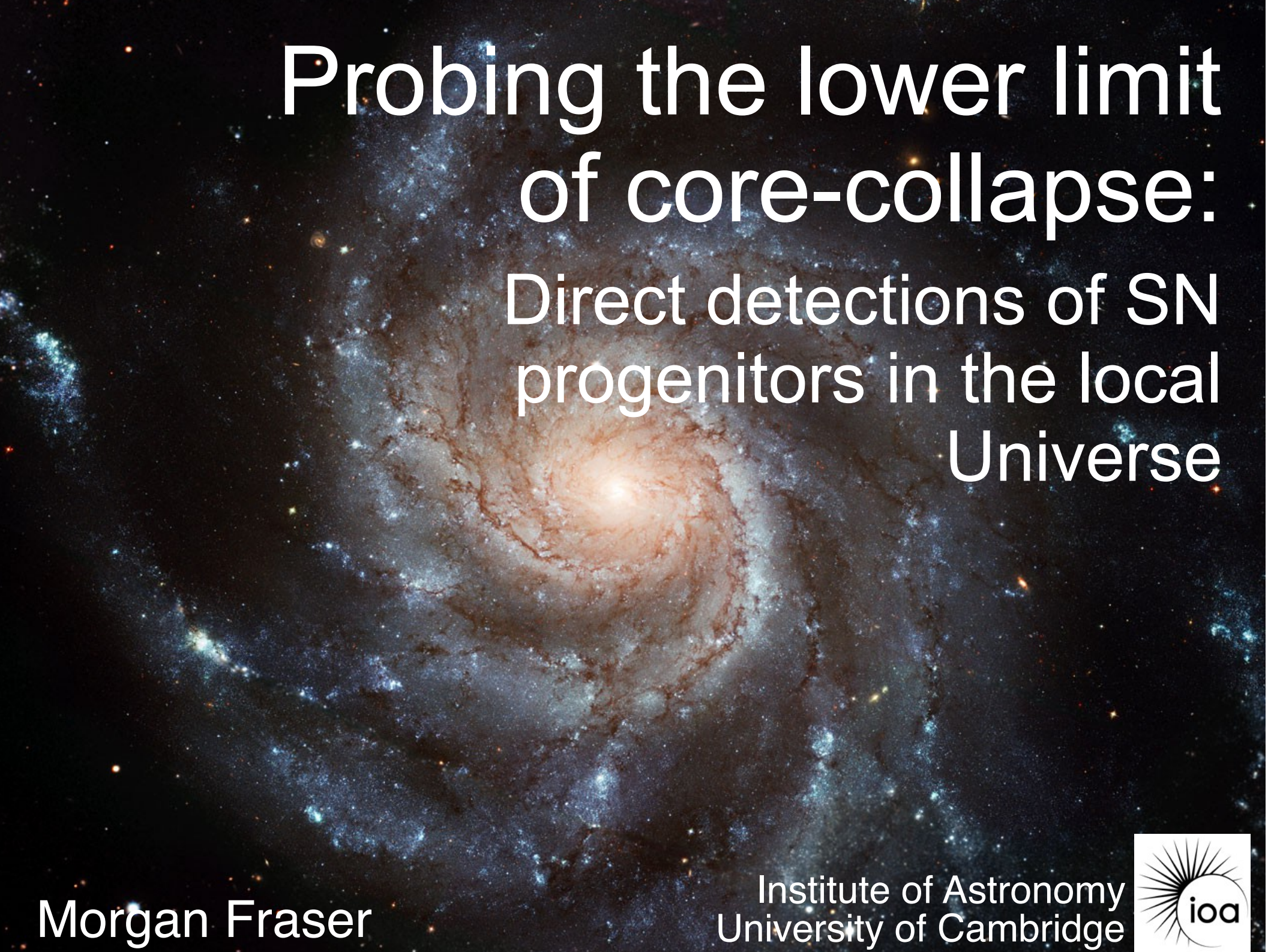
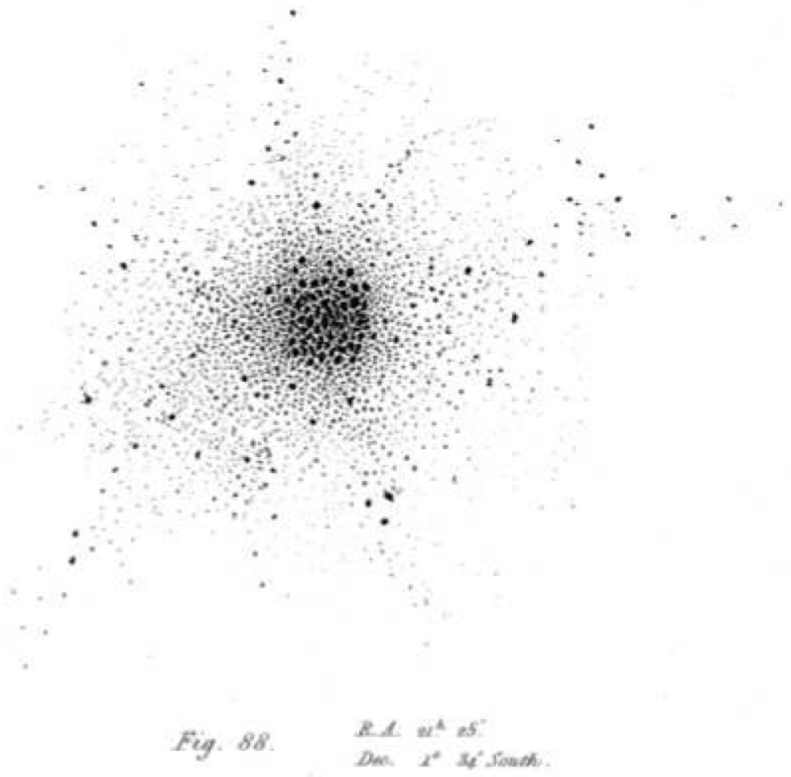


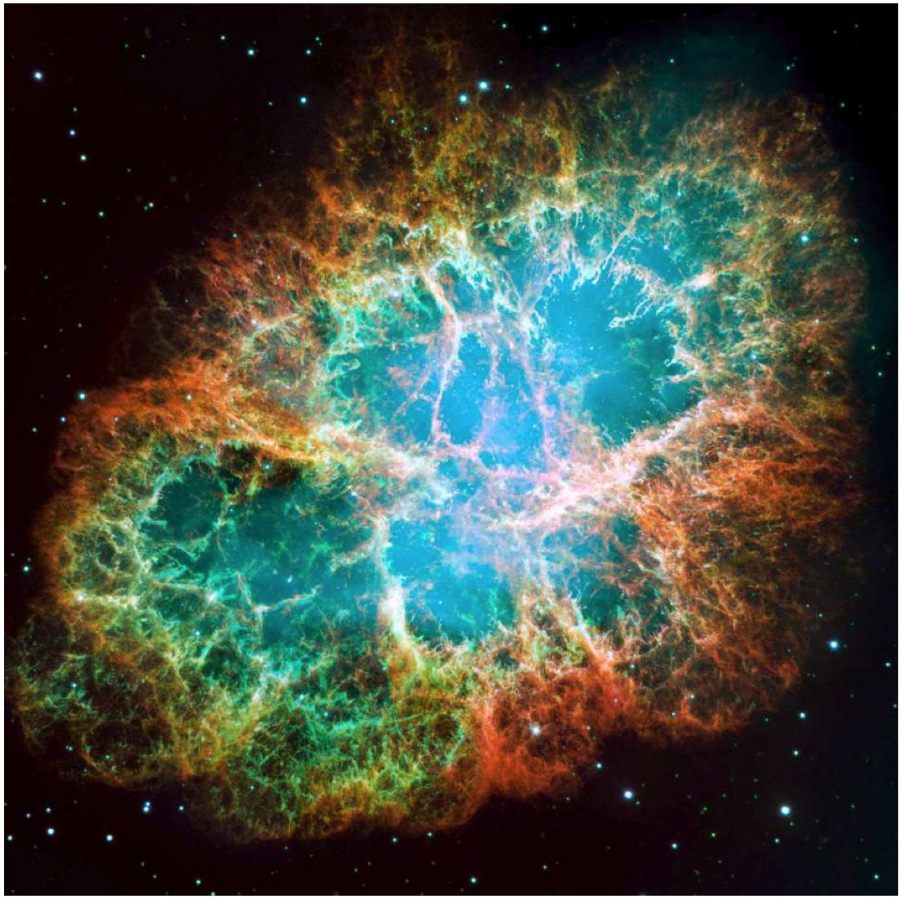
Probing the lower limit of core-collapse:

Direct detections of SN progenitors in the local Universe

Morgan Fraser

Institute of Astronomy
University of Cambridge





The Crab SN, possibly seen by Irish monks...

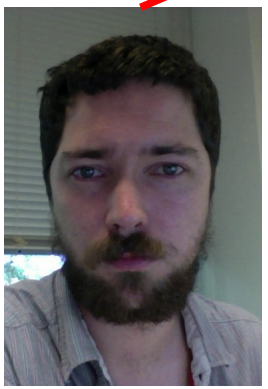
McCarthy, D. & Breen, A. 1997, Vistas in Astronomy, 41, 117

(Some of) the guilty parties...

Stephen Smartt (Queens University Belfast)

Anders Jerkstrand (Queens University Belfast)

Seppo Mattila (University of Turku)



Morgan Fraser (University of Cambridge)

Nancy Elias Rosa (University di Padova)

John Eldridge (University of Auckland)

Outline

- Searching for supernova progenitors
  - H-rich supernovae
  - H-poor supernovae
- What's happening at the low mass end?
- Supernovae with a CSM
- Conclusions

Definitions:

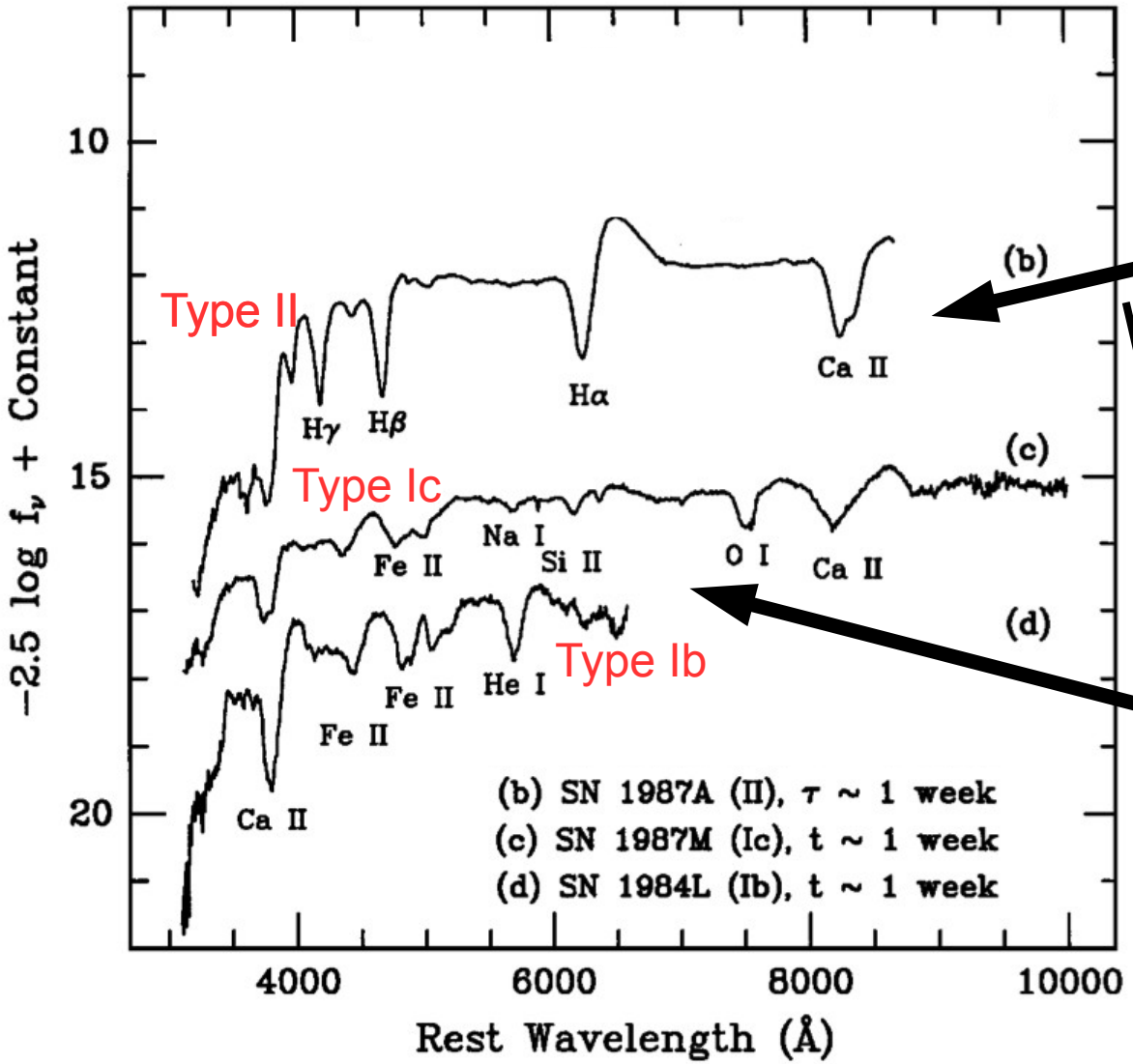
"Low mass" ~ 8-10 $M_\odot$

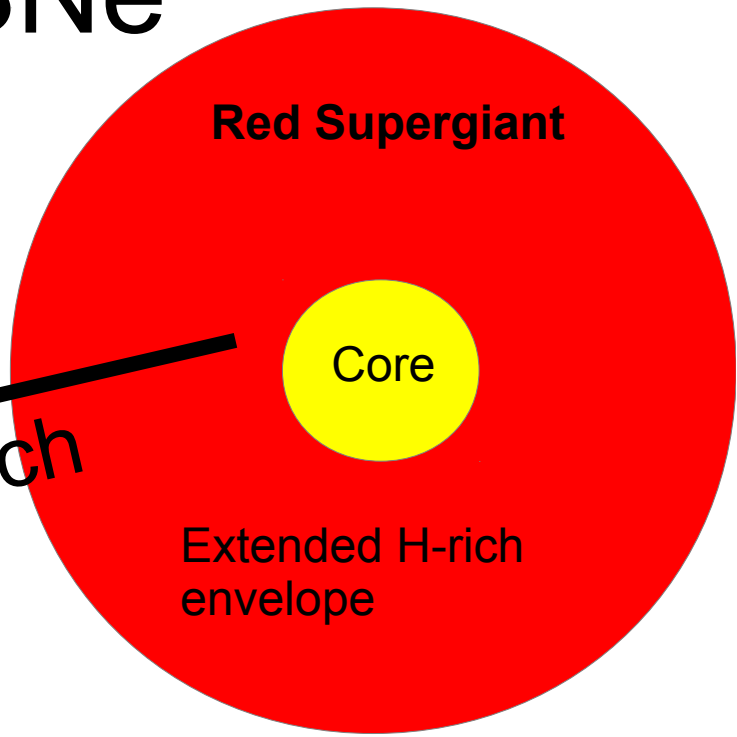
"High mass" > 20 $M_\odot$

"Nearby" < 25 Mpc

"Distant" > 25 Mpc

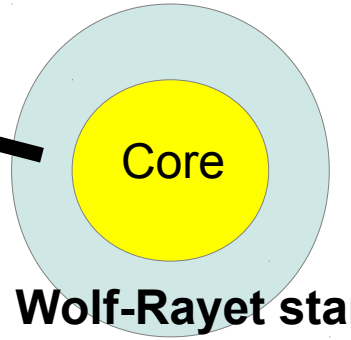
Core collapse SNe





H-rich

H-poor



Wolf-Rayet star?
Low-mass binary?

Outline

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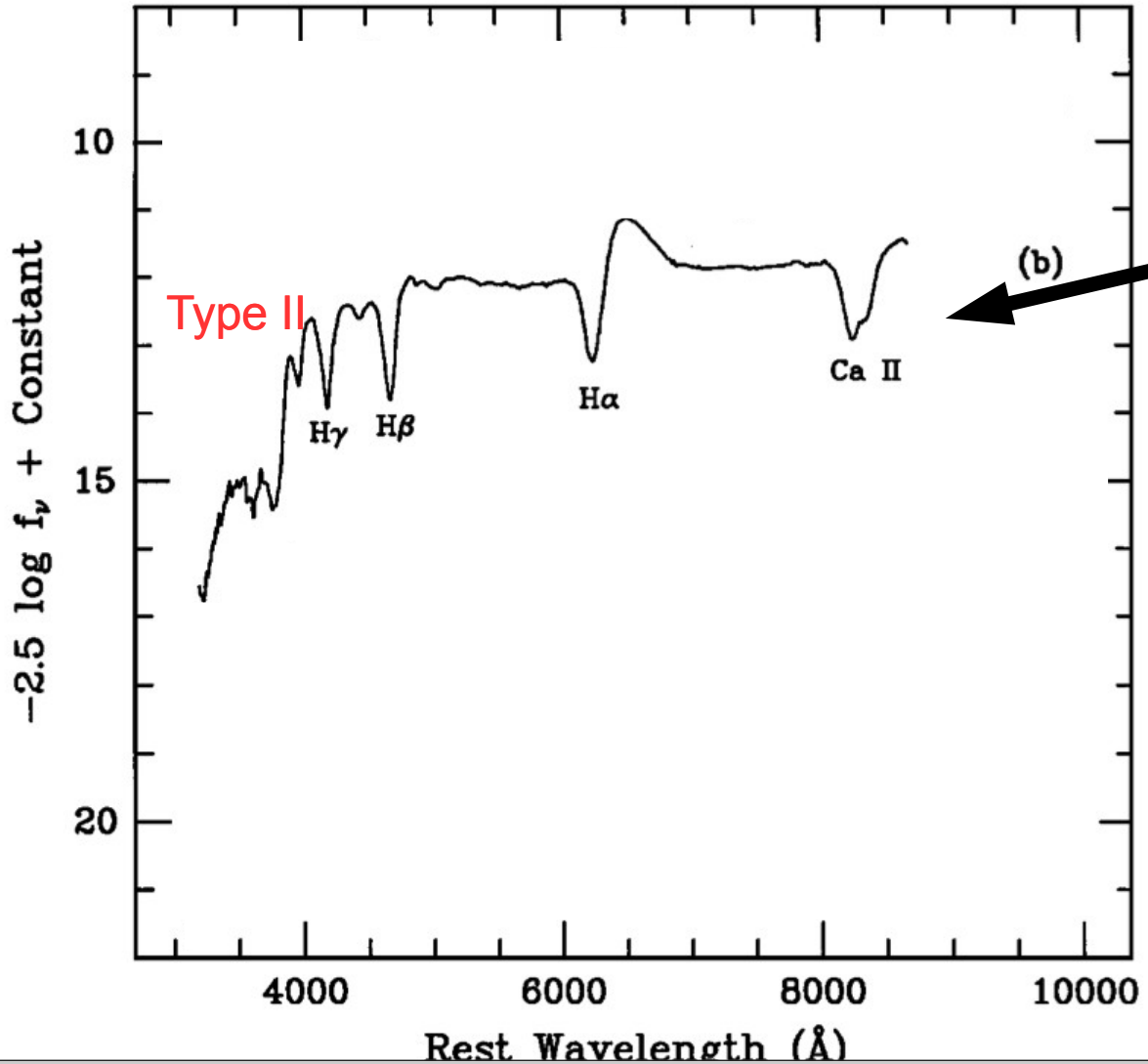
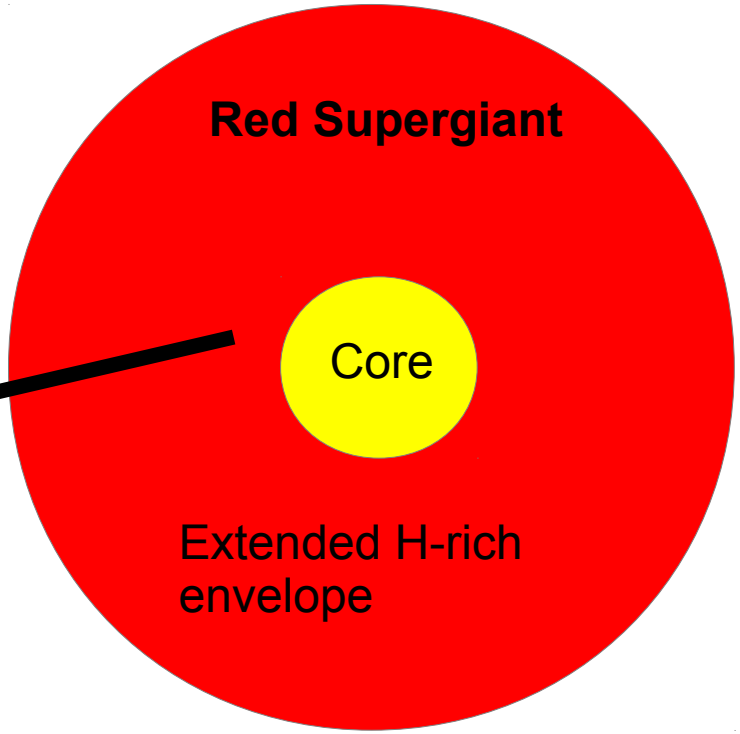
The H-rich Supernovae





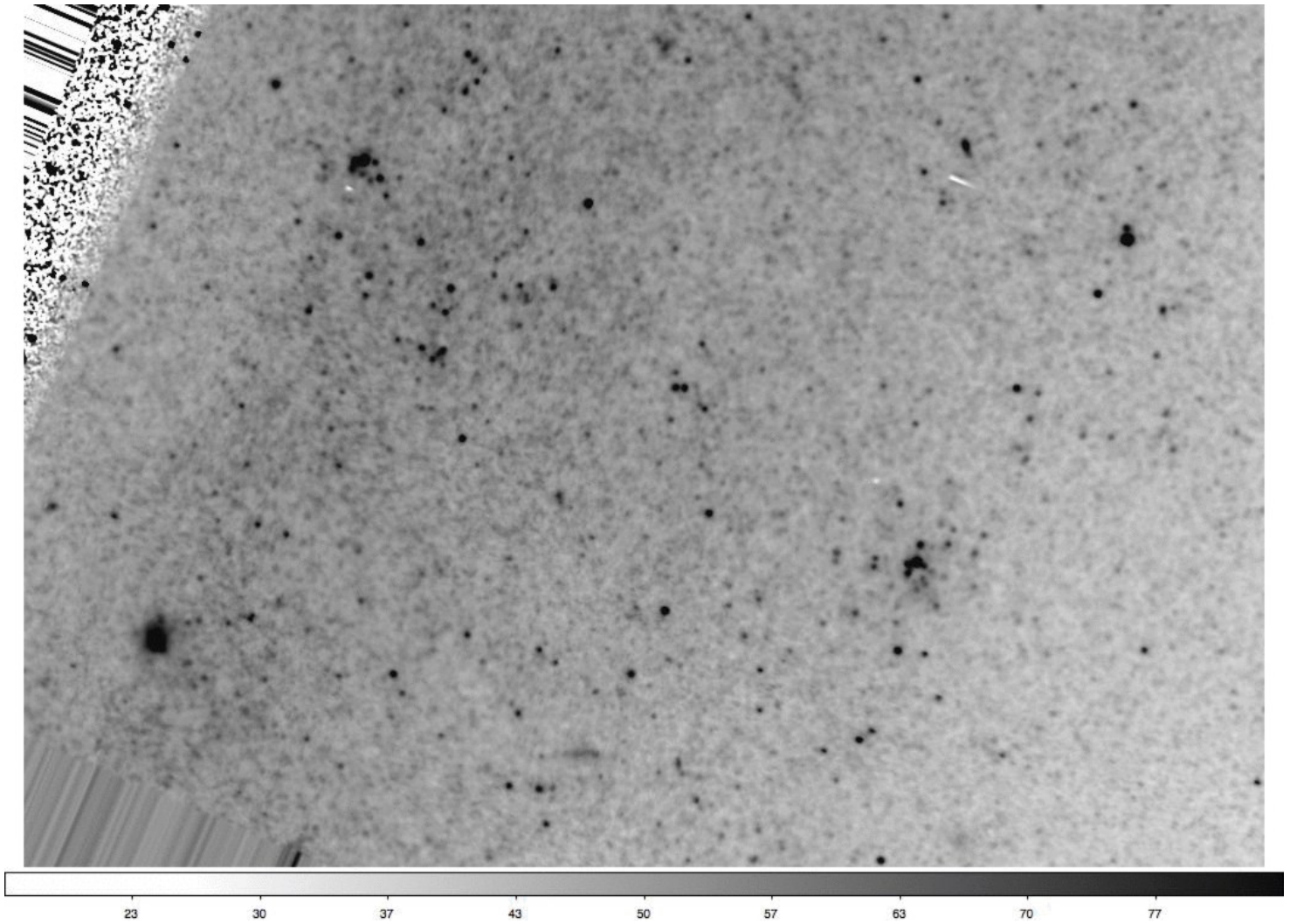
M51 HST+ACS mosaic (Mutchler et al. 2005)

Searching for SN progenitors

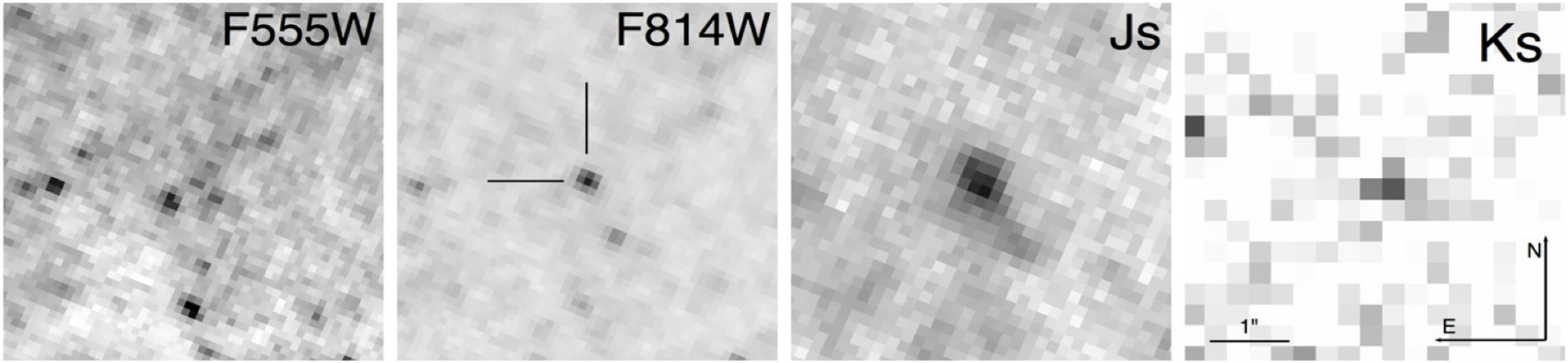
- What we need:

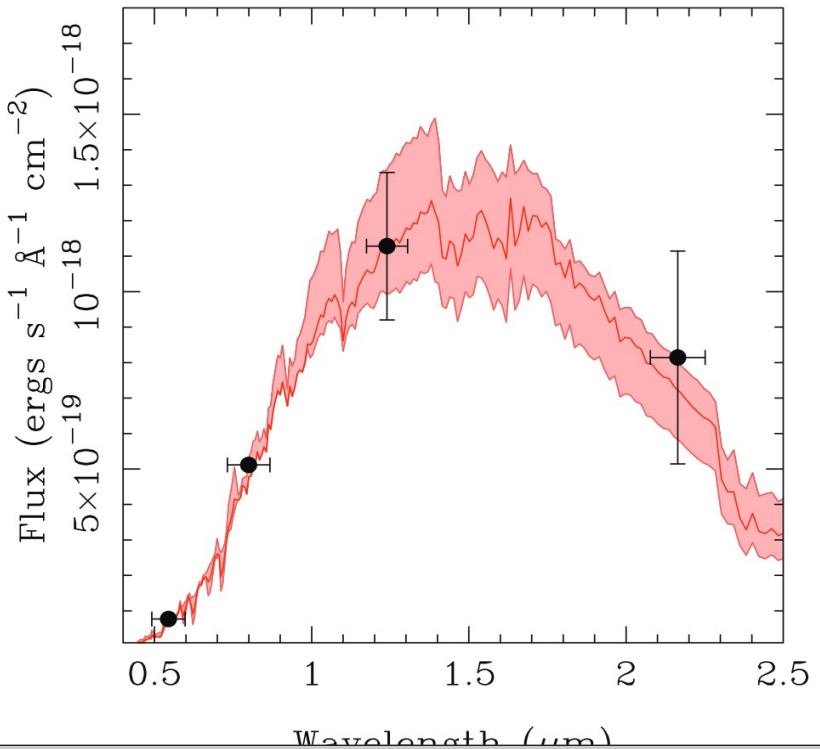
Limiting mag V~25
Spatial resolution ~0.1”

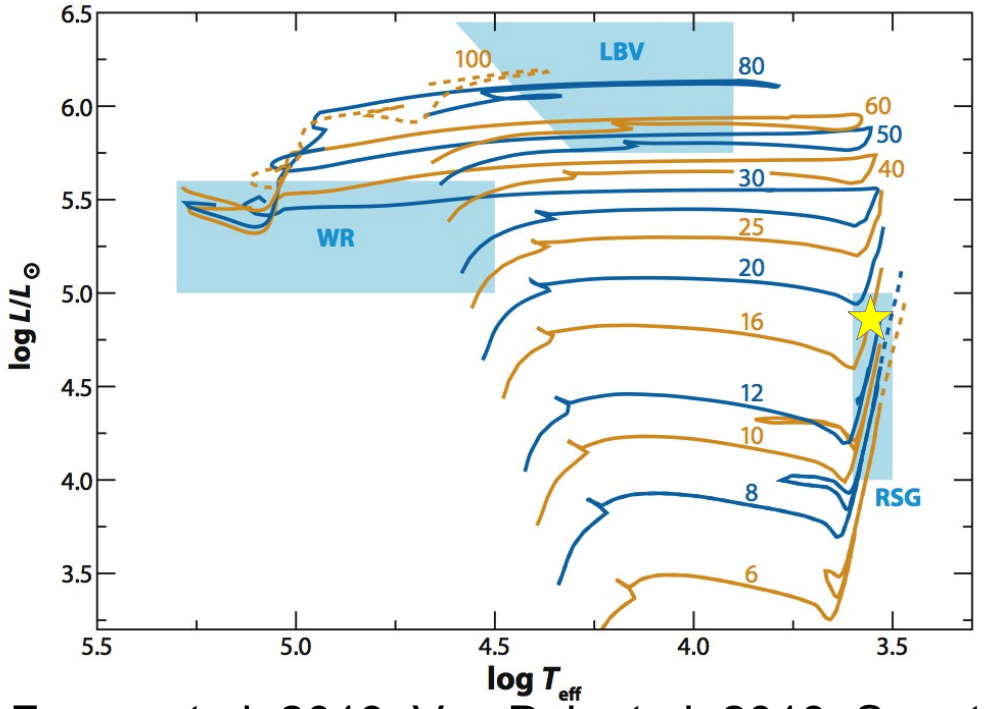
Messier 95



SN 2012aw in M95

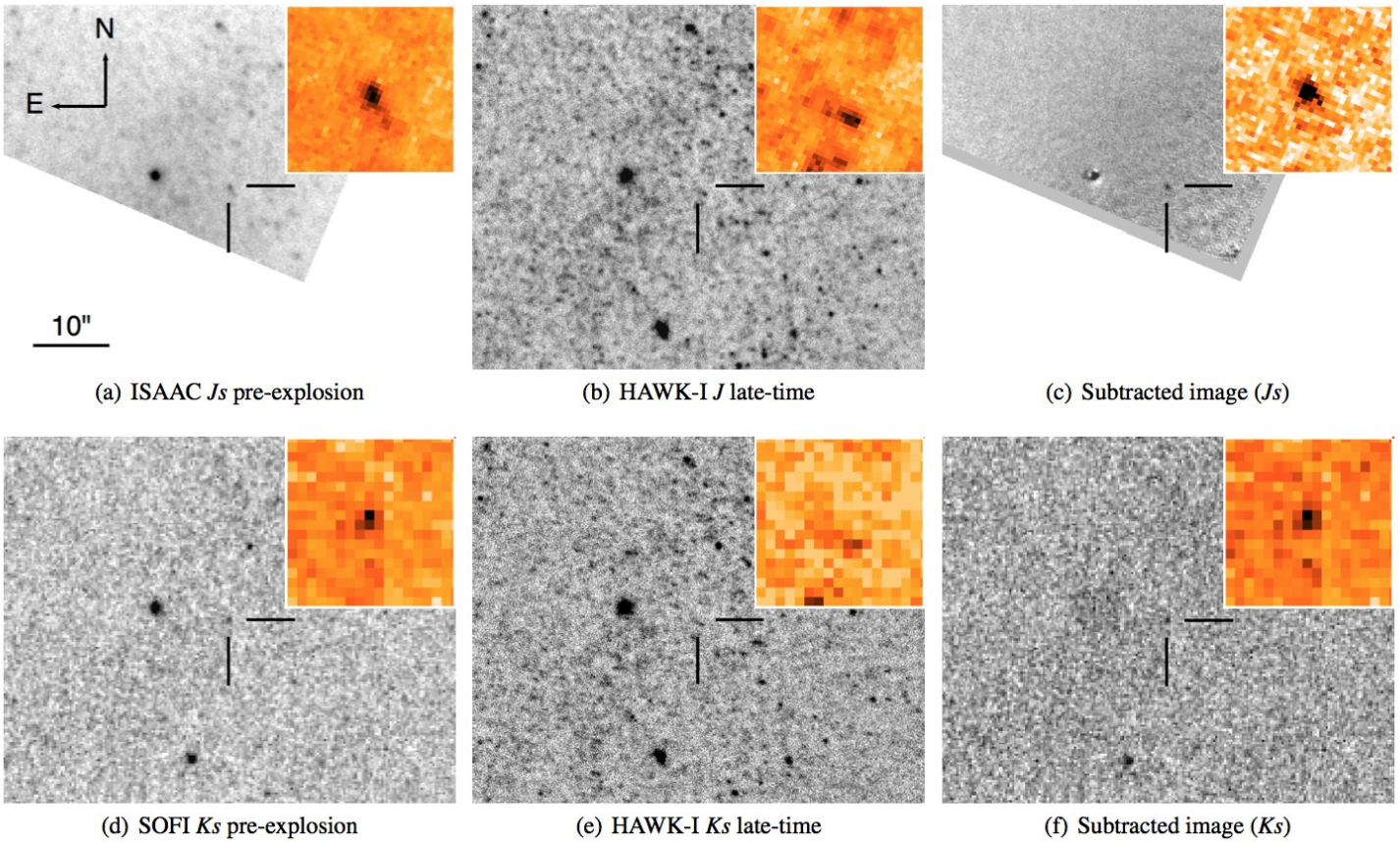






Fraser et al. 2013; Van Dyk et al. 2013, Smartt 2009

Confirmation

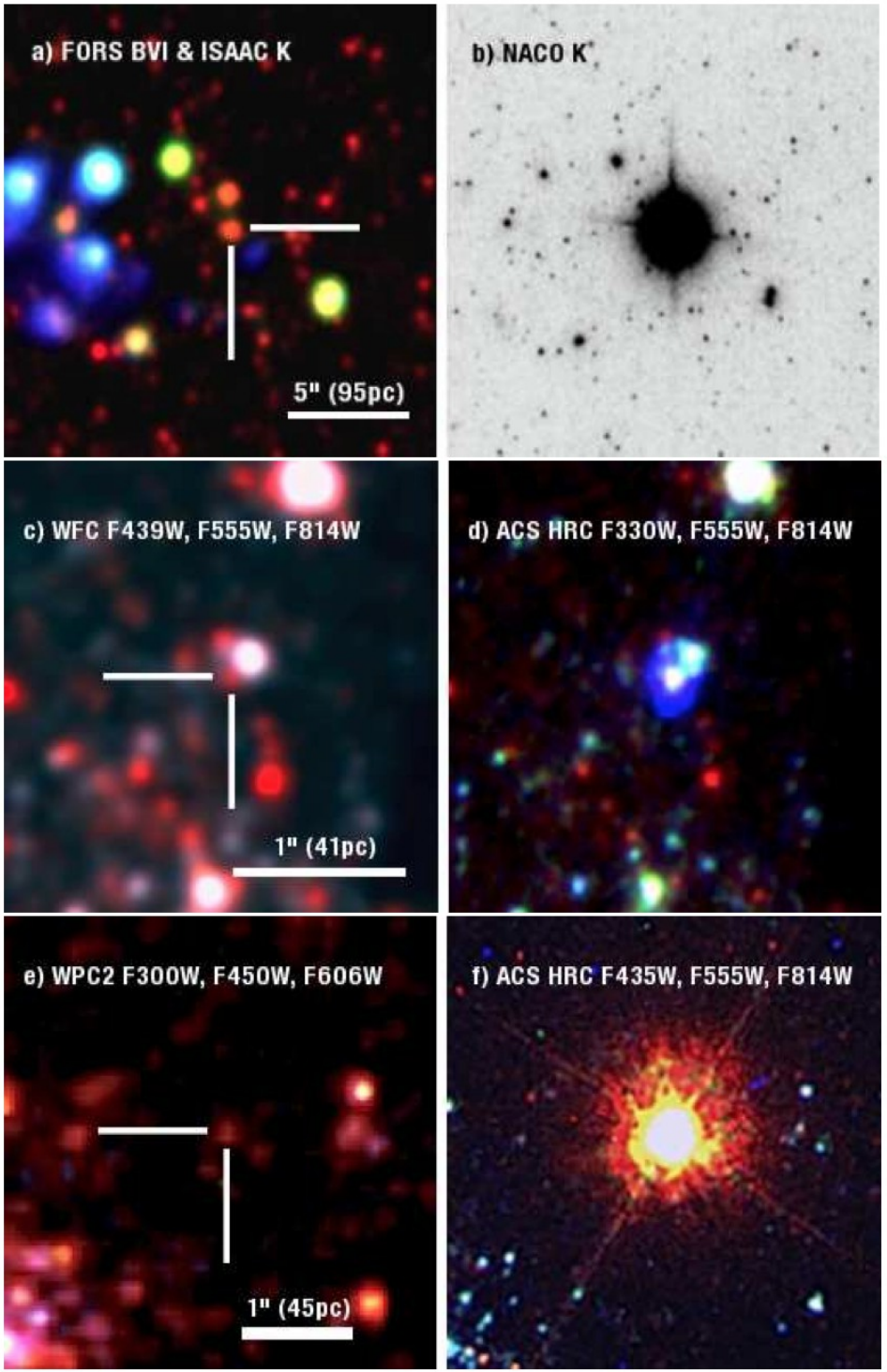


(a) ISAAC *Js* pre-explosion (b) HAWK-I *J* late-time (c) Subtracted image (*Js*)

(d) SOFI *Ks* pre-explosion (e) HAWK-I *Ks* late-time (f) Subtracted image (*Ks*)

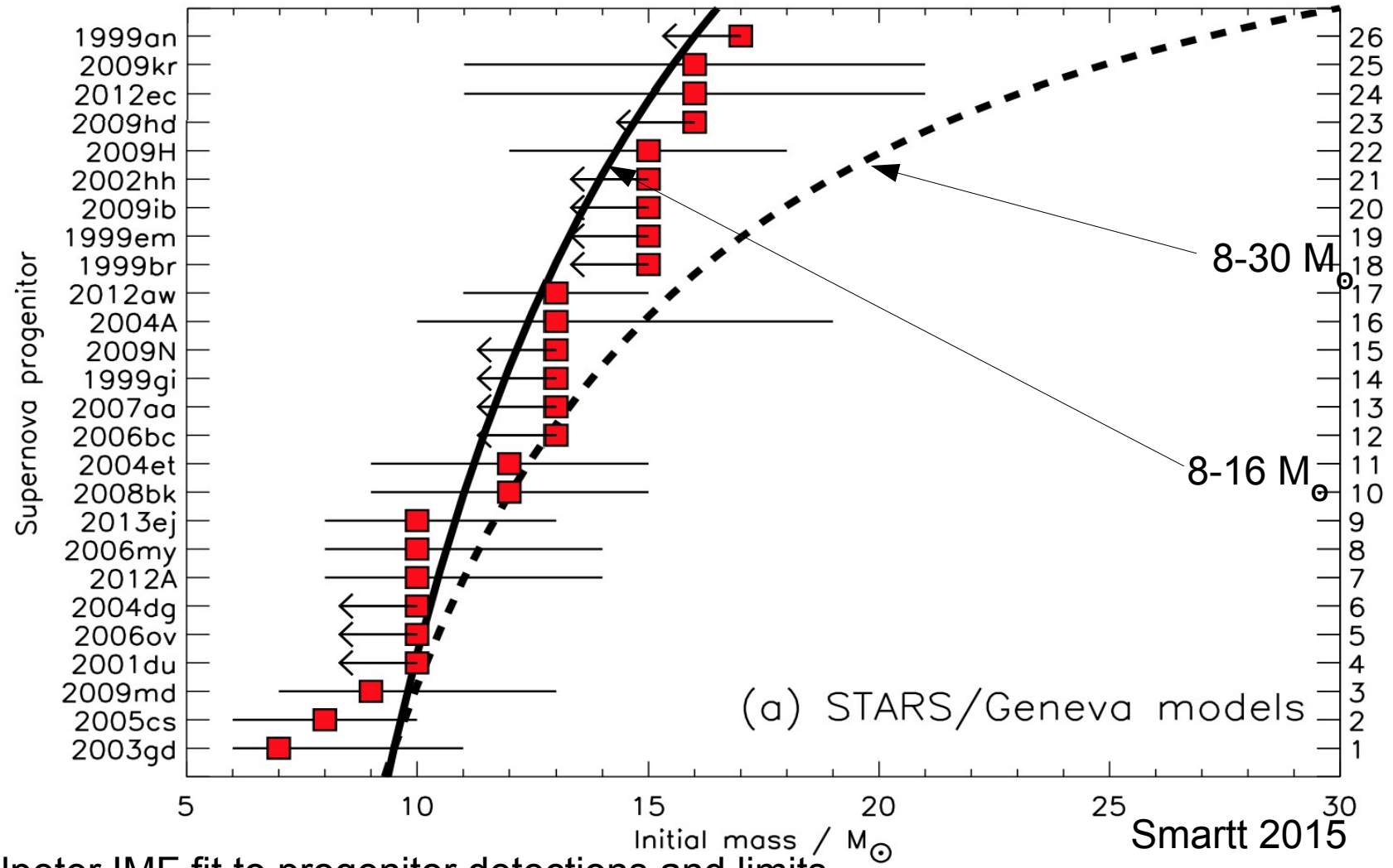
The disappearance of progenitors after the SN has faded can be used to confirm the identification (eg. SN 2008bk, 2012aw, 2005cs)

Mattila et al. 2010
Van Dyk et al. 2013
Maund et al. 2013
Fraser 2015


a) FORS BVI & ISAAC K
5" (95pc)
b) NACO K
c) WFC F439W, F555W, F814W
1" (41pc)
d) ACS HRC F330W, F555W, F814W
e) WPC2 F300W, F450W, F606W
1" (45pc)
f) ACS HRC F435W, F555W, F814W

Smartt 2009

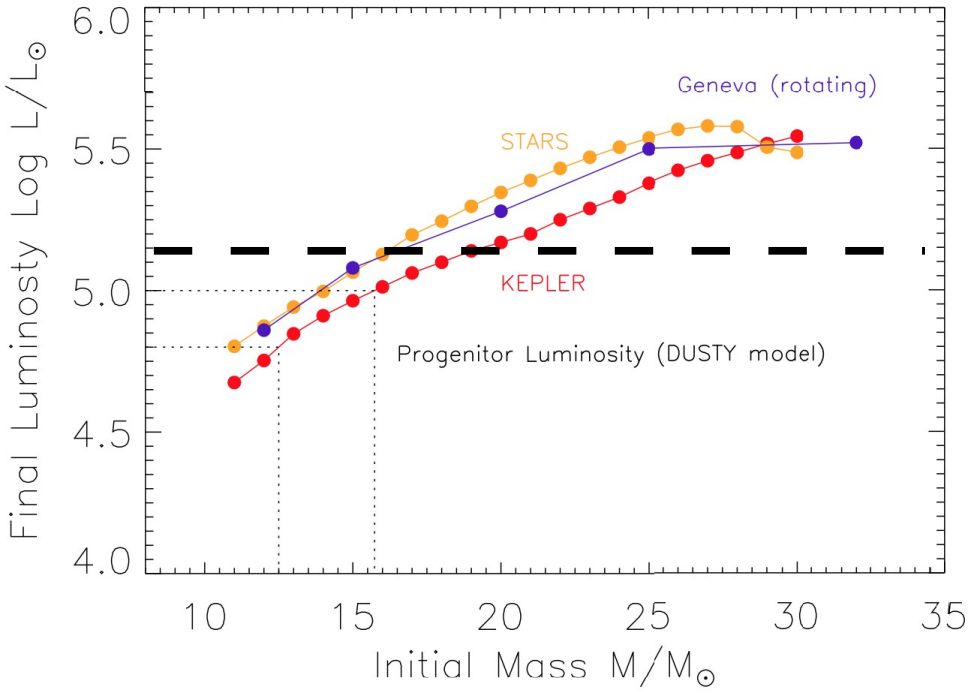
What have we found?



Salpeter IMF fit to progenitor detections and limits

No progenitors above ~16 $M_\odot$ so far!

Systematics – Progenitor models

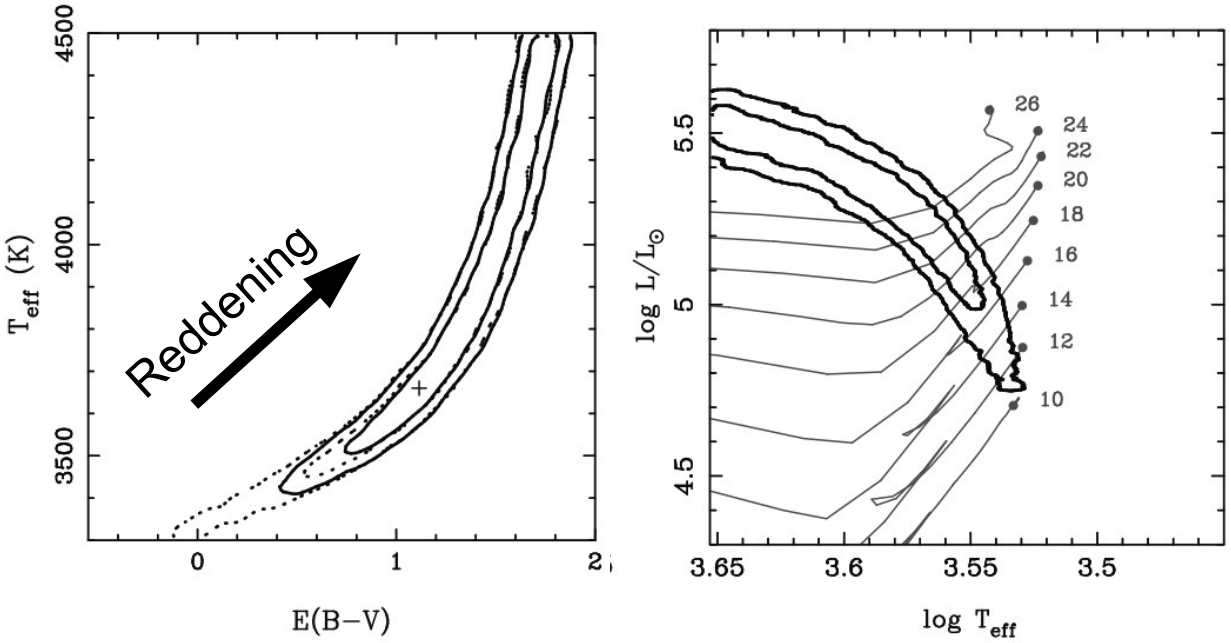


Jerkstrand et al. (2014)

Stellar evolutionary codes are consistent!

Dashed line shows the brightest (non-interacting) H-rich progenitor seen so far

Systematics – Dust

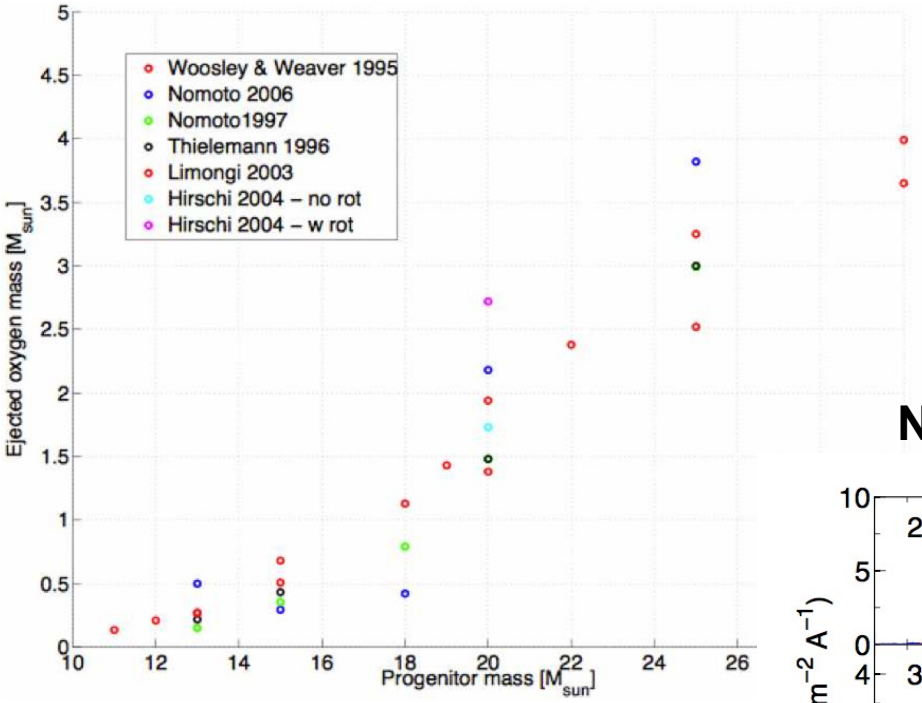


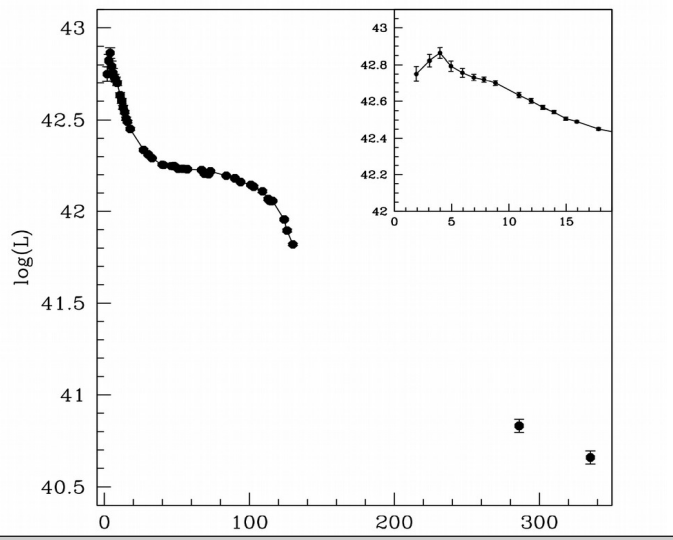
Fraser et al. (2012)

Few IIP SN progenitors are very red – SN 2012aw was one of the few examples.

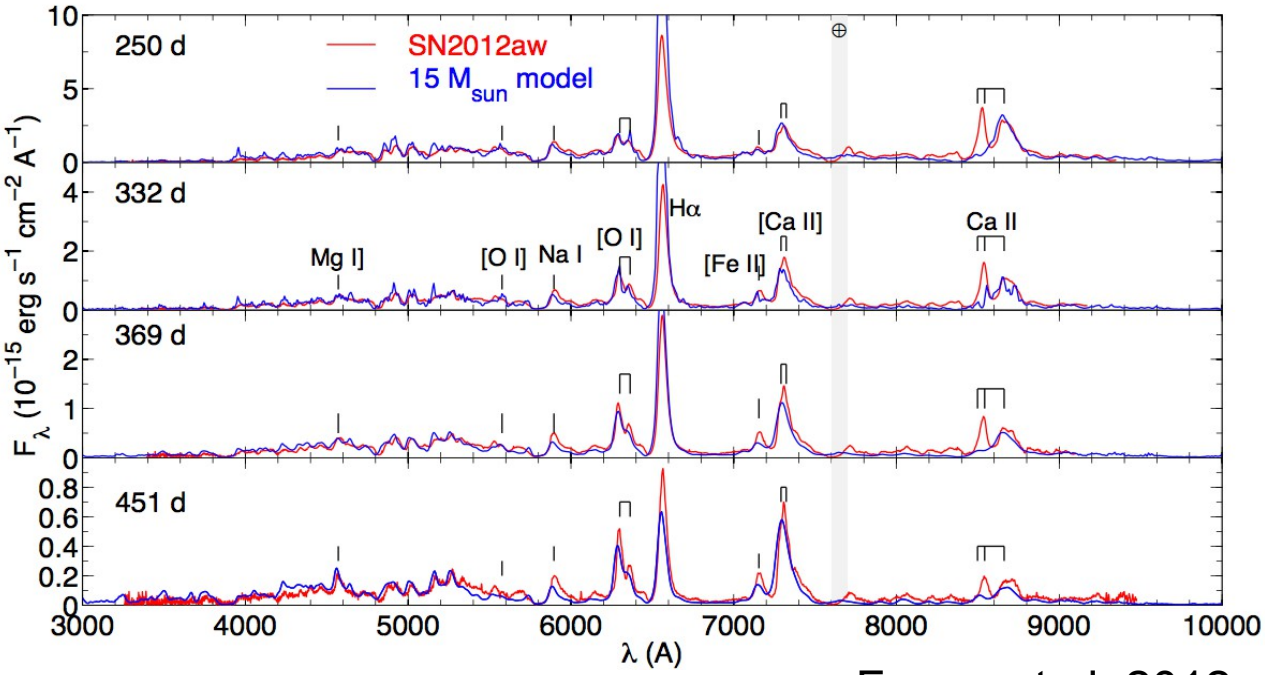
But Kochanek et al. (2013) showed that extinction estimates were over-estimates

Testing progenitor detections



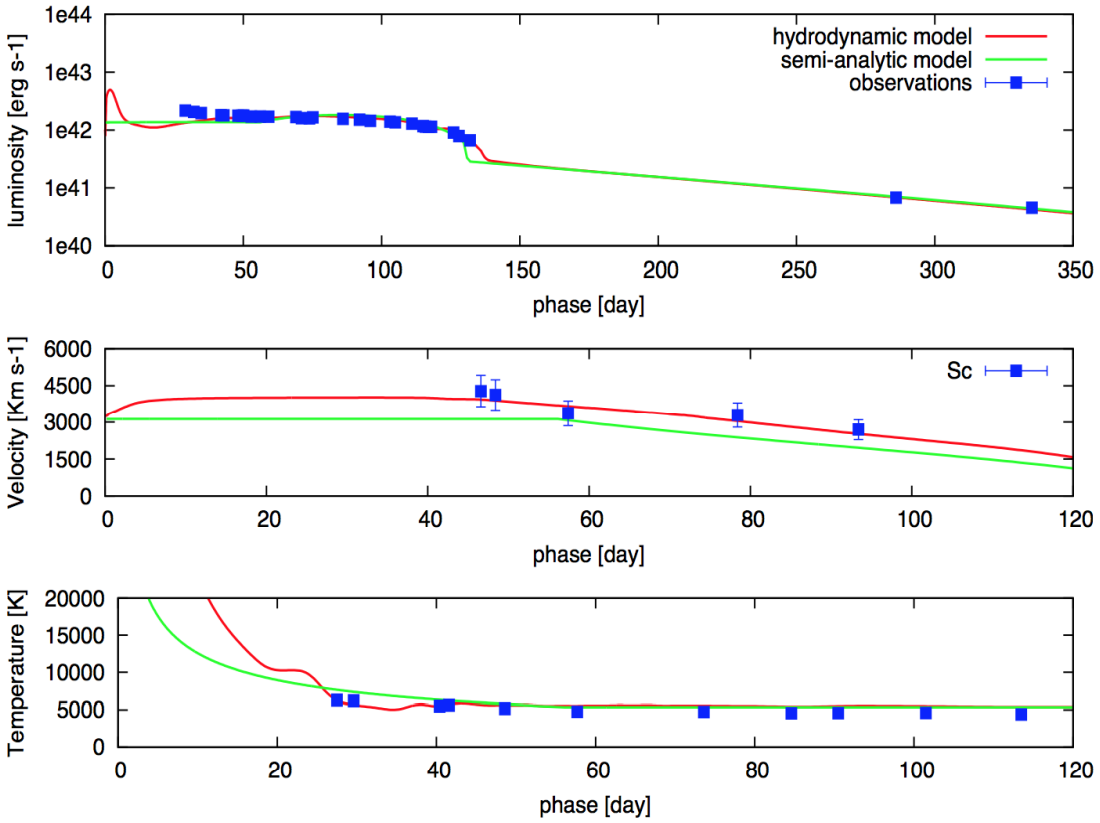


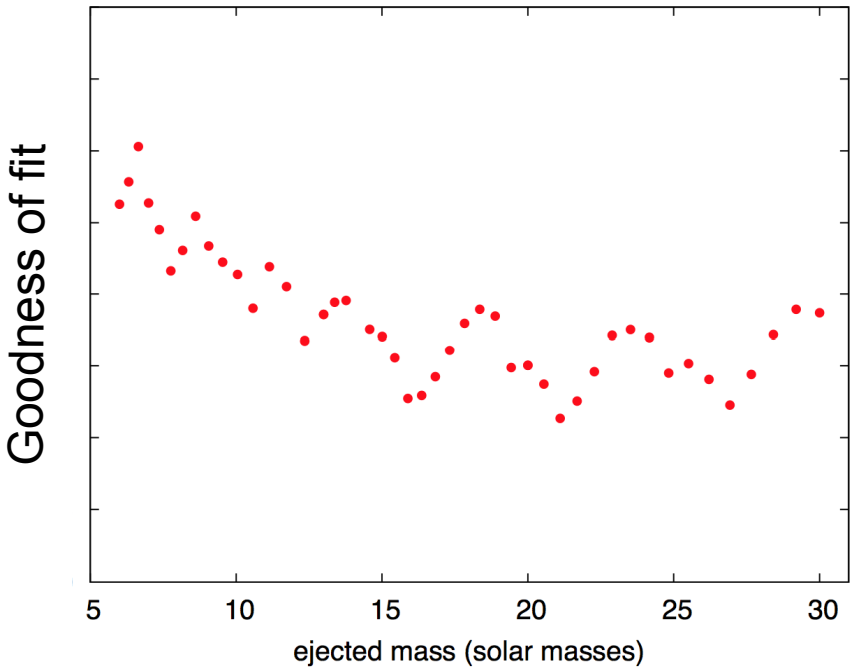
No nucleosynthetic signatures from >15 $M_{\odot}$ stars



Fraser et al. 2012
Jerkstrand, Smartt, Fraser et al. 2013

Testing progenitor detections

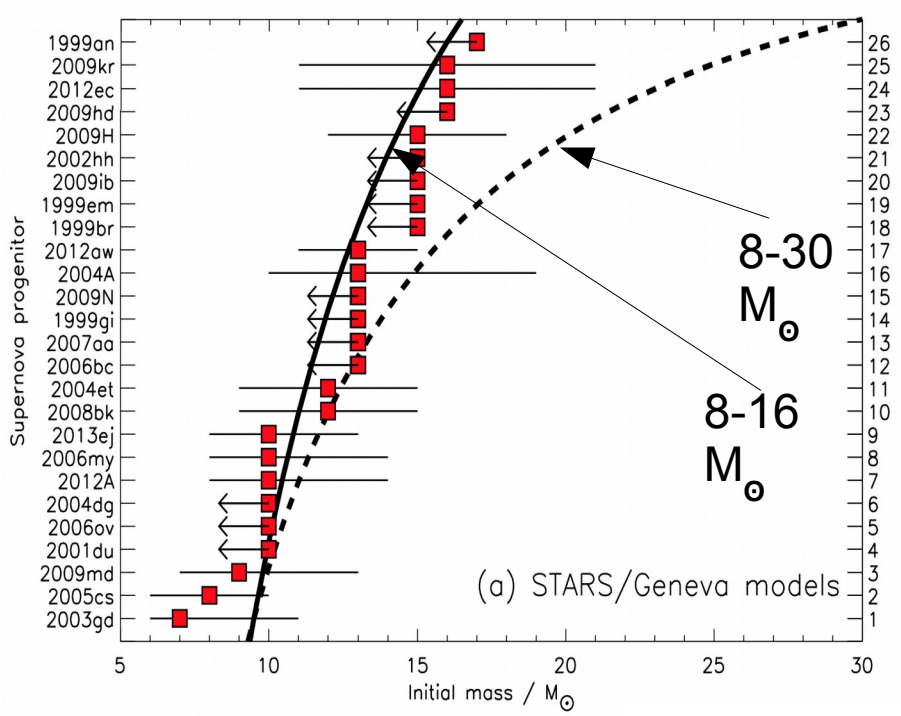


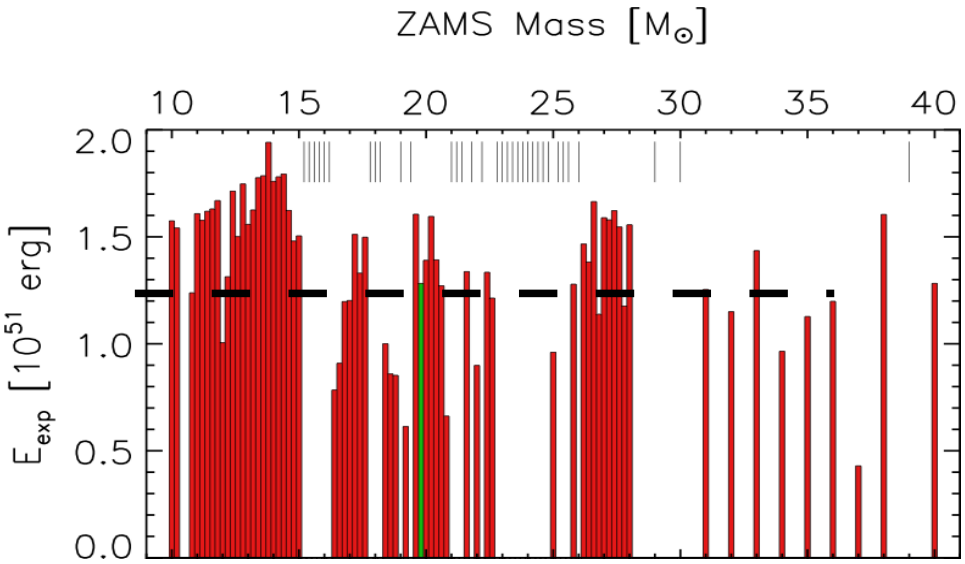


Dall'Ora et al 2014

(Also see many papers by Utrobin, Chugai, Zampieri, Pumo)

Where are the 16$M_\odot$+ RSGs?





Uglaiano et al. 2012

"Failed" SNe giving rise to BHs?

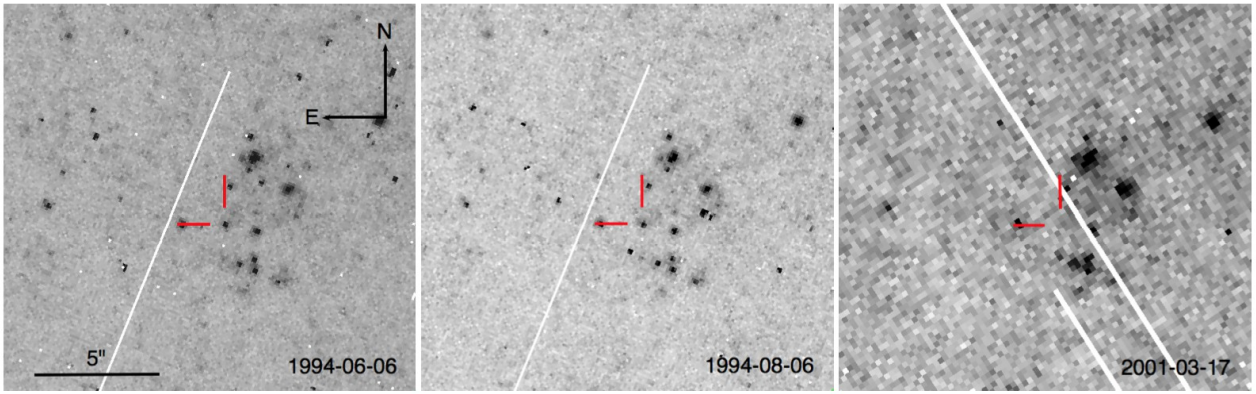


FIG. 7.— NGC4496cand21994.

Reynolds, Fraser & Gilmore, 2015

Outline

- Searching for supernova progenitors
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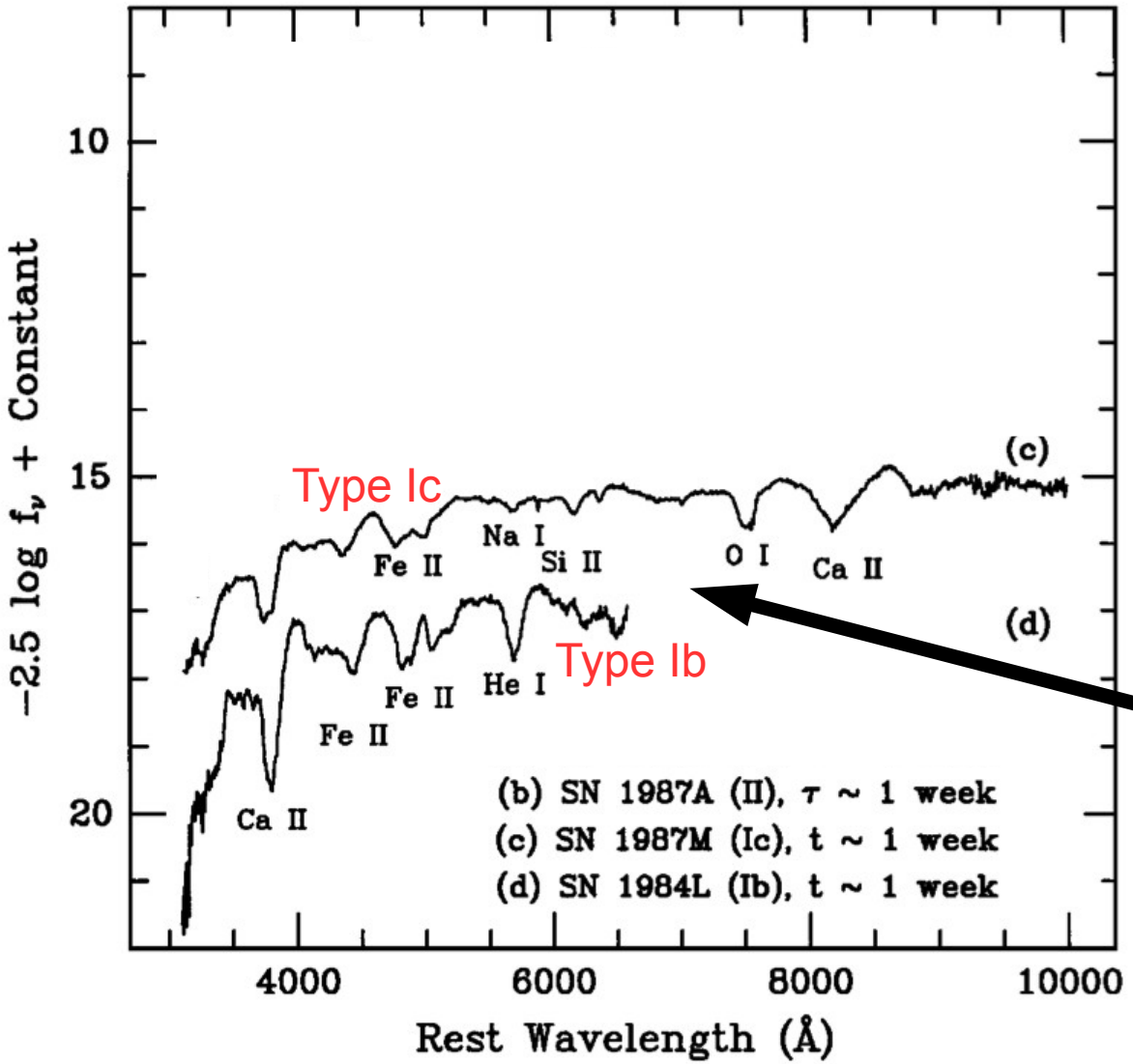
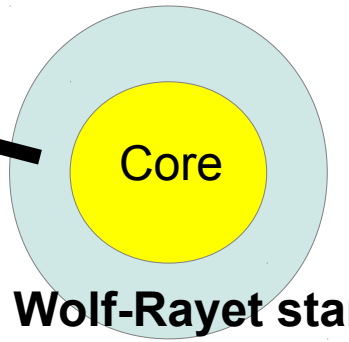
Core collapse SNe





Wolf-Rayet star?
Low-mass binary?

Two paths to a H-poor SN?

- Need to lose H (and possible He) envelope.

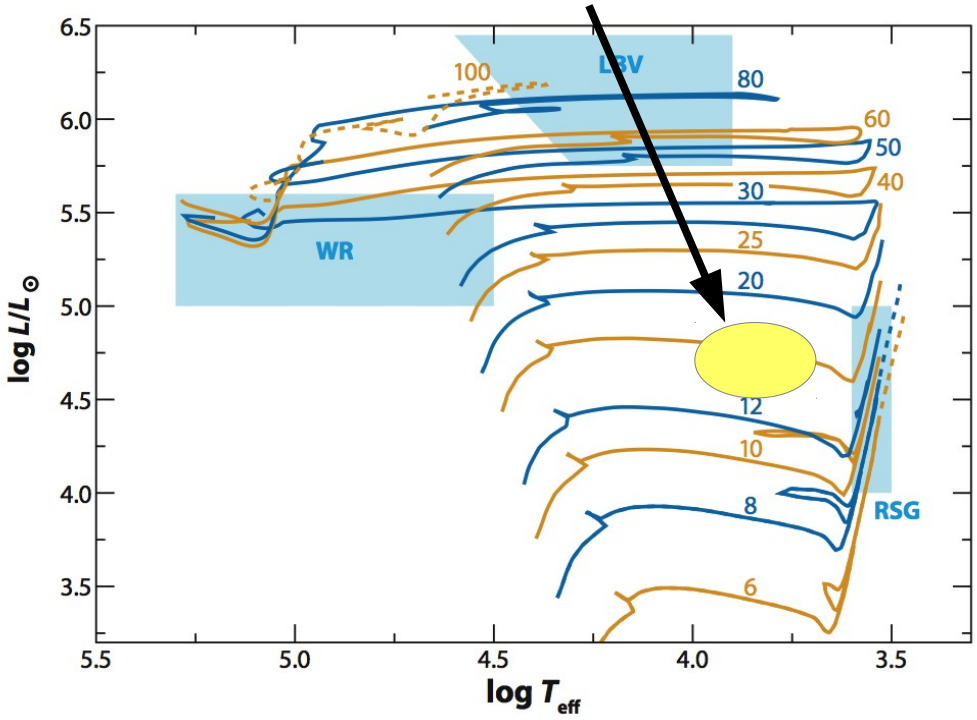
  Low mass star stripped in binary?

  Massive WR star?

- Pre-explosion imaging can discriminate between these scenarios.

Where are the progenitors of H-poor SNe?

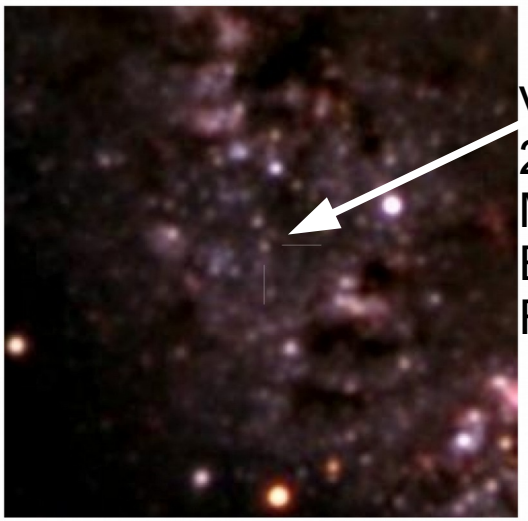
The nearly H-free (Type IIb SNe) :



Several detections (SNe 1993J, 2011dh) or deep limits (SN 2008ax)

~15 M yellow supergiants in binaries!

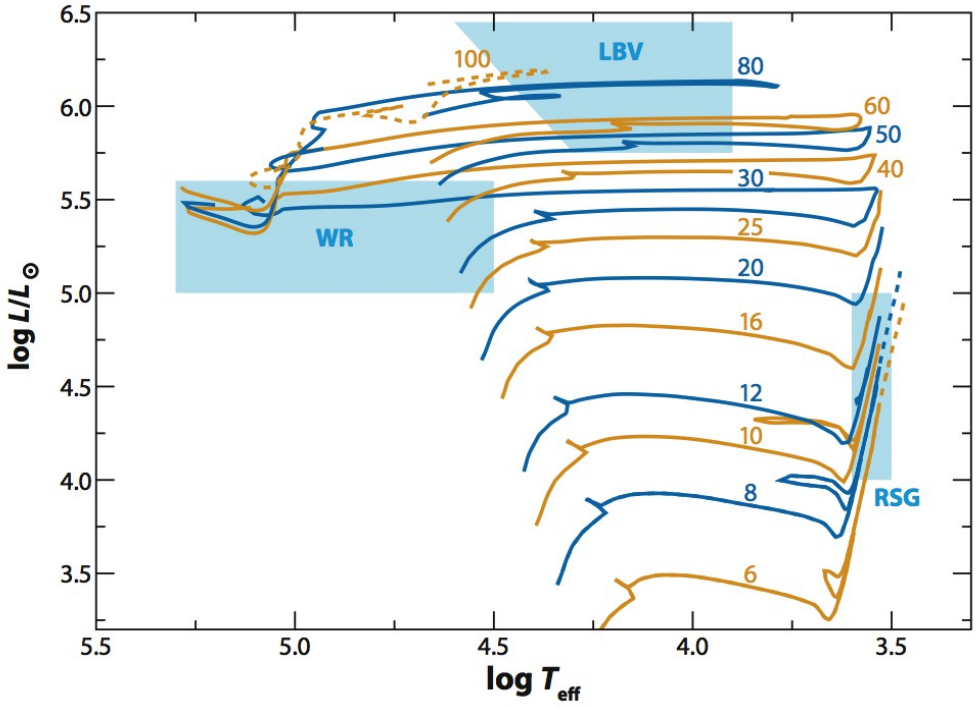
Not sufficient numbers to solve lack of exploding high mass RSGs!



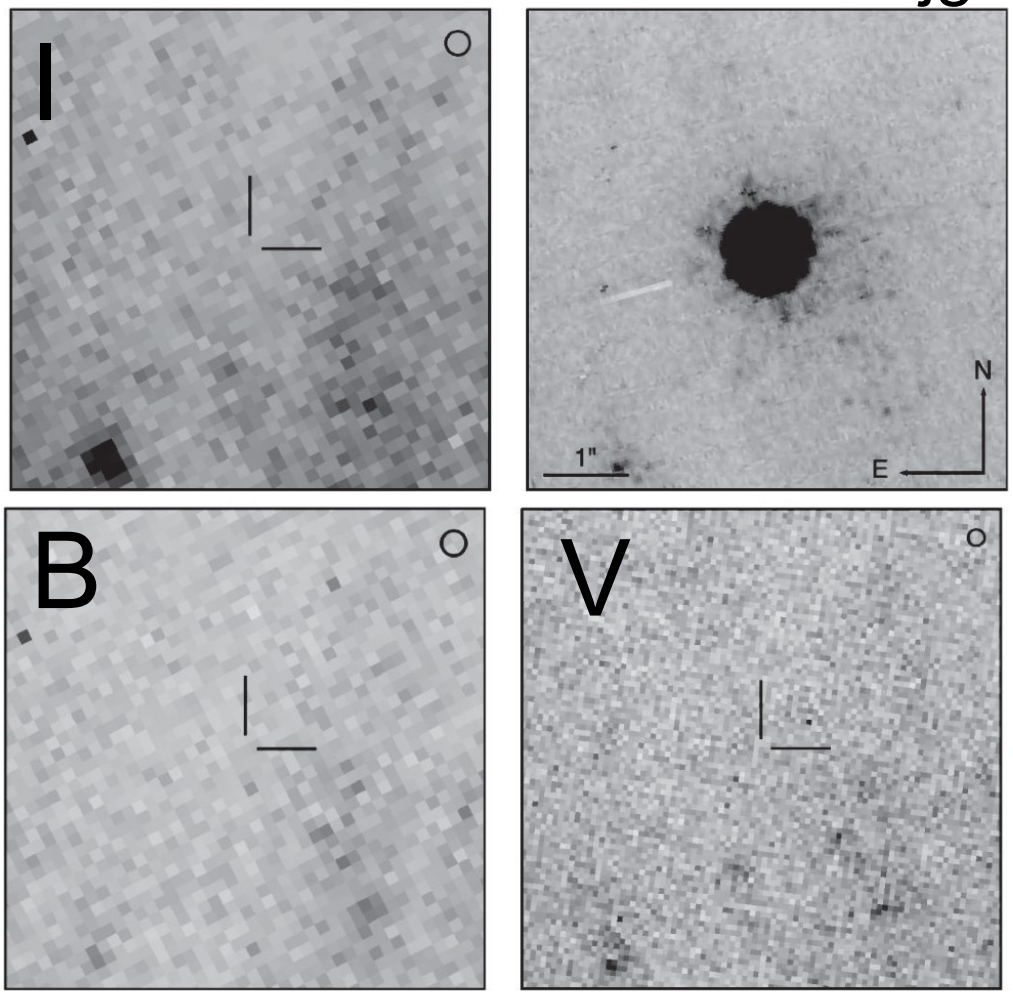
Van Dyk et al. (2011, 2014)
Maund et al. (2011)
Ergon et al. (2013)
Folatelli et al. (2014)

Where are the progenitors of H-poor SNe?

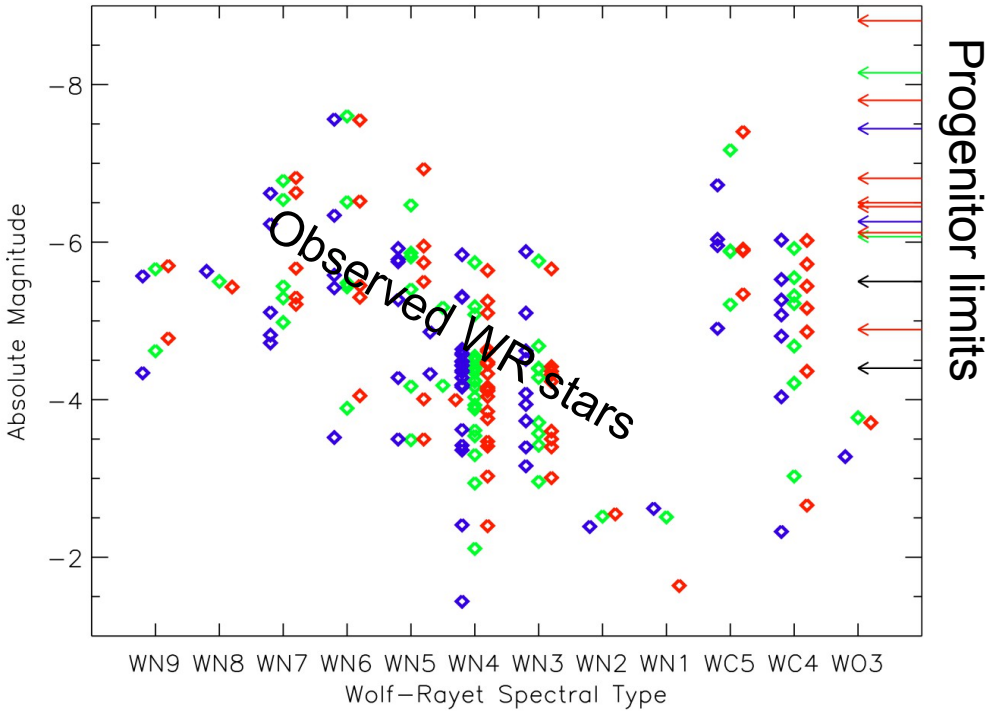
The completely H-free:



SN 2003jg

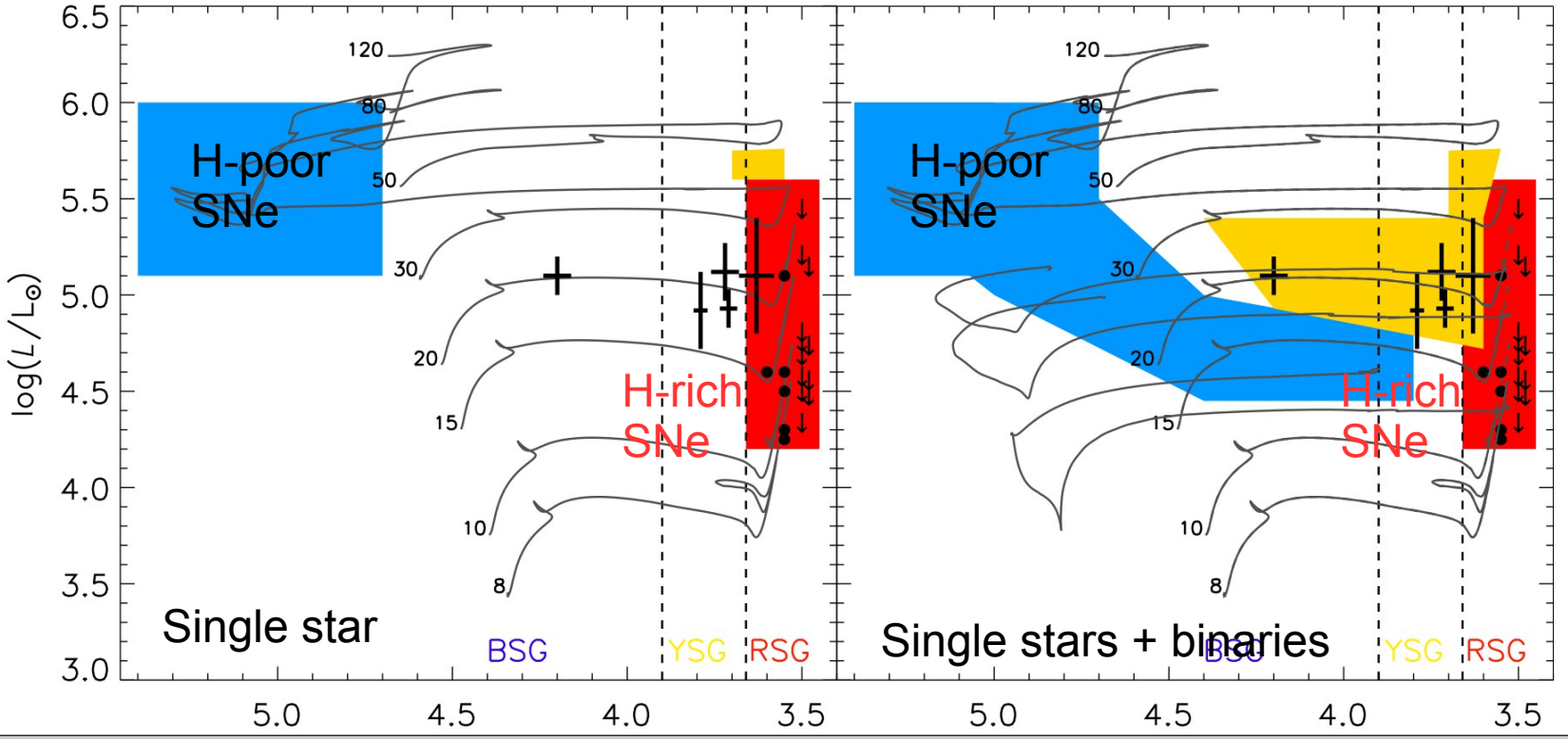


Fraser et al. 2011; Eldridge, Fraser et al. 2013

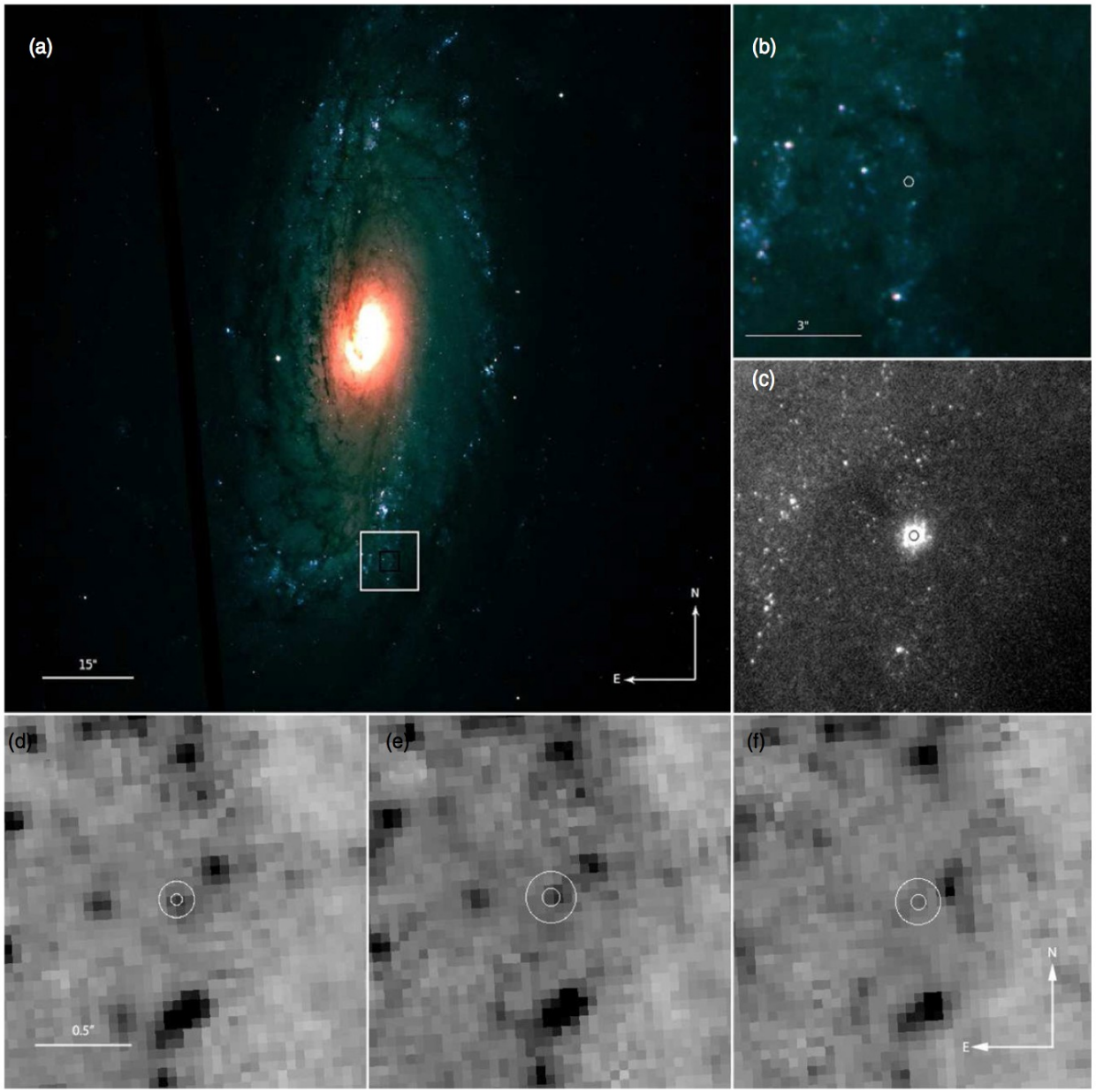


Binarity?

Eldridge, Fraser et al. 2013



iPTF13bvn

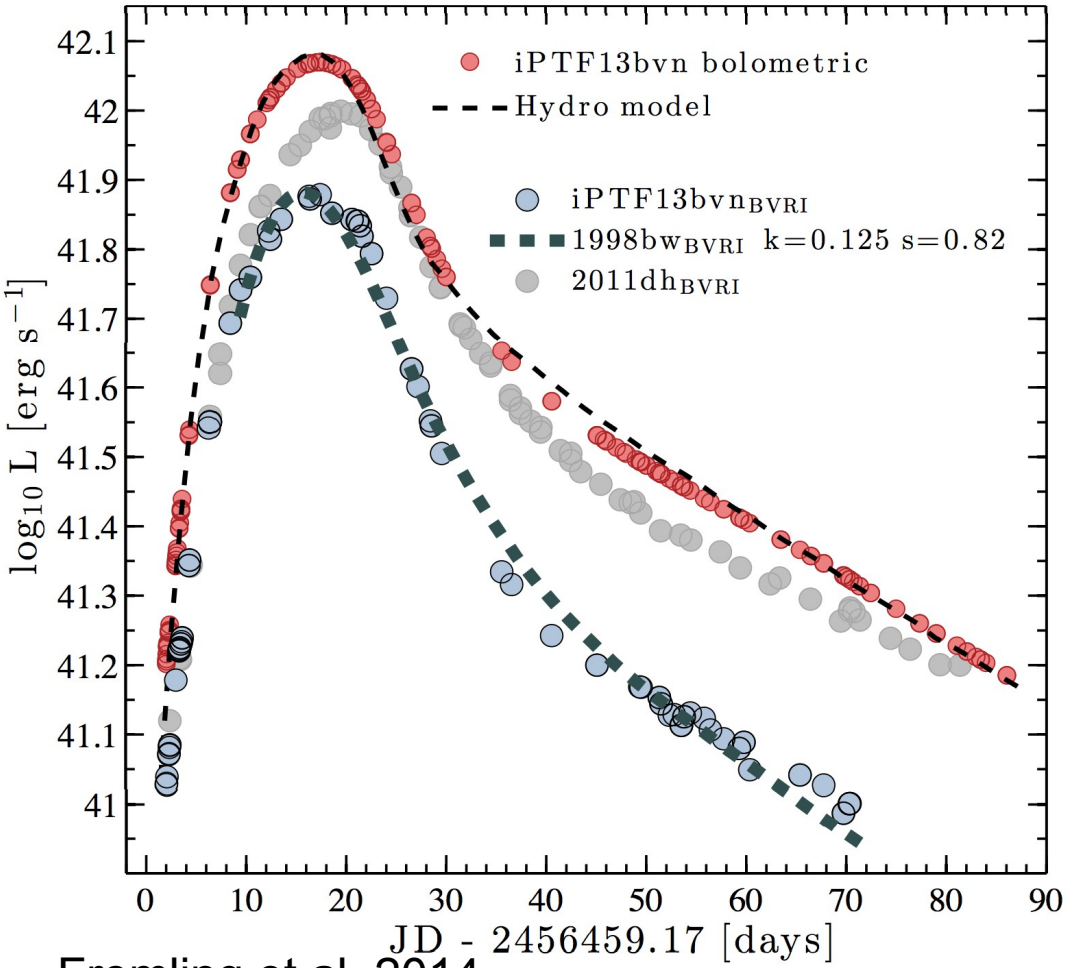


Bright source coincident with a H-poor SN in pre-explosion imaging.

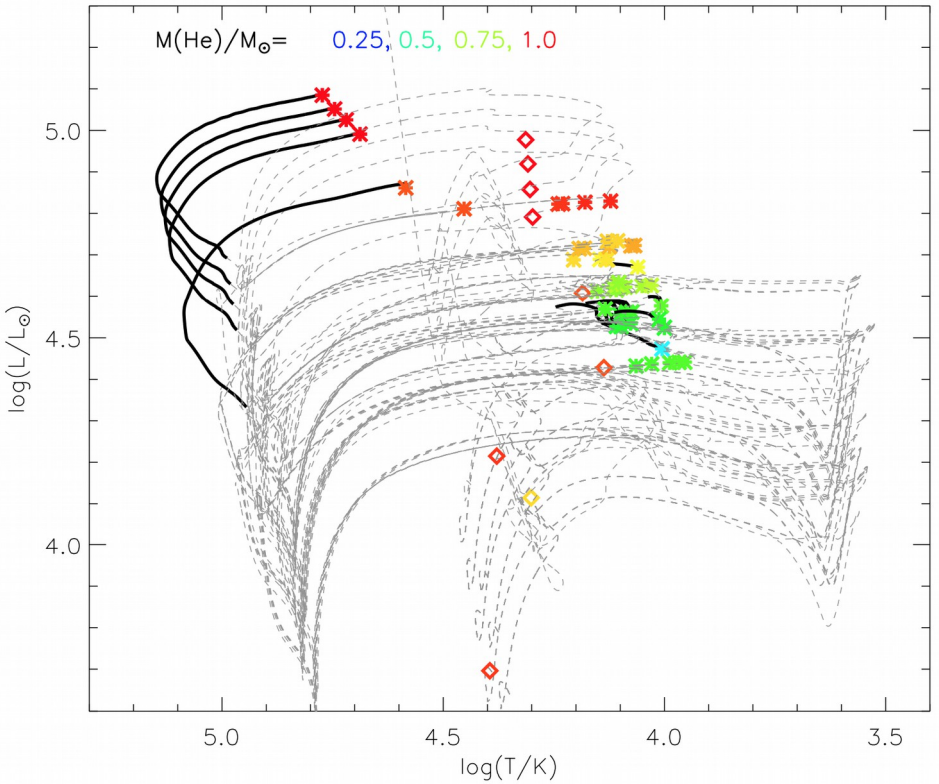
Claimed to be a candidate WR star progenitor...

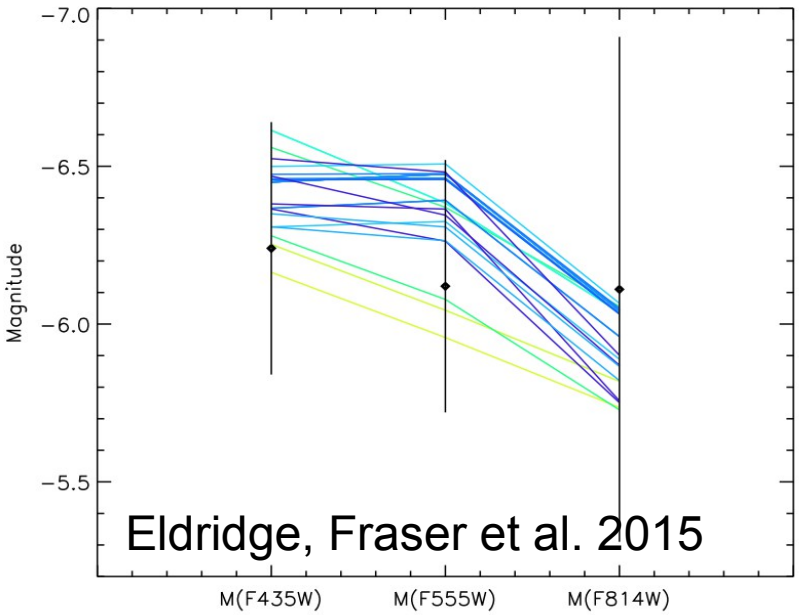
Cao et al. 2013

iPTF13bvn



Fremling et al. 2014
Bersten et al. 2014



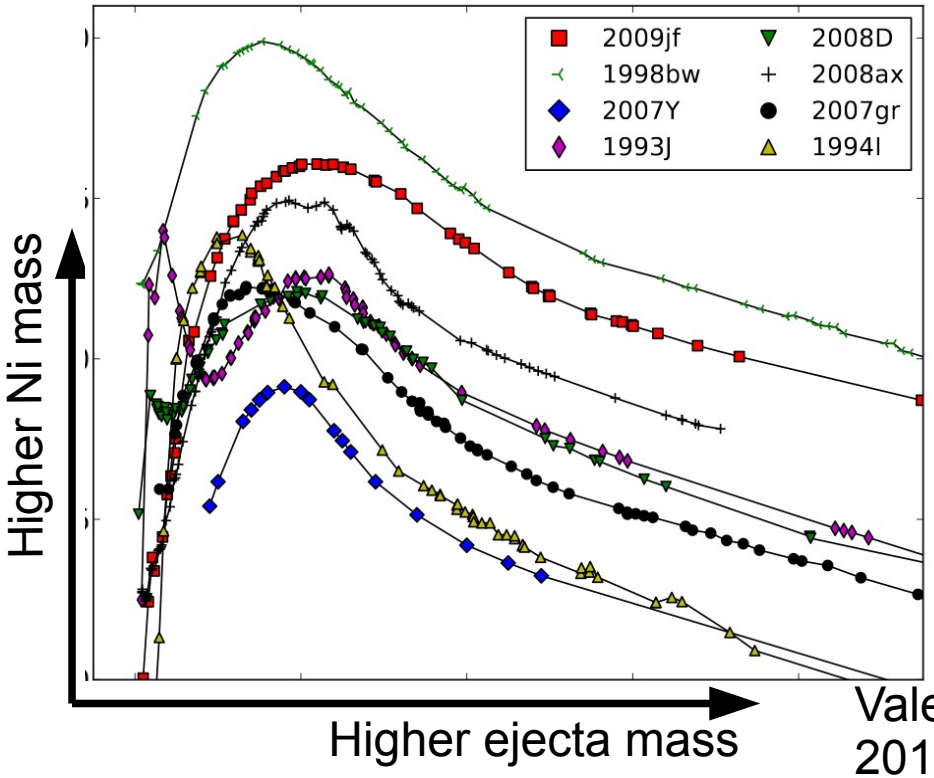


Eldridge, Fraser et al. 2015

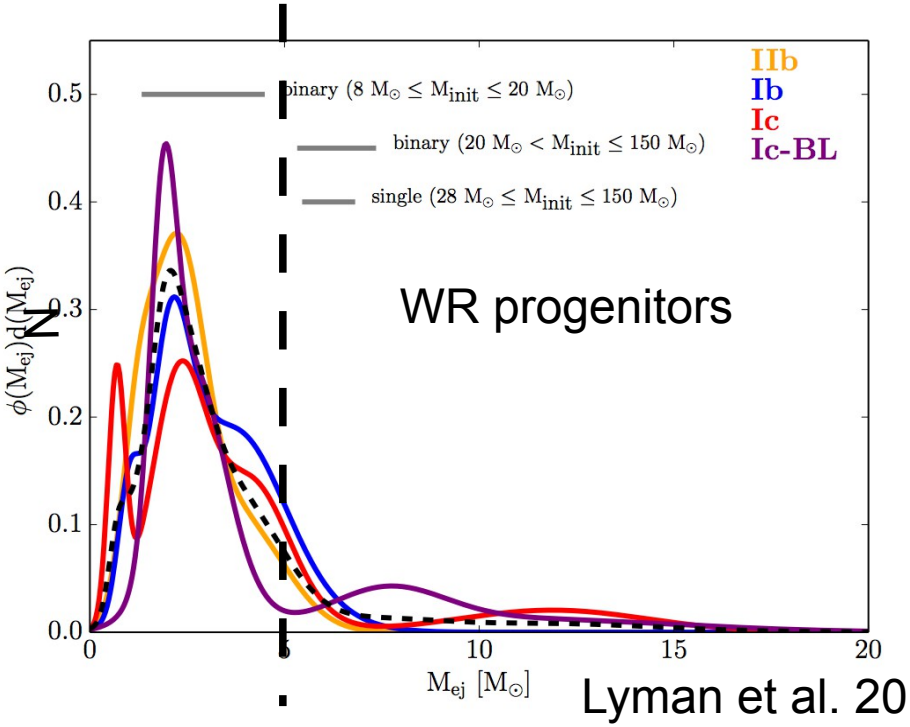
Ejecta masses

Most H-poor SNe seem to have low (1-2 $M_\odot$) ejecta masses.

This is inconsistent with the explosion of a massive WR star.

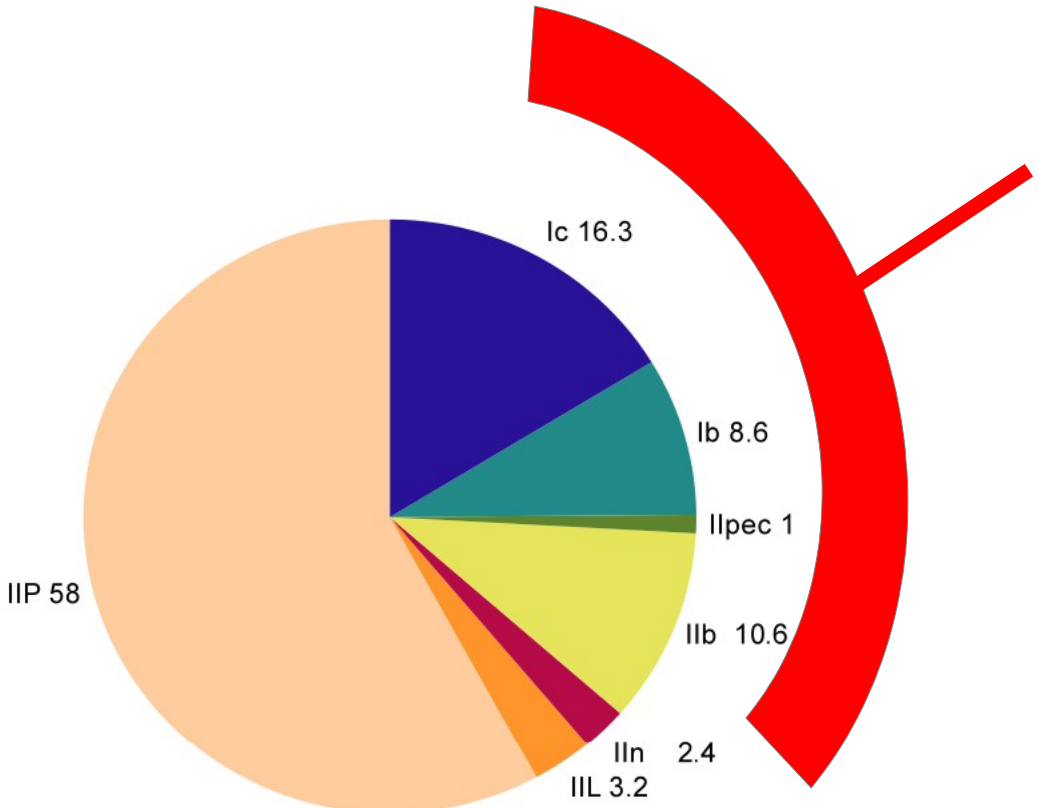


Valenti, Fraser et al. 2011



Lyman et al. 2016

IMF and SN rate constraints



Too many H-poor SNe to be all coming from single WR sta, given the shape of the IMF and the relative rates of H-poor and H-rich SNe (Smith et al. 2011, Eldridge et al. 2013)

Outline

- An overview of supernovae
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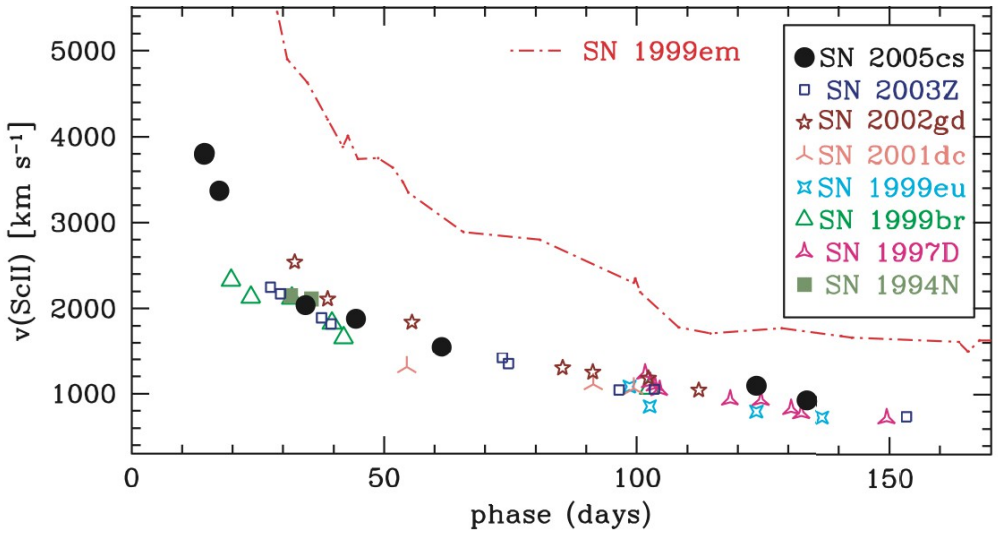
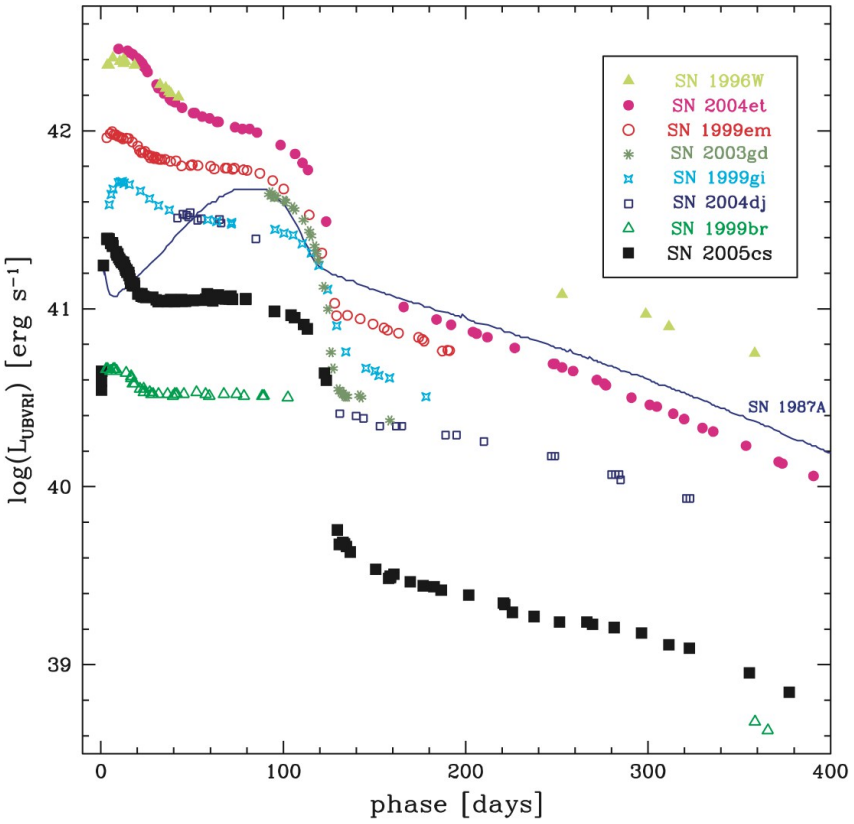
- Conclusions

What's happening at the low mass end?

Faint Type IIP SNe
(SNe 2005cs, 2008bk 2009md)

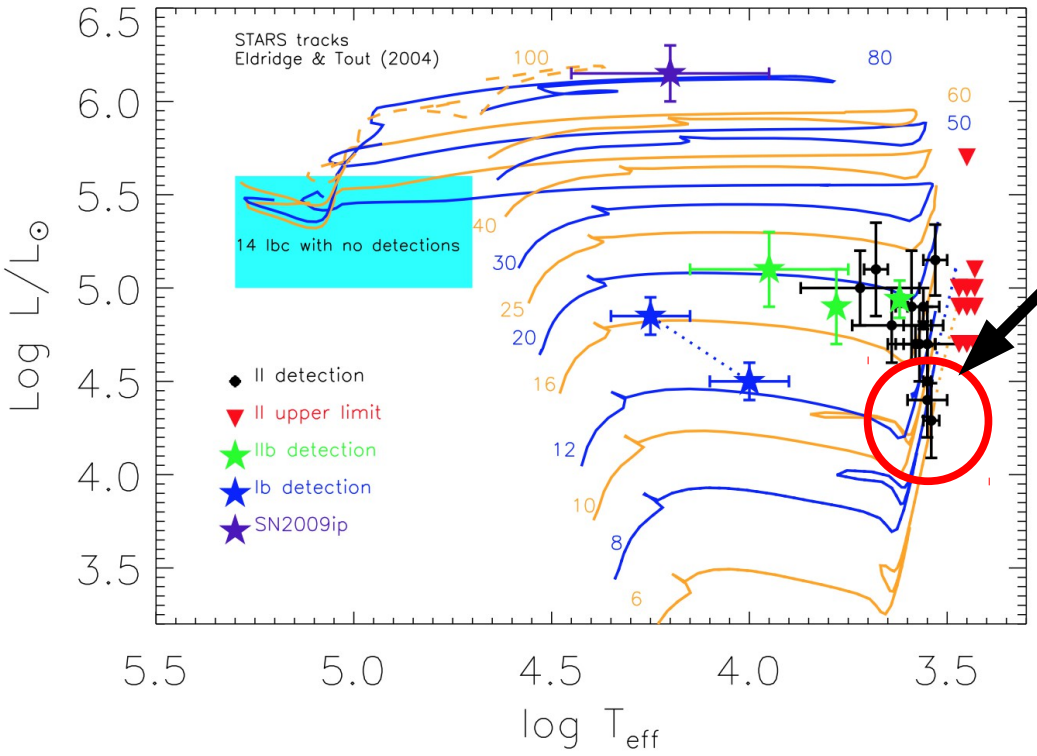


Originally associated with fallback in more massive progenitors (Turatto et al. 1998)



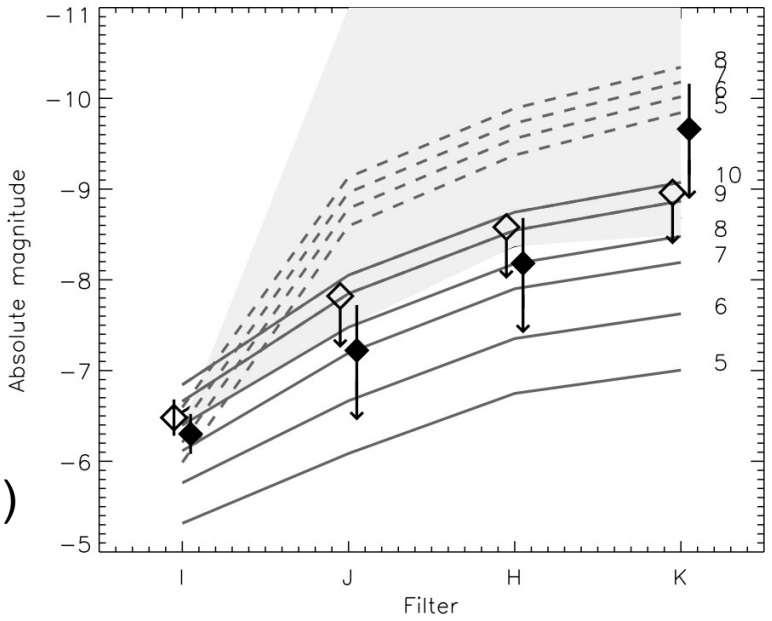
Pastorello et al. 2009

What's happening at the low mass end?



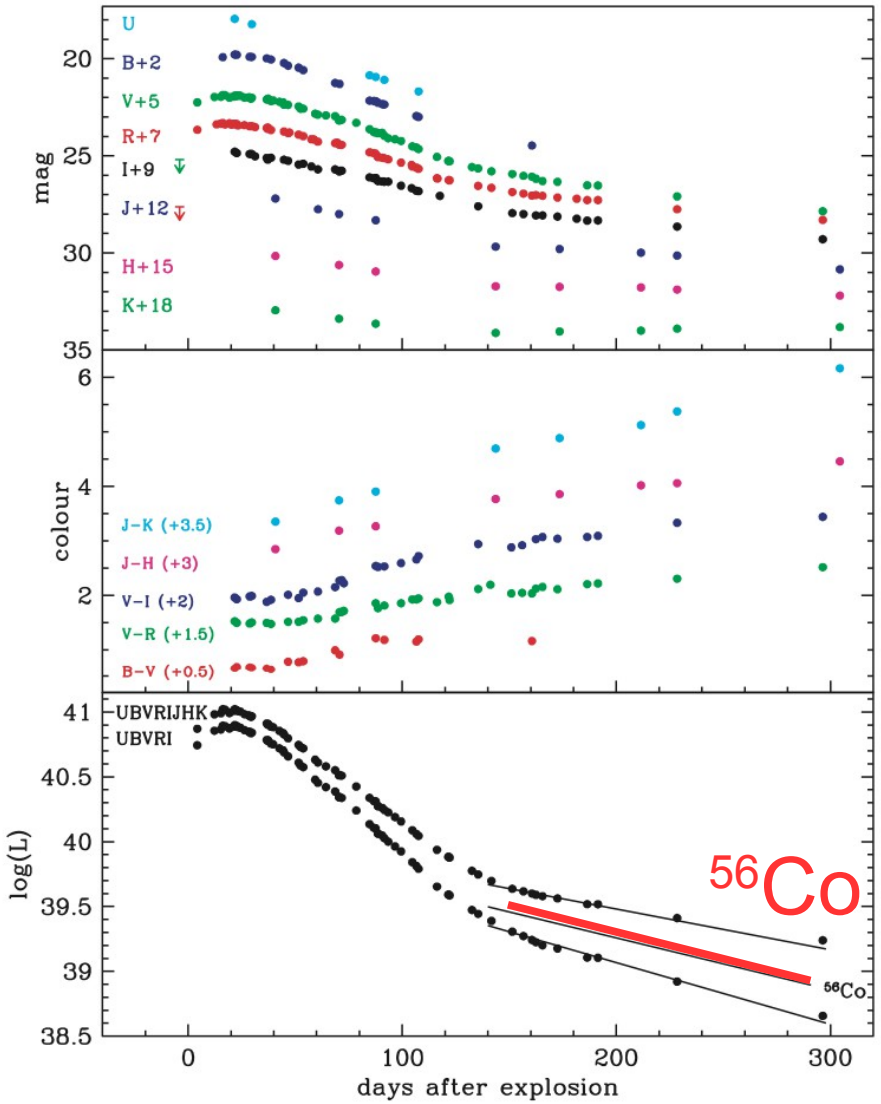
The lowest mass RSGs give weak IIP SNe:

- SN 2008bk (logL = 4.57 ± 0.06)
  Van Dyk et al. 2012
- SN 2005cs (logL = 4.4 ± 0.2)
  Maund et al. (2014)
- SN 2009md (logL = 4.5 ± 0.20)
  Fraser et al. (2011)

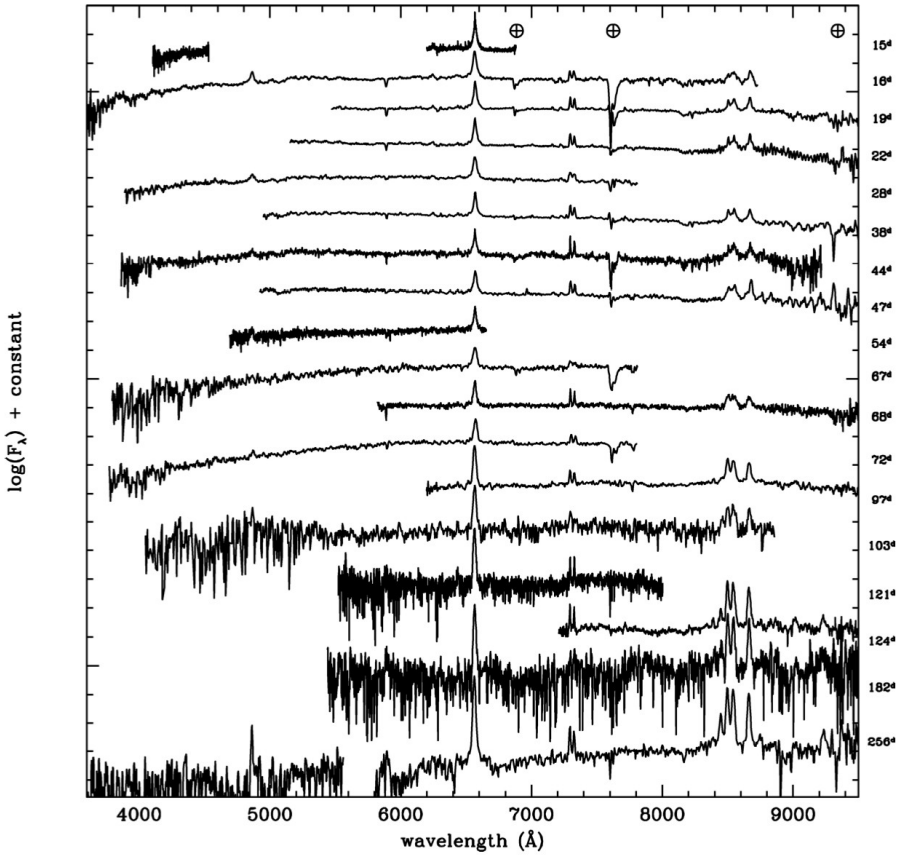


But can only rule out an SAGB progenitor for SN 2005cs (from deep NIR limits)
Eldridge, Mattila & Smartt (2007)

Do EC-SNe look different?

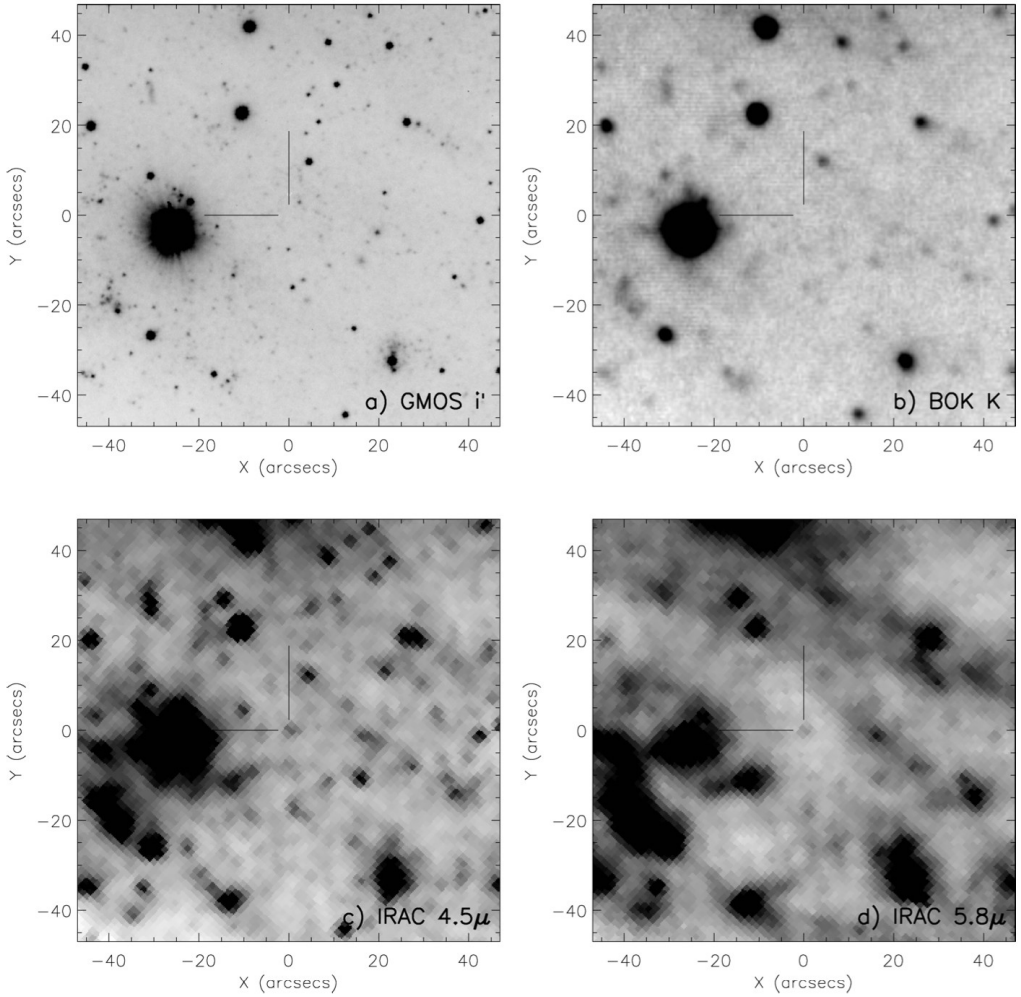


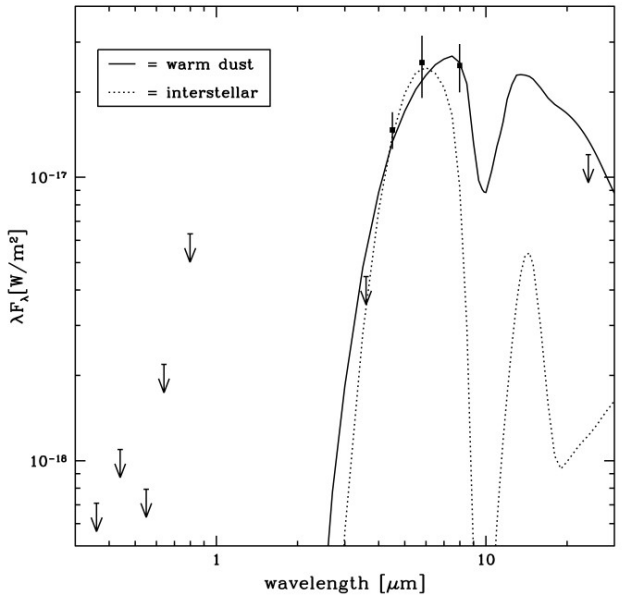
SN 2008S – nearby, low energy, dust enshrouded explosion.

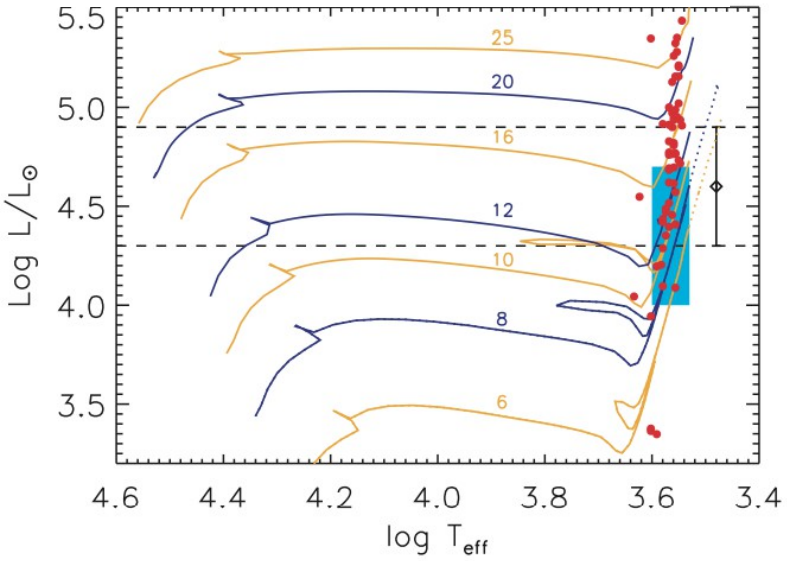


Botticella et al. (2009)

The progenitor of SN 2008S





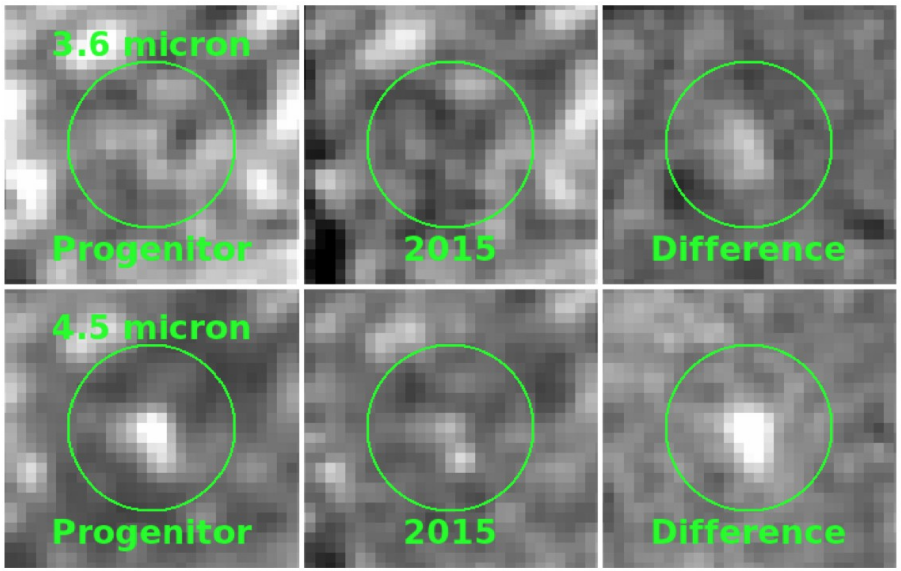


Botticella et al. (2009)
Prieto et al. (2008) *(also see Smith et al. 2009)*

Late time data

Smith et al. (2009) argued that SN 2008S was a SN impostor (LBV-outbust)...

but Adams et al. (2015) presented new late time data where the progenitor had faded!



Are we missing similar transients?

Probably... but hard to tell!

Khan+, Thompson+ 2009 find very few similar progenitors to SN 2008S.

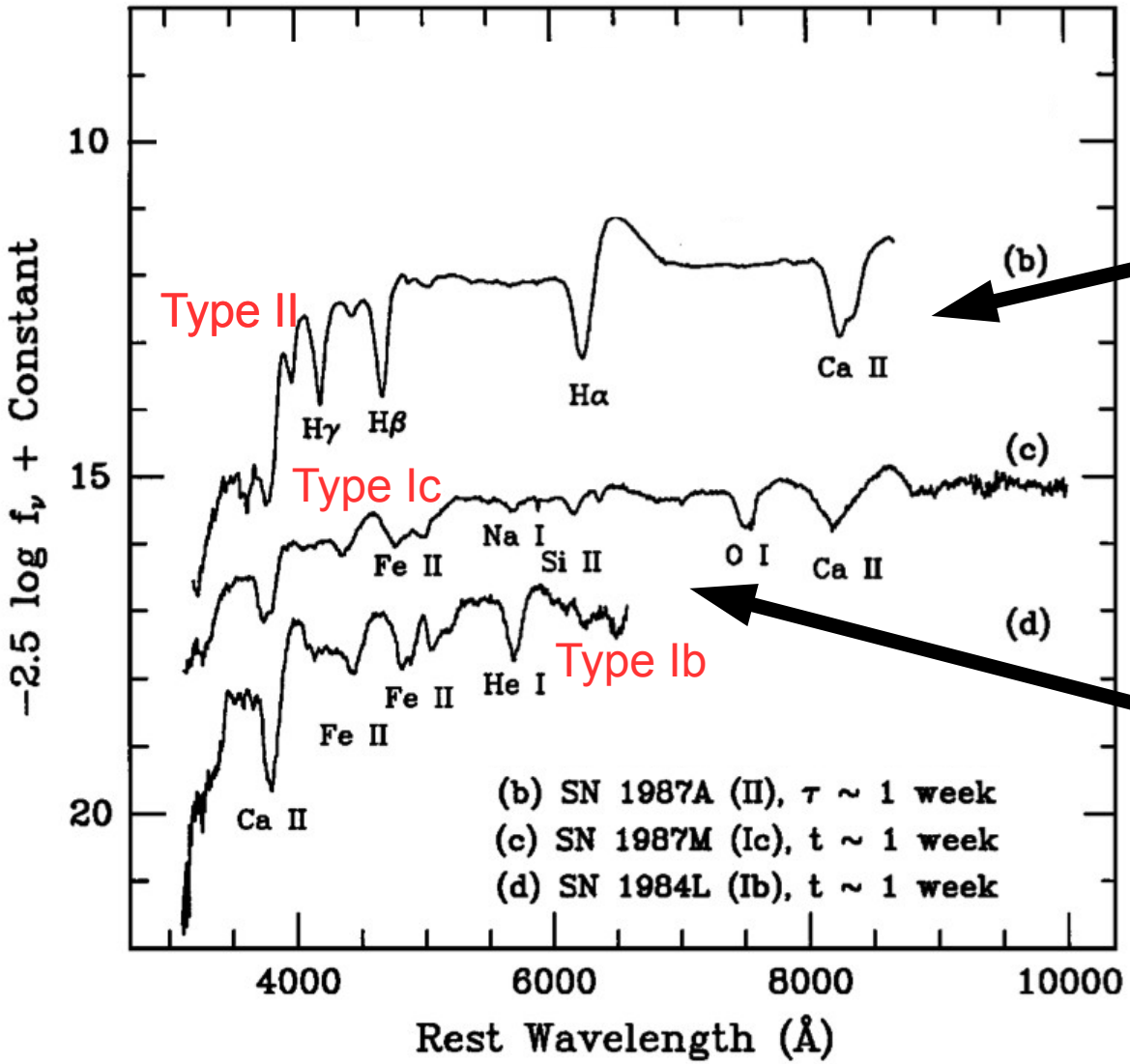
Very brief stage in the lives of massive (or not-so-massive) stars.

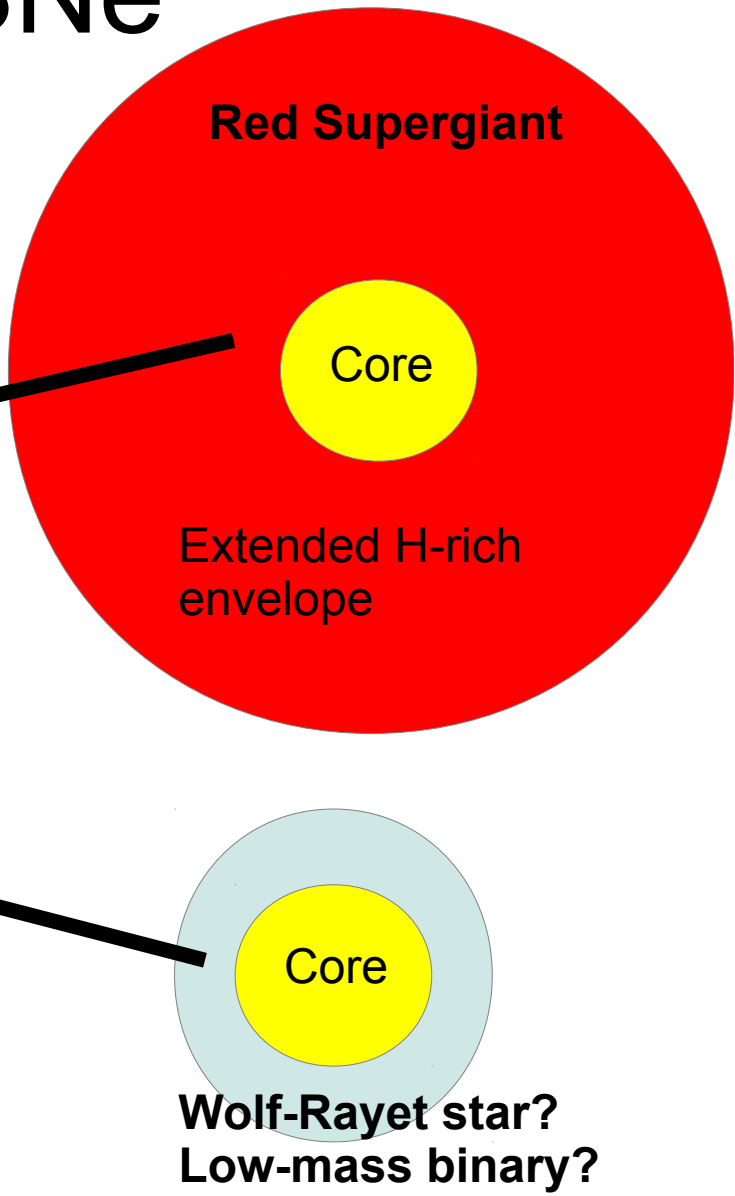
But with a little more extinction, we would not have found 08S!

Outline

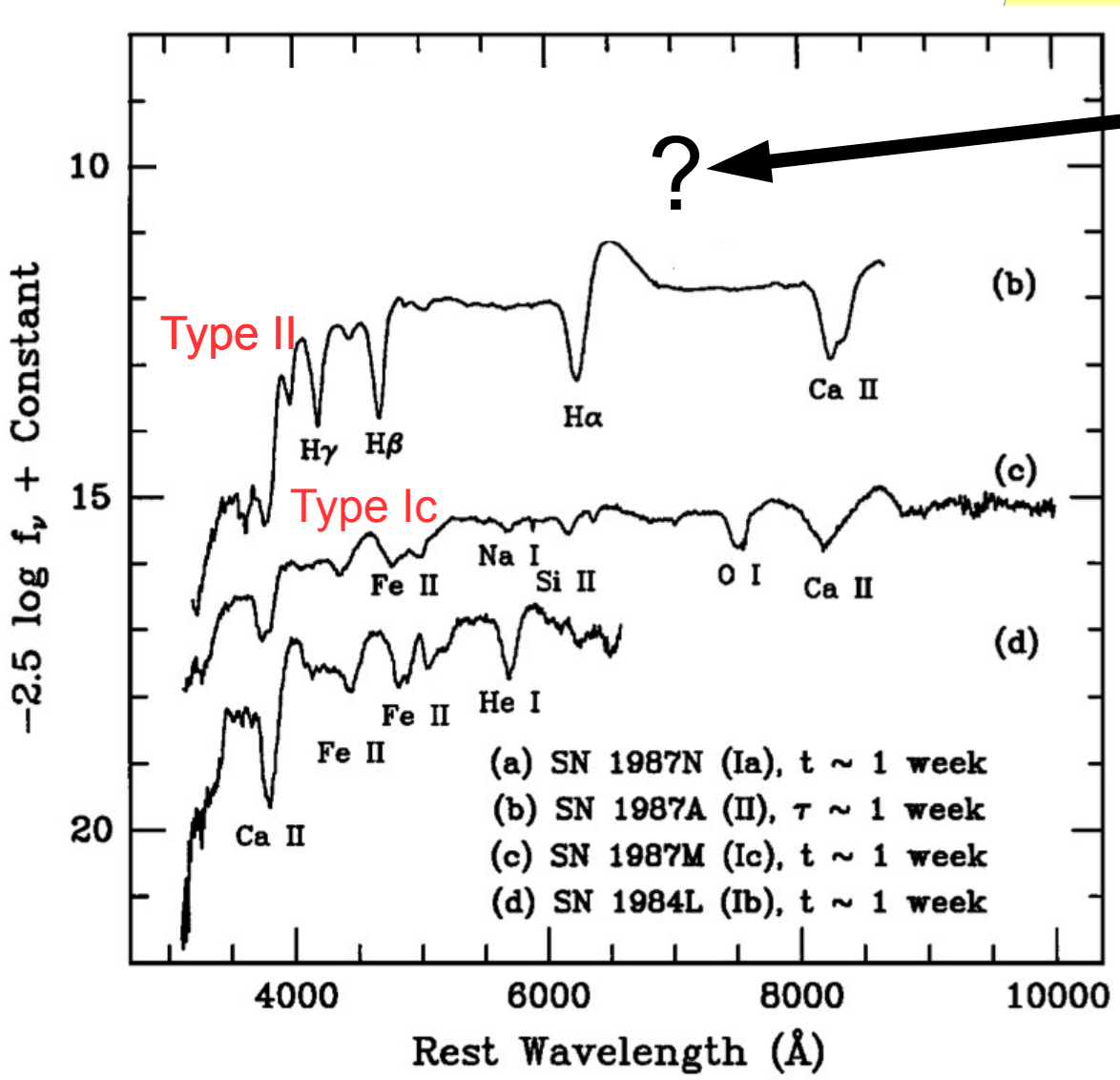
- Searching for supernova progenitors
  - H-rich supernovae
  - H-poor supernovae
- What's happening at the low mass end?
- Supernovae with a CSM
- Conclusions

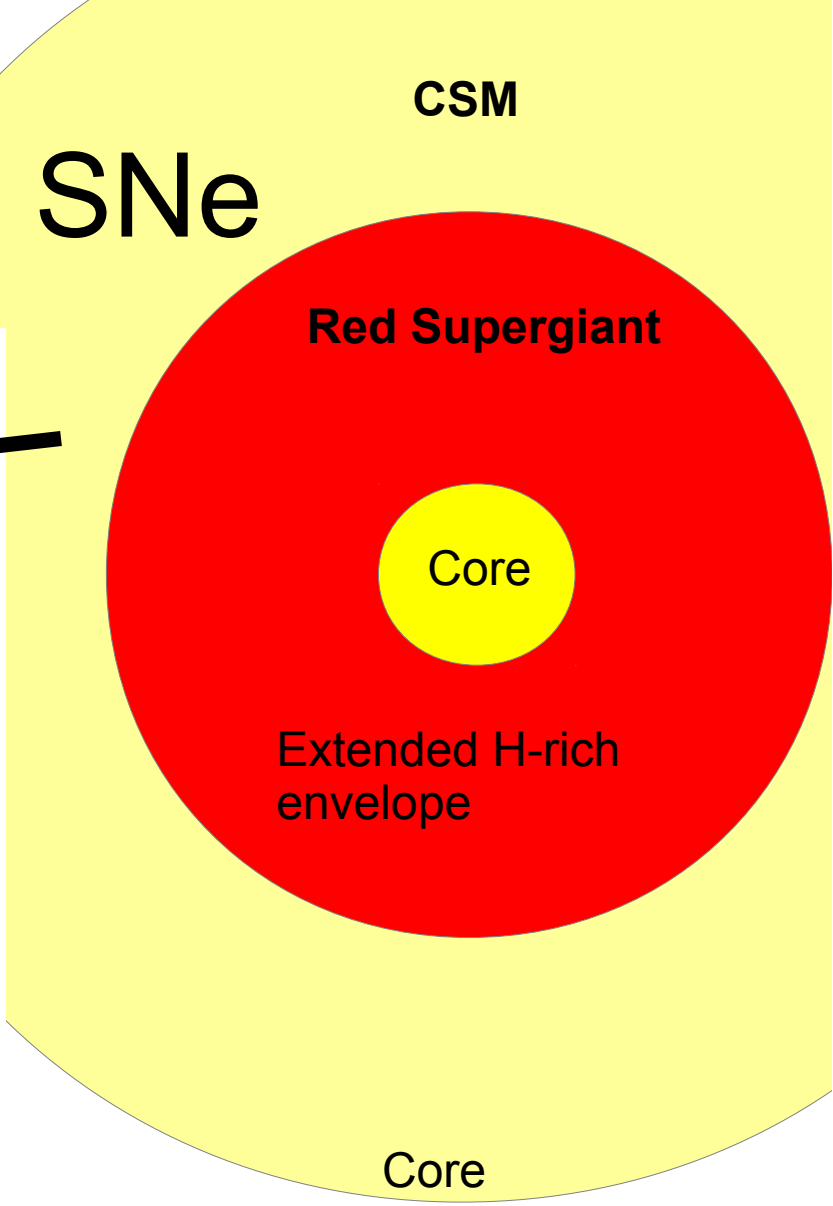
Core collapse SNe



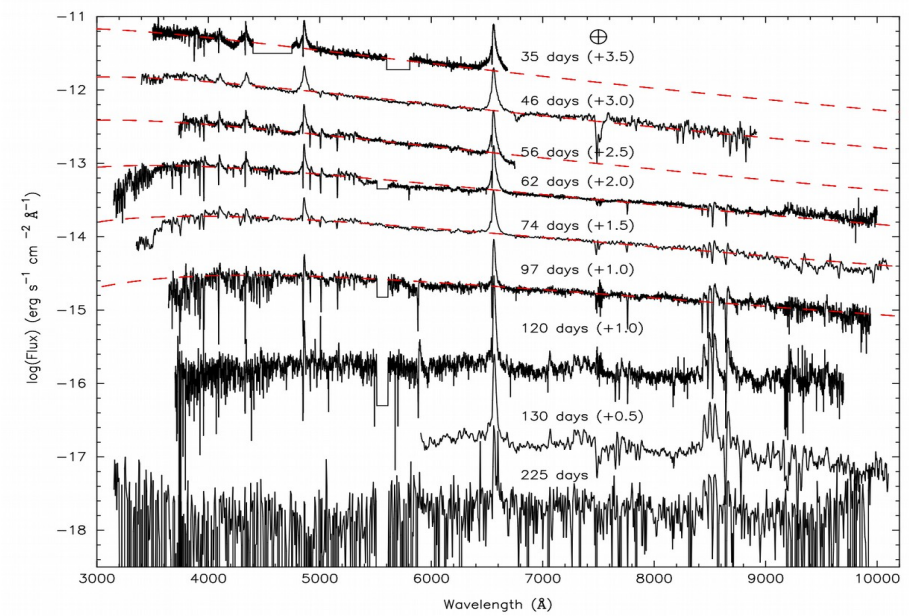


Core collapse SNe

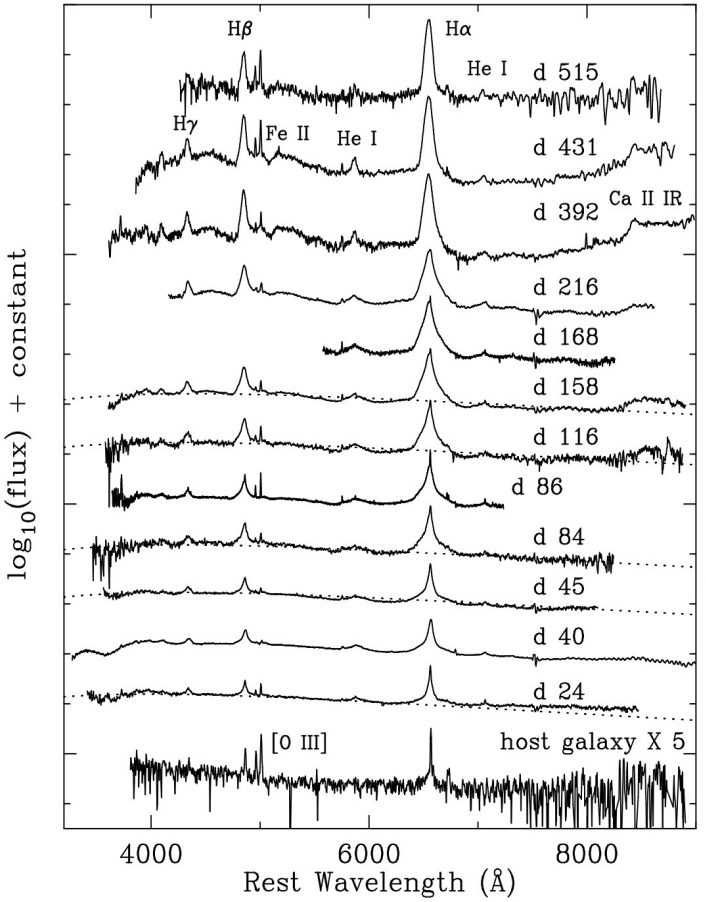




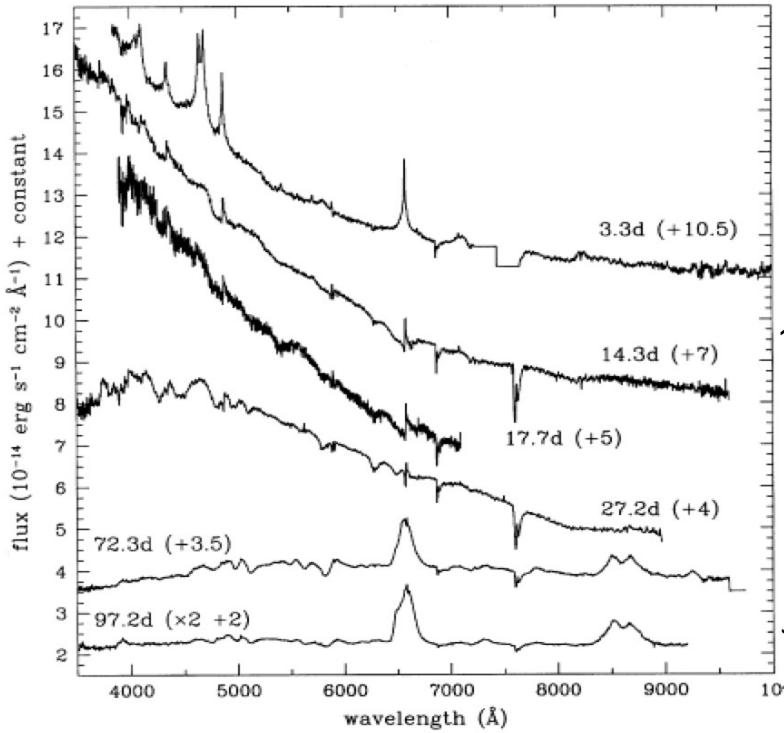
Spectral diversity of IIn's



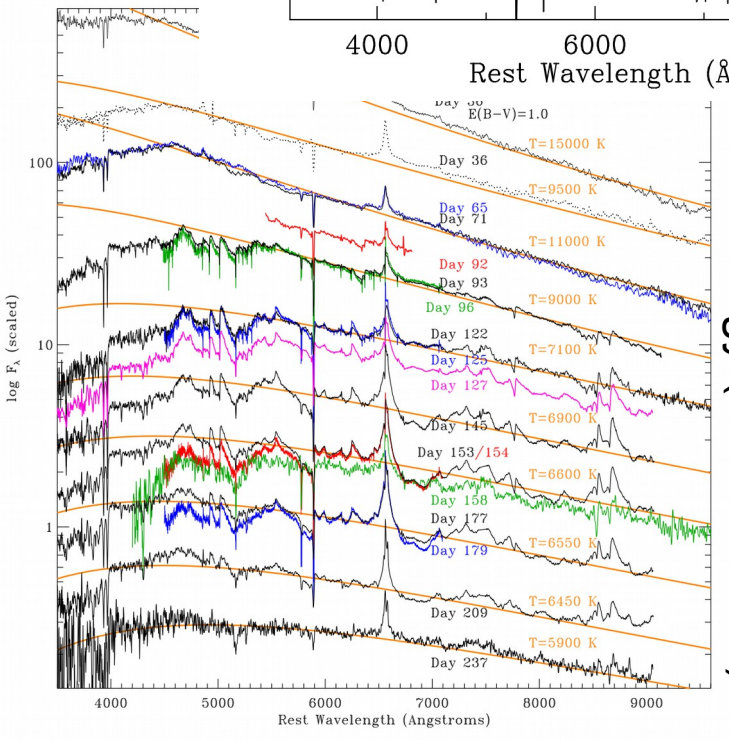
SN 2009kn (Kankare+ 2012)



SN 2010jl (Zhang+ 2012)

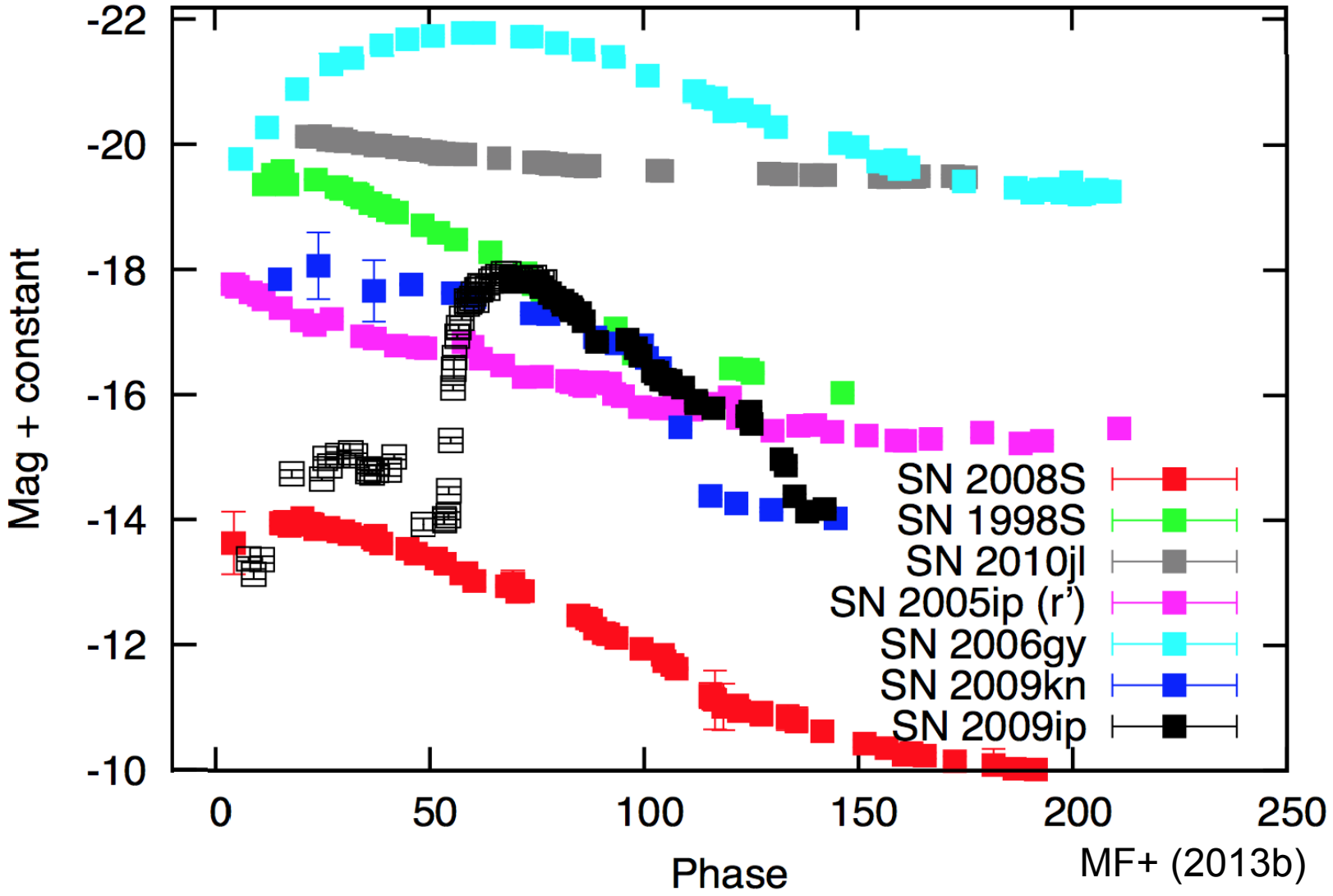


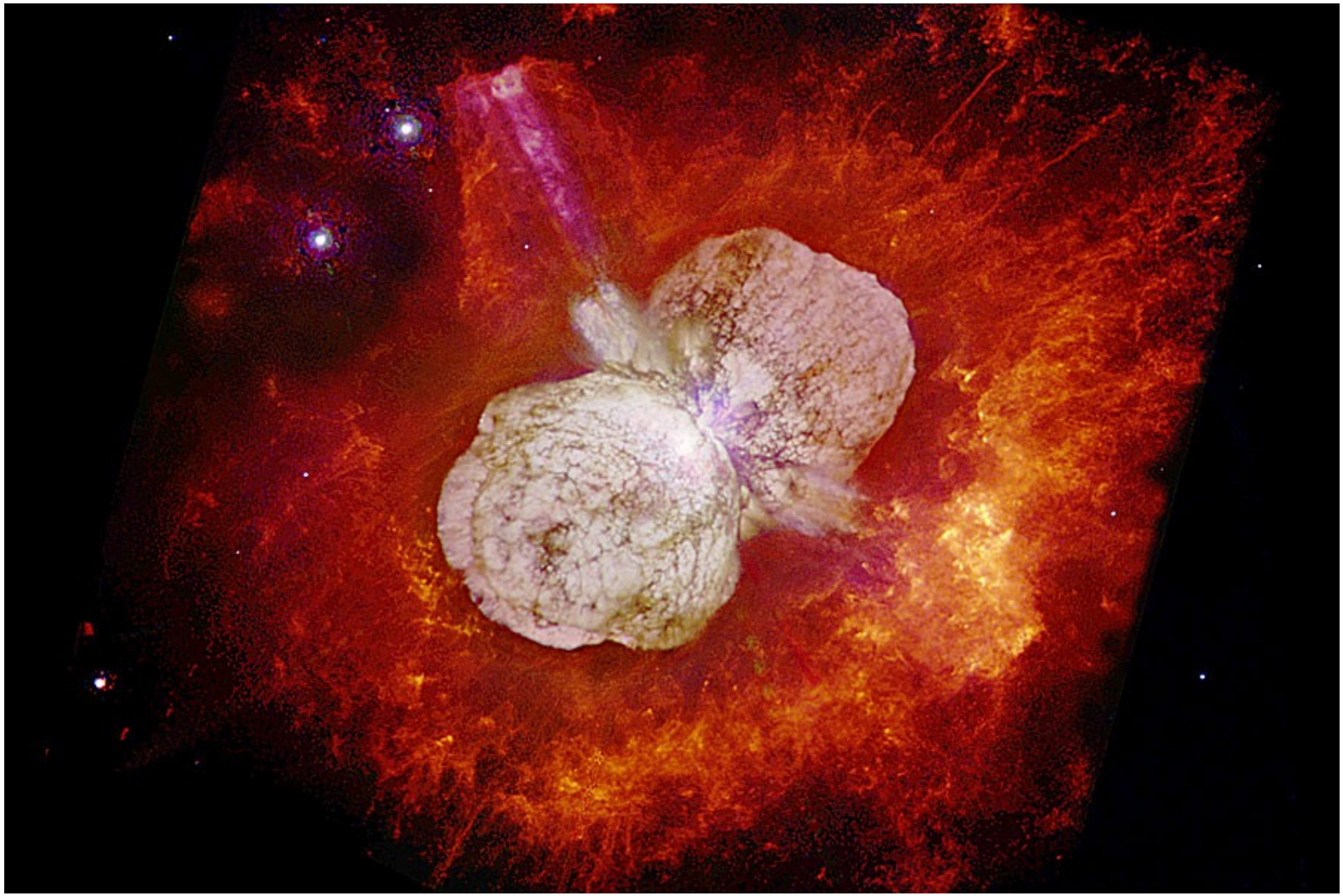
SN 2008S (Fassia+ 2001)



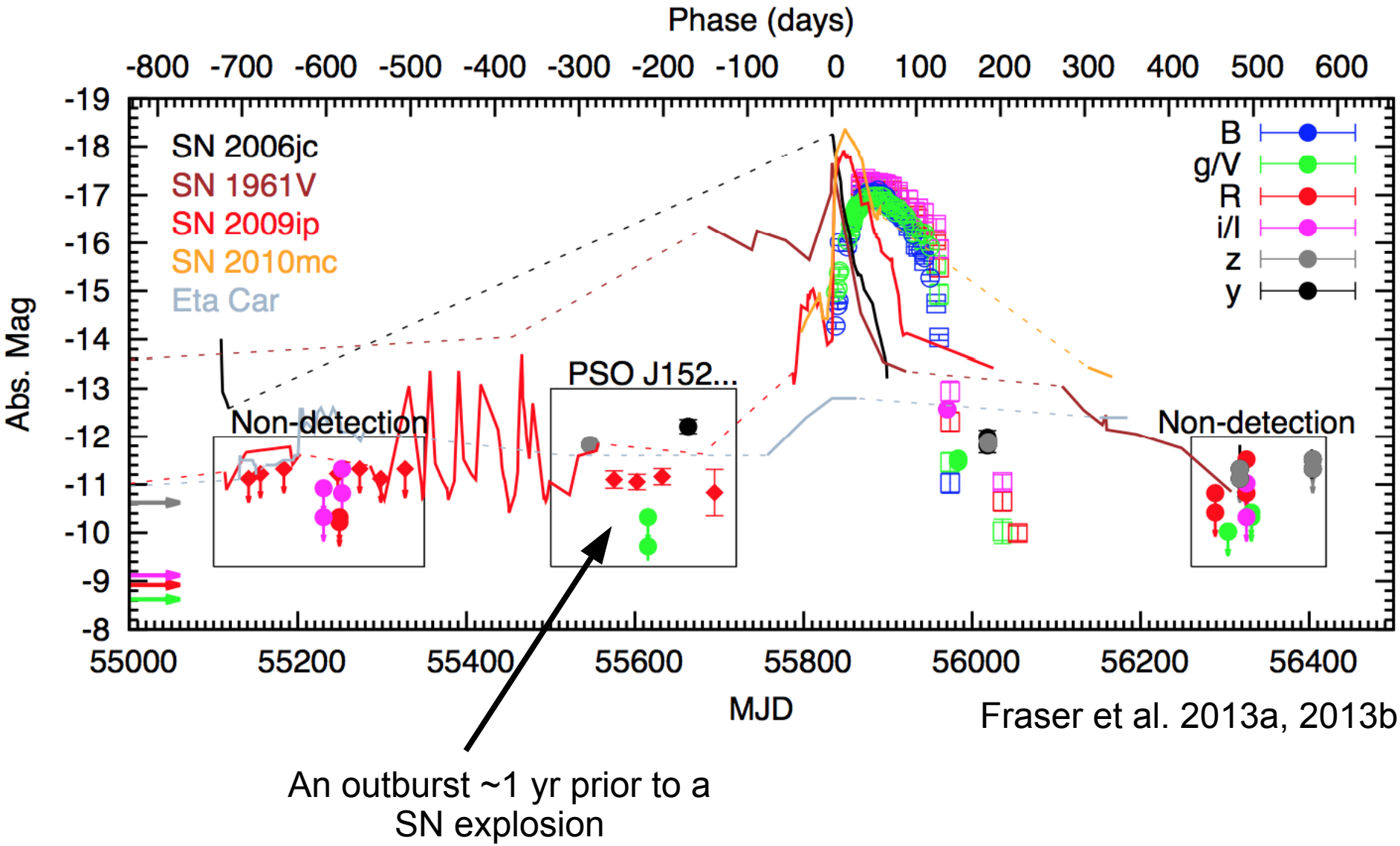
SN 2009gy (Smith+ 2009)

Photometric diversity of IIn's:





SN 2011ht - another interacting SN



Outline

- Searching for supernova progenitors
  - H-rich supernovae
  - H-poor supernovae
- Where are the more massive progenitors?
- Supernovae with a CSM
- Conclusions

- Can link SNe with their stellar progenitors
- But we haven't found what we expected
- **No H-rich SN progenitors >16 $M_{\odot}$**
- **Binarity probably plays a role – no WR progenitors of H-poor SNe**
- **Many of the more massive stars probably collapse to form BH with no optical display.**
- **Surveys can now try and find such events, by searching for the disappearance of a massive star.**
- **The low mass end is unclear – do we know what an ECSN looks like (either SN or progenitor)?**

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