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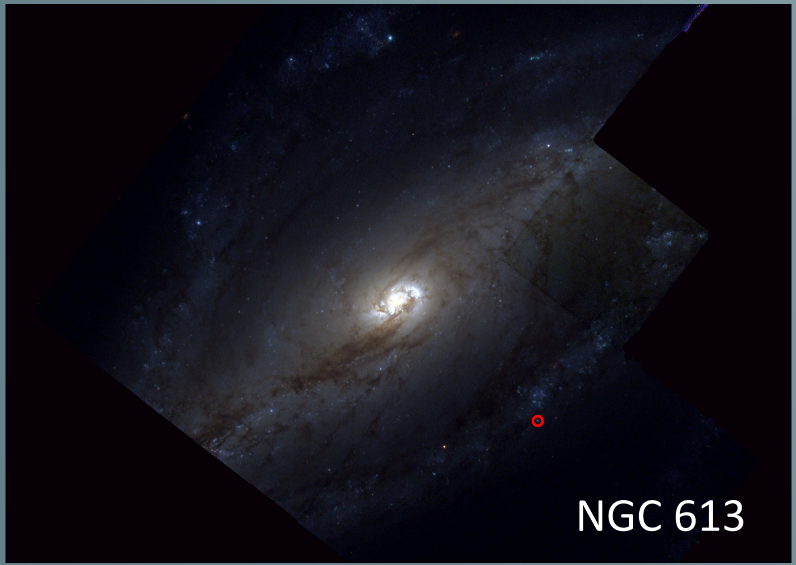
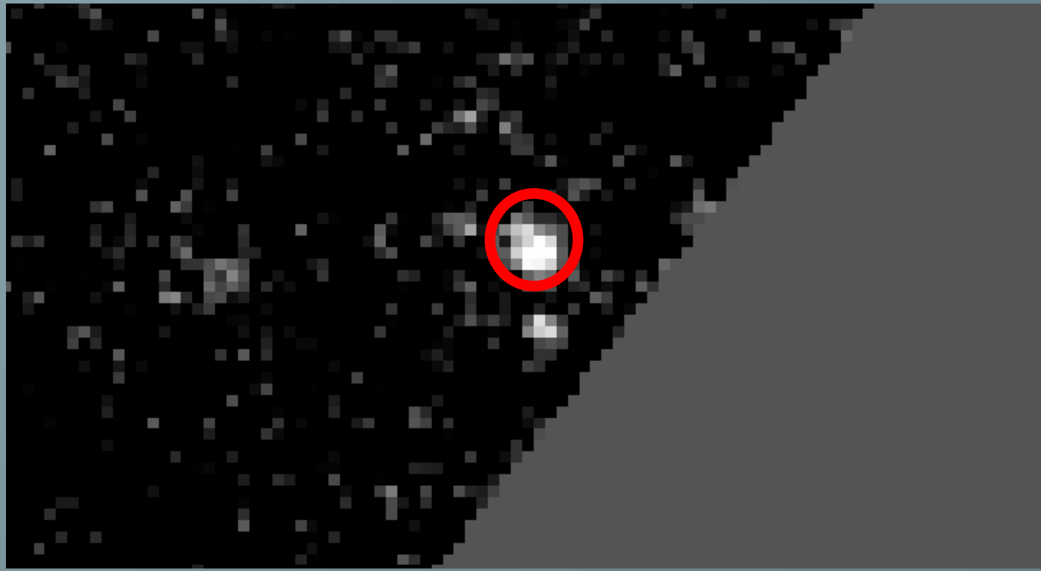
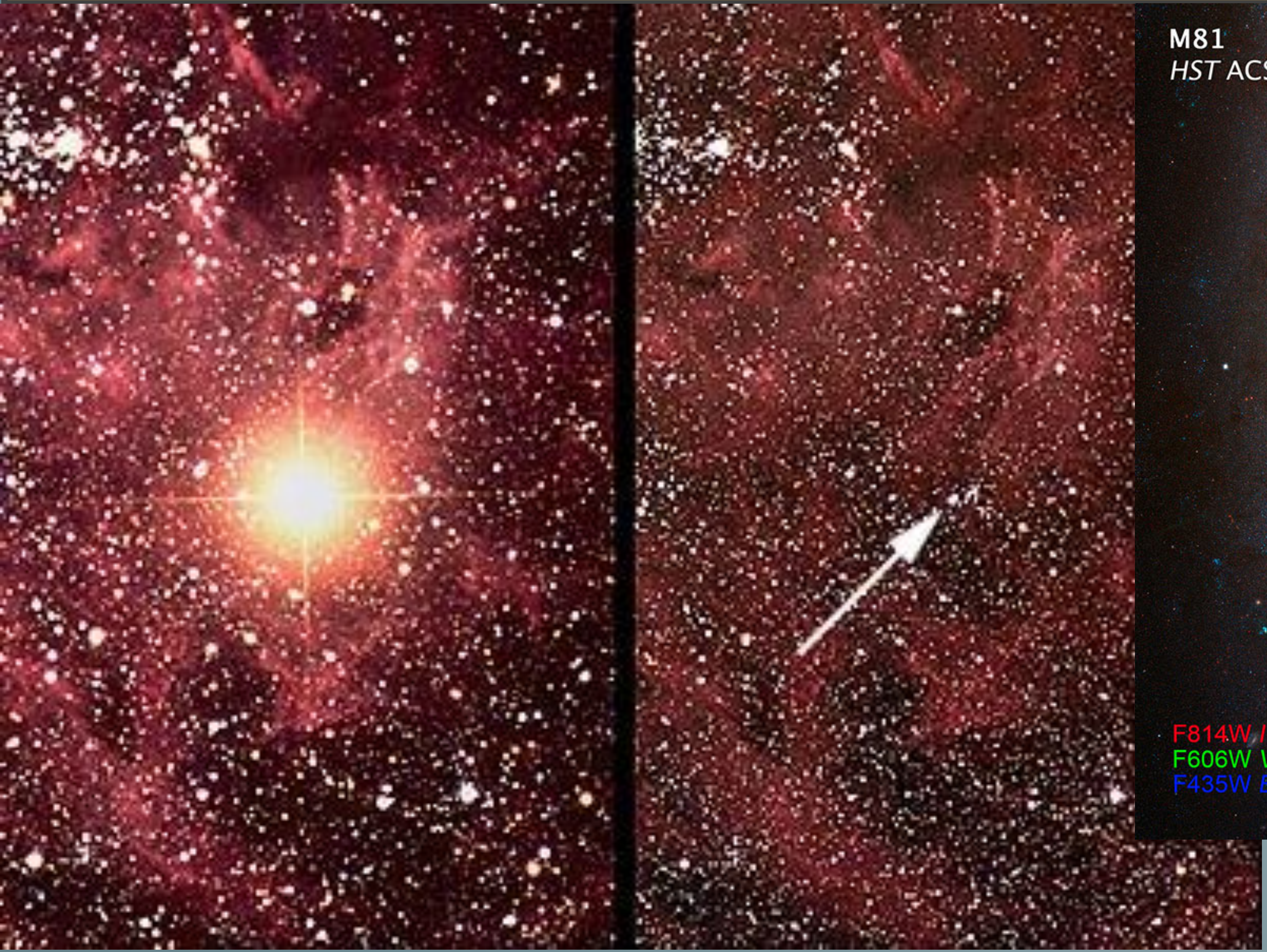
IAU 331, 20 February 2017



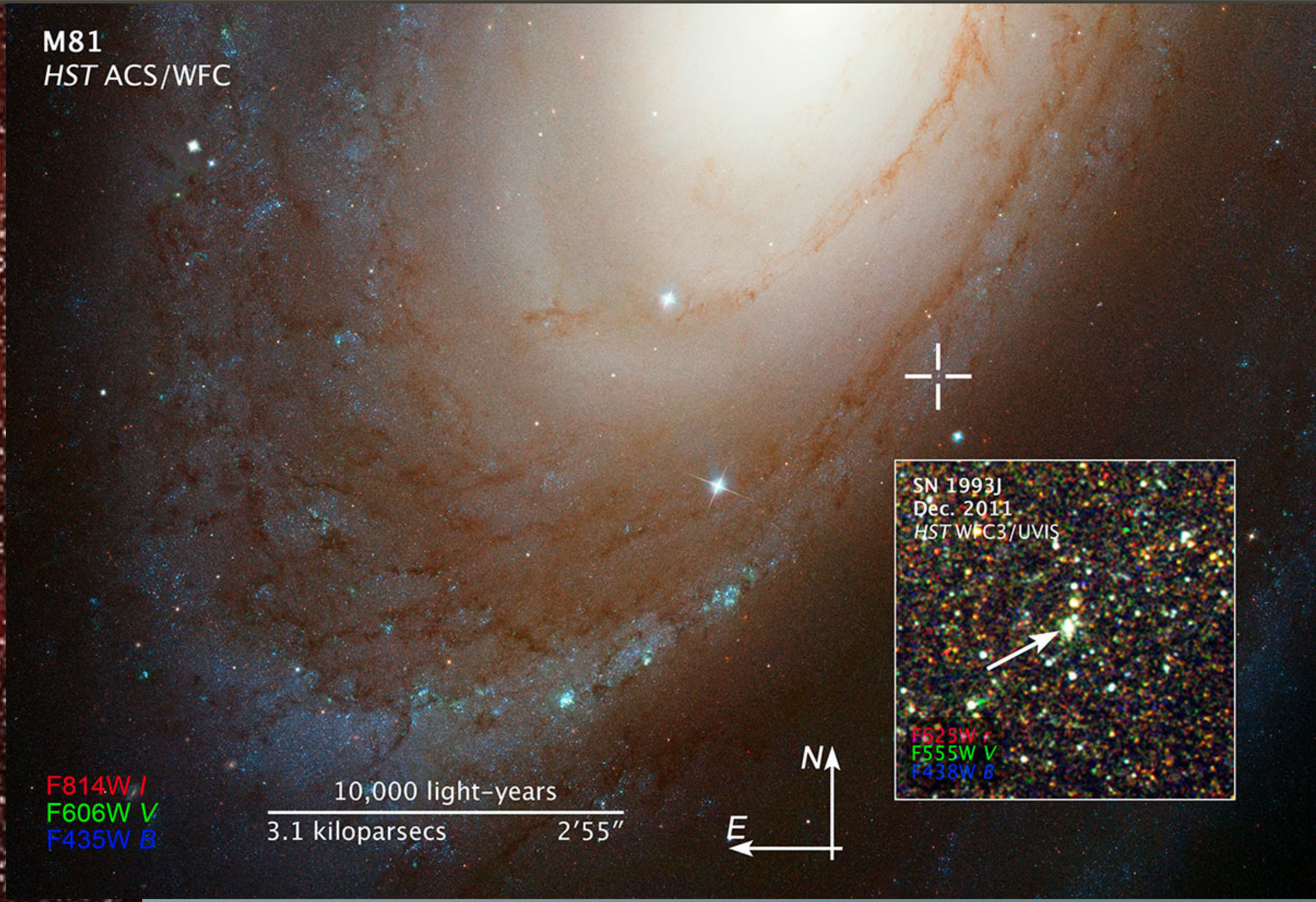


SUPERNOVAE WITH DETECTED PROGENITOR STARS



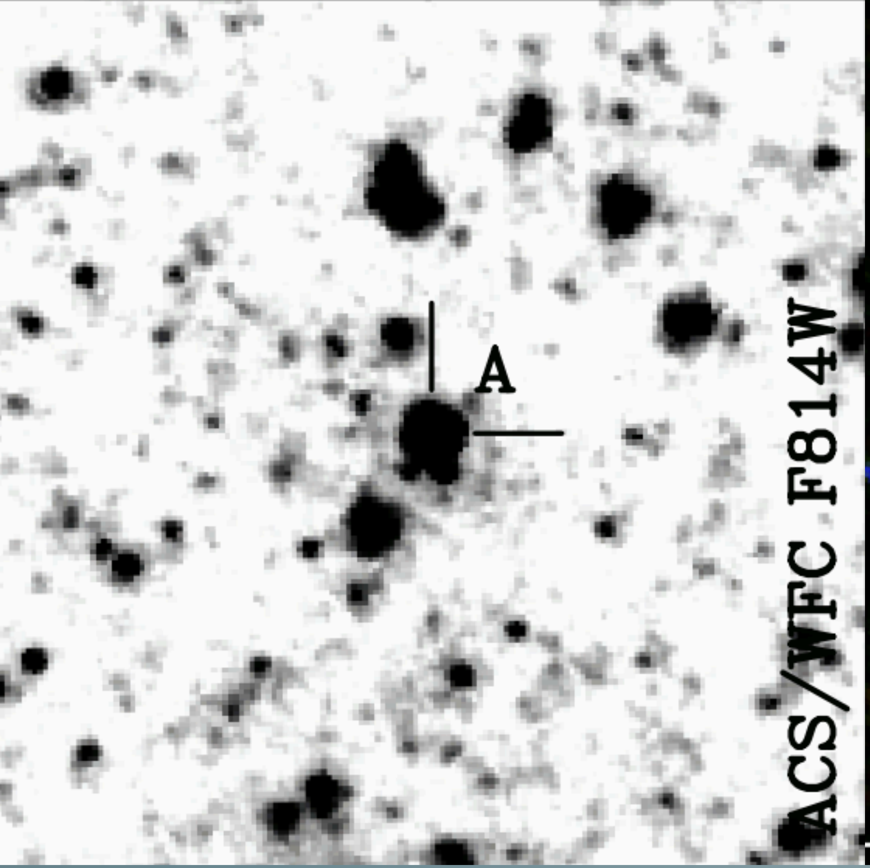
SN 1987A (Type II-pec)

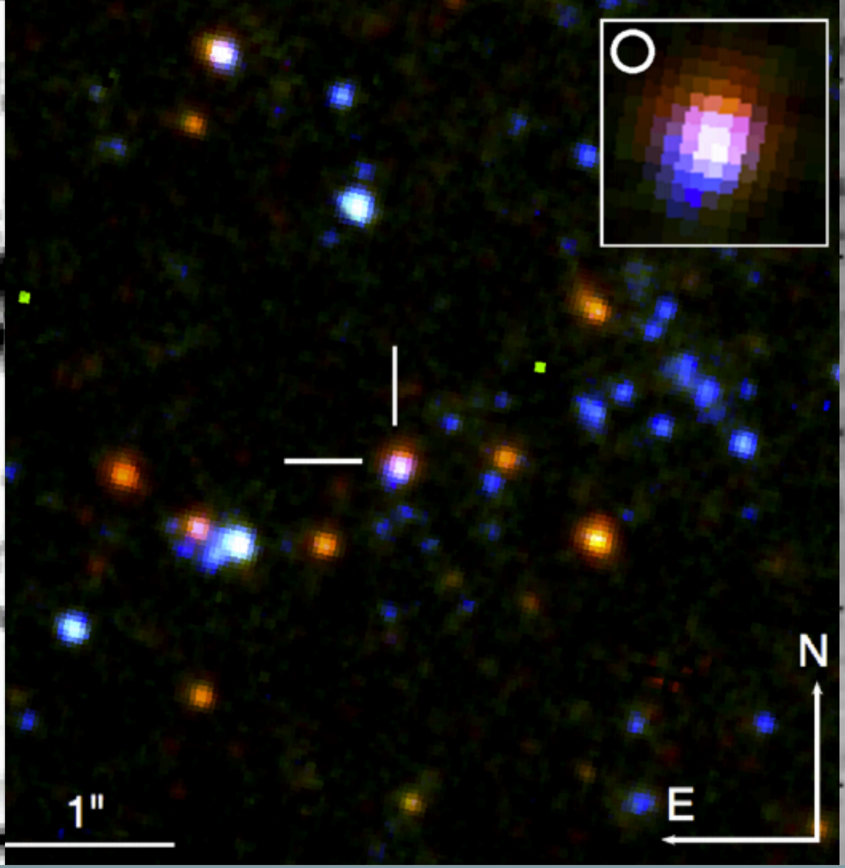
a peculiar supernova with hydrogen in its spectrum, requires a hydrogen-rich but compact progenitor star

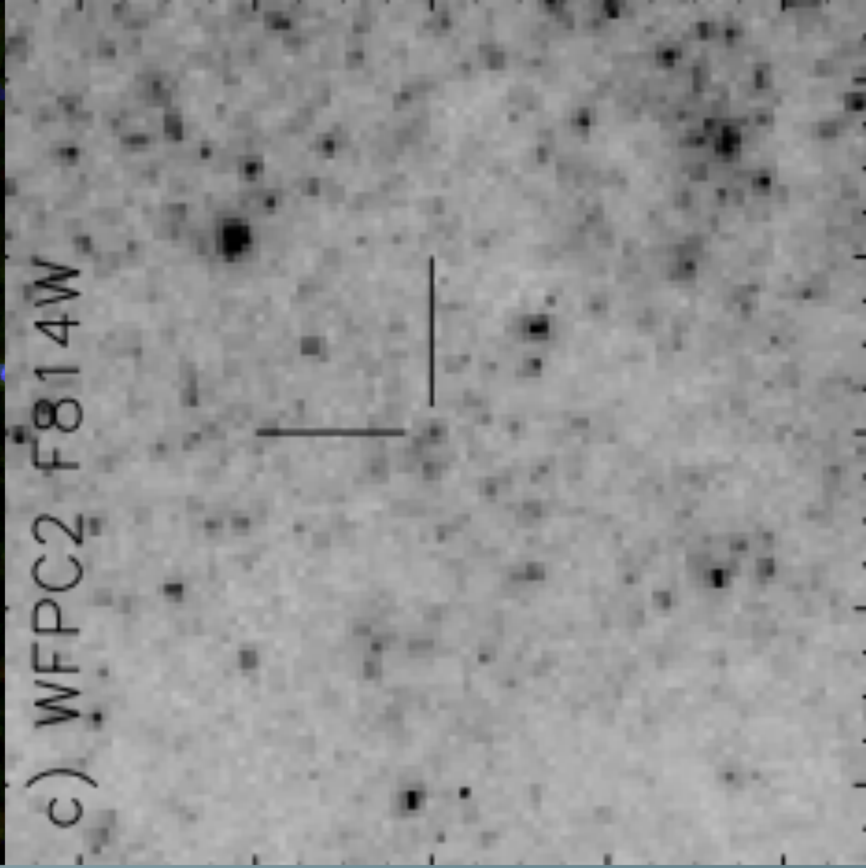


SN 1993J (Type IIb)

a supernova that exhibits hydrogen at first but it disappears over time, requires a star with an extended but low-mass hydrogen envelope







2011dh

SN IIb in M51 (7 Mpc), Maund+11

2013ej

SN IIP in M74 (10 Mpc), Fraser+14

2008ax

SN IIb in NGC 4490 (8 Mpc), Crockett+08

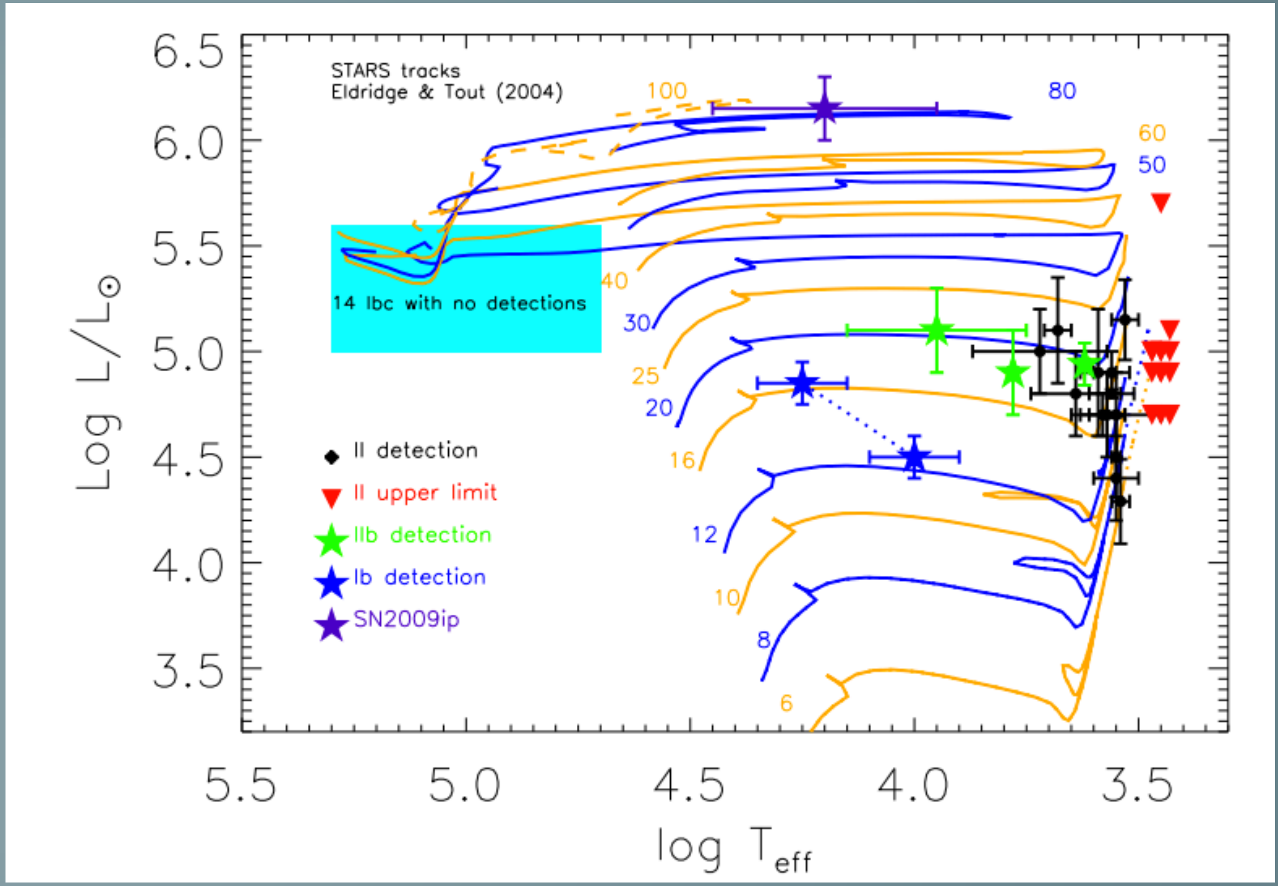
- Only *HST* has the depth, resolution, and coverage to find potential progenitor stars
- We can reasonably expect to resolve and detect individual giant stars out to 30 Mpc

If a transient occurs in a z < 0.007 galaxy, the probability its position was imaged by *HST* (WFPC2, ACS, WFC3) is about 25% (Smartt+09, Smartt 15)

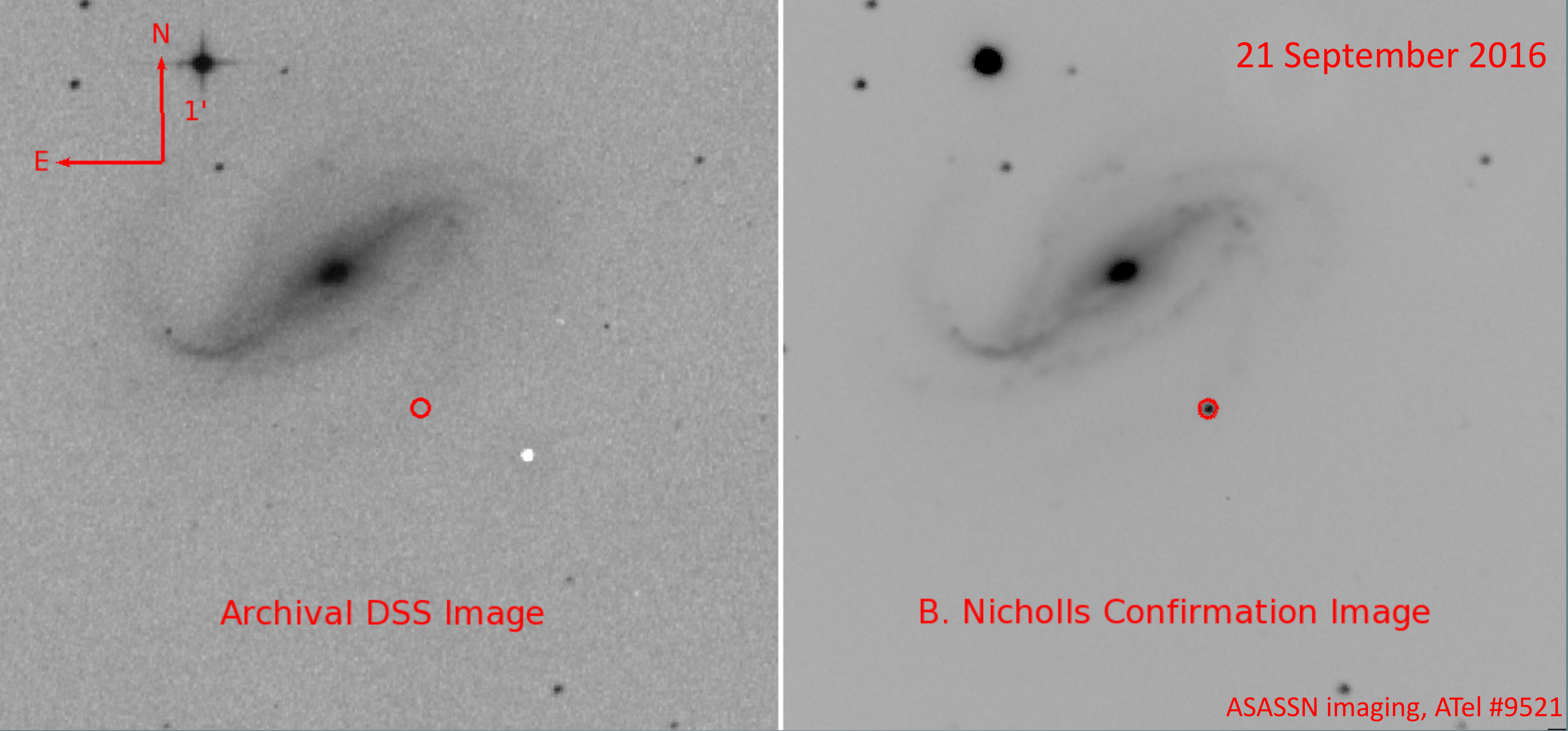
Roughly 1,000 confirmed SNe occurred last year, and 14 had z < 0.007 (TNS, OSC)

We can expect about 3 or 4 events per year with possible progenitor detections in *HST* imaging

Only by waiting long enough and actively following up every nearby SN can we accumulate statistics on SN progenitors



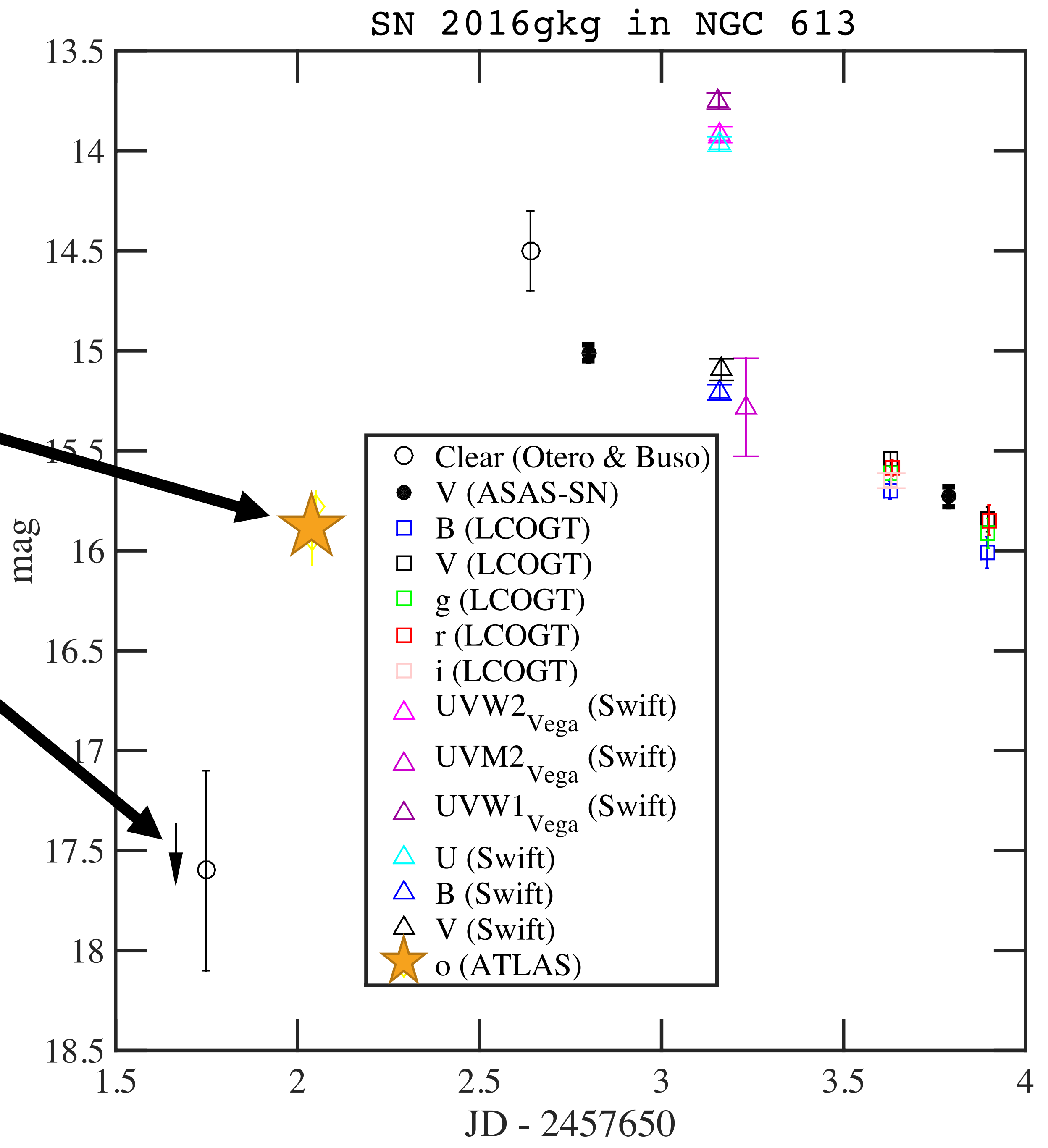
Smartt 2015

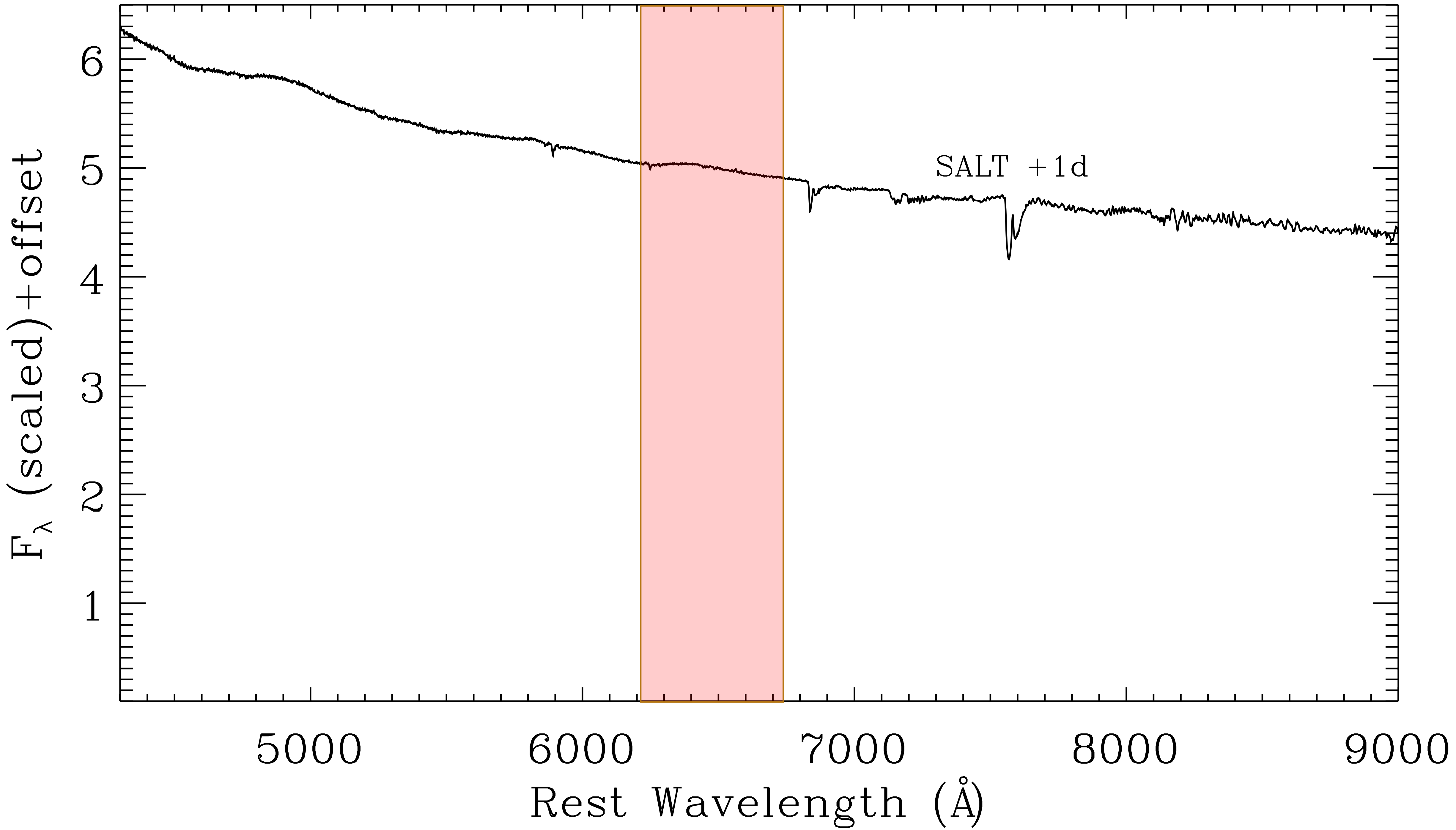


- Reported by ASASSN and an amateur astronomer simultaneously on Sep 21
- Discovered 93 arcseconds southwest of the core of NGC 613 (25 Mpc)

Supernova rose quickly within hours of discovery

Upper limits from immediately before discovery indicate the supernova was likely first observed hours after explosion




SALT +1d
F$_\lambda$ (scaled)+offset
Rest Wavelength (Å)
1
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8000
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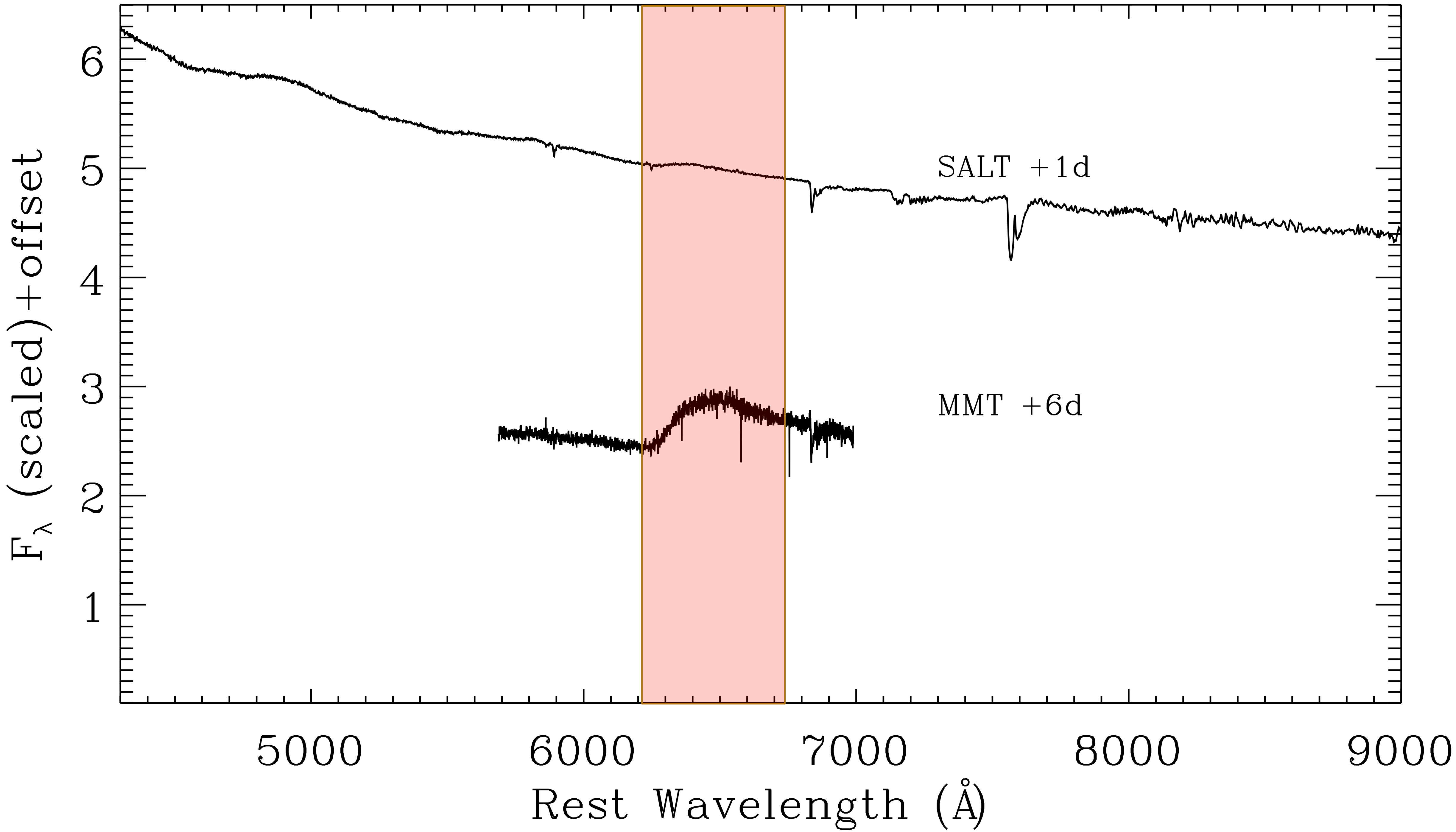

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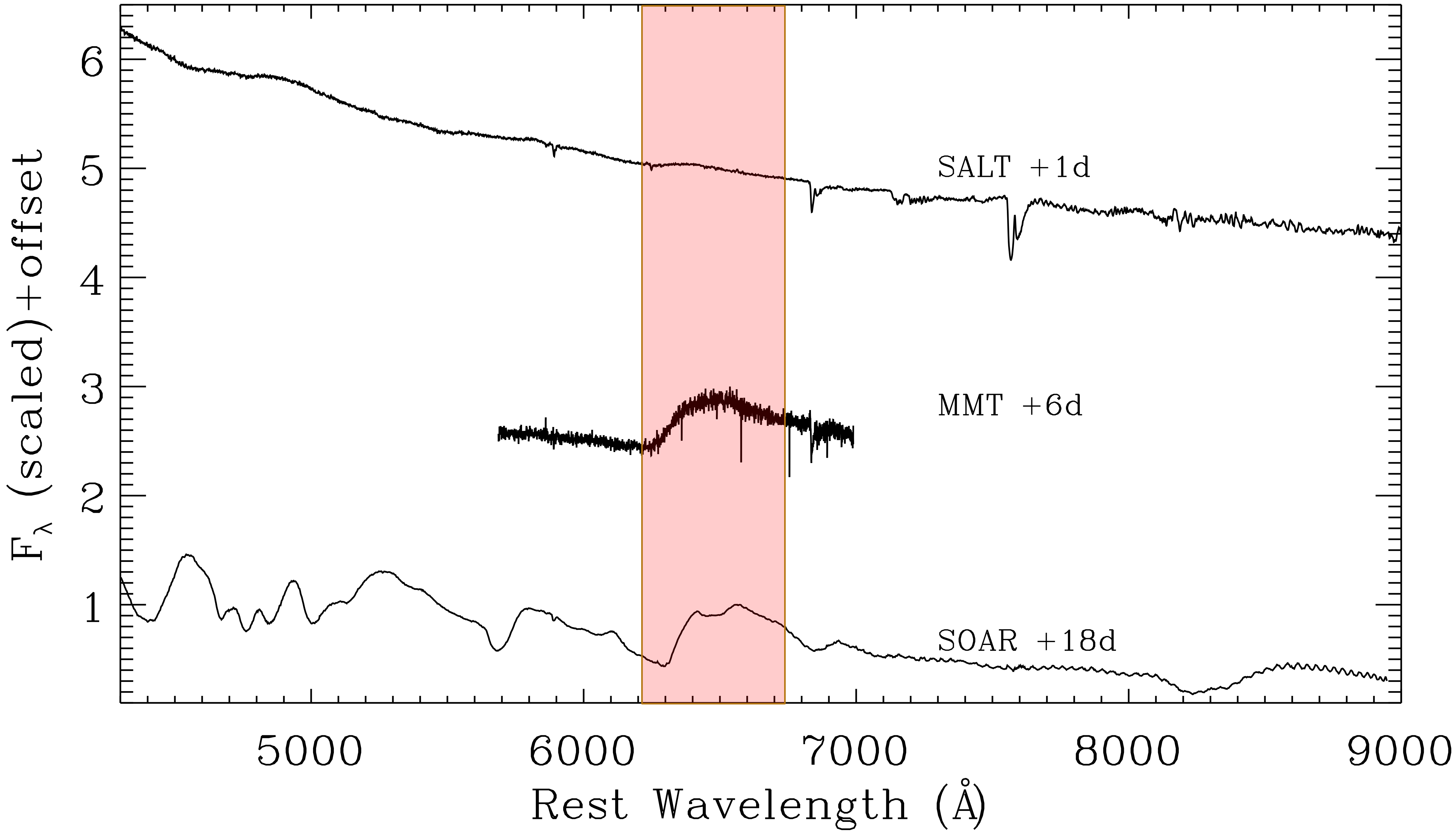
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MMT +6d
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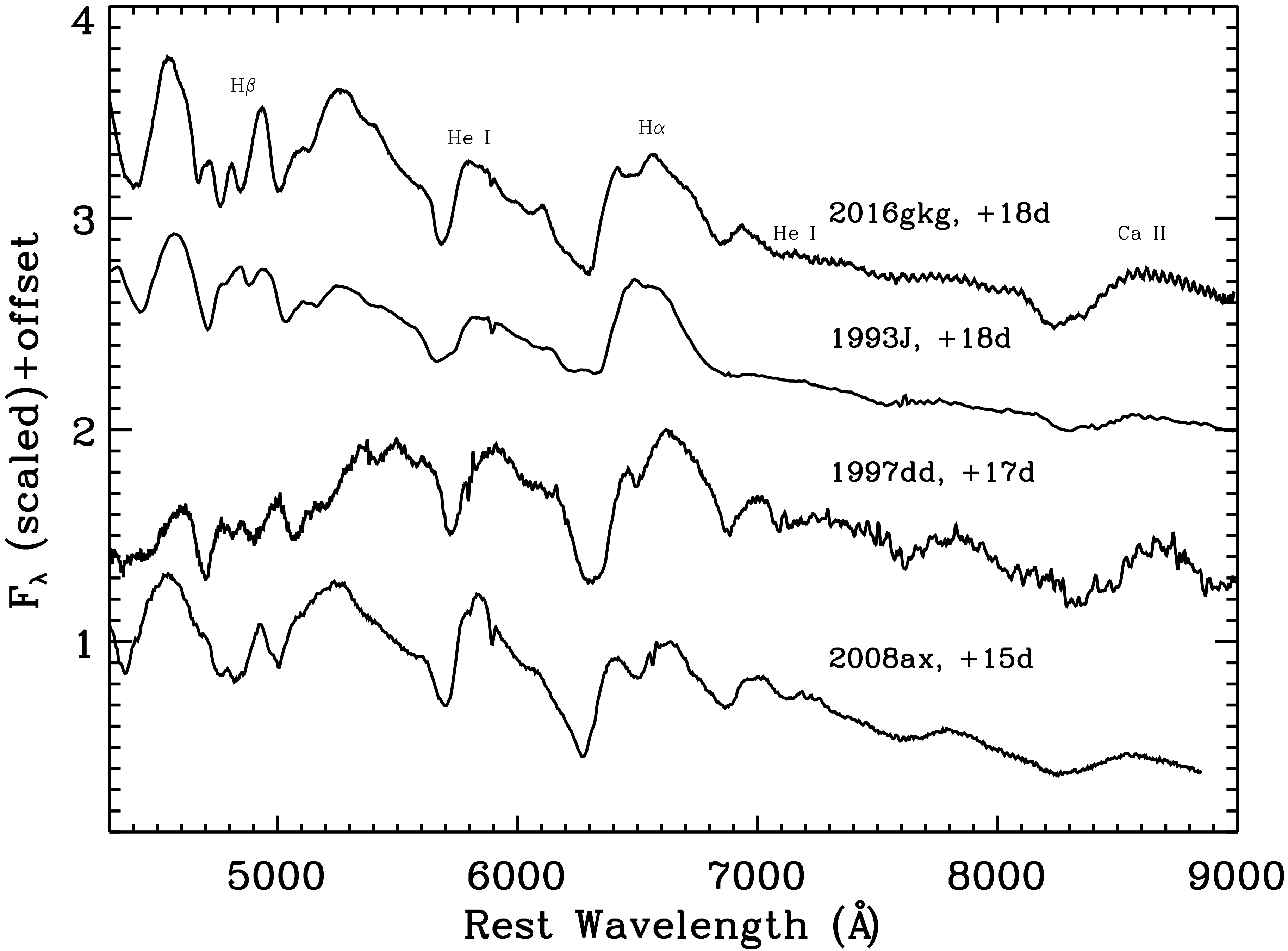
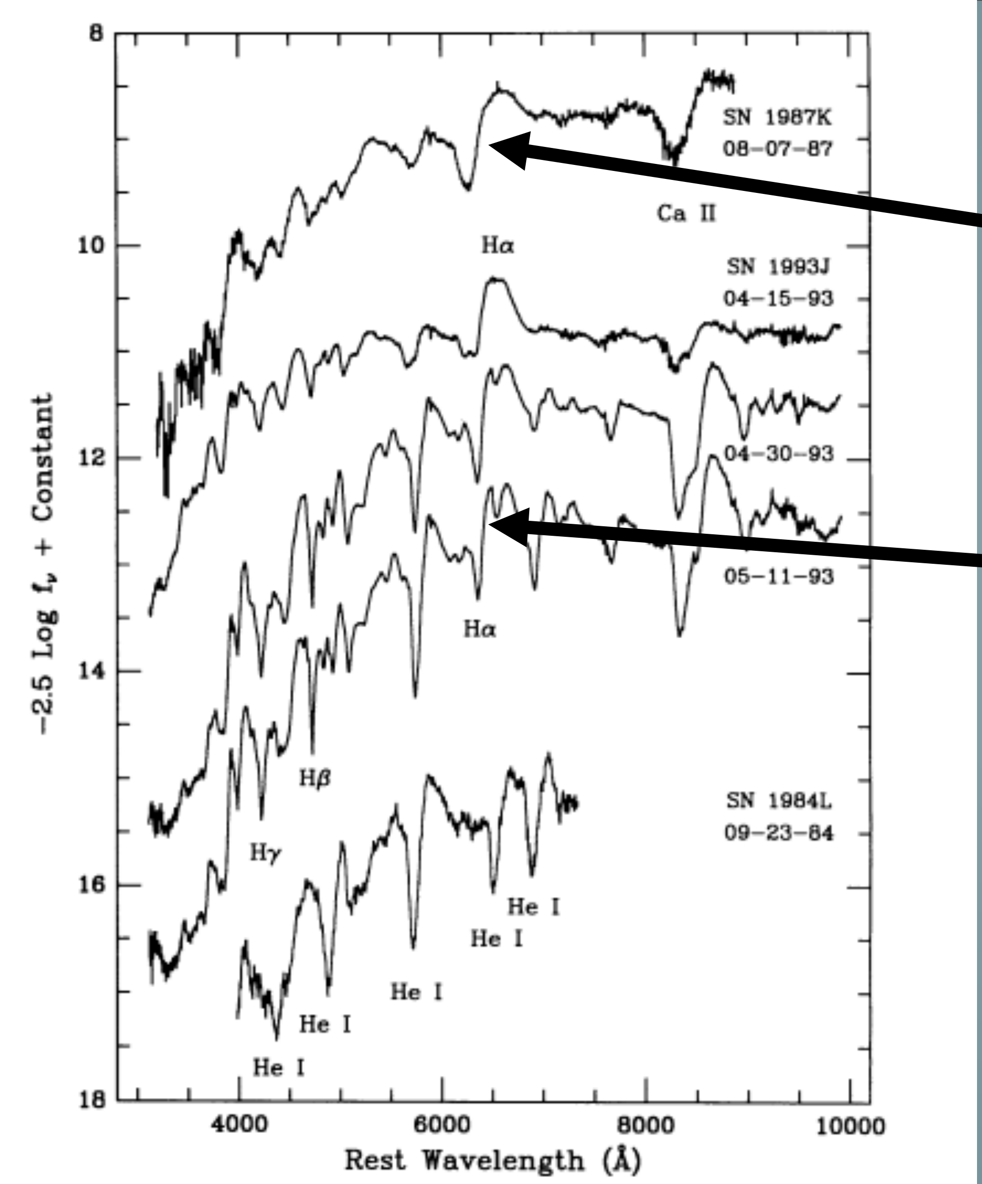


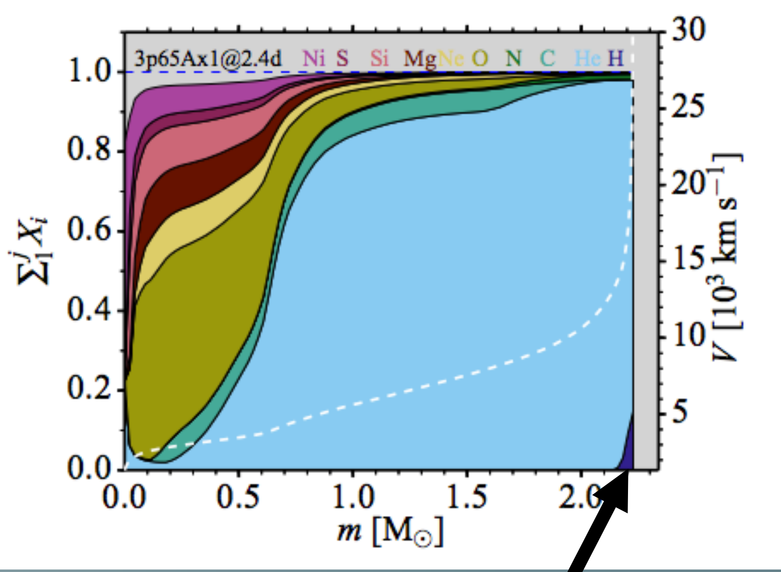
Spectra within a few weeks of explosion were well-matched to other Type IIb supernovae

TYPE IIB SUPERNOVA



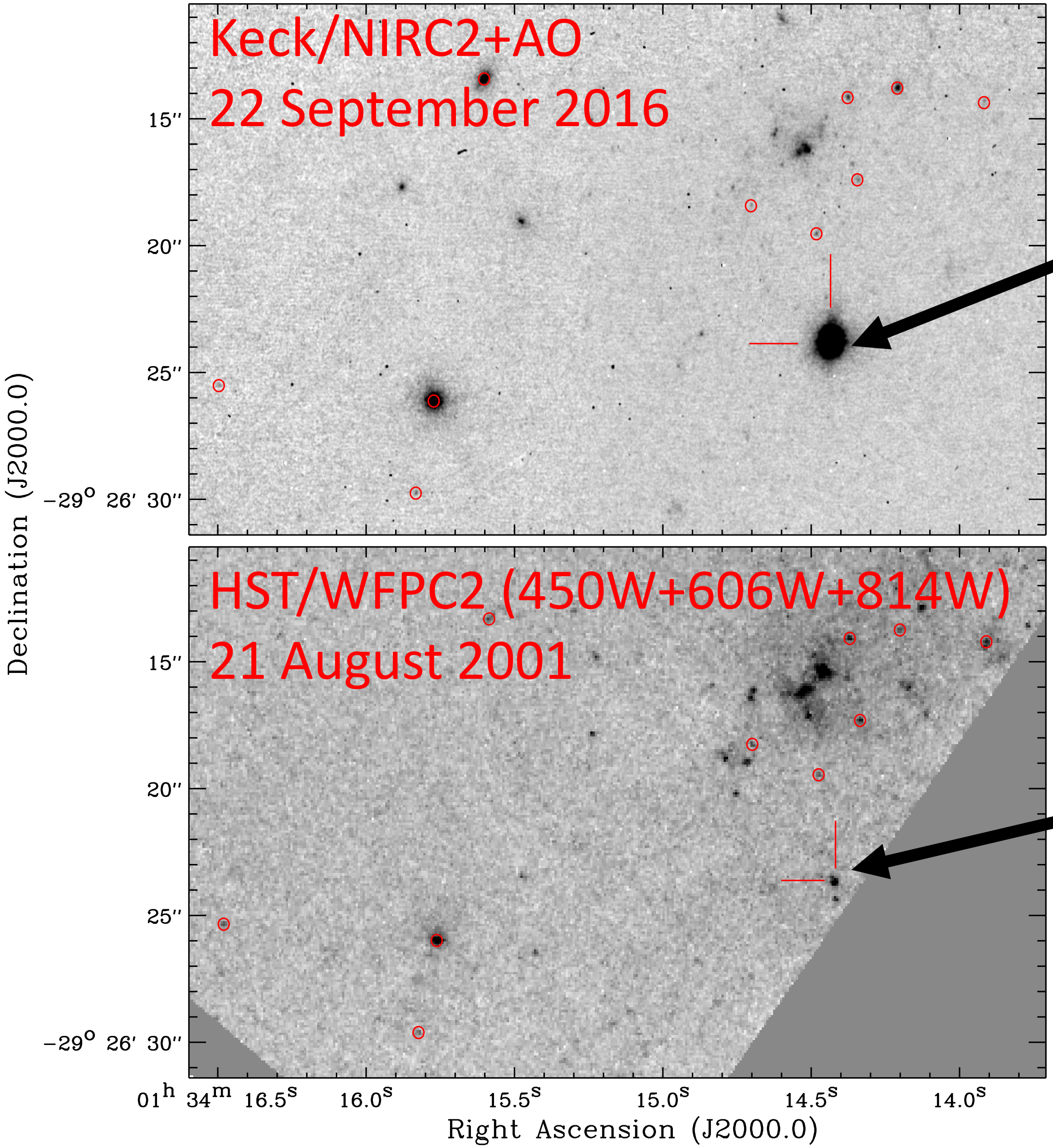
Filippenko, Matheson, & Ho (1993)

- SN IIb start out with characteristic P-Cygni profile in Halpha
- Over the first few weeks, Halpha disappears and helium is dominant!
- How do you make a star with just enough hydrogen to be visible at early times?



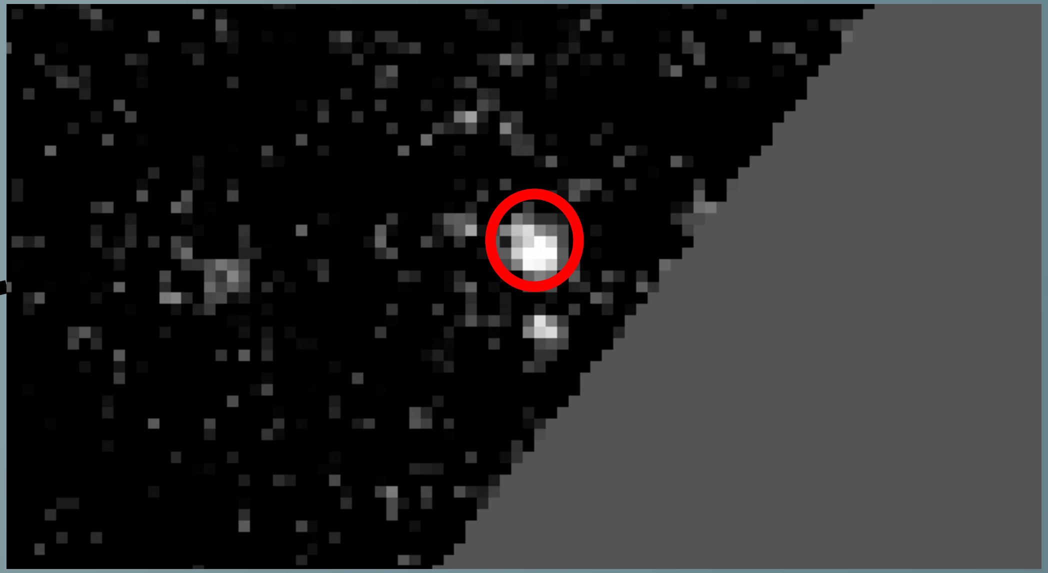
Dessart+15

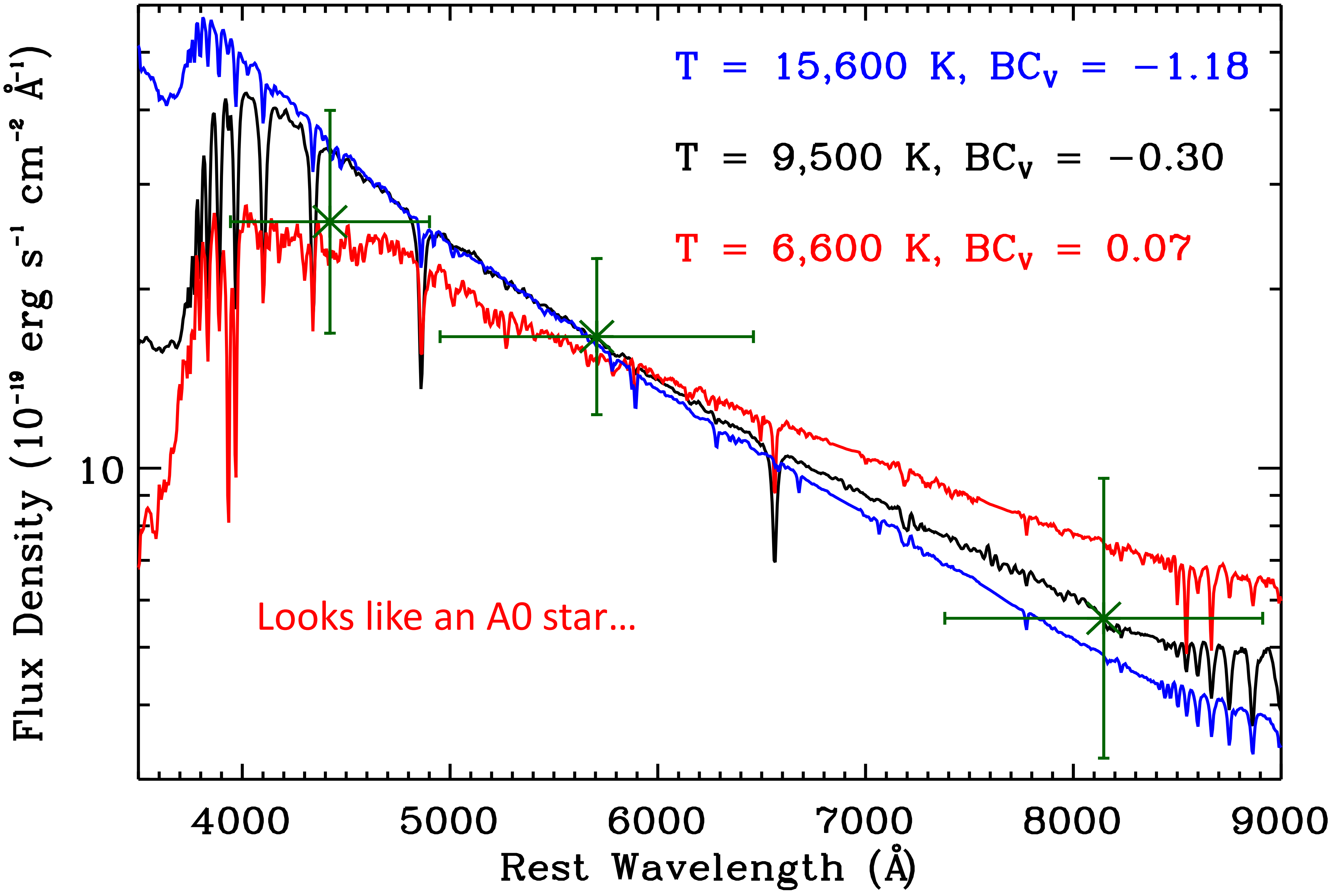
This type of explosion requires the progenitor to have 15-25 M$_\odot$ with < 0.005 M$_\odot$ hydrogen



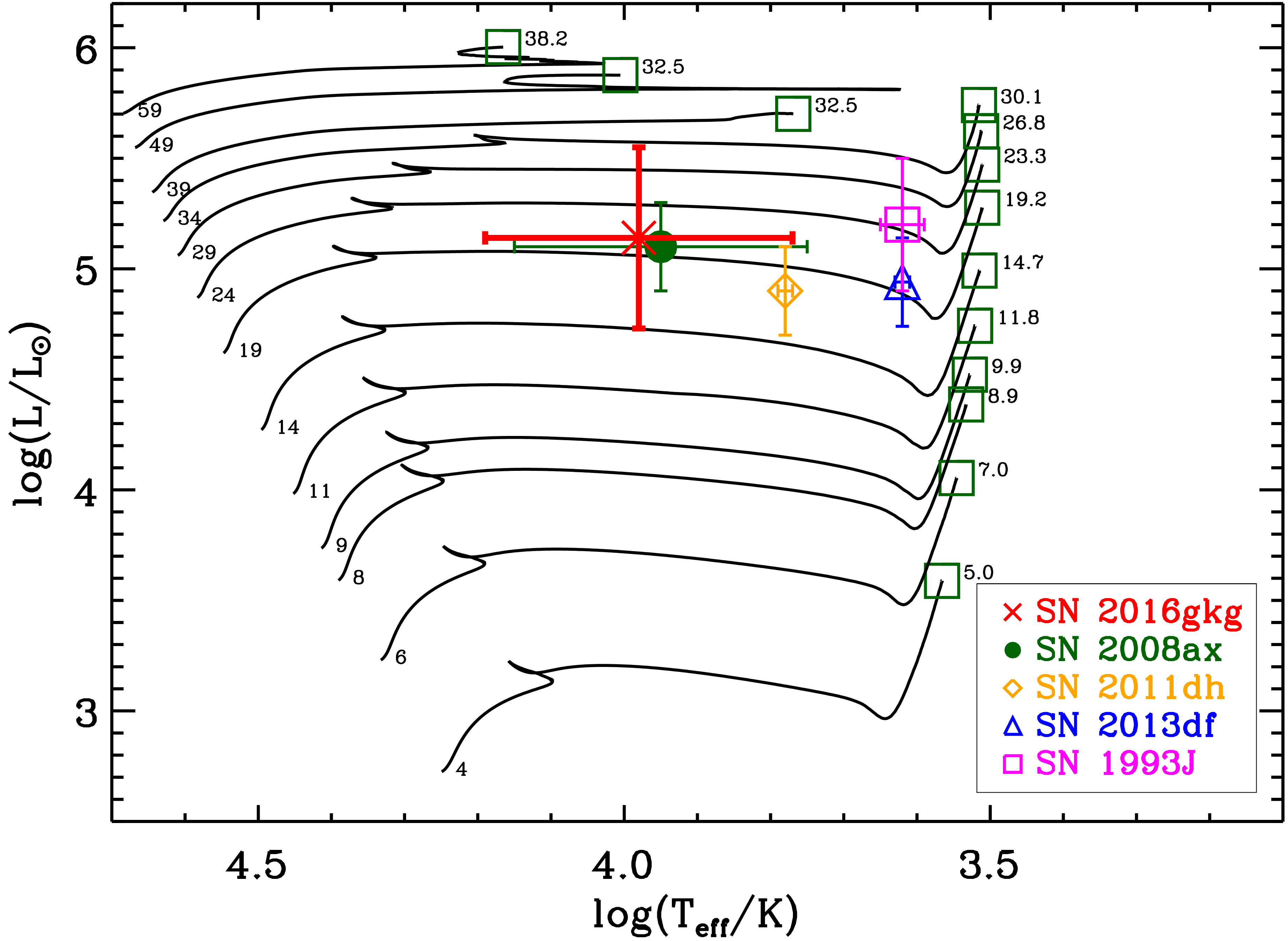
Kilpatrick et al. (2017)

Relative astrometry between sources near the SN and sources in the *HST* image allow us to pinpoint the location of the progenitor



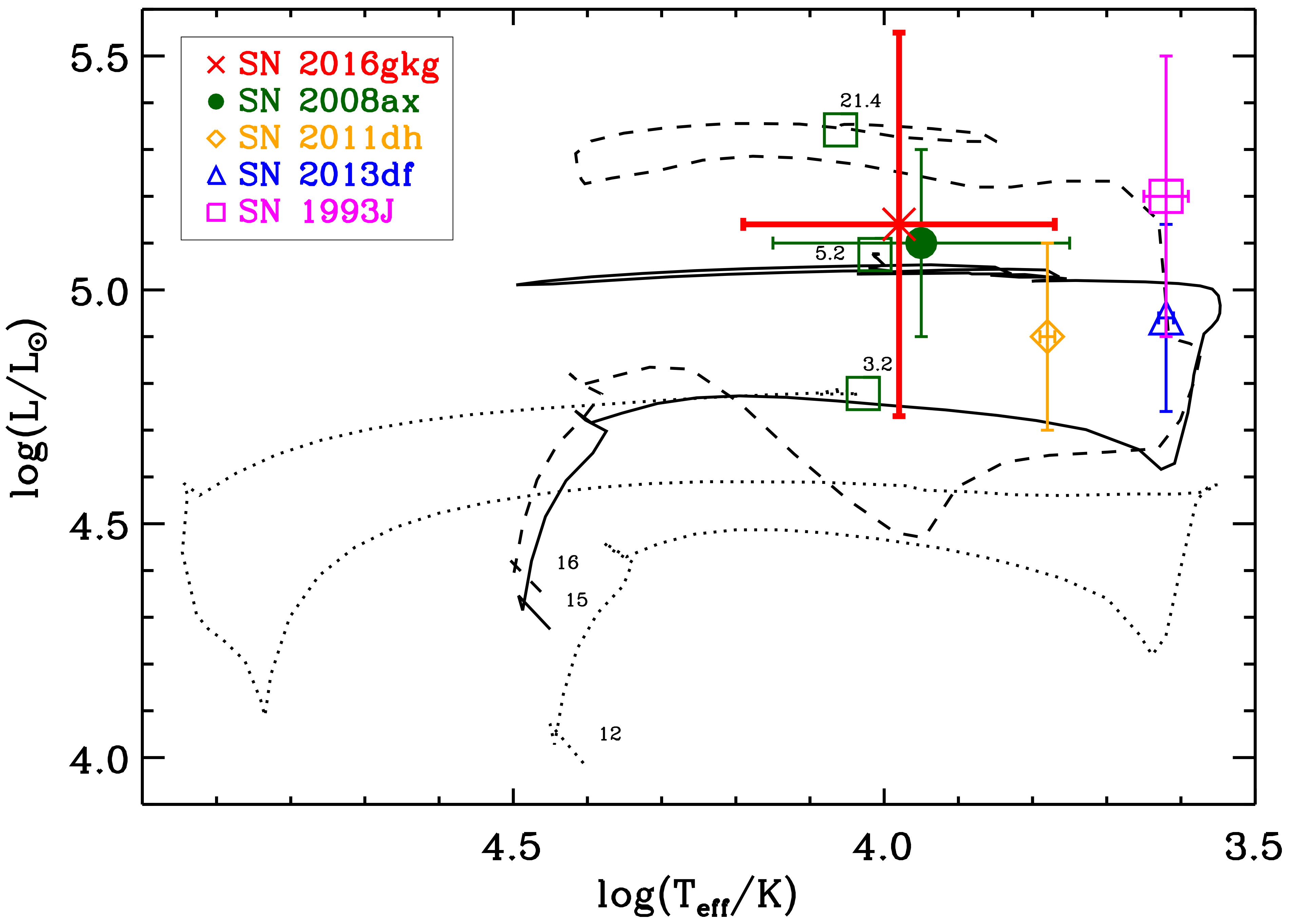


Kilpatrick – 20 Feb 2017



The detected progenitor star along with other SN IIb progenitor stars

Normal single-star evolutionary models cannot explain SN 2016gkg

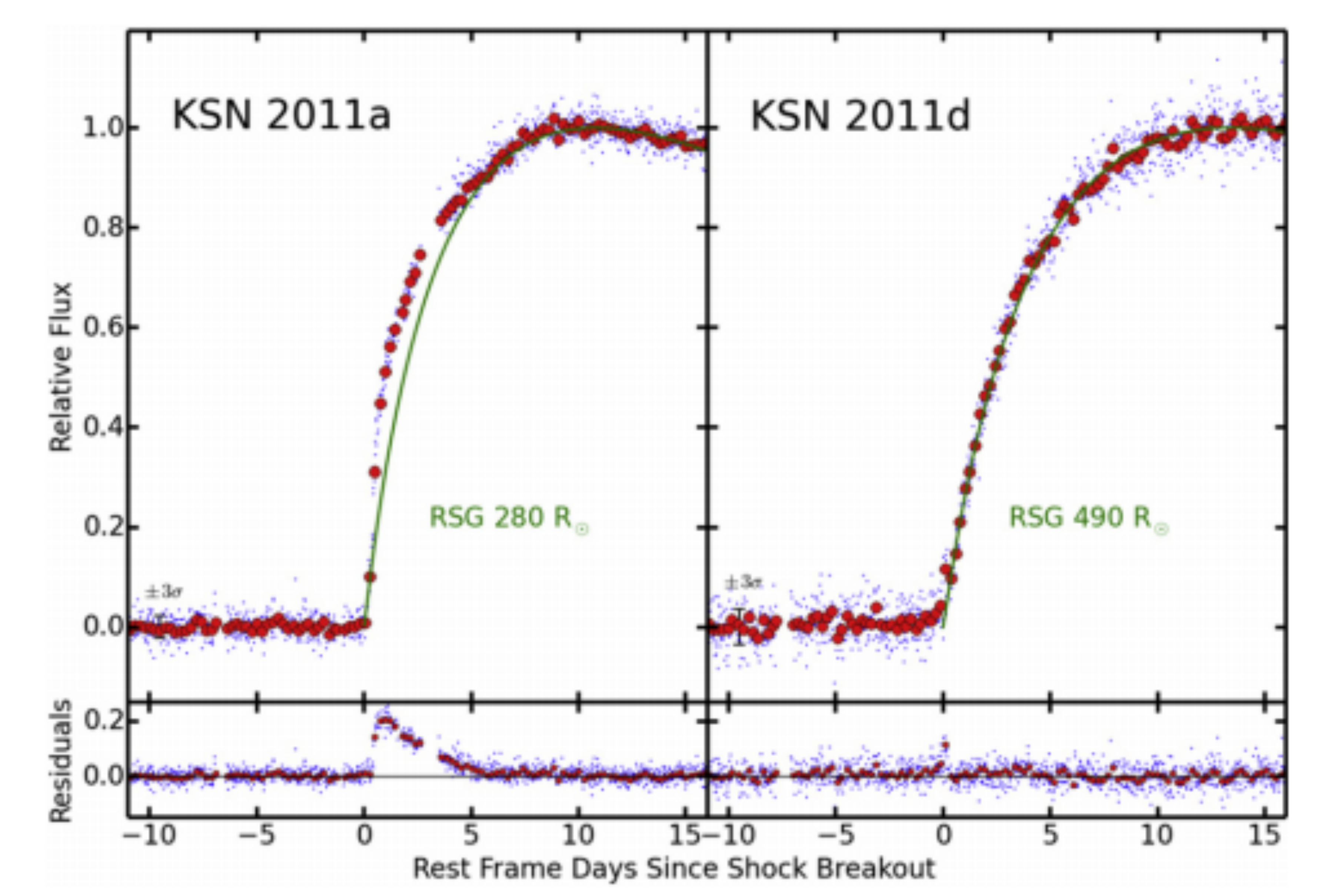


Binary star models fit the data the best

Progenitor star requires an unusual terminal luminosity and temperature

Spectra require low-mass hydrogen envelope

COOLING AFTER SHOCK BREAKOUT

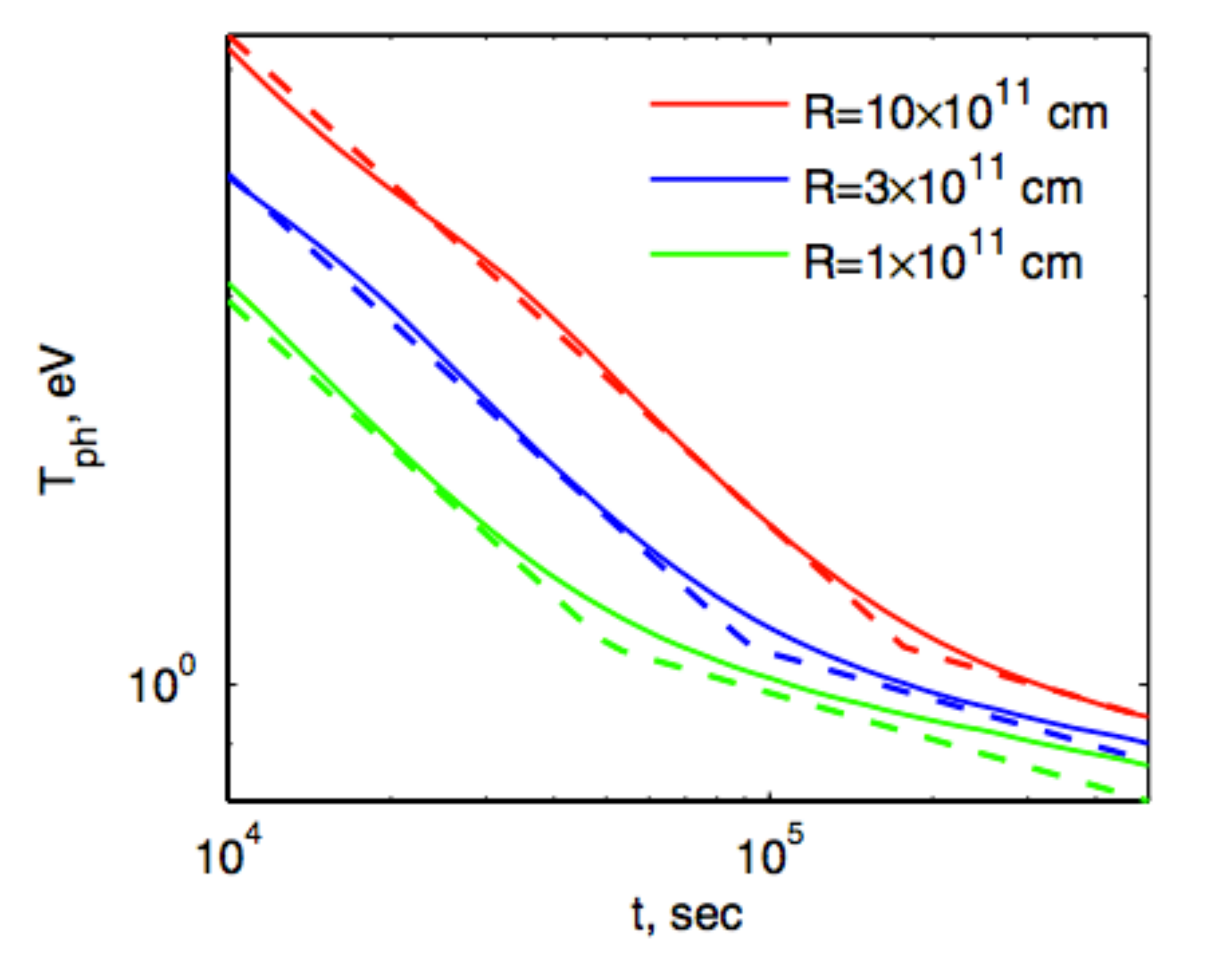


Garnavich et al. (2016), ApJ, 820, 23

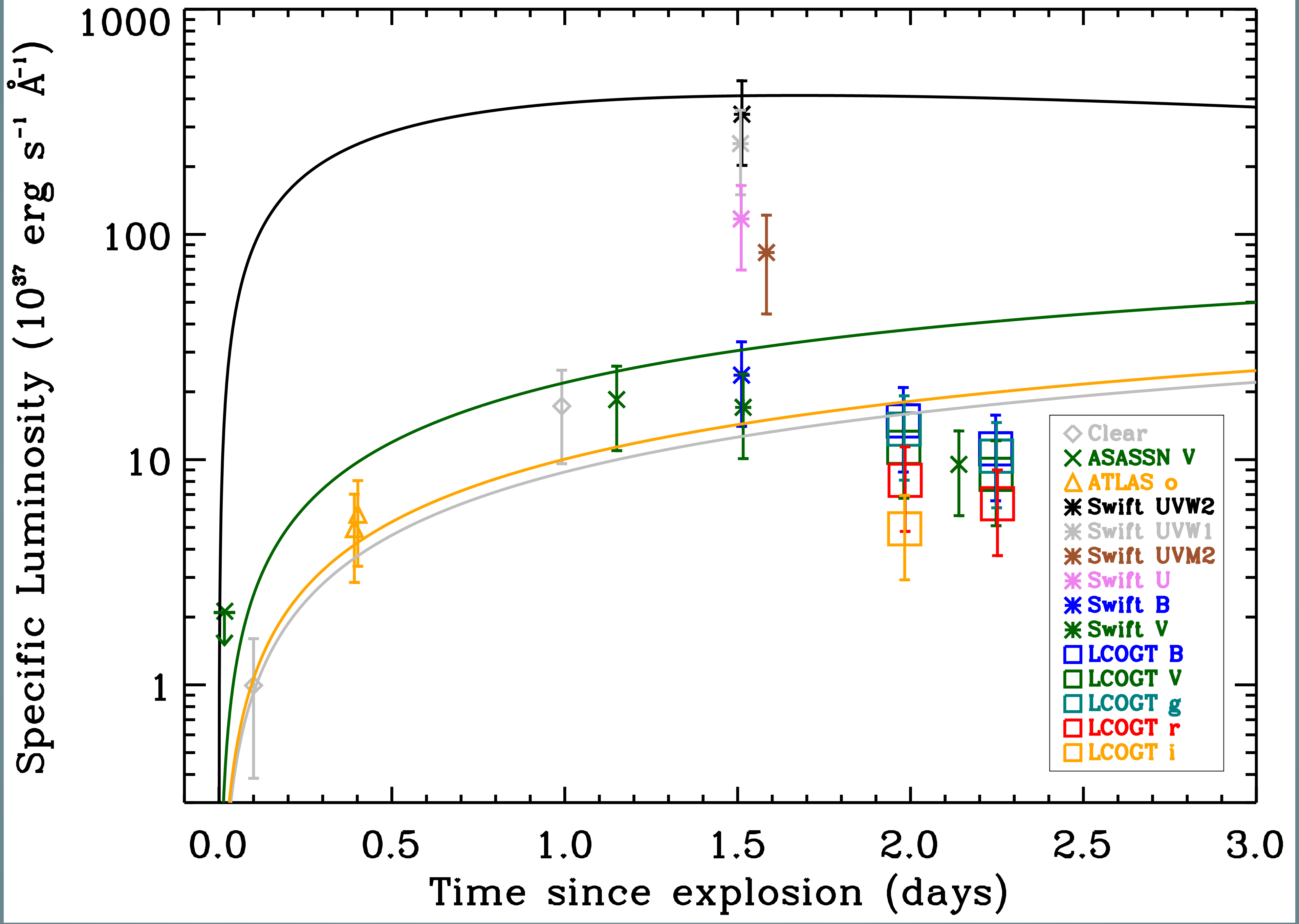
COOLING AFTER SHOCK BREAKOUT

Immediately following shock breakout, the envelope is hot and cools adiabatically:

> Larger stellar radii imply a hotter initial photosphere



Rabinak & Waxman (2011)



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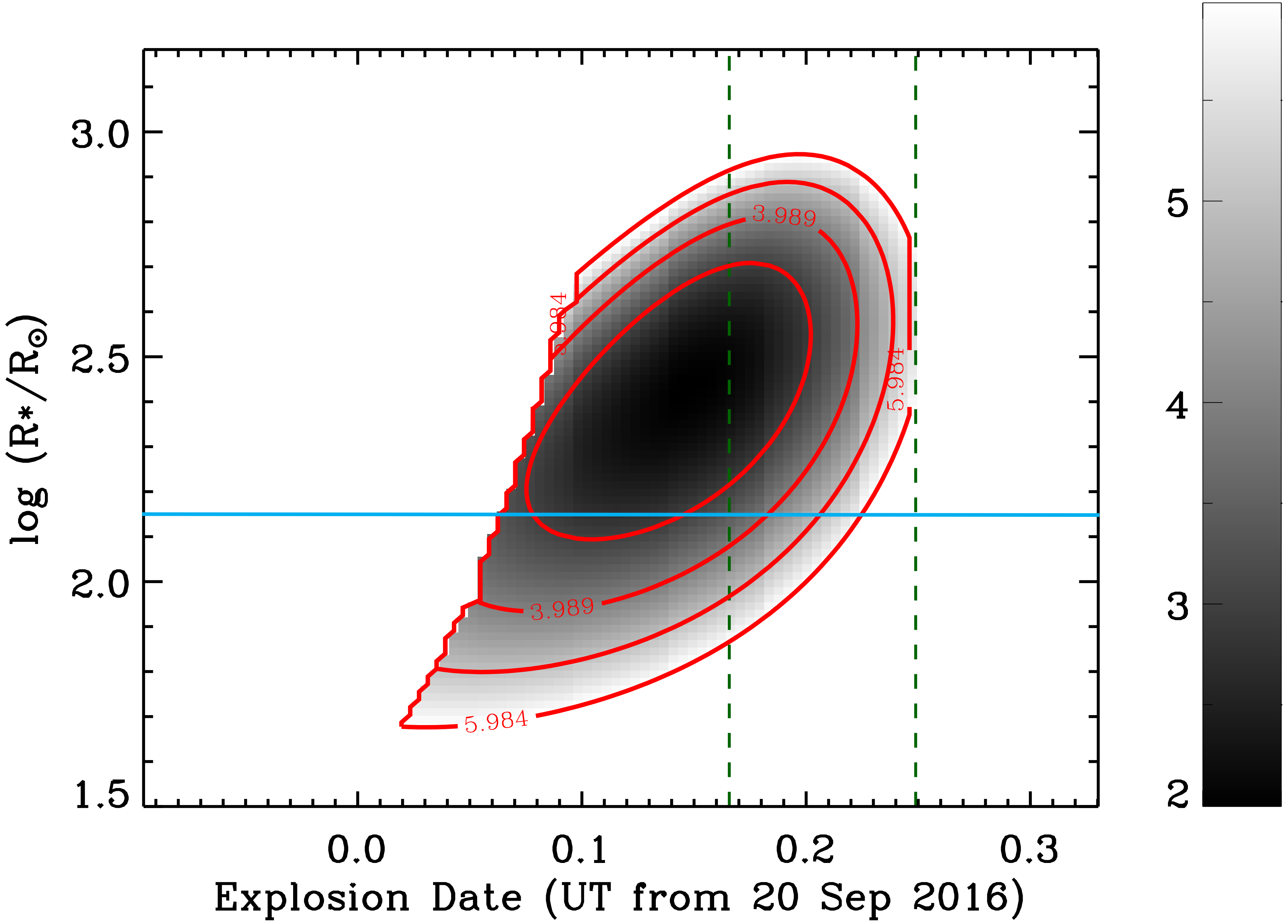
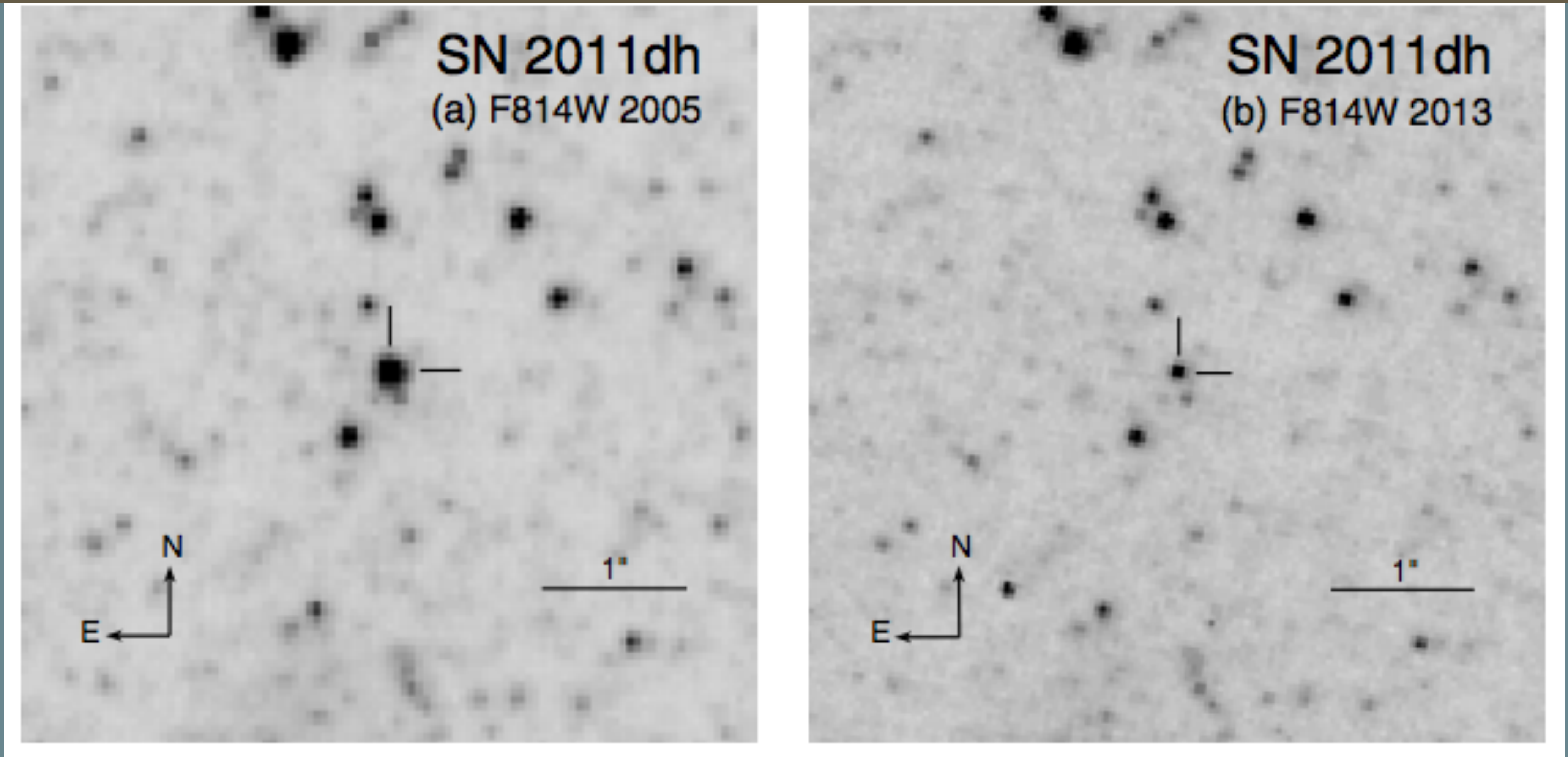


SN 2016gkg progenitor star parameters:

log L = 5.14, T = 9500
-> log R = 2.14 +/- 0.51

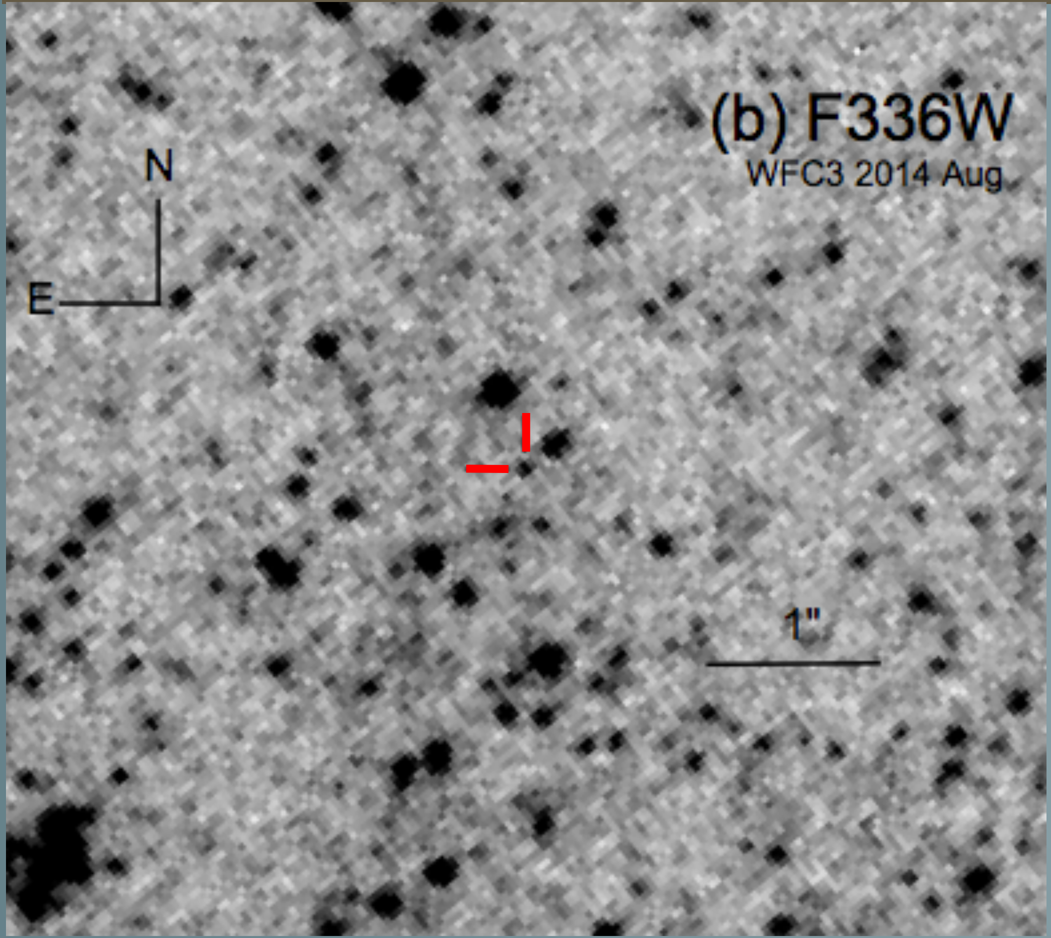
Light curve fitting:
-> log R = 2.4 +/- 0.4

TEST OF PROGENITOR STAR



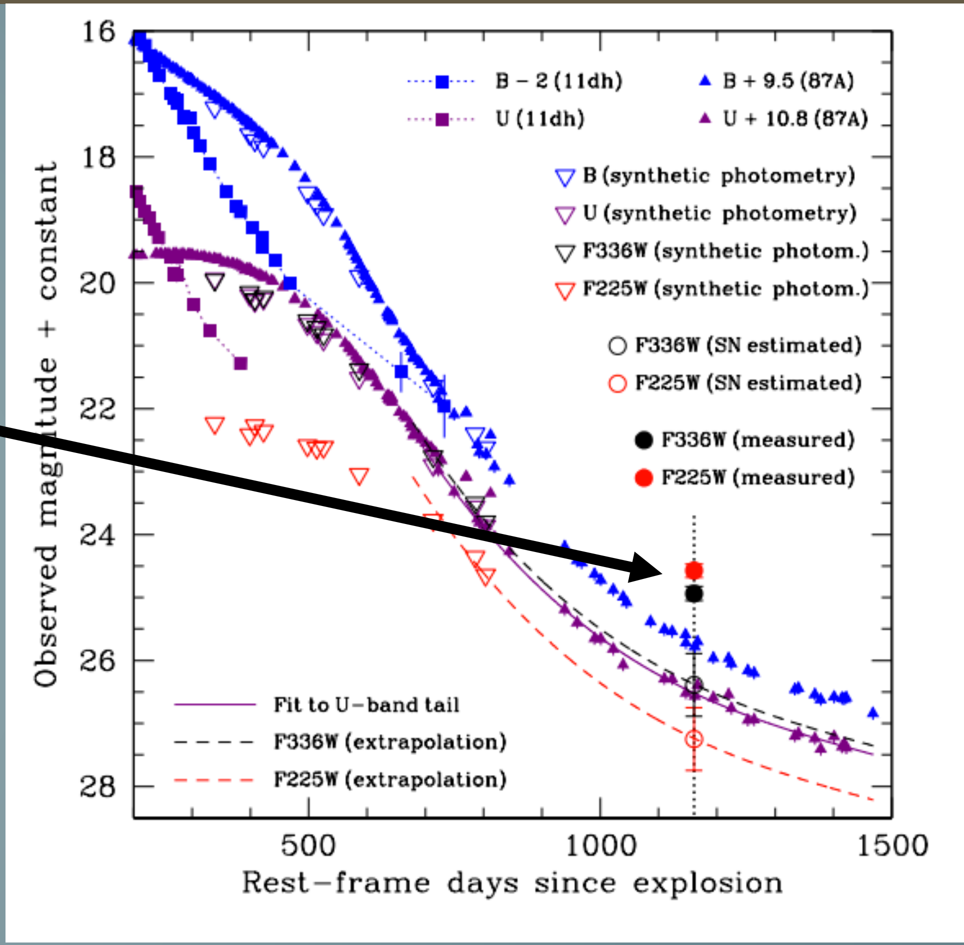
- Show the supernova is fainter than the progenitor star -> the progenitor star has disappeared
- Once the supernova has faded significantly, we might even be able to see a companion

OTHER WAYS TO TEST THE PROGENITOR



Point source is well above the inferred ^{56}Ni decay rate for late-time SNe

SN 2011dh (Folatelli+14)



- Our binary models suggest SN 2016gkg likely has a companion with F300W = 26 mag
- Once the SN has faded to that level, we might detect a binary counterpart in deep imaging

SUMMARY

- 2016gkg adds to progenitor studies and demonstrates that progenitor systems can be resolved out to 25 Mpc
- Early-time spectra and light curves can be used to check the consistency of a progenitor system by inferring the primary star radius
- Late-time *HST* follow-up will be necessary both for verifying the progenitor has disappeared and looking for possible binary companions