Angular correlation function from small to BAO scale

Fernando de Simoni
Observatório Nacional/DES-Brazil

Definition and Estimators

Joint probability 2-point correlation definition

$$dP_{12} = \mathcal{N}(\theta_1)\mathcal{N}(\theta_2)\left[1 + \omega(\theta)\right] d\Omega_1 d\Omega_2$$

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DARK ENERGY SURVEY

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Landy & Szalay estimator

ApJ **412**, 64 (1993)

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$$dP_{12} = \mathcal{N}(\theta_1)\mathcal{N}(\theta_2)\,[1+\omega(\theta)]\,d\Omega_1 d\Omega_2$$

$$\boxed{\omega(\theta) = \int_0^\infty dz_1\,\phi(z_1)\int_0^\infty dz_2\,\phi(z_2)\,\xi(r;\bar{z})}$$

Angular to spatial theoretical relation

$$\boxed{\omega(\theta) = \int_0^\infty dz_1\, \phi(z_1) \int_0^\infty dz_2\, \phi(z_2)\, \xi(r; \bar{z})}$$

Assuming a power law for the spatial correlation function under the Limber and small angle approximations, follows

$$\xi(r) = \left(\frac{r_0}{r}\right)^\gamma \Rightarrow$$

$$\omega(\theta) = A_\omega(\theta; r_0, \gamma) \int_0^\infty dz\, \phi^2(z) H(z) r^{1-\gamma}$$

$$A_\omega(\theta; r_0, \gamma) = \frac{\Gamma(\frac{1}{2})\Gamma(\frac{\gamma-1}{2})}{\Gamma(\frac{\gamma}{2})}\, r_0^\gamma\, \theta^{1-\gamma}$$

The selection function

Normally in the literature there are 2 ways to denote the selection function:

$$\phi(z) \quad \text{or} \quad \frac{dN}{dz}$$

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Redshift limits must be the survey limits

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Redshift limits must be the survey limits

The selection function must be the true and not the observed

Estimating the ACF from photo-z surveys

DARK ENERGY SURVEY

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2 ways to handle the photo-z on the ACF appear on the literature:

Method 1	Method 2
Arnouts et al. MNRAS **329**, 355 (2002) or any CFHTLS photo-z paper.	Budavári et al. ApJ **595**, 59 (2003) or any SDSS photo-z paper.
• Includes photo-z issues on the ACF estimator. • The selection function is the redshift distribution dN/dz. • Is estimated in the real/"spectroscopic" redshift.	• Does not include the photo-z issues on the ACF estimator. • The selection function models the photo-z uncertainty. • Is estimated in the photo-z redshift.

Method 1

Arnouts et al. MNRAS **329**, 355 (2002)

The idea is to incorporate the photo-z uncertainty is the ACF estimator using the PDFz of each galaxy

$$\hat{\omega}(\theta) = \frac{N_r(N_r-1)}{N_g(N_g-1)}\frac{DD}{RR} - 2\frac{N_r-1}{N_g}\frac{DR}{RR} + 1$$

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$$\boxed{DD = \sum_{i,j}^{N_g} P^i P^j} \Rightarrow P^i = \int_{z_1}^{z_2} dz\, \mathrm{PDF}^i(z)$$

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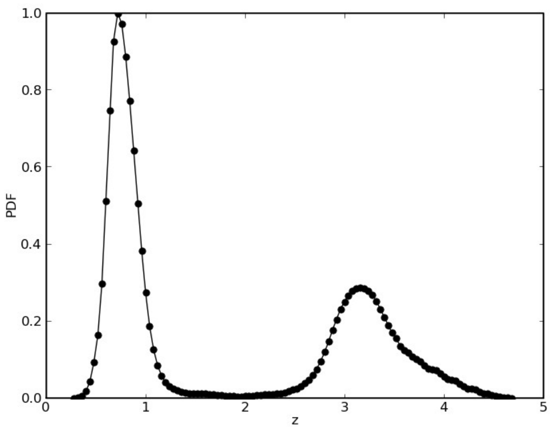

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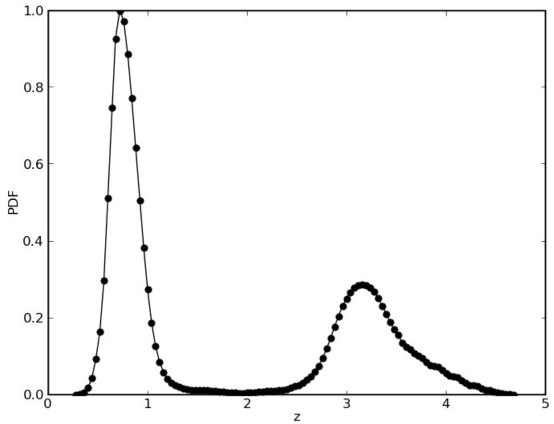
Real redshift



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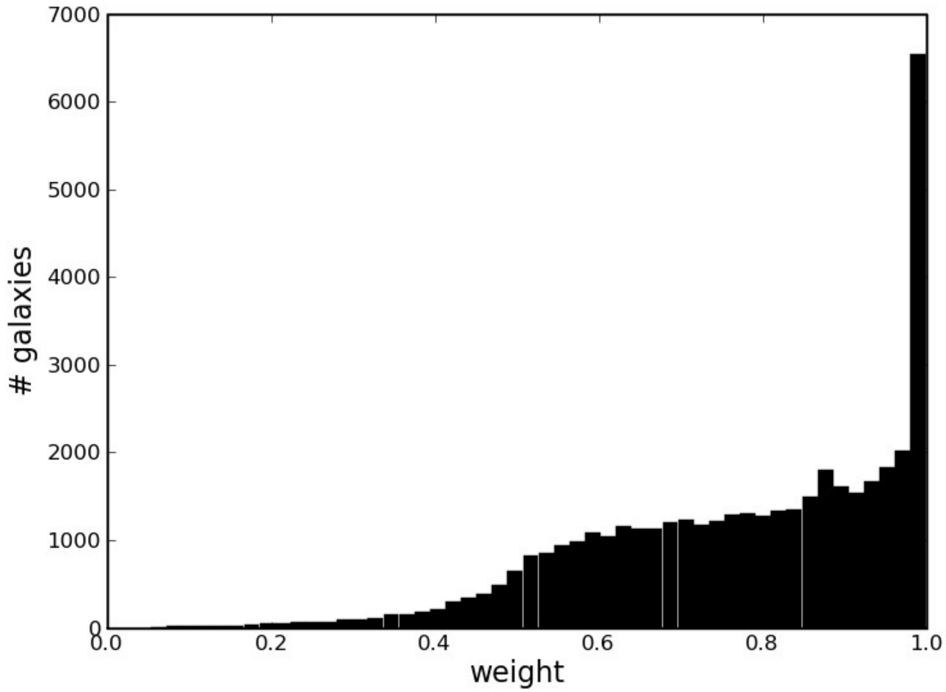
What about the random distribution?



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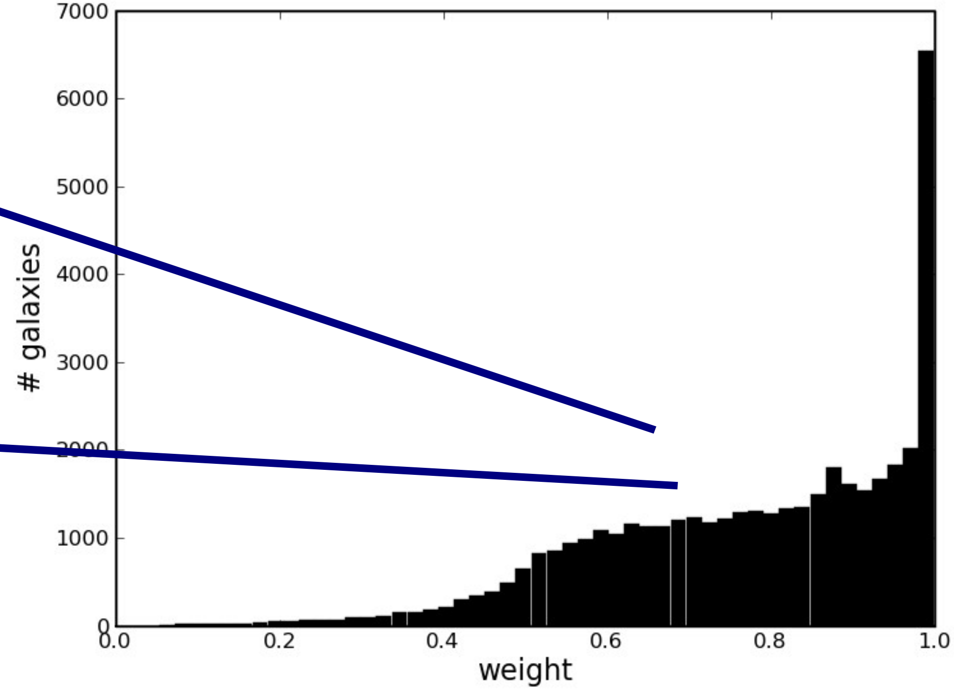
What about the random distribution?

$$RR = \sum_{i,j}^{N_r} P_r^i P_r^j$$

$$DR = \sum_{i,j}^{N_g, N_r} P^i P_r^j$$



The photo-z uncertainty is include in the pair count

Method 2

Budavári et al. ApJ **595**, 59 (2003)

How to incorporate the photo-z uncertainty on the selection function?

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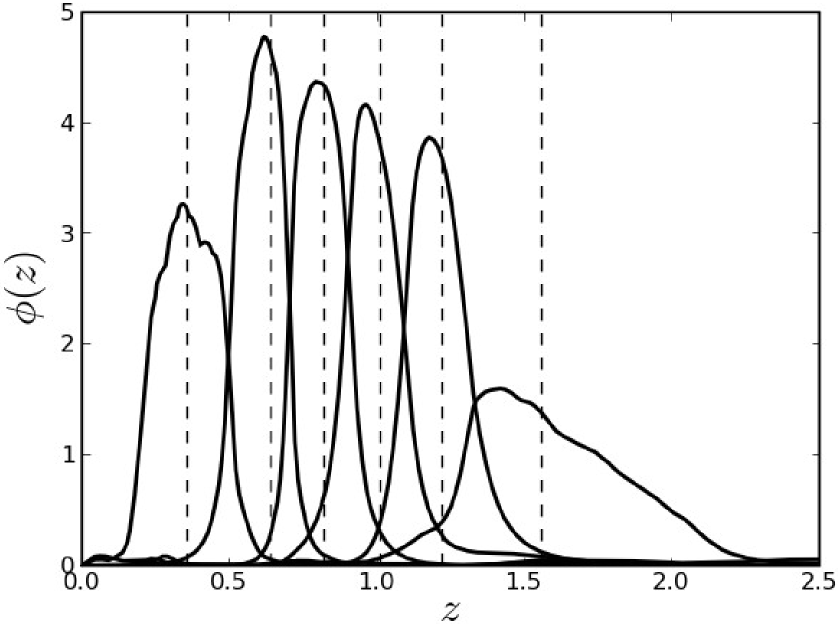
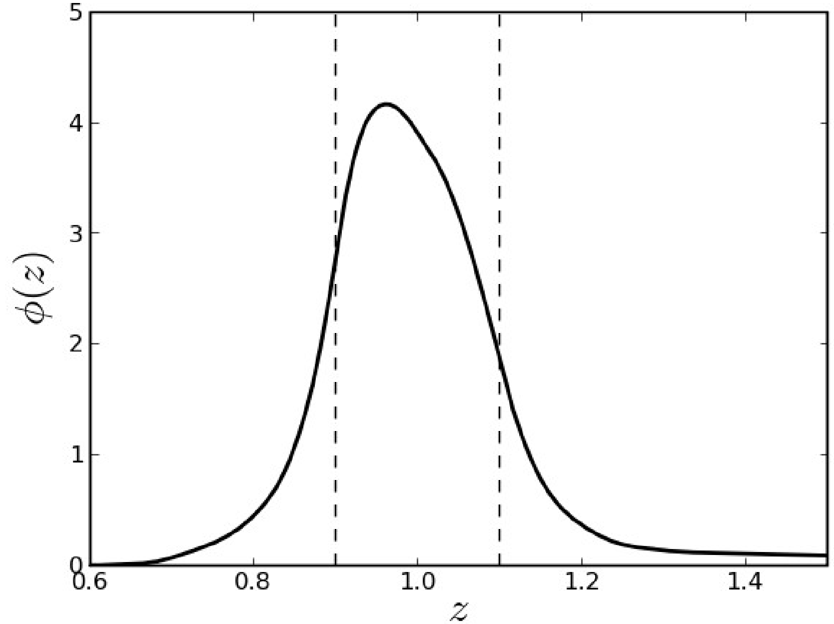
How to incorporate the photo-z uncertainty on the selection function?

$$\phi(z) \propto \sum_{i=1}^{N_g} PDF^i(z)$$





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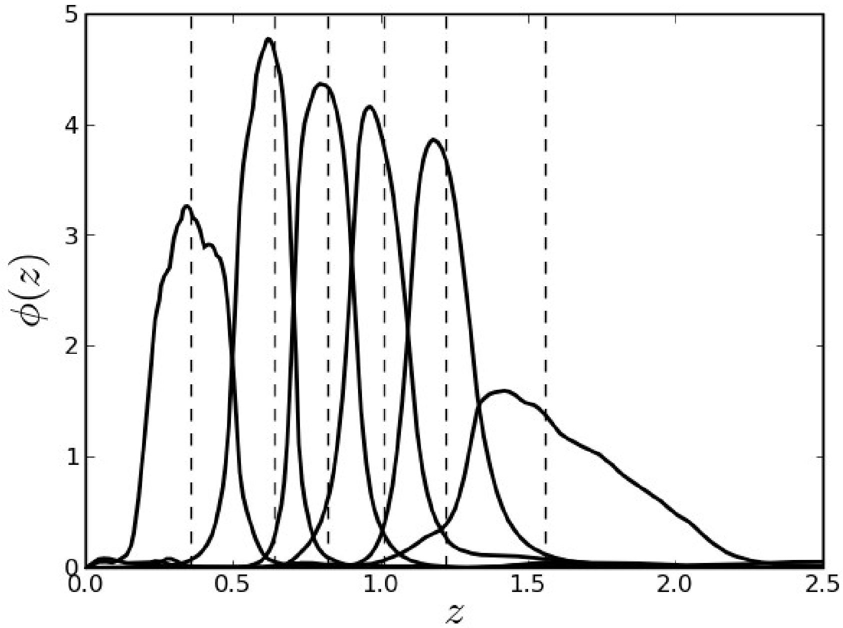
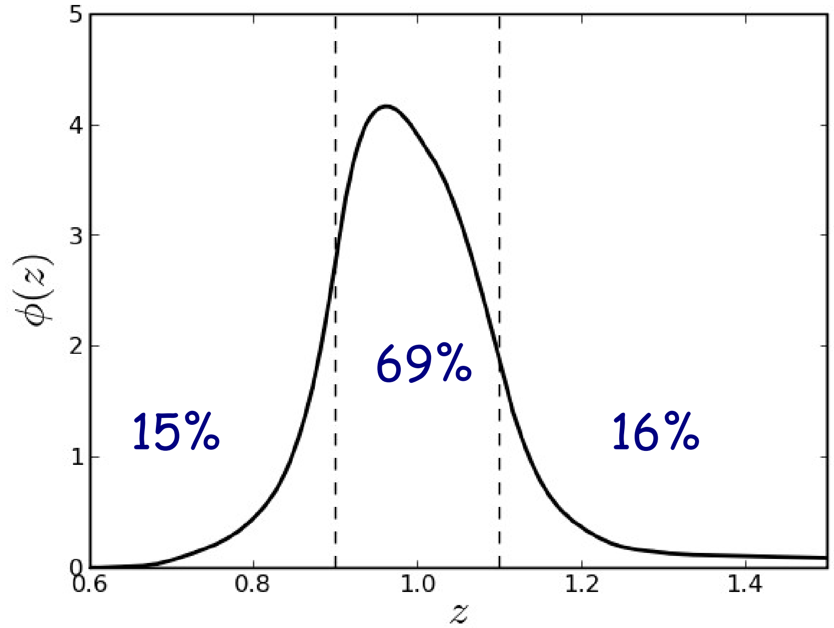
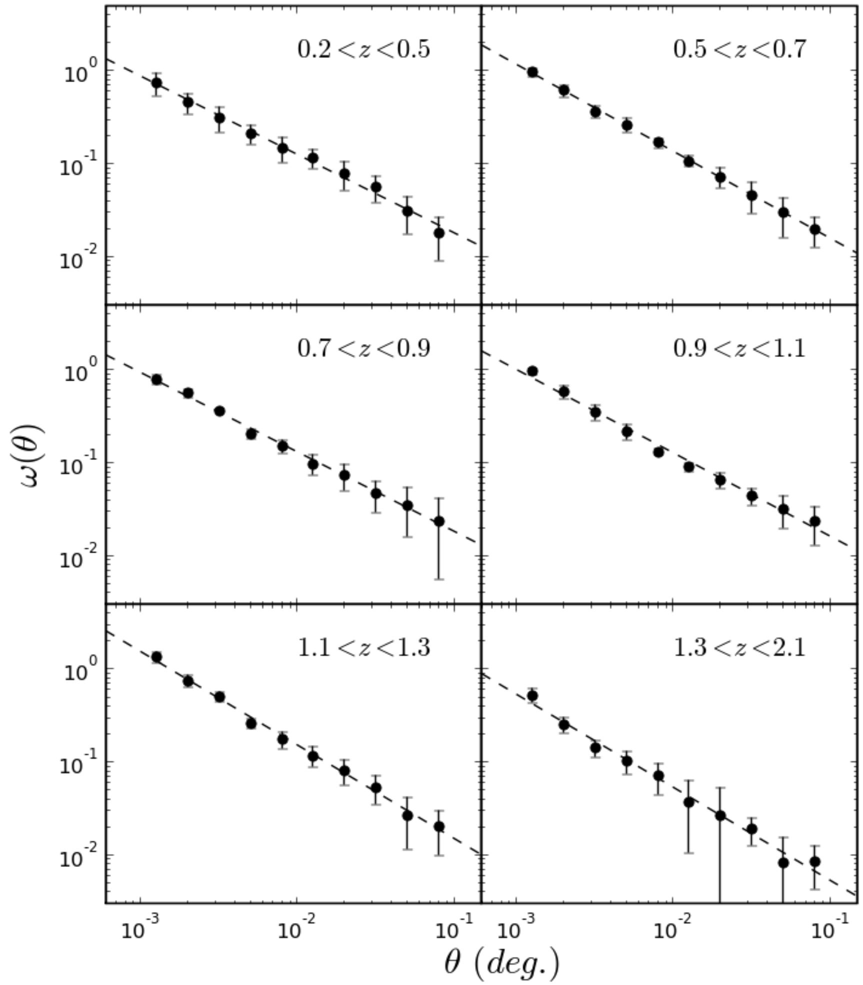




CFHTLS results



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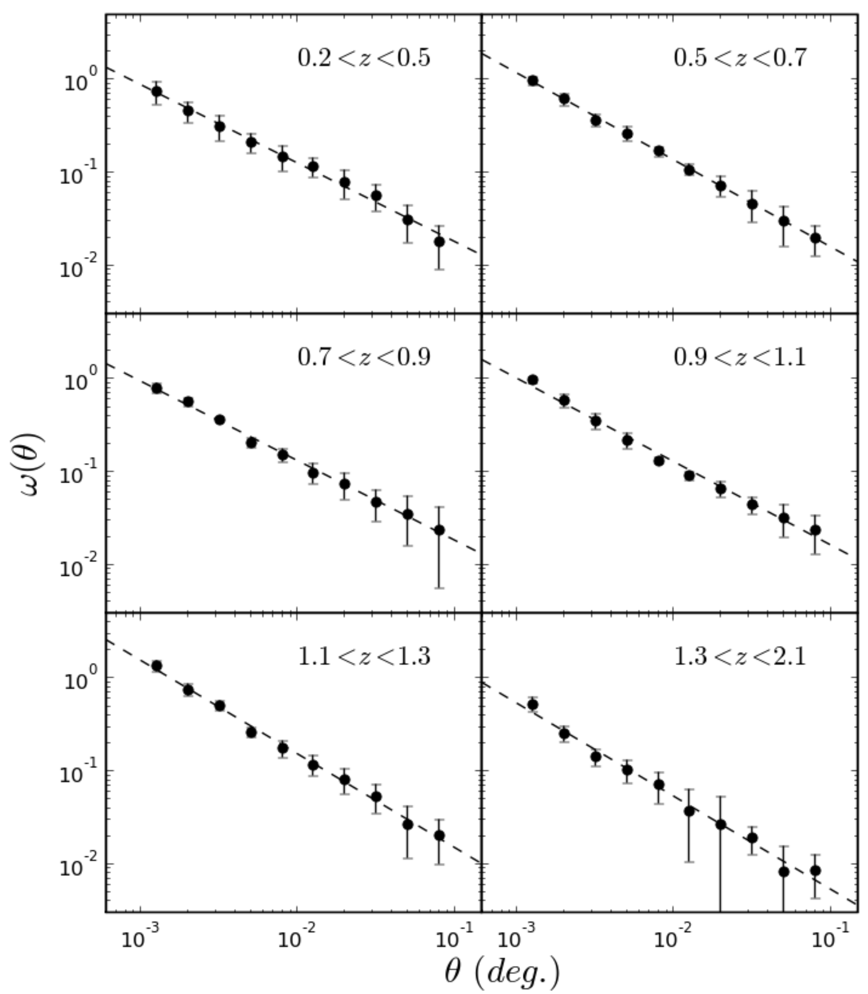
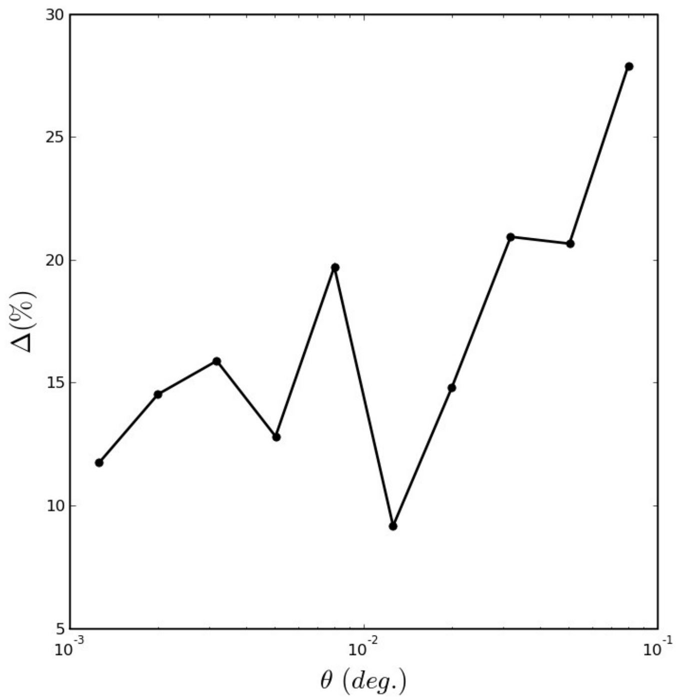
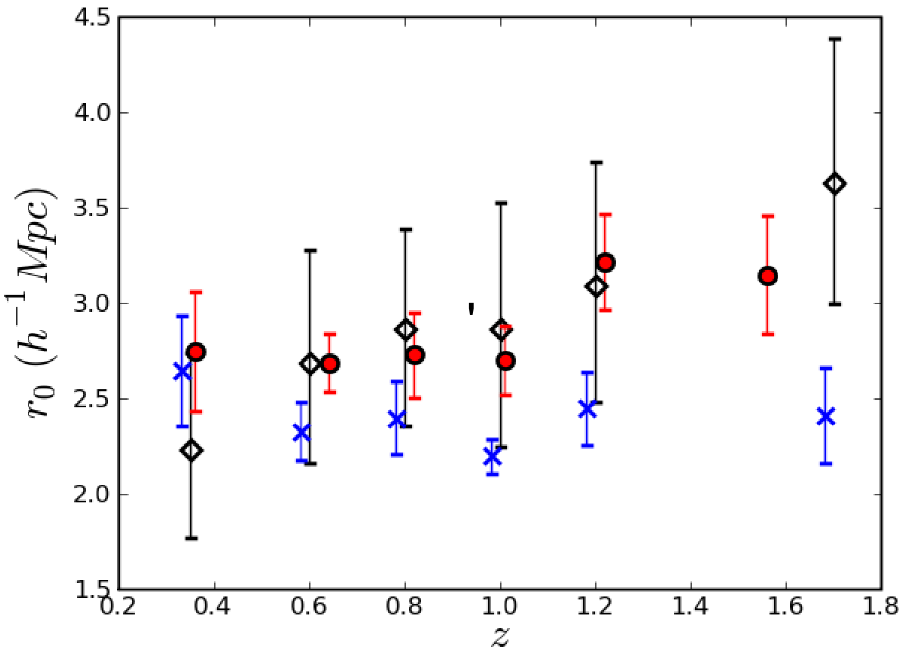
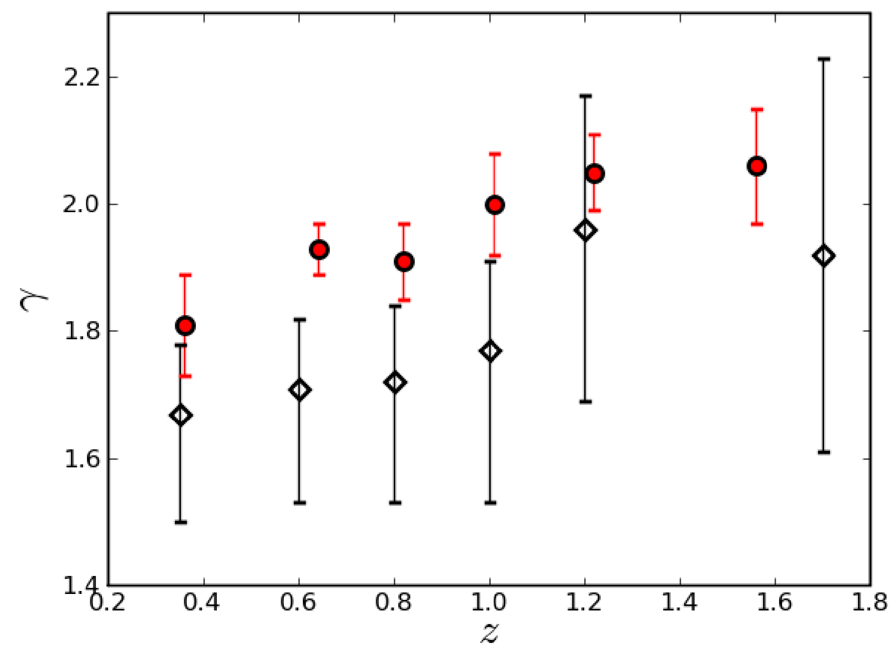




Appling the PDF on the pair count increases the ACF power by ~15%

CFHTLS results





	Method 1		Method 2		MIX	
redshift	$r_0\ (h^{-1}Mpc)$	γ	$r_0\ (h^{-1}Mpc)$	γ	$r_0\ (h^{-1}Mpc)$	γ
$0.2 \leq z \leq 0.5$	2.65 ± 0.29	1.83 ± 0.08	2.75 ± 0.31	1.81 ± 0.08	2.93 ± 0.33	1.83 ± 0.08
$0.5 \leq z \leq 0.7$	2.33 ± 0.15	1.94 ± 0.05	2.69 ± 0.15	1.93 ± 0.04	2.78 ± 0.19	1.94 ± 0.05
$0.7 \leq z \leq 0.9$	2.40 ± 0.19	1.91 ± 0.06	2.73 ± 0.22	1.91 ± 0.06	2.96 ± 0.25	1.91 ± 0.06
$0.9 \leq z \leq 1.1$	2.20 ± 0.09	2.02 ± 0.04	2.70 ± 0.18	2.00 ± 0.08	2.94 ± 0.14	2.02 ± 0.04
$1.1 \leq z \leq 1.3$	2.45 ± 0.19	2.05 ± 0.07	3.22 ± 0.25	2.05 ± 0.06	3.36 ± 0.29	2.05 ± 0.07
$1.3 \leq z \leq 2.1$	2.41 ± 0.25	2.01 ± 0.10	3.15 ± 0.31	2.06 ± 0.09	3.25 ± 0.38	2.01 ± 0.10

Angular BAO standard ruler

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In the RW comoving metric is the standard ruler principle

$$d\ell^2 = d\chi^2 + S_K(\chi)^2 d\theta^2$$

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$$\boxed{\frac{dz}{H(z)}}$$

Radial

$$\boxed{\chi(z) = \int_0^z \frac{dz}{H(z)}}$$

Transverse

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Radial

$$\boxed{\chi(z) = \int_0^z \frac{dz}{H(z)}}$$

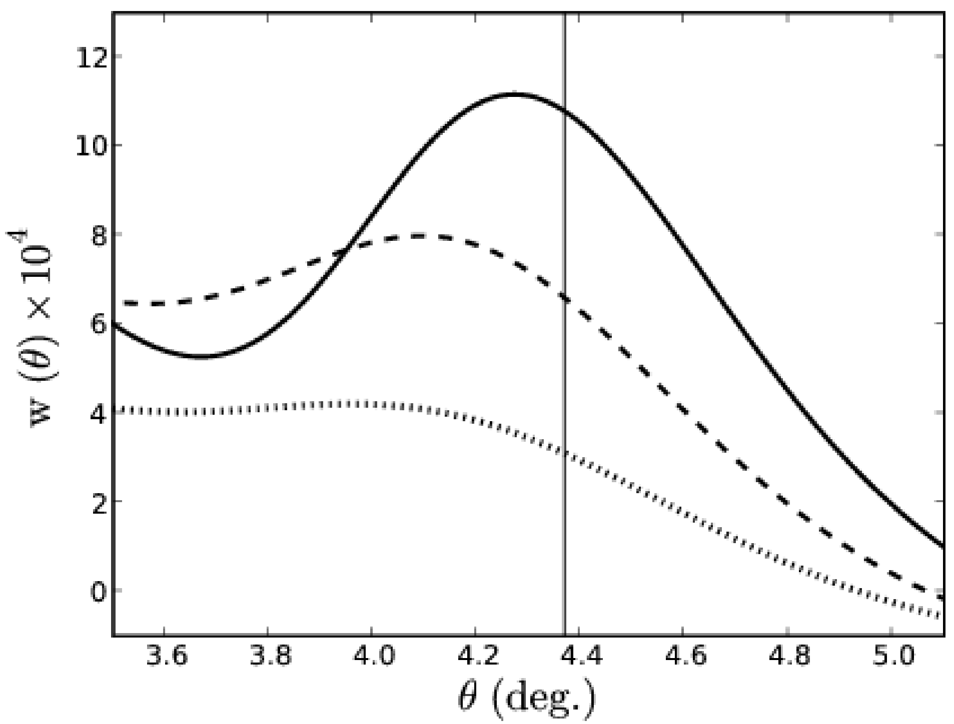
Transverse

In the spatial correlation function is measured a combination of the radial and transverse relation

$$D_V(z) \propto \left(\frac{S_K^2(\chi)}{H(z)}\right)^{1/3}$$

Angular BAO

Is the BAO peak position in the ACF a standard ruler?



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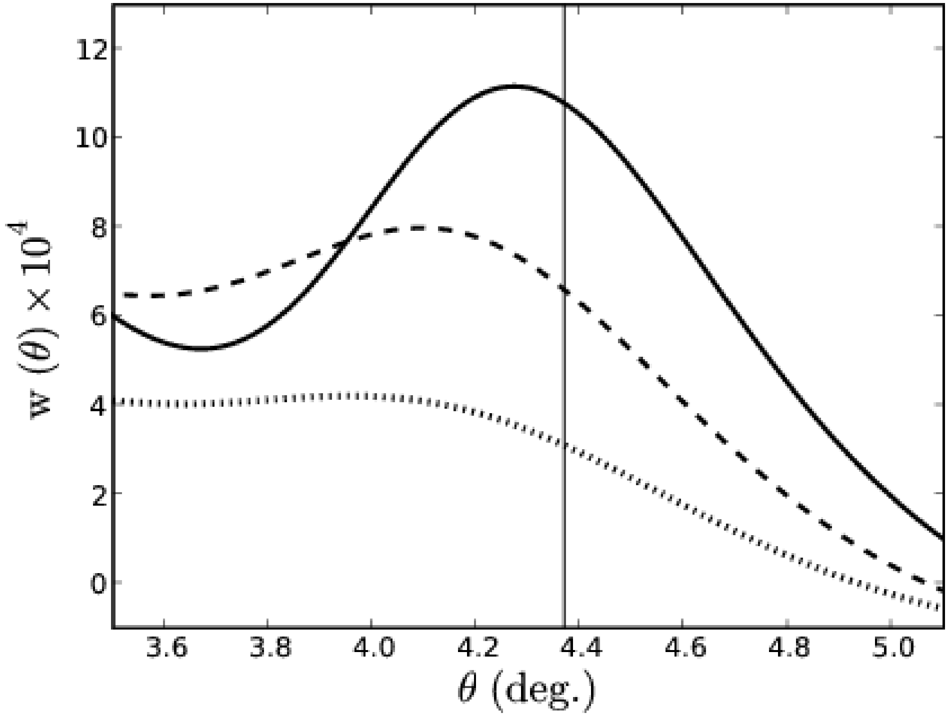

Projection offset

$$\theta_p = \frac{r_p}{\chi(z)}\sqrt{1 - \frac{\Delta r^2}{r_p^2}}$$

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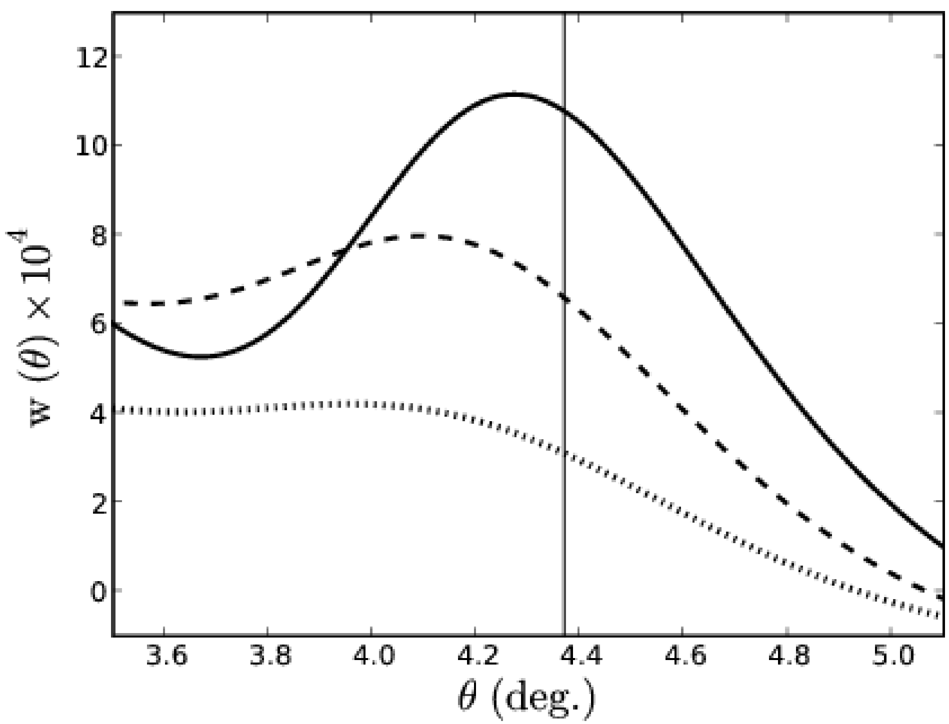
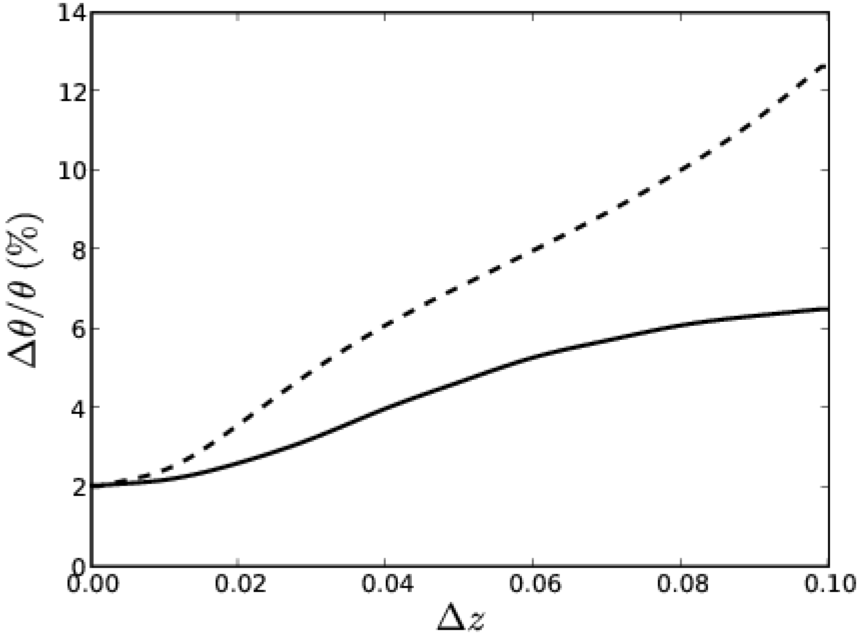


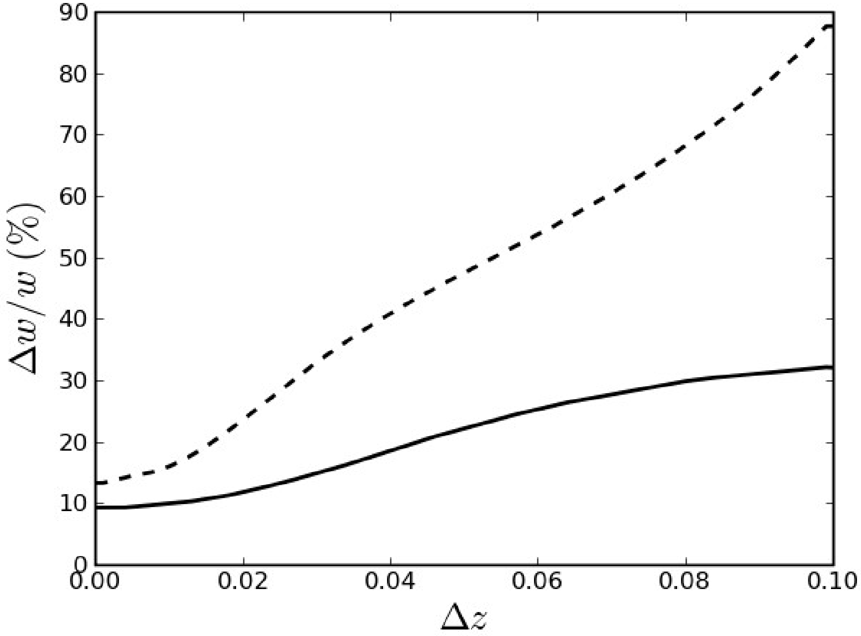
Projection offset

$$\theta_p = \frac{r_p}{\chi(z)}\sqrt{1 - \frac{\Delta r^2}{r_p^2}}$$

Always less than 1

Projection offset





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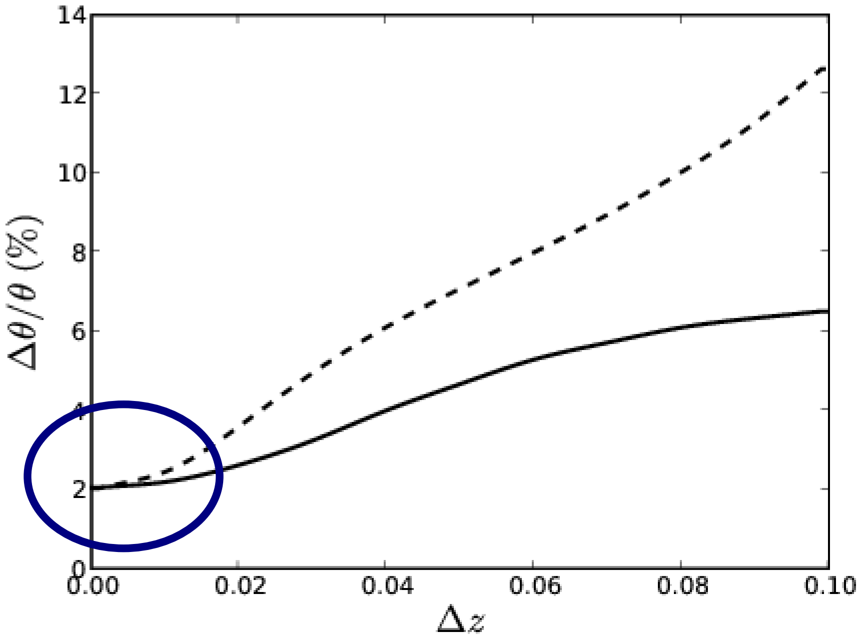
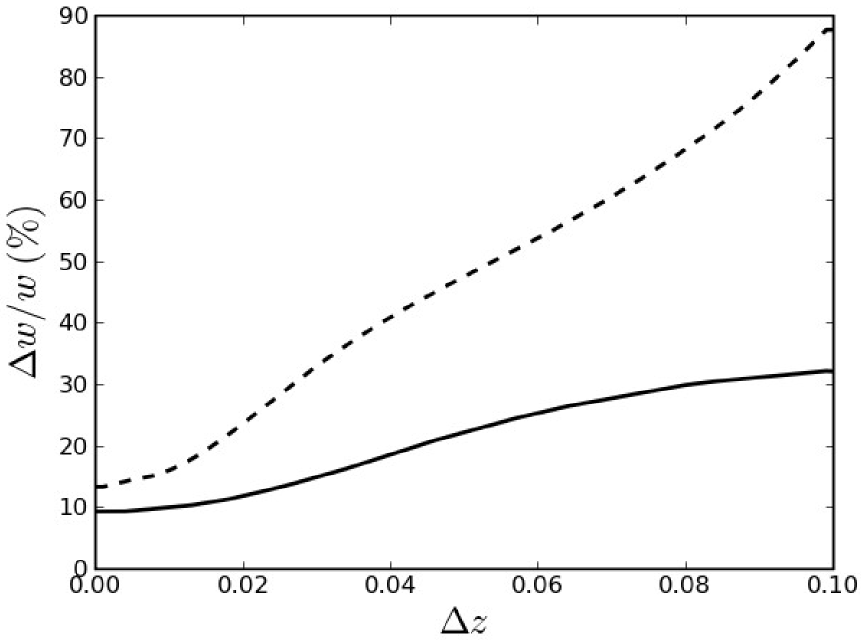
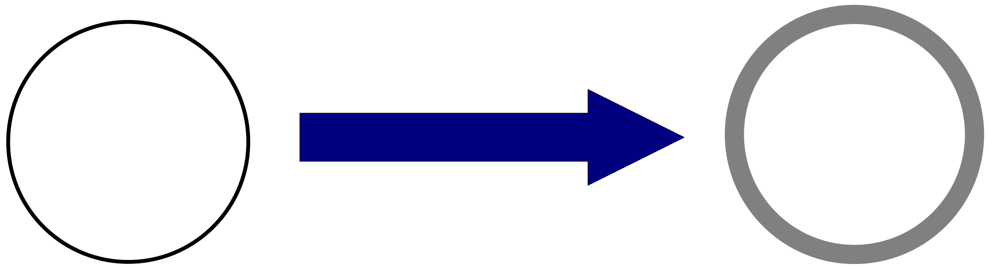




Bias between the BAO peak position and the sound horizon scale:
Silk Damping (Sanchez et al. 2008)

Non-linearities



Non-linearities

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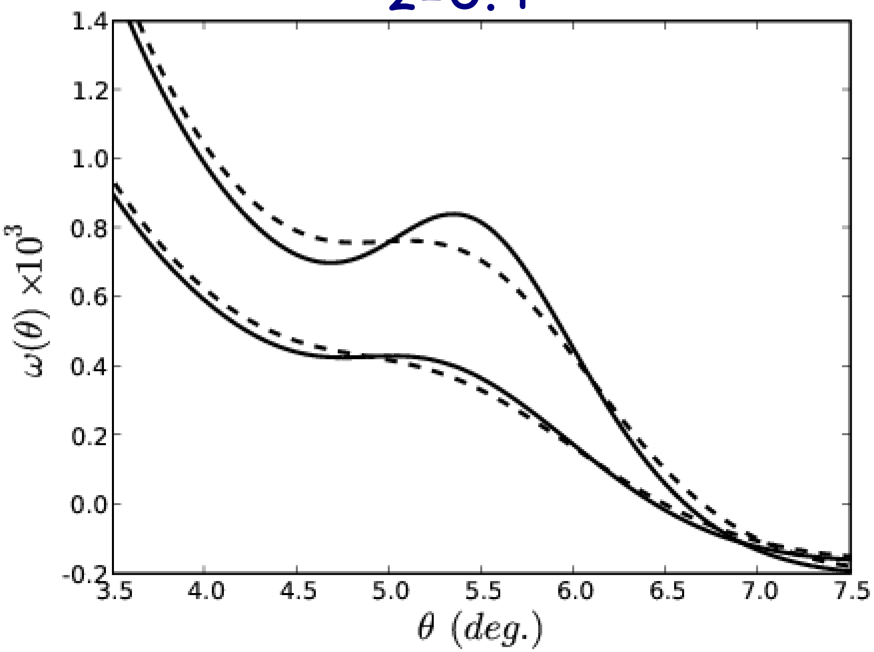
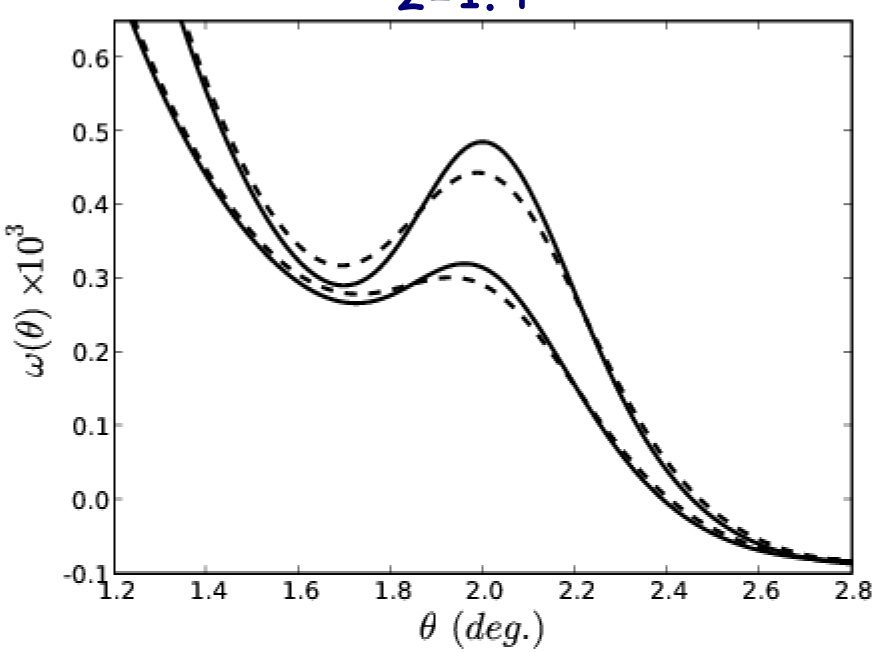
$$\xi_{NL}(r) = b^2\{\xi_L(r) \otimes \mathrm{e}^{-(k^* r)^2} + A_{MC}\, \xi_L'(r)\xi_L^{(1)}(r)\}$$ (RPT)

$$k^*(z) = \left[\frac{1}{3\pi^2}\int_0^\infty dk P_L(k;z)\right]^{-1/2}$$

z=0.4



z=1.4



Non-linearities

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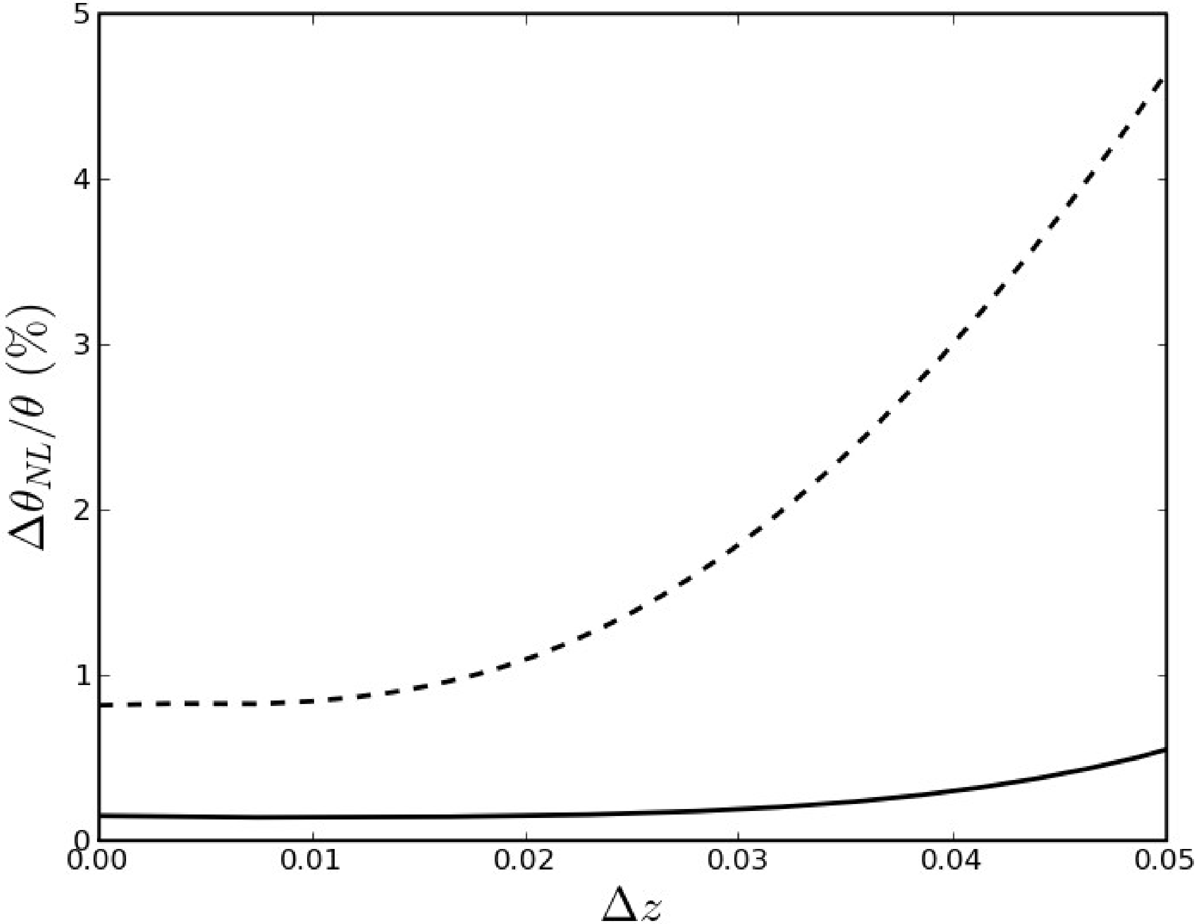
Shift of the BAO peak due to non-linearities compared to the linear model



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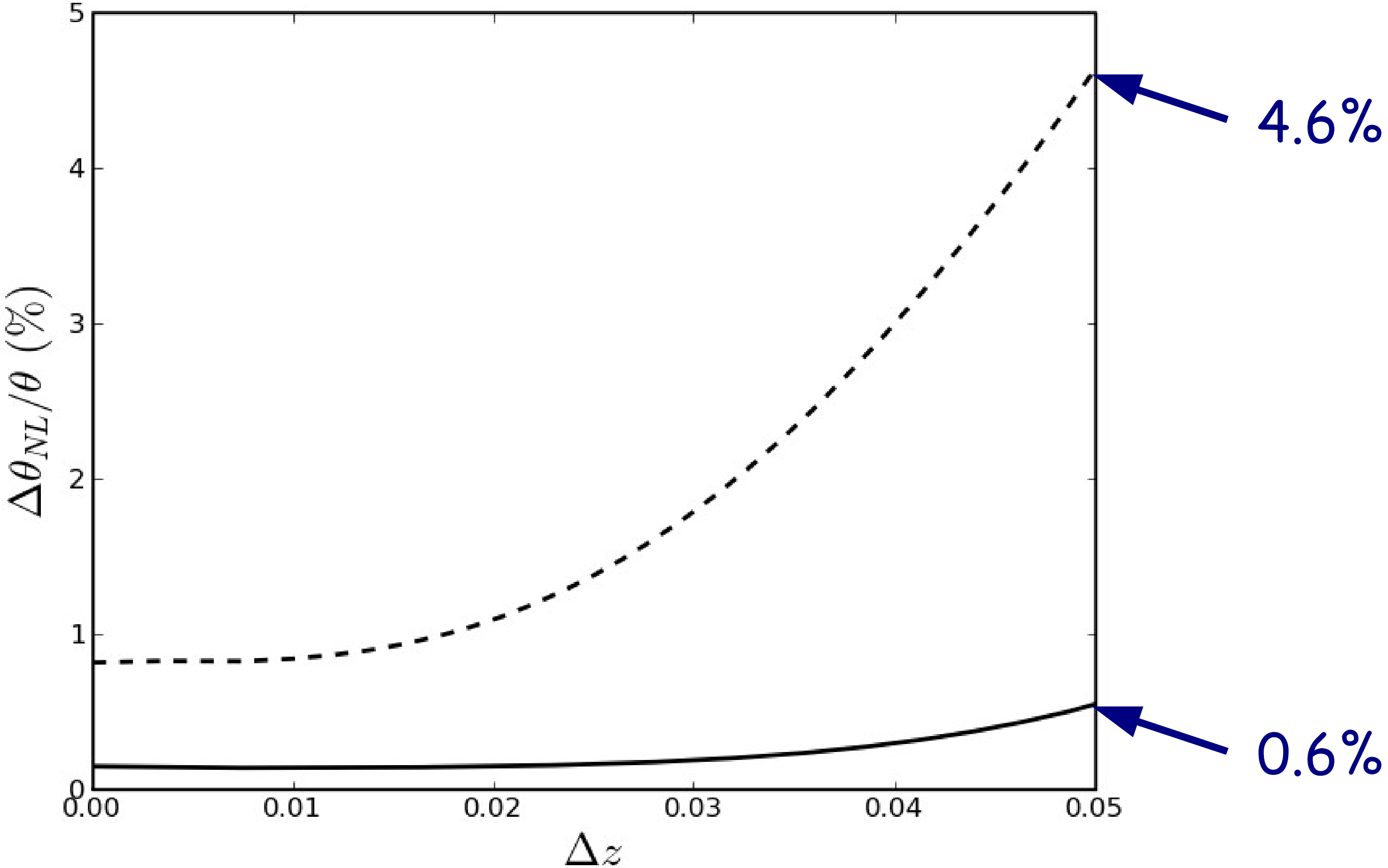

Photo-z

The peak position on the ACF only approaches the sound horizon scale for infinitesimal shells. But when working with photo-z there will be no such thing!

$$\Delta z = \sqrt{\Delta z_p^2 + 12\sigma_z^2}$$

Photo-z

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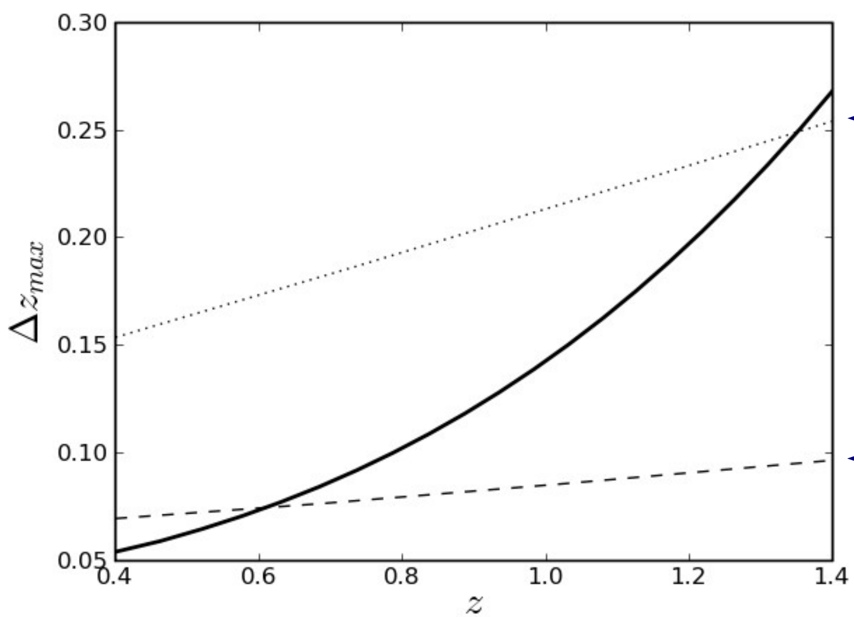
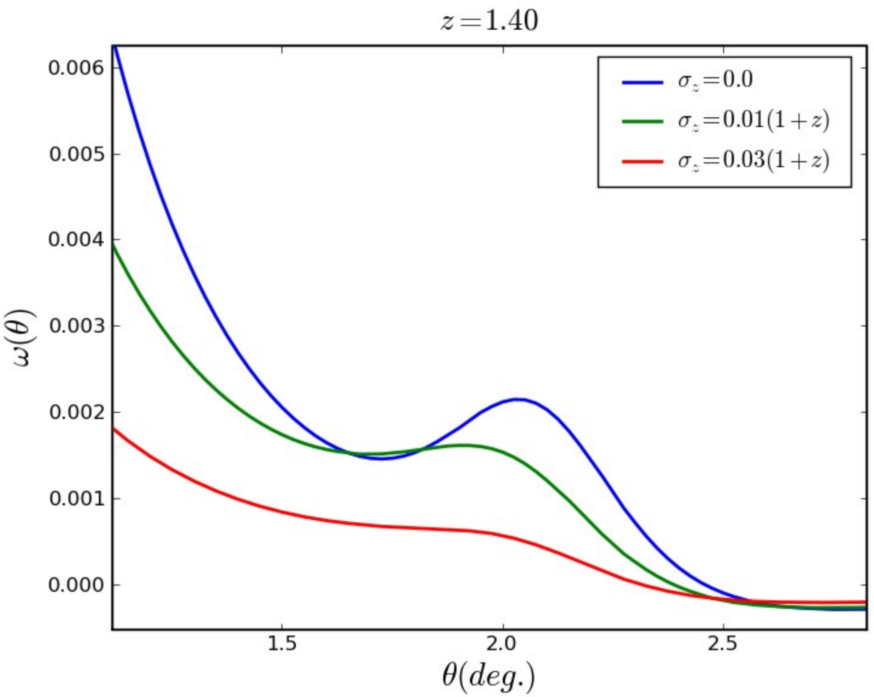


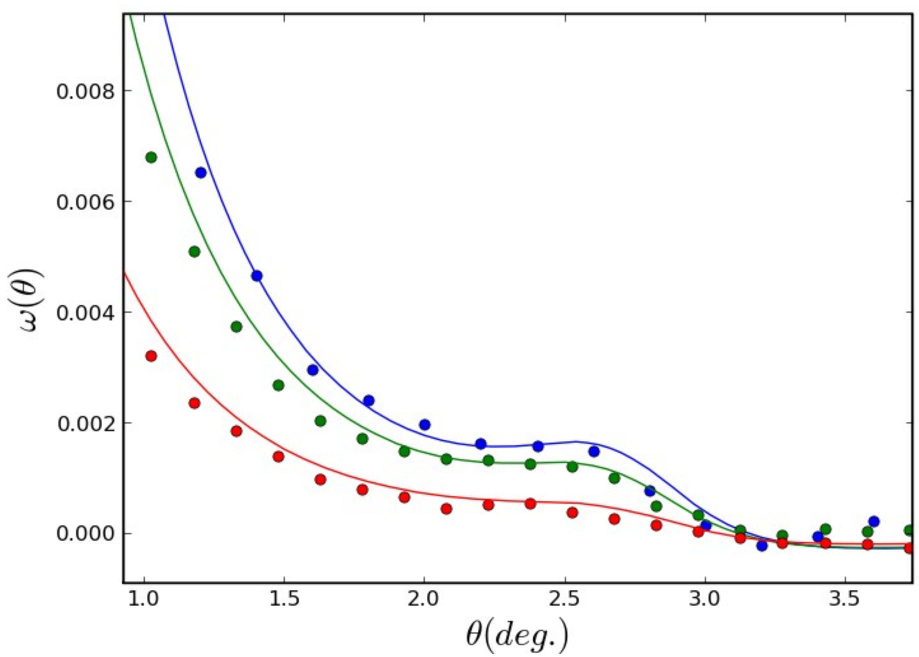
Width = 0.05
error = 0.03(1+z)

Width = 0.05
error = 0.01(1+z)

Photo-z



0.92<z<0.98



A model dependent offset correction

$$\hat{\theta}_{BAO} = \theta_p^{obs} + \left[\frac{r_s}{\chi(z)} - \theta_p^{model} \right]$$

A model dependent offset correction

DARK ENERGY SURVEY

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$$\hat{\theta}_{BAO} = \theta_p^{obs} + \left[\frac{r_s}{\chi(z)} - \theta_p^{model}\right]$$

Observed peak position

A model dependent offset correction

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Offset correction

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Observed peak position

Offset correction

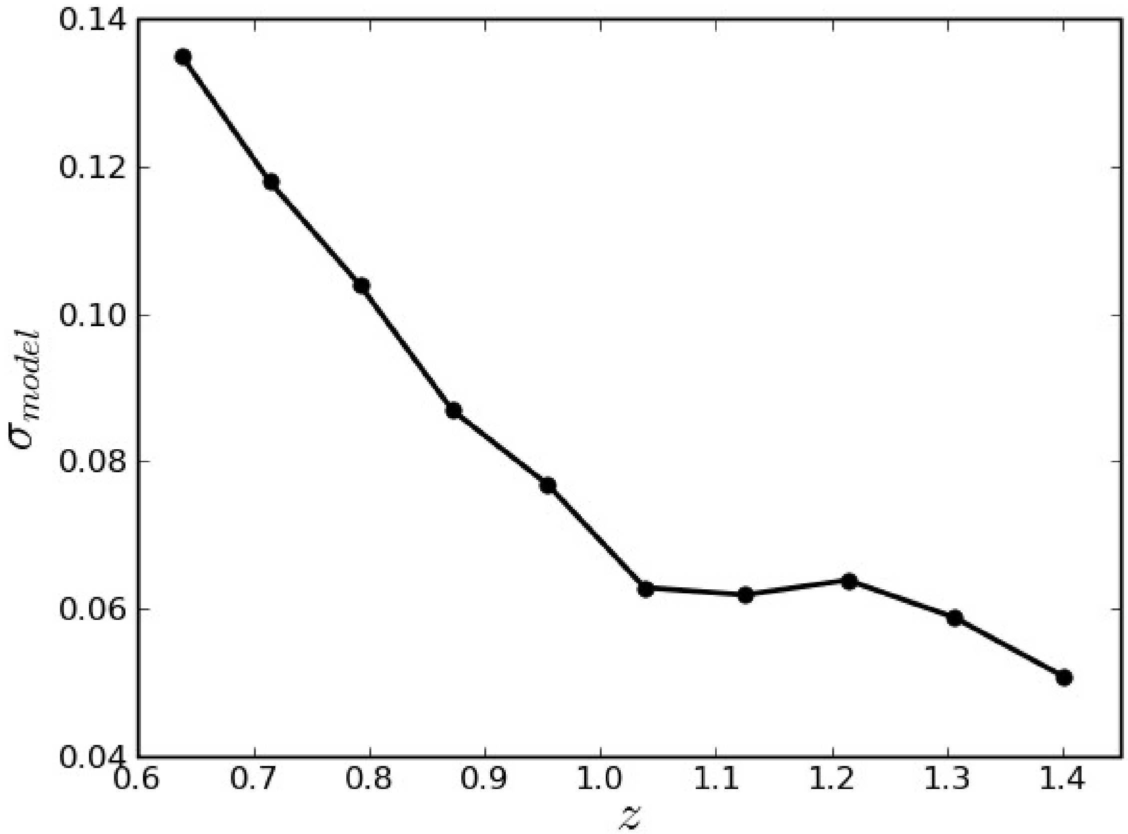
<u>Need of a fiducial cosmology to be computed</u>

WMAP5 recommended cosmology

Hinshaw et al. (2009)

Error from WMAP5 uncertainty

$$\hat{\theta}_{BAO} = \theta_p^{obs} + \boxed{\left[\frac{r_s}{\chi(z)} - \theta_p^{model}\right]}$$



Mostly due to the dependence of the comoving distance with cosmology

Cosmological constraint

We will apply 2 methods in order to constraint the cosmological parameters with a BAO peak position measurement in the ACF

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Sound horizon scale

$$\theta_{BAO}(z) = \frac{r_s}{\chi(z)}$$

Depends on other measurements

Cosmological constraint

DARK ENERGY SURVEY

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Sound horizon scale

$$\theta_{BAO}(z) = \frac{r_s}{\chi(z)}$$

Depends on other measurements

Relative shells

$$\frac{\theta_{BAO}(z_i)}{\theta_{BAO}(z_j)} = \frac{\chi(z_j)}{\chi(z_i)}$$

Low constraining power

Cosmological constraint

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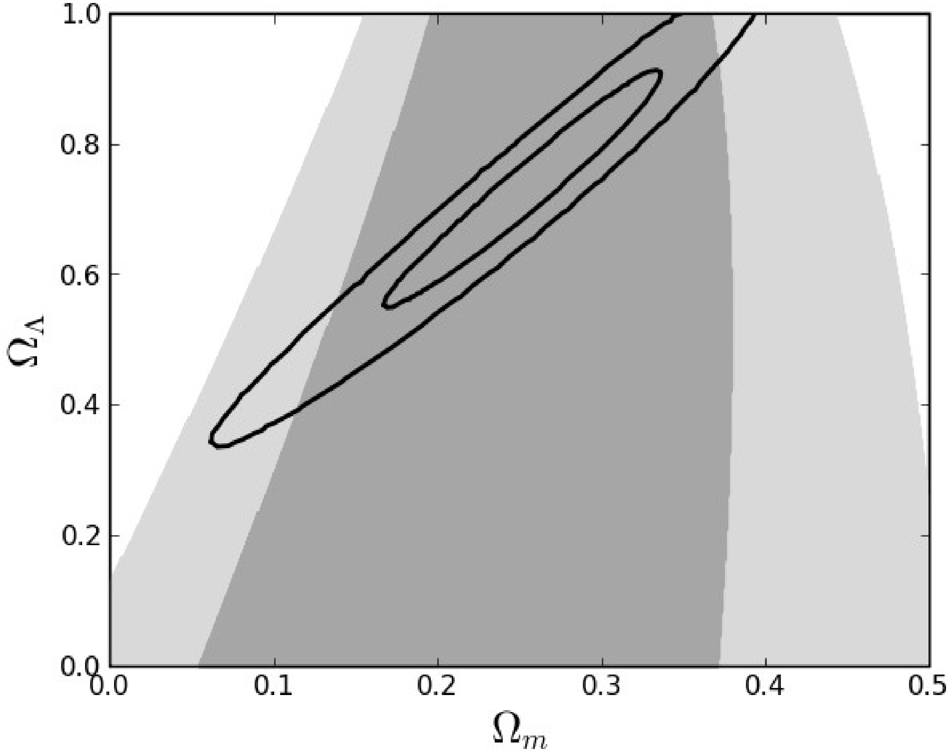
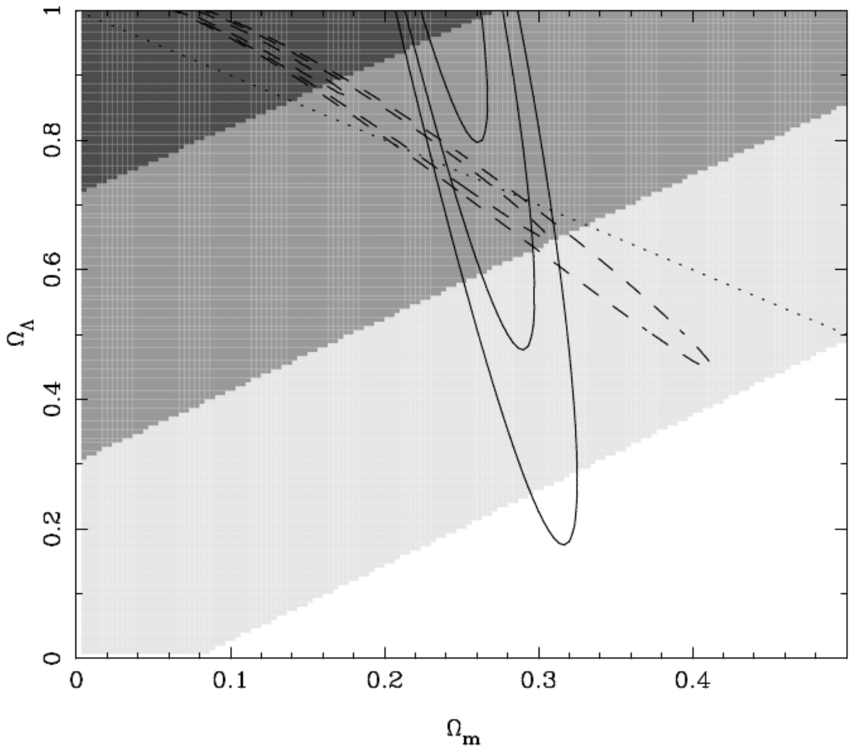
10 redshifts shells 0.6<z<1.45





Percival et al. (2007) 381, 1053

Cosmological constraint

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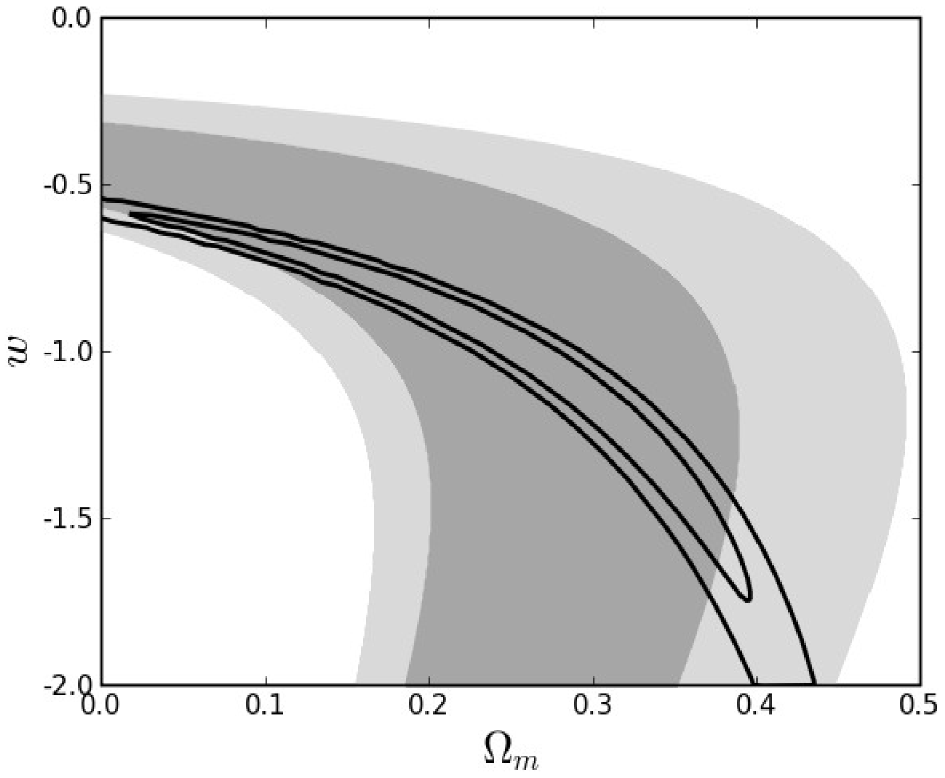

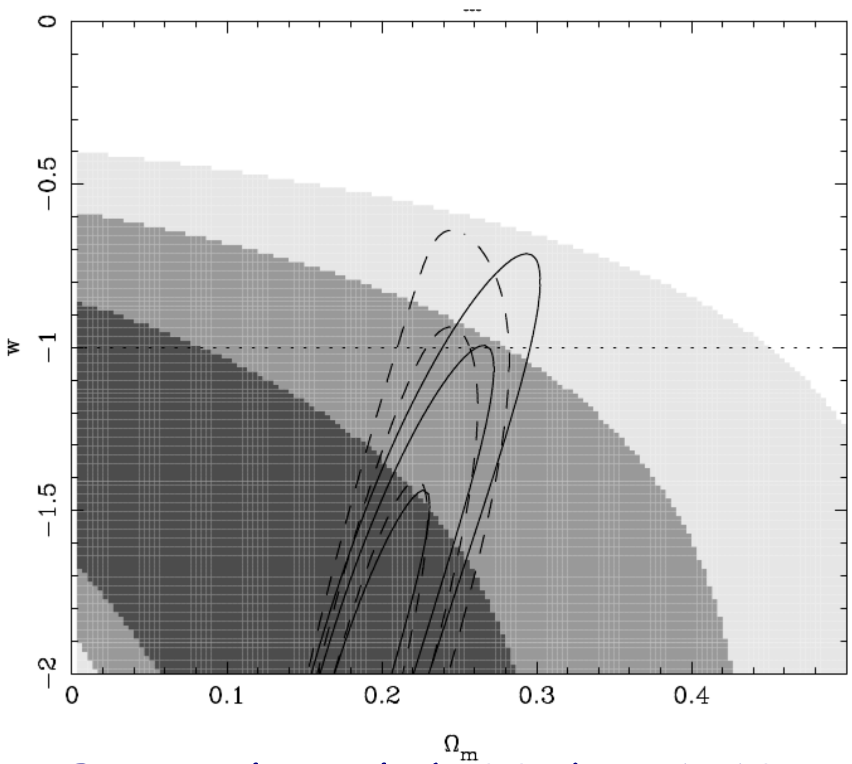

Percival et al. (2007) 381, 1053

Can the BAO peak position in the ACF be applied as a standard ruler?

DARK ENERGY SURVEY

DES-BRAZIL

2 angular scale: observed peak position and the BAO.

The BAO peak is a subtle feature in the ACF, develop a way to enhance it.

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DARK ENERGY SURVEY

DES-BRAZIL

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$$\boxed{\xi_{fit}(r) = A\, \xi_{lin}(B\, r_a) \otimes e^{r_{NL} k^2} + C}$$


Muito obrigado