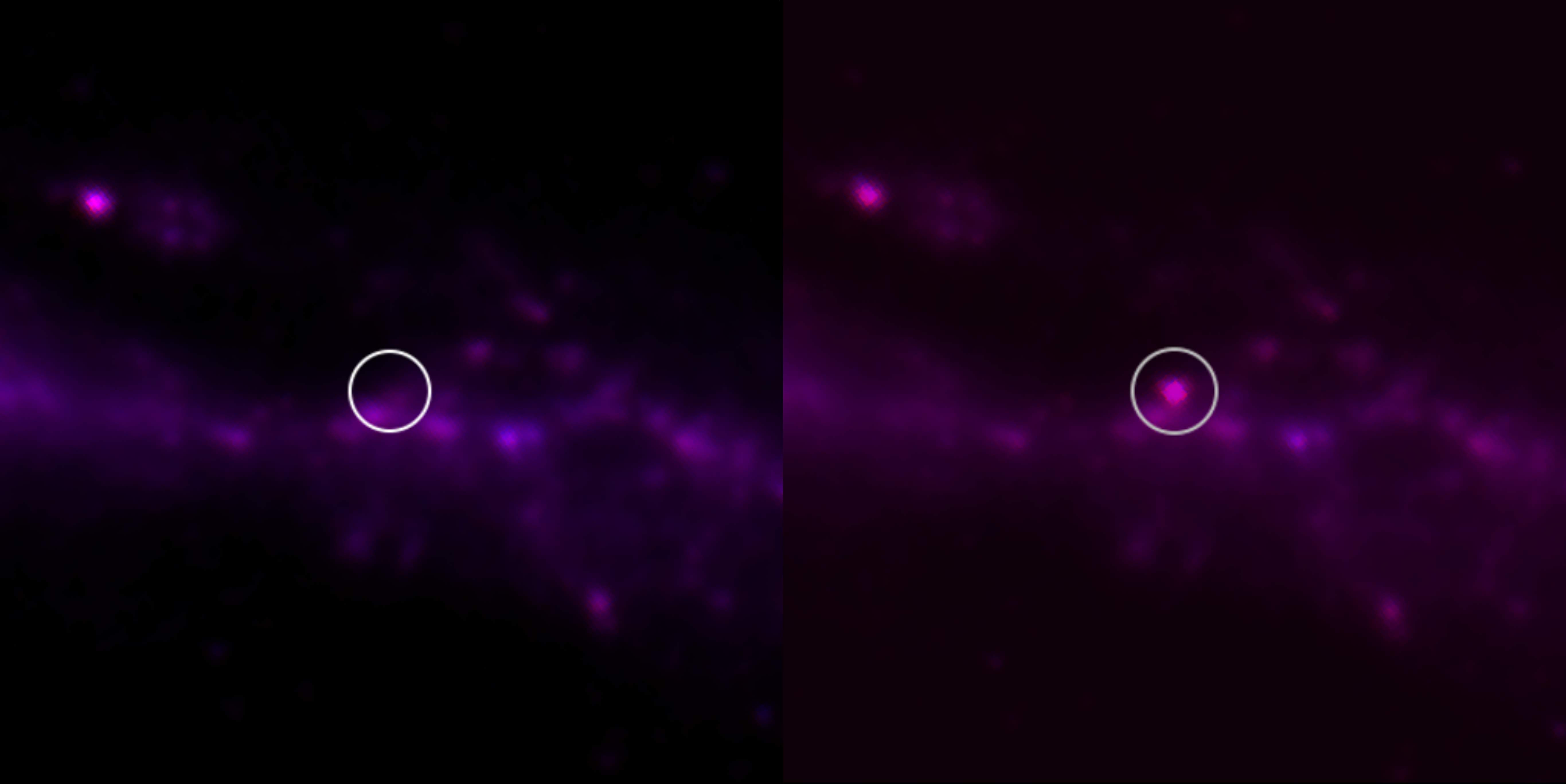


HUNTING FOR HIDDEN SUPERNOVAE

Jacob Jencson
Caltech Astronomy
Advisor: Mansi Kasliwal

Pasadena, CA
July 16, 2018

Many supernovae hidden by dust may be missed by transient searches.

Searches at redder wavelengths can provide a way forward, but have been hindered by detector cost and the brighter night sky background

Optical/IR transient surveys now coming online can systematically search for reddened supernovae

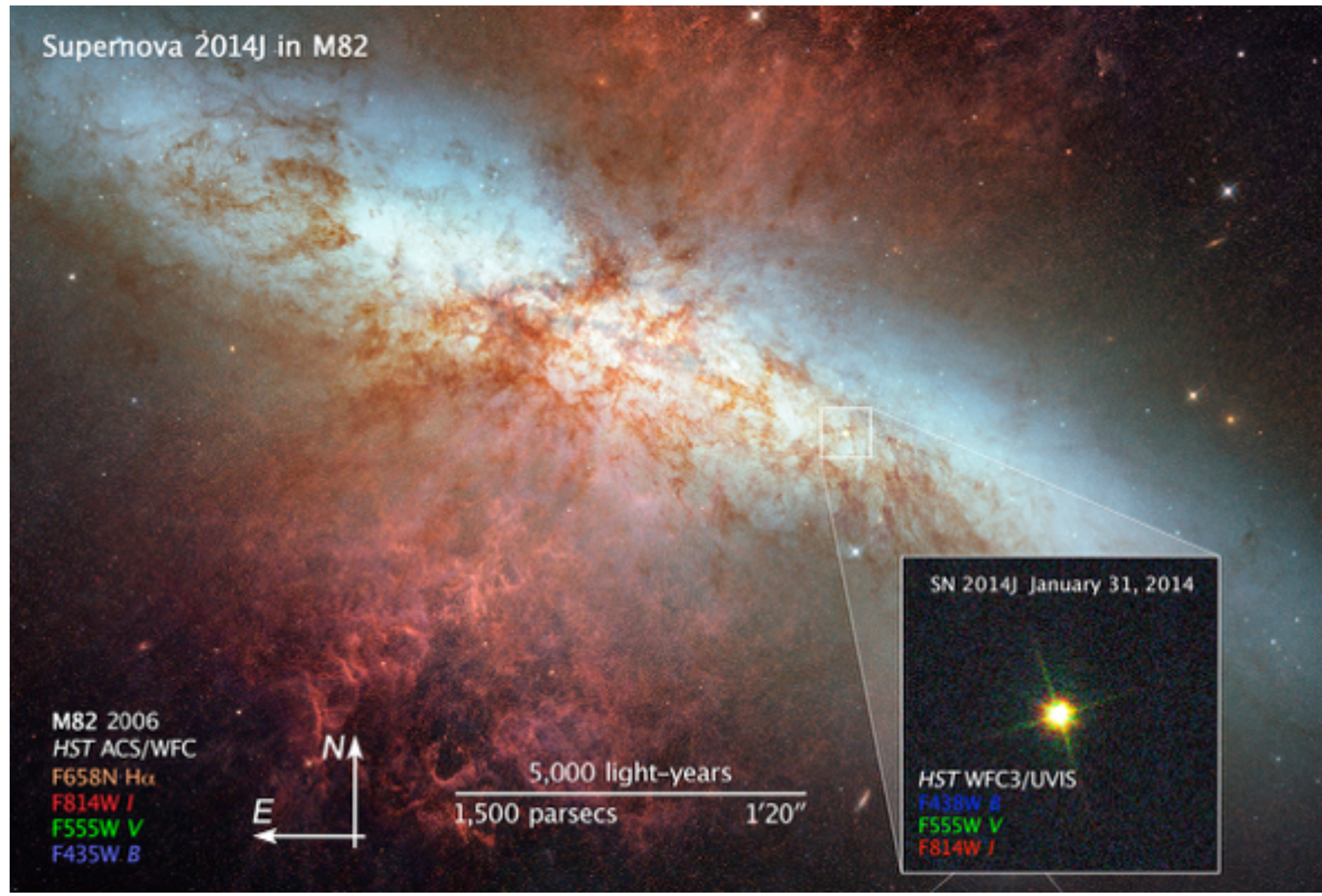


Image Credit: NASA, ESA, A. Goobar (Stockholm University), and the Hubble Heritage Team (STScI/AURA)

SPIRITS: A targeted search of nearby galaxies for transients in the mid-IR

~1700 hours over 6 years with *Spitzer*/IRAC

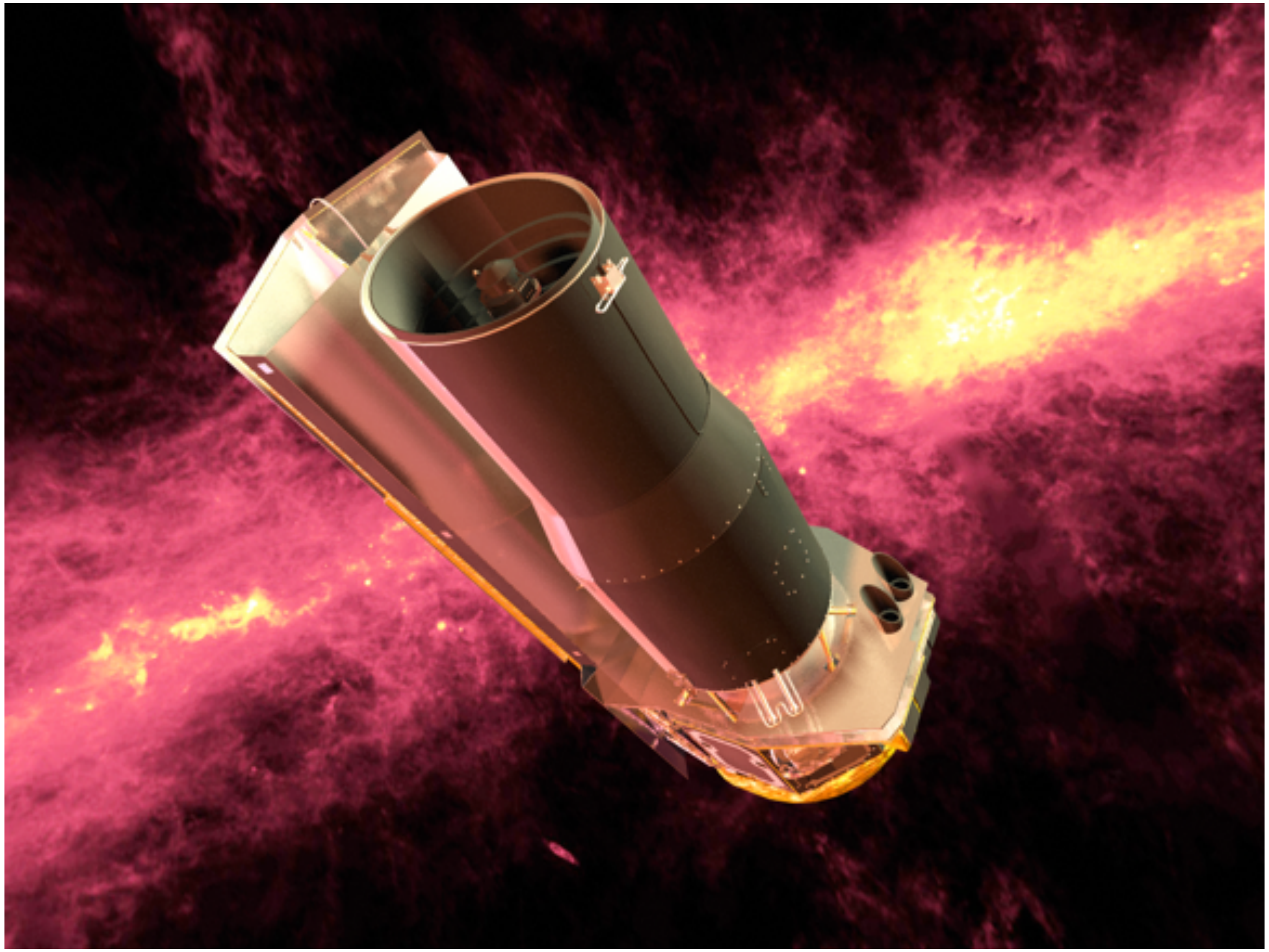
Cycles 10-12 (2014-2016)
194 galaxies x 10 epochs

Cycles 13 & 14 (2017-2019)
105 galaxies x 8 epochs

Sample < 20 Mpc

Depth of 20 mag (Vega) at [3.6] and 19 mag at [4.5]

Cadence baselines spanning one week to several years



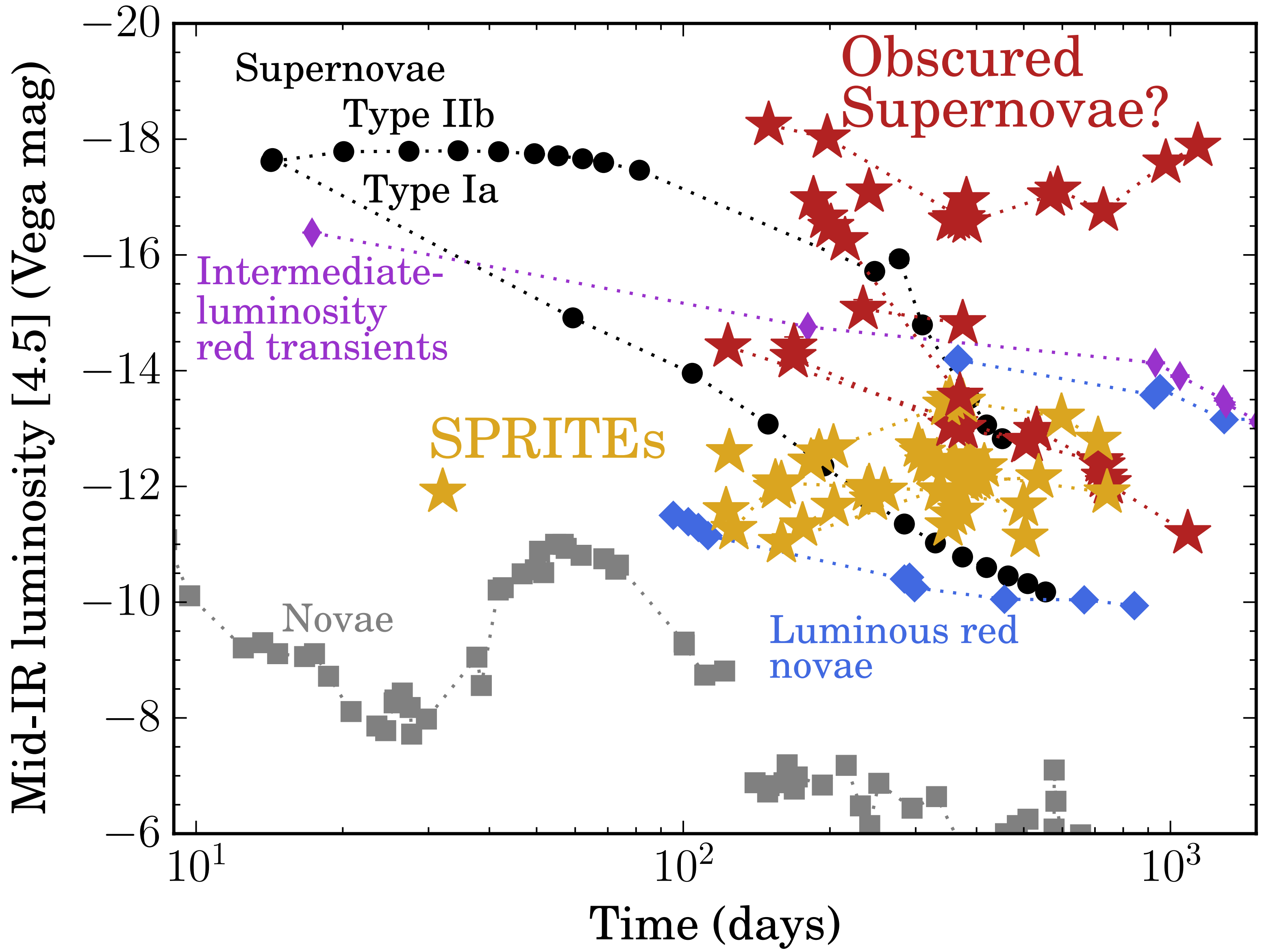
PI: M Kasliwal, Project Scientist: J Jencson
Team: S Adams, R Lau, S Tinyanont, D Perley, F Masci, G Helou, L Armus, S Van Dyk, A Cody, M Boyer, H Bond, A Monson, J Bally, O Fox, R Williams, P Whitelock, R Gehrz, N Smith, J Johansson, E Hsiao, M Phillips, N Morell, C Contreras, M Ressler, A Moore+

SPIRITS is discovering a wide range of IR transient sources.

Identified 125+ transients:

- 49 known supernovae
- 6 likely novae
- 60+ eSPecially Red Intermediate-Luminosity Transient Events (SPRITEs; Kasliwal+ 2017)

10 luminous transients are newly discovered candidate obscured SNe.



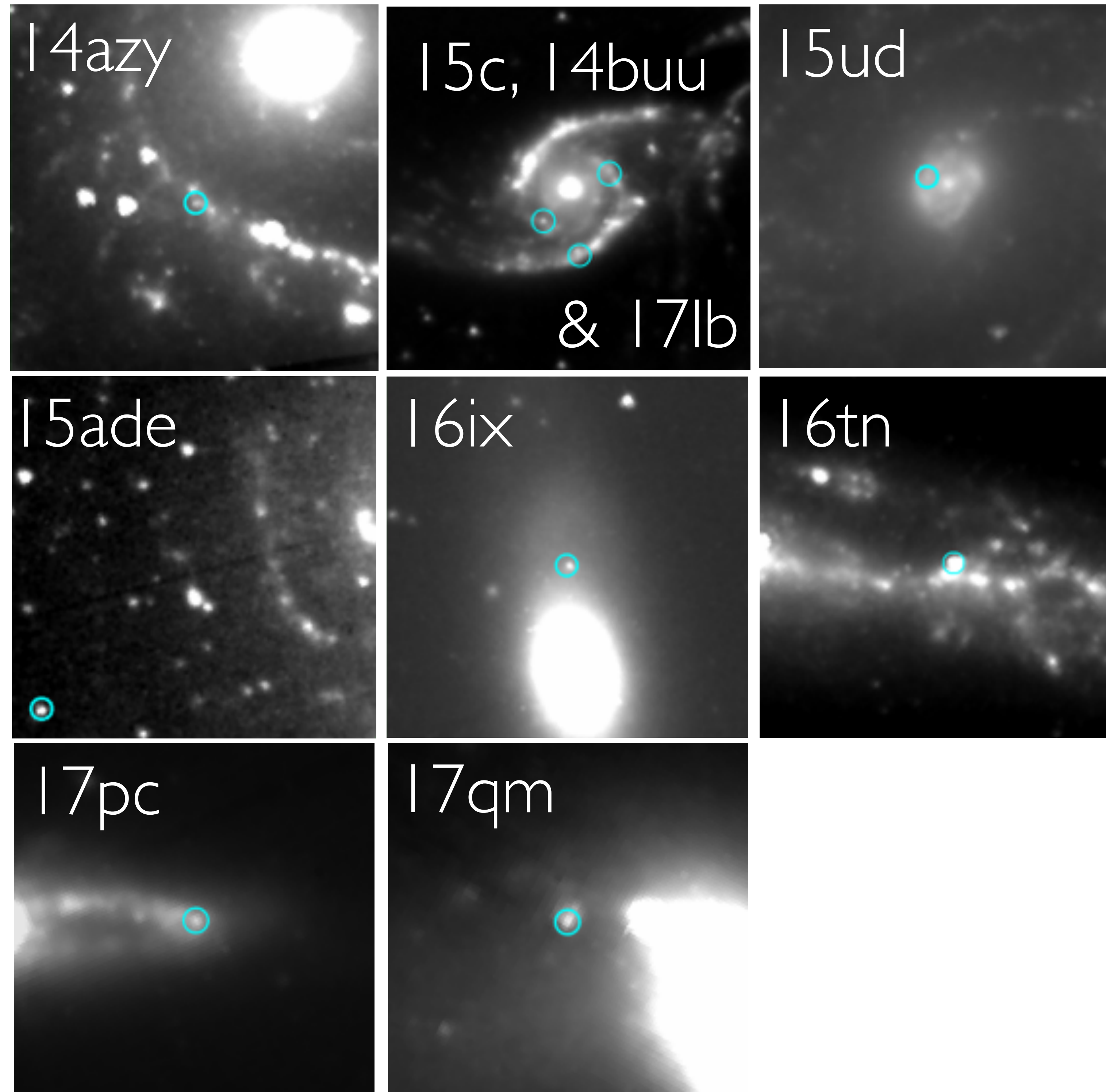
ATels: Kasliwal+ 2014: #6644
Jencson+ 2015-18: #7929, 8688, 8940, 9434, 10171, 10172, 10488, 10903, 11575

Fraction of obscured events in nearby galaxies may be as high as ~ 50%.

Comparable number of optically discovered core-collapse SNe in our sample since 2014

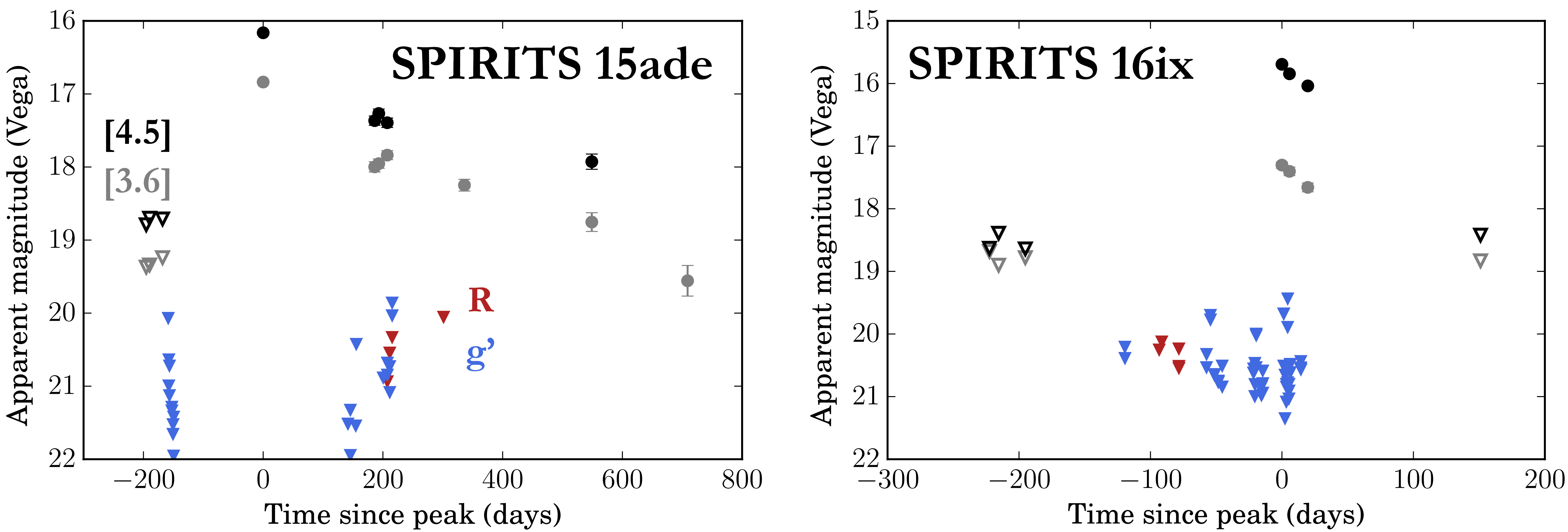
6 with spectroscopy and one additional based on optical/near-IR light curves (Jencson+ 2017; Jencson+ 2018, in press; Jencson+ 2018 in prep.)

Radio follow-up with VLA and ATCA ongoing



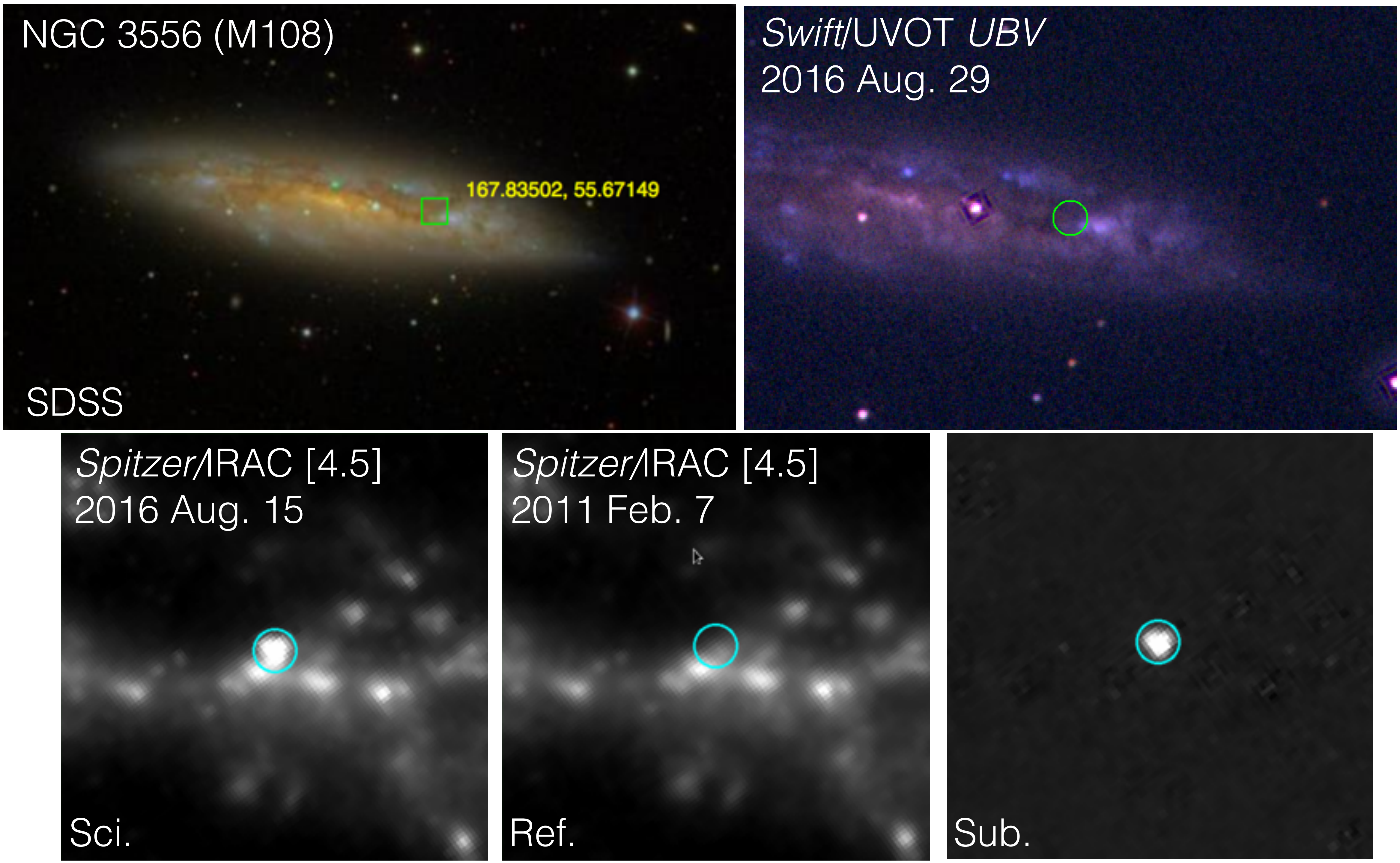
Optical/near-IR coverage from Palomar provides key information on extinction.

Optical limits from iPTF:



Regular coverage by ZTF will continue to constrain optical emission from SPIRITS events

SPIRITS 16tn: a highly obscured, likely core-collapse SN at only 9 Mpc

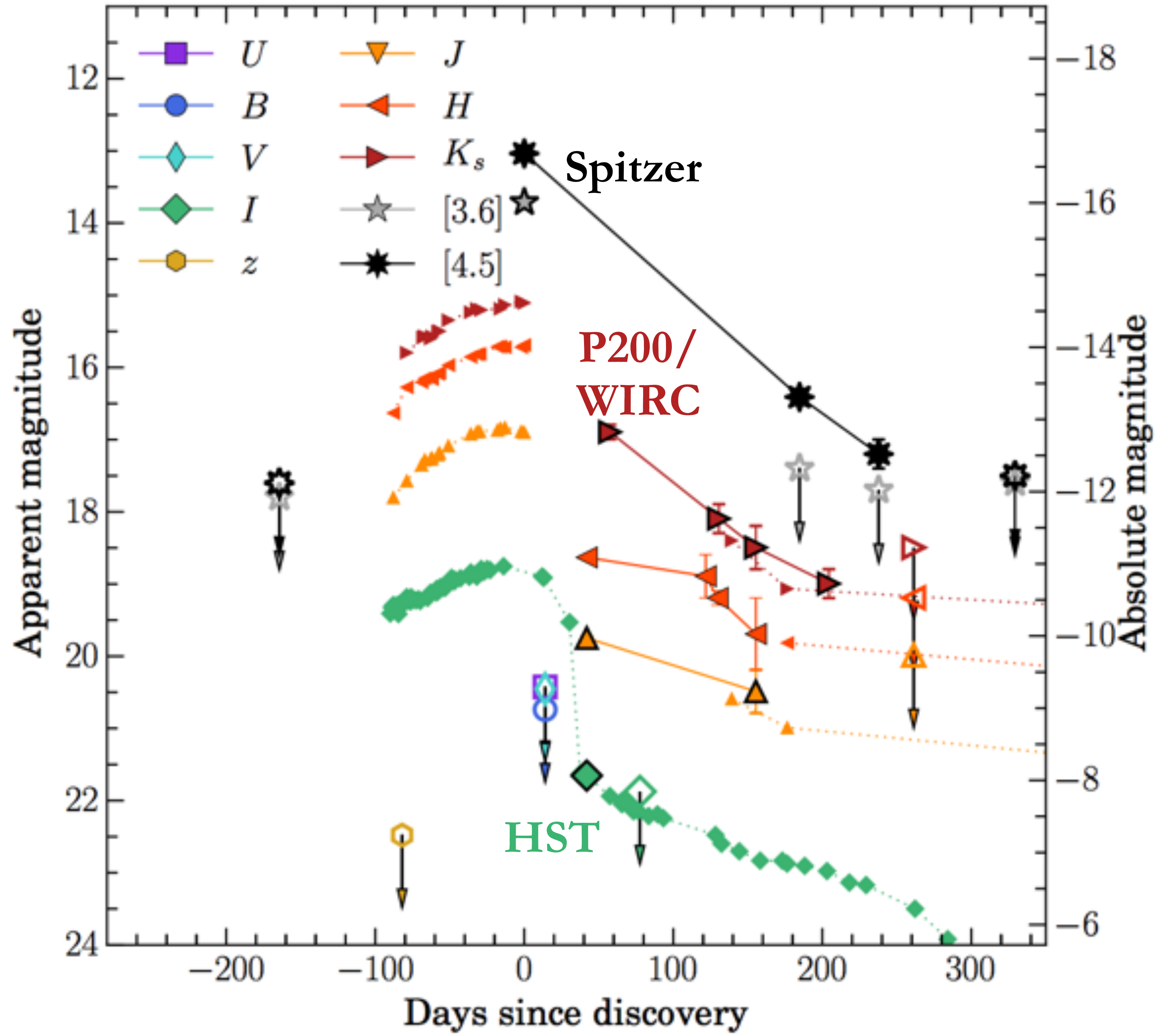


Jencson+ 2018, in press
arXiv:1803.00574

Optical/near-IR coverage from Palomar provides key information on extinction.

SPIRITS 16tn: Light curve comparison SN 2005cs indicates $A_V \sim 8$ mag

See also:
SPIRITS 15c (type IIb with $A_V \sim 2.2$ mag) and **SPIRITS 14buu** (type IIP with $A_V = 1.5$) in IC 2163 (Jencson+ 2017)



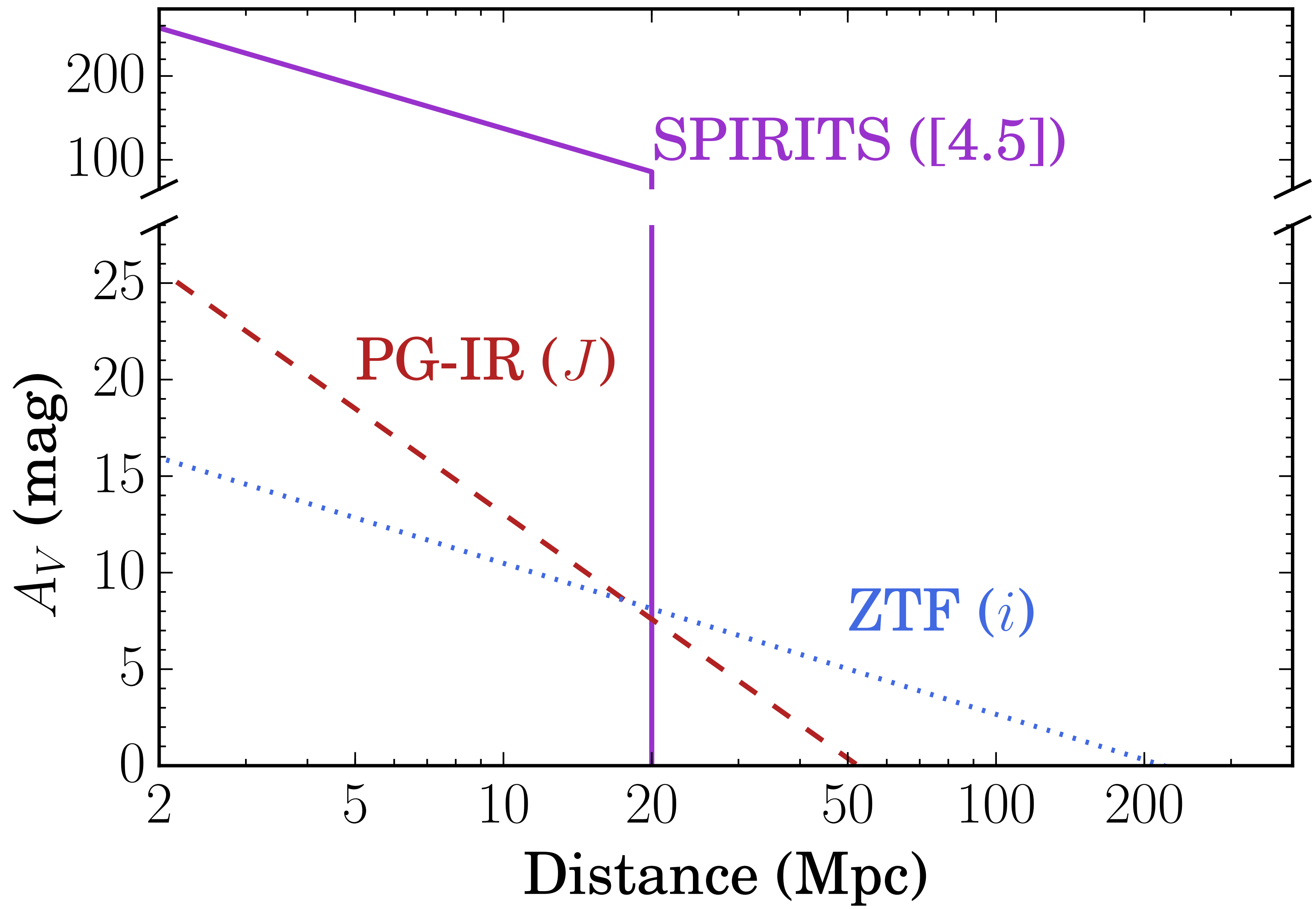
Jencson+ 2018, in press
arXiv:1803.00574

A combination of optical/IR searches will be sensitive to obscured supernovae at a range of distances.

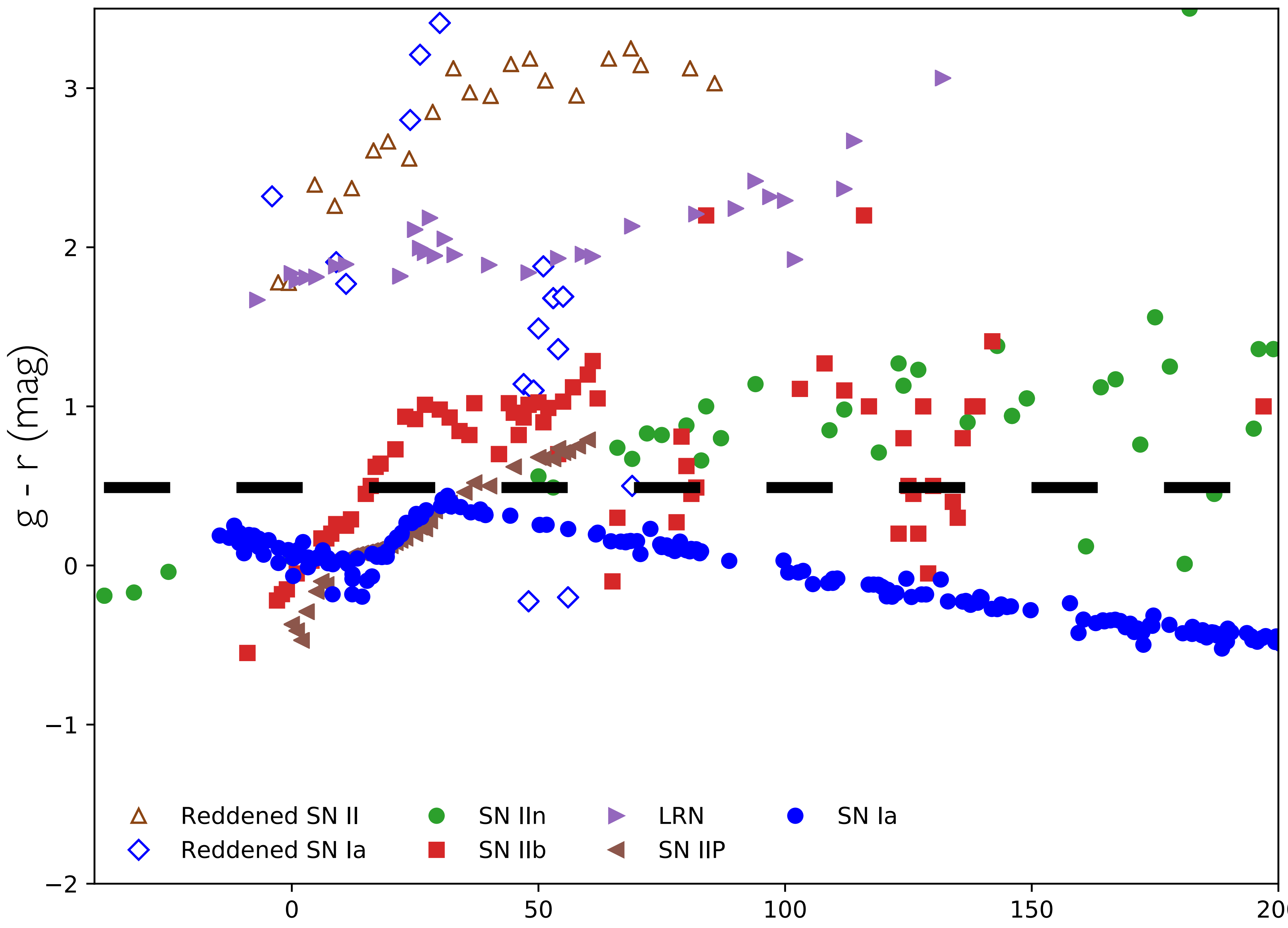
SPitzer InfraRed Intensive Transients Survey (SPIRITS):
- 3.6 and 4.5 μm targeted survey of nearby galaxies

Zwicky Transient Facility (ZTF):
- i-band survey of 6700 deg^2 at 4-day cadence
- Expect ~ 50 CCSN within 100 Mpc in 1 year

Palomar Gattini-IR (PG-IR):
- Nightly J-band survey of 15000 deg^2
- Expect ~ 13 SNe within 50 Mpc in 1 year



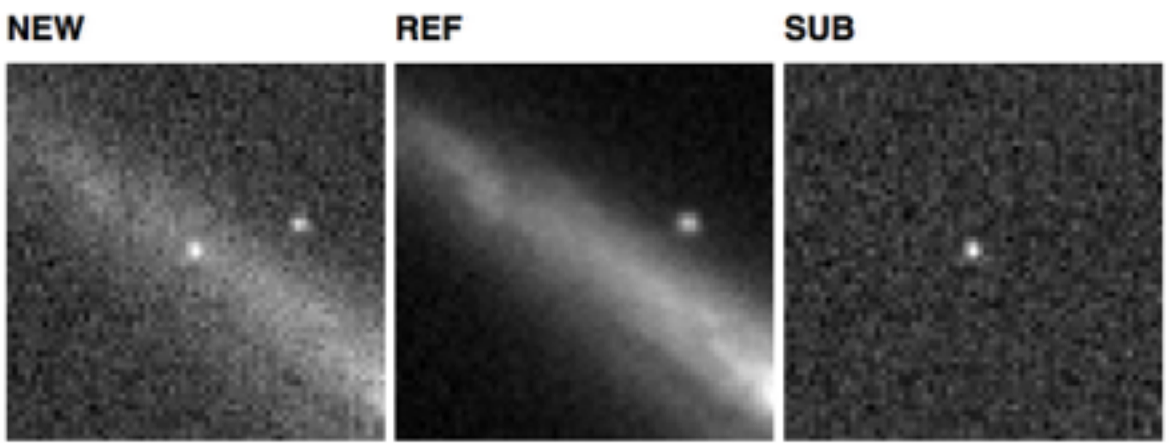
Optical broadband colors can be used to identify promising candidates from ZTF.

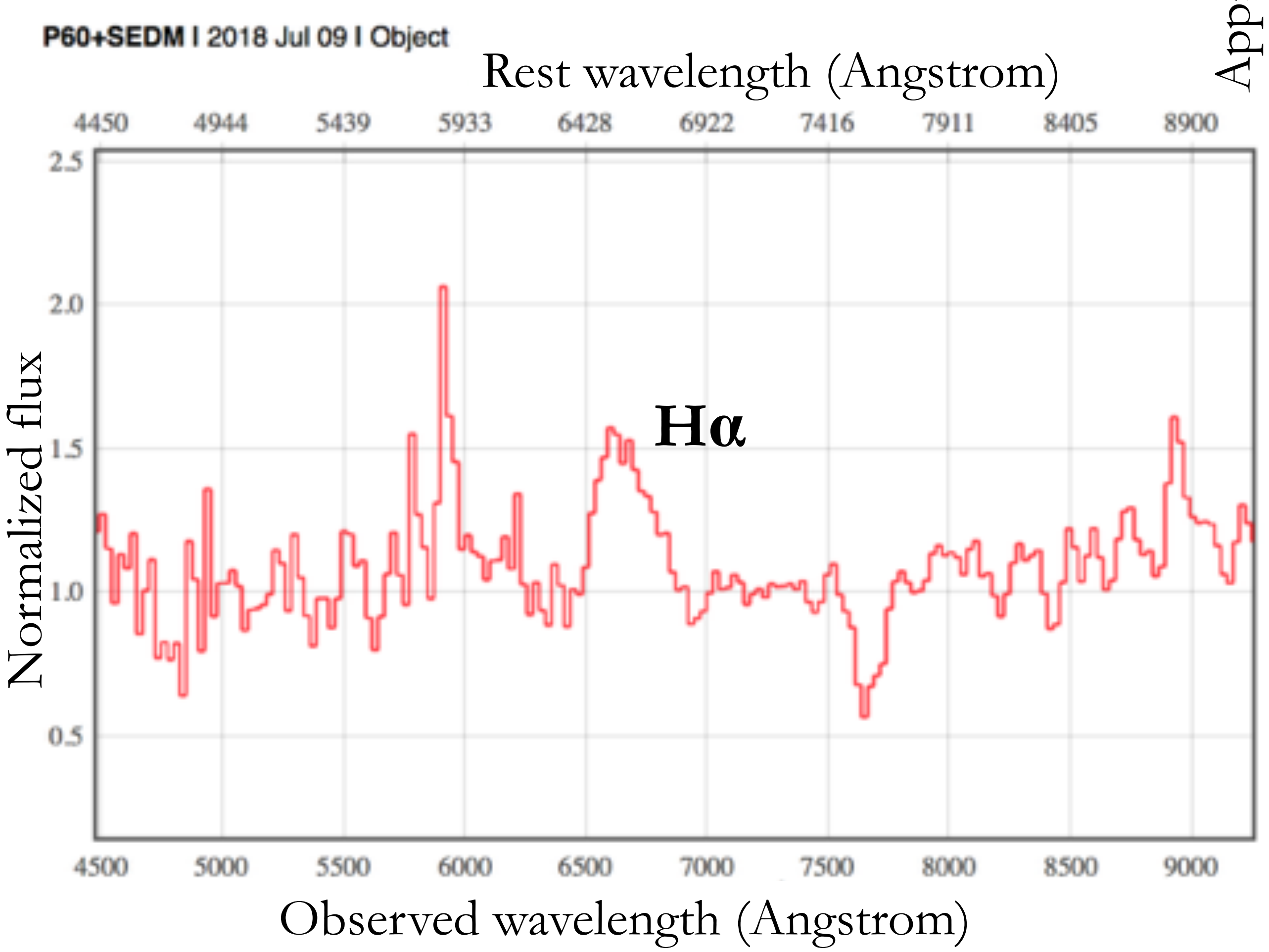


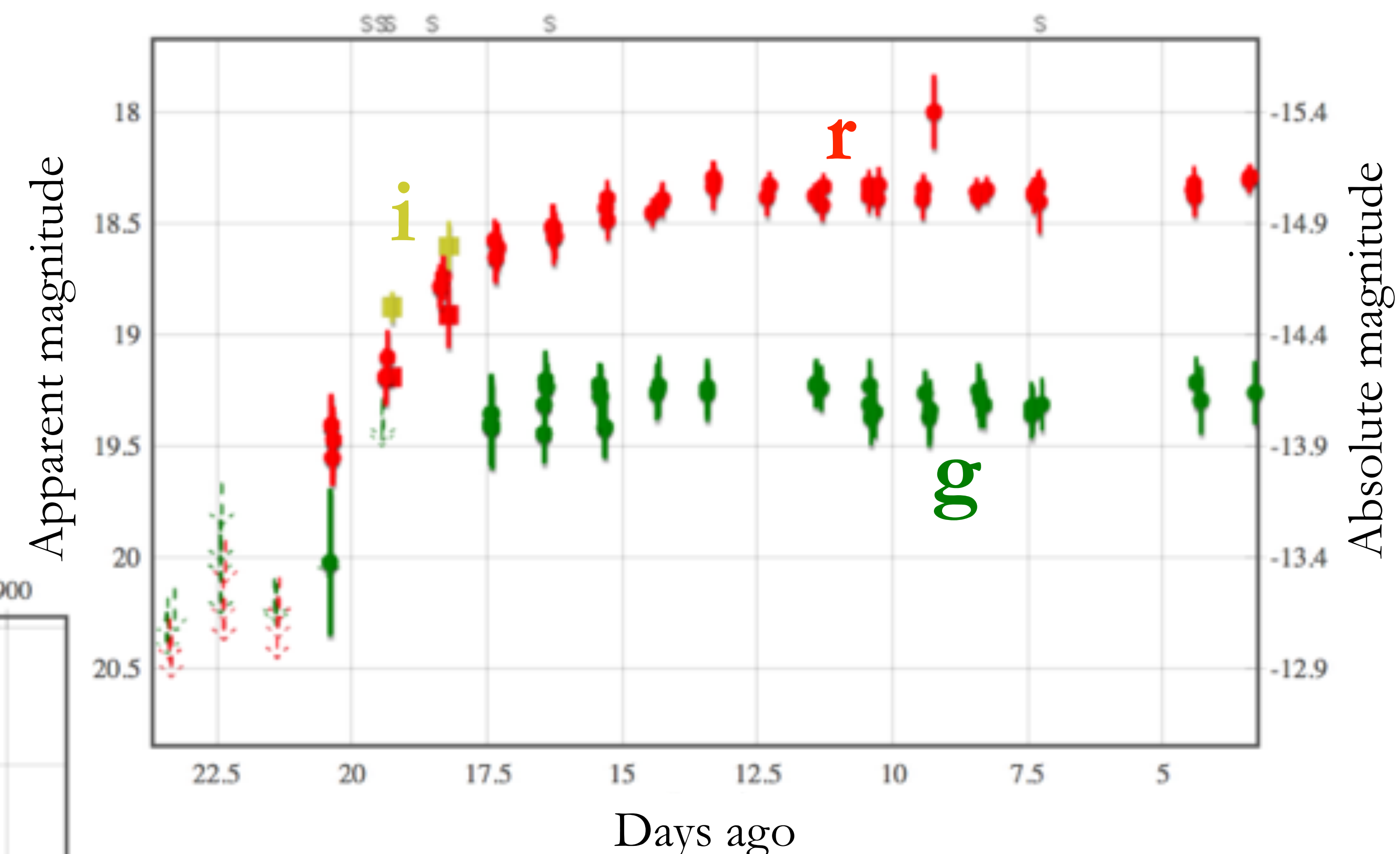
Courtesy N. Blagorodnova

Red transient discoveries from ZTF so far:

ZTF18abdbysy: Reddened SN II



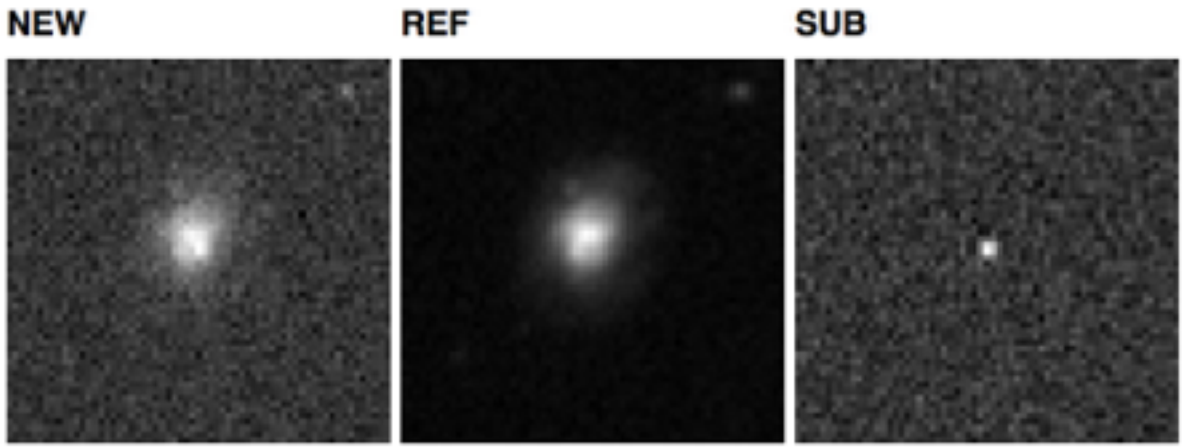


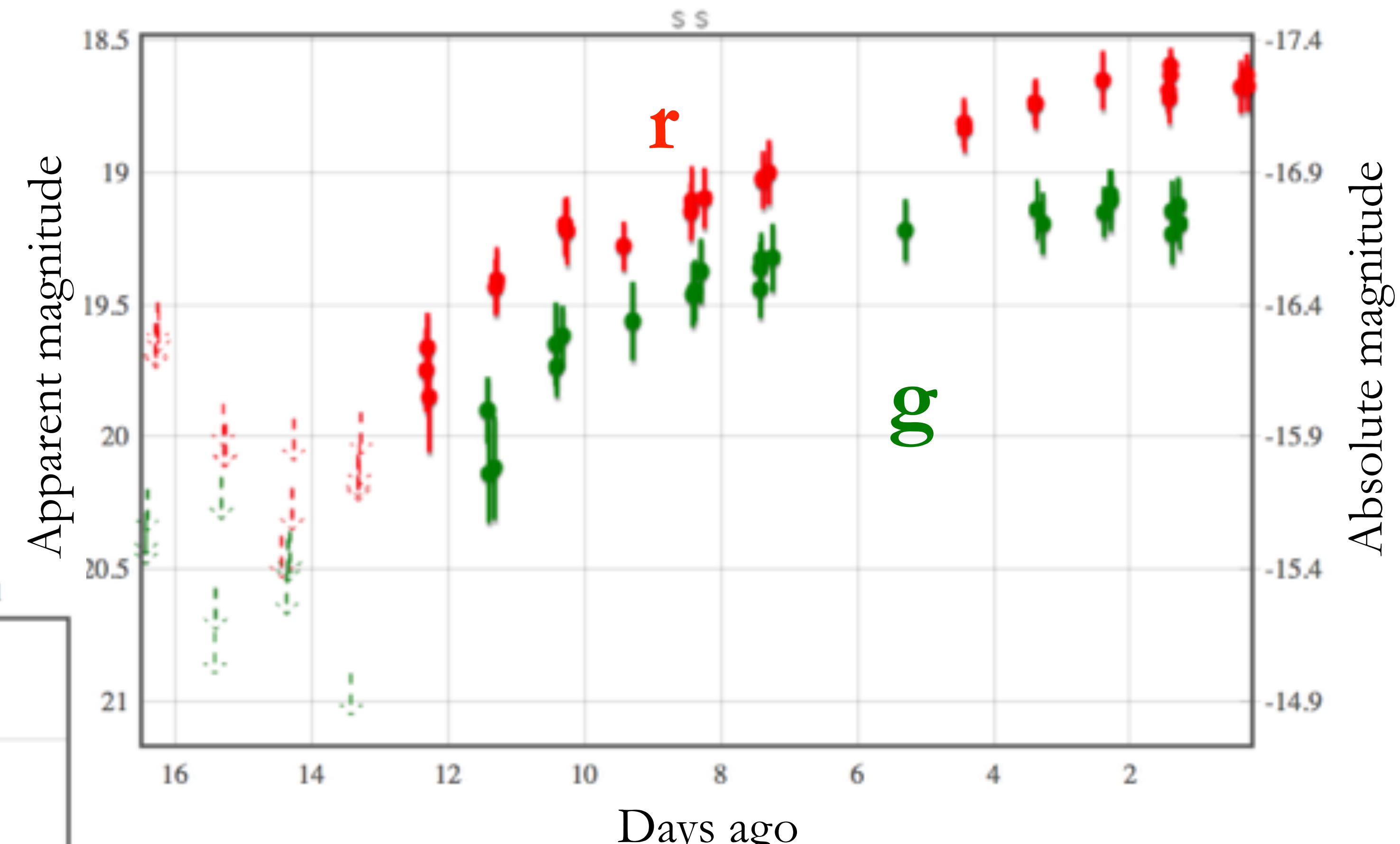


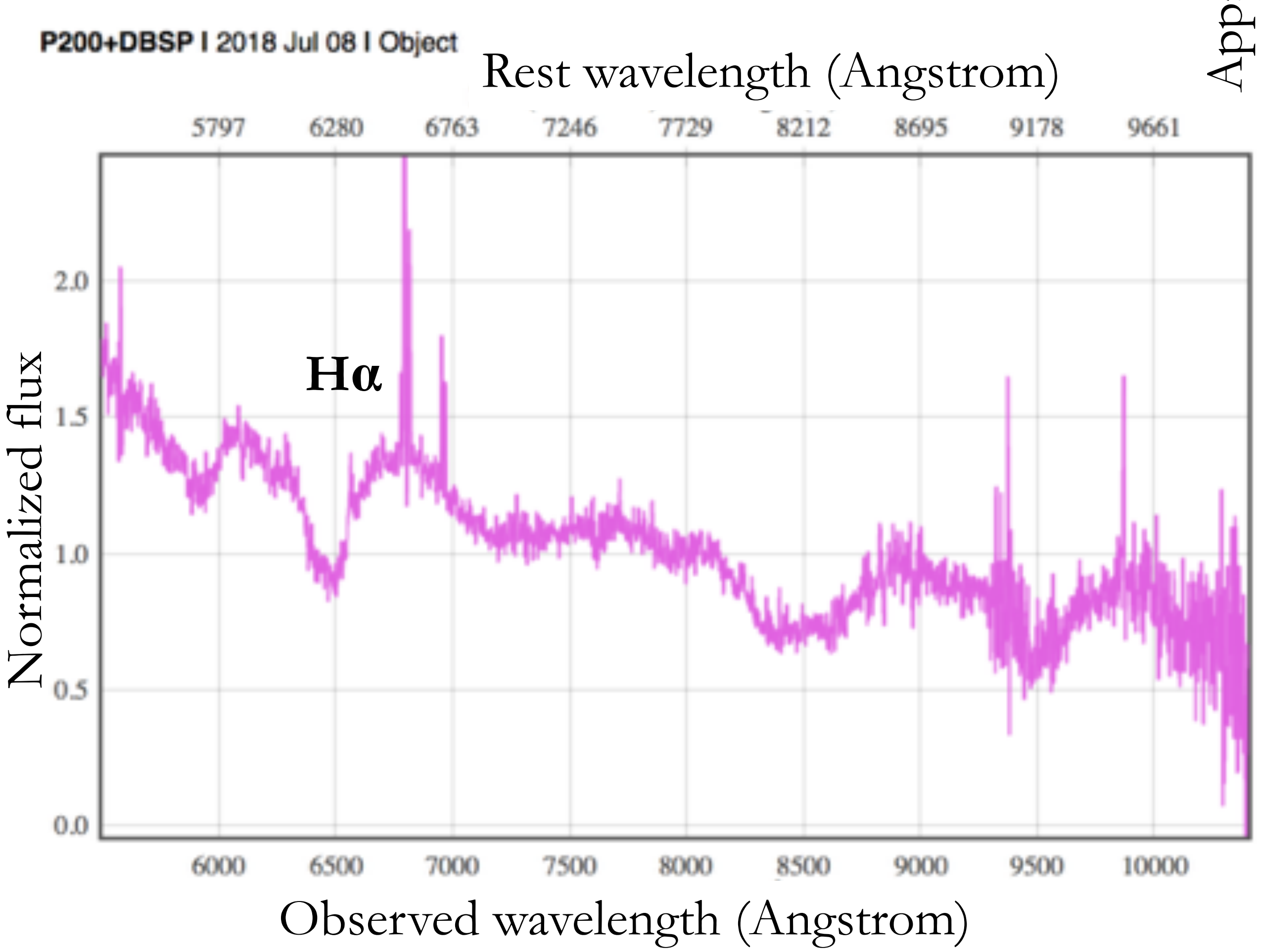
g - r = 0.8 mag

Red transient discoveries from ZTF so far:

ZTF18abeamgv: Reddened SN IIb?







g - *r* = 0.4 mag

Palomar Gattini-IR: a new wide-field, ground-based IR transient survey

300 mm aperture telescope

25 deg^2 FOV

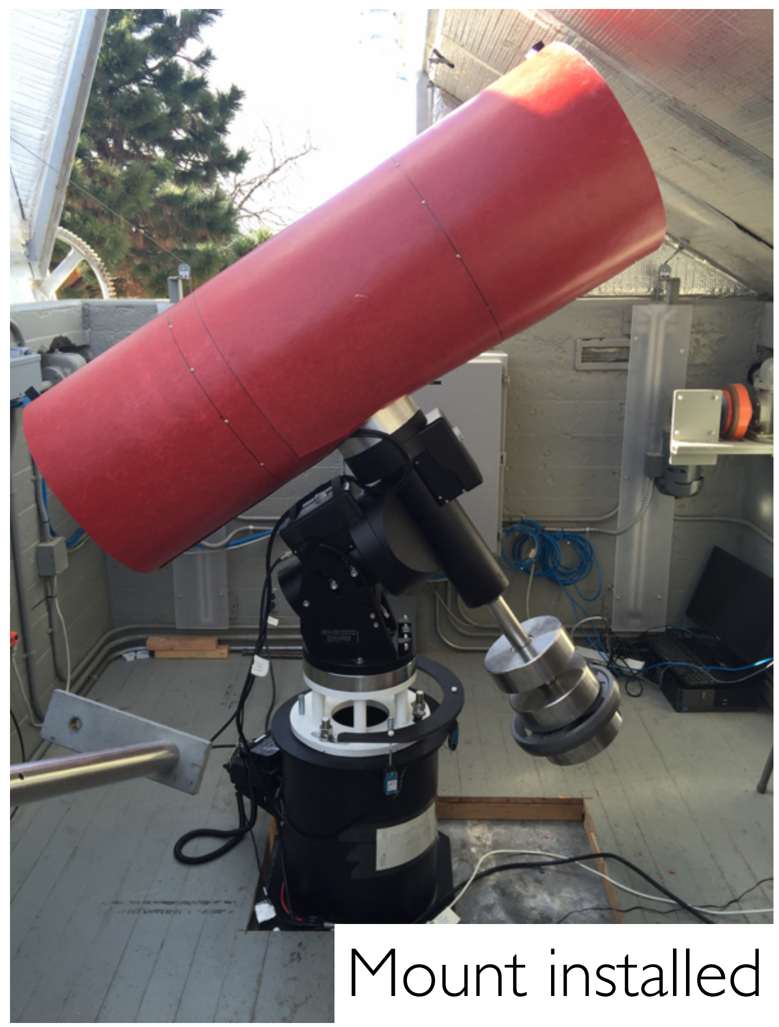
Survey 15000 deg^2 to J = 16.4 mag AB every night

Reach 17.5 mag in one week stack

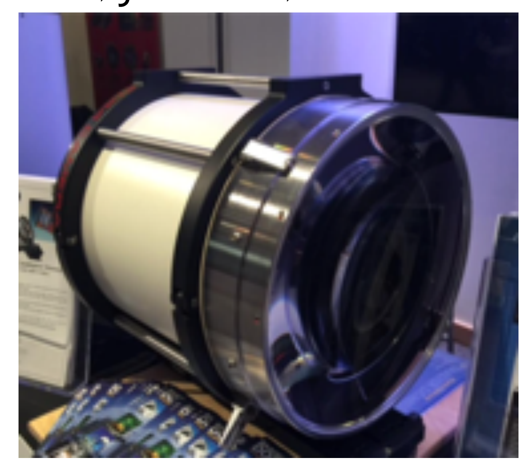
Rooftop testing complete. Commissioning at Palomar soon.

Expect ~ 13 SNe within 50 Mpc in one year

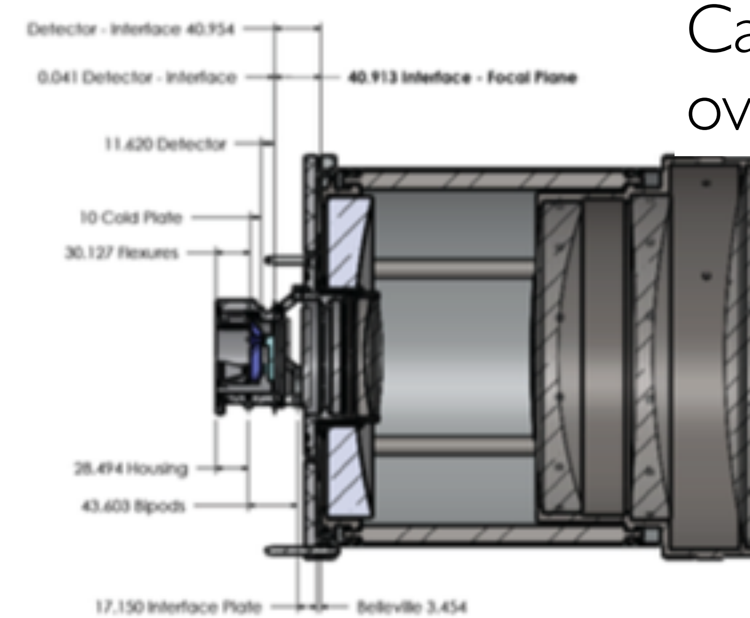
PG-IR Team: M Kasliwal, A Moore, S Adams, R Lau, K De, J Jencson, A Delacroix, R Smith, D McKenna, D Hale, R Dekany, J Burhnam, T Travouillon, M Ashley, J Sokoloski, J Soon, E Ofek+



Mount installed



TEC-300VT prototype



Camera overview

Moore+ 2016

Summary

Searches for supernovae and transients may miss events obscured by dust.

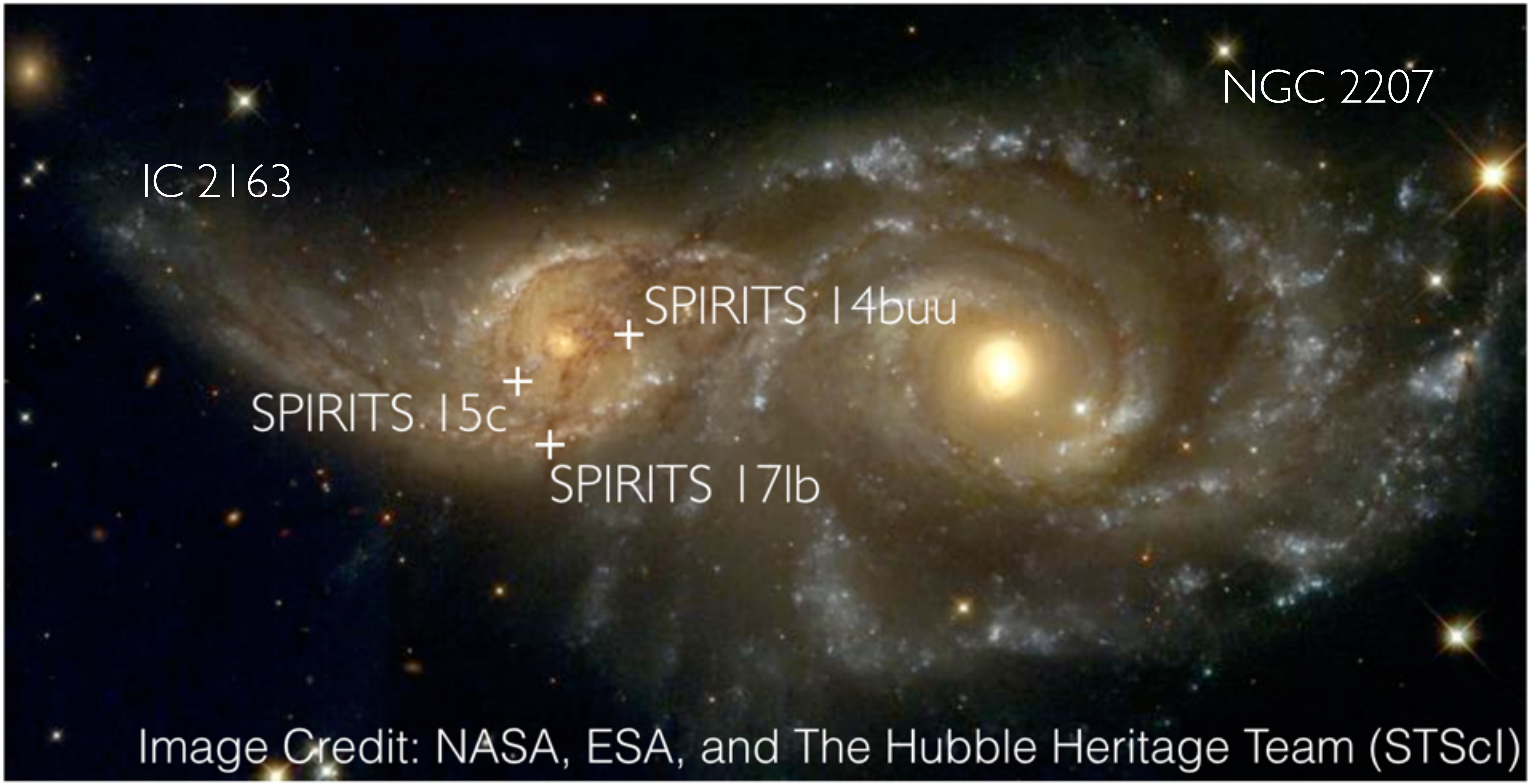
SPIRITS is an ongoing search for transients in nearby galaxies in the mid-IR with Spitzer, and support from Palomar telescopes provides more detailed characterizations.

ZTF (*gri*) and Palomar Gattini-IR (*J*) will conduct wide-field surveys sensitive to reddened SNe and varying levels of extinction and distances, allowing us to build spectroscopically complete samples.

Searching for and characterizing obscured SNe will allow us to probe their significance for the missing SN fraction, and whether these events represent a separate population originating from extreme environmental conditions and/or progenitor systems.

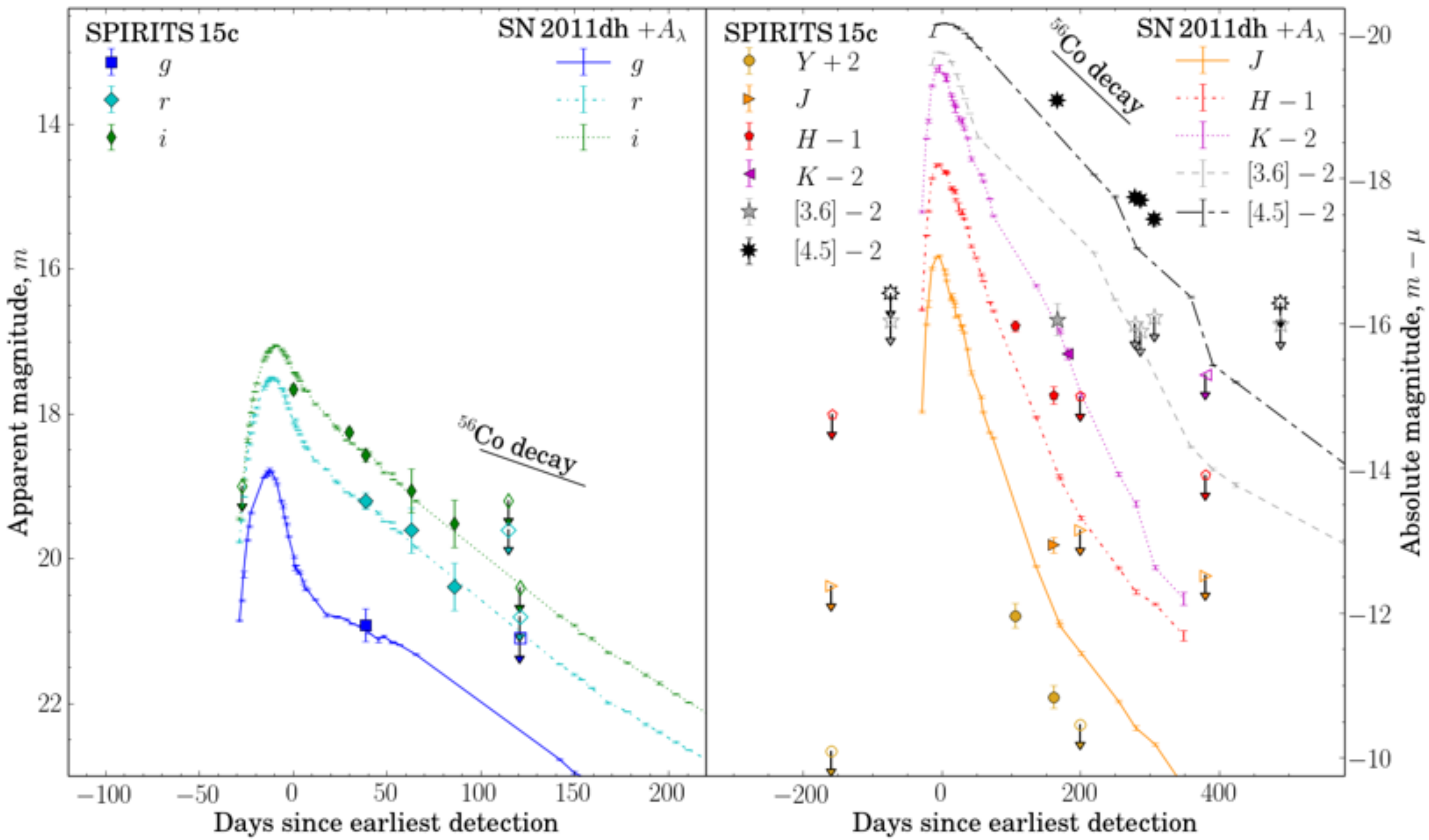
Auxiliary slides

SPIRITS 14buu, 15c, & 17lb: 3 SNe in 4 years in IC 2163.



A simple reddening law can explain the observed light curves.

A_V =2.2 mag, $E(B-V)$ = 0.72 mag, R_V =3.1 (Fitzpatrick 99)



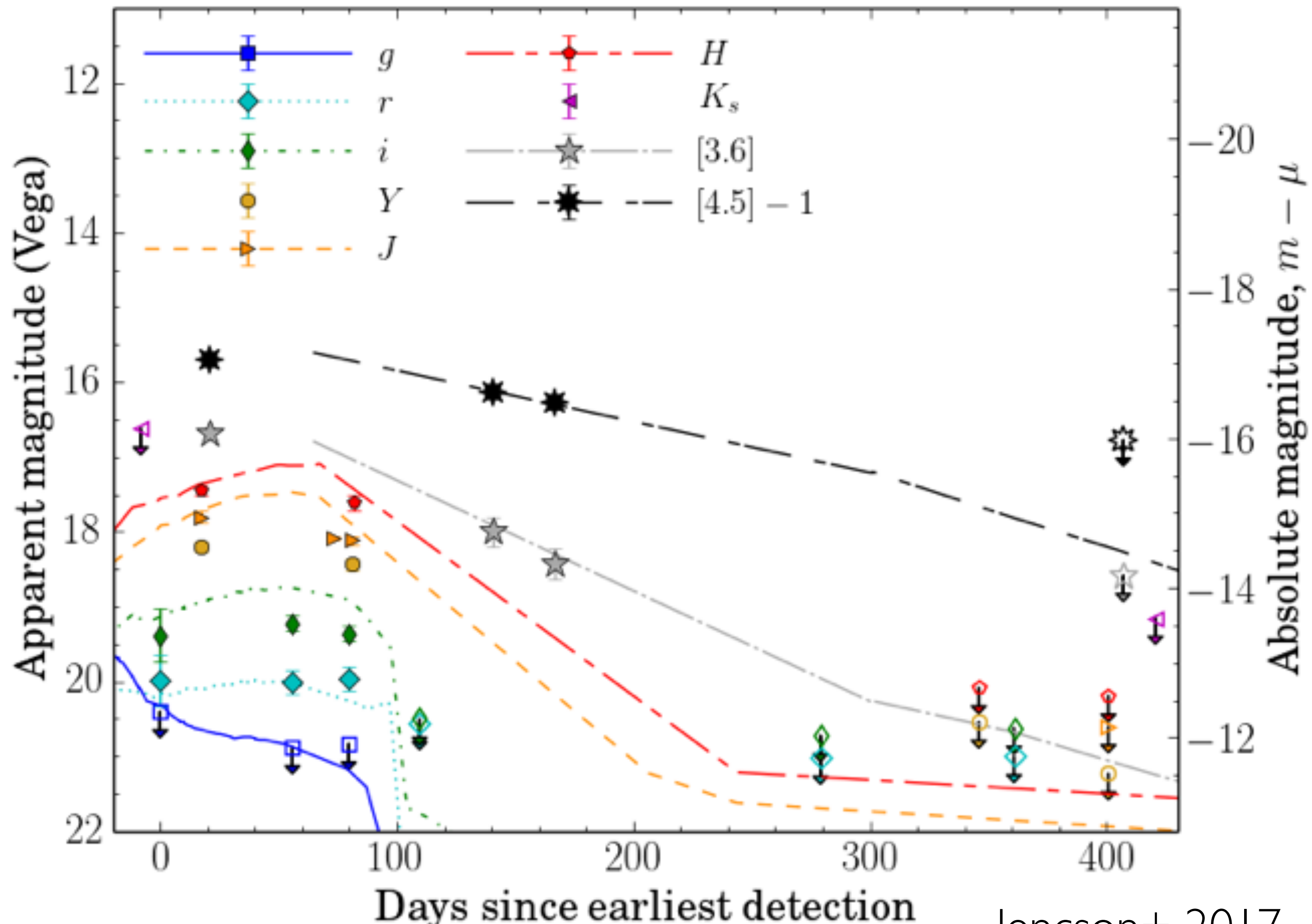
SN 2011dh data, Ergon et al. 2014,2015

Jencson+ 2017

Light curves of SPIRITS 14buu consistent with a reddened SN IIP.

Appears similar to the type IIP SN 2005cs in the optical and near-IR with $A_V = 1.5$ mag.

Mid-IR evolution similar to SN 2004et (shifted by 2.4 mag).

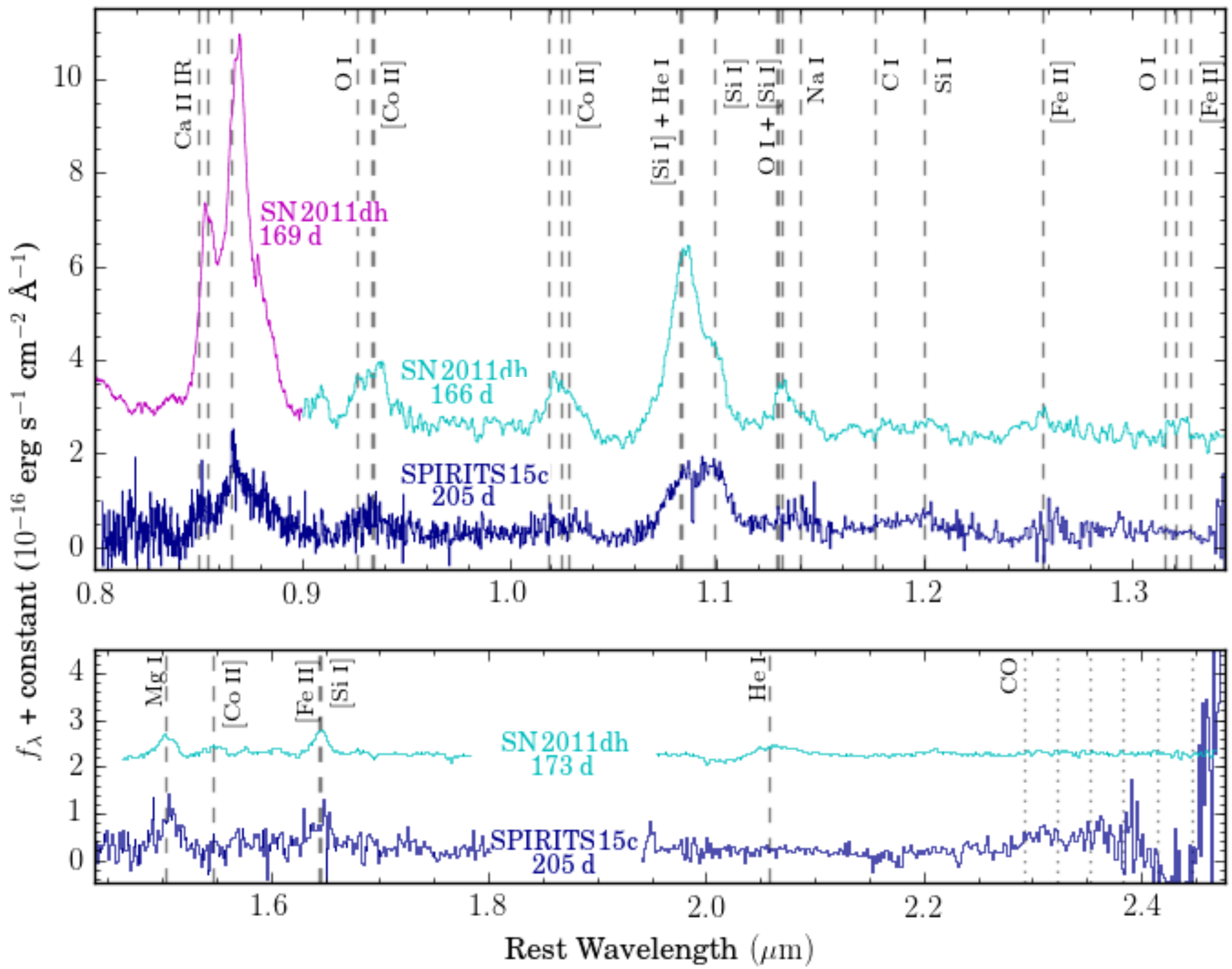


SN 2005cs data, Pastorello et al. 2009

SN 2004et data, Kotak et al. 2009

Jencson+ 2017

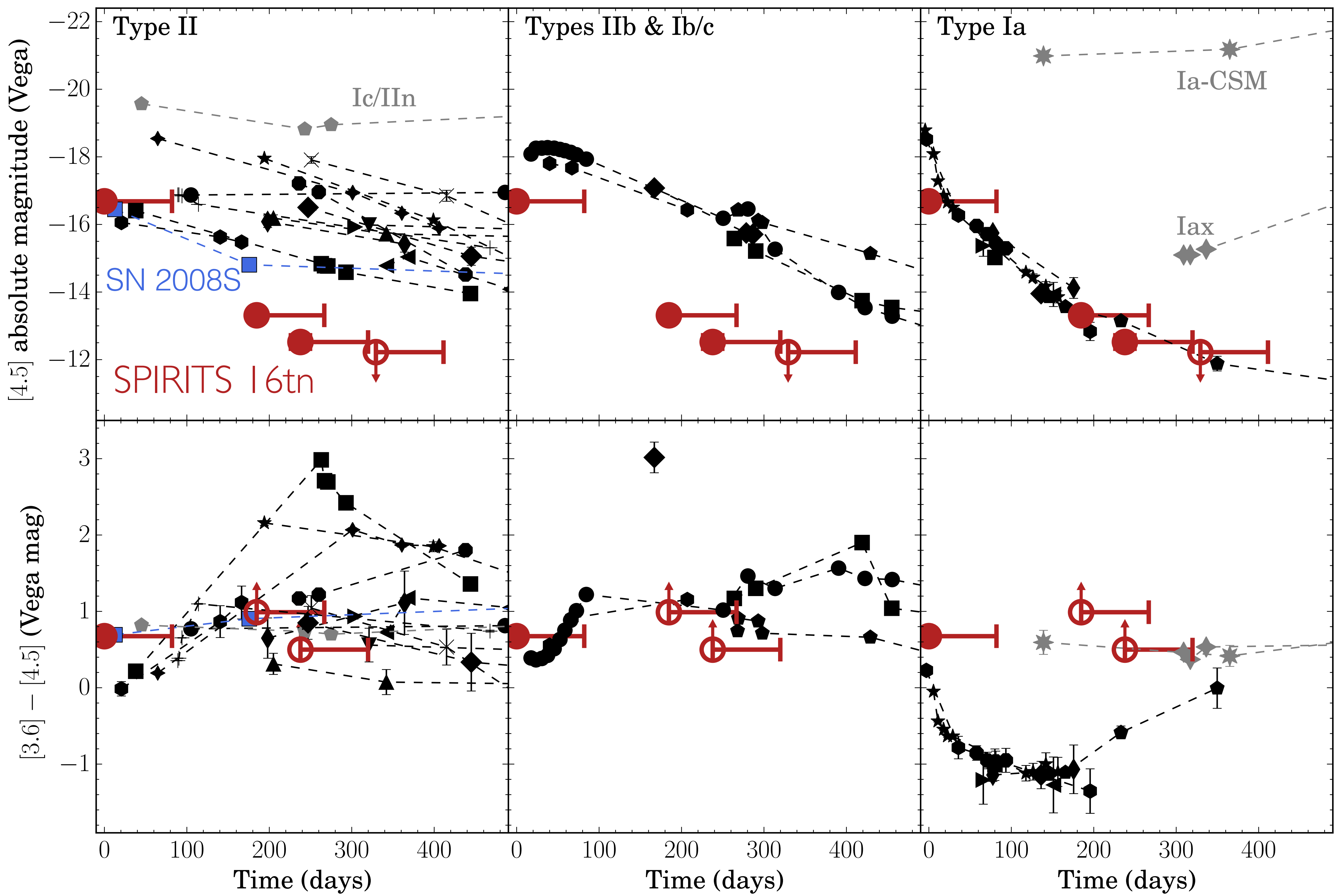
The near-IR spectrum of SPIRITS 15c is similar to that of Type IIb SN 2011dh.



SN 2011dh spectra and line IDs, Ergon et al. 2015, Jerkstrand et al. 2015

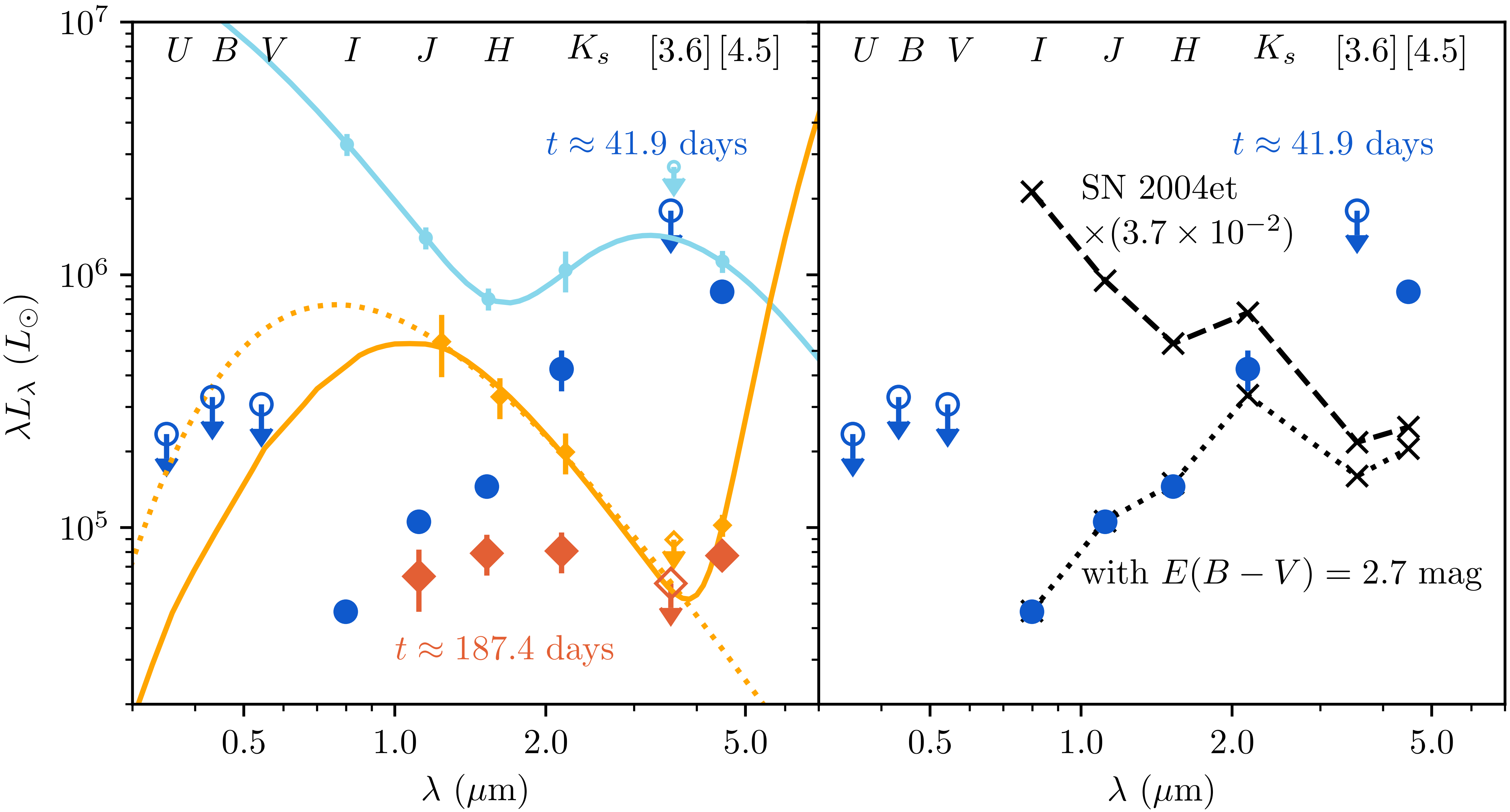
Jencson+ 2017

SPIRITS 16tn is unique in its mid-IR properties.



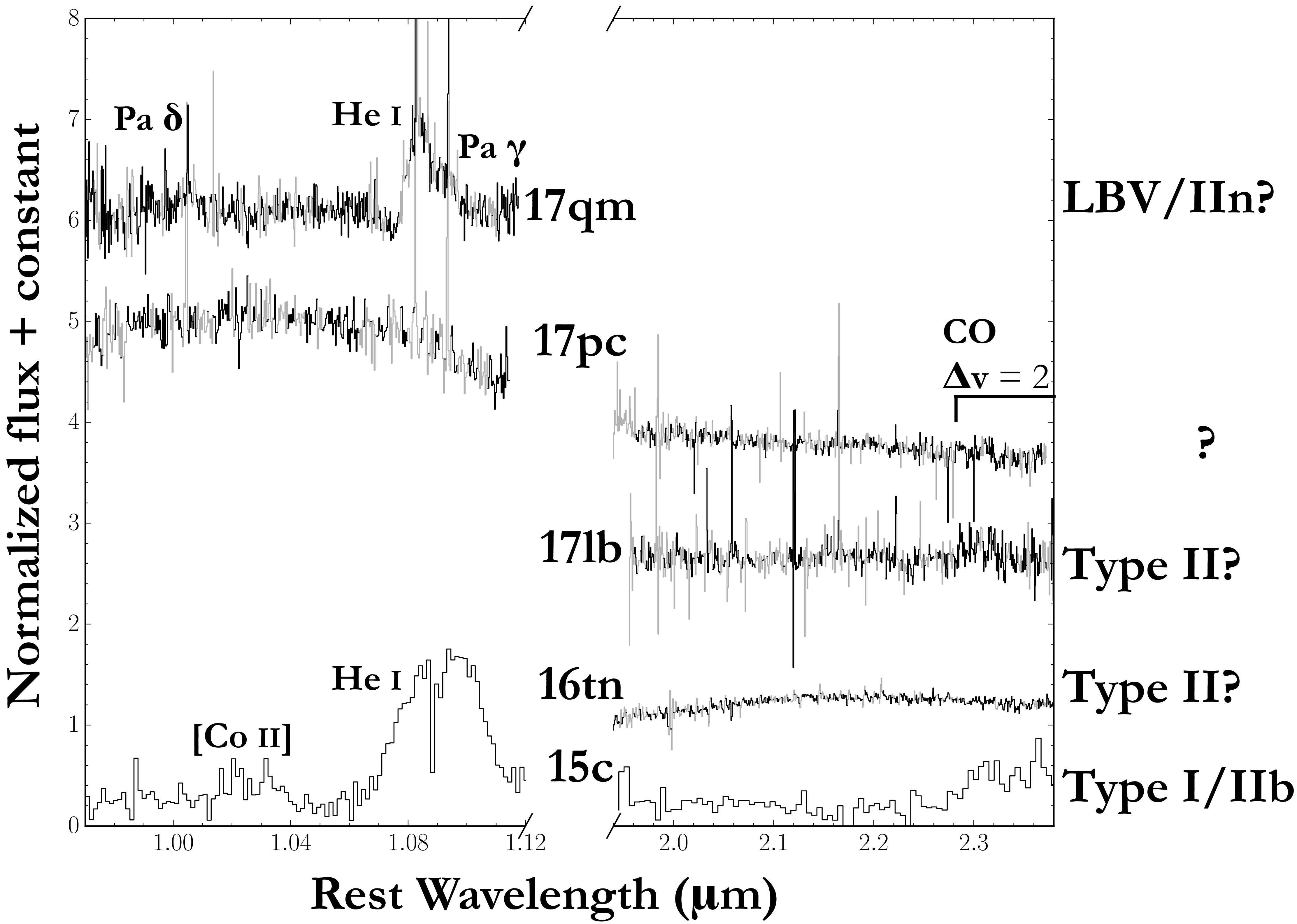
Jencson+ 2018, submitted

Comparisons with Type II SNe suggest $A_V \sim 7 - 9$ mag.

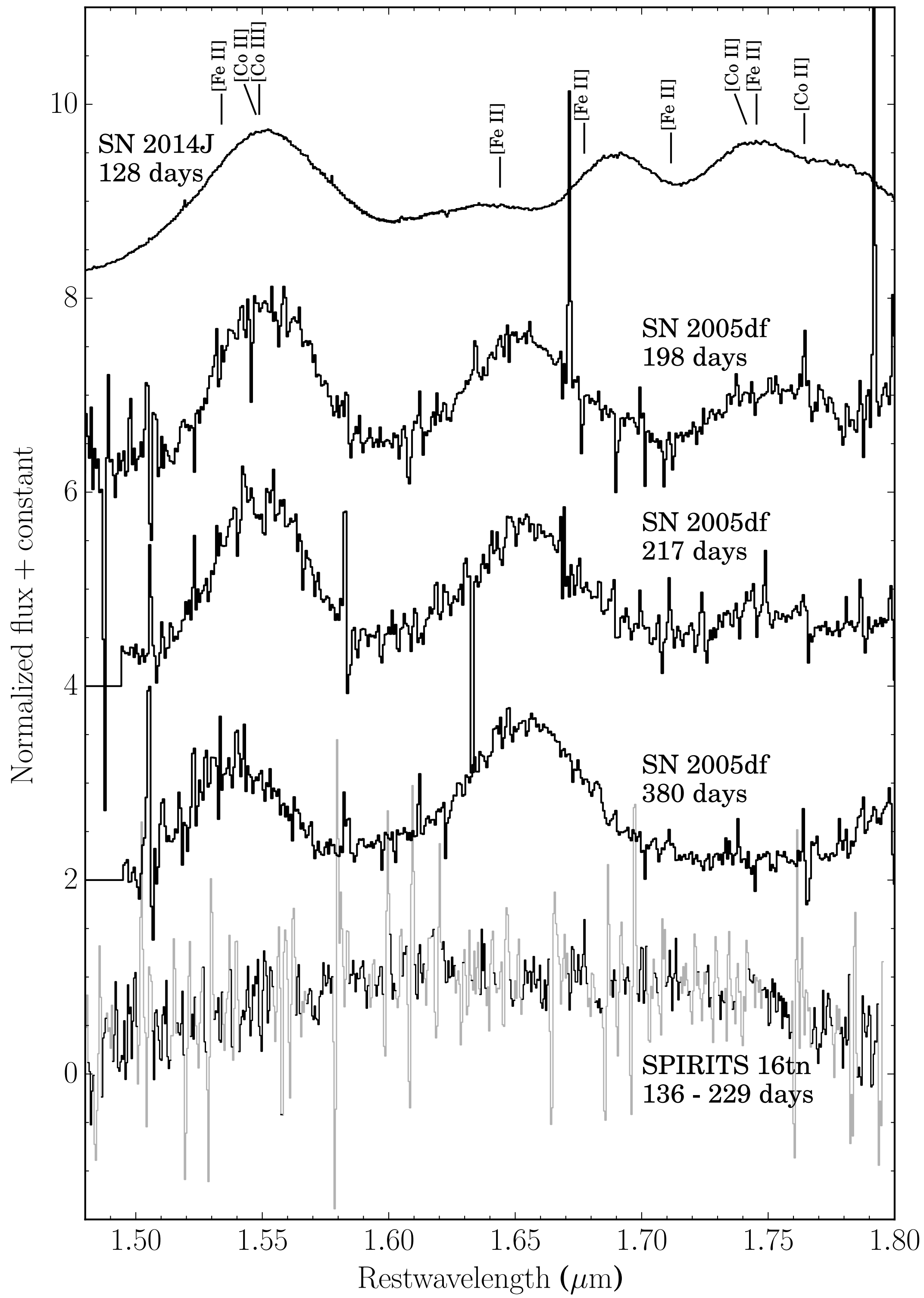


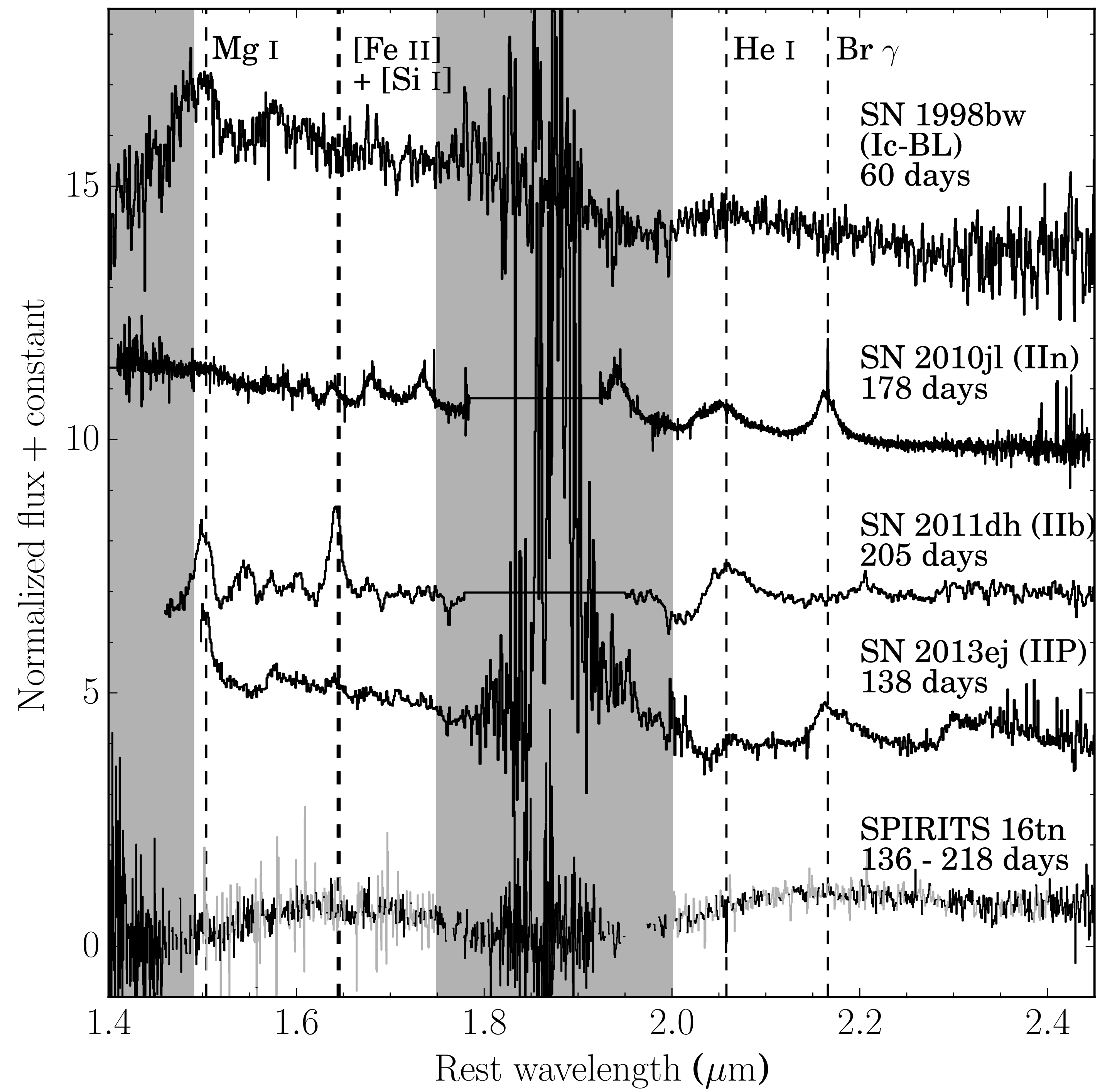
Jencson+ 2018, submitted

Near-IR spectra can provide classifications.



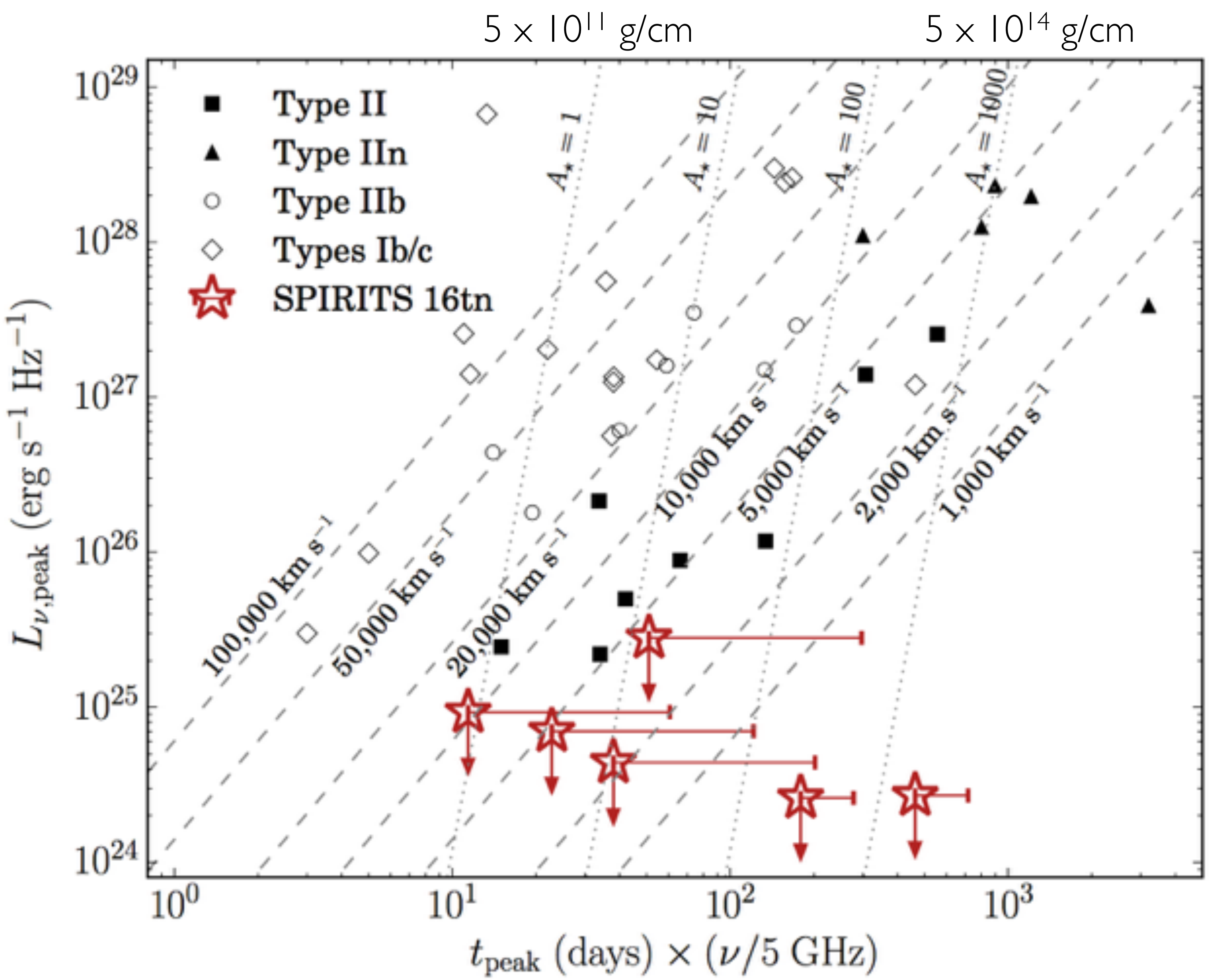
Near-IR spectrum rules out an SN Ia.





Jencson+ in prep.

VLA and AMI radio non-detections suggest a weak event or significant absorption.



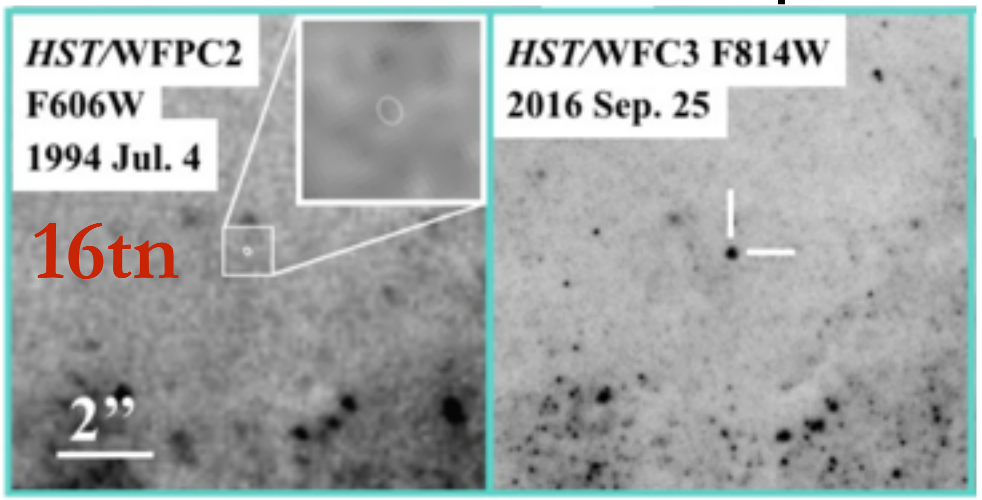
Infer a limit on the pre-SN mass loss rate:

$\dot{M} < 2.4 \times 10^{-6} \times (v_w/10\ \mathrm{km/s})\ M_\odot/\mathrm{yr}$

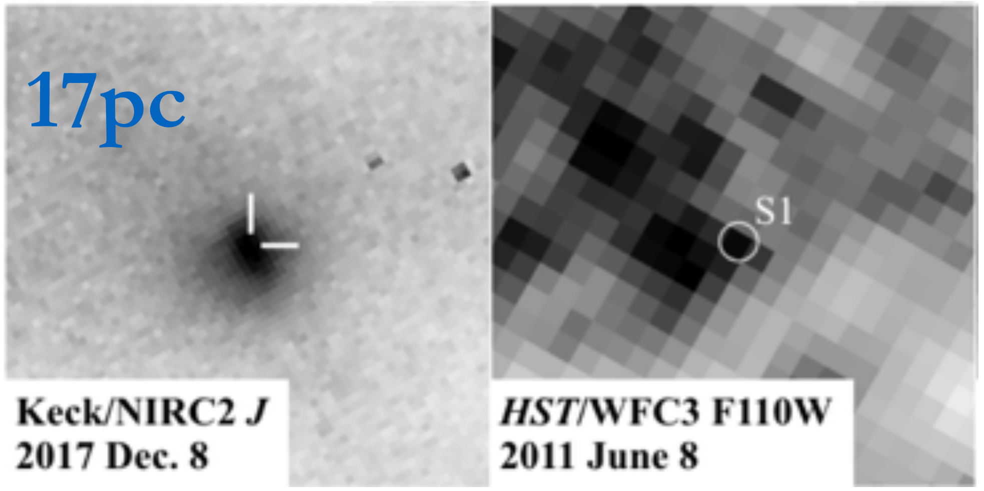
Figure adapted from Romero-Cañizales+ 14.

Jencson+ 2018

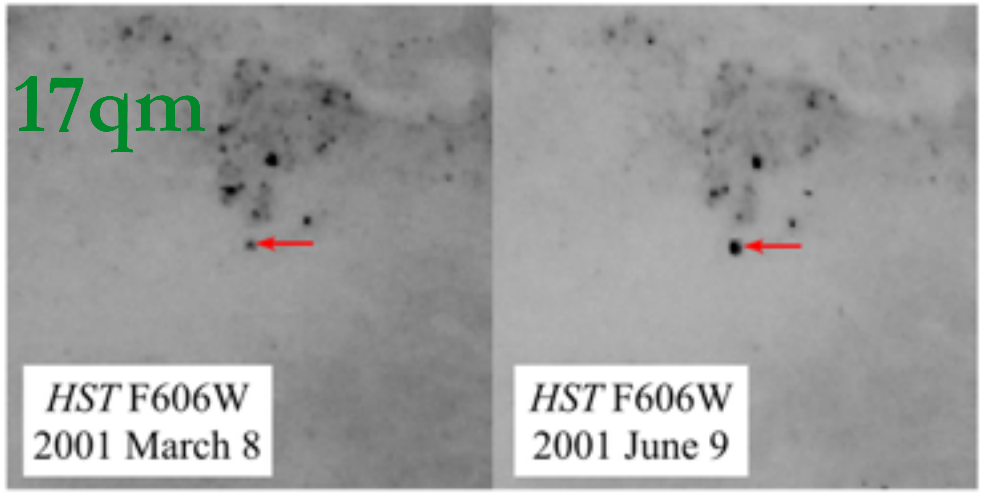
Archival *HST* provides progenitor constraints.



Jencson+ 2018



Jencson+ 2018, ATel #11577



Jencson+ 2018, ATel #11579

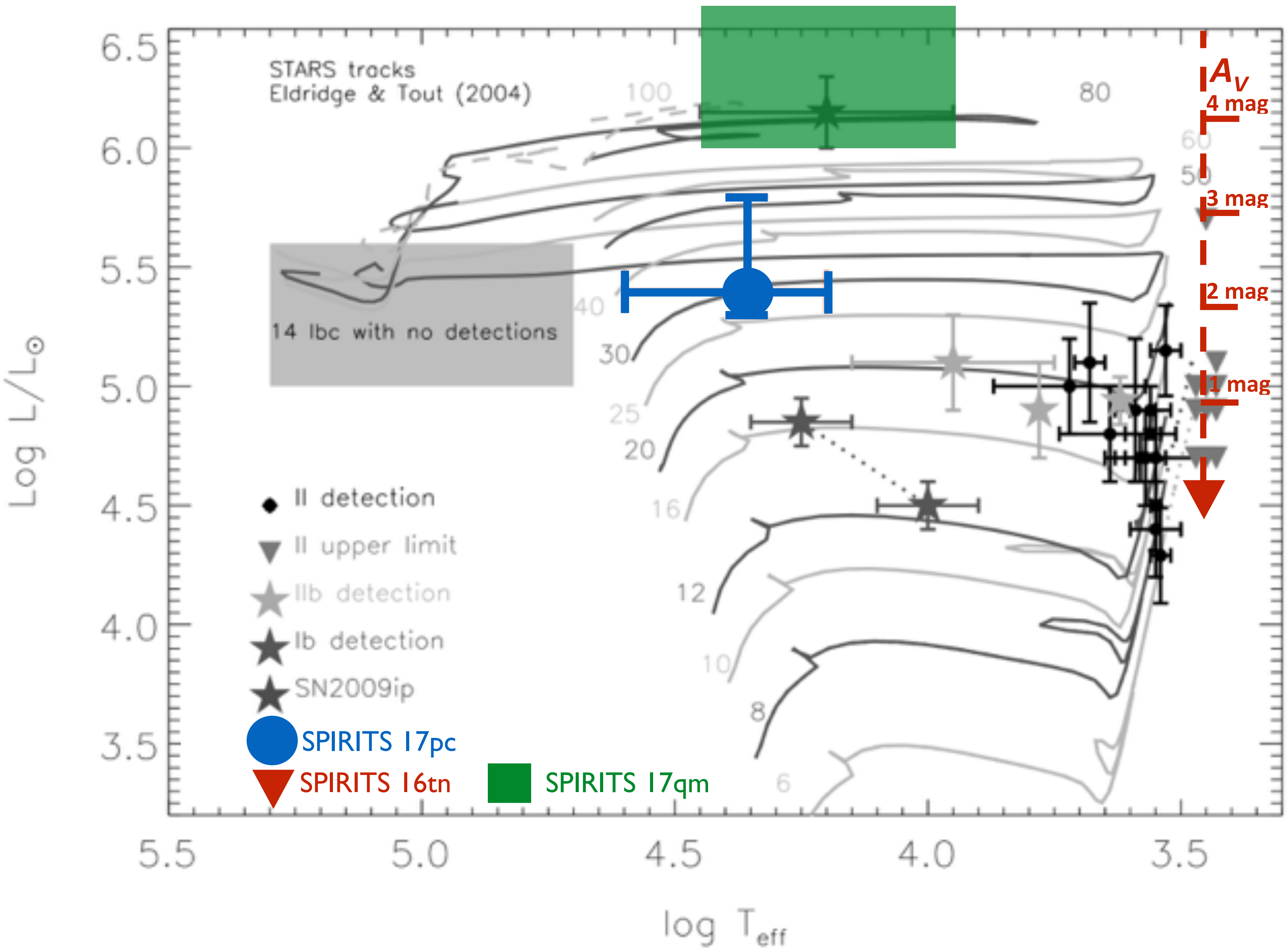
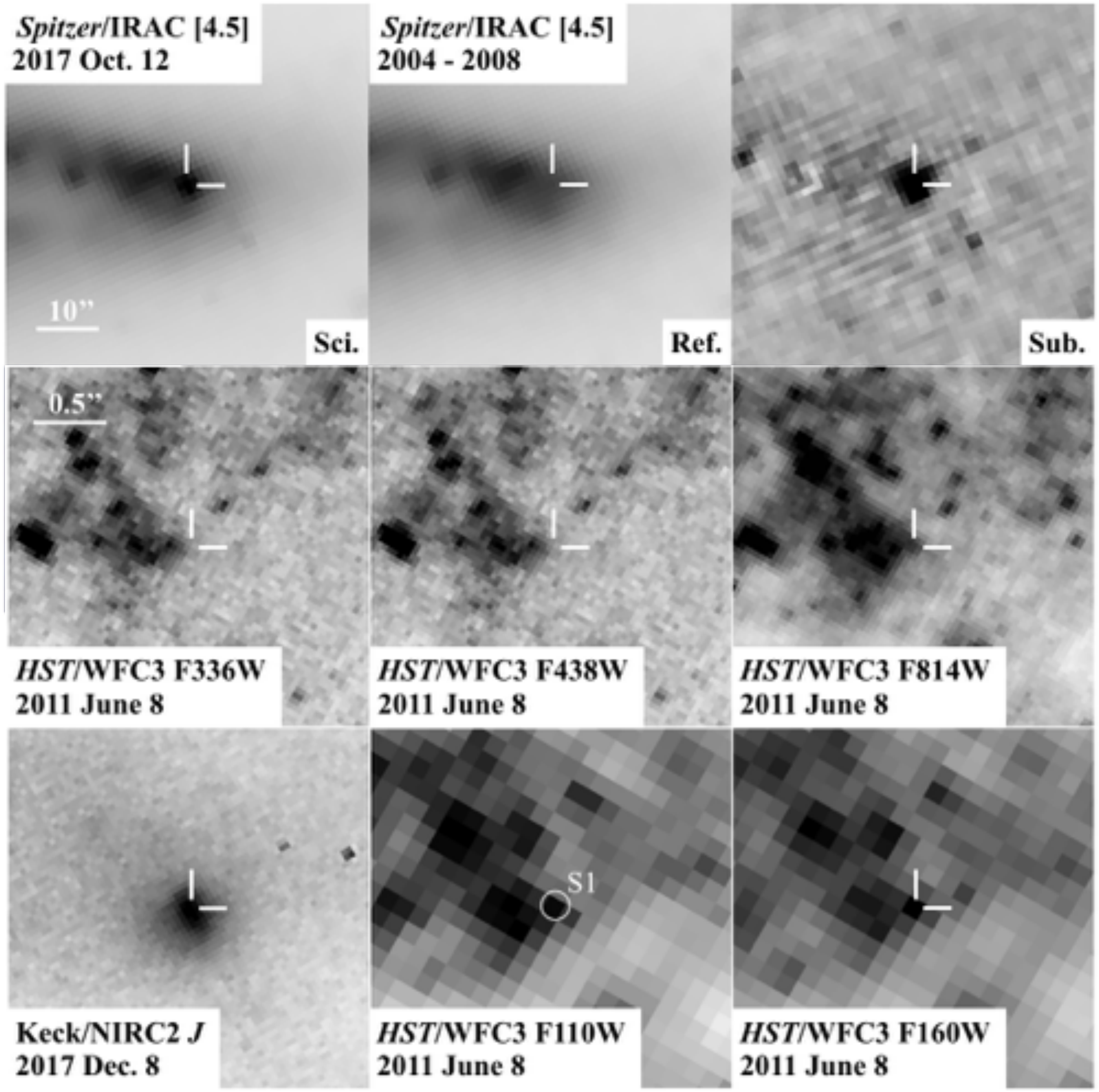


Fig. adapted from Smartt 2015

SPIRITS 17pc has a hot blue progenitor with active dust formation.



Jencson+ 2018, ATel #11577

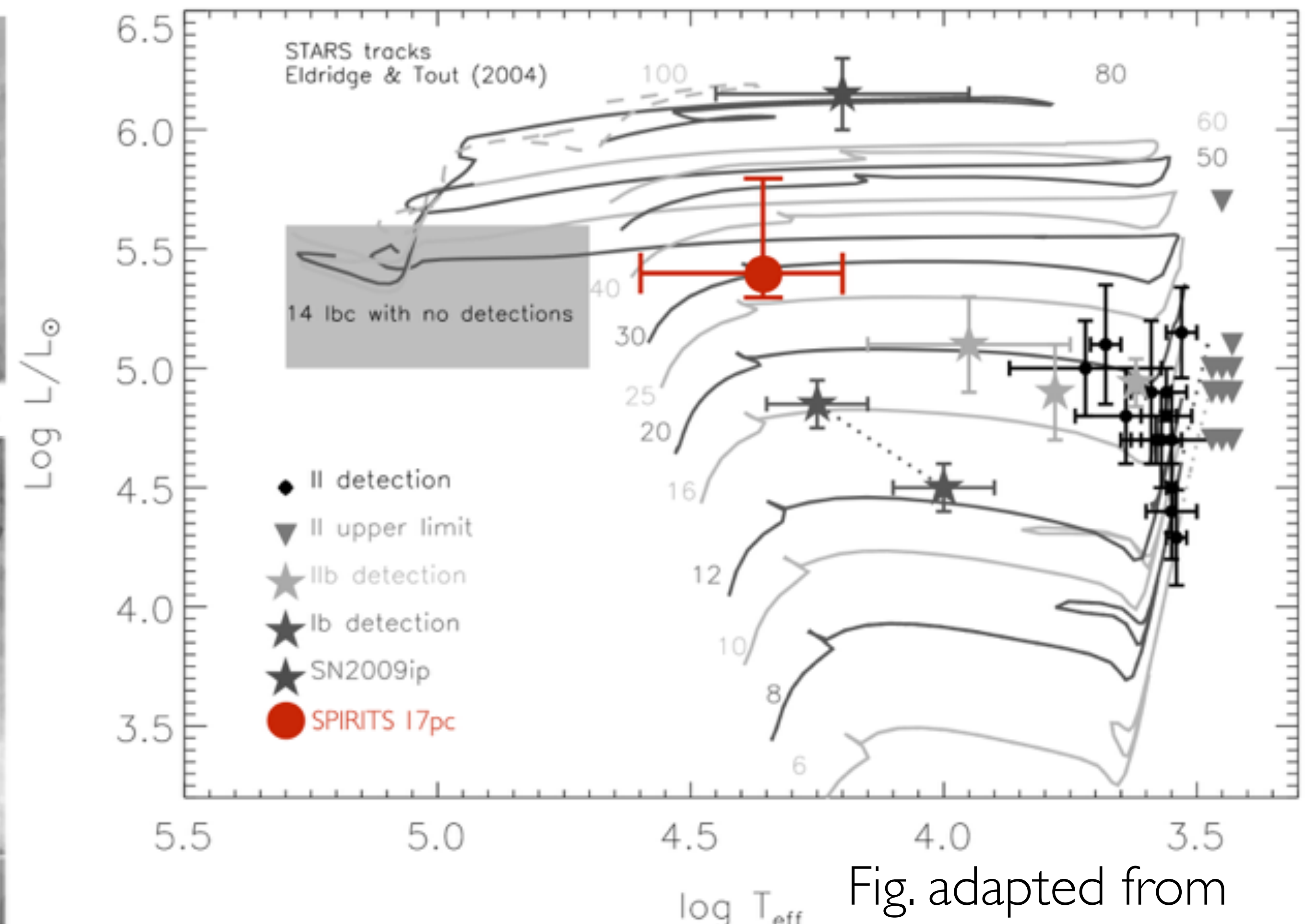
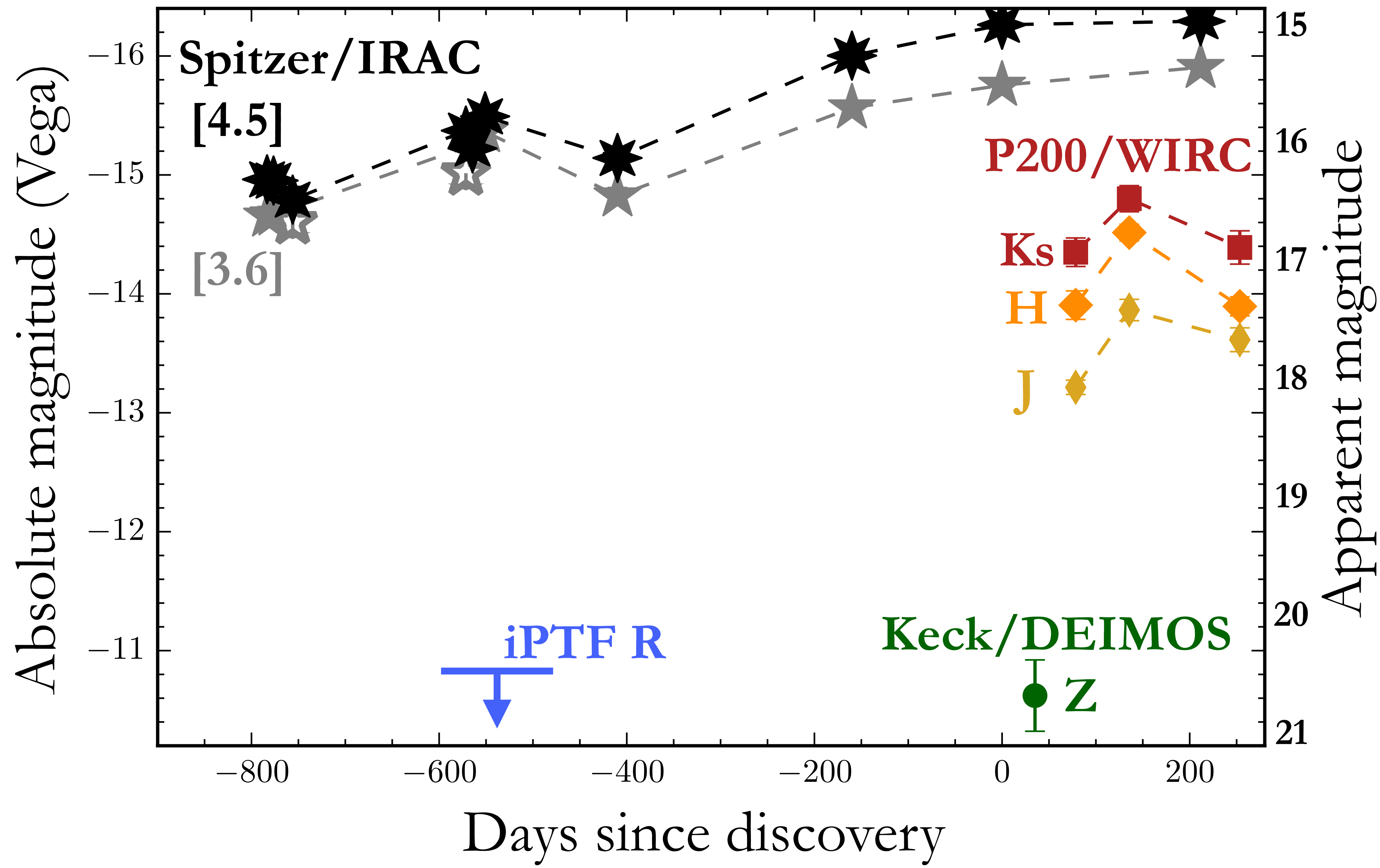


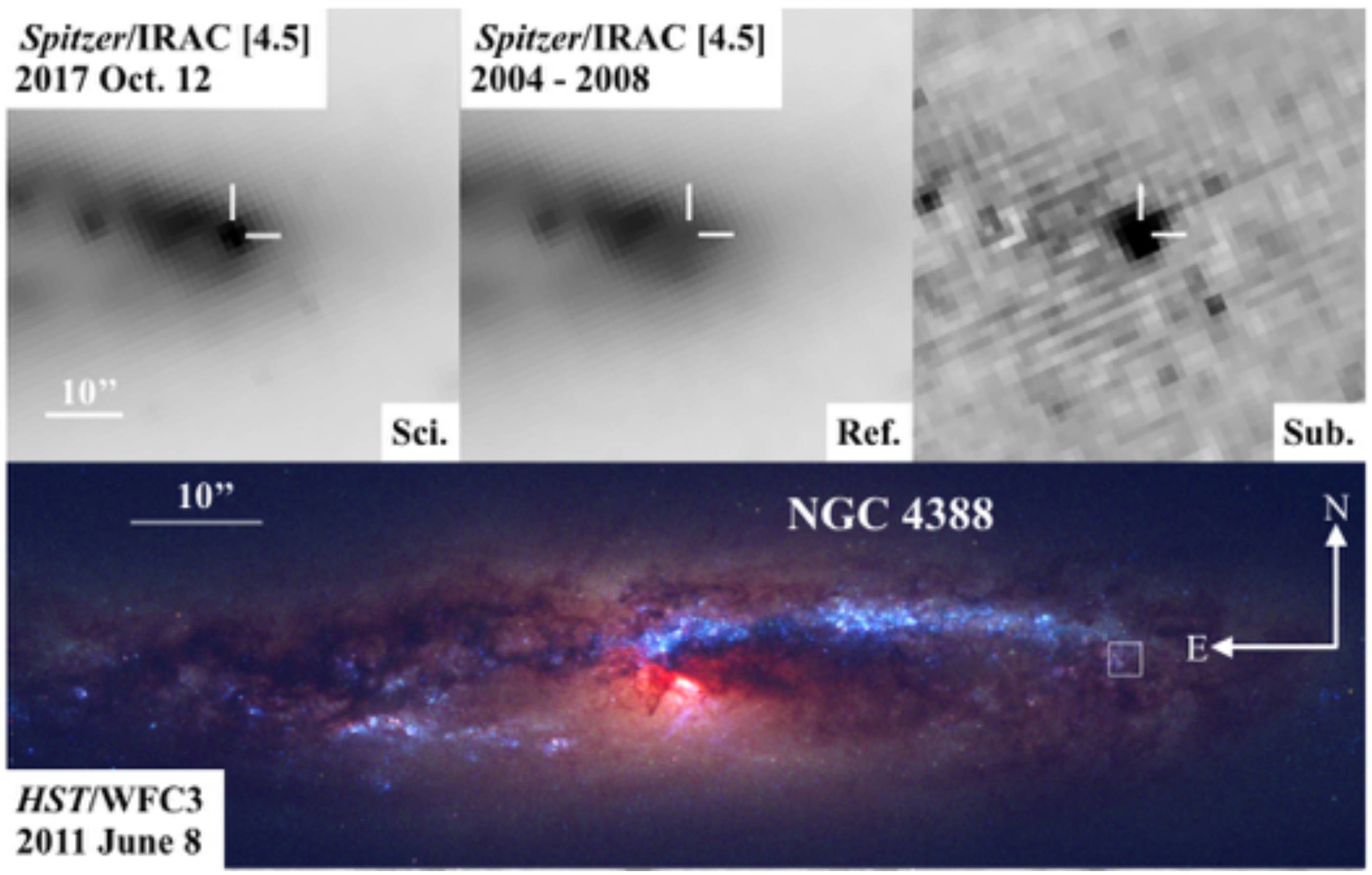
Fig. adapted from Smartt 2015

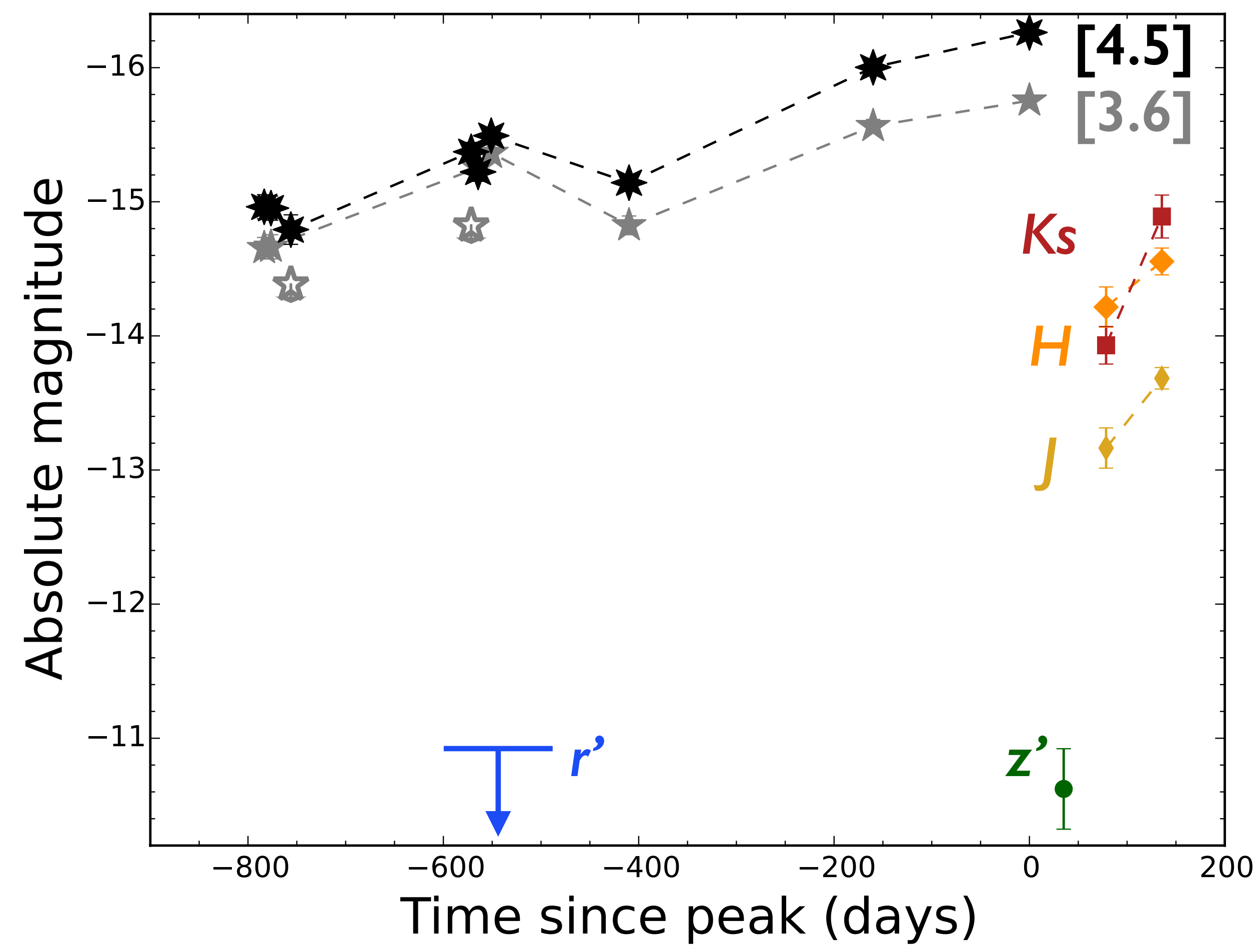
$L \sim 2 \times 10^5 L_\odot$
$T \sim 20{,}000$ K
$T_{dust} \sim 1{,}800$ K
$E(B\text{-}V)_{host} < 0.5$ mag

Palomar imaging reveals multiple self-obscuring outbursts in **SPIRITS 17pc**.

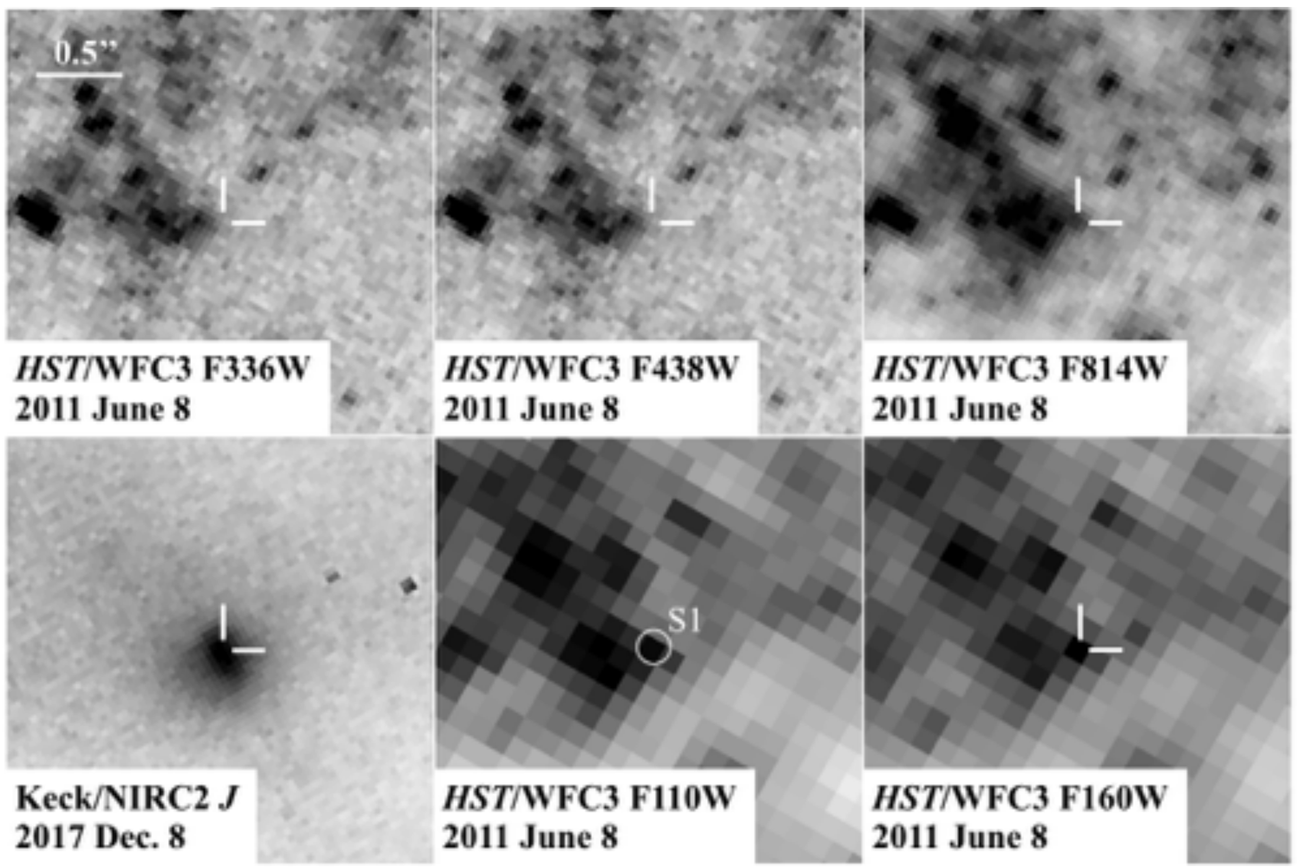


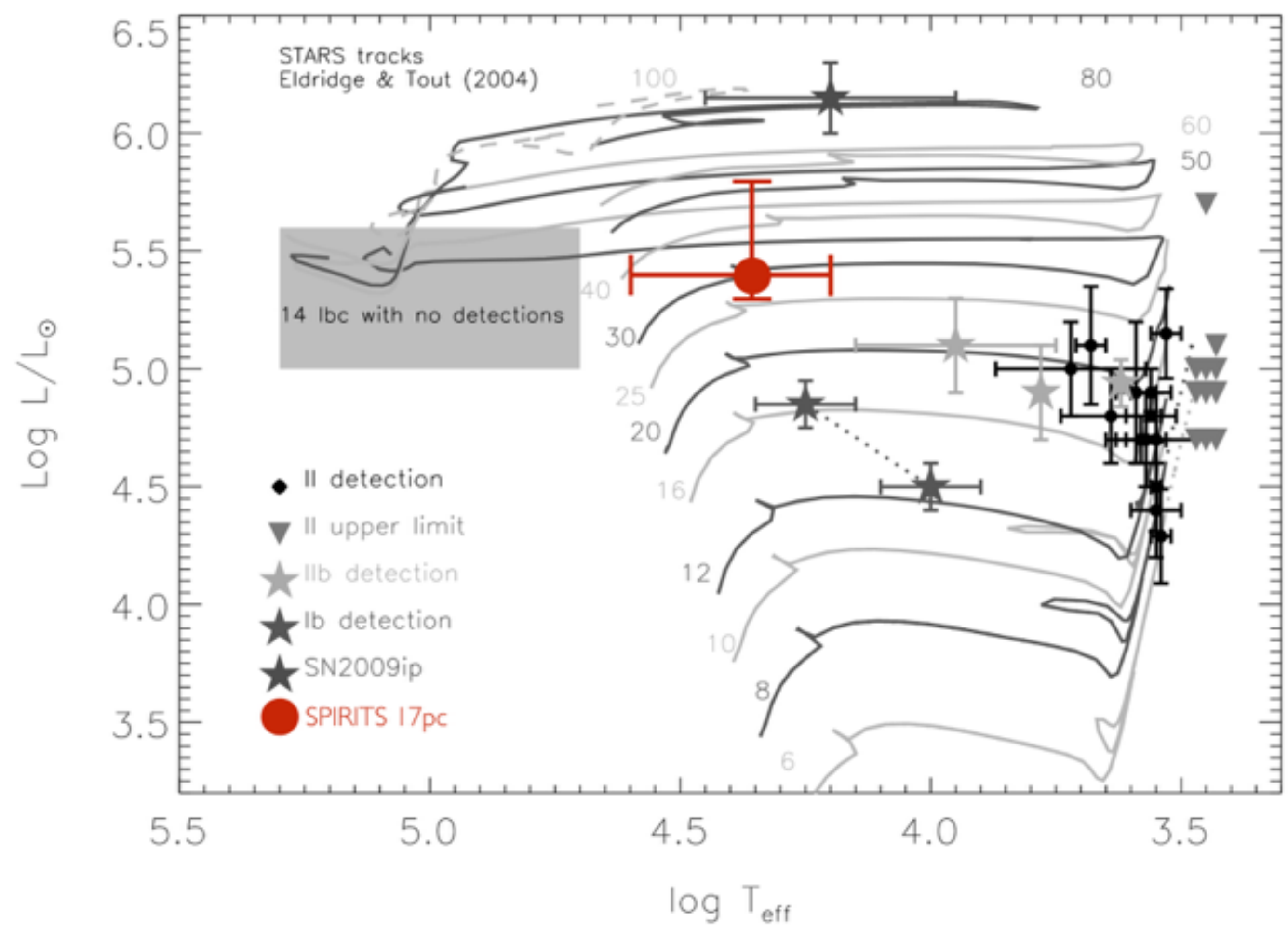
SPIRITS17pc shows multiple progressively intensifying mid-IR outbursts.





Progenitor consistent with a hot, blue star with active dust formation.





$L \sim 2 \times 10^5 L_\odot$ Jencson+ 2018, ATel #11577

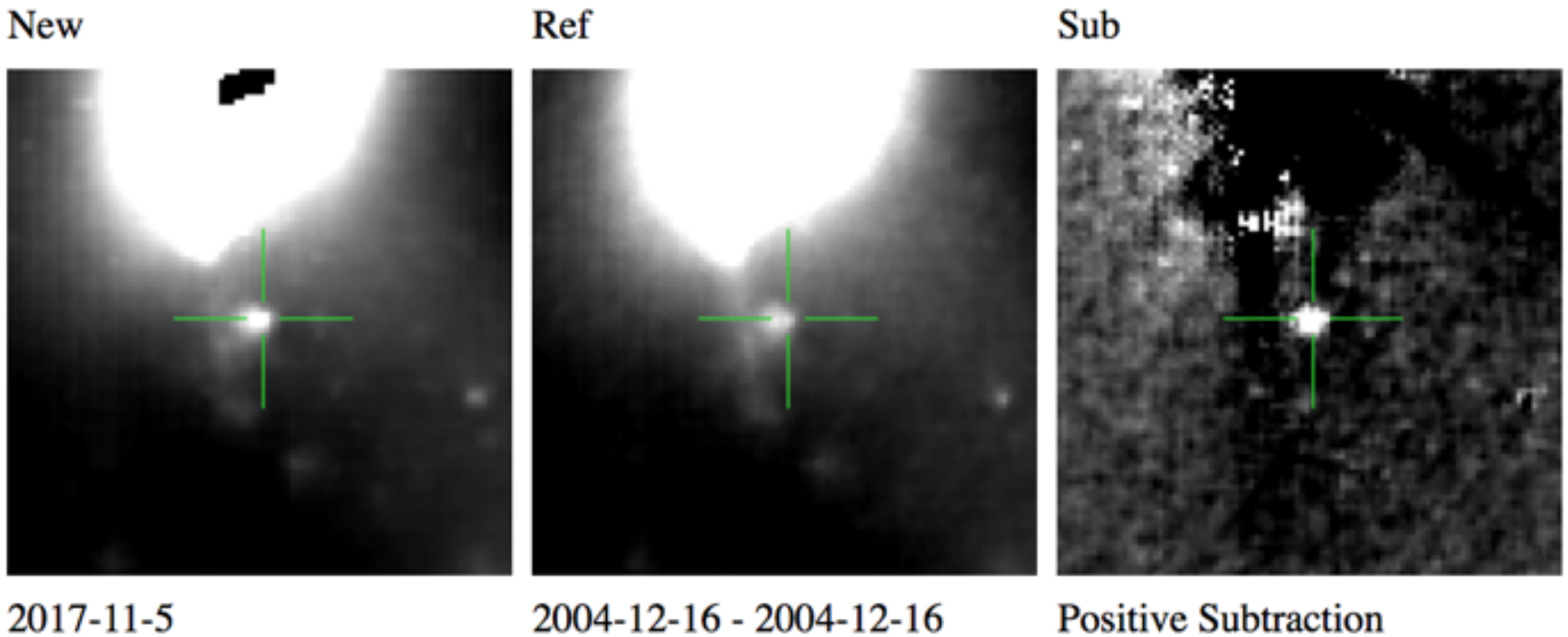
$T \sim 20{,}000$ K

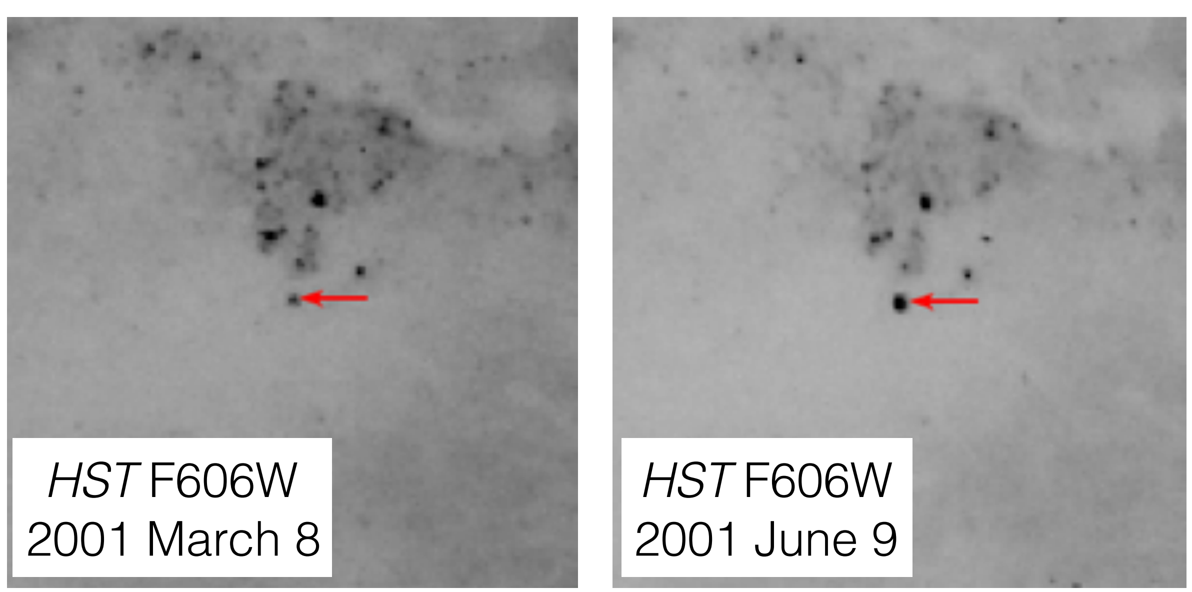
$T_{dust} \sim 1{,}800$ K

$E(B\text{-}V)_{host} < 0.5$ mag

Fig. adapted from Smarrt 2015

SPIRITS 17qm has a luminous, highly variable progenitor.





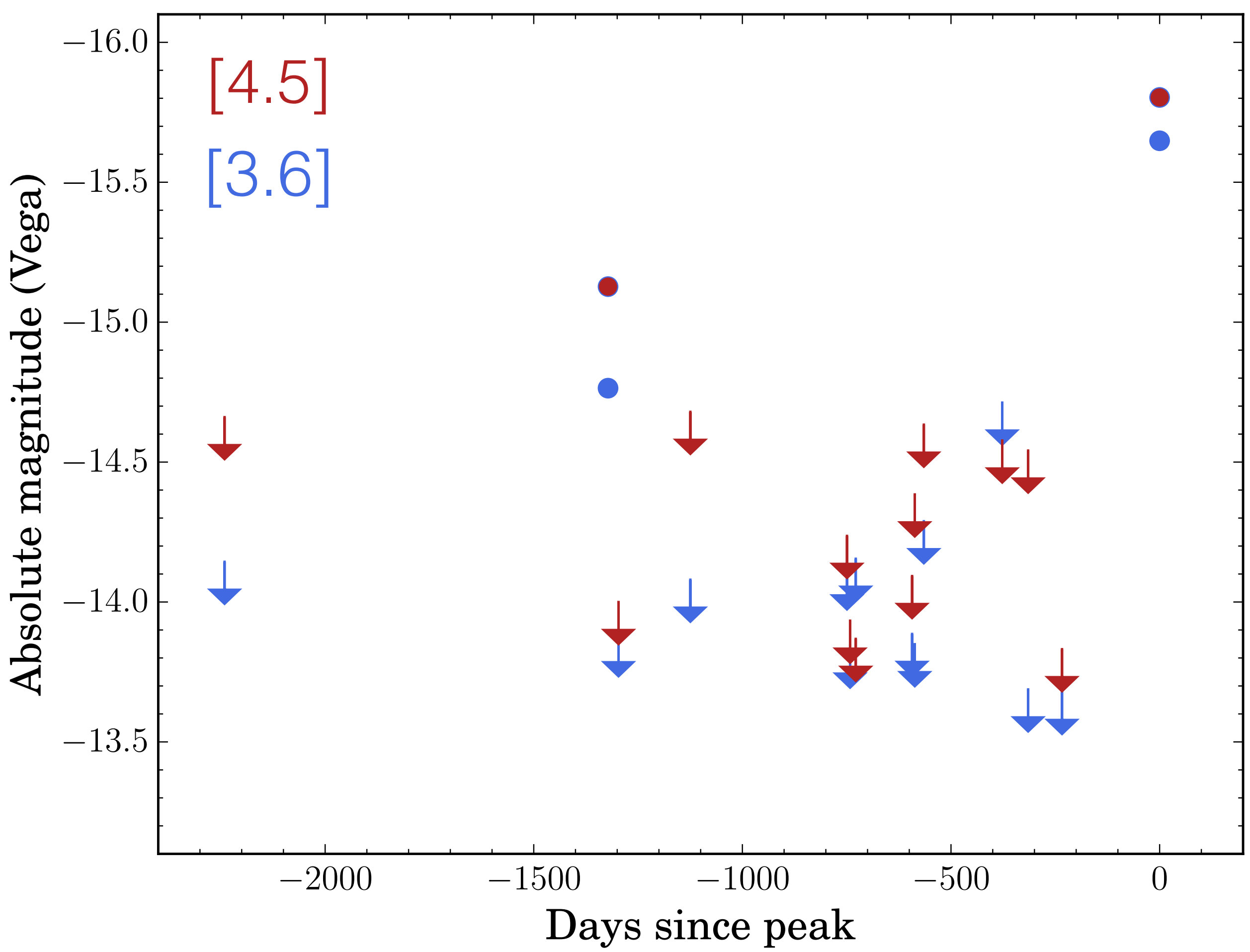
M_V = -9.3 mag

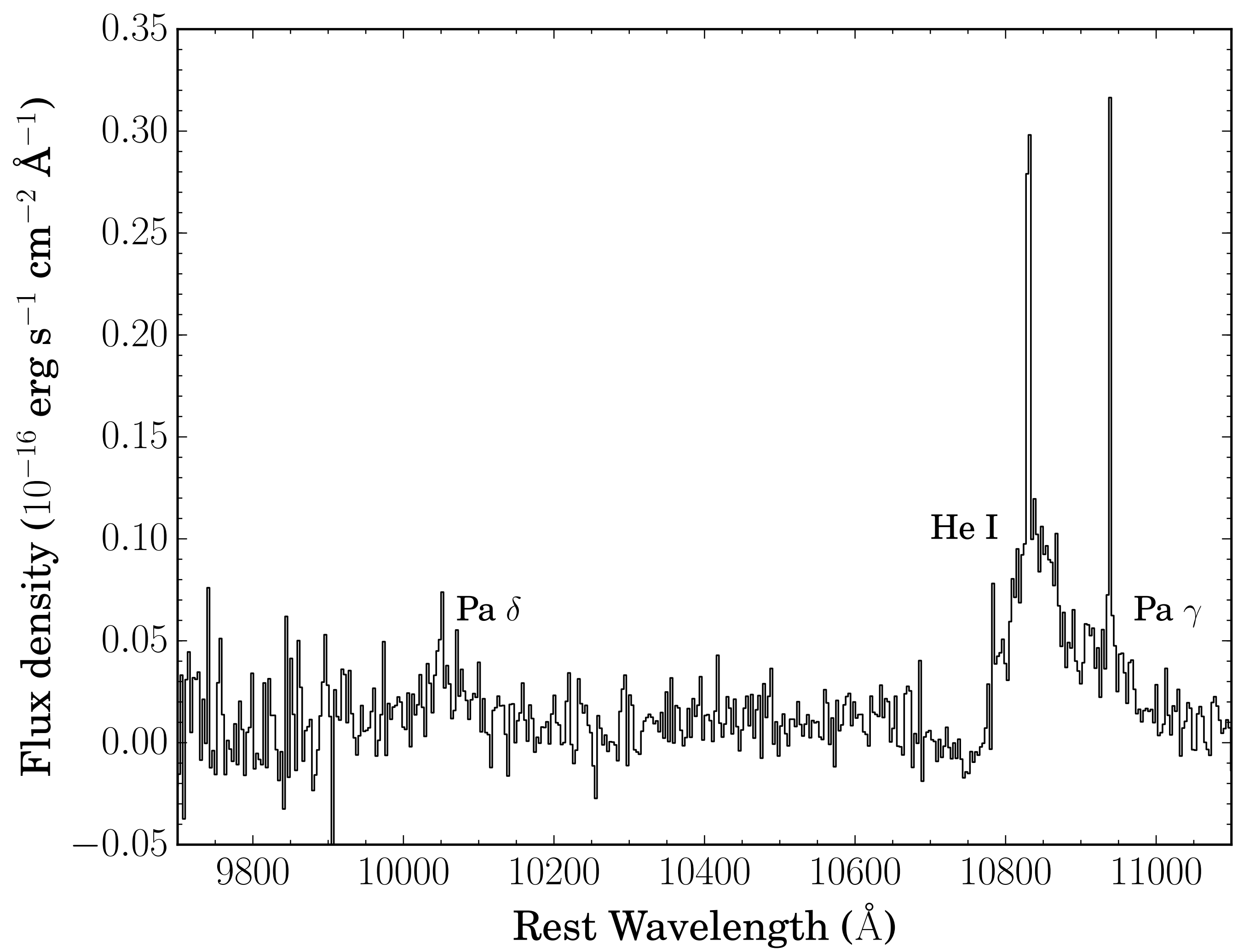
$L \sim 10^6 L_\odot$

Δm = 1.7 mag

Jencson+ 2018, ATel #11579

Multiple luminous mid-IR outbursts detected with *Spitzer*.





Radio observations provide additional type information and probe circumstellar environment.

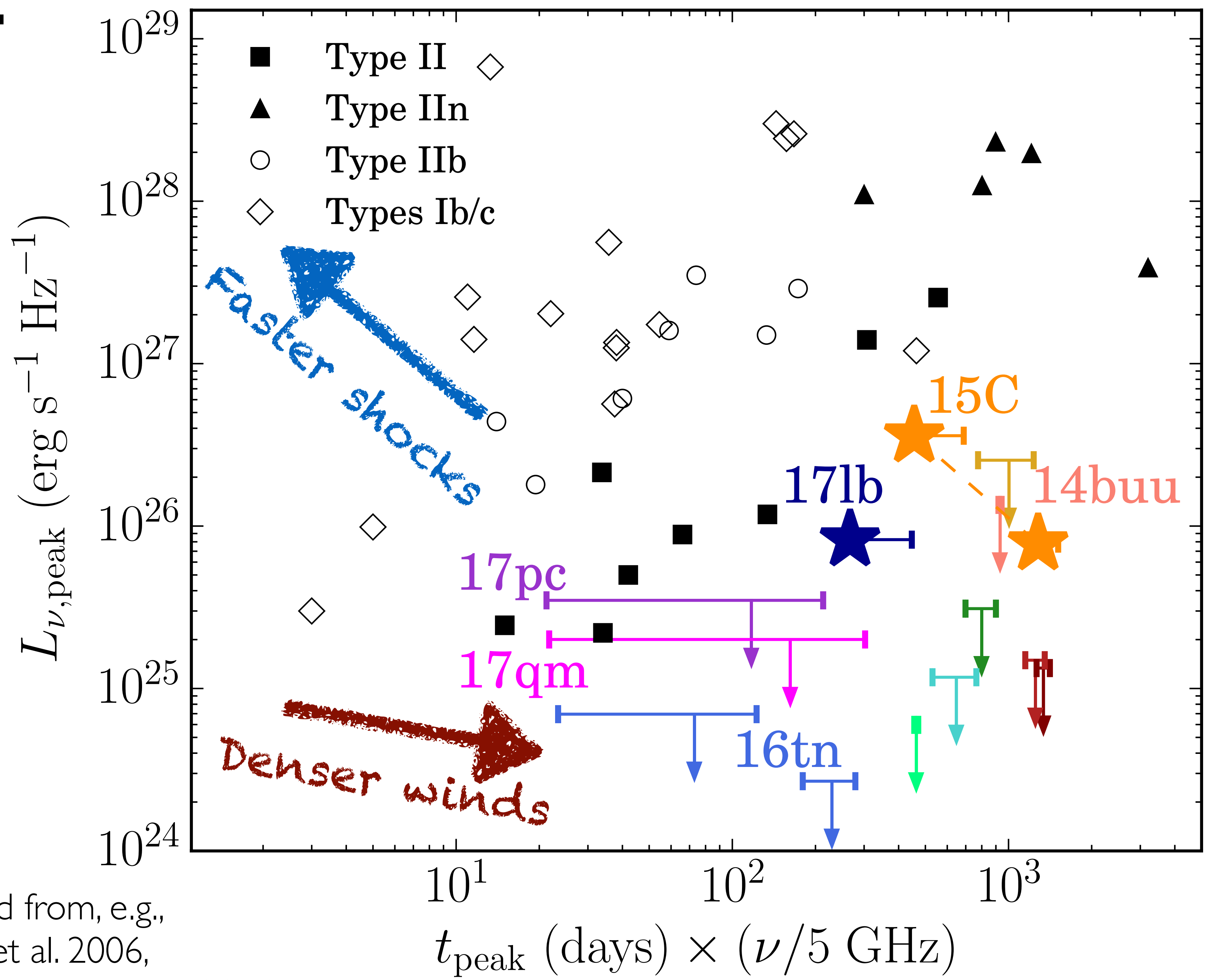


Fig. adapted from, e.g., Chevalier et al. 2006, Romero-Cañizales et al. 2014

Zwicky Transient Facility

Successor to iPTF on Palomar 48-in. Oschin Telescope

47 deg^2 FOV

Optical *g* and *R*-band surveys

i-band survey of 6700 deg^2 to 20.1 mag (AB) at 4 day cadence

Expect ~ 50 CCSNe within 100 Mpc in one year

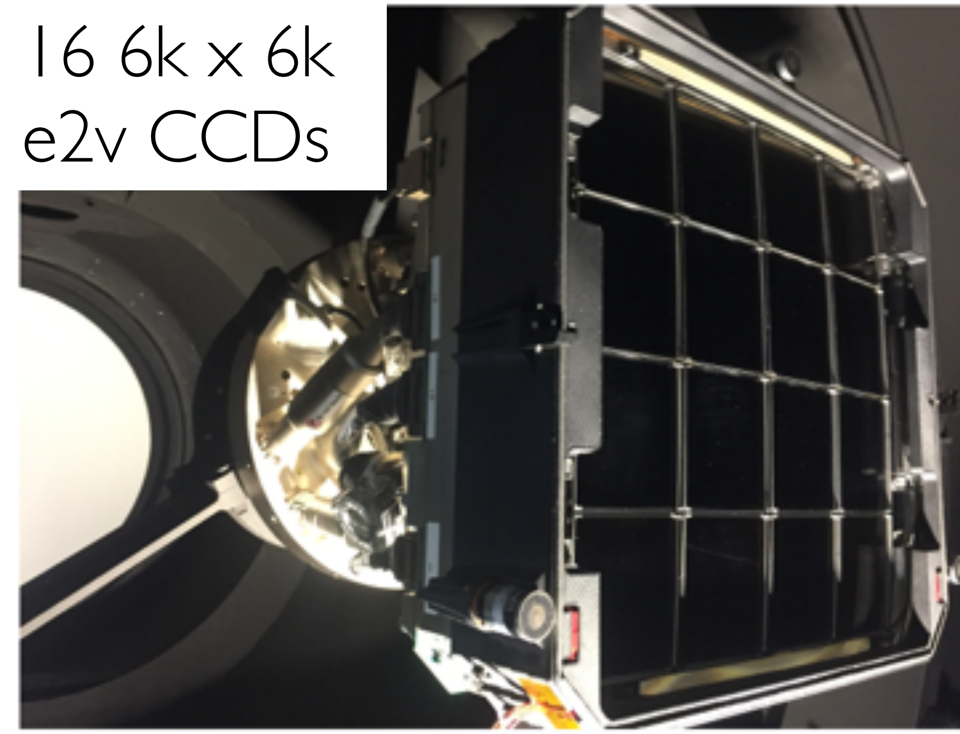
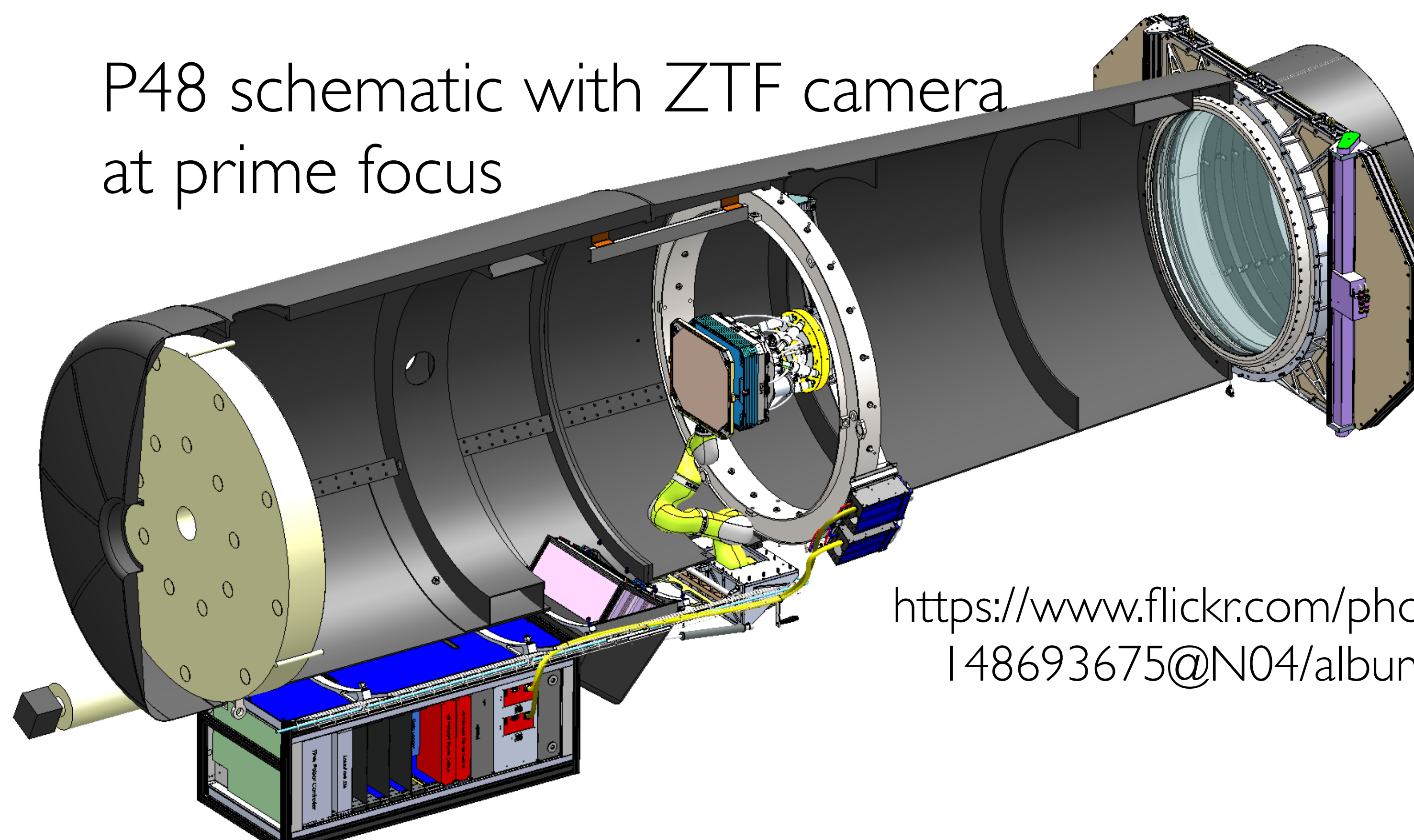


Photo credit: Michael Feeney

P48 schematic with ZTF camera at prime focus



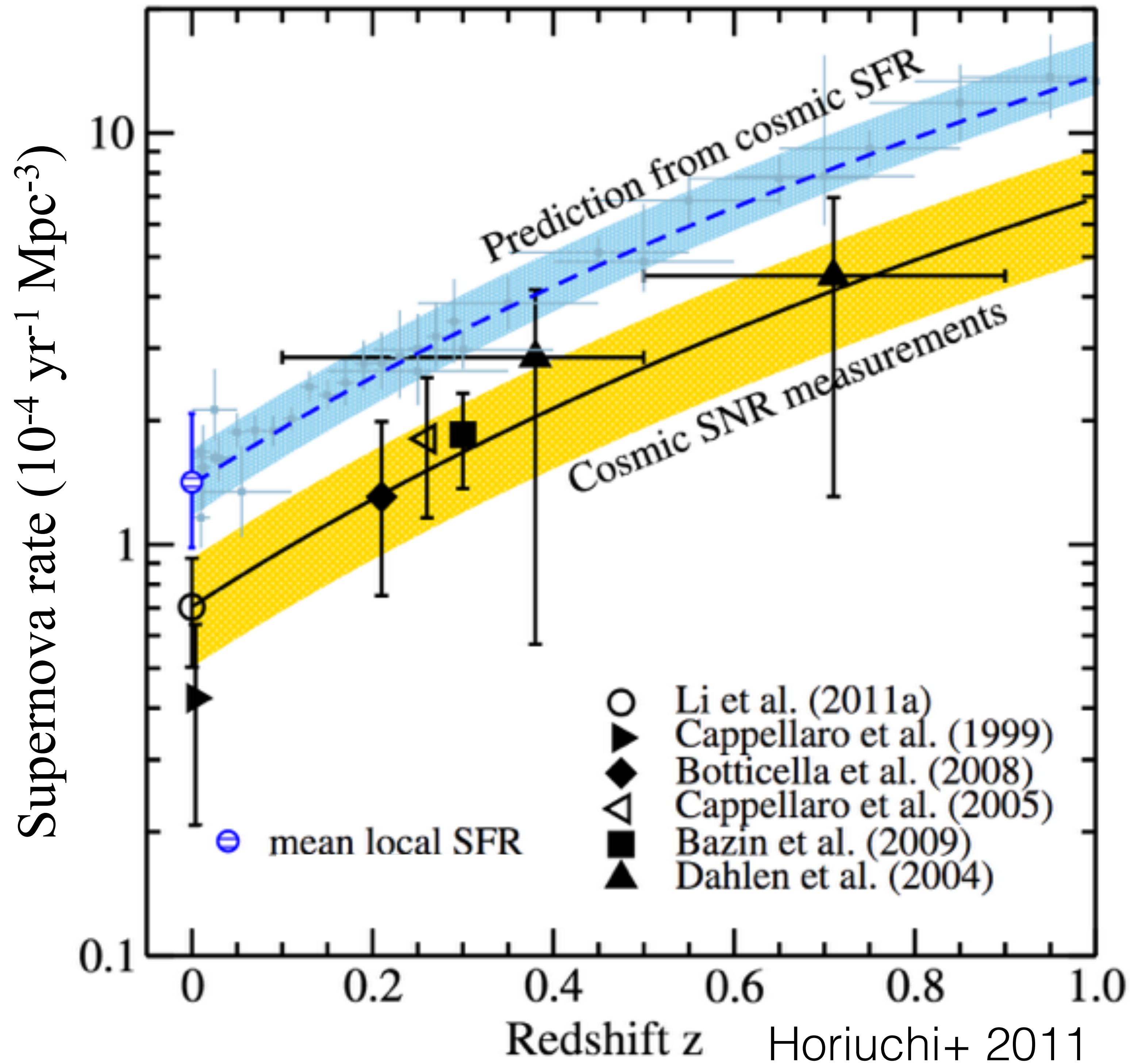
https://www.flickr.com/photos/148693675@N04/albums

"Supernova Rate Problem": The core-collapse supernova rate does not match the formation rate of massive stars.

SN rate tracks trend in star formation

Overall normalization discrepancy by factor of 2

Not enough supernovae are seen for the number of massive stars formed in the Universe

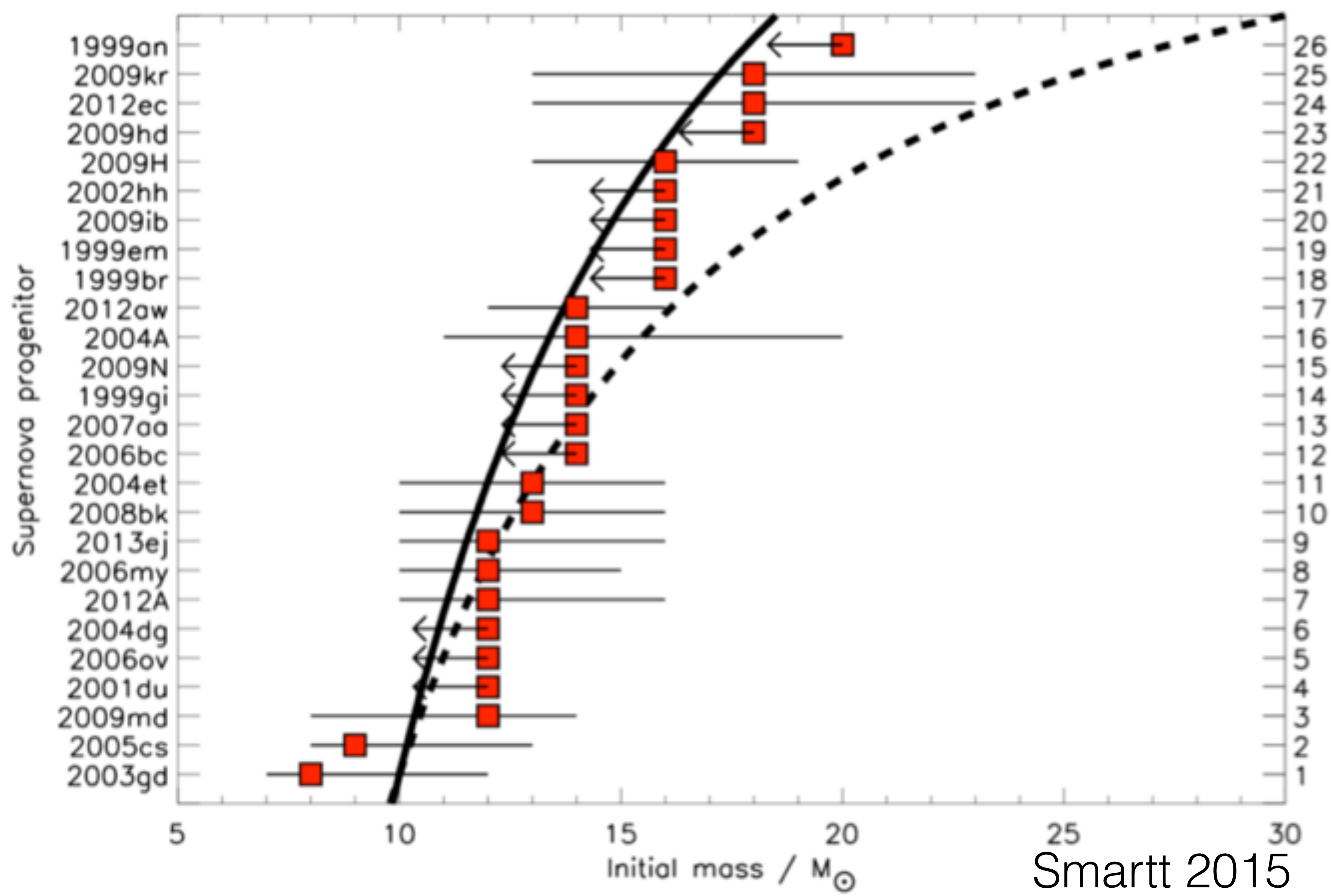


Horiuchi+ 2011

“Red Supergiant Problem”: No high-mass progenitors of type II SNe are observed.

Data inconsistent with progenitor initial masses drawn from Salpeter IMF up to 30 $M_{\odot}$

We are not observing SNe from progenitors with $M > 18\ M_{\odot}$



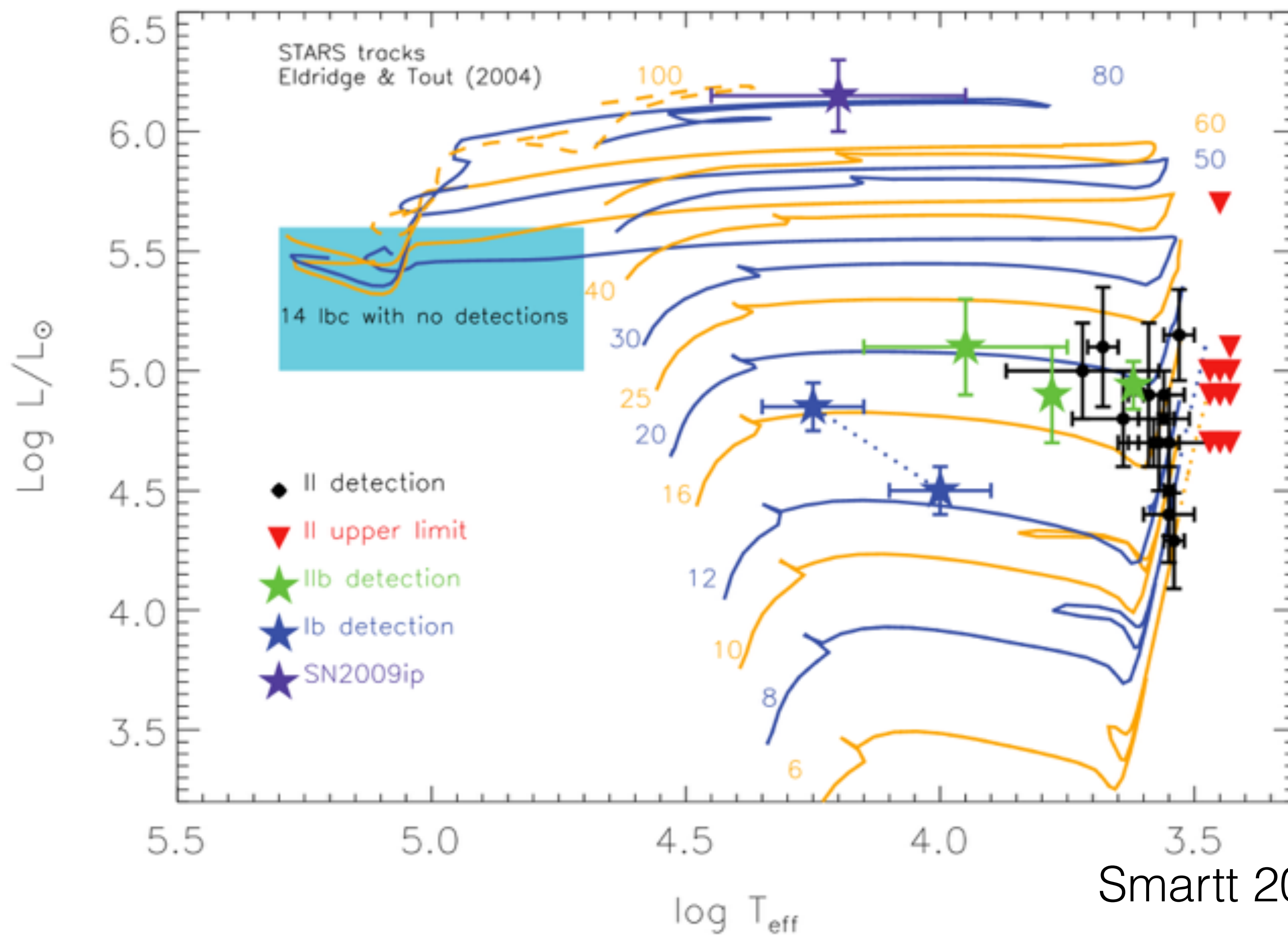
Smartt 2015

Archival searches of high-resolution imaging have allowed for direct detections of SN progenitors.

Type Ib/c:
massive Wolf-Rayet stars or lower mass binaries?

Not enough type IIn's observed

Observational bias:
Are SNe from massive progenitors preferentially missed?

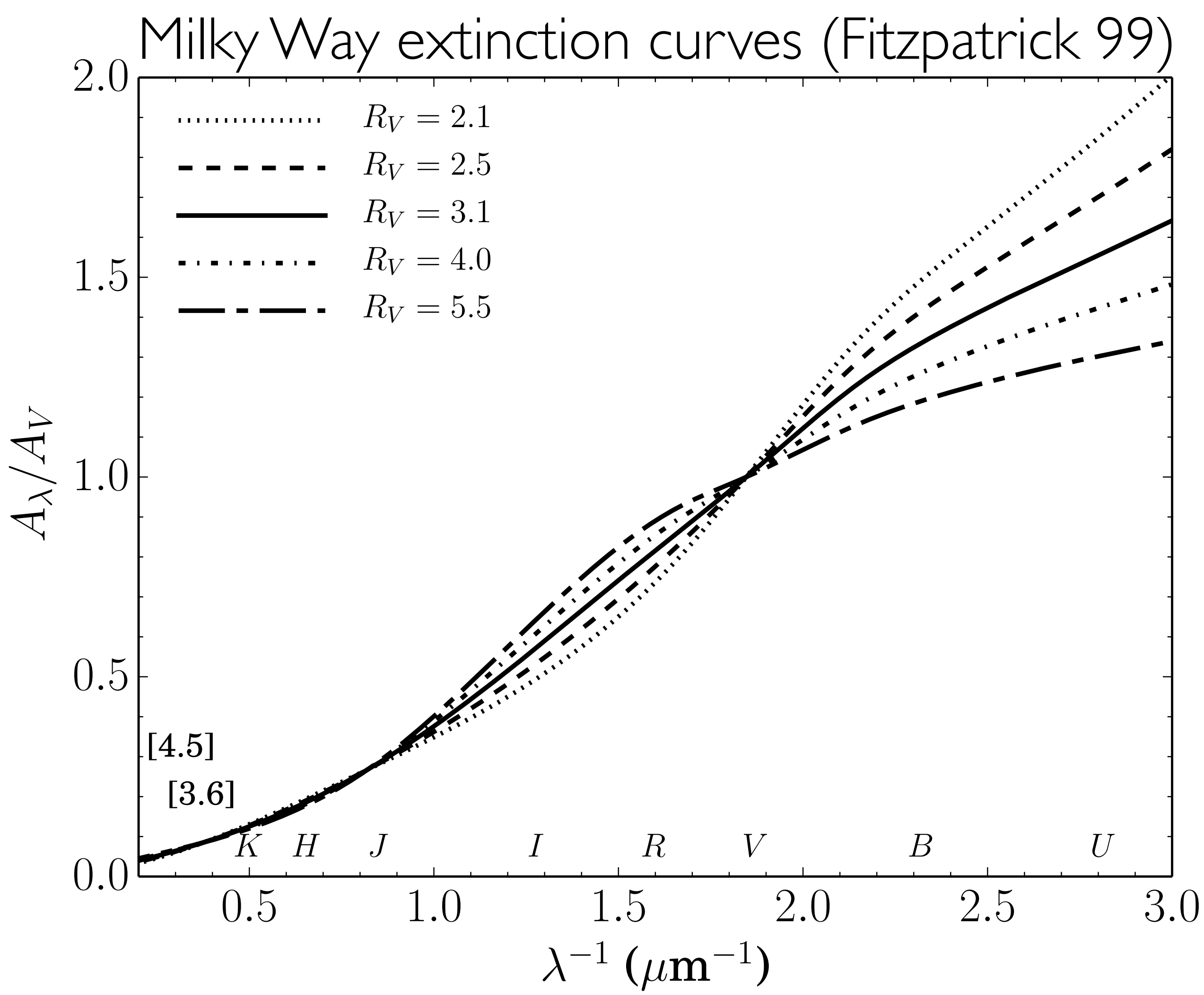


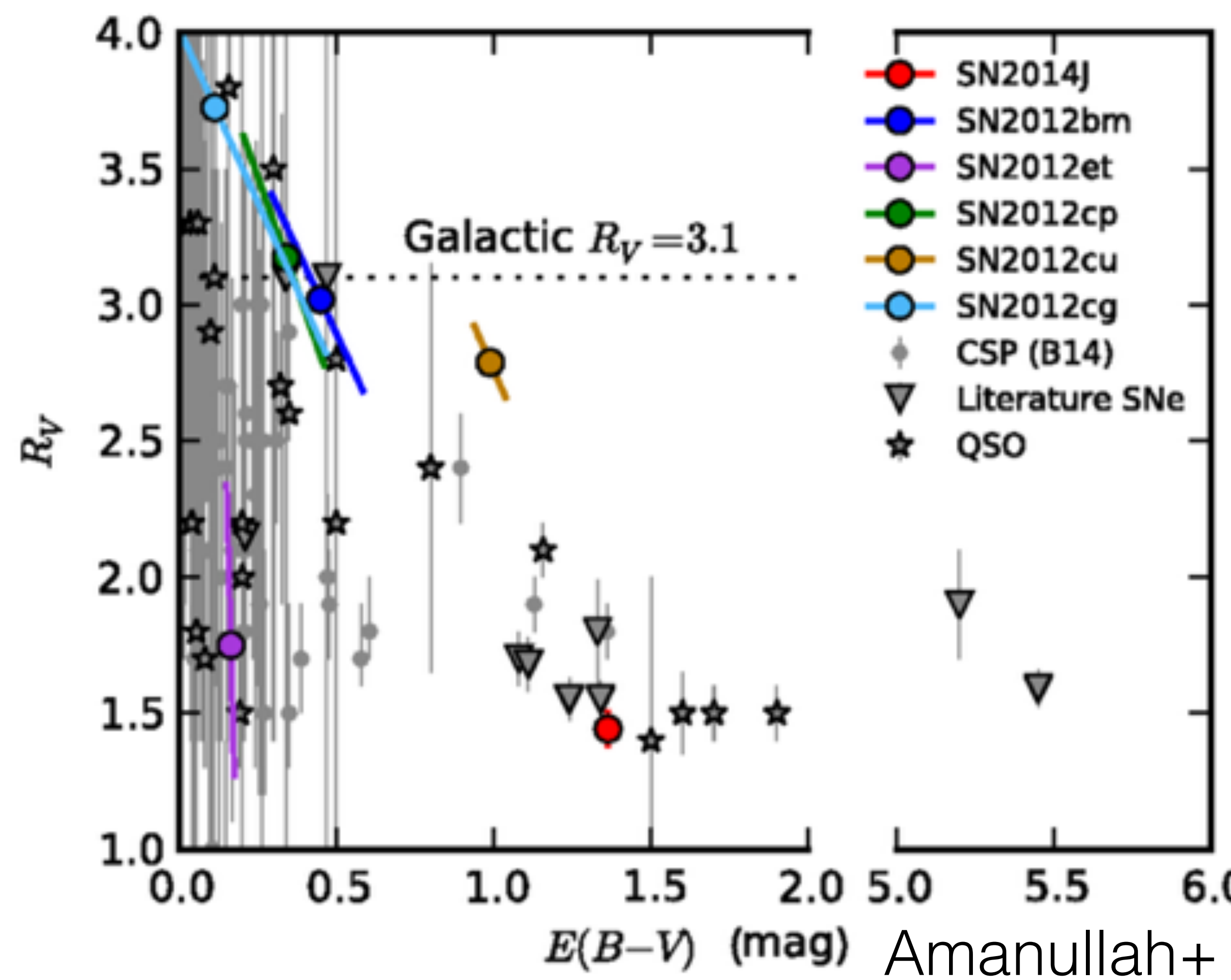
Smartt 2015

Characterizing the extinction in obscured SNe can probe local conditions.

$$R_V = A_V/E(B - V)$$

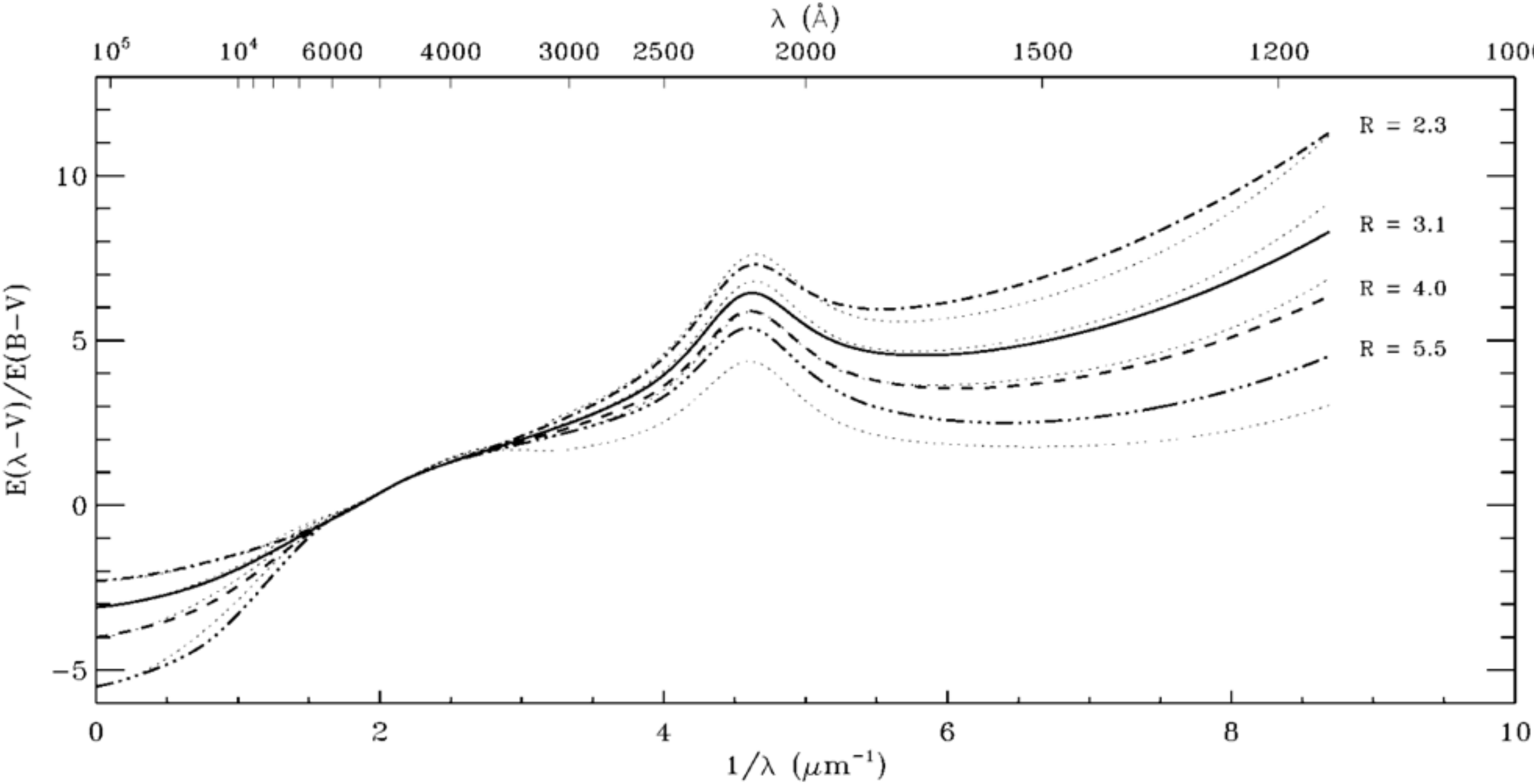
Low values of R_V observed in some SNe Ia



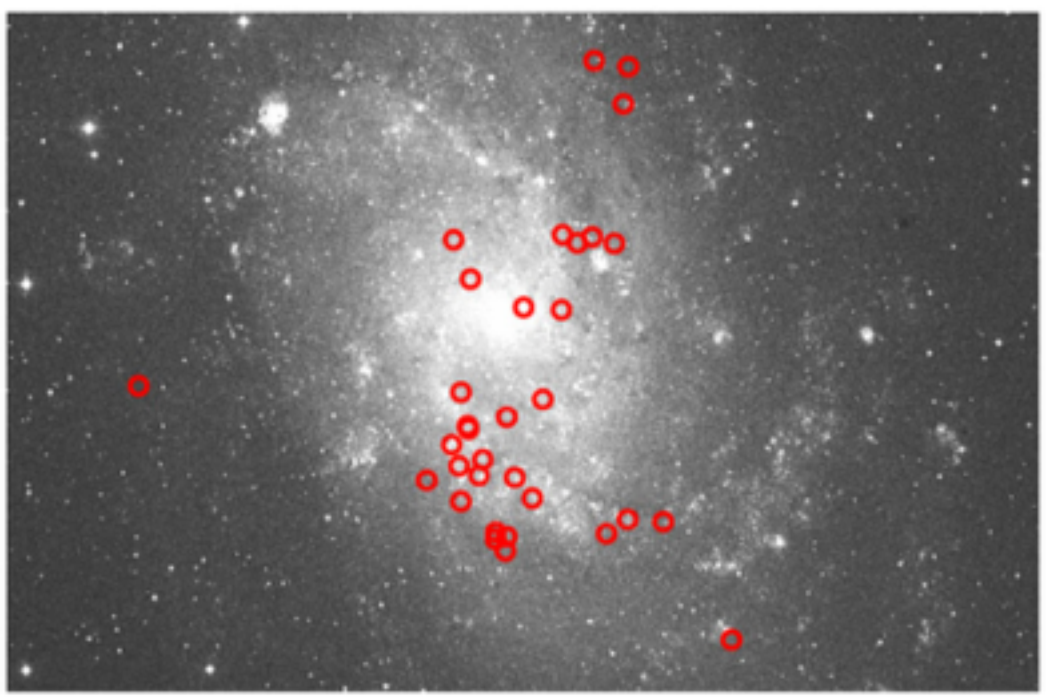


Amanullah+ 2015

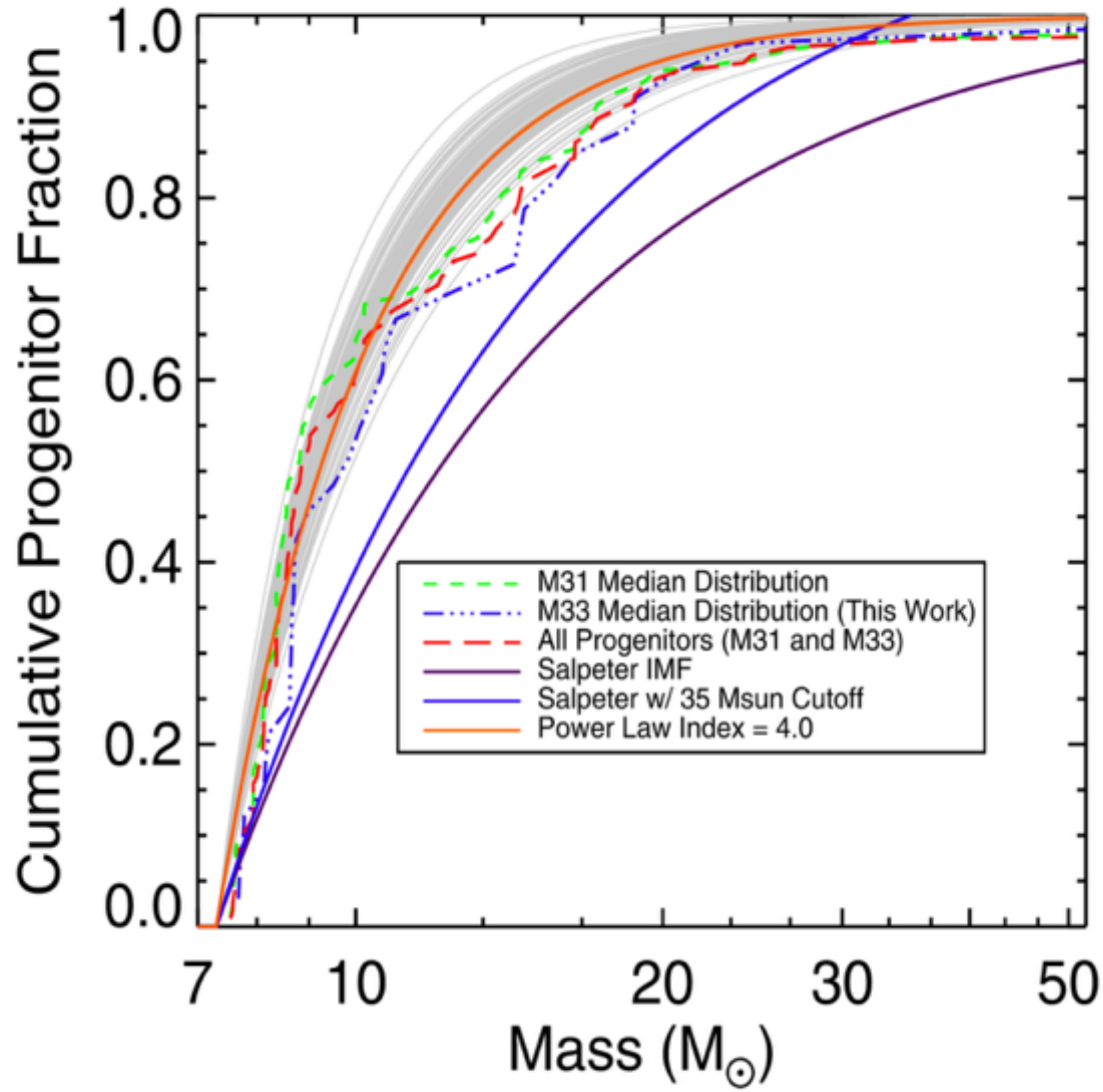
R_V dependent extinction curves



Stellar populations near SN remnants offer further evidence for a high-mass cutoff.



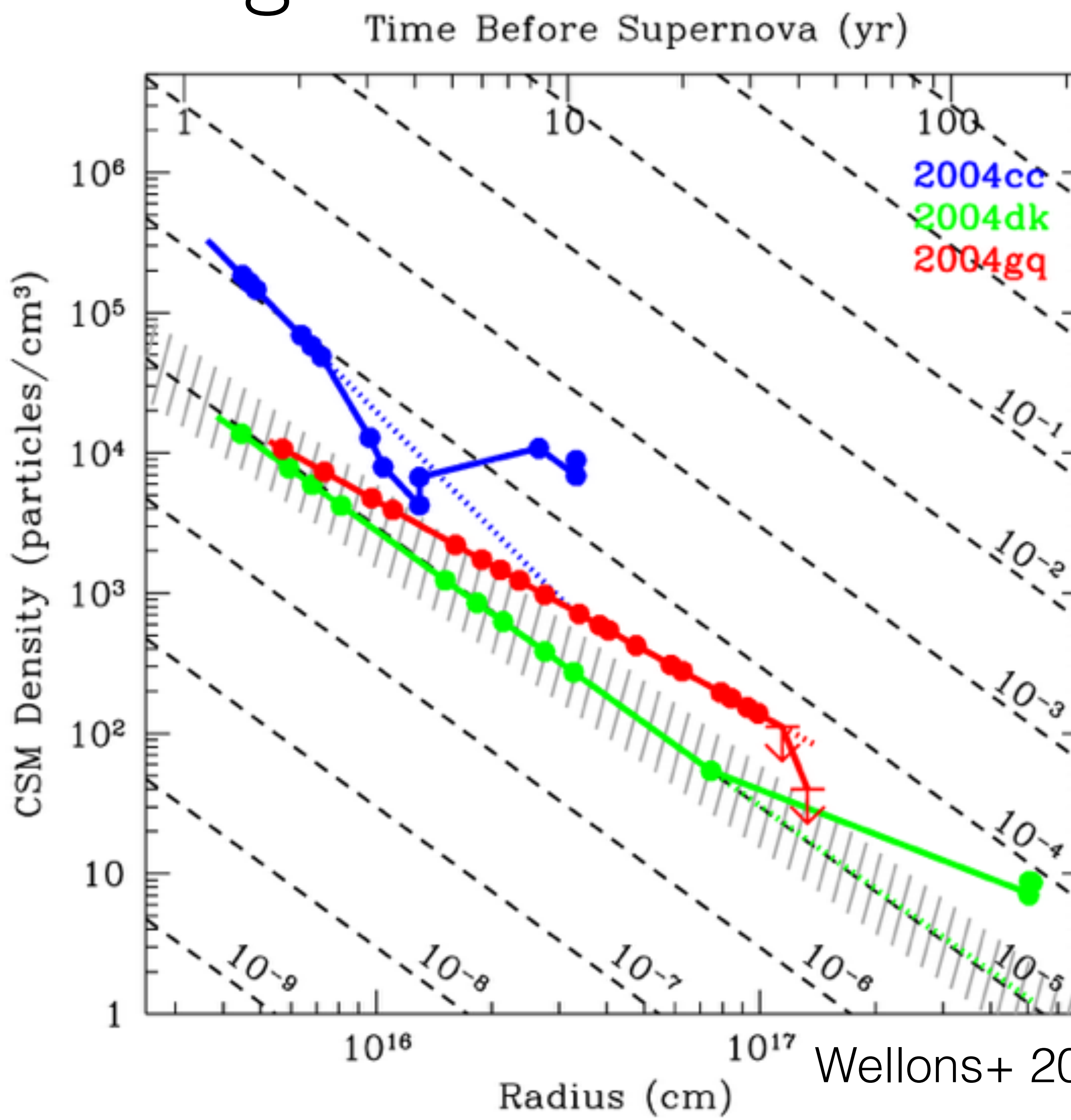
Jennings+ 2014



Radio observations probe the interaction of SN ejecta with surrounding material.

Synchrotron emission generated by interaction of shockwave with circumstellar material

Absorbed at early time by external ionized medium (free-free) or synchrotron self-absorption in interaction region

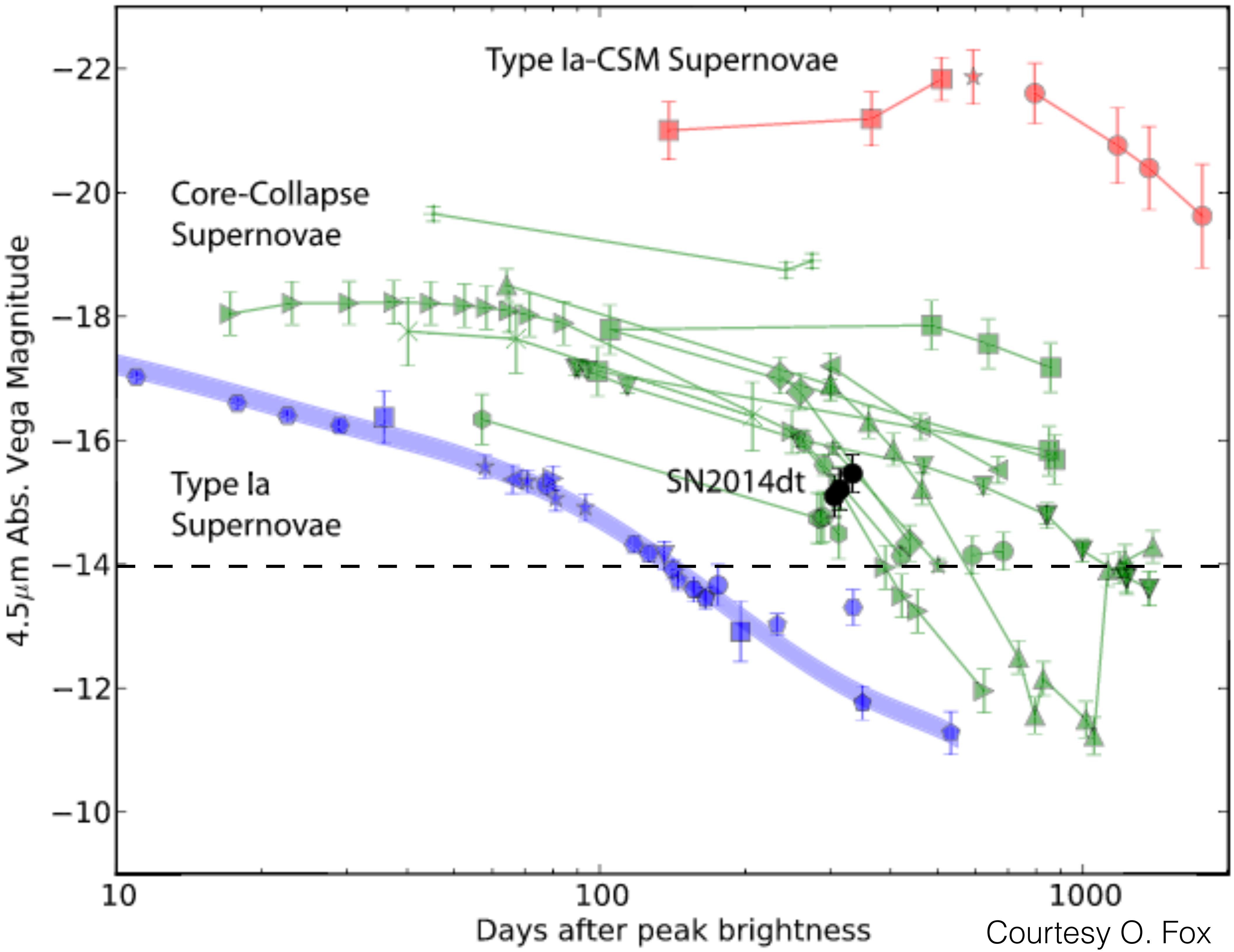


Wellons+ 2012

Core-collapse progenitors

	II-P	IIb	Ib/c	IIn
SN characteristics	H-rich most common CC 100 day plateau	II early times, evolves to Ib He-rich spectrum	H/He-stripped envelope	CSM-interaction
Progenitor luminosity	log L/Lsun < 5	log L/Lsun = 4.9-5.2	All limits (extinction, W-R evolve before collapse)	log L/Lsun = 6
Progenitor initial mass	8-15 (18) Msun	13-17 Msun	25-30 Msun (W-R) or lower mass binary (12-20 Musn)	>30 Msun, 60-80 Msun
Progenitor characteristics	low mass Red supergiant	Yellow-supergiant with compact companion mass loss?	massive Wolf-Rayet? Or He-star binary relative SN rates suggest binaries	LBV-like outbursts
Famous SNe	2012aw, 2004A	2011dh, 1993J, 2008ax, 2013df, Cas A	iPTF13bvn	2009ip, 2010jl

Known SNe in SPIRITS



Courtesy O. Fox