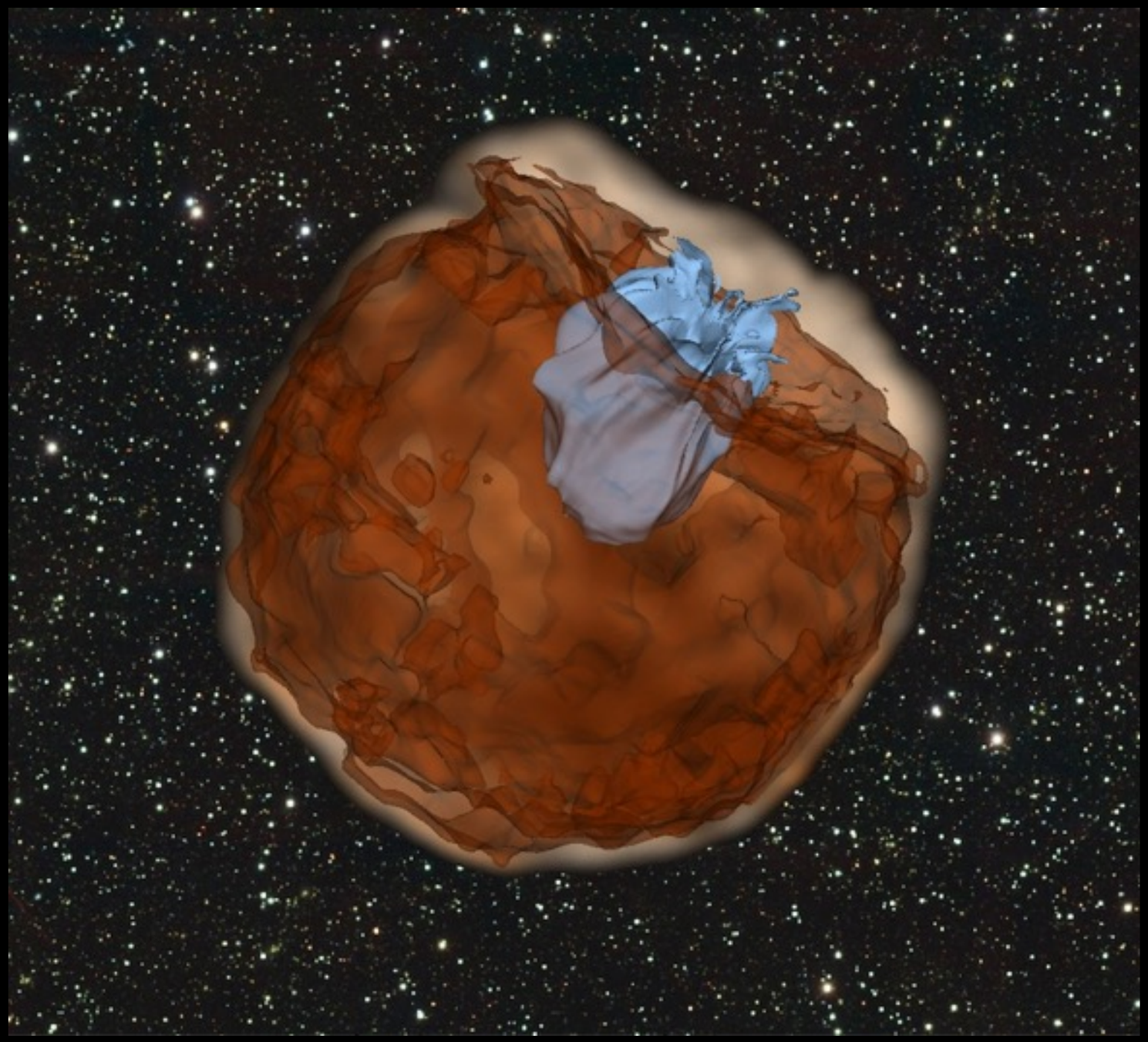
Clues to SN Ia progenitors from LCOGT

Andy Howell

Las Cumbres Observatory
Global Telescope Network

University of California
Santa Barbara



Simulation by Dan Kasen (Berkeley / LBL)

From July/ Aug 2013 **American Scientist**

McDonald Observatory
Texas

Tenerife
Canary Islands
(possible future site)

Urumqui
China
(possible future site)

Haleakala
Hawaii

Sliding Spring Observatory
Australia

supernova

Cerro Tololo Inter-American Observatory
Chile

South African Astronomical Observatory
Sutherland

LCOGT.net

2 meter Faulkes | 1 meter | proposed

The Supernova Group at LCOGT

Curtis McCully
Postdoc

Stefano (Stef'-ano) Valenti
Postdoc

me

Iair ("Ya-eer") Arcavi
Postdoc

Griffin Hosseinzadeh
Graduate Student

Andrew Zheng
Undergraduate

~ Half of the Supernova Key Project

LCOGT
Iair Arcavi
Andy Howell
Griffin Hosseinzadeh
Curtis McCully
Stefano Valenti

South Africa
Bruce Bassett
Steve Crawford
Eli Kasai
Roy Maartens
Matthew Smith
Abiy Tekola

University of Colorado
Alexander Conley
Emily Levesque

iPTF
Yi Cao
Avishay Gal-Yam
Ariel Goobar
Mansi Kasliwal
Peter Nugent
Eran Ofek
Robert Quimby
Jesper Sollerman

University of Texas
Howie Marion
Jeffrey Silverman
Jozsef Vinko
Craig Wheeler

PESSTO
e.g. Stephen Smartt
Mark Sullivan
…

LaSilla-QUEST
Charles Baltay
Nan Ellman
Ryan McKinnon
David Rabinowitz
Emma Walker

Australian National University
Michael Childress
Richard Scalzo
Brian Schmidt
Brad Tucker
Fang Yuan

Chile?
e.g. Santiago Gonzalez Gaitan
...

KMTNet
Dae-Sik Moon

Other
Melissa Graham
Eric Hsiao
Mark Phillips
David Sand

China
Guojie Feng
Hubiao Niu
Lifan Wang
Xiaofeng Wang

Supernova Key Project

Allocation LCOGT time over 3 years:
1m time (lightcurves): 2200 hours / year
2m time (spectroscopy): 700 hours / year

Goals Build a sample of 600 supernovae to:

1. Observe supernovae soon after explosion to search for signs of their progenitors

2. Measure Dark Energy

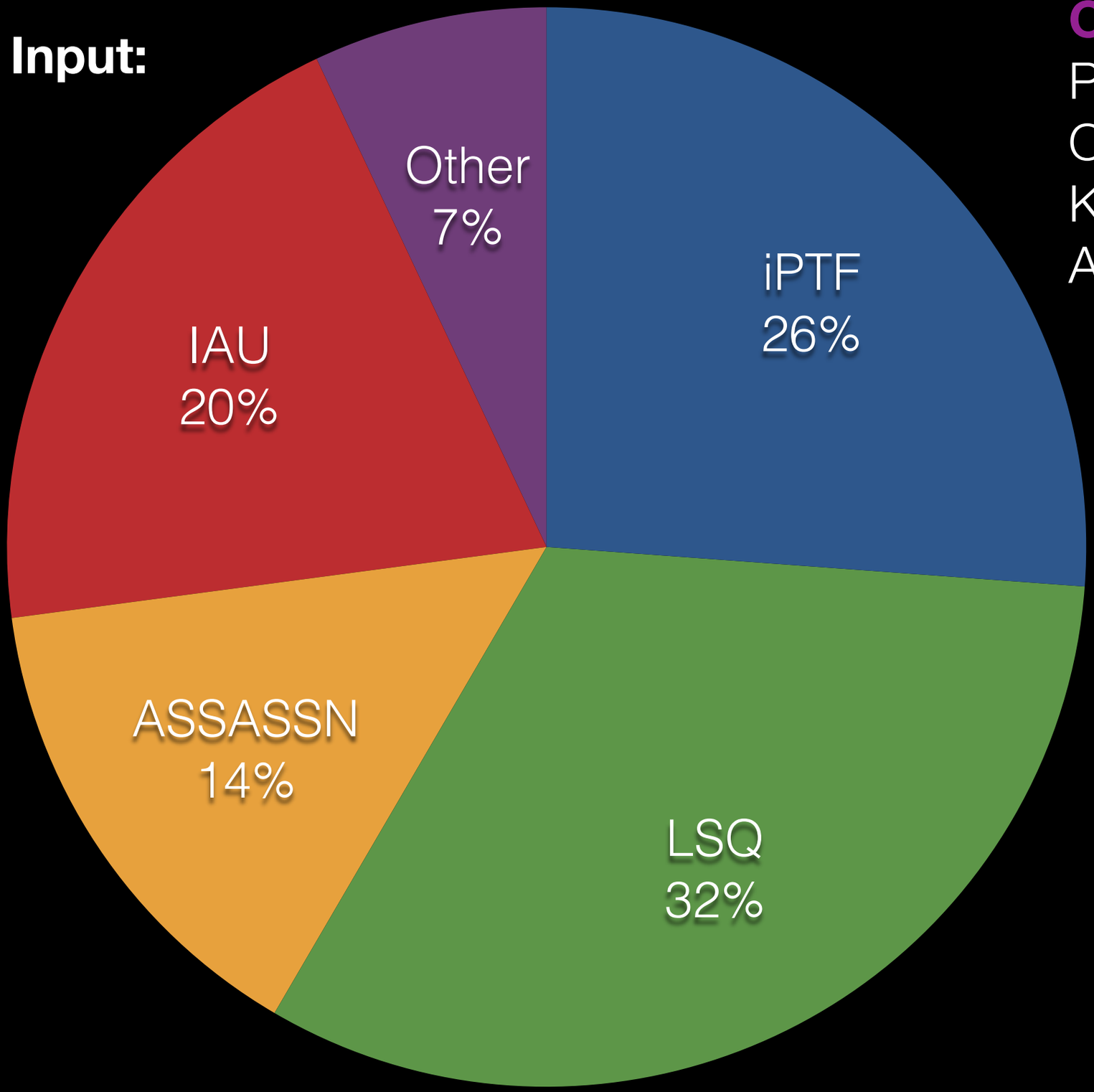
3. Do statistical population studies

4. Build the first statistical samples of exotic SNe

5. Obtain optical light curves and spectroscopy in support of UV observations, IR imaging and spectroscopy, host galaxy studies, high resolution spectroscopy, and late-time spectroscopy with large telescopes.

What did we observe in year 1?

Input:



Others:
Pan-STARRS
OGLE
KAIT
Amateurs

Future:
KMTNet
Skymapper
Gaia

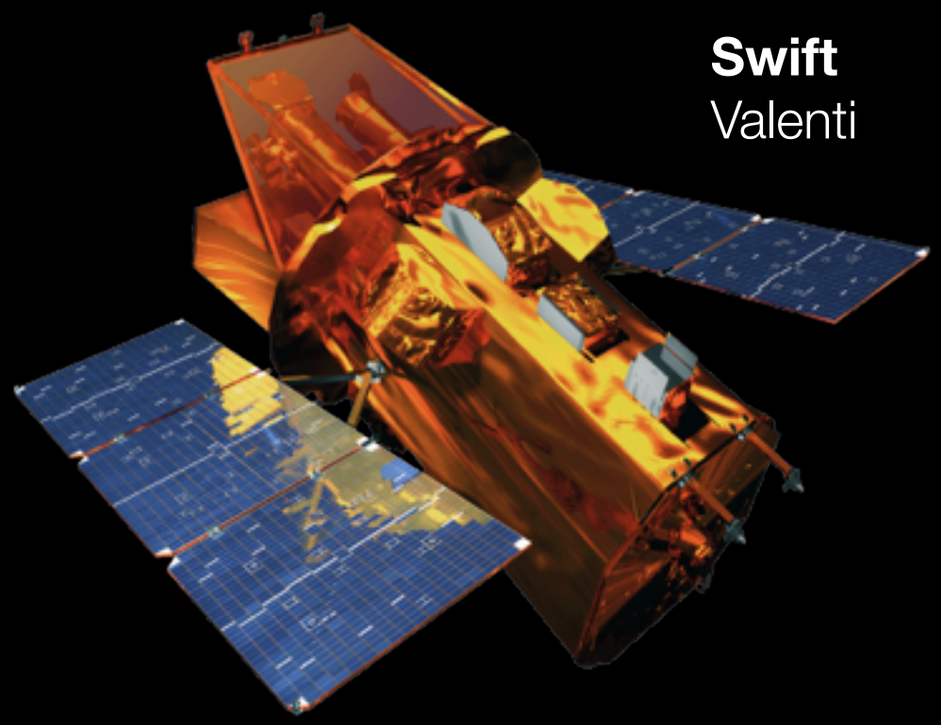
Output:
SNe with at least 20 photometry points: **209**

SNe with at least 1 LCOGT spectrum: **141**

Major Followup

NTT
PESSTO

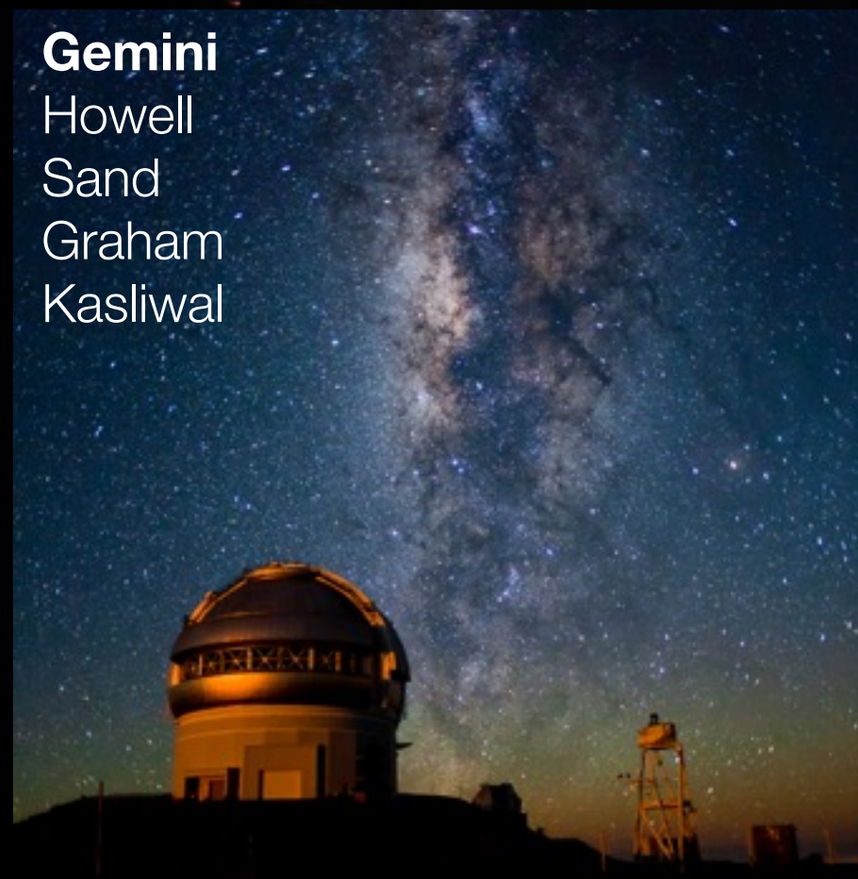
Keck iPTF, Filippenko



Swift
Valenti

IRTF
Sand

Palomar 200
iPTF



Gemini
Howell
Sand
Graham
Kasliwal

Submitted publications within the past year.

18, all with LCOGT data, many others in prep.

1st Author	Year	Journal	Title
Marion	2015	ApJ, submitted	SN 2012cg: evidence for interaction between a normal Type Ia supernova and a non degenerate binary companion.
Childress	2015	MNRAS, submitted	Measuring nickel masses in Type Ia supernovae using cobalt emission in nebular phase spectra
Morales-Garoffolo	2015	MNRAS, submitted	SN 20011fu: A type IIb supernova with a luminous double-peaked light curve
IceCube	2015	ApJ	Detection of a Type IIn supernova in optical follow-up of IceCube neutrino events
Cao	2015	Nature	Ultraviolet Radiation from Supernova-Companion Collision in a Type Ia Supernova
Fraser	2015	MNRAS, submitted	SN 2009ip at late times - an interacting transient at +2 yrs
Pastorello	2015	MNRAS	Massive stars exploding in a He-rich circumstellar medium. VI. Observations of two distant type Ibn supernova candidates discovered by La Silla-QUEST
Pastorello	2015	MNRAS	Massive stars exploding in a He-rich circumstellar medium. V. Observations of the slow-evolving SN Ibn OGLE-2012-SN-006
Hsiao	2015	A&A	Strong near-IR carbon in the Type Ia supernova iPTF13ebh
Valenti	2015	MNRAS	SN 2013by: A Type IIL Supernova with a IIP-like light curve drop
Bose	2015	MNRAS	SN 2013ab: A normal type IIP supernova in NGC5669
Mauerhan	2015	MNRAS	SN Hunt 248: a super-Eddington outburst from a massive cool hypergiant
Pan	2015	MNRAS	Type Ia supernova spectral features in the context of their host galaxies
Inserra	2015	ApJ	OGLE-2013-SN-079: A lonely supernova consistent with a helium shell detonation
Marion	2015	ApJ	Early observations and analysis of the Type Ia SN 2014J in M82
Maguire	2014	MNRAS	Exploring the spectral diversity of low-redshift Type Ia supernovae using the Palomar Transient Factory
Nicholl	2014	MNRAS	Superluminous supernovae from PESSTO
Graham	2014	ApJ	Clues to the nature of SN 2009ip from photometric and spectroscopic evolution to late times

02cx / 02es - like SNe

SN 2002cx was a peculiar SN Ia. Properties of this class (see papers by Foley, Jha, Valenti, White, etc.):

- Lower expansion velocities
- Generally fainter than SNe Ia, but don't follow Phillips relation
- Don't necessarily go nebular at late times
- Theoretically: a "failed Ia?" They may leave a bound remnant.

Properties of SN 2002cx and SN 2002es Families

Property	02cx-like	02es-like
Host type	Generally Late	Early
Host g–i color (mag)	0.59–1.47	1.26–1.58
Host luminosity (R-band, mag)	−14 to −21	−19 to −22
Peak luminosity (R-band, mag)	−13 to −19	−18
Rise time (days)	18–23	14–17
Decline rate (Δm_{15}, mag)	0.3–1.0	0.6–0.7
Ti II trough?	No	Yes
Ejecta speed (km s^{-1})[a]	4000–9000	4000–7000

Note. [a] At approximately 10 days post-maximum.

White et al. (+DAH) 2015

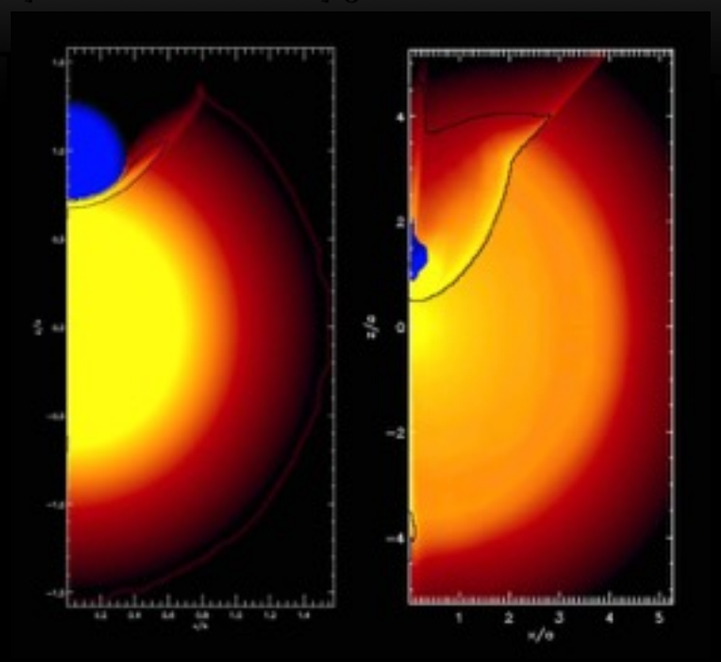
iPTF14atg Cao et al. 2015

LETTER

doi:10.1038/nature14440

A strong ultraviolet pulse from a newborn type Ia supernova

Yi Cao[1], S. R. Kulkarni[1,2], D. Andrew Howell[3,4], Avishay Gal-Yam[5], Mansi M. Kasliwal[6], Stefano Valenti[3,4], J. Johansson[7], R. Amanullah[7], A. Goobar[7], J. Sollerman[8], F. Taddia[8], Assaf Horesh[5], Ilan Sagiv[5], S. Bradley Cenko[9], Peter E. Nugent[10,11], Iair Arcavi[3,12], Jason Surace[13], P. R. Woźniak[14], Daniela I. Moody[14], Umaa D. Rebbapragada[15], Brian D. Bue[15] & Neil Gehrels[9]



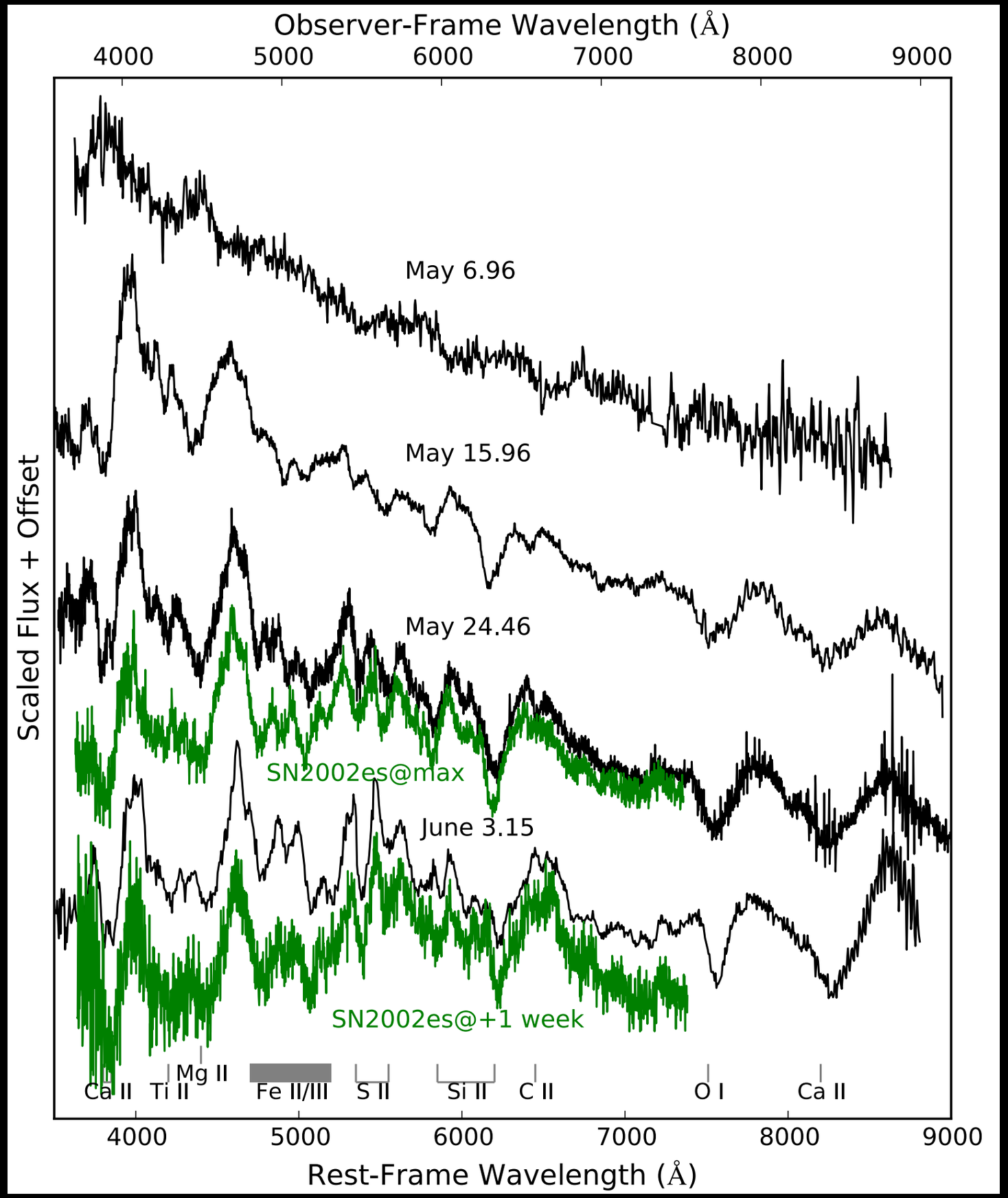
Testing theoretical prediction by Kasen 2010

iPTF14atg
spectra

iPTF14atg is a peculiar subluminous Type Ia supernova, like SN 2002es.

02es max spectrum was blueshifted by 2000 km/s

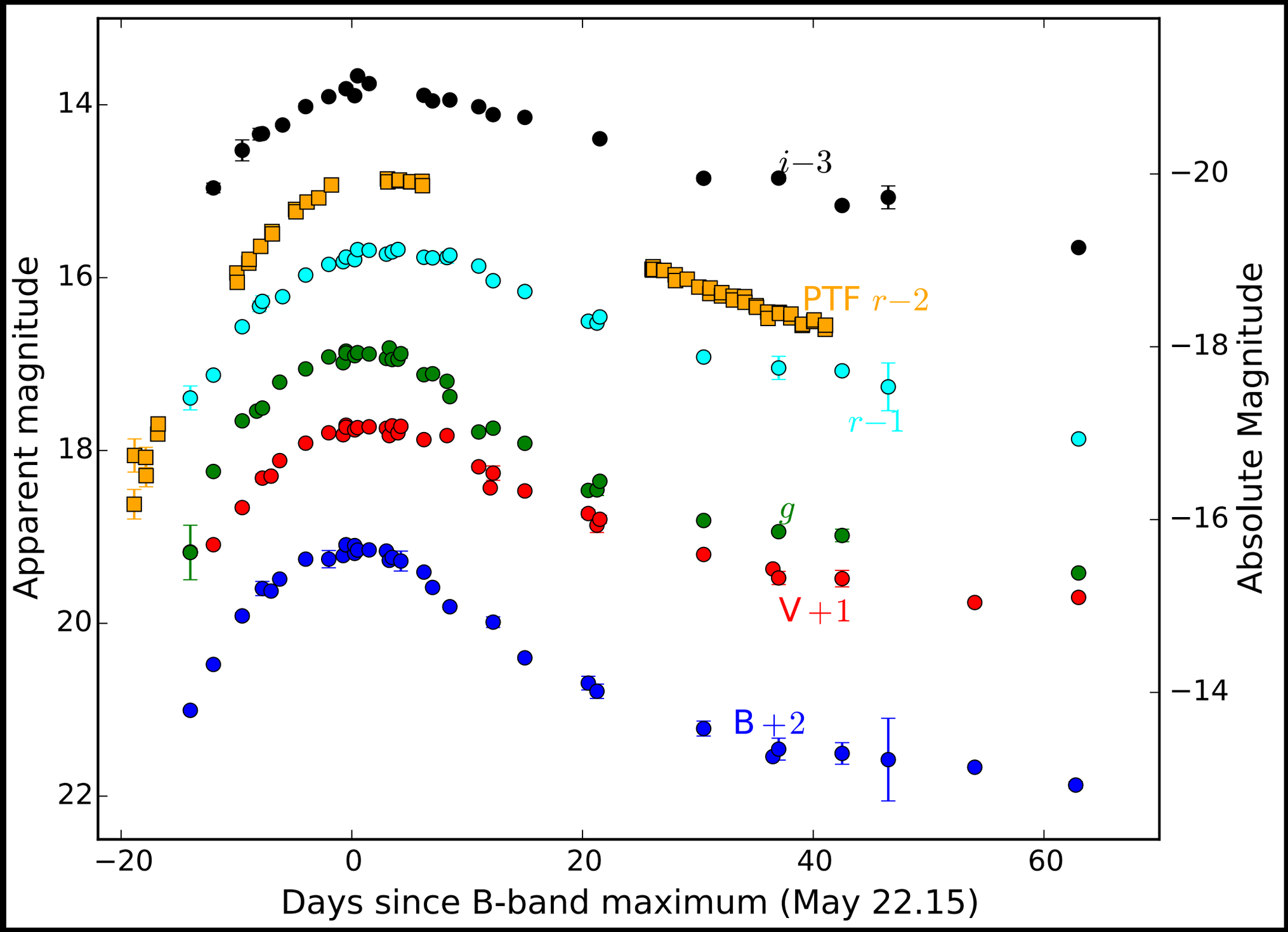
+1wk 02es spectrum blueshifted by 1000 km/s



Cao et al. 2015

iPTF14atg: lightcurves

Cao et al. 2015



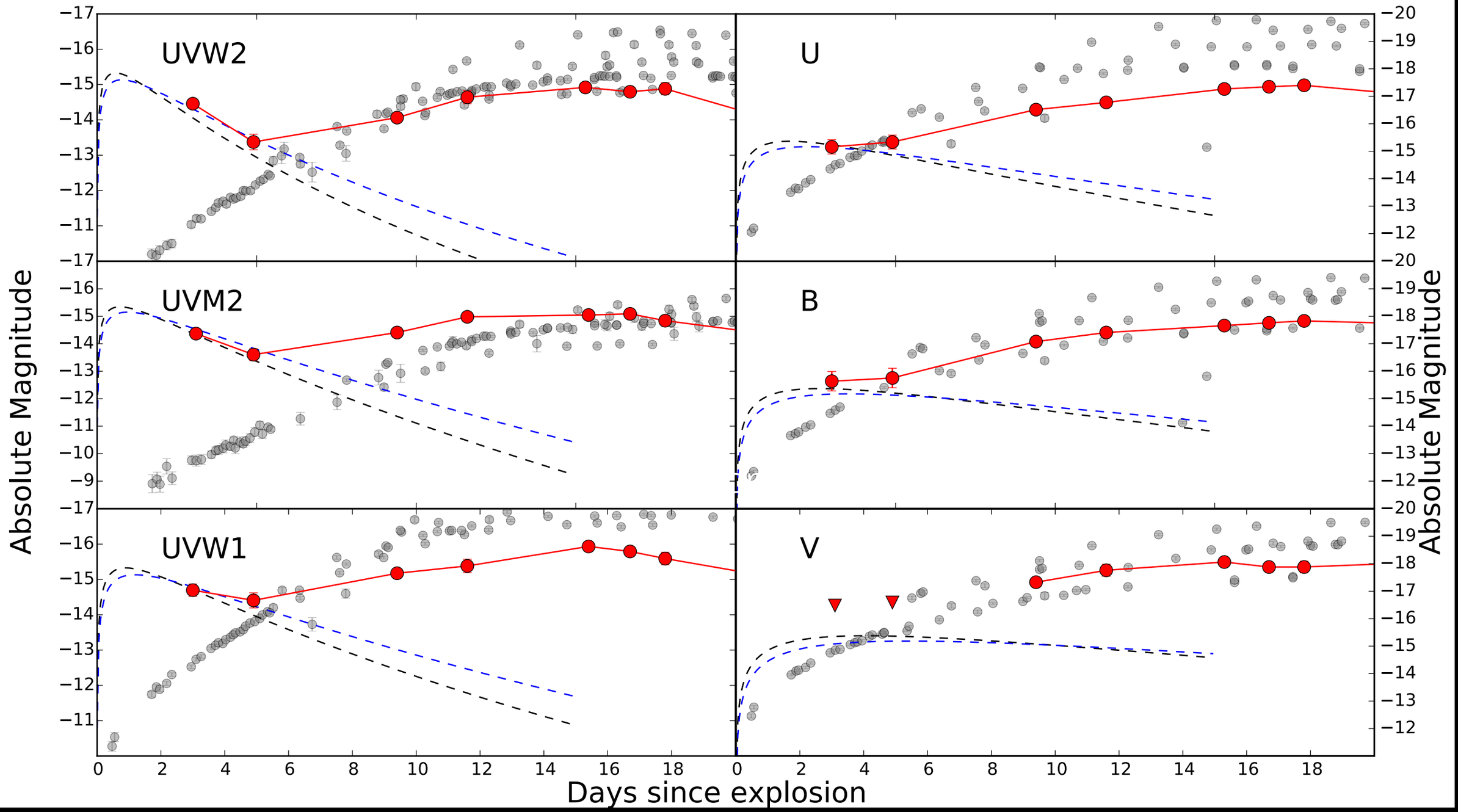
M_B=-17.8; Δm_{15}(B) = 1.2

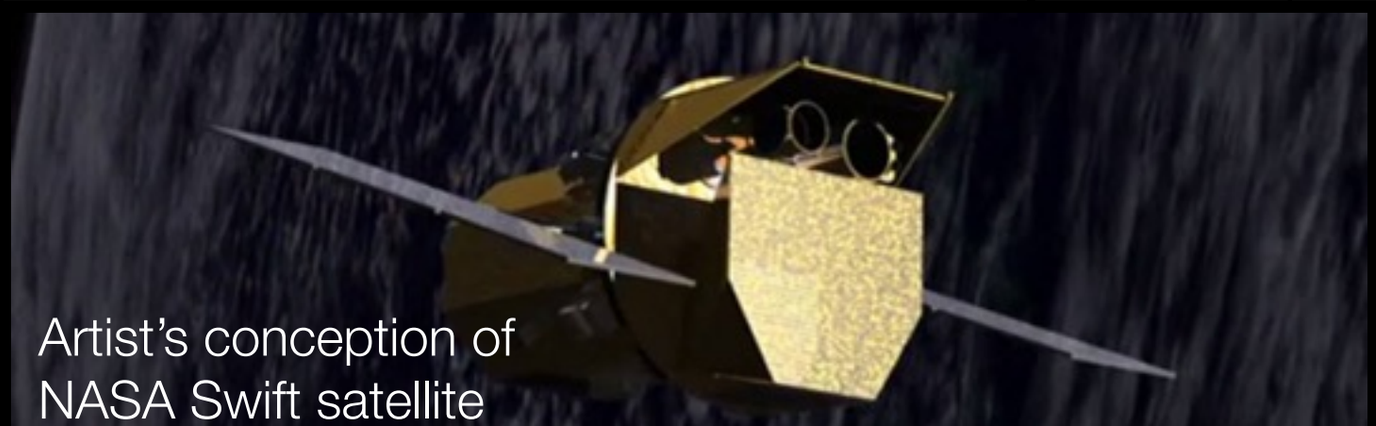
Lightcurves from LCOGT (Except PTF r)

iPTF14atg is one magnitude fainter at peak than SN 2002es

Shocking in iPTF14atg: lightcurves

Cao et al. 2015





Artist's conception of
NASA Swift satellite

Red: data from Swift

Gray: data from other supernovae

Blue dashed: Expected effect from shocking hypothesis

SN 2012cg

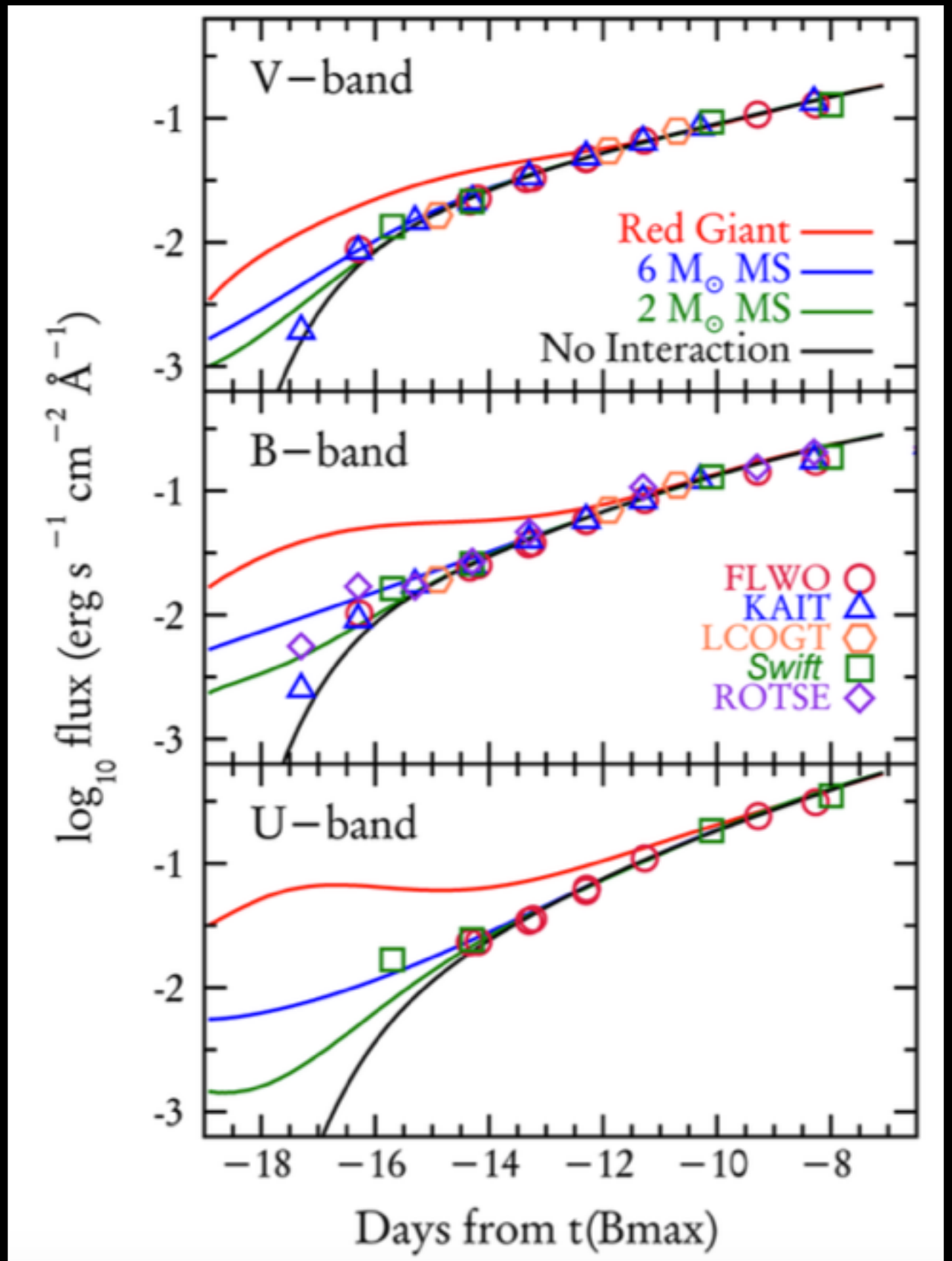
Companion shocking in a normal SN Ia

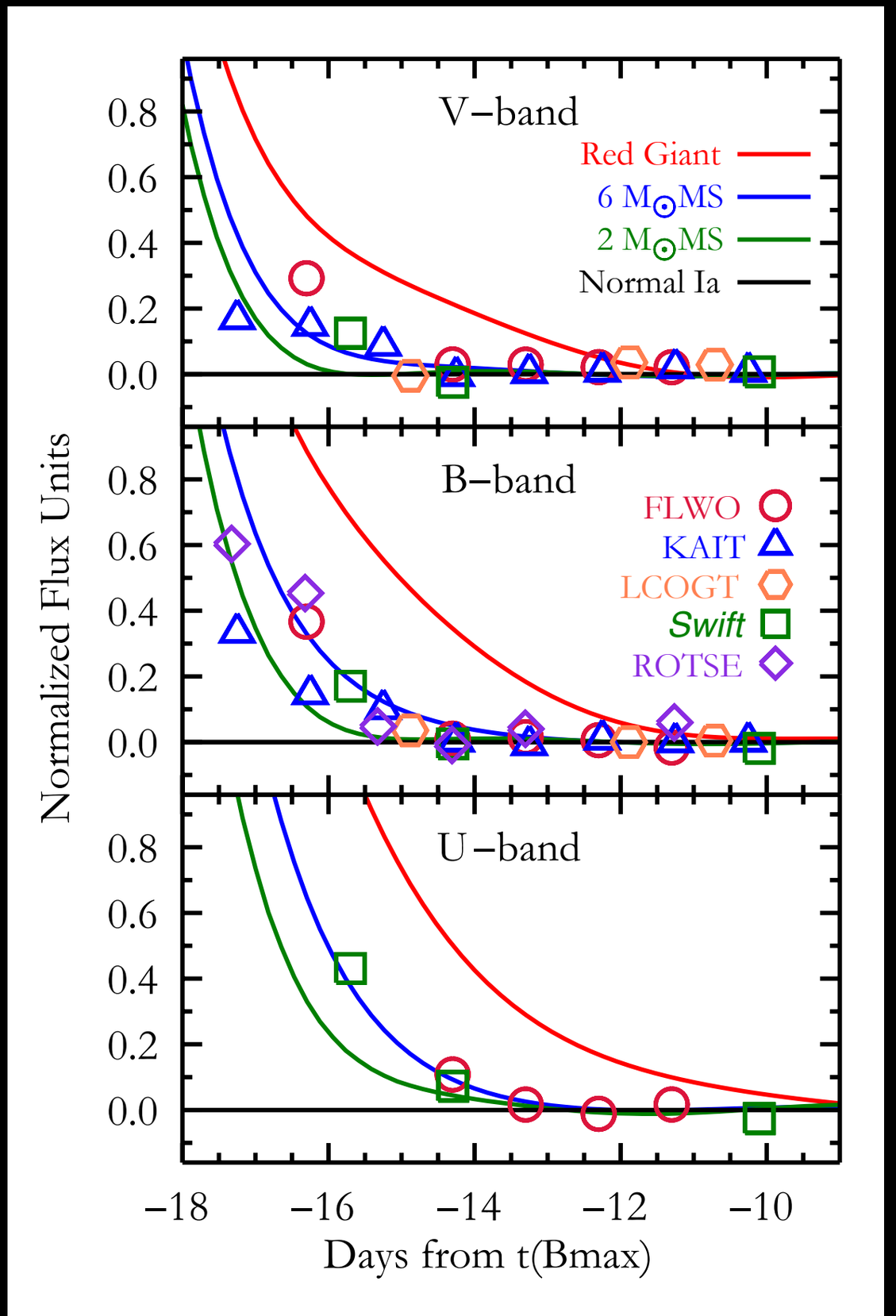
SN 2012cg: EVIDENCE FOR INTERACTION BETWEEN A NORMAL TYPE Ia SUPERNOVA AND A NON-DEGENERATE BINARY COMPANION

G. H. Marion[1,2], Peter J. Brown[3], Jozsef Vinkó[1,4], Jeffrey M. Silverman[1,5], David J. Sand[6], Peter Challis[2], Robert P. Kirshner[2], J. Craig Wheeler[1], Perry Berlind[2], Warren R. Brown[2], Michael L. Calkins[2], Yssavo Camacho[7,8], Govinda Dhungana[9], Ryan J. Foley[10,11], Andrew S. Friedman[12,2], Melissa L. Graham[13], D. Andrew Howell[14,15], Eric Y. Hsiao[16,17], Jonathan M. Irwin[2], Saurabh W. Jha[7], Robert Kehoe[9], Lucas M. Macri[3], Keiichi Maeda[17,18], Kaisey Mandel[2], Curtis McCully[14], Viraj Pandya[7,20], Kenneth J. Rines[21], Steven Wilhelmy[21] and Weikang Zheng[13]

Draft version August 2, 2015

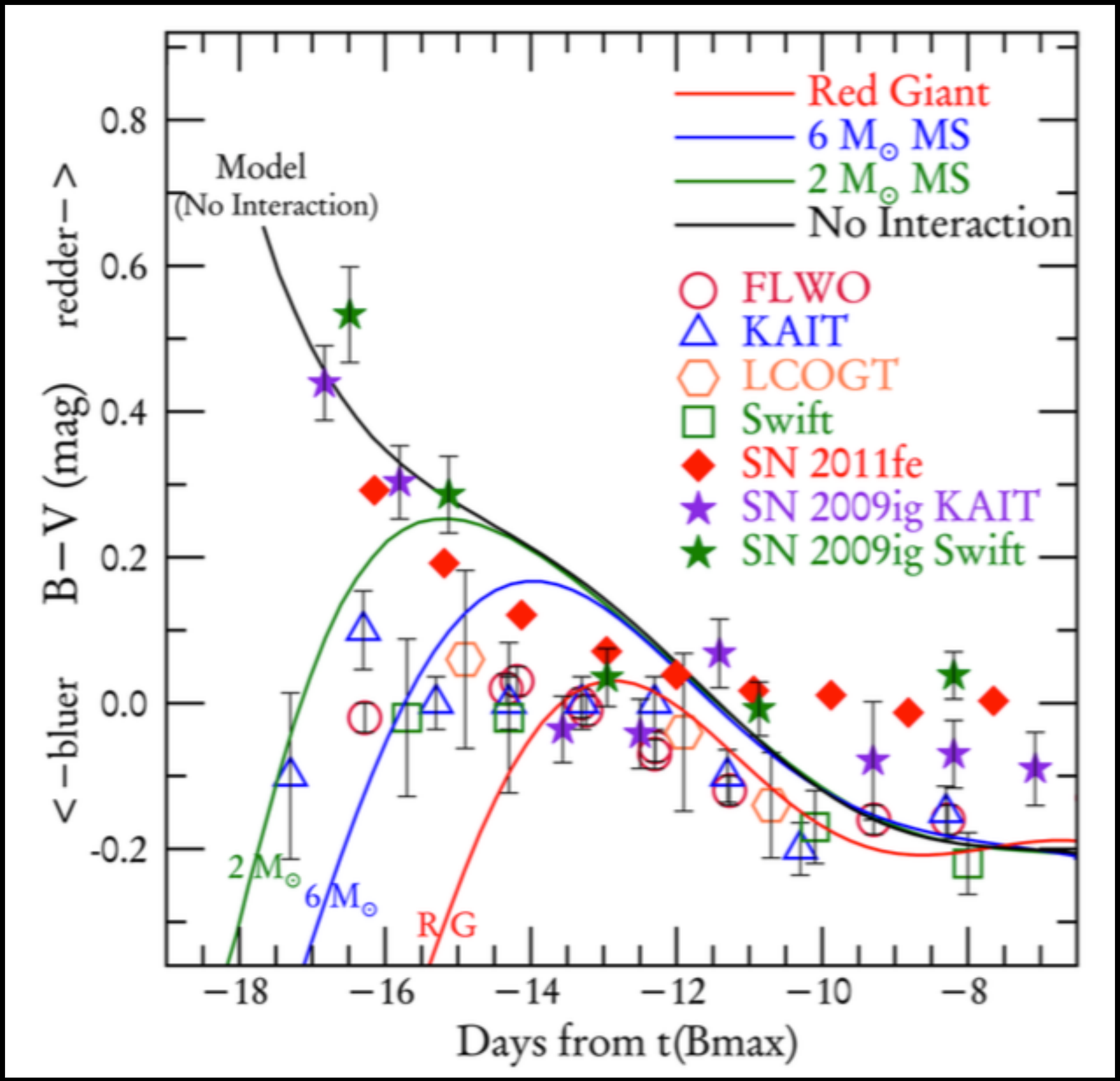
Shocking in SN 2012cg: lightcurves





Marion et al. 2015

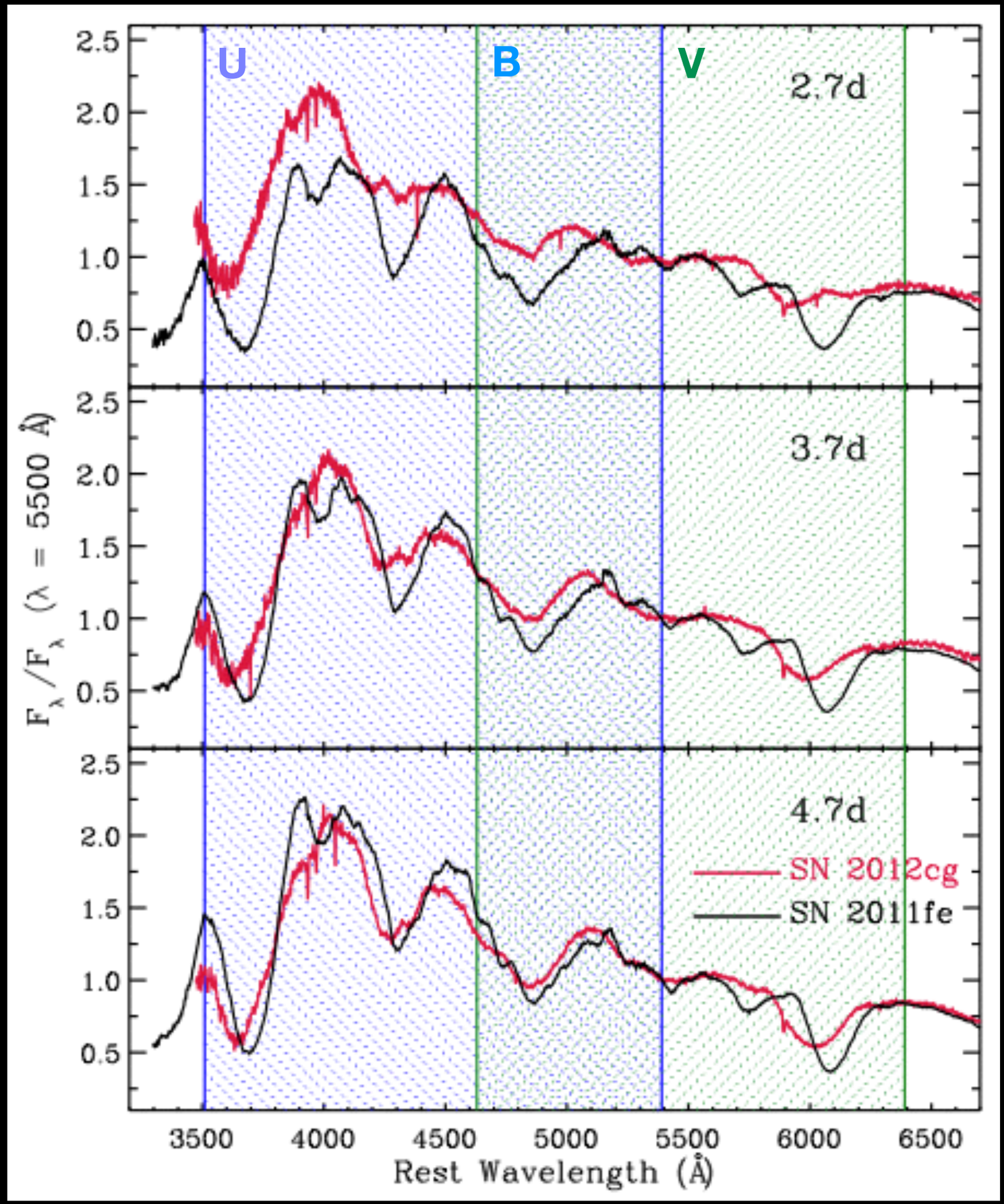
Shocking in SN 2012cg: colors Marion et al. 2015



Shocking in SN 2012cg:
spectra

Marion et al. 2015

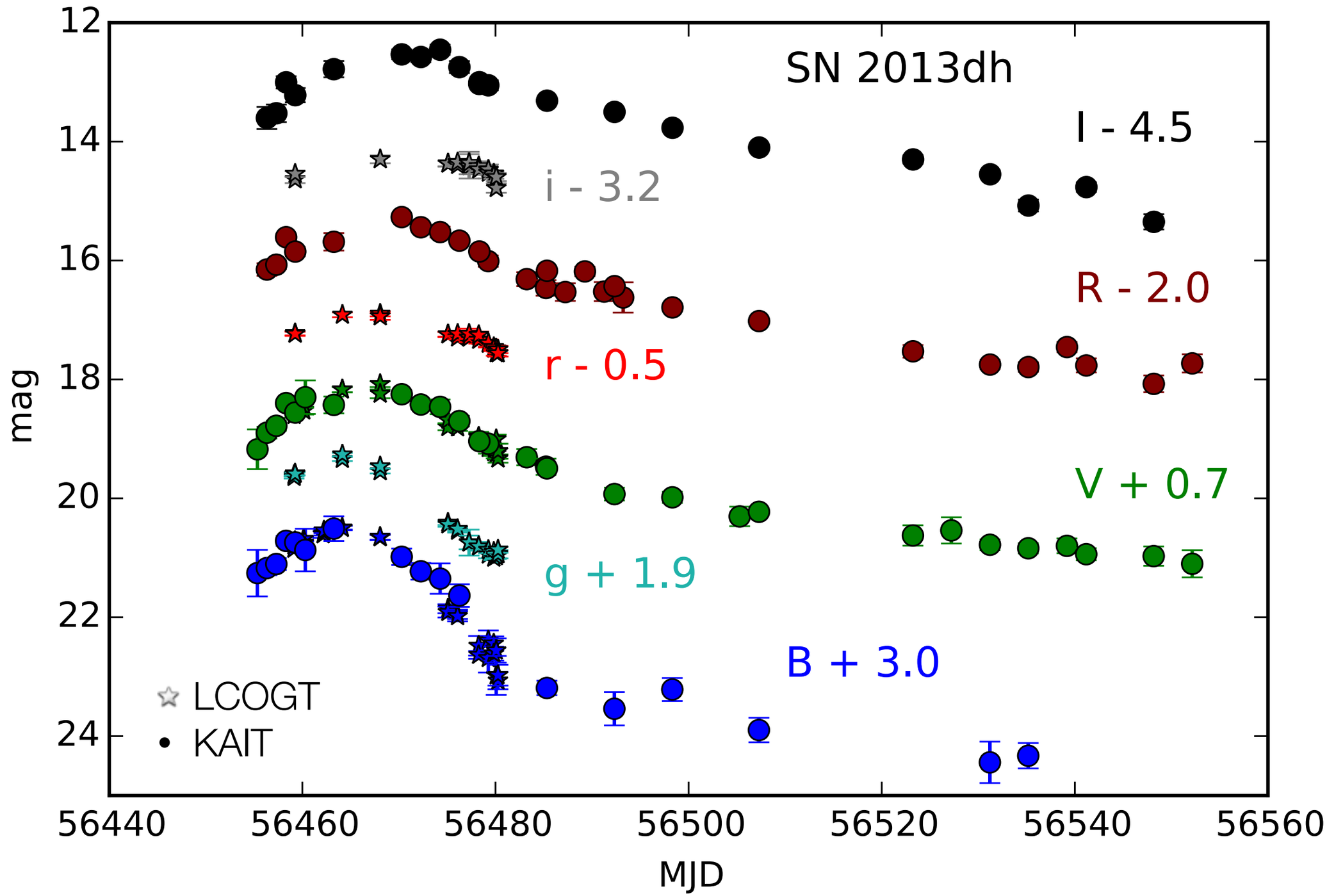
Expect dilution of spectrum by continuum, stronger at early times, shorter wavelengths



SN 2013dh 02cx-like

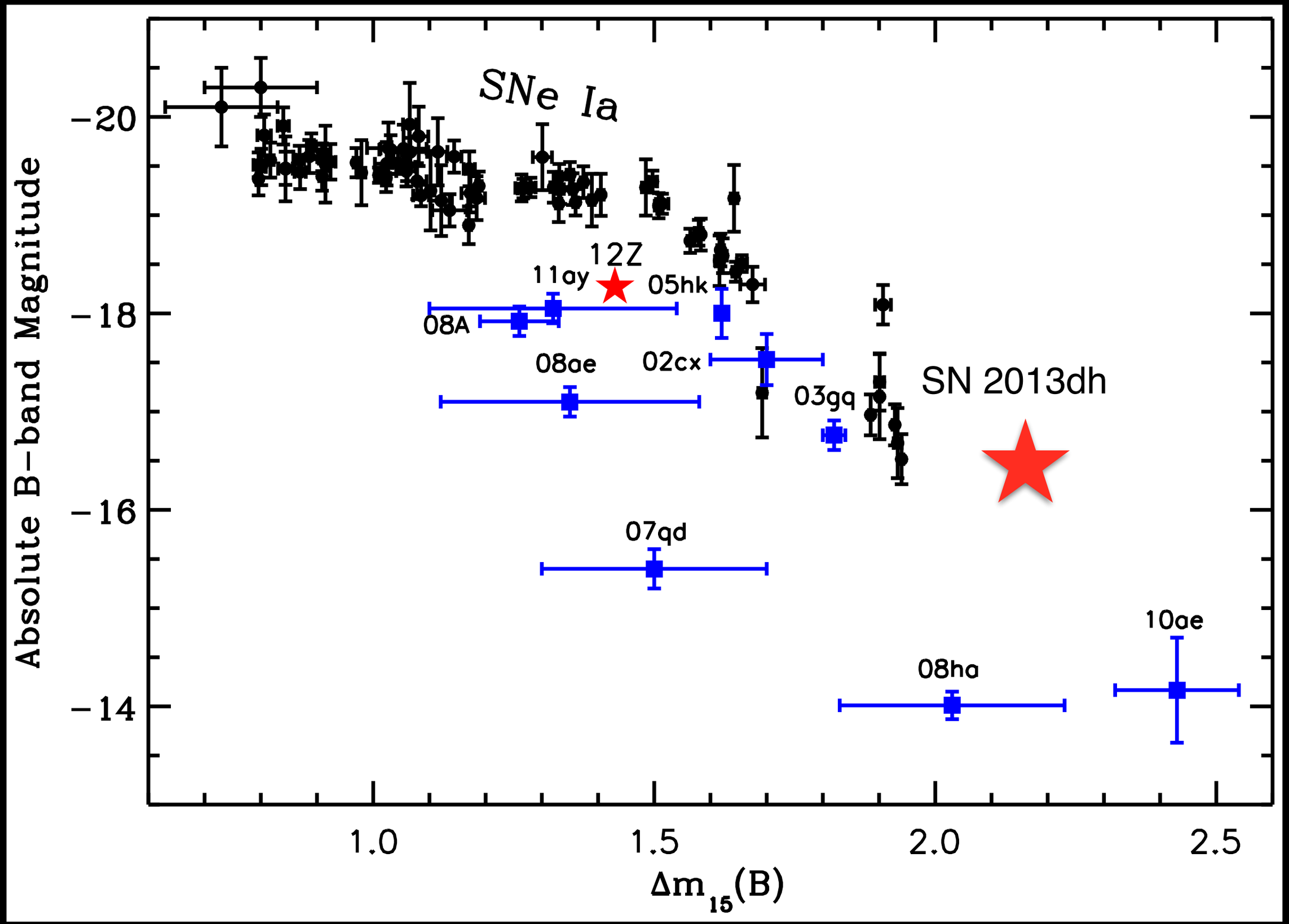
McCully et al., in prep

SN 2013dh 02cx-like



McCully et al., in prep

SN 2013dh 02cx-like



McCully et al., in prep. — adapted from Stritzinger et al. 2014

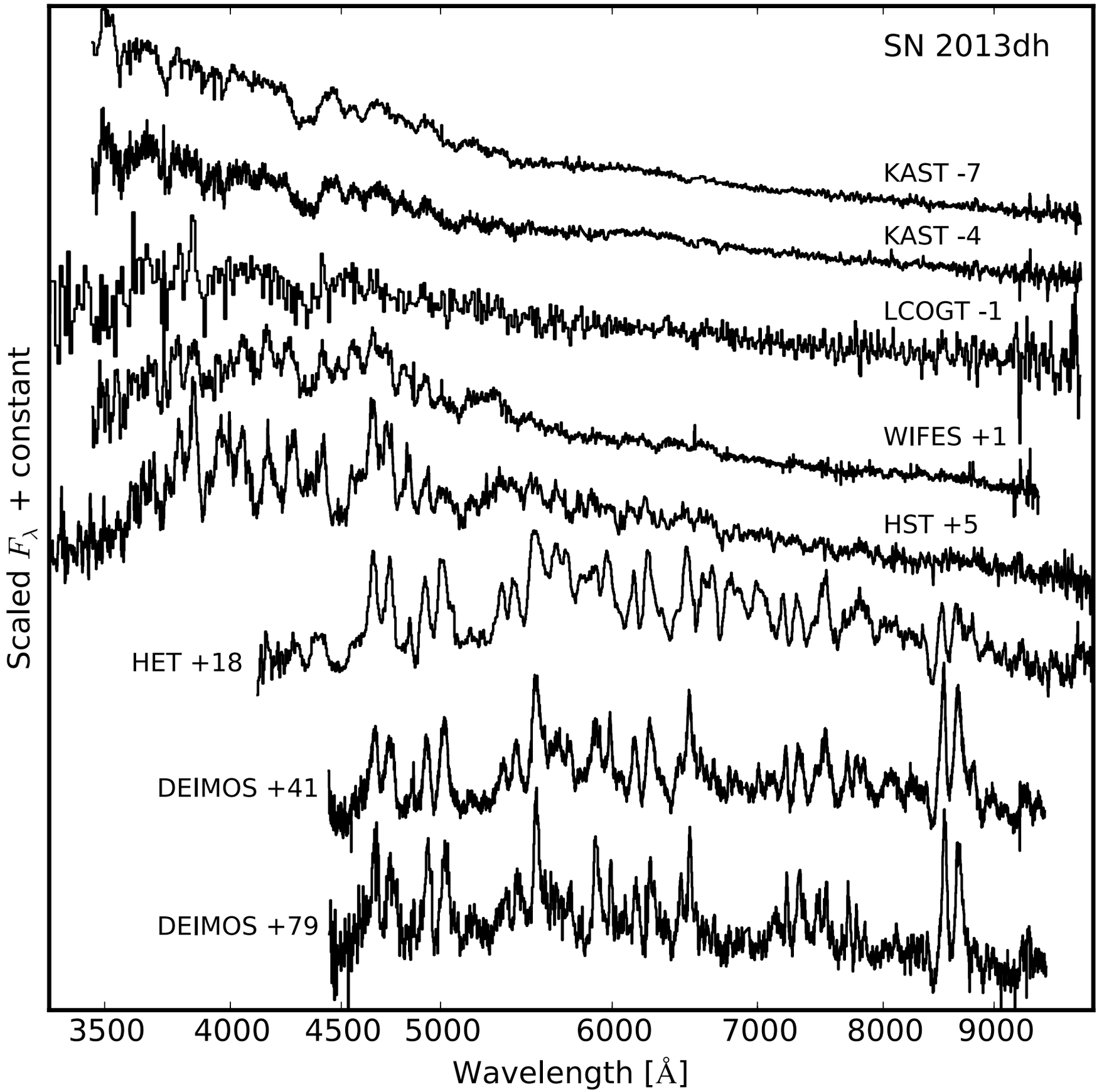
SN 2013dh

02cx-like

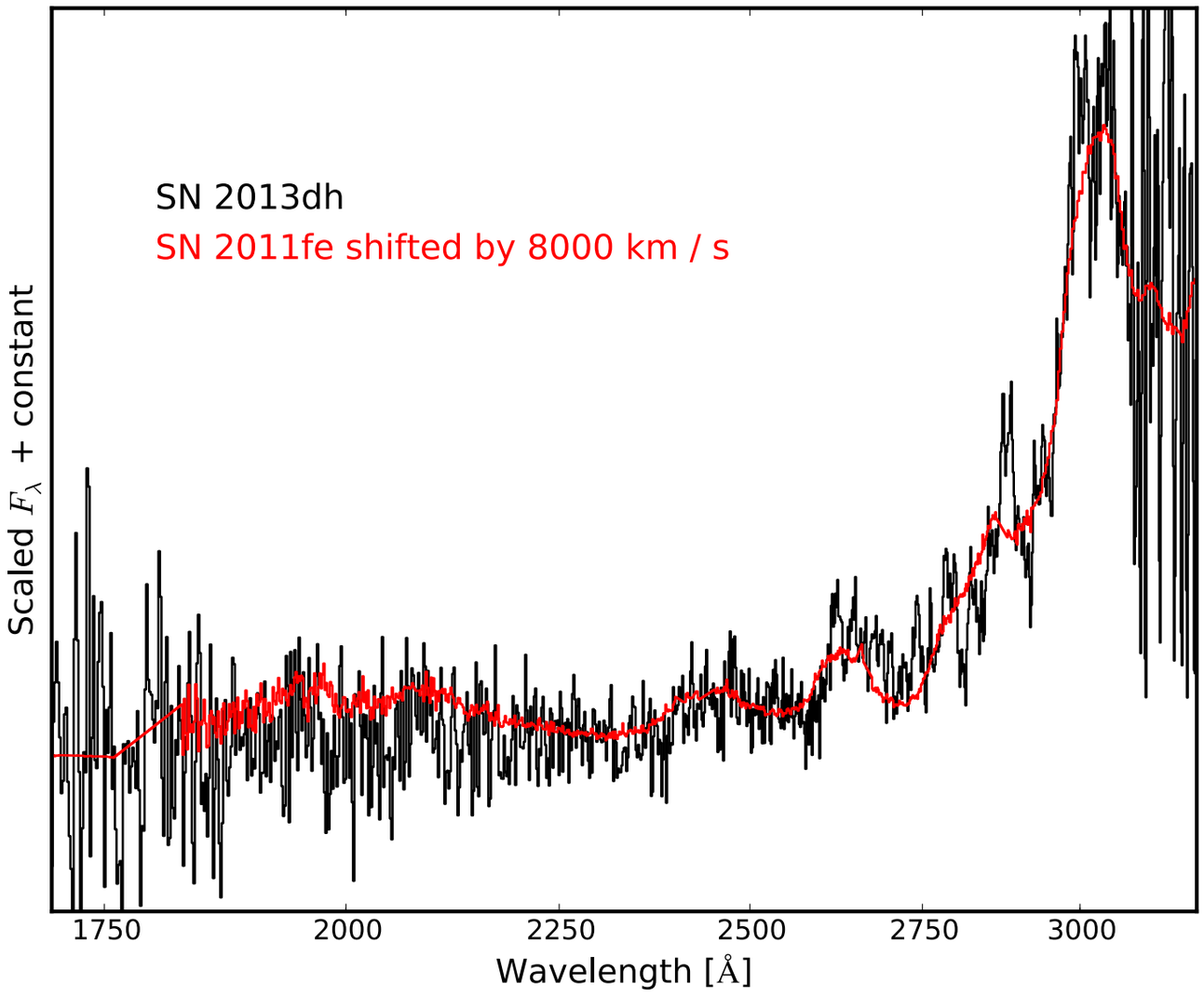
Representative spectra, there are more.

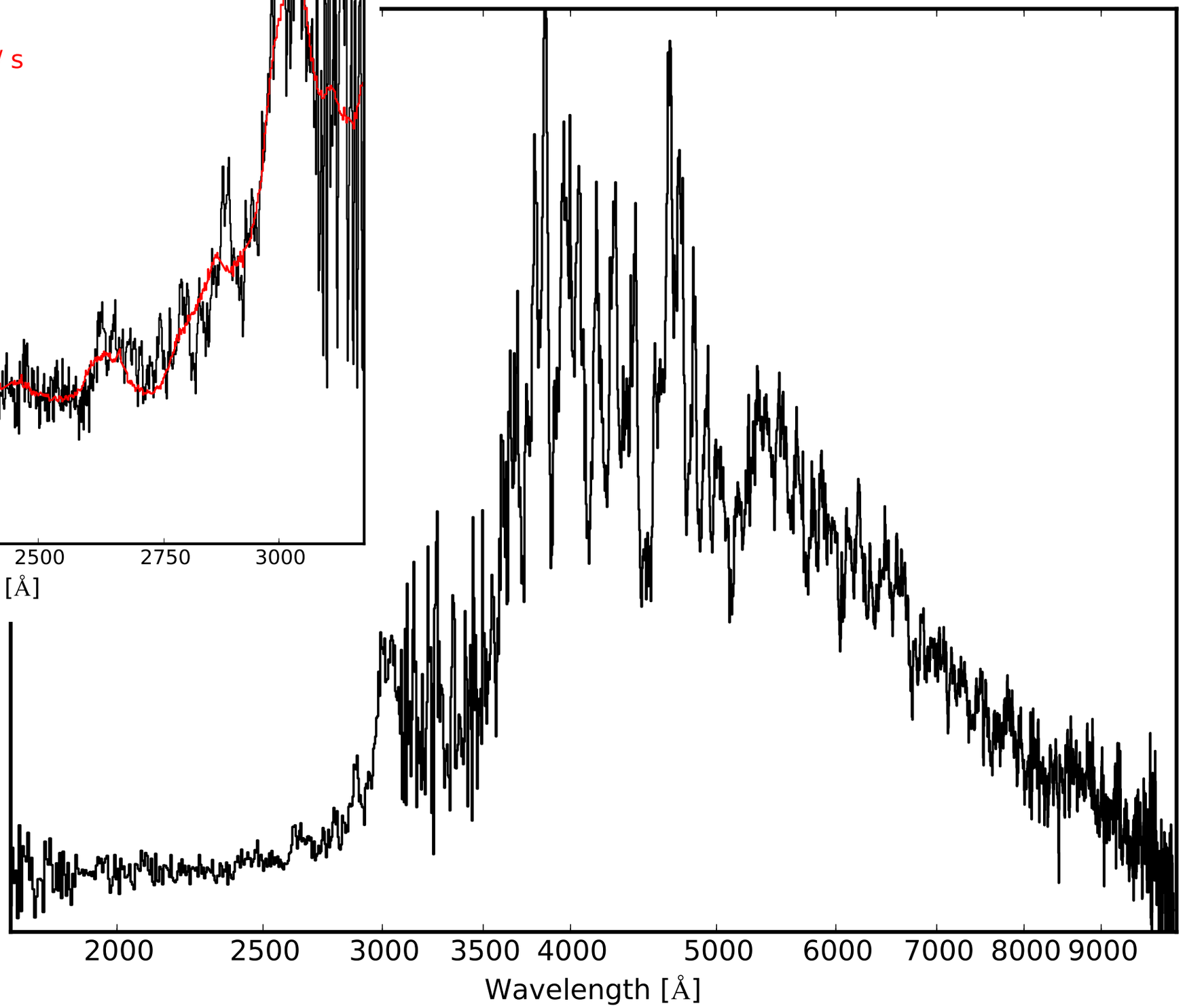
Velocities near 4000 km/s

McCully et al., in prep



HST spectrum





02cx - like
SN 2013dh

McCully et al., in prep

SN 2014ck 02cx-like

Tomasella et al. 2015

Optical and near infrared observations of SN 2014ck: an outlier among the Type Iax supernovae*

L. Tomasella,[1] E. Cappellaro,[1] S. Benetti,[1] A. Pastorello,[1] E.Y. Hsiao,[2] D. Sand,[3] M. Stritzinger,[2] S. Valenti,[4,5] I. Arcavi,[4,5] N. Elias-Rosa,[1] J. Harmanen,[6] A. Harutyunyan,[7] G. Hosseinzadeh,[4,5] D.A. Howell,[4,5] E. Kankare,[8] C. McCully,[4,5] A. Morales-Garoffolo,[9] F. Taddia,[10] L. Tartaglia,[1] G. Terreran,[1,10] M. Turatto[1]

4.2 HST pre-discovery images

nancy: NOTE: Forse si puo' aggiungere di qualche forma questo: $M_V < -8.6$ mag is the threshold suggested for compact star clusters ?) and ?)

Io rifarei la figura 5 facendola piu' chiara e con lettere invece di numeri, e la tabella 7 con la media delle mag.

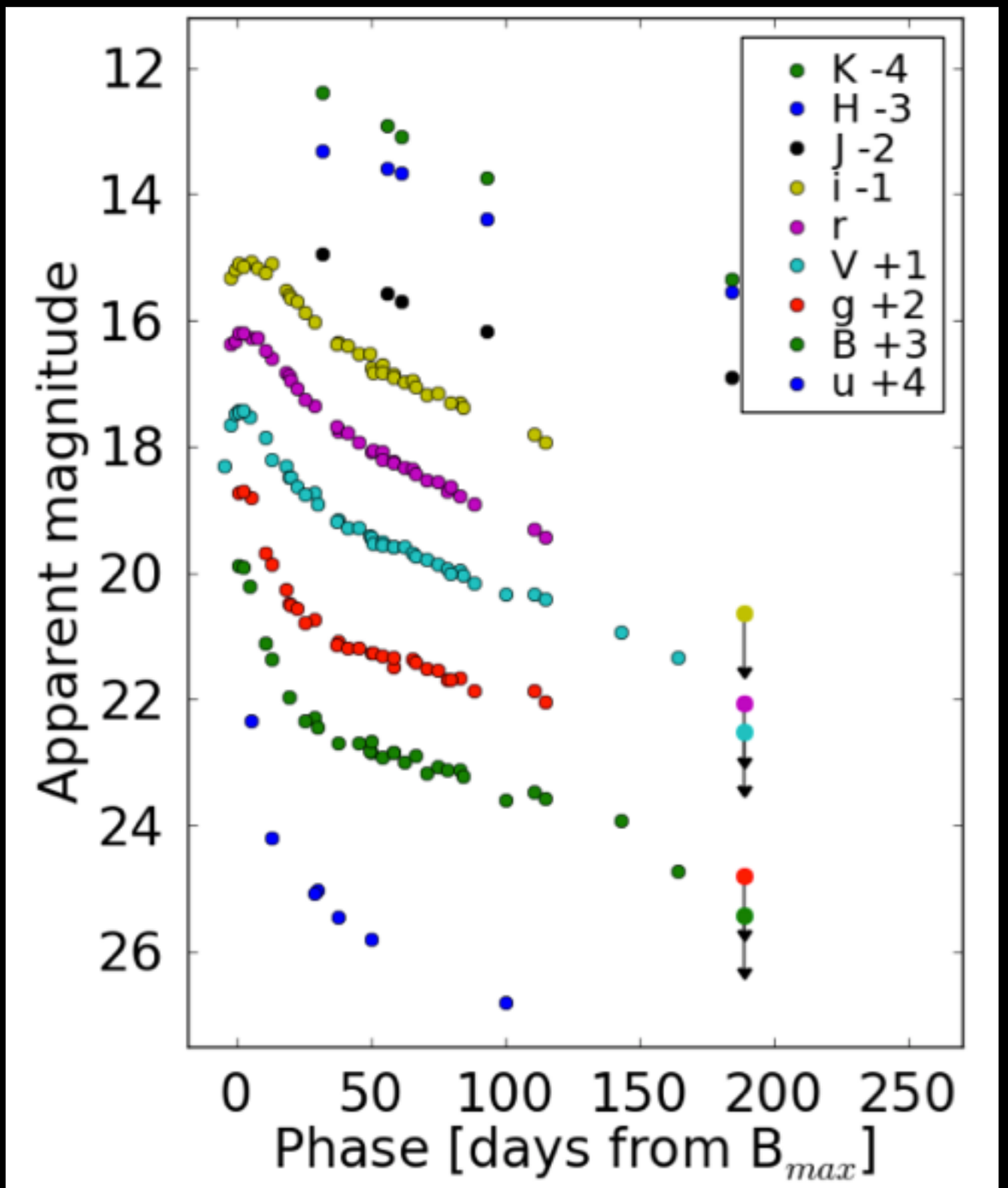
As mentioned before, another transient, SN 2006fp, was discovered in the host galaxy of SN 2014ck. The nature of this transient was unclear, it could have been either a SN IIn or an outburst of a SN impostor, the latter favoured by the spectral analysis (Blondin et al. 2006). With the purpose to test the nature of SN 2006fp, deep imaging was obtained with the Hubble Space Telescope (*HST*), using the Wide Field Camera 3 (WFC3) Ultraviolet-Visible (UVIS) Channel (pixel scale of $0\farcs04$ pix^{-1}). The UVIS data were

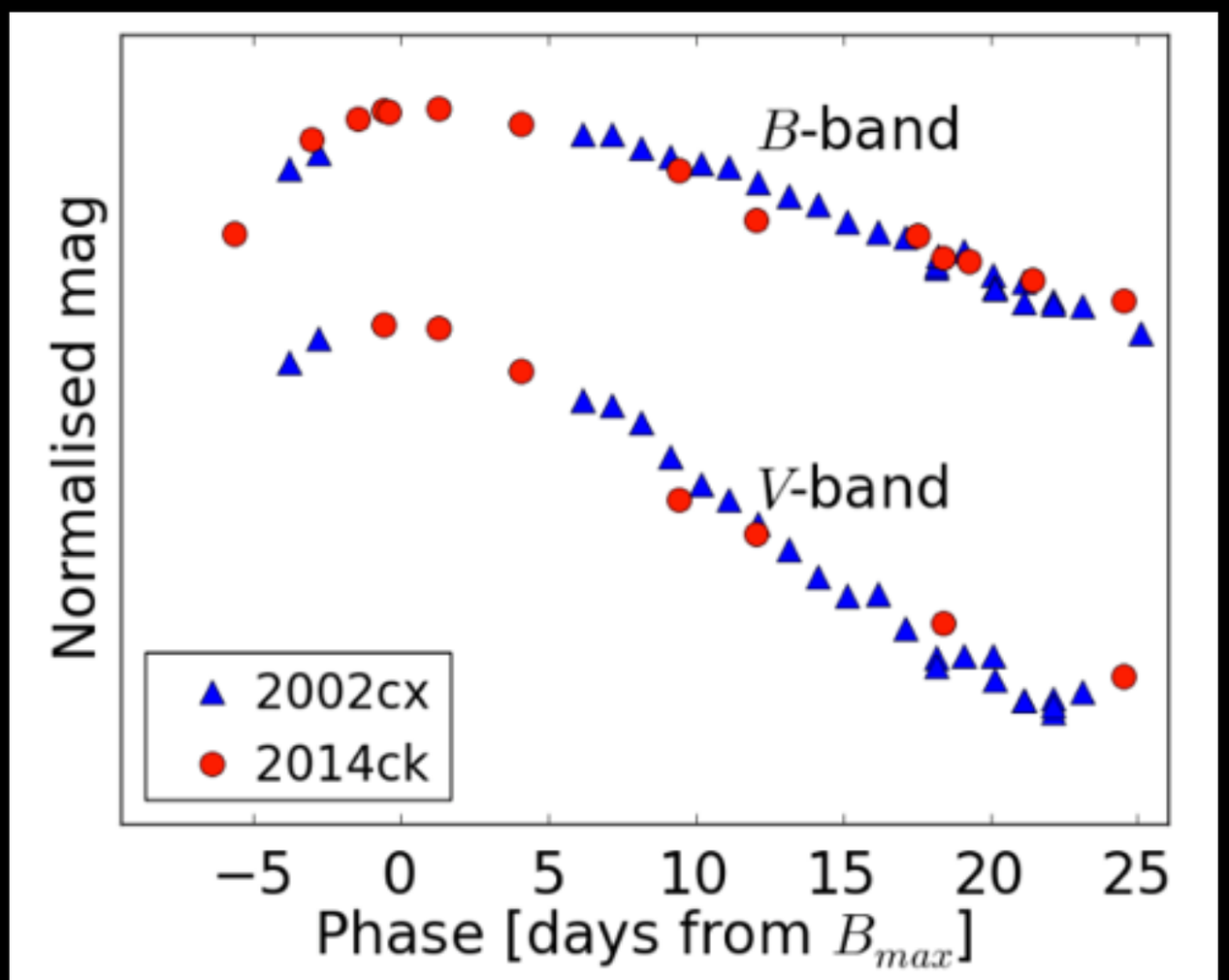
SN 2014ck Lightcurves

Tomasella et al. 2015

M_B = -17.37

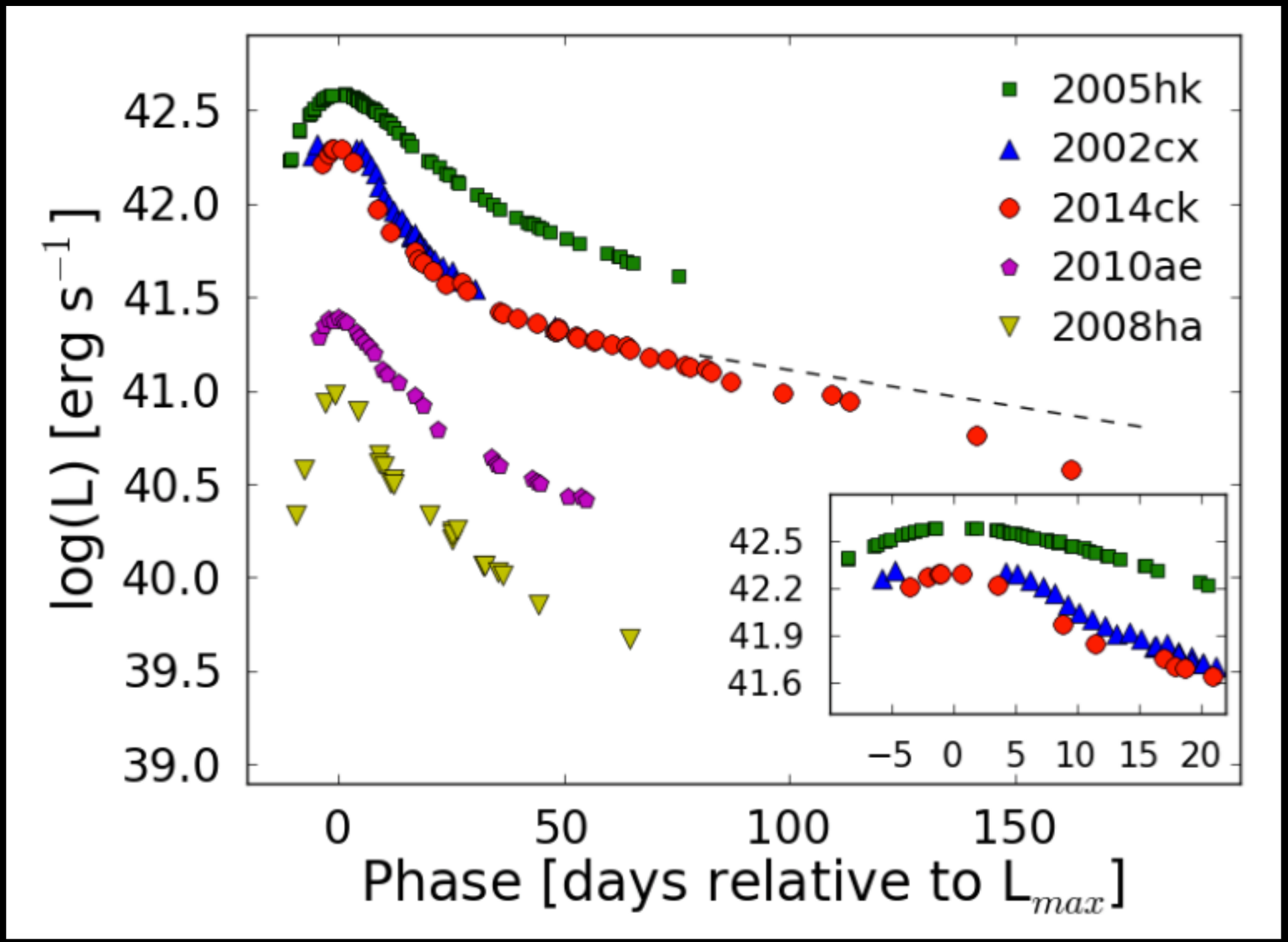
Δm_{15}(B) = 1.76





SN 2014ck Bolometric LC

Tomasella et al. 2015



Peak luminosity, 15 day rise imply 0.08±0.02 $M_\odot$ ^{56}Ni.

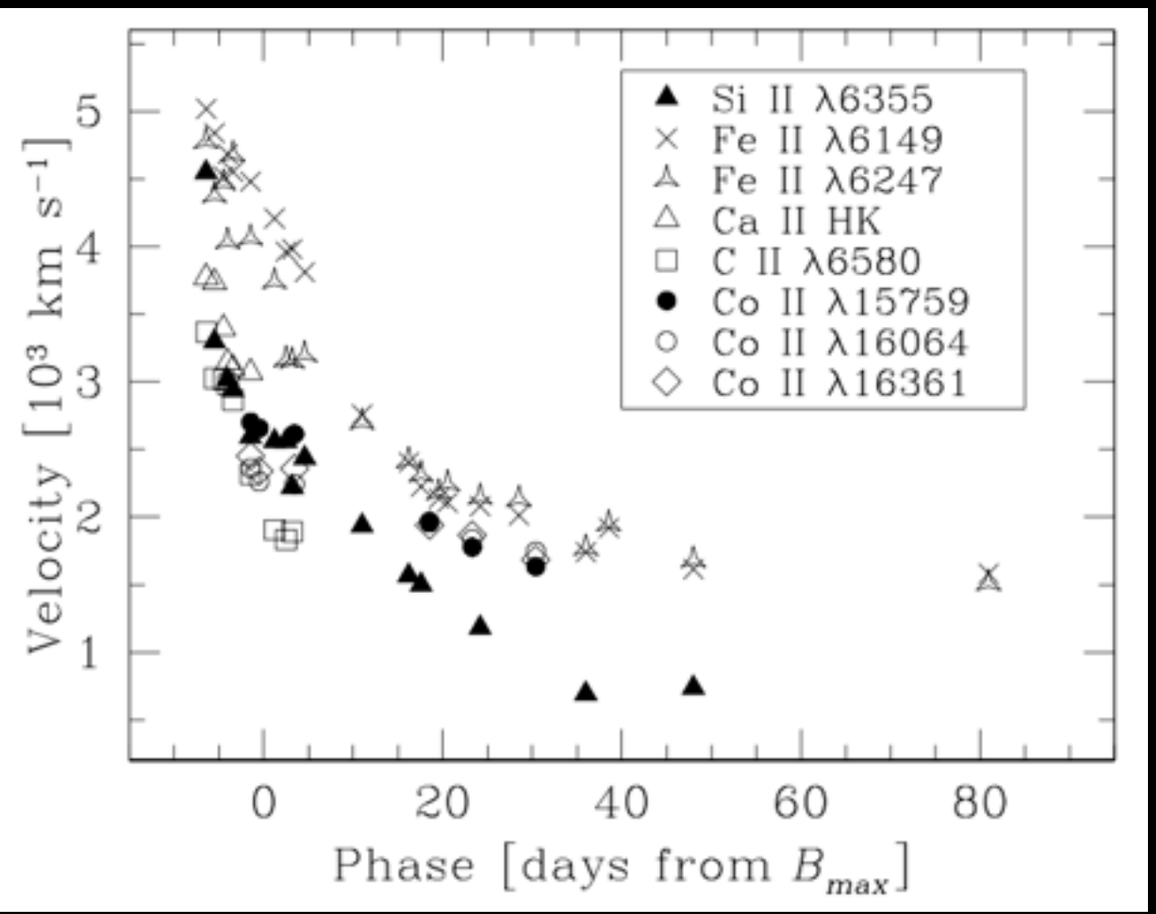
Whole LC implies M_{ej} ~0.25 $M_\odot$

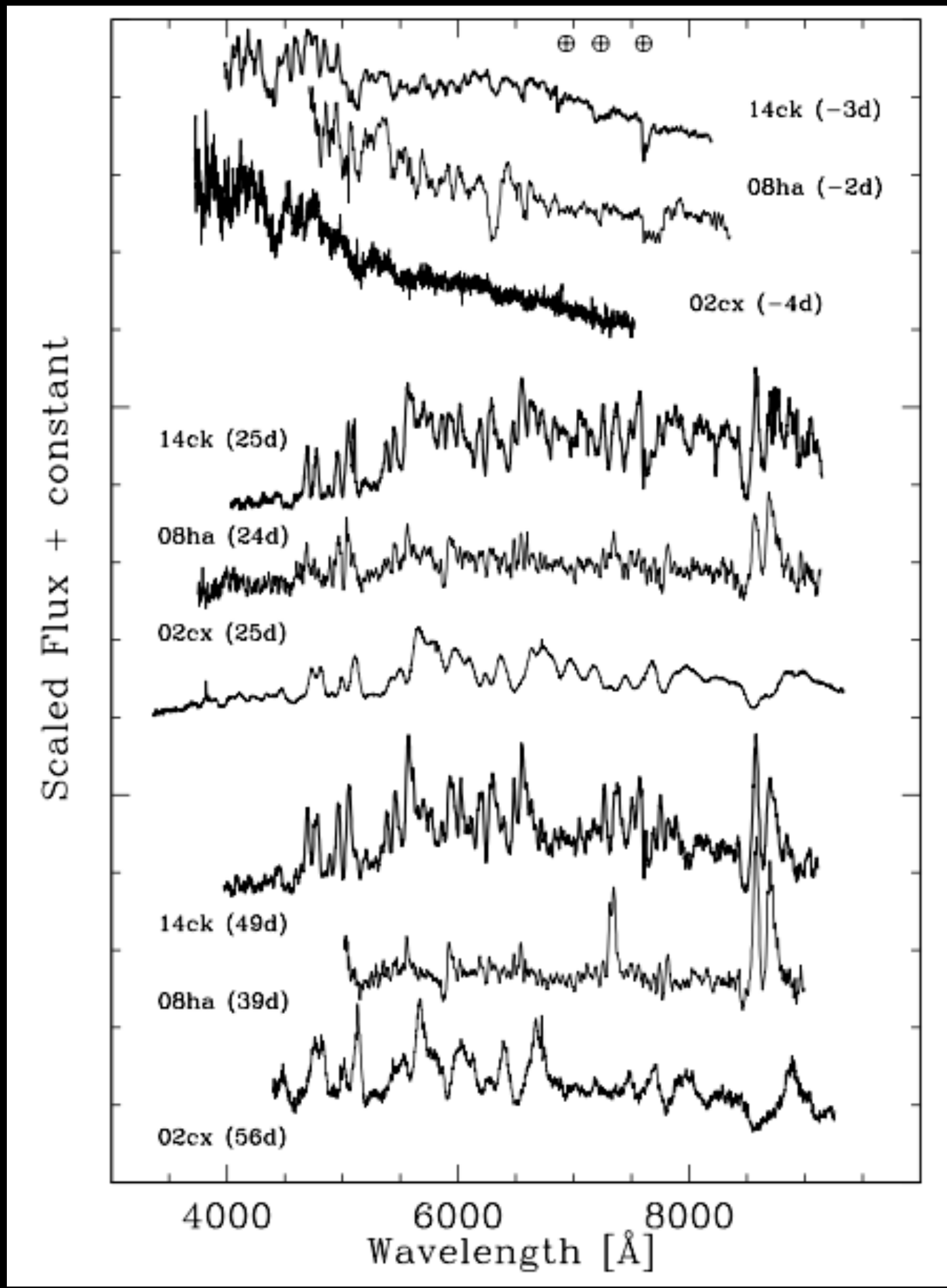
SN 2014ck spectra

Tomasella et al. 2015

SiII velocity at max: 2500 km/s
Half that of 02cx
Closer to 08ha (e.g. Ca lines)

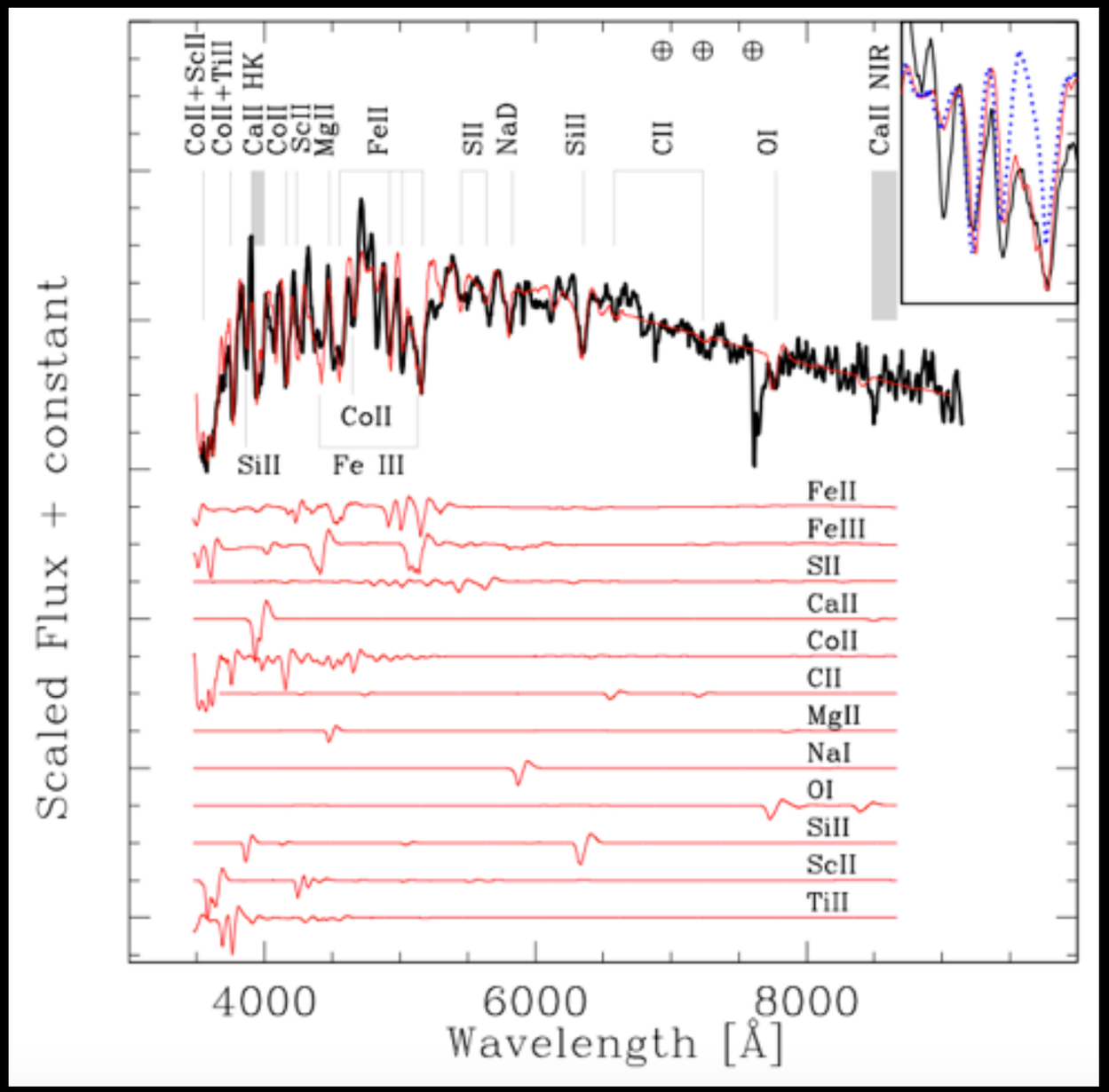
E_k~2% of SN Ia
M_{ej}~0.25 $M_\odot$



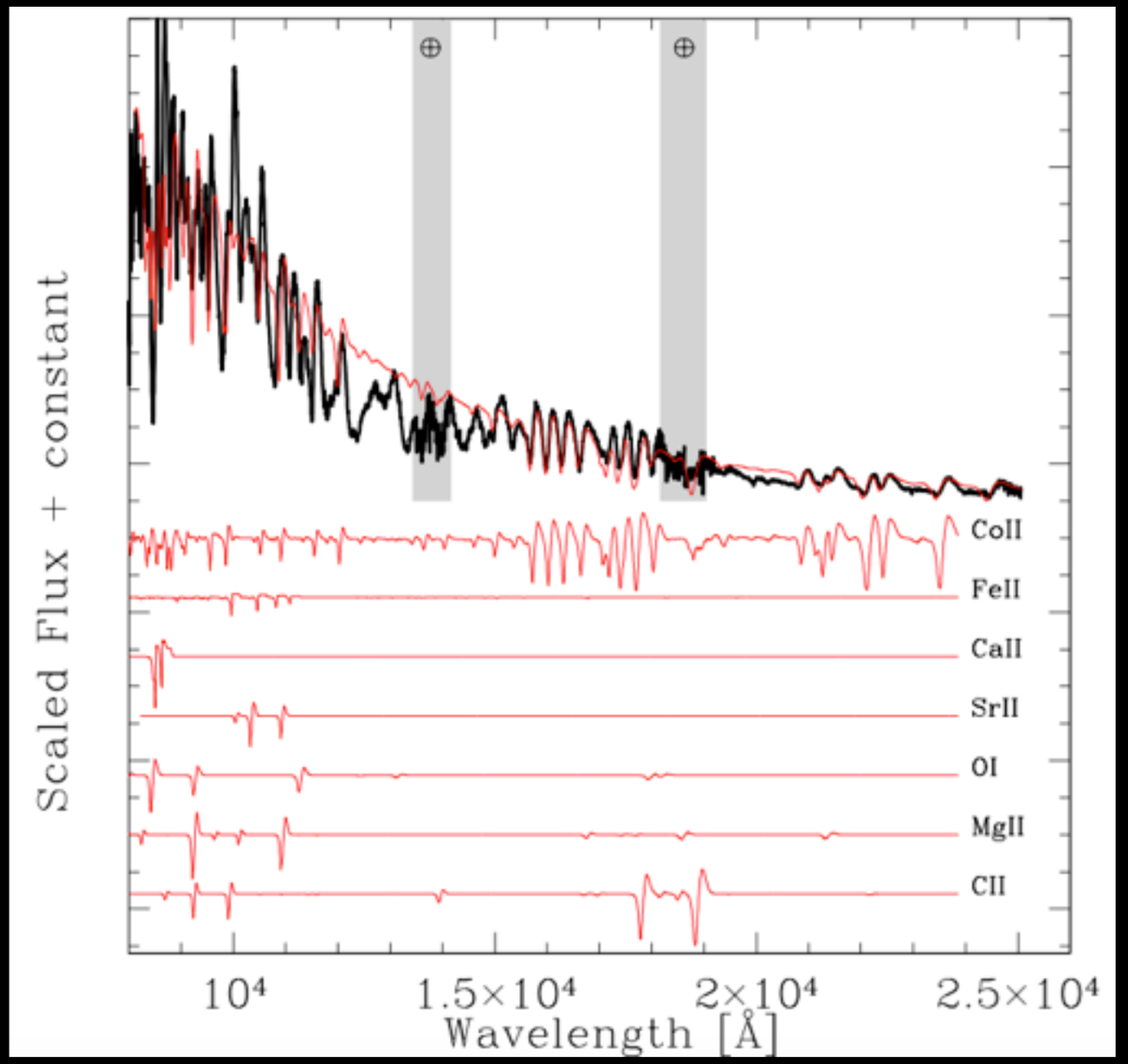


SN 2014ck composition

Tomasella et al. 2015



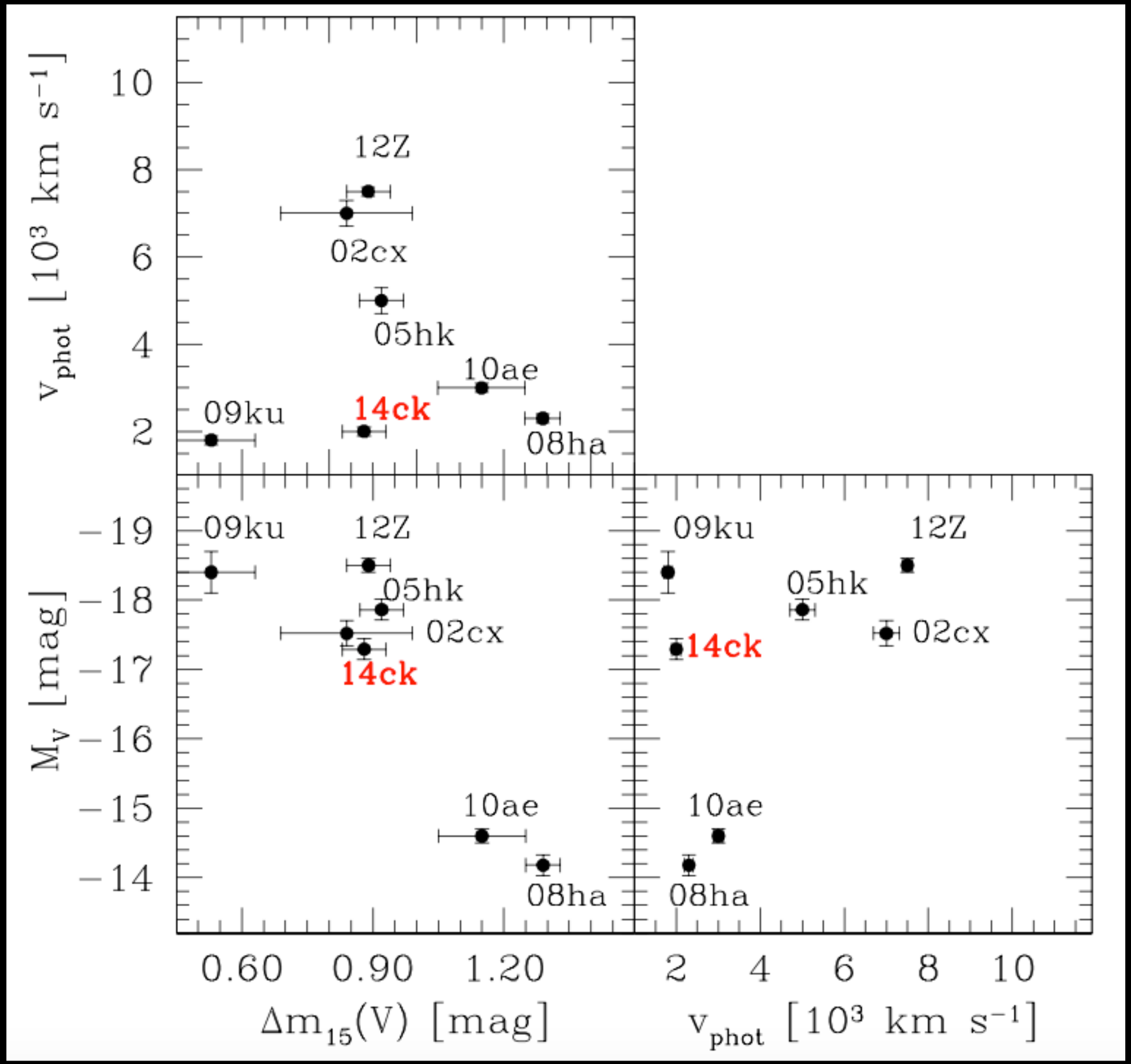
Optical spectrum at 2.2d.
Blue inset shows w/o FeIII



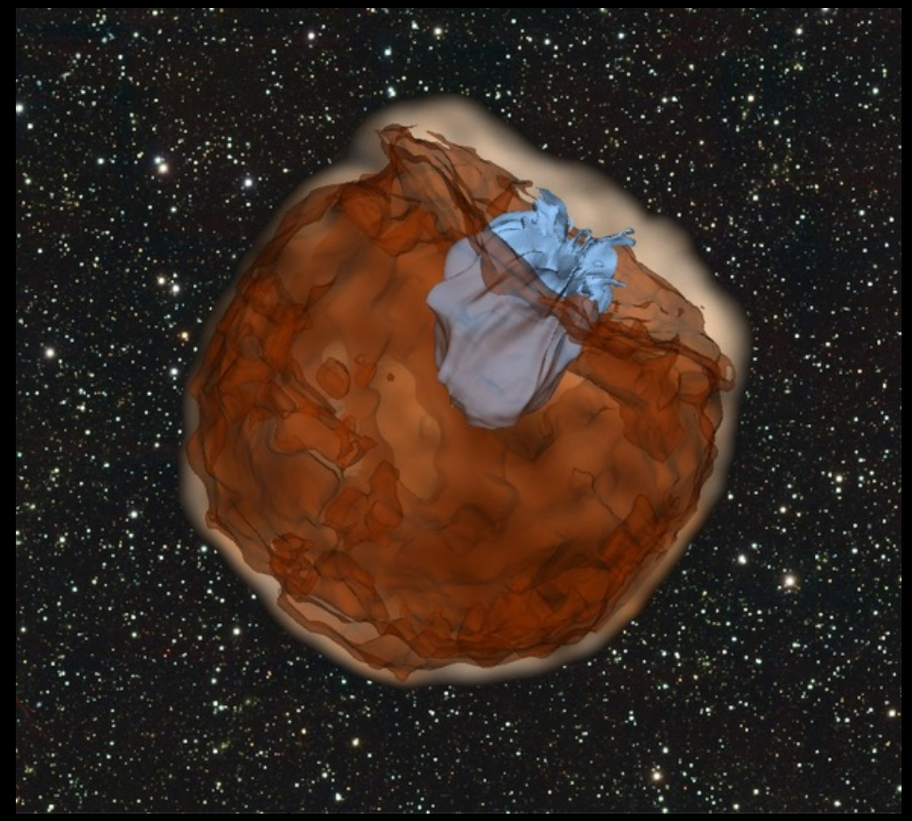
NIR spectrum at 20d

SN 2014ck
correlations

Tomasella et al. 2015



Conclusions



Early UV or blue light curve excesses are seen in:
- An 02es-like (iPTF14atg; Cao et al. 2015)
- Normal SN Ia (SN 2012cg; Marion et al. 2015).
- The interpretation is shocking by a main sequence or red giant companion.

SN 2013dh (McCully et al. in prep) is an 02cx-like supernova with:
- a large $\Delta m_{15}(B) = 2.1$; $M_B = -16.5$; v~4000 km/s
- a UV spectrum that looks like a SN Ia, but with lower velocities.

SN 2014ck (Tomasella et al. 2014)
- Photometrically like 02cx, but has low velocities (2500 km/s in Si at max).
- Inferred ^{56}Ni: 0.08±0.02 $M_\odot$, M_{ej} ~0.25, E_k =2% of a SN Ia.
- CoII, SiII, CII unambiguously seen — clearly a thermonuclear explosion.
- Simultaneous permitted and forbidden Ca, Fe, Co lines at late times. Ejecta clumpy?
- There probably isn't a correlation between v_{phot} and $\Delta m_{15}(B)$

LCOGT SN Key Project: On track for 600 SNe over 3 years. Robotic lightcurves and spectra. Rapid-follow-up.