Photometric Diversity from the Carnegie Supernova Project (CSP)

Mark M. Phillips
Carnegie Observatories
Las Campanas Observatory

PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC
99:592-605, July 1987

THE TYPE Ia SUPERNOVA 1986G IN NGC 5128: OPTICAL PHOTOMETRY AND SPECTRA

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Received 1987 April 13

*Cerro Tololo Inter-American Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

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My first paper on a SN Ia (Phillips et al. 1987)

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Special thanks to R. Kirshner, both for his encouragement during this project and for alerting us early on to the discovery of SN 1986G. We are also grateful to D. Branch for critical comments on a draft of this manuscript. M.A.S. acknowledges the support of a Berkeley graduate fellowship.

My first paper on a SN Ia (Phillips et al. 1987)

CSP Observational Goals

1. Obtain precision ugriBVYJH light curves and spectrophotometry of
    - ≥ 100 SNe Ia ($z \leq 0.07$)
    - ≥ 100 SNe II ($z \leq 0.05$)
    - ≥ 20 SNe Ibc ($z \leq 0.05$)
2. Obtain rest system i band light curves of ~100 SNe Ia at $0.1 < z < 0.7$

CSP Science Goals

1. Gain insight into the progenitors and explosion mechanisms of SNe
2. Refine methods for determining distances to SNe Ia and SNe II
3. Provide a new fundamental reference for observations of high-z SNe
4. Characterize dark energy by producing an i-band Hubble diagram of low and high-z SNe Ia where reddening corrections are small

CSP Telescopes/Instruments

Optical (ugriBV) Photometry:

Las Campanas Swope 1 m telescope + CCD

Infrared (YJsHKs) Photometry:

Las Campanas Swope 1 m telescope + RetroCam (YJH)
Las Campanas du Pont 2.5 m telescope + WIRC (YJHK)
Las Campanas Baade 6.5 m telescope + PANIC (YJHK)

Optical (0.32-1.0 μm) Spectroscopy:

Las Campanas du Pont 2.5-m telescope + WFCCD (or Modspec, or B&C)
Magellan 6.5-m telescope + LDSS-3 (or IMACS)
CTIO 1.5-m telescope + Cassegrain Spectrograph (service mode)
ESO NTT+EMMI

Swope 1-m

Du Pont 2.5-m

Magellan 6.5-m

CSP People

Chile

Mark Phillips (OCIW/LCO) P.I. Low-z
Mario Hamuy (U. Chile) Original P.I. Low-z
Max Stritzinger (OCIW/LCO, postdoc)
Gastón Folatelli (U. Chile, former postdoc)
Miguel Roth (OCIW/LCO)
Nidia Morrell (OCIW/LCO)
Alejandro Clocchiatti (PUC)
Wojtek Krzeminski (OCIW/LCO retired)
Carlos Contreras (former research assistant)
Sergio Gonzalez (research assistant)
Luis Boldt (research assistant)
Francisco Salgado (research assistant)
Abdo Campillay (research assistant)

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Eric Persson (OCIW)
Chris Burns (OCIW, postdoc)
Barry Madore (OCIW/Pasadena)
Don Neill (Caltech)
Pamela Wyatt (OCIW/IPAC)
David Murphy (OCIW)

Texas A&M

Nick Suntzeff
Kevin Krisciunas
Lifan Wang
Darren Depoy

Other collaborators

Alex Filippenko (UC Berkeley)
Weidong Li (UC Berkeley)
Ray Carlberg (Univ. Toronto)
Josh Frieman (Chicago/Fermi Lab.)
Jose Luis Prieto (Ohio St./OCIW)

Recent CSP Papers

- "The Carnegie Supernova Project: First Near-Infrared Hubble Diagram to z ~ 0.7", Freedman et al. 2009, ApJ, in press (arXiv:0907.4524)

- "The Carnegie Supernova Project: First Photometry Data Release of Low-Redshift Type Ia Supernovae", Contreras et al. 2009, AJ, submitted

- "The Carnegie Supernova Project: Analysis of the First Sample of Low-Redshift Type Ia Supernovae", Folatelli et al. 2009, AJ, submitted

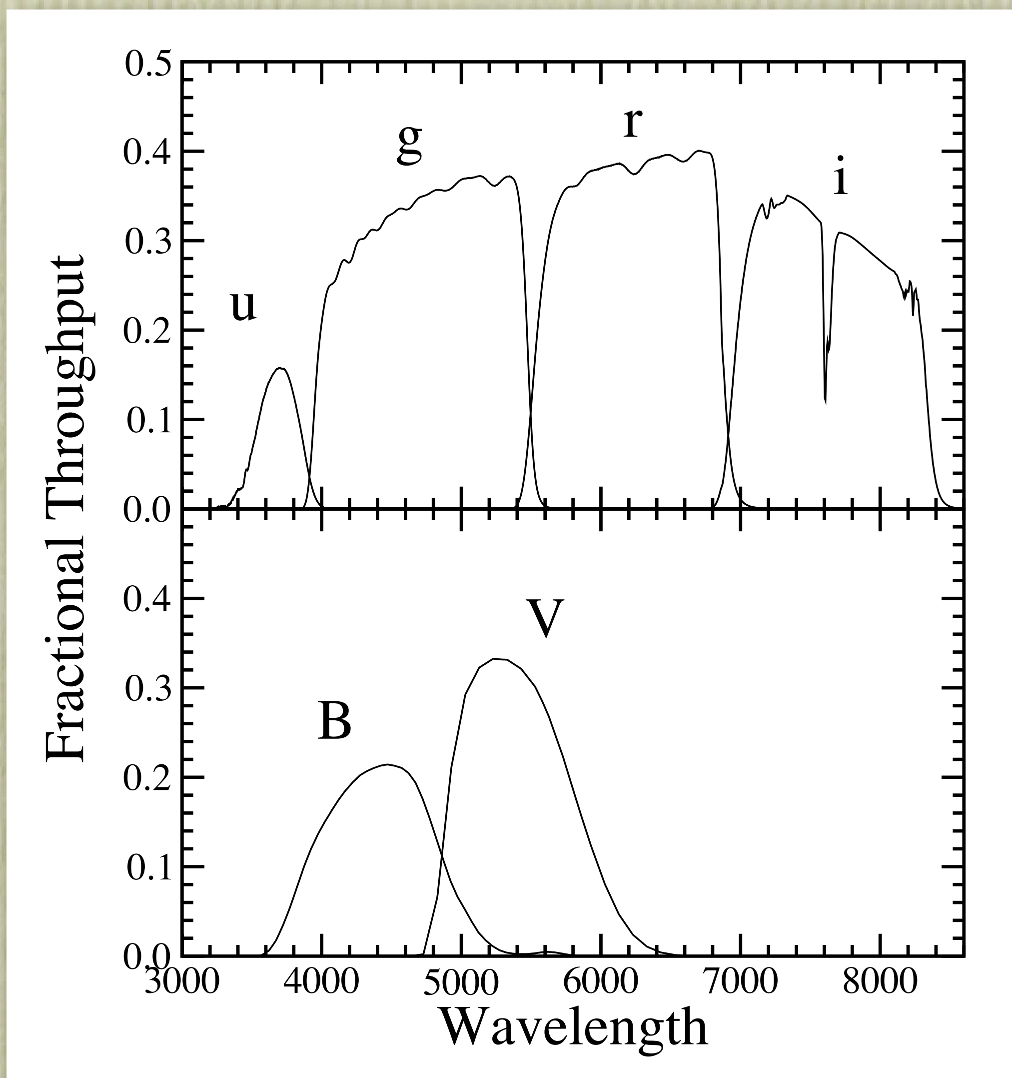
Recent CSP Papers

Carlos Contreras

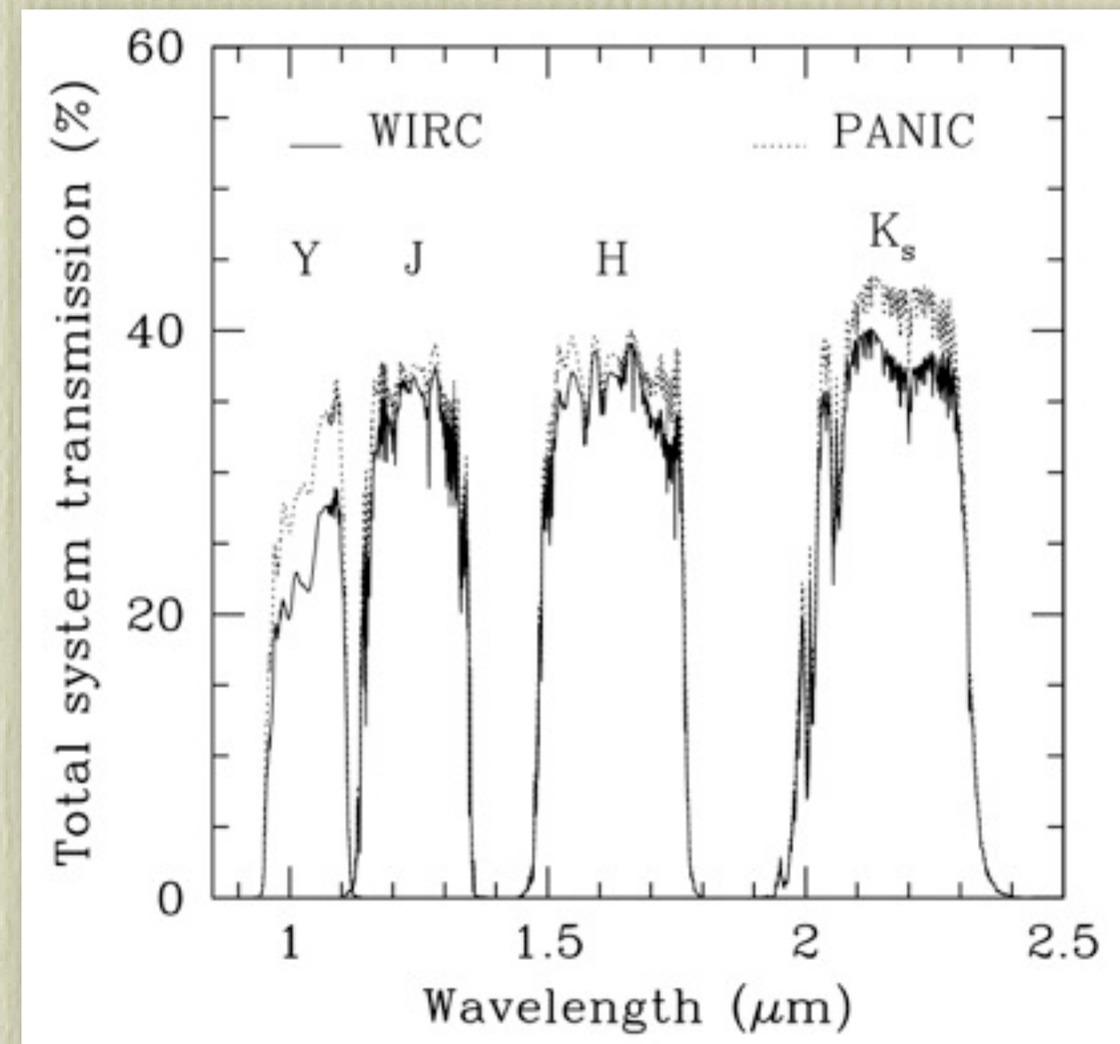
Gastón Folatelli

CSP Low-Redshift Passbands

Optical

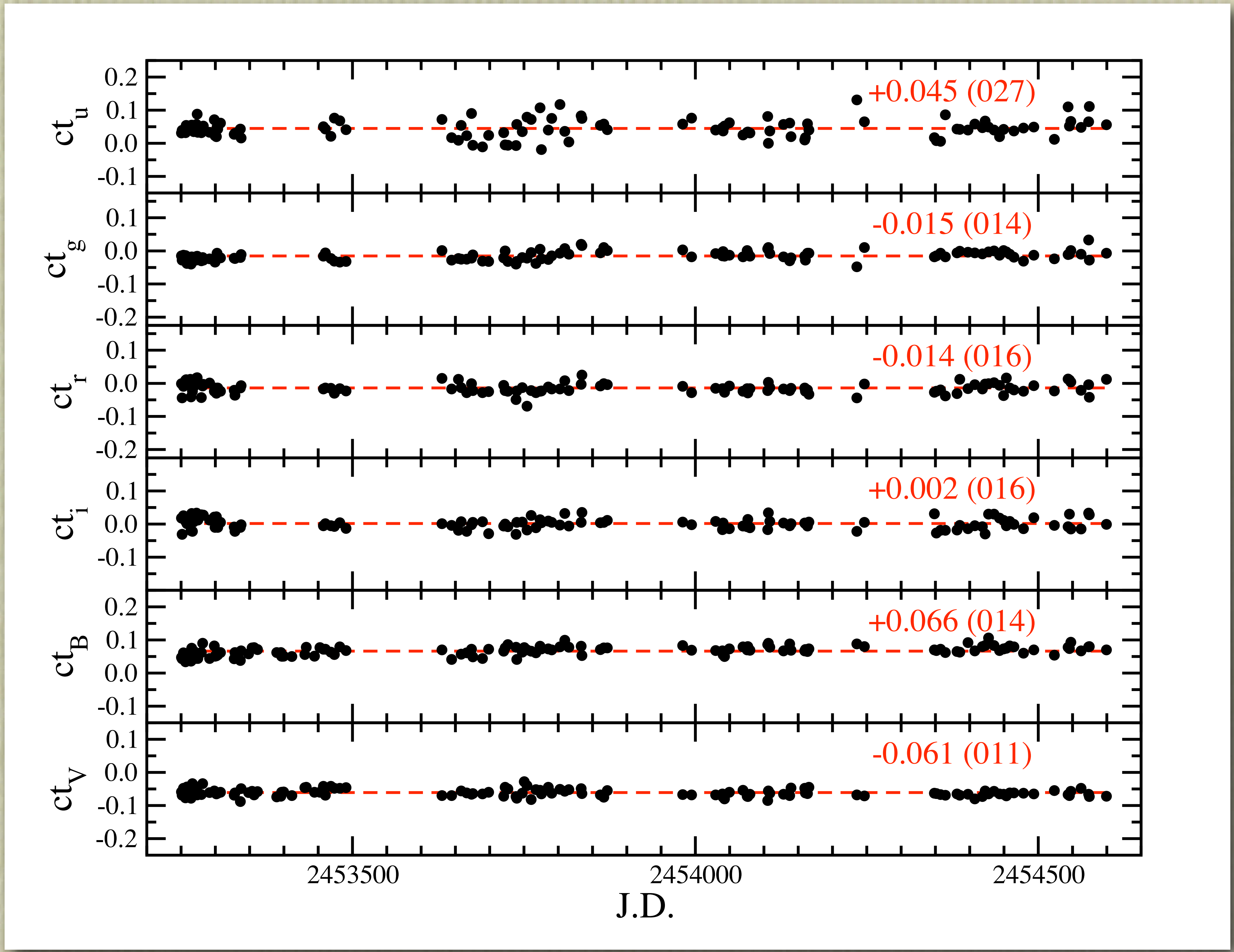


Near-infrared

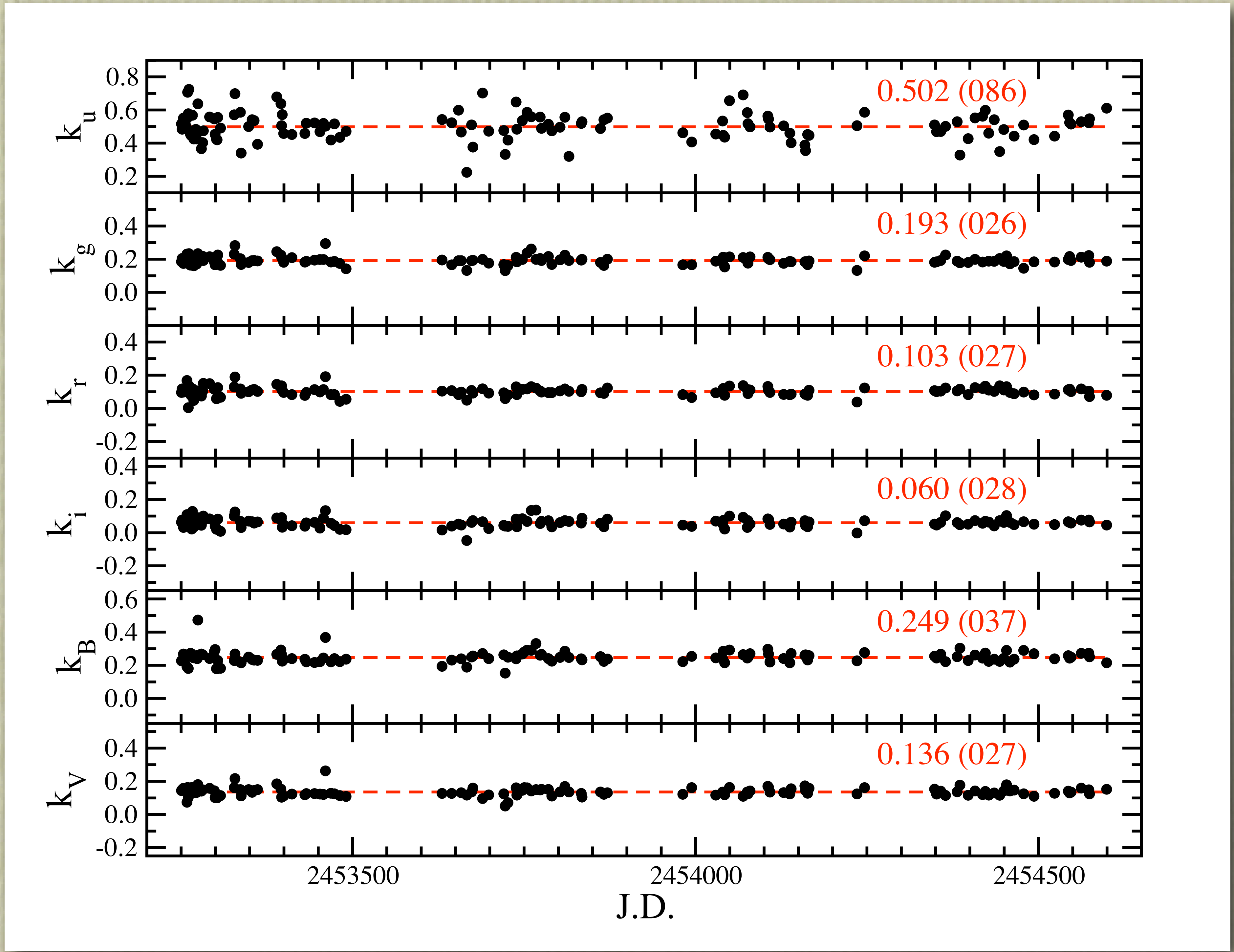


Precise measurements of the CSP passbands are scheduled for January 2010

Color Term Coefficients



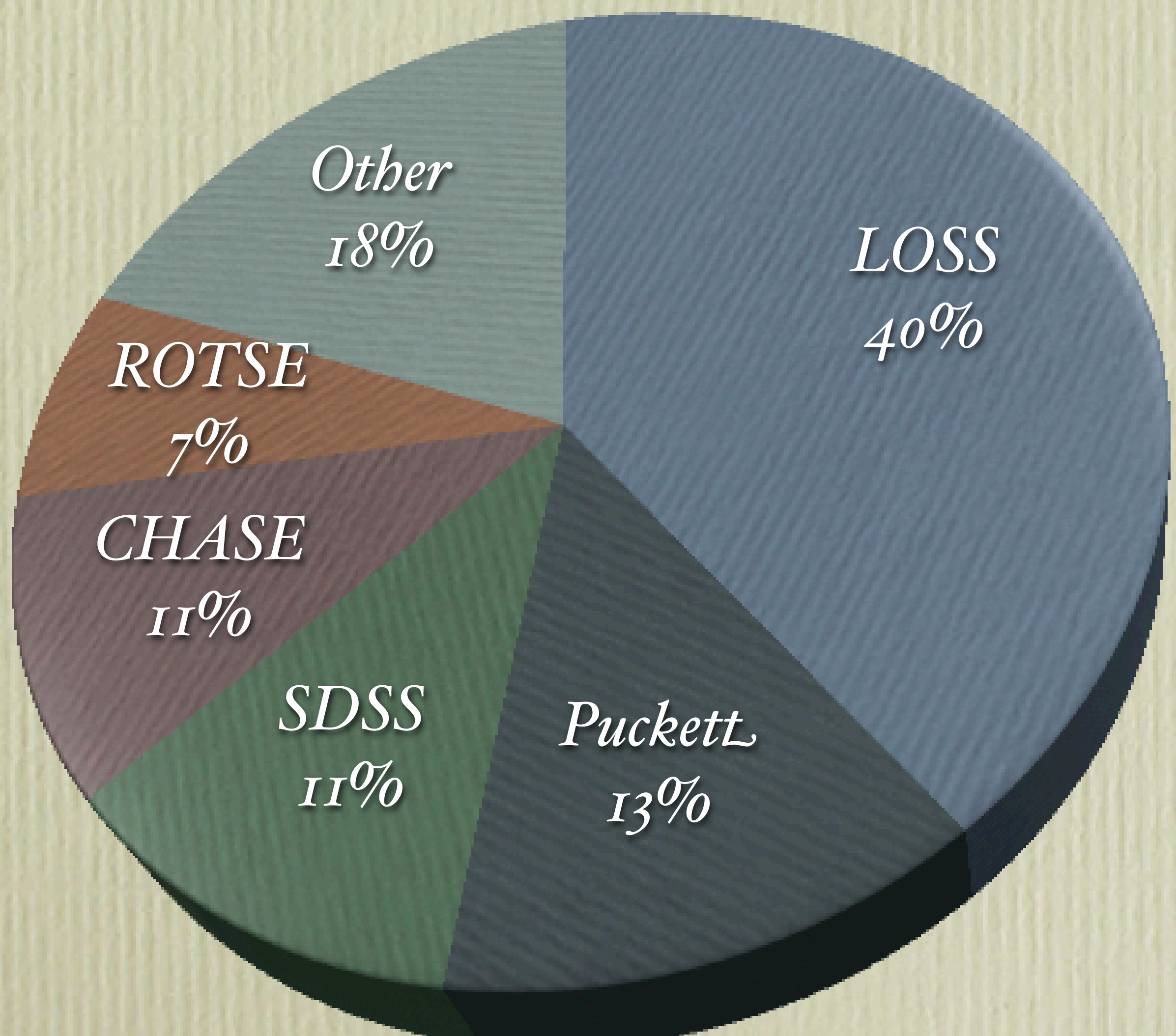
Extinction Coefficients

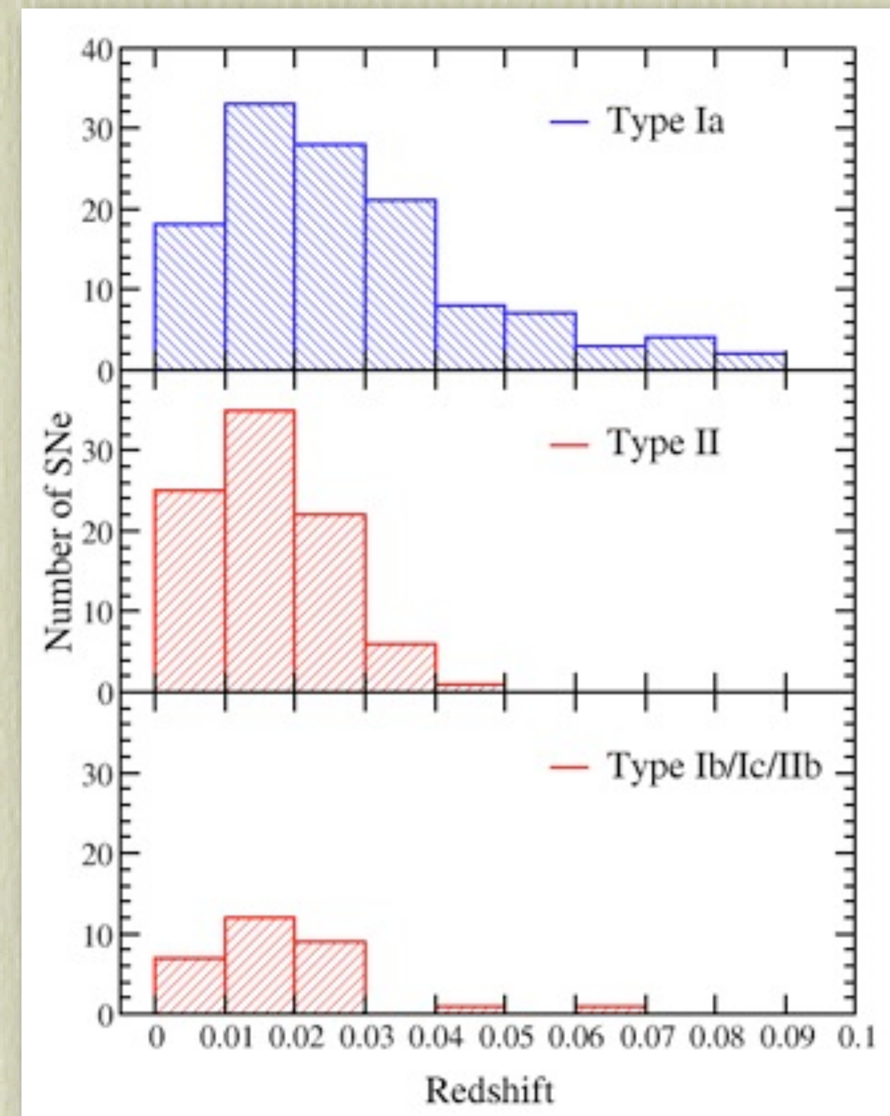


2 out of every 3 nights were photometric

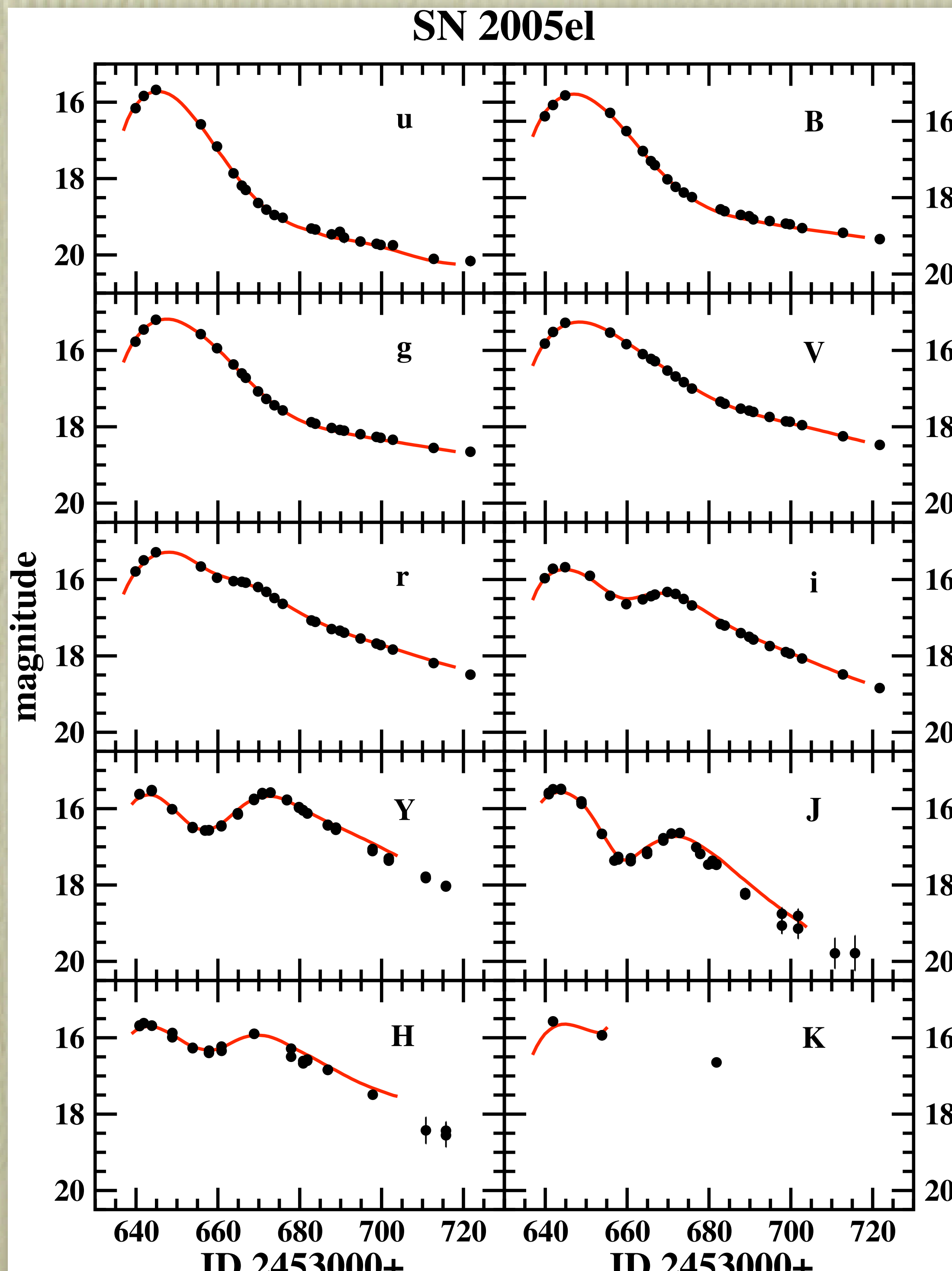
CSP Low-Redshift Sample

	Ia	II	Ib/Ic/IIb	Total
Actual	129	93	31	253
Expected	100	100	25	225

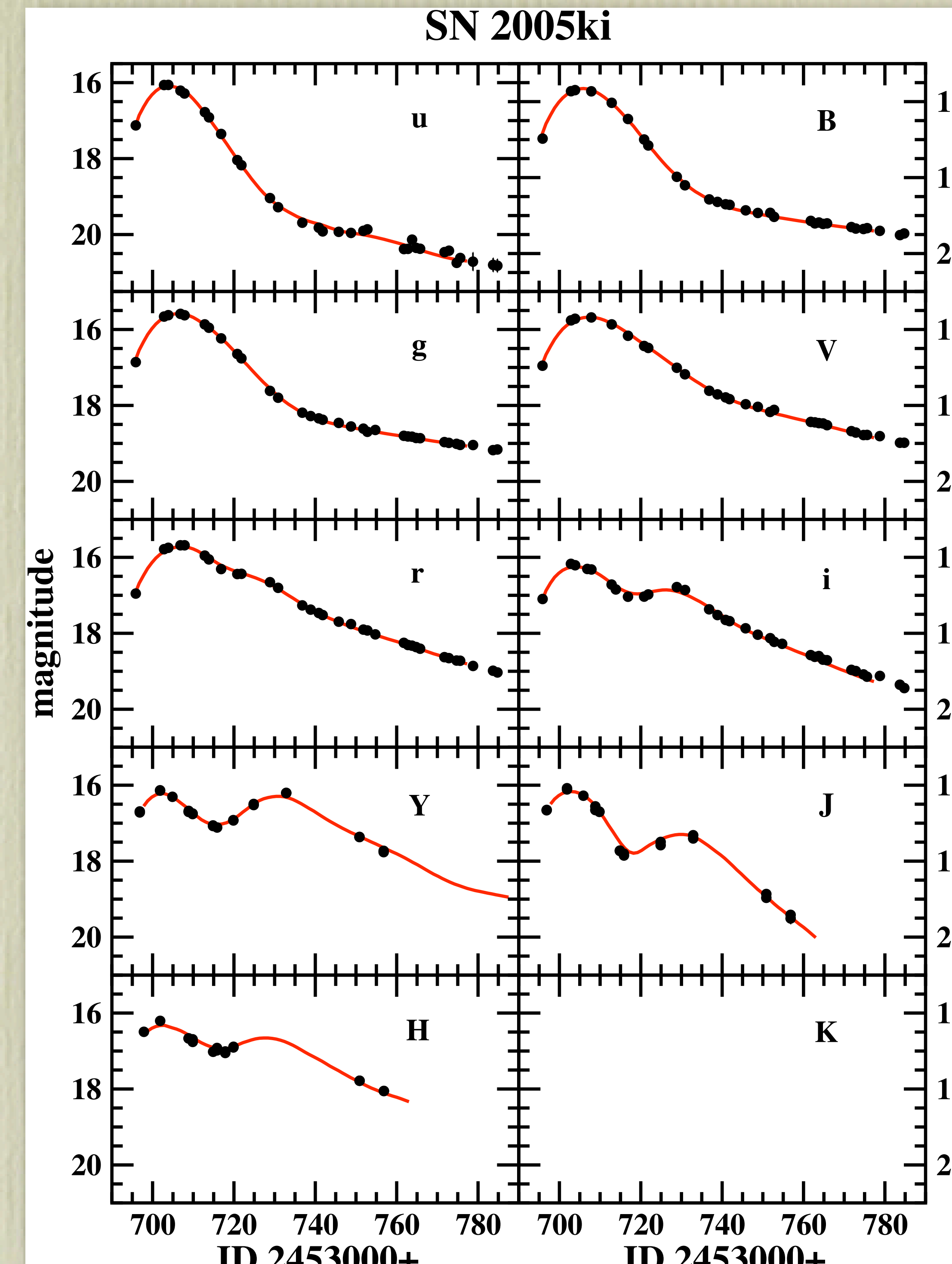




Examples of Light Curves I

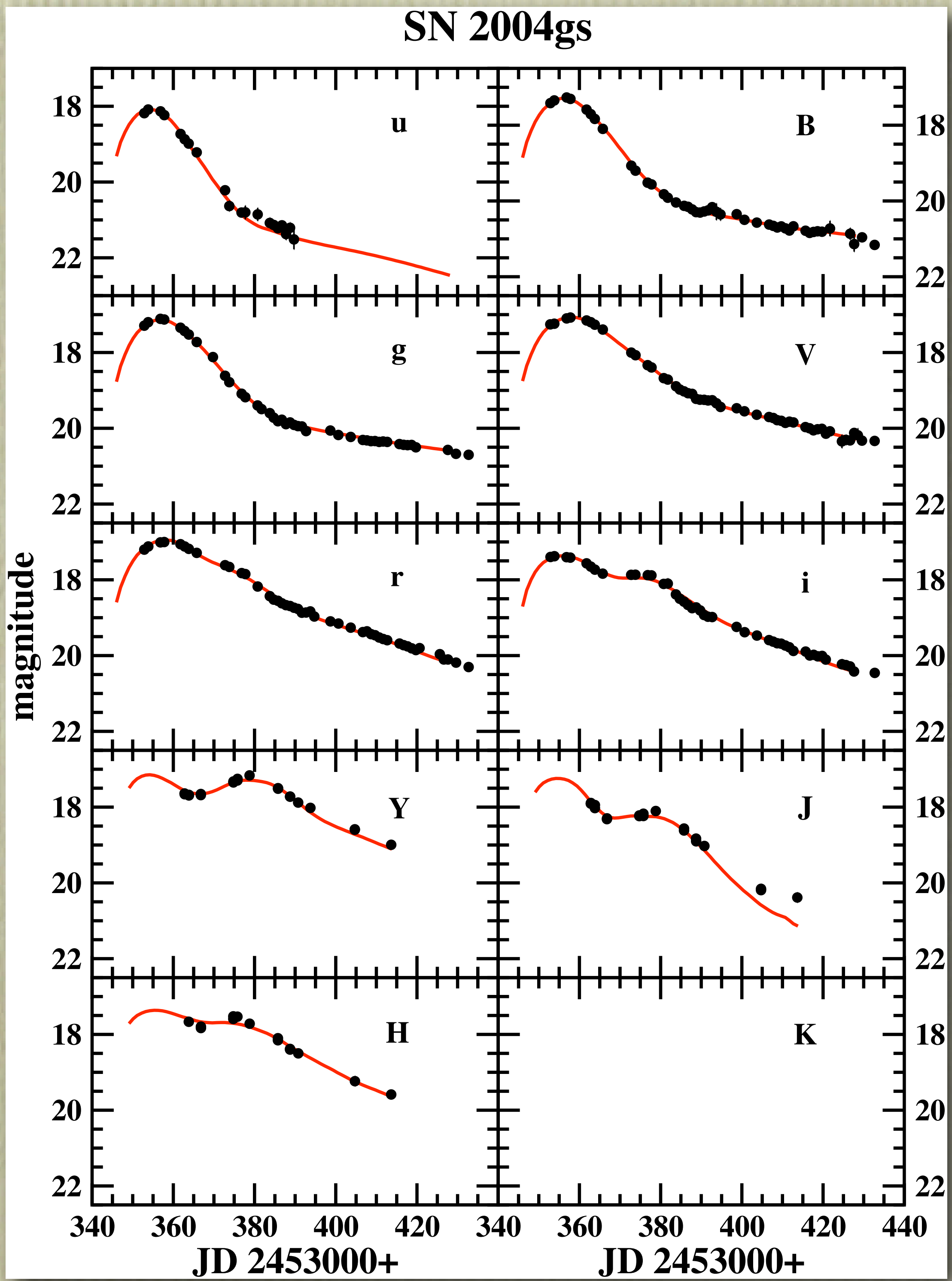


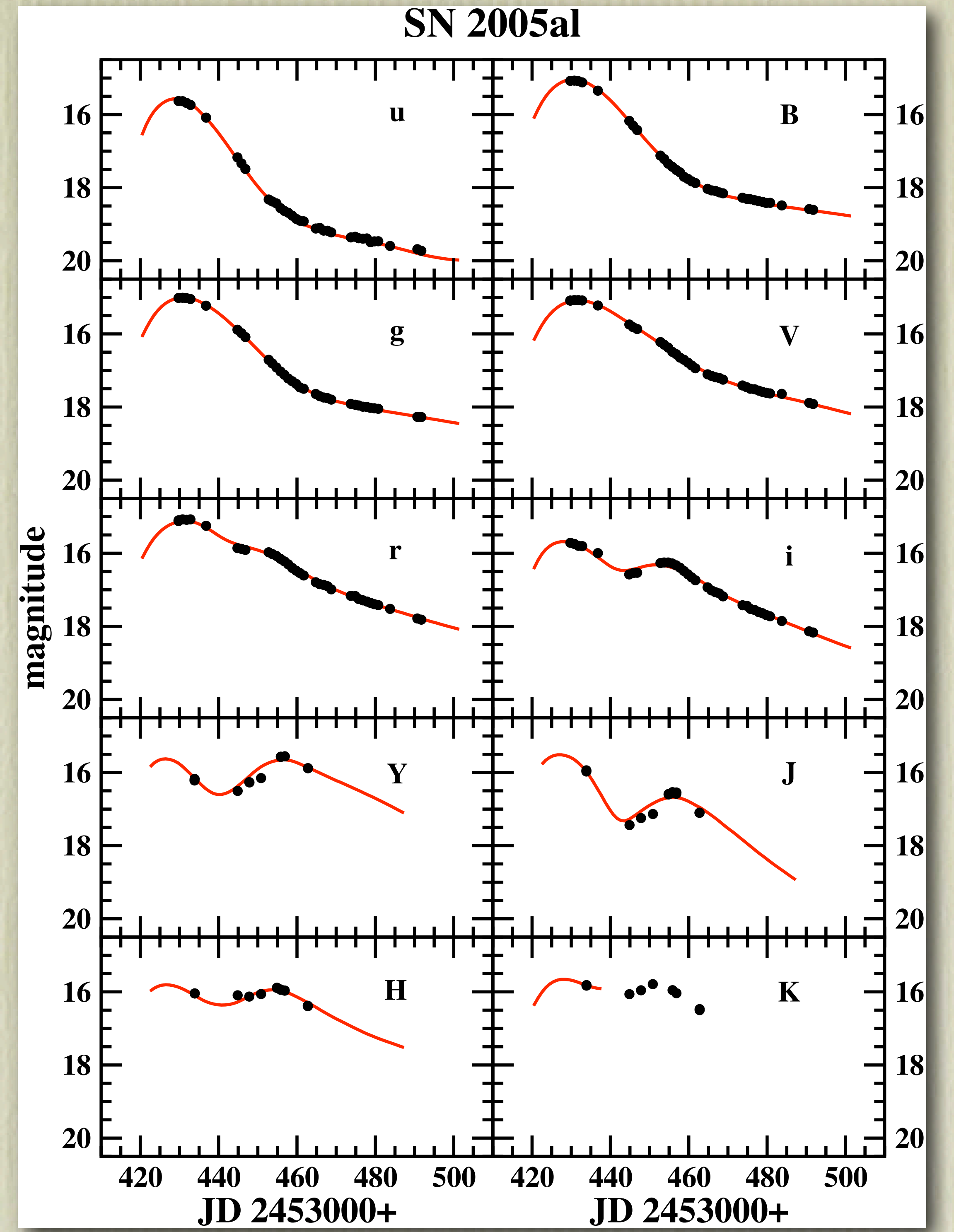
z = 0.015



z = 0.019

Examples of Light Curves II

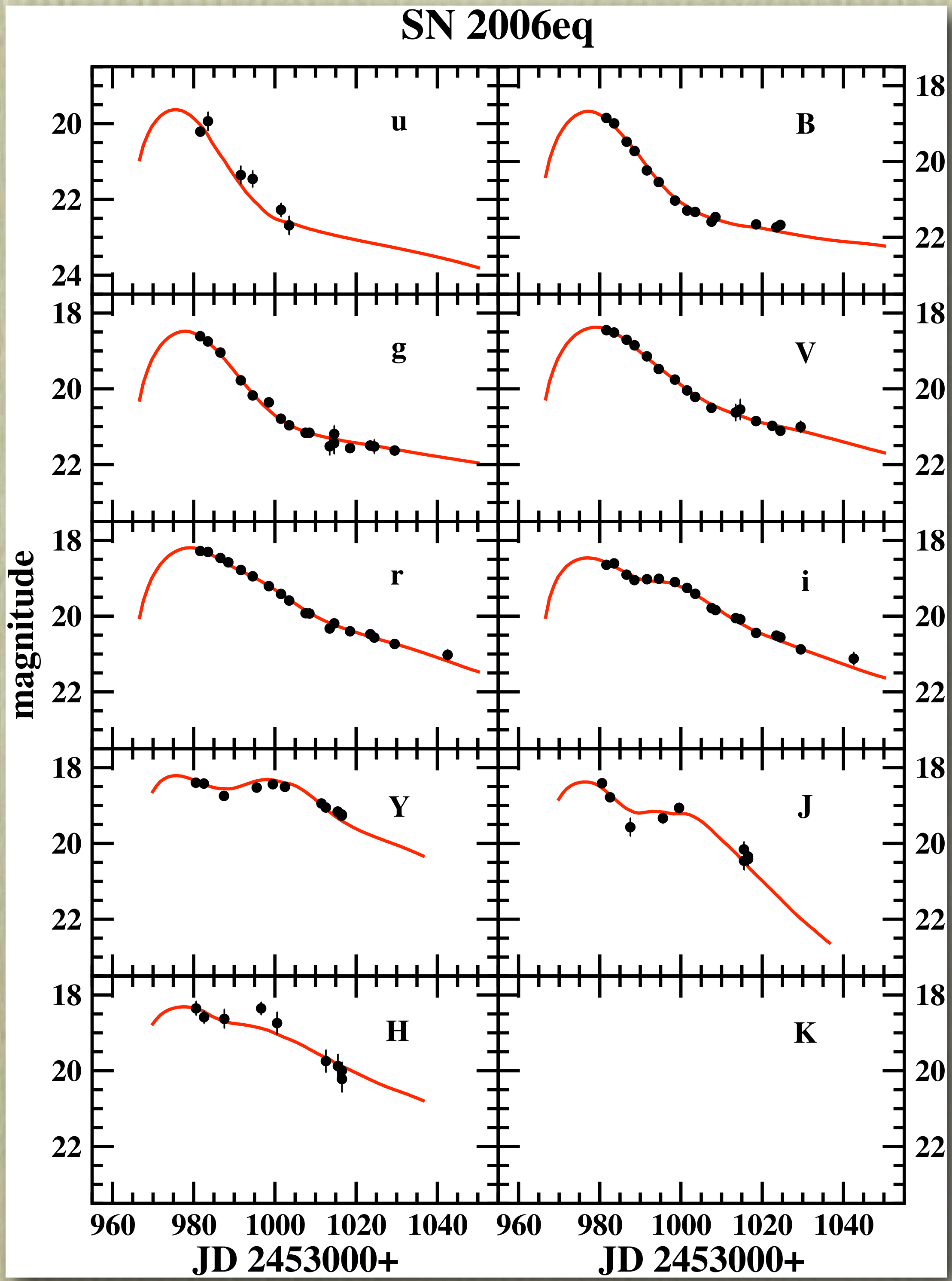


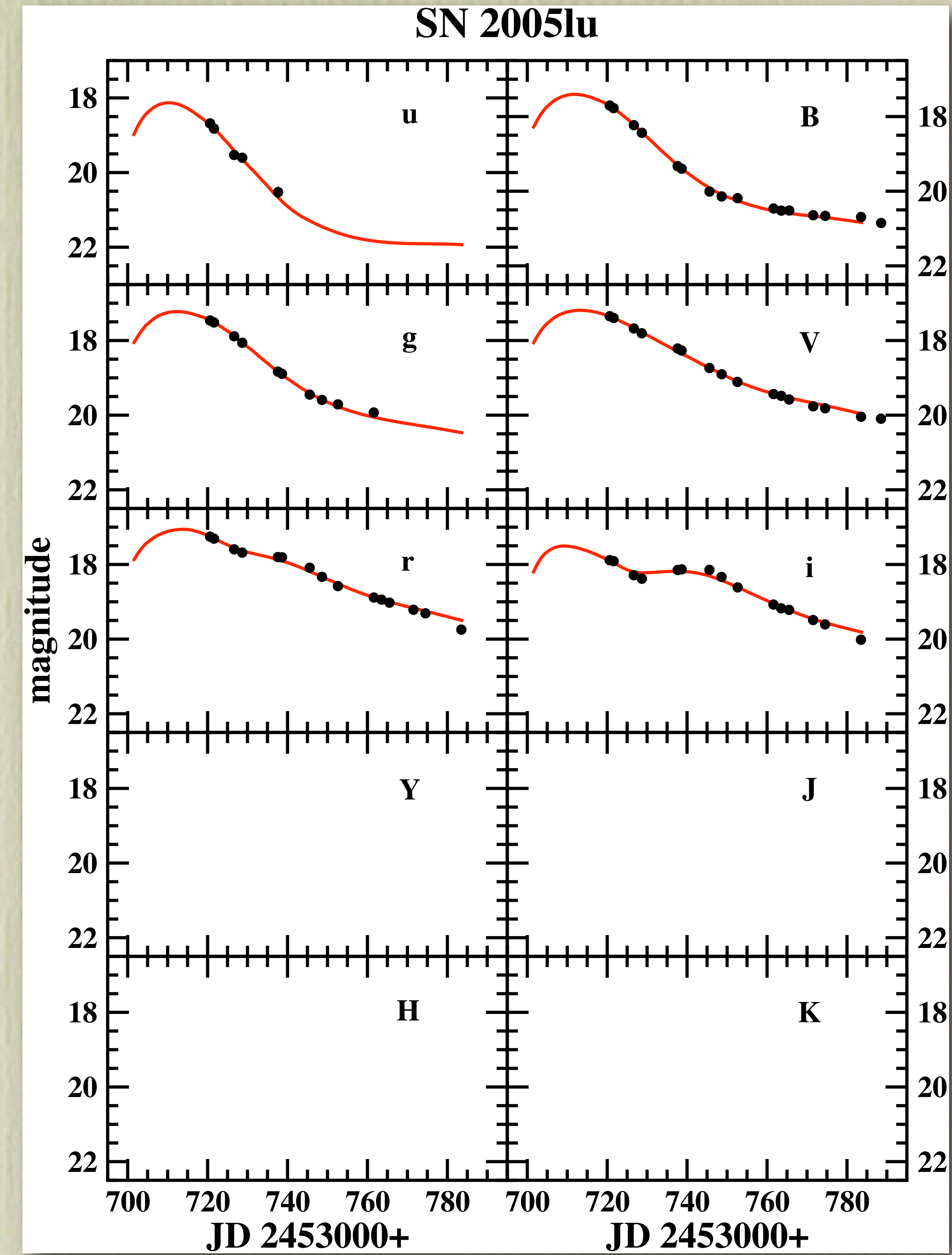


z = 0.027

z = 0.012

Examples of Light Curves III

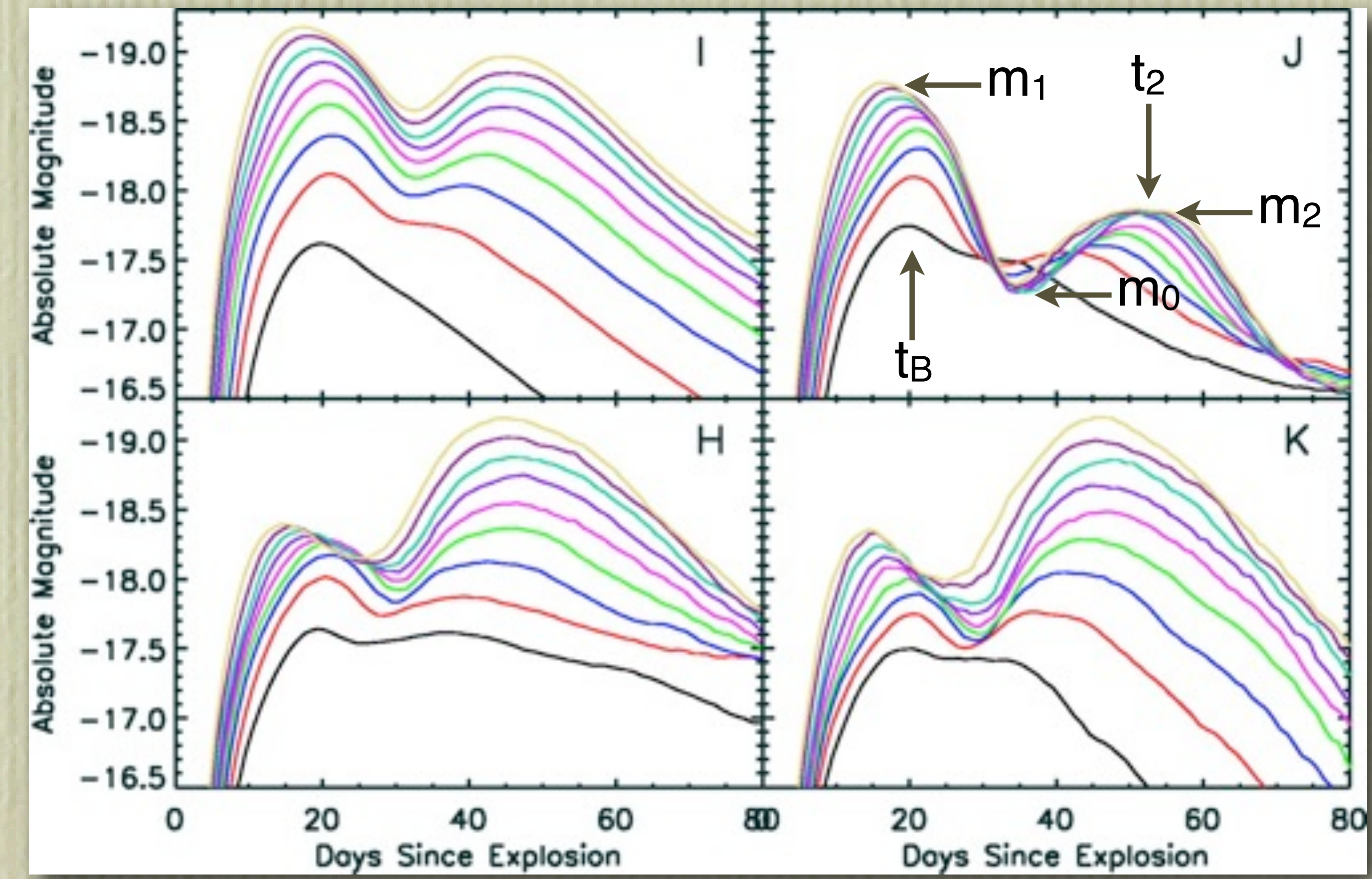


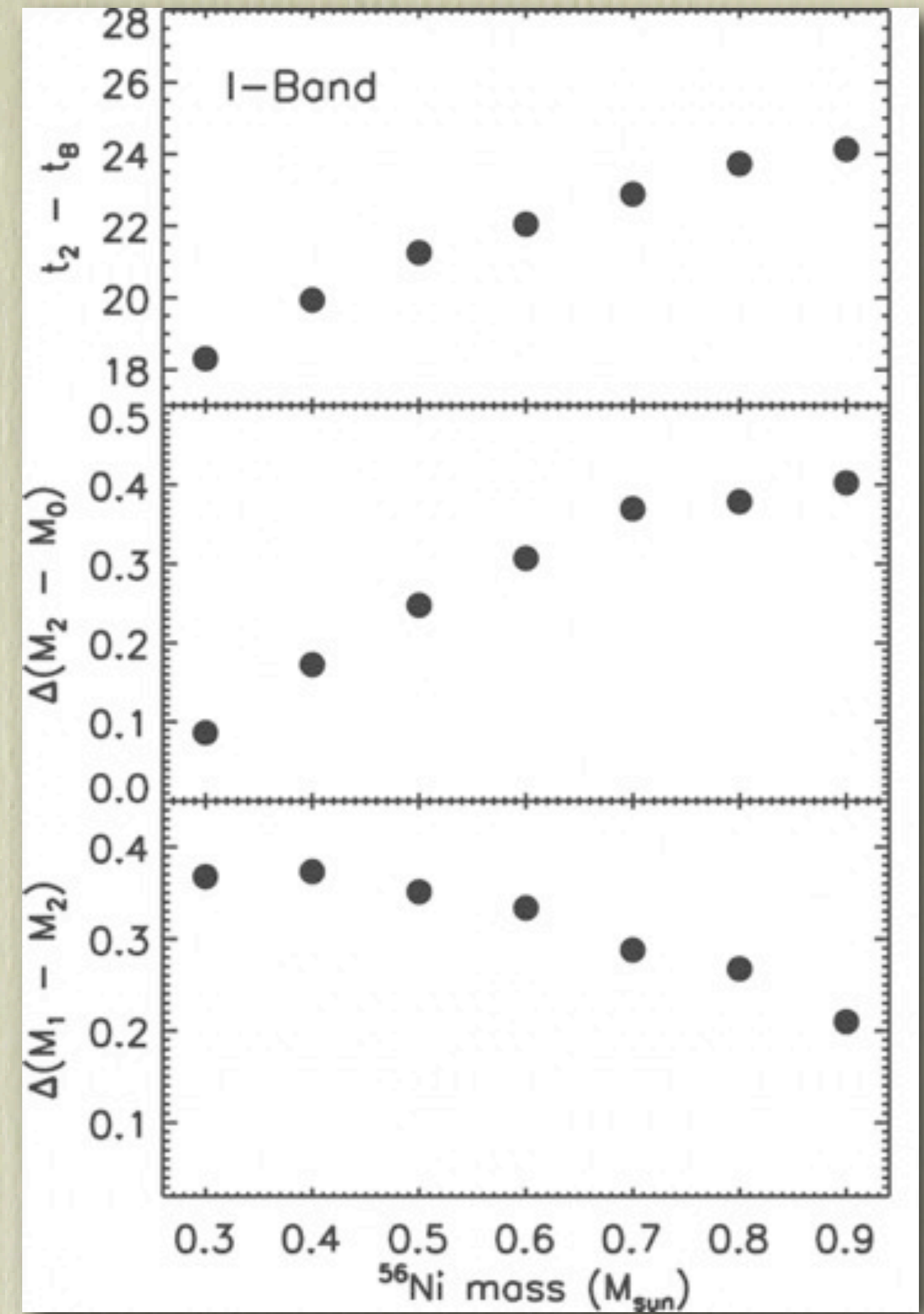


z = 0.050

z = 0.032

The Secondary Maximum

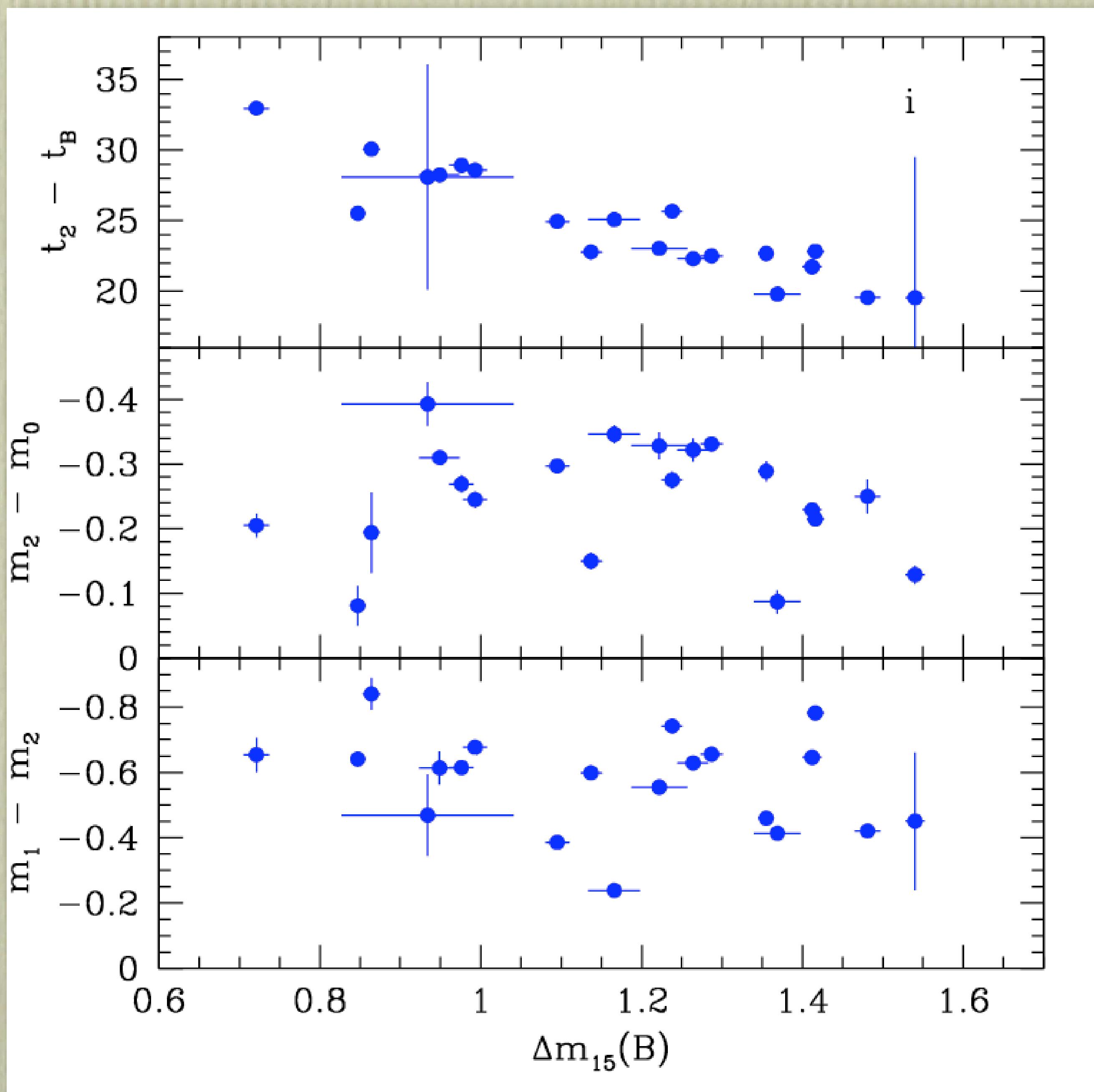




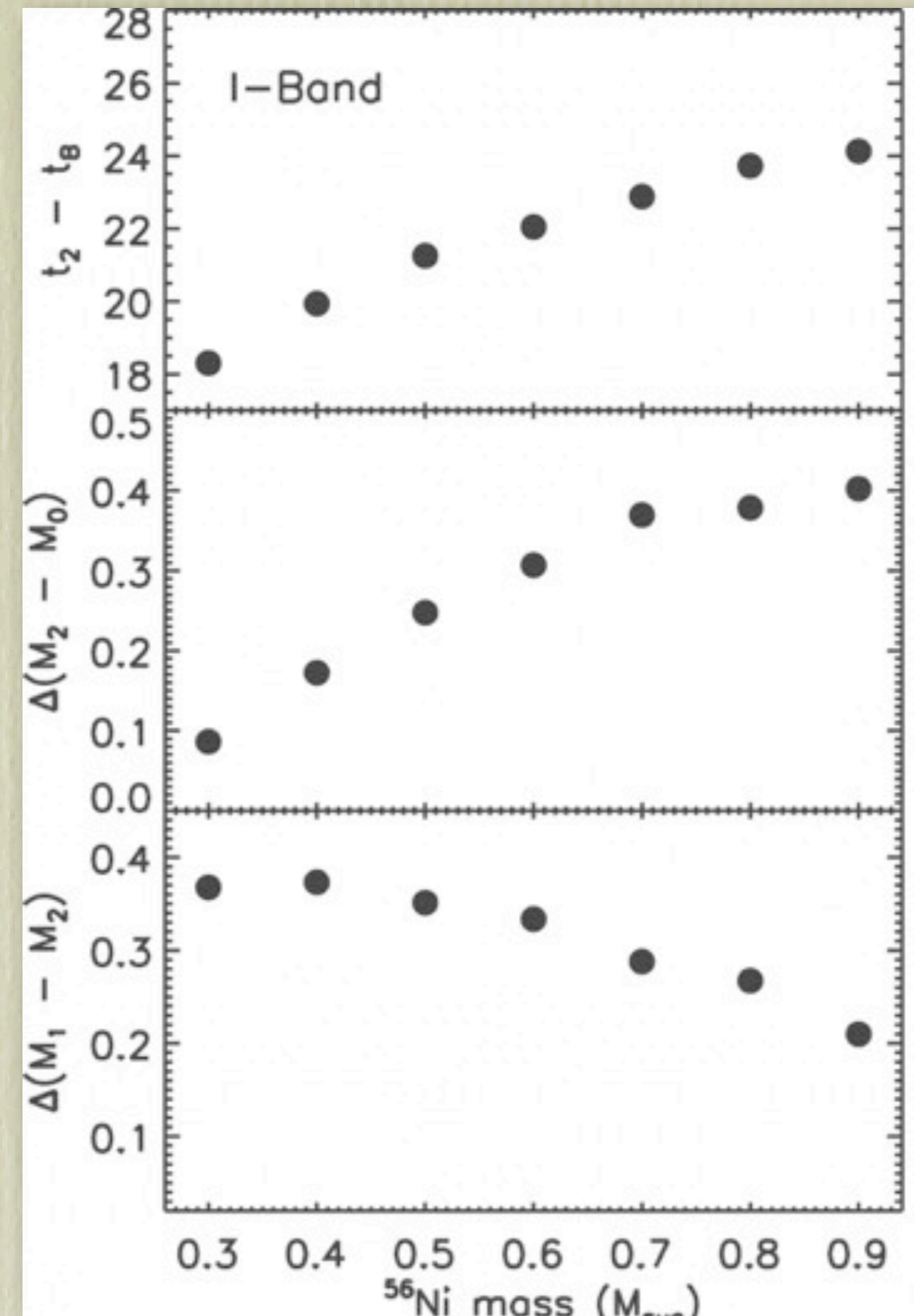
The timing and strength of the secondary maximum is predicted to be primarily a function of the ^{56}Ni mass -- and, therefore, $\Delta m_{15}(B)$

Kasen (2006)

The Secondary Maximum



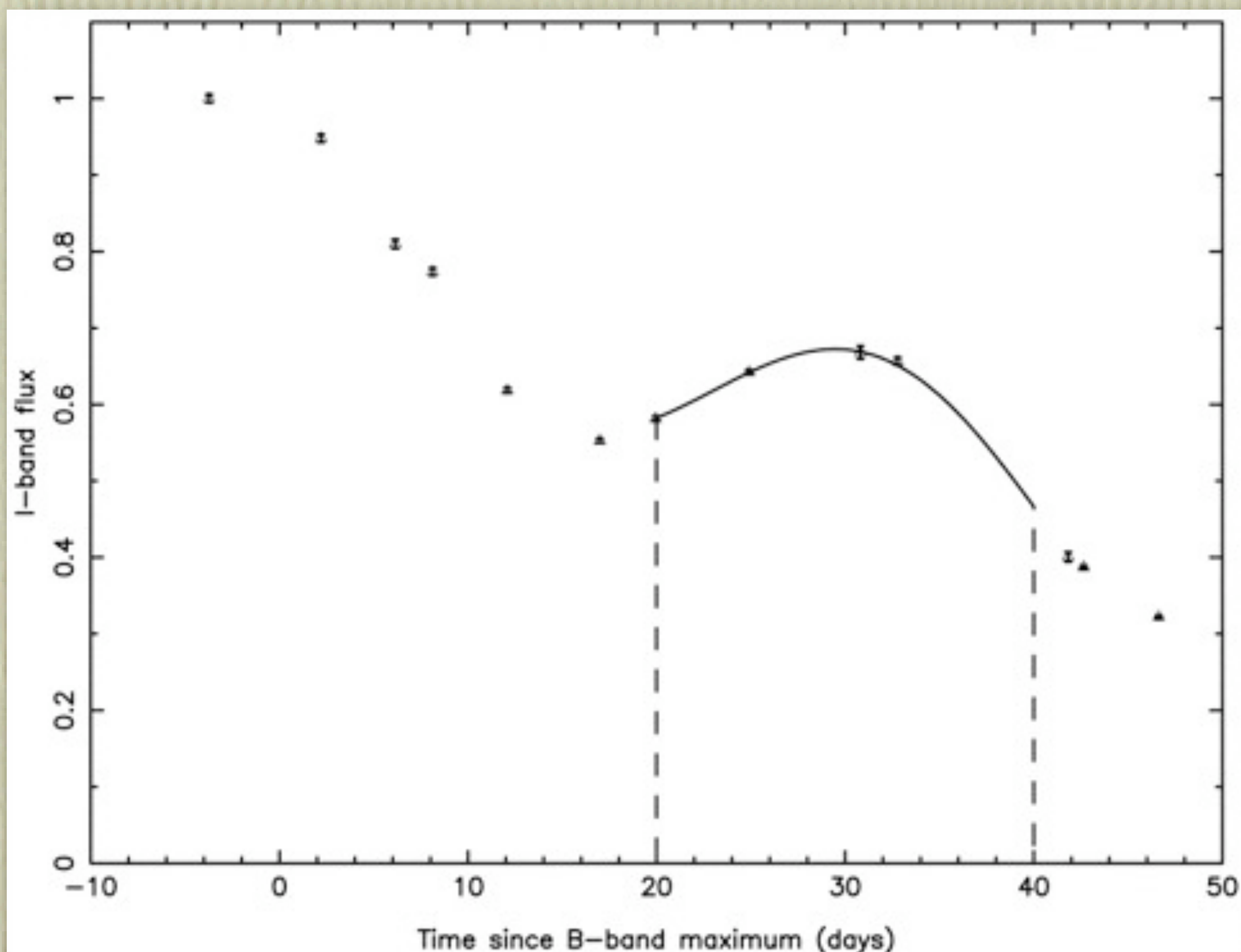
CSP data

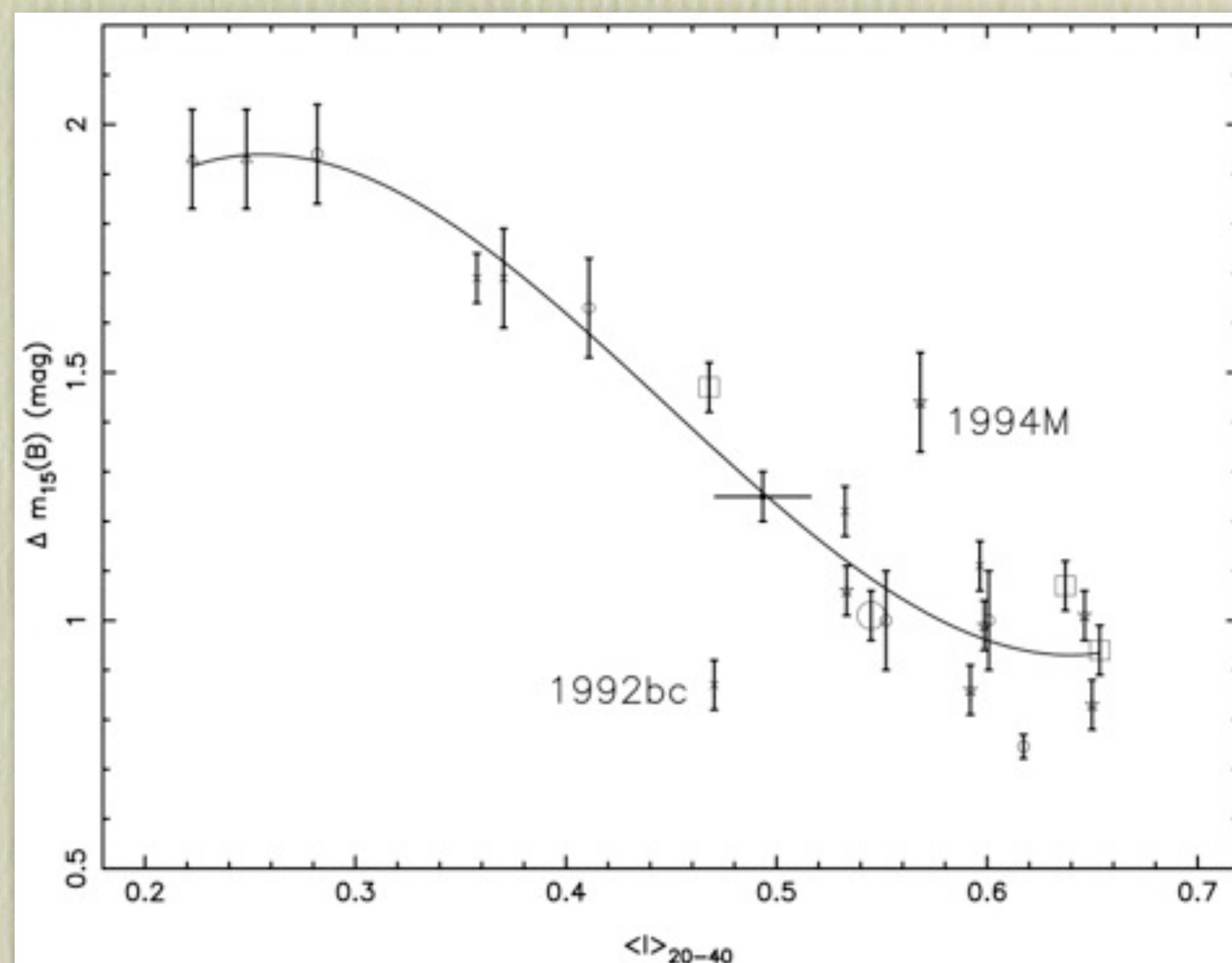


Kasen (2006)

The Secondary Maximum

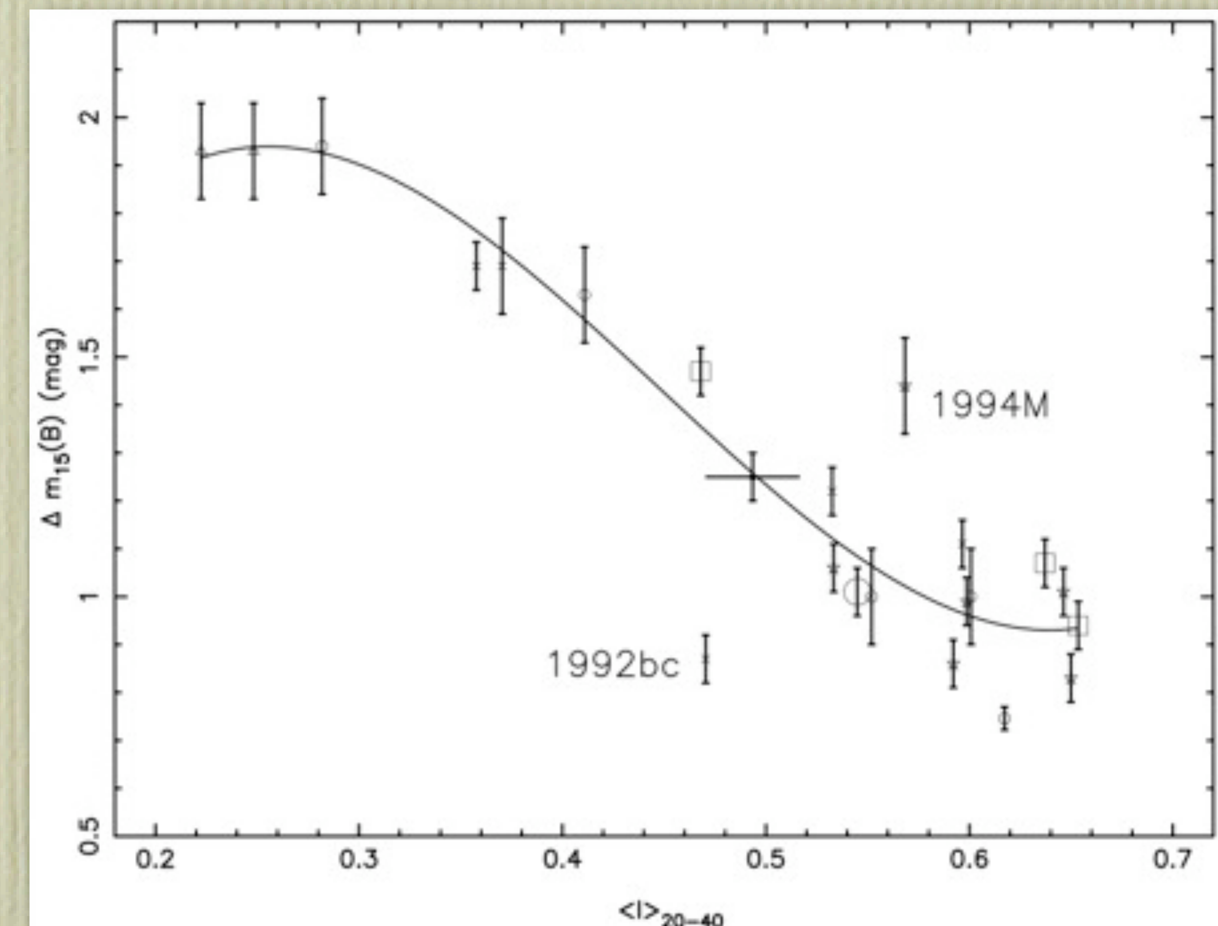
An alternative method to measure the strength of the secondary maximum is the $\langle i \rangle_{20\text{-}40}$ parameter

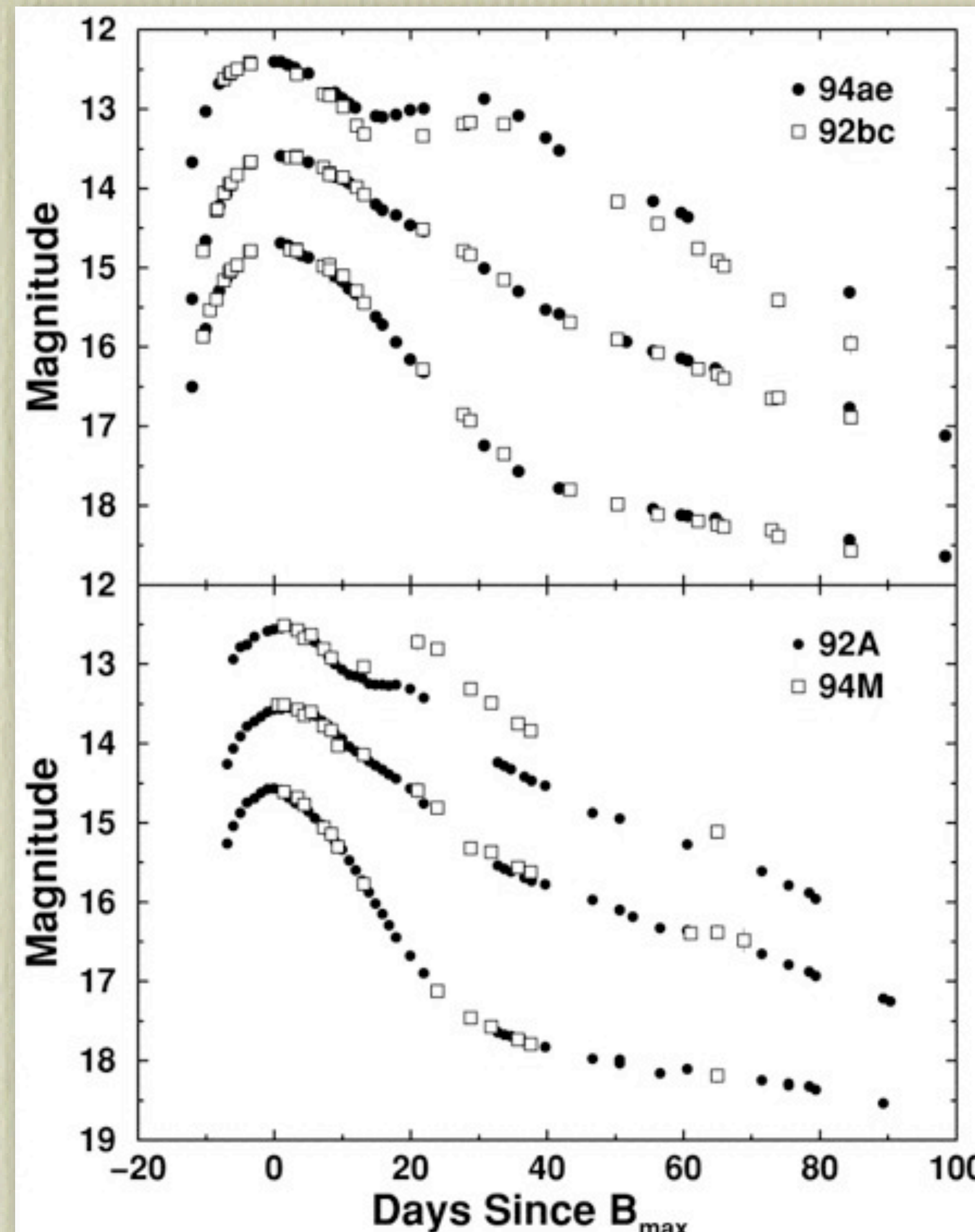




Krisciunas et al. (2001)

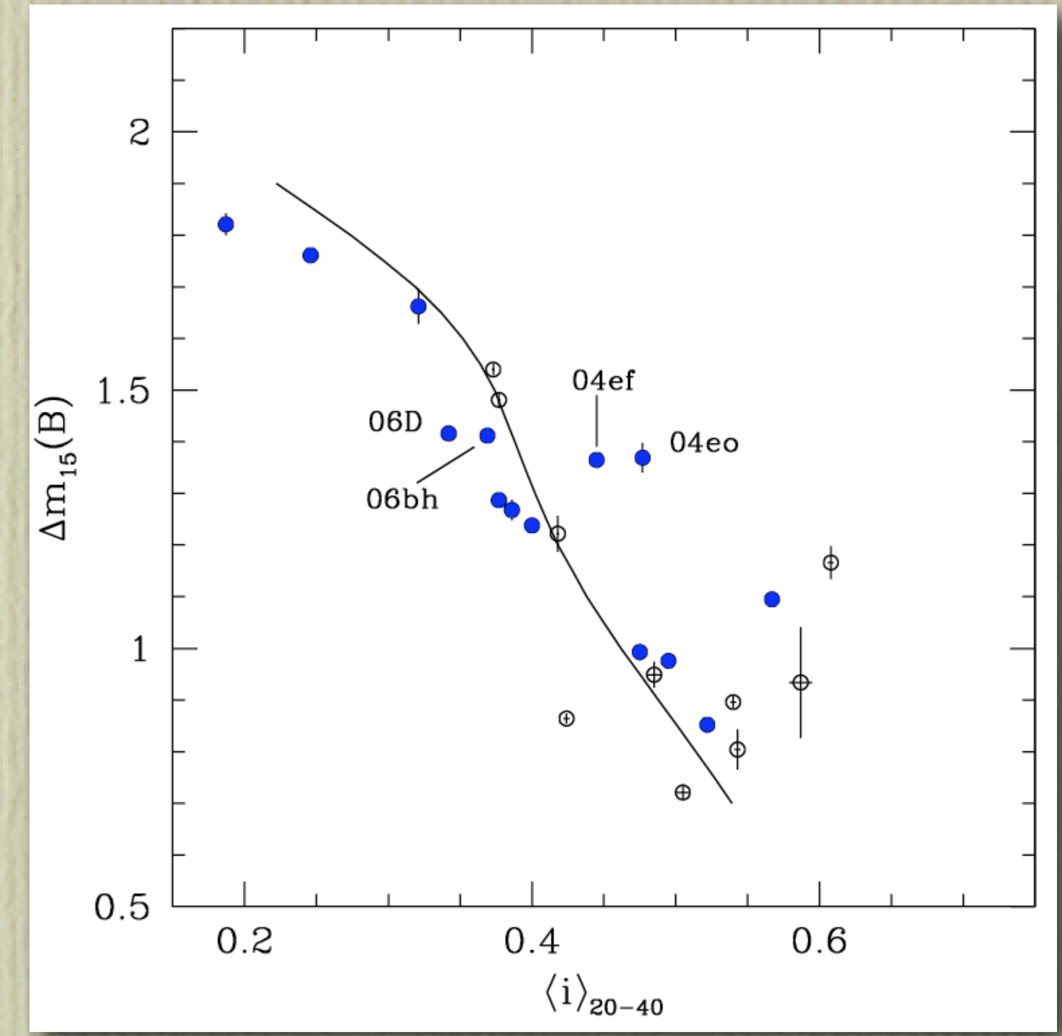
The Secondary Maximum

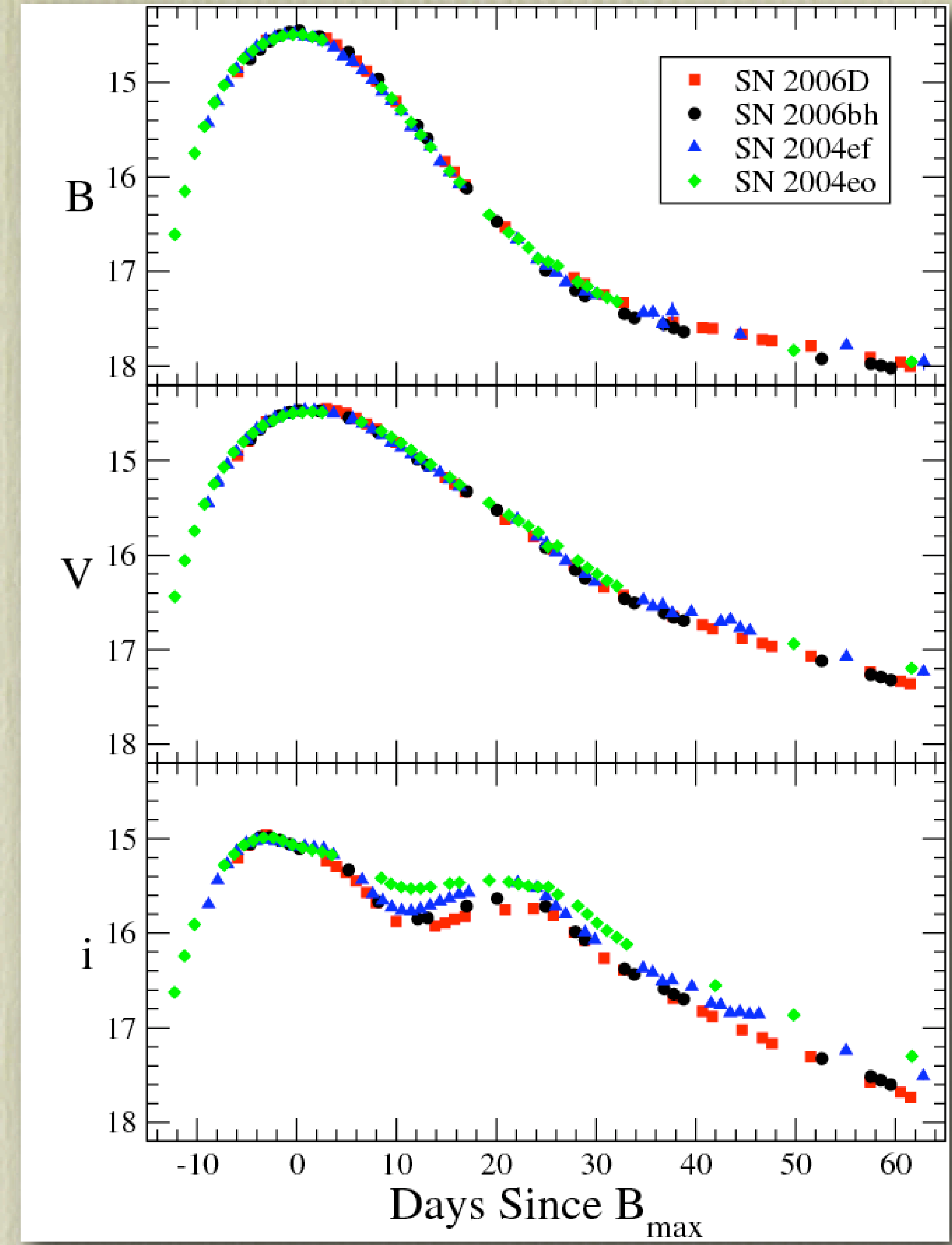




Krisciunas et al. (2001)

The Secondary Maximum



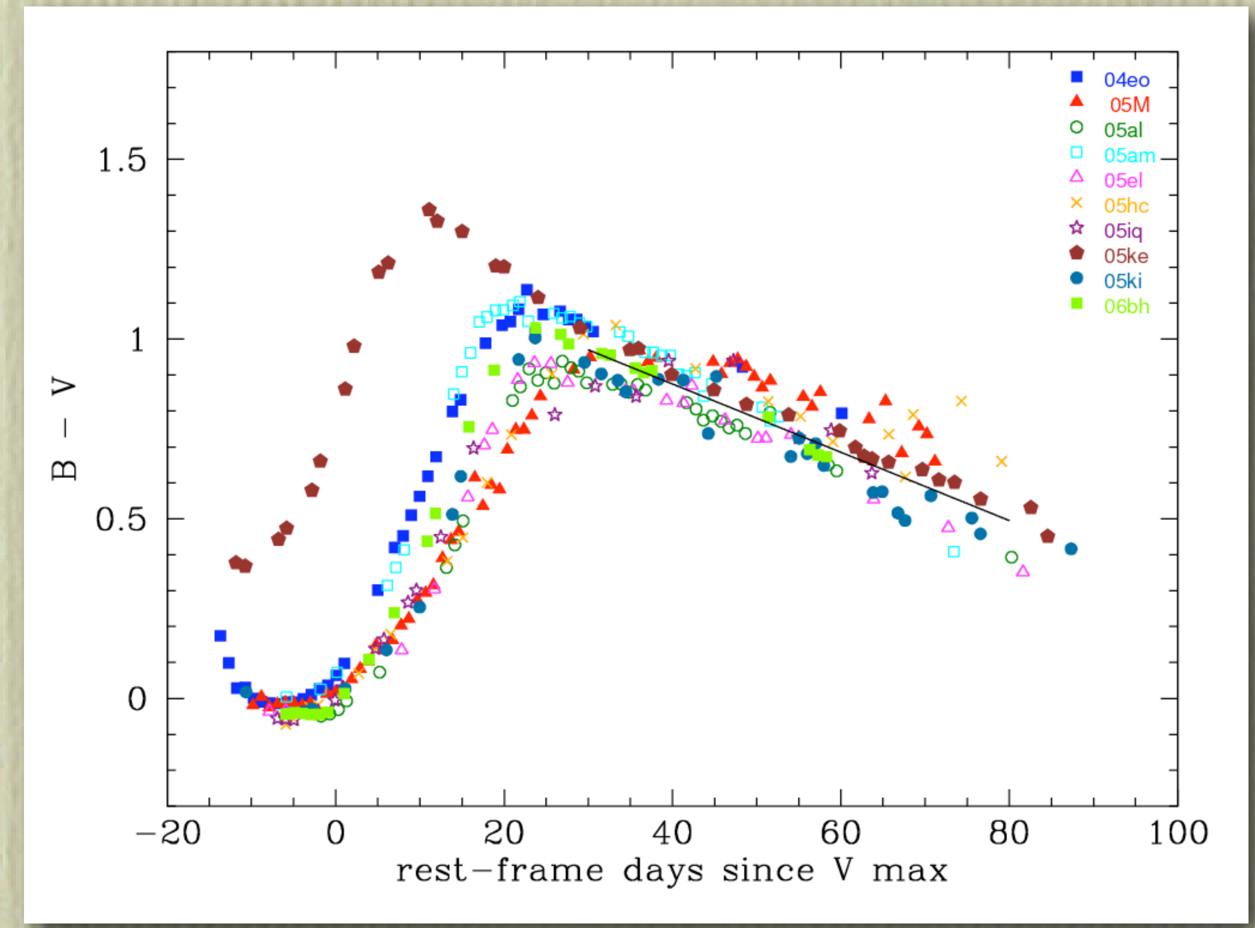


What produces this?

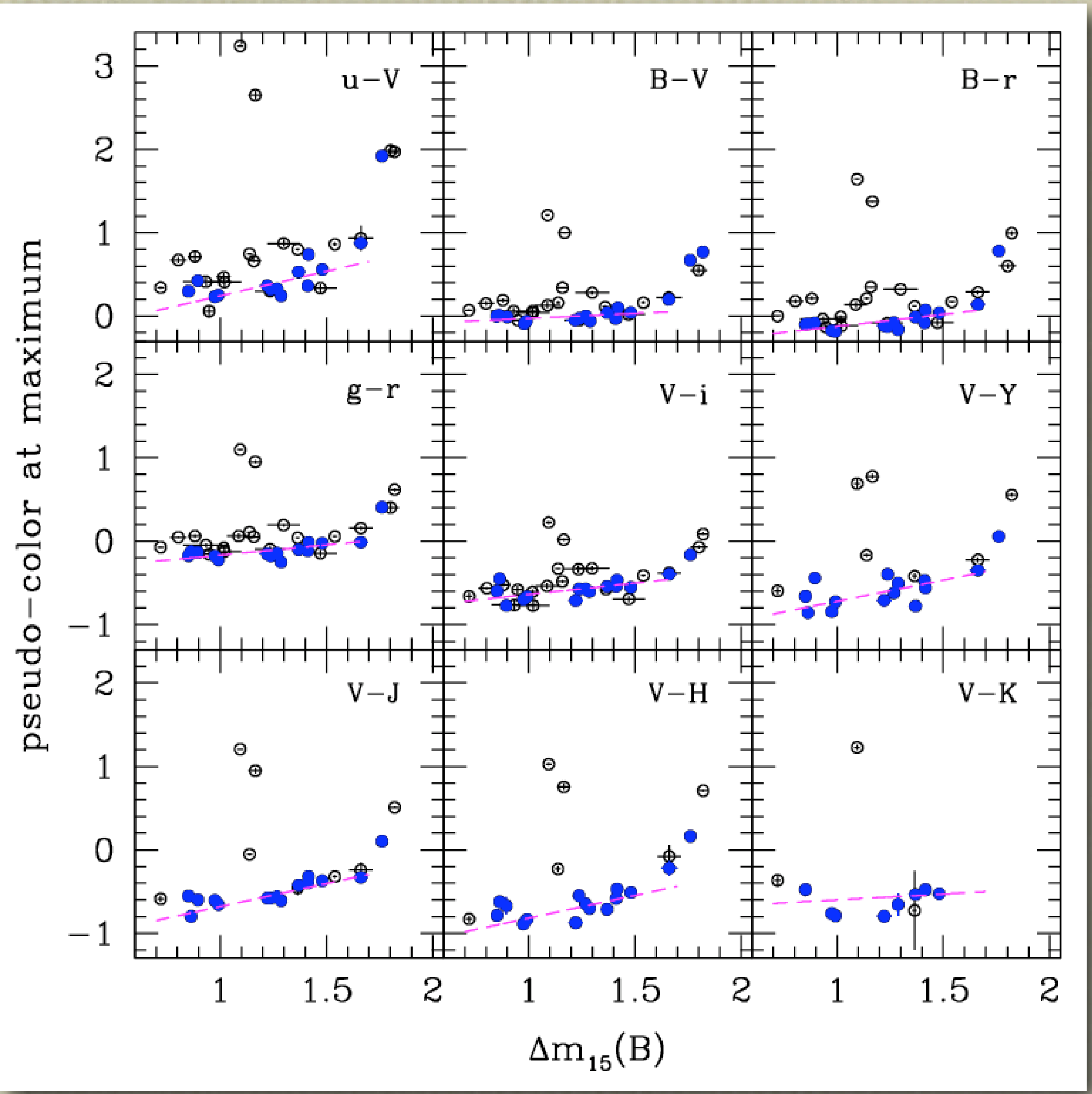
- Mixing?
- Metallicity?
- Geometry?

Is this a possible third parameter for reducing the dispersion in the Hubble diagram???

SN Ia Color Excesses

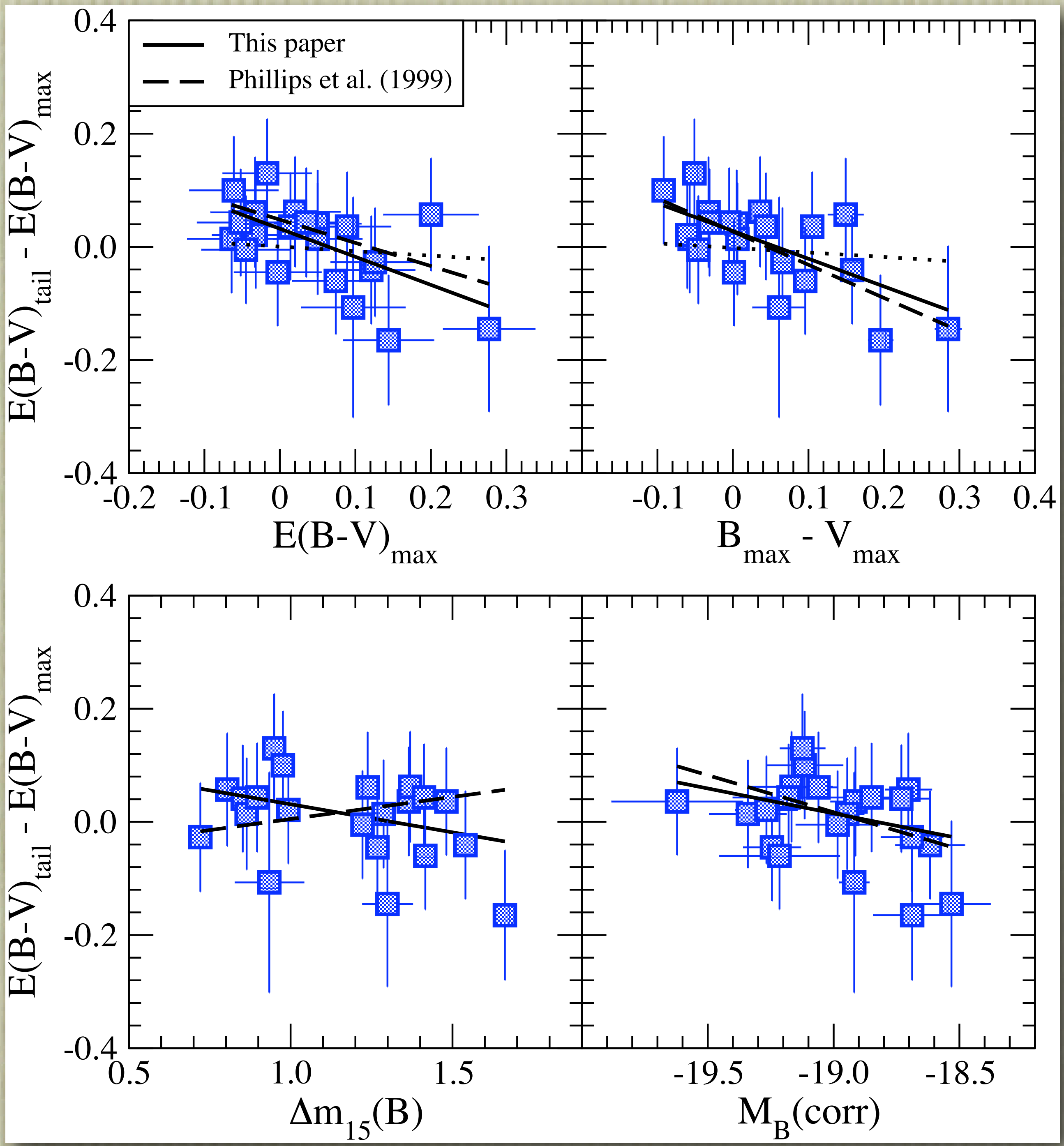


Lira Relation for Suspected Low-Reddening SNe Ia



Implied Intrinsic Color vs. Decline Rate Relations

SN Ia Color Excesses

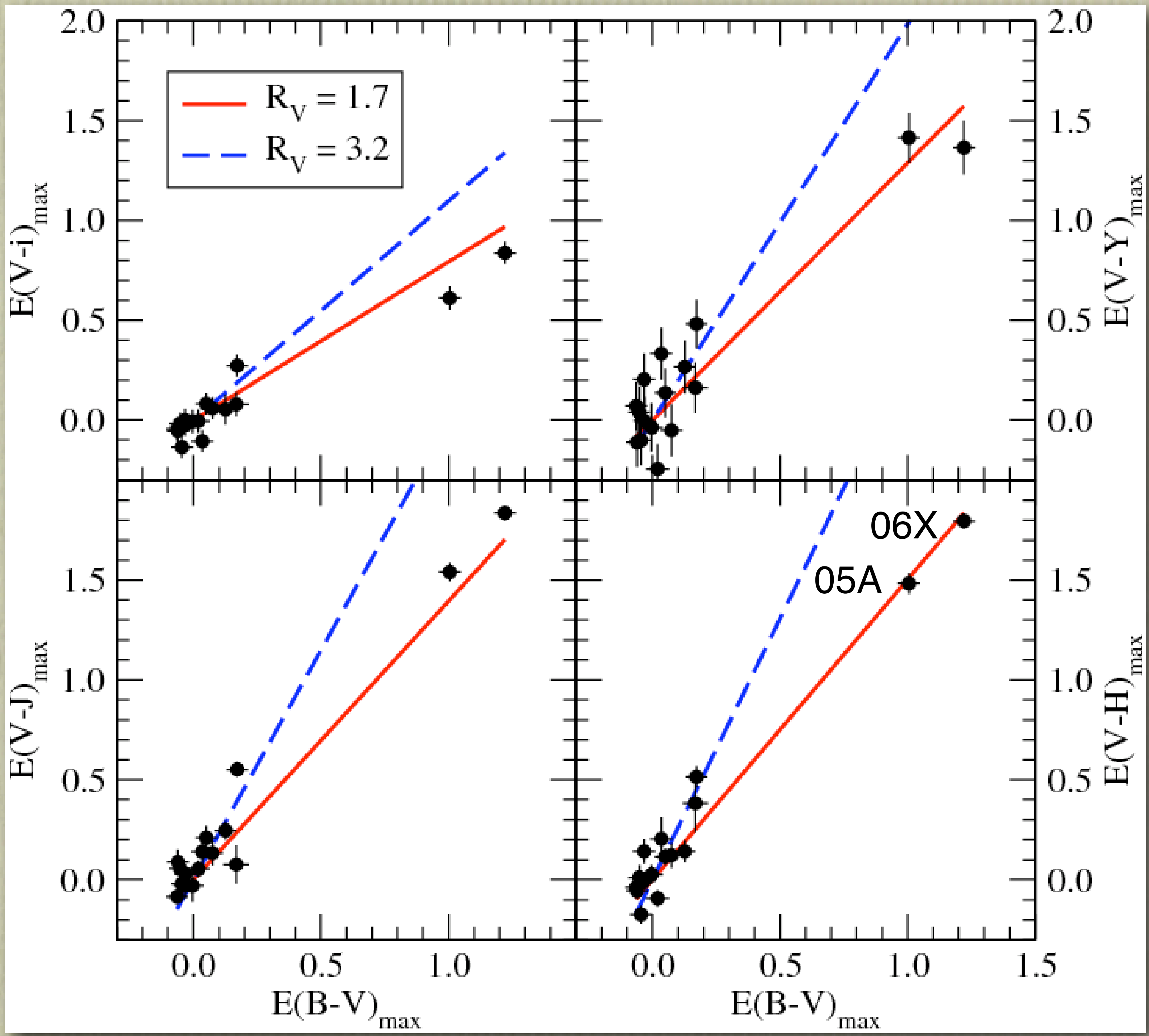


How can this be?

- Is there is a component of one or the other of these color excesses which is not due to dust?

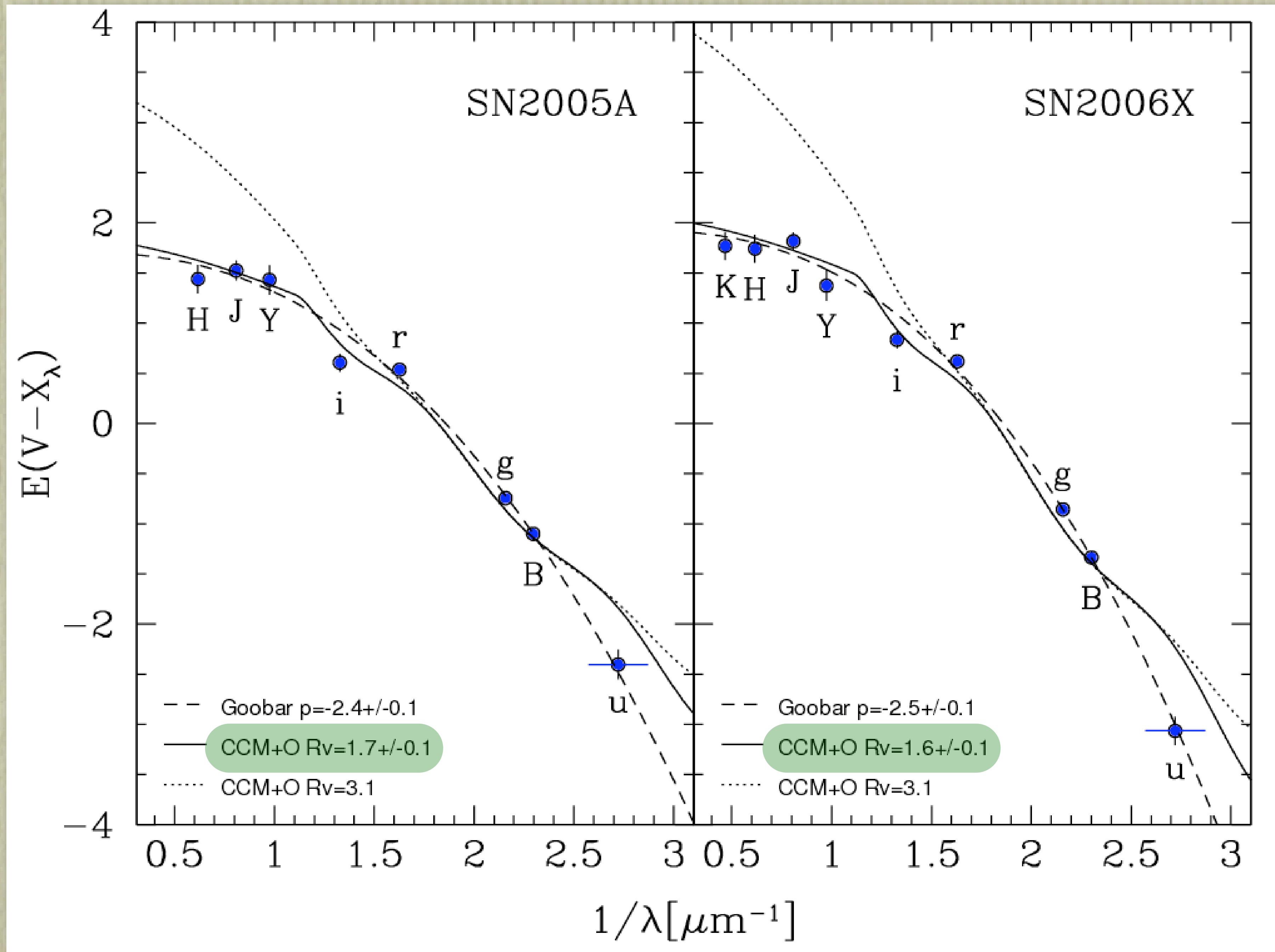
- Are we seeing evidence for time-variable extinction??

The Reddening Law



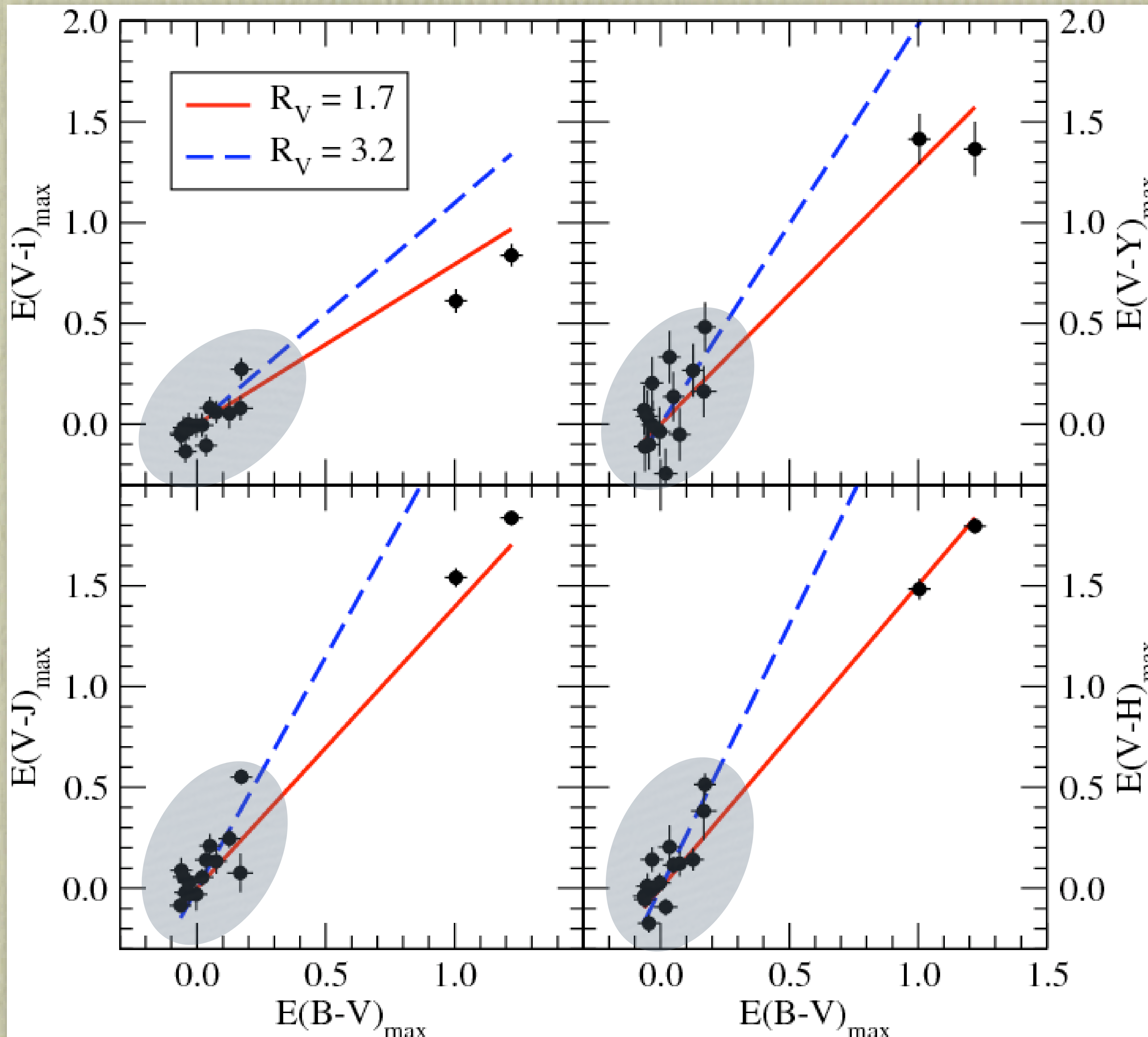
Color excess ratios are a function of R_V

The Reddening Law



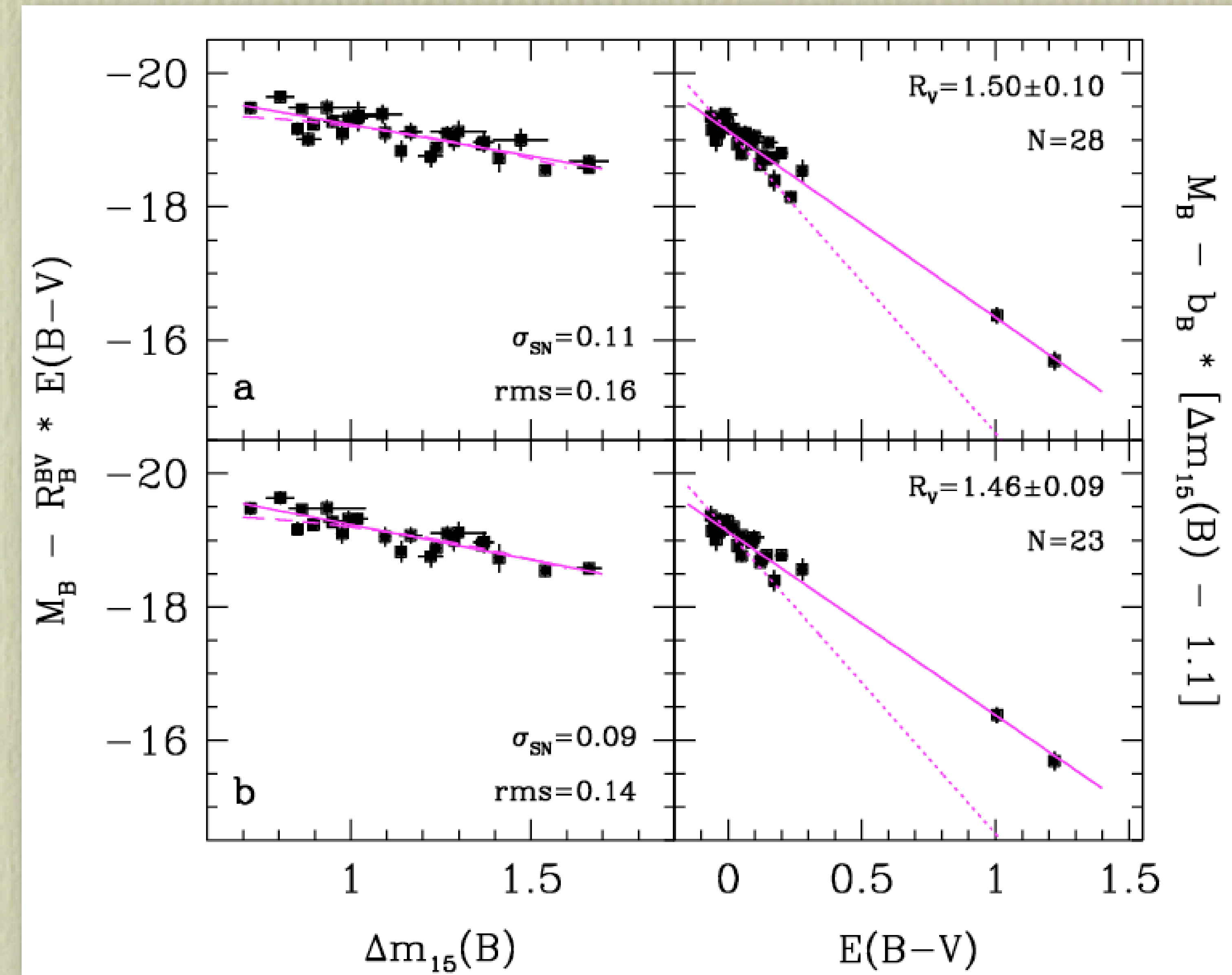
The Wang/Goobar dust scattering model looks promising to explain the low R_V values of highly reddened SNe Ia

The Reddening Law



SNe Ia with low reddenings are consistent with $R_v \sim 3$

The Reddening Law

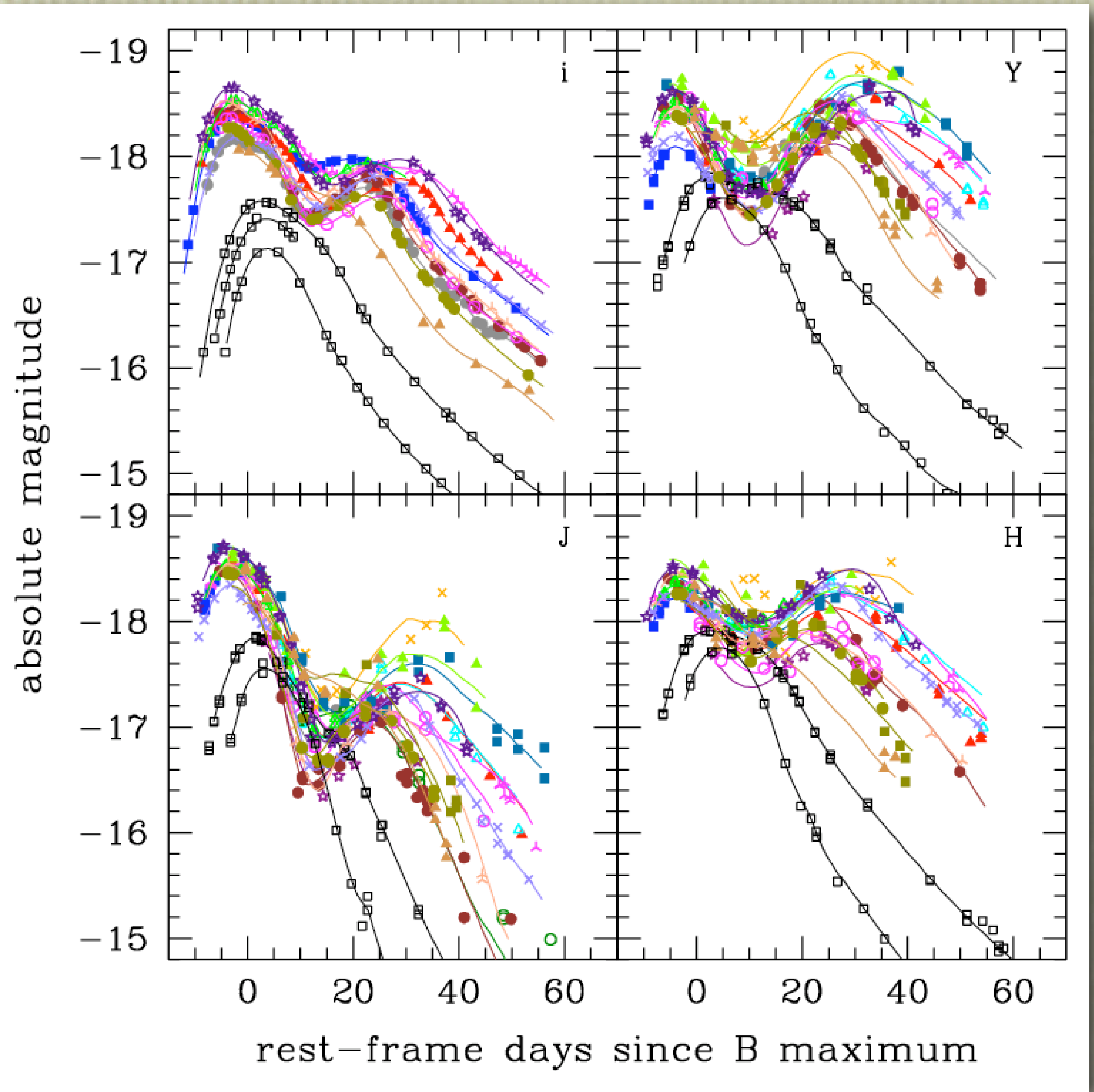


But when R_V is treated as a free parameter to minimize

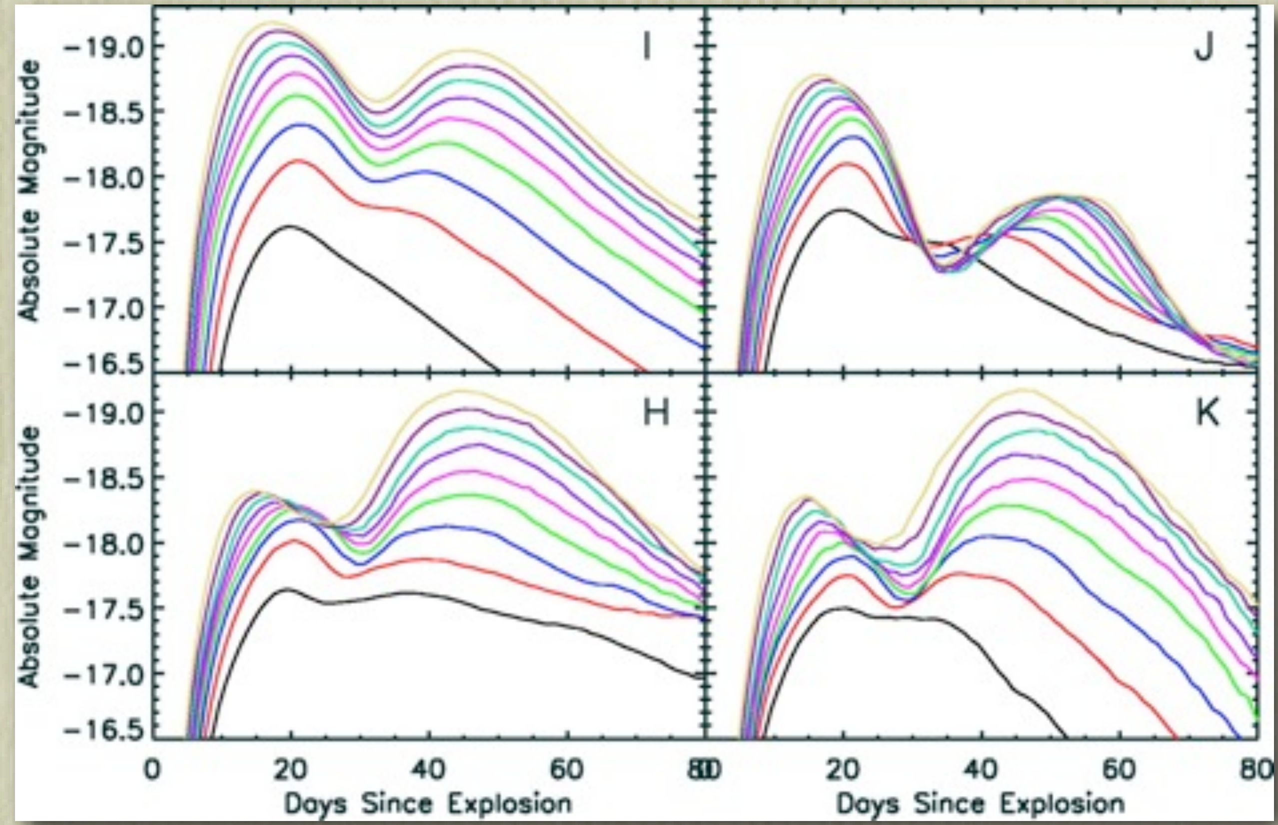
$$B = M_B + b * \{\Delta m_{15}(B) - 1.1\} + R_B * E(B-V) + \mu ,$$

a value of $R_V \sim 1.5$ is obtained, even for low-reddening events

Near-IR Light Curves

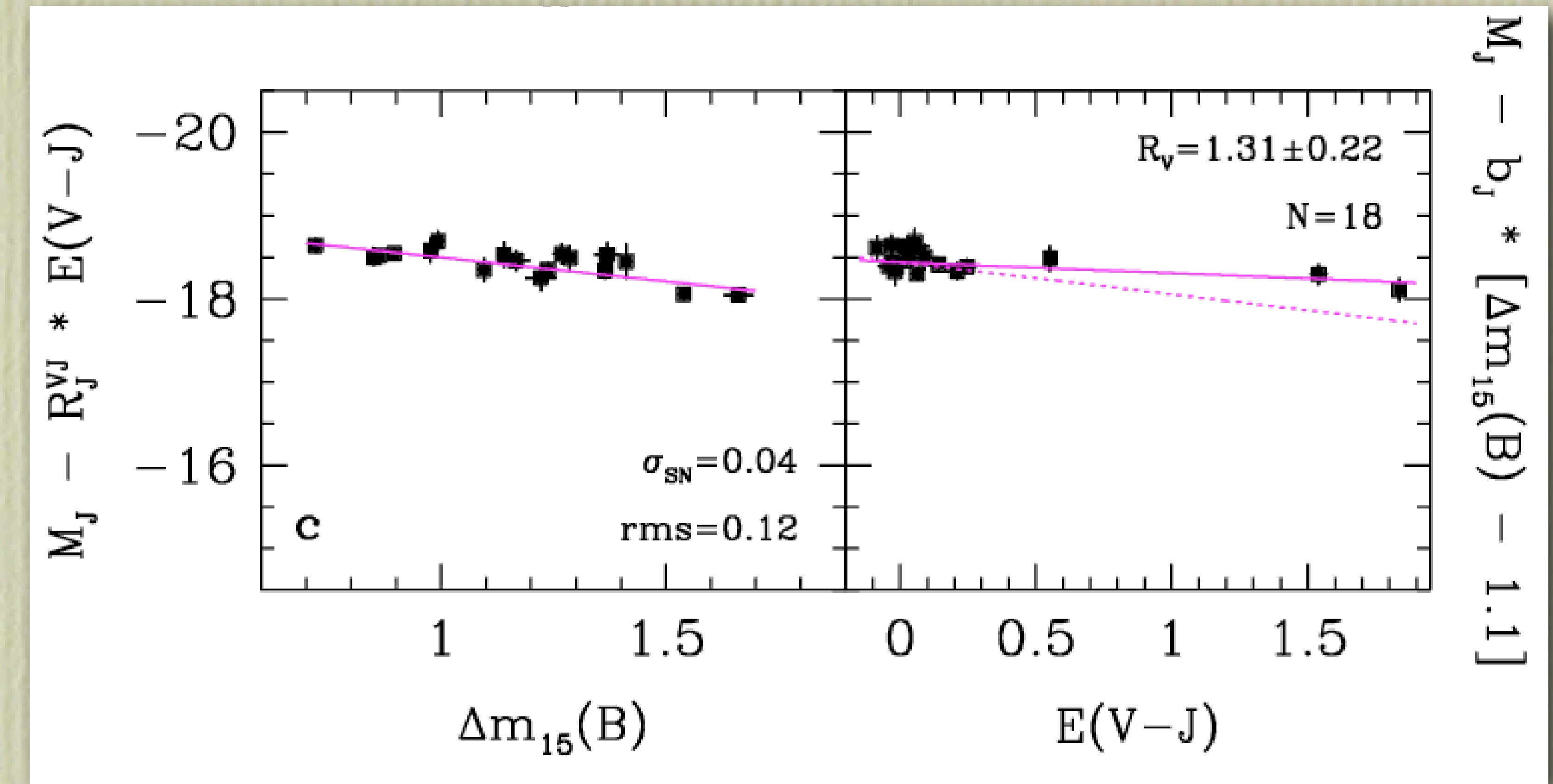


CSP data



Kasen (2006)

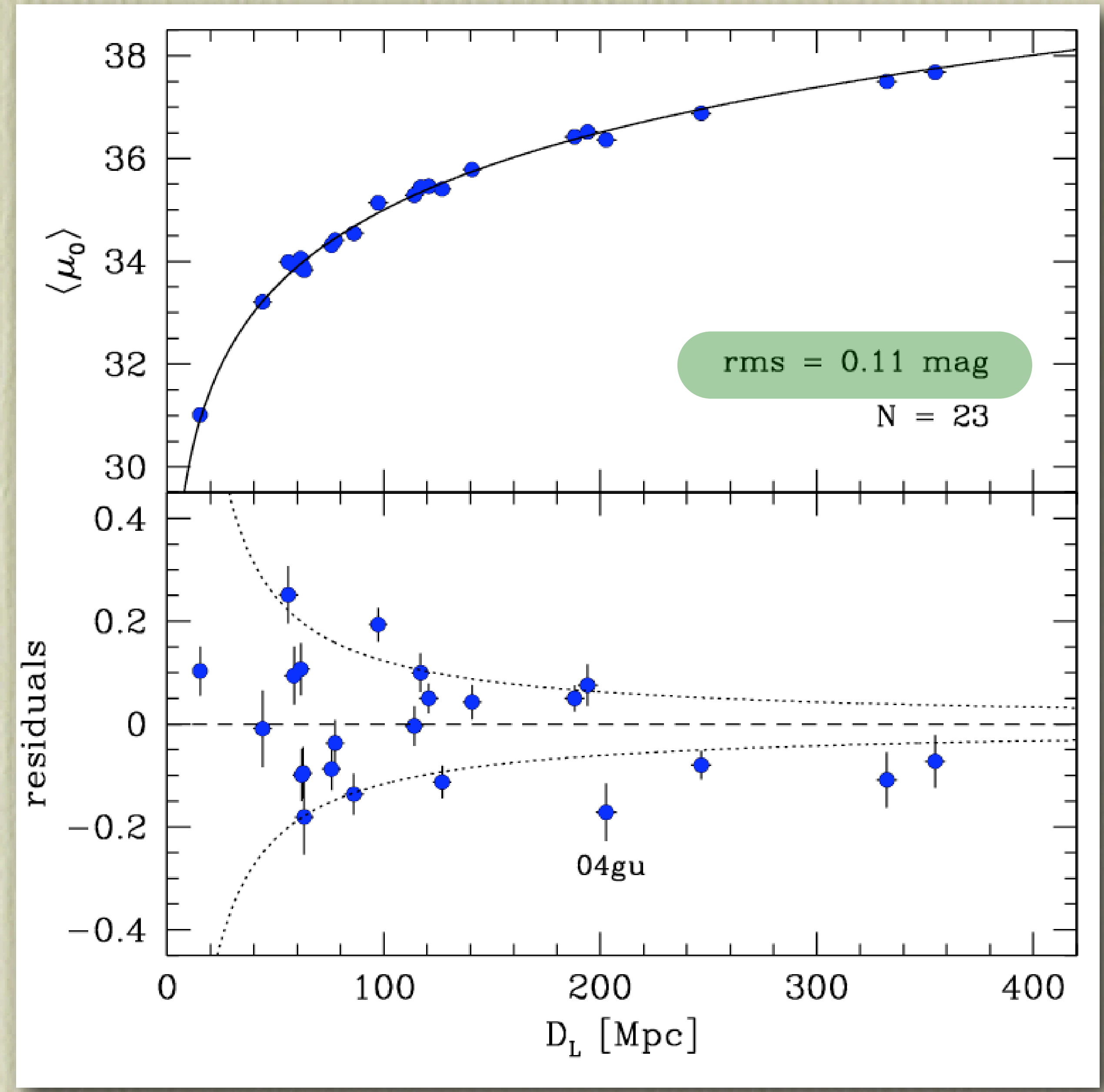
Near-IR Light Curves



- Over the decline rate range $0.7 < \Delta m_{15}(B) < 1.7$, the dispersion in absolute magnitudes in J and Y is < 0.20 mag, with no correction for $\Delta m_{15}(B)$
- There is some evidence for a slight dependence on $\Delta m_{15}(B)$ in J

SNe Ia as Precision Standard Candles

Filter	σ (mag)
u	0.13
g	0.14
r	0.13
i	0.14
B	0.14
V	0.14
Y	0.15
J	0.12
H	0.16

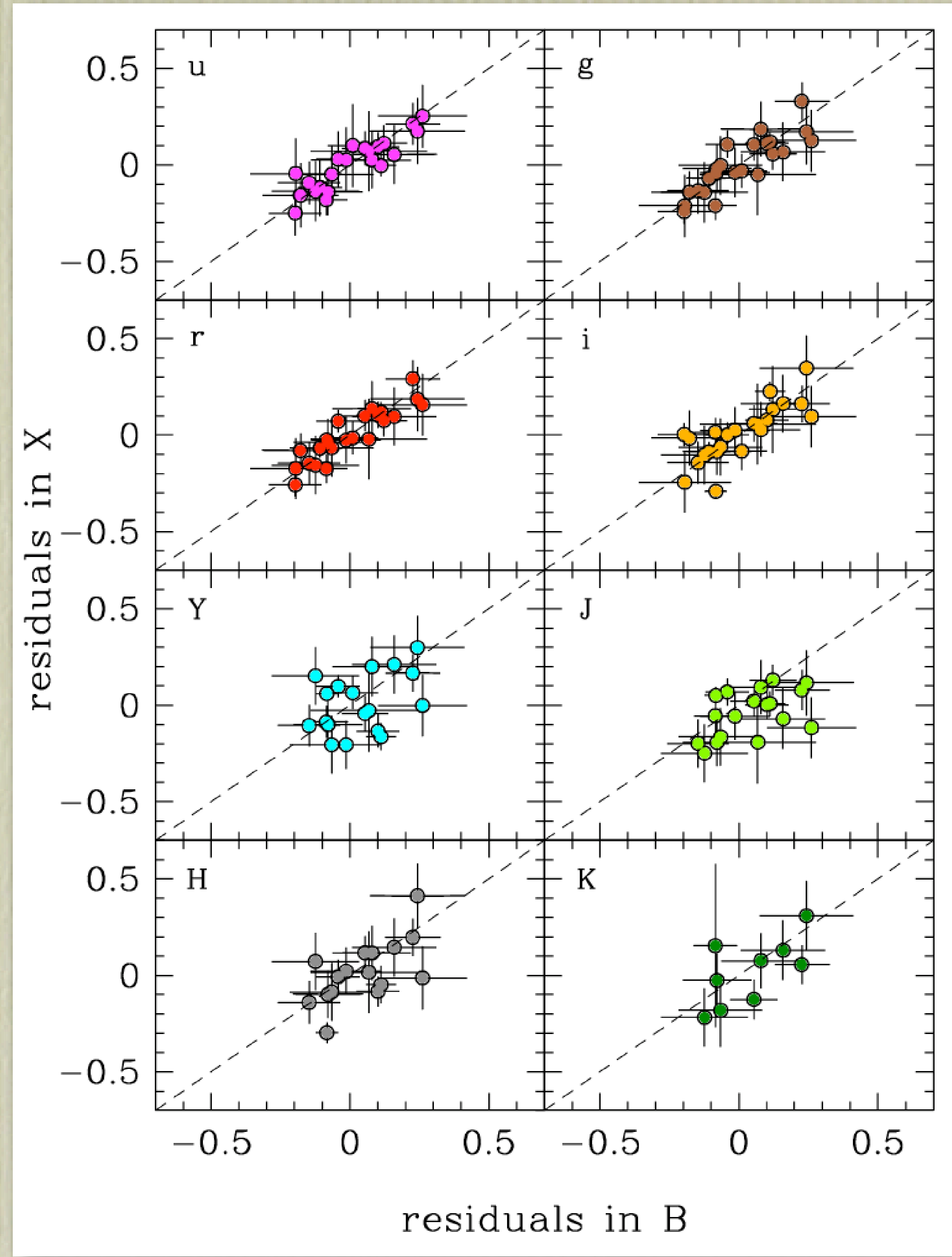


Combining Hubble diagrams in different bands does not yield a significant improvement in the observed dispersion

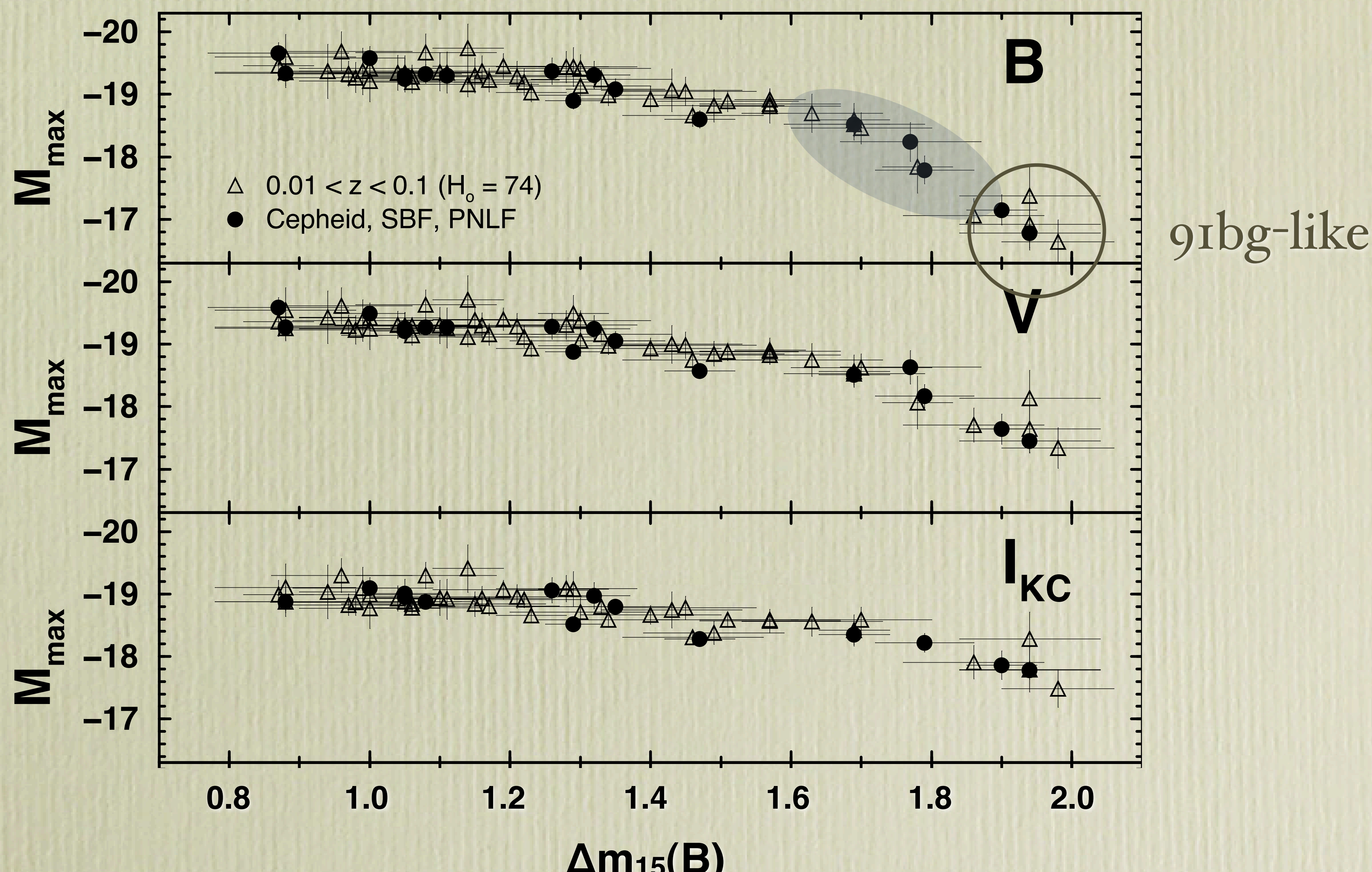
SNe Ia as Precision Standard Candles

This is because the residuals in each color are highly correlated, presumably due to peculiar velocities

The implication is that we are actually measuring distances to a precision of 3-4%

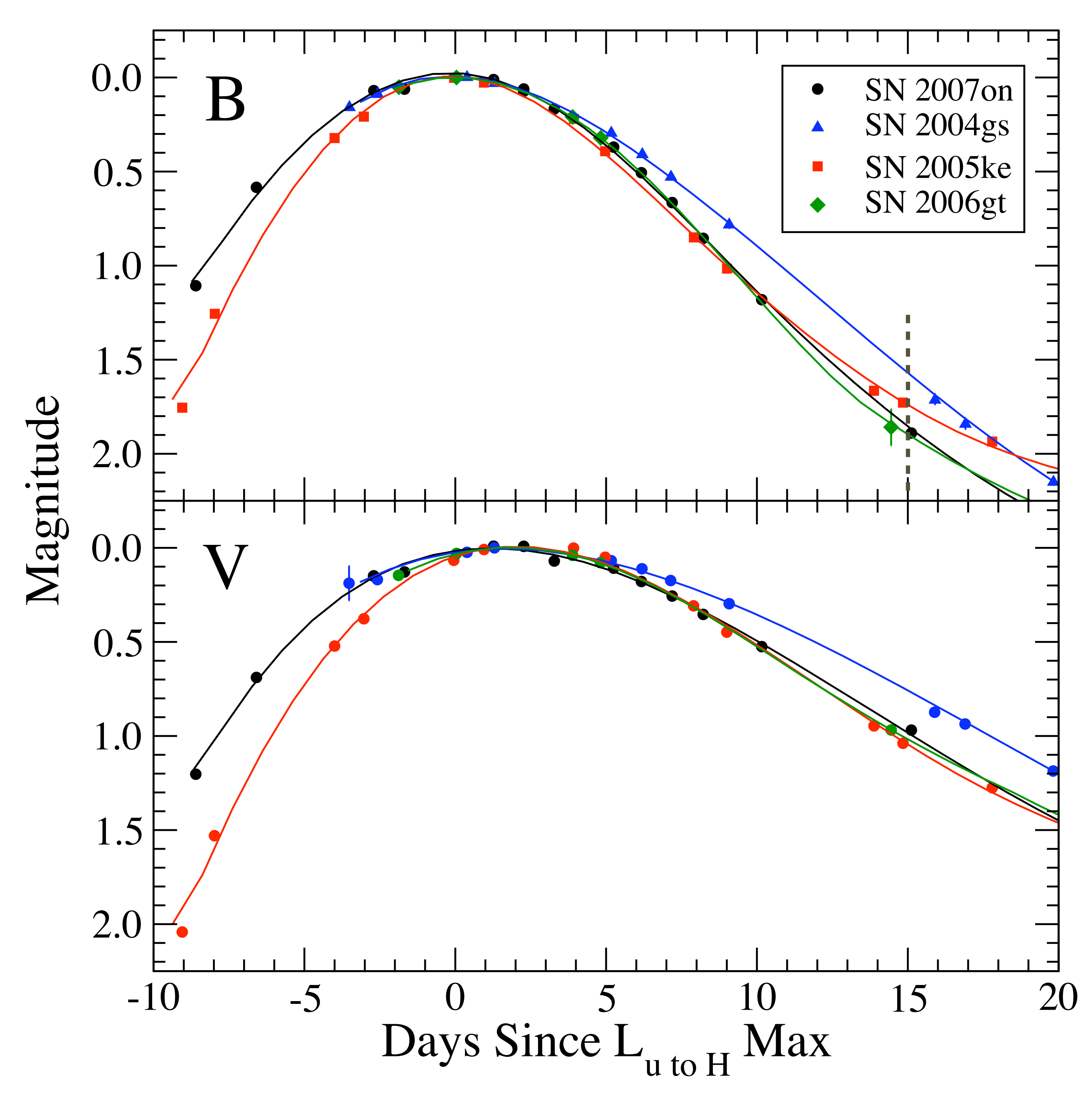


The Transition from "Normal" SNe Ia to 1991bg-like Events



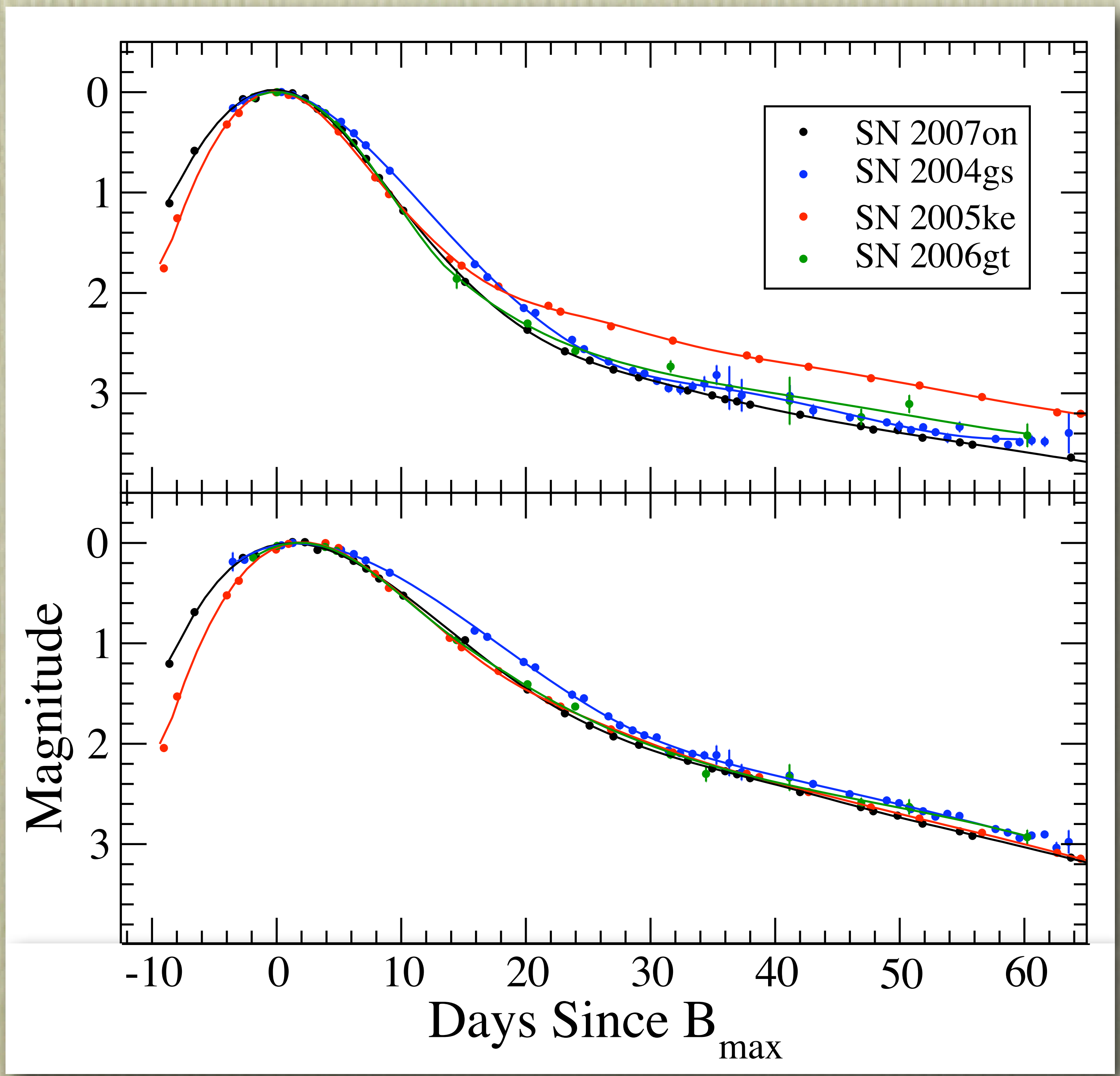
Phillips (2005)

The Transition from “Normal” SNe Ia to 1991bg-like Events



SN	$\Delta m_{15}(B)$
2004gs	1.57
2005ke	1.74
2007on	1.85
2006gt	1.90

The Transition from "Normal" SNe Ia to 1991bg-like Events



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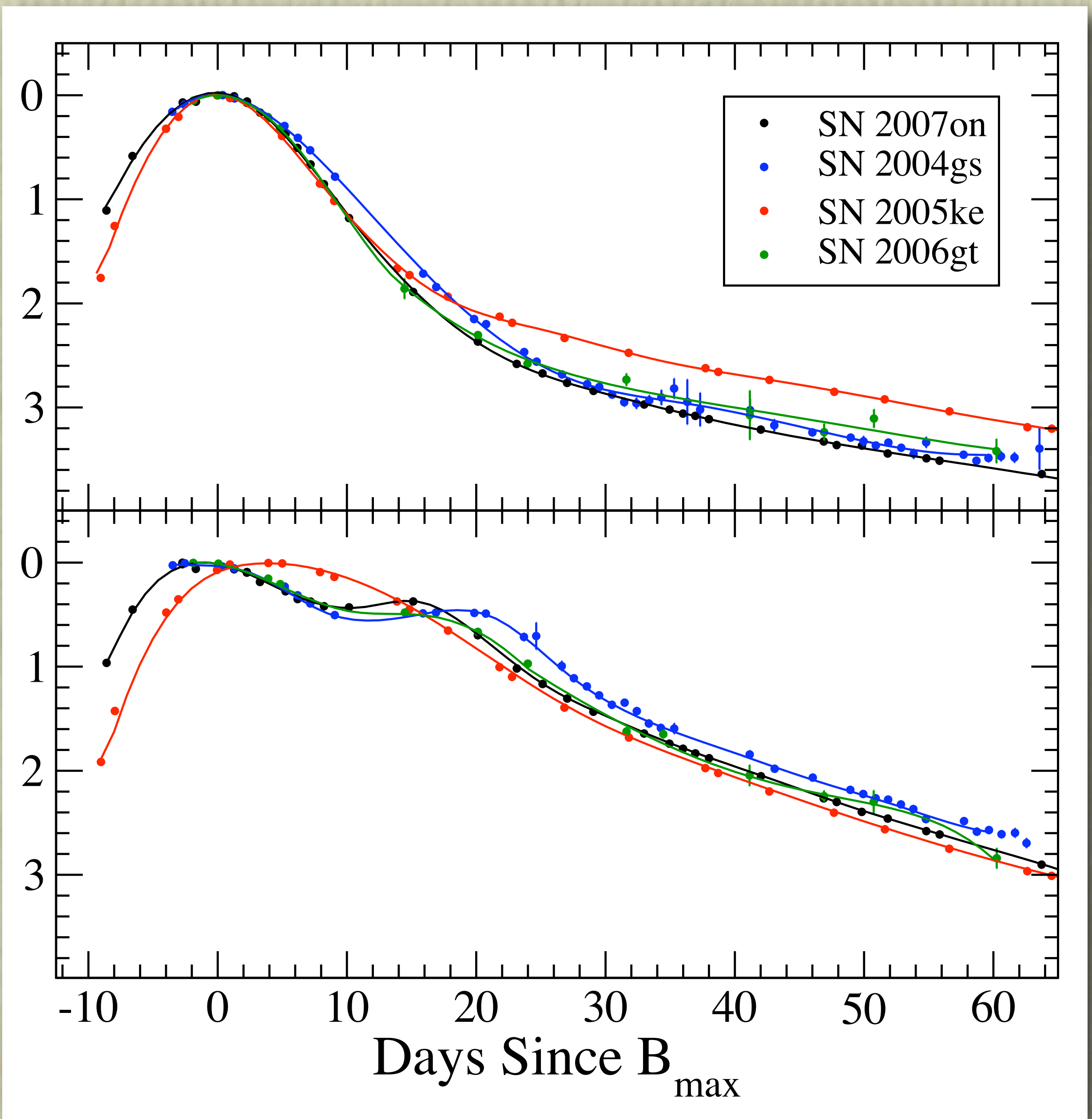

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SN 2005ke appears to be the oddball

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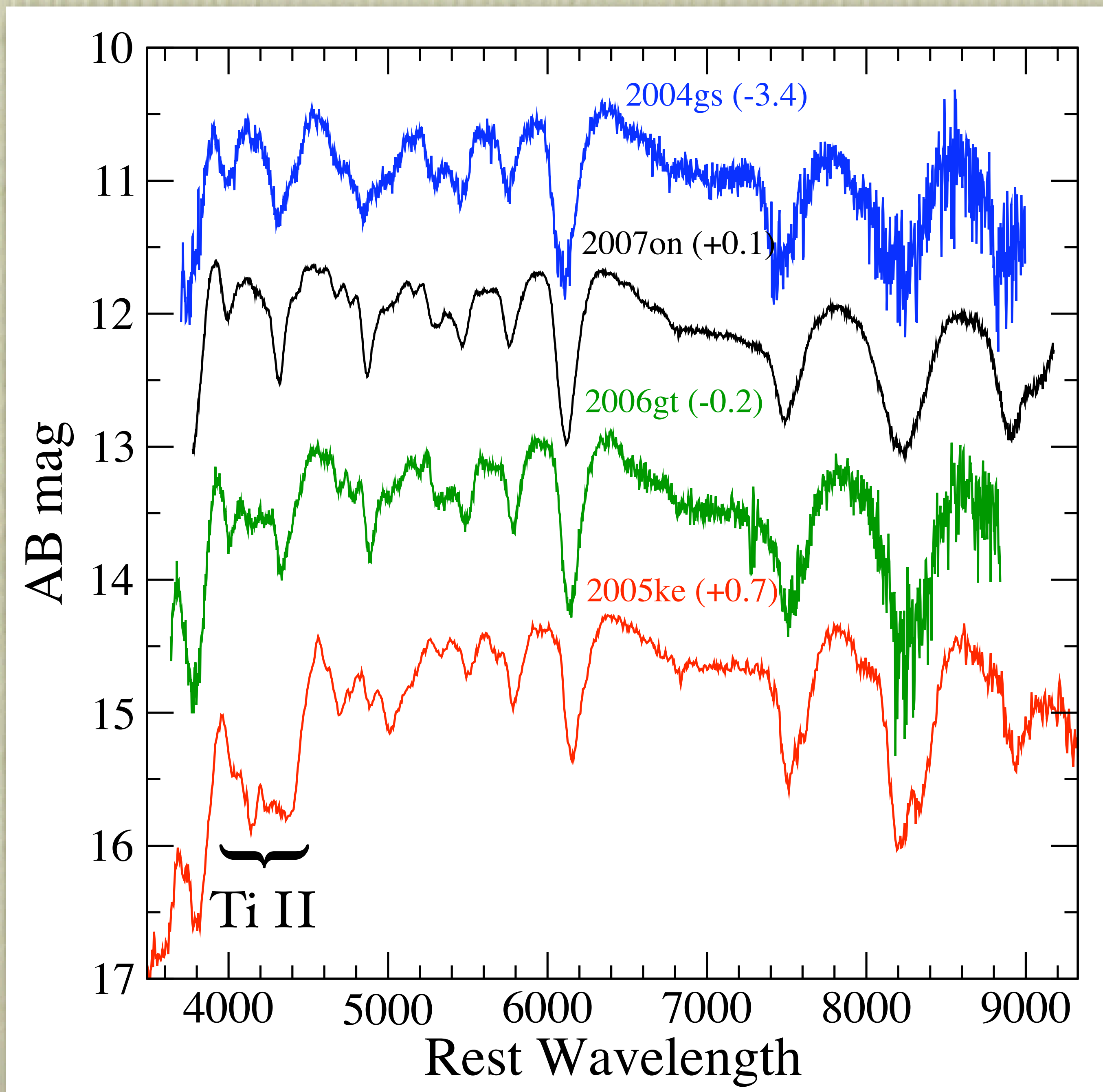

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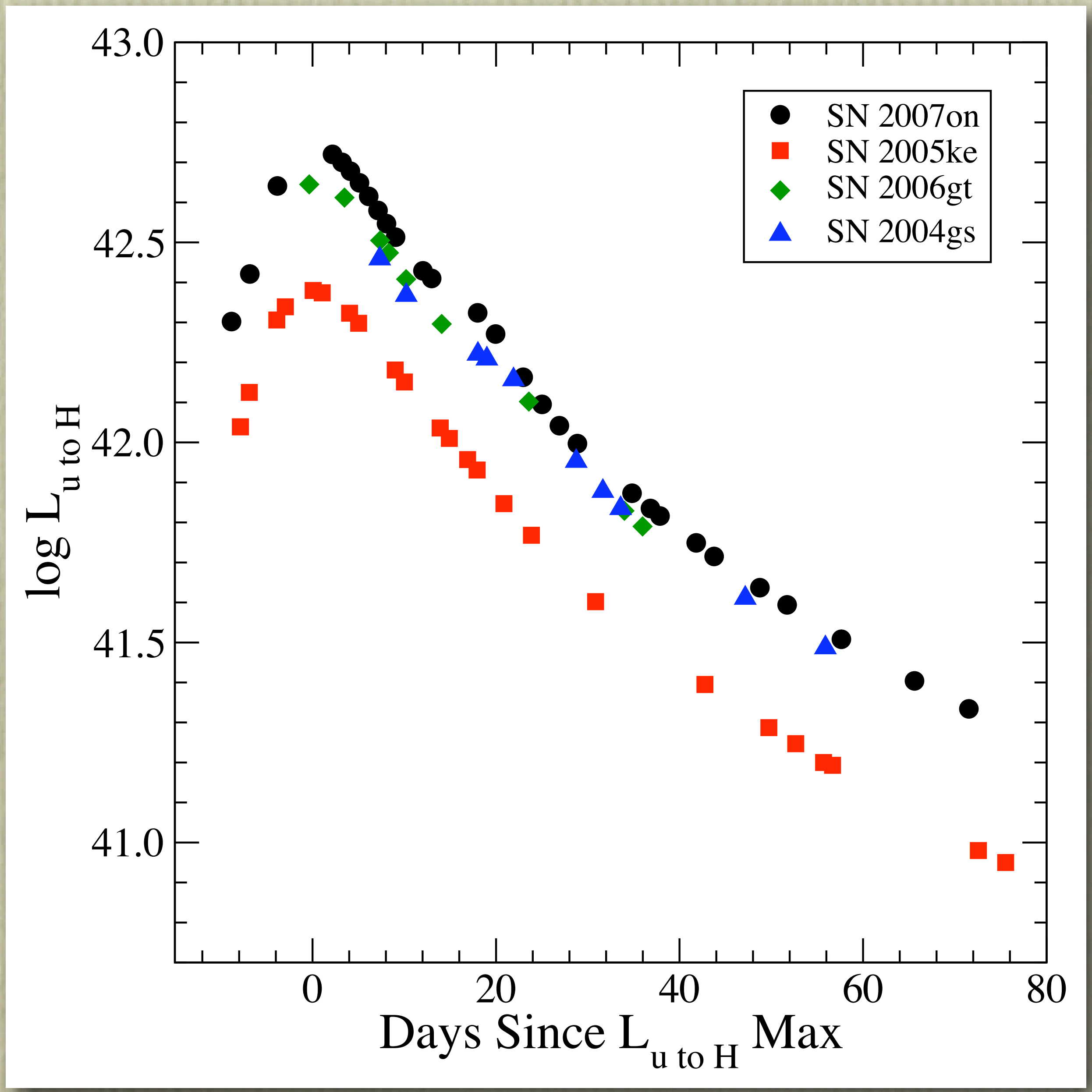

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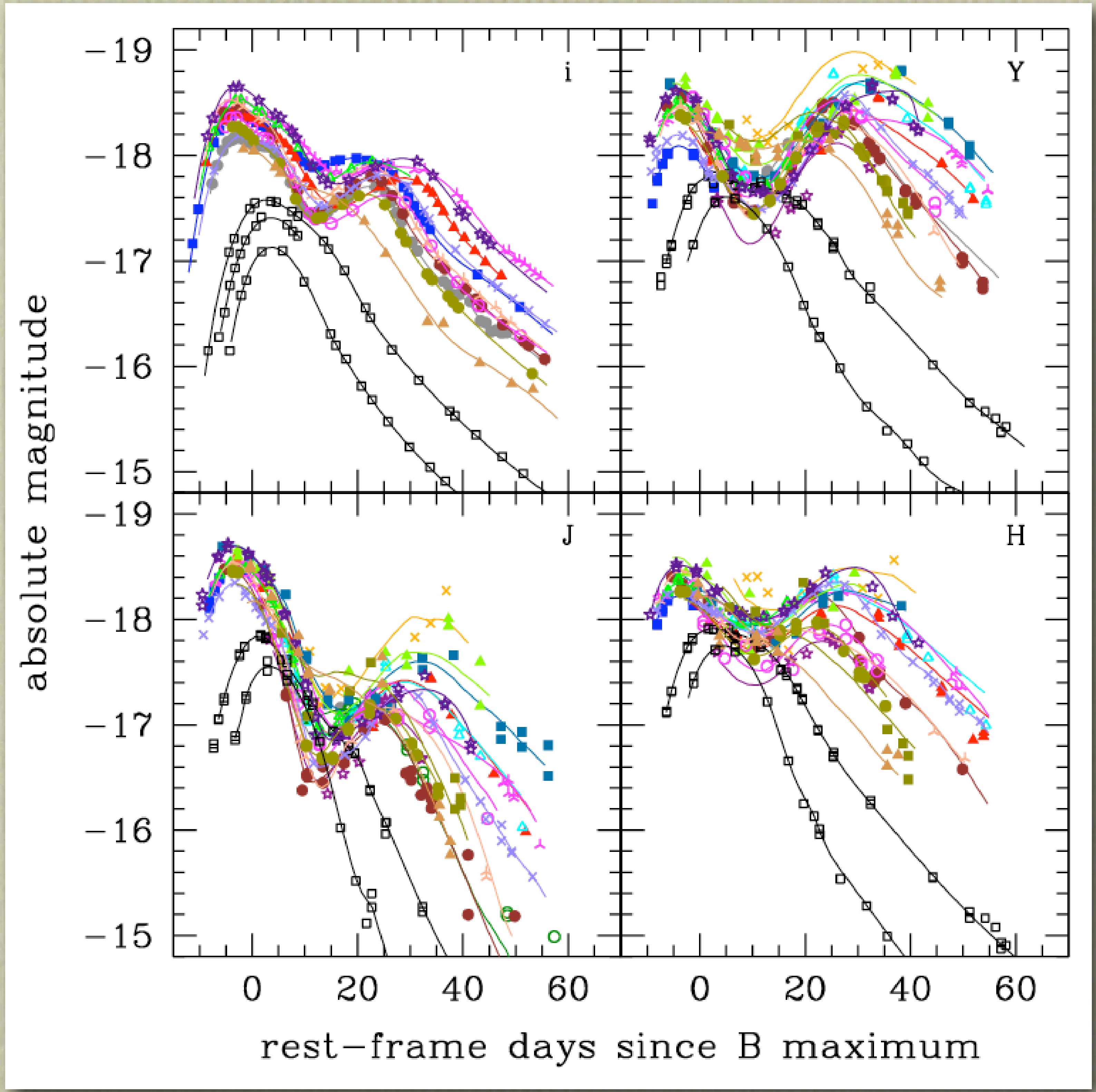
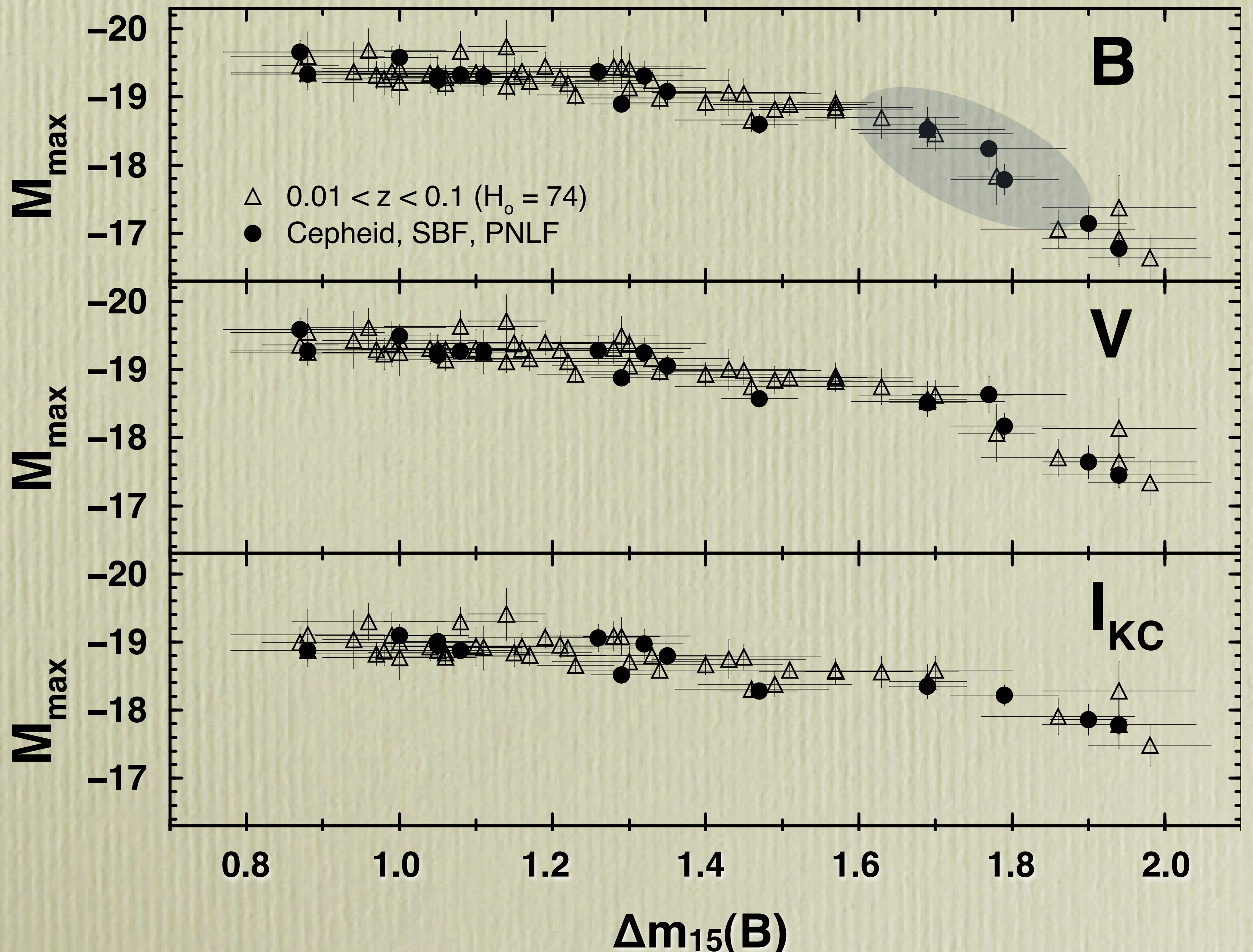
2006gt	1.90

Again, SN 2005ke appears to be the oddball

Near-IR Light Curves



The Transition from "Normal" SNe Ia to 1991bg-like Events



The transition region appears to be populated by two different subtypes of SNe Ia:

- The low-luminosity extension of "normal" events, and
- 1991bg-like events

Phillips (2005)

Conclusions

- The strength and timing of the secondary maximum of the iYJH light curves is a function of $\Delta m_{15}(B)$, but with some significant intrinsic variation

- Color excesses derived from the Lira relation and the $B_{max} - V_{max}$ color show systematic differences

- Ratios of color excesses provide evidence of "normal" ($R_V \sim 3$) dust reddening, while minimizing the Hubble diagram dispersion gives $R_V \sim 1.5$

- Correlated residuals in ugriBVYJH Hubble diagrams strongly suggest that SNe Ia yield distances that are good to 3-4%

- The transition region in the luminosity vs. decline rate relation at $1.6 \le \Delta m_{15}(B) \le 1.9$ appears to be populated by two different subtypes of SNe Ia

Aspen Workshop on SNe Ia

Weeks of 2010 August 8 & 15