Improving the Standardization of Type Ia Supernovae

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Cosmology with Type Ia Supernovae

Betoule+ 2014
Cosmology with Type Ia Supernovae

Perlmutter+ 1998

![Graphs showing the relationship between absolute magnitude ($M_V$) and time for Type Ia supernovae.](image)

- **Left graph:** $M_V - 5 \log(h \times S)$ plotted against time, labeled as measured.
- **Right graph:** $M_V - 5 \log(h \times S)$ plotted against time, labeled as corrected for light-curve timescale "stretch-factor".

Perlmutter+ 1998
flux(phase, \lambda) =

\begin{align*}
\Delta \mu &= m_B - M + \alpha x_1 - \beta c \\
\end{align*}
Cosmology with Type Ia Supernovae

![Graph showing distance modulus and Hubble diagram residual vs. redshift with citations for various studies such as Rodney et al. (2012), Suzuki et al. (2012) (SCP), Amanullah et al. (2010) (SCP), Riess et al. (2007), Tonry et al. (2003), Miknaitis et al. (2007), Astier et al. (2006), Knop et al. (2003) (SCP), Amanullah et al. (2008) (SCP), Barris et al. (2004), Perlmutter et al. (1999) (SCP), Riess et al. (1998) + HZT, Holtzman et al. (2009), Contreras et al. (2010), Hicken et al. (2009), Kowalski et al. (2008) (SCP), Iha et al. (2006), Riess et al. (1999), Kristian et al. (2005), Hamuy et al. (1996).]
Cosmology with Type Ia Supernovae

SeeChange

DES

SSP

LSST

+ more
Dispersion indicates unmodeled processes in the supernovae, which can lead to bias.

Dispersion $\sim 0.16$ mags
Lower dispersion in standardized magnitudes

➡ Less potential for systematic errors

➡ Supernovae become more powerful cosmological tools.
Option 1: Choose a more standard part of the supernovae
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Dispersion in H = 0.116 mags
Dispersion in J = 0.085 mags
Option 2: Turn supernovae into perfect standard candles

\[ \kappa = \frac{f_{SN_A}(p, \lambda) 10^{-0.4C(\lambda)E(B-V)}}{f_{SN_B}(p, \lambda)}; \quad \Delta M = -2.5 \log(\kappa) \]
Option 2: Turn supernovae into perfect standard candles
Option 3a: Build a more complete model for Type Ia supernovae

The Nearby Supernova Factory

- Over 300 Type Ia SNe below \( z=0.1 \)

- Spectrophotometric time series
Option 3a: Build a more complete model for Type Ia supernovae: SNEMO

SNEMO: Supernova Empirical Model

- Use Gaussian Processes to project supernova data onto grid in phase and wavelength.

- Calculate principal components of the set of all supernovae.

- Use K-fold cross-validation to determine model parameters.

\[
f_{SN}(p, \lambda) = c_{SN,0} \left( e_0(p, \lambda) + \sum_{i=1}^{N} c_{SN,i} e_i(p, \lambda) \right) 10^{-0.4 A_{\odot} C(\lambda)}
\]
Option 3a: Build a more complete model for Type Ia supernovae: SNEMO

Saunders+ in prep.
Option 3a: Build a more complete model for Type Ia supernovae: SNEMO

\[ \mu_g = m_g^{\text{std}} - M_g = m_g + \sum_i \alpha_i c_i + \alpha_c \times A_S - M_g \]

Total dispersion = 0.113 mags
Intrinsic Dispersion = 0.097 mags
Option 3a: Build a more complete model for Type Ia supernovae: SUGAR

SUGAR: Supernova Useful Generator and Reconstructor

- Calculate spectral indicators of the training set supernovae at maximum.
- Perform PCA on the space of spectral indicators.
Option 3a: Build a more complete model for Type Ia supernovae

\[ M(t; \lambda) = M_0(t; \lambda) + \sum_{i=1}^{i=3} \alpha_i(t; \lambda)q_i + A_V f(R_V; \lambda) + \Delta M_{\text{grey}} \]
Option 3a: Build a more complete model for Type Ia supernovae

Total dispersion = 0.13 mags

Leget+ in prep.
Conclusions

• Current and future surveys will reduce statistical uncertainties in Type Ia supernovae.

• The near-IR and ‘supernova twins’ methods can turn Type Ia supernovae into standard candles when the necessary data is available.

• SNEMO and SUGAR provide more general approaches for improving magnitude standardization.

• Understanding the host-mass correlation and the impact of reddening due to dust will provide further improvements.