Clustering Tomography: Measuring cosmological distances through angular clustering in thin redshift shells

(arXiv:1402.3590)

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OUTLINE

- Introduction
- Angular correlation functions in redshift-shells
- Models
- Forecast of cosmological constraints with BOSS
- Summary

INTRODUCTION

LARGE SCALE STRUCTURE (**LSS**)

- Characterisation of the distribution of structures at large scales: two point statistics, such as the correlation function or the power spectrum

- Bigger and deeper galaxy catalogues, such as 2dFGRS, BOSS, DES, HETDEX or EUCLID

CORRELATION FUNCTION

- Excess of probability of finding a pair, separated by a given separation, with respect to a random distribution

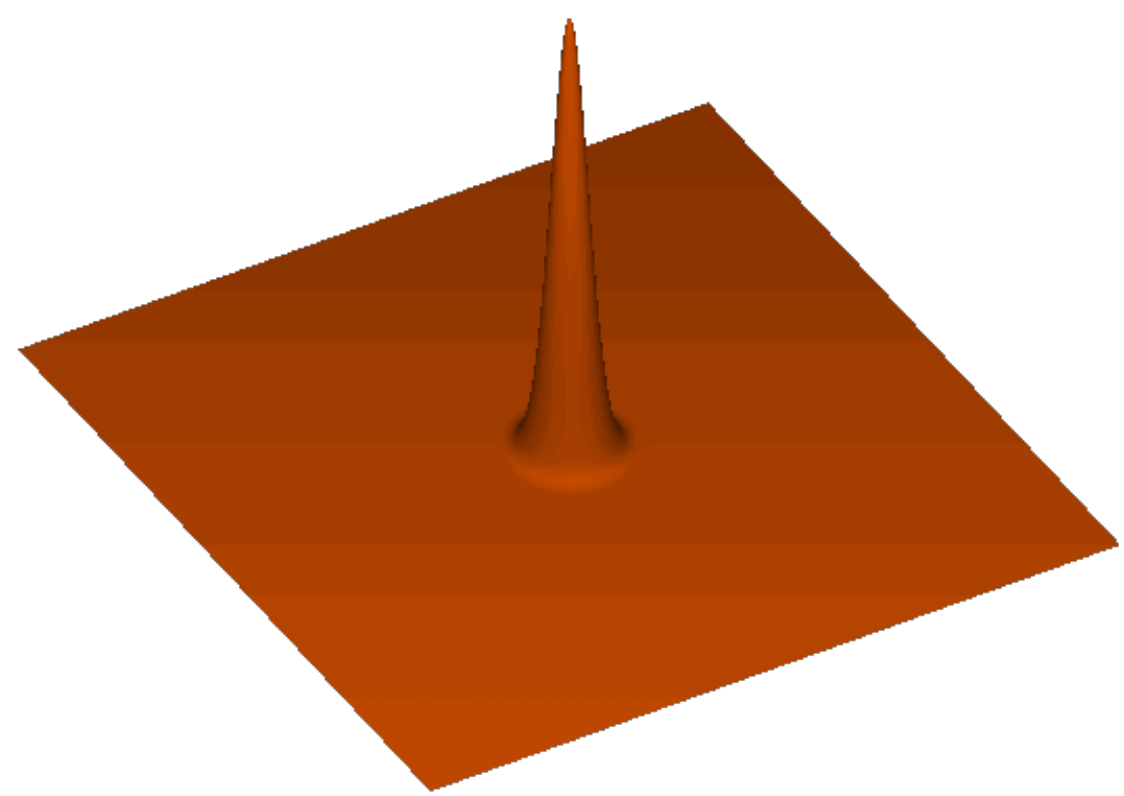
$$dP = n^2(1+\xi(r))dV_1 dV_2$$

$$dP = n^2(1+\omega(\theta))d\Omega_1 d\Omega_2$$

BARYON ACOUSTIC OSCILLATION (**BAO**)

- Small primordial perturbations induce sound waves in the relativistic plasma of the early Universe

- At recombination epoch, the Universe becomes transparent to photons which decouple from baryons: wave stops



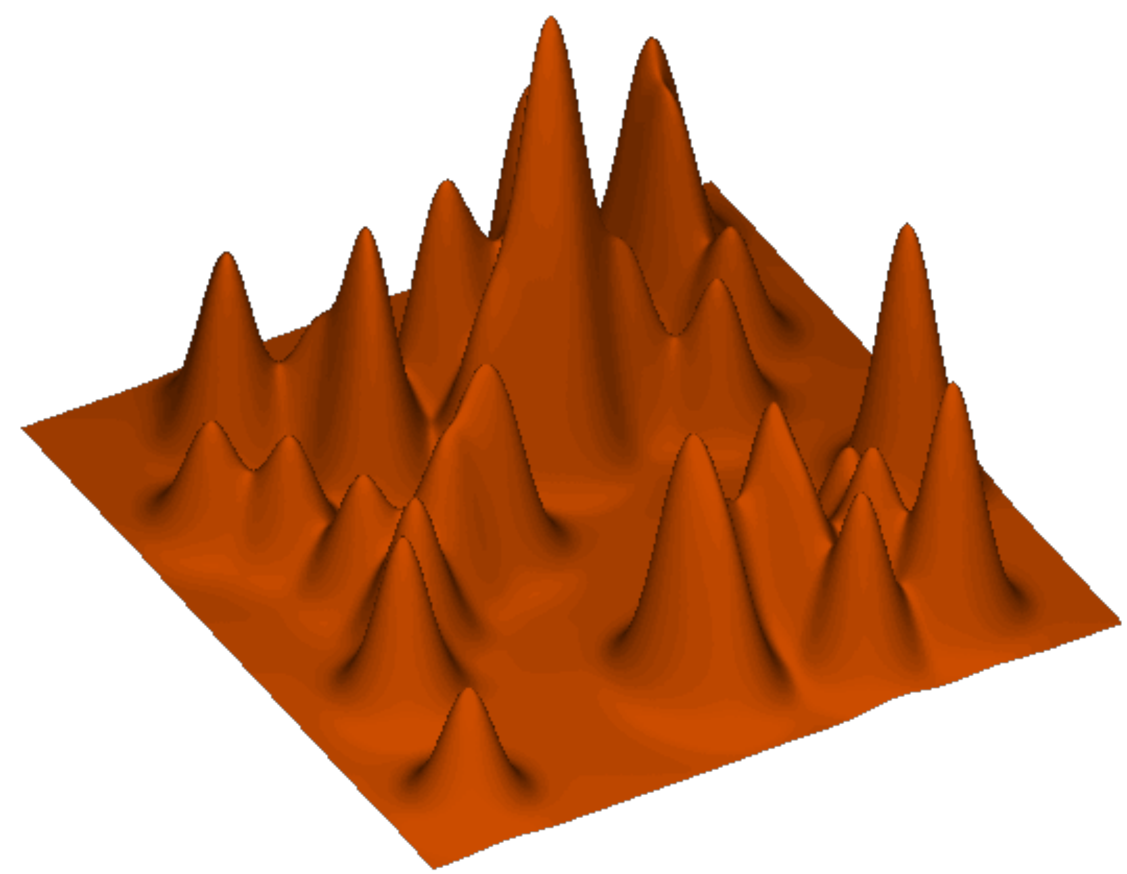
By Daniel Eisenstein

BARYON ACOUSTIC OSCILLATION (**BAO**)

- Small primordial perturbations induce sound waves in the relativistic plasma of the early Universe

- At recombination epoch, the Universe becomes transparent to photons which decouple from baryons: wave stops

- Imprint onto two-point statistics



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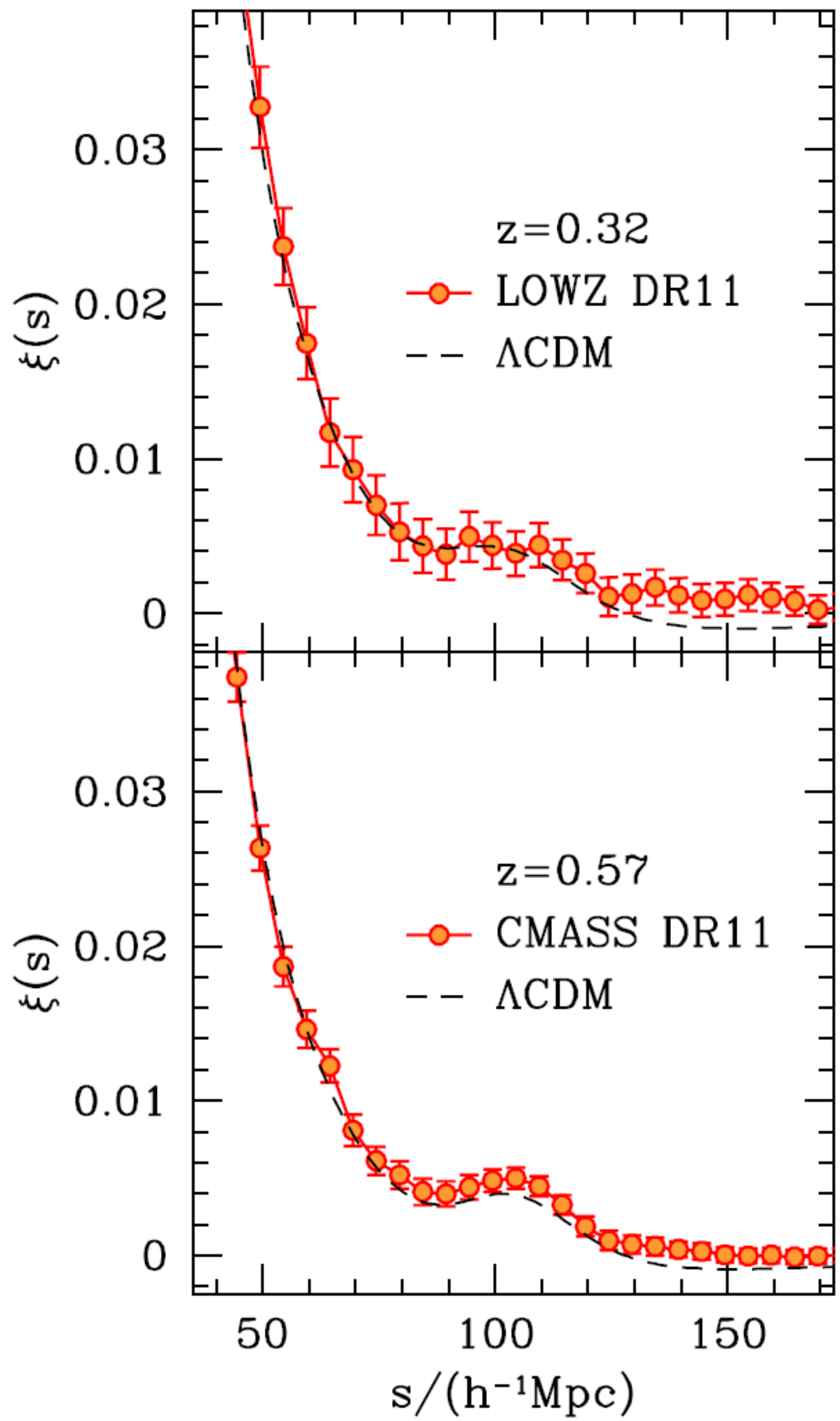
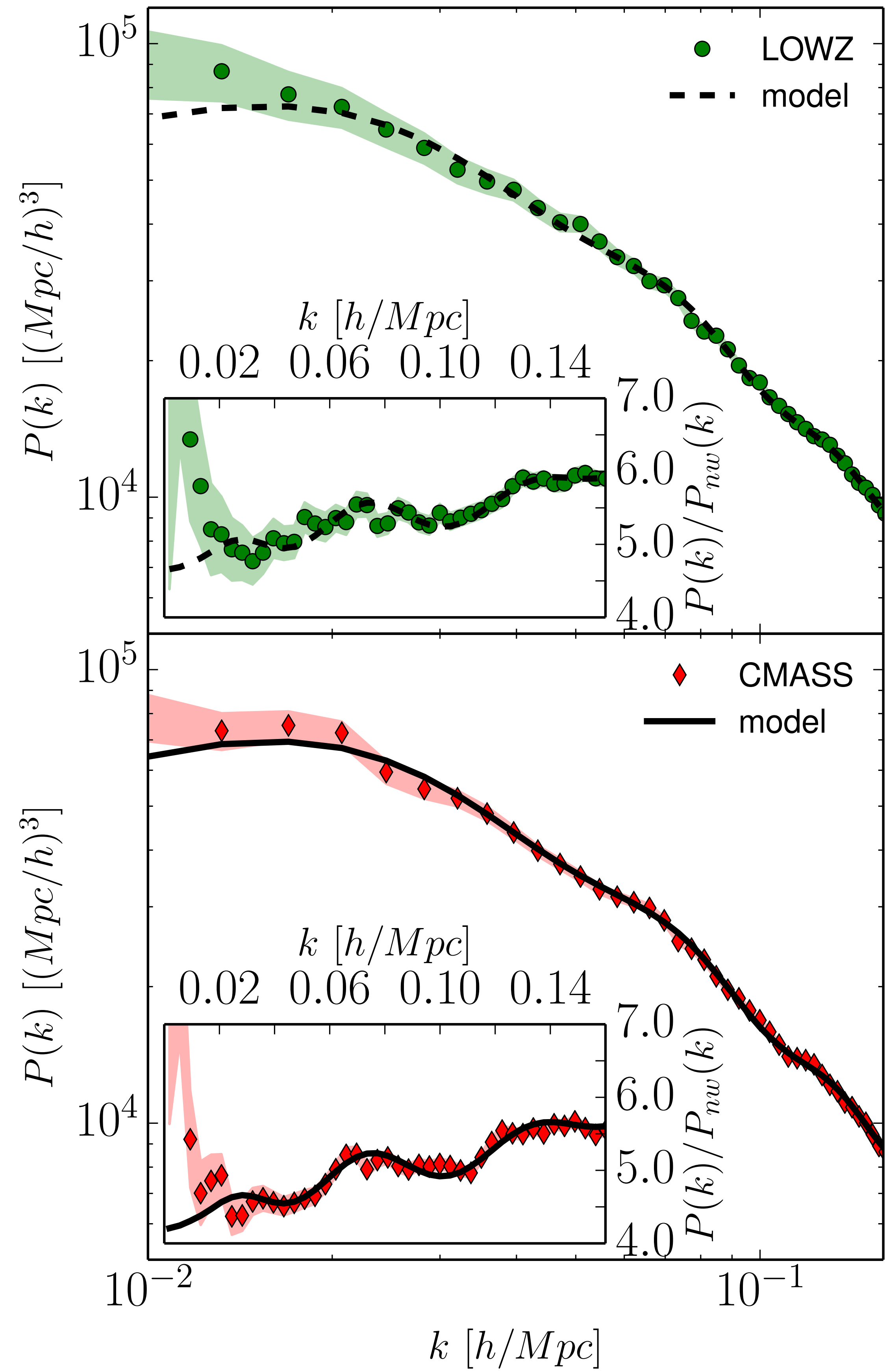
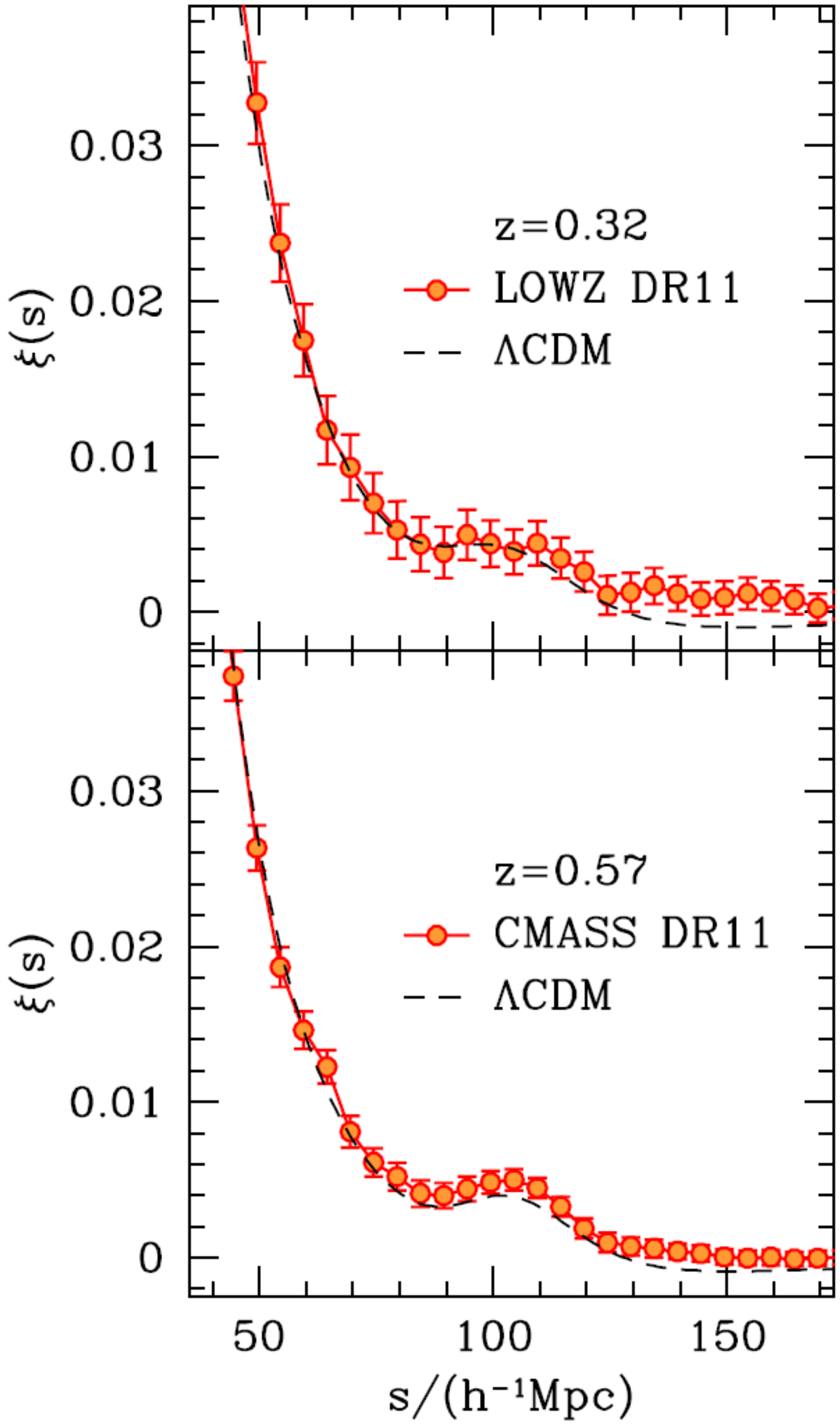


Sánchez et al. 2013b



Montesano et al. in prep.



Sánchez et al. 2013b

- Needs a fiducial cosmology
- No redshift evolution
- Only one distance measurement

ANGULAR CORRELATION FUNCTIONS IN REDSHIFT-SHELLS

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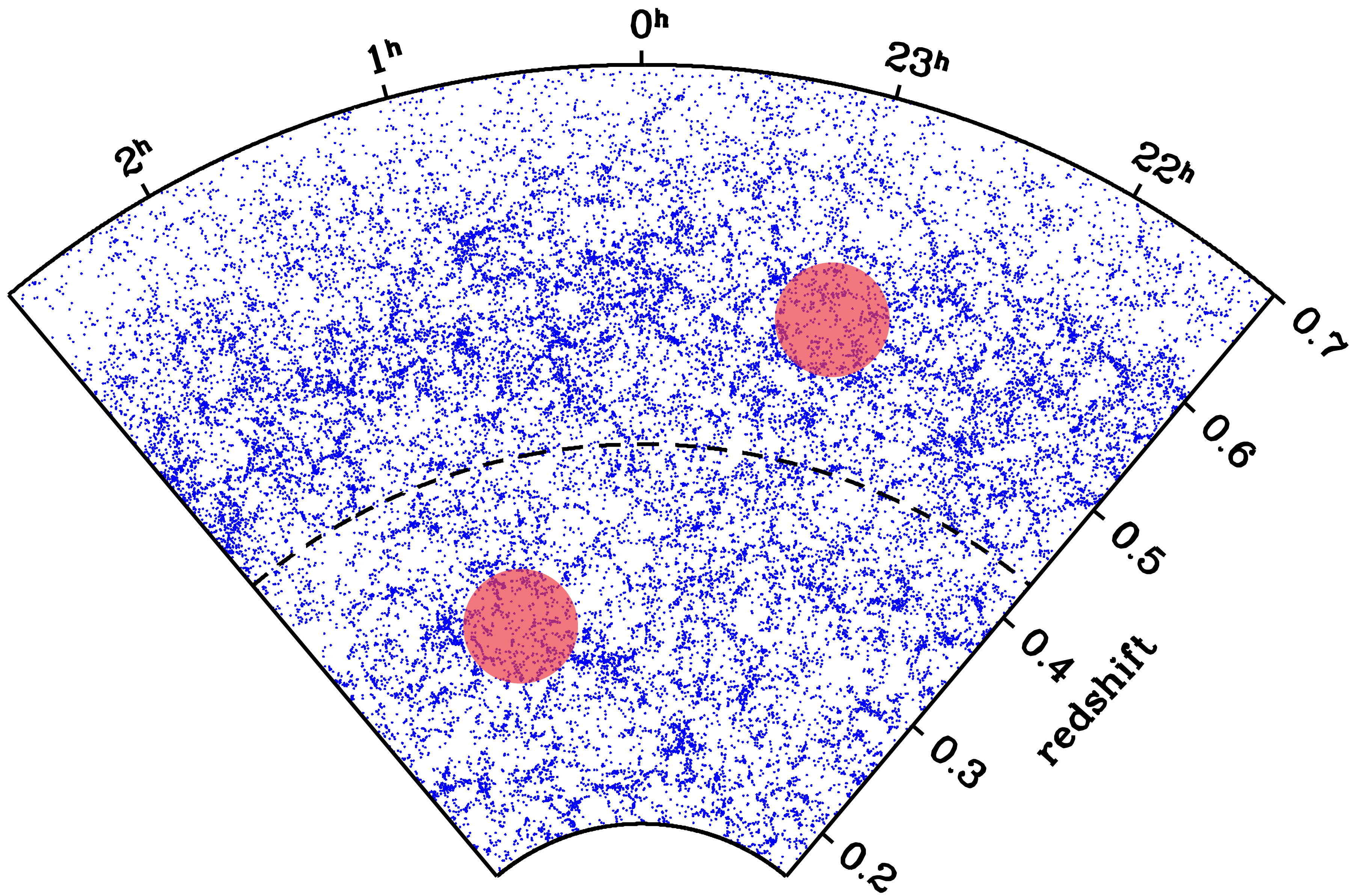

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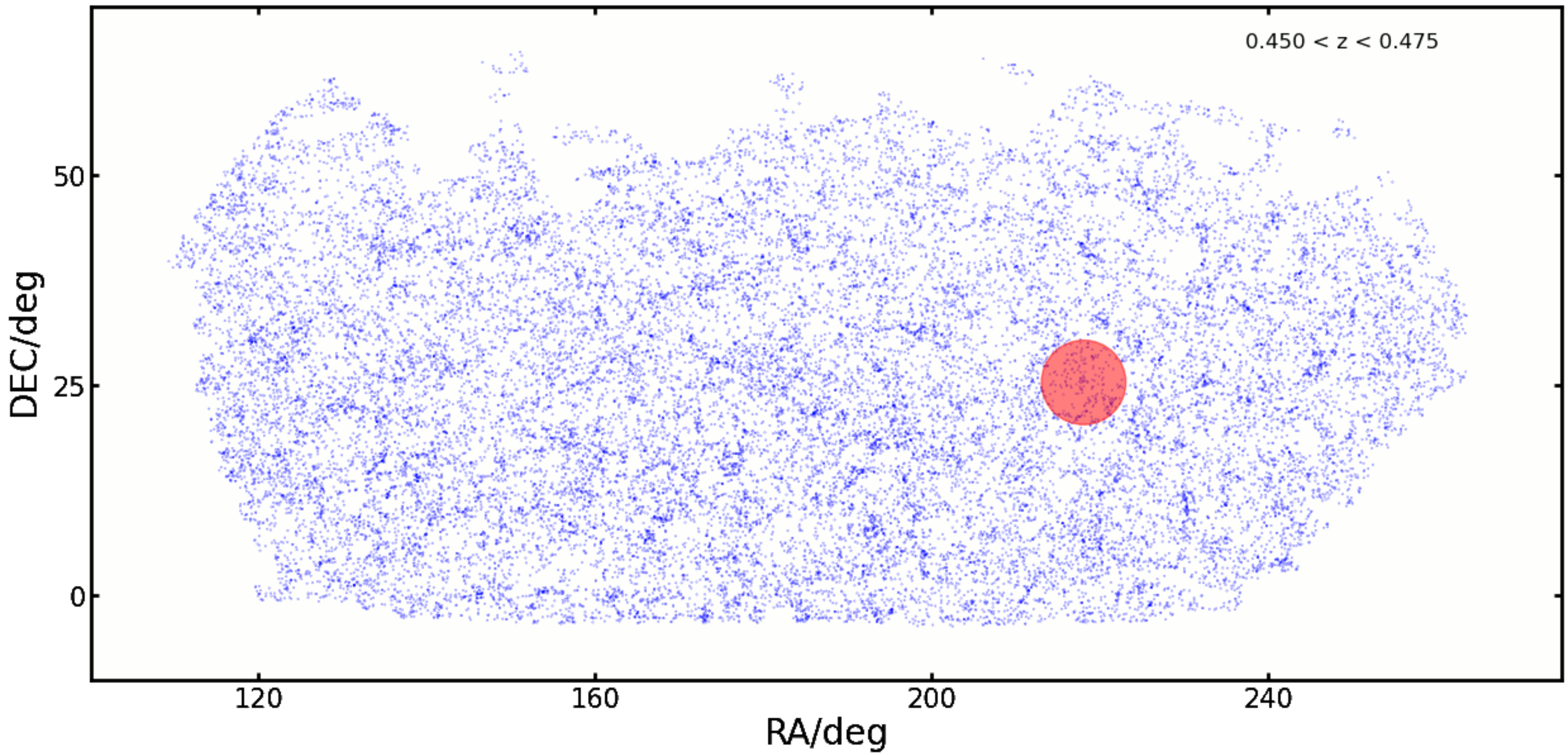
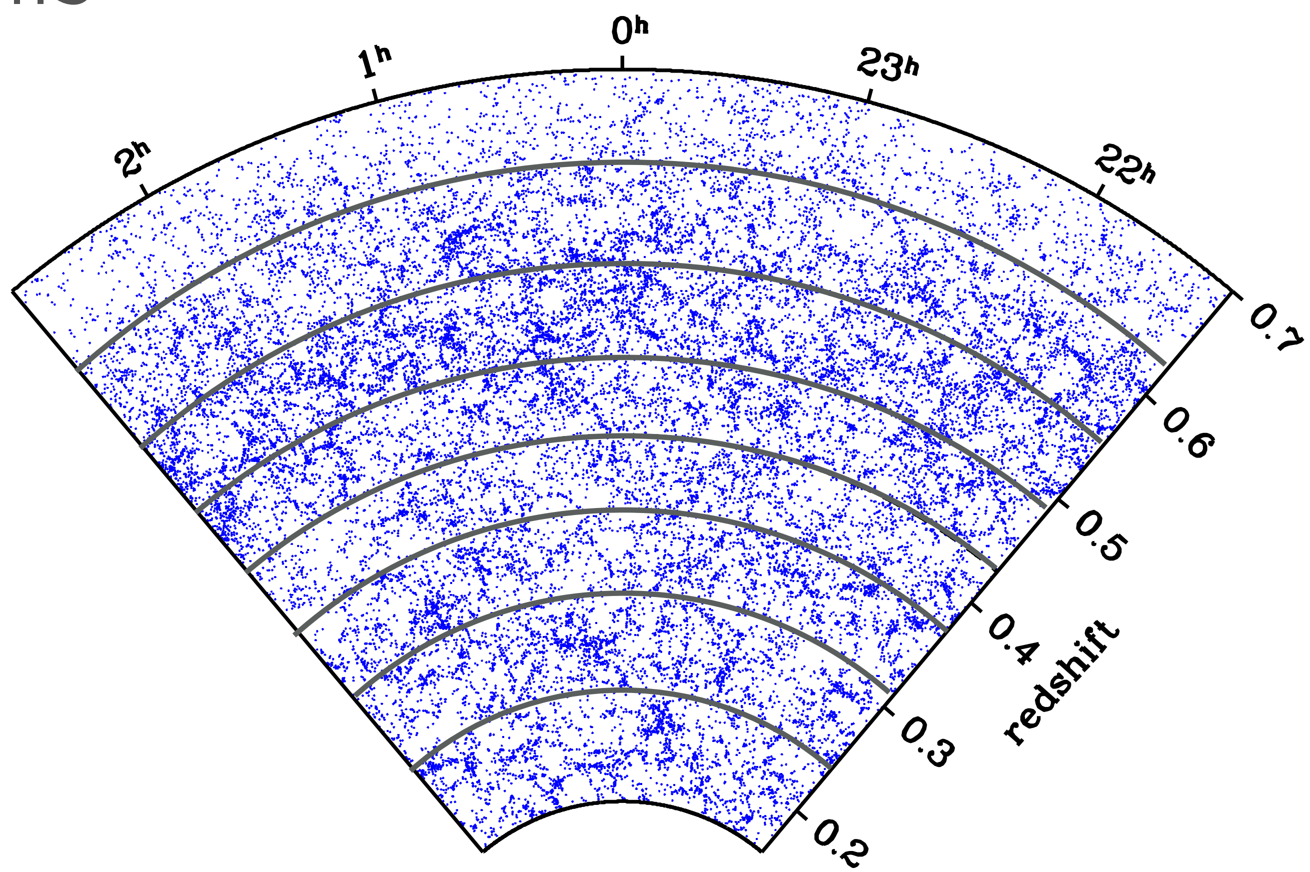


$$\theta_s(z) = \frac{r_s\left(z_d\right)}{D_A(z)}$$

ANGULAR CORRELATION FUNCTIONS IN REDSHIFT-SHELLS

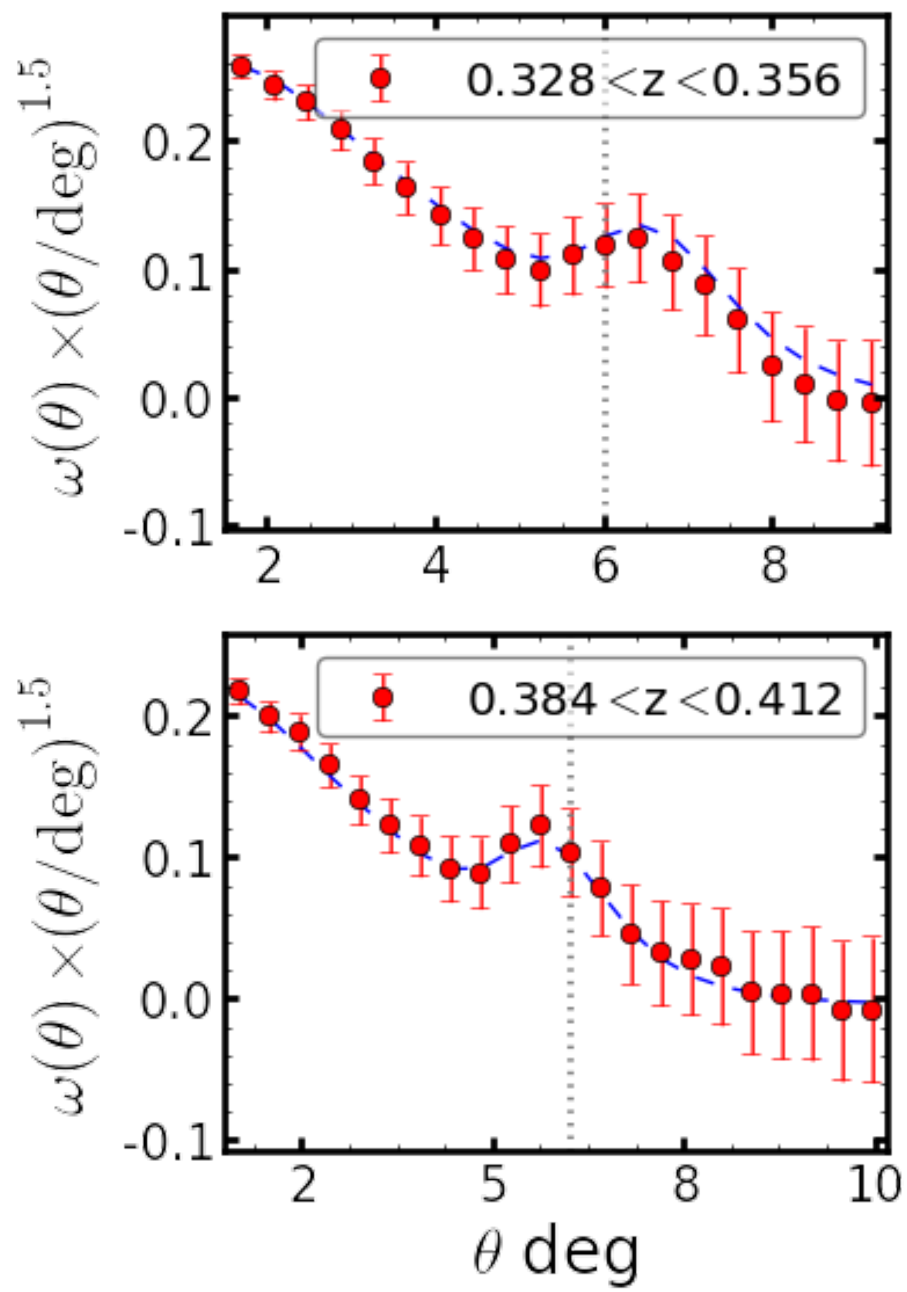
- Measure the angular correlation function in several redshift-shells



ANGULAR CORRELATION FUNCTIONS IN REDSHIFT-SHELLS

- No need for a fiducial cosmology
- Takes into account redshift evolution of the galaxy clustering
- Several distance measurements

$$\theta_s(z) = \frac{r_s(z_d)}{D_A(z)}$$



ANGULAR CORRELATION FUNCTIONS IN REDSHIFT-SHELLS

- We can relate two measurements as

$$\theta_s(z_i) = \alpha_{ij}\theta_s(z_j) \qquad \alpha_{ij} := \frac{D_A(z_j)}{D_A(z_i)}$$

- This can be extended to $\omega(\theta)$

$$\omega(\theta, z_i) \cong \omega(\alpha_{ij}\theta, z_j)$$

A MODEL FOR THE FULL SHAPE OF $\omega(\theta)$ AND ITS COVARIANCE MATRIX

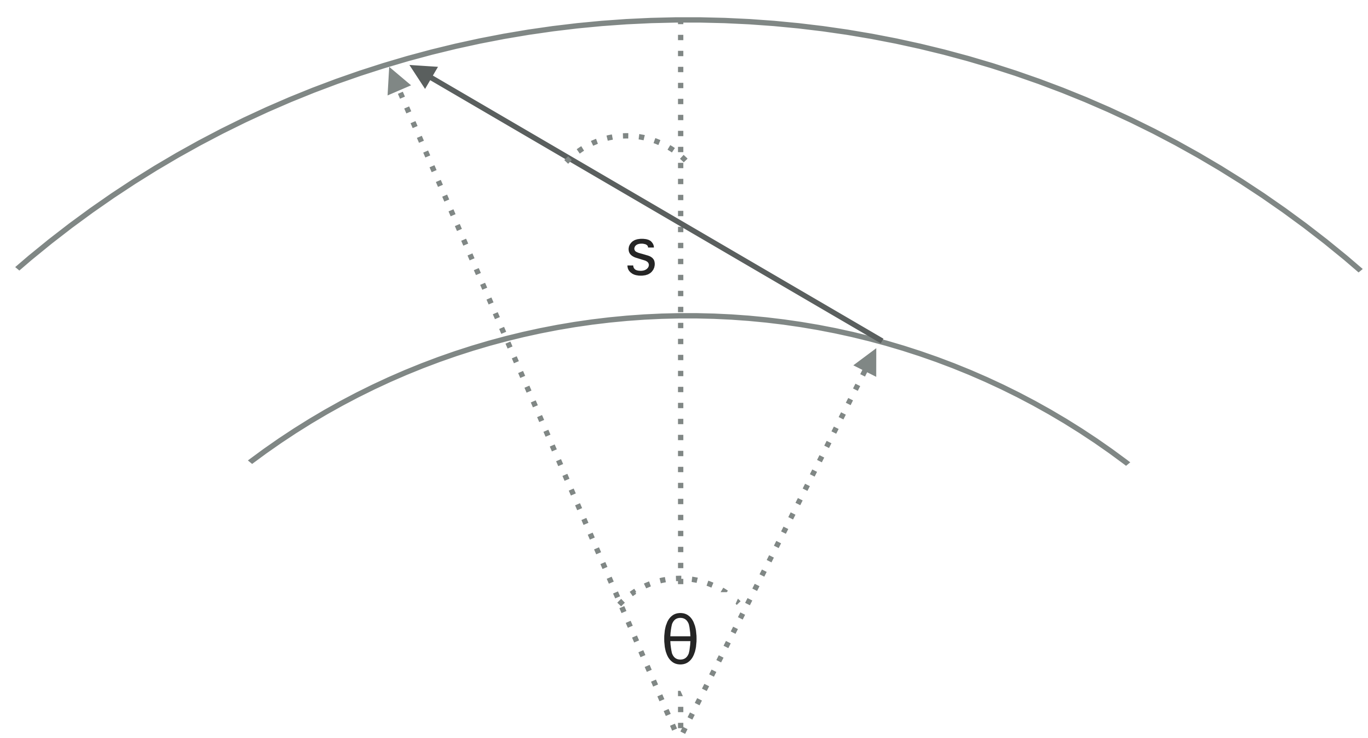
MODELLING THE ANGULAR CORRELATION FUNCTION

- The projection of the spatial correlation function within a redshift-shell

$$\omega(\theta) = \int\int dz_1 dz_2 \phi(z_1)\phi(z_2)\xi(s,\mu)$$

$$s = \sqrt{r^2(z_1)+r^2(z_2)-2r(z_1)r(z_2)\cos(\theta)}$$

$$\mu = \frac{1}{s}[r(z_2)-r(z_1)]\cos\left(\frac{\theta}{2}\right)$$



MODELLING THE ANGULAR CORRELATION FUNCTION

- The projection of the spatial correlation function within a redshift-shell
- Non-linear effects: fluctuations growth and redshift space distortions (RSD)

MODELLING THE ANGULAR CORRELATION FUNCTION

- Only a few multipoles are needed (Sánchez et al. 2013a)

$$\xi(s,\mu) = \xi_0(s) + L_2(\mu)\xi_2(s)$$

- Each multipole is obtained from its Fourier counterpart

$$\xi_l(s) = \frac{i^l}{2\pi^2}\int dk\, k^2 P_l(k)\, j_l(ks)$$

$$P_l(k) = \frac{2l+1}{2}\int d\mu_k P(k,\mu_k) L_l(\mu_k)$$

MODELLING THE ANGULAR CORRELATION FUNCTION

- Non-linear P(k) based on RPT (Crocce & Scoccimarro 2006)

$$P_{NL}(k,z) = b^2\left[P_L(k,z)e^{-(k\sigma_v)^2} + A_{MC}P_{MC}(k,z)\right]$$

$$\sigma_v = \sigma_v^0 \frac{D(z_{shell})}{D(z_{\mathrm{ref}})}$$

$$b = b_0 + b'(z_{shell} - z_{\mathrm{ref}})$$

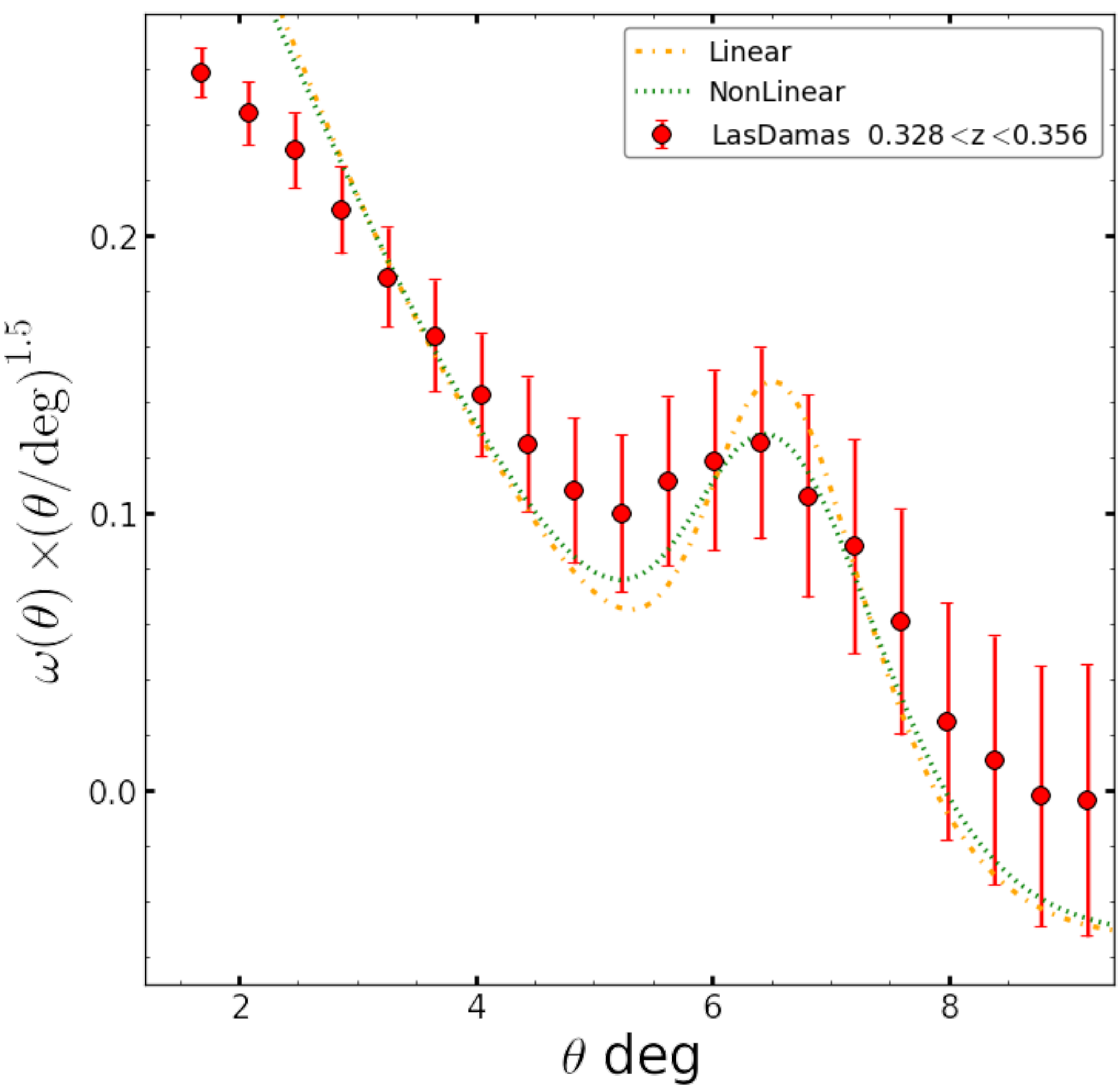
- RSD: *Fingers of God* effect

$$P(k,\mu_k,z) = \left(\frac{1}{1+(kf\sigma_v\mu_k)^2}\right)^2 (1+\beta\mu_k^2)^2 P_{NL}(k,z)$$

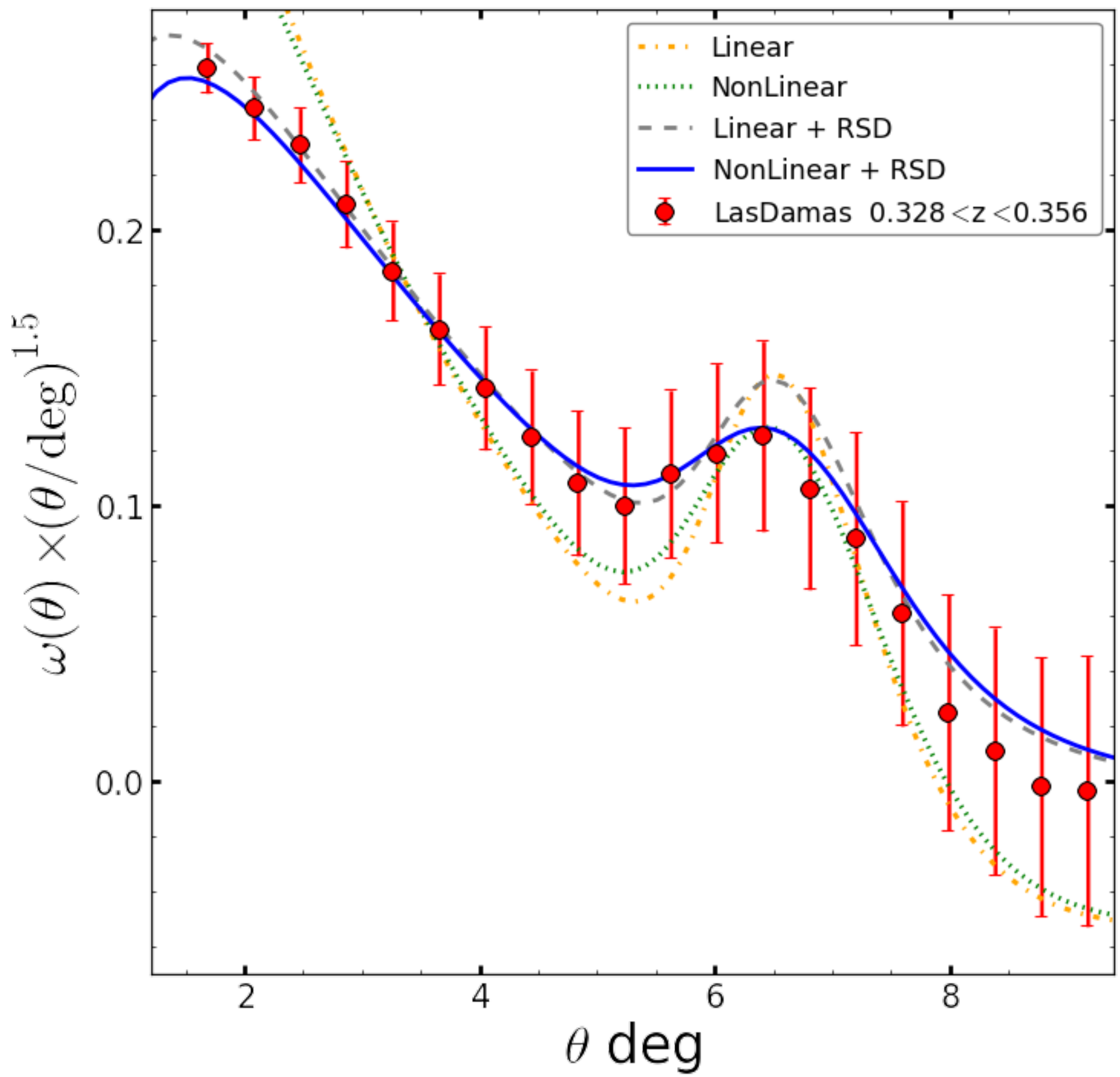
$$\beta = \frac{f}{b}$$

$$f = \frac{\partial \ln D}{\partial \ln a} \approx (\Omega_m(z))^\gamma$$

MODELLING THE ANGULAR CORRELATION FUNCTION



MODELLING THE ANGULAR CORRELATION FUNCTION



ANALYTICAL MODEL FOR THE COVARIANCE MATRIX

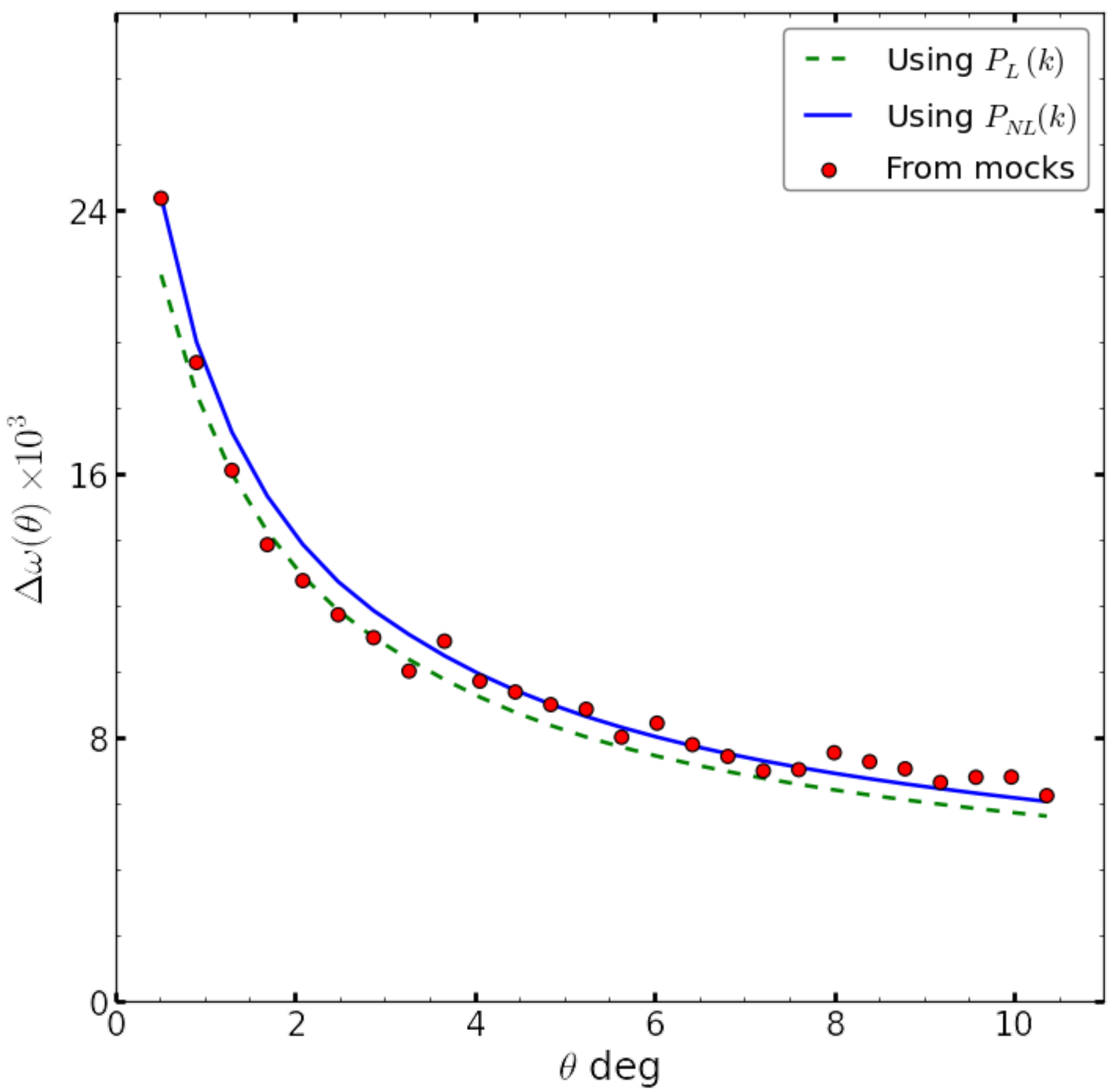
- A very large number of mock catalogues is needed to make a good direct estimate

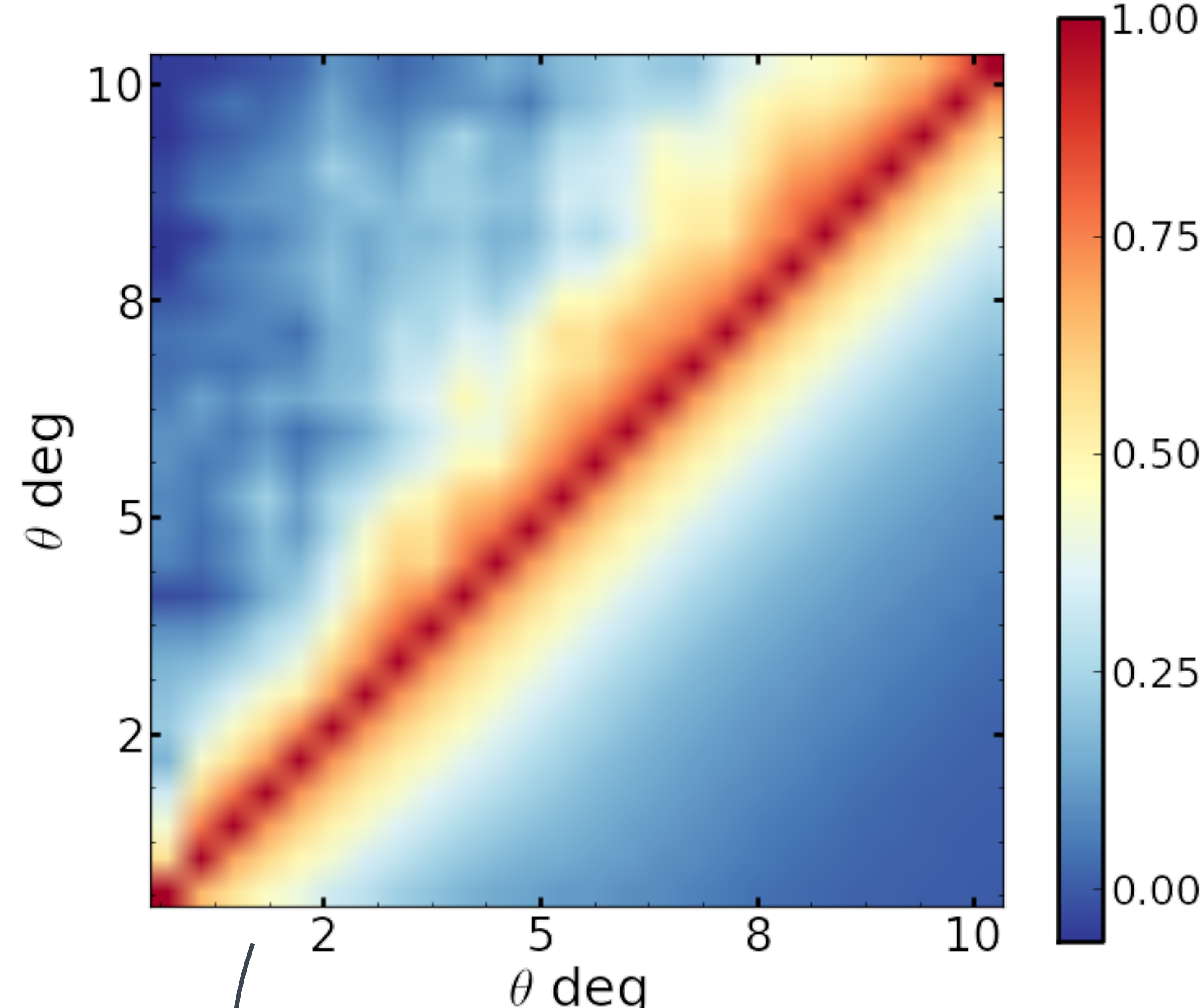
- Analytical model following Crocce et al. (2011a)

$$\mathrm{C}ov_{\theta_1\theta_2} = \frac{2}{f_{sky}} \sum_{l \in N_0} \frac{2l+1}{(4\pi)^2} L_l(\cos\theta_1) L_l(\cos\theta_2) \left(\mathrm{C}_l + \frac{1}{N_s} \right)^2$$

$$\mathrm{C}_l = \frac{2}{\pi} b^2 \int dk\, k^2 P(k,z) \left(\Psi_l(k) + \beta \Psi_l^r(k) \right)^2$$

ANALYTICAL MODEL FOR THE COVARIANCE MATRIX

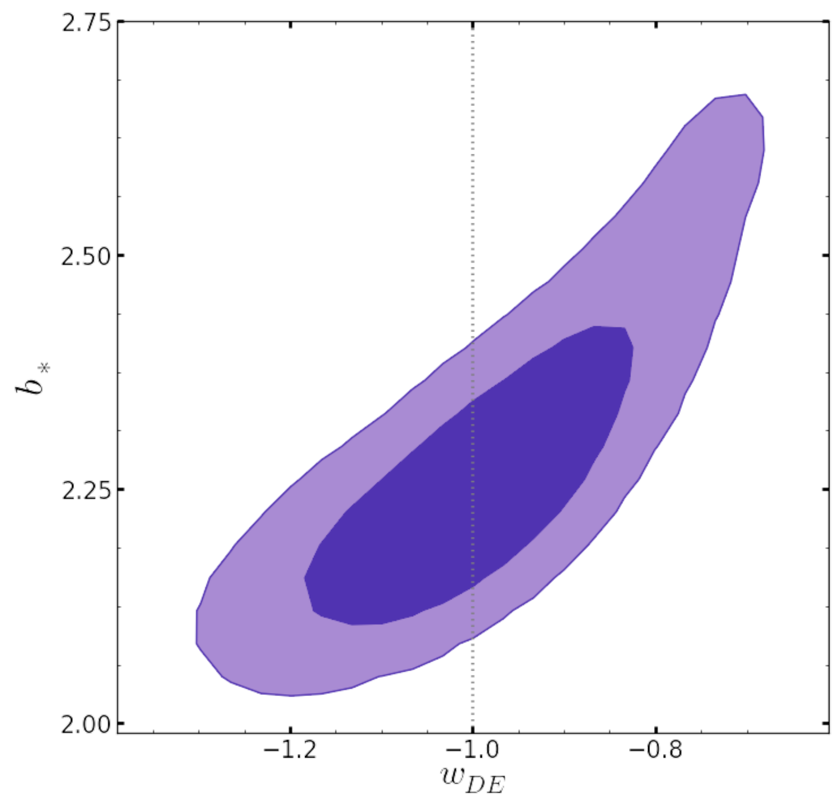




$$\frac{Cov_{\theta_i\theta_j}}{\sqrt{Cov_{\theta_i\theta_i}Cov_{\theta_j\theta_j}}}$$

TESTING THE MODEL

- Using measurements of $\omega(\theta)$ in the mocks and these models, we performed a MCMC test
- Parameter space explored $\left\{ A_{MC},\ \sigma_v^0,\ b_0,\ b',\ w_{DE} \right\}$



FORECASTING COSMOLOGICAL PARAMETER CONSTRAINTS

BARYON OSCILLATION SPECTROSCOPIC SURVEY: **BOSS**

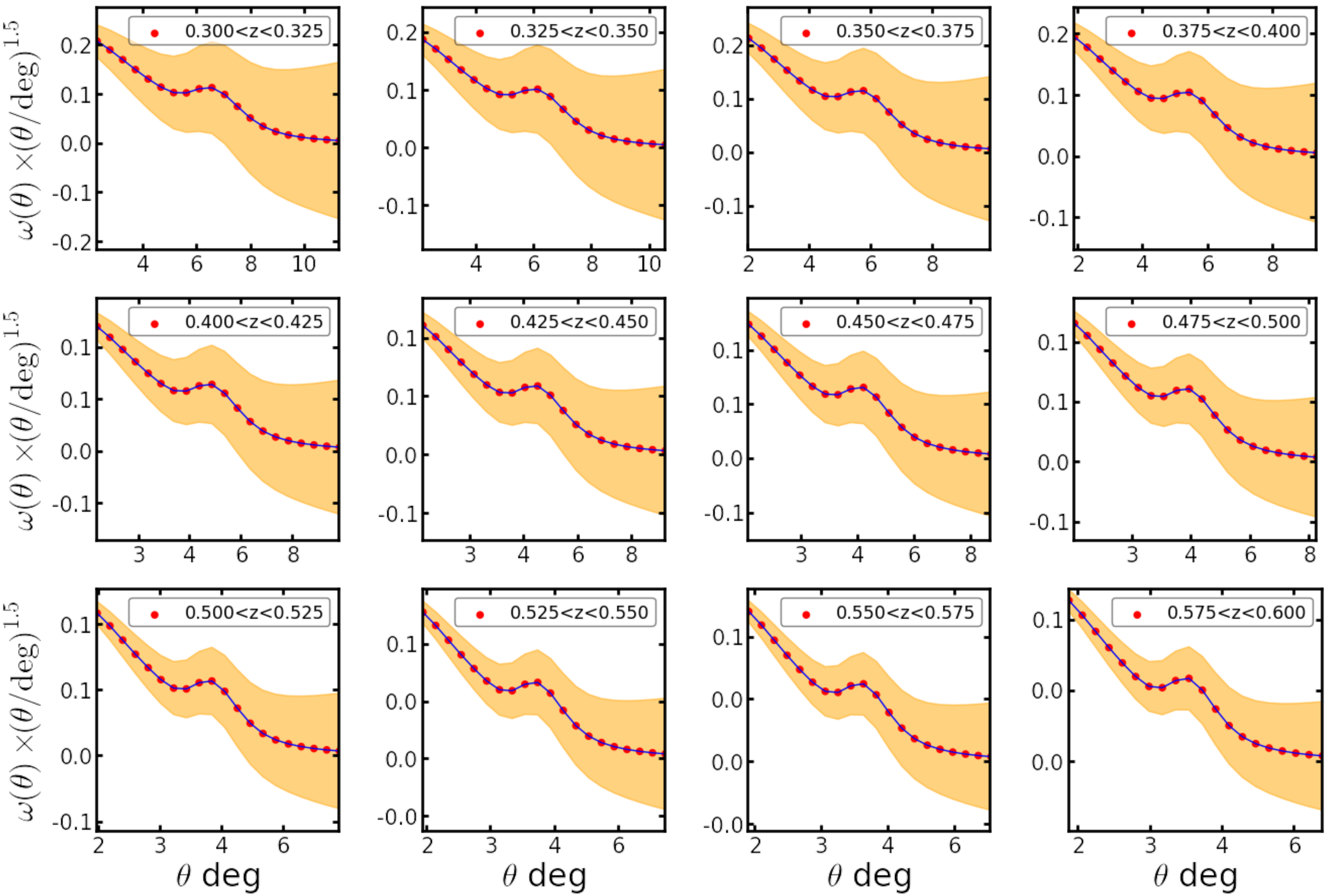
- 10000 square deg.
- Galaxy sample $0.1<z<0.7$: LOWZ & CMASS
- BAO measurements to 1%

BOSS: SYNTHETIC DATA SET

- Best-fit LCDM model from Planck+WP
- Constant $n(z) = 3\times10^{-4} h^3 Mpc^{-3}$ between 0.2<z<0.6
- Area of 10000 sqdeg.
- Bias model by Guo et al. (2013)

$$b = 1 + \frac{(b_0\text{-}1)}{D(z_{shell})}$$

- Fiducial values for A_{MC}=1.5, σ_v^0=4.29, b_0=1.55



0.300<z<0.325
0.325<z<0.350
0.350<z<0.375
0.375<z<0.400
0.400<z<0.425
0.425<z<0.450
0.450<z<0.475
0.475<z<0.500
0.500<z<0.525
0.525<z<0.550
0.550<z<0.575
0.575<z<0.600
$\omega(\theta) \times (\theta/\mathrm{deg})^{1.5}$
θ deg

ADDITIONAL DATA SETS

- Planck CMB distance priors (Wang & Wang 2013)
  $\{ l_A, R, \omega_b, A_s, n_s \}$

- Isotropic BAO post-reconstruction on BOSS

$$y(z) = \frac{D_V(z)}{r_s(z_d)}$$

assuming an accuracy of 2% & 1% for LOWZ and CMASS respectively (Anderson et al. 2013)

PARAMETER SPACES

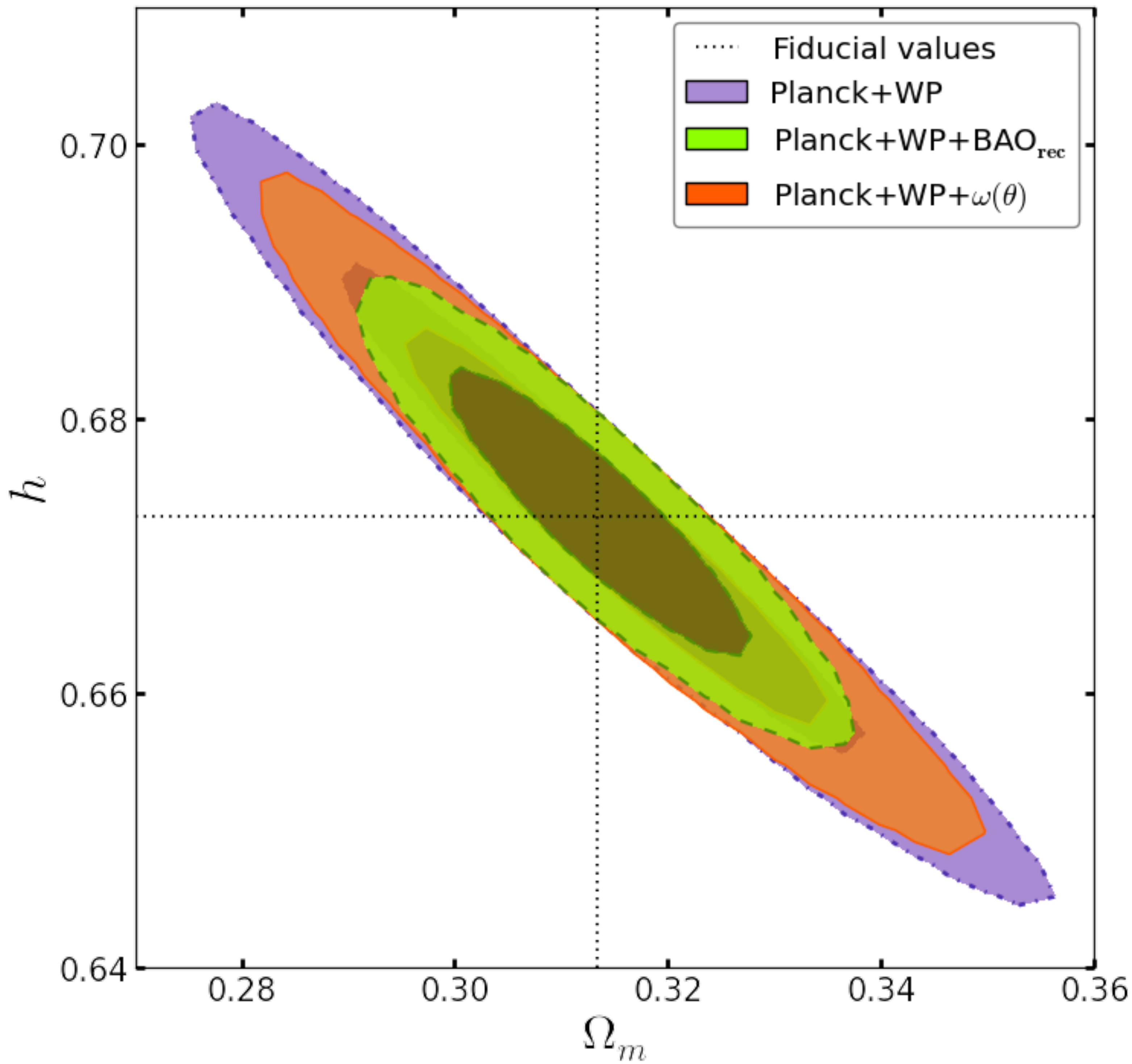
- Base model (LCDM)

$$\{\omega_b, \omega_c, \omega_{de}, A_s, n_s, A_{MC}, b_0, \sigma_v^0\}$$

- Extended models, allowing w_{DE} deviate from -1, as a constant or as a function of time following (Chevallier & Polarski 2001; Linder 2003)

$$w_{DE}(a) = w_0 + w_a(1\text{-}a)$$

FORECASTING COSMOLOGICAL PARAMETER CONSTRAINTS



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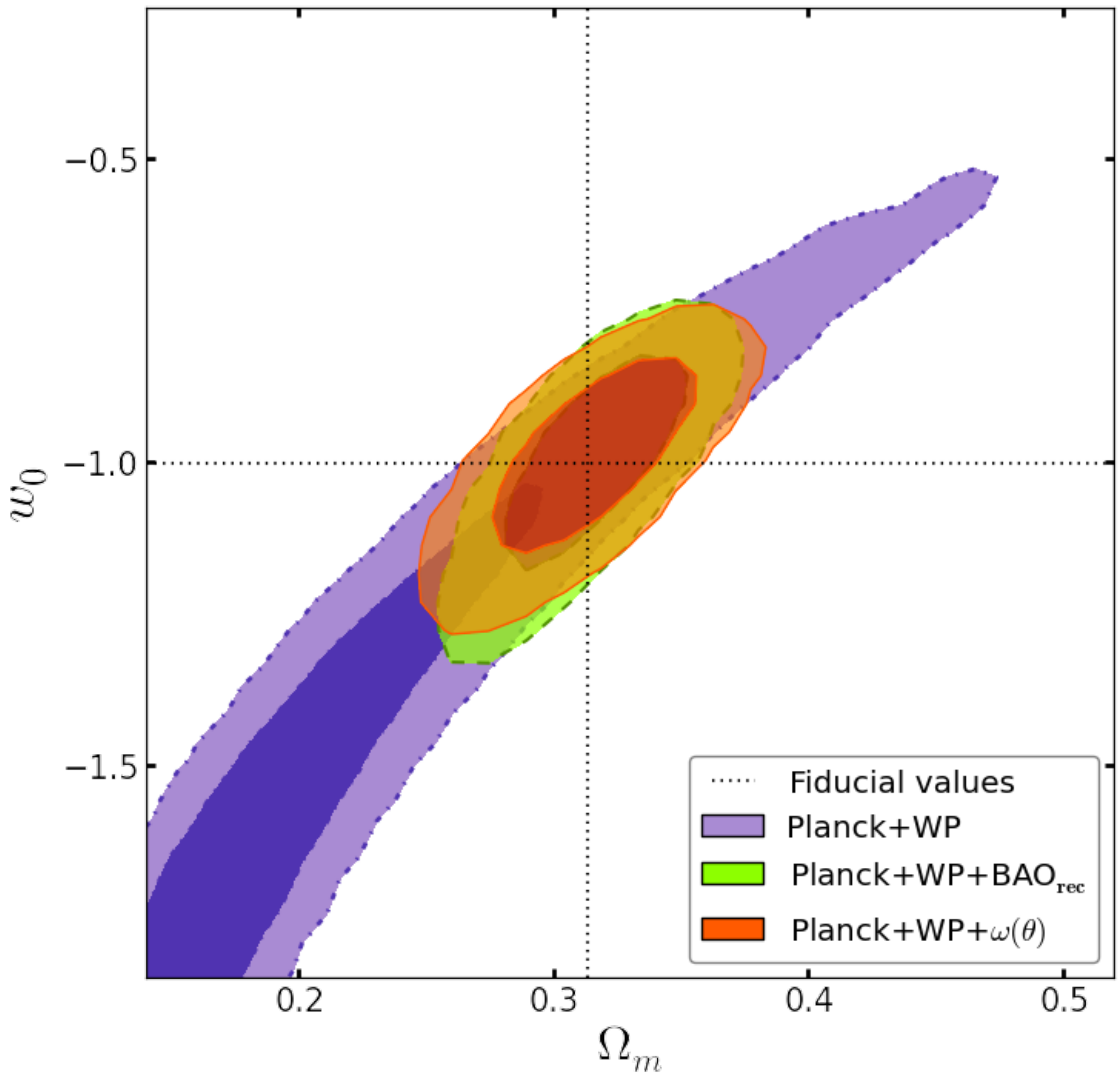
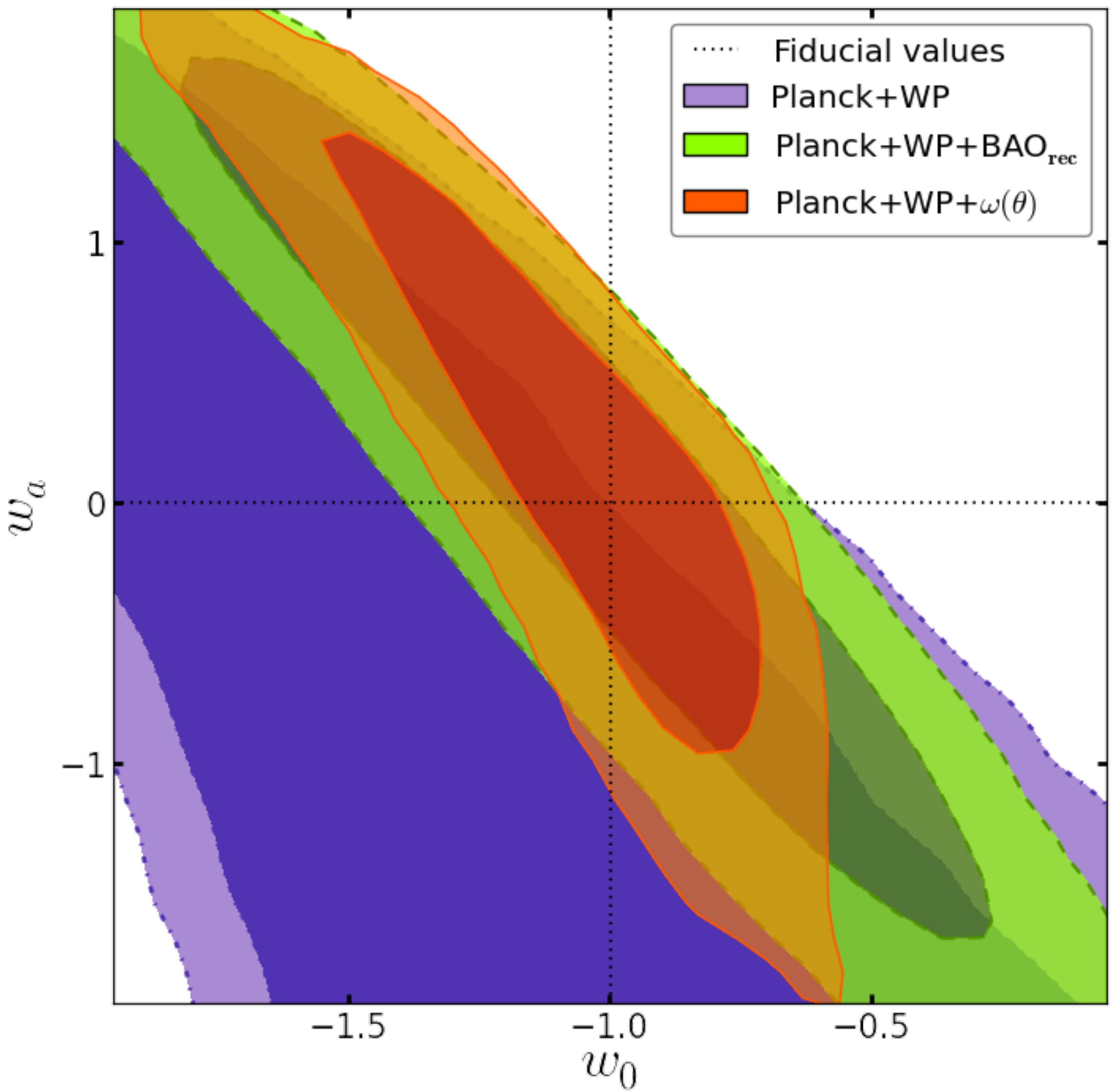


FORECASTING COSMOLOGICAL PARAMETER CONSTRAINTS



FORECASTING COSMOLOGICAL PARAMETER CONSTRAINTS

- Figure-of-Merit (Albrecht et al. 2006; Wang, Y. 2008)

$$FoM = \det[\mathrm{C}ov(w_0, w_a)]^{-\frac{1}{2}}$$

- Tomographic approach increases the FoM by a factor of ~1.4

SUMMARY

- We test a tomographic approach to analyse the galaxy clustering using $\omega(\theta)$ in redshift-shells
- We model the full shape of $\omega(\theta)$ and its covariance matrix
- These models are able to extract unbiased cosmological constraints
- Using these models we constructed a synthetic dataset with the aim of forecasting the accuracy of this technique applied on BOSS
- Better performance compared to isotropic BAO post-reconstruction for models with dynamic w_{DE}