“Overview of supernova progenitor evidence”

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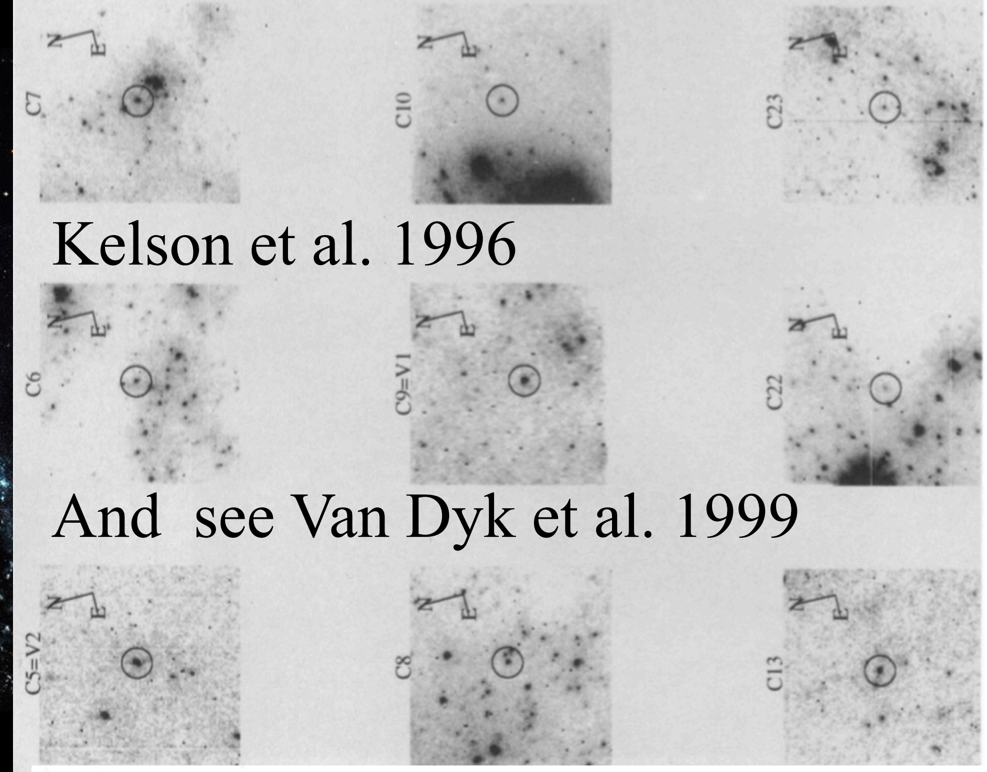
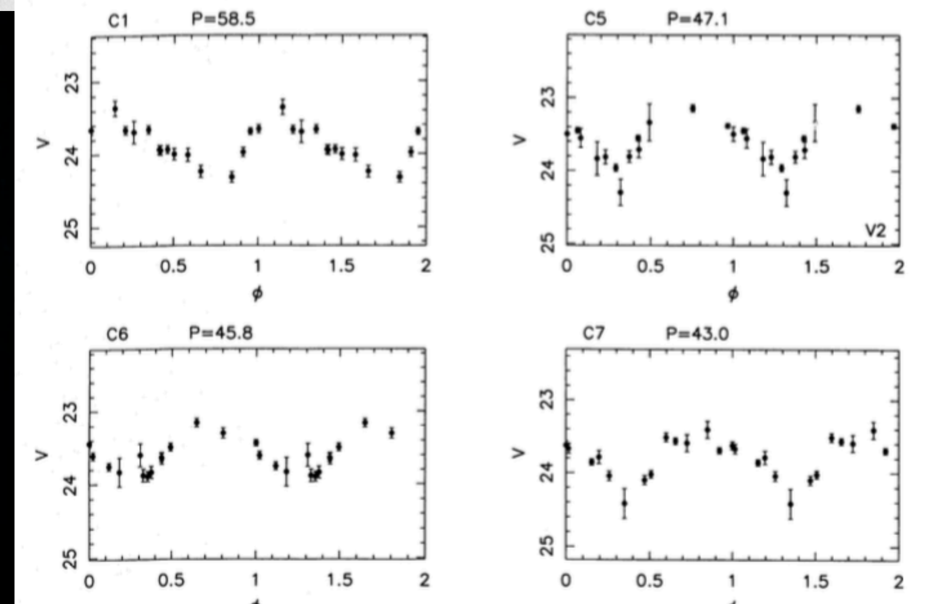
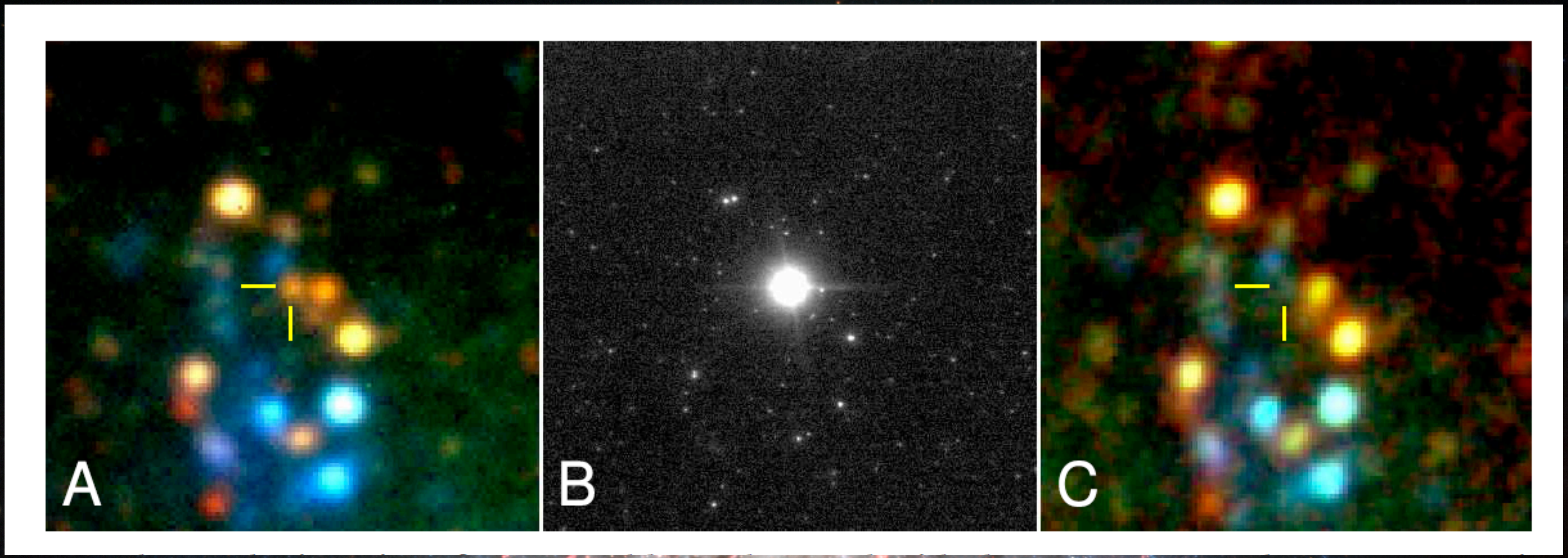




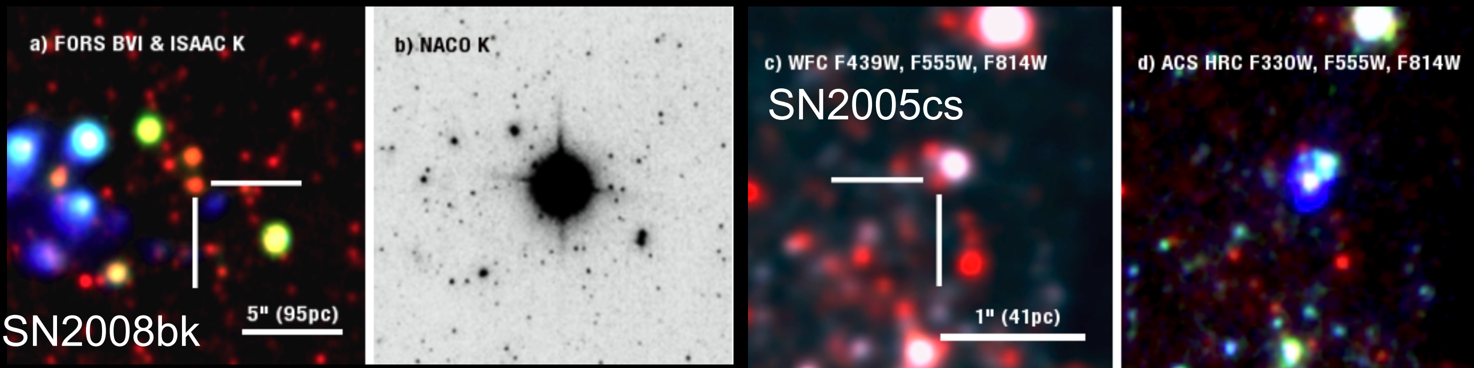
Credit : NASA/ESA, HST

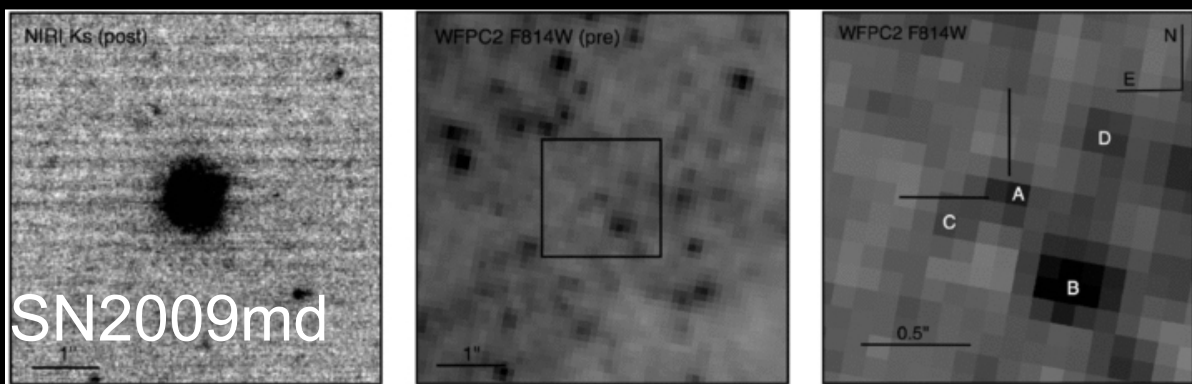
NGC7793 with VLT FORS

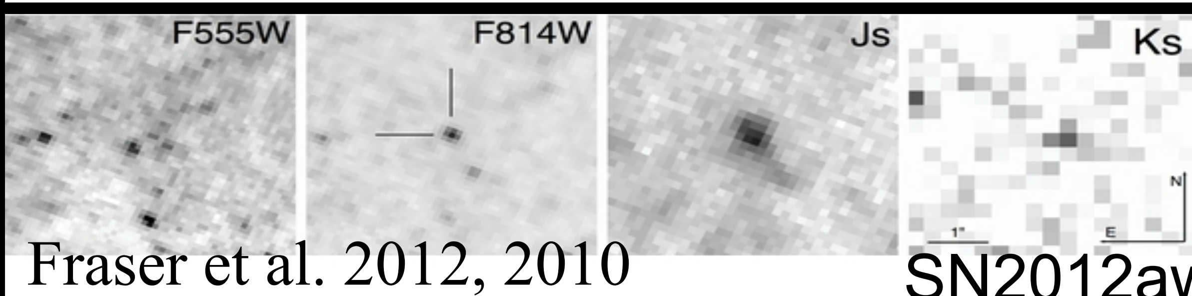


Mattila et al. 08, 11
Van Dyk et al. 12
Maund et al. 2014

Detection of progenitors 2004 to now







- Red stars identified coincident with II-P SNe
- Typical magnitudes : $M_V \sim -4.5$; $M_I \sim -6.5$
- Review in Smartt (2009)
- See
  - Van Dyk et al. 2003, 2012a, 2012b, 2011,
  - Li et al. 2005,

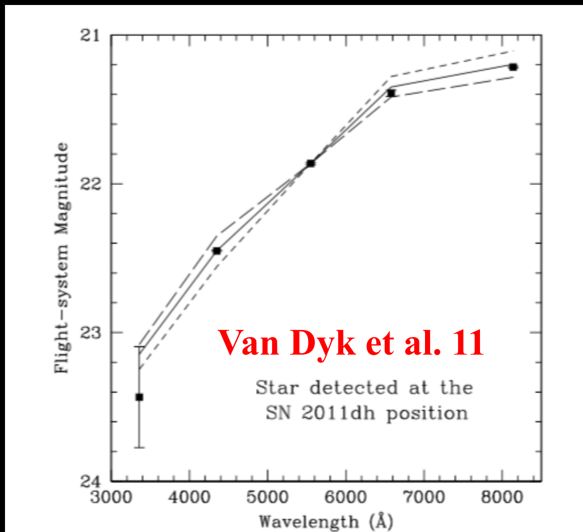
Summary of progenitor search project

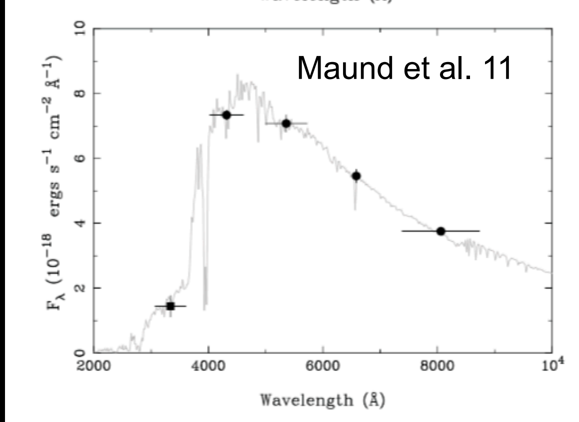
- Since 1998 to present : for **ALL** core-collapse SNe in galaxies, with $V_{vir} \leq 2000$ kms^{-1} *(d ≤ 27Mpc)*
- Search HST archive for any pre-discovery imaging
- Supplement with any deep, high resolution ground-based imaging
- Progenitor search for all – high resolution (HST, Ground based AO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

Our survey :
Smartt et al. 2009, MNRAS
Eldridge et al. 2013, MNRAS
(Crockett et al. 2011, 2008a, 2008b, 2007
Fraser et al. 2014, 2012, 2011, 2010
Maund et al. 2013, 2011)

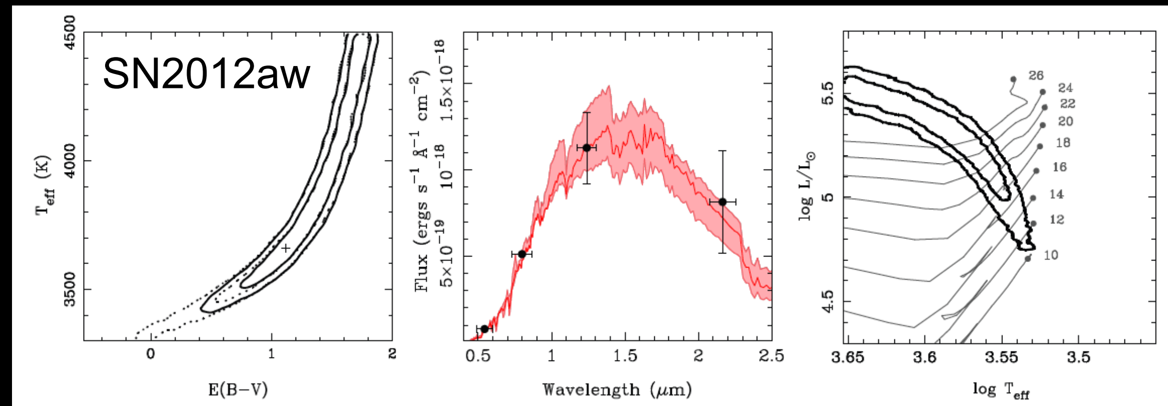
Caltech/Berkeley group:
Van Dyk et al. 2014, 2013, 2012a, 2012b, 2011
Elias-Rosa et al. 2011, 2010
Li et al. 2007, 2006

Photometry and stellar SED





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



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

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

Citations for the following slide :

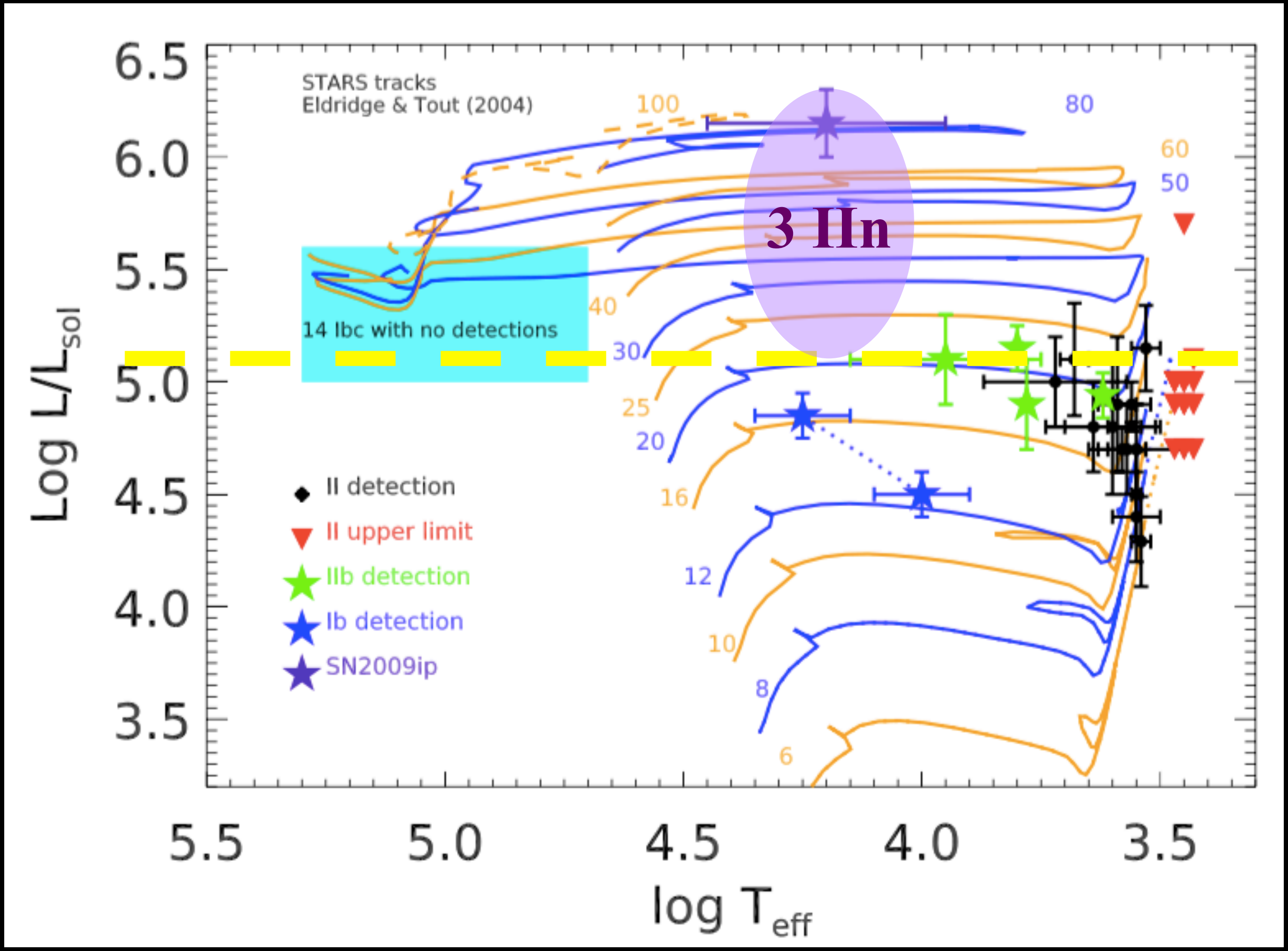
Smartt et al. 2009
Eldridge et al. 2013, MNRAS
Fraser et al. 2014, 2012, 2011, 2010
Fraser 2012 (PhD thesis)
Maund & Smartt 2009
Maund et al. 2011, 2013, 2014a, 2014b
Mattila et al. 2008
Crockett et al. 2011, 2008a, 2008b, 2007
Tomasella et al. 2013
Kochanek et al. 2012
Van dyk et al. 2014, 2013, 2012, 2011
Li et al. 2005
Elias-Rosa et al. 2013, 2011
Eldridge et al. 2015
Bersten et al. 2014

Reviewed in Smartt 2015, PASA, 32, 16

With addition of :
SN2009ip (e.g. Smith et al. 2010, Fraser et al. 2015)
ASASSN 16fq (Kochanek et al 16)
SN2016gkg: (Tartaglia et al. 17, Kilpatrick et al. 17)
SN2015bh : Elias-Rosa et al, (2016)
SN2016jbu: Fraser et al 2016, (2017 in prep)

And see Poster on 2013ej – Van Dyk et al.

HRD for progenitors

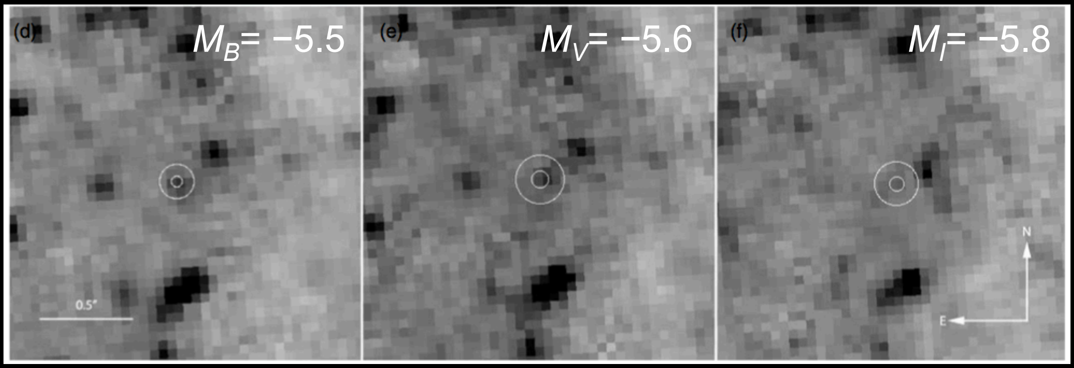


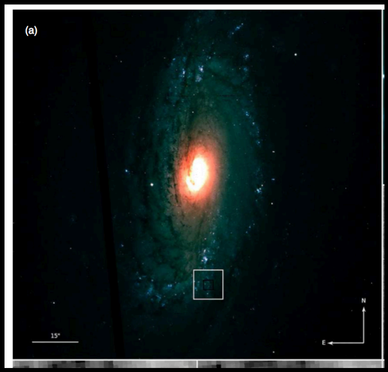
- Results 1998 – 2016 ; within 28 Mpc
- 51 objects in total
- Apparent upper luminosity limit : Log $L/L_{\odot} \approx$ 5.1

For Salpeter IMF : 75% of 8-100$M_{\odot}$ stars are 8-20$M_{\odot}$

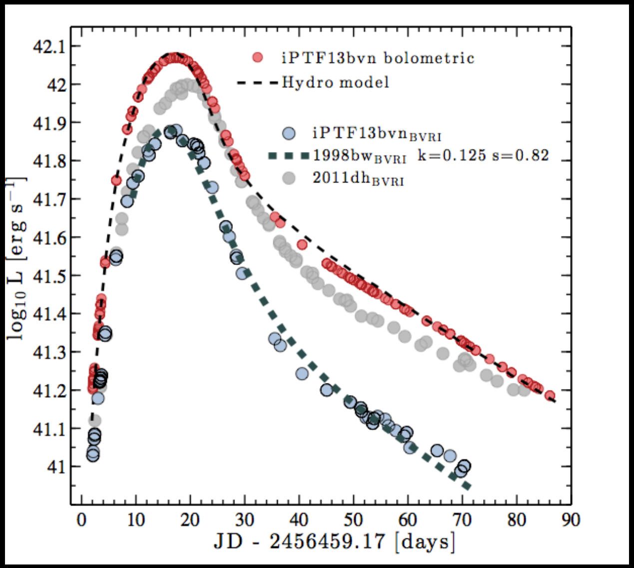
Expect 12 high mass progenitors >20$M_{\odot}$

iPTF13bvn : Ib progenitor



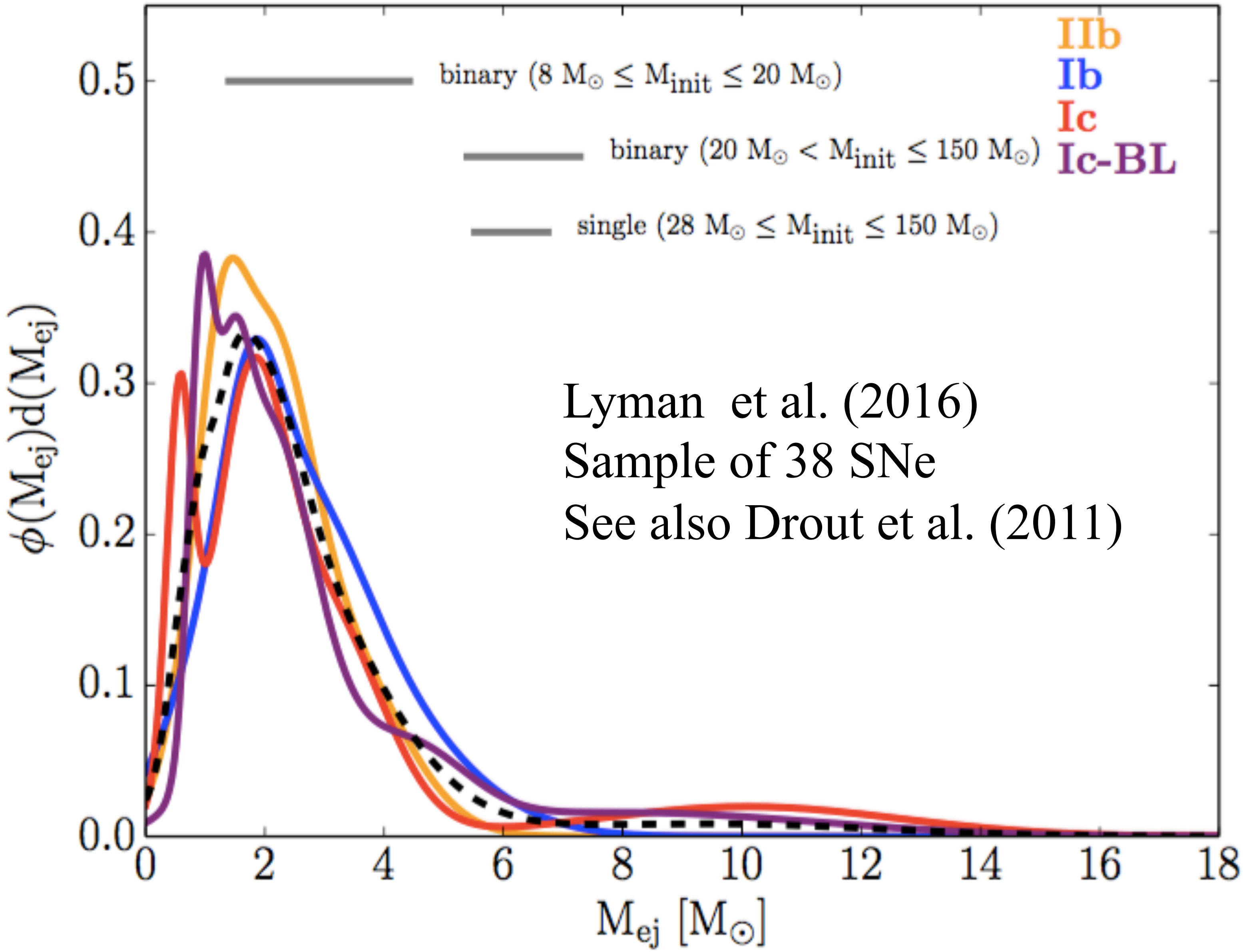


NGC5806
SN Ib
D = 22 Mpc
μ= 31.8
Discovery : Cao et al. 2013



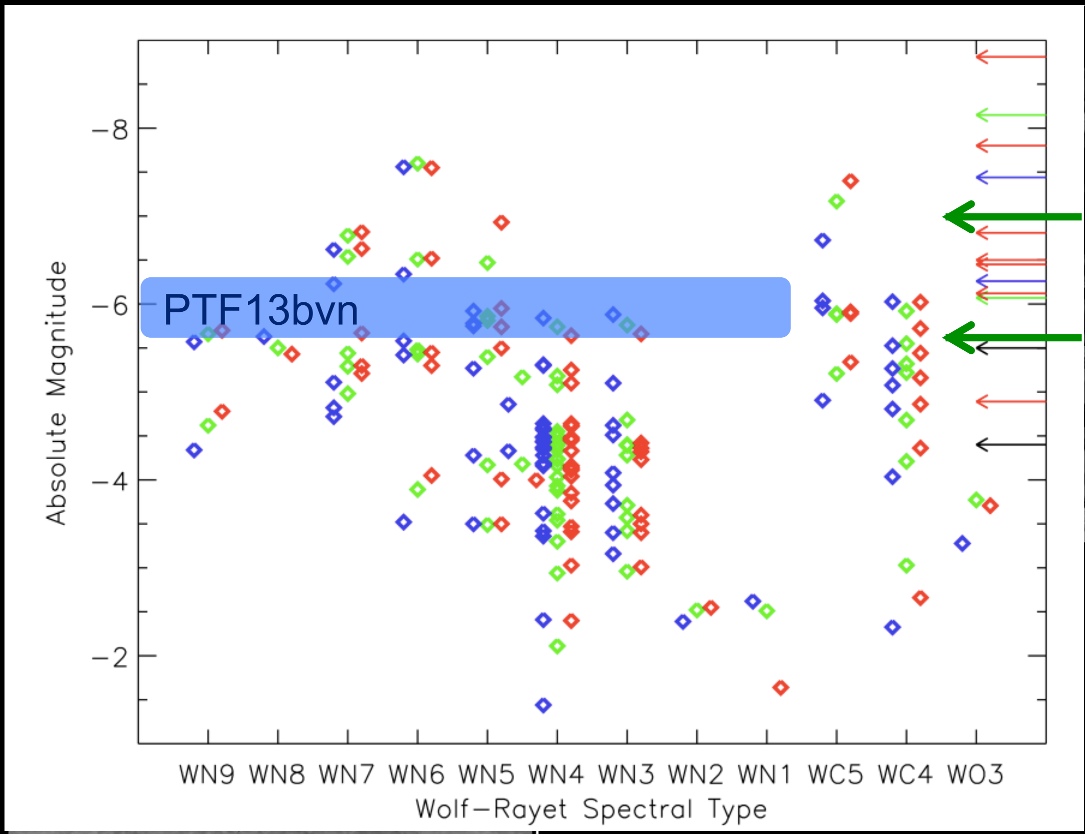
- Groh et al. : logL ~ 5.6, T_{eff}=46kK WN star with $M_{fin}=10M_\odot$
- Fremling et al. : lightcurve suggests $M_{ej} = 2M_\odot$
- Bersten et al. $M_{ej} = 2M_\odot$ and quantitative binary evolution model
- Eldridge & Maund (2016), Folatelli et al. (2016) – progenitor has disappeared

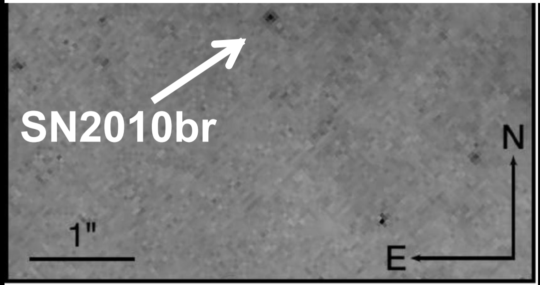
Binary system $11+6M_\odot$: evolves to $M_{fin} \approx 3\text{-}4M_\odot$



Lyman et al. (2016)
Sample of 38 SNe
See also Drout et al. (2011)

Type Ibc progenitor sites

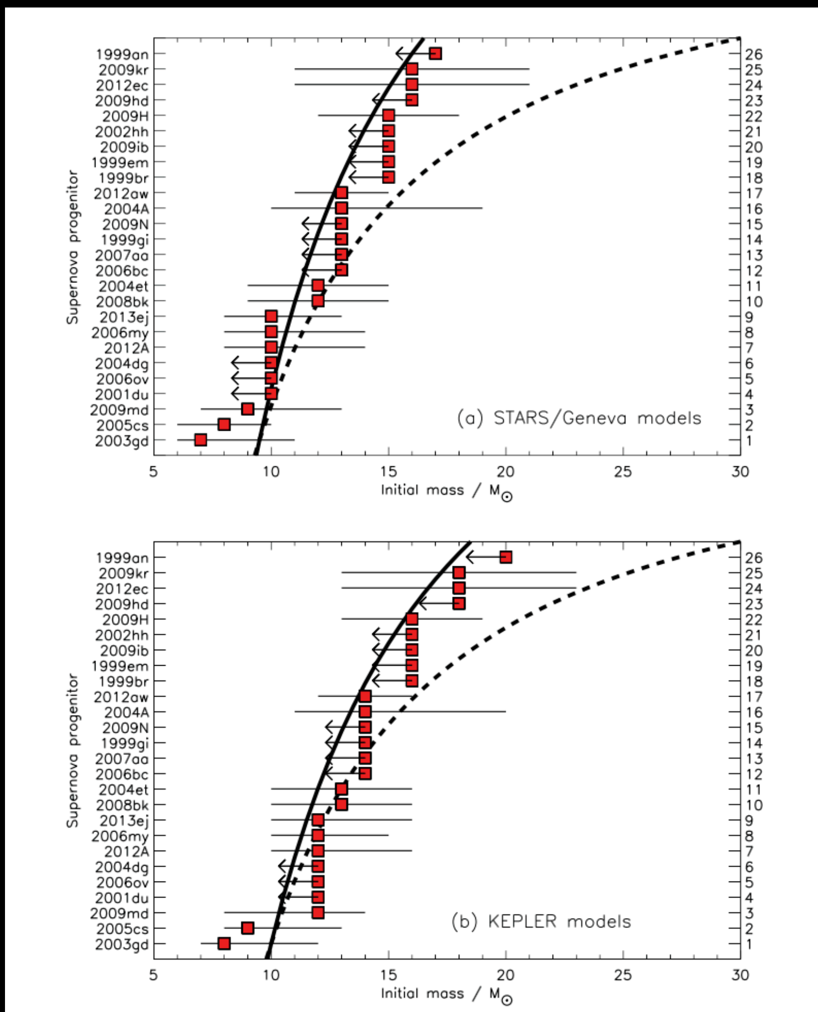


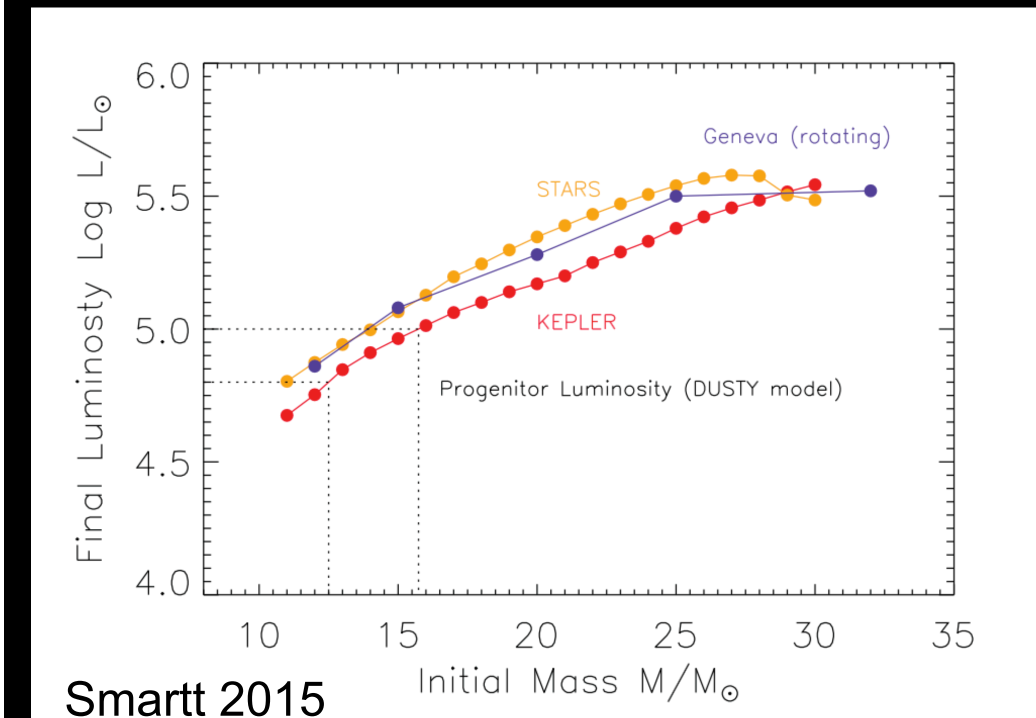


(b)

- **Eldridge et al. (2013) + Elias-Rosa et al. (2014), Grauer & Maoz (Atel 4199)**
- 14 Type Ibc SNe with HST or deep ground based imaging
- No progenitor detections, probability the Ibc progenitor population is drawn from known WR stars is 12%
- Rate to high at 26% of CCSN (Smith et al. 2011)

IMF and different stellar models

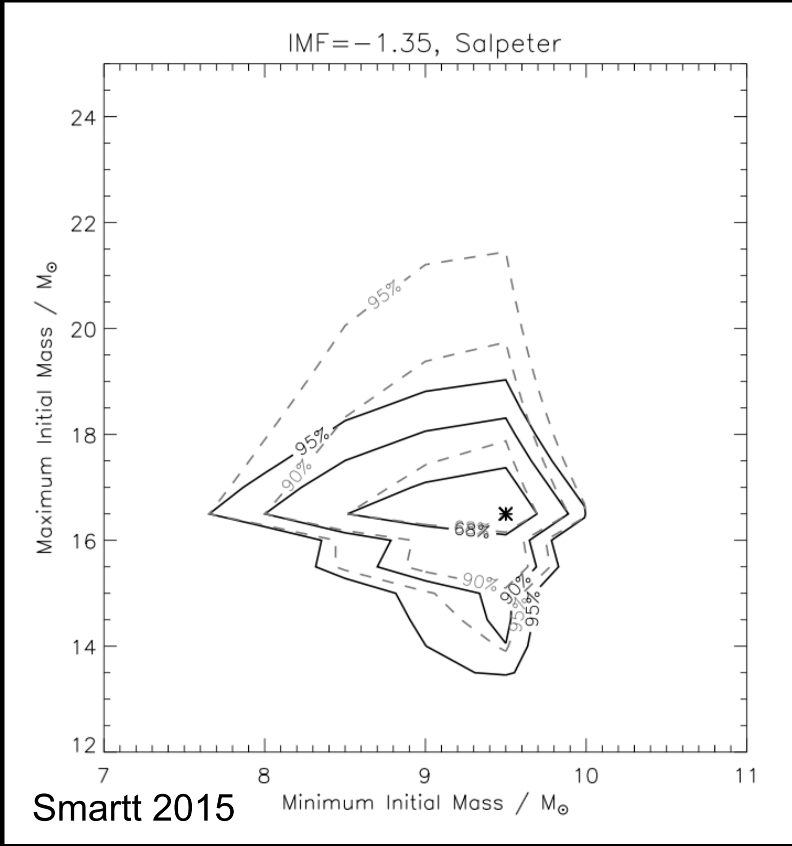




Smartt 2015

STARS : Eldridge & Tout 2004
Geneva : Hirschi et al. 2004
KEPLER : Woosley & Heger 2007

IMF and probability of missing high mass stars

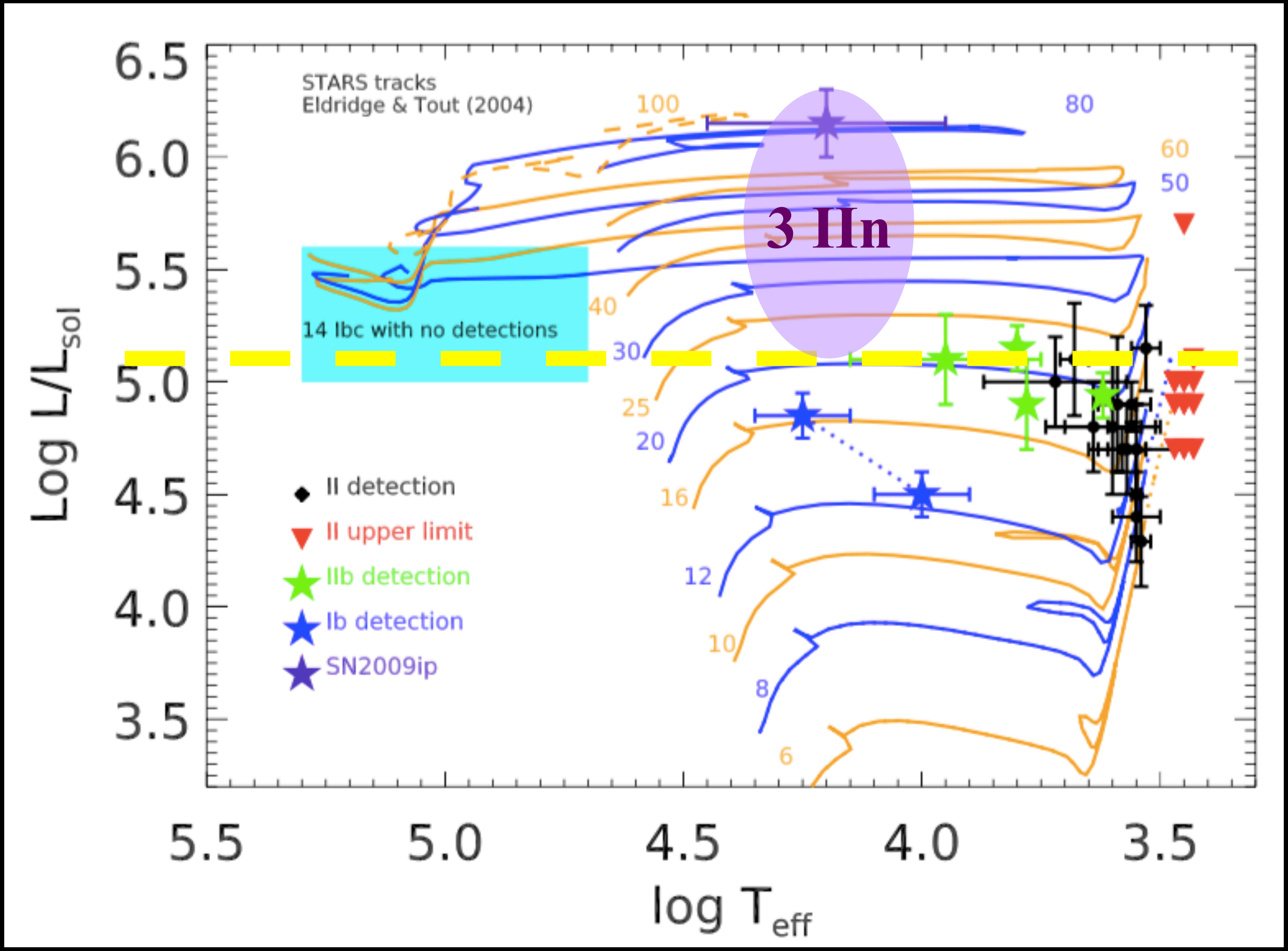


Smartt 2015

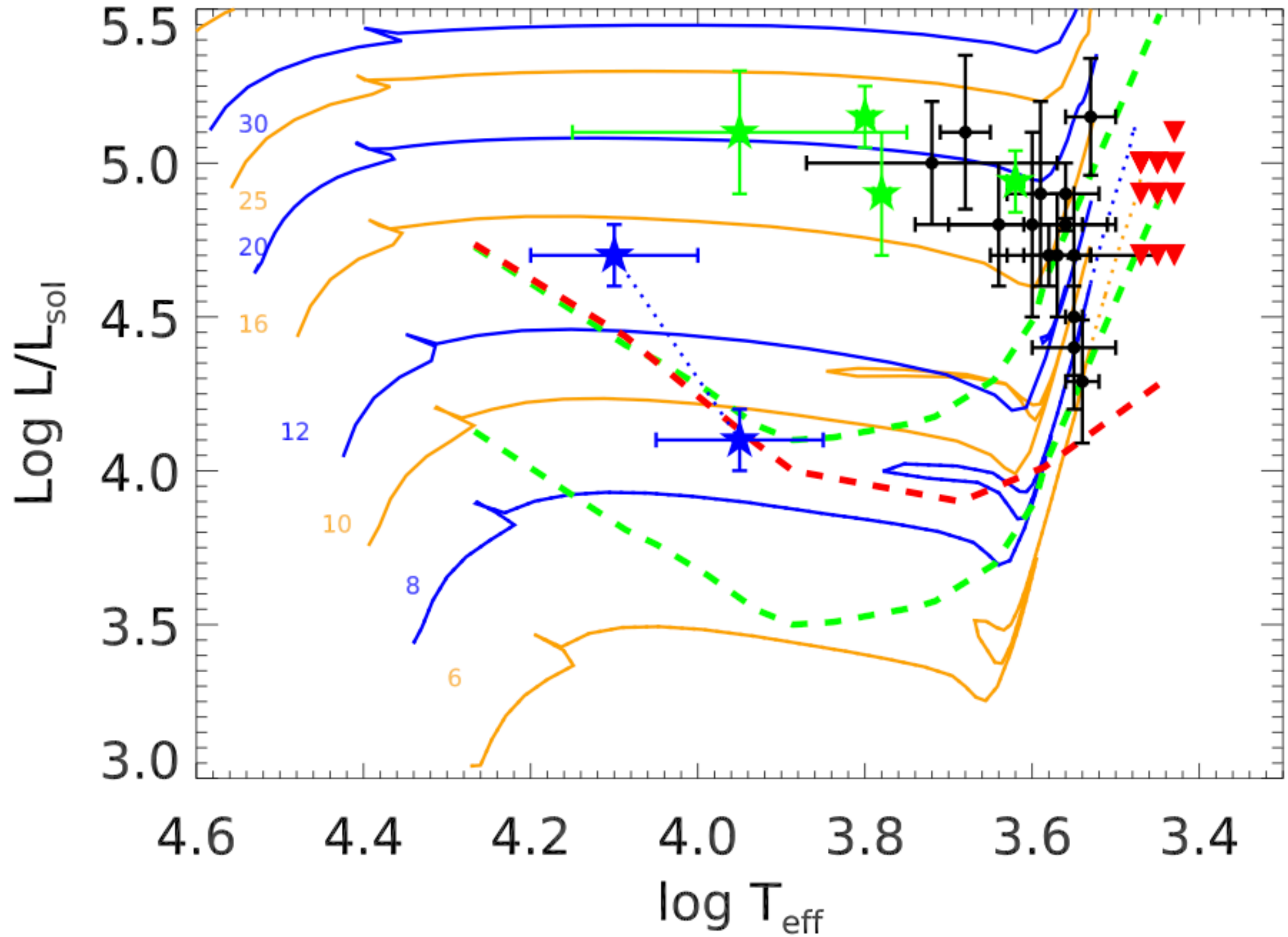
- Maximum likelihood calculation implies
  $M_{min} = 9.5^{+0.5}_{-2} M_\odot$
  $M_{max} = 16.5^{+2.5}_{-2.5} M_\odot$
  (95% confidence limits)

- For Salpeter IMF, $\alpha = -2.35$: $54^{+20}_{-16}\%$ of all massive stars are in this mass range
- With 34 stars below M_{min} we would expect to see 12 stars above $19M_\odot$ (for 74%)
- Prob of $n \leq 3$ if expectation is 12
  p = 0.0023 (3σ significance)
- *Statistical deficit of massive progenitors*

HRD for progenitors

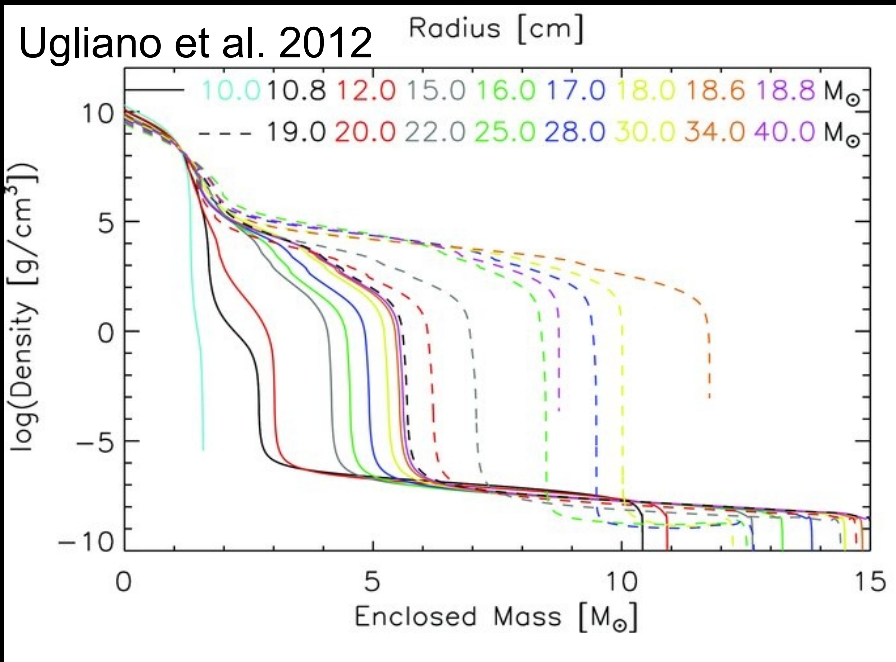


- Results 1998 – 2016 ; within 28 Mpc
- 51 objects in total
- Apparent upper luminosity limit : $\log L/L_{\odot} \approx 5.1$

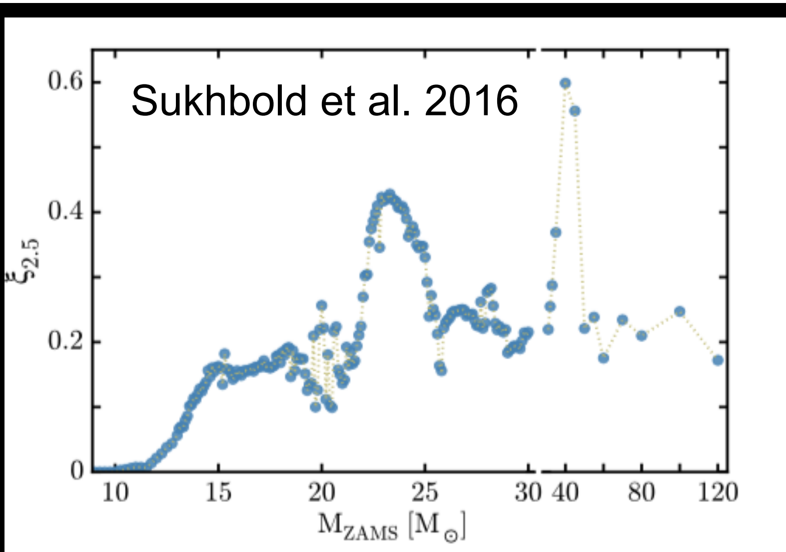


Log L/L$_{sol}$
log T$_{eff}$
5.5
5.0
4.5
4.0
3.5
3.0
4.6
4.4
4.2
4.0
3.8
3.6
3.4
30
25
20
16
12
10
8
6

Compactness and explodability



$$\xi_{2.5} \equiv \frac{M/M_{\odot}}{R(M)/1000\,\mathrm{km}},$$



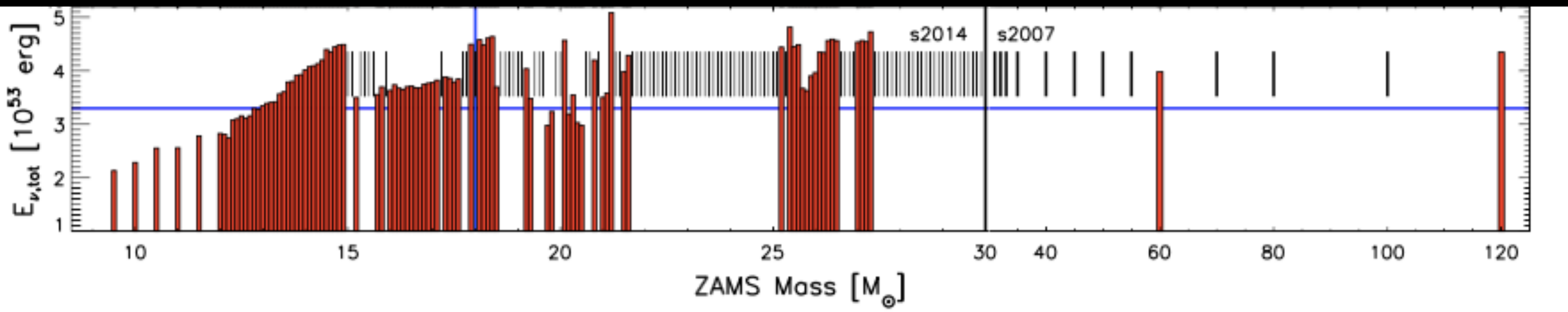
"Compactness"

M=2.5M$_{\odot}$

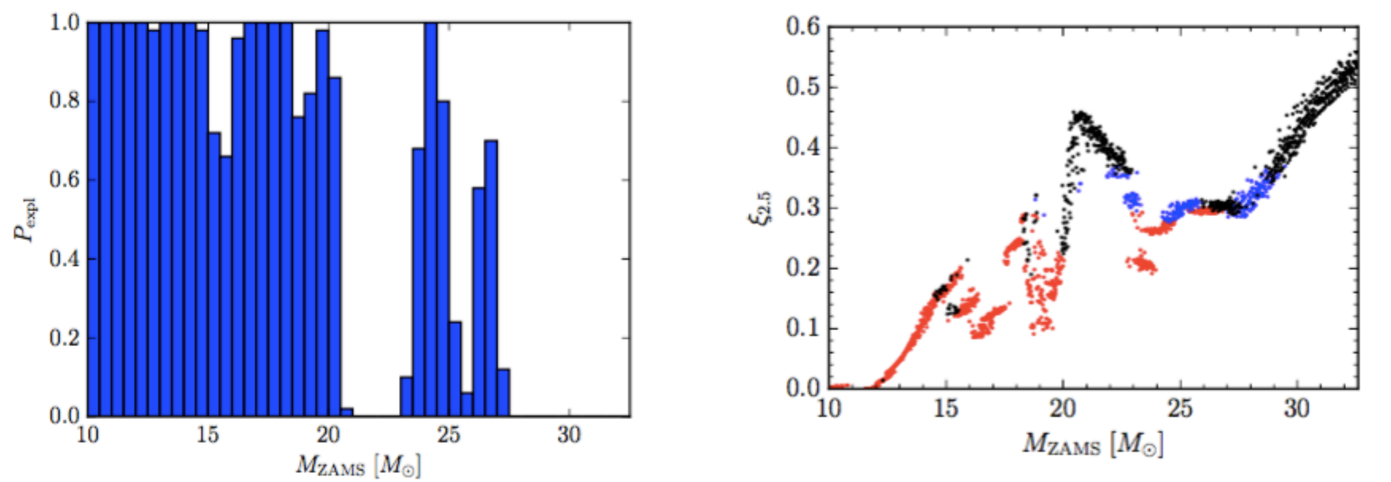
- O'Connor & Ott 2011, 2013
- Ugliano et al. 2012
- Sukhbold & Woosley 2014

Explodability by mass

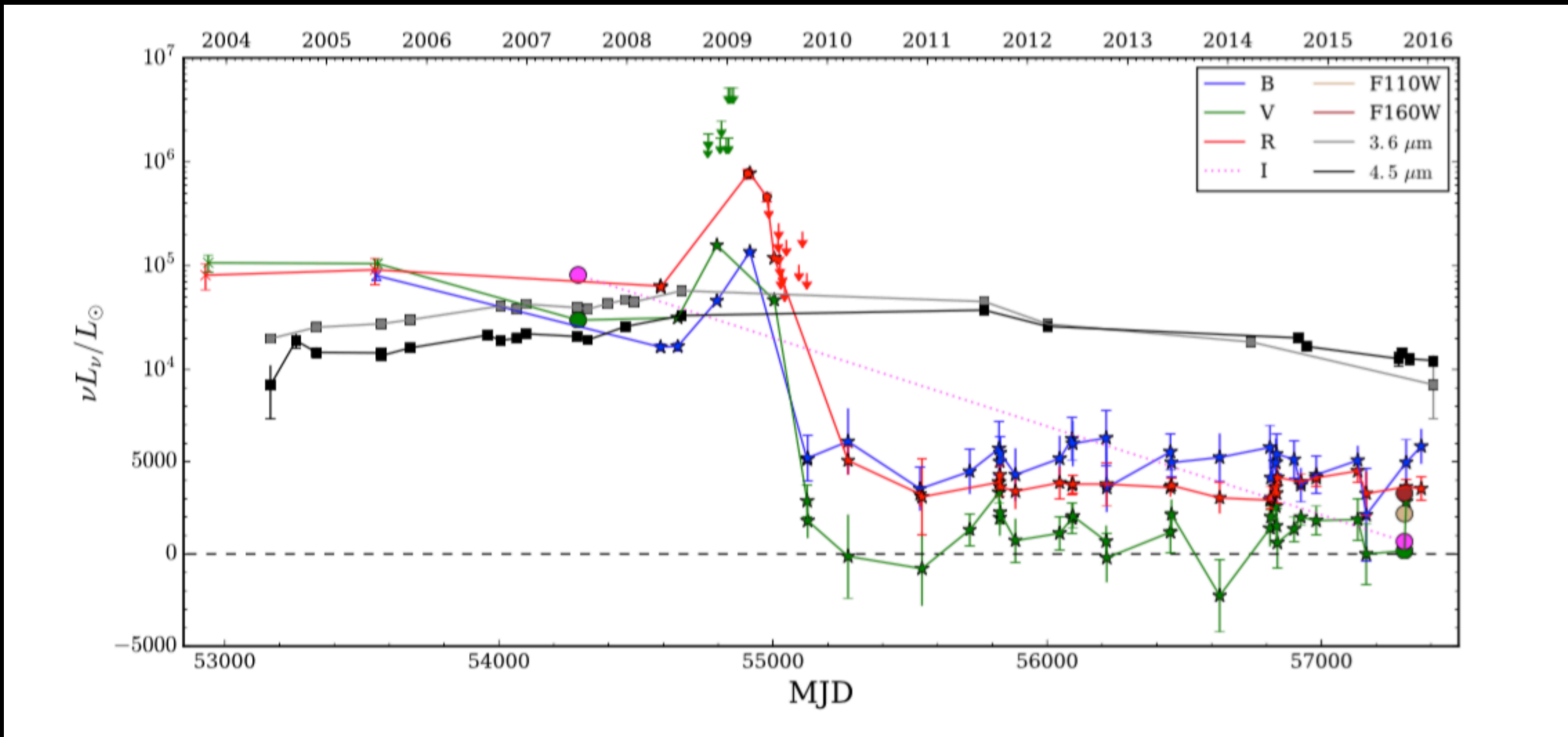
Sukhbold et al. 16, Ertl et al. 16



Mueller et al. 16 *A Simple Approach to the Supernova Progenitor-Explosion Connection* 11



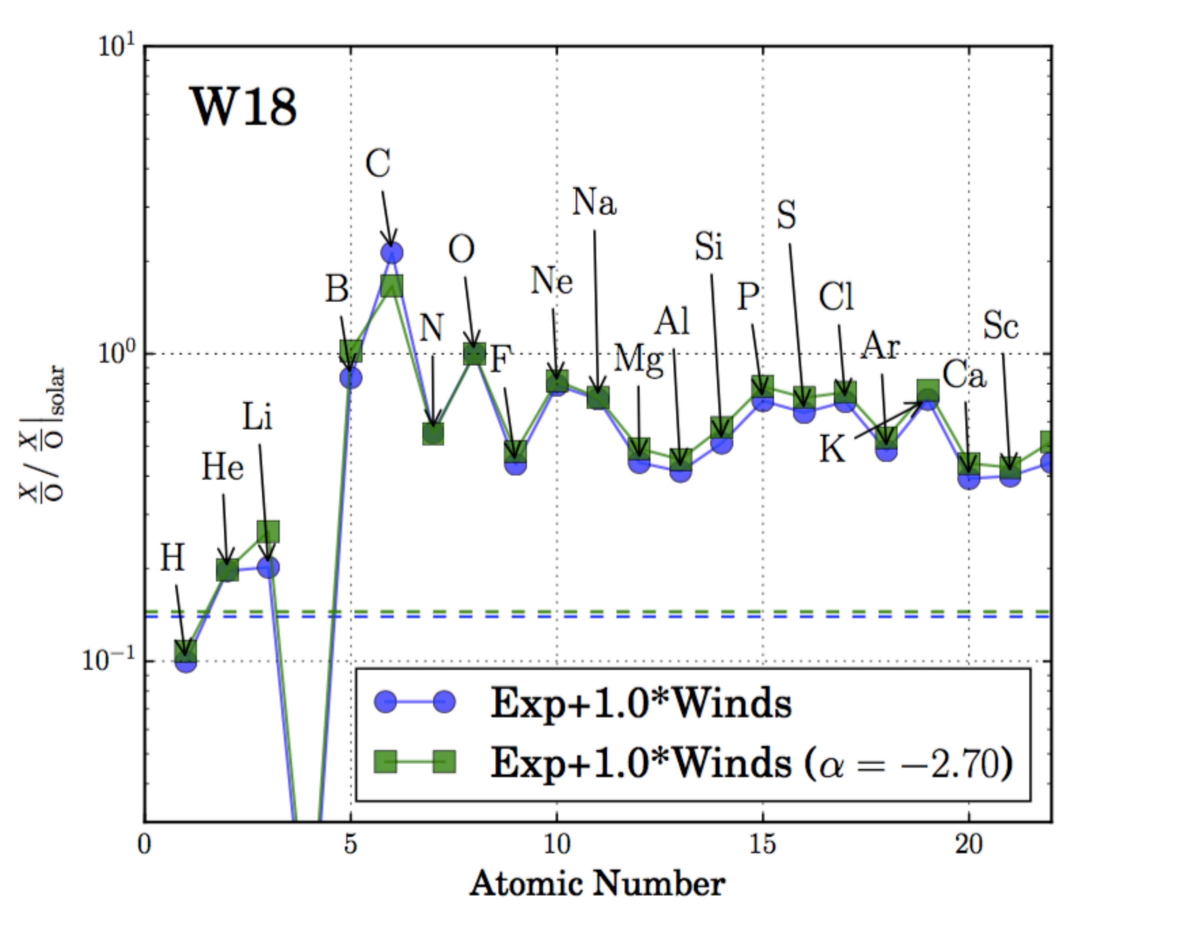
"Lightcurve of a failed SN"



Adams, Kochanek, Gerke, Stanek 2017, https://arxiv.org/abs/1610.02402

Also see Reynolds, Fraser, Gilmore 2016

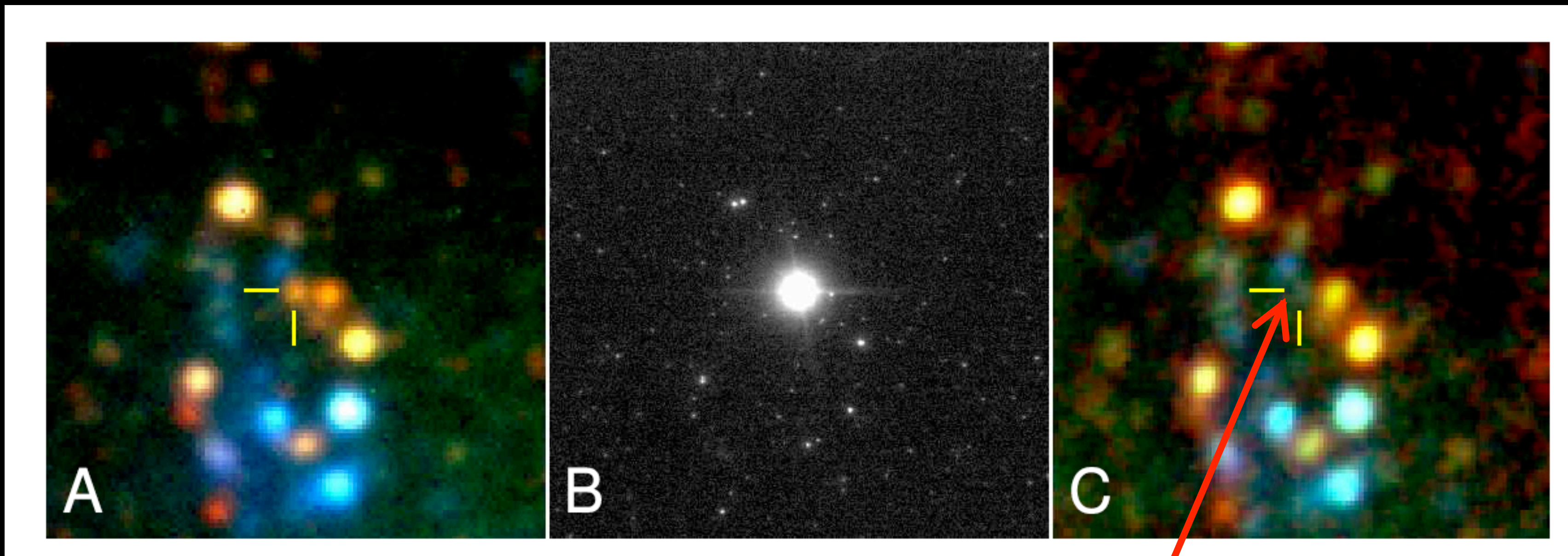
Nucleosynthesis : oxygen mass as function of progenitor mass



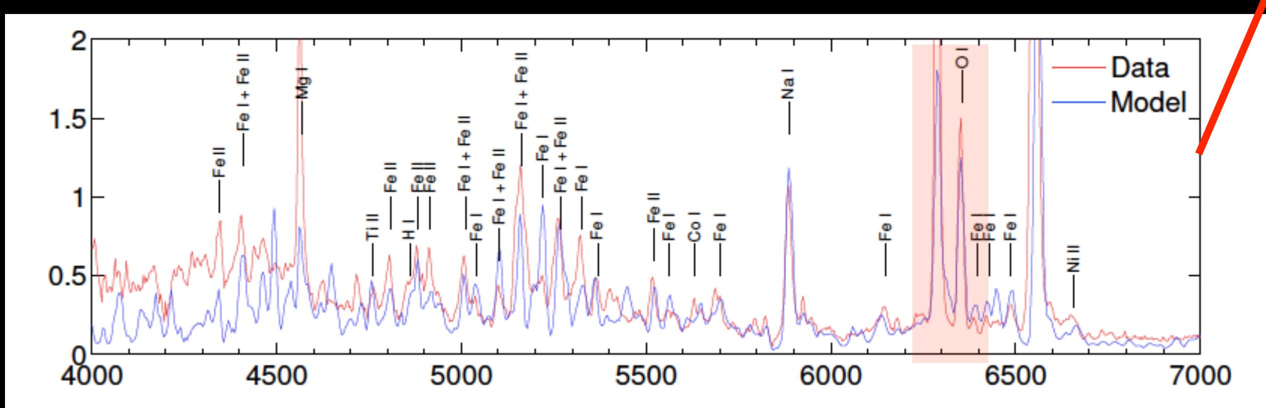
Sukhbold et al 16: integrating over $9 - 120 M_{\odot}$ (winds + successful explosions) provides satisfactory nucleosynthesis ratios across most isotopes

Also : Brown & Woosley (2013)

Core-collapse SN : progenitor to enrichment



VLT FORS+HAWKI VLT NACO NTT EFOSC2

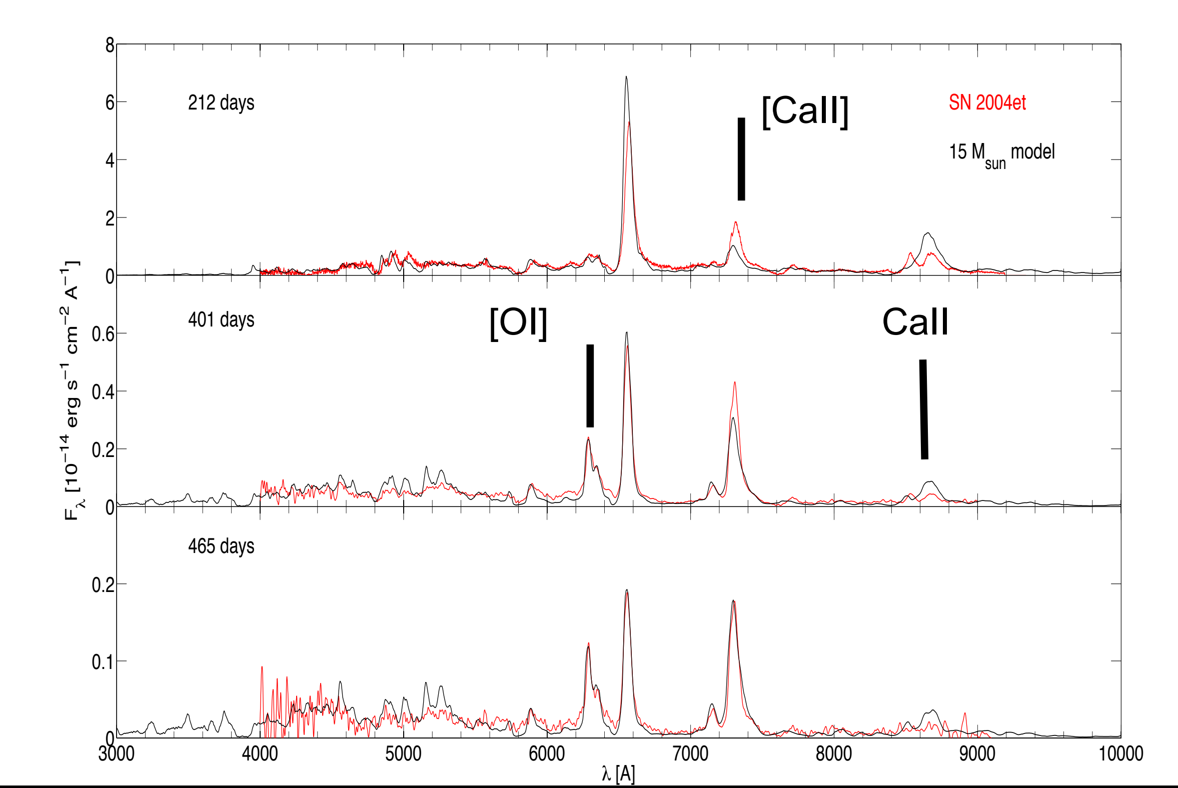


VLT FORS

Mattila et al. 08, Maguire et al. 2012

SUMO: Radiative transfer code

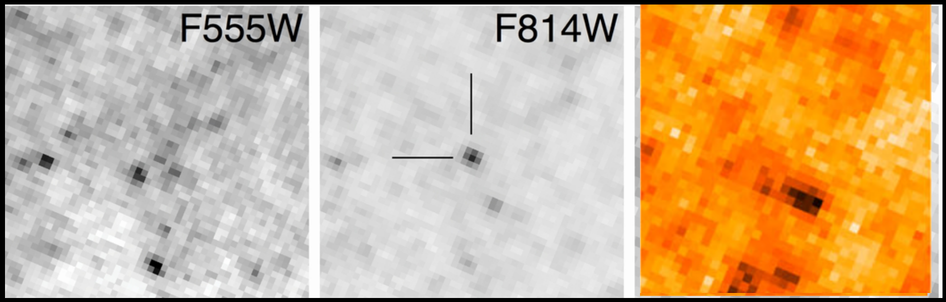
- Radioactive deposition
- Temperature, ionization and excitation solutions
- Radiative transfer calculations
- Macroscopic mixing



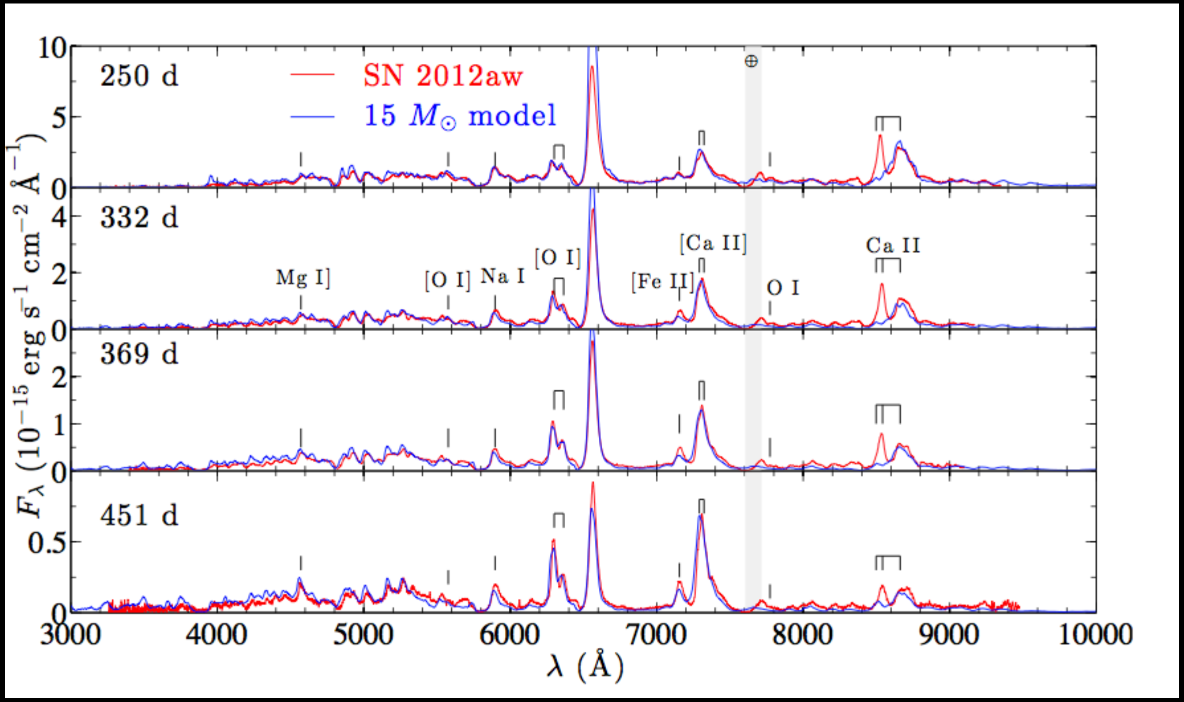
SN 2004et compared to a 15 M_{sun} model (~0.5M_{sun} oxygen)

Kozma & Fransson 1998
Jerkstrand et al. 2014, 2012 ; 2010

SN2012aw in M95 (10Mpc)



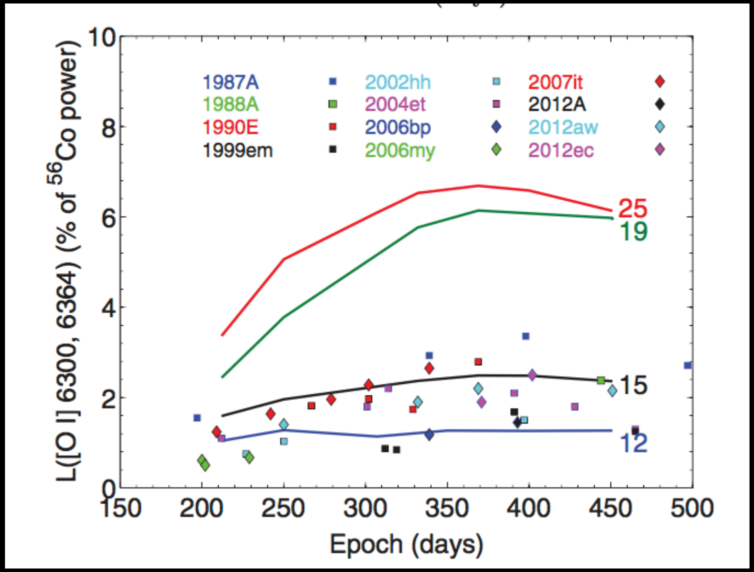
Fraser et al. 2012,
Fraser 2015
Also : Kochanek et al. 2012,
Van Dyk et al. 2012



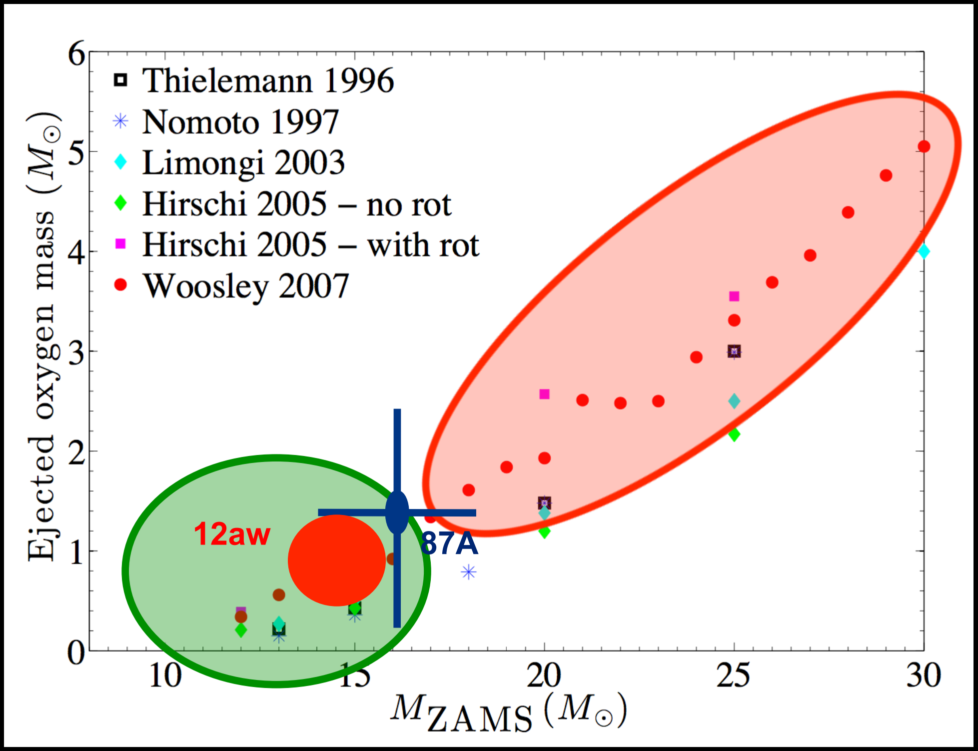
Jerkstrand, Smartt et al. 2014
13-16 $M_\odot$ progenitor, $0.6^{+0.3}_{-0.1} M_\odot$ of synthesised oxygen

Type IIP and IIb SNe and oxygen production

[O I] 6300, 6364 Å



Jerkstrand et al. 12, 14, 15



Oxygen production convolved with an IMF

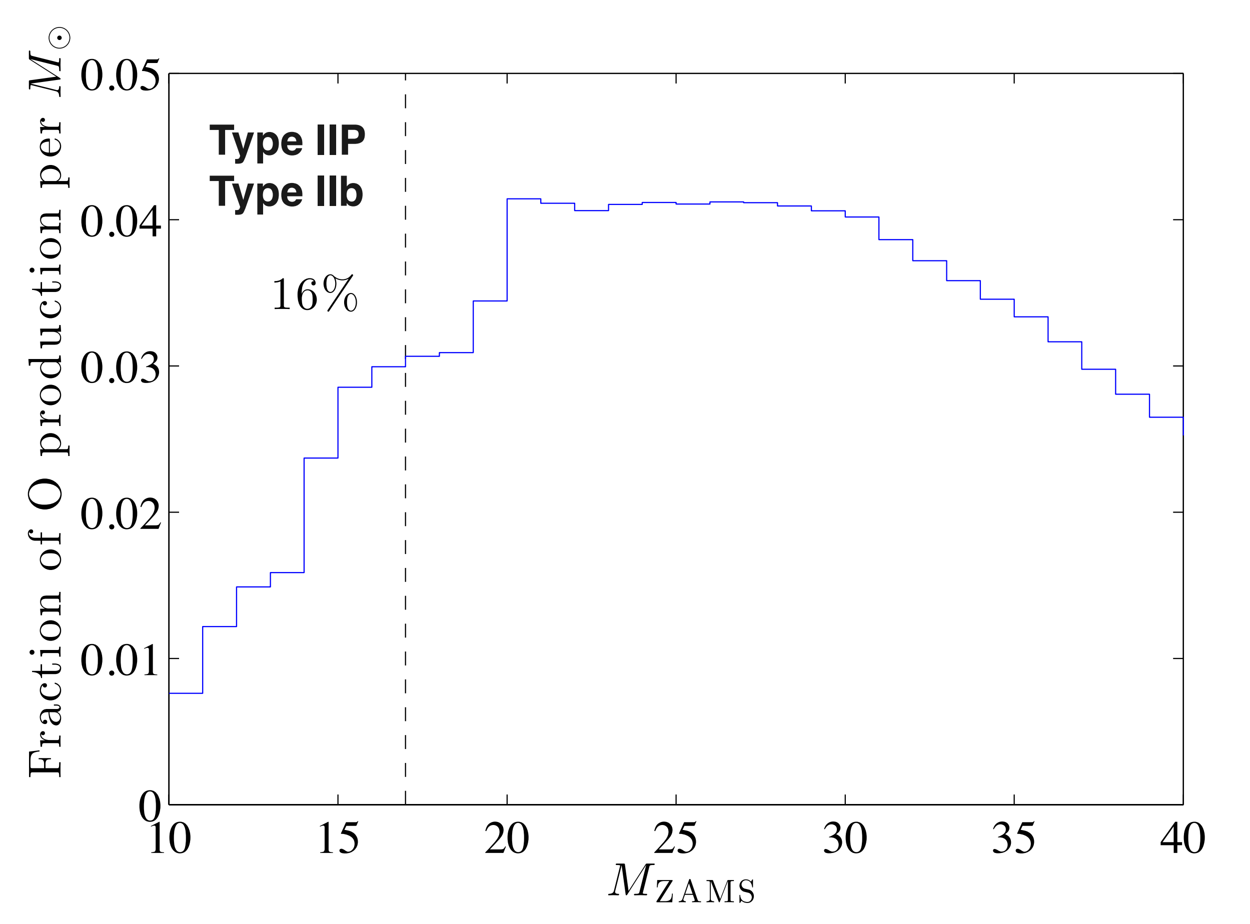


Image Credit : A. Jerkstrand
Integrate stellar yields with IMF

Overview and summary

- All SNe closer than ~20-30Mpc now routinely have a progenitor search (several teams)
- High resolution archive images (HST + good seeing ground based) commonly detect progenitors.
  - Massive stars M > ~16-18$M_{\odot}$ “missing”
  - Not inconsistent with explosion modeling results
  - Type Ibc : rates, ejecta masses and non-detections imply binaries
- Nebular spectra and radiative transfer models give O, Mg, Ca ejected masses
- The channel for cosmic oxygen not quantitatively demonstrated