Observational constraints on the progenitors of II-P SNe

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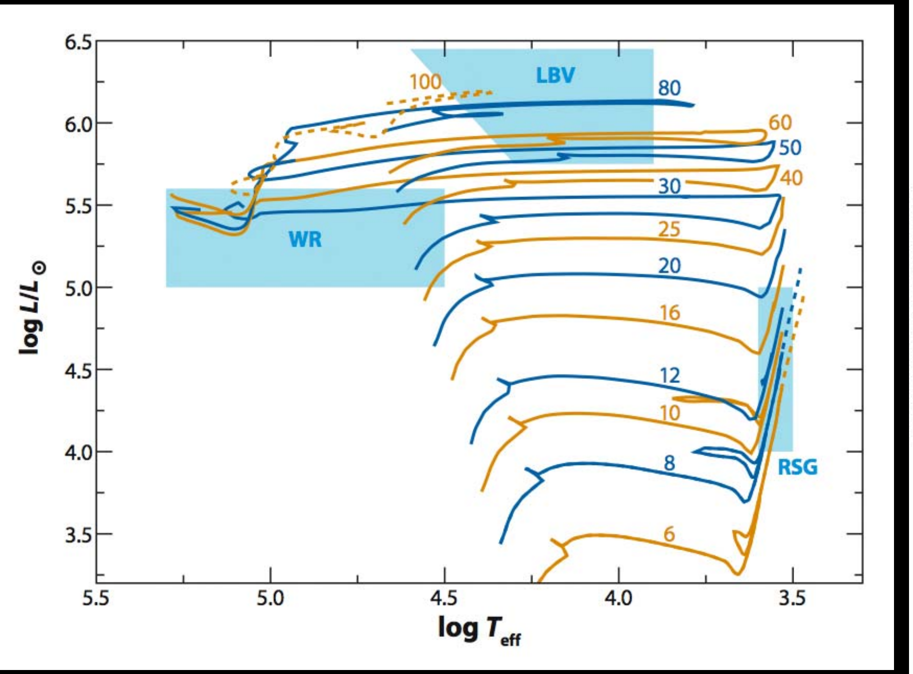
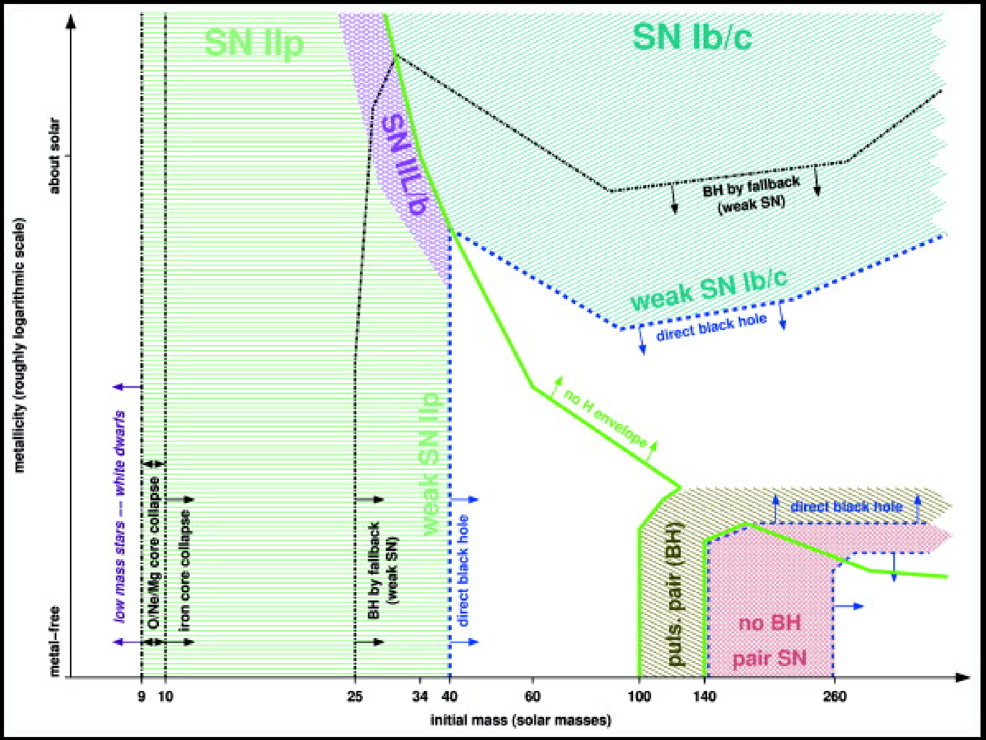
Others: M. Crockett (Oxford) J. Eldridge (IoA), J. Maund (DARK), S. Mattila (Turku), J. Danziger (Trieste), A. Gal-Yam (Weizman), A. Stephens (Gemini)

Overview and motivation

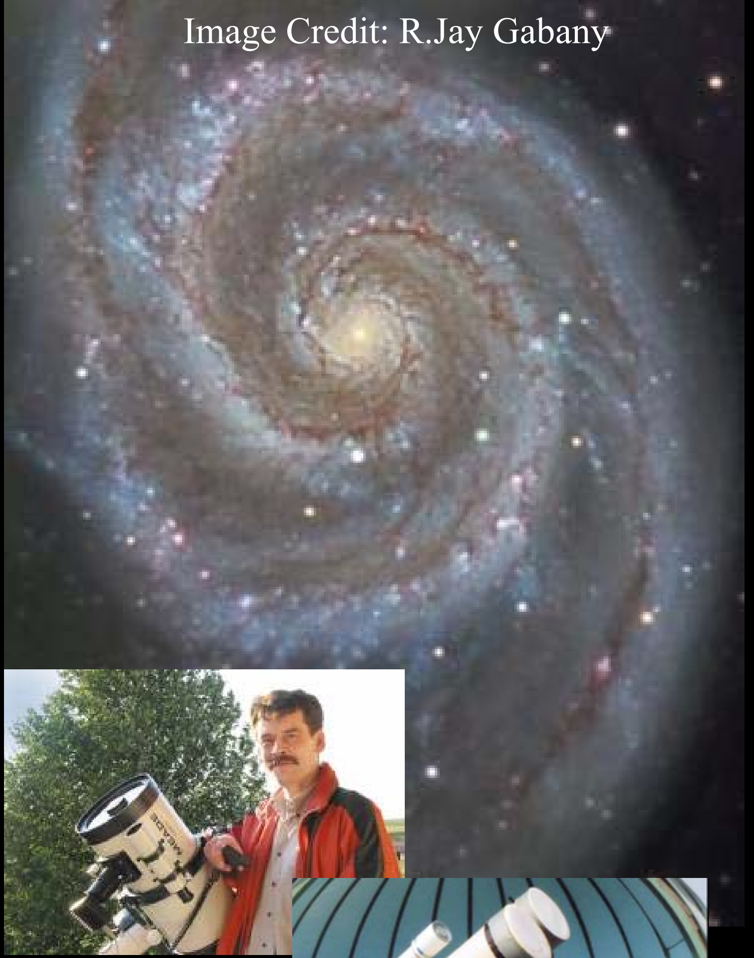
- Direct constraints on progenitor stars
- Test of final stages of stellar evolution
- Consistency with spectral and lightcurve modeling ?
- Range in energy and ejected masses : link to explosions ?
- Black hole and NS formation : which stars

Testing theory





Heger et al. (2003); Eldridge & Tout 2004 : now can place observational constraints



Nearby SNe discovered by amateur astronomers , LOSS (Filippenko talk) and CHASE (Pignata poster)

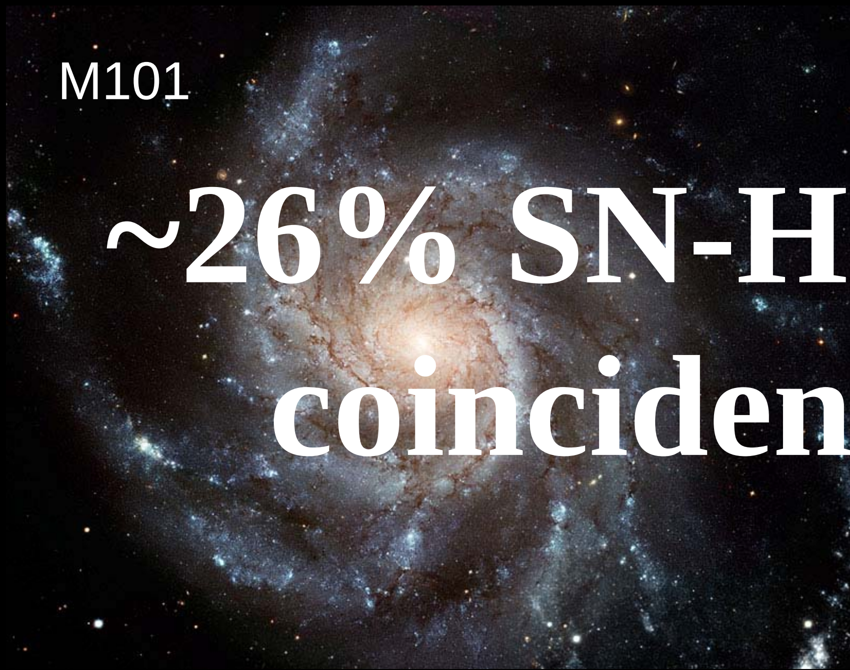
Relative SN rates 10.5 yrs

Smartt et al., 2009

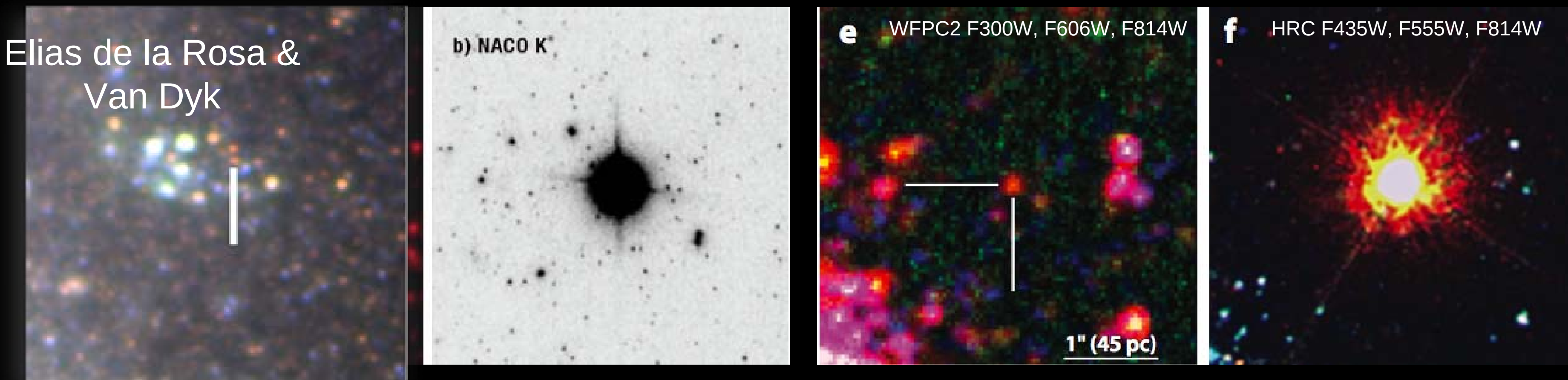
		Relative	Core-Collapse only
Type	No.	/ per cent	/ per cent
II-P	55	39.6	59.1
II-L	2.5	1.8	2.7
IIn	3.5	2.5	3.8
IIb	6	4.3	6.5
Ib	9	6.5	9.7
Ic	17	12.2	18.3
Ia	37	27.6	...
LBVs	7	5.0	...
Unclassified	2	1.4	...
Total	139	100	100
Total CCSNe	93	66	100

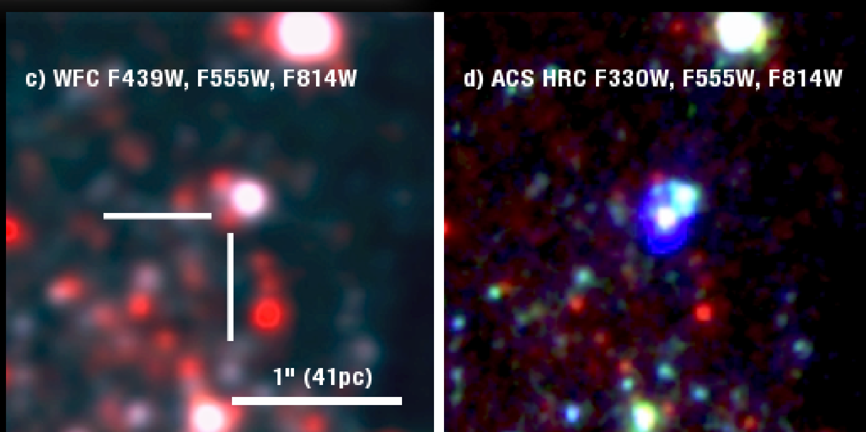
- 19980101-20080630
- 139 SNe discovered in galaxies with V_{vir}<2000 kms^{-1} (13.2 SNe yr^{-1})

~26% SN-HST image coincidence rate



Detection of progenitors



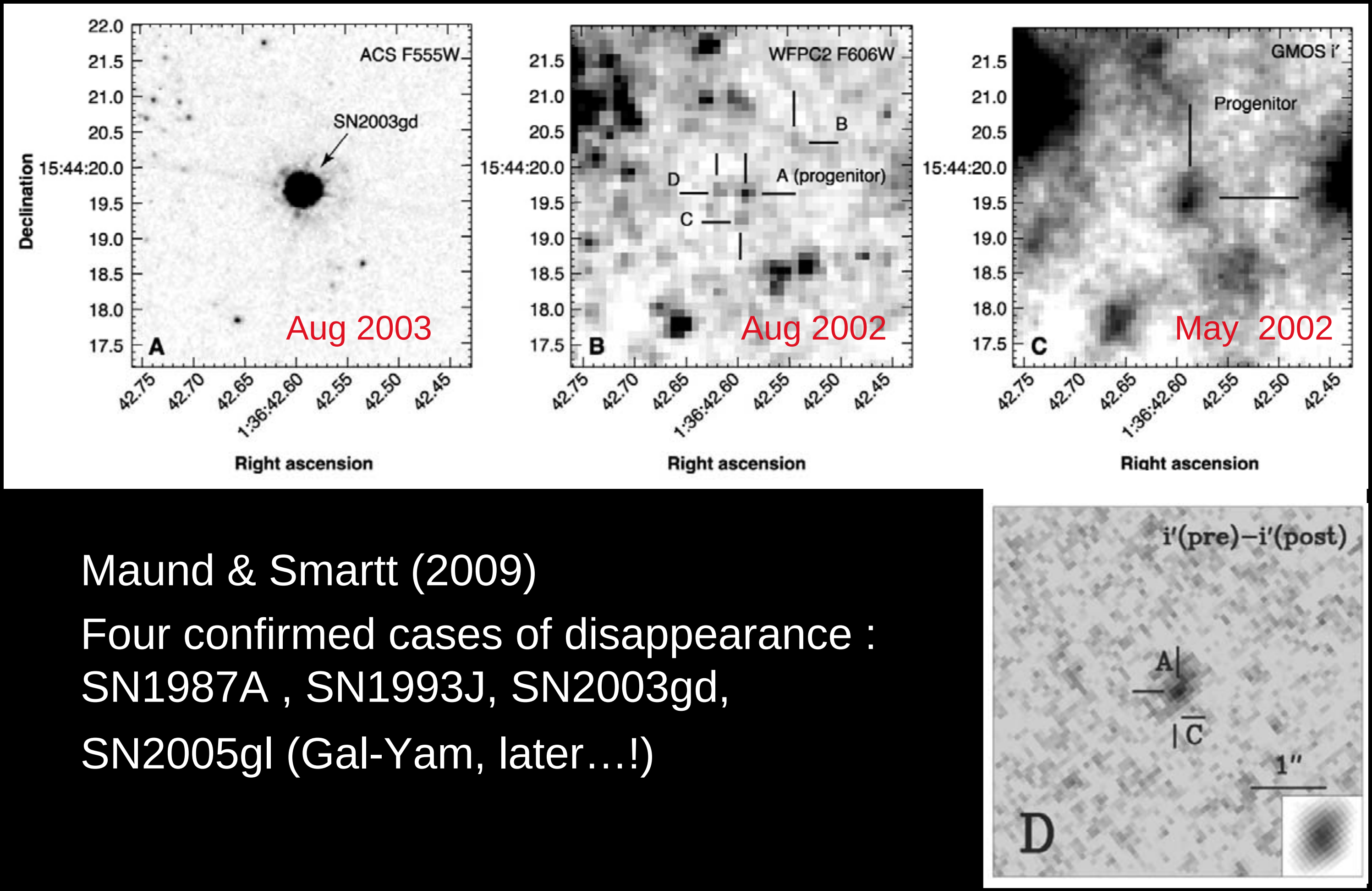


Figures from Smartt 2009 ARAA

- Within the volume limited, 10.5 yr survey for progenitors : three “gold” events
- SN2008bk, SN2005cs, SN2003gd
- Red star identified coincident with all three.
- Typical magnitudes : M_V ~ -4.5 ; M_I ~ -6.5
- Discovery papers :

  Van Dyk et al. 03, Smartt et al. 04, Maund et al. 05, Li et al. 06, Mattila et al. 08.

The disappearance of 2003gd



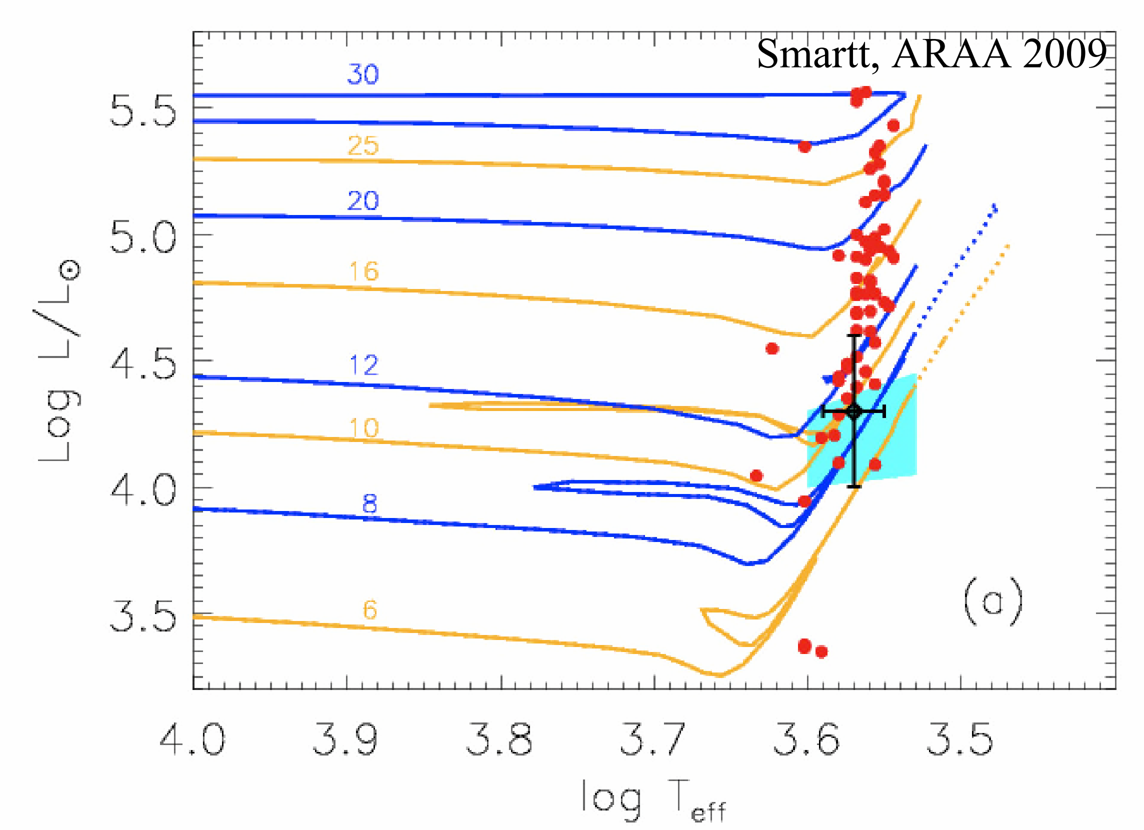
SN2003gd:
V=25.8 ± 0.15
V–I=2.5 ± 0.2
Smartt et al. 04,
Van Dyk et al. 03

Maund & Smartt (2009)

Four confirmed cases of disappearance :
SN1987A , SN1993J, SN2003gd,

SN2005gl (Gal-Yam, later…!)

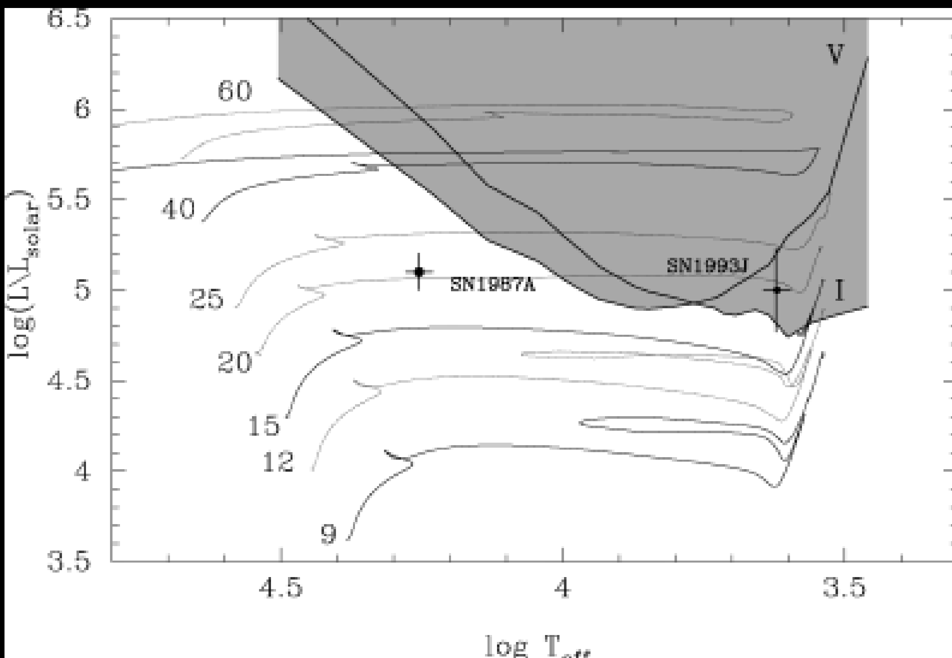
Mass estimates from stellar evolutionary tracks

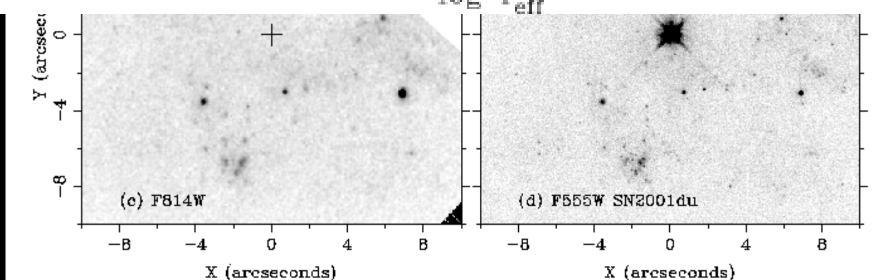


Red points : Milky Way red supergiants (Levesque et al. 2005)
STARS stellar evolutionary tracks
SN progenitors : SN2003gd (black), SN2005cs (blue box)

See Gezari talk – UV shock breakout from II-P SNe implies RSGs

Other examples: no detection





Smartt et al. 02, Van Dyk et al 02

- **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 $M_\odot$

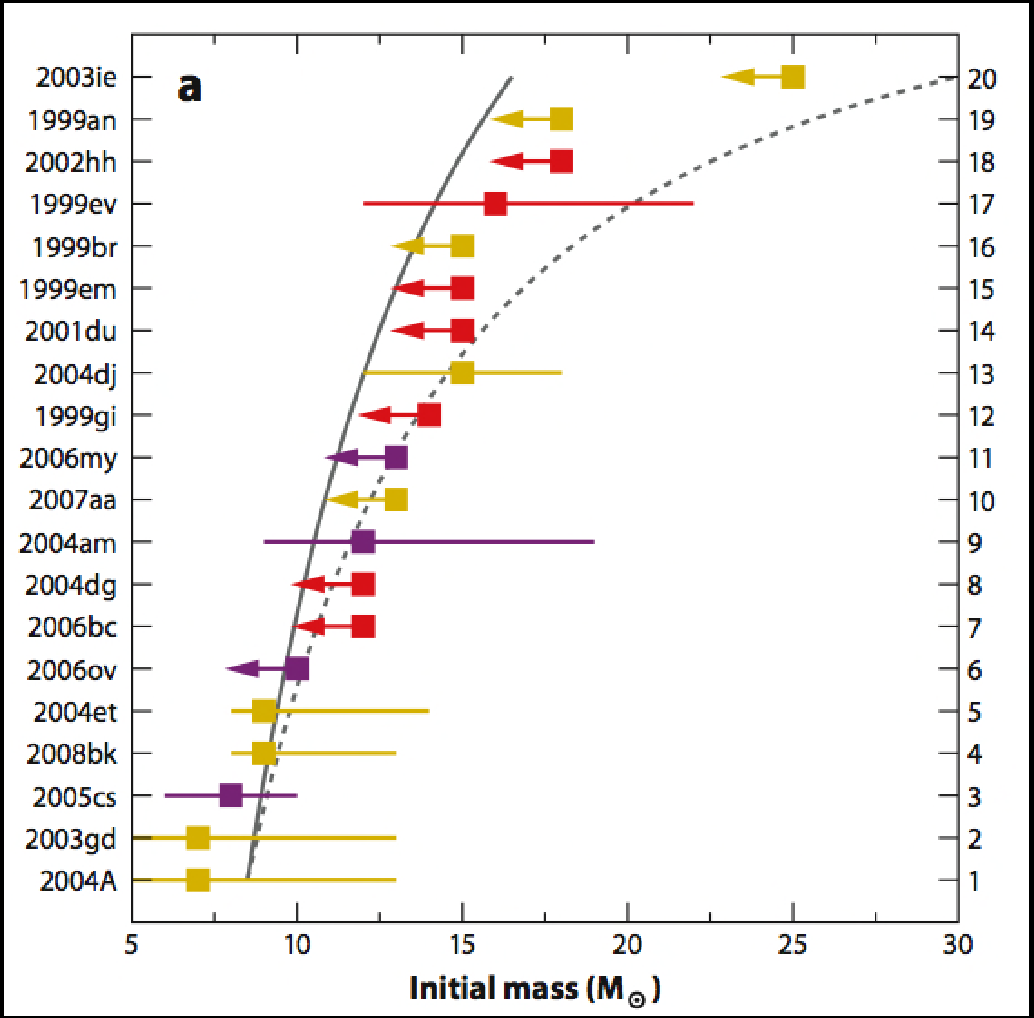
Summary of II-P progenitors : 10.5yr search

Supernova	SN Type	Galaxy	Galaxy Class	Distance Mpc	Distance Method	A_V	r_G (kpc)	r_G/r_{25}	[O/H] (dex)	$\log L/L_\odot$ (dex)	ZAMS ($M_\odot$)
1999an	II	IC 755	SBb	18.5 ± 1.5	TF	0.40 ± 0.19	4.7	0.82	8.3	< 5.16	< 18
1999br	II-P	NGC 4900	SBc	14.1 ± 2.6	Kin.	0.06 ± 0.06	3.1	0.69	8.4	< 4.76	< 15
1999em	II-P	NGC 1637	SBc	11.7 ± 1.0	Cep.	0.31 ± 0.16	1.6	0.28	8.6	< 4.69	< 15
1999ev	II-P	NGC 4274	SBab	15.1 ± 2.6	Kin.	0.47 ± 0.16	5.3	0.46	8.5	5.1 ± 0.2	16^{+6}_{-4}
1999gi	II-P	NGC 3184	SABc	10.0 ± 0.8	Mean	0.65 ± 0.16	3.1	0.30	8.6	< 4.64	< 14
2001du	II-P	NGC 1365	SBb	18.3 ± 1.2	Cep.	0.53 ± 0.28	14.7	0.53	8.5	< 4.71	< 15
2002hh	II-P	NGC 6946	SABc	5.9 ± 0.4	Mean	5.2 ± 0.2	4.1	0.45	8.5	< 5.10	< 18
2003gd	II-P	NGC 628	Sc	9.3 ± 1.8	Mean	0.43 ± 0.19	7.5	0.58	8.4	4.3 ± 0.3	7^{+6}_{-2}
2003ie	II?	NGC 4051	SABb	15.5 ± 1.2	TF	0.04	7.3	0.66	8.4	< 5.40	< 25
2004A	II-P	NGC 6207	Sc	20.3 ± 3.4	Mean	0.19 ± 0.09	6.7	0.79	8.3	4.5 ± 0.25	7^{+6}_{-2}
2004am	II-P	NGC 3034	Sd	3.3 ± 0.3	Cep.	3.7 ± 2.0	0.64	0.14	8.7	Cluster	12^{+7}_{-3}
2004dg	II-P	NGC 5806	SBb	20.0 ± 2.6	Kin.	0.74 ± 0.09	4.3	0.50	8.5	< 4.45	< 12
2004dj	II-P	NGC 2403	SABc	3.3 ± 0.3	Cep.	0.53 ± 0.06	3.5	0.37	8.4	Cluster	15 ± 3
2004et	II-P	NGC 6946	SABc	5.9 ± 0.4	Mean	1.3 ± 0.2	8.4	0.92	8.3	4.6 ± 0.1	9^{+5}_{-1}
2005cs	II-P	NGC 5194	Sbc	8.4 ± 1.0	PNLF	0.43 ± 0.06	2.7	0.22	8.7	4.25 ± 0.25	7^{+3}_{-1}
2006bc	II-P	NGC 2397	SBb	14.7 ± 2.6	Kin.	0.64	1.4	0.30	8.5	< 4.43	< 12
2006my	II-P	NGC 4651	Sc	22.3 ± 2.6	TF	0.08	4.4	0.37	8.7	< 4.51	< 13
2006ov	II-P	NGC 4303	SBbc	12.6 ± 2.4	TF	0.07	2.3	0.26	8.9	< 4.29	< 10
2007aa	II-P	NGC 4030	Sbc	20.5 ± 2.6	Kin.	0.09	10.3	0.91	8.4	< 4.53	< 12
2008bk	II-P	NGC 7793	Scd	3.9 ± 0.5	TRGB	1.0 ± 0.5	3.9	0.66	8.4	4.6 ± 0.1	9^{+4}_{-1}

Smartt et al. 2009,MNRAS : used Cambridge STARS code, homogeneous analysis, consistent luminosity and mass estimates

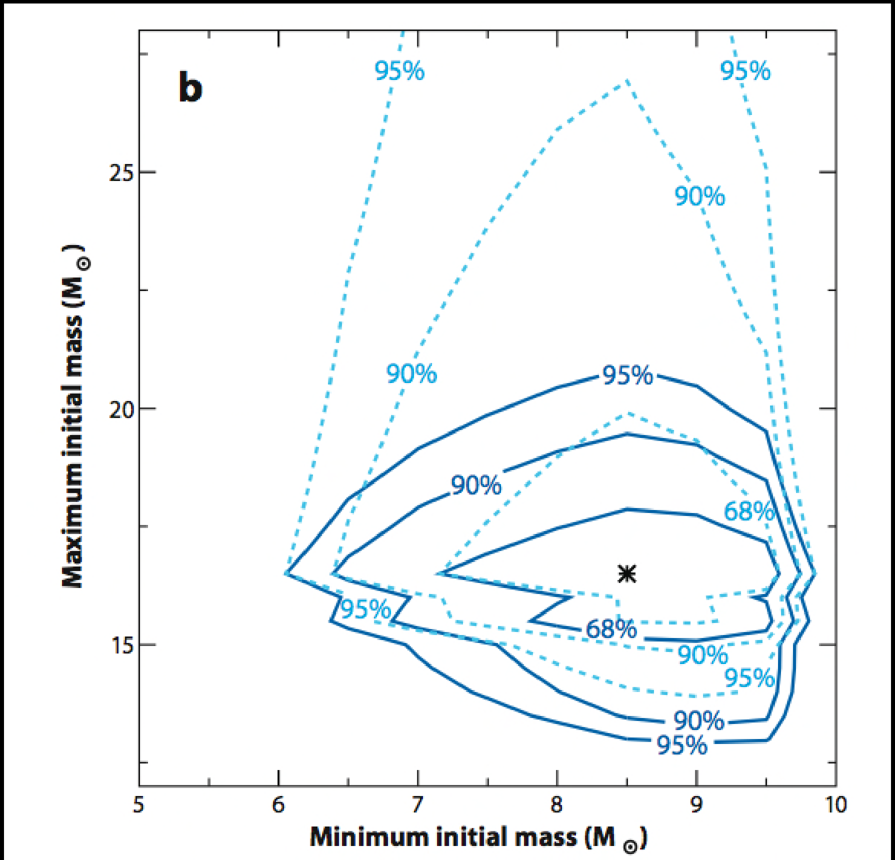
Does a Salpeter/Scalo IMF fit ?

- Solid : Salpeter IMF maximum mass of 16.5$M_\odot$
- Dashed : Salpeter IMF, maximum mass of 30$M_\odot$
- Lower mass limit : 7-8$M_\odot$ (WD limits : Williams talk)



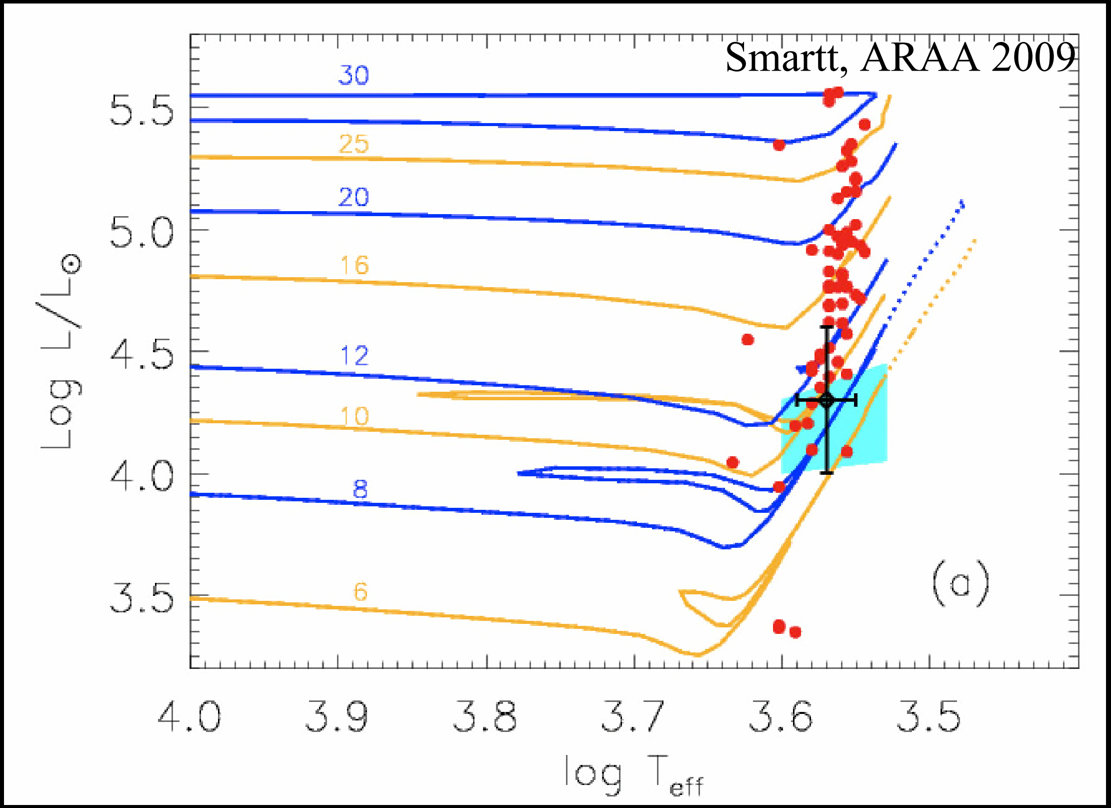
Maximum likelihood approach

- m_{min} : is better measured with the detections only. Unconstrained IMF if limits used.
- m_{max} : calculated using both detections and limits :
  - $m_{min} = 8^{+1}_{-1.5}\,M_\odot$
  - $m_{max} = 16.5 \pm 1.5\,M_\odot$



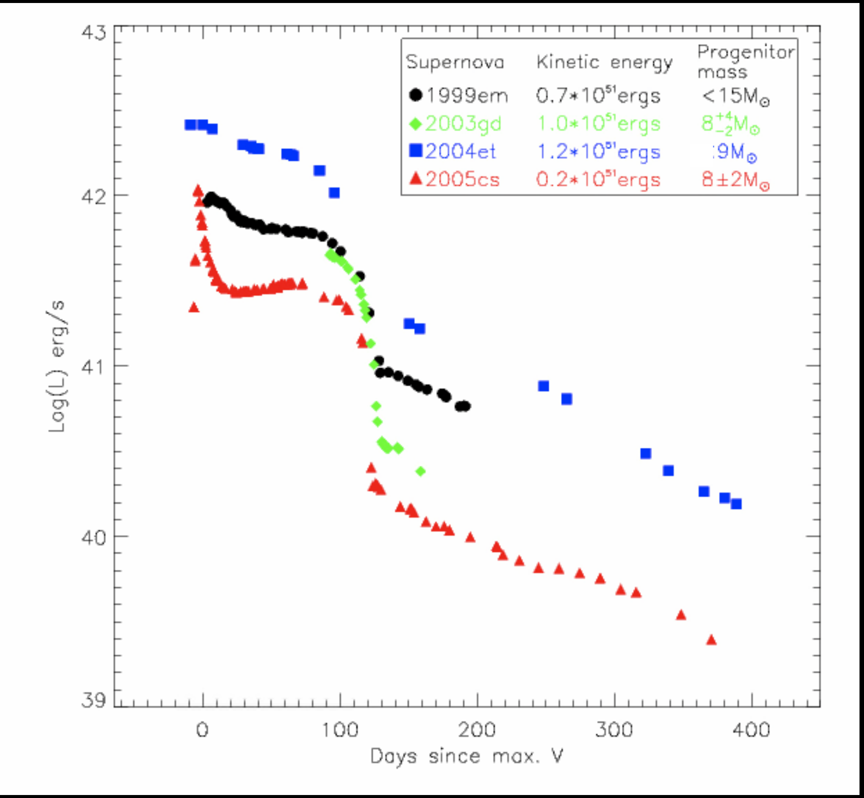
The “red supergiant problem”

- Most massive RSGs in MW and LMC are 25-30$M_\odot$
- Where are these progenitors ?
- Would be the easiest to detect in the pre-explosion images
- From Salpeter/Scalo IMF we would have expected 4-5 bright, massive progenitors
- Do they produce IIn and II-L ?

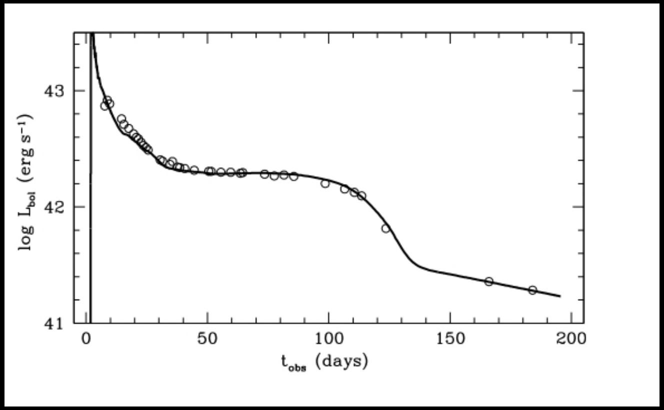


Levesque et al 05,06 : new Teff for RSGs

Probing the explosion



- Chugai & Utrobin : hydro models of LCs
- Factors of 2 -3 higher masses (2005cs, 2004et, 1999em…)



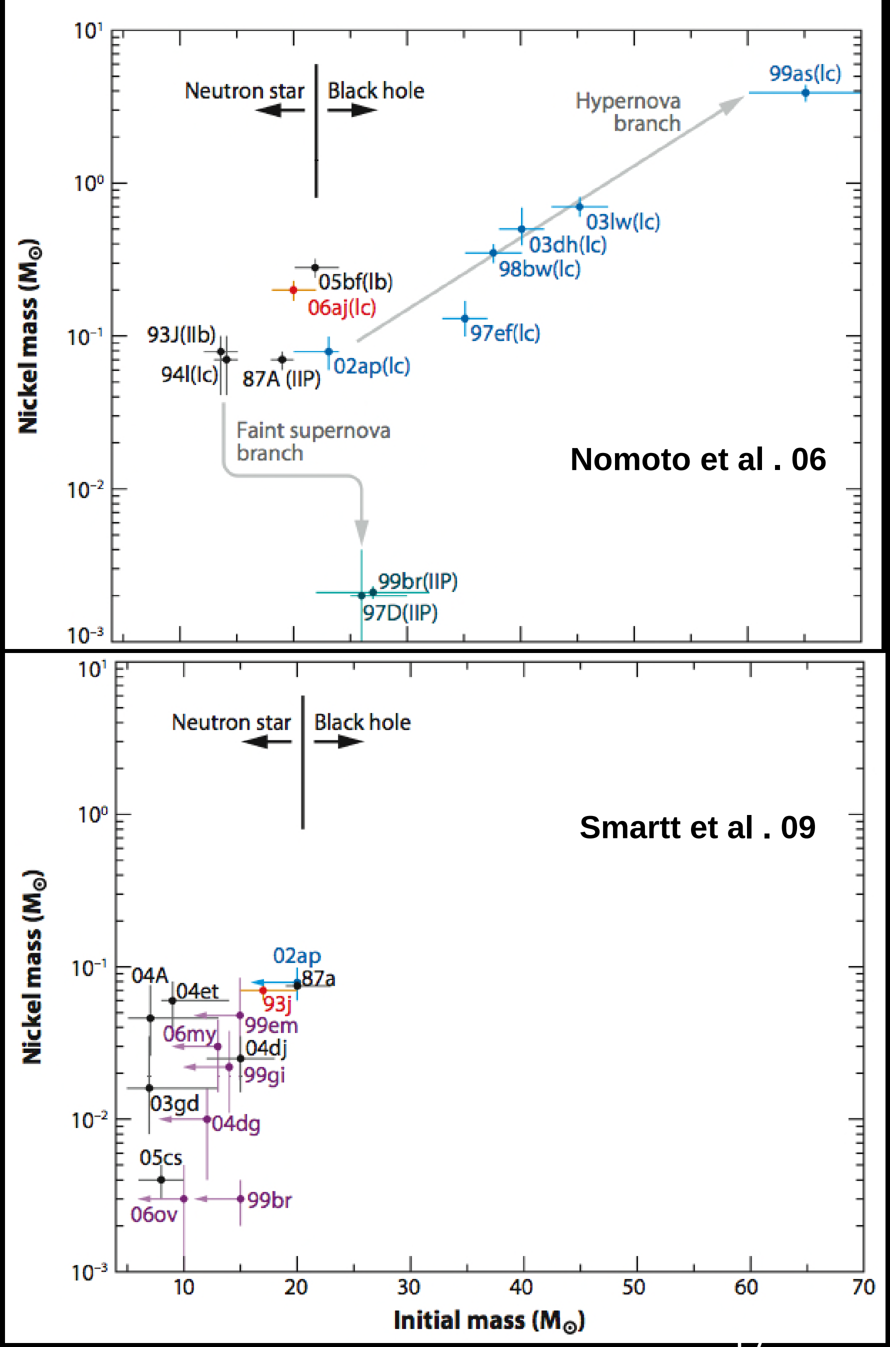
- See Posters :
  Kate Maguire (explosion energies)
  Melina Bersten (Hydro models)

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

- Nomoto et al. 2006 : ejecta mass from lightcurve and spectral models
  - Assume WR stars and use stellar evolution models to determine initial mass
  - Faint, ^{56}Ni poor branch : fall-back SNe from high mass stars

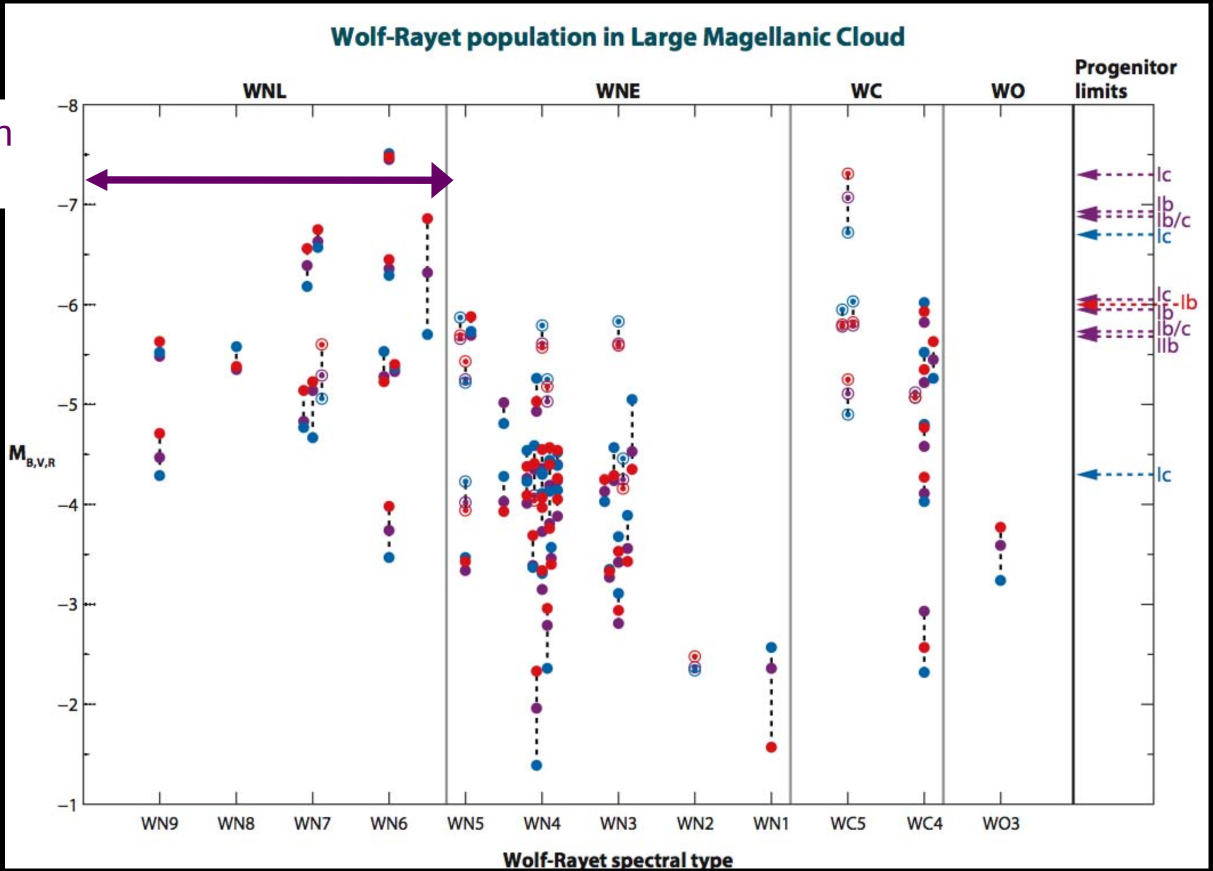
- Direct progenitor identification results :
  - All faint II-P, have low KE, and low ^{56}Ni
  - <u>No evidence </u>of high mass progenitors
  - Large diversity in explosion energies between 7-16$M_\odot$

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



Wolf Rayet stars : not Ibc progenitors?

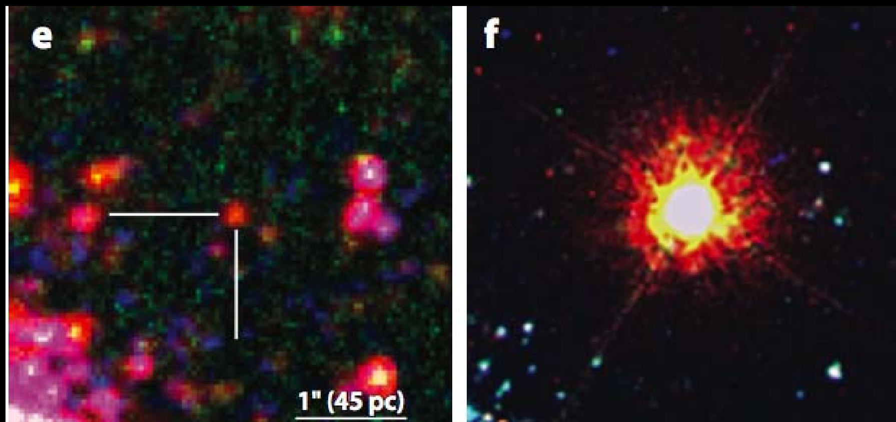
SN2008ax detection
$M_V = -7.4$

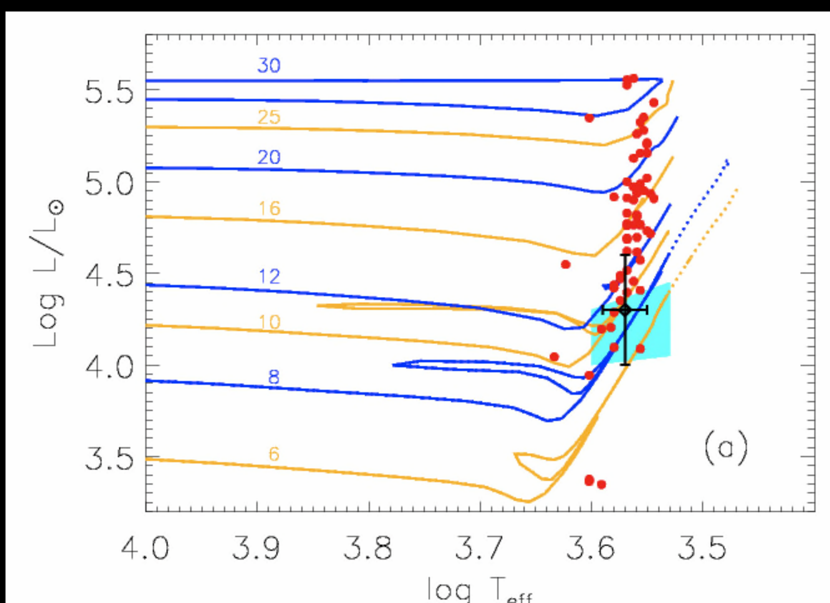


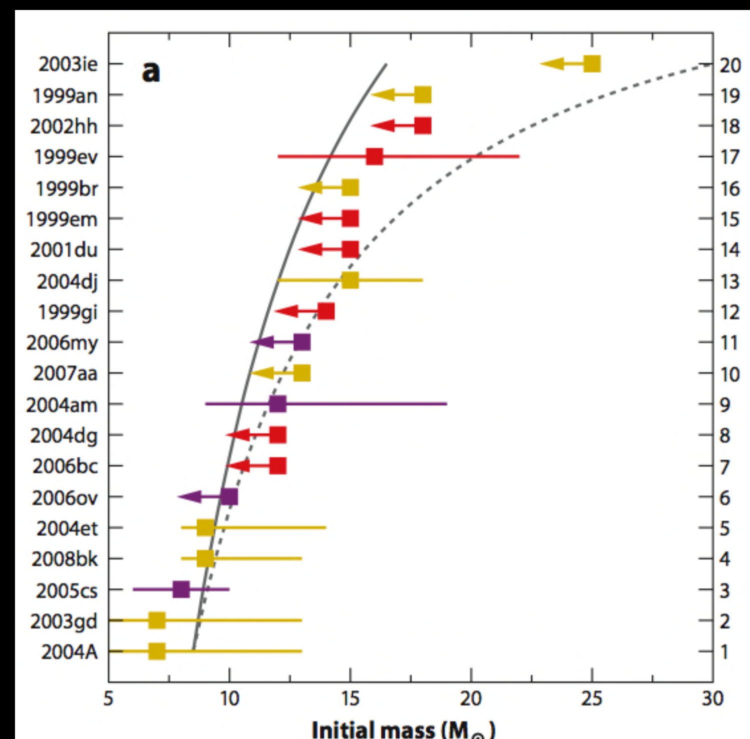
From Crockett 2009 (PhD Thesis),
See also
Van Dyk et al. 03
Maund & Smartt 05,
Maund et al. 05
Gal-Yam et al. 05

- LMC (or M31) WR magnitude distributions ⇒ ~5-10% probability we have had no detections by chance
- SN2008ax : detection of WNL progenitor of a IIb (Crockett et al. 08)

Summary


e
f
1" (45 pc)


30
25
20
16
12
10
8
6
(a)
Log L/L$_\odot$
log T$_{eff}$
5.5
5.0
4.5
4.0
3.5
4.0
3.9
3.8
3.7
3.6
3.5


a
2003ie
1999an
2002hh
1999ev
1999br
1999em
2001du
2004dj
1999gi
2006my
2007aa
2004am
2004dg
2006bc
2006ov
2004et
2008bk
2005cs
2003gd
2004A
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
5
10
15
20
25
30
Initial mass (M$_\odot$)

Summary

- Red supergiants are progenitors of II-P Sne (as predicted by Chevalier, Falk & Arnett)
- Confident detections of 3 (+ several others) low luminosity progenitors : log $L/L \approx 4.3 \pm 0.3$, colours imply M-type supergiants
- Suggests these stars *do NOT* go through 2nd dredge up

- Lower limit for core-collapse : no more than 7-8$M_{\odot}$
- Lack of high mass progenitors – statistically significant ?
- No detection of Ibc progenitors – the known massive WR population is not the progenitor population of Ibc SNe
- Massive stars collapse to black holes – we have not yet detected the SN ? $16 \rightarrow 60 ?\ M_{sol}$

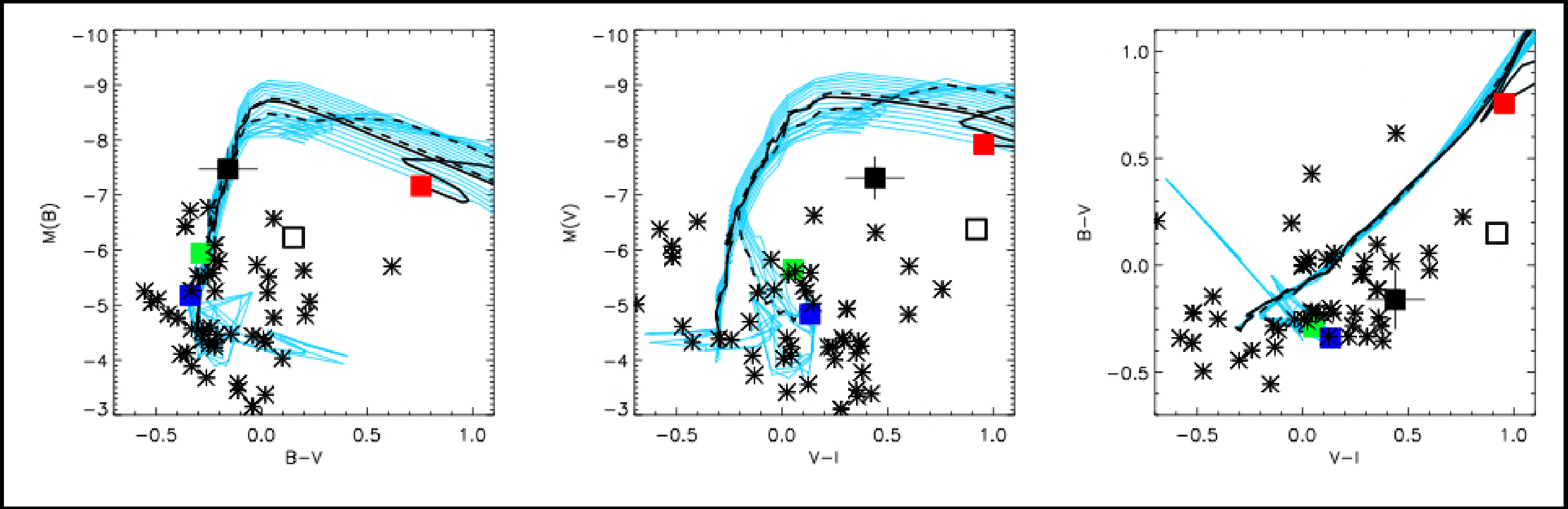
Lessons Learned

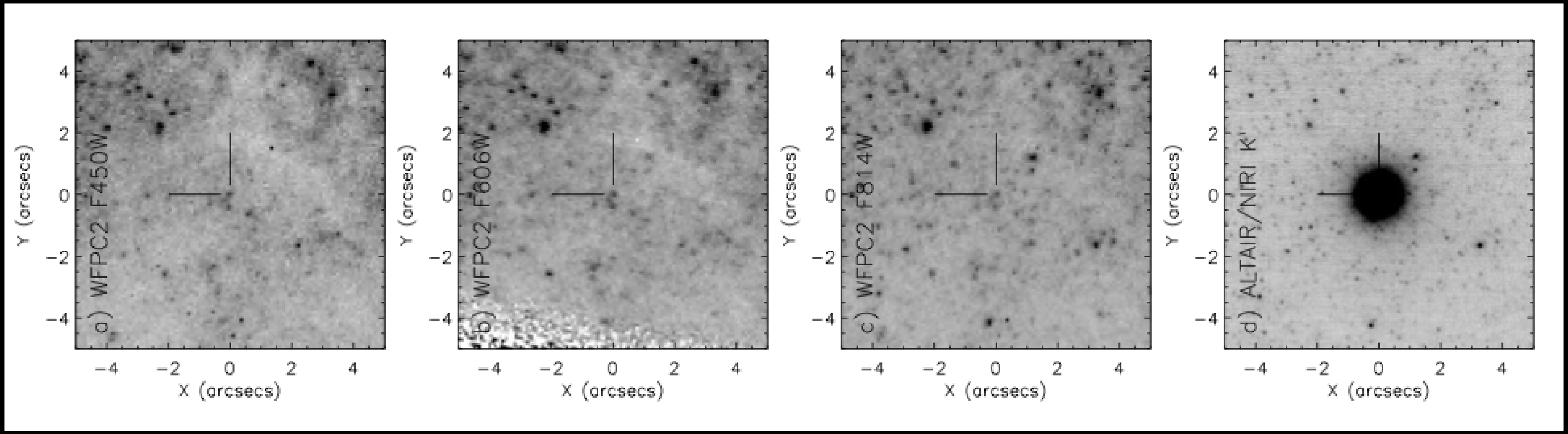
- 10 years of searching – not as easy as first thought
- 93 CCSNe within 28Mpc : ~32 with good pre-explosion images
- 4 high significance, unambiguous detections. 3 questionable ones, plus 3 on unresolved host clusters
- 5-10% yield (but large number of upper limits restrictive)
- High resolution images (HST or 8m AO) crucial

The future :

- Extend to another 10-20 years (any takers….!)
- Focus on the 10Mpc volume : HST MCTP for all high SFR galaxies (800 orbits). Huge legacy science (D. Calzetti)
- Guaranteed ~15 CCSNe in 10 years. With full mosaic, deep WF3/ACS of the galaxies, discovery potential high

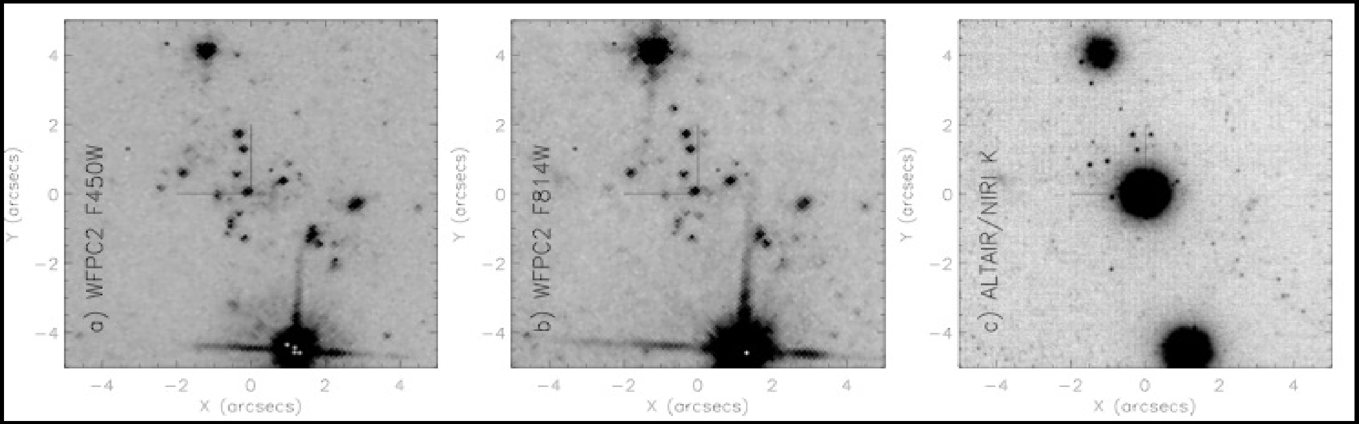
SN2008ax : IIb + WNL progenitor ?



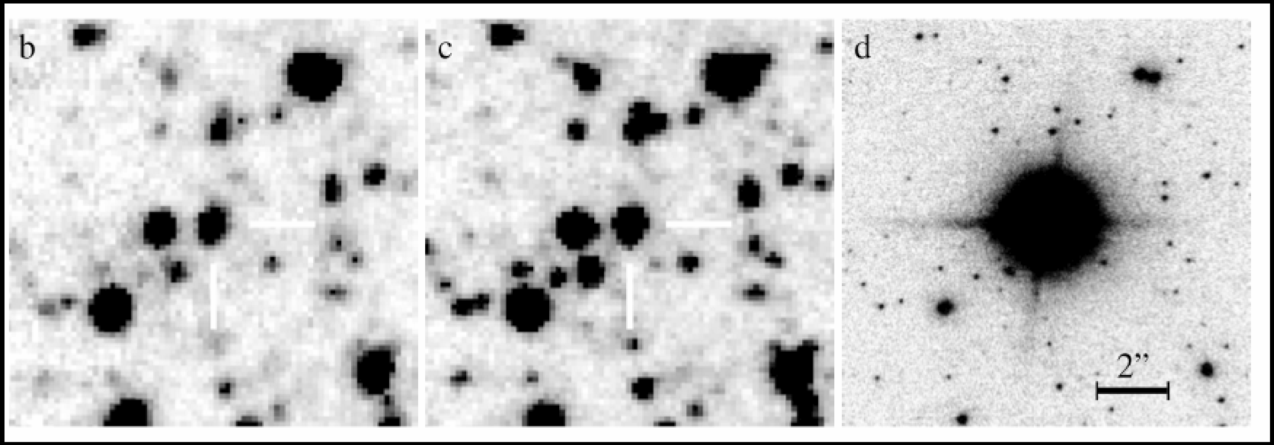


Crockett et al. 2008, Pastorello et al. 2008

8m AO imaging - new approach



Gemini + Altair :
Crockett et al. 07



VLT + NACO :
Mattila et al. 08

Gemini and VLT diffraction limited *K*-band AO images

0.08” and ~0.02” pixels = well sampled PSF

Typical ~15 - 20 stars identified in common between K_S and *V* or *I* band

Differential astrometry ~ 20 milliarcseconds RMS

Comparison of codes