Cosmology of Photometrically-Classified Type Ia Supernovae

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Outline

• Background
• Motivation
• Data – SDSS-II SN survey & BOSS host galaxy redshift
• Photometric Classification
• Simulation optimization
• Data
• Hubble Diagram
• Cosmology
Background: Type Ia Supernovae

- Standard candles
- Used to discover the accelerated expansion of the Universe

Riess et al. 1998

Perlmutter et al. 1999
Background: Current Results

- Best current cosmological constraints combination of SNe Ia data: SDSS-II SN survey and SNLS combined with BAO and CMB

- All SNe Ia are spectroscopically confirmed

Kessler et al. 2009

Sullivan et al. 2011
Background: Classification

- Spectroscopic classification
- Lack of Hydrogen and Helium features
- Presence of Si II absorption line at 6150A
Motivation: Classification

• How do we do SN surveys in the future?
• Too many SNe for spectroscopic follow up
  - DES (4000 SNe for cosmology)
  - Gaia (6000 low redshift SNe)
  - LSST (100,000 SNe)
• SDSS + BOSS is a case study
• Aim: Show cosmological constraints are possible and competitive
SDSS-II Supernova Project
Sako et al. in prep

- Sept-Nov between 2005 and 2007
- Regularly scanned “Stripe 82”
- Database of 10,000s of transient objects
- SDSS-II SN survey 504 spectroscopically confirmed Type Ia
- Cosmological analysis of the first year SDSS-II data
SDSS-II Supernova Project
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Stripes in Sloan

The SDSS observes the sky in stripes. Each of these eight long stripes contains millions of galaxies.
BOSS Host Galaxy Follow-up
Olmstead et al. in prep

- 3323 galaxies with accurate redshifts
  1) Probability of being a SNe (2382)
  2) Random sample of transients (941)
- *Plates drilled with 1000 holes*
- Spectroscopic redshift
  - Anchors SNe Ia on Hubble diagram
  - Improves classification and light curve fit
- *Large sample of Host galaxy spectra: investigate intrinsic scatter*
PSNID Photometric Classification

- Fits templates to the light curves to find lowest $X^2$
- Calculated Bayesian probabilities of the SN being a Type Ia, Type Ib/c or Type II

\[ E_{Ia} = \int P(z) e^{-\chi^2/2} \, dz \, dA_v \, dT_{max} \, d\Delta m_{15} \, d\mu, \]

\[ P(z) = \frac{1}{\sqrt{2\pi}\sigma_z} e^{(z-z_{ext})^2/2\sigma_z^2}. \]

\[ P_{Ia} = \frac{E_{type}}{E_{Ia} + E_{Ibc} + E_{II}} \]

- BOSS host galaxy redshift used as a prior
Classification optimization using Simulations

- Public SDSS-II SN Simulations (Kessler) created using SNANA
- *Redshift range and observing conditions to replicate SDSS-II SN survey*

High efficiency, low purity

Higher purity, low efficiency
Classification optimization using Simulations

SATL2 parameter cut

Color-magnitude cut
Simulations Results

<table>
<thead>
<tr>
<th>Selection cut</th>
<th>Contamination</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIa &lt; Pnon Ia (PSNID)</td>
<td>41.8%</td>
<td>99.1%</td>
</tr>
<tr>
<td>X2 &lt; 1.2 (PSNID)</td>
<td>27.8%</td>
<td>91.0%</td>
</tr>
<tr>
<td>X1 and color cut (SALT2)</td>
<td>8.3%</td>
<td>71.6%</td>
</tr>
<tr>
<td>Color-magnitude cut (SALT2)</td>
<td>3.9%</td>
<td>70.8%</td>
</tr>
</tbody>
</table>
Data: Classification

SALT2 parameter cut

Color-magnitude cut

COLOR DATA

DATA
Bias Tests: Contamination Bias

- True cosmology – contaminates that are photometrically-classified as SNe Ia, with all selection criteria
- Redshift dependent contamination bias is small
Bias Tests: Malmquist Bias

- 30,000 SNe Ia SNANA simulations
- Model for the Malmquist bias as a function of redshift.

\[ \mu_{\text{corr}}(z) = a e^{bz} + c \]
Photometric Hubble Diagram

752 SN Ia (SDSS-II SN light curves + BOSS host redshifts)

2.5 times larger than SDSS-II SN spectroscopic SNe Ia sample
Cosmological Constraints

Cosmological constraints comparable to SNLS3 (SN data only)

Statistics only-result favors an accelerating Universe at 99.96% confidence
Cosmological Constraints

![Cosmological Constraints Diagram](image-url)

- **DATA**
- **BOSS Photometric SNe Ia**
- **SDSS Spec-Ia (z<0.3)**
- **SHOES H0 prior**
- **SDSS DR7 LRGs + WMAP7 CMB power spectrum + SHOES H0 prior**
SNe Ia Weak Lensing
Smith et al. 2013

- Find a correlation (1.7sigma) between the estimate of weak lensing convergence for each supernova and the Hubble residuals - consistent with the prediction from lensing

- Distance estimates improved by including a new parameter for lensing

- Lensing of marginal significance in this low redshift sample,

- Will be important for the next generation of surveys, such as Gaia, DES and LSST
Summary

- 3392 BOSS redshifts of SDSS-II SN candidate host galaxies
- Largest single survey Hubble diagram (752) using only photometric classification
- 3.9% contamination: shows it has no effect on our cosmological constraints
- Cosmological constraints comparable to spectroscopic surveys
- Demonstrates the potential of photometrically classified SN Ia samples in improving cosmological constraints
- This sample can be used to test systematics, which will be important for the next generation of SNe Ia surveys.