Type Ia supernovae in the near-infrared: nickel all over

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The promise of the (near-)infrared

• Extinction is much reduced in the near-IR
  – $A_H/A_V \approx 0.19$ (Cardelli et al. 1989)

• SNe Ia much better behaved

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SN $\Delta m_{15}(B)$

- ▲ = 1980N (1.29)
- ▼ = 1986G (1.79)
- ▲ = 1998bu (1.05)
- ▼ = 1999aw (0.81)
- ▼ = 1999ee (0.94)
- ■ = 1999ee (0.94)
- ▲ = 2000ca (1.01)
- ▲ = 2001el (1.15)

Krisciunas et al. (2004)
Mark Phillips
Others find this too

- Light curves in the near-IR very uniform at peak, but large differences at later times
Large literature sample

- Scatter minimal at first maximum in Y (1.04\(\mu\)m), J (1.24\(\mu\)m), H (1.63\(\mu\)m) and K (2.14\(\mu\)m)
- \(~90\) objects in J and H
  - \(58\) in Y, \(22\) in K
- Mostly Carnegie SN Project data
  (Contreras et al. 2010, Stritzinger et al. 2011)
Infrared light curves

\[
\begin{array}{cccc}
\text{Filter} & t (\text{days}) & \sigma(M) (\text{mag}) & \text{Phase range} (\sigma(M) < 0.2\text{ mag}) & \text{SN sample} \\
Y & -4.4 & 0.15 & [-4, +1] & \text{CSP} \\
J & -3.6 & 0.16 & [-4, +3] & \text{CSP} \\
J & -3.8 & 0.17 & [-6, +1] & \text{non-CSP} \\
H & -5.1 & 0.17 & [-5, +1] & \text{CSP} \\
H & -4.7 & 0.14 & [-7, +2] & \text{non-CSP} \\
\end{array}
\]
NOT after maximum

4 days

14 days

30 days

Dhawan et al. 2014

maximum

minimum

second maximum
Late decline ($t > 40$ days)

Dhawan et al. 2014

![Graphs showing late decline phases in Y, J, and H bands with statistical analysis of late decline rates.]
Correlations

Phase of the second maximum appears to be a strong discriminator among SNe Ia.
Correlations

Luminosity of late decline and the phase of the second maximum are linked.
Correlations with the optical

- IR properties correlate with optical decline rate
- Phase of secondary maximum strongly correlated $\Delta m_{15}$
Correlation with optical colour

Phase of second maximum and beginning of the Lira relation are also tightly linked.
Consistent picture emerging

• Second peak in the near-IR is the result of the recombination of Fe++ to Fe+ (Kasen 2006)
  – he predicted a later second maximum for larger Ni masses

• Optical colour evolution faster for objects with lower nickel mass
  (Kasen & Woosley 2007)

• Ejecta structure uniform
  – late declines very similar
  ➔ higher luminosity indicates a higher Ni mass
  ➔ later secondary peak also indicates higher Ni mass
  ➔ Ni mass and (optical) light curve parameters correlate (Scalzo et al. 2014)
Nickel masses directly?

- Correlate phase of second maximum with observed nickel masses
  - avoid ‘detour’ through optical light curve shape parameter ($\Delta m_{15}$)
Absorption-free subsample

- Select SNe with $E(B-V)<0.1$
- Pseudo-bolometric light curves (UBVRIYJH)

Dhawan et al., in prep
Nickel masses

• Using a timing parameter for nickel masses
  – completely independent on reddening and multiple light curves

• Explore different methods to calculate the nickel mass (currently still all Chandrasekhar-mass progenitors)

Dhawan et al., in prep
Summary

• Nickel seems the dominant parameter for the light curves of SNe Ia
  – phase of second maximum, start of uniform B-V colour evolution (Lira law), optical light curve shape ($\Delta m_{15}$), luminosity of the late decline phase

• Second maximum in the IR light curves strong parameter for SN Ia characterisation \(\rightarrow\) simple way to measure nickel mass