Near-infrared distances to type Ia supernovae

Saurabh W. Jha

NOAO 4m image of SN 2011fe in M101 (T.A. Rector, H. Schweiker & S. Pakzad)

SN 2014J in M82 (Marco Burali, Osservatorio MTM Pistoia)
Observational properties of thermonuclear supernovae

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The explosive death of a star as a supernova is one of the most dramatic events in the Universe. Supernovae have an outsized impact on many areas of astrophysics: they are major contributors to the chemical enrichment of the cosmos and significantly influence the formation of subsequent generations of stars and the evolution of galaxies. Here we review the observational properties of thermonuclear supernovae—exploding white dwarf stars resulting from the stellar evolution of low-mass stars in close binary systems. The best known objects in this class are type-Ia supernovae (SNe Ia), astrophysically important in their application as standardizable candles to measure cosmological distances and the primary source of iron group elements in the Universe. Surprisingly, given their prominent role, SN Ia progenitor systems and explosion mechanisms are not fully understood; the observations we describe here provide constraints on models, not always in consistent ways. Recent advances in supernova discovery and follow-up have shown that the class of thermonuclear supernovae includes more than just SNe Ia, and we characterize that diversity in this review.
Why NIR?

- mitigate dust extinction

Tripp (1998) standardization, e.g., SALT2

\[ m_B = \alpha x_1 + \beta c \]

\[ \alpha \approx 0.14 \quad x_1 \in [-2,2] \Rightarrow -0.28 \leq \alpha x_1 \leq +0.28 \text{ mag} \]

\[ \beta \approx 3.1 \quad c \in [-0.1,0.3] \Rightarrow -0.31 \leq \beta c \leq +0.93 \text{ mag} \]

color gives the largest correction for supernova cosmology analysis
intrinsic colors depend on host galaxy, viewing angle, velocity? (ask Rutgers grad student Kyle Dettman here!)

intergalactic extinction could be significant for highest-z SN Ia
Menard et al. (2010)

evidence for CSM: variable Na I D lines
Patat et al. (2007), Blondin et al. (2009), Simon et al. (2009), Sternberg et al. (2011), Phillips et al. (2013), Maguire et al. (2013)

what affects SN Ia colors?
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• observations (and theory) show SN Ia are better standard candles in NIR

Second, an examination of the use of infrared photometry of Type Ia supernovae for distance determinations suggests that distance moduli to individual galaxies may be accurate to +0.2 mag, and possibly ±0.1 mag, but the data set is still too small for this conclusion to be independent of our initial assumptions.

Elias et al. (1981, 1985)

The light curves of the six similar supernovae can be represented fairly consistently with a single light curve in each of the three bands. In all three IR bands the dispersion in absolute magnitude is about 0.15 mag, and this can be accounted for within the uncertainties of the individual light curves. No significant variation of absolute IR magnitude with $B$-band light curve decline rate, $\Delta m_{15}(B)$, is seen over the range $0.87 < \Delta m_{15}(B) < 1.31$. However, the data are insufficient to allow us to decide whether or not the decline rate relation is weaker in the IR than in the optical region. IR light curves of type Ia supernovae should eventually provide cosmological distance estimates that are of equal, or even superior, quality to those obtained in optical studies.

Meikle (2000)
Why NIR?

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\[ \sigma = 0.14 \text{ mag} \]
\[ \sigma = 0.18 \text{ mag} \]
\[ \sigma = 0.12 \text{ mag} \]
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\begin{align*}
\sigma &= 0.14 \text{ mag} \\
\sigma &= 0.18 \text{ mag} \\
\sigma &= 0.12 \text{ mag}
\end{align*}

Kasen (2006)

Why NIR?

- mitigate dust extinction
- observations (and theory) show SN Ia are better standard candles in NIR
- NIR has only a few percent of SN Ia flux; standardizing the tail rather than the dog?

Kasen (2006)


\[ \sigma = 0.14 \text{ mag} \]

\[ \sigma = 0.18 \text{ mag} \]

\[ \sigma = 0.12 \text{ mag} \]
The rows and columns have been sorted by increasing variance. The levels determine the values consistently without having to deal with the Cepheid data itself. Many previous analyses have investigated numerous systematics and show the large range of uncertainty in the Cepheid data, one can experiment with well-understood systematics as part of the online data, and they can be used to improve the estimates of reddening and the slope of the intrinsic dispersion.

In Sect. 4.1, we described the light curve fitting methodology for SN Ia as standard candles in their peak magnitude. We have not attempted to derive them in a uniform way. Rather, quantities are taken from the literature and tabulated in Table A.1. The high precision of modern SN Ia provides a natural set of standard candles for cosmology. Some SN Ia are outliers, and their absolute magnitudes of fast-declining SN Ia diverge considerably from their more normal counterparts (similar to the behaviour of fast-declining SN Ia that are excluded from our fiducial sample as outliers).

Similarly the “ideal” calibrators have low host reddening and high host-galaxy morphology, host-galaxy reddening, and optical light-curve decline rate. Blue circles show the whole similar to the calibrators. In Fig. A.2, but for the Hubble flow sample in Fig. 1, we plot the light curves of the SN Ia in our sample along with the Gaussian process fits to J-band peak magnitude. The same is plotted for the Hubble flow sample in Fig. A.1. We have not attempted to derive them in a uniform way. Rather, quantities are taken from the literature and tabulated in Table A.1.

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For these objects, we reduce the scale and increase the amplitude on the same scale, as a function of host-galaxy morphology. These objects are noted in Table A.1. The high precision of modern SN Ia provides a natural set of standard candles for cosmology. Some SN Ia are outliers, and their absolute magnitudes of fast-declining SN Ia diverge considerably from their more normal counterparts (similar to the behaviour of fast-declining SN Ia that are excluded from our fiducial sample as outliers). Similarly the “ideal” calibrators have low host reddening and high host-galaxy morphology, host-galaxy reddening, and optical light-curve decline rate. Blue circles show the whole similar to the calibrators. In Fig. A.2, but for the Hubble flow sample in Fig. 1, we plot the light curves of the SN Ia in our sample along with the Gaussian process fits to J-band peak magnitude. The same is plotted for the Hubble flow sample in Fig. A.1. We have not attempted to derive them in a uniform way. Rather, quantities are taken from the literature and tabulated in Table A.1.

Because our Fig. 3.

consistent with SH0ES results (Riess et al. 2016) [using same Cepheid distances]

Hubble tension does not result from a wavelength-dependent systematic uncertainty in the SN Ia

Note. Sample median values of the fit parameters are given, with 16th and 84th percentile differences (statistical uncertainties only). This is an extremely restrictive cut to make the calibrators and Hubble flow sample as similar as possible: low EBV (host $E(B-V) \leq 0.3$ mag) + spirals only + $1.0 \leq \Delta m_{15}(B) \leq 1.2$ + Milky Way $A_V \leq 0.15$ mag.
Correlations with host mass?

- NIR Hubble residual
- Template fit with optical prior
- FSPS fit to host photometry
- SDSS: Optical photometry
- 2MASS: NIR
- Fitted with FAST (Kriek+2009)

- No evidence for correlation (< 1σ)
- Small sample

- MC simulation: consistent with 0.06 mag
- New VIRCAM follow-up will help

Fig: The J-band absolute magnitude versus host stellar mass, no significant evidence for "mass step" (Dhawan et al. in prep.)

Dhawan et al., in prep.
We vary the traditional analysis slightly to account for the necessary when varying cosmological parameters within their observations. In principle the estimate parameter, which is independent of redshift, should be separate from the intrinsic scatter. In that case, we find that the intrinsic scatter is largely dominated by the peculiar velocity uncertainty. Nevertheless, adopting the peculiar velocity uncertainty affects the results with either approach, so using the medians or means gives similar results.

Fig. 3. Using the median intrinsic scatter of 0.160 mag, the Hubble flow objects have a mean redshift of 0.016, and the Fiducial objects have a mean redshift of 0.081.

The results of the Fiducial analysis are presented in Table 1. The Hubble flow objects are a much more heterogeneous sample than the Fiducial objects, and the Hubble flow intrinsic scatter is largely determined by the peculiar velocity uncertainty. The Fiducial intrinsic scatter is largely determined by the peculiar velocity uncertainty, as used in Cardona et al. (2017).

Notes. Sample median values of the fit parameters are given, with 16th and 84th percentile differences (statistical uncertainties only). This is an extremely restrictive cut to make the calibrators and Hubble flow sample as similar as possible: low EBV (host E(B − V) ≤ 0.3 mag) + spirals only + 1.0 ≤ ΔmV(B) ≤ 1.2 + Milky Way A_j ≤ 0.15 mag.
significant cosmological leverage for rest-frame NIR SN Ia data from WFIRST!
• 24 Hubble-flow SN Ia (0.02 < z < 0.07) with HST WFC3/IR in Cycles 27 and 28
• F098M, F105W, F125W, F140W, F160W photometry + grism spectroscopy (above the atmosphere!) 1 orbit, 2 epochs
• 3 key science goals:
  ✴ rest-frame NIR SEDs for WFIRST
  ✴ 2.7% NIR SN Ia H<sub>0</sub> measurement
  ✴ w/RAISINs, WFC3/IR-only Hubble diagram to z = 0.6
• need ground-based support, join us! ~2 objects/month starting Feb 2020
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