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Preliminary cosmological constraints from the Dark Energy Survey Supernova Program using the 3 year Spectroscopic Sample

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The Dark Energy Survey (DES) is using four probes to investigate the dynamics of the expansion of the Universe. The DES Supernova Program (DES-SN) is observing 27 square degrees with a 6-day cadence to obtain a large sample of type Ia supernovae for cosmology. In collaboration with DES, the Australian Dark Energy Survey (OzDES) is using the AAT to obtain redshifts and classifications for objects in the DES fields. While probing dark energy using type Ia supernovae is the primary aim of the supernova survey, the observing strategy enables us to conduct a number of other investigations, such as AGN reverberation mapping and galactic evolution studies. We present preliminary cosmological constraints from the first 3-years of the DES-SN survey. The sample contains 206 spectroscopically confirmed Type Ia Supernovae ($0.02 < z < 0.9$) discovered during the first 3 years of the DES-SN. The photometric calibration, scene modeling photometric pipeline, additional low-z supernovae samples ($z < 0.1$), as well as the cosmological results and systematics analysis are discussed.

1 Introduction

Since the discovery of the accelerated expansion of the Universe using type Ia supernovae [17,15], an enormous effort has been dedicated to understand the properties of dark energy. Type Ia supernovae (SNe Ia) used as standardizable candles are an important tool to constrain the nature of dark energy since they probe the geometry of the Universe, while other probes such as weak lensing and large scale structure probe a combination of geometry and growth of structure.

Numerous surveys have been dedicated to constrain the expansion of the Universe by discovering SNe Ia in a wide range of redshifts. At high redshift joint analyses of SNe Ia surveys, such as SNLS and SDSS-II in the Joint-Lightcurve Analysis (JLA) [3] and Pan-STARRS1 (PS1) Medium Deep Survey in the Pantheon sample [19], have provided stringent constraints to the nature of dark energy. More recent surveys, such as the Dark Energy Survey [2], have discovered thousands of supernovae, a factor of 10 increase over previous surveys. The upcoming Large Synoptic Survey Telescope (LSST) survey will discover even more supernovae [1]. These cosmological surveys are designed to improve the measurement of the dark energy equation of state parameter, w ($w = p_{\rm DE}/\rho_{\rm DE}$, where $p_{\rm DE}$ and $\rho_{\rm DE}$ are the pressure and energy density of dark energy, respectively), and constrain its variation with time.

2 The Dark Energy Survey

DES is a photometric survey with the main goal to understand the physics behind the accelerating expansion of the Universe. For this, it uses four astronomical probes: galaxy clusters, large

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scale structure, weak lensing, and SNe Ia. DES images the sky with DECam [8], a 3 square-degree imager (2.1 degrees in diameter) mounted on the 4-meter Blanco Telescope at Cerro Tololo Inter-American Observatory (CTIO) in Chile. DES consists of a wide-field survey covering a quarter of the Southern sky, and the deep-survey which is dedicated to supernovae consisting of 27 square degrees [2]. DES started obtaining survey quality images in 2013.

The Dark Energy Survey Supernova program images 10 fields [2] to study the cosmic expansion with type Ia supernovae. These ten fields, 8 shallow fields (C1, C2, E1, E2, S1, S2, X1 and X2) and 2 deep fields (C3 and X3), are repeatedly observed in the g, r, i, z passbands with a cadence of ~ 1 week. The observing strategy has been optimized to produce high-quality light curves for thousands of SNe Ia which are suitable for measuring cosmological parameters.

3 OzDES

OzDES uses the 2dF fiber positioner feeding the AAOmega spectrograph on the 4-m Anglo-Australian Telescope (AAT) to obtain redshifts for the DES survey [21]. This instrument is ideal for the spectroscopic follow-up of DES, as the field-of-view of DECam is well matched to the 2 degree field-of-view of AAOMega. OzDES only focuses on the 10 DES deep fields. OzDES is capable of obtaining redshifts for tens of thousands of objects, some which are usually considered to be too faint ($r = 24$) for a 4m class telescope, by simply continuing to observe them over multiple runs and stacking the signal until the redshift is obtained.

OzDES has two main scientific goals. The first one is to to provide redshifts for the SN Ia Hubble diagram. The second goal is to map out the growth of supermassive black holes, from 12 billion years ago to the present, using AGN reverberation mapping [14]. To date, OzDES has spectroscopically classified over 150 supernovae, which means the AAT has classified more DES SNe Ia than any other telescope in the world. The majority of DES supernovae, however, will be classified by their photometry alone, and their redshifts obtained using spectra of the host galaxies. So an arguably more important role of OzDES has been to obtain over 15,000 redshifts for transients and galaxies up to $r \lesssim 24.5$ [6].

4 DES 3-year supernovae

We present preliminary results of the analysis of the first three years of spectroscopically confirmed type Ia supernovae. From the first three years of DES-SN we have 251 spectroscopically confirmed type Ia supernovae ($0.02 < z < 0.9$). Details on the sample and spectroscopic follow-up program can be found in (D'Andrea et al. in prep.). For the cosmological analysis, we require each SN Ia to have a good light-curve sampling and the fitted color and shape parameters to lie in the range of validity of the SALT2 model, described in the JLA analysis [3]. The DES 3-year spectroscopic sample is composed by 206 DES SNe Ia after cuts and 128 low-redshift supernovae from CSP and CFA surveys [18,9,10,7,20] required to set the low-redshift anchor for the analysis.

Supernovae are discovered by subtracting a template image from a search image using a difference imaging pipeline and selecting significant positive detections, at least two filters with signal-to-noise > 5 [11]. Promising supernovae candidates are sent for spectroscopic follow-up (D'Andrea et al. in prep.). Spectra provide typing of supernovae, as well as redshifts.

To perform a cosmological analysis both redshifts and light-curves from our type Ia supernova sample are required. Light-curves, the evolution of flux over time, provide the necessary measurements for SN Ia standardization. The performance of our scene-modeling photometry was evaluated by introducing fake SNe Ia onto images. The obtained photometric distance bias $< 1\%$ is equivalent to a 3 $mmag$ systematic per band up to $mag \approx 23.5$ (Brout et al. in prep.).

Distances measured from the supernova sample are biased by selection effects from the instrument, spectroscopic follow-up and analysis requirements. We use simulations to asses biases. For example, the efficiency of the difference imaging pipeline is determined by introducing fakes on images [11]. Due to the spectroscopic follow-up strategy, only a subsample of DES discovered supernovae are spectroscopically typed. This selection effect can be modeled by comparing our spectroscopically classified sample with realistic simulations of SNe Ia in DES. The simulations are performed using SNANA [13] and include the survey detection efficiency. The obtained selection efficiency can be used to correct the distance bias in the cosmology analysis.

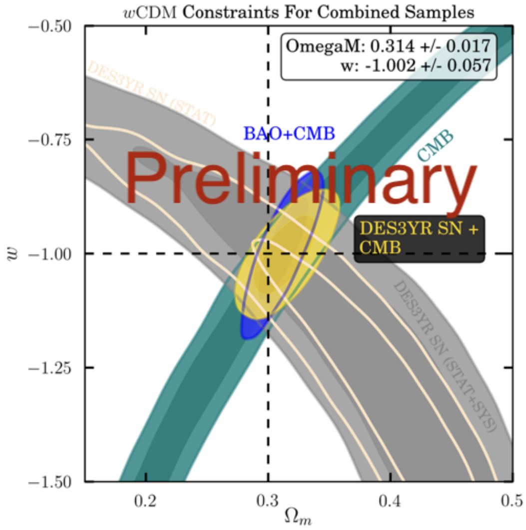

Figure 1 – Preliminary DES 3 year supernovae cosmological parameter constraints: dark energy equation of state parameter, w, versus Ω_m. Preliminary constraints from DES 3 year supernovae using BBC+Cosmo MC (gray), CMB (turquoise), CMB and BAO (blue) and joint constraints CMB + SN (yellow) are shown.

5 Cosmological analysis

For the DES 3-year spectroscopic sample, three analyses are being prepared: a JLA [3]-like analysis using CosmoMC, a Pantheon [19]-like using BBC and CosmoMC and a new hierarchical Bayesian model for Supernova Cosmology (Hinton et al. in prep.). We blind all cosmological analyses and test them using 100 simulated datasets. In this work we present the Pantheon-like analysis which was unblinded on December 22nd, 2017 [5].

To correct for biases in distance, we perform BEAMS with bias corrections [12]. This method determines a redshift bin averaged Hubble diagram and nuisance parameters, α, β, γ_0 and σ_{int} to standardize the SN Ia brightness; then the bin-averaged HD is fit to a cosmological model where priors can be imposed. For the DES 3-year analysis we assemble a redshift binned covariance matrix with statistical and systematic errors. 58 Sources of systematic uncertainty were taken into account including: calibration (accounting for 20 low-z bands and 4 DES bands), SNe Ia light-curve model, distance bias corrections (e.g. peculiar velocities) and Milky Way extinction. A calibration systematic of 6 mmag for this preliminary analysis was found for the DES sample[4].

Cosmological fitting is performed using CosmoMC with a wCDM model and Planck CMB priors [16]. The DES 3-year sample, which includes DES discovered high-redshift supernovae and a low-redshift supernova anchor from CSP and CFA surveys, provides cosmological parameter constraints shown in Figure 1. Together with CMB measurements we obtain preliminary constraints of $\Omega_m = 0.314 \pm 0.017$ and $w = -1.002 \pm 0.057$. This analysis is currently being finalized with a set of steps planned pre-unblinding, including but not limited to improvements in photometry and calibration (several papers DES collaboration et al. in prep.).

6 Summary

We have presented the preliminary Dark Energy Survey 3-year supernovae constraints on cosmology. With a sample of 334 SNe Ia, made by 206 DES SNe Ia and 128 supernovae for the low-redshift anchor, DES is able to obtain an uncertainty on the equation-of-state parameter of dark energy comparable to previous supernovae survey samples that were double in size. A series of papers detailing this analysis is in preparation. Afterwards, the survey expects to perform a new cosmological analysis with thousands of photometrically classified type Ia supernovae.

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