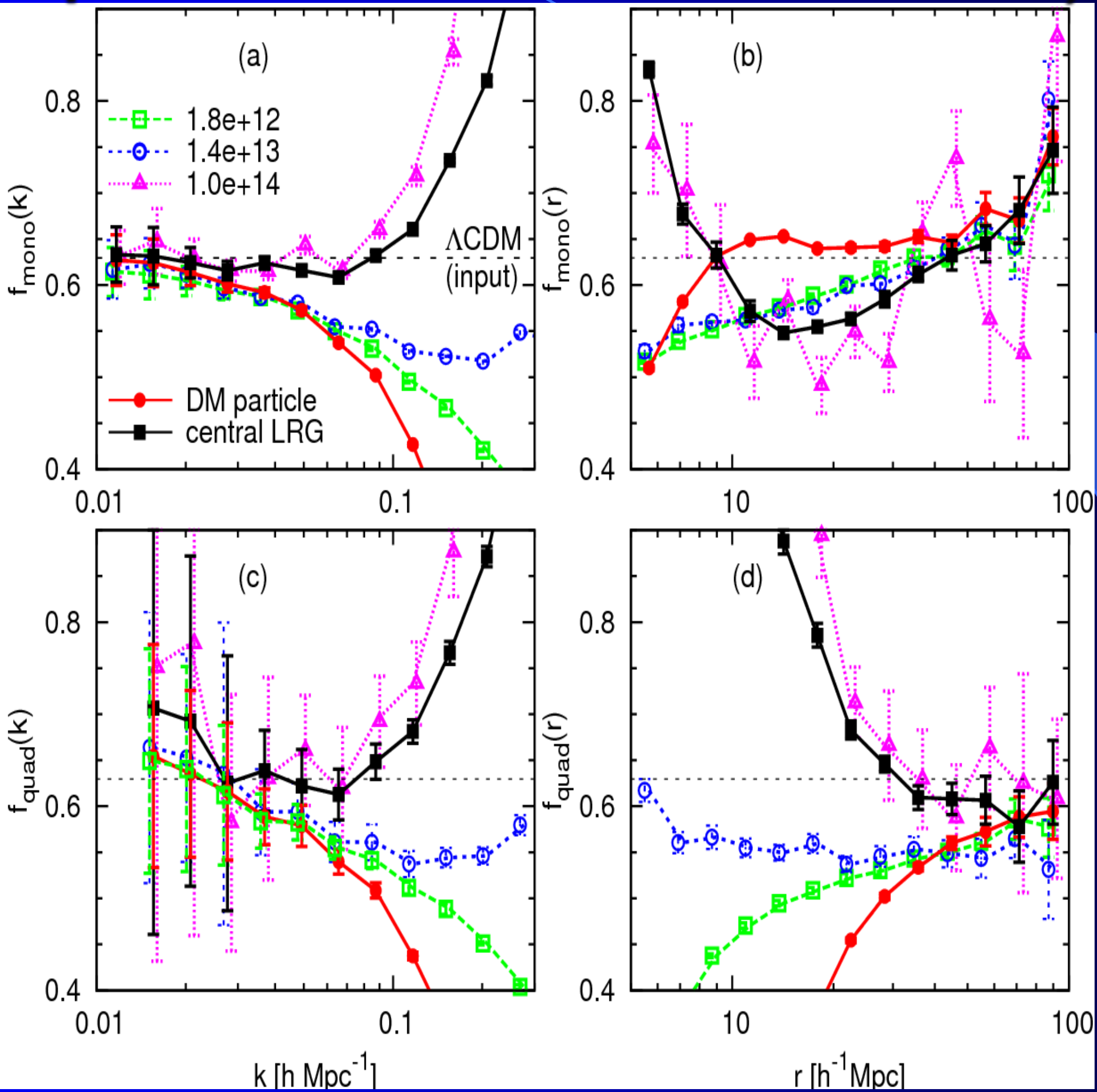
Bias with mass

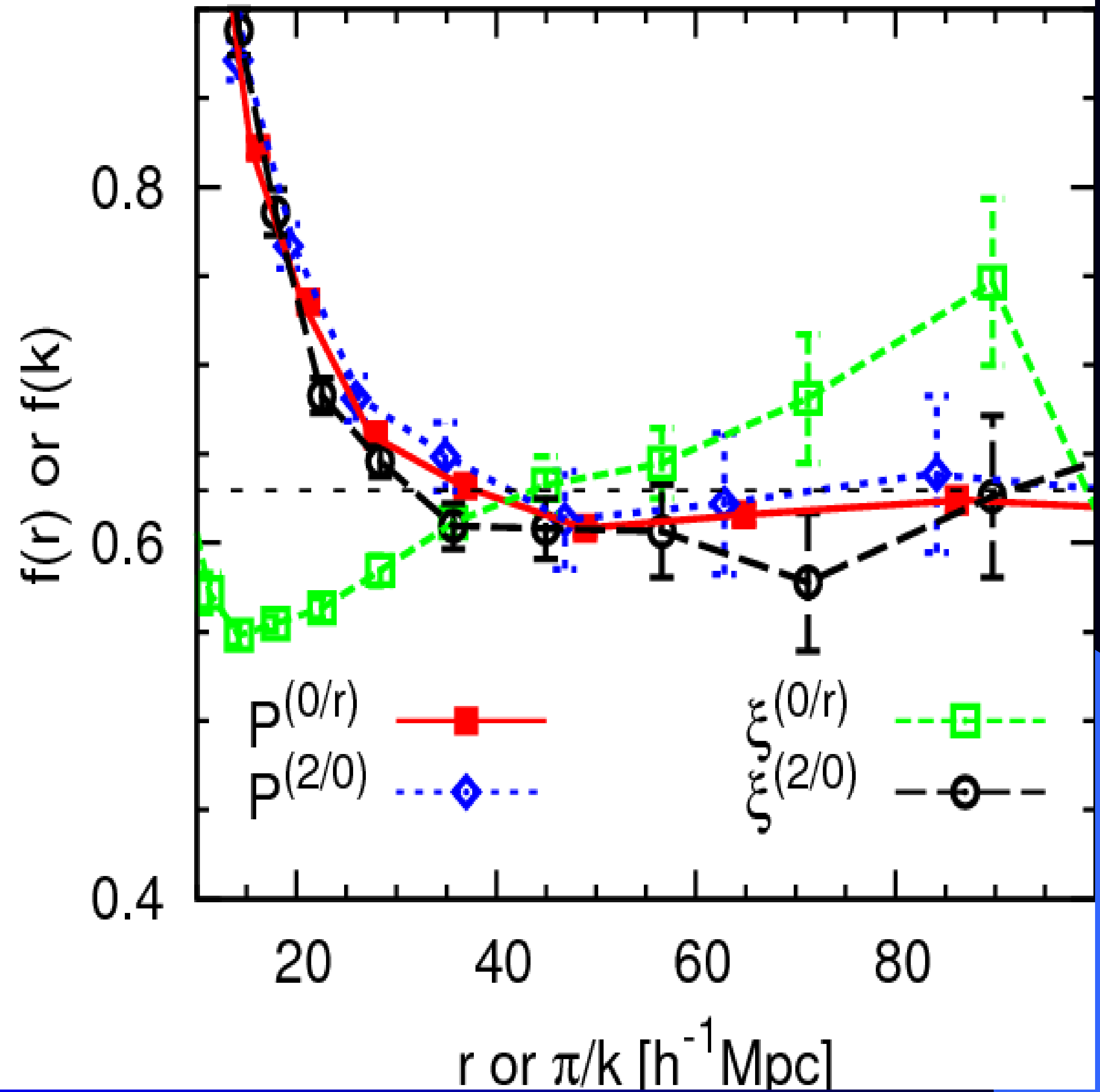


The bias factors



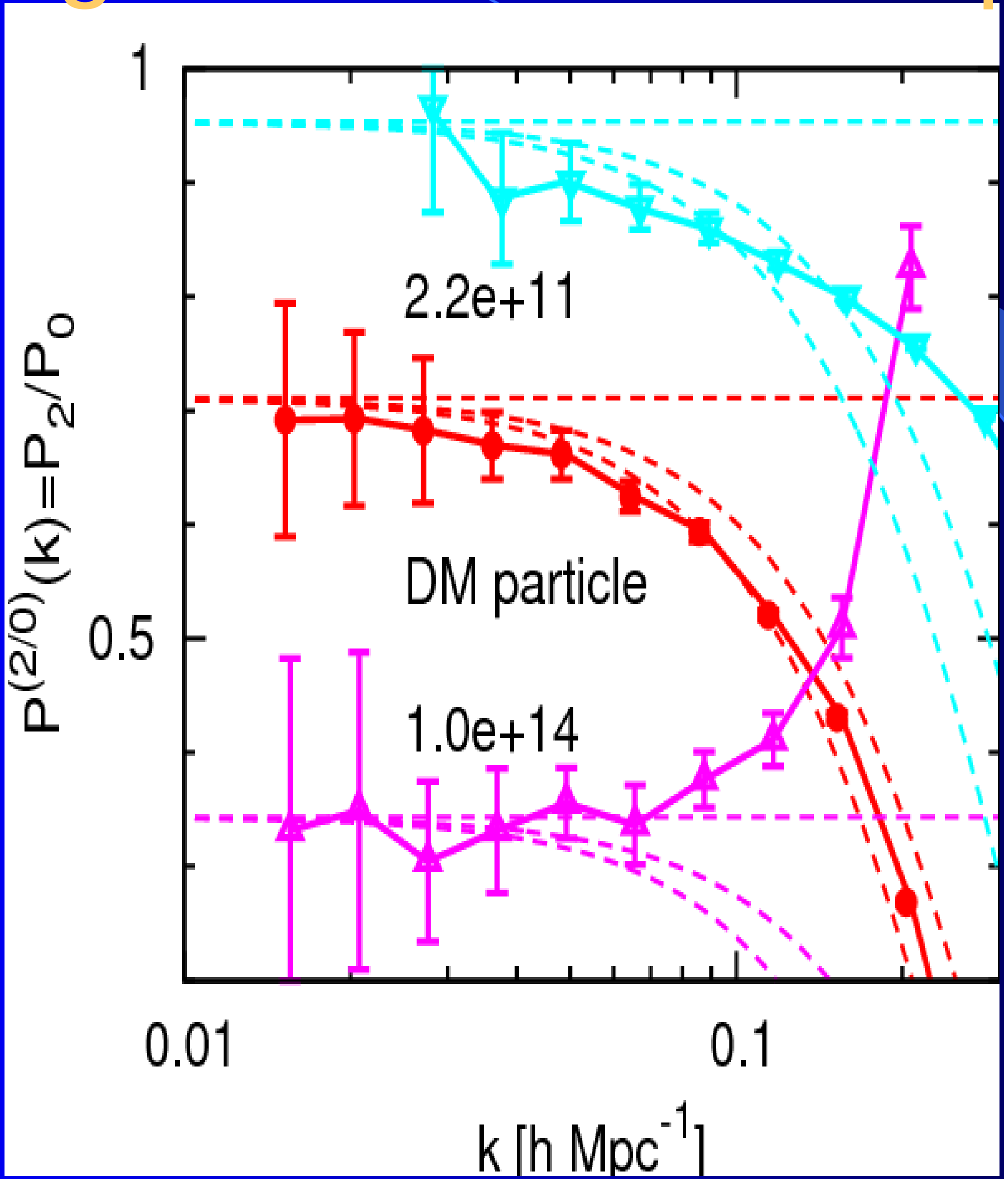
The growth factor (scale-dependent bias included)





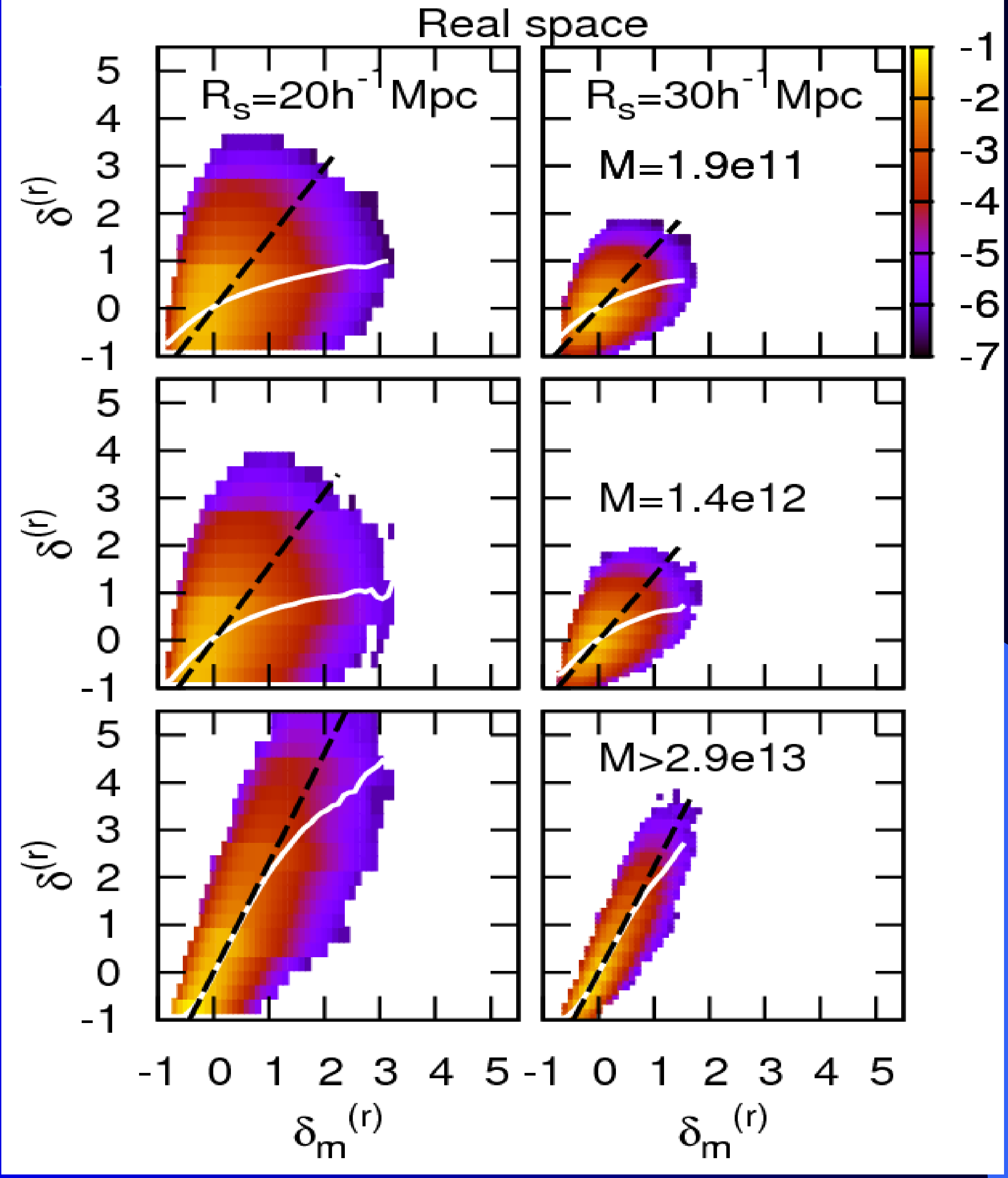
0.8
0.6
0.4
f(r) or f(k)
20
40
60
80
r or π/k [h^-1 Mpc]
P^(0/r)
P^(2/0)
ξ^(0/r)
ξ^(2/0)

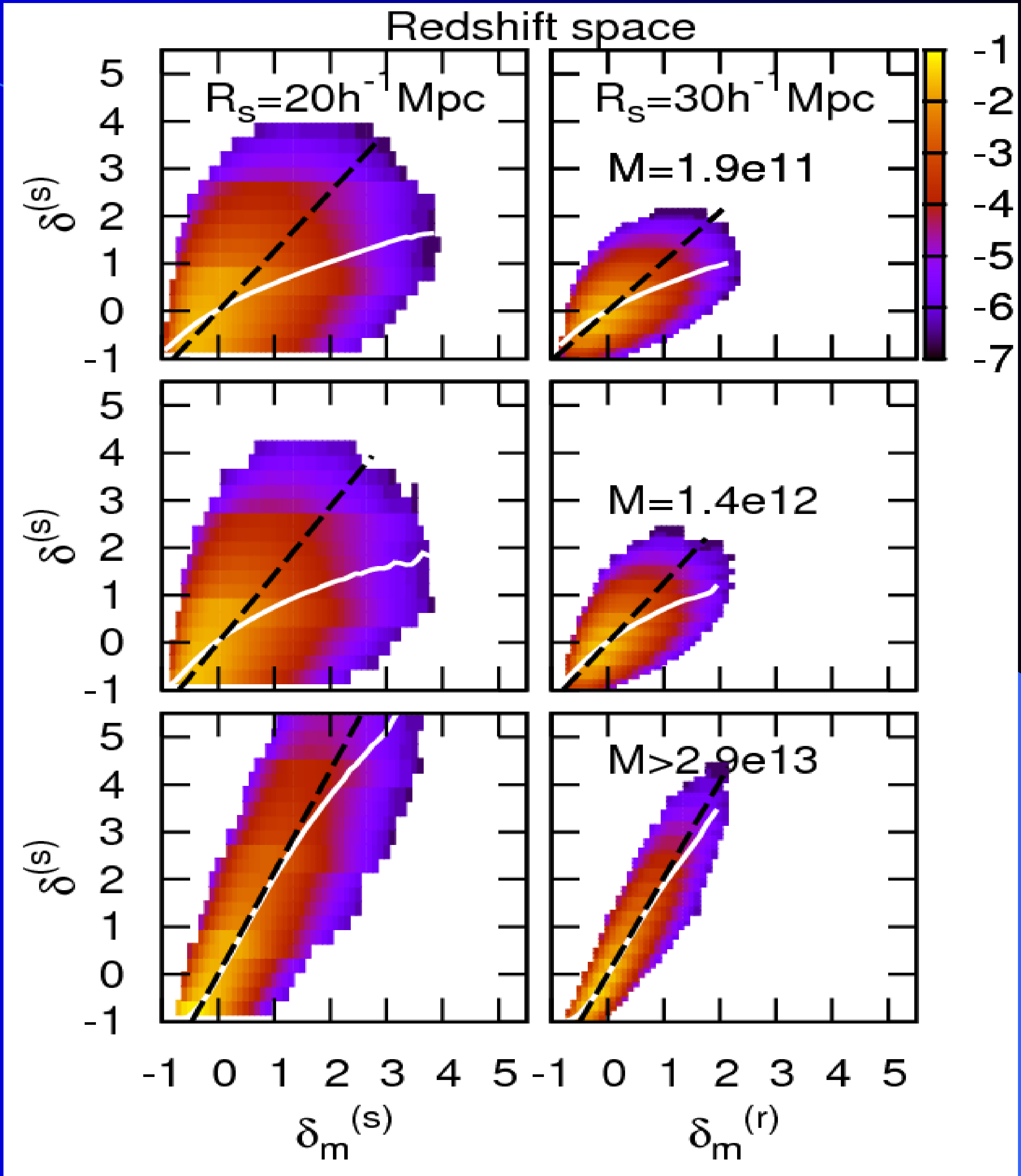
The finger-of-god effect (Lorentz damping factor in Fourier space)



Check if the linear bias relation

There is no dynamical velocity bias in our simulation





Redshift space
R_s=20h^{-1}Mpc
R_s=30h^{-1}Mpc
M=1.9e11
M=1.4e12
M>2.9e13
$\delta^{(s)}$
$\delta_m^{(s)}$
$\delta_m^{(r)}$

Quantifying

1) Correlation

$$b_{\rm var} \equiv \sqrt{\frac{\langle\delta^2\rangle}{\langle\delta_m^2\rangle}}, \quad r_{\rm corr} \equiv \frac{\langle\delta\delta_m\rangle}{\sqrt{\langle\delta^2\rangle\langle\delta_m^2\rangle}}.$$

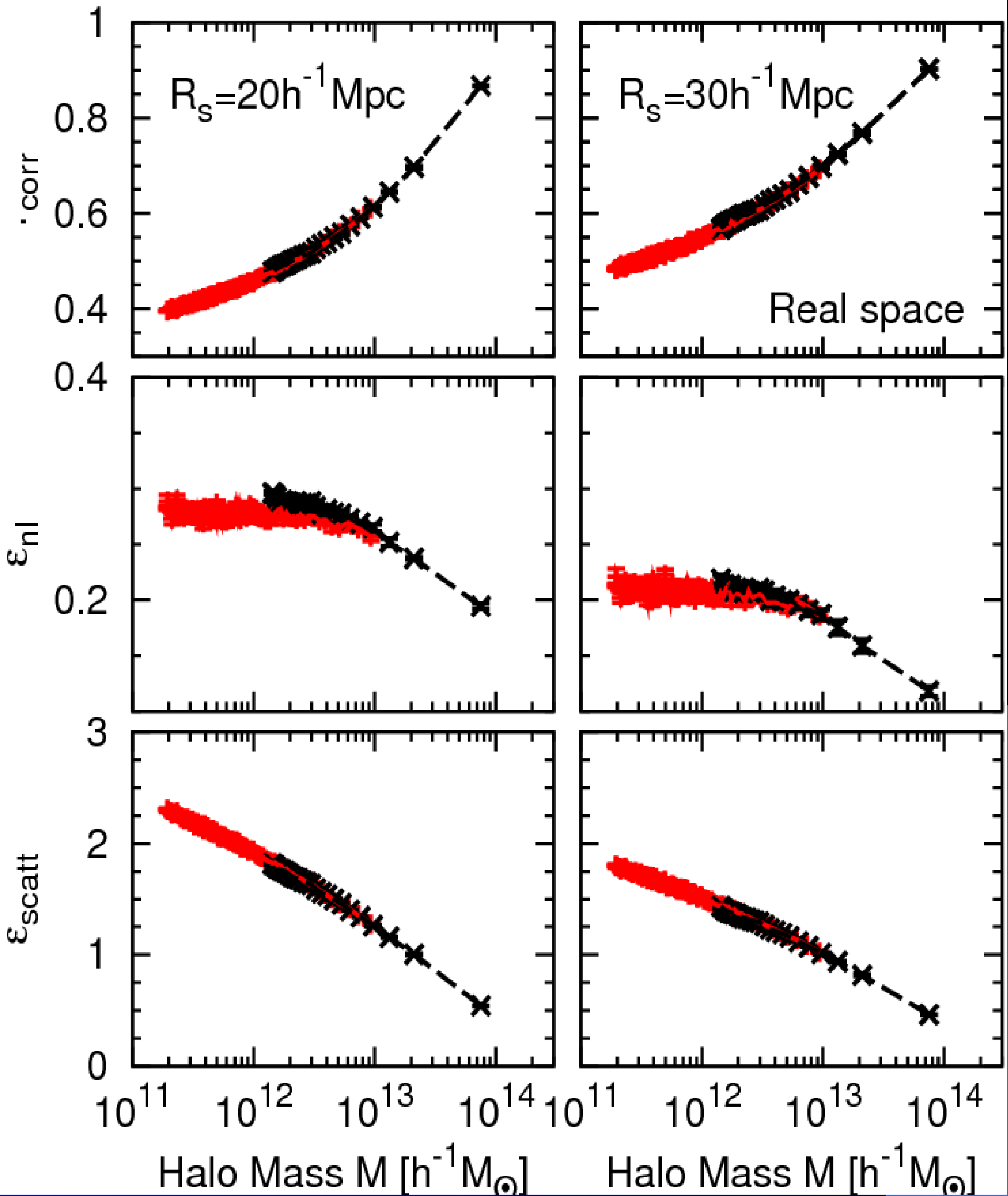
2) Nonlinearity

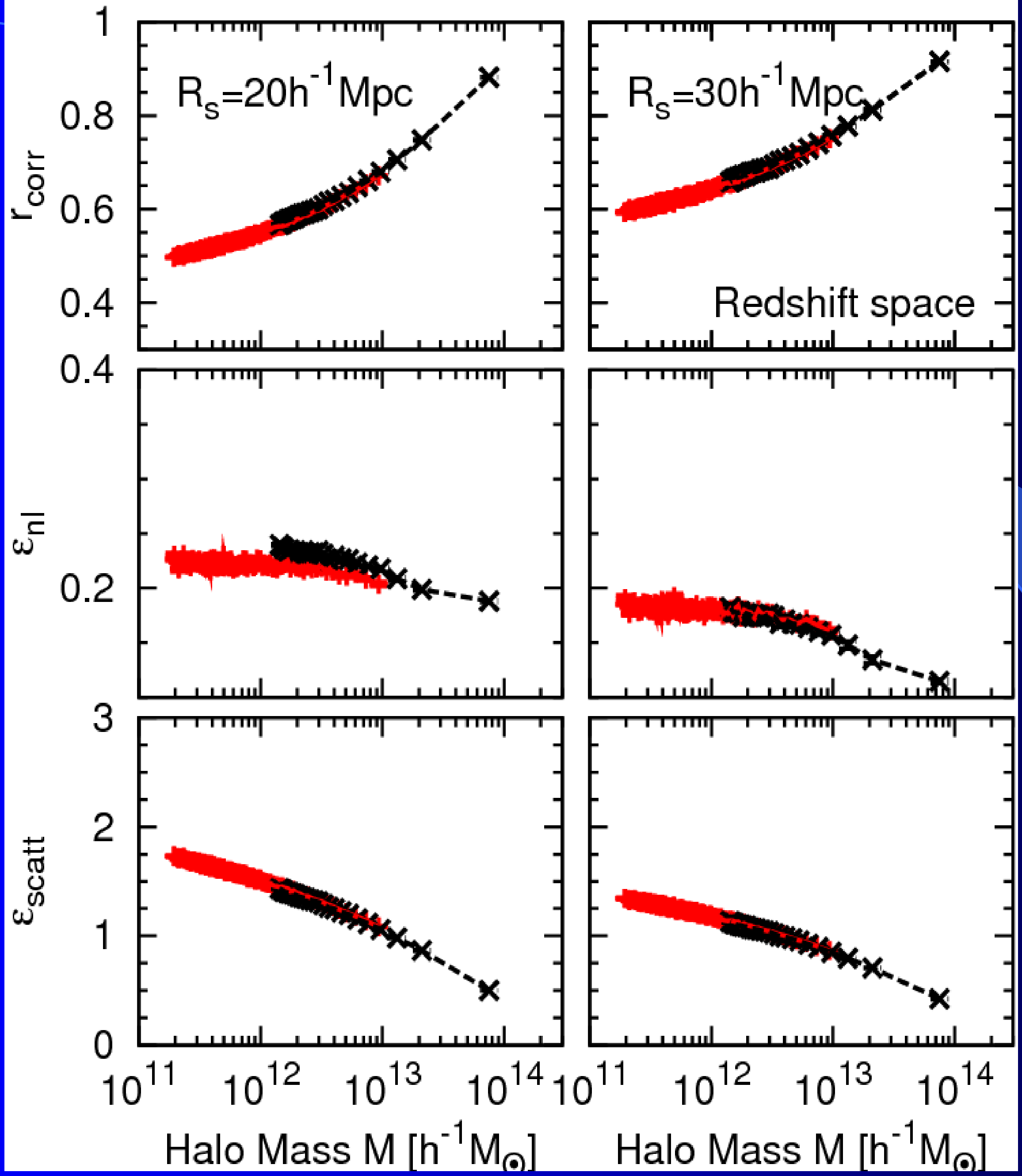
$$\epsilon_{\rm nl} \equiv \frac{\langle\delta_m^2\rangle\langle\bar{\delta}^2\rangle}{\langle\bar{\delta}\delta_m\rangle^2} - 1,$$

3) Stochasticity

$$\epsilon_{\rm scatt} \equiv \frac{\langle\delta_m^2\rangle\langle(\delta-\bar{\delta})^2\rangle}{\langle\bar{\delta}\delta_m\rangle^2},$$

Taruya and Suto for the definitions





R$_s$=20h^{-1}Mpc
R$_s$=30h^{-1}Mpc
Redshift space
r_{corr}
ϵ_{nl}
ϵ_{scatt}
1
0.8
0.6
0.4
0.4
0.2
3
2
1
0
10^{11} 10^{12} 10^{13} 10^{14}
Halo Mass M [$h^{-1}M_\odot$]
Halo Mass M [$h^{-1}M_\odot$]

Remarks

- II correlation and GI correlation
  - The correlations were determined accurately up to 30-100h^{-1}Mpc.
  - the GI correlation can be well modeled in the current LCDM model if the misalignment angle between host halo and central galaxies is 35 degrees;
  - If not corrected, each can lead to contamination at 5~10% levels to cosmic shear, danger to precision cosmology!
- Implication: they can be modeled and corrected with HOD (ongoing work!)
- The systematics for the growth factor measurement from the redshift distortion have identified, and must be treated with caution

Thanks!