Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **536,** 1948–1966 (2025) https://doi.org/10.1093/mnras/stae2703
Advance Access publication 2024 December 9

Evaluating cosmological biases using photometric redshifts for Type Ia Supernova cosmology with the Dark Energy Survey Supernova Program

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Accepted 2024 December 4. Received 2024 October 30; in original form 2024 July 23

ABSTRACT

Cosmological analyses with Type Ia Supernovae (SNe Ia) have traditionally been reliant on spectroscopy for both classifying the type of supernova and obtaining reliable redshifts to measure the distance–redshift relation. While obtaining a host-galaxy spectroscopic redshift for most SNe is feasible for small-area transient surveys, it will be too resource intensive for upcoming large-area surveys such as the Vera Rubin Observatory Legacy Survey of Space and Time, which will observe on the order of millions of SNe. Here, we use data from the Dark Energy Survey (DES) to address this problem with photometric redshifts (photo-z) inferred directly from the SN light curve in combination with Gaussian and full $p(z)$ priors from host-galaxy photo-z estimates. Using the DES 5-yr photometrically classified SN sample, we consider several photo-z algorithms as host-galaxy photo-z priors, including the Self-Organizing Map redshifts (SOMPZ), Bayesian Photometric Redshifts (BPZ), and Directional-Neighbourhood Fitting (DNF) redshift estimates employed in the DES 3 × 2 point analyses. With detailed catalogue-level simulations of the DES 5-yr sample, we find that the simulated w can be recovered within ±0.02 when using SN+SOMPZ or DNF prior photo-z, smaller than the average statistical uncertainty for these samples of 0.03. With data, we obtain biases in w consistent with simulations within $\sim 1\sigma$ for three of the five photo-z variants. We further evaluate how photo-z systematics interplay with photometric classification and find classification introduces a subdominant systematic component. This work lays the foundation for next-generation fully photometric SNe Ia cosmological analyses.

Key words: (cosmology:) dark energy – transients: supernovae.

1 INTRODUCTION

Type Ia Supernovae (SNe Ia) are standardizable candles used as a key cosmological probe to measure the distance–redshift relation and understand the nature of dark energy. In order to precisely constrain the dark energy equation-of-state parameter w, the largest SN surveys and compilations to date such as Pantheon+ (Brout et al. 2022) have relied on access to spectroscopy of the live SN to confirm the type of the SN, as well as of the host galaxy to obtain an accurate redshift. Recent cosmological analyses such as the Dark Energy Survey 5-yr SN analysis (DES-SN5YR; Vincenzi et al. 2024; DES Collaboration 2024) have shown that a transition to photometric classification immensely boosts our statistical constraining power without introducing significant systematic uncertainty. Upcoming surveys such as the Vera Rubin Observatory Legacy Survey of Space

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