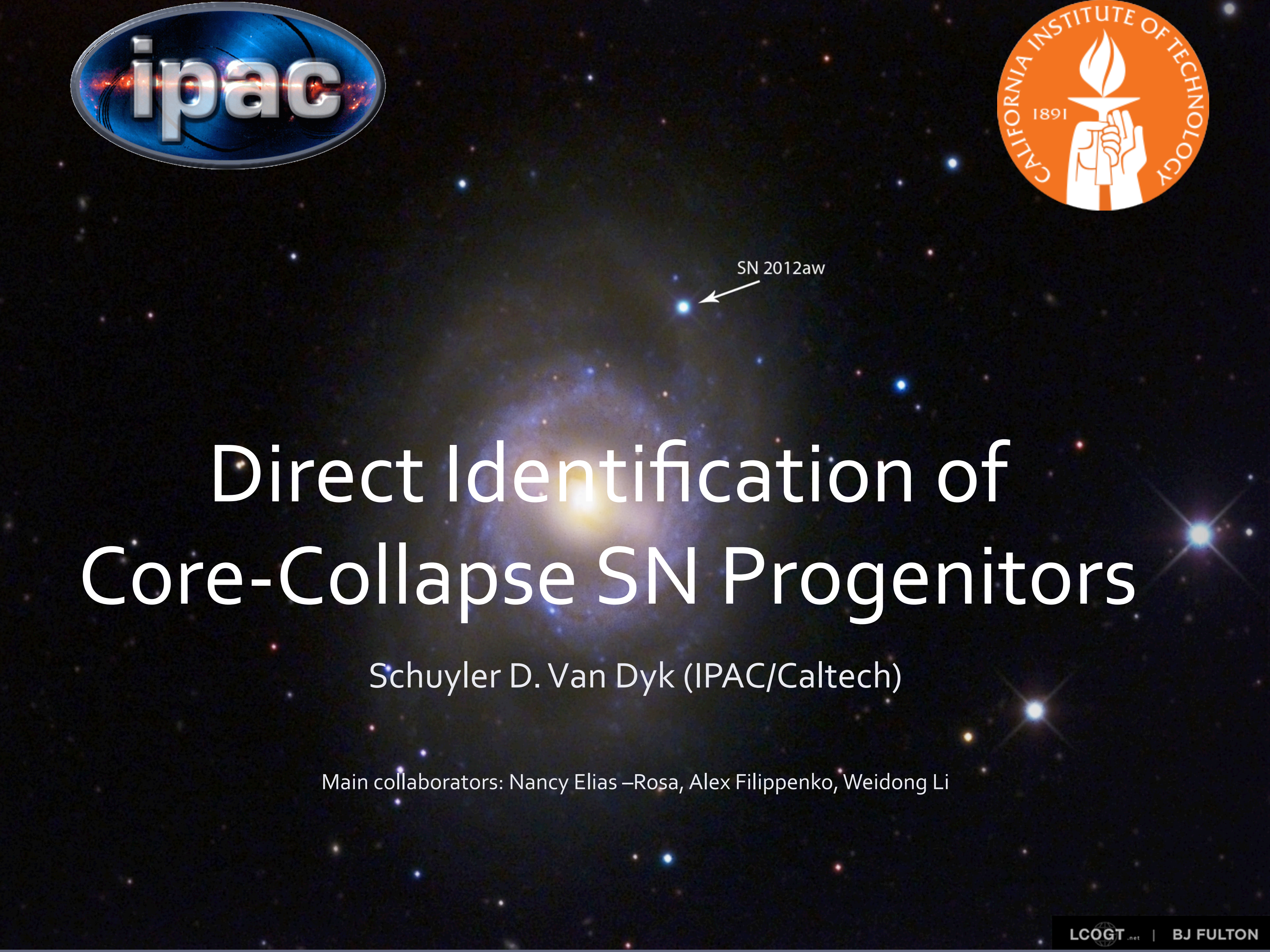
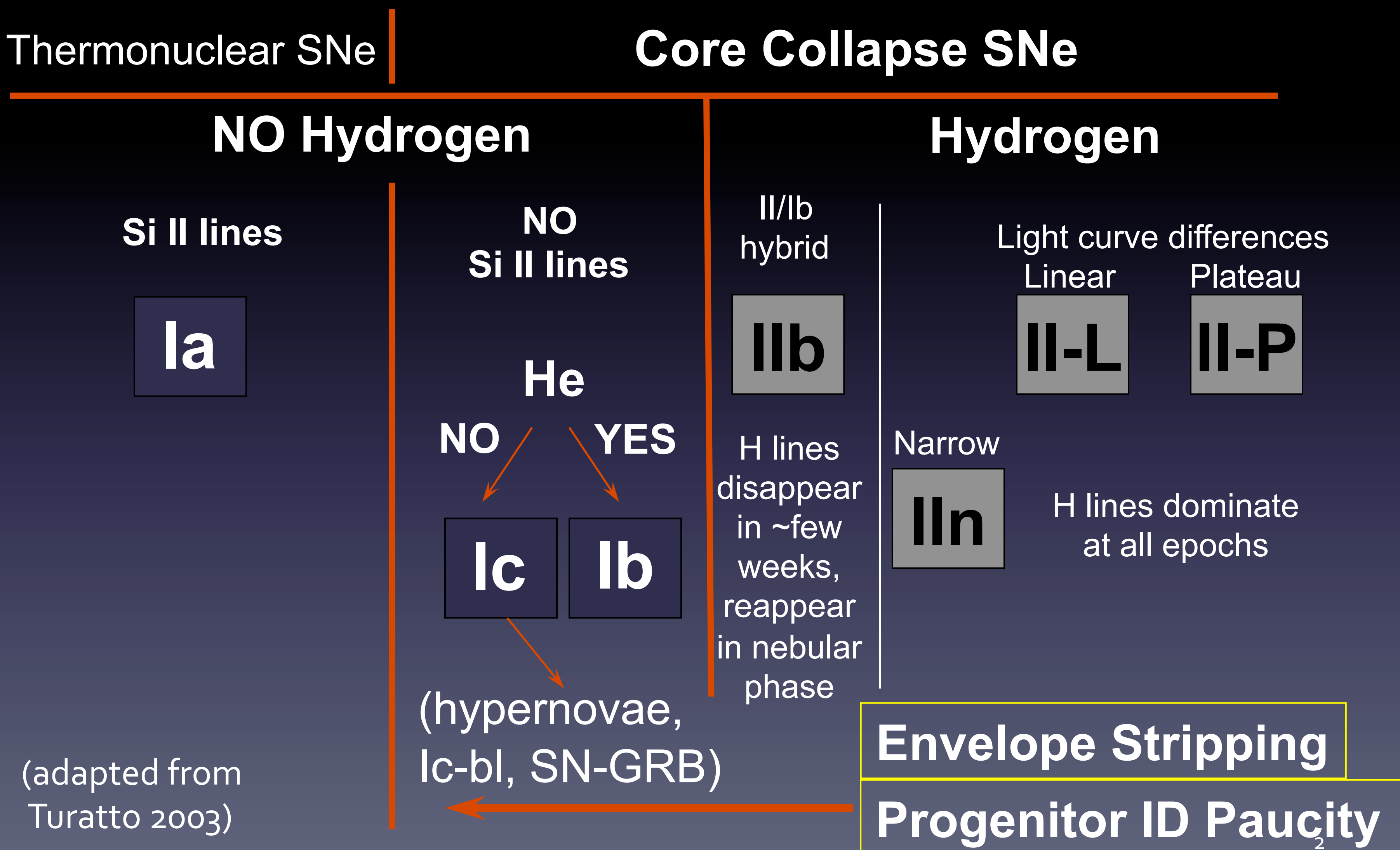


Direct Identification of Core-Collapse SN Progenitors

Schuyler D. Van Dyk (IPAC/Caltech)

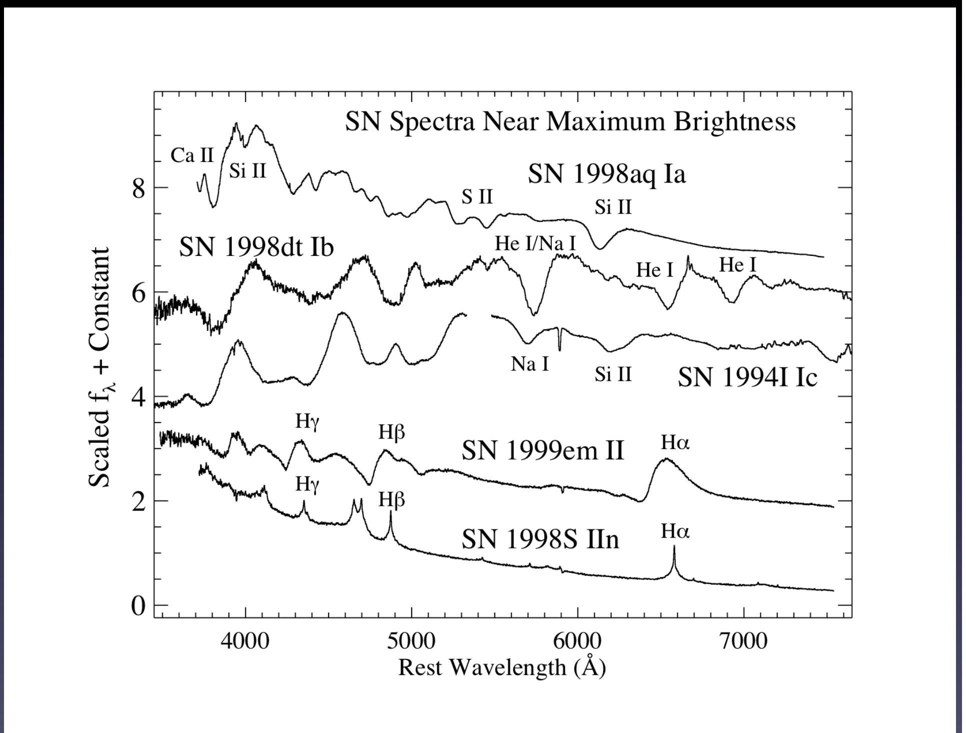
Main collaborators: Nancy Elias –Rosa, Alex Filippenko, Weidong Li

Core-Collapse SNe: Classification

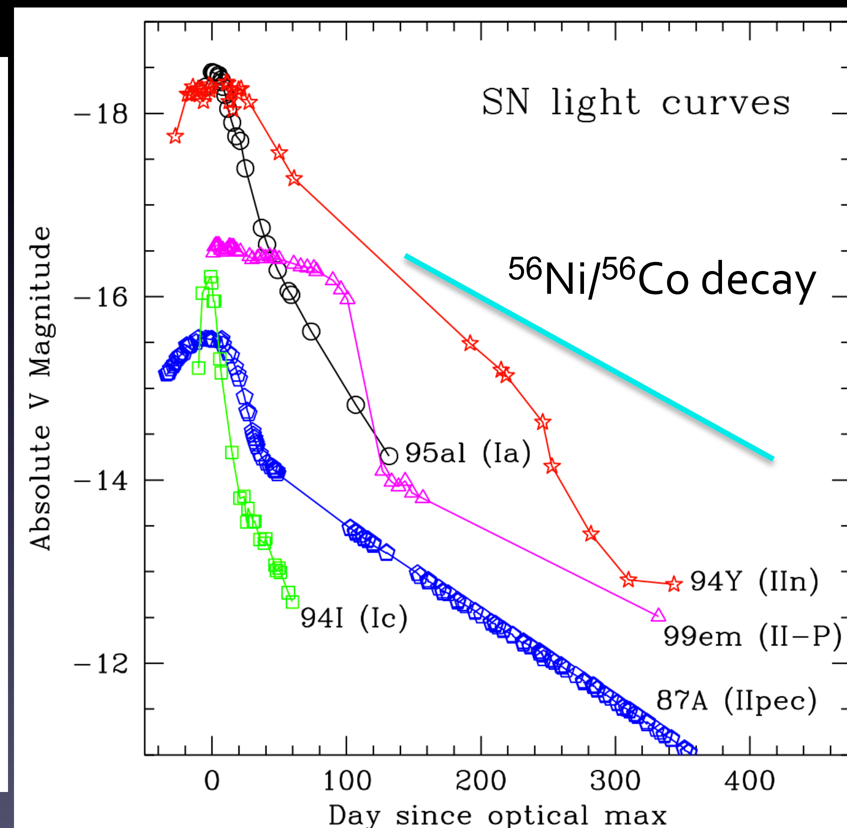


(adapted from
Turatto 2003)

Core-Collapse SNe: Classification



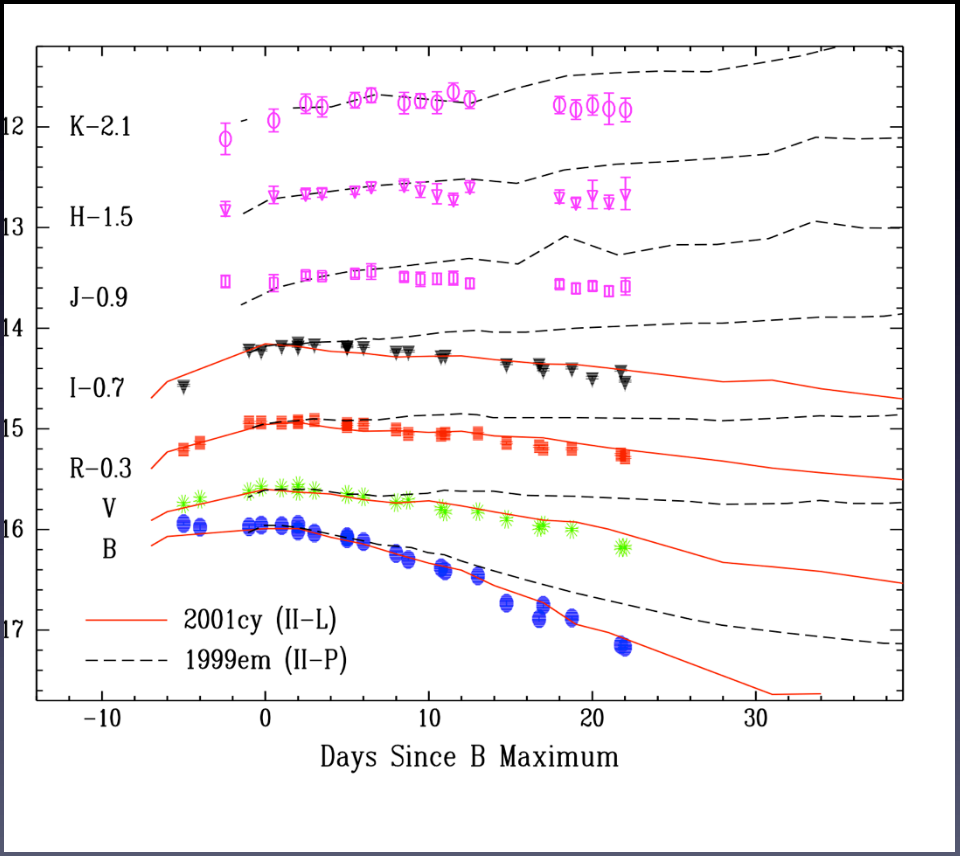
(Van Dyk & Matheson 2012)

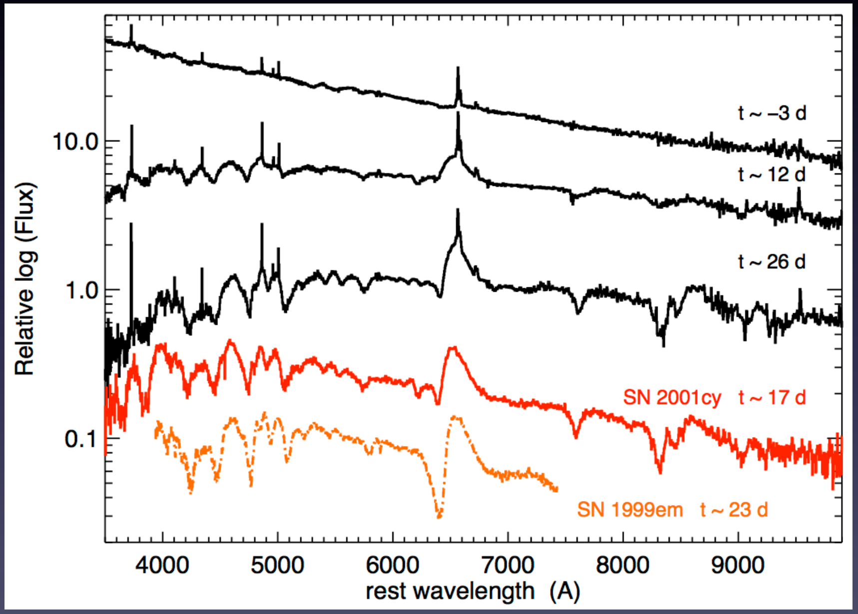


Mass of ^{56}Ni depends on mass of core

Core-Collapse SNe: Classification

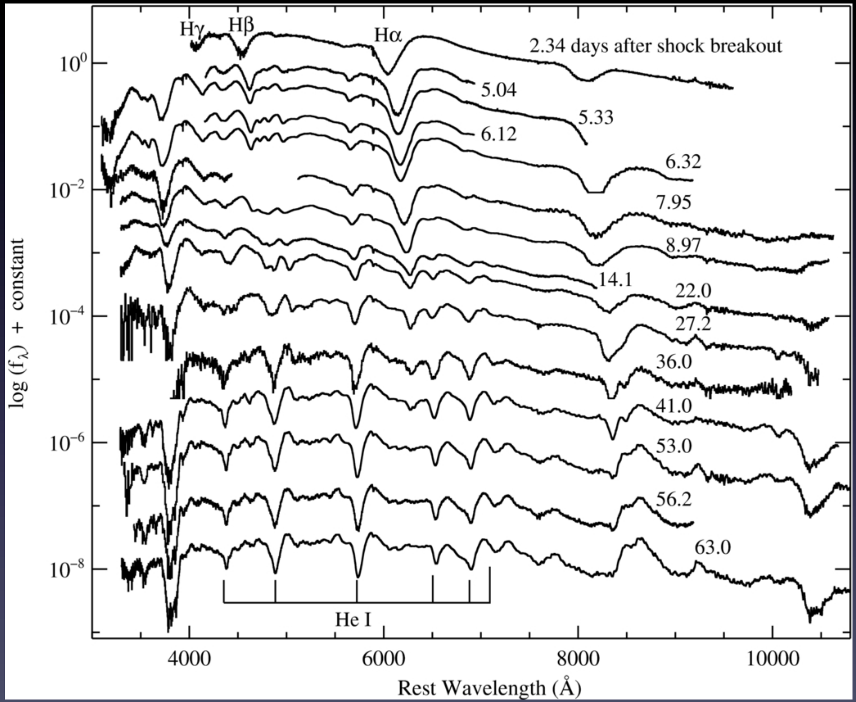
SN II-L 2009kr in NGC 1832 (Elias-Rosa et al. 2010)



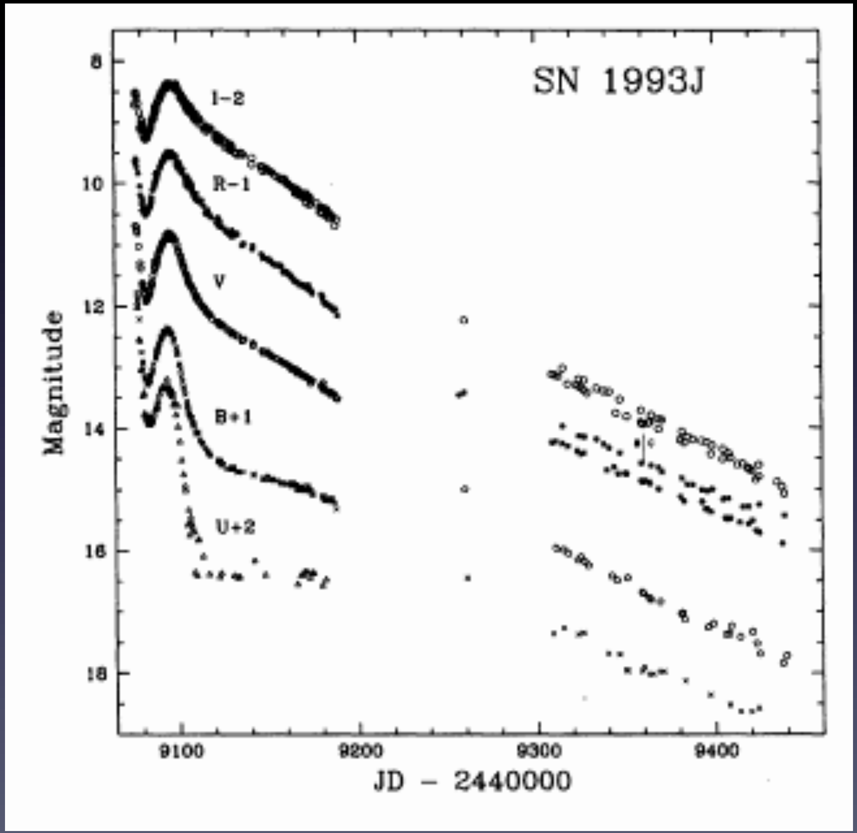


Core-Collapse SNe: Classification

SN IIb 2008ax in NGC 4490
(Chornock et al. 2011)

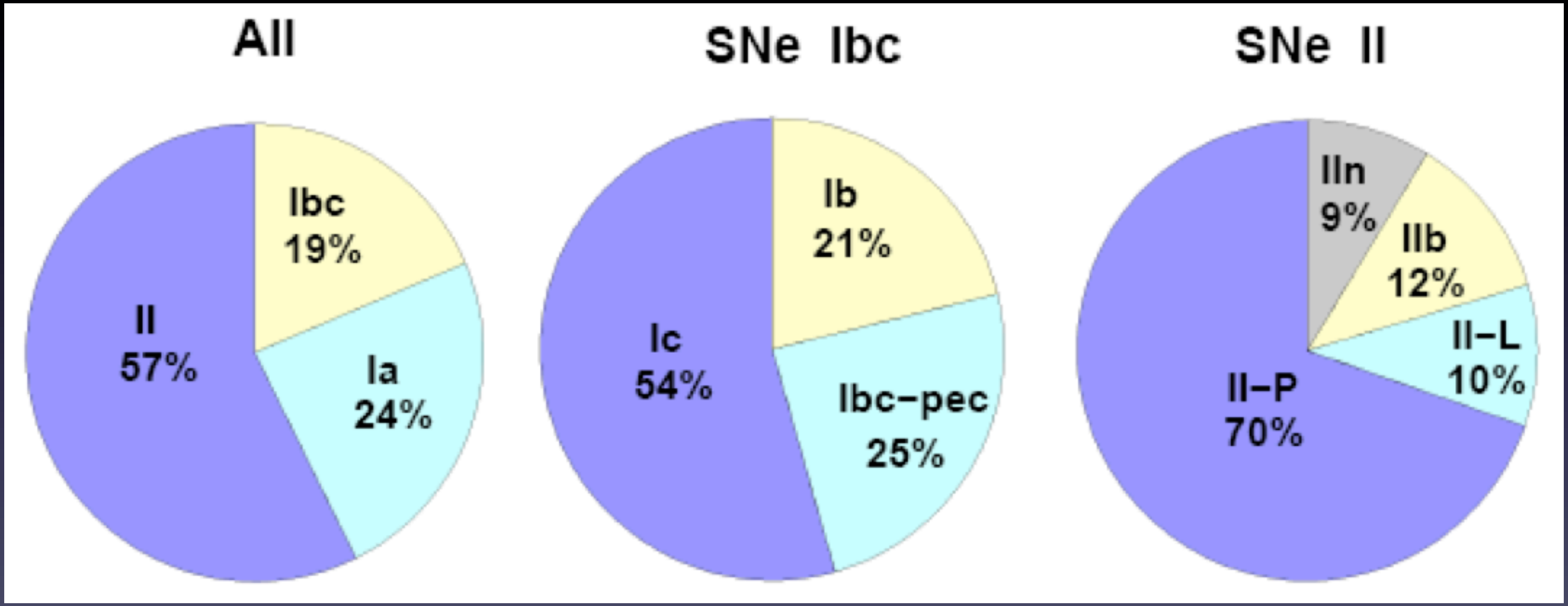


SN IIb 1993J in M81
(Richmond et al. 1996)



Core-Collapse SNe: Rates

Li et al. (2010) Lick Observatory SN Search



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)

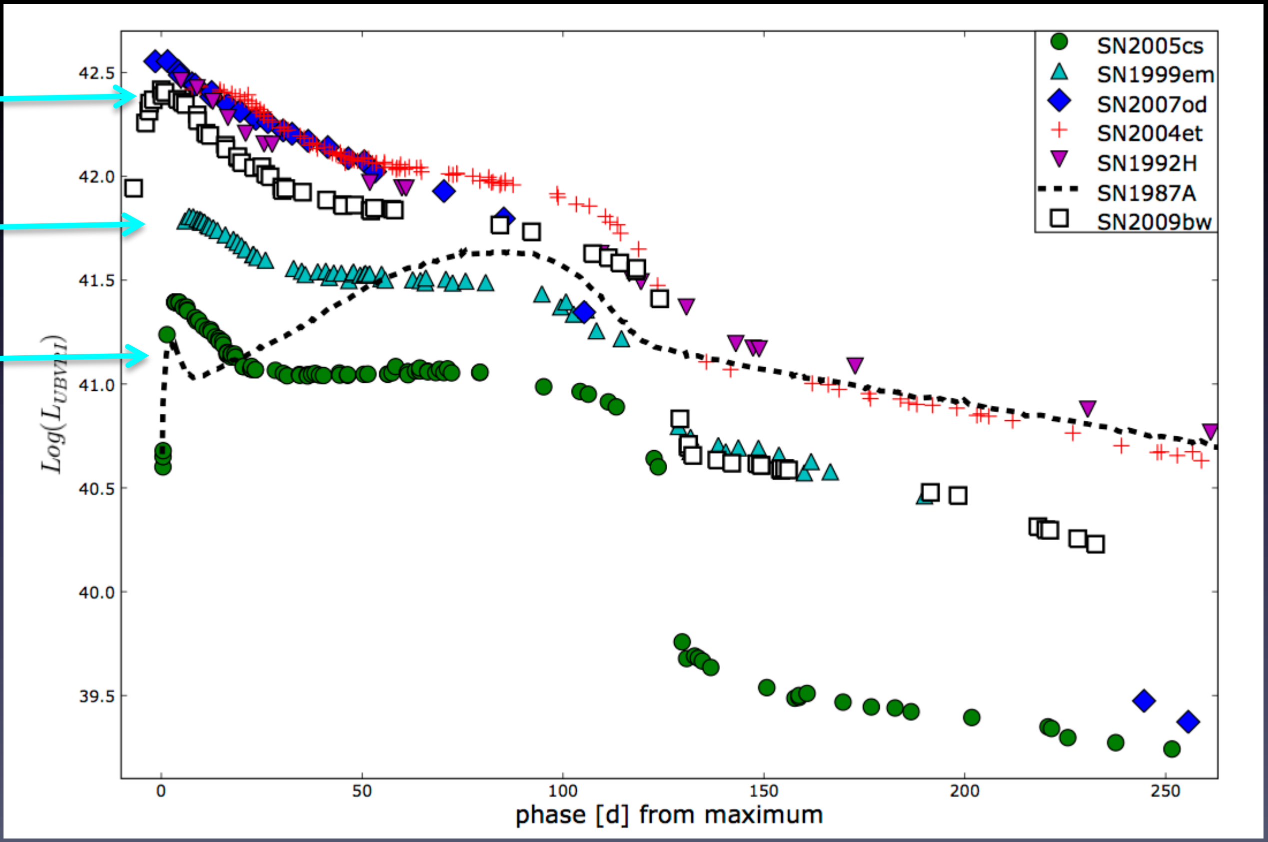
SN II-P Progenitors

The most common core-collapse SNe

high-lum II-P

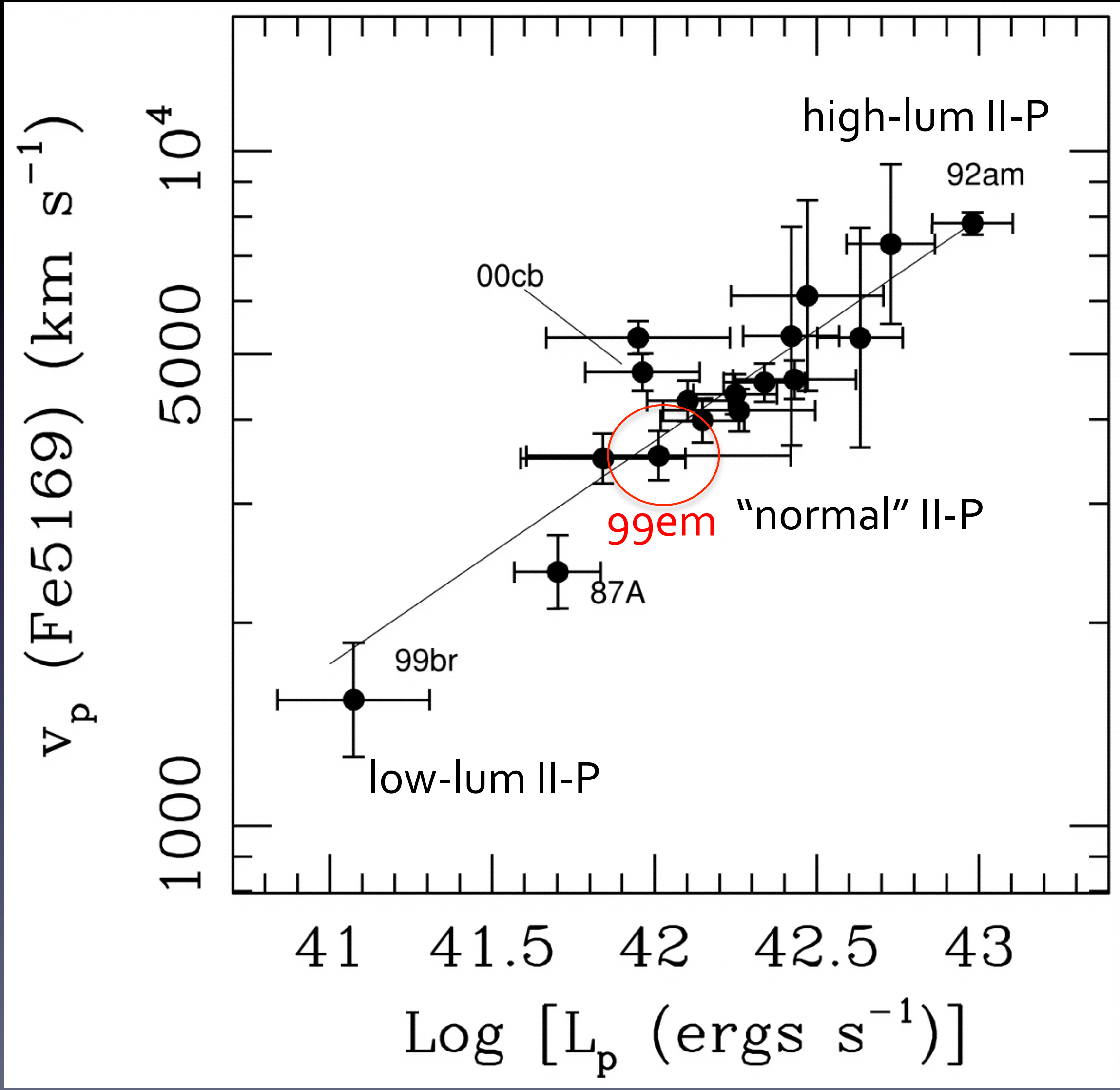
“normal” II-P

low-lum II-P



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)

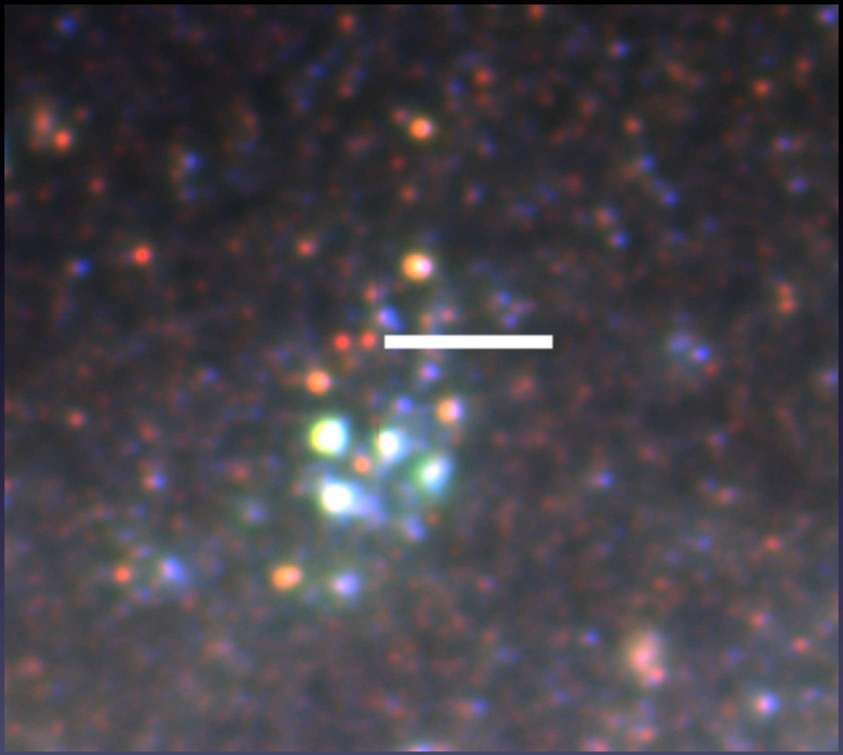
SN II-P pec 1987A

(David Malin AAT image)

Sanduleak -69° 202
The star was a B3I !!! (Isserstedt 1975, Rousseau et al. 1978)

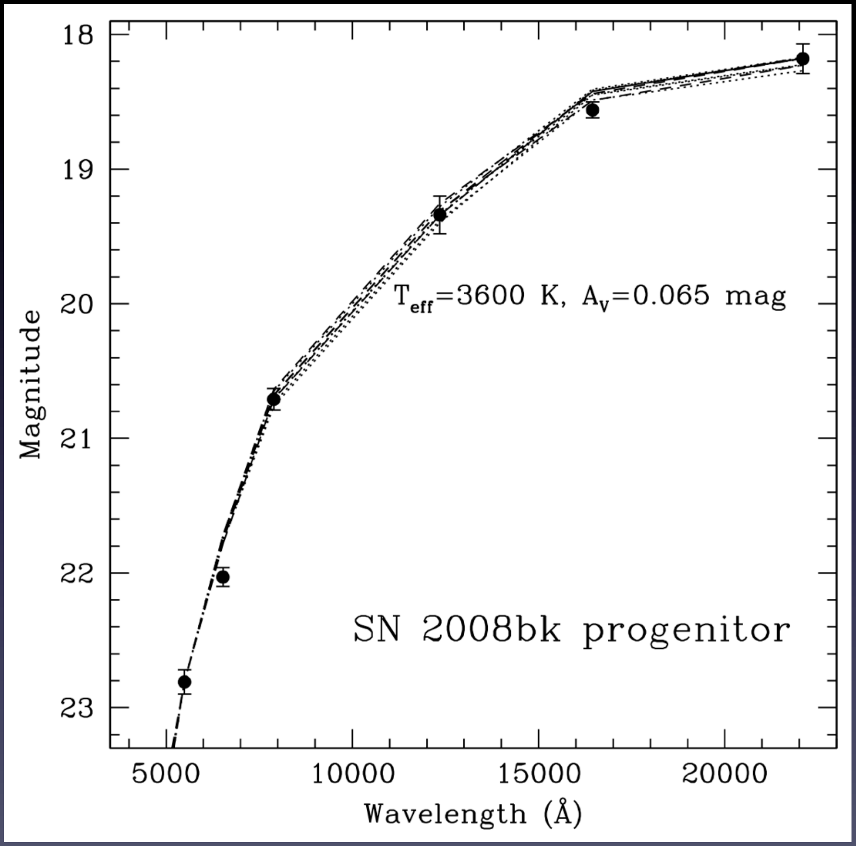
(low lum) SN II-P 2008bk

The "second best" progenitor detection ever



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

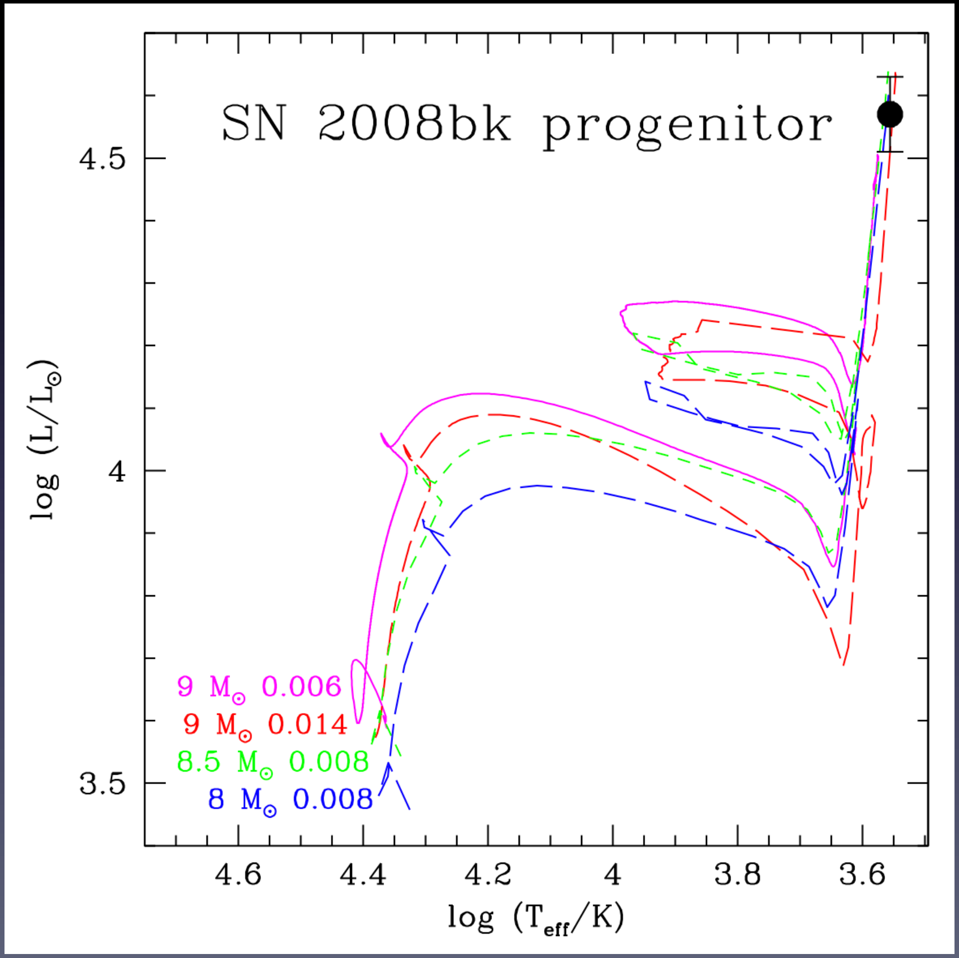
Van Dyk et al. (2012)
also, Mattila et al. (2008)



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 ???



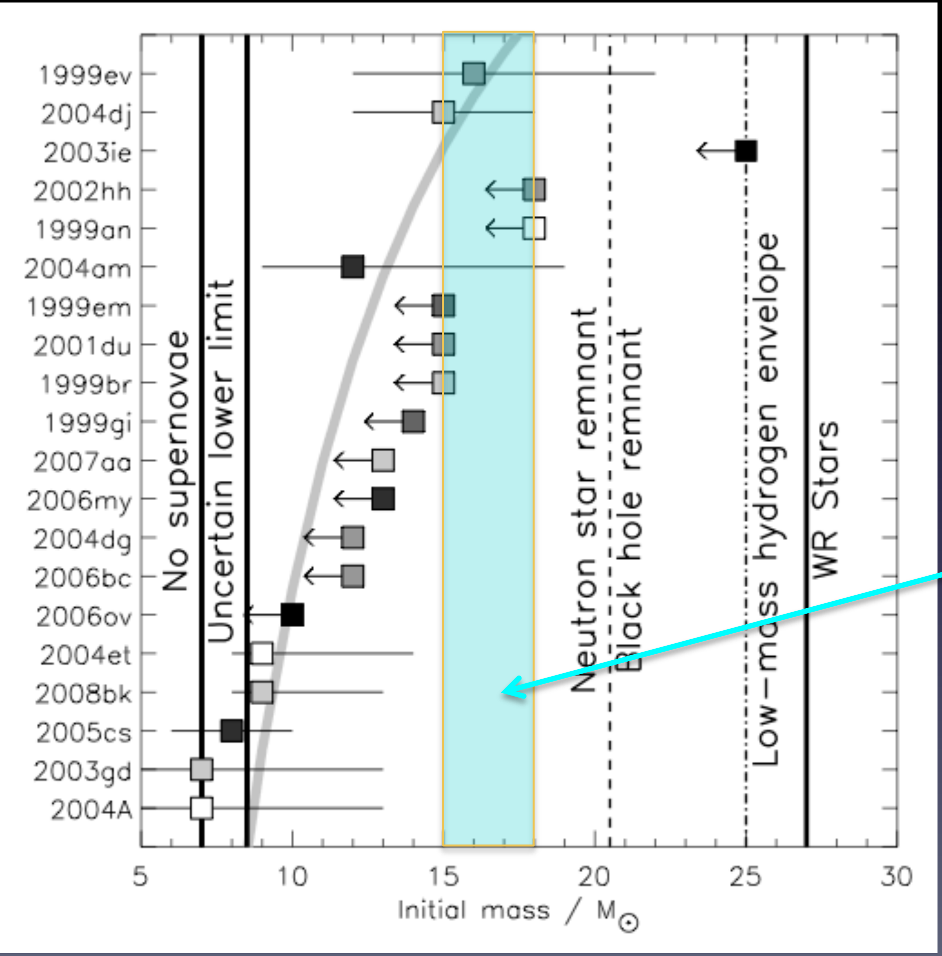
Van Dyk et al. (2012)

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

Magenta: Geneva rotating LMC
Red: Geneva rotating solar
Green, blue: Cambridge LMC

SN II-P Progenitors

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

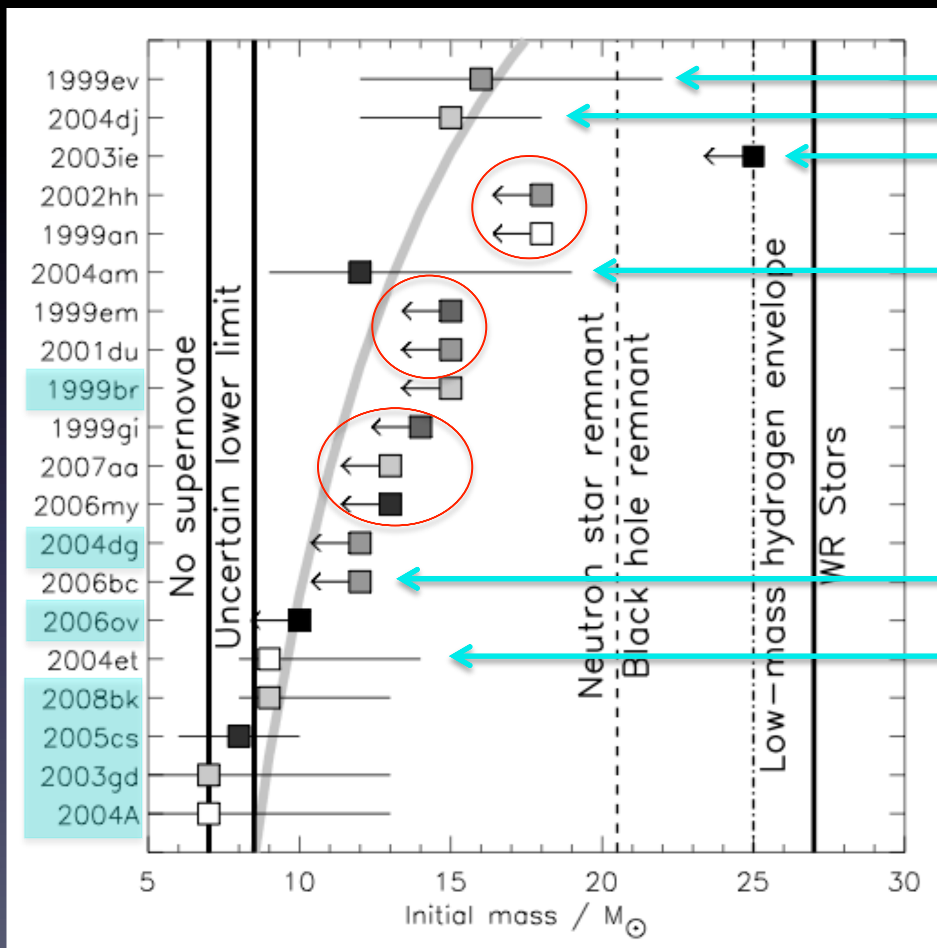


Smartt et al. (2009)

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 !

Low-lum II-P

Probable II-L ** !

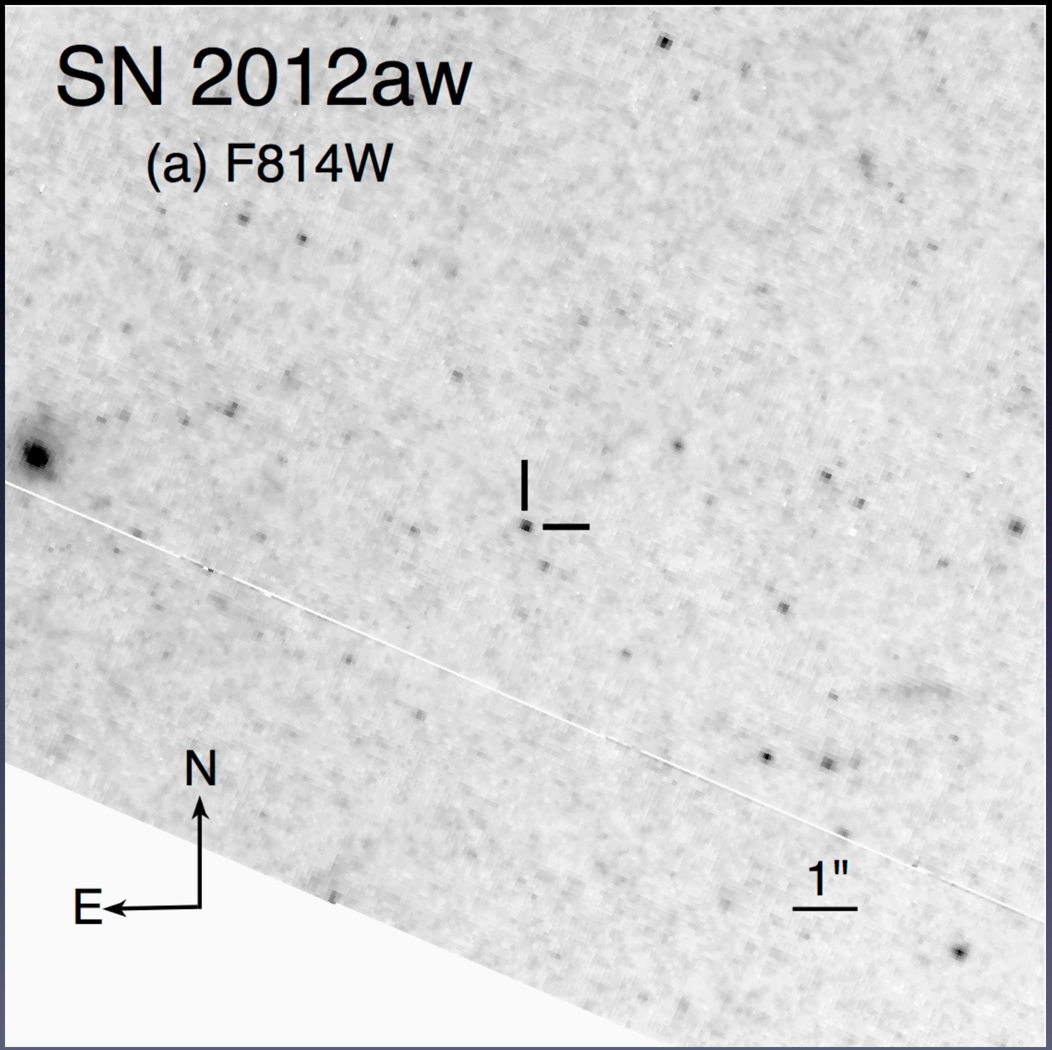
This is wrong

(from Smartt et al. 2009)

*Harutyunyan et al. (2008)

**Gallagher et al. (2010)

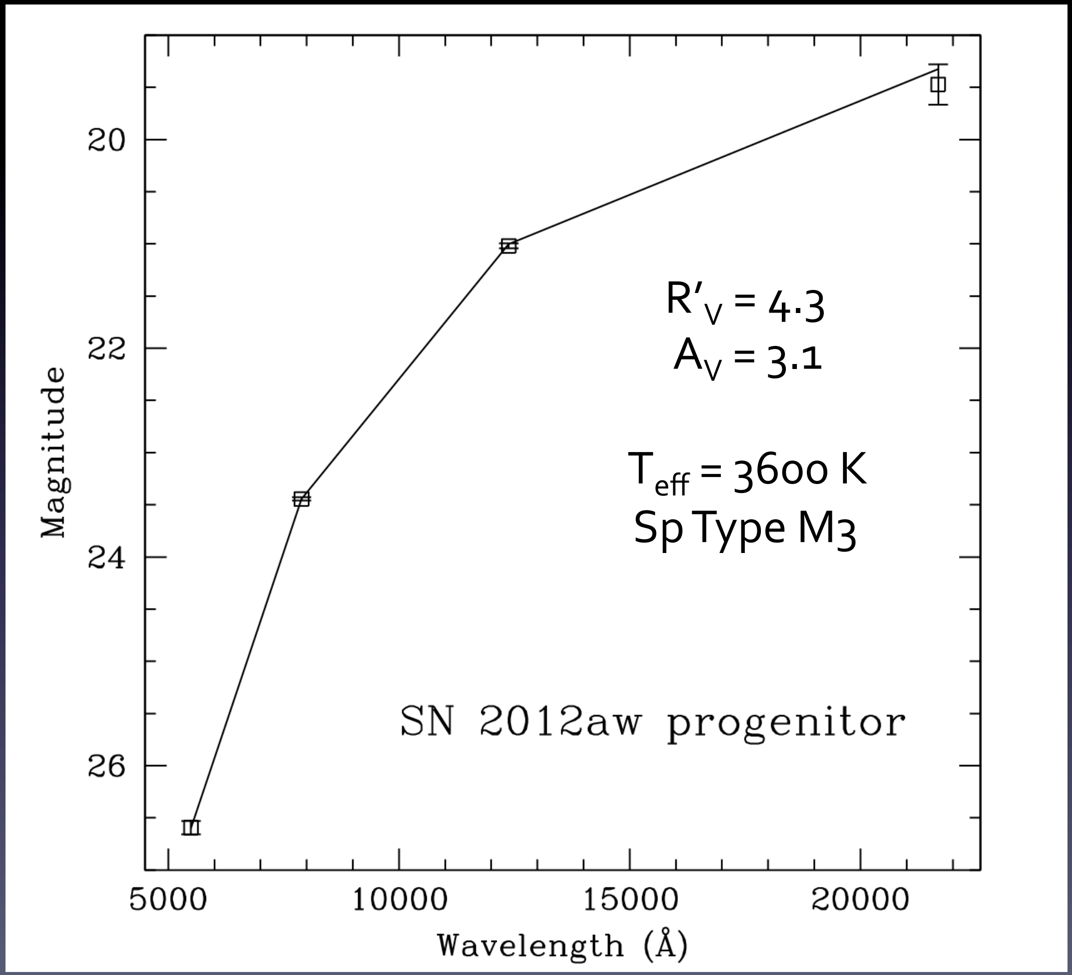
("normal") SN II-P 2012aw in M95



Van Dyk et al. (2012, in press, arXiv: 1207.2811)

Hubble Legacy Archive F555W and F814W image mosaics from 1994

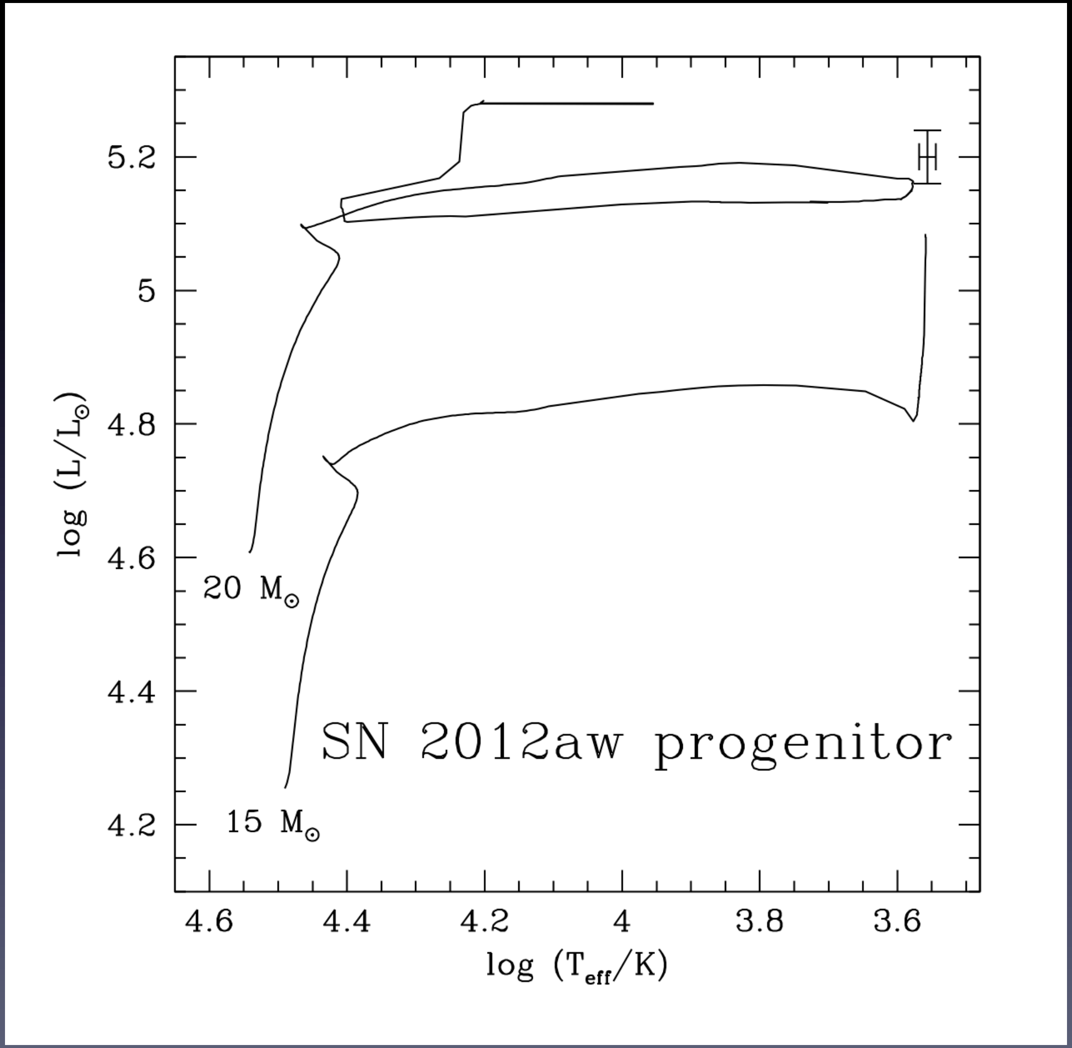
SN II-P 2012aw in M95



Van Dyk et al. (2012, in press)

MARCS RSG stellar atmospheres (Gustafsson et al. 2008)

SN II-P 2012aw in M95



Van Dyk et al. (2012, in press)

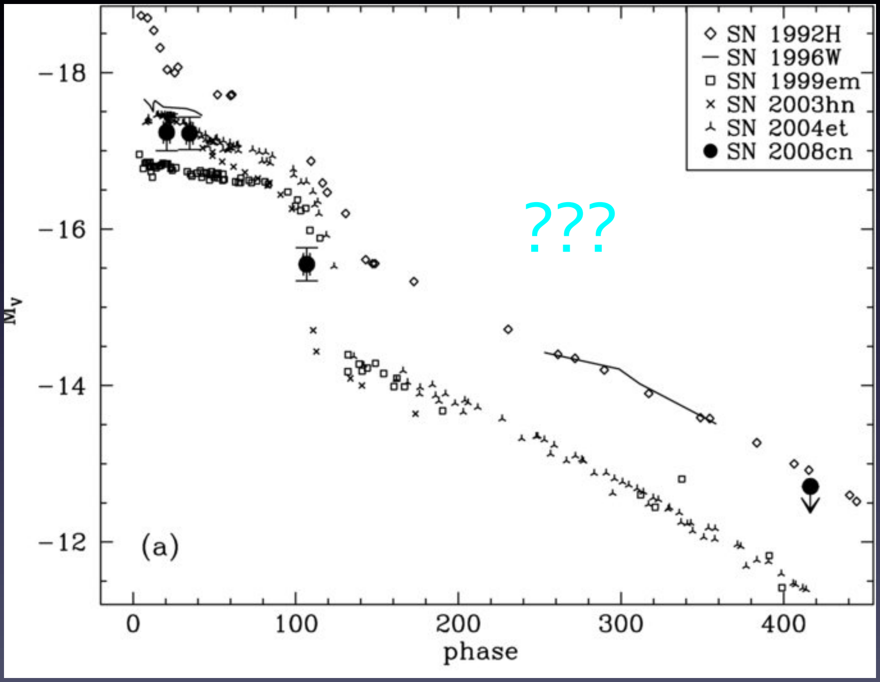
Ekström et al. (2012) rotating models at solar metallicity

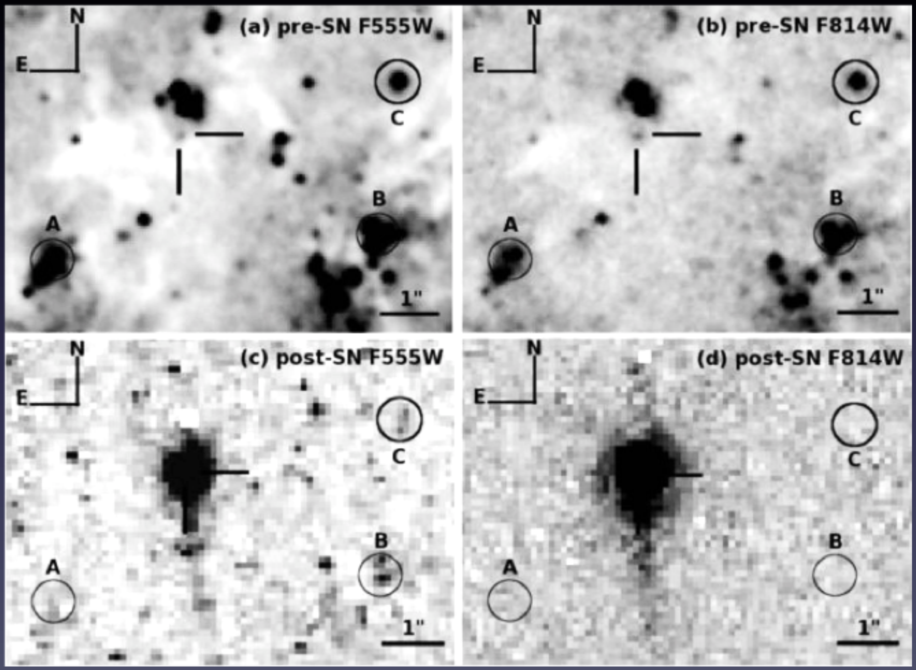
$M_{ini} \approx 17\text{--}18\ M_\odot$

R = 1040 $R_\odot$

High-luminosity SNe II-P

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





High-luminosity SNe II-P

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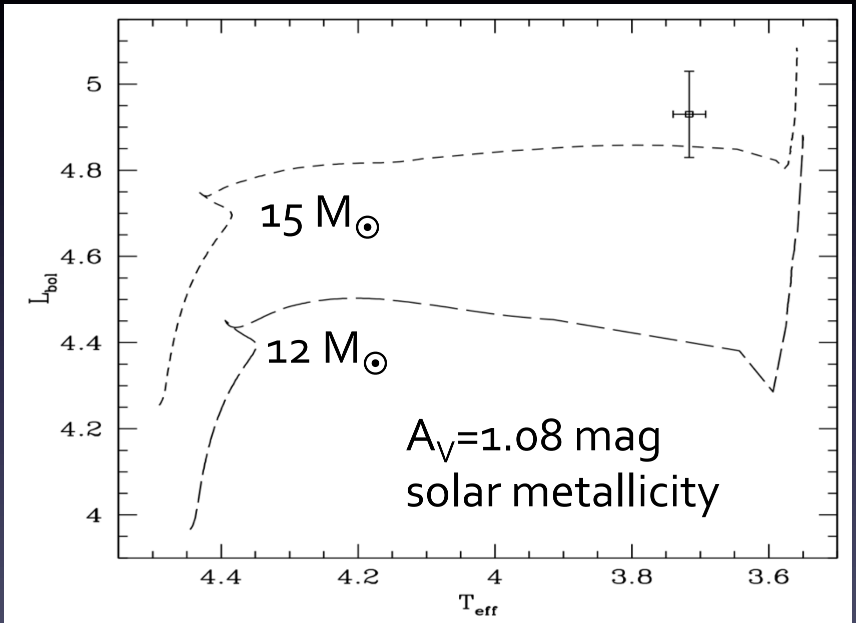
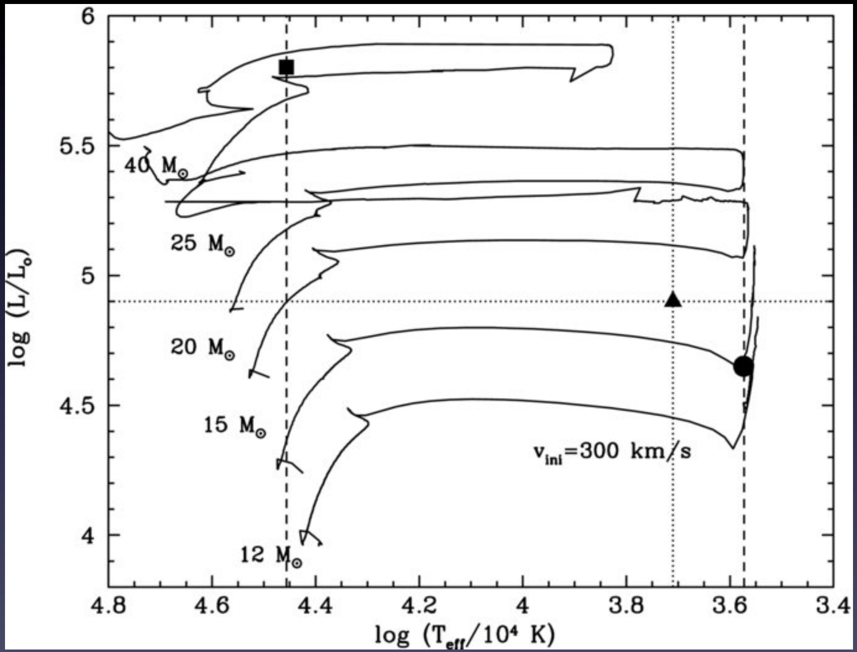


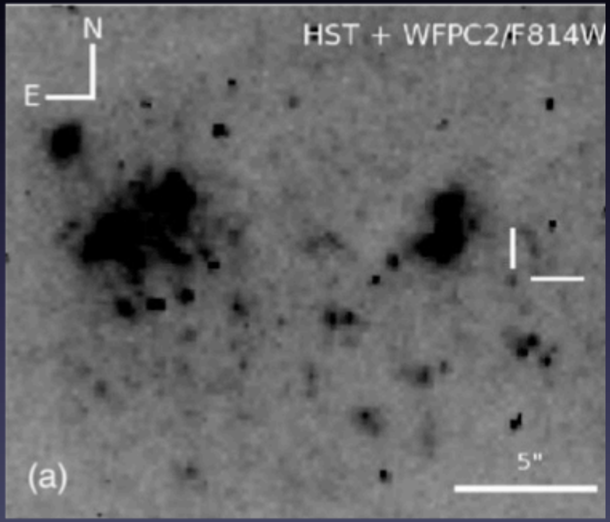


Yellow supergiant (?!?) with $M_{ini} = 15 \pm 2\ M_\odot$

SN II-L Progenitors

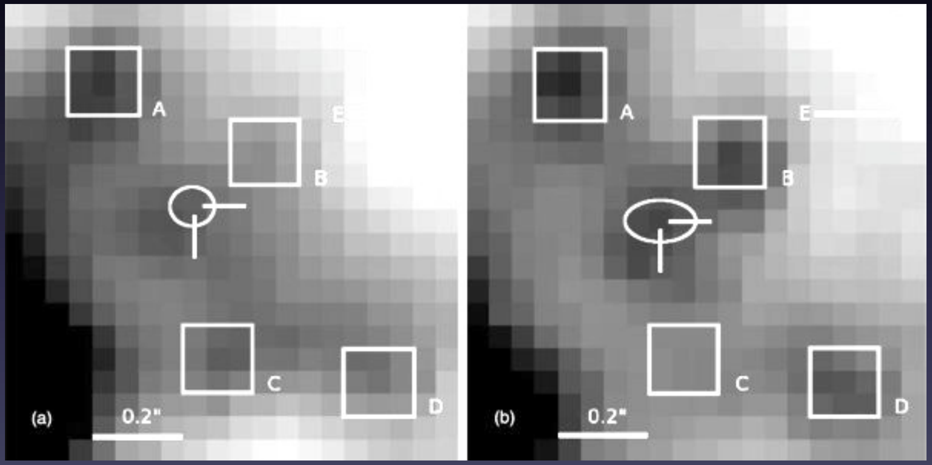
SN 2009kr in NGC 1832
(Elias-Rosa et al. 2010)

d = 26 Mpc A_V=0.25 mag



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

d = 9.4 Mpc $A_V \approx 3.8$ mag



F555W F814W

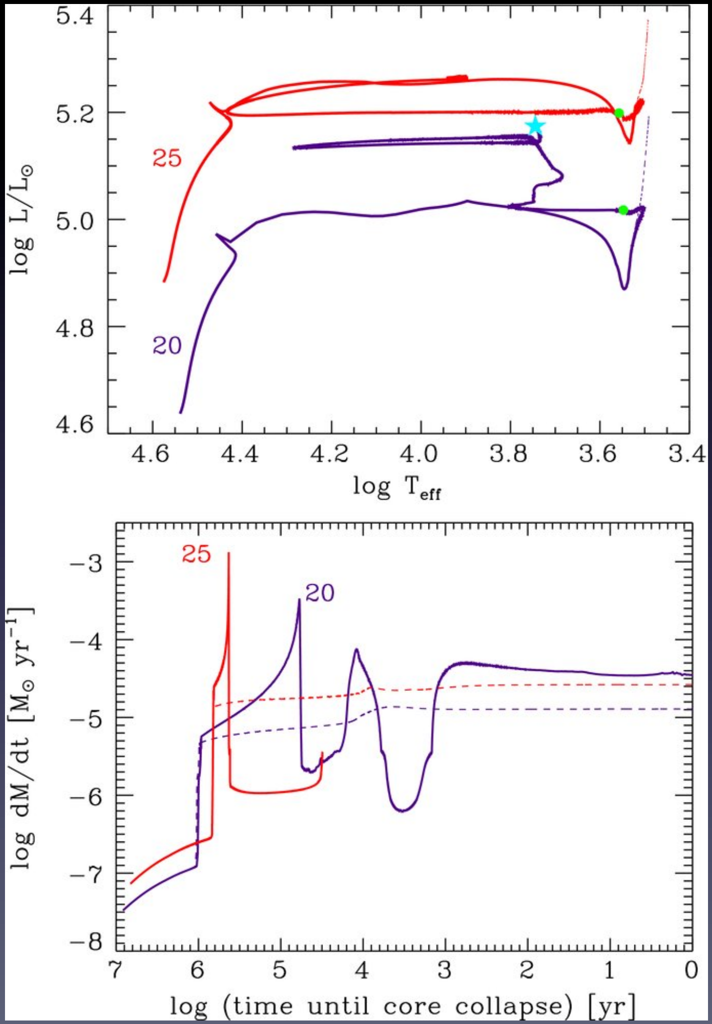
At M_V (max) = -17.2 mag,
SN 2009hd is probably a SN II-L

Evolution of Massive Stars

What do theoretical stellar evolutionary tracks predict/explain?

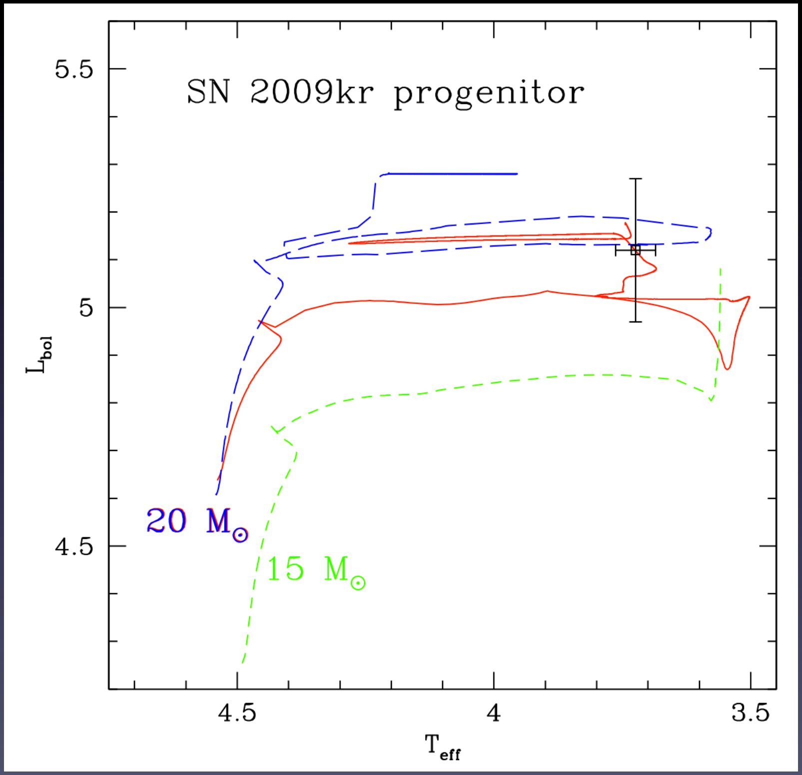
Departure from standardized
Mass loss formulation

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

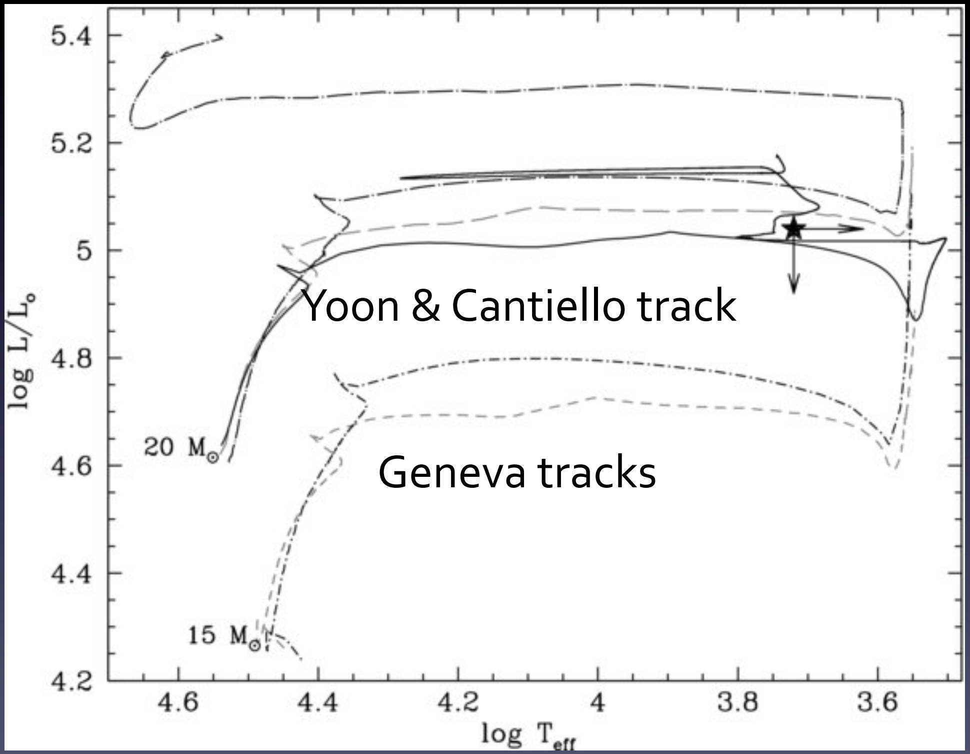


SN II-L Progenitors

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



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



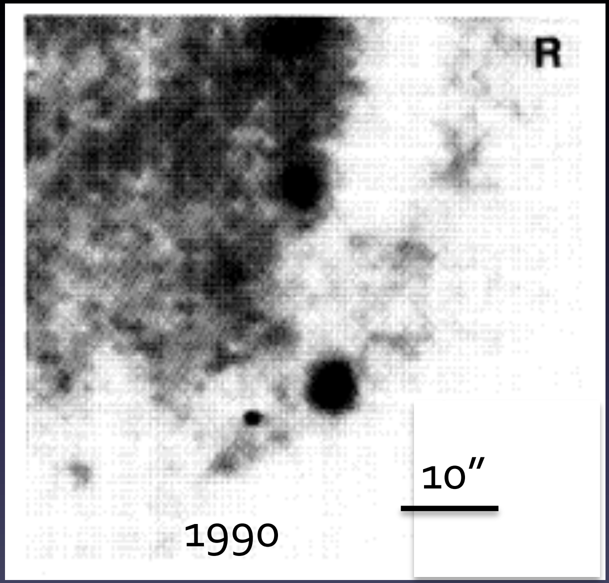
Yellow supergiant (!) with $M_{ini} = 18 - 24\ M_\odot$

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

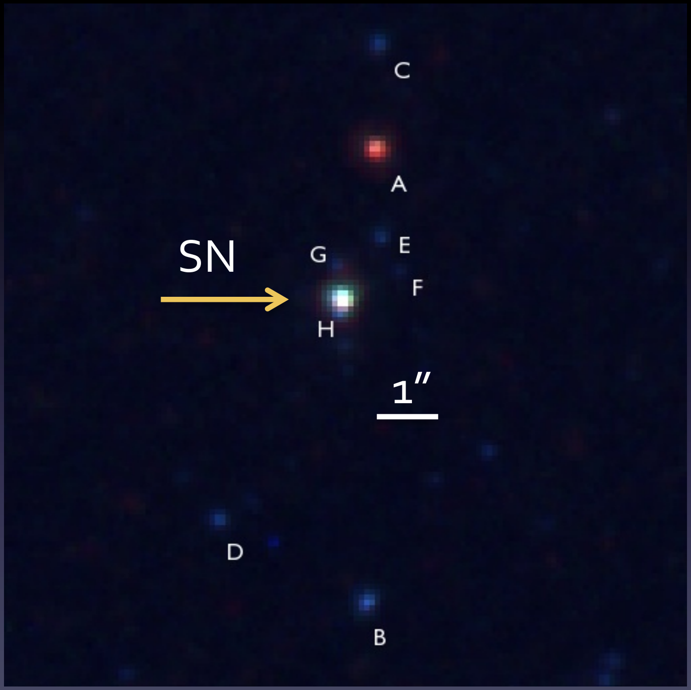
Yellow or red supergiant (?)
with $M_{ini} \leq 20\ M_\odot$

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

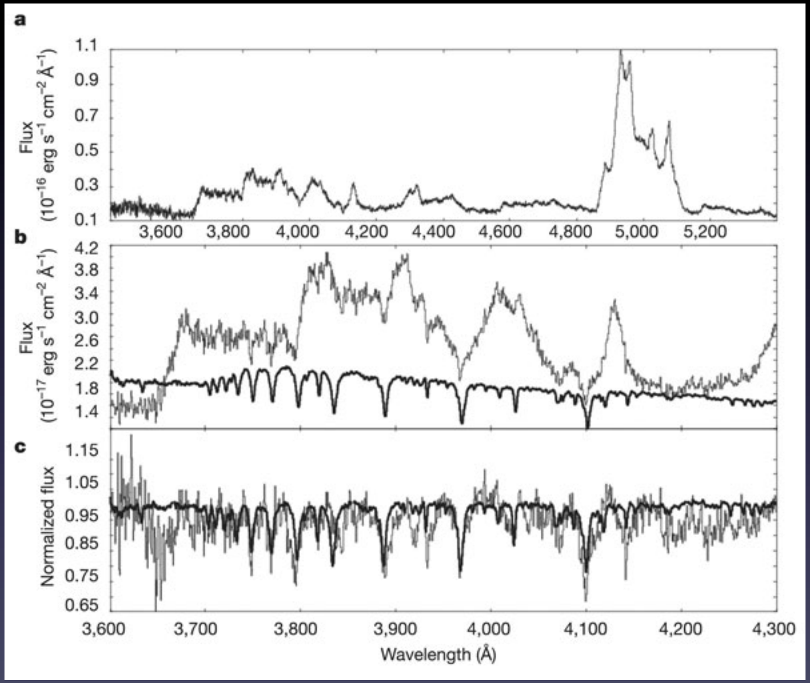


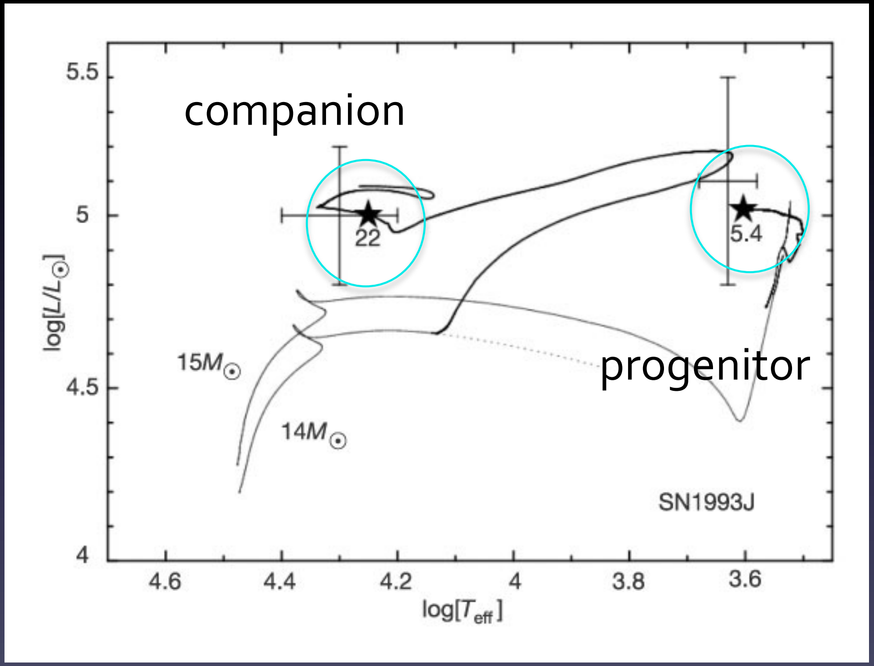
Van Dyk et al. (2002)
HST WFPC2 from 2001

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

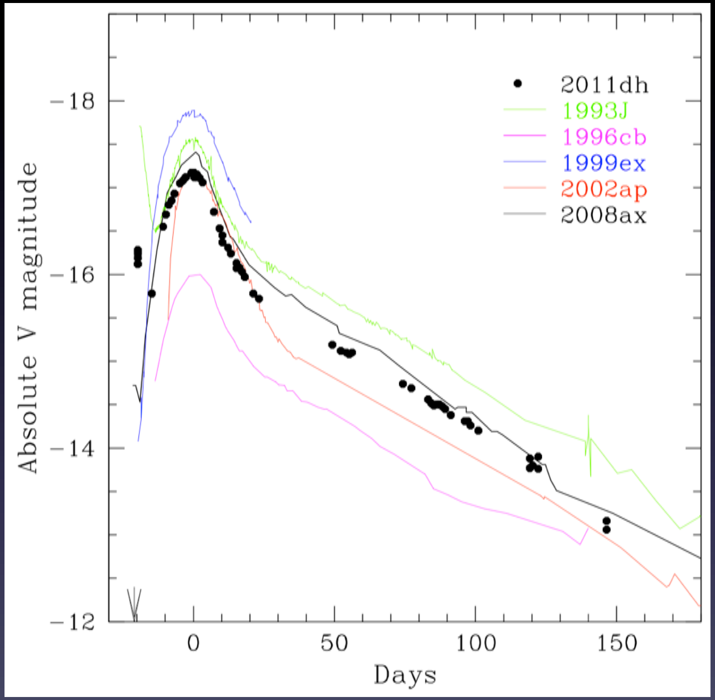




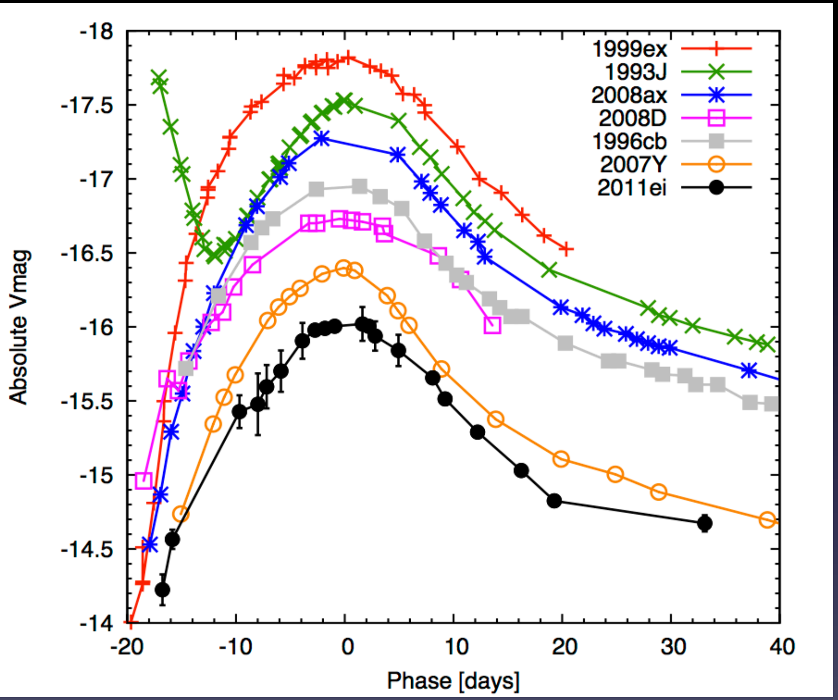
Maund et al. (2004); also Maund & Smartt (2009)

SN IIb Progenitors

Light curve comparisons



Tsvetkov et al. (2012)



Milisavljevic et al. (2012)

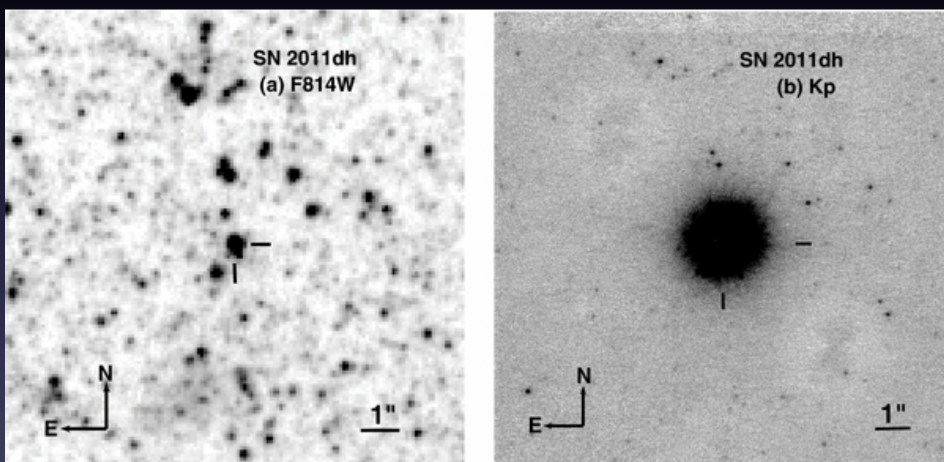
Chevalier & Soderberg (2010): SNe IIb from *extended* (R ≈ 10^{13} cm) progenitors, e.g, SN 1993J, and from *compact* (R ≈10^{11} cm) progenitors, e.g., SN 2008ax

SN IIb Progenitors

SN 2011dh in M51

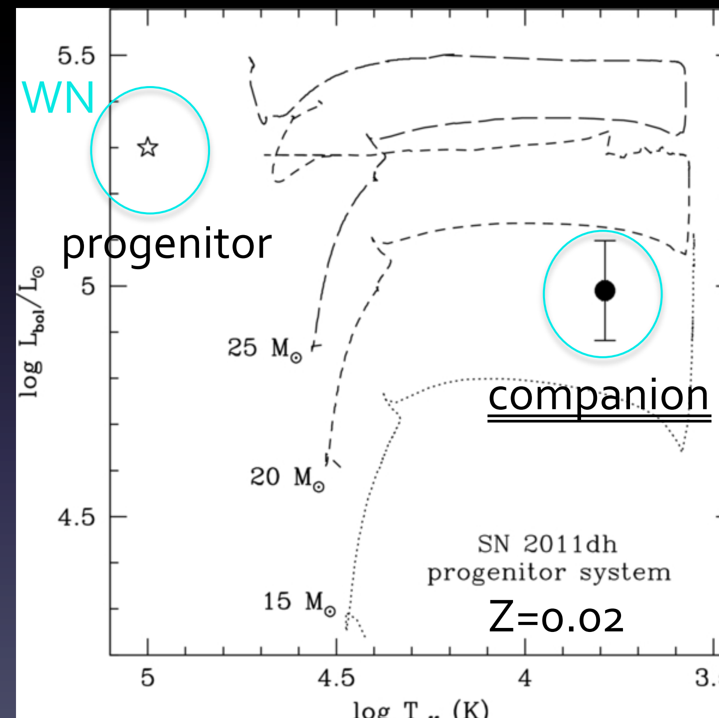
A_V=0.12 mag, d = 7.7 Mpc

Van Dyk et al. (2011)



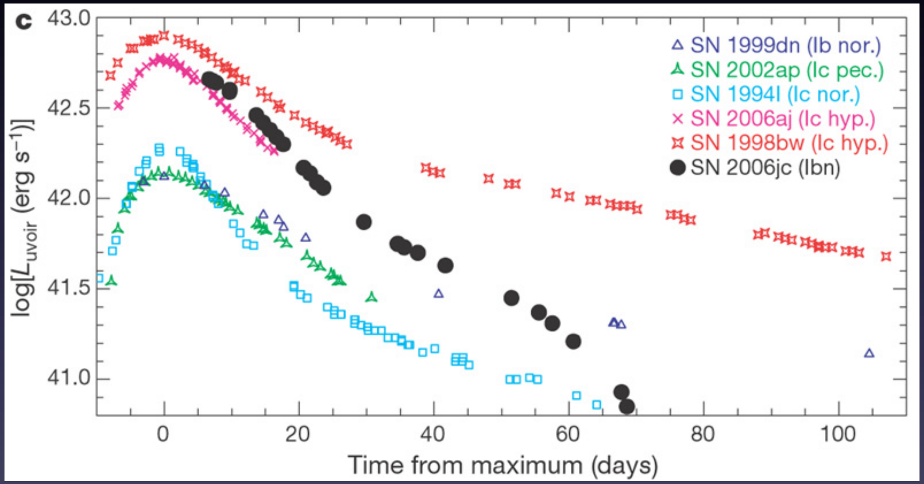
HLA data from 2005

Keck-II NIRC2 AO

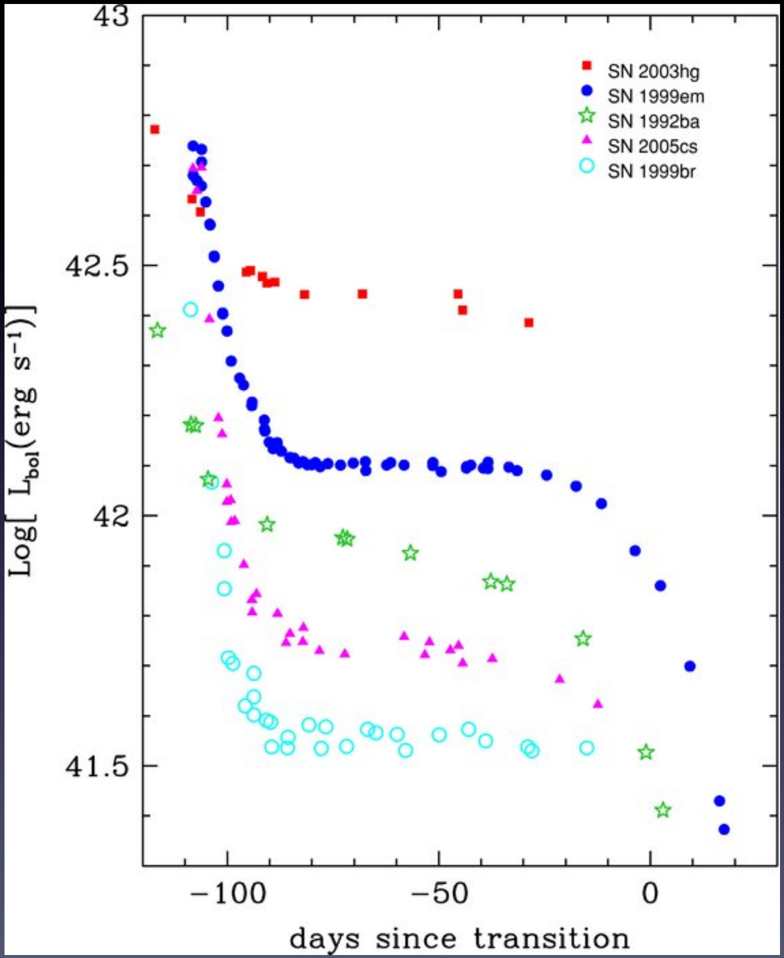


Maund et al. (2011) claim that the F-type supergiant is the progenitor
however, SN 2011dh had a *compact* progenitor (Arcavi et al. 2011, Soderberg et al. 2012)

SN Ib/c Progenitors

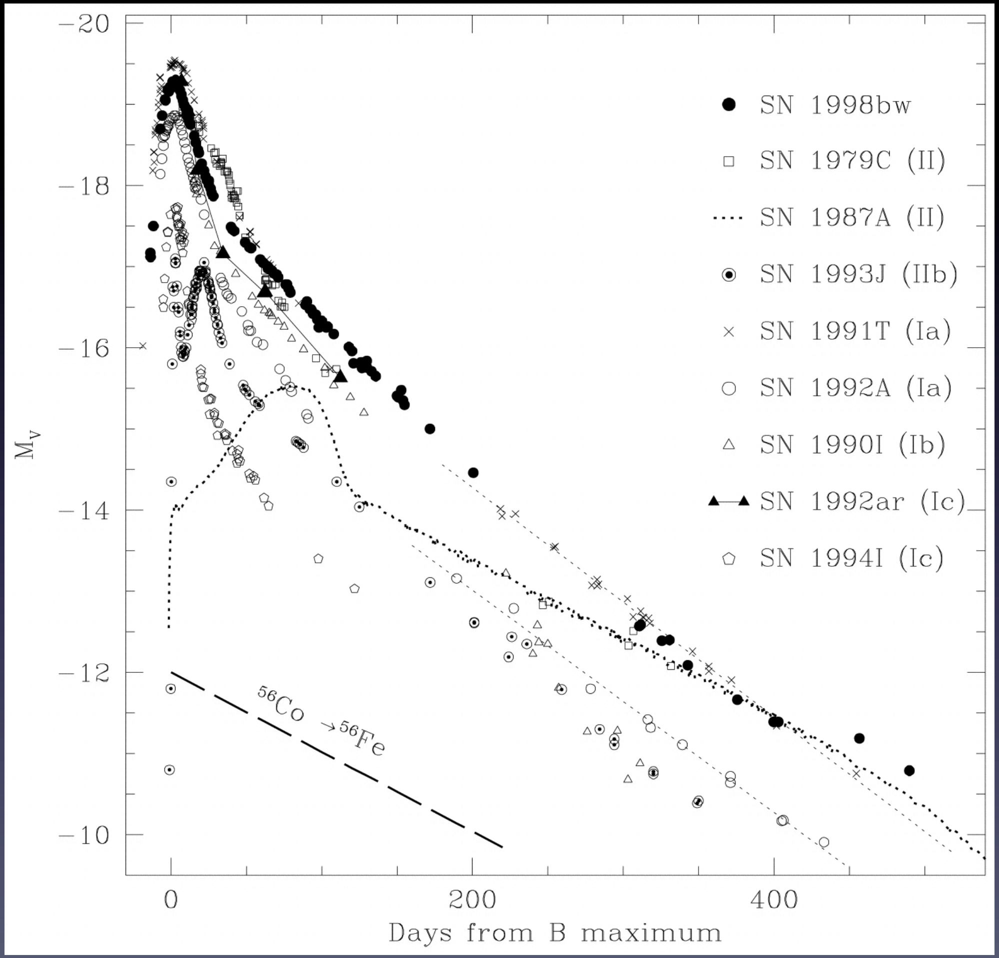


Pastorello et al. (2007)



Bersten & Hamuy (2009)

LC comparison for all SNe types

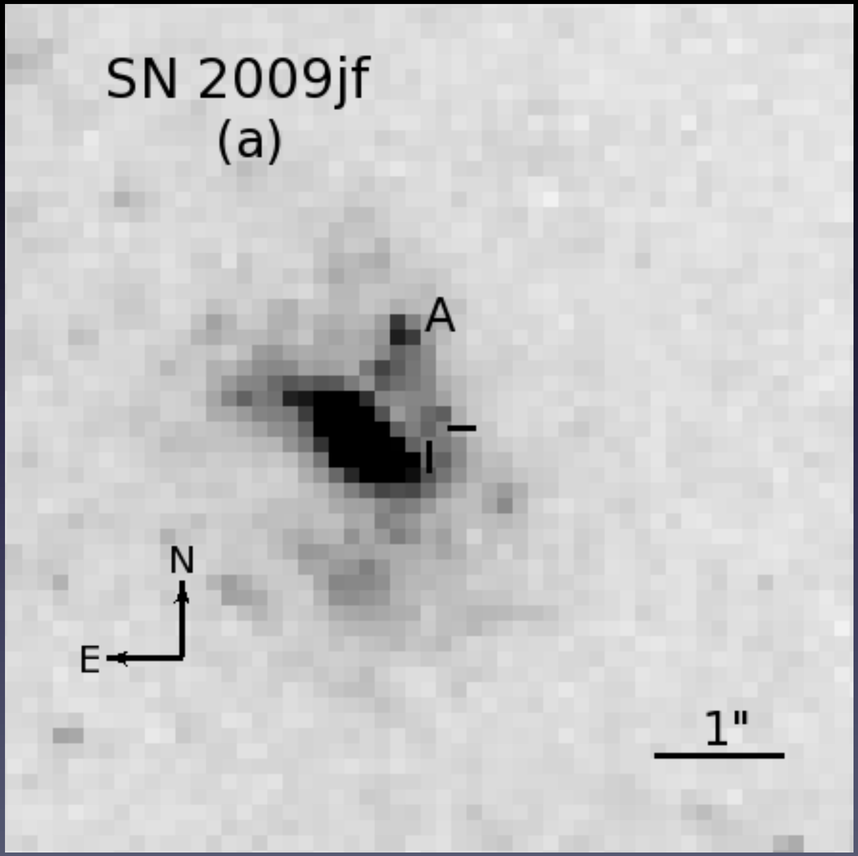


Patat et al. (2001)

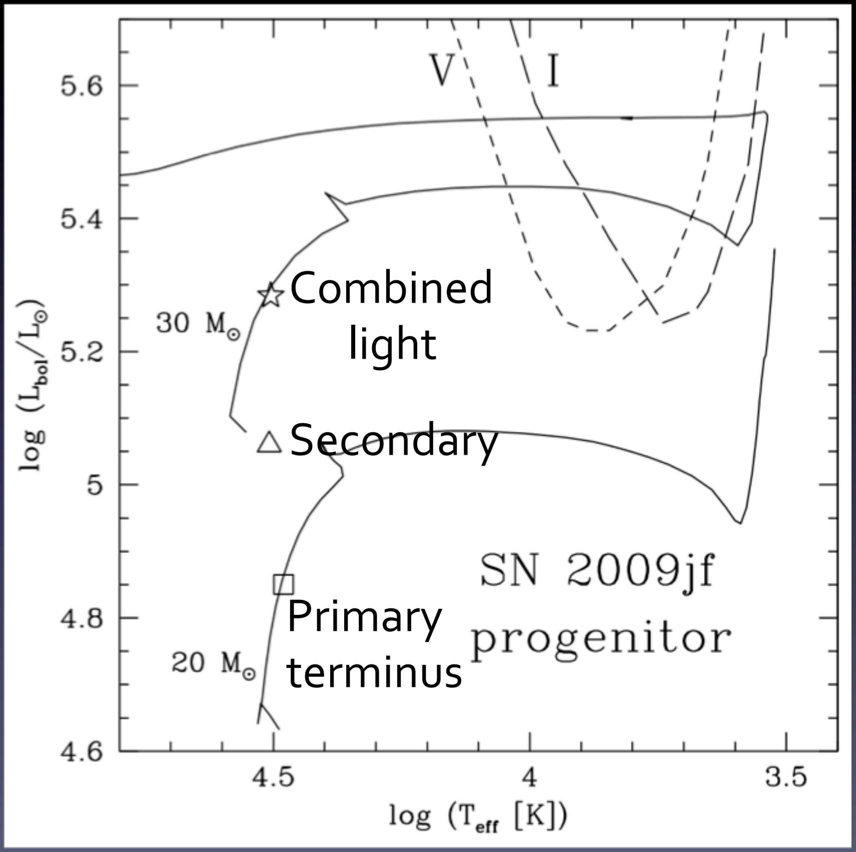
SN Ib Progenitors

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

A_V= 0.53 mag, d = 33.9 Mpc



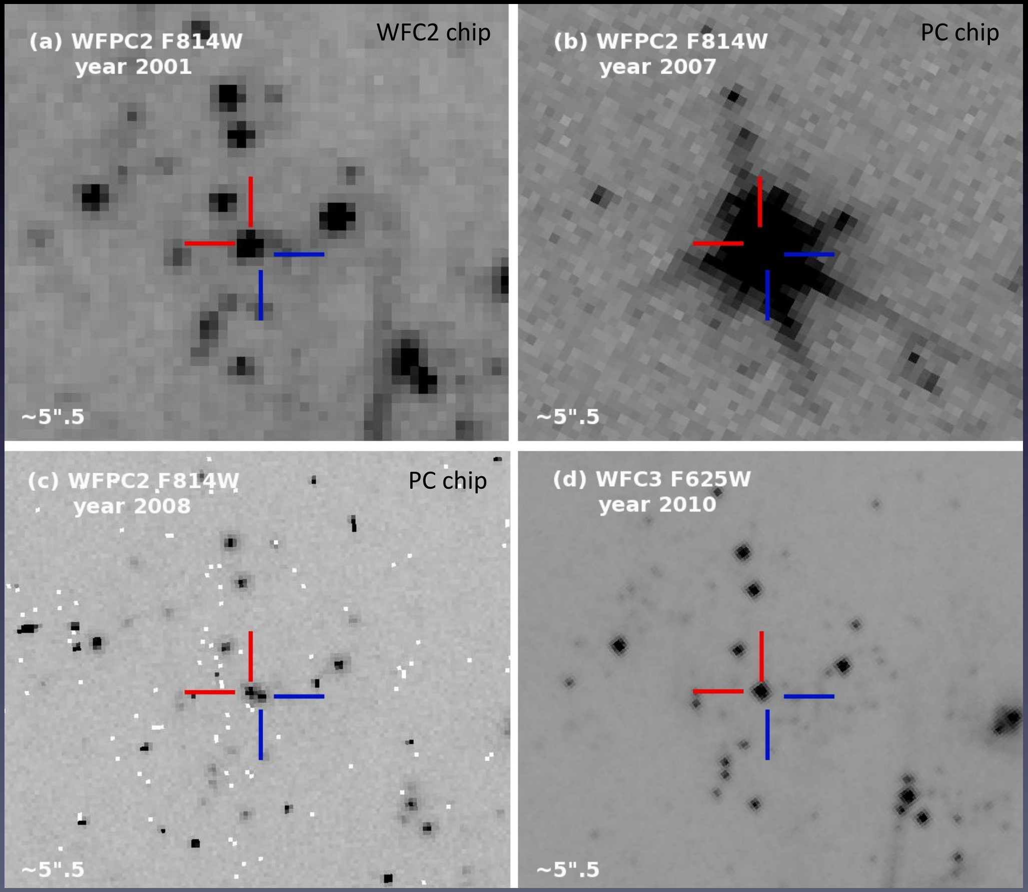
HST/WFPC2 F569W from 1995



NO PROGENITOR IDs !

SN Ic Progenitors

SN Ic 2007gr in NGC 1058
d=9.3 Mpc, $A_{V,tot} \approx 0.3$ mag



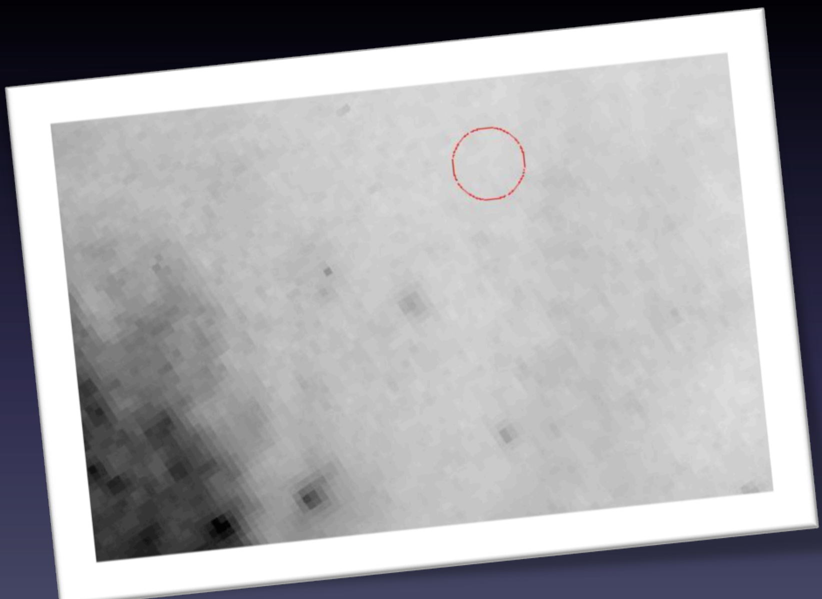
Not very restrictive limits, based on properties of star cluster
(Crockett et al. 2008)

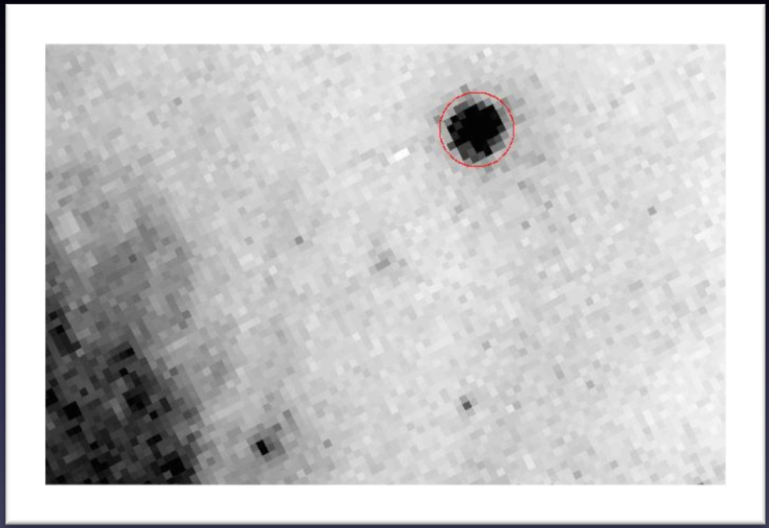
... may not be in the cluster after all ....

NO PROGENITOR IDs !

SN Ic Progenitors

SN Ic 2003jg in NGC 2997
d ≈ 11 Mpc, $A_{V,tot}$ ≈ 4 mag



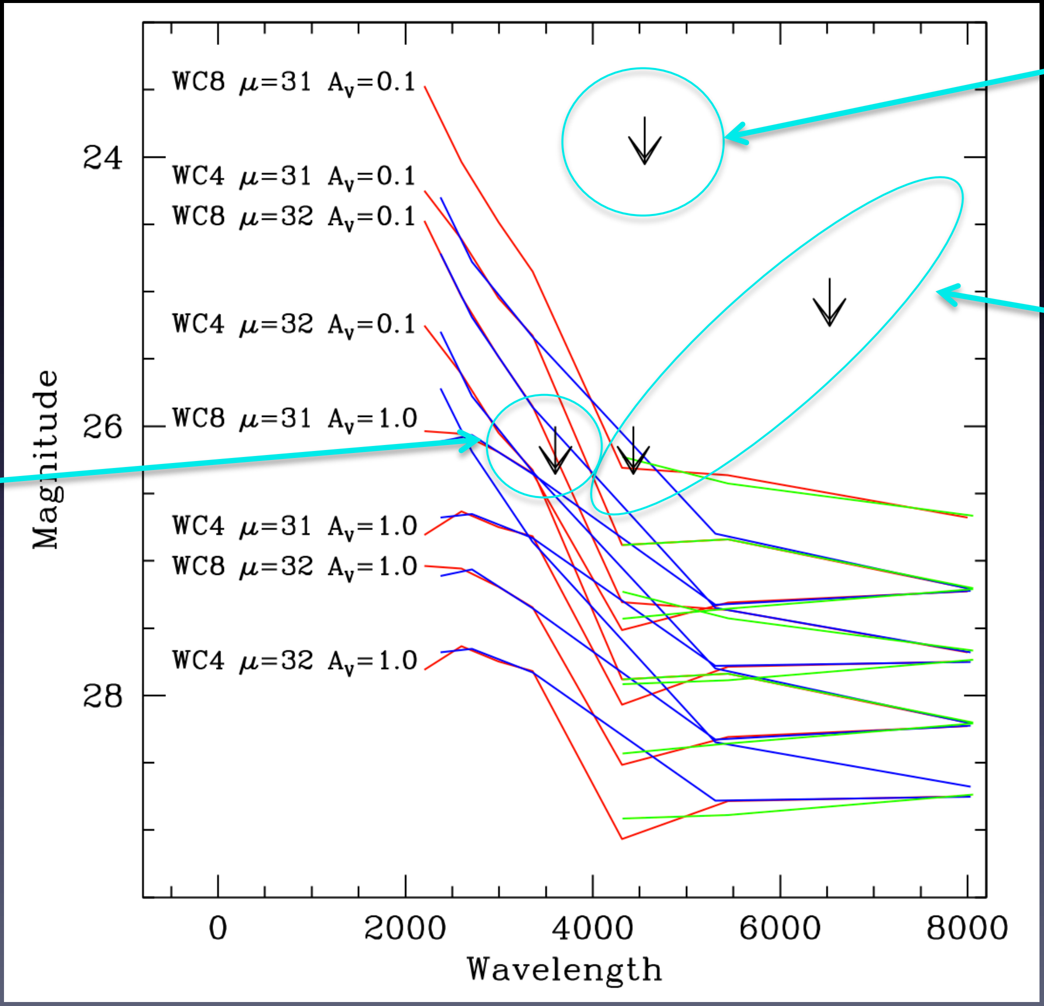


Subsections of NGC 2997 before (*left* - *HST*/WFPC2) and after (*right* - *HST*/ACS-HRC) the SN 2003jg explosion, in F814W. The position of the SN is indicated by a circle

NO PROGENITOR IDs !

SN Ic Progenitors

WC star detectability



SN 2007gr
(Crockett et al. 2008)

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

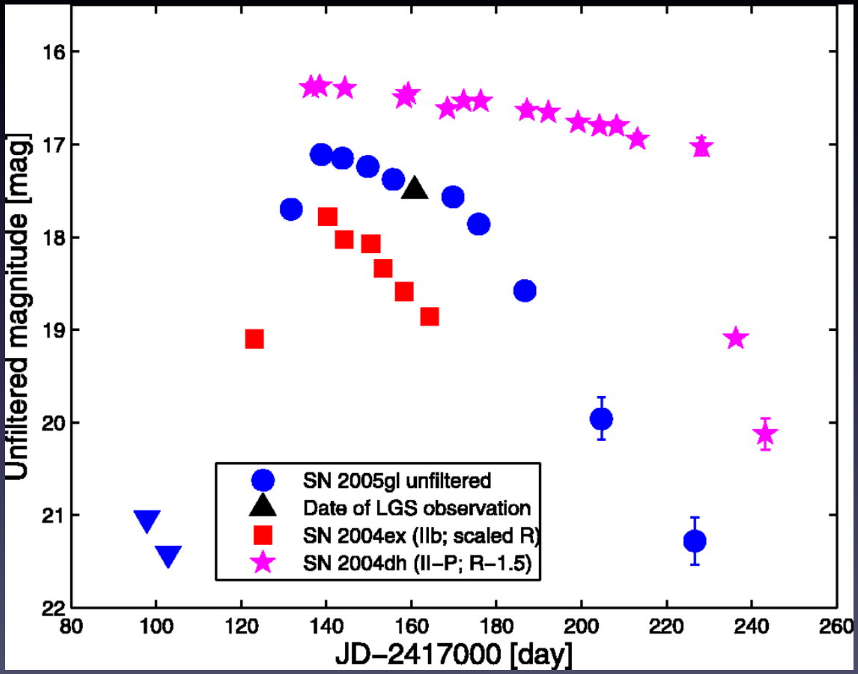
GO-12229
(PI :L. Smith)
WFC3 F336W
imaging of 10 local starburst galaxies

Sander et al. (2012)

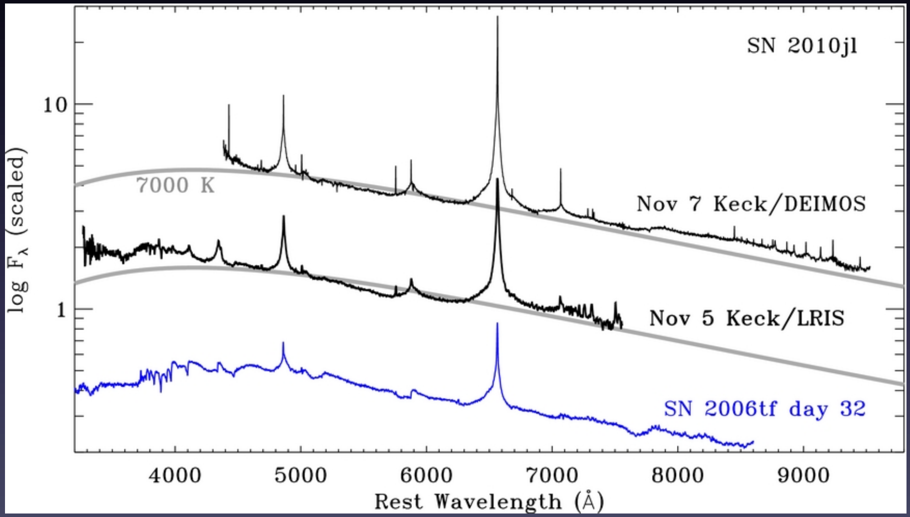
Red = WFPC2
Blue = WFC3
Green = ACS/WFC

SN IIn Progenitors

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

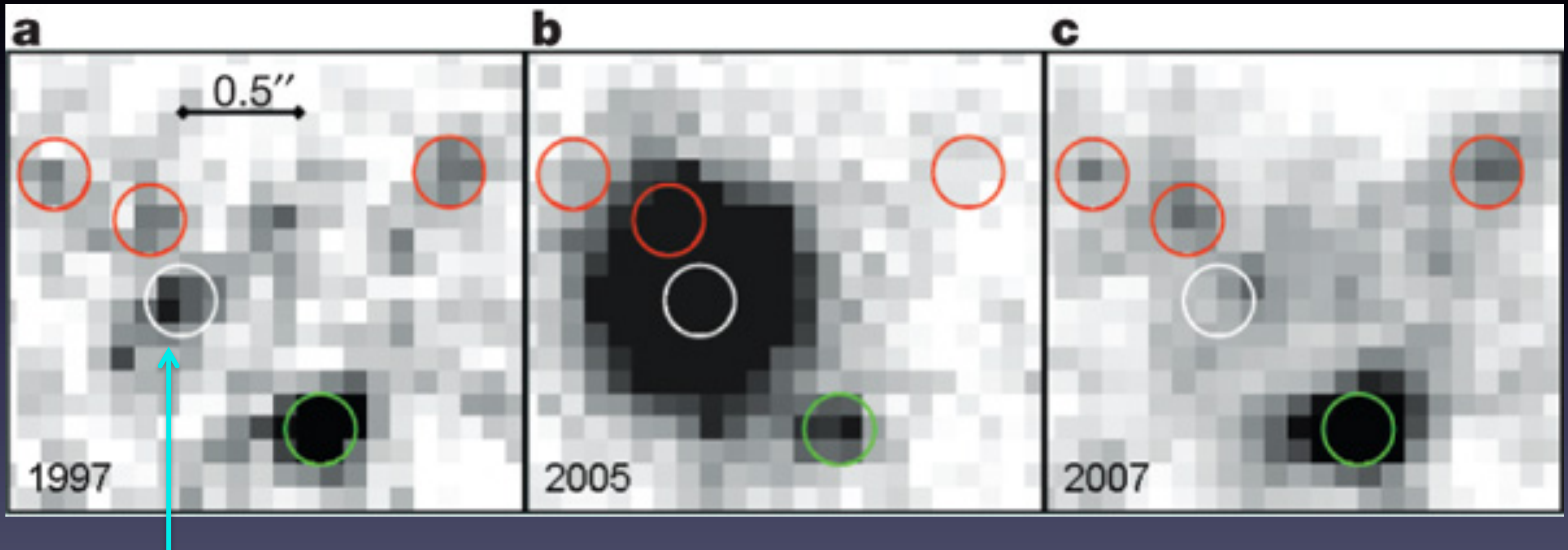


SN 2010jl in UGC 5189A (d = 50 Mpc)
(Smith et al. 2011)



SN IIn Progenitors

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



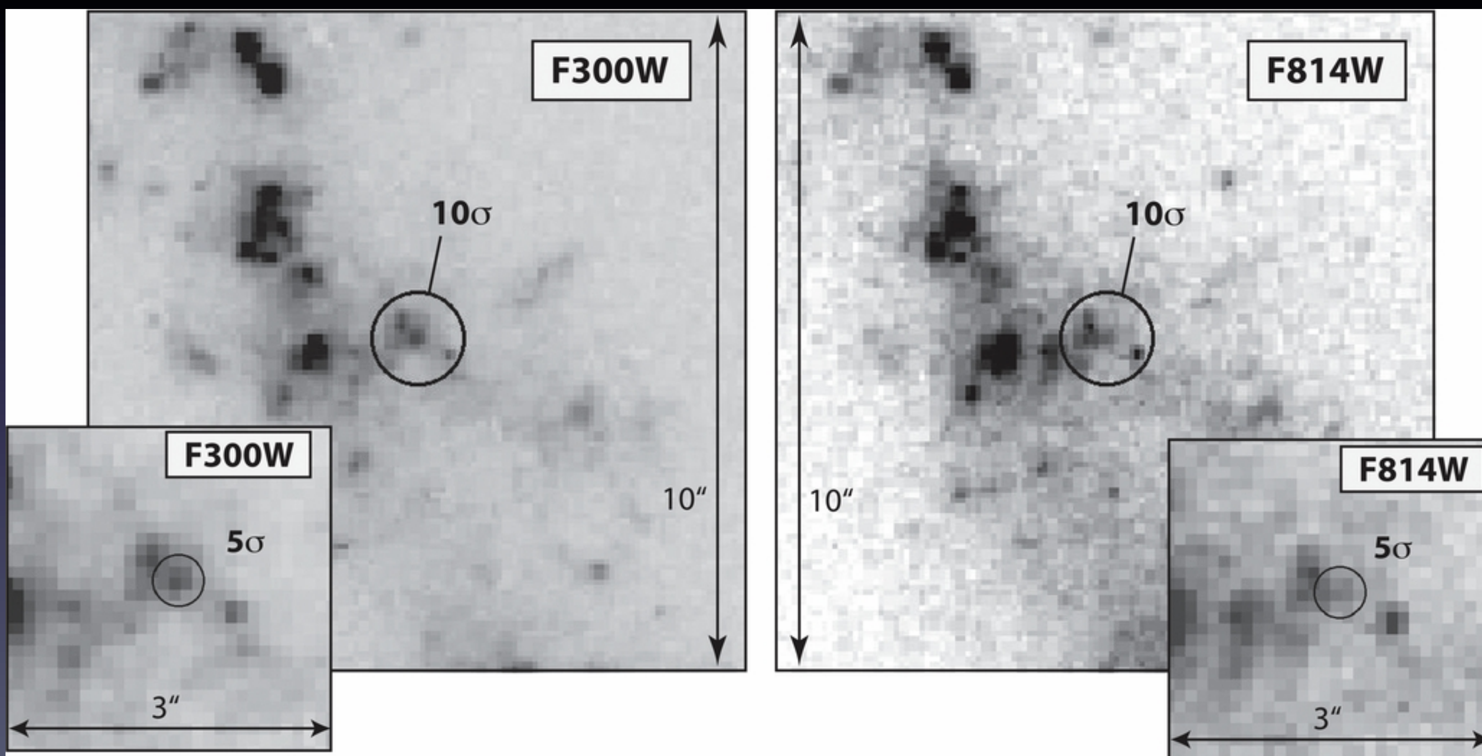
HST WFPC2 F547M
$M_V \approx$ -10.3 mag (!!)

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 ????