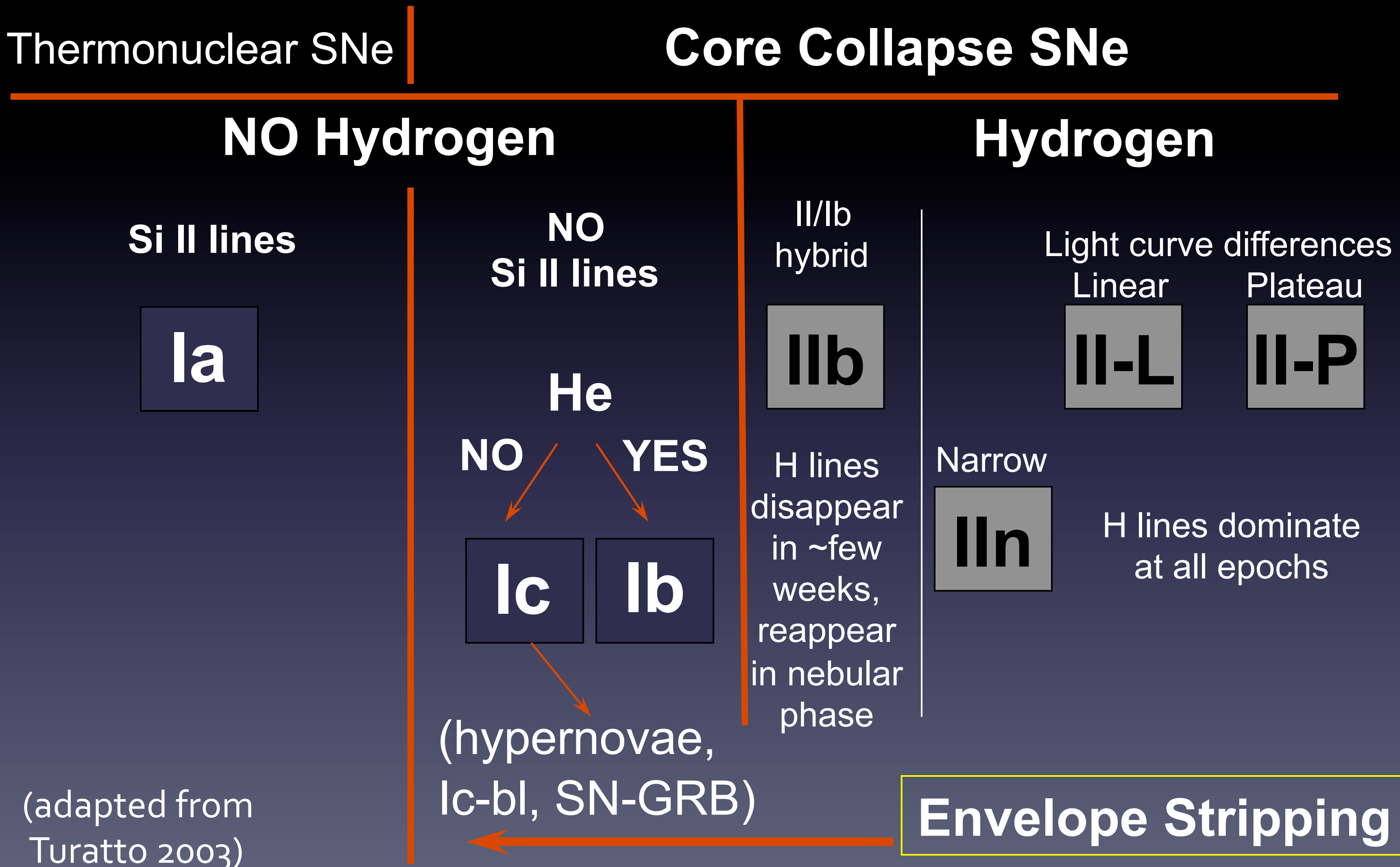
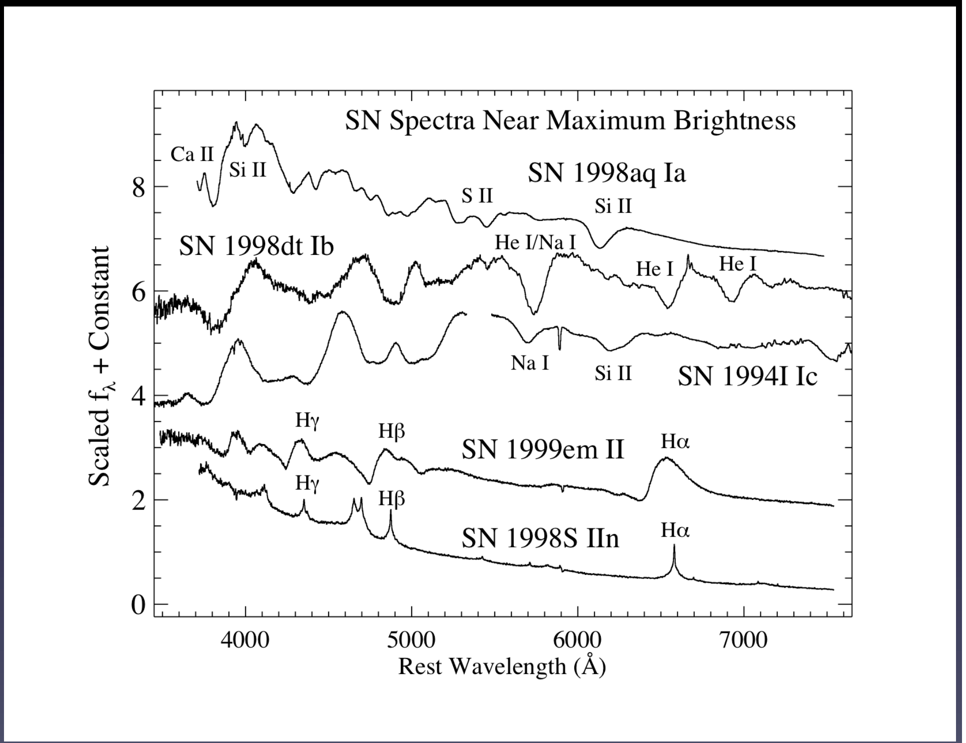
Direct Identification of Core-Collapse SN Progenitors

Schuyler D. Van Dyk (IPAC/Caltech)

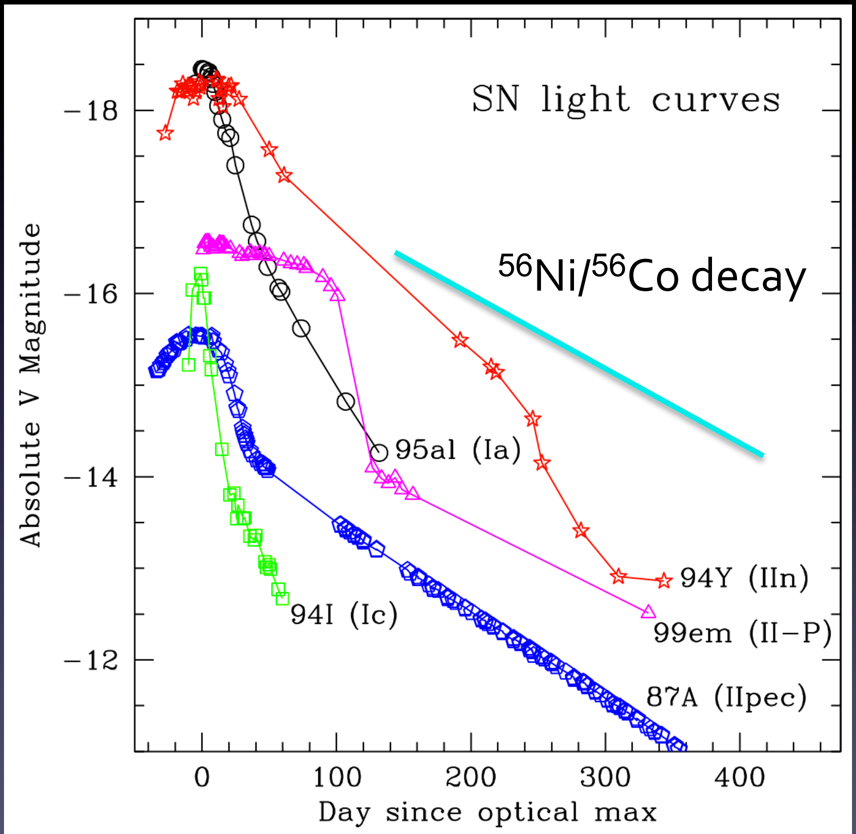
Core-Collapse SNe: Classification



Core-Collapse SNe: Classification

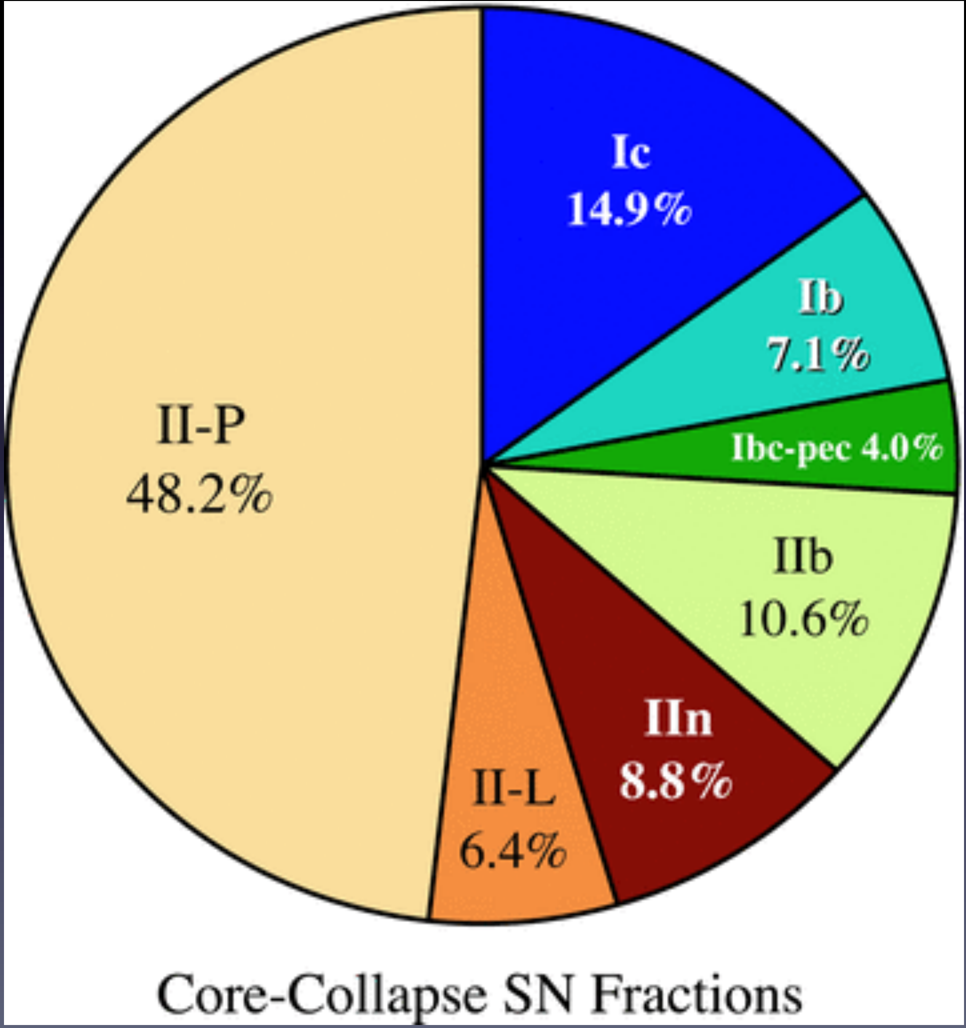


(Van Dyk & Matheson 2012)



Mass of ^{56}Ni depends on mass of core

Core-Collapse SNe: Rates



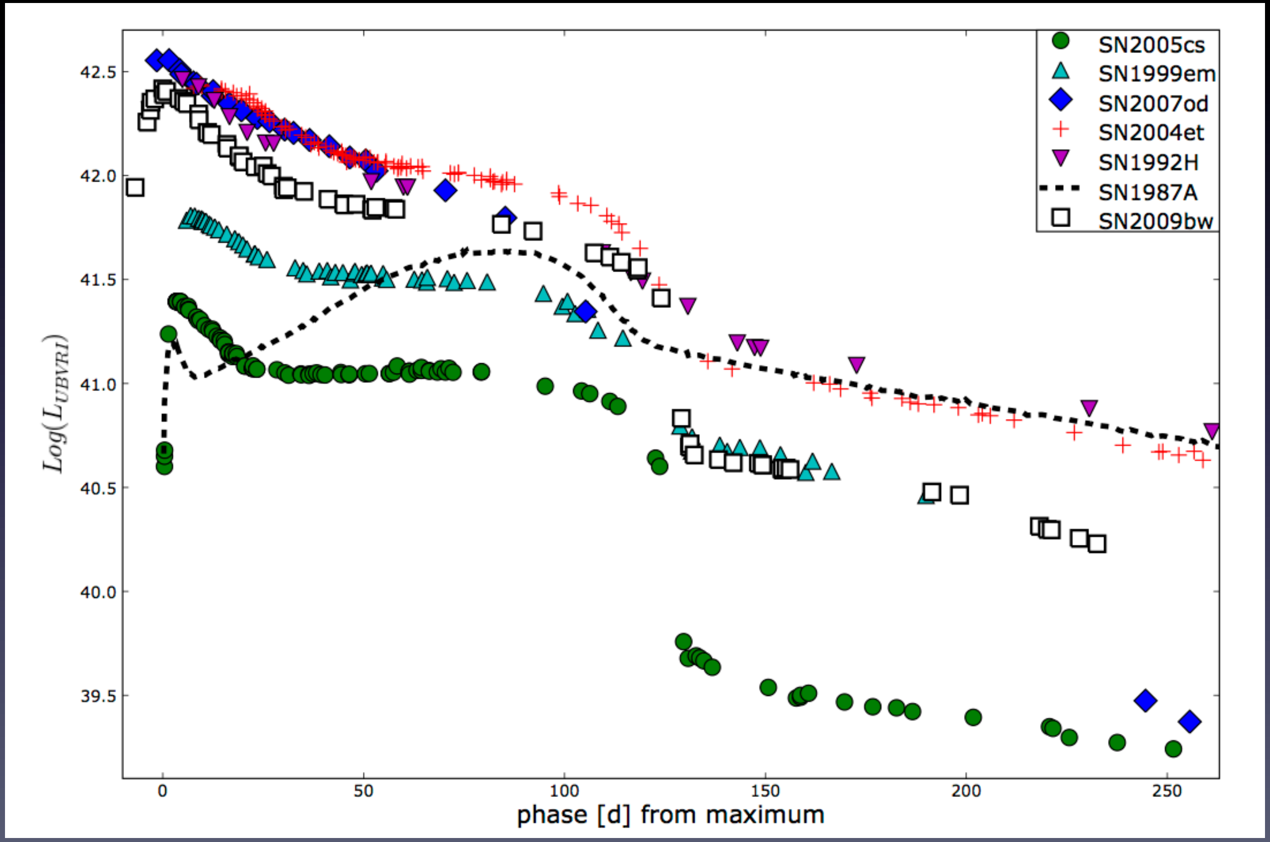
Smith et al. (2011)

Direct Identification of SN Progenitors

- SN 1978K (IIn)
- SN 1987A (II pec)
- SN 1993J (IIb)
- SN 1999ev (II-P)
- SN 2003gd (II-P)
- SN 2004A (II-P)
- SN 2004et (II-P)
- SN 2005cs (II-P)
- SN 2005gl (IIn)
- SN 2008ax (IIb)
- SN 2008bk (II-P)
- SN 2008cn (II-P ?)
- SN 2009hd (II-L ?)
- SN 2009kr (II-L)
- SN 2009md (II-P)
- SN 2010jl (IIn) ?
- SN 2011dh (IIb)
- SN 2012A (II-P)
- SN 2012aw (II-P)

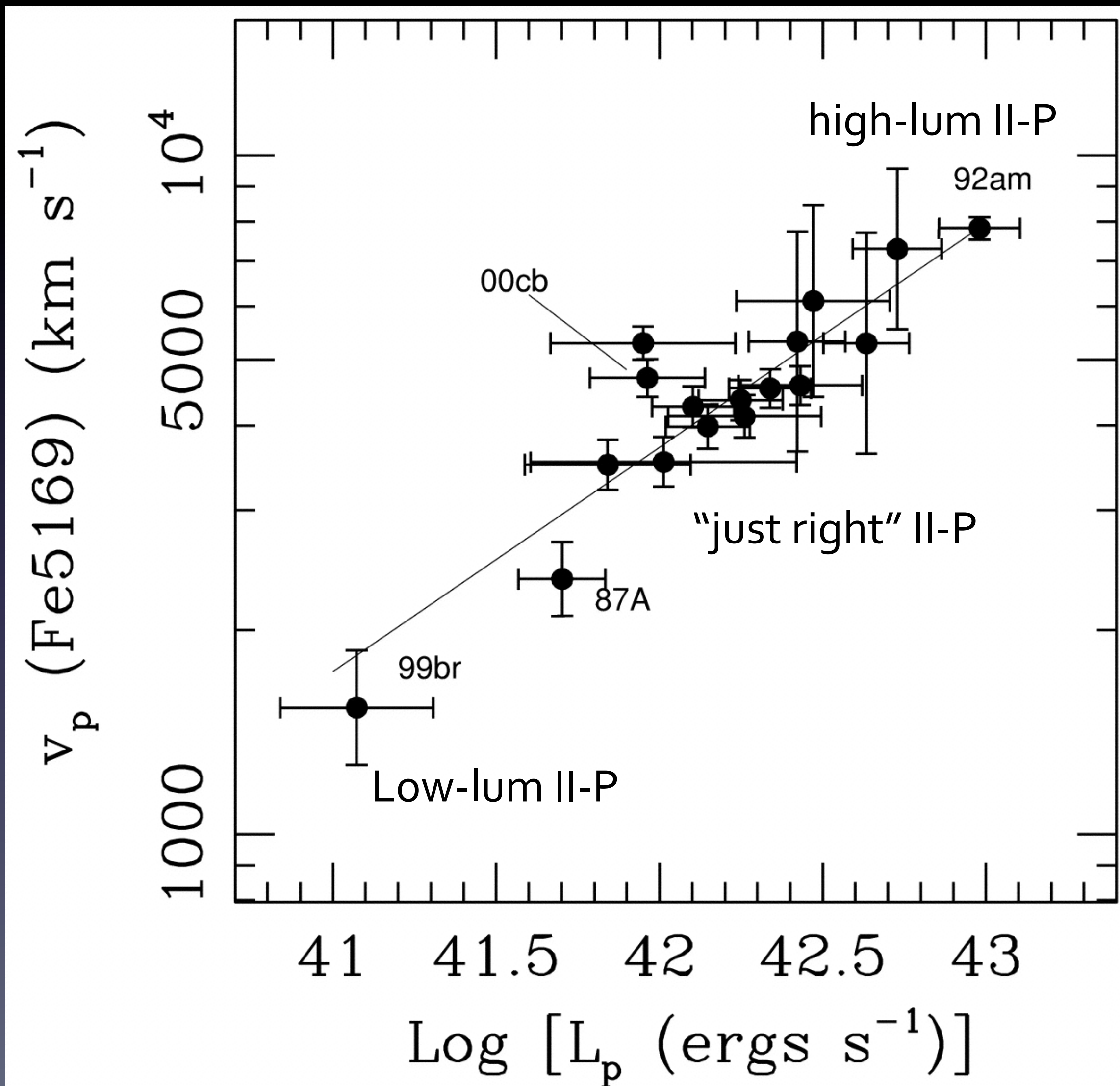
SN II-P Progenitors

The most common core-collapse SNe



Inserra et al. (2011)

L_{bol}-v_{exp} relation for SNe II-P



Defined at age ~ 50 d
(on the plateau)

$V_p \sim L_p^{0.33}$

(Hamuy & Pinto 2001)

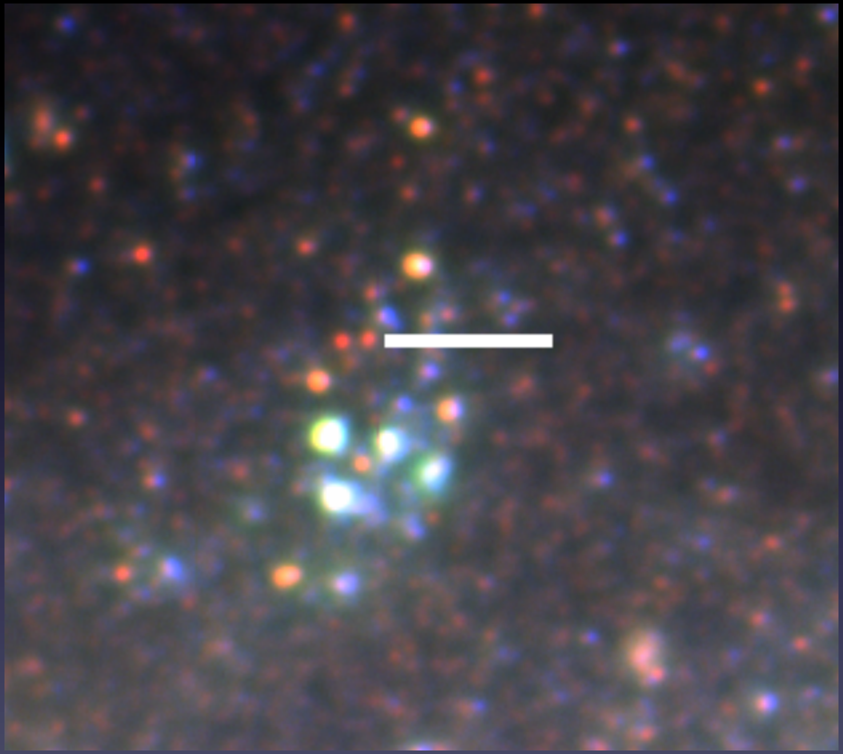
SN 1987A: Sk -69° 202

(David Malin AAT image)

SN 1987A is a ***peculiar*** SN II-P
The star was a B3I !!! (Isserstedt 1975, Rousseau et al. 1978)

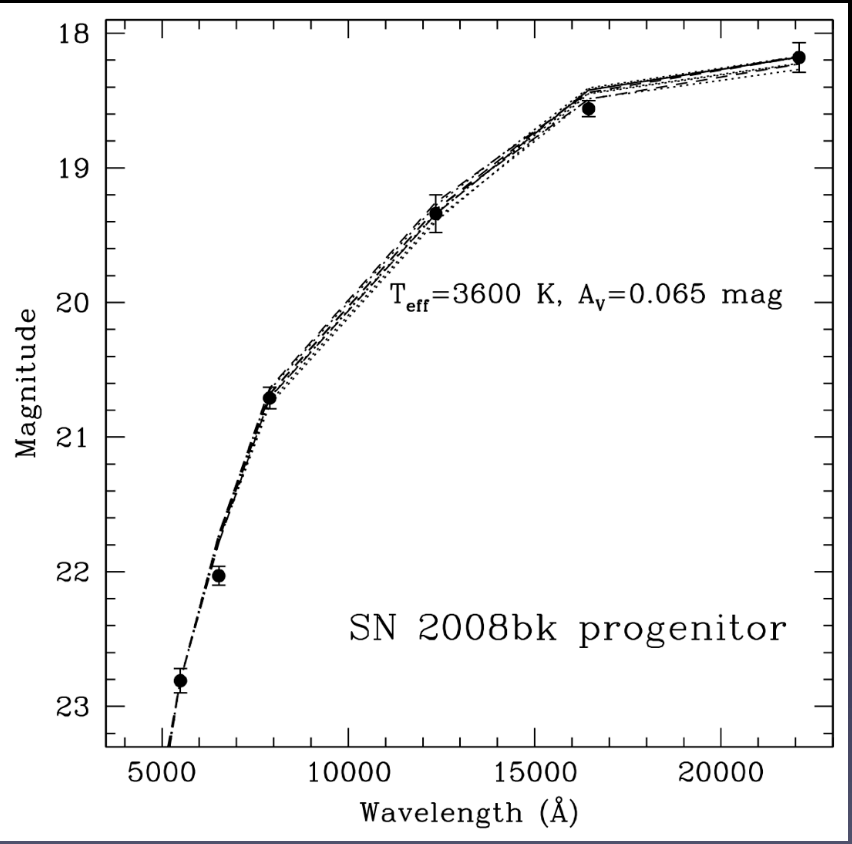
SN II-P 2008bk

The "second best" progenitor detection ever



Gemini-S GMOS g'r'i' from 2007

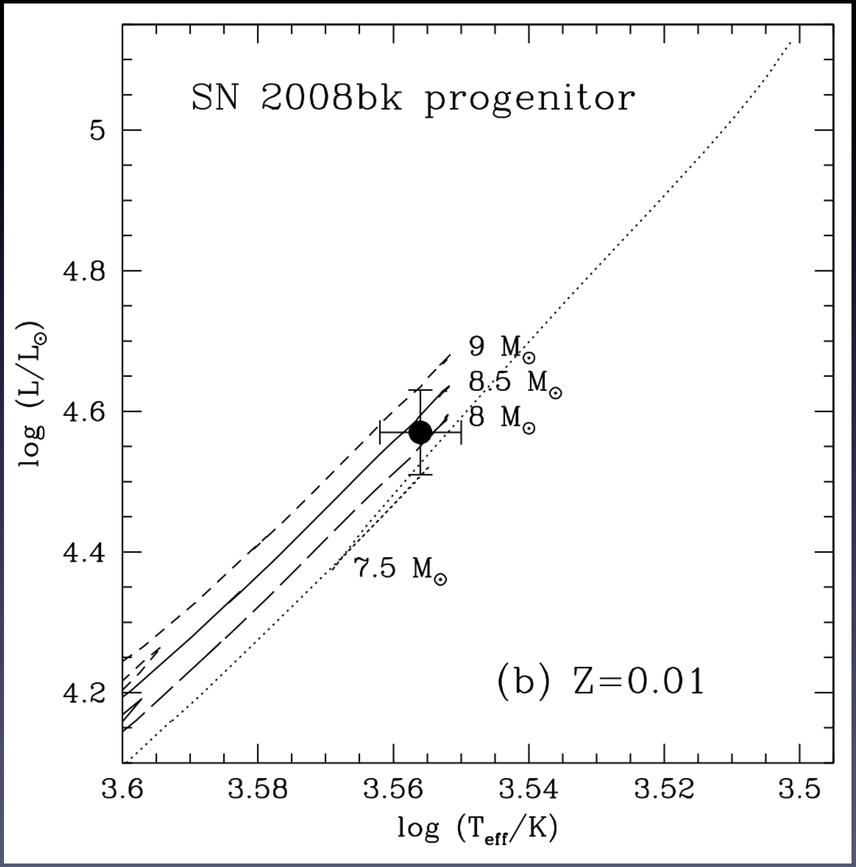
Van Dyk et al. (2012)
also, Mattila et al. (2008)

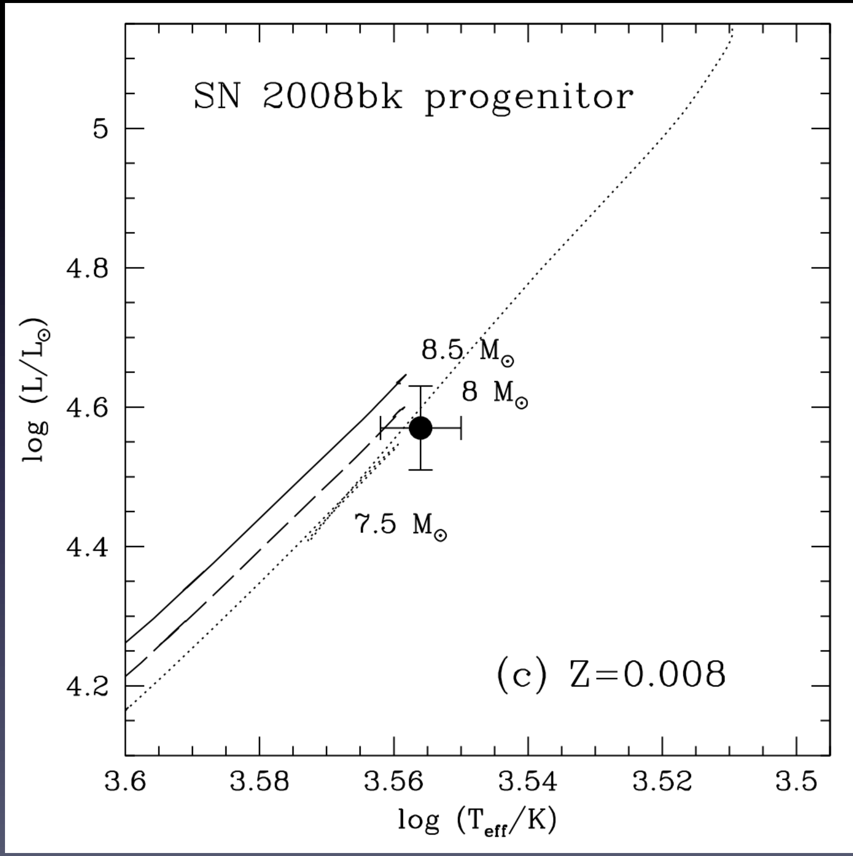


Gemini + archival VLT ISAAC & HAWK-I
(MARCS stellar atmospheres)

SN II-P 2008bk

Low luminosity --- low ^{56}Ni mass, NSE reached in thin O/Si-rich layer around core
Explosion of super-AGB star at low(er) metallicity ???



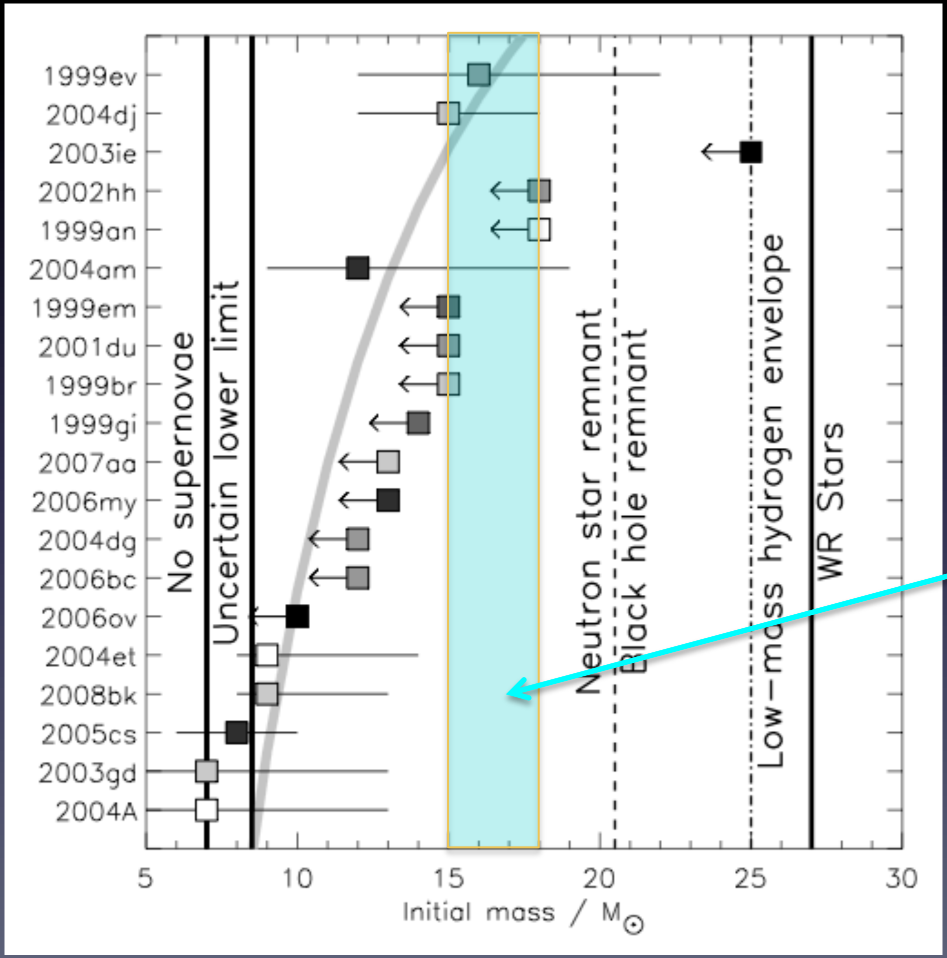


Van Dyk et al. (2012)

$M_{ini} = 8 - 8.5\, M_\odot$

SN II-P Progenitors

What *is* the mass range for the RSG progenitors of SNe II-P ???

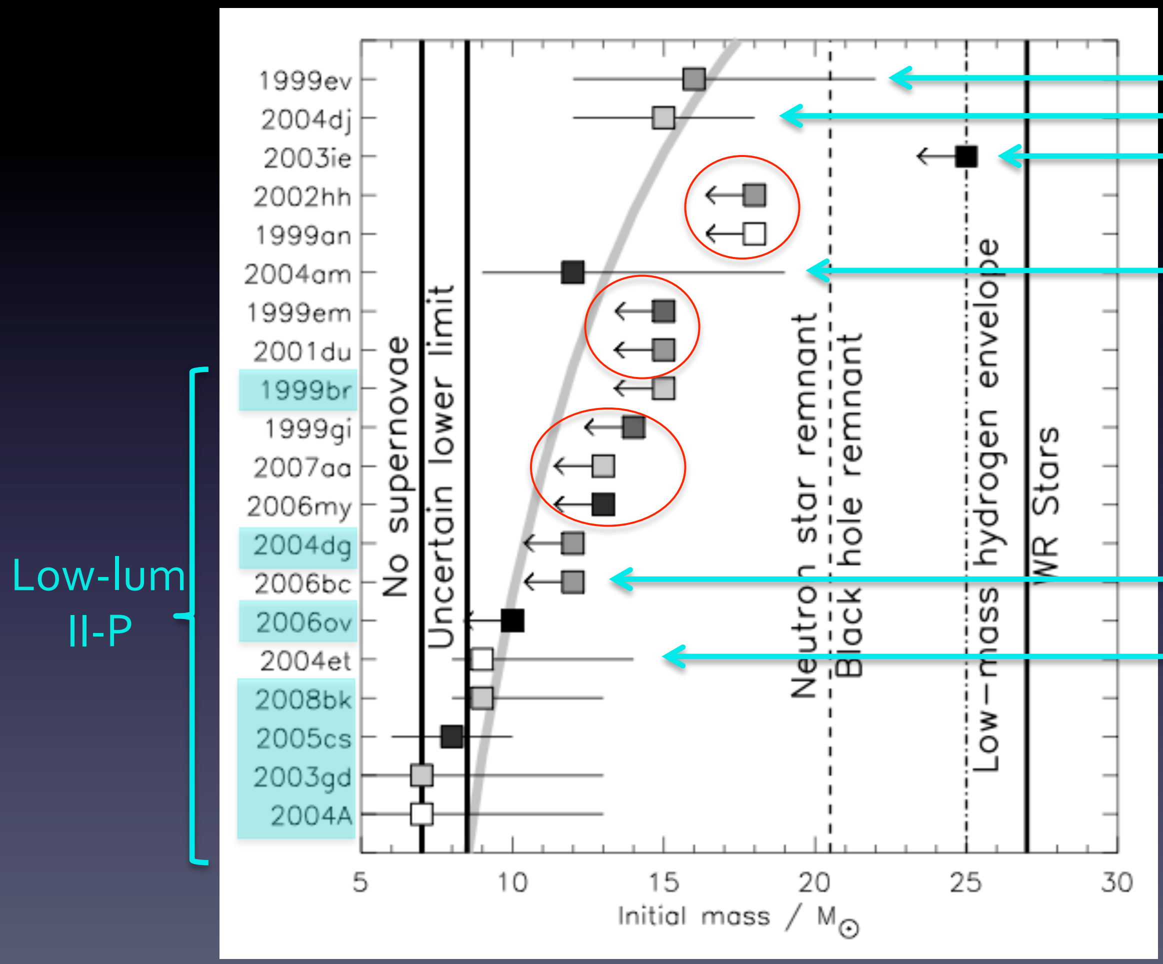


Smartt et al. (2009)

Upper mass limit for SNe II-P progenitors

SN II-P Progenitors

What *is* the mass range for the RSG progenitors of SNe II-P ???



Properties unknown

A constraint, not a detection !

99A/87A-like II-P (pec) *: BSG !

A constraint, not a detection !

Probable II-L ** !

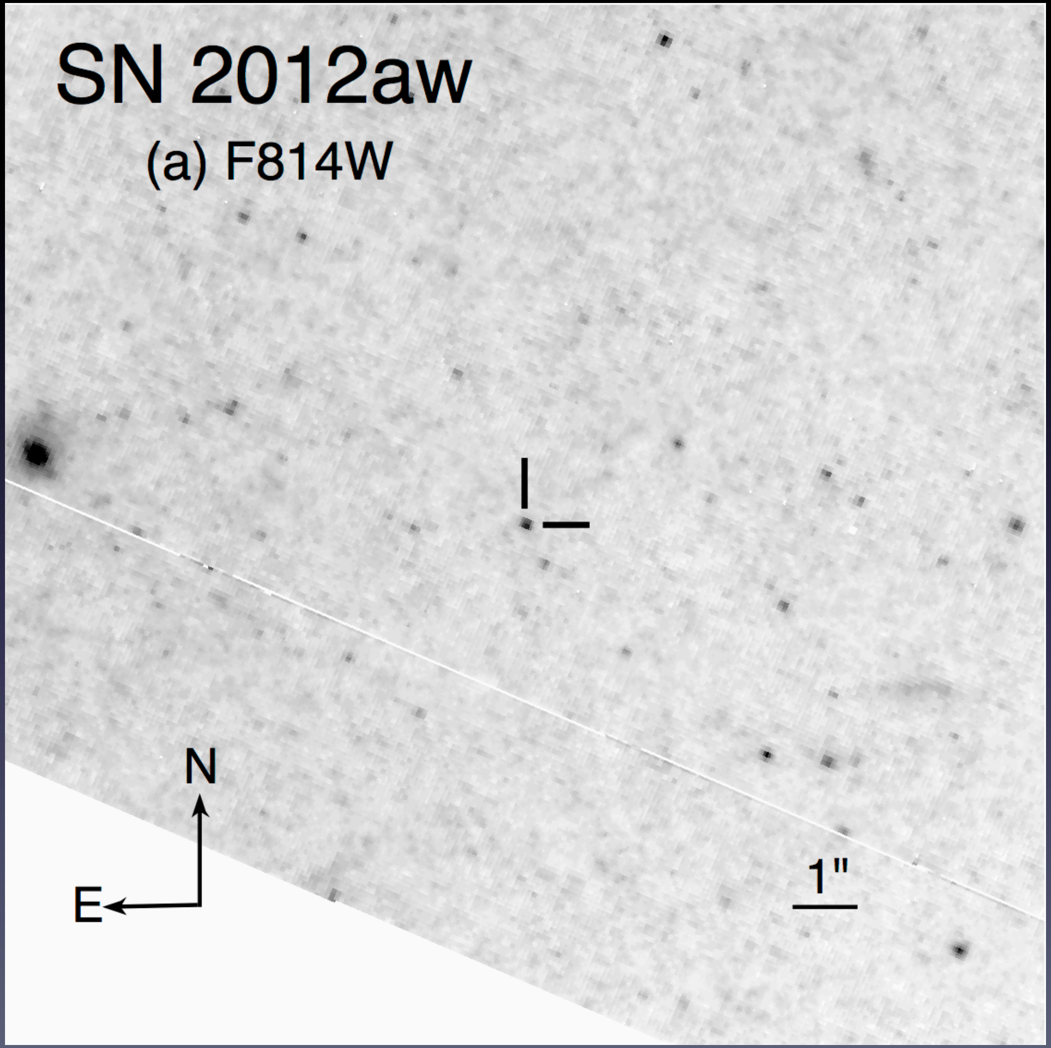
Possible "normal" II-P !

(from Smartt et al. 2009)

*Harutyunyan et al. (2008)

**Gallagher et al. (2010)

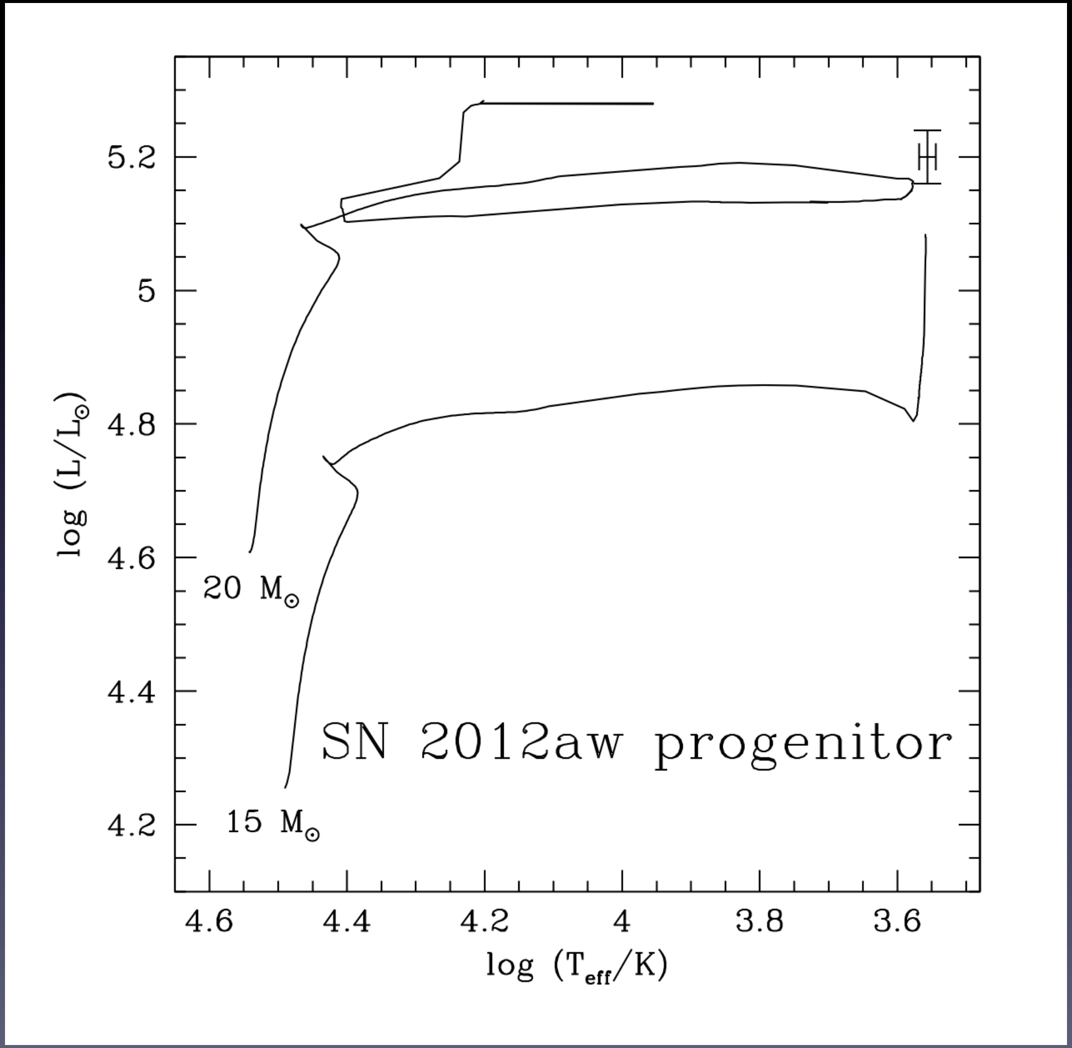
SN II-P 2012aw in M95



Van Dyk et al.
(2012,
in revision)

Hubble Legacy Archive
F555W and F814W
image mosaics
from 1994

SN II-P 2012aw in M95



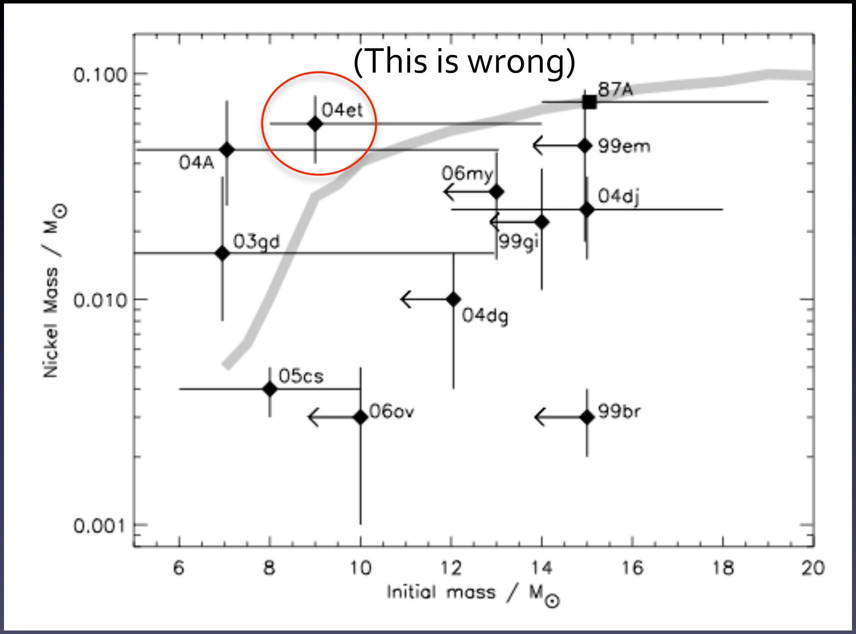
Van Dyk et al. (2012, in revision)

Ekström et al. (2012) rotating models at solar metallicity

$M_{ini} \approx 17\text{--}18\ M_\odot$

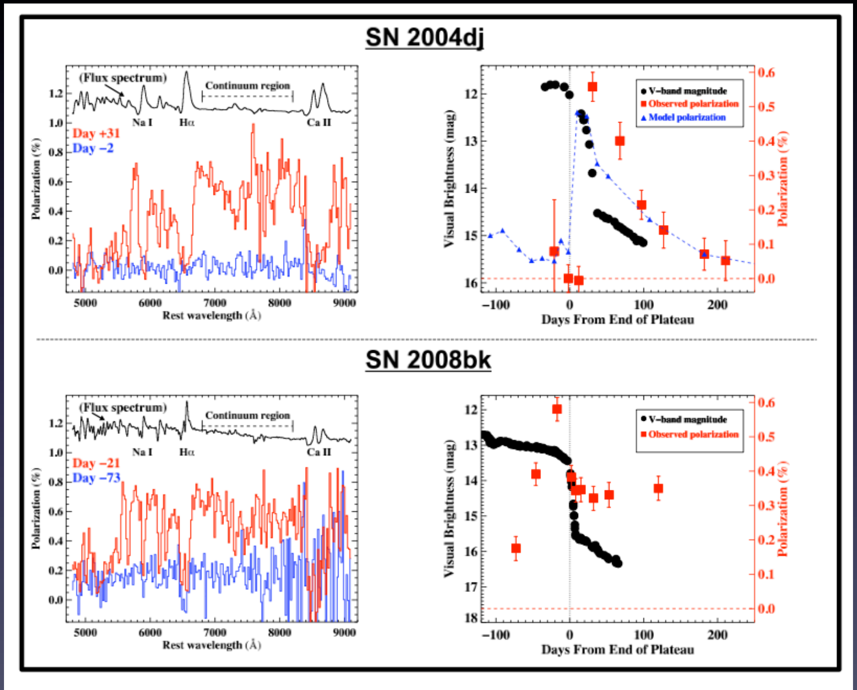
SN II-P Progenitors

^{56}Ni yield vs. progenitor mass



Smartt et al. (2009)
Grey curve is ratio of M(O) in the CO core to M(core)

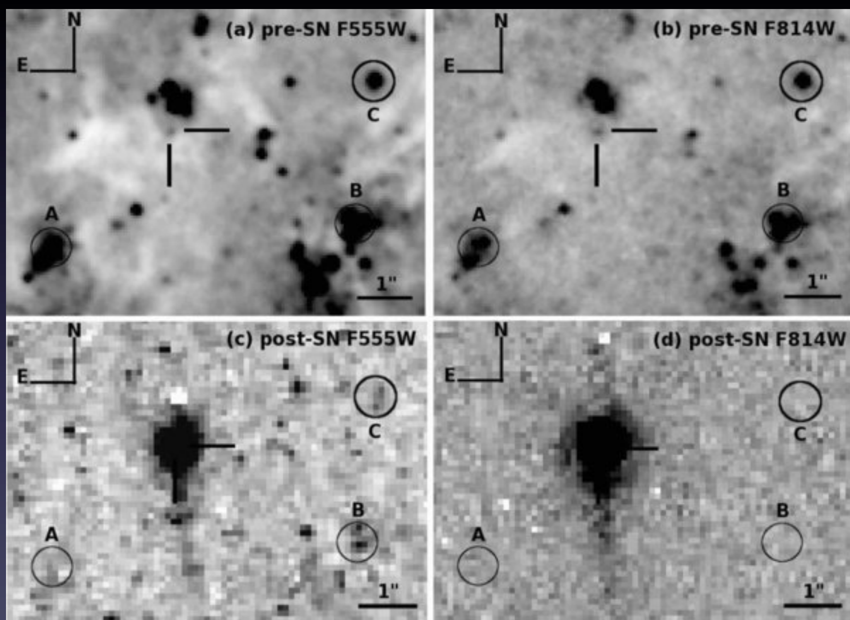
SN II-P spectropolarimetry

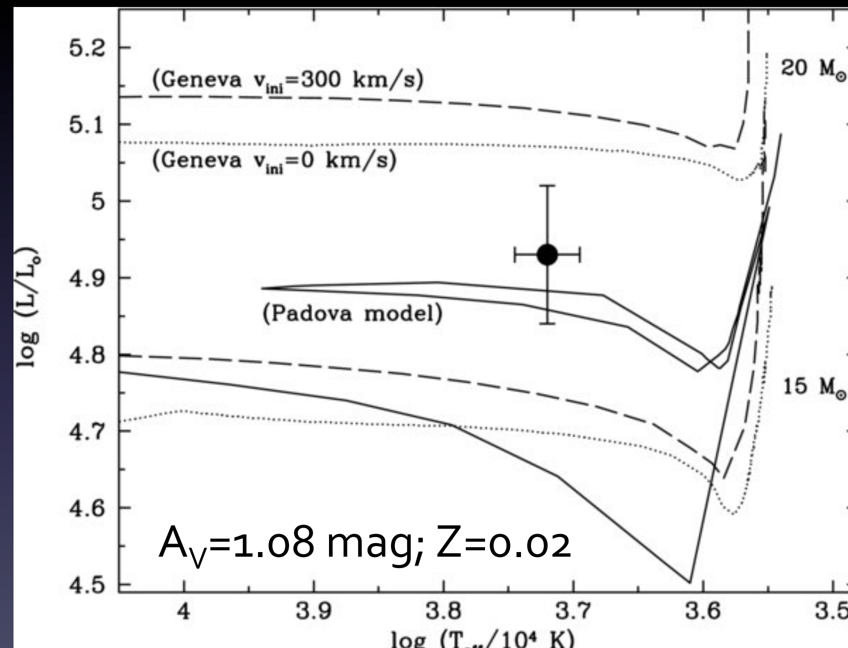


Leonard et al. (2012)

High-luminosity SNe II-P

SN 2008cn in NGC 4603 (Elias-Rosa et al. 2009)
most distant direct identification, at 33 Mpc

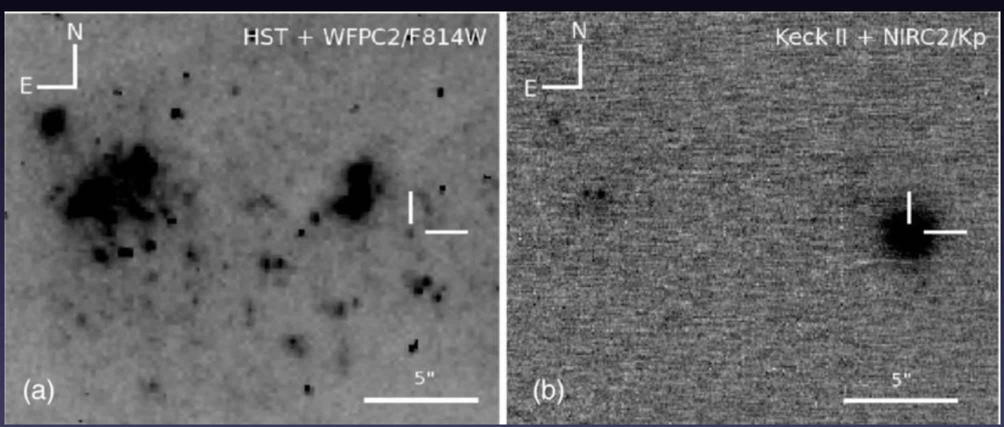


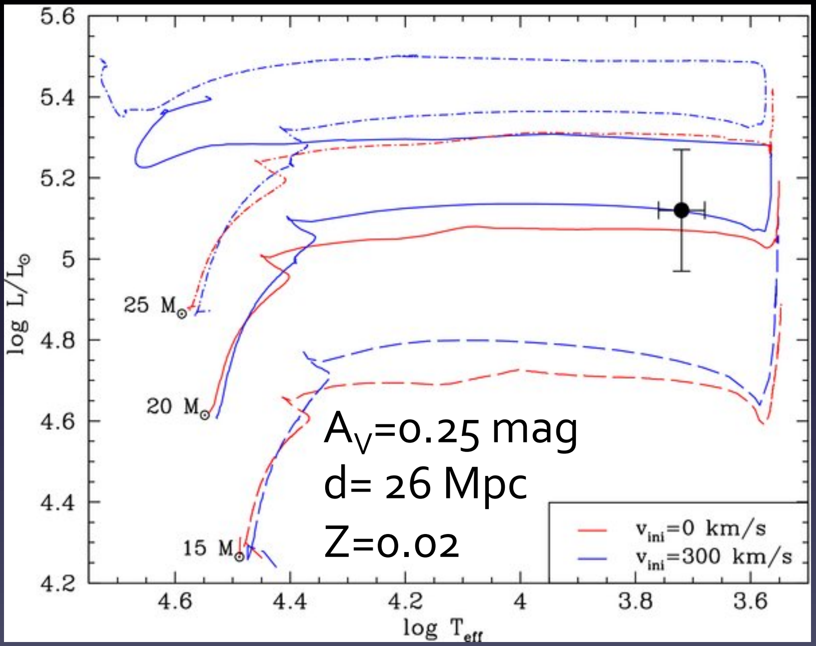


Yellow supergiant (!) with $M_{ini} = 15 \pm 2\ M_\odot$

SN II-L Progenitors

SN 2009kr in NGC 1832 (Elias-Rosa et al. 2010)





Yellow supergiant (!) with $M_{ini} = 18 – 24\ M_\odot$

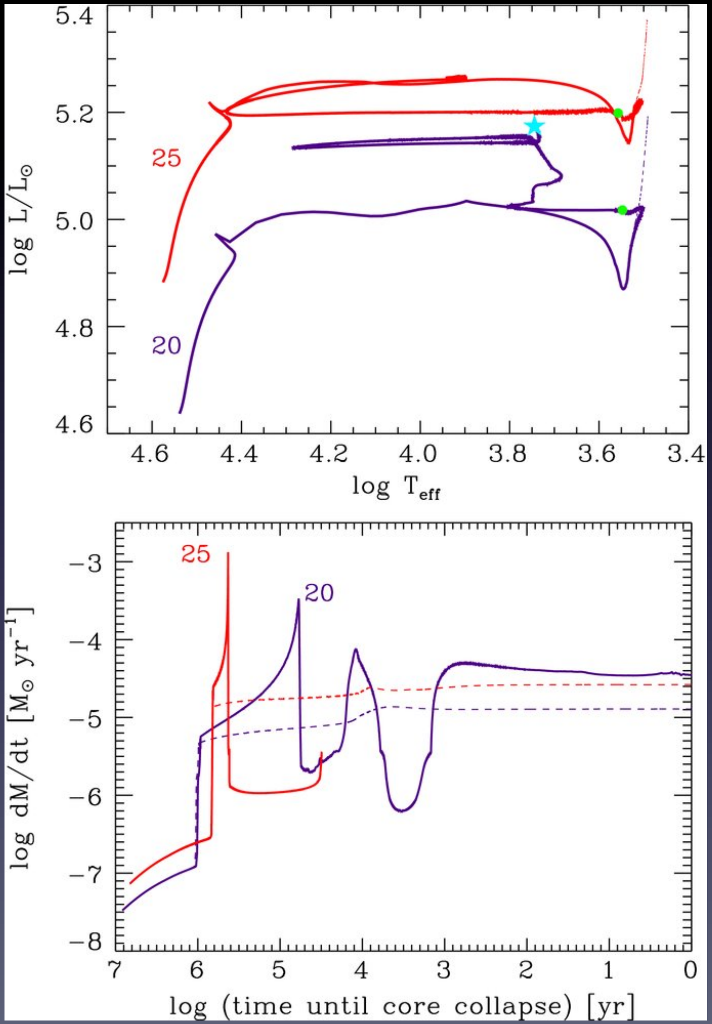
(also Fraser et al. 2010; $M_{ini} = 15^{+5}_{-4}\ M_\odot$)

Evolution of Massive Stars

What do theoretical stellar evolutionary tracks predict/explain?

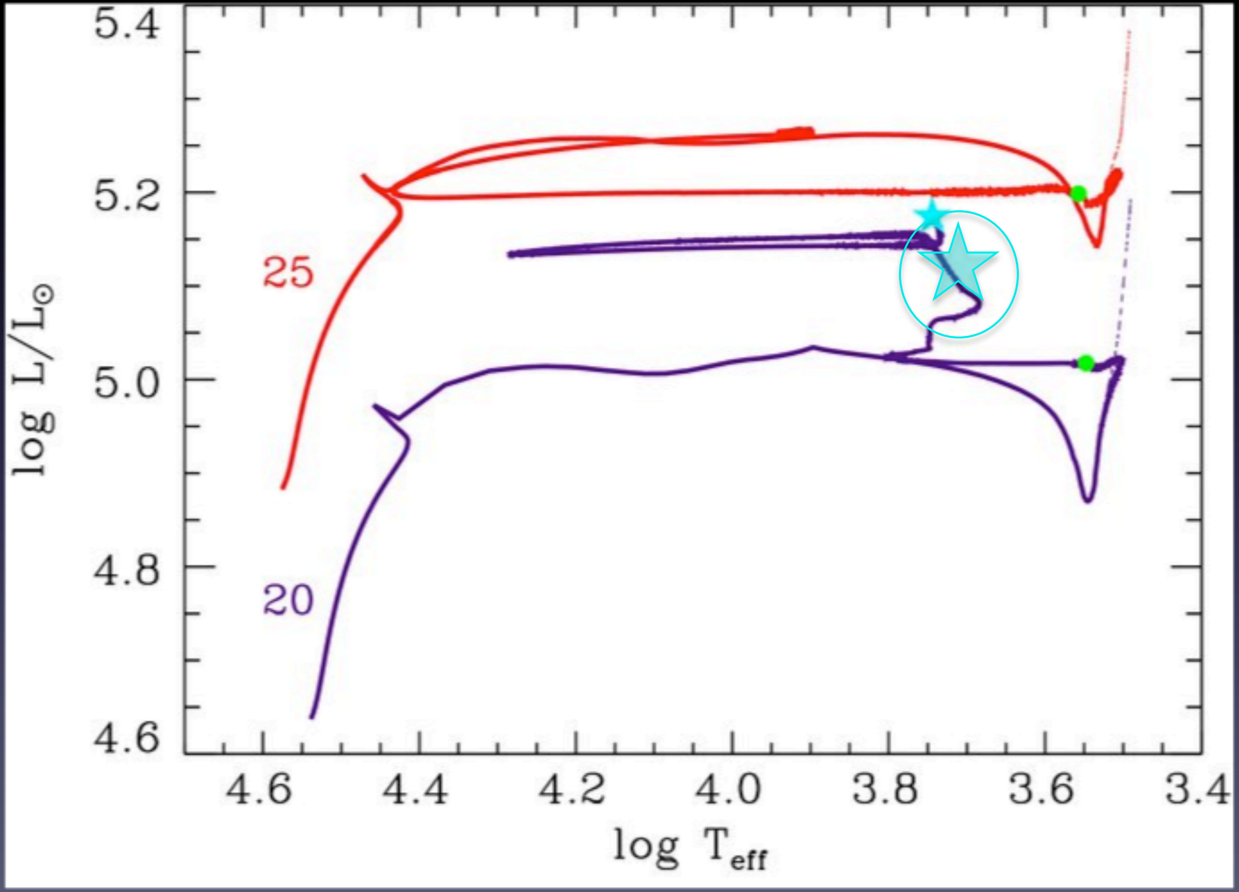
Departure from standardized
Mass loss formulation

Pulsationally-driven
superwinds from RSGs, solar Z
(Yoon & Cantiello 2010)



SN II-L Progenitors

SN 2009kr in NGC 1832 (Elias-Rosa et al. 2010)



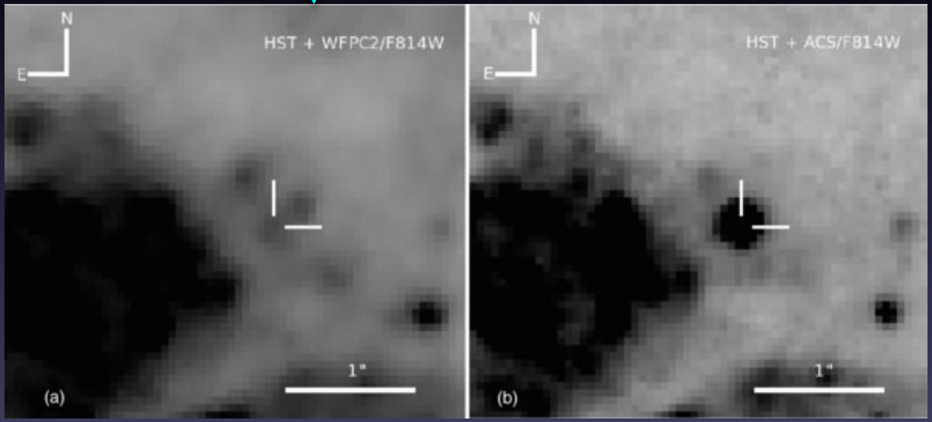
Yoon & Cantiello (2010) track

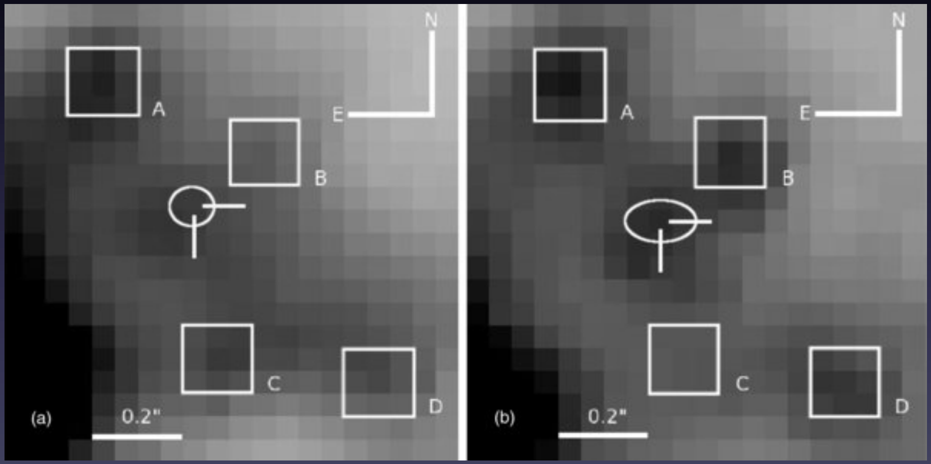
Yellow supergiant with $M_{ini} \approx 19 - 20\ M_{\odot}$?

SN II-L Progenitors

SN 2009hd in M66 (Elias-Rosa et al. 2011)

Hubble Legacy Archive data
from 1997 - 1998





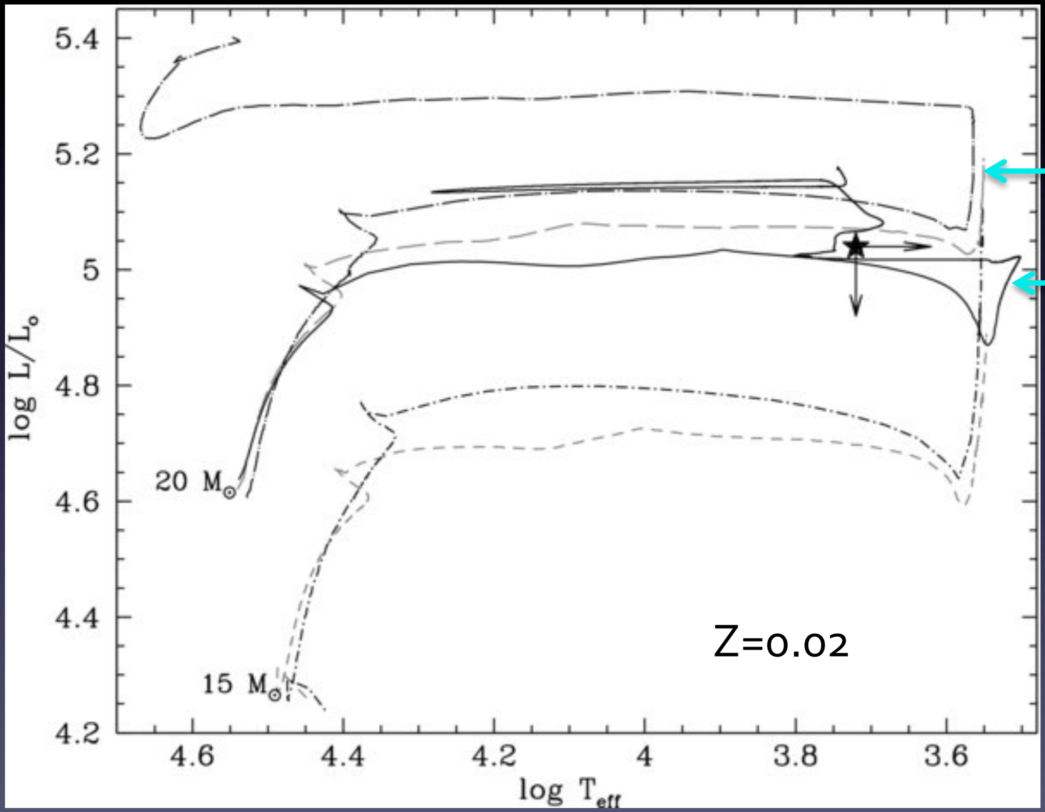
d =9.4 Mpc $A_V \approx 3.8$ mag

F555W   F814W

At M_V(max) = -17.2 mag, SN 2009hd is probably a SN II-L

SN II-L Progenitors

SN 2009hd in M66 (Elias-Rosa et al. 2011)

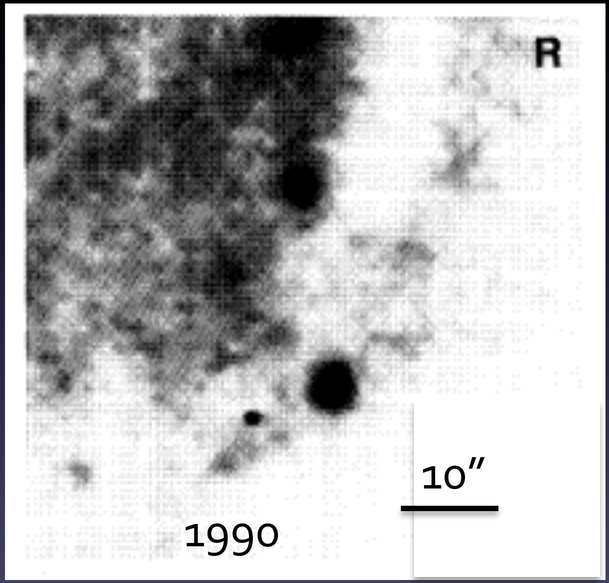


Yellow or red supergiant (?) with $M_{ini} \leq 20\ M_\odot$

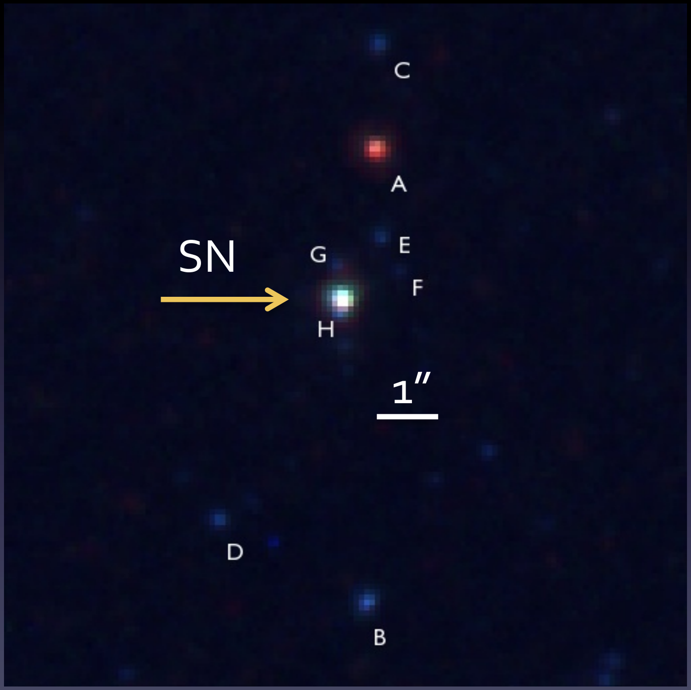
SN IIb Progenitors

SN 1993J in M81

A_V=0.75 mag, d = 3.6 Mpc



Aldering, Humphreys, & Richmond (1994)
Ground-based archival plates/images

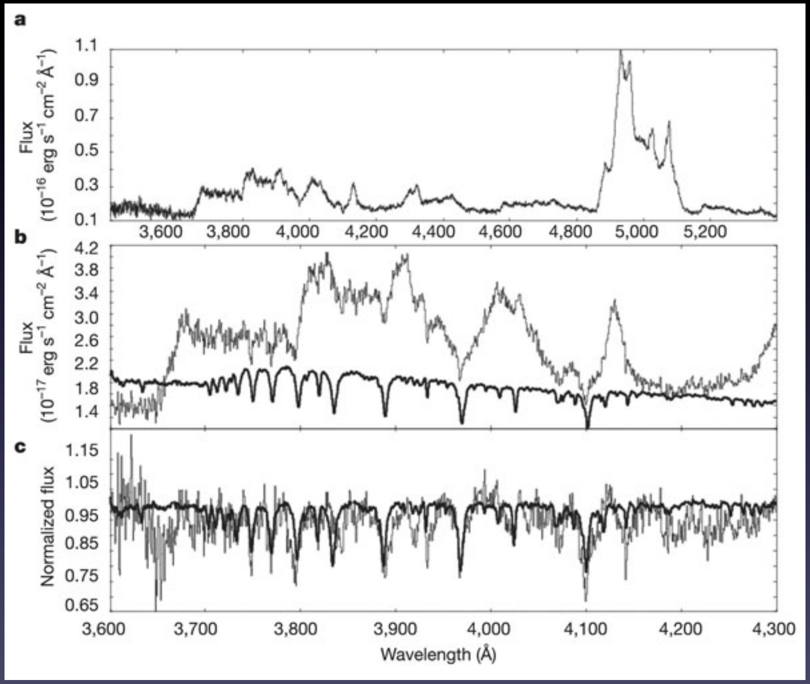


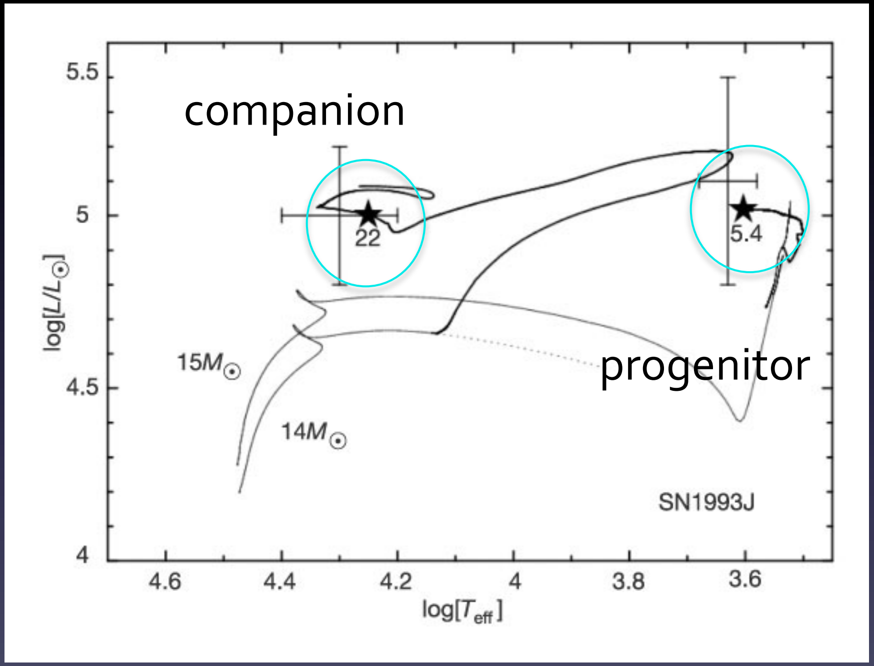
Van Dyk et al. (2002)
HST WFPC2 from 2001

Early K-type supergiant with $M_V^o \approx -7.0$ mag and $M_{ini} \approx 13 - 22\ M_\odot$

SN IIb Progenitors

SN 1993J in M81





Maund et al. (2004); also Maund & Smartt (2009)

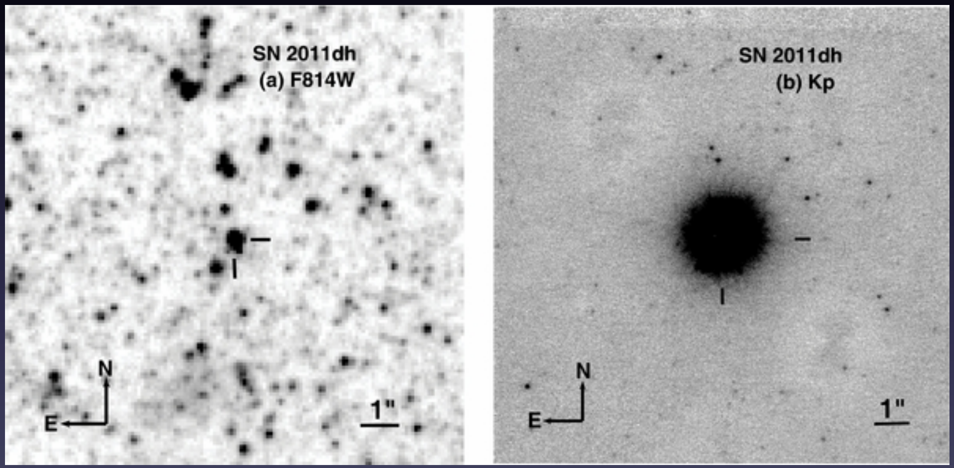
Chevalier & Soderberg (2010): SNe IIb from *extended* (R ≈ 10^{13} cm) progenitors, e.g, SN 1993J, and from *compact* (R ≈10^{11} cm) progenitors, e.g., SN 2008ax

SN IIb Progenitors

SN 2011dh in M51

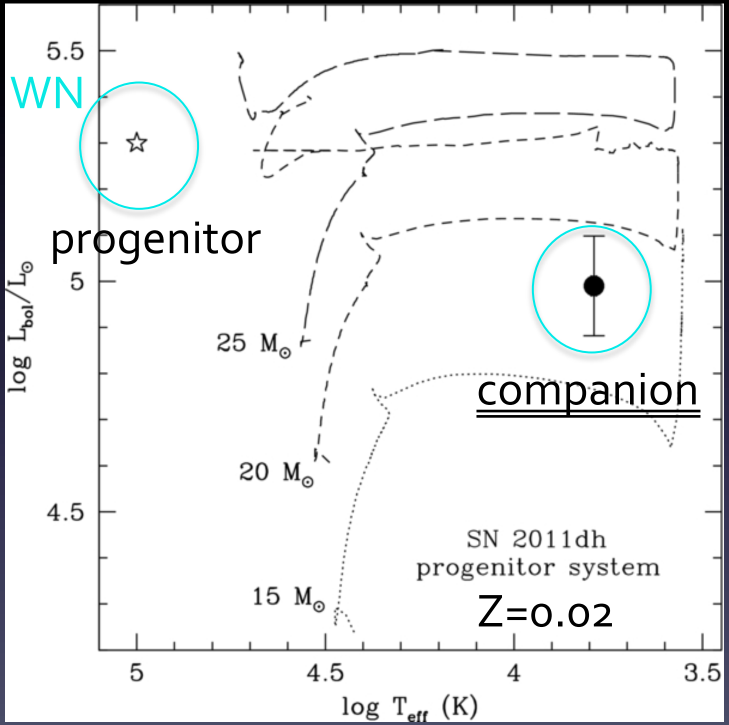
A_V=0.12 mag, d = 7.7 Mpc

Van Dyk et al. (2011)



HLA data from 2005

Keck-II NIRC2 AO

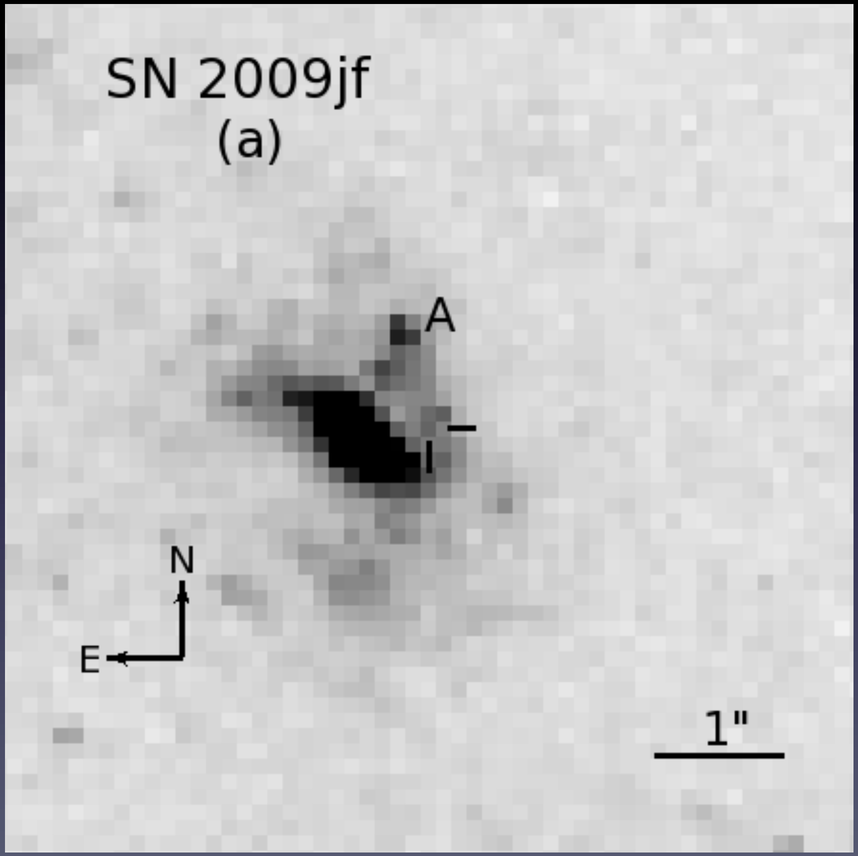


Maund et al. (2011) claim that the F-type supergiant is the progenitor however, SN 2011dh had a *compact* progenitor (Arcavi et al. 2011)

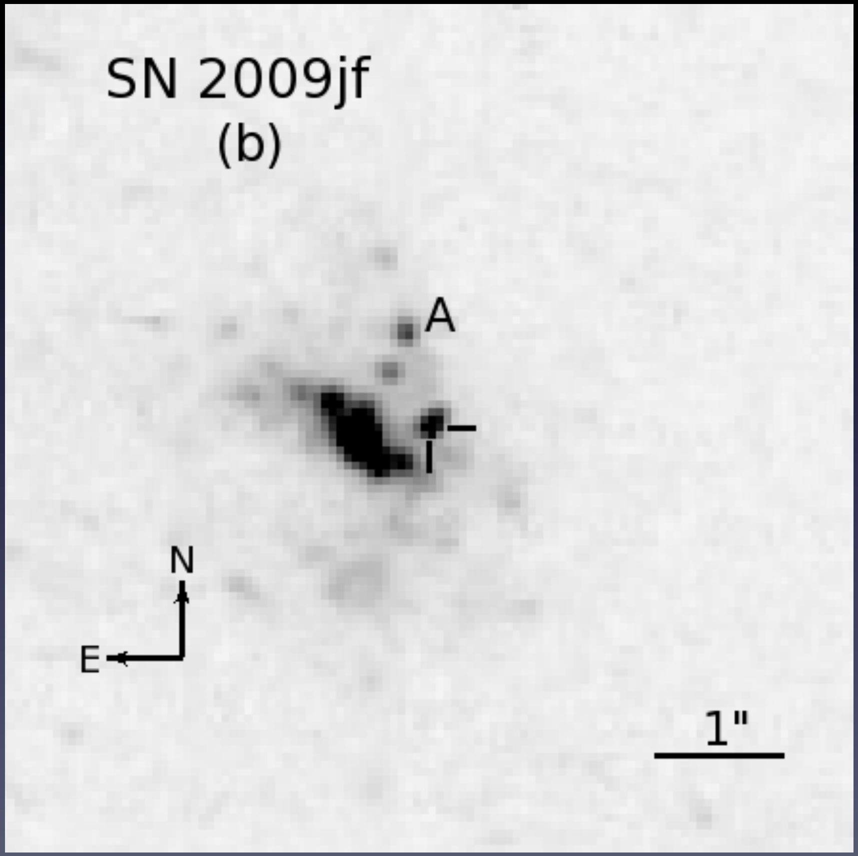
SN Ib Progenitors

SN Ib 2009jf in NGC 7479 (Van Dyk et al., in prep.)

A_V= 0.53 mag, d = 33.9 Mpc

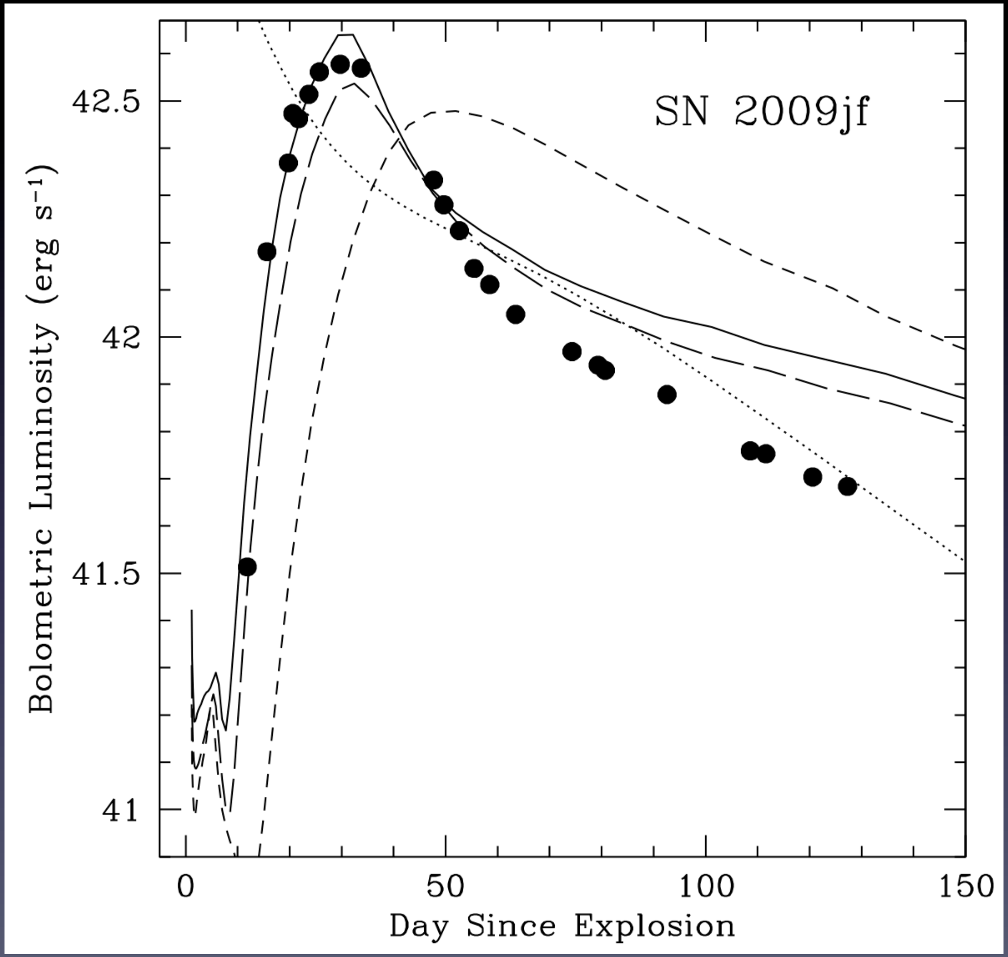


HST/WFPC2 F569W from 1995



HST/ACS F555W

SN Ib Progenitors



(Van Dyk et al., in prep.)

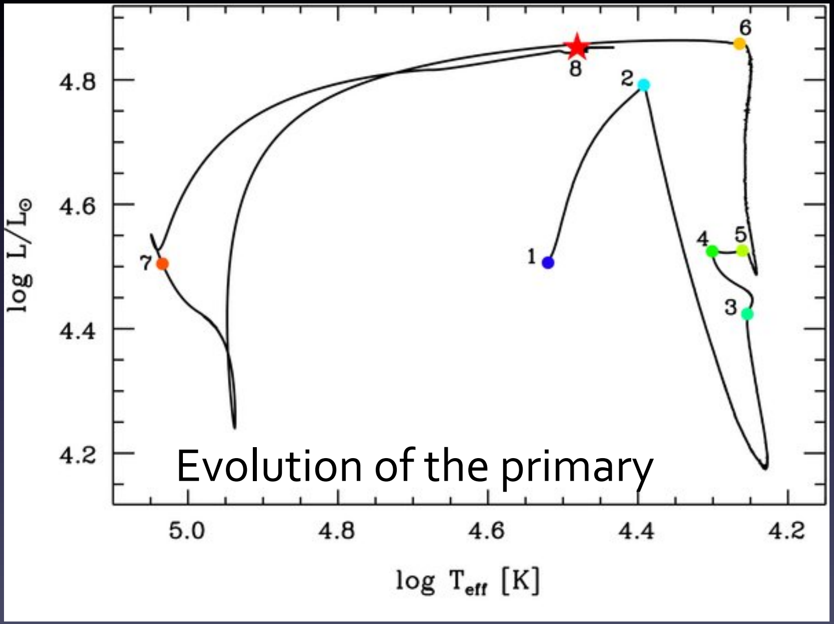
Comparison of the bolometric light curve for SN 2009jf with the models by Dessart et al. (2011)

The light curve is consistent with the close binary model with a primary of M_{ini} = 18 $M_{\odot}$ and M_{fin} = 3.79 $M_{\odot}$
WN star

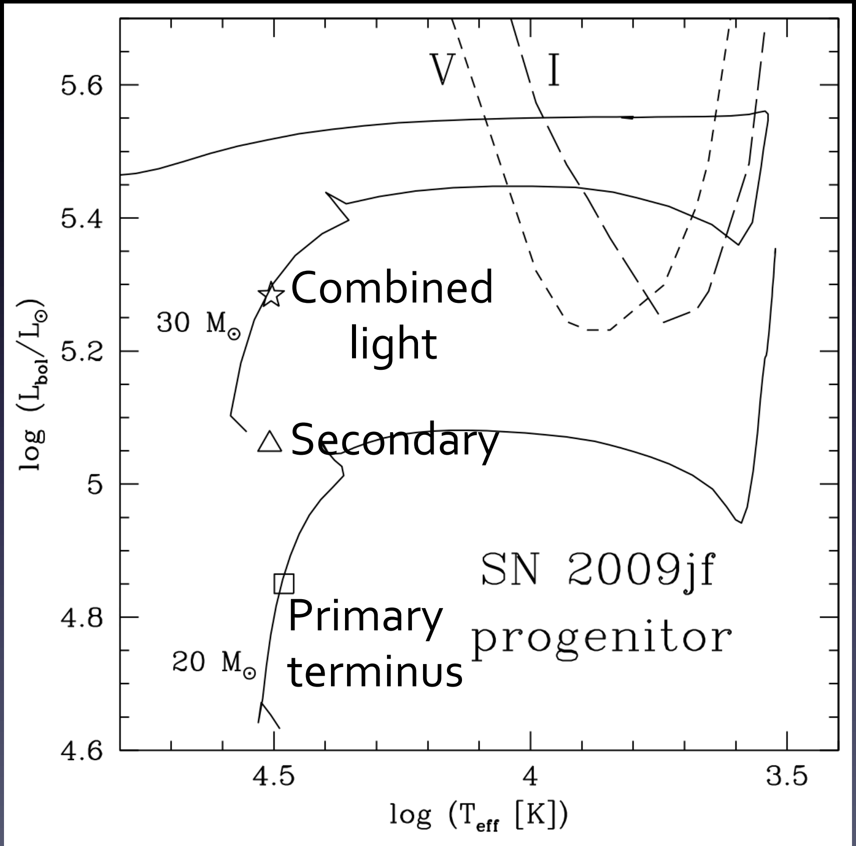
Secondary has Mini = 17--23 $M_{\odot}$
(Yoon, Woosley, & Langer 2010)
SN Ib

SN Ib Progenitors

SN Ib 2009jf in NGC 7479 (Van Dyk et al., in prep.)

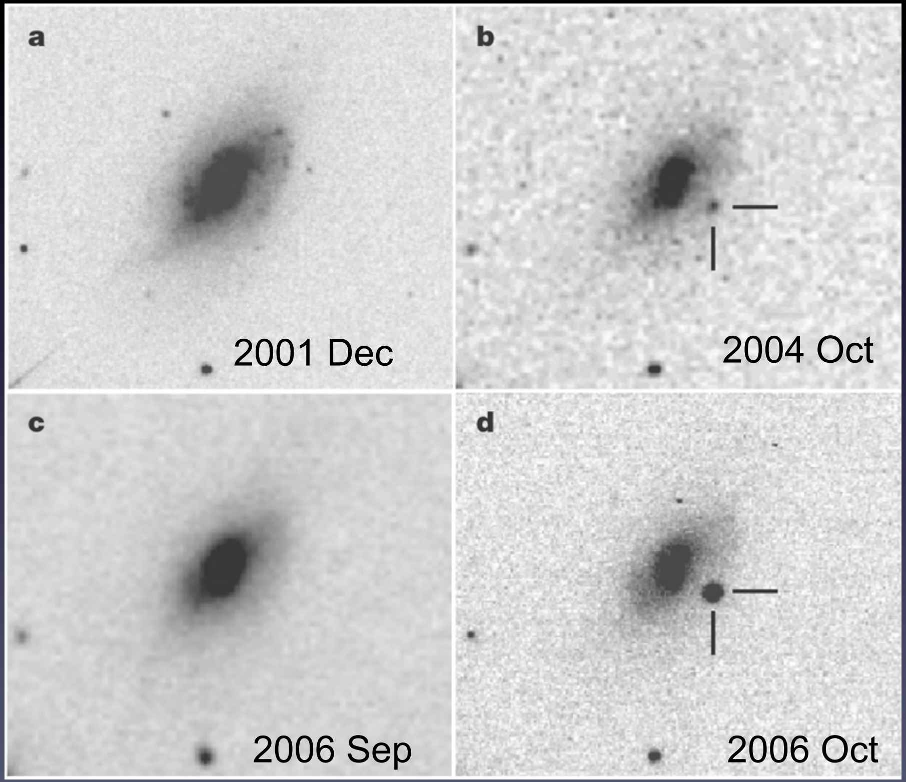


Yoon, Woosley, & Langer (2010)



SN “Ibn” Progenitor

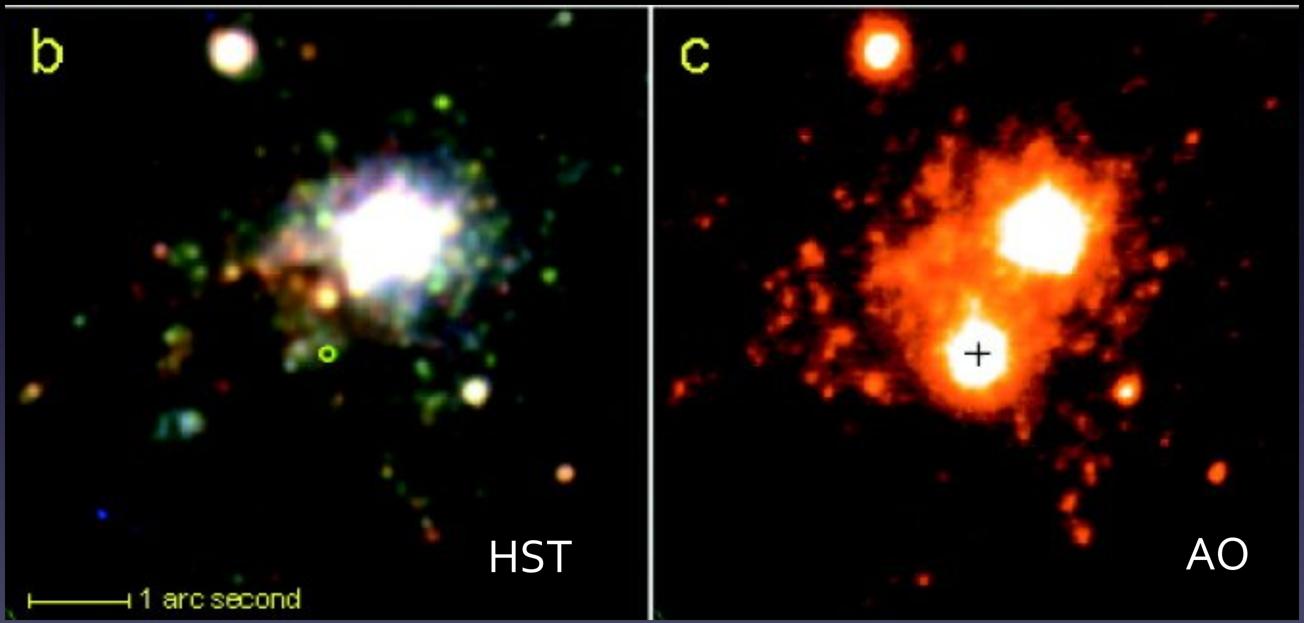
SN 2006jc in UGC 4904
(Pastorello et al. 2007; Foley et al. 2007)



Preceded by an LBV-like eruption 2 years prior to explosion!

SN Ic Progenitors

SN Ic 2004gt in NGC 4038 (Gal-Yam et al. 2005; Maund et al. 2005)

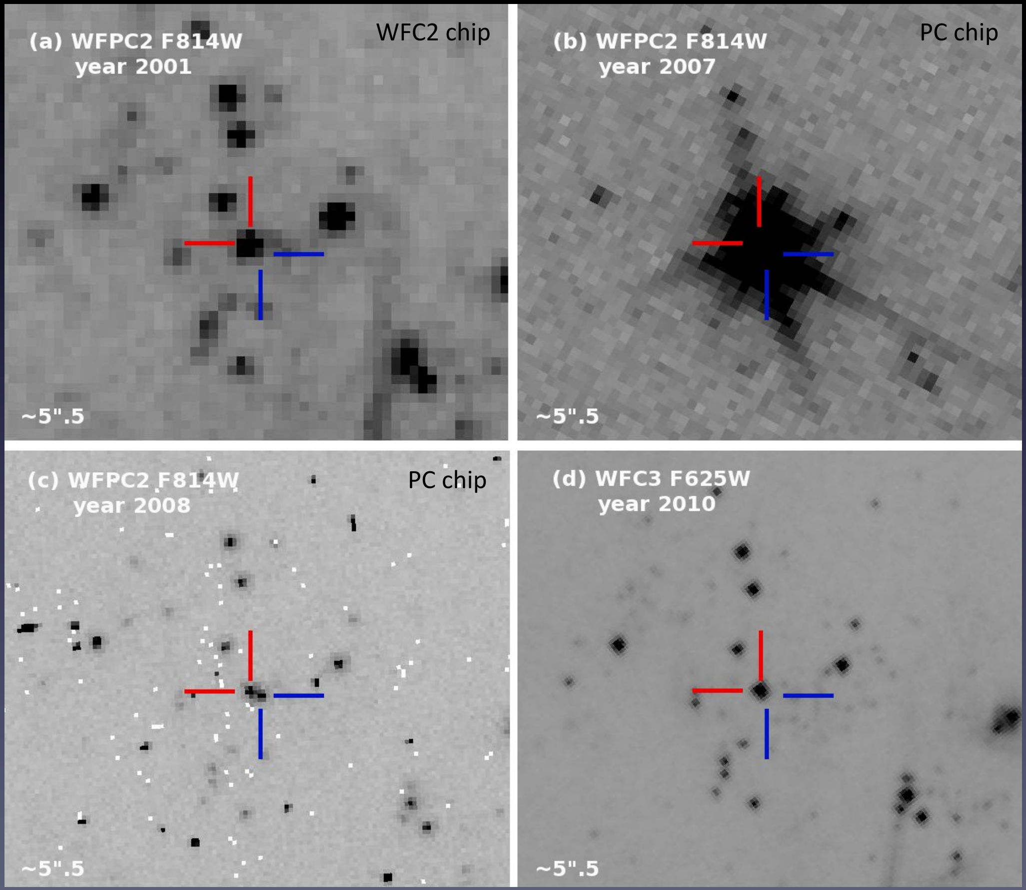


Not very restrictive limits, based on detection limits/star cluster properties

SN Ic Progenitors

SN Ic 2007gr in NGC 1058

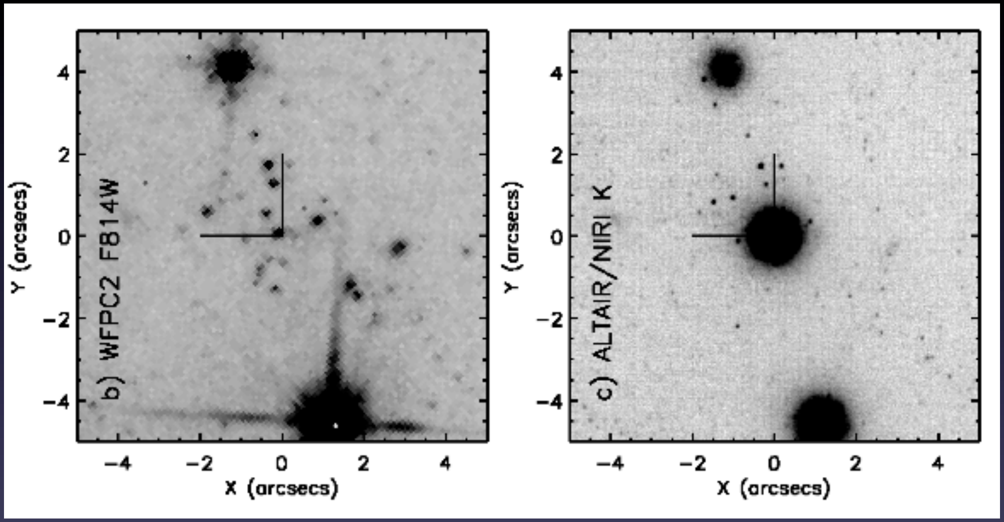
<u>d=9.3 Mpc, $A_{V,tot} \approx 0.3$ mag</u>

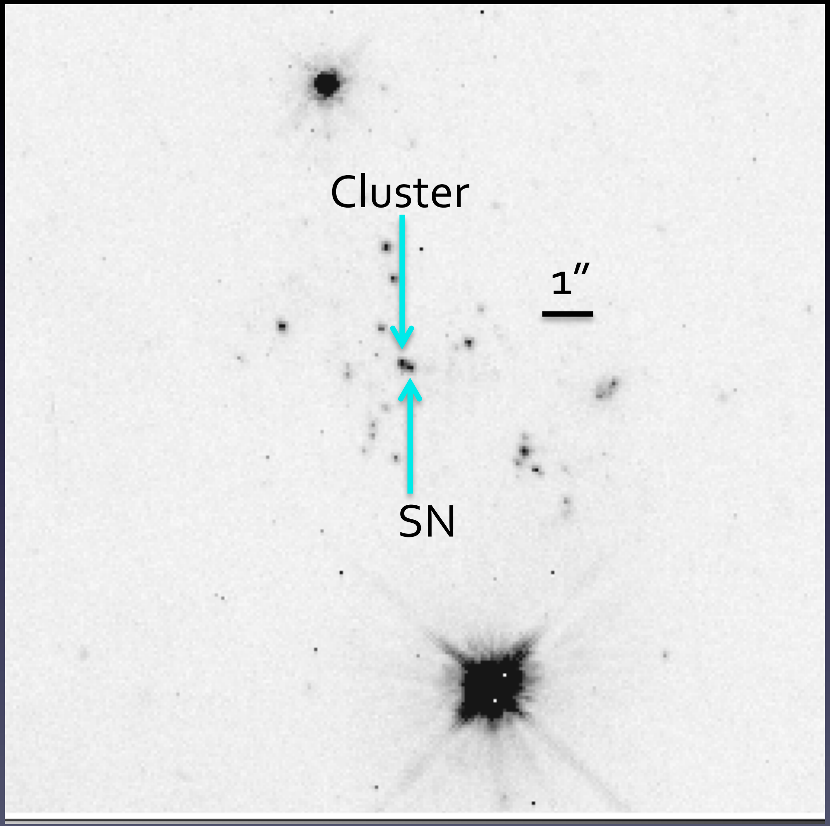


Not very restrictive limits, based on properties of star cluster
(Crockett et al. 2008)

may not be in the cluster after all

SN Ic Progenitors

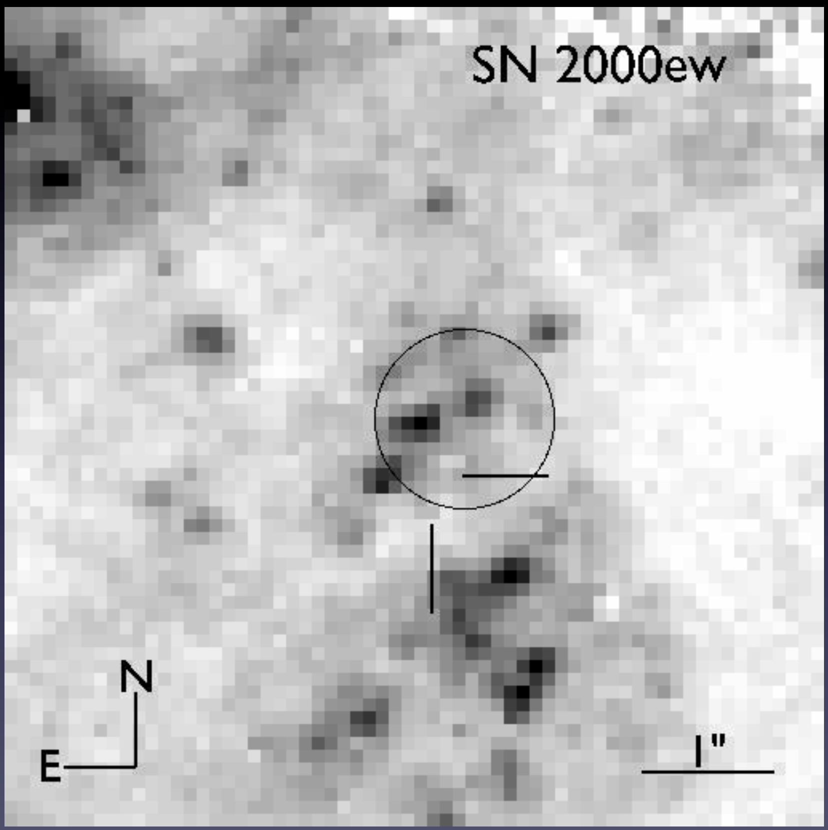


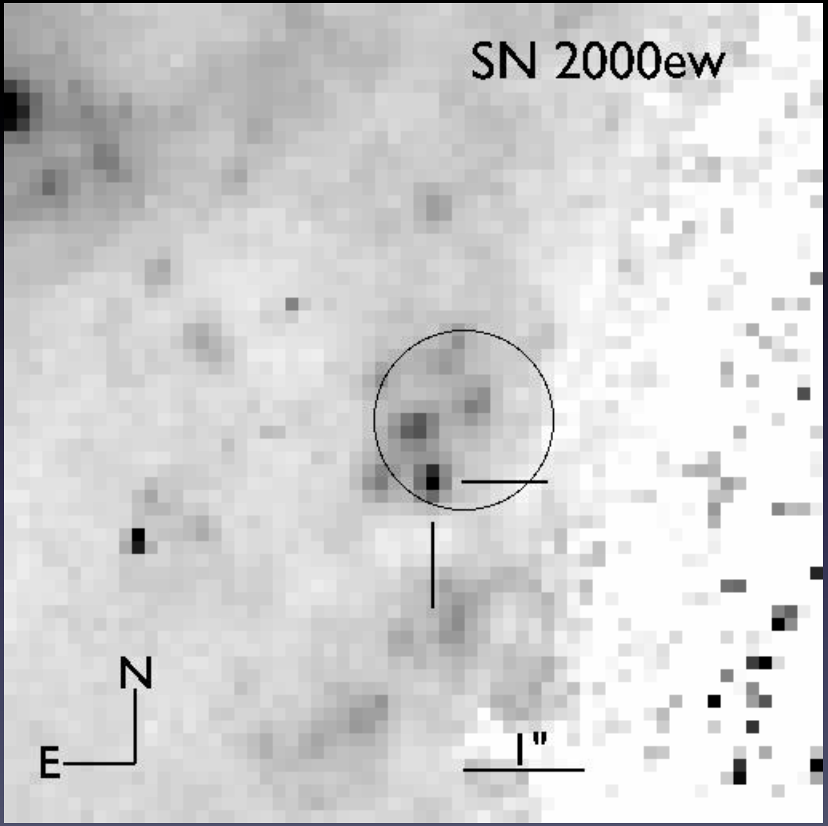


HST WFPC2 F555W from 2008

SN Ic Progenitors

e.g., SN Ic 2000ew in NGC 3810 (Van Dyk, Li, & Filippenko 2003a)



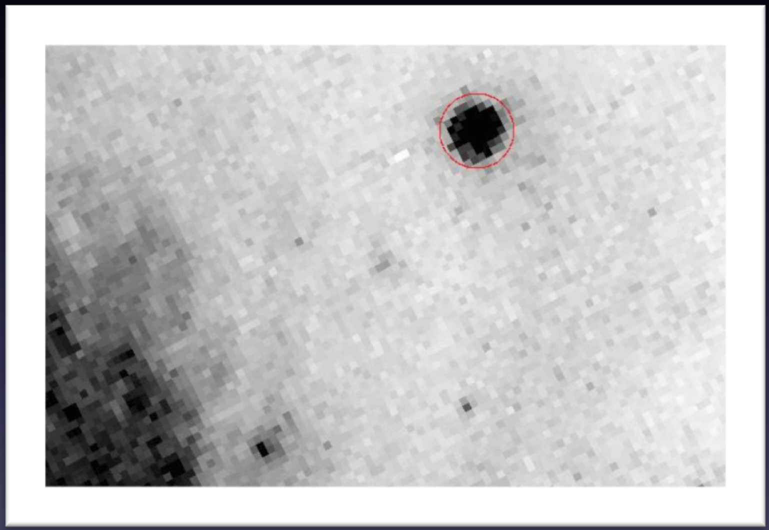


Also, SN 2003jg in NGC 2997, SN 2004cc in NGC 4568, SN 2005V in NGC 2146, etc. (Elias-Rosa et al. in prep.) --- *These are all highly extinguished*

SN Ic Progenitors

SN Ic 2003jg in NGC 2997

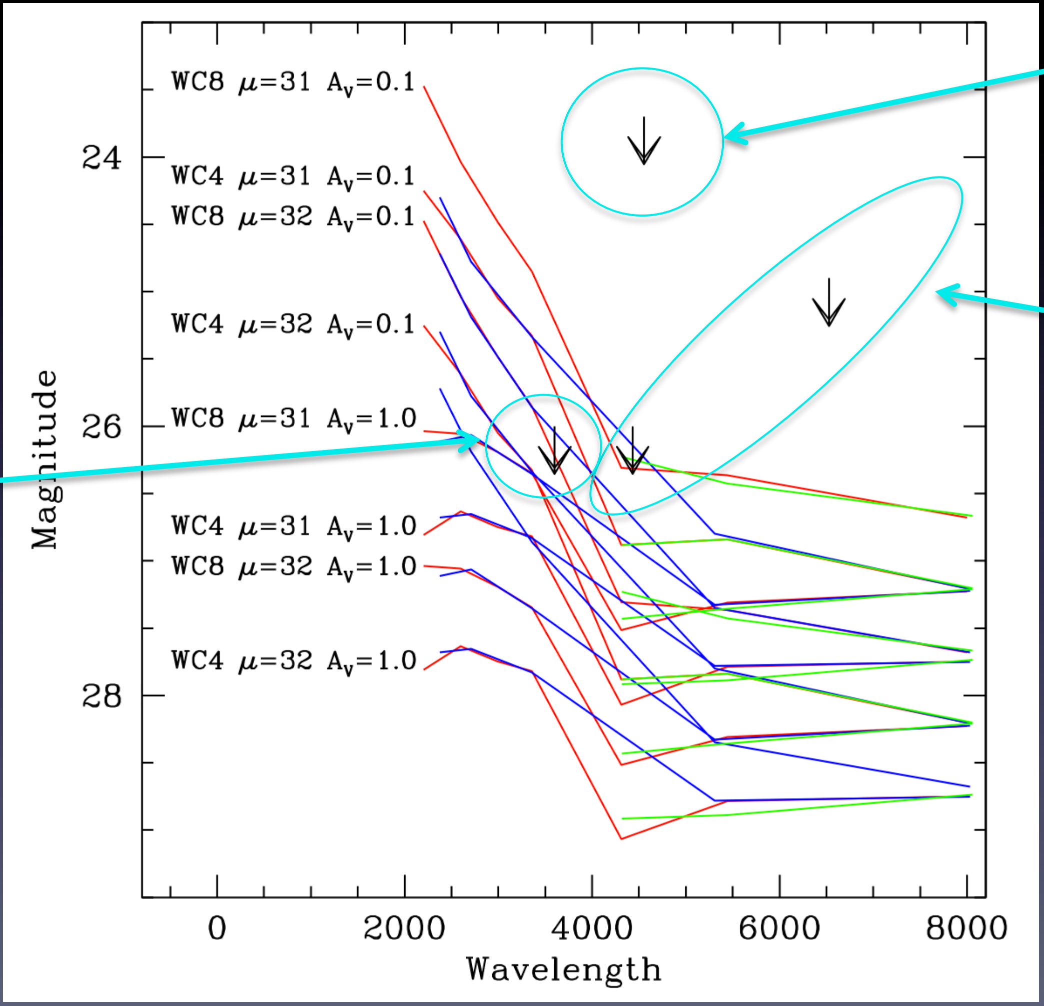
$A_{V,tot}$ ≈ 4 mag



Subsections of NGC 2997 before (*left* - *HST*/WFPC2) and after (*right* - *HST*/ACS-HRC) the SN 2003jg explosion, in F814W. The position of the SN is indicated by a circle

SN Ic Progenitors

WC star detectability



SN 2007gr
(Crockett et al. 2008)

SN 2002ap
(Crockett et al. 2007)
ground-based

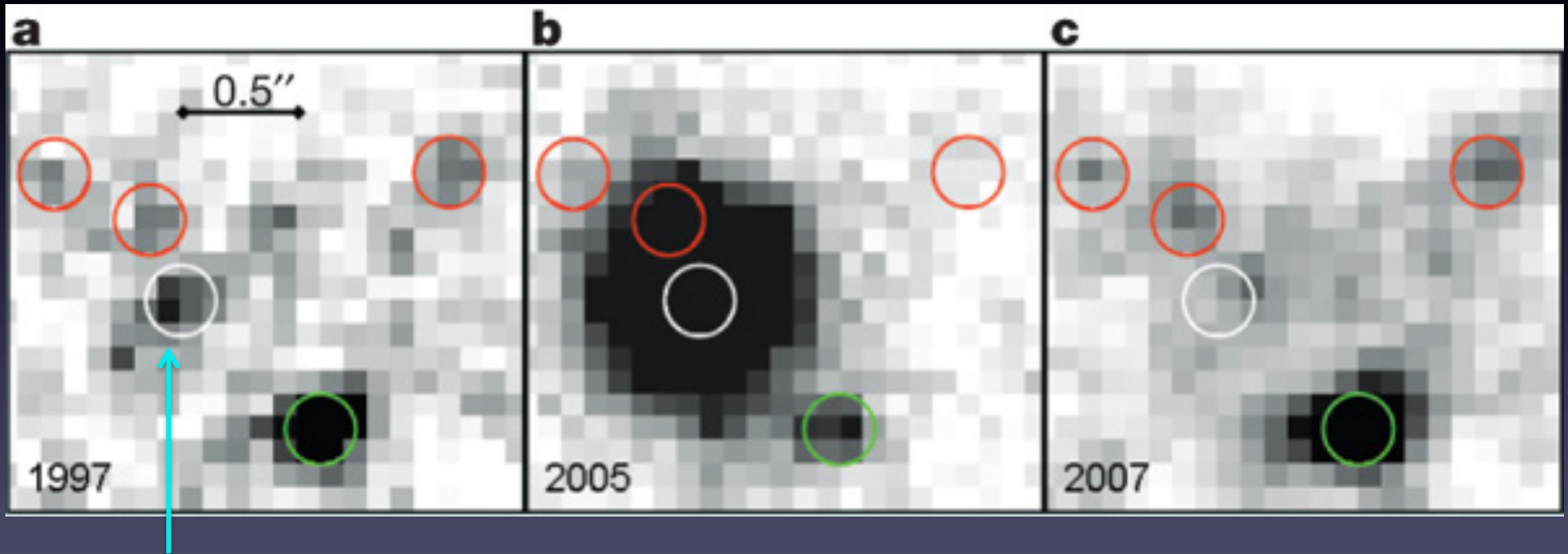
L. Smith
WFC3 F336W
survey

Sander et al. (2012)

Red = WFPC2
Blue = WFC3
Green = ACS/WFC

SN IIn Progenitors

SN 2005gl in NGC 266 (d = 66 Mpc)
(Gal-Yam et al. 2007; Gal-Yam & Leonard 2009)



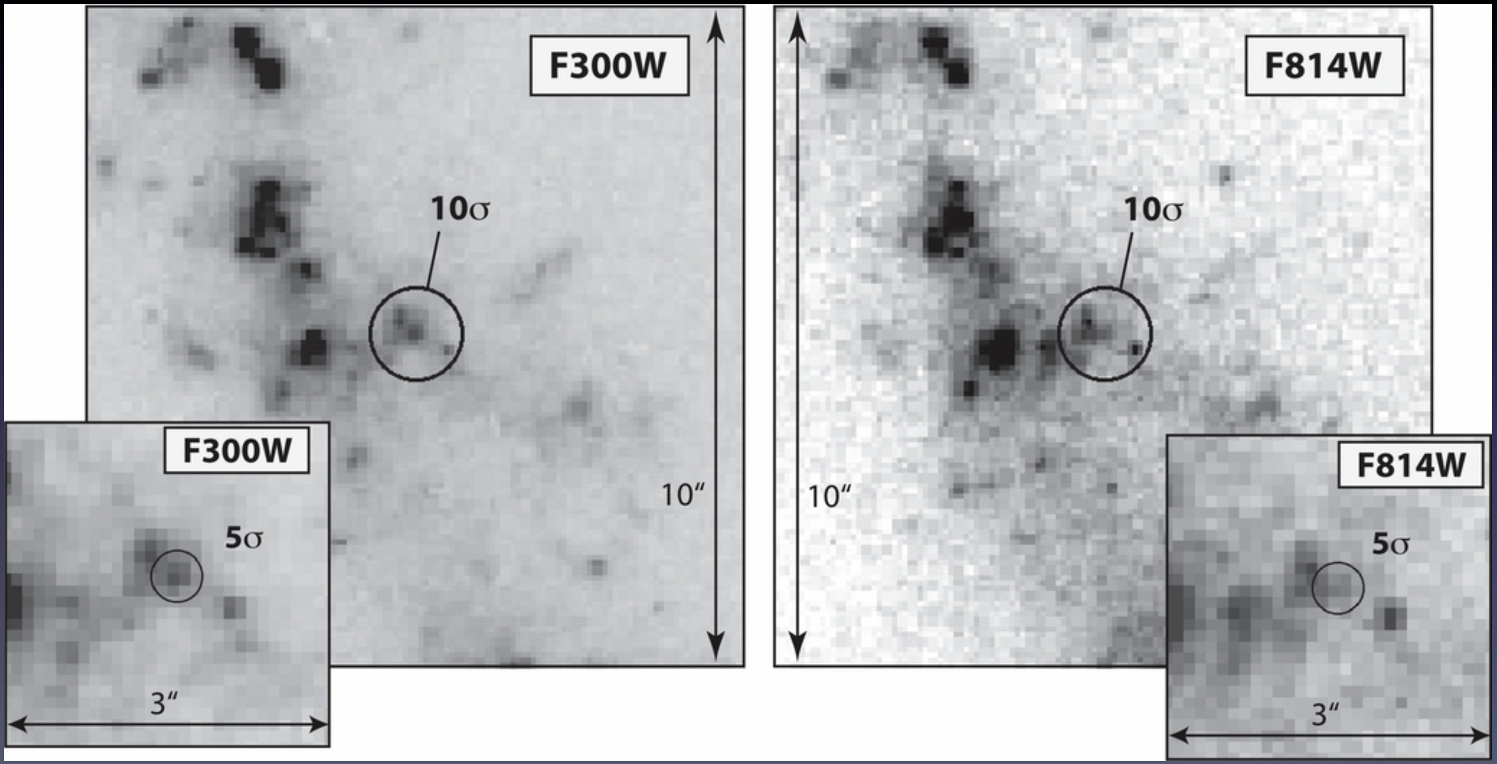
HST WFPC2 F547M
$M_V \approx$ -10.3 mag (!!)

Keck-II NIRC2 AO

HST WFPC2 F547M

SN IIn Progenitors

SN 2010jl in UGC 5189A (d = 50 Mpc)
(Smith et al. 2011)



Conclusions

- Progression of progenitor initial mass related to stripping of H envelope (… binarity?)
- SNe II-P have M_{lower}= 8--9 $M_{\odot}$: low-luminosity (lower ^{56}Ni mass produced, super-AGB?)
- Not clear yet what is M_{upper} (largest initial mass) for SN II-P RSG progenitors
- High-luminosity SNe II-P may arise from YSGs with $M_{ini} \approx 15\ M_{\odot}$ (??)

Current evolutionary tracks do not adequately predict observed pre-SN stars

- SNe II-L may also arise from YSGs, with $M_{ini} \approx 20\ M_{\odot}$ (??)

Envelope has been stripped --- dense circumstellar matter, leading to radio/X-ray emission

- *Some* SNe IIn arise from LBVs (see also Kiewe et al. 2011): very high-mass stars
- SNe IIb may have high-mass extended or compact progenitors

  (stripped components in interacting binaries)
- SNe Ib *may* have similar high-mass compact (WR) progenitors in binaries
- SNe Ic: high-mass, single WC stars … or binaries ????