Cosmology with DES Year-1 data: from 3x2pt analyses to the CMB imprint of cosmic voids

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Abstract

New generation of photometric galaxy surveys are mapping large volumes of the Universe, measuring the angular positions and shapes of hundreds of millions (or billions) of galaxies. This will allow cosmological measurements with an unprecedented level of precision, leading to a considerable step forward in our understanding of cosmology and particularly of the nature of dark energy. In this perspective, here will be present two different aspects of the cosmological results obtained by the Dark Energy Survey (DES) first year of observation. More specifically we present the results coming form combination lensing of galaxies statistics and galaxy clustering information. In a second part we will exposed the correlations of DES observations that can be measured using external probes and more specifically the imprint of cosmic voids on the lensing measurement of the cosmic microwave background (CMB).

1 Introduction

The Dark Energy Survey ([1]) is a photometric galaxy survey, that has for main objective to understand the physics behind the accelerating expansion of our universe. After 6 years of observations (2013-2019) DES have observed about 300 million of galaxies in and area of about 5000 sq. deg. of the southern sky through 5 photometric filters (grizY) with a nominal limiting magnitude iAB$\simeq$24. We will focus on the main cosmological constrained perform by the DES collaboration using the data collected after the first year of observations DESY1 which are covering about 1300 square degree survey area. More specifically we will start in section 2 to present the results obtained combining both gravitational lensing and galaxy clustering. We will then follow in section 3 by presenting a specific example of possible correlation of DESY1 observations with external observation, namely the imprint of cosmic voids with the lensing signal extracted from the Planck CMB observations.

2 First cosmological results with the Dark Energy first year of oberservation (DESY1)

2.1 Methodology and samples

As mentioned above, the first analysis of the DESY1 galaxy samples have allowed the collaboration to provide cosmological constraints using a combination of various probes. Here will be presented the first cosmological results from the first year of observation using and combining three different two-point statistic signal (3X2pt analysis) :

- Galaxy clustering : correlation signal of galaxy positions as a function of their angular separation ($\propto b^2\sigma_8^2$) [2],
- Cosmic shear : correlations between galaxy shapes as a function of their angular separation ($\propto \Omega_m^2\sigma_8^2$) [3],
- Galaxy-galaxy lensing : correlations between the shape of background galaxy (source galaxies) with the position of foreground ones (lenses) as a function of their angular separation ($\propto b\Omega_m\sigma_8^2$) [4].

In order to proceed to the analysis, one had to in one hand define optimal galaxy catalog and on the other hand measure with the highest precision possible galaxy property such as galaxy 3D position and galaxy shape. To be more robust, two different approaches have been used to evaluate the shape of the DESY1 galaxy sample the (`METACALIBRATION` ([5, 6]) and `IM3SHAPE` ([7])) catalog. While for clustering statistics the *redMaGiC*code identified red luminous galaxies (LRG) with high-quality photometric redshift. that have been measured using treecorr [**?**] in 20 log-spaced bins of angular separation $2.5^{'<\theta<250'}$.

While cosmic shear measurements, can be used alone to infer cosmological constraints, galaxy clustering and galaxy-galaxy lensing will have to be combined to break the degeneracy due to their dependance on galaxy bias.

2.2 Results

Cosmic shear being mostly sensitive to the clustering amplitude (S_8 parameter) and the matter parameter (Ω_m), it is possible to make an estimation of these parameter marginalizing over the other ones. The results obtained in [3], are, for ΛCDM: $\sigma_8(\Omega_m/0.3)^{0.5} = 0.782^{+0.027}_{-0.027}$ and $\Omega_m = 0.260^{+0.065}_{-0.037}$ at 68 % C.L. These values have improved by a factor of three the results obtained in the cosmic shear measurement of previous science DES science verification measurement. The main results of the combined analysis described above are shown in Figure (1). In the left panel of the figure we can see the comparison of the results obtained weather one combines the different probes or not. As it can be seen in the figure, the results here are showing a good agreement between clustering statistics and lensing statistics in cosmological parameter inference. Moreover, the combination of the three different probes shows to improve our constraints on cosmological parameters. The main constraints obtained by combining the three two-point statistics are for ΛCDM: $\sigma_8(\Omega_m/0.3)^{0.5} = 0.783^{+0.021}_{-0.025}$ and $\Omega_m = 0.264^{+0.032}_{-0.019}$ at 68 % C.L. On the other hand, the right panel of the figure shows the 68% confidence levels of S_8 and Ω_m in the ΛCDM parametrization for DESY1 alone and combined to external datasets. Thus one can see that first cosmological analysis made by DESY1 studying large scale structures at low redshift are in fair agreement with the CMB measurements at $z = 1100$ and second that the DESY1 analysis is actually reaching a level where the accuracy of cosmological parameter estimation is competitive with the one inferred by CMB experiments.

3 Correlation of the DESY1 underdensed regions with the CMB lensing signal

Similarly to galaxy shape distortions due to the foreground matter field in cosmic shear analysis, one expects the light coming from the cosmic microwave background (CMB) towards us to be also lensed by the large structures it crosses aloneg its path. Correlations is then expected between the foreground structures of our universe and the CMB radiation. In [9], using a stacking methodology, we developed a methodology to optimize and evaluate the imprint of cosmic voids, these large ($\sim$ tens of Mpc/h) underdensed region of the cosmic web, identified in the DESY1 observed galaxy in the reconstructed CMB lensing map provide by the Planck collaboration.

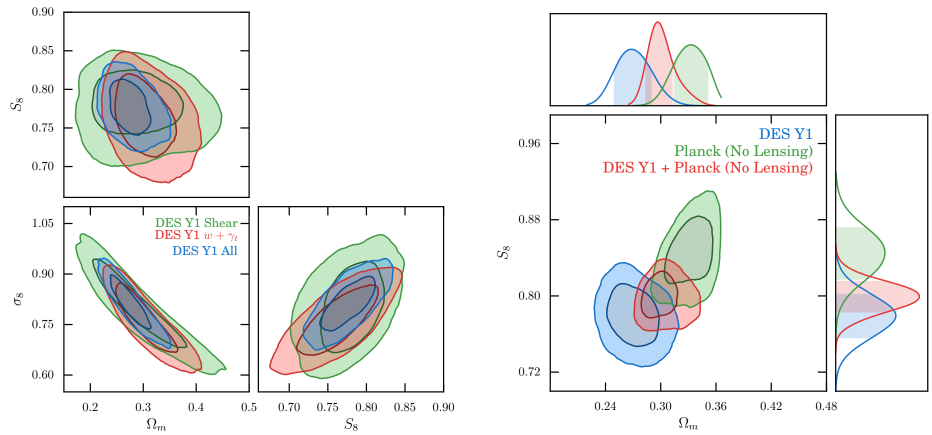

Figure 1: *Left panel:* constraints from DESY1 on Ω_m, σ_8 and S_8 from cosmic shear (green), *redMaGiC*galaxy clustering plus galaxy– galaxy lensing (red), and their combination (blue). Here, and in all such 2D plots below, the two sets of contours depict the 68% and 95% confidence levels. *Right panel :* ΛCDM constraints from the three combined probes in DES Y1 (blue), Planck with no lensing (green), and their combination (red). The agreement between DES and Planck can be quantified via the Bayes factor, which indicates that in the full, multi-dimensional parameter space, the two data sets are consistent. (Figures from [8])

3.1 Methodology

In order to be less affected by photometric redshift bias that is known to be a source of error in the void finding procedure, we have identified underdensed region of the DESY1 catalog in the high-precision photometric redshift *redMaGiC*luminous red galaxy sample.[10]. We have identified cosmic void in the DESY1 *redMaGiC*sample using the 2D void finder presented in [11]. The void finder is identifying voids in the following way: (1) Divide the sample in redshift slices 100Mpc/h slices are shown to be a good compromise considering *redMaGiC*redshift accuracy, (2) Compute the density field for each slice by counting the galaxy number in each pixel and smoothing the field with a Gaussian with a predefined smoothing scale, (3) Select the most underdense pixel and grow around it the void until it reaches the mean density, (4) Save the void, erase it from the density map and iterate the process with the following underdense pixel. The finder have been run two different *redMaGiC*catalogs, probing different smoothing parameter for the void finder ($\sigma = 10Mpc/h$ and $\sigma = 20Mpc/h$) in both DESY1 observed galaxies, and MICE ([12, 13, 14]) simulated galaxies. In order to be more complete, we have also considered a different definition of voids to probe the effect on the CMB lensing signal, the 3 dimensional voids identified with the VIDE toolkit ([15]).

To detect the imprint of cosmic voids in the CMB lensing maps, we have used a stacking methodology which consist in cutting out patches of the smoothed CMB map (different smoothing kernel have been probe) centered at superstructure position using `healpix` maps ([16]), re-scale the patches given the angular size of the structure, stack all patches and finally measure the average signal in different concentric radius bins around the center.

3.2 Results

Along the analysis, we observed good agreement between the simulated MICE ΛCDM results and the our observations. As a measure of the signal-to-noise (S/N) of simulated and observed signals given the measurement errors and their covariance, we aim to constrain an amplitude A (and its error

σ_A) as a ratio of DES Y1 and MICE signals using the full profile up to $R/R_v = 5$ in 16 radial bins. We expect $A = 1$ if the DESY1 and MICE ΛCDM results are in close agreement and we aim to test this hypothesis. In order to estimate the value of A, we have followed the statistic :

$$\chi^2 = \sum_{ij} (\kappa_i^{DES} - A\kappa_i^{MICE}) C_{ij}^{-1} (\kappa_j^{DES} - A\kappa_j^{MICE}) \quad (1)$$

where κ_i is the mean lensing signal in the radius bin i, and C is the covariance matrix computed using the variance of the lensing signal measured by rotating randomly 500 times the MICE lensing map to which we have add a *Planck*-like noise.

The final results of the detection level achieved for each void sample and the three different smoothing approaches studied can be seen in Fig.(2), from the figure, we can see that we robustly detected imprints at the 3σ significance level with most of our analysis choices, reaching $S/N \approx 4$ in the best predicted measurement configurations using DES Y1 high luminosity *redMaGiC*data.

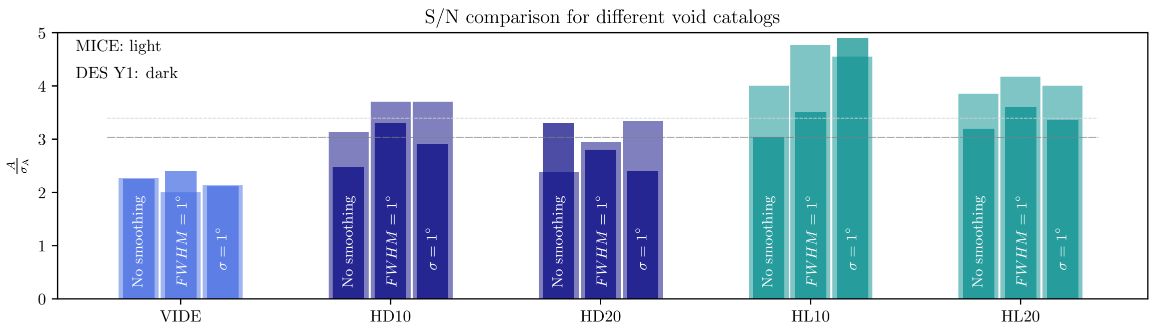

Figure 2: Measurement significance in the form of A/σ_A. The conservative VIDE sample also provides useful consistency tests in agreement with our 2D analyses. The dashed horizontal lines mark the mean of the DES Y1 (dark) and the MICE (light) significances with values 3.03 and 3.39, respectively

4 Conclusions

In this presentation, have been presented first the main cosmological results inferred from the DESY1 galaxy catalog, using the three different 2-point statistics probes after one year of observations. The Dark Energy survey has now collected 6 years of data and we saw its abilities after this first observation year, to be competitive in cosmological inference, more in particular, it has been shown that by combining different probes, DES have been able for the first time after one year of observation to infer cosmological parameter constraints at the level of accuracy of CMB experiments. So far, no significant deviations from the ΛCDM model have been found. In the future months, the Dark Energy Survey will present the analysis coming from the second and third year of observation, during this period DES has already covered the full expected final area (up to a given magnitude). The analysis will thus be realised in an area more than three times larger than the DESY1.

In a second part, we have shown that we have now entering the era where large and precise sample will allow us to use cosmic voids as cosmological probe. We robustly detected imprints at the 3σ significance level with most of our analysis choices, reaching S/N ≈ 4 in the best predicted measurement configurations using DES Y1 high luminosity *redMaGiC*data. Our goal for the future is to create a bigger catalogue of voids, and potentially superclusters, using galaxy catalogues from three years of observed DES data (DES Y3). These presumably more accurate future detections with more voids will most probably allow cosmological parameter constraints

References

[1] The Dark Energy Survey Collaboration, *The Dark Energy Survey*, *arXiv e-prints* (Oct., 2005) astro–ph/0510346, [astro-ph/0510346].

[2] J. Elvin-Poole and DES Collaboration, *Dark Energy Survey year 1 results: Galaxy clustering for combined probes*, **98** (Aug., 2018) 042006, [arXiv:1708.01536].

[3] M. A. Troxel and DES Collaboration, *Dark Energy Survey Year 1 results: Cosmological constraints from cosmic shear*, **98** (Aug., 2018) 043528, [arXiv:1708.01538].

[4] J. Prat and DES Collaboration, *Dark Energy Survey year 1 results: Galaxy-galaxy lensing*, **98** (Aug., 2018) 042005, [arXiv:1708.01537].

[5] E. Huff and R. Mandelbaum, *Metacalibration: Direct Self-Calibration of Biases in Shear Measurement*, *ArXiv e-prints* (Feb., 2017) [arXiv:1702.02600].

[6] E. S. Sheldon and E. M. Huff, *Practical Weak-lensing Shear Measurement with Metacalibration*, **841** (May, 2017) 24, [arXiv:1702.02601].

[7] J. Zuntz, T. Kacprzak, L. Voigt, M. Hirsch, B. Rowe, and S. Bridle, *IM3SHAPE: a maximum likelihood galaxy shear measurement code for cosmic gravitational lensing*, **434** (Sept., 2013) 1604–1618, [arXiv:1302.0183].

[8] Dark Energy Survey Collaboration, *Dark Energy Survey year 1 results: Cosmological constraints from galaxy clustering and weak lensing*, **98** (Aug., 2018) 043526, [arXiv:1708.01530].

[9] P. Vielzeuf and DES Collaboration, *Dark Energy Survey Year 1 Results: the lensing imprint of cosmic voids on the Cosmic Microwave Background*, *arXiv e-prints* (Nov., 2019) arXiv:1911.02951, [arXiv:1911.02951].

[10] E. Rozo and DES Collaboration, *redMaGiC: selecting luminous red galaxies from the DES Science Verification data*, **461** (Sept., 2016) 1431–1450, [arXiv:1507.05460].

[11] C. Sánchez and DES Collaboration, *Cosmic voids and void lensing in the Dark Energy Survey Science Verification data*, **465** (Feb., 2017) 746–759, [arXiv:1605.03982].

[12] P. Fosalba, E. Gaztañaga, F. J. Castander, and M. Crocce, *The MICE Grand Challenge light-cone simulation - III. Galaxy lensing mocks from all-sky lensing maps*, **447** (Feb., 2015) 1319–1332, [arXiv:1312.2947].

[13] M. Crocce, F. J. Castander, E. Gaztañaga, P. Fosalba, and J. Carretero, *The MICE Grand Challenge lightcone simulation - II. Halo and galaxy catalogues*, **453** (Oct., 2015) 1513–1530, [arXiv:1312.2013].

[14] P. Fosalba, M. Crocce, E. Gaztañaga, and F. J. Castander, *The MICE grand challenge lightcone simulation - I. Dark matter clustering*, **448** (Apr., 2015) 2987–3000, [arXiv:1312.1707].

[15] P. M. Sutter, G. Lavaux, B. D. Wandelt, D. H. Weinberg, M. S. Warren, and A. Pisani, *Voids in the SDSS DR9: observations, simulations, and the impact of the survey mask*, *Monthly Notices of the Royal Astronomical Society* **442** (06, 2014) 3127–3137, [https://academic.oup.com/mnras/article-pdf/442/4/3127/4168371/stu1094.pdf].

[16] K. M. Górski, E. Hivon, A. J. Banday, B. D. Wandelt, F. K. Hansen, M. Reinecke, and M. Bartelmann, *HEALPix: A Framework for High-Resolution Discretization and Fast Analysis of Data Distributed on the Sphere*, **622** (Apr., 2005) 759–771, [astro-ph/0409513].