The Abdus Salam International Centre for Theoretical Physics

2419-23

Workshop on Large Scale Structure

30 July - 2 August, 2012

Testing Gravity using Large-Scale Redshift-Space Distortions

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Testing Gravity with Large-Scale RSD

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&

California Institute of Technology

In collaboration with Olivier Doré

&

D. Bertacca, D. Pietrobon, L. Samushia, F. Schmidt, N. Bartolo, C. Clarkson, R. Maartens, S. Matarrese, W. Percival

Testing Gravity with Large-Scale RSD

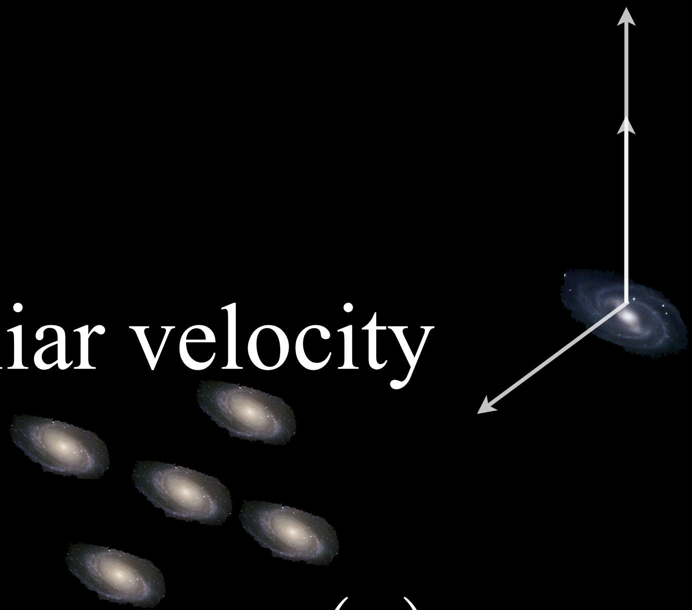
Outline:

- Redshift-Space Distortions
- Wide Angle RSD
- Testing Cosmologies with SDSS
- GR Corrections

Real and Redshift Space

Hubble expansion + peculiar velocity

peculiar velocity

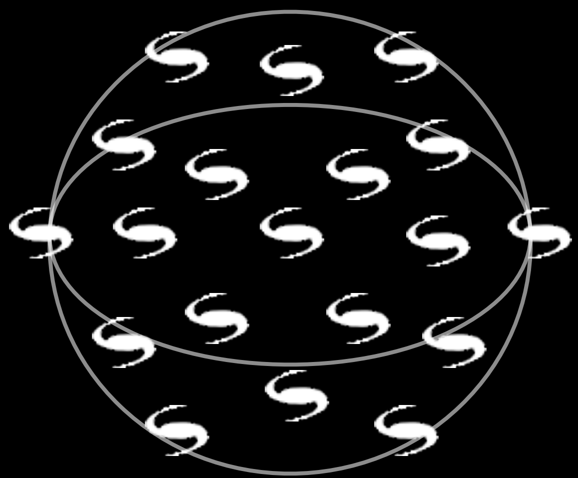


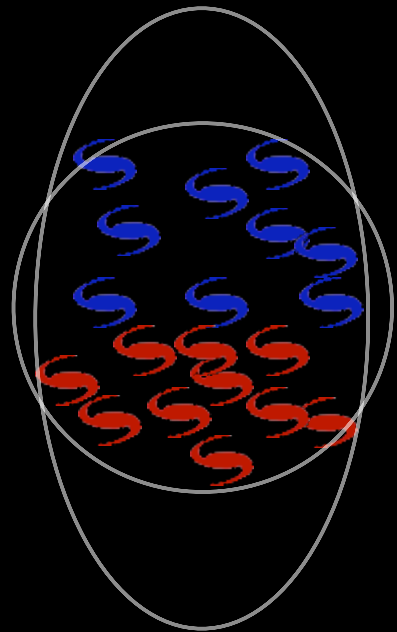
$$\mathbf{s}(\mathbf{r}) = \mathbf{r} - v_r(\mathbf{r})\hat{\mathbf{r}}$$

Redshift-Space Distortions

Large Scale → Kaiser Effect (pancakes of God)

Small Scale → Fingers Of God





The linear Redshift-Space Distortion Operator

$$\delta^s = \mathbf{S}\delta^r$$

The linear Redshift-Space Distortion Operator

conservation of galaxies

$$N^s(s)d^3s = N^r(r)d^3r$$

The linear Redshift-Space Distortion Operator

Jacobian

$$d^3 s = \left(1 + \frac{v}{r}\right)^2 \left(1 + \frac{\partial v}{\partial r}\right) d^3 r$$

The linear Redshift-Space Distortion Operator

RSD operator

$$\mathbf{S} = 1 + \beta \left(\frac{\partial^2}{\partial r^2} + \frac{\alpha(r)\partial}{r\partial r} \right) \nabla^{-2}$$

$$\alpha(r) = \frac{\partial \ln r^2 \bar{N}^s(r)}{\partial \ln r}$$

$$\beta = \frac{f}{b} \qquad f = \frac{d\ln D}{d\ln a}$$

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

$$\gamma_{GR} \approx 0.55$$

$$\gamma_{DGP} = 0.68$$

RSD test models of gravity


Alvise Raccanelli
JPL
ICTP
The Abdus Salam
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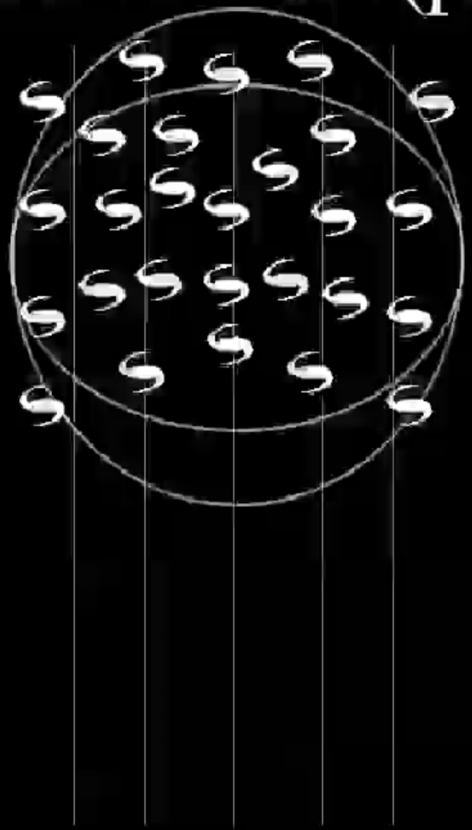
for Theoretical Physics
01 August 2012

Play

Introducing an observer

From pancakes of God (plane-parallel)



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play

Tripolar Spherical Harmonics expansion

Szalay et al. (1998), Szapudi (2004), Papai & Szapudi (2008)

$$\xi^s(\hat{r}_1, \hat{r}_2, \hat{r}) = \sum_{\ell_1, \ell_2, \ell} B^{\ell_1 \ell_2 \ell}(r, \phi_1 . \phi_2) S_{\ell_1, \ell_2, \ell}(\hat{r}_1, \hat{r}_2, \hat{r})$$

$$S_{l_1 l_2 l}(\hat{x}_1, \hat{x}_2, \hat{x}) =$$

$$= \sum_{m_1, m_2, m} \begin{pmatrix} l_1 & l_2 & l \\ m_1 & m_2 & m \end{pmatrix} C_{l_1 m_1}(\hat{x}_1) C_{l_2 m_2}(\hat{x}_2) C_{lm}(\hat{x})$$

3-j Wigner symbols

normalised spherical harmonics

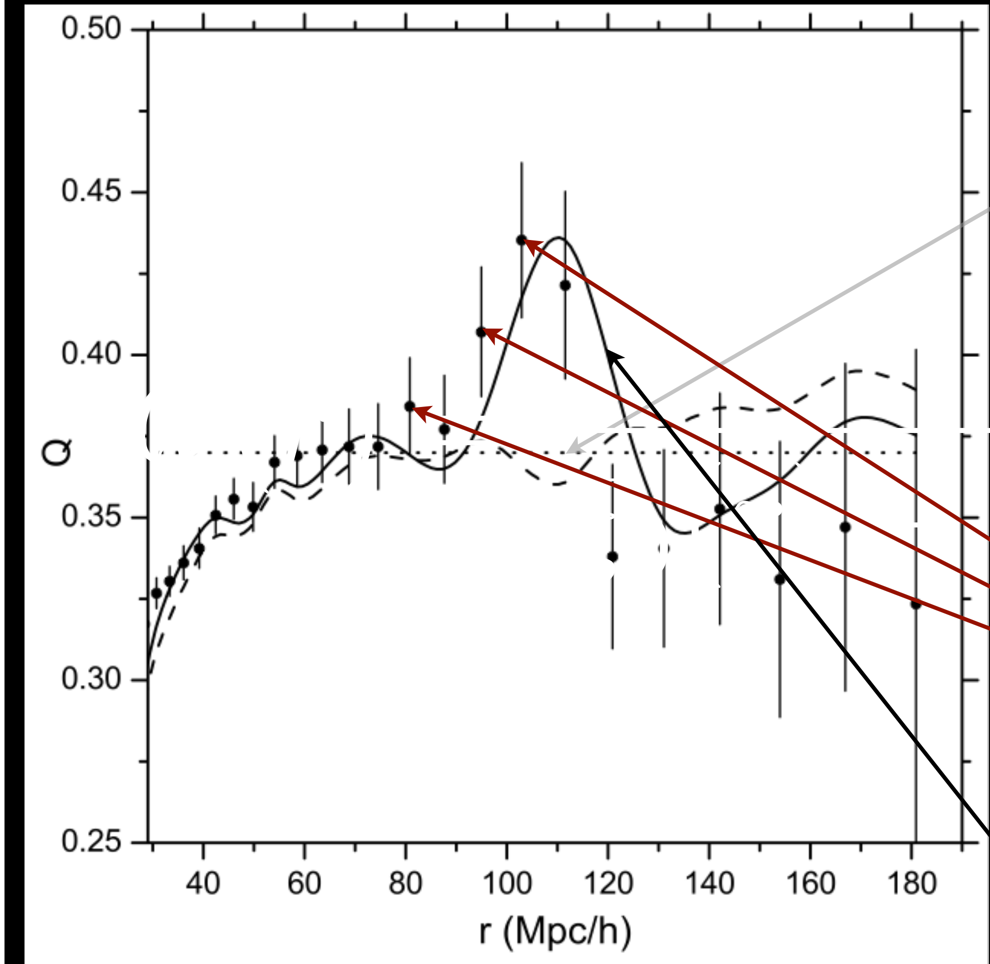
Interpreting large-scale RSD measurements

Application to real data:
We need a good theoretical model

simplifying assumptions
(e.g. geometry, non-linearities, selection function, ...)

error up to 20%

Q with NL and WA corrections
Normalised quadrupole Q



Kaiser formula
(dotted straight line)

$$\frac{\xi_2(r)}{\frac{3}{r^3}\int_0^r \xi_0(r')r'^2 dr'}$$

Las Damas mocks
(measured points)

Our formula
(solid line)

Measurements of γ

Neglecting large-scale corrections leads to a wrong estimate of γ

(also Durrer's talk)

$$\xi_0(\vartheta = 0.1\ /\ 0.05) \longrightarrow \Delta\gamma \approx 2\%\ /\ 9\%$$

Testing Cosmological Models

Cosmological models with a different growth history can be tested against data

Testing Gravity Using Large-Scale Redshift-Space Distortions

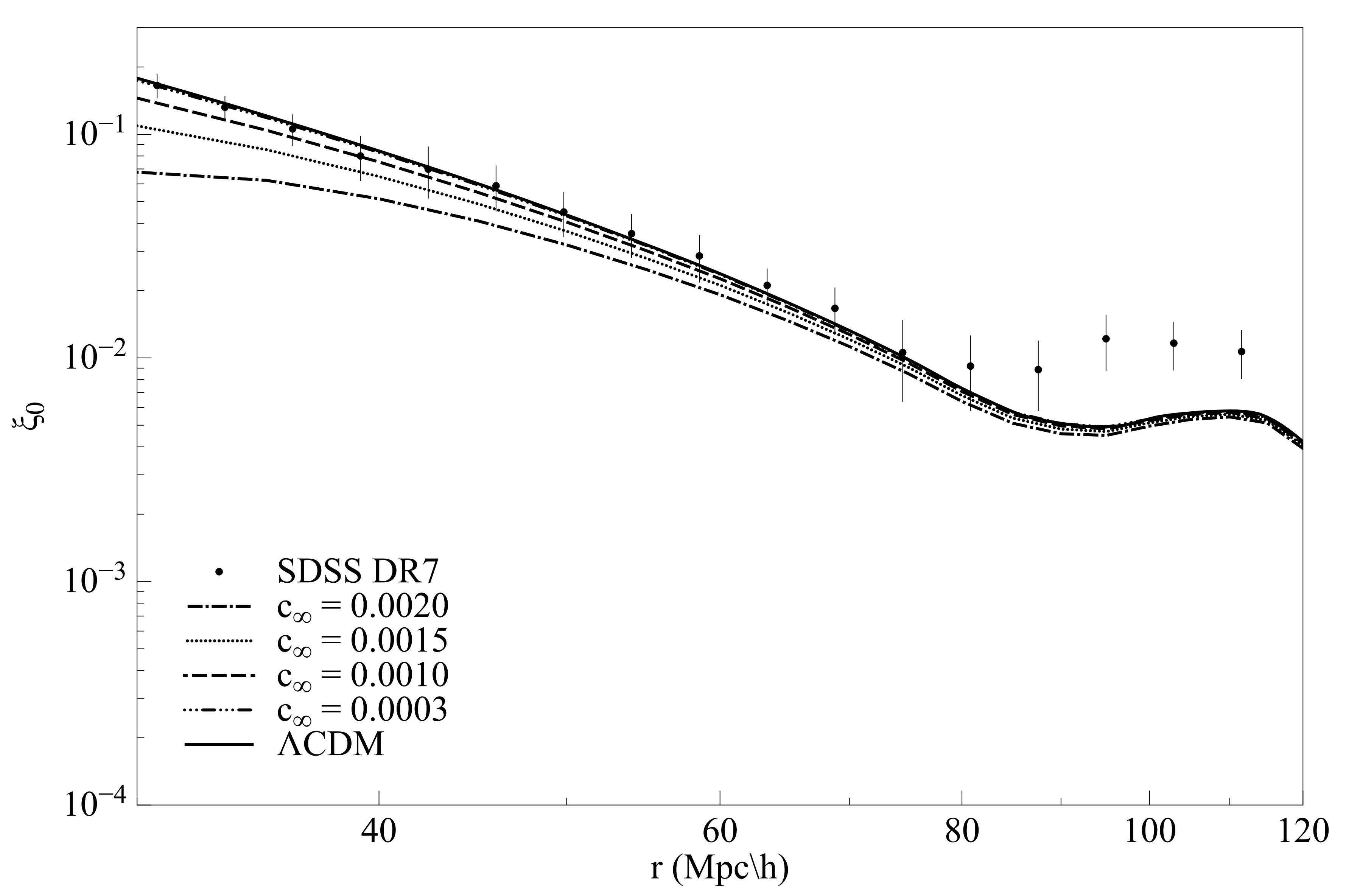
Alvise Raccanelli[1,2], Daniele Bertacca[3,4], Davide Pietrobon[1], Fabian Schmidt[2], Lado Samushia[6], Nicola Bartolo[4,5], Olivier Doré[1,2], Sabino Matarrese[4,5], Will J. Percival[6]

arXiv:1207.0500

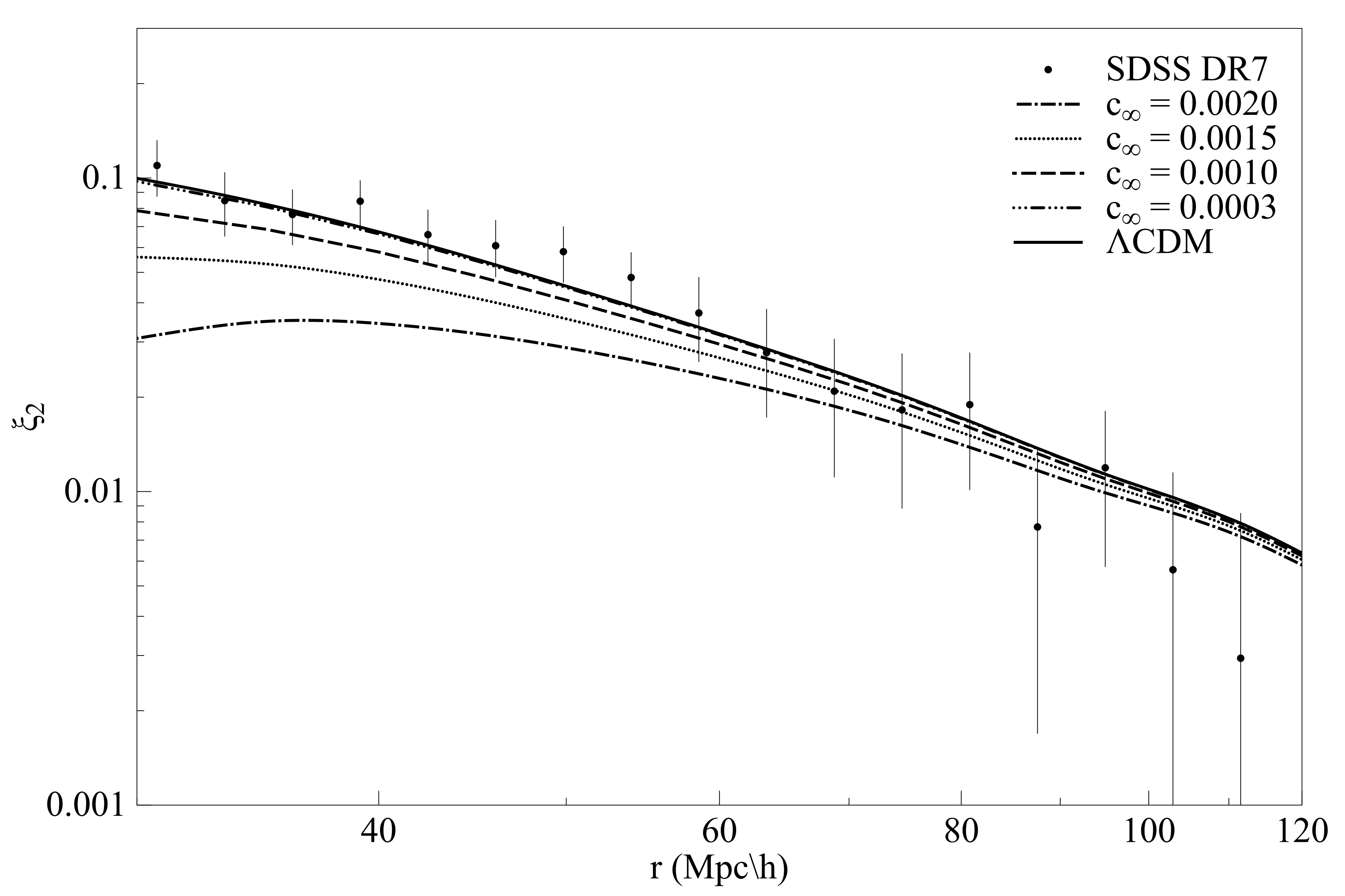
We measured ξ0 and ξ2 of SDSS-II LRGs, and compared them to predictions from UDM and nDGP as a function of their parameters.

Robust methodology including corrections from BAO nl, wide-angle, pair orientation and geometry allowed us to extend the range of scales used

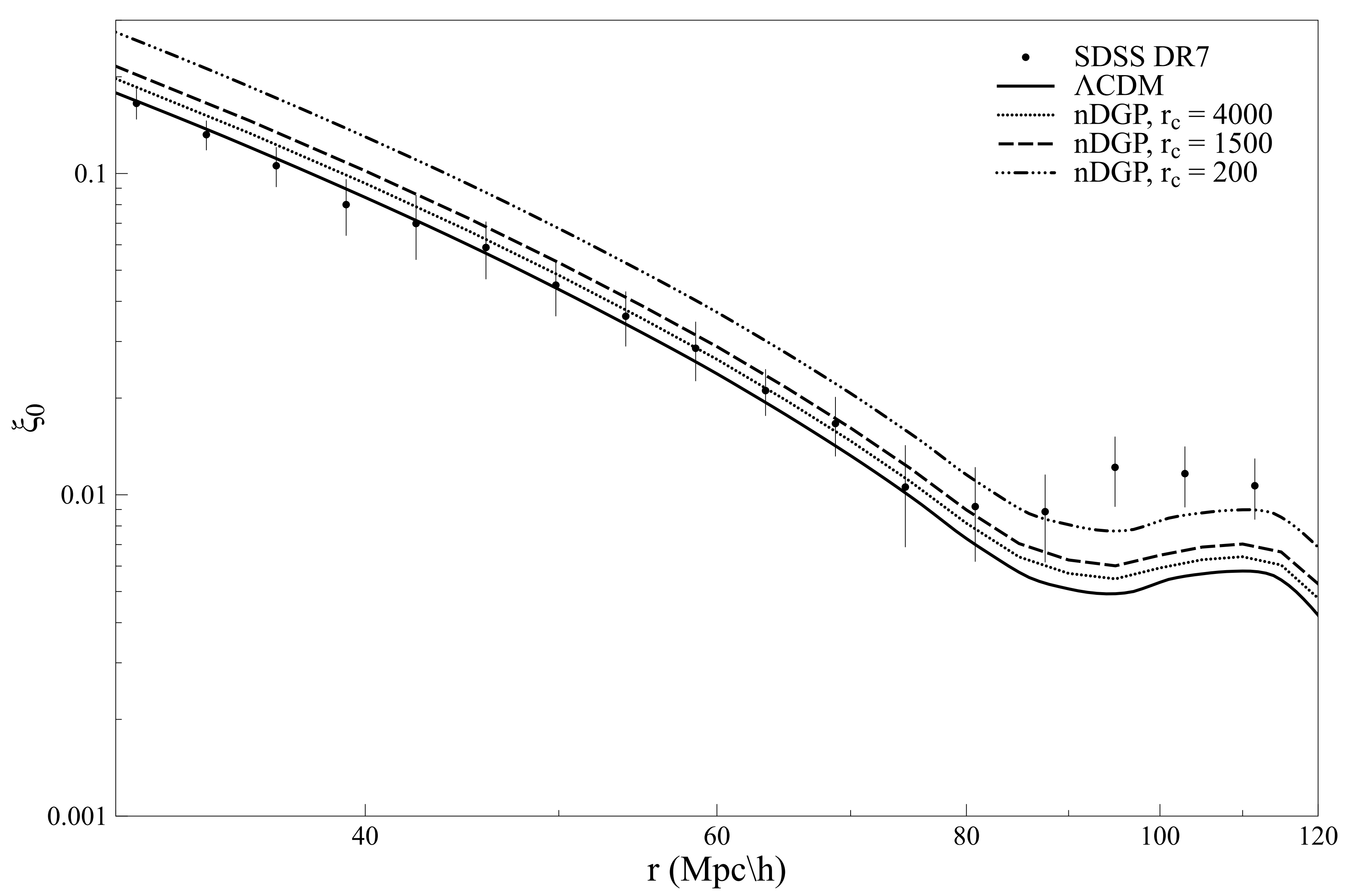
Unified Dark Matter ξ_0



Unified Dark Matter ξ_2

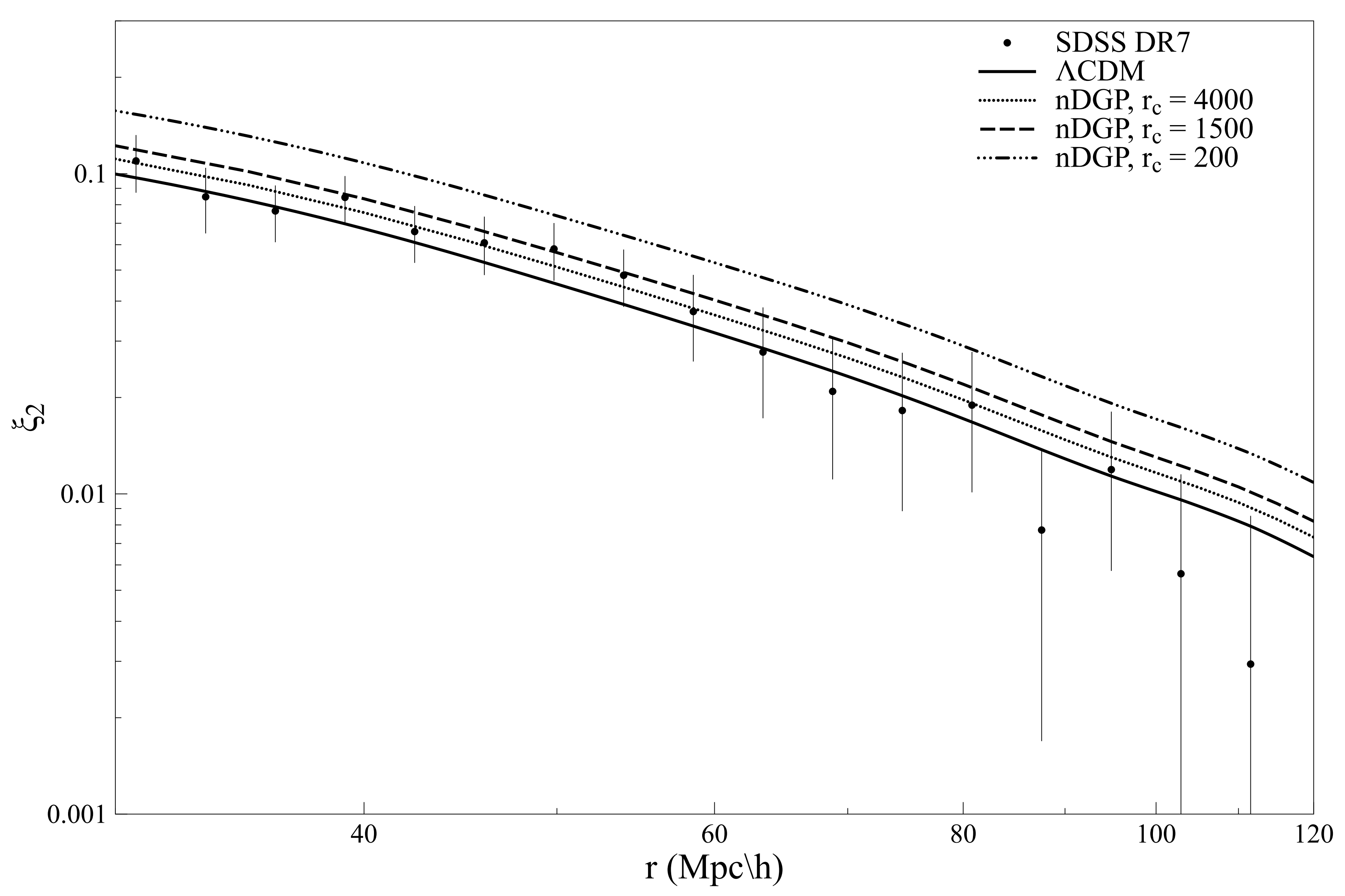


nDGP ξ_0



SDSS DR7
ΛCDM
nDGP, r_c = 4000
nDGP, r_c = 1500
nDGP, r_c = 200
0.1
0.01
0.001
ξ_0
40
60
80
100
120
r (Mpc\h)

nDGP ξ_2



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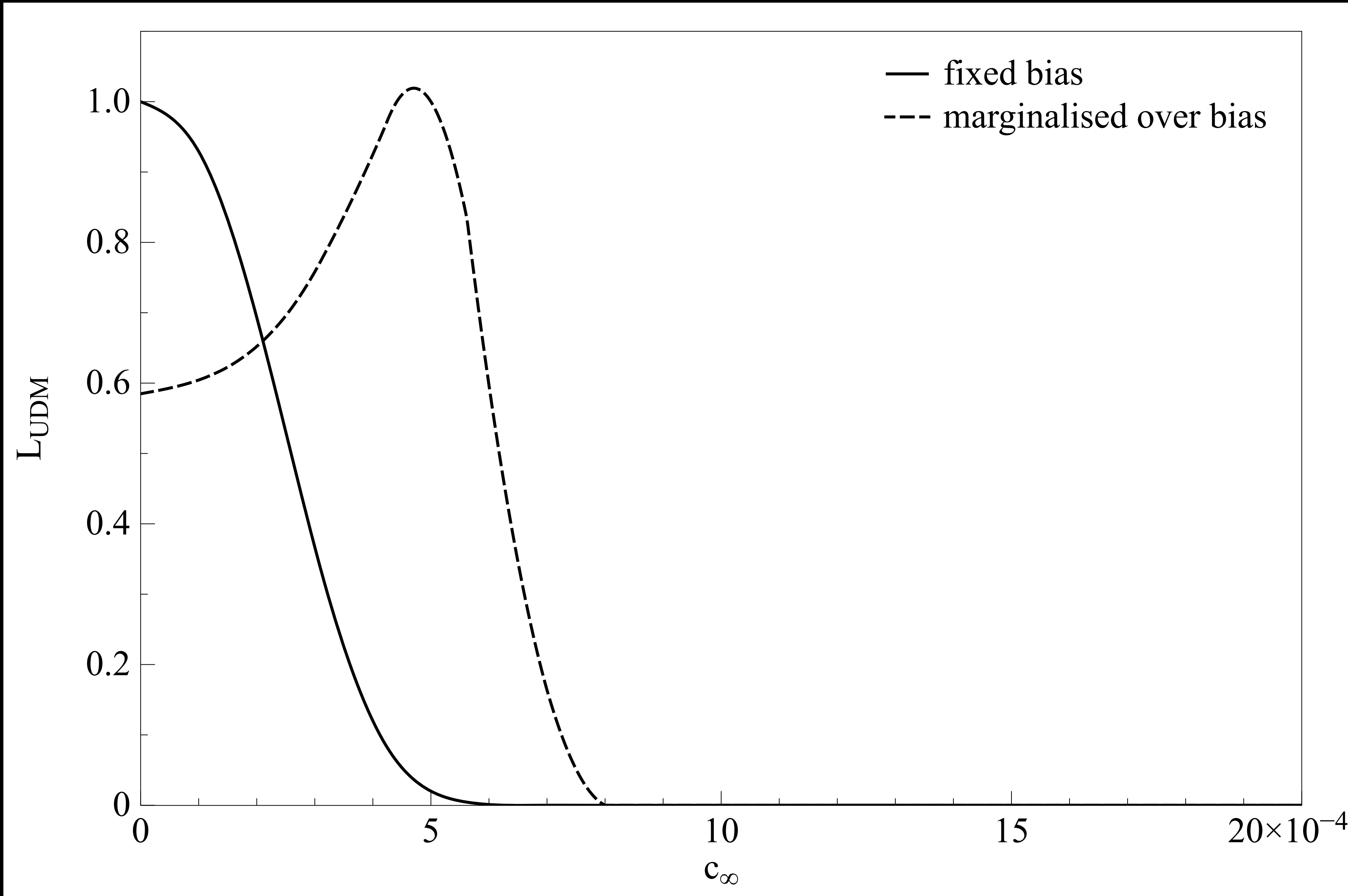
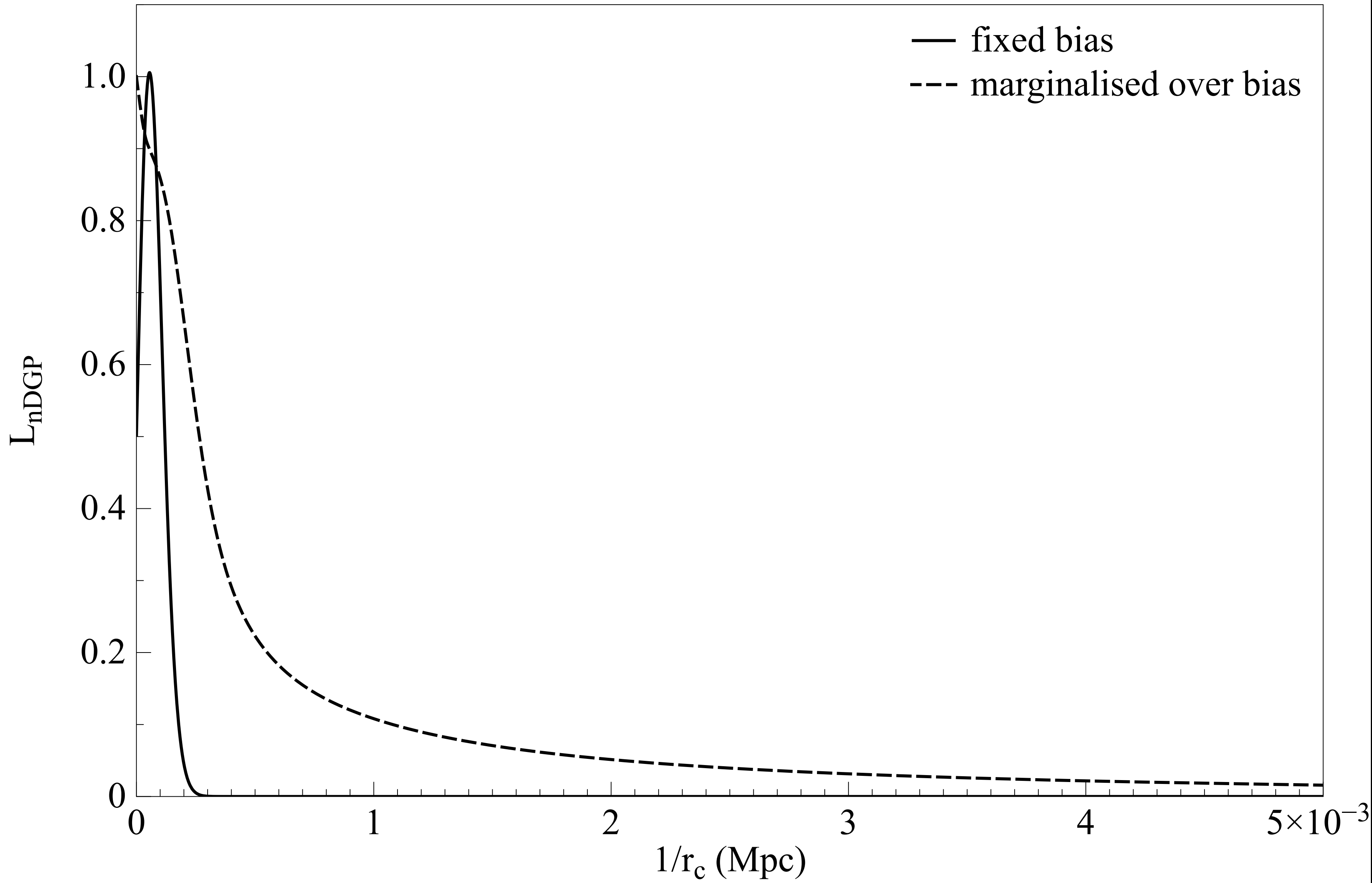
UDM Likelihood



nDGP Likelihood



Results

- UDM: $c_\infty \leq 6.1\text{e-}4$ (95%)
  2 orders of magnitude improvement

- nDGP: $r_c \geq$ 340 Mpc (95%)
  first constraints

Future Tests

The same test can be done with other models:
Galileon, f(R), ...
or ΛCDM with different parameters
And new data (e.g. BOSS, BigBOSS, PFS, Euclid, SKA)

Wide-angle redshift distortions in general relativity

Beyond the plane-parallel and Newtonian approach: Wide-angle redshift distortions and convergence in general relativity

Daniele Bertacca[a], Roy Maartens[a,b], Alvise Raccanelli[c,d], Chris Clarkson[e]

arXiv:1205.5221

AR, Bertacca, Maartens, Clarkson, in prep.

GR corrections

When looking at larger scales the Newtonian description is not anymore accurate.

We need to include General Relativistic corrections

Gauge-invariant overdensity

$$\Delta_s = b\left[\left(1+\frac{1}{3}\beta\right)\mathcal{A}_0^0 + \gamma\mathcal{A}_0^2 + \frac{\alpha\beta}{\chi}\mathcal{A}_1^1 + \frac{2}{3}\beta\mathcal{A}_2^0\right]$$

$$\mathcal{A}_\ell^n(\mathbf{x},\mathbf{z}) = \int \frac{\mathbf{d^3k}}{(\mathbf{2}\pi)^\mathbf{3}}(\mathbf{ik})^{-\mathbf{n}}\mathbf{L}_\ell(\mathbf{n}\cdot\hat{\mathbf{k}})\mathbf{e}^{\mathbf{ik}\cdot\mathbf{x}}\delta(\mathbf{k},\mathbf{z})$$

γ is a purely GR term that vanishes in the Newtonian limit

Expansion of the correlation function

$$\xi_{ss} = b(z_1)b(z_2) \sum_{\ell_1,\ell_2,L,n} B^{\ell_1,\ell_2,L}_{ss\ n}(\chi_1,\chi_2) S_{\ell_1,\ell_2,L}(\mathbf{n_1},\mathbf{n_2},\mathbf{n_{12}}) \times$$
$$\times \xi^n_L(\chi_{12}; z_1, z_2)$$

$$\xi^n_L(\chi; z_1, z_2) = \int \frac{dk}{2\pi^2} k^{2-n} j_L(\chi k) P_\delta(k; z_1, z_2)$$

$$B^{000}_{ss\,0} = \left(1 + \frac{1}{3}\beta_1\right)\left(1 + \frac{1}{3}\beta_2\right)$$

$$B^{000}_{ss\,4} = \gamma_1\gamma_2$$

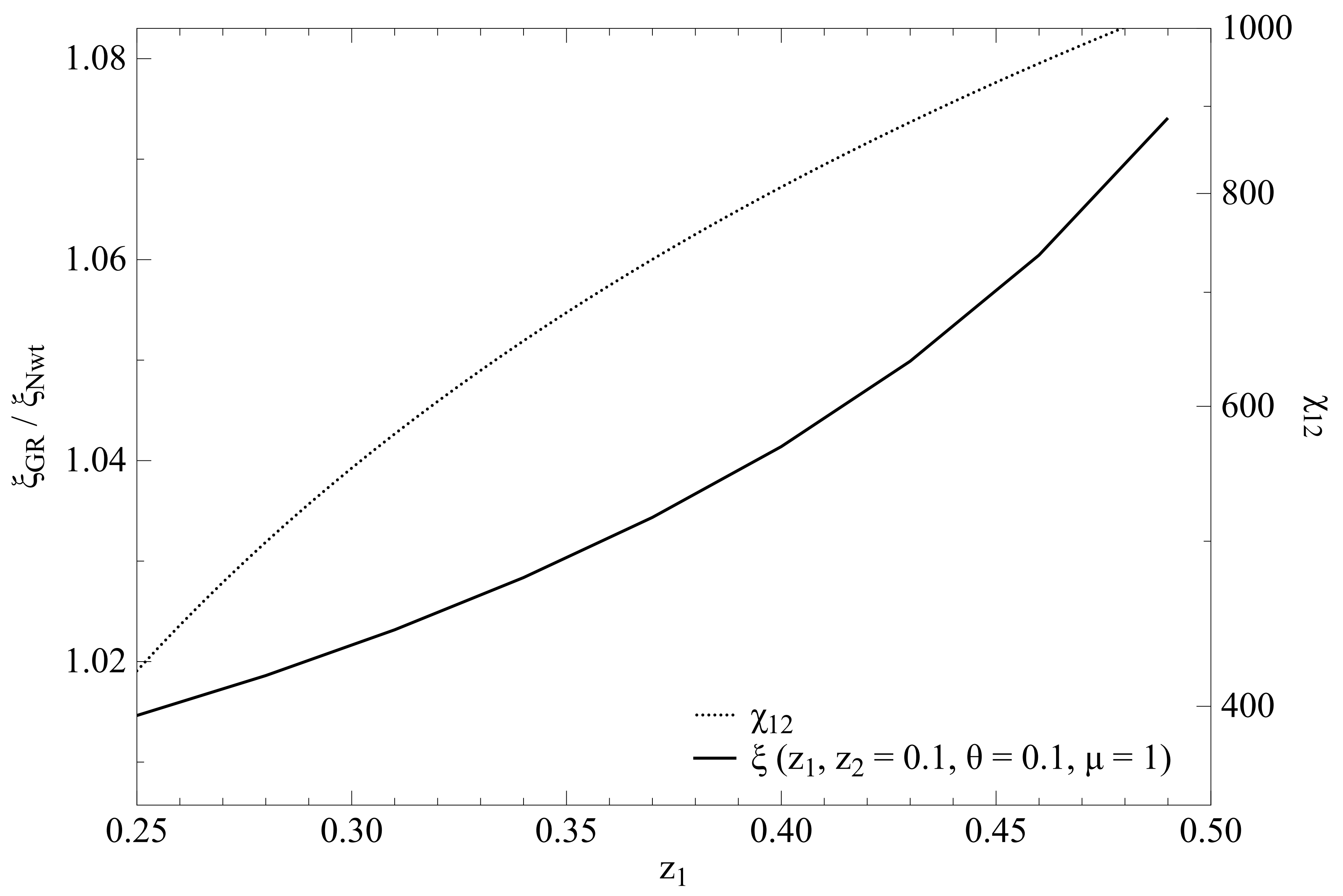
$$B^{101}_{ss\,3} = \sqrt{3}\chi_1^{-1}\beta_1\alpha_1\gamma_2$$

Standard terms

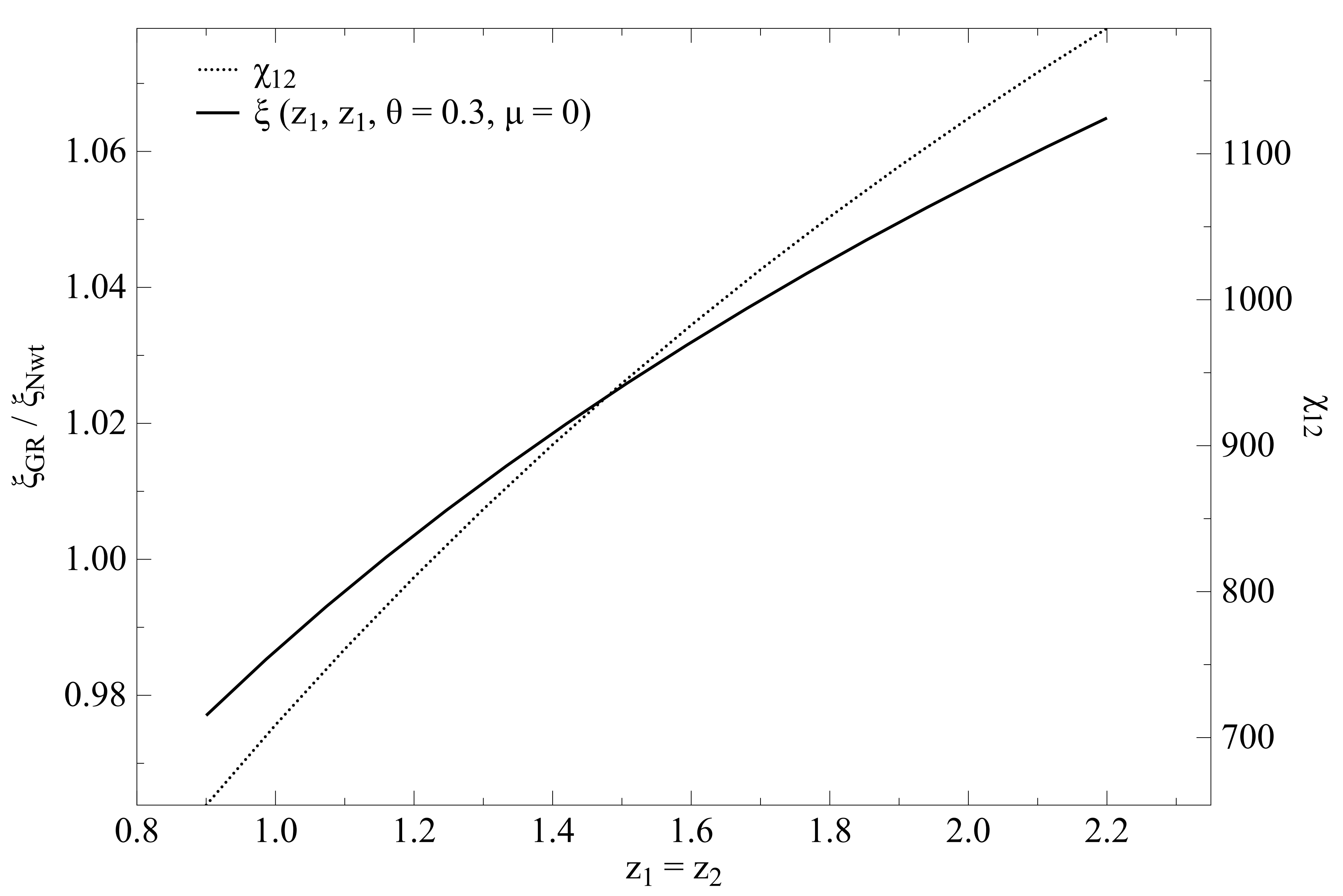
Pure GR term

Mixed terms including mode coupling and GR

Along the line of sight



Across the line of sight



Wide-angle redshift distortions in general relativity

Sample variance is a problem

BUT

future surveys and new ideas (e.g. Seljak et al. multi-tracer) might help, so we need to have a precise theoretical model

Conclusion

Large-scale RSD can be used to test cosmological models

If we want to measure the growth with high precision (see White and Guzzo's talks), we need precise modeling and to drop simplifying assumptions

Thank

You