Dark Energy Quest - Ringberg 2012

Using redshift space distortions to test Modified Gravity & Dark Energy

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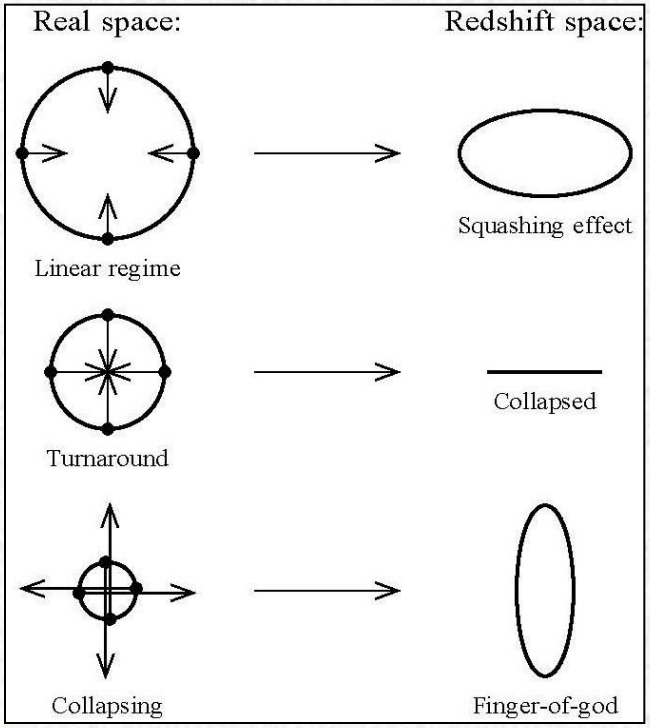
MATHEMATICS & THE PHYSICAL SCIENCES

Outline

- Redshift space distortions
- RSD in f(R) modified gravity
- Recovering $P_{\theta\theta}$ and $P_{\delta\delta}$ from $P(k,\mu)$
- Alcock-Paczynski effect :Testing dark energy using pairs of galaxies

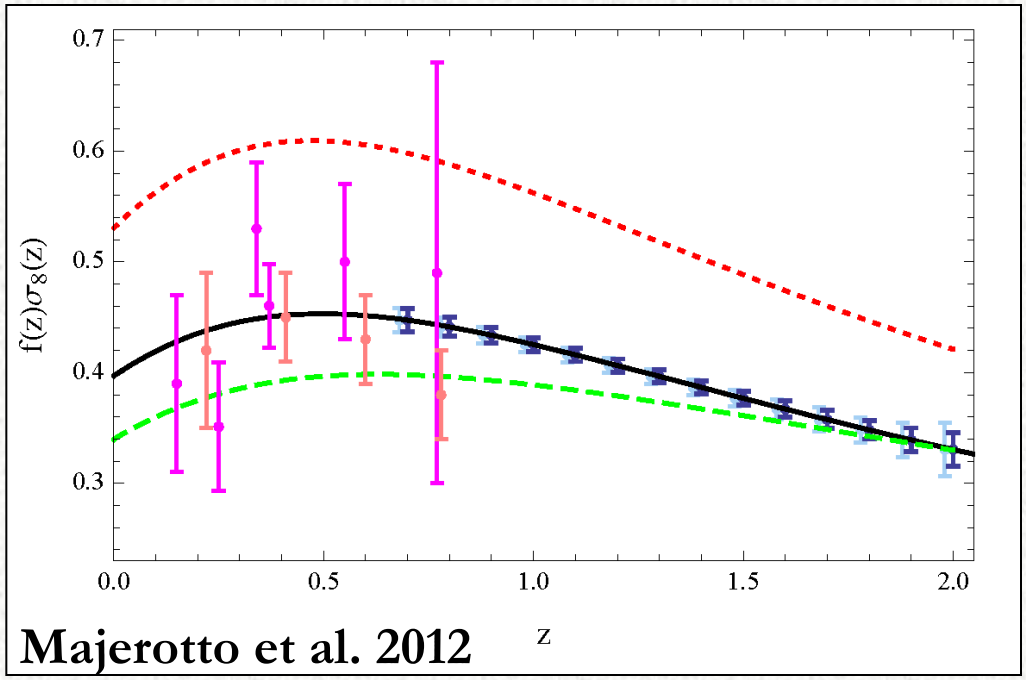
Redshift space distortions



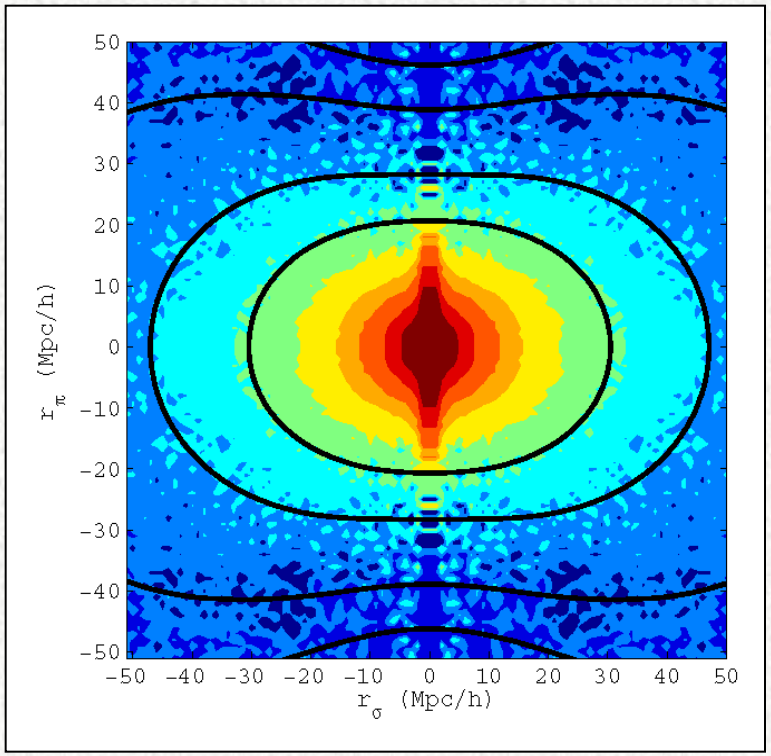
$$s = r + v$$

$$\delta_s(r) = \delta_r(r)(1 + \mu^2\beta)$$

$$\beta = f/b$$



Majerotto et al. 2012



Reid et al. 2012

Redshift space distortions

$$P^s(k,\mu) = \int \frac{\mathrm{d}^3\mathbf{r}}{(2\pi)^3} e^{-i\mathbf{k}\cdot\mathbf{r}} \langle e^{i\lambda\Delta u_z} [\delta(\mathbf{x}) - \theta(\mathbf{x})] \times [\delta(\mathbf{x}') - \theta(\mathbf{x}')] \rangle ,$$

Models for redshift space distortions:

Linear theory

$$P_z(k) = (1 + 2/3\beta + 1/5\beta^2) P_r(k)$$

Kaiser (1987)

$$\beta = f/b$$

Quasi – linear model

$$P^s(k,\mu) = (P_{\delta\delta} + 2\mu^2 P_{\delta\theta} + \mu^4 P_{\theta\theta}) e^{-(k\mu\sigma_v)^2}$$

Redshift space distortions

P^s

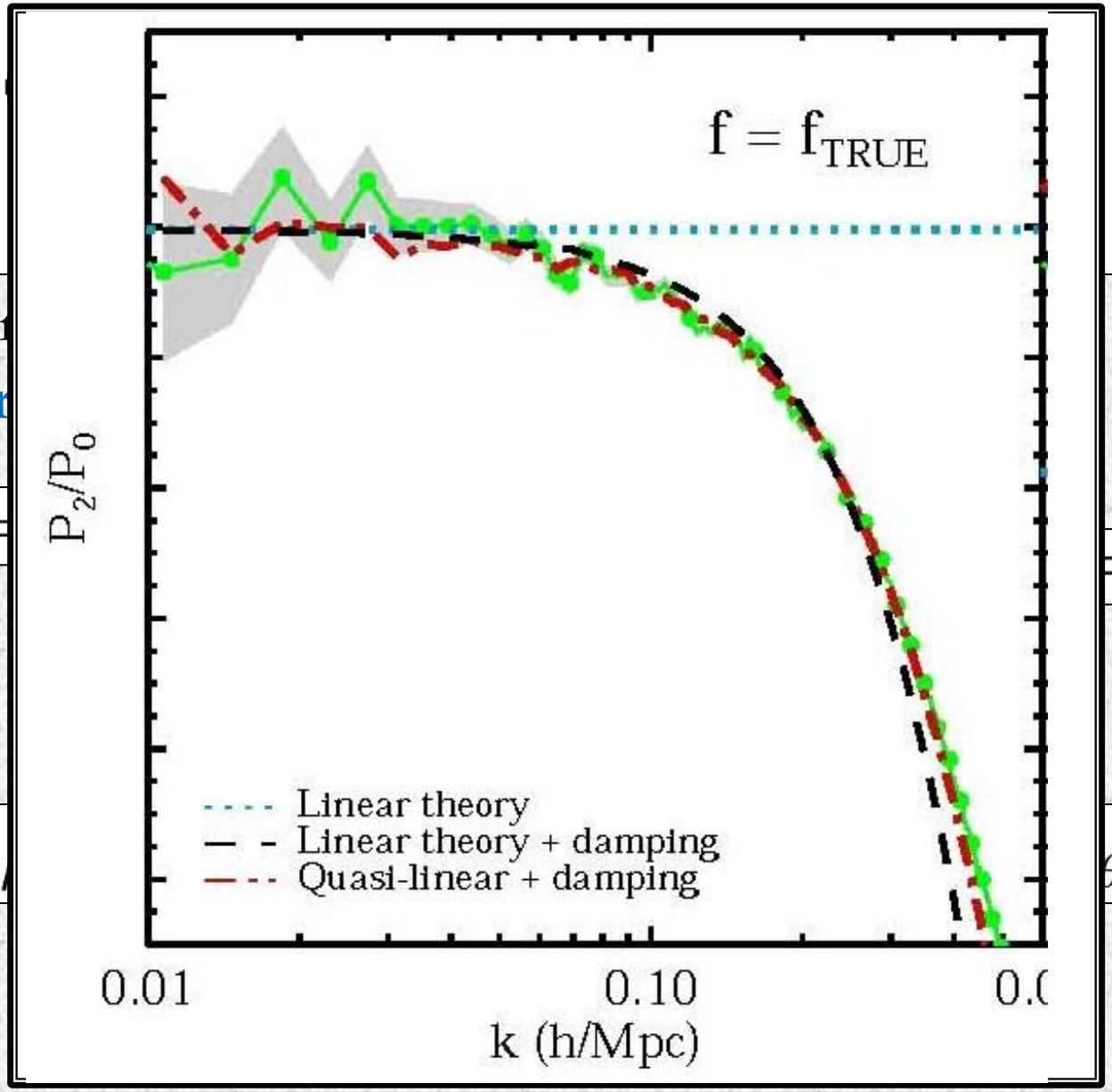
Models for

Linear

$P_z(k) =$ $= f/b$

Quasi

$P^s(k,$ $\theta(k))$

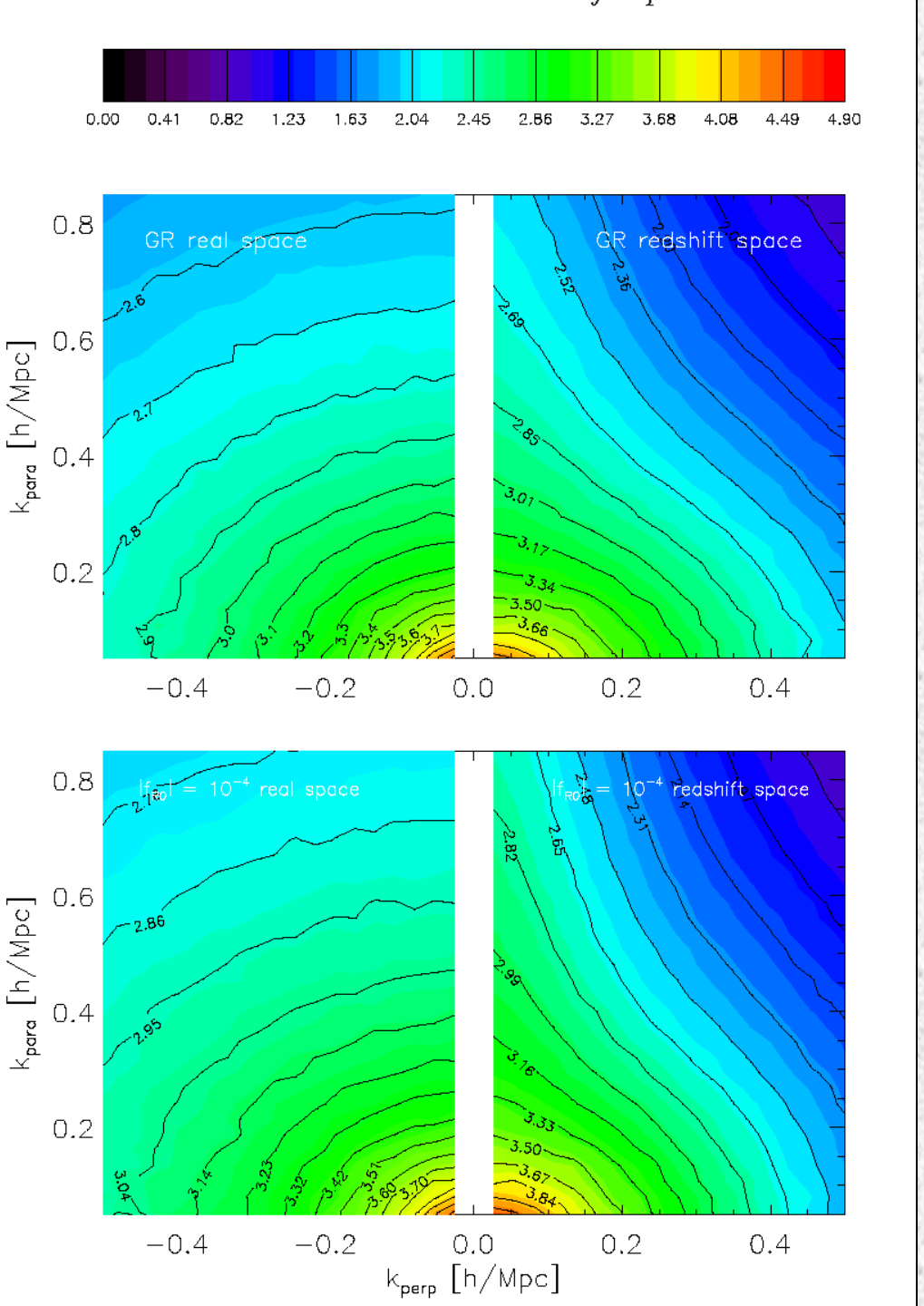


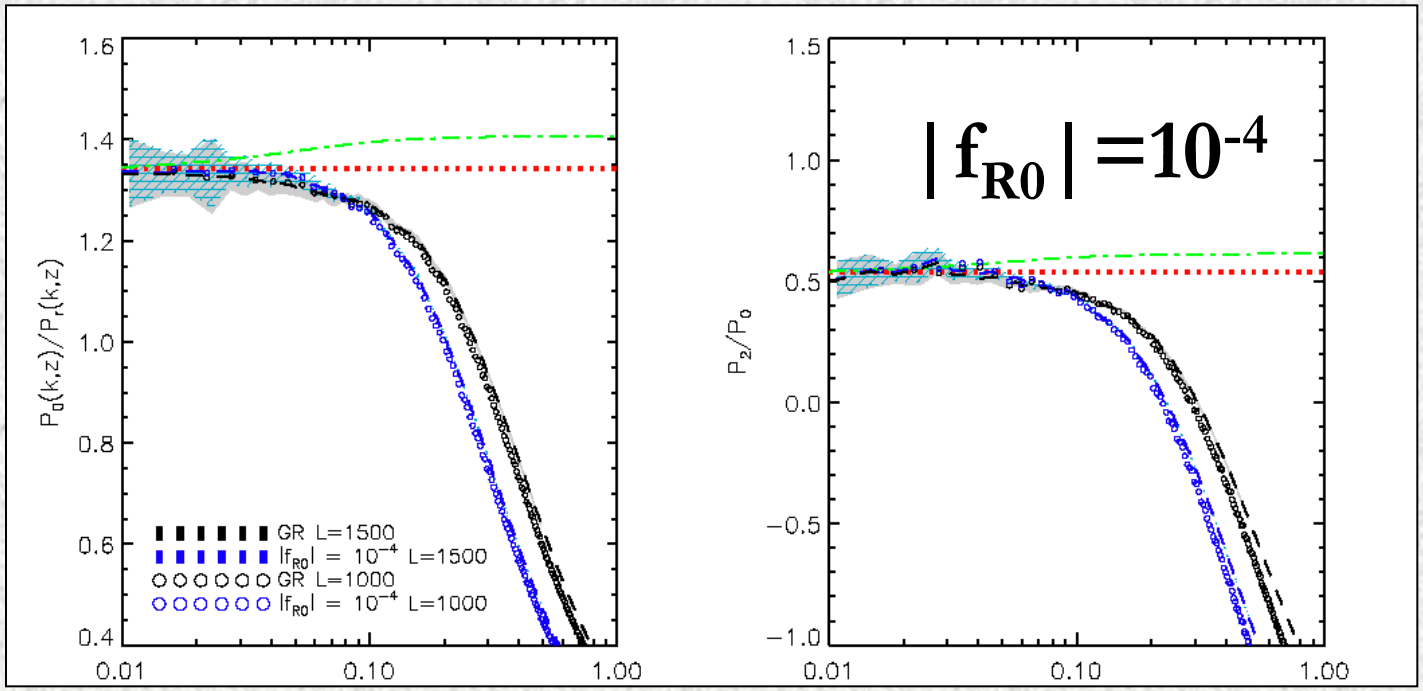
EJ, Baugh & Pascoli 2011

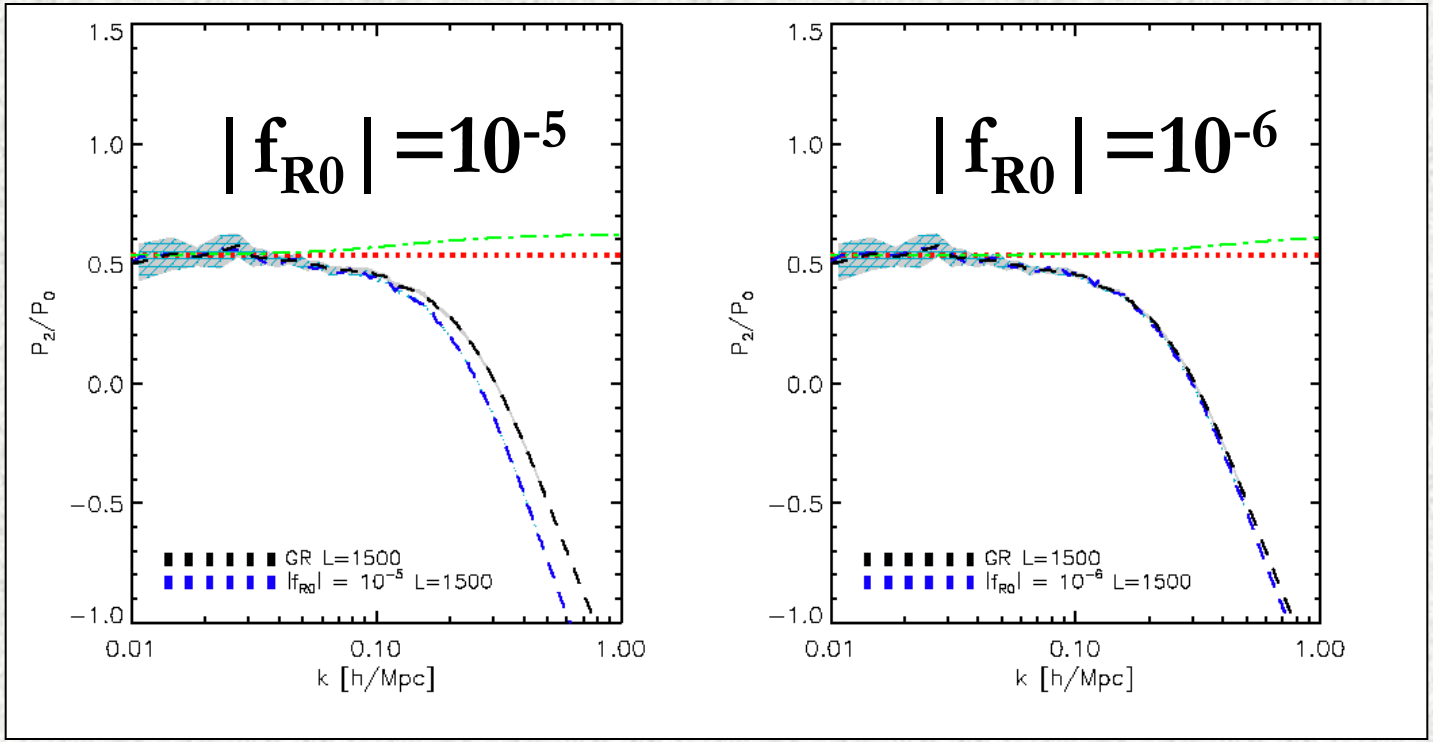
RSD in f(R) gravity

Model of Hu & Sawicki (2007)

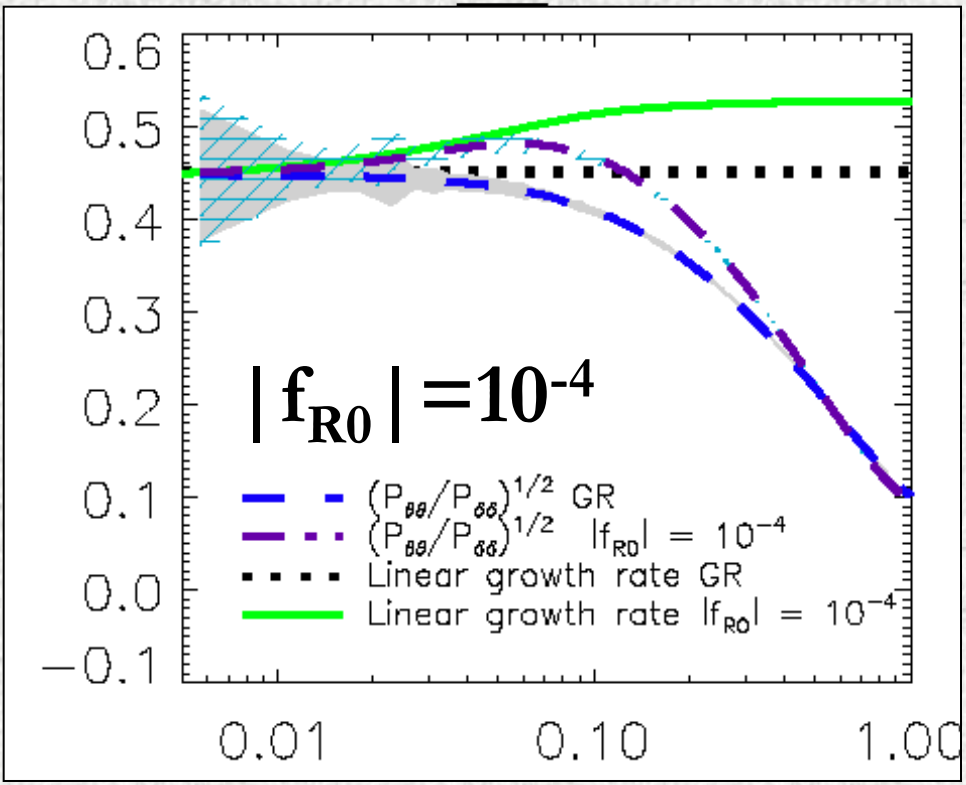
EJ, Baugh, Li, Zhao & Koyama 2012

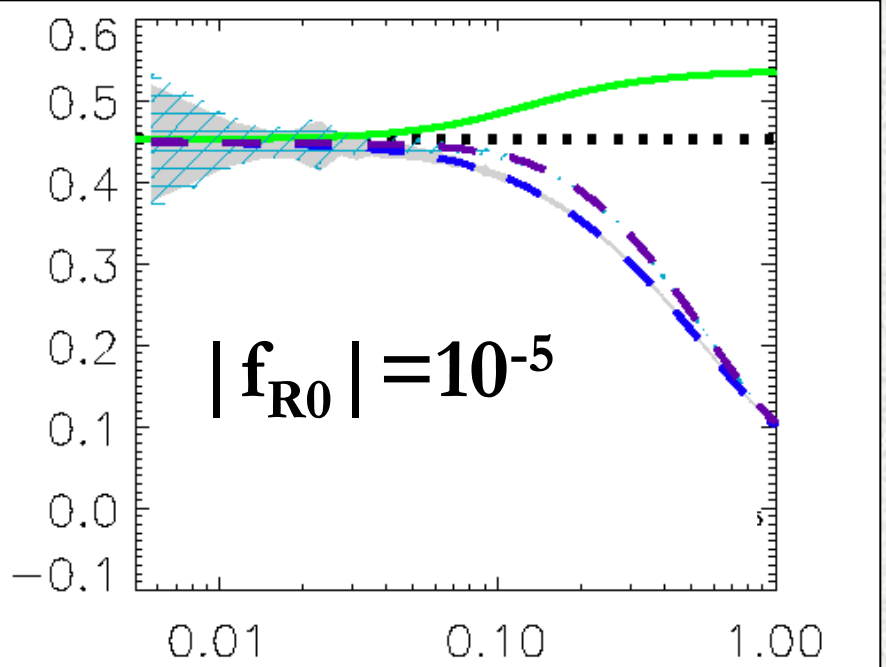


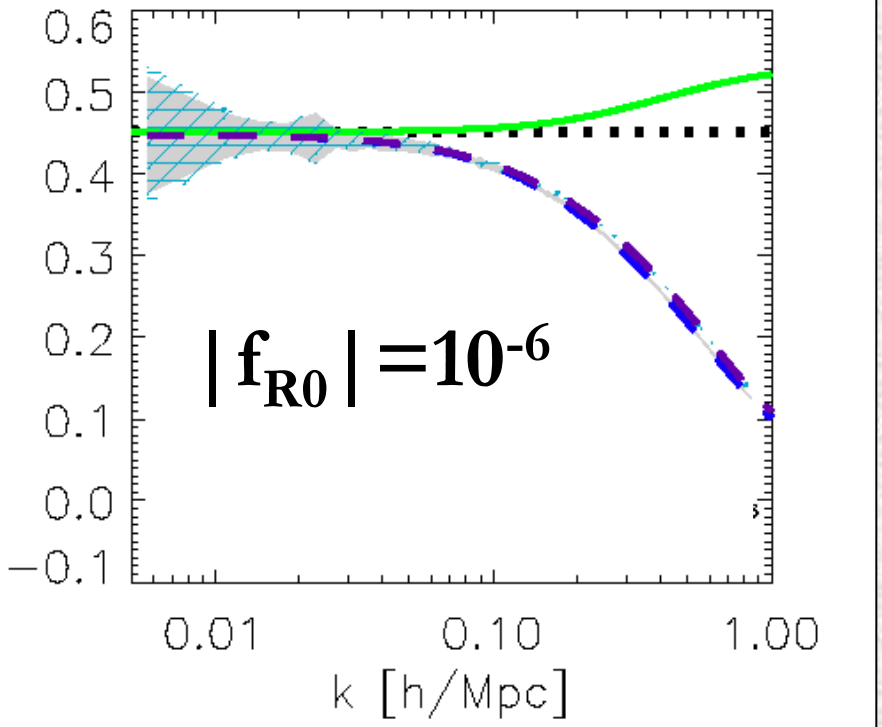

$P_0(k,z)/P_r(k,z)$
GR L=1500
$|f_{R0}| = 10^{-4}$ L=1500
GR L=1000
$|f_{R0}| = 10^{-4}$ L=1000
$|f_{R0}| = 10^{-4}$
P_2/P_0


$|f_{R0}| = 10^{-5}$
$|f_{R0}| = 10^{-6}$
P_2/P_0
GR L=1500
$|f_{R0}| = 10^{-5}$ L=1500
$|f_{R0}| = 10^{-6}$ L=1500
k [h/Mpc]

$P_{\theta\theta}$





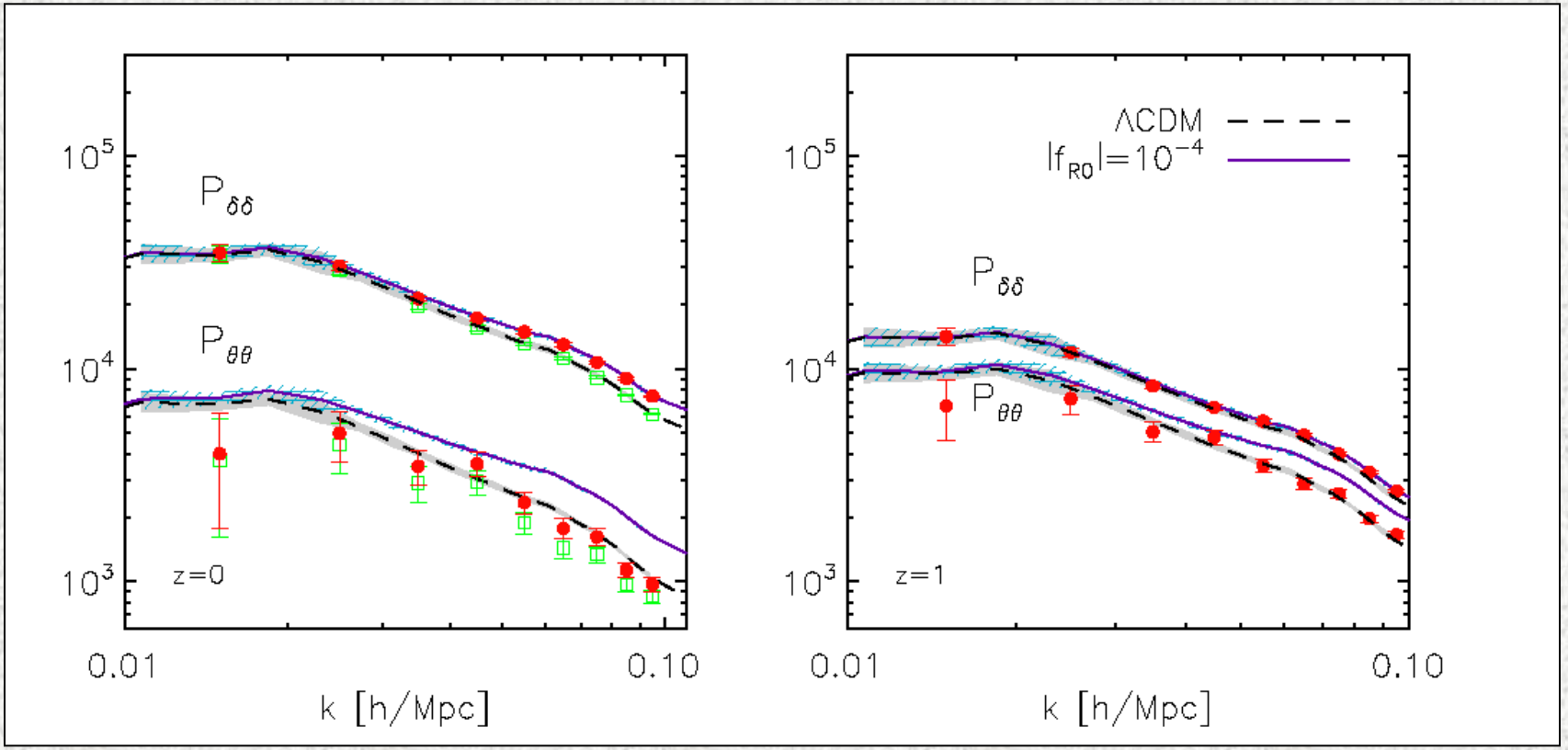


$$\vec{\nabla}\cdot\vec{v} = \theta = -Hf(a)\delta(a)$$

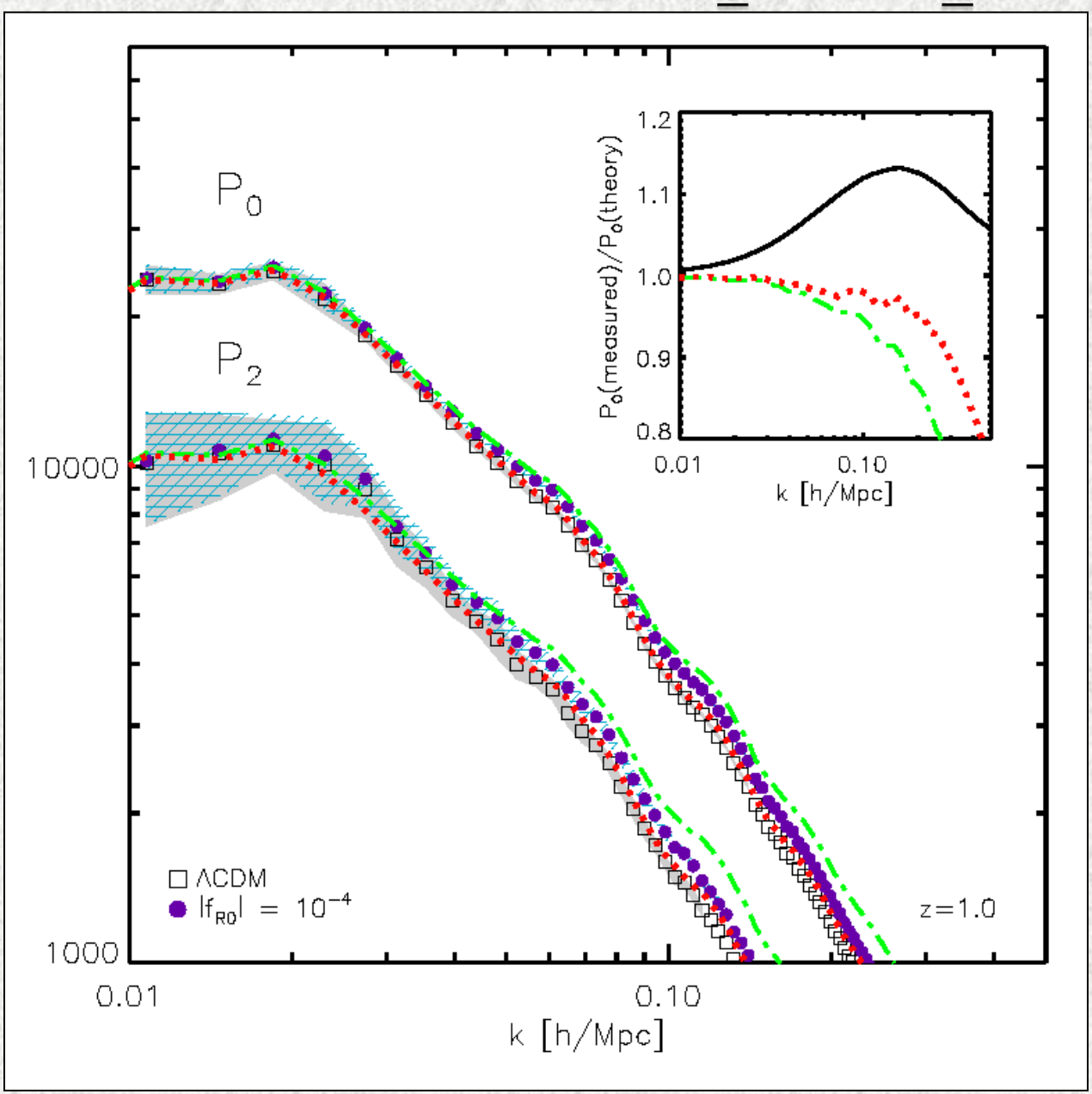
EJ, Baugh, Li, Zhao & Koyama 2012

Extracting $P_{\theta\theta}$ & $P_{\delta\delta}$

$$P^s(k,\mu) = (P_{\delta\delta} + 2\mu^2 P_{\delta\theta} + \mu^4 P_{\theta\theta})$$



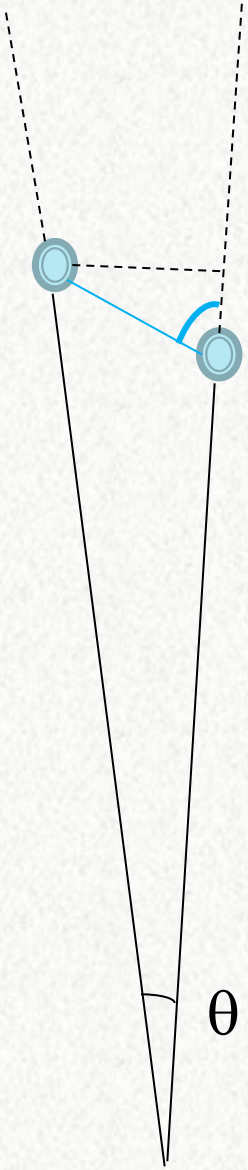
Modelling P_0 & P_2



EJ, Baugh, Li, Zhao & Koyama 2012

Testing DE
using redshift space distortions
& pairs of galaxies

Distribution of pairs of galaxies



Real space

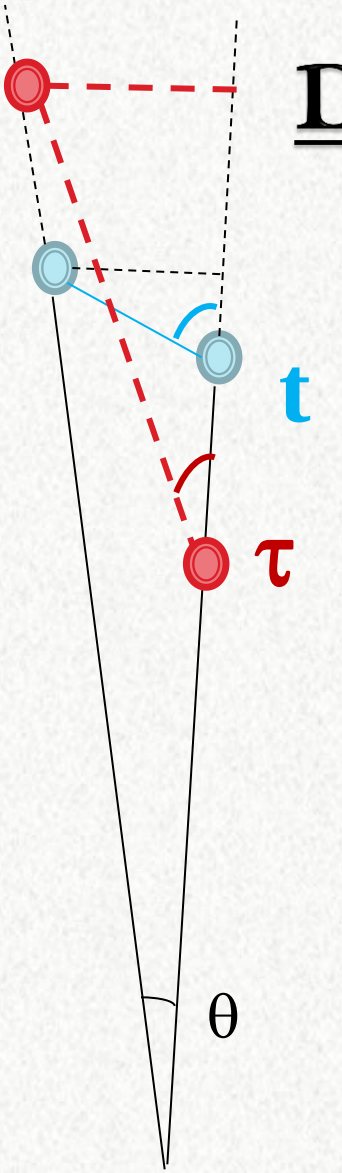
Assuming homogeneity & isotropy & flat Universe

$$\sin^2 t = \{1 + \left(\cot\theta - \frac{\chi_A}{\chi_B \sin\theta} \right)^2 \}^{-1}$$

Expect the separation vector to be randomly orientated

$$\mathrm{PDF(t)} = \phi(\mathrm{t})$$

Distribution of pairs of galaxies



Redshift space

Apparent angle of inclination

$$t \longrightarrow \tau$$

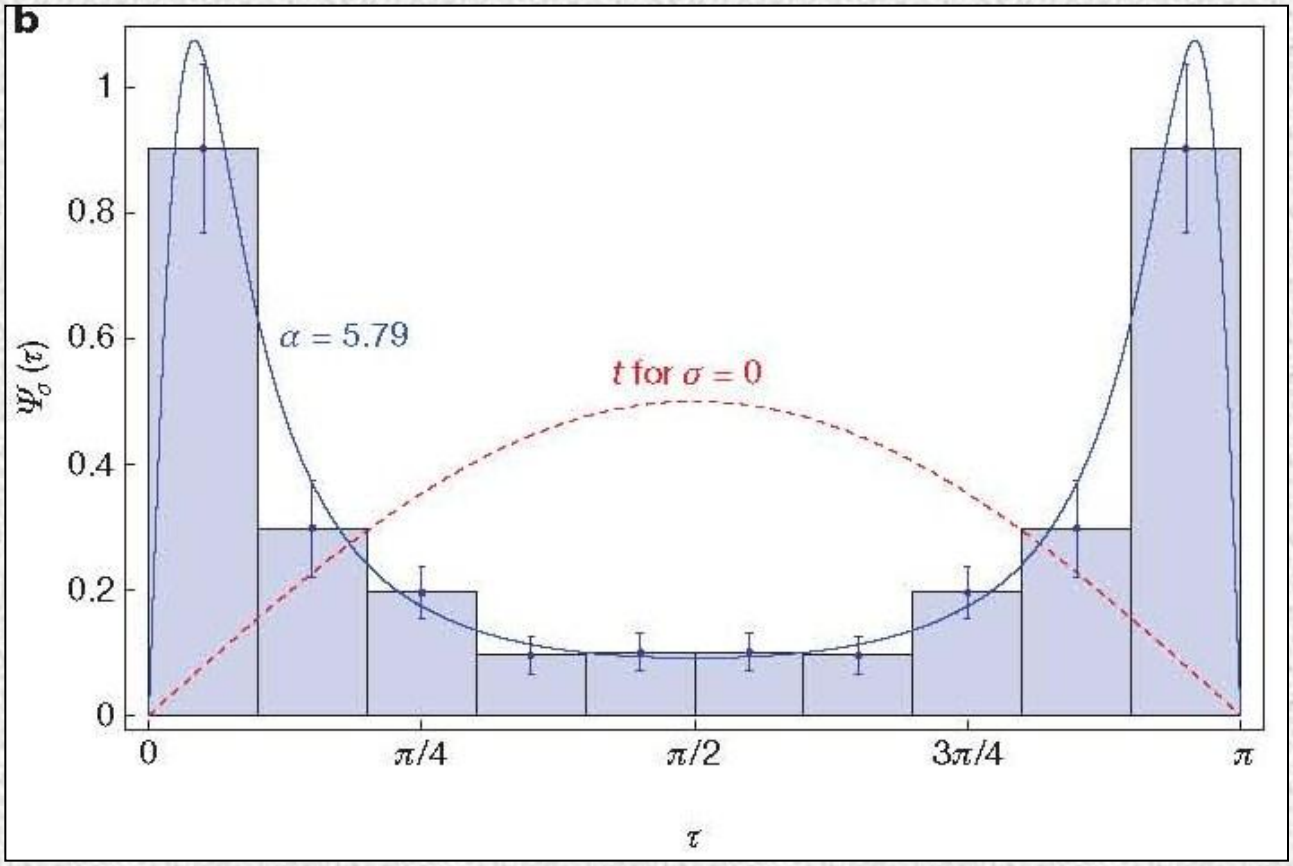
Distant observer approximation

$$\frac{\tan\tau}{\tan t} \approx \frac{\mathrm{dr}^{\mathrm{obs}}}{\mathrm{dr}}$$

Conservation of probability

$$\psi(\tau)\mathrm{d}\tau = \phi(\mathrm{t})\mathrm{dt}$$

The test in practice...

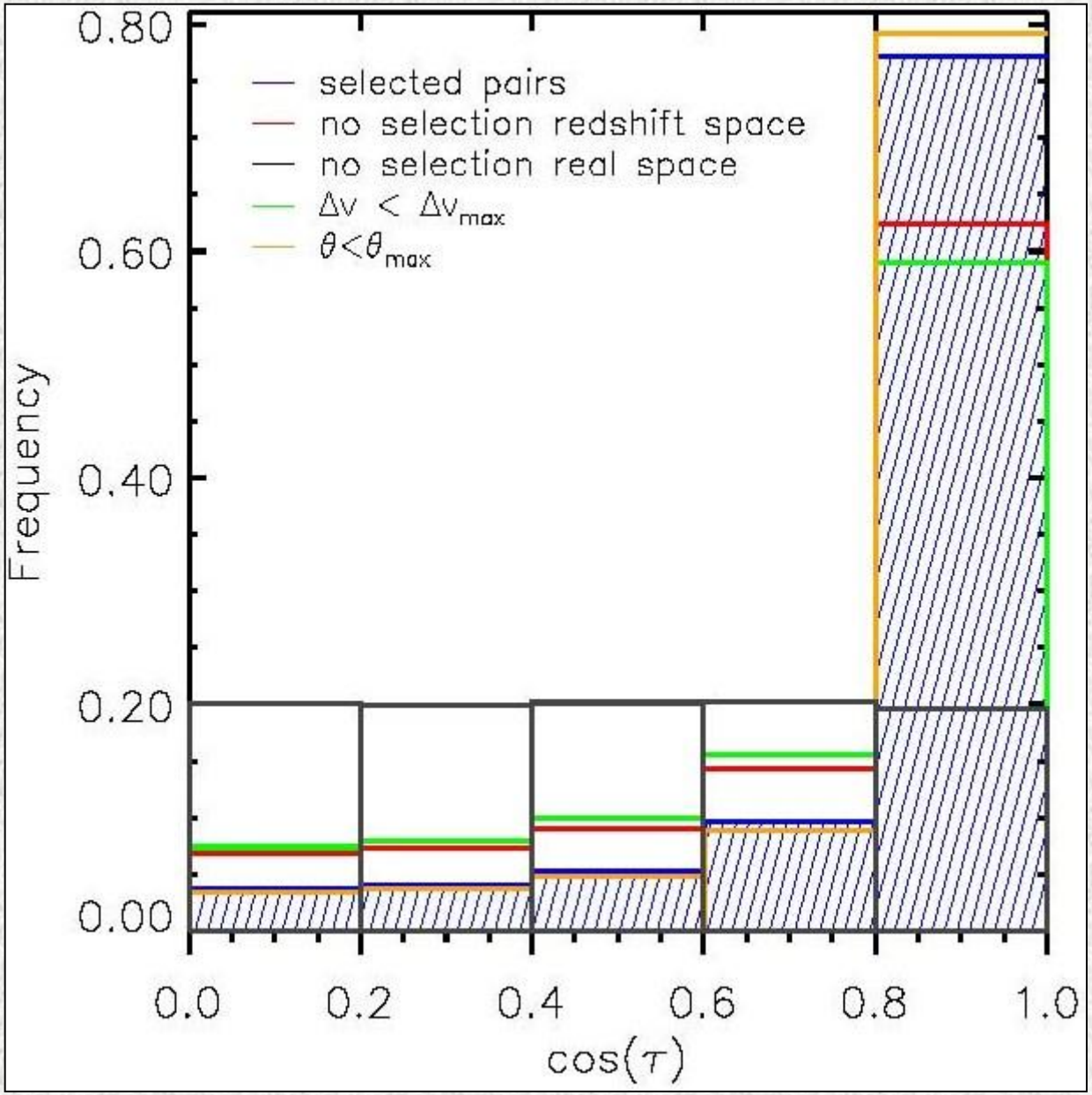


Marinoni & Buzzi 2011

Normalisation parameter α depends on selected pairs

- **How robust is the selection criterion?**
- **Is the normalisation independent of z?**
- **How well does this test work in different cosmologies?**

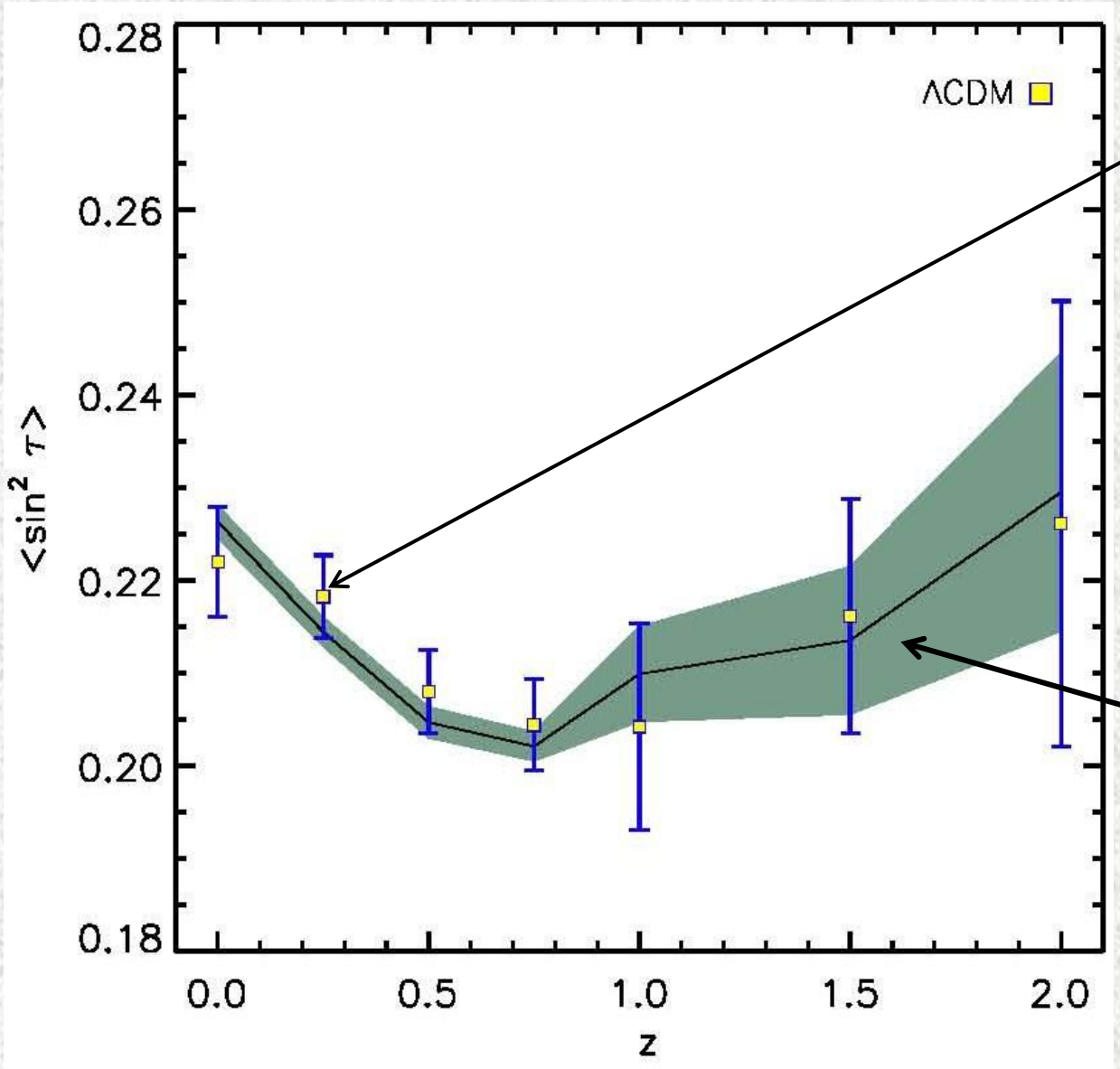
Simulation results



Measurements of the distribution in LCDM at z=0

Selection effects very important as including outliers randomizes the distribution

Simulation results



Measurements the first moment of the distribution

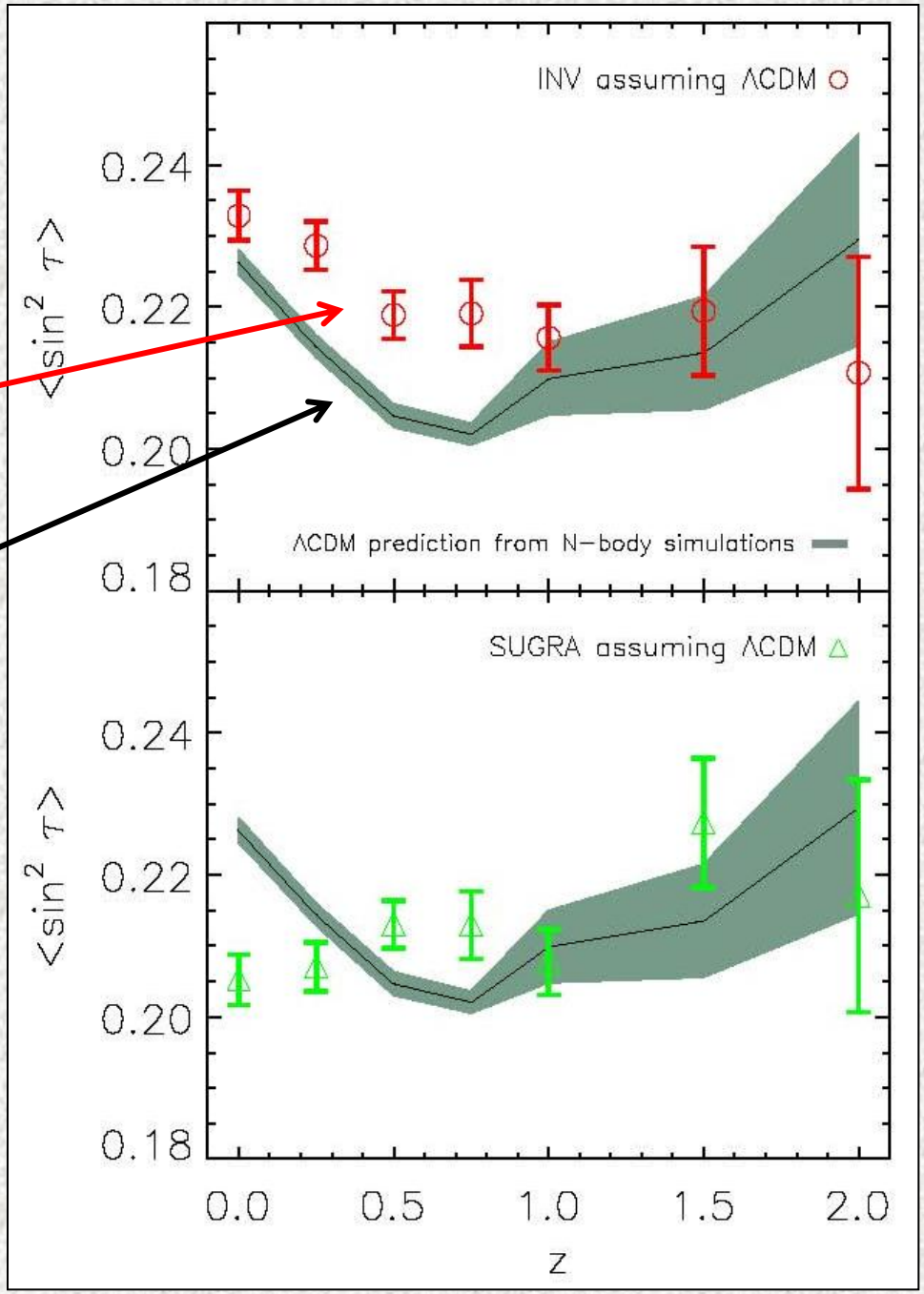
LCDM prediction using normalisation measured from simulation

EJ, CMB & SP 2011

Improved test using simulations

Measured assuming LCDM cosmology

Prediction from a LCDM simulation



EJ, CMB & SP 2011

Summary

- **RSD signal in f(R) gravity:**
  - P_2/P_0 deviations at small scales
  - Velocity P(k) – see also Li et al. 2012
- **RSD models for P(k,μ)**
  - not accurate enough to extract $P_{\theta\theta}$
  - $P_{\delta\delta}$ can be reconstructed
- **Future work – signals of MG in z-space clustering of halos/galaxies.**
- Using pairs of galaxies in z-space – promising probe of dark energy.