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Type Ia supernovae selection and forecast of cosmology constraints for the Dark Energy Survey

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ABSTRACT

We present the results of a study of selection criteria to identify Type Ia supernovae photometrically in a simulated mixed sample of Type Ia supernovae and core collapse supernovae. The simulated sample is a mockup of the expected results of the Dark Energy Survey. Fits to the MLCS2k2 and SALT2 Type Ia supernova models are compared and used to help separate the Type Ia supernovae from the core collapse sample. The Dark Energy Task Force Figure of Merit (modified to include core collapse supernovae systematics) is used to discriminate among the various selection criteria. This study of varying selection cuts for Type Ia supernova candidates is the first to evaluate core collapse contamination using the Figure of Merit. Different factors that contribute to the Figure of Merit are detailed. With our analysis methods, both SALT2 and MLCS2k2 Figures of Merit improve with tighter selection cuts and higher purities, peaking at 98% purity.

1. Motivation

In the next decade, the number of detected Type Ia supernovae (SNIa) will increase dramatically [1,2], surpassing the resources available for spectroscopic confirmation of each supernova (SN). This has produced an increased interest in the photometric identification of SNIa in samples including significant numbers of core collapse supernovae (SNcc). In order to improve the contraints on the accelerated expansion of the universe, discovered with SNIa in the late 1990's [3,4], photometric typing of supernovae (SNe) must be very robust. Two recent studies of simulated SNe have approached the subject of SN photometric identification in different ways: (1) the first, Kessler et al. [5], compared a wide variety of photometric-typing algorithms, but did not evaluate the impact on cosmology constraints, (2) the second, Bernstein et al. [1] studied the impact on cosmology in detail, but only used one photometric-typing algorithm (MLCS2k2 fit quality cuts). The analysis presented in this paper is a follow-up to Bernstein et al., and incorporates several new features in the analysis.

Using tight signal-to-noise ratio (SNR) cuts and a SNIa fit quality cut (MLCS2k2 model [6]), Ref. [1] achieved a purity (SNIa/Total) above 95%. The remaining SNcc had a negligible effect on cosmology. This was achieved for the case where the redshifts of the SNe were assumed to be measured accurately in a spectroscopic follow-up of the host galaxies. In this article, we follow a similar approach but extend the analysis by studying the effects of relaxing the SNR cuts. We also extend the analysis to include the SALT2 SNIa model fit quality. In addition, we vary the fit quality selection for both the SALT2 and MLCS2k2 models. Detailed purity and efficiency plots and tables are presented. We use data samples simulated for the 10-field hybrid footprint of the Dark Energy Survey[1] (DES), performed with the SNANA package as in Ref. [1]. We have updated the SNcc simulation inputs to reflect improved knowledge of their relative fractions and brightnesses (see Section 2). We present four distinct sets of SNR cuts for both the MLCS2k2 and SALT2 models (using the SALT2mu procedure in Ref. [7] to obtain distance moduli for the SALT2 model).[2] The quantity SNRMAX is defined to be the SNR at the measured epoch of maximum signal-to-noise in

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[1] http://www.darkenergysurvey.org.

[2] The SALT2 simulations used $\alpha = 0.135$ and $\beta = 3.19$. The SALT2mu evaluation of the distance modulus also used the same fixed values of α and β. The fitting of α and β, in the presence of significant SNcc contamination, is beyond the scope of this paper.

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each of the four DES broadband filters used in the supernova analysis. Within a single survey strategy in terms of average observing conditions and cadence, this quantity may be used as a rough proxy for how well the supernova light curve was measured. Our goal is to find the purity levels that optimize the Dark Energy Task Force (DETF) [8] Figure of Merit (FoM). In order to do so, we examined the most important factors that affect the FoM. As part of the optimization, significant factors were studied including the scaling with supernova statistics, impact of DETF stage II and Planck priors, and the core collapse systematic uncertainty.

One obvious question is: what is a significant level of change in FoM? Our goal is to have the uncertainty in FoM due to the SNcc sample to be much smaller than the largest uncertainty in Ref. [1], which was due to the filter zeropoint uncertainty. The filter zeropoint uncertainty caused a 70 unit reduction in the FoM (30%). Therefore, we consider changes of > 10% to be significant in our analysis. We are not considering the entire suite of systematic uncertainties in this analysis, only the impact of photometric typing and selection cuts for the mixed SNe sample.

The outline of the paper is as follows. We present the changes in the simulation of the SNcc sample in Section 2. Our variety of SNR selection criteria, the SNIa models we are using, and the resulting purities and efficiencies are presented in Section 3. The DETF Figure of Merit calculation, some relevant factors and examples, and the final results are presented in Section 4. We discuss the results in Section 5 and include more details of the new simulation inputs in Appendix A. Finally, we include supplementary figures in Appendix B.

2. Supernova sample simulations

The SNANA package [9] is used to simulate the light curves of the 5-year SNIa and SNcc samples for the DES. The simulations are very similar to those in Ref. [1] but have been updated and improved with more recent information. The list of changes since Ref. [1] are:

- The SNANA version was updated to v9_89b from v8_37. Our model choices were MLCS2k2.v007 and SALT2.LAMOPEN.
- Four more SNcc templates (2 Ib/c and 2 IIP) are added to the 40 templates used in Ref. [1]. The templates are from the Supernova Photometric Classification Challenge [5].
- The results of Li et al. [10] are now used for the relative fractions of the SNcc sample, instead of those of Smartt et al. [11], due to a better analysis of the sample completeness.
- The Li et al. [10] results are now used for the absolute brightnesses of the SNcc sample, instead of those of Richardson et al. [12]. This is also due to the better analysis of sample completeness.
- We now use separate relative fractions for SN Types Ib and Ic, as well as different average brightnesses based on Li et al. (Type II SNe already had separate relative fractions in [1].)
- Since the Li et al. sample is complete, and the absolute brightnesses are not corrected for dust extinction, our simulation does not include dust extinction applied to the SNcc sample.
- The widths of the absolute brightness distributions for each type of SNcc template are matched to the measured widths from Li et al.

The details of these changes are available in Appendix A. The changes mostly cancel each other in terms of the overall purity of the sample with Ref. [1] cuts. The relative mixture of the SNcc sample passing cuts is more uniform, however, with less dominance from the Type Ib/c SNe.

Table 1
These are the definitions of the signal-to-noise cut symbols used throughout this work. For the first two cuts listed in the table, we removed SNe for which the third filter SNRMAX was less than zero. For the remainder of the paper when we refer to the "tightest" and "loosest" SNR cuts we mean SNR-10-5-5 and SNR-3-3-0 respectively.

Cuts	Symbol
2 filters with SNRMAX $\geqslant$ 3	SNR-3-3-0
2 filters with SNRMAX $\geqslant$ 5	SNR-5-5-0
3 filters with SNRMAX $\geqslant$ 5	SNR-5-5-5
1 filter SNRMAX $\geqslant$ 10, 2 more filters SNRMAX $\geqslant$ 5	SNR-10-5-5

3. Selection criteria and Type Ia SN models

3.1. Supernova sample signal-to-noise cuts

As mentioned previously, our SNR is defined at the measured epoch of maximum SNR in each filter (SNRMAX). We present four distinct sets of SNR cuts for both the MLCS2k2 and SALT2 models. For simplicity, we define the symbols used in the rest of the paper for these four sets of cuts in Table 1.

3.2. Type Ia model fit probabilities

Core collapse SNe light curves fit to a SNIa light curve model might be expected to have bad fit qualities, and this was demonstrated in Ref. [1]. Motivated by this, we reject SN candidates which have deviations from the best fit light curve model (whether MLCS2k2 or SALT2) that are statistically large compared to the errors. This is quantified in terms of fit probabilities[3] obtained from the light-curve χ^2 and the number of degrees of freedom. Fig. 1 shows the results of the fit probabilities for both models, and for our tightest and loosest cuts. It is evident that the SALT2 model has larger fit probabilities for the SNcc sample and hence we obtain lower purities for SALT2 compared to those of MLCS2k2. This is most likely due to the use of tight dust extinction priors used in the MLCS2k2 fits [1]. But as described in Ref. [1], these MLCS2k2 priors lead to additional SNe color systematics not present in SALT2 fits.

3.3. Purities and efficiencies

In this section, we present the results for purities and SNIa efficiencies for the four sets of SNRMAX cuts and with the MLCS2k2 and SALT2 fit probability cuts described above. We define the SNIa efficiency as the ratio of the number of SNIa passing all cuts that define the sample to the total number of SNIa simulated. For our calculation of efficiency, the denominator is the complete sample of SNIa generated with zero SNR cuts and the rates described in Ref. [1]. Many studies of SNIa efficiencies apply different sets of base SNR cuts, making it difficult to compare efficiencies from different analyses. We define the sample purity as the ratio of the number of SNIa to the total number of SNIa + SNcc passing all cuts. The numbers of SNIa and SNcc and the related purities and efficiencies integrated over all redshifts are presented in Table 2. Fig. 2 shows the purities and efficiencies as functions of redshift for the tightest and loosest SNR cuts for both the MLCS2k2 and SALT2 models. As discussed above for Fig. 1, the SALT2 model without tight priors is more flexible and leads to lower purities than our current implementation of the MLCS2k2

[3] If the observed deviations from the best fit model were due to Gaussian fluctuations compatible with the reported errors on observations, this is the probability of the χ^2 being larger than the observed χ^2 for the number of degrees of freedom in the light curve fit.