SDSS-II Photometrically-Classified Type Ia Supernova

Heather Campbell

Thanks to all my collaborators in the SDSS II SN survey
• Motivation
• Data – SDSSII SN survey and BOSS host $z$
• Photometric Classification
• Selection cuts: Choosing with Simulations
• Selection cuts: Data
• Hubble Diagram
Motivation

• How do we do SN surveys in the future?

• *SDSS* + *BOSS* is a case study

• Cosmology from a photometrically classified sample of hundreds of SNe

• Also unbiased compare to spectroscopic surveys (good check of past results)

Dark Energy Survey Camera
SDSS II Supernovae Project

• Ran for 3 seasons between 2005 and 2007

• Regularly scanned “Stripe 82”

• Database of 10,000s of transient objects

• SDSS II SN survey 504 spec Ia

• Cosmological analysis of the first year SDSS II data

The Sloan Telescope
SDSS II Supernovae Project

- Ran for 3 seasons between 2005 and 2007
- Regularly scanned “Stripe 82”
- Database of 10,000s of transient objects
- SDSS II SN survey 504 spec Ia
- Cosmological analysis of the first year SDSS II data
BOSS Host Galaxy Follow up

• Spec $z$ – Anchors SNe on Hubble diagram
  – Improves classification & light curve fit

• Large sample of Host galaxy spectra: investigate intrinsic scatter

• Plates drilled with 1000 holes

• 3655 targets:
  1) Probability of being a SNe$>0.2$ (2654)
  2) Random sample of transients (1001)
• **3392** galaxies with accurate redshifts (263 lost)

• 2433 from main sample (black)

• 959 from random sample (blue)

• Complete to 22 magnitude
Fig. 3.— Spectra from BOSS, top left is a low redshift galaxy, which has a high continuum, whereas the spectra on the top right has virtually no continuum, but several clear emission lines, and is at a slightly higher redshift. The bottom two are higher redshift, ranging between $0.3 < z < 0.4$. 

Plate 3607 Fiber 316 MJD=55186

GALAXY
$X^2 = 1.04$

z = 0.04592

Flux [$10^{-17}$ erg/s/cm²/Ång]

Observed Wavelength [Ång]

Plate 4219 Fiber 71 MJD=55480

GALAXY
$X^2 = 1.09$

z = 0.43038

Flux [$10^{-17}$ erg/s/cm²/Ång]

Observed Wavelength [Ång]
PSNID Photometric Classification

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

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

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

- Fits templates to the light curves to find lowest \( \chi^2 \)

- *Host redshift used as a prior*

- Calculated Bayesian probabilities of the SN being a Type Ia, Type Ib/c or Type II
Data cuts and SALT

- Sako et al. classifier is good, but how do I make a cosmology sample?
- Data cuts quality
- Cuts on probability
- Cuts on salt parameters (really a 3D space)
SALT2 Light Curve Fitting

\[ \mu = m_\star_B - M + \alpha X_1 - \beta c \]

\[ m_\star_B = -2.5 \log_{10}(X_0) \]
Simulations to Optimize
Selection cuts

- Public SDSS SN Simulations (Kessler) created using SNANA

- Redshift range and observing conditions to replicate SDSS SN survey.

- 5018 Type Ia

- 7185 Non Ia

- Run all simulated SN through classifier and fitted light curves

\[ E_{\text{Ia}} = \frac{N_{\text{true}}}{N_{\text{cut}}} \]

\[ P_{\text{Ia}} = \frac{N_{\text{true}}}{N_{\text{true}} + N_{\text{false}}} \]

\[ FoM(5)_{\text{Ia}} = \frac{N_{\text{true}}}{N_{\text{cut}}} \frac{N_{\text{true}}}{N_{\text{true}} + W_{\text{false}} N_{\text{false}}} \]
Selection cuts: Simulations
Probability and $X^2$

- $P_{Ia} > P_{\text{non}}$ (inclusive)
- $X^2 > 1.2$ (peak of FoM)

- Light curve quality cuts:
  - $-5 < 1 \text{ epoch } <+5$
  - $+5 < 1 \text{ epoch } <+15$
Selection cuts: Simulations
SALT2 Parameters 3D space
Selection cuts: Simulations
SALT2 Parameters Color and X1

- Color and X1 cut an ellipse

\[
\frac{y^2}{a^2} + \frac{(x + 0.2)^2}{b^2} = 1 - 0.02
\]

\[a = \text{semi-major axis} = 3 \text{ (X1 axis)}\]
\[b = \text{semi-minor axis} = 0.25 \text{ (color axis)}\]

Center at (-0.2, -0.02)
Selection cuts: Simulations
SALT2 Parameters Color and X1

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Selection cuts: Simulations

Color vs magnitude cut

- $i$-band – $z$-band vs $i$-band
  > blue line shown (peak of FoM)
## Selection cuts: Simulations

### All cuts summary

<table>
<thead>
<tr>
<th>Selection cut</th>
<th>Contamination</th>
<th>Efficiency</th>
<th>FoM (W=5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{Ia} &gt; P_{non}$</td>
<td>41.7%</td>
<td>99%</td>
<td>21.7%</td>
</tr>
<tr>
<td>$X^2 \geq 1.2$</td>
<td>27.8%</td>
<td>91.8%</td>
<td>31.4%</td>
</tr>
<tr>
<td>X1, color ellipse</td>
<td>8.1%</td>
<td>71.6%</td>
<td>49.6%</td>
</tr>
<tr>
<td>i-band – z-band vs i-band</td>
<td>3.7%</td>
<td>70.9%</td>
<td>59.8%</td>
</tr>
</tbody>
</table>
Selection cuts: Simulations
All cuts Hubble Diagram

After all cuts have:

- **Purity** = 96.3%
- **Efficiency** = 70%
- **FoM** ($W=5$) = 60%
- 2644 Type Ia
- 98 non Ia
Selection cuts: Data
Probability, $X^2$, Color and X1 ellipse

- Light curve quality cuts:
  - $-5 < 1 \text{ epoch} <+5$
  - $+5 < 1 \text{ epoch} <+15$

- $P_{\text{Ia}} > P_{\text{non}}$

- $X^2 > 1.2$

- Color vs X1 ellipse
Selection cuts: Data
Color vs Magnitude cut

• $i$-band – $z$-band vs $i$-band > blue line
## Selection cuts: Summary

<table>
<thead>
<tr>
<th>Selection Cut</th>
<th>Number SNe removed</th>
<th>Number of SNe kept</th>
<th>Number Spec Ia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accurate Redshift</td>
<td></td>
<td>3392</td>
<td>289</td>
</tr>
<tr>
<td>Quality</td>
<td>1429</td>
<td>2515</td>
<td>221</td>
</tr>
<tr>
<td>( P_{\text{Ia}} &gt; P_{\text{non}} )</td>
<td>552</td>
<td>1963</td>
<td>219</td>
</tr>
<tr>
<td>( \chi^2 )</td>
<td>587</td>
<td>1376</td>
<td>213</td>
</tr>
<tr>
<td>Color and X1 cut</td>
<td>614</td>
<td>762</td>
<td>187</td>
</tr>
<tr>
<td>i-band – z-band vs i-band cut</td>
<td>23</td>
<td>739</td>
<td>187</td>
</tr>
</tbody>
</table>
Photometric Hubble Diagram

739 SN with host redshifts on Hubble Diagram
Can it get better?

- Cut on host distance
- Photoz
- Other color plane cuts
Steps to Cosmology

- Summary!
- Malmquist bias - simulations can help
- Host galaxy (We have all the spectra!)
- Systematic errors
Summary

- 3394 reliable host galaxy redshifts
- Photometric classification of SNe, using host $z$ as a prior.
- New Hubble diagram with 739 SN Ia (187 spec Ia, and 552 New)
- Very important for the next generation of SNe surveys
Extra slides!
Quality Criteria: Host galaxy cut

- Distance to Host Galaxy cut:
  - If the separation between SNe and host galaxy is > 15kpc then candidate is removed
Bias Tests: Malmquist Bias

- 30,000 SNe Ia SNANA simulations
- Model for the Malmquist bias as a function of redshift.
- 10 random samples, size and redshift distribution of photometric sample
- Cosmological analysis with and without Malmquist Bias correction
- All samples were $>> 2\sigma$ away from input $w$ without correction and $<< 1\sigma$ when included.
- Checked correction not stretch or cosmology dependent

\[ \Delta \mu = \mu_{\text{obs}} - \mu_{\text{exp}} \]

Fig. 12.— Plot of the Malmquist bias which is found by taking the difference between the observed distance modulus $\mu_{\text{obs}}$ and the expected distance modulus $\mu_{\text{exp}}$ as a function of redshift, in $\delta z$ bins of 0.02. The errors are the errors on the weighted mean. The line is the linear fit to the plot and is used as the Malmquist bias correction.

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Bias Tests: Malmquist bias

- Spec SNe Ia at a given redshift have systematically higher S/N than the photo Ias.

- $z > 0.3$ we see effect of $S/N > 5$ selection cut, curtailing the distribution.

- Leads to the “Malmquist bias”

- See same in simulations
Host Galaxy Correlations

- Have spectra for all hosts
- SALT2 X1 color distributions in Red/blue galaxies: SALT color same in both galaxies, X1 different, same relation at all distances from centre of galaxy
- Host masses form BOSS pipelines (cosmology corrected for the host galaxy mass correlation)
Host Galaxy Correlations

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Systematic Errors

Instrumental:
- Photometric calibration
- Light curve fitting techniques

Astrophysical:
- Correlations with hosts galaxy properties
- SN lensing
- Peculiar velocities
- Galactic dust
- Possible SN evolution
Implications for DES

• Possible to use photometrically classified supernovae for cosmological analysis – Good for DES which can’t follow up all SNe

• Host galaxy z are important for classification and Hubble diagram - minimum DES needs for each SNe

• Low contamination – appears to create no bias on cosmology

• Need to model the Malmquist bias for magnitude limited samples