The Carnegie Supernova Project: Analysis of the First Sample of Low-z SNe Ia

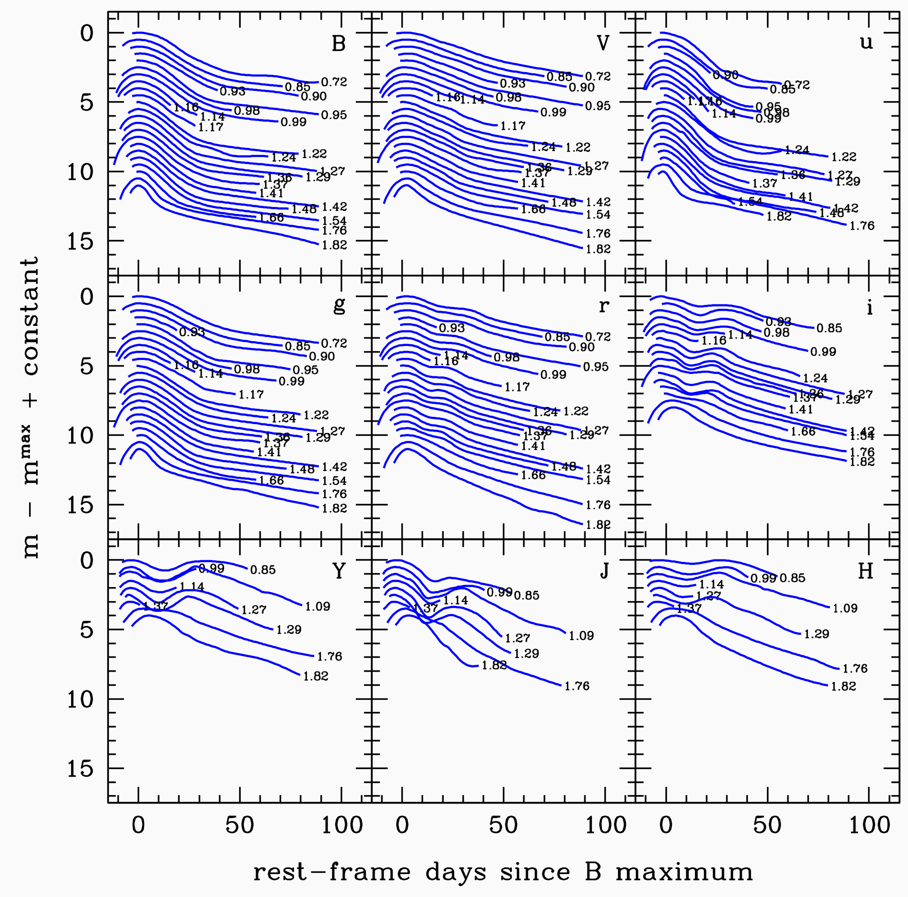
G. Folatelli[1,2], M. M. Phillips[1], C. R. Burns[3], C. Contreras[1], M. Hamuy[2], W. L. Freedman[3], S. E. Persson[3], M. Stritzinger[1], N. B. Suntzeff[1,5], K. Krisciunas[1,5], L. Boldt[1], S. Gonzalez[1], W. Krzeminski[1], N. Morrell[1], M. Roth[1], F. Salgado[1,2], B. F. Madore[3,6], D. Murphy[3], P. Wyatt[6], W. Li[7], A. V. Filippenko[7], N. Miller[2]

[1] LCO, [2] U. Chile, [3] OCIW, [4] Texas A&M, [5] Mitchell Institute, [6] Caltech/JPL, [7] UC Berkeley gaston@das.uchile.cl

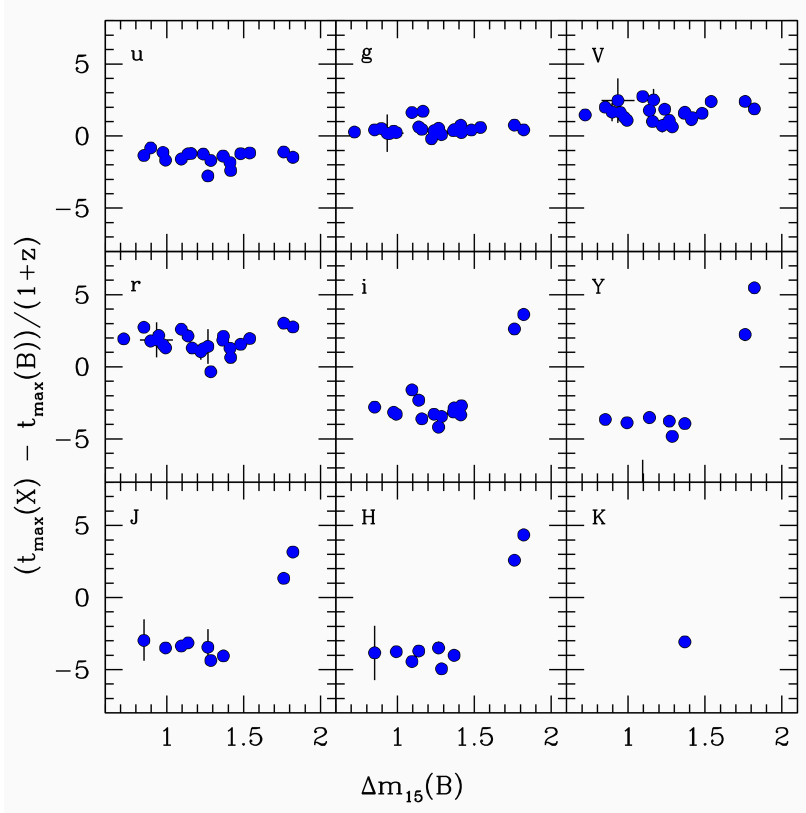
Abstract

- Sample of 35 Type Ia supernovae (SNe Ia) at $z < 0.08$
- High-quality optical ($ugriBV$) and near-infrared ($YJHK_s$) light curves
  - Spline function fits ⟶ set of template LC's
- Intrinsic color laws ⟶ color excesses (optical–NIR colors)
- Detailed study of host-galaxy reddening law
  - Heavily reddened SNe: $R_V \sim 1.7$
  - Moderately reddened SNe: $R_V \sim 3.2$
  - Test of an alternative reddening law due to circumstellar dust
- Calibration of peak luminosity versus decline rate and color (or color excess)
  - Dispersions of 0.12–0.16 mag
  - Effective $R_V \sim$1–2 even with highly-reddened SNe excluded
  - Dispersion of 0.11 mag when combining all bands
  - Precision appears to be limited by peculiar velocities
  - Strong correlation in residuals ⟶ distance precision may be of 3–4%
- SNe Ia are good standard candles in the NIR (dispersion 0.18–0.19 mag in JH)

Light-Curve Properties

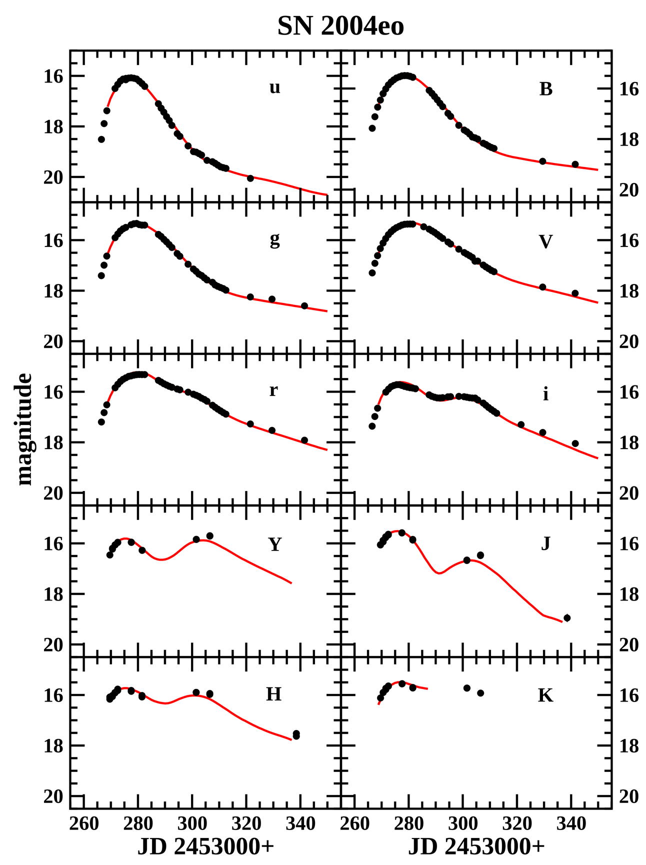


Set of template LC's in $ugriBVYJH$ obtained from spline fitsto the best-observed SNe. LC parameters [$m_{\rm max}$, $t_{\rm max}$, and $\Delta m_{15}(B)$] define the templates.



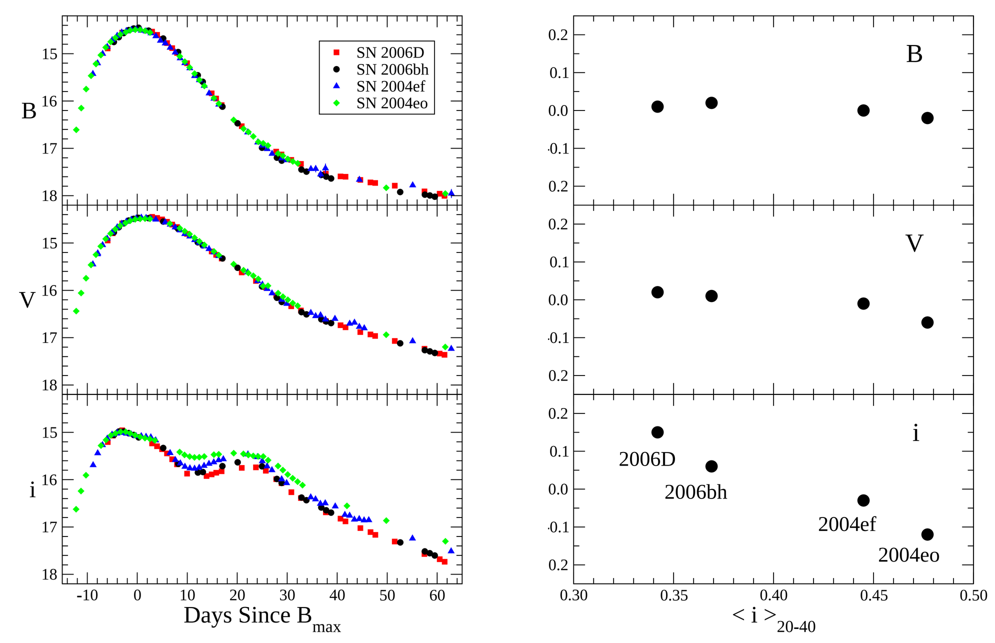
Example of LC property analysis: delay of the time of maximum in each band with respect to B band.

Template LC Fits



Example of template LC fits for SN 2004eo.

Secondary Maximum in NIR

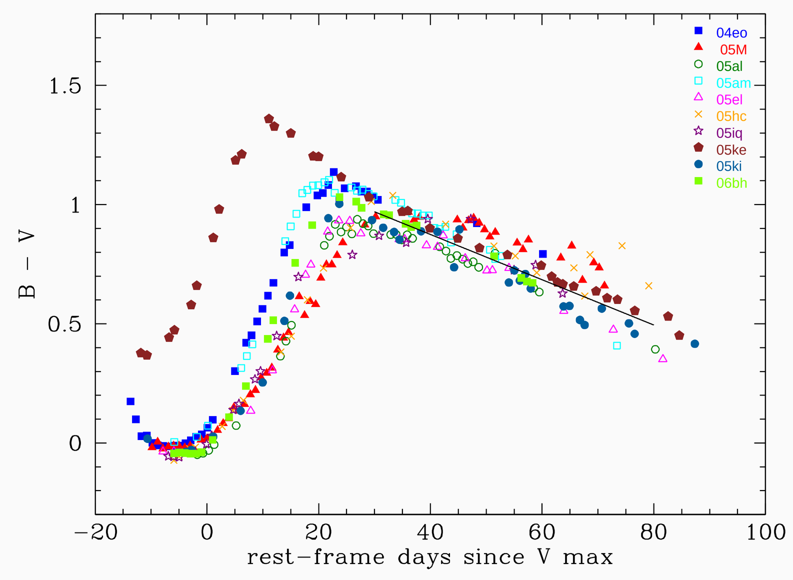


(*Left*) Four SNe with similar $\Delta m_{15}(B)$ present differences in the secondary maximum in i. (*Right*) Difference in the peak magnitudes between spline and template fits as a function of the flux between +20 and +40 days relative to maximum [$\langle i \rangle_{20-40}$] [3].

Host-Galaxy Reddening

Low-reddening sub-sample

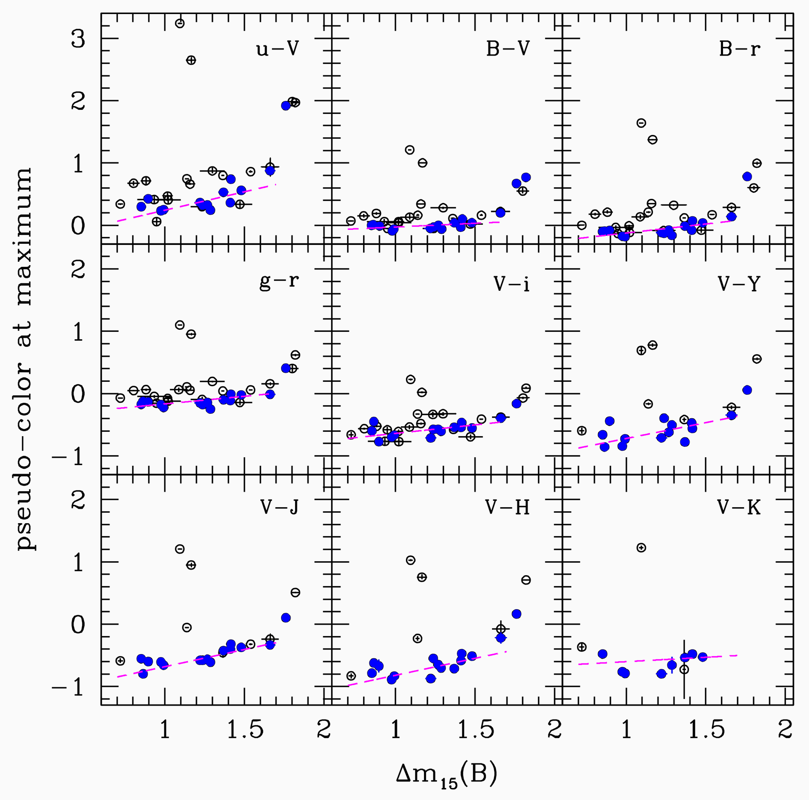
- Starting criteria:
  - E/S0 host galaxy, or SN located far from nucleus and arms, and
  - No detectable IS Na I D absorption in early-time spectra
- Built Lira law for $(B-V)$ [4]
- Added SNe compatible with $E(B-V) = 0$



$(B-V)$ colors for the low-reddening SNe and the Lira law.

Color excesses

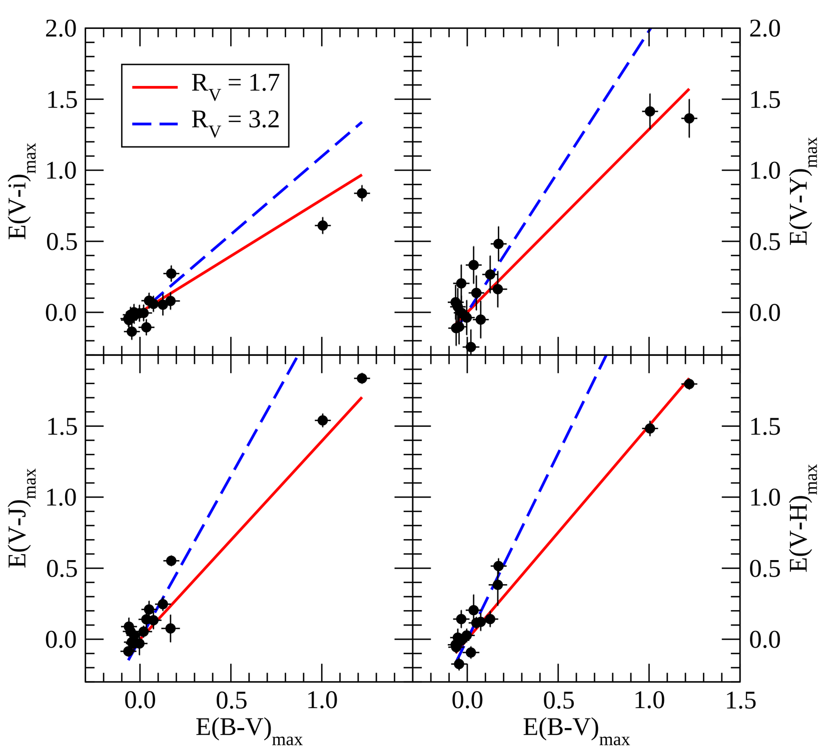
- Linear fits to pseudo-colors at maximum light for low-reddening sample
- Valid for $0.7 < \Delta m_{15}(B) < 1.7$
- Optical–NIR color excesses for the whole sample



Color excesses derived from pseudo-colors at maximum light compared with fits to low-reddening SNe.

The reddening law

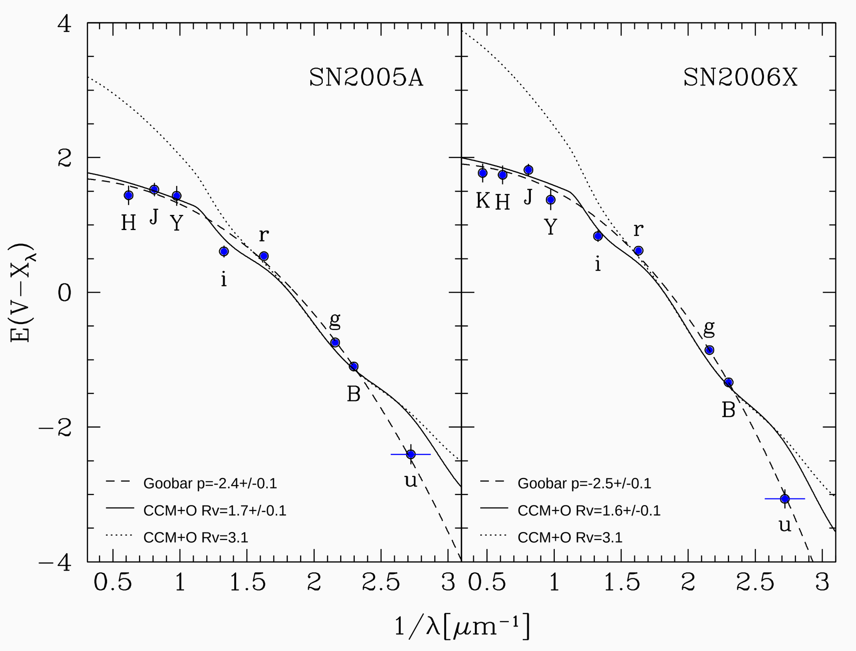
- Slopes of color vs. color determine the value of R_V. Assuming standard reddening by dust (CCM+O) [1, 5]
- Whole sample: $R_V \sim 1.7$ (red)
- Excluding heavily reddened SNe: $R_V \sim 3.2$ (blue) (standard Galactic value)



Reddening law studied with optical–NIR color escesses.

Heavily reddened SNe

- Two heavily reddened SNe: 2005A and 2006X
- $E(V-X)$ color excesses for each band X, as a function of effective wavelength
- For CCM+O $R_V \sim 1.7$ (solid line)
- Model for circumstellar dust [2] gives better fit for u band (dashed line)

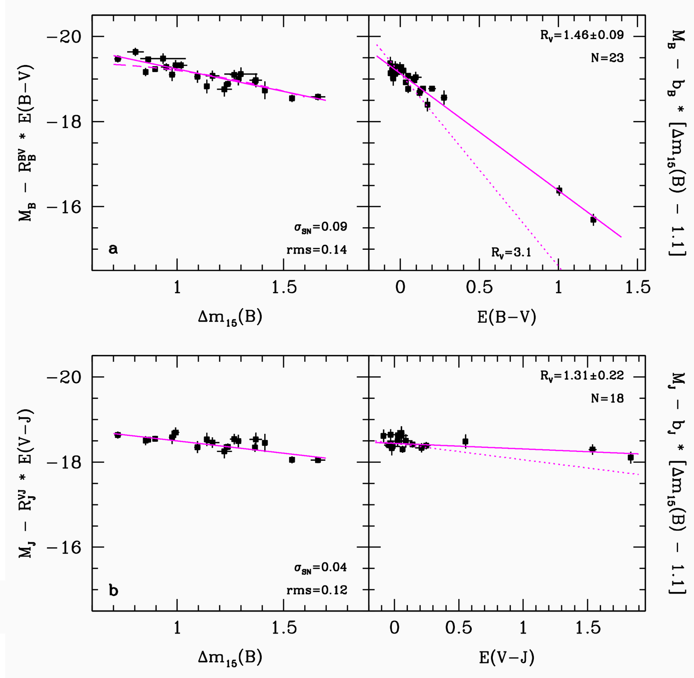


Color excesses for two highly reddened SNe and reddening models.

Precision of SN Ia Distances

Two-parameter calibration

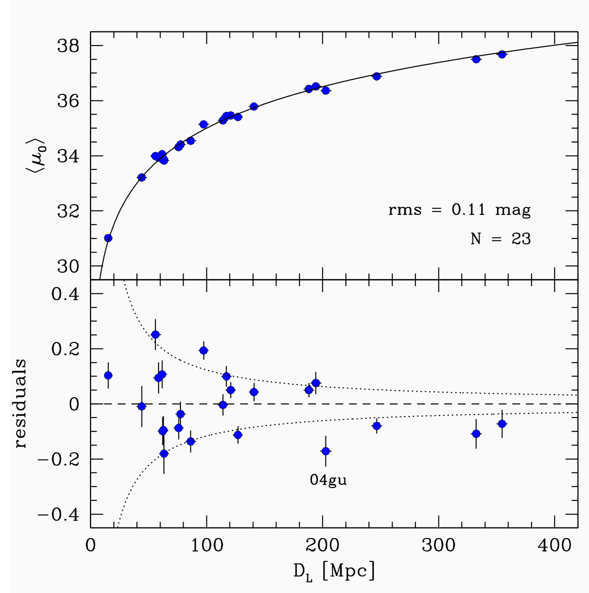
- Luminosity versus $\Delta m_{15}(B)$ and color excess
- Various filter-color combinations
- Scatter of 0.12–0.16 mag
- Low values of $R_V \sim 1-2$ *even when excluding heavily reddened SNe*
- There seems to be an intrinsic dispersion in SN Ia colors which correlates with luminosity but not with decline rate

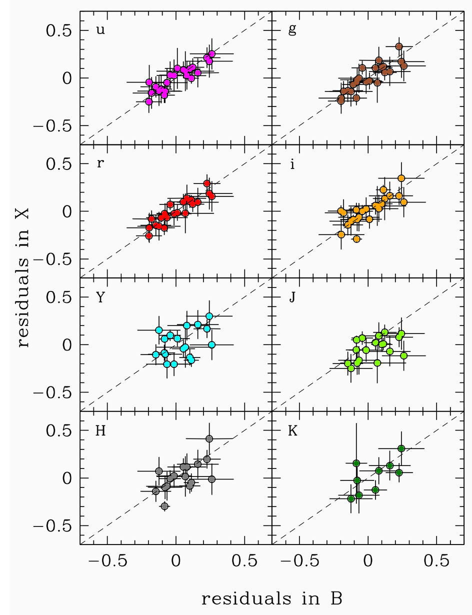


Examples fits of luminosity versus decline rate and reddening for B and J.

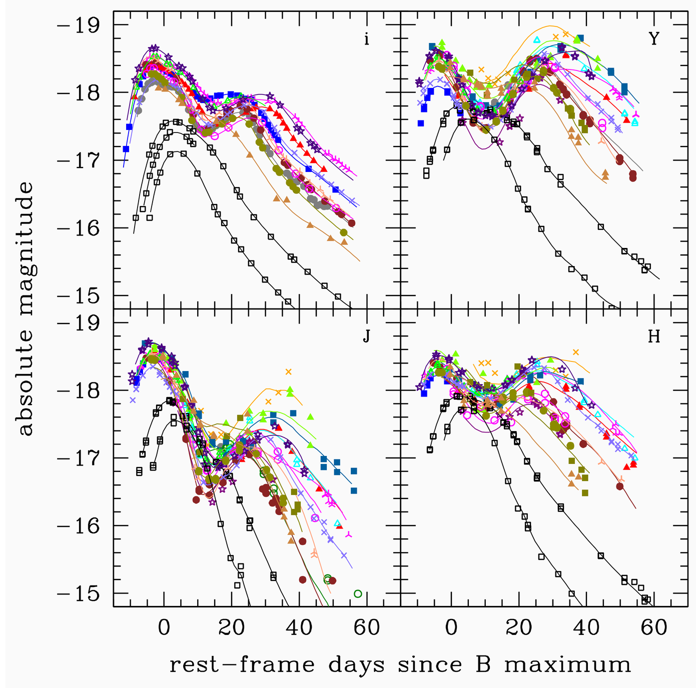
Combined Hubble diagram

- Combining fits from all 10 bands
- Scatter ~0.11 mag ⟶ small improvement
- Residuals compatible with peculiar velocity dispersion
- Strongly correlated residuals
- Distance precision for optical bands may be of 3–4%





SNe Ia as *standard candles* in the NIR



Absolute NIR light curves of SNe Ia in $iYJH$.

- Smaller reddening corrections
- Shallower dependence on decline rate

Precision of SNe Ia as standard candles

	Y	J	H	K_s
$M_{\rm max}$	−18.44(07)	−18.43(07)	−18.42(08)	−18.47(12)
rms	0.24	0.18	0.19	0.27

References

[1] Cardelli, J. A. et al. 1989, ApJ, 345, 245
[2] Goobar, A. 2008, ApJ, 686, L103
[3] Krisciunas, K., et al. 2001, AJ, 122, 1616
[4] Lira, P. 1995, Masters thesis, University of Chile
[5] O'Donnell, J. E. 1994, ApJ, 422, 158