Observational constraints on SN progenitors

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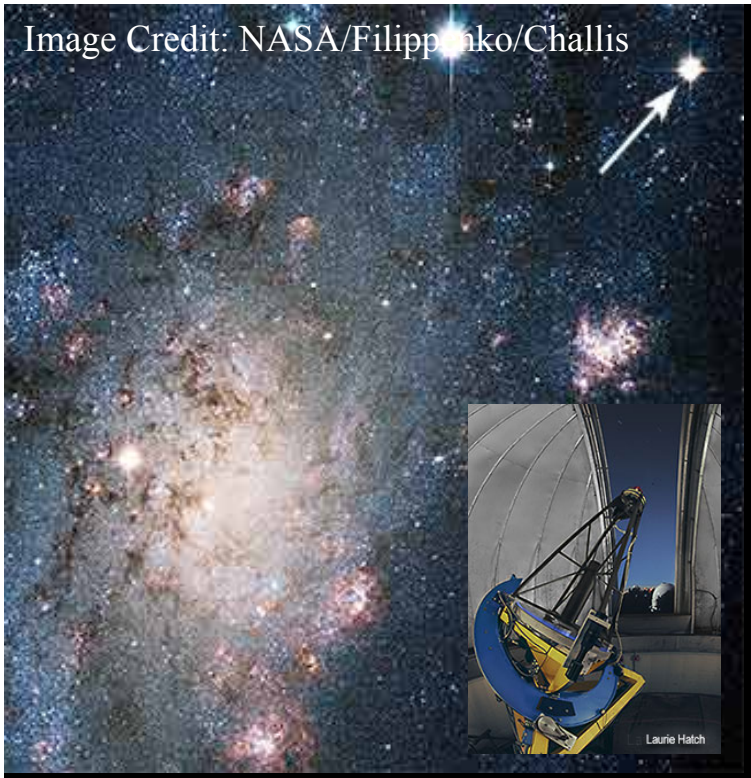
NGC7793 with VLT FORS

Afternoon talks :
N. Elias-Rosa,
S. Van Dyk

50 YEARS 1962–2012
ESO
European Southern Observatory



Until 2010 :

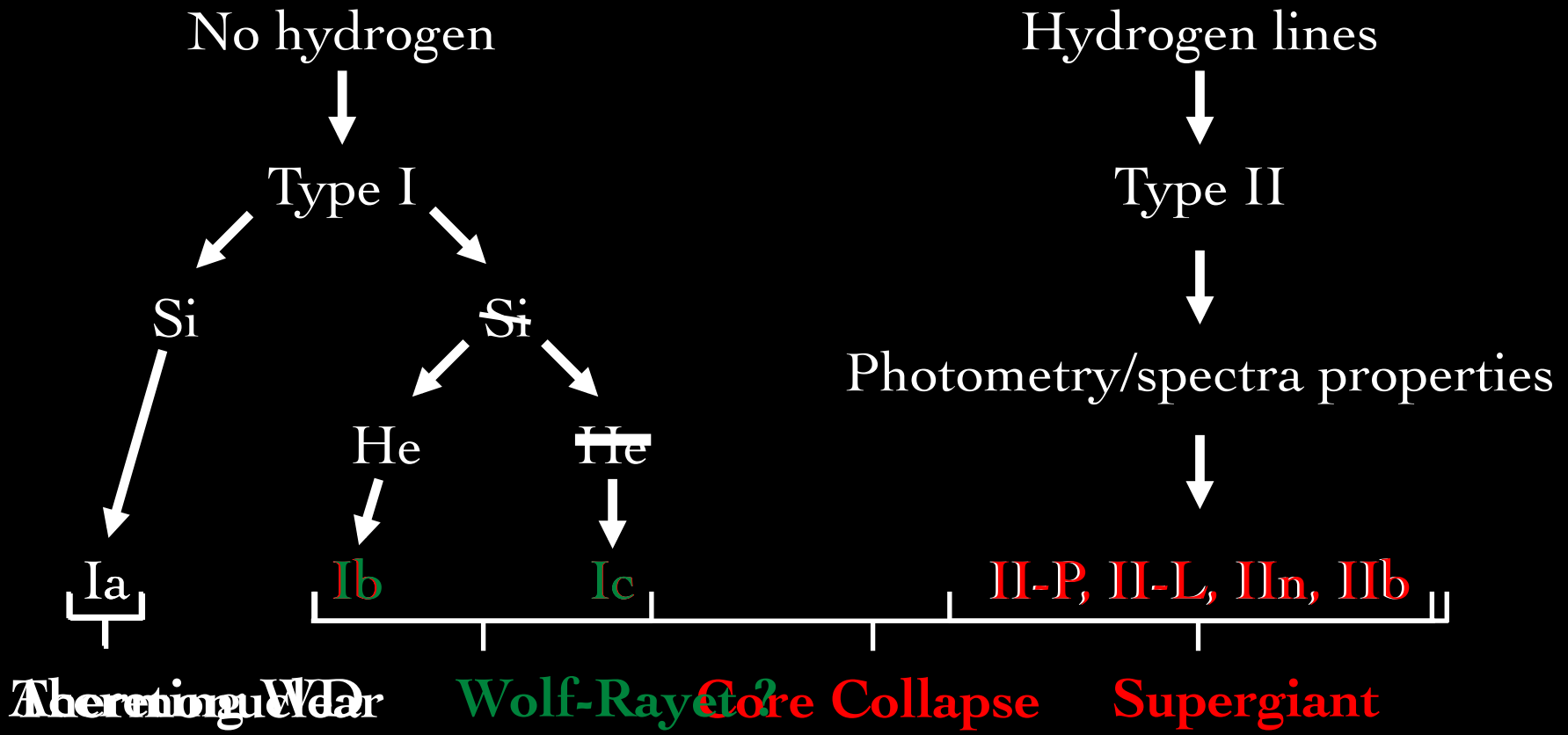
All Nearby SNe discovered by amateur astronomers , and two professional search teams:

North : LOSS (Filippenko & Li)

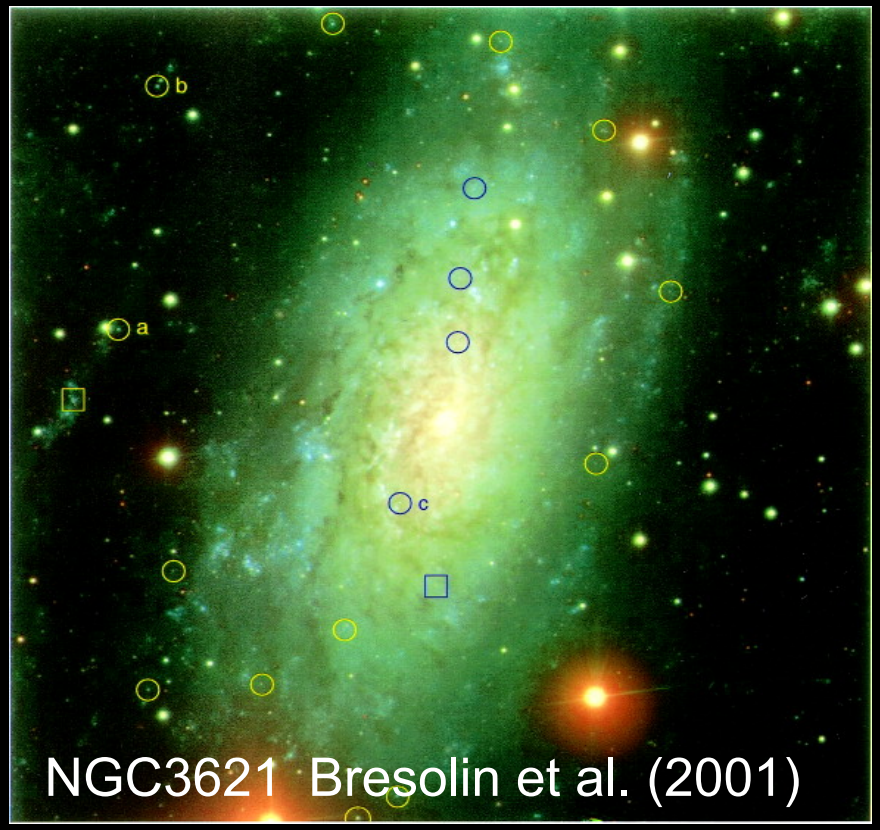
South : CHASE (Pignata et al.)

Supernova types

Supernovae are classified by their optical spectra



M101


b
a
c
NGC3621 Bresolin et al. (2001)

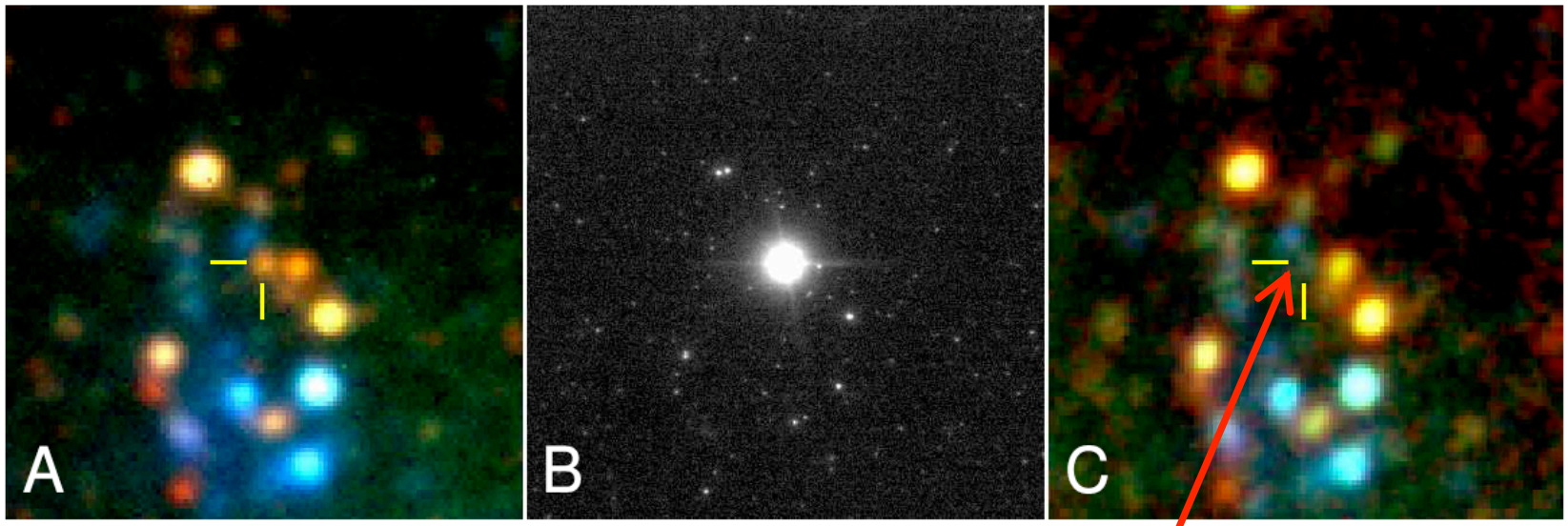
NGC3949

Barred Spiral Galaxy NGC 1672
Hubble Heritage
NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration • Hubble Space Telescope ACS • STScI-PRC07-15

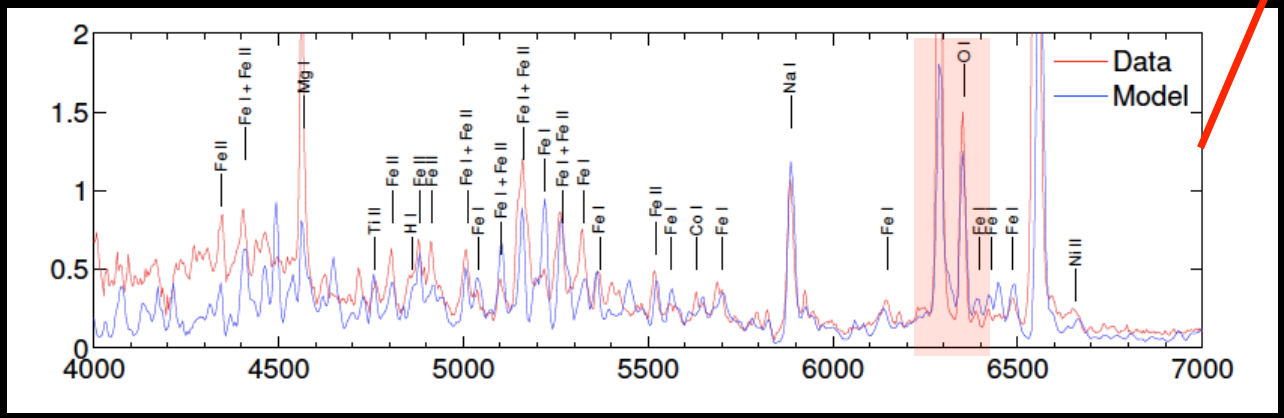
NGC1672

b

Core-collapse SN : progenitor to enrichment



VLT FORS+HAWKI VLT NACO NTT EFOSC2



VLT FORS

Mattila et al. 08, Maguire et al. 2012

Summary of progenitor search project

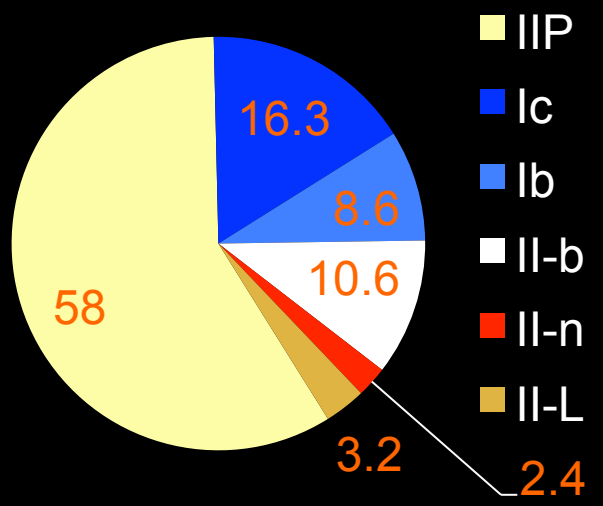
- **Since 1998 to present : for <u>ALL</u>** core-collapse SNe in galaxies $V_{vir} \leq 2000$ kms^{-1} , or $d < 27$ Mpc
- Search HST archive for any pre-discovery imaging
- Supplement with any deep, high-resolution ground-based imaging
- Progenitor search for all – high resolution imaging (Ground-based AO or HST) for astrometry to ~30-50 milliarcsec
- Volume and time limited survey

Detected SN rates in Local Volume

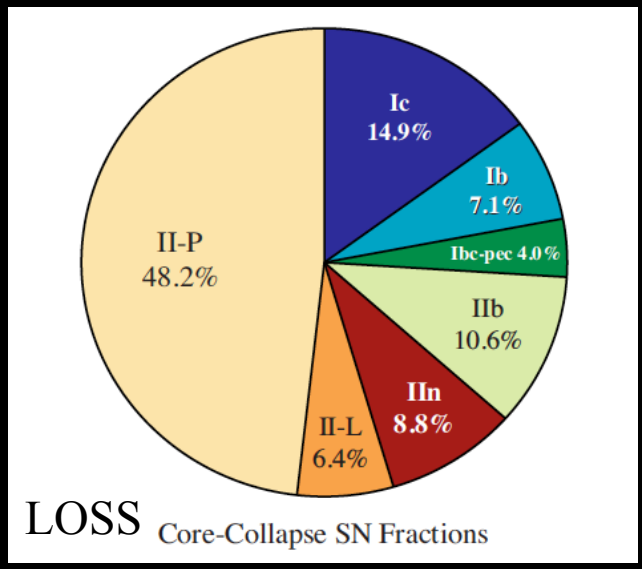
Smartt et al., 2009; Eldridge et al. 2012, in prep. (14.25yrs)

SN Type	Number	Relative rate (per cent)
IIP	55 (73.6)	58.0 ± 6.8
IIL	3 (4)	3.2 ± 1.6
IIn	3 (3)	2.4 ± 1.4
IIb	11 (13.4)	10.6 ± 2.9
IIpec (87A-like)	1 (1.3)	1.0 ± 0.9
Ib	9 (10.9)	8.6 ± 2.6
Ic	17 (20.7)	16.3 ± 3.6
Total	99 (126.9)	

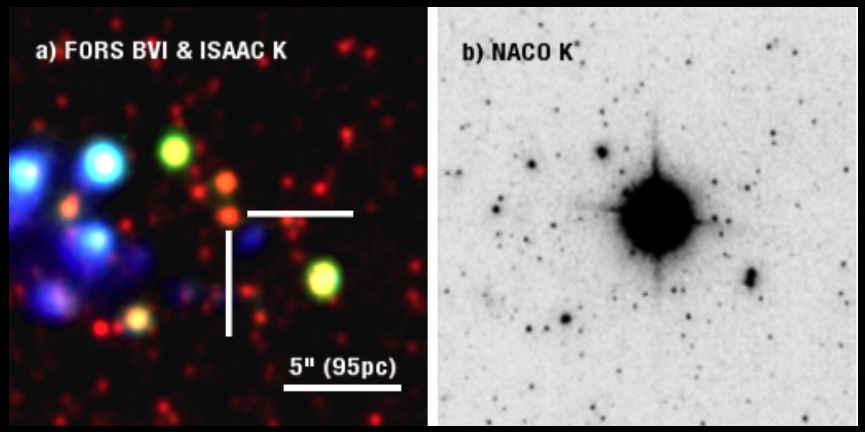
28Mpc rates

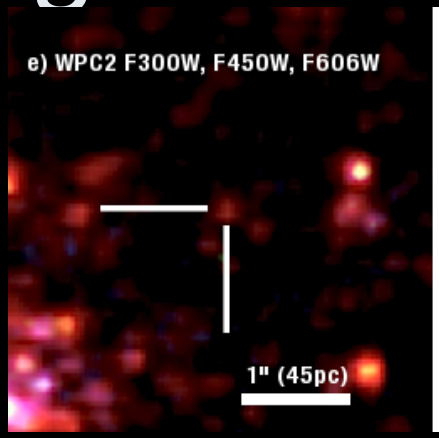


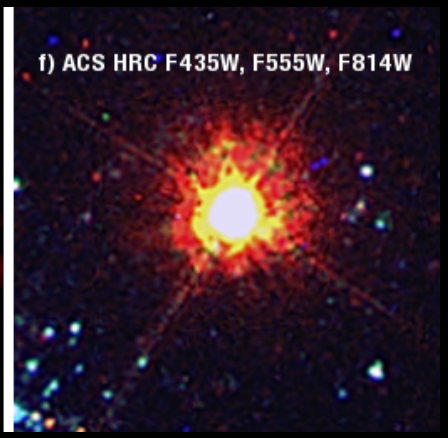
- 19980101-2012033121: 127 CCSNe discovered in galaxies with V_{vir}<2000 kms^{-1} (9 CCSNe yr^{-1})
- LOSS : controlled, within ~60Mpc. Leaman et al, Li et al., Smith et al. 11

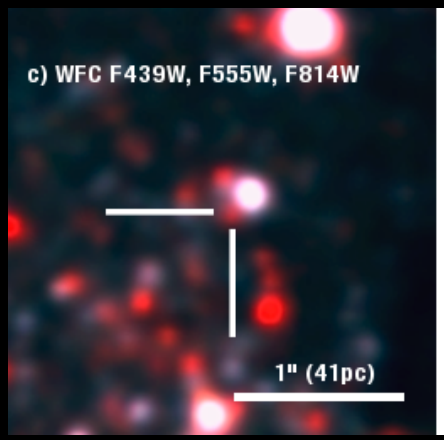


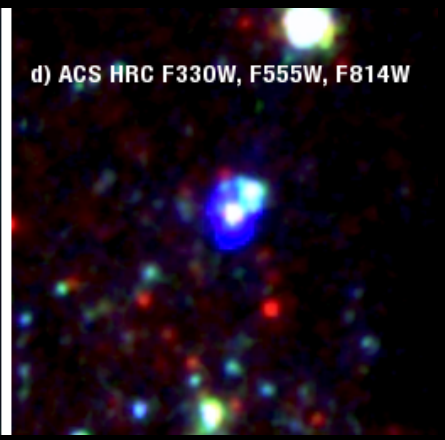
Detection of progenitors





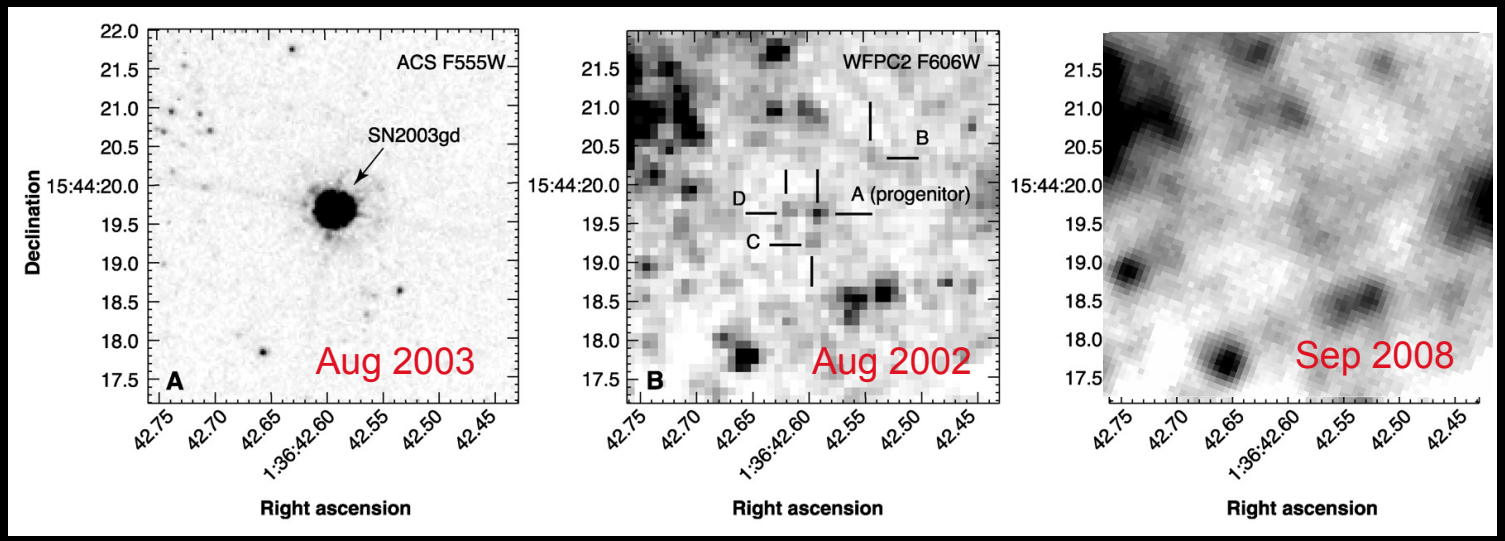






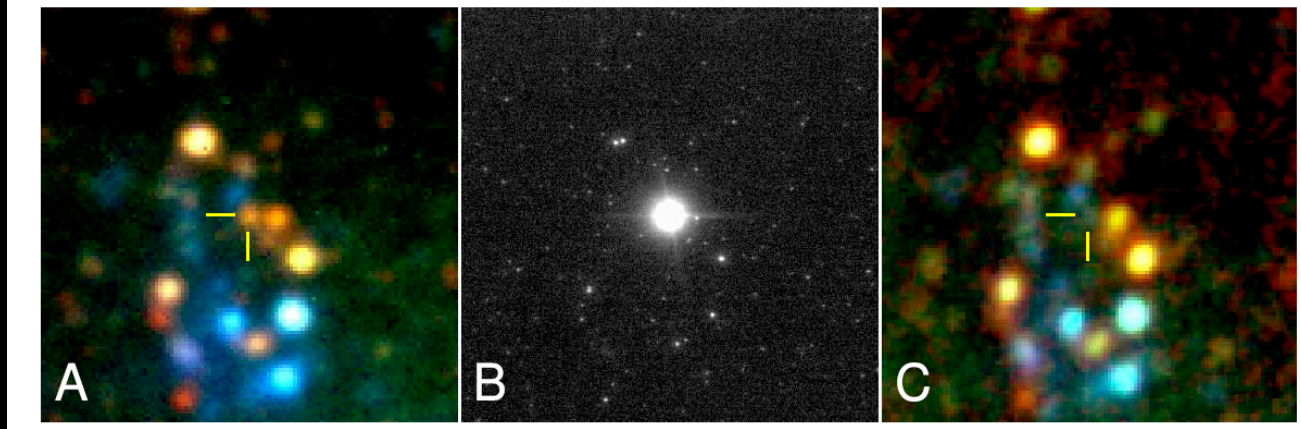
- SN2008bk, SN2005cs, SN2003gd
- Red star identified coincident with all three.
- Typical magnitudes : M_v ~ -4.5 ; M_I ~ -6.5
- Review in Smartt 2009
  - Van Dyk et al. 2003, 2010, Li et al. 2006
  - Smartt et al. 2004, 2009, Maund et al. 2005, Mattila et al. 2008

Progenitor disappearance



SN2003gd:
V=25.8 ± 0.15
V–I=2.5 ± 0.2
Smartt et al. 04,
Van Dyk et al. 03

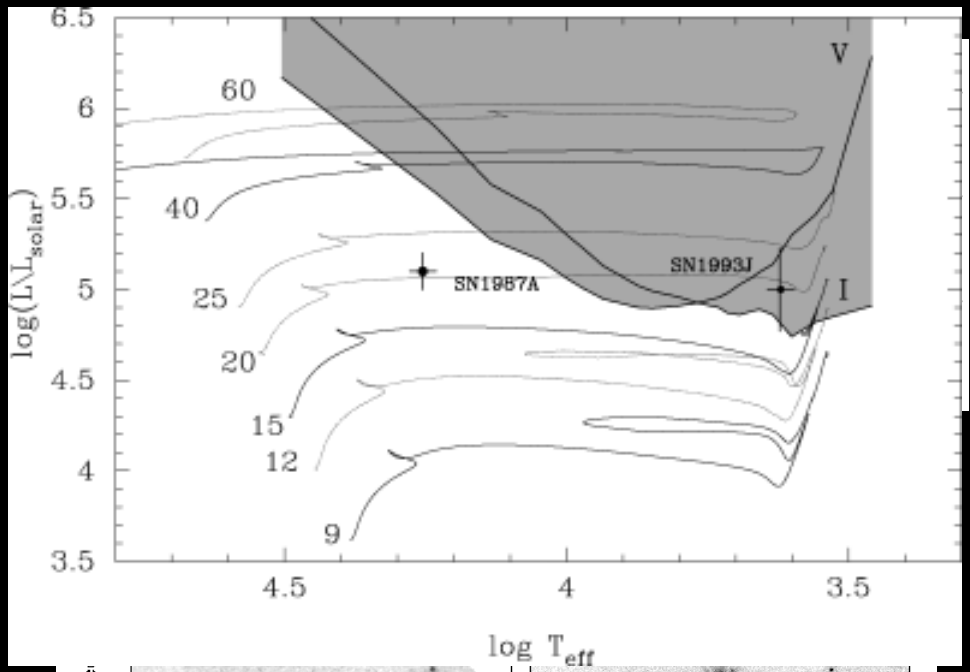
Disappearance
Maund &
Smartt 09

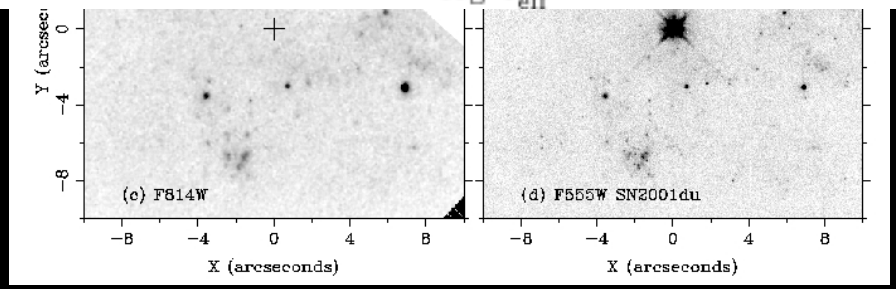


SN2008bk
Mattila et al. 08
Mattila, Maund,
Smartt et al. in prep

Five confirmed cases of disappearance : SN1987A , SN1993J, SN2003gd, 2008bk, SN2005gl (Gal-Yam & Leonard 2009)

Other examples: no detection



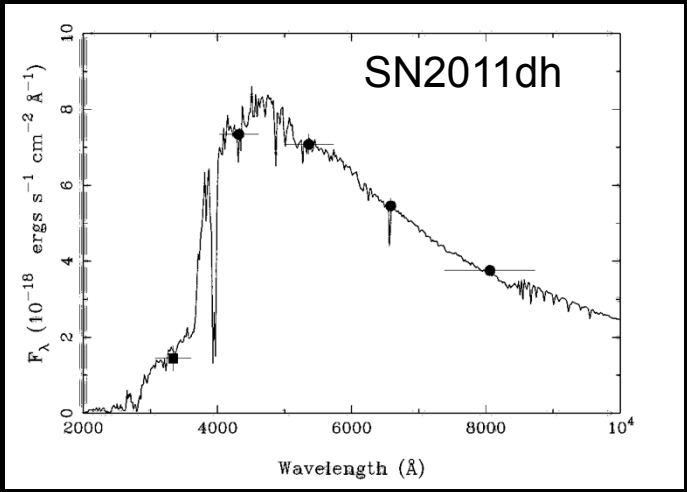


- **SN1999gi** in NGC3184,
- HST *U+V* pre-explosion
- D=11Mpc (Leonard et al. 2002)
- M ≤ 12 $M_\odot$

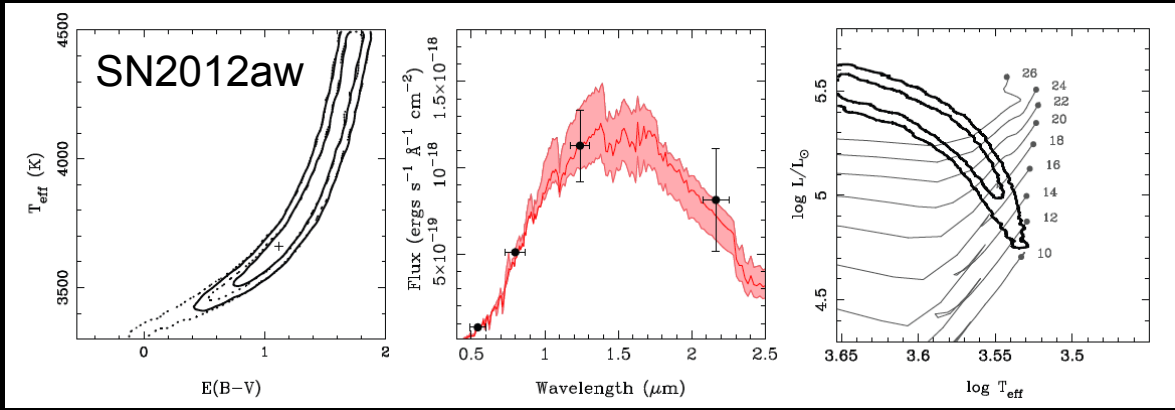
- **SN2001du** in NGC1365
- HST *UVI* pre-explosion
- D=17Mpc (Cepheid Key P.)
- M ≤ 15 $M_\odot$

Smartt et al. 02, Van Dyk et al 02

Photometry and stellar SED



Maund et al. 11 ; Van Dyk et al. 11



Fraser et al. 12 ; Van Dyk et al. 12 ; Kochanek et al. 12

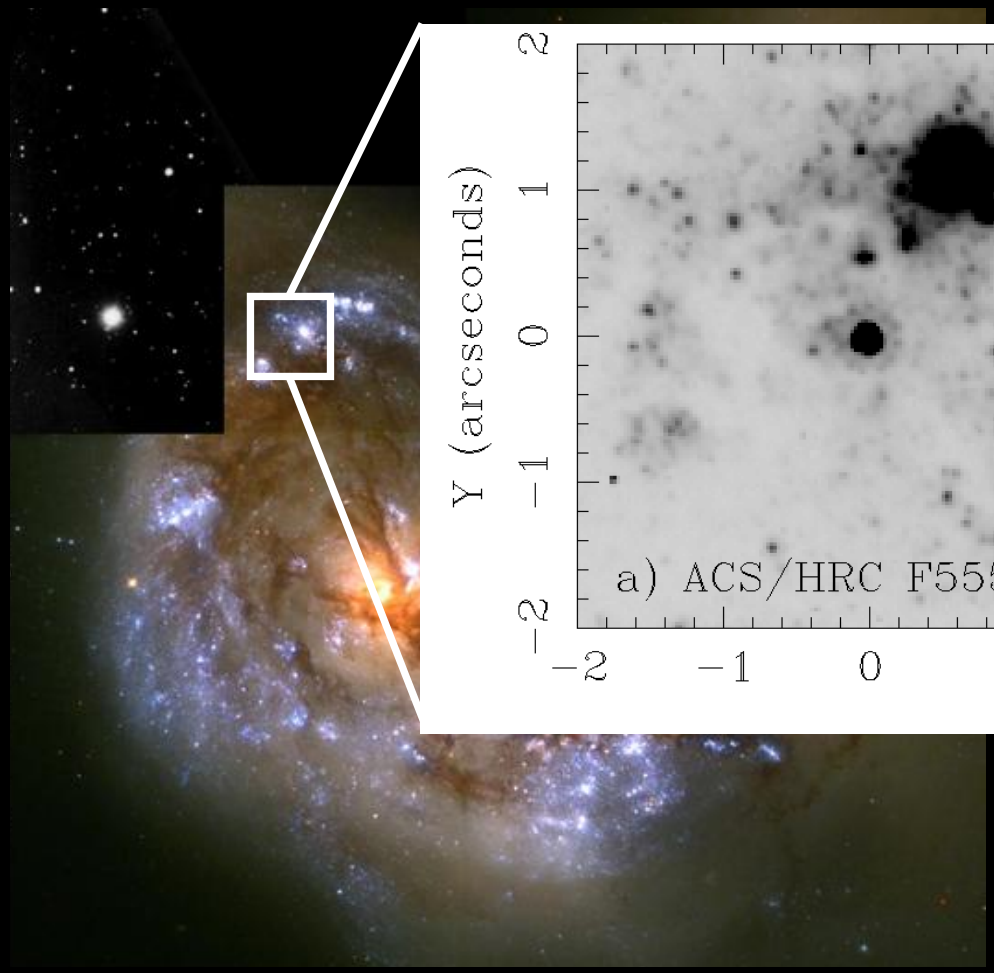
Single stellar SED
T_{eff}= 6000 K ; F8 supergiant ;
M_V = *-7.5*

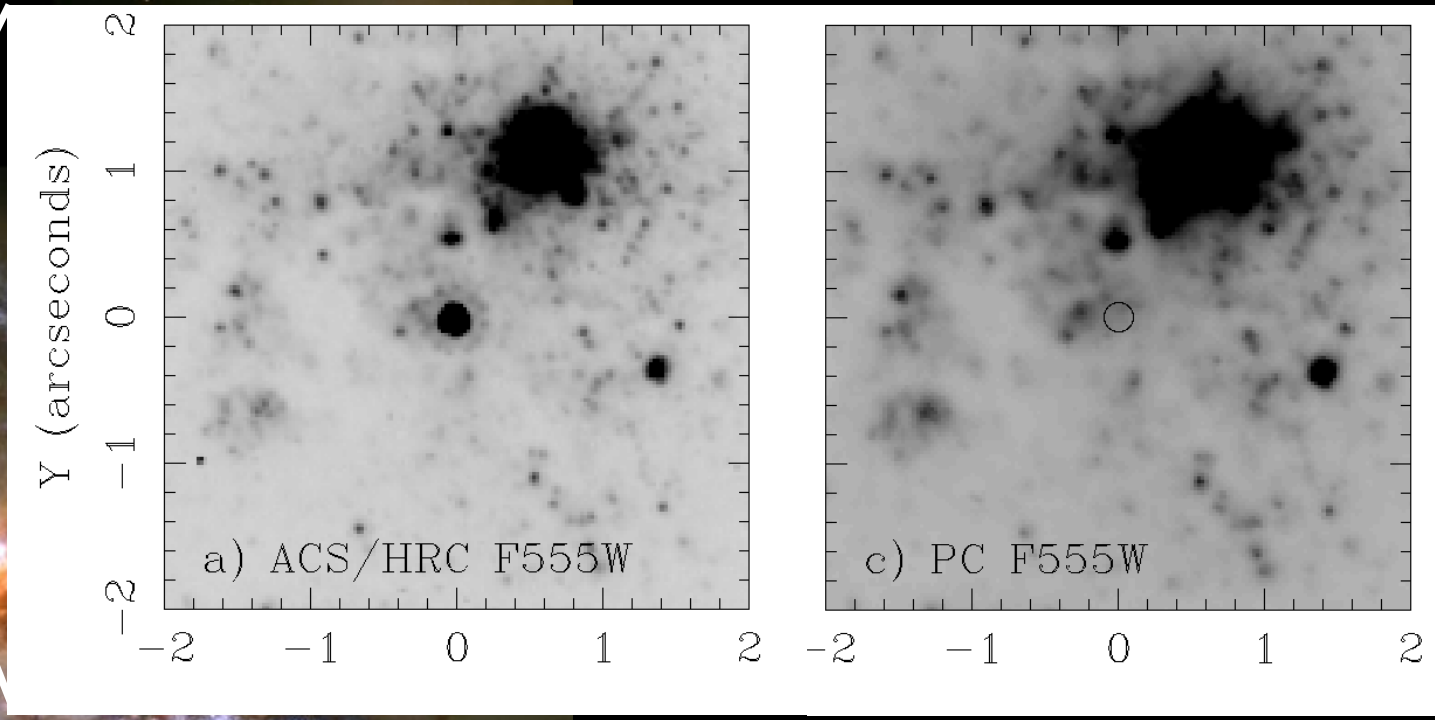
What is the extinction ?
Kochanek et al : R≠ 3.1 , silicate dust
Log L < 5.0 dex

Dust extinction is largest uncertainty – CSM dominated ?
Walmswell & Eldridge (2011) : underestimate $A_{V,I}$
Kochanek et al. (2012) : overestimate $A_{V,I}$

See also Elias-Rosa et al. 10, 11

Constraints on Type SNe Ib/Ic

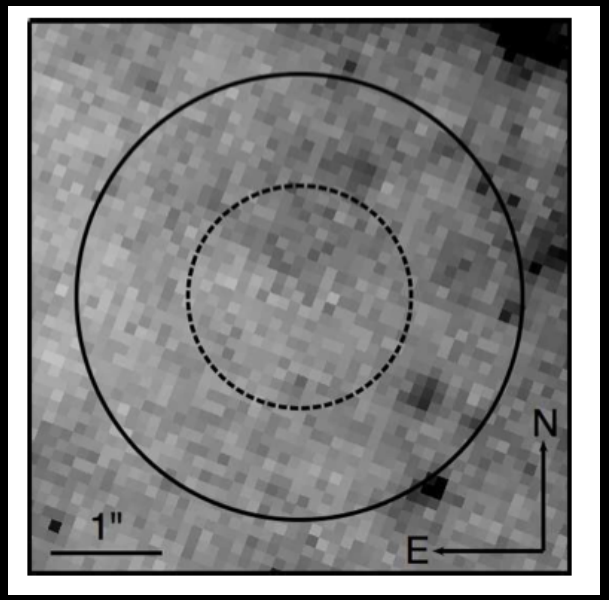




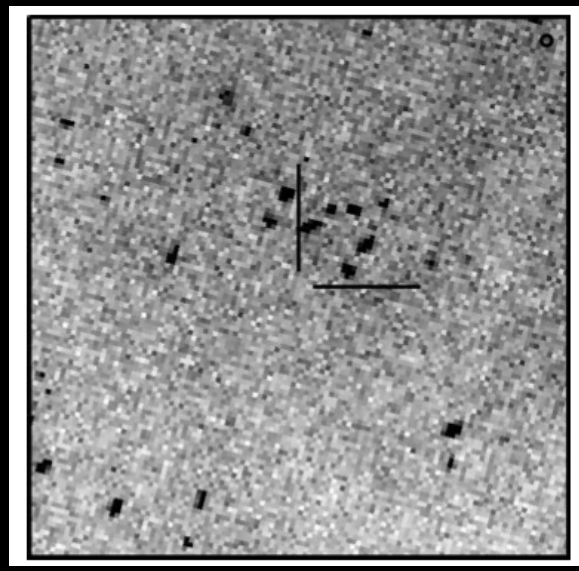
- Example: SN2004gt - type Ic
- Ic SNe : Related to long Gamma-ray burst

Maund et al. 2004, Gal-Yam et al. 2005

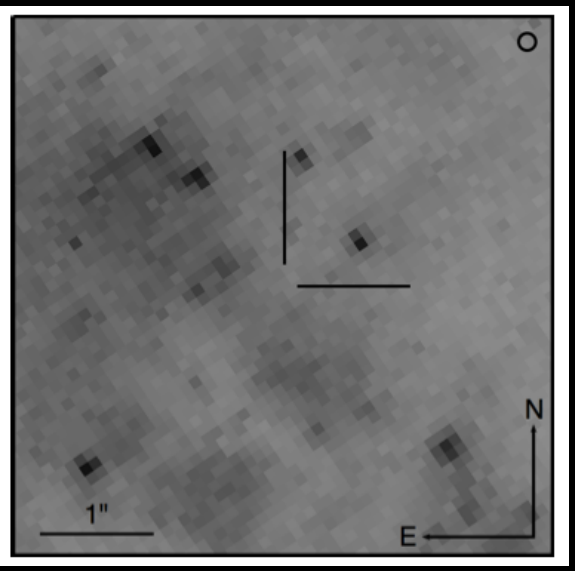
Constraints on Type SNe Ib/Ic



SN2004gn



SN2010br



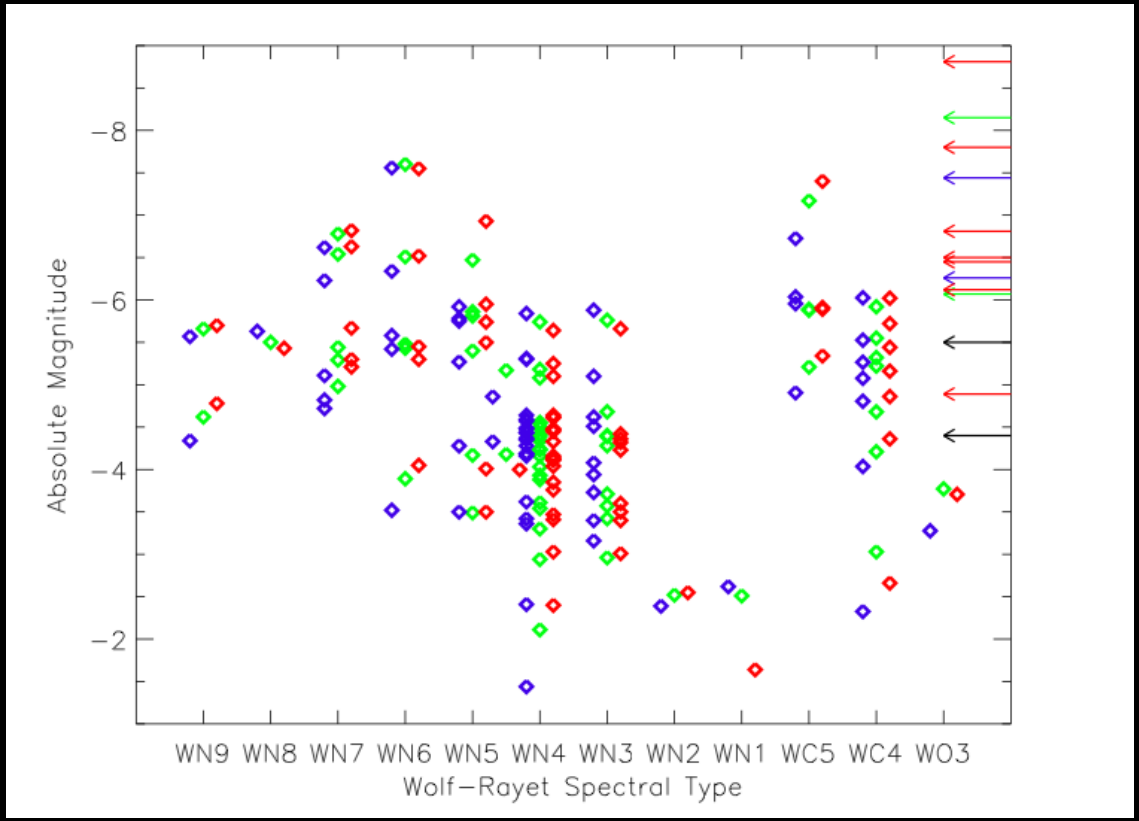
SN2011hp

- 1999.5 – 2012.5
- Volume limited (all SNe in galaxies with V_{vir}<2000 kms^{-1})
- No detections
- Is this significant ?

Wolf Rayet stars : not Ibc progenitors?

LMC WR stars from Massey (2002), converted to HST filters :

Blue : F450W
Green : F555W
Red: F606W



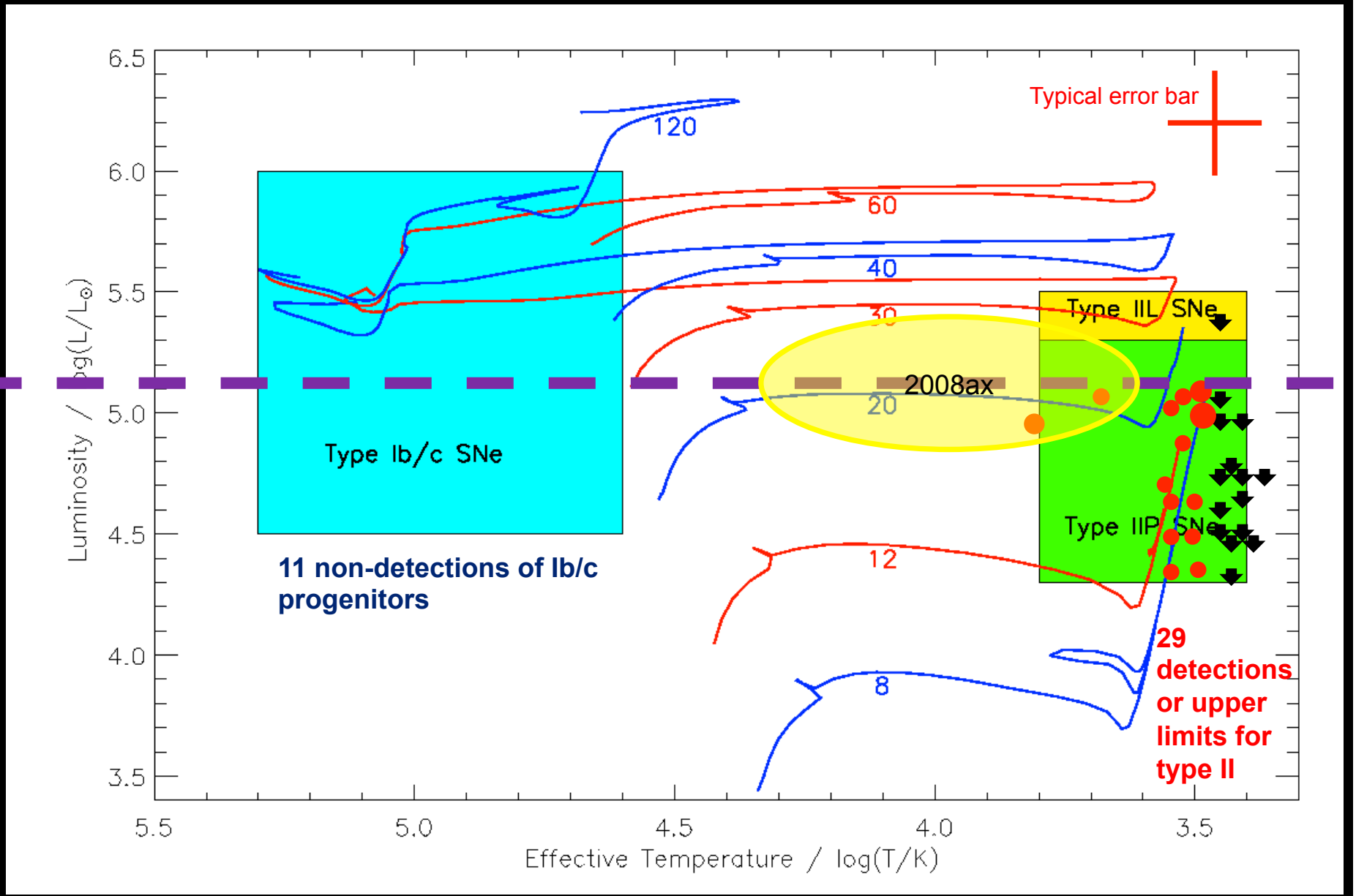
Eldridge et al. (2012 in prep).

Crockett 2009 (PhD Thesis),

See also
Van Dyk et al. 03
Maund & Smartt 05,
Maund et al. 05
Gal-Yam et al. 05

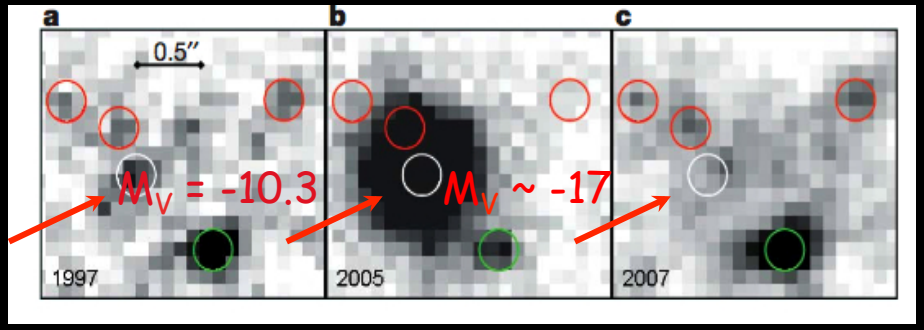
- LMC (or M31) WR magnitude distributions ⇒ ~5-10% probability we have had no detections by chance.

Results 1998 – 2012.5 ; within 28 Mpc (41 total)

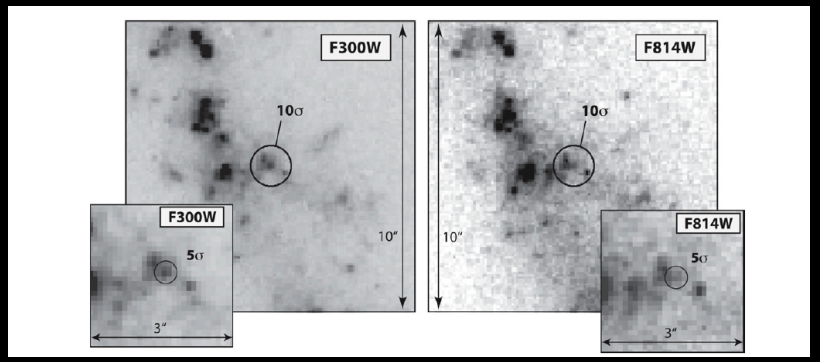


For Salpeter IMF : 75% of 8-100$M_\odot$ stars are 8-20$M_\odot$ (13 “missing”)

What of the LBV-like progenitors ?



- SN 2005gl (~66Mpc) Progenitor gone
- Gal-Yam & Leonard 09



- SN2010jl (~50Mpc) - either massive young cluster, or LBV
- Suggests M_{ZAMS} > 30M
- Smith et al. 2011

But both *d* >50Mpc , can they be common enough to account for the “missing” high mass progenitors ?

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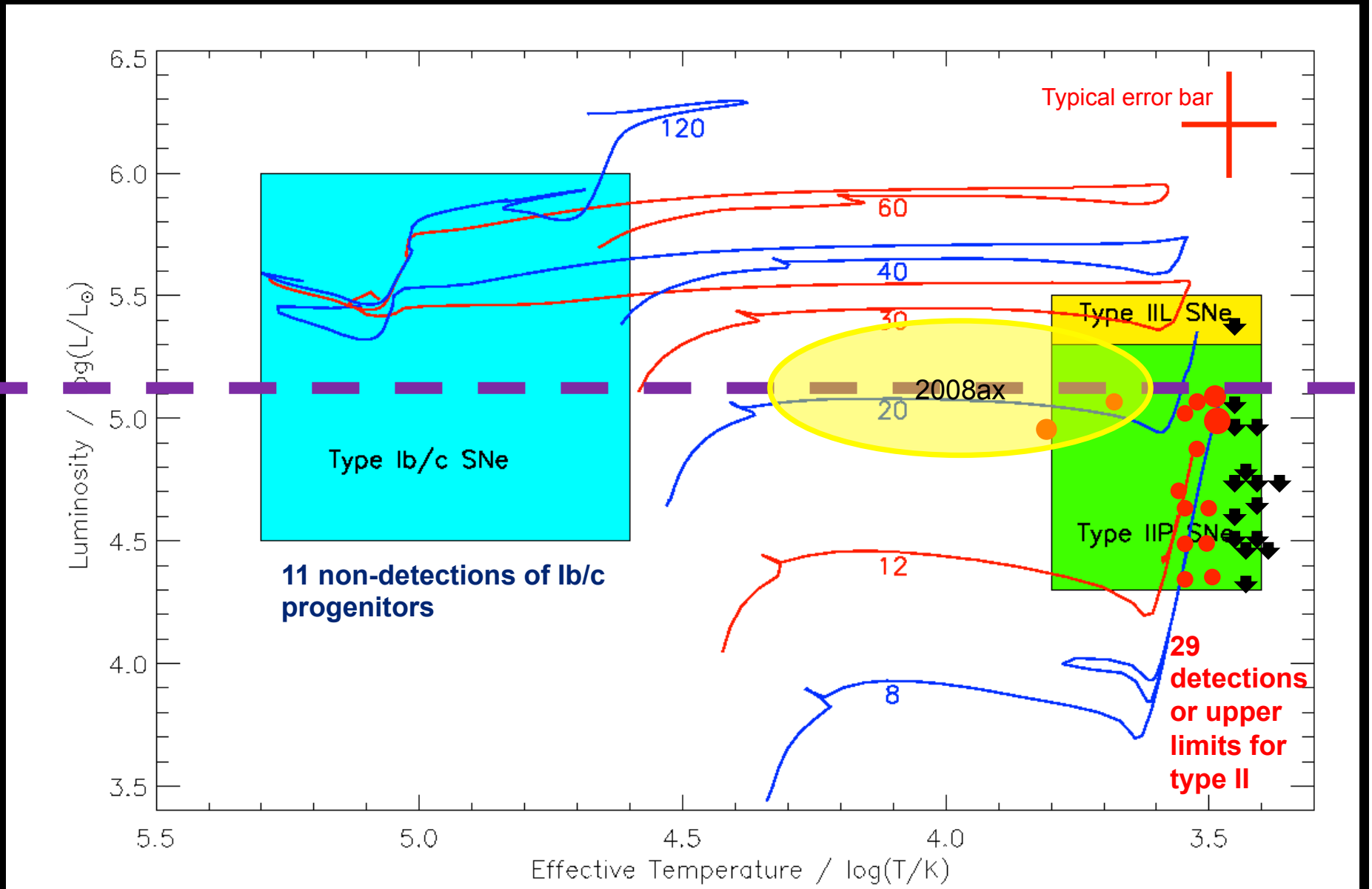

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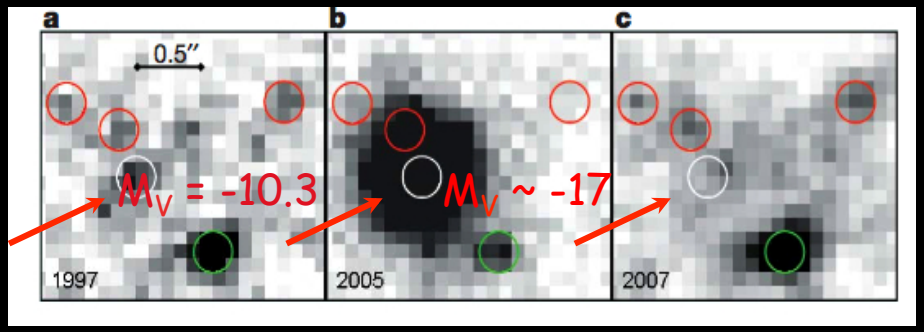

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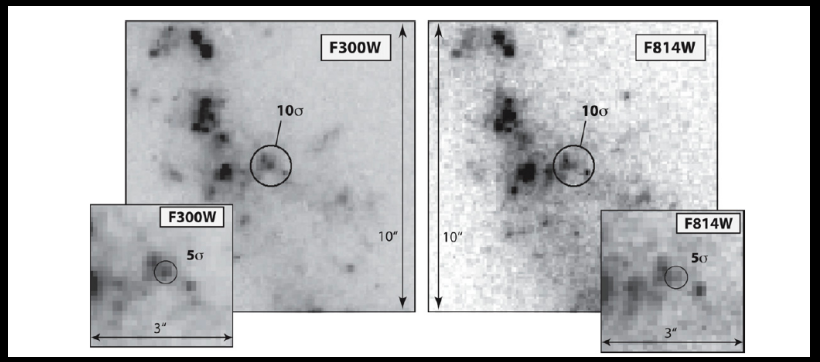

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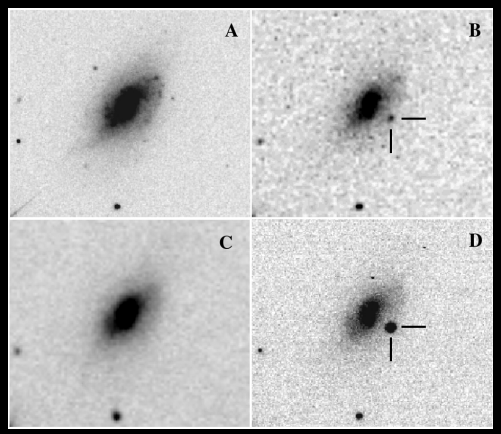
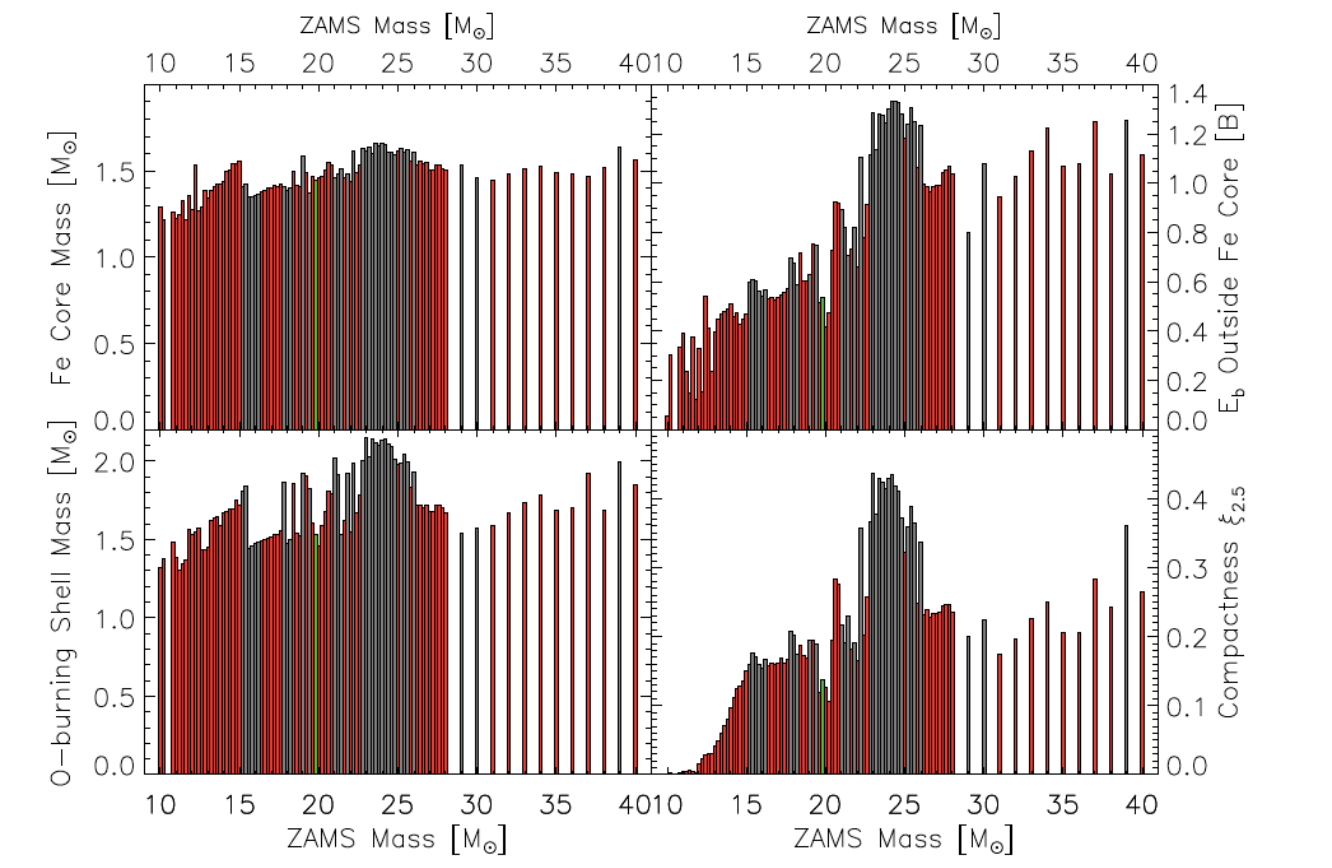


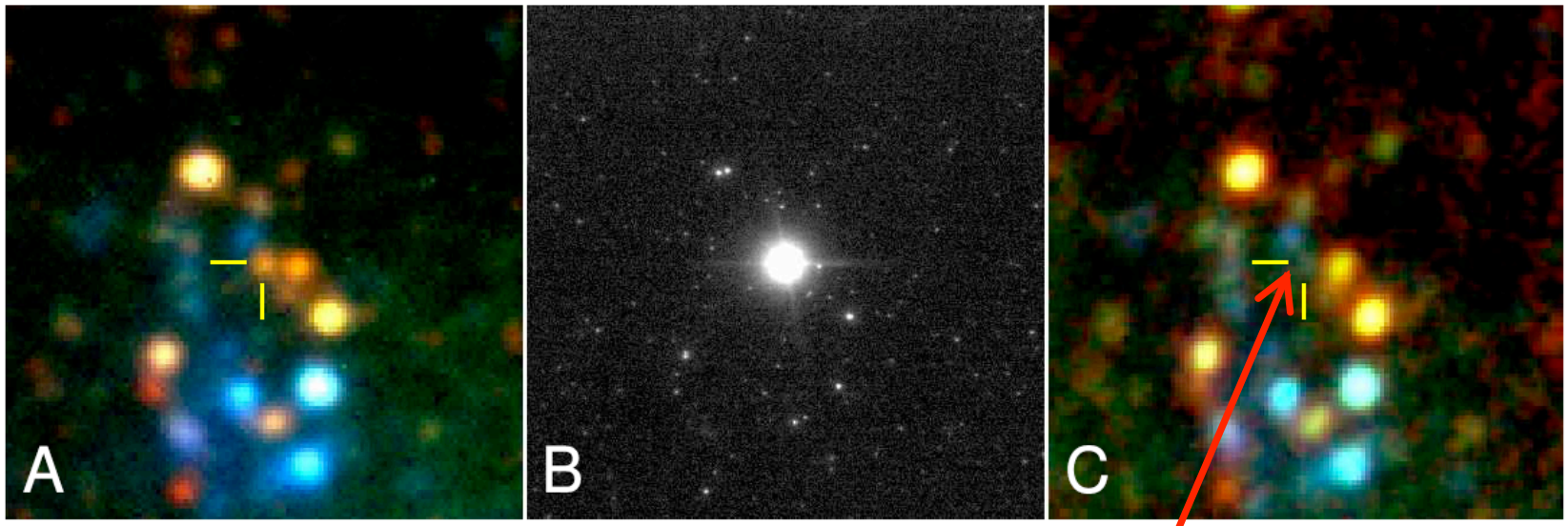
- SN2006jc : LBV-like outburst detected (Pastorello et al. 07 Foley et al. 07)
- SN2009ip : see Nathan's talk

Black hole formation

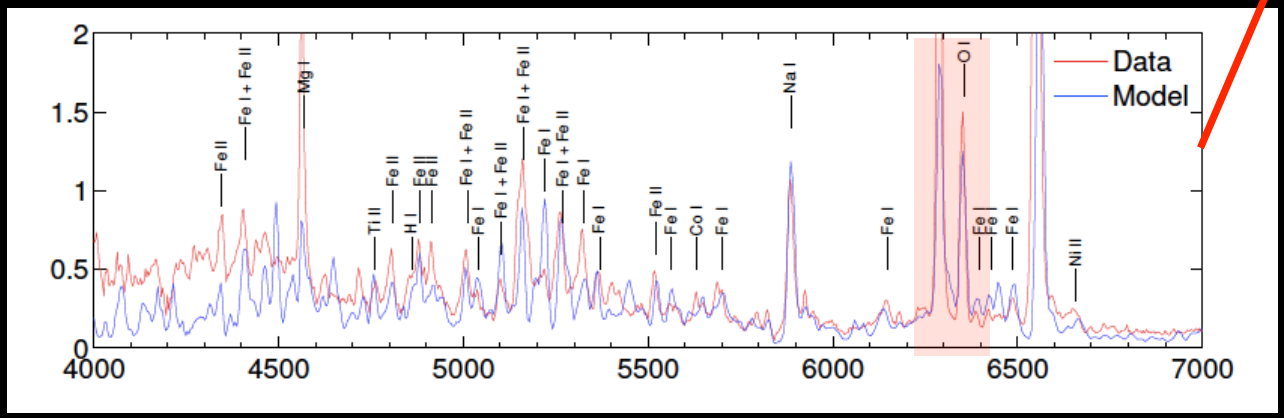


- Ugliano, Janka et al. 2012, arXiv**1205.3657**
- Neutrino driven explosions – no simple mass dependency

Core-collapse SN : progenitor to enrichment



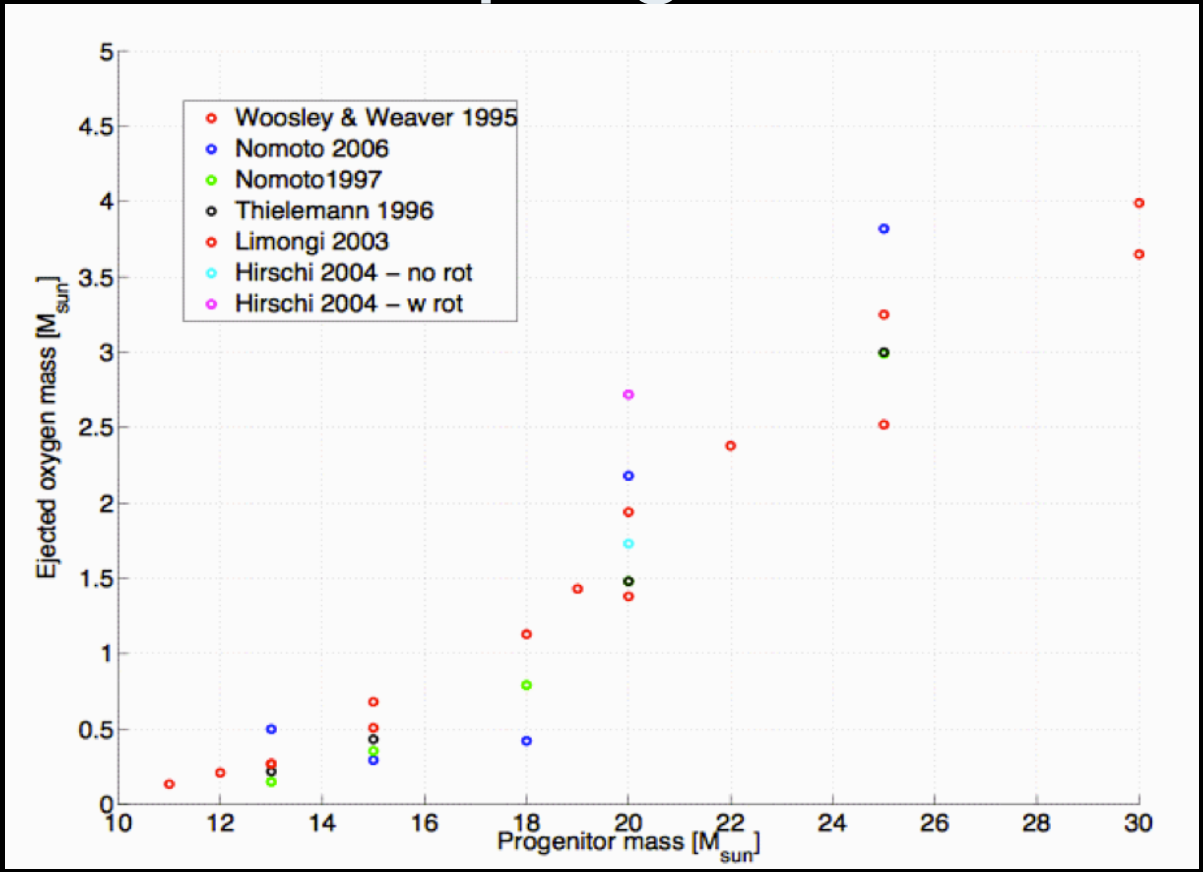
VLT FORS+HAWKI VLT NACO NTT EFOSC2



VLT FORS

Mattila et al. 08, Maguire et al. 2012

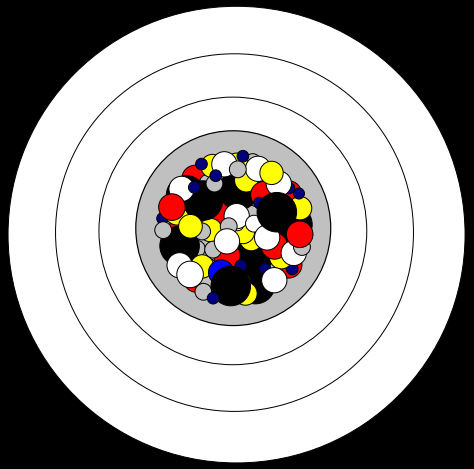
Nucleosynthesis : oxygen mass as function of progenitor mass

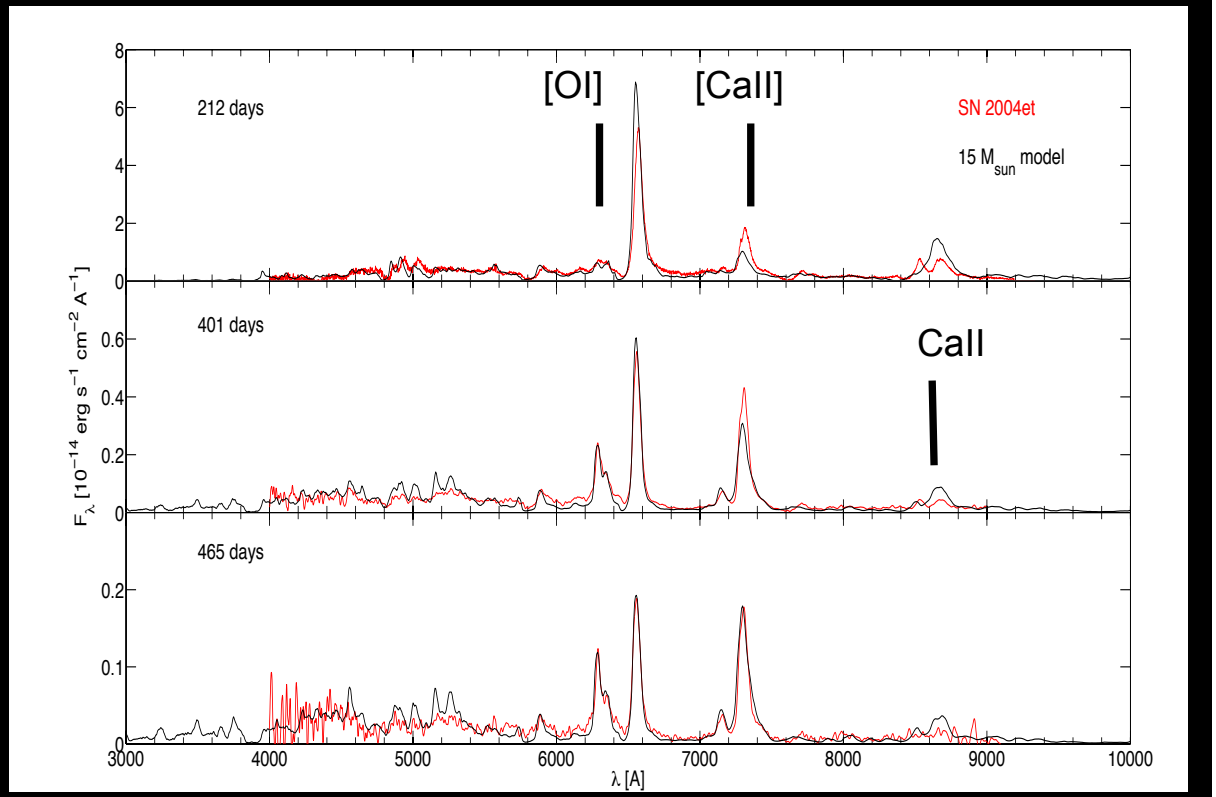


Data : stellar evolutionary calculations
Image credit : Anders Jerkstrand

Stockholm : Radiative transfer model

- Radioactivity
- Temperature, ionization and excitation solutions
- Radiative transfer
- Macroscopic mixing



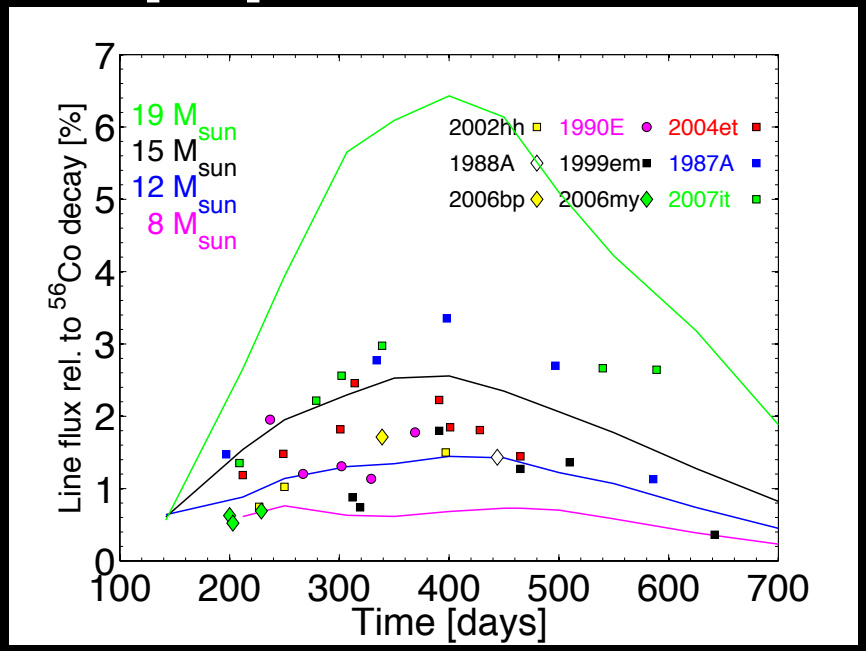


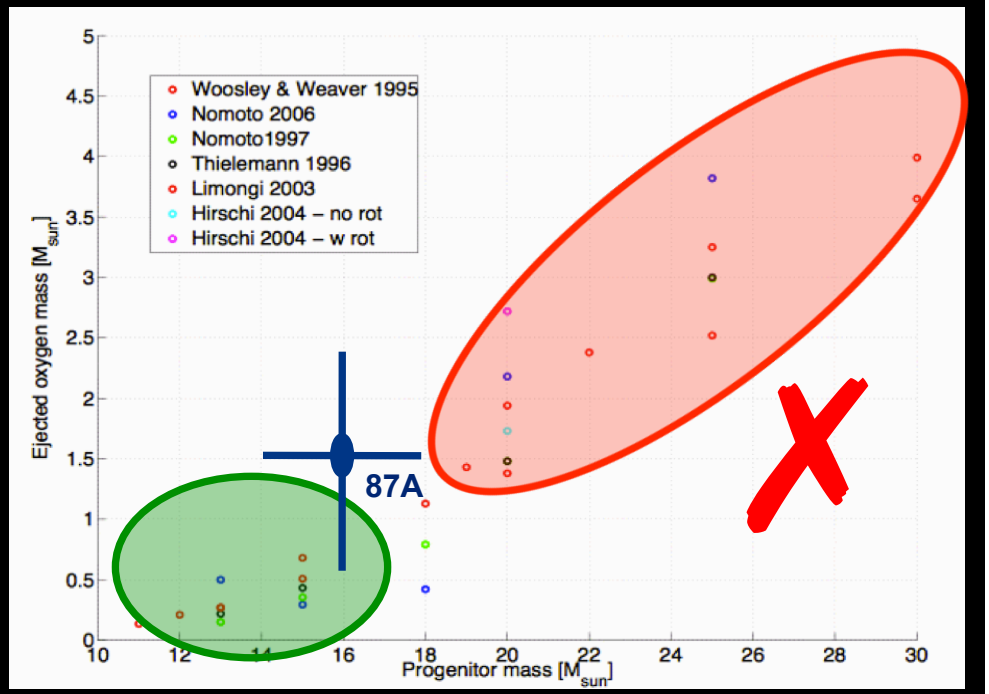
SN 2004et compared to a 15 M_{sun} model (~0.5M_{sun} oxygen)

Kozma & Fransson 1998
Jerkstrand et al. 2012 ; 2010

Type IIP line luminosities in nebular phase

[O I] 6300, 6364 Å





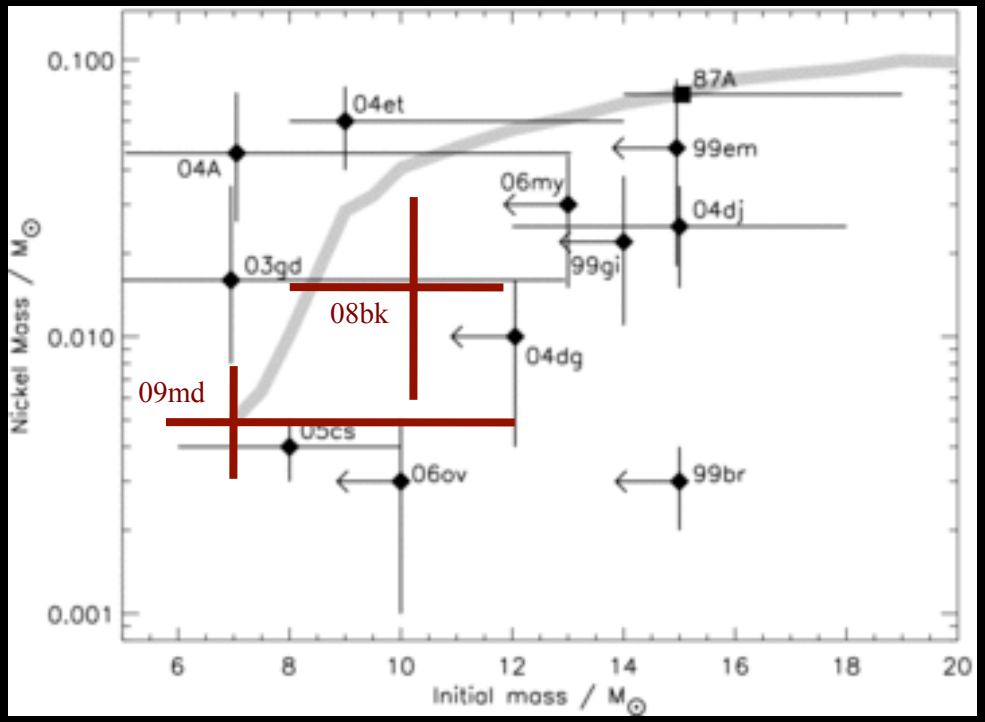
Jerkstrand et al. in prep
Maguire et al. 2012

We haven't detected the cosmic oxygen producers

^{56}Ni mass *vs.* ejecta mass

- Lower mass progenitors produce lower amounts of ^{56}Ni
- Grey line – relative mass of O-core/ He-core
- Perhaps due to steep density gradient in inner regions ?

- The low luminosity, low KE, II-P SNe come from low mass progenitors
- E-capture explosions ?



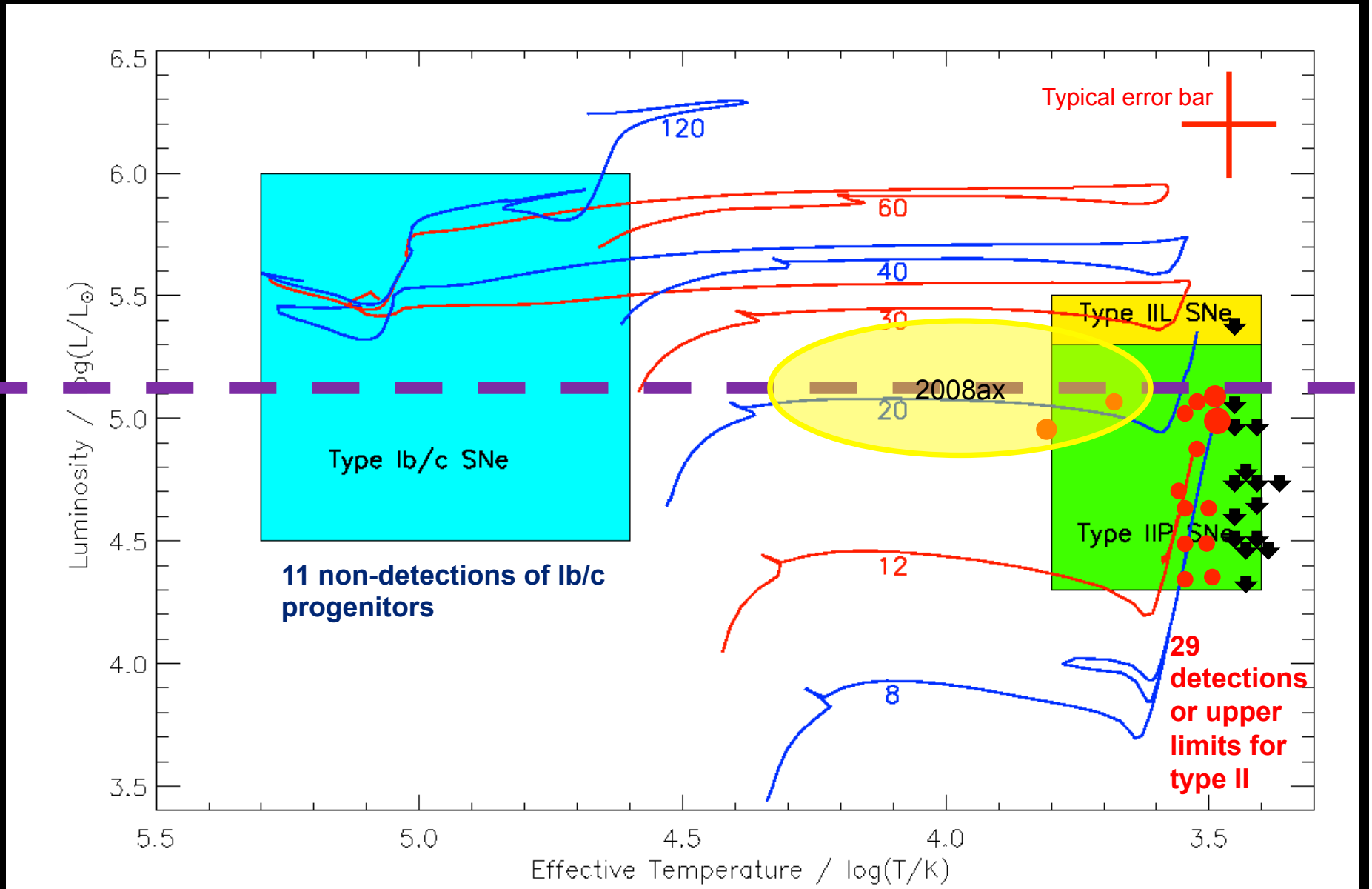
Smartt et al. 2009

Faint IIP: Pastorello et al. 09, 06
Kitaura et al. 04, Wanajo et al. 09

Summary

- Direct detections of progenitors – now routine
- Attempting to be complete witin fixed volume, as far as data allows (14 yrs+)
- Statistical dearth of progenitors above luminosity Log $L/L_{\odot}$ ~ 5.1 dex
- No SN with ejected oxygen mass > $1M_{\odot}$
- Implication : most, but not all, stars $M_{zams}>20M_{\odot}$ make black holes and no (or faint) SNe
- Future :
  - progenitor model consistent with pre-discovery log($L/L_{\odot}$) and ejected O mass
  - Find the cosmic oxygen producers

Results 1998 – 2012.5 ; within 28 Mpc (41 total)



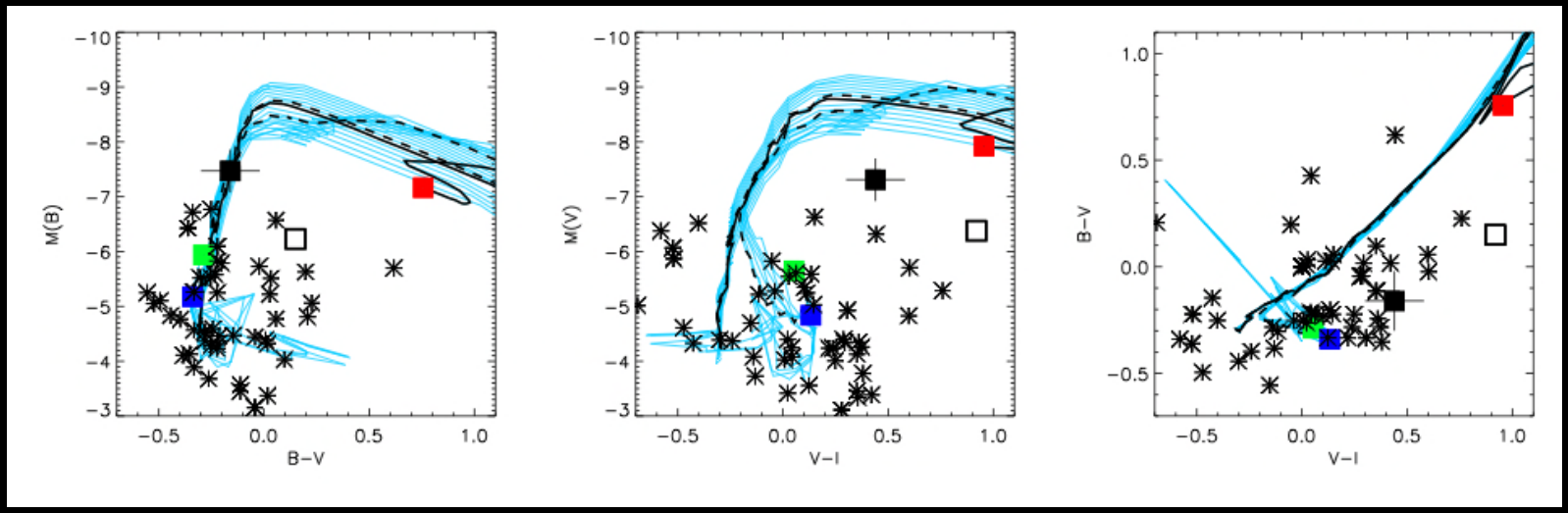
For Salpeter IMF : 75% of 8-100$M_\odot$ stars are 8-20$M_\odot$ (13 “missing”)

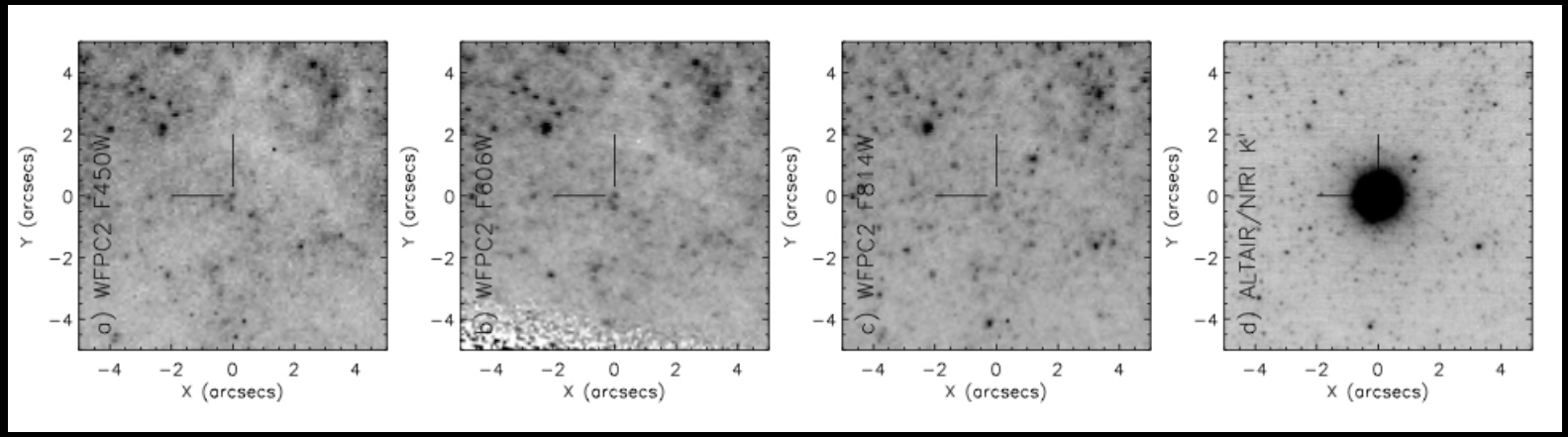
Eldridge et al. (2012, in prep)

Table 7. Properties and limits for the observed progenitors in our sample. The broad-band magnitudes with asterisks next to the value are in the standard Johnson-Cosuings broad-band filters, the rest are HST filters with: U–F336W, B–F450W, V–F555W, R–F606W and I–F814W

SN	SN Type	Galaxy	Dist(Mpc)	E(B-V)	M_U	M_B	M_V	M_R	M_I
2001B	Ib	IC391	25.5±2.5	0.14	-	-	-8.25	-	-
2002ap	Ic	NGC628	9.3±1.8	0.09	-8.85*	-4.4*	-	-5.5*	-
2003jg	Ic	NGC2997	12.5±1.2	0.11	-	-6.30	-	-6.16	-6.99
2007gr	Ic	NGC4527			Cluster	-	-	-	-
2004gt	Ib	NGC4038	22±3	0.07	-9.15	-7.44	-6.07	-	-7.49*
2000ew	Ic	NGC3810	18.2±3.3	0.04	-	-	-	-6.81	-
2005V	Ibc	NGC2146	17.1±3.2	0.90	-	-10.60	-	-8.80	-9.93
2004gn	Ic	NGC4527	14.2±1.3	0.07	-	-	-	-6.45	-
2010br	Ibc	NGC4051	12.7±2.0	0.04	-	-	-	-4.92	-
2011am	Ib	NGC4219	24.5±5.6	0.12	-	-	-	-8.06	-
2011hp	Ic	NGC4219	24.5±5.6	0.12	-	-	-	-6.76	-

SN2008ax : IIb + WNL progenitor ?





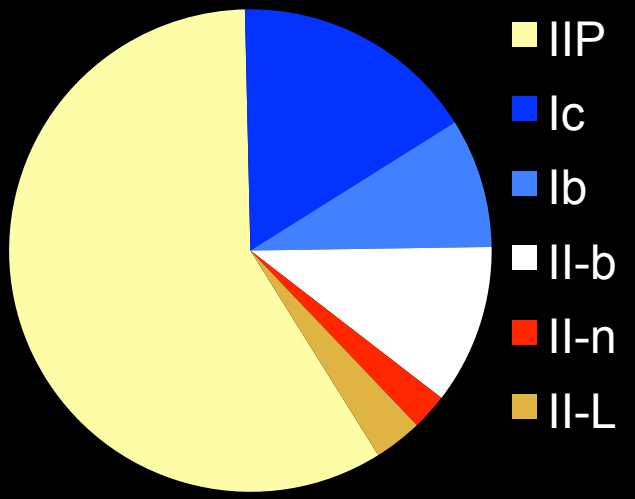
Crockett et al. 2008, Pastorello et al. 2008

Detected SN rates in Local Volume

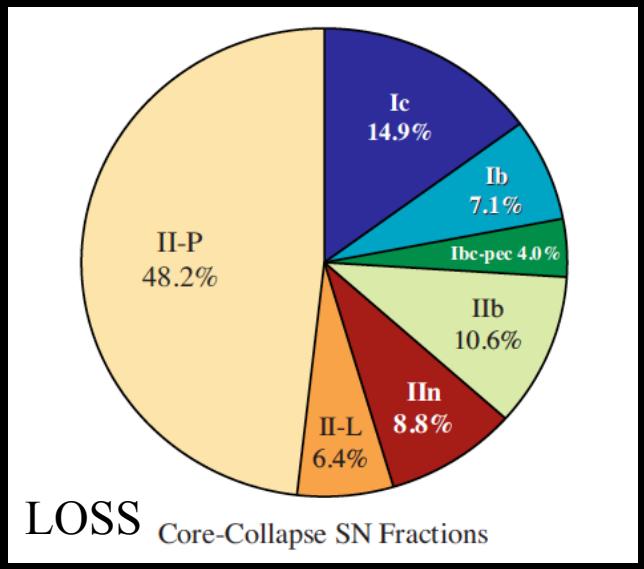
Smartt et al., 2009;
Eldridge et al.
2012, in prep.

SN Type	Number	Relative rate (per cent)
IIP	55 (73.6)	58.0 ± 6.8
IIL	3 (4)	3.2 ± 1.6
IIn	3 (3)	2.4 ± 1.4
IIb	11 (13.4)	10.6 ± 2.9
IIpec (87A-like)	1 (1.3)	1.0 ± 0.9
Ib	9 (10.9)	8.6 ± 2.6
Ic	17 (20.7)	16.3 ± 3.6
Total	99 (126.9)	

28Mpc rates



- 19980101-20080630 : 139 SNe discovered in galaxies with V_{vir}<2000 kms^{-1} (13.2 SNe yr^{-1})
- LOSS : controlled, within ~60Mpc. Leaman et al, Li et al., Smith et al. 11

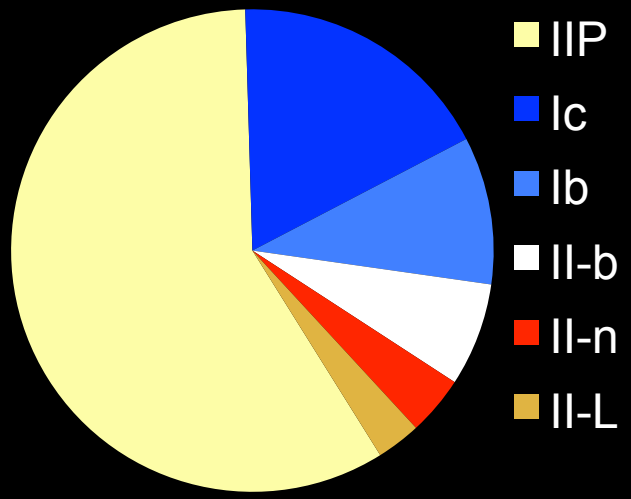


Detected SN rates in Local Volume

Smartt et al., 2009

Type	No.	Relative / per cent	Core-Collapse only / per cent
II-P	55	39.6	59.1
II-L	2.5	1.8	2.7
IIn	3.5	2.5	3.8
IIb	6	4.3	6.5
Ib	9	6.5	9.7
Ic	17	12.2	18.3
Ia	37	27.6	...
LBVs	7	5.0	...
Unclassified	2	1.4	...
Total	139	100	100
Total CCSNe	93	66	100

28Mpc rates



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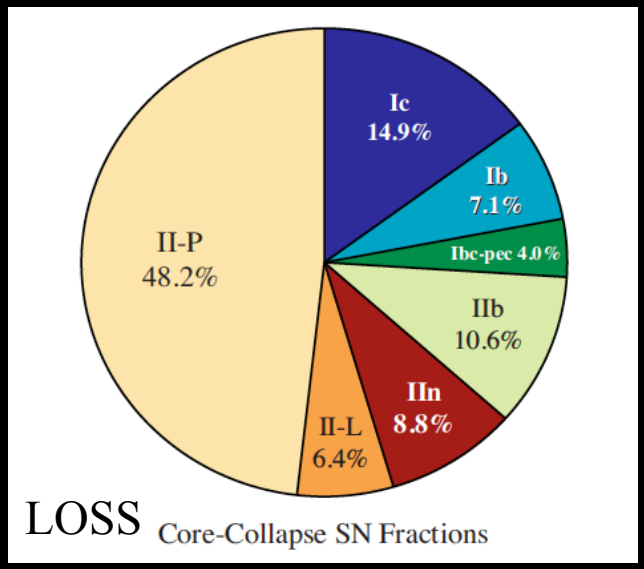

Maximum mass : lowest mass that can produce a WR

- MW clusters: M_{ZAMS} ~ $25M_{\odot}$ stars enter WR phase (WN) at ~solar metallicity (Massey et al. 2001, Crowther 2007)
- LMC clusters: >$30M_{\odot}$ become WN stars

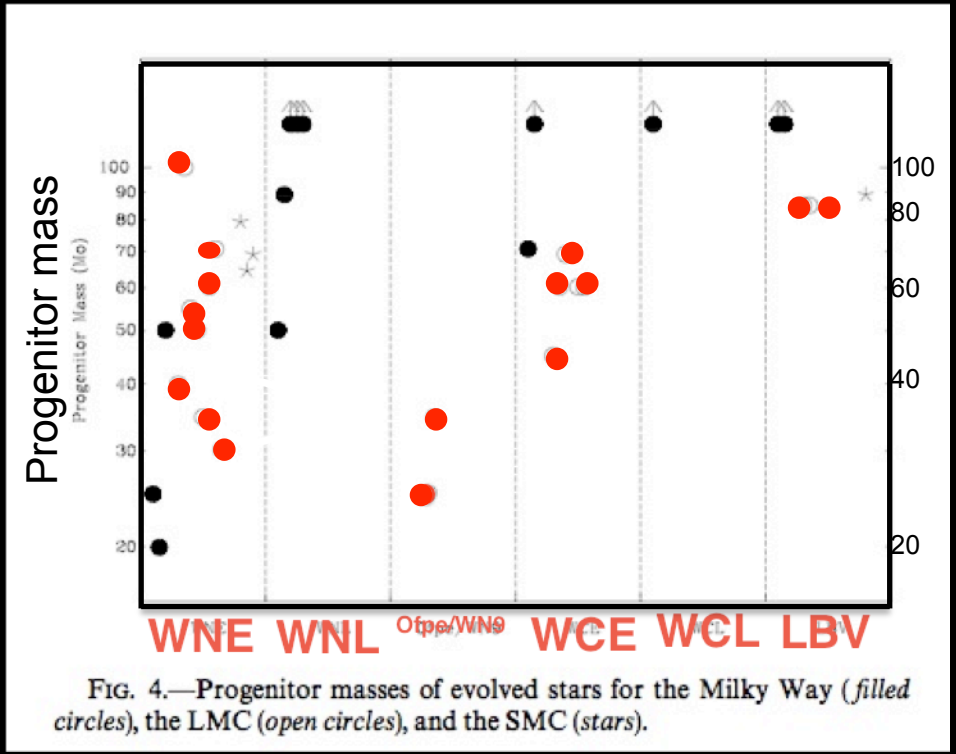

FIG. 4.—Progenitor masses of evolved stars for the Milky Way (*filled circles*), the LMC (*open circles*), and the SMC (*stars*).