Centro de Investigaciones
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Baryon Acoustic Oscillations in DES-Y3 data

DARK ENERGY SURVEY

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On behalf of the DES collaboration

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The Dark Energy Survey (DES) is a visible and near-infrared survey that aims to probe the physical nature of the dark energy with several methods. Among them, the dynamics of the expansion of the Universe and the growth of large-scale structure. In order to achieve this, it has imaged about 5000 square degrees of the southern sky in a 6-year photometric survey from Cerro Tololo (Chile).

In this work we explain how an optimized galaxy sample to study the expansion history of the Universe using the Baryon Acoustic Oscillations (BAO) scale is selected from the DES-Y3 data (comprising the first three years of data). The systematic errors from the observing conditions are studied and corrected. We present a method to obtain the BAO angular scale from the angular correlation function (ACF). This method is tested with the ACFs of 1000 mocks (simulated galaxy catalogs). The cosmology of the simulations is recovered with a precision of a few percent on the distance measurement. The final goal of the analysis is to measure the evolution of the angular diameter distance from the DES-Y3 data, from redshift ~0.6 to redshift 1.1, a range previously unexplored.

1. Context of the research

The **Dark Energy Survey (DES)** has already finished its 6 years of observations. It has imaged about **5000 square degrees** of the southern sky in **5 photometric bands** (g, r, i, z, Y). Large amounts of data have to be processed and analyzed:

- Year 1 results have already been published.
- **Year 3 is currently being analyzed** and results will be published soon (Y3 comprises the first 3 years of data).
- Year 6 analysis will start once Y3 results have been published (Y6 comprises the whole survey).

The **Large-Scale Structure** (LSS) working group prepares and performs the scientific exploitation of **galaxy clustering** in DES. One on the main things we do is cosmology using distance-scale rulers based on **baryonic acoustic oscillations (BAO)**, for which we have to define a BAO sample from the original catalog. **The DES-Y3 BAO sample** is a red galaxy dominated sample with a good compromise between **photo-z accuracy and number density**. It is selected with the cuts

$$1.7 < \mathrm{i} - \mathrm{z} + 2(\mathrm{r} - \mathrm{i}) \quad \text{(color selection)},$$
$$17.5 < \mathrm{i} < 19 + 3\mathrm{z}_{ph} \quad \text{(flux selection)},$$
$$0.6 < \mathrm{z}_{\mathrm{ph}} < 1.1 \quad \text{(photo-z range)}.$$

The BAO sample is divided in **5 redshift bins** with bounds $[0.6, 0.7, 0.8, 0.9, 1.0, 1.1]$. In this work, we will focus on how the BAO is measured in the **2-point angular correlation function (ACF)**. Since the ACF of the DES-Y3 data is still blinded, we will measure the BAO in a set of **1000 realistic mocks** (simulated galaxy catalogs) instead. This will be useful to validate the methods and to obtain an estimation of the error in the BAO from the 1000 mocks.

2. Methodology

1. Generate the mocks (**1000** in total). Firstly, we have to **fix an input cosmology** (in this case, **MICE cosmology**) and a **redshift distribution of the galaxies** for each redshift bin (we will use the ones of the DES-Y3 BAO sample).

2. Calculate the ACFs of each mock for the **5 redshift bins**. Also, calculate the **full covariance matrix** of the ACFs.

3. **Obtain the BAO scale of each mock** by fitting its ACFs using the full covariance matrix. The χ^2 of the fit is

$$\chi^2_{mock}(\vec{p}) = \sum_{z_1,z_2} \sum_{i,j} \left[\omega^{z_1}_{mock}(\theta_i) - \omega^{z_1}_{model}(\theta_i;\vec{p}^{z_1})\right] \cdot (cov^{-1})^{z_1,z_2}_{i,j} \cdot \left[\omega^{z_2}_{mock}(\theta_j) - \omega^{z_2}_{model}(\theta_j;\vec{p}^{z_2})\right].$$

The model is given by

$$\omega^{z_{bin}}_{model}(\theta;\vec{p}^{z_{bin}}) = A^{z_{bin}}\omega^{z_{bin}}_{template}(\alpha\cdot\theta) + B^{z_{bin}} + \frac{C^{z_{bin}}}{\theta} + \frac{D^{z_{bin}}}{\theta^2}, \quad \vec{p}^{z_{bin}} = \left(A^{z_{bin}}, \alpha, B^{z_{bin}}, C^{z_{bin}}, D^{z\_bin}\right),$$

where $\boldsymbol{\omega^{z_{bin}}_{template}(\theta)}$ **is the ACF computed is some cosmology**. The BAO scale is given in terms of the **shift** $\boldsymbol{\alpha}$ with respect to the template cosmology,

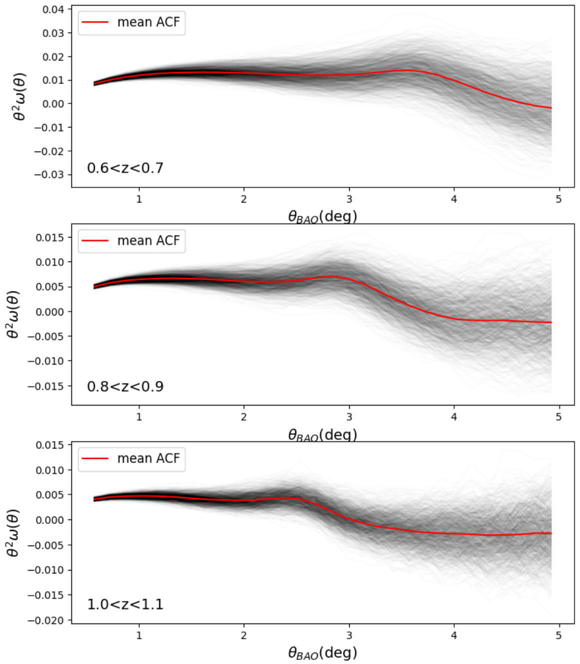
$$\alpha = \theta^{template}_{BAO}/\theta^{mock}_{BAO}.$$

The other 20 parameters of the fits are not interesting for the BAO study.

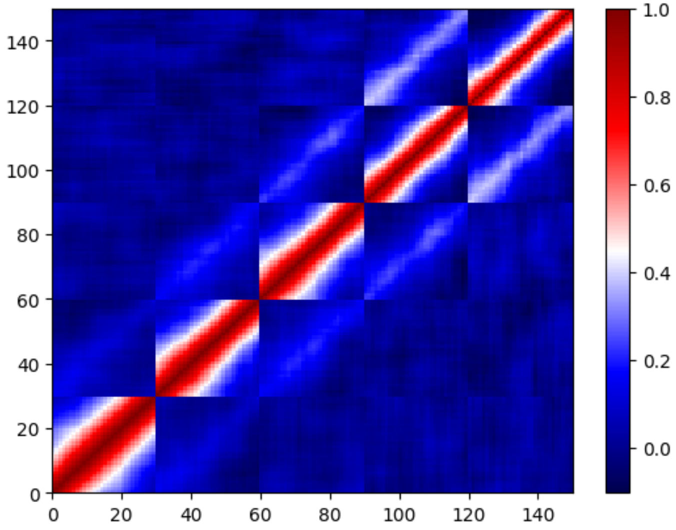
4. Calculate the **mean** and the **standard deviation** of the 1000 α values. We will use two different template cosmologies in order to test if we get the same standard deviation of α.

3.1. Results (I)

ACFs of the 1000 mocks



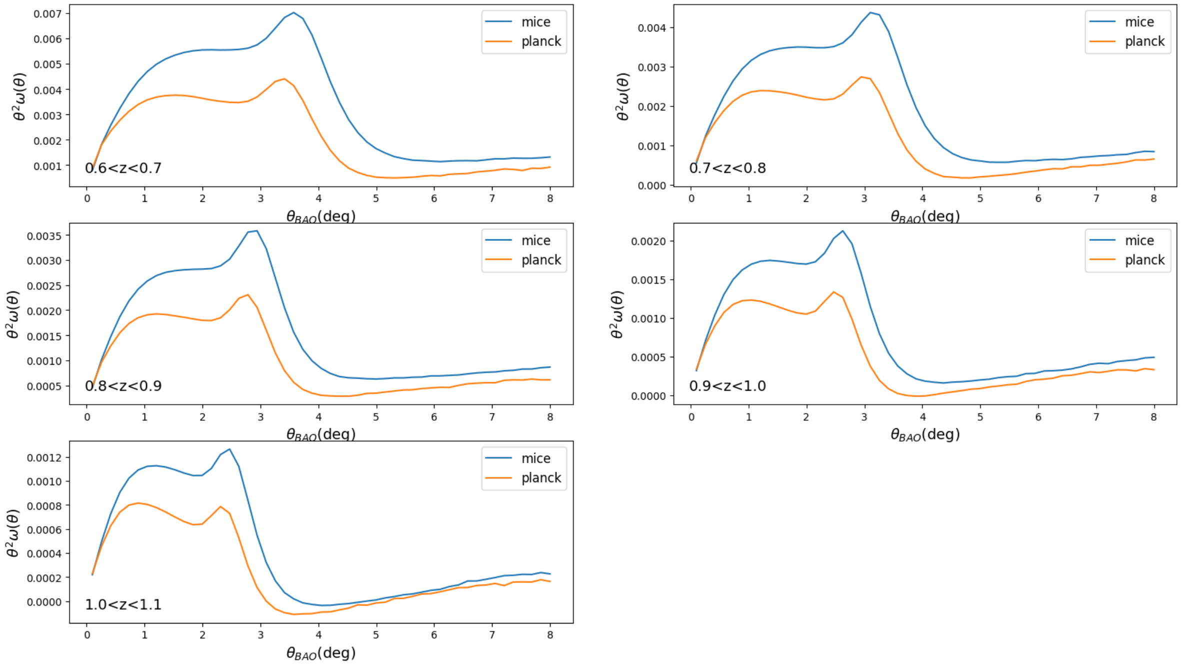
Full correlation matrix



Template ACFs: two different cosmologies

MICE: $\Omega_b = 0.044$ $\Omega_c = 0.206$ $h = 0.7$ $\sigma_8 = 0.8$ $n_s = 0.95$

Planck: $\Omega_b = 0.0494$ $\Omega_c = 0.2656$ $h = 0.6727$ $A_s = 2.101 \times 10^{-9}$ $n_s = 0.9649$

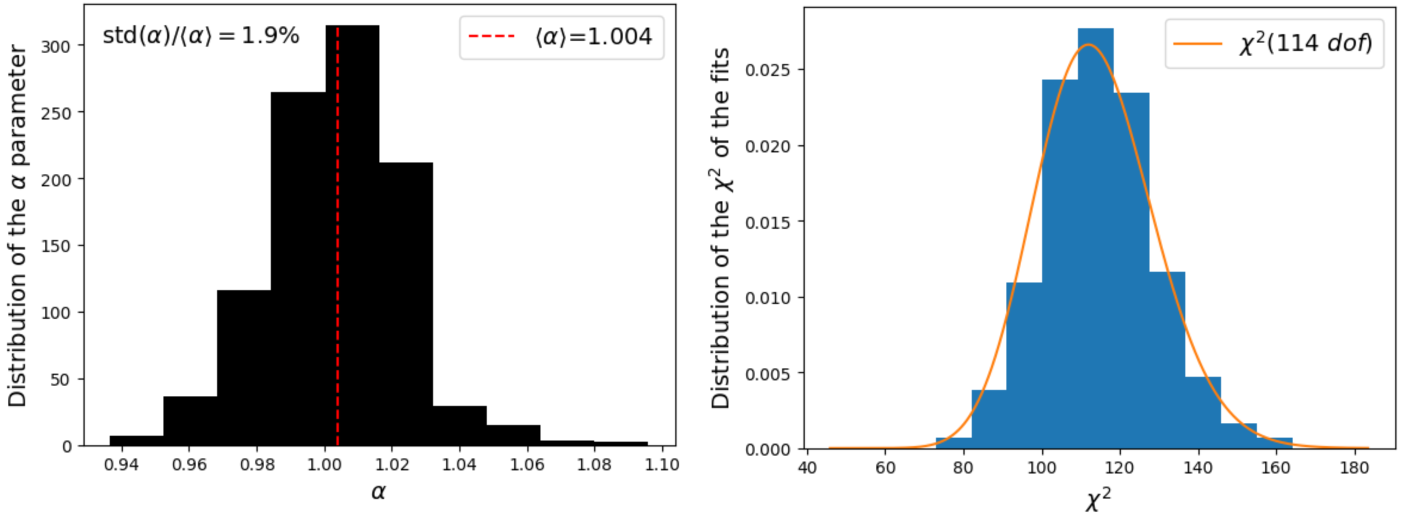


- Since the background cosmology is MICE, we expect $\langle\alpha\rangle = 1$ when fitting the mocks with the MICE template.
- When fitting the mocks using a template of another cosmology, we expect $\langle\alpha\rangle \neq 1$ but a similar value for $std(\alpha)/\langle\alpha\rangle$.

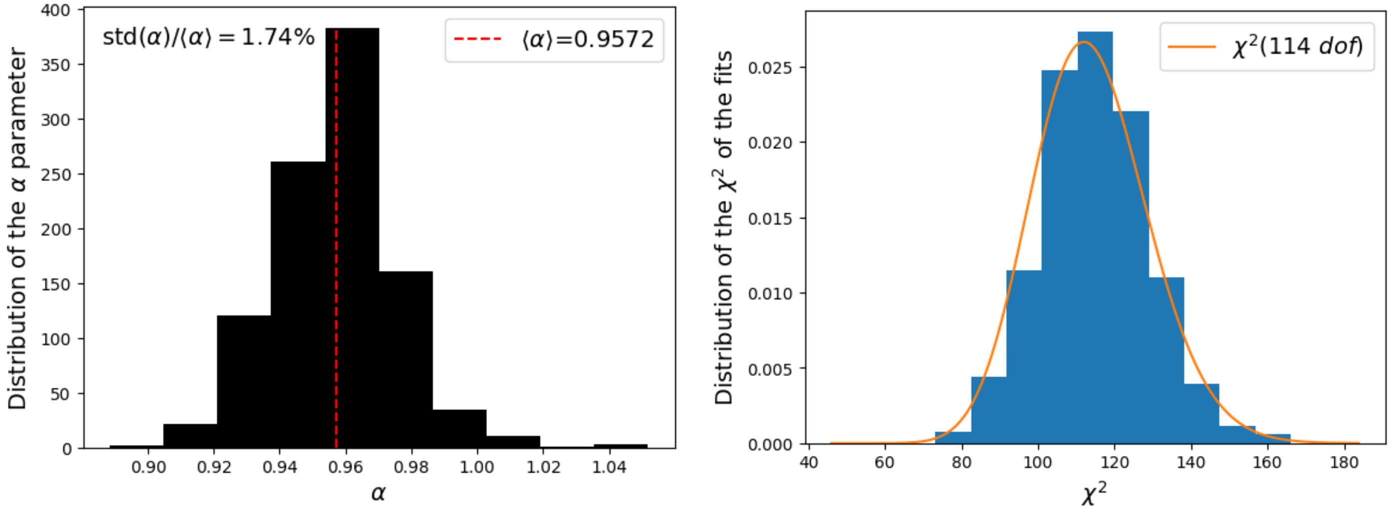
Scale cuts for the fits: $1^\circ < \theta < 5^\circ$ $\forall$ redshift bin → $(\mathbf{5 \times 27 = 135})$ **data points – 21 parameters = 114** $\boldsymbol{dof}$.

3.2. Results (II)

1. Using the MICE template



2. Using the Planck template



Summary of the results

	MICE temp	Planck temp
$\langle\alpha\rangle$	1.0040	0.9572
$std(\alpha)/\langle\alpha\rangle$	1.90%	1.74%
$\alpha_{th}(z_{eff})$	1	0.9528
$\langle\alpha\rangle/\alpha_{th}$	1.0040	1.0046

- As expected, using **the MICE template gives $\langle\alpha\rangle \approx 1$**.
- A relative error of $\sim 2\%$ in the BAO position is a very competitive result. This number is **similar using both templates**.
- The χ^2 of the 1000 fits **follow a χ^2 distribution** with the correct dof.

4.1 Conclusions

- We have obtained a **standard deviation** of the 1000 α values **of** $\sim 2\%$ **with respect to the mean** $\boldsymbol{\alpha}$.
- This standard deviation **does not depend on the cosmology of the template** used to do the fits. Also, **the mean** $\boldsymbol{\alpha}$ **corresponds to the theoretical value** in a very good approximation, which allows us to use this method with real data (for which we don't know the exact cosmology).

4.2 Prospects for the future

- Apply the method to **obtain the BAO scale from the DES-Y3 BAO sample** whenever the ACF is unblinded.
- In Y3, we will **combine these BAO results with 3x2pt** results.

References

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[2] Martín Crocce, Anna Cabré, and Enrique Gaztañaga. Modelling the angular correlation function and its full covariance in photometric galaxy surveys. Monthly Notices of the Royal Astronomical Society, 414(1):329–349, 2011.

[3] N. Aghanim, Y. Akrami, M. Ashdown, J. Aumont, C. Baccigalupi, M. Ballardini, AJ. Banday, RB. Barreiro, N. Bartolo, S. Basak, et al. Planck 2018 results VI. Cosmological parameters. Astronomy and Astrophysics, 2018.