Supernovae from binary
Pair-instability supernovae

Takashi Moriya
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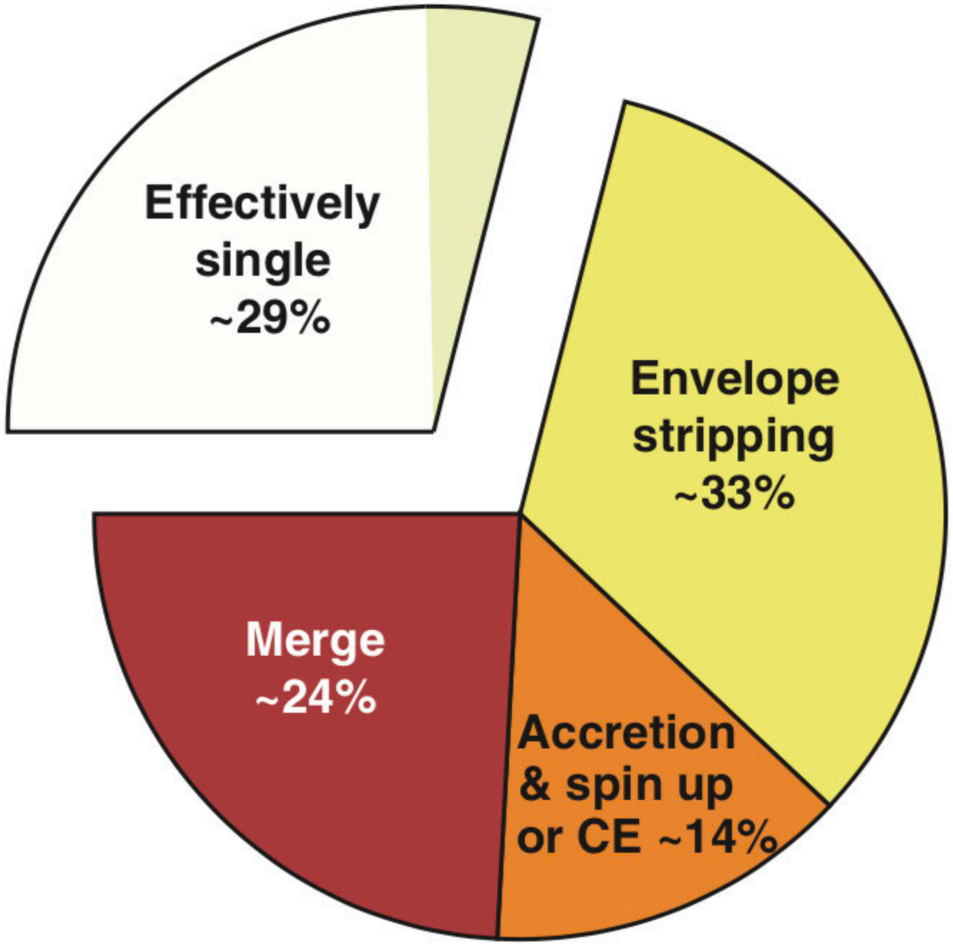
Supernovae from binary

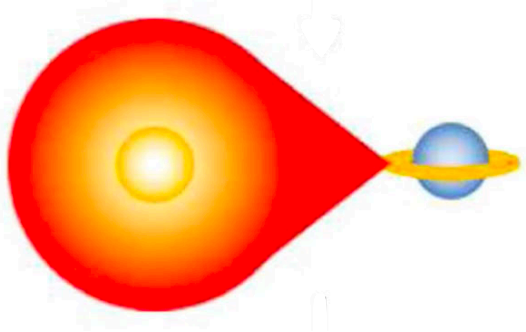
Massive stars are born in binary



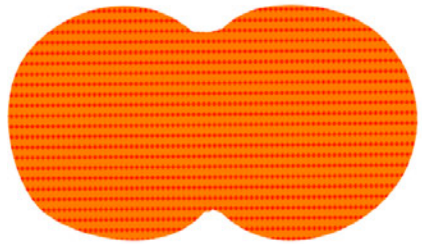
Sana et al. (2012)

How the companion stars affect stellar evolution?

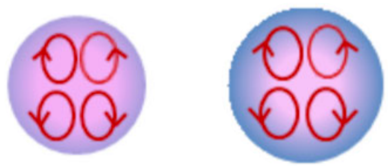
mass stripping



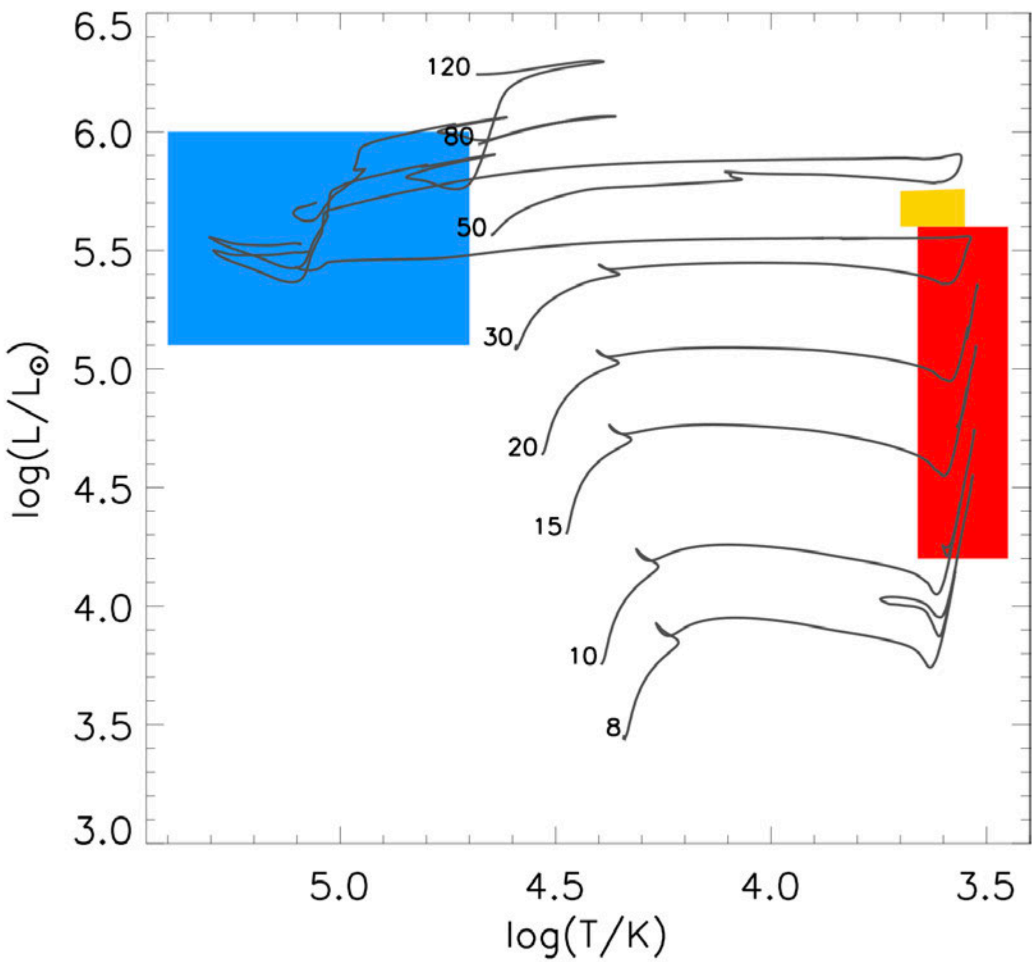
merger

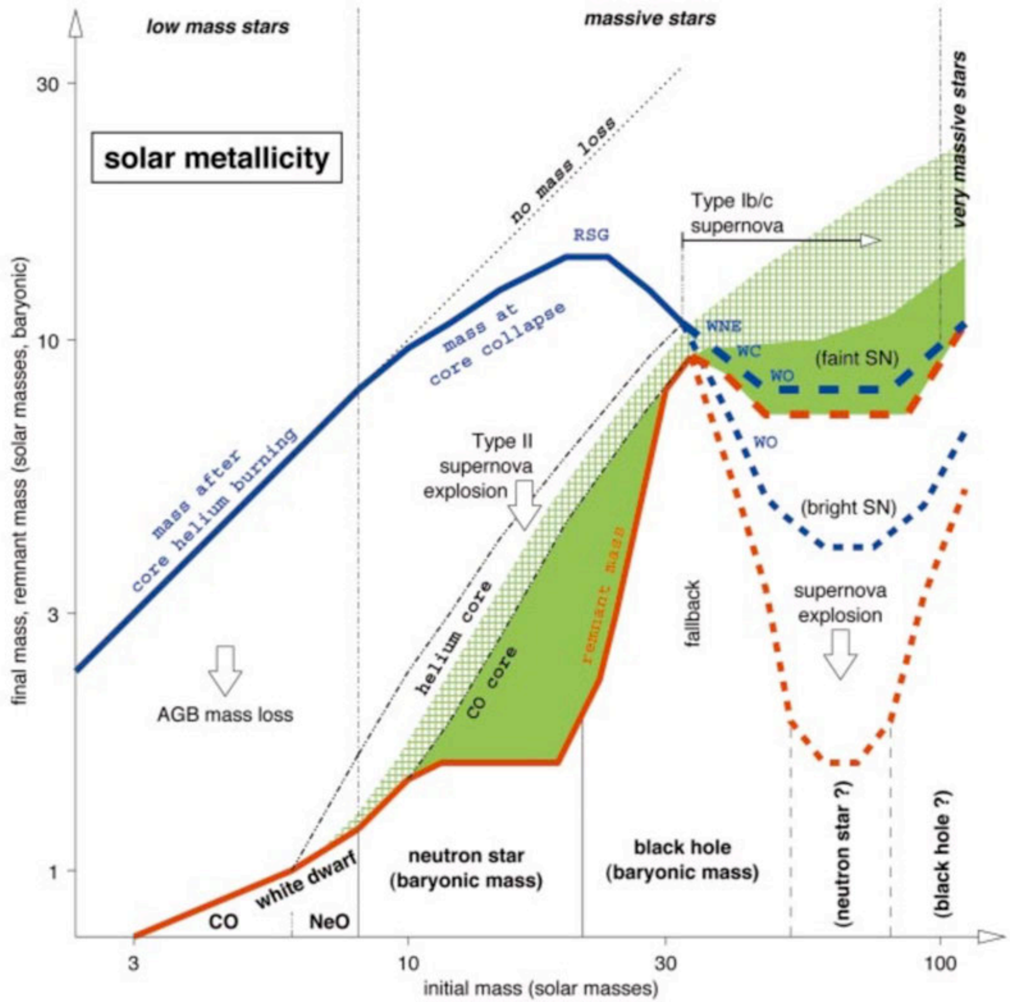


rotation



Mass of Wolf-Rayet stars from single stars



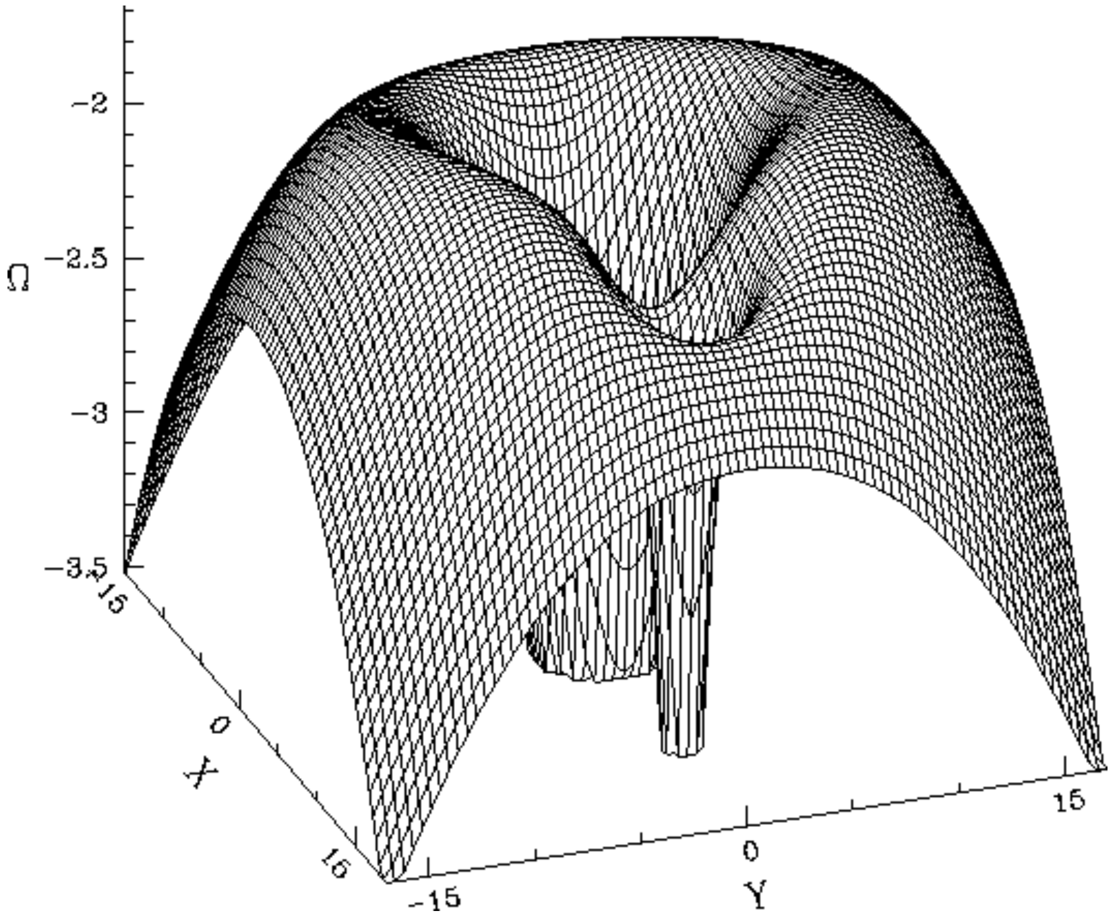


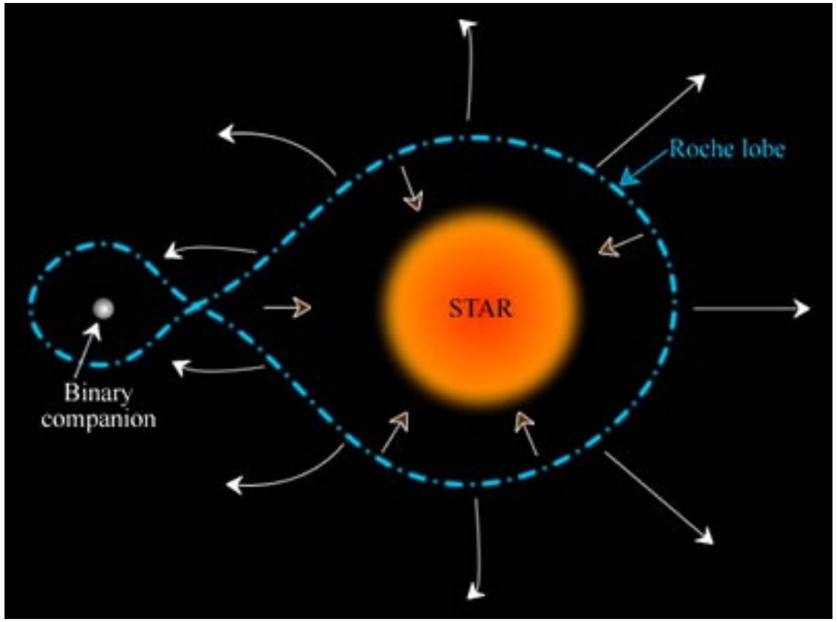
Eldridge et al. (2013)

Woosley et al. (2002)

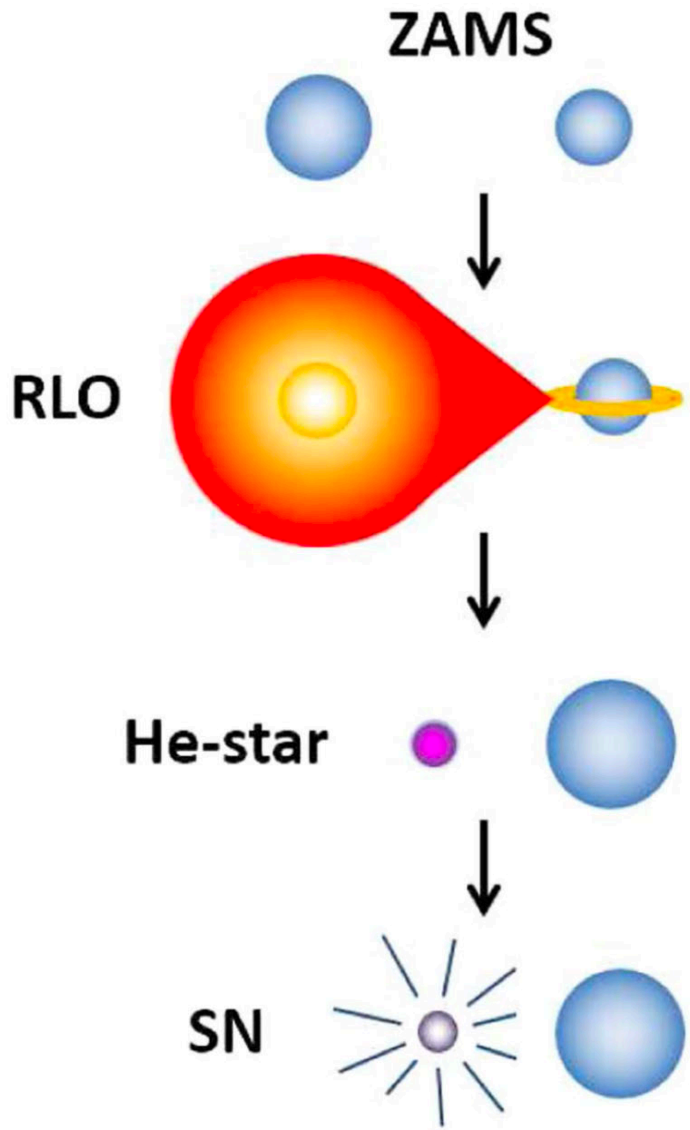
Mass stripping

- Roche-robe overflow

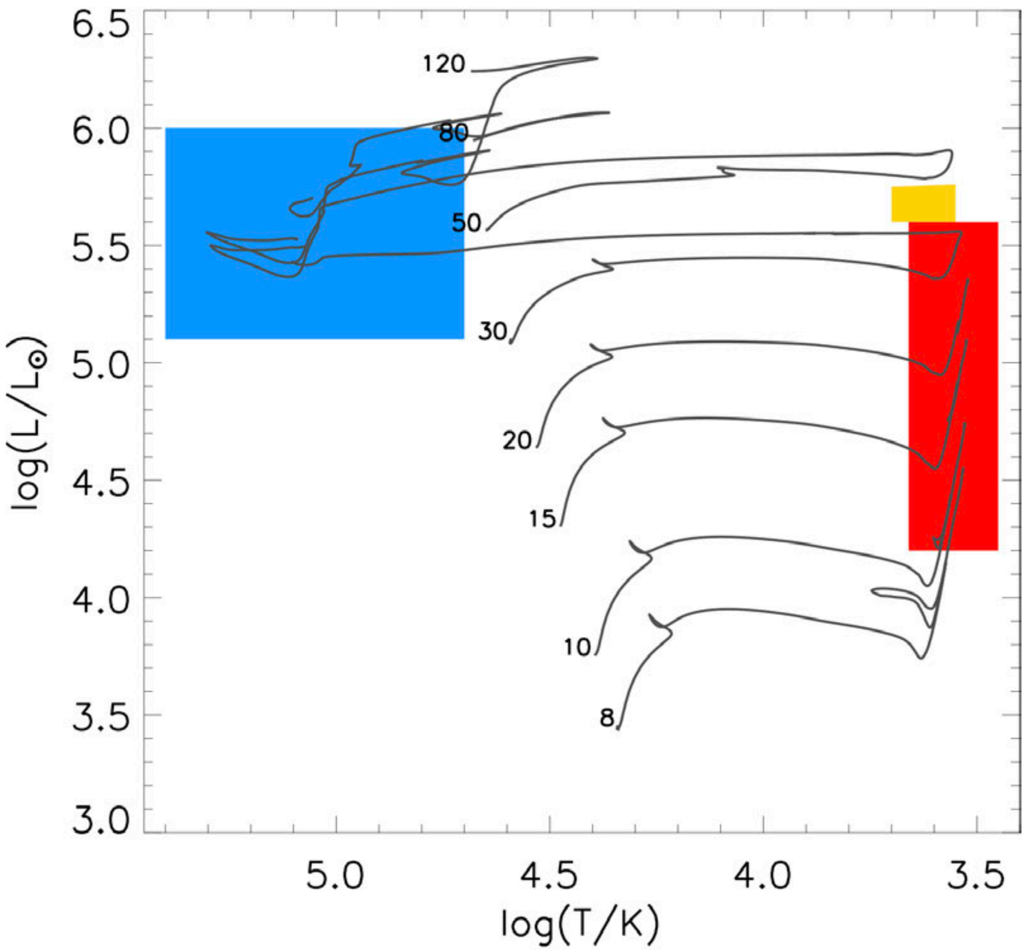


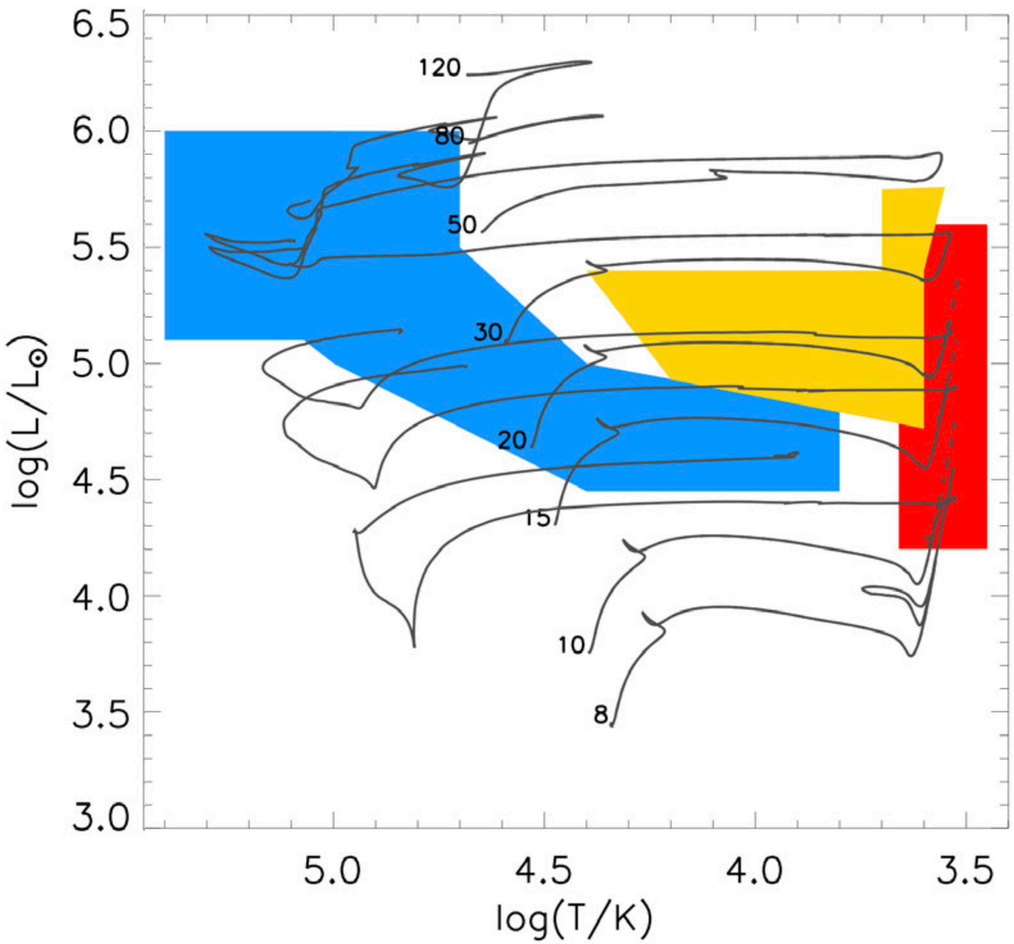


Mass stripping



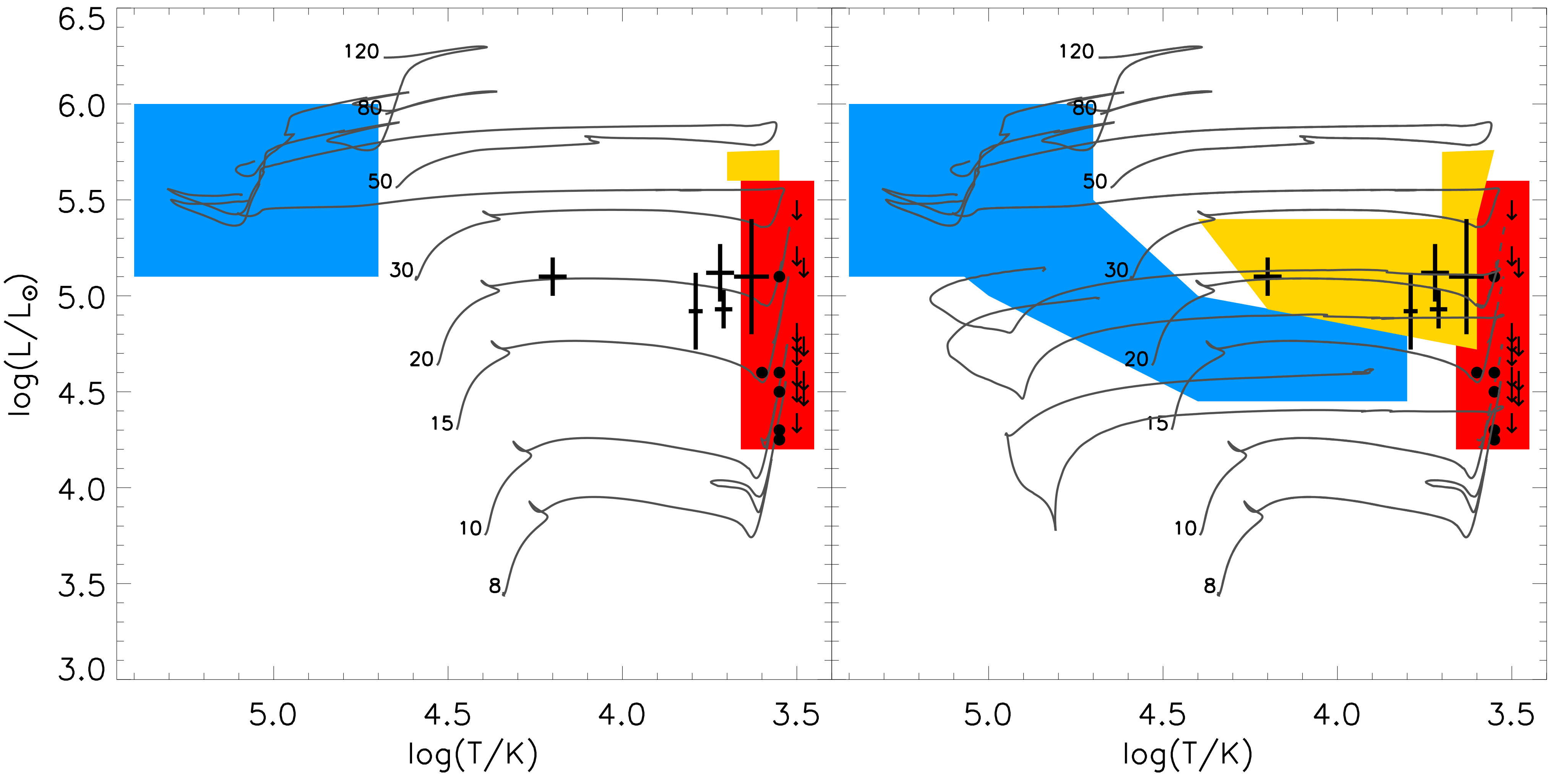
Binary evolution extends SN progenitor possibilities





Eldridge et al. (2013)

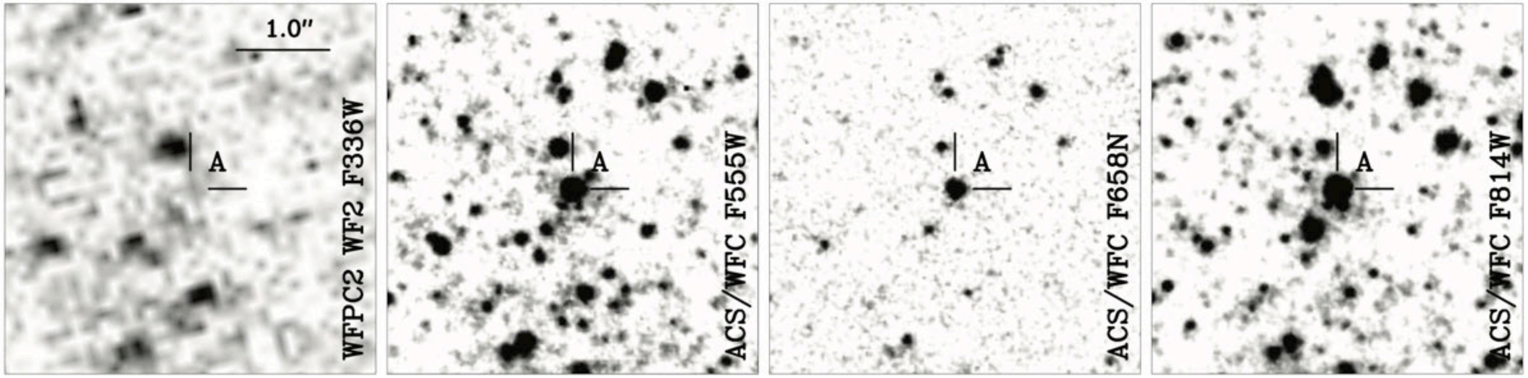
Binary evolution extends SN progenitor possibilities

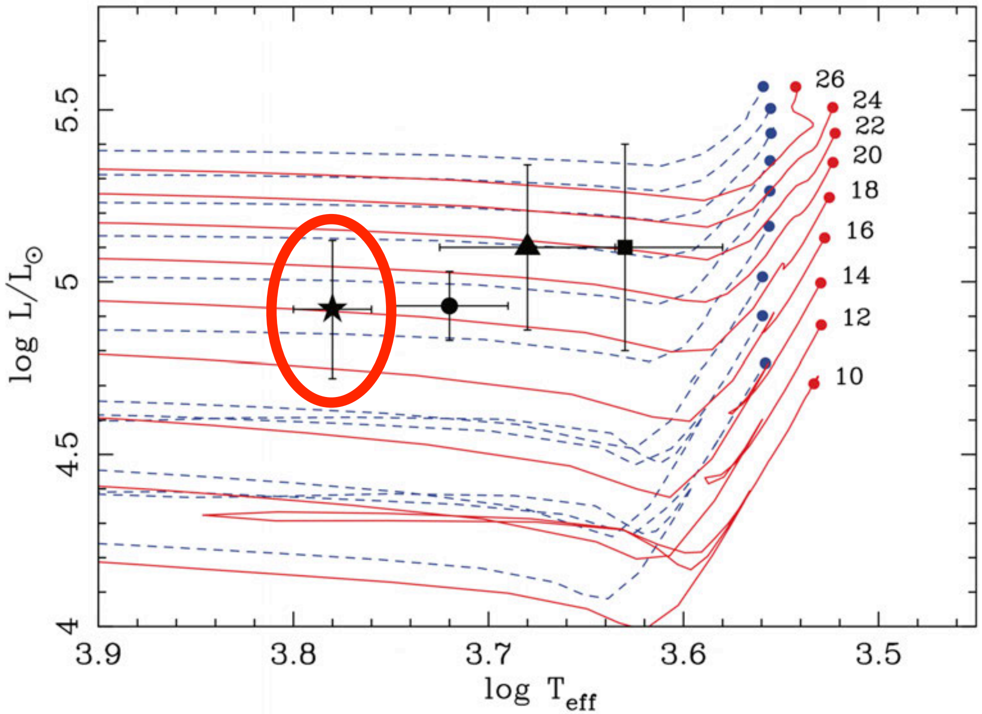


Eldridge et al. (2013)

Binary companion for the SN 2011dh progenitor

- SN 2011dh: a SN with H-rich envelope of ~ 0.1 Msun

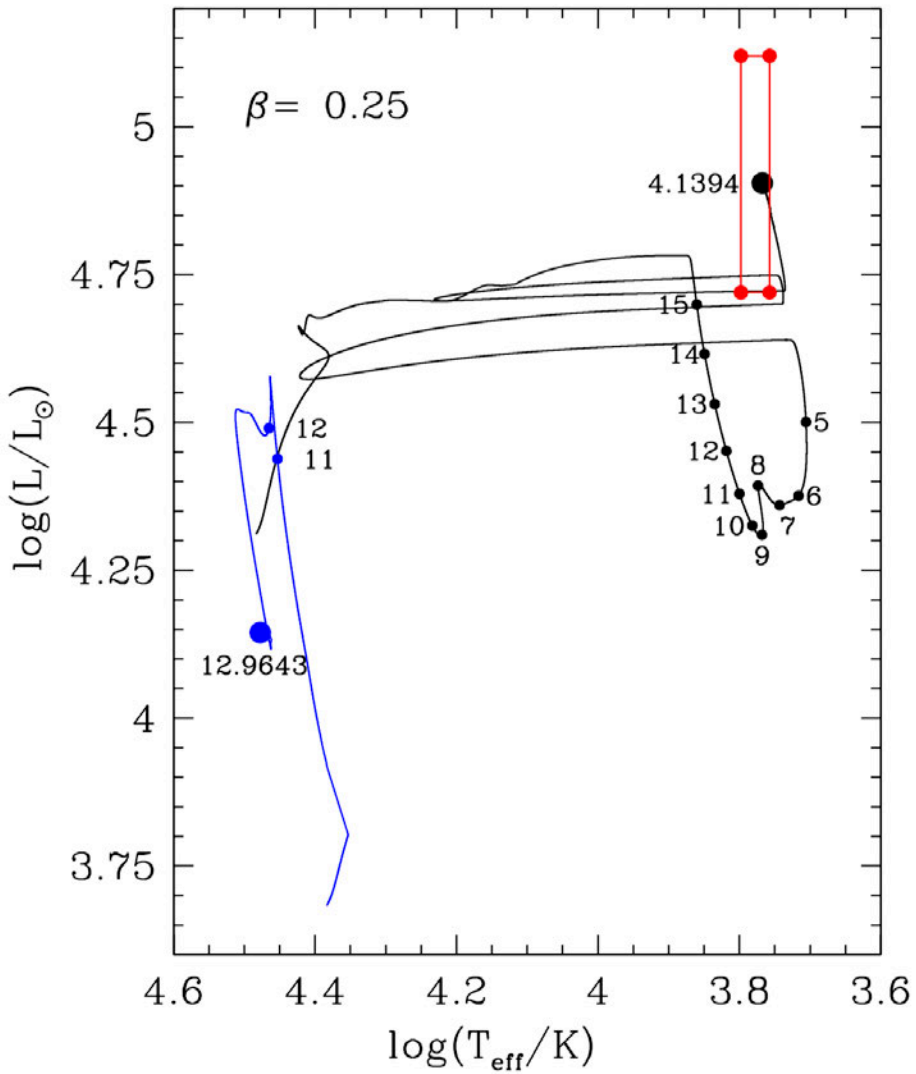




Maund et al. (2011)

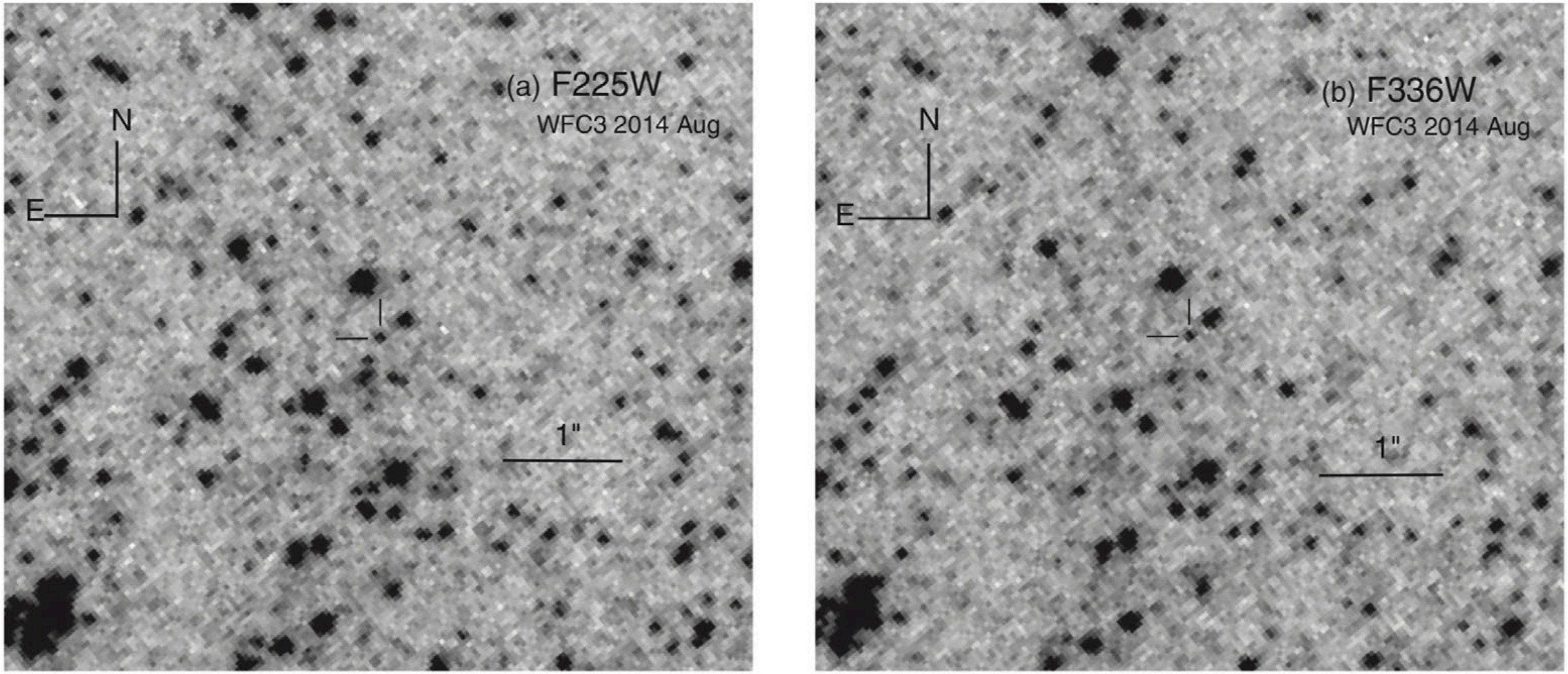
Binary companion for the SN 2011dh progenitor

- SN 2011dh: a SN with H-rich envelope of ~ 0.1 Msun



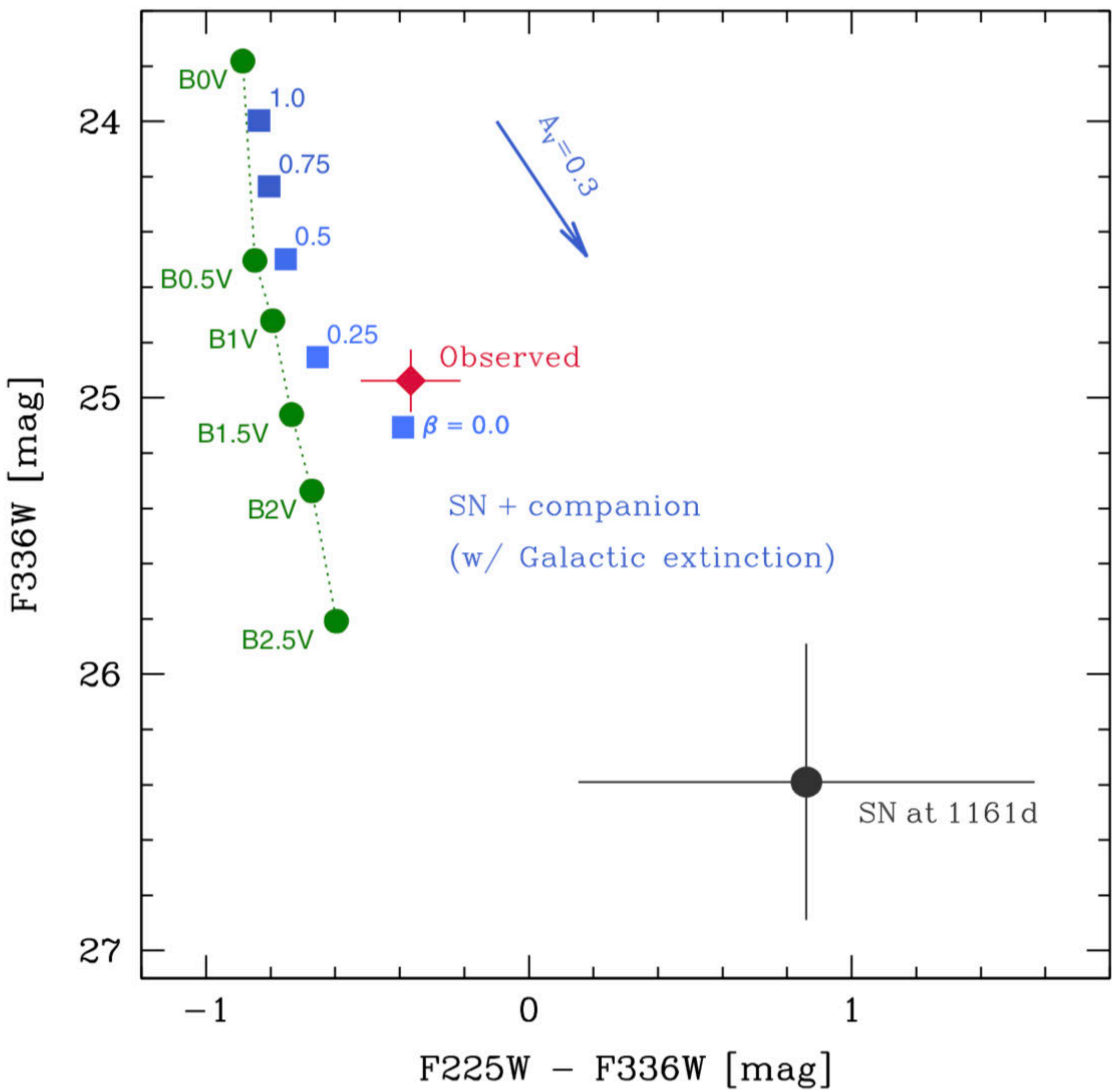
Bersten et al. (2012)

About 4 years later…



Folatelli et al. (2014)

Binary companion for the SN 2011dh progenitor



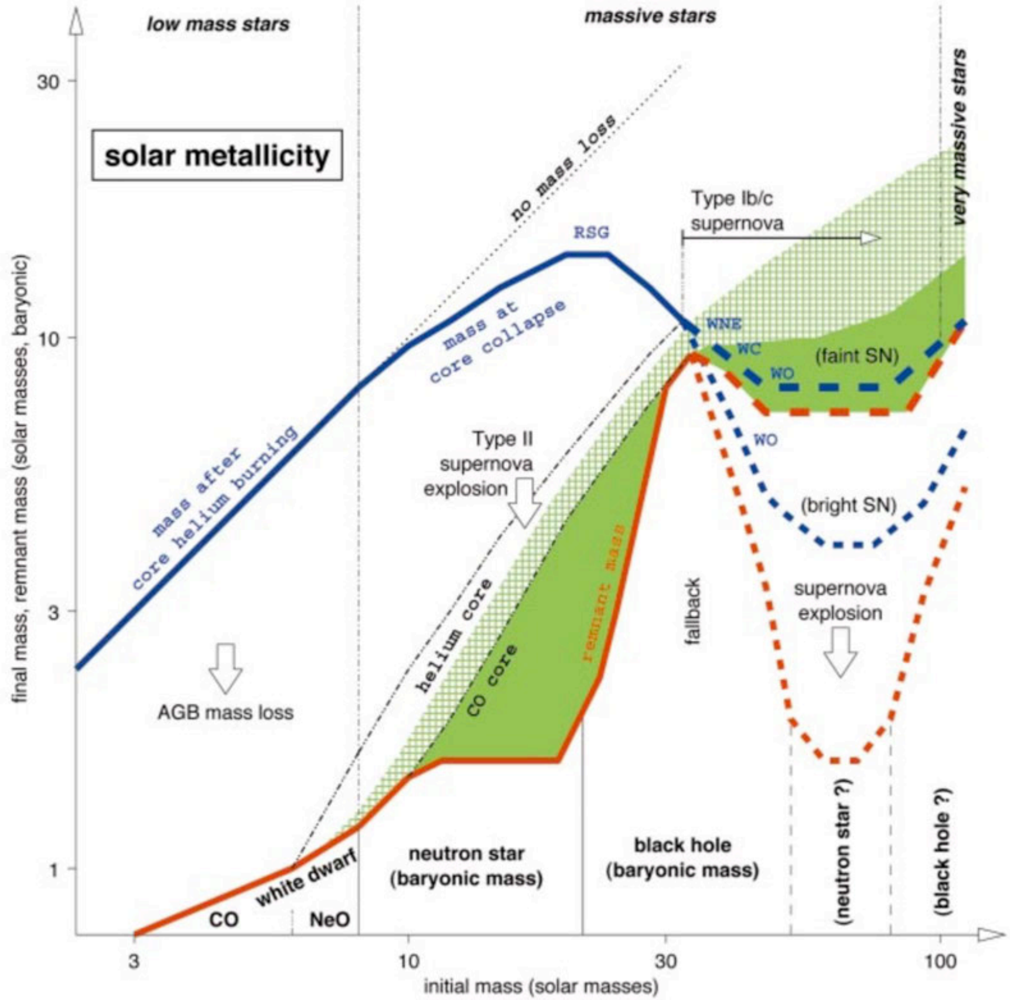
Folatelli et al. (2014)

Indications of binary in supernova observations

- ejecta mass predictions for stripped-envelope SNe

- single stars
  - > ~ 5 Msun

- binary stars
  - from ~ 1 Msun

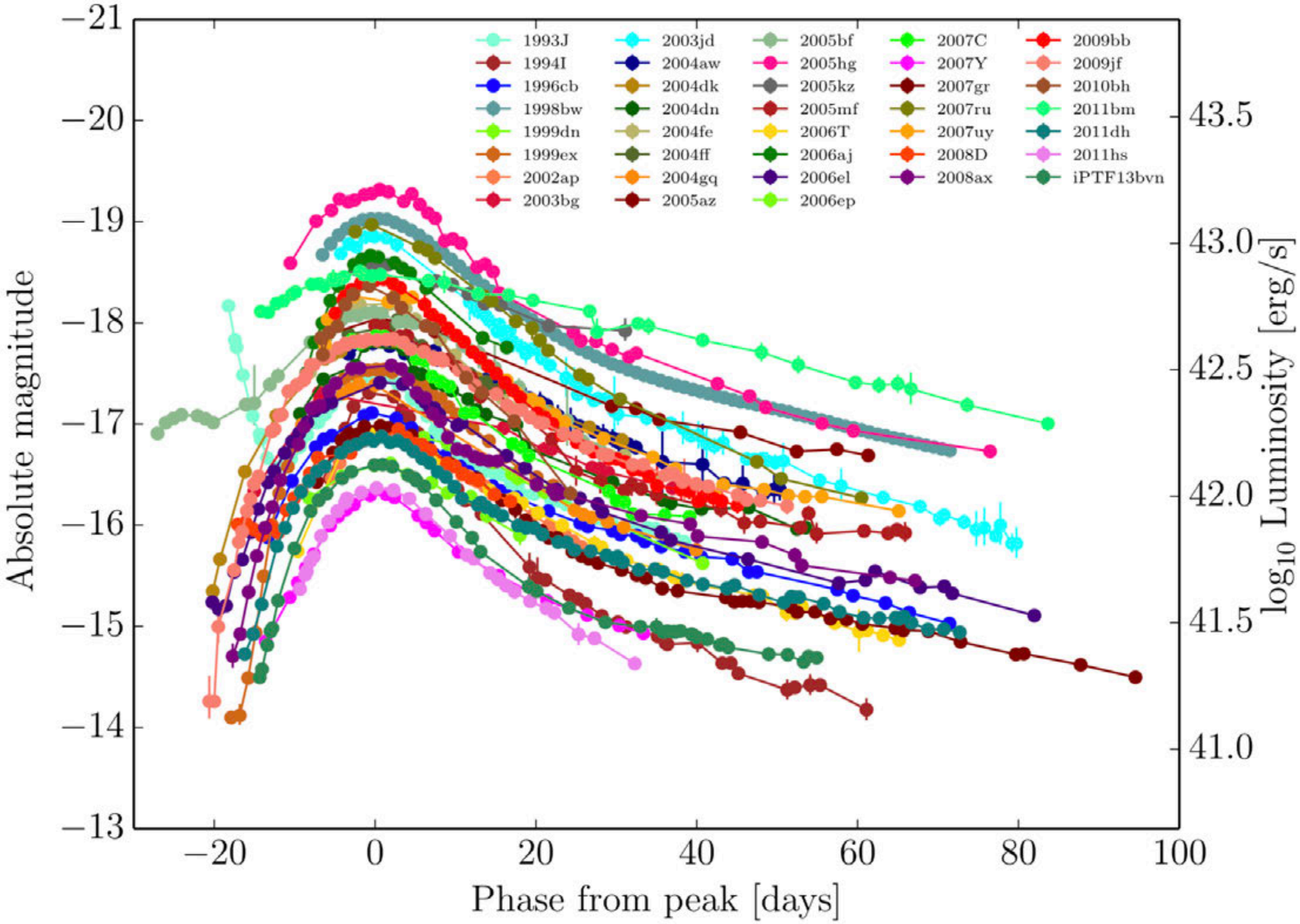


Woosley et al. (2002)

Estimating ejecta mass from stripped-envelope SNe

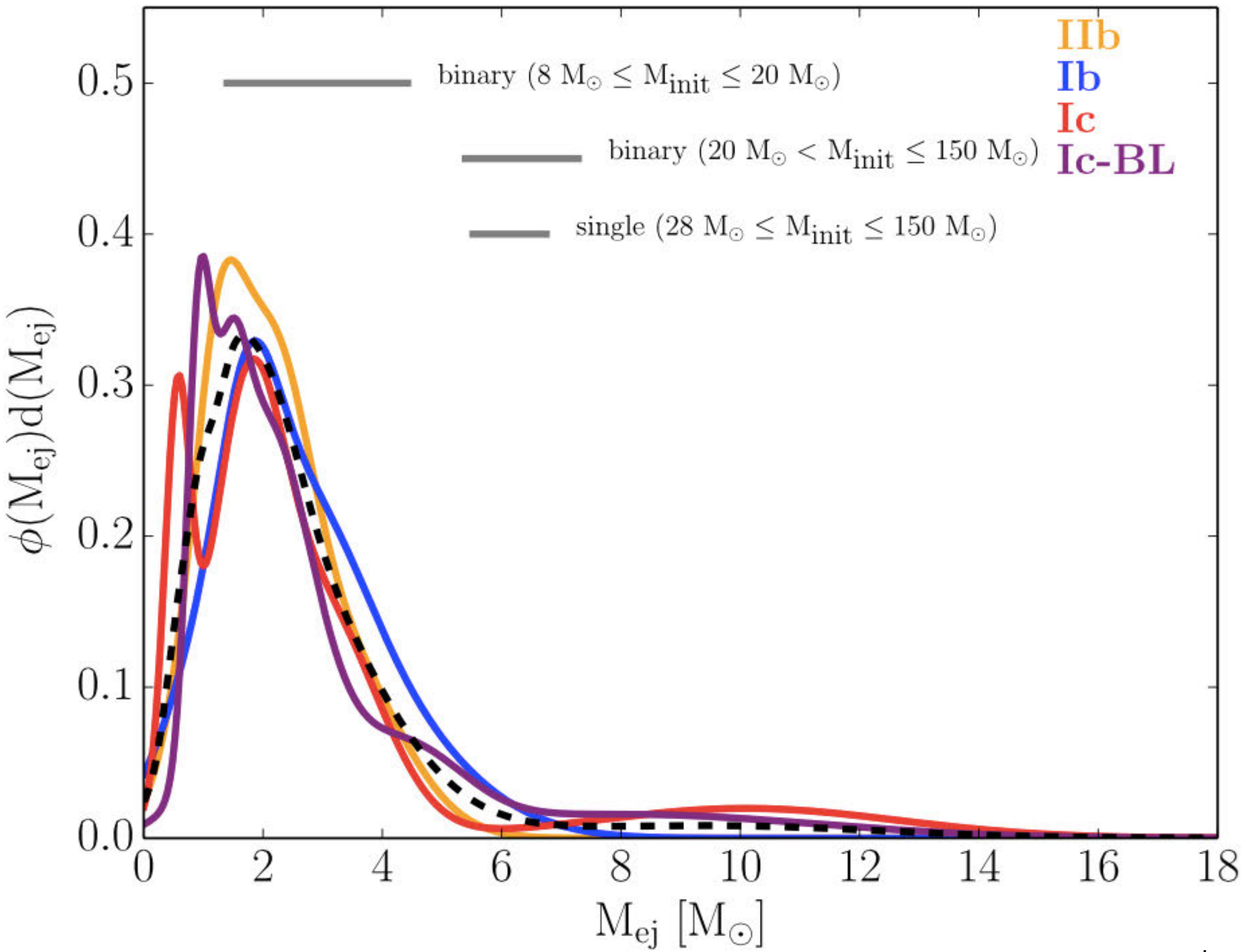
$$t_{\rm rise} \propto \frac{M^{3/4}}{E^{1/4}}$$

$$v \propto \frac{E^{1/2}}{M^{1/2}}$$



Lyman et al. (2016)

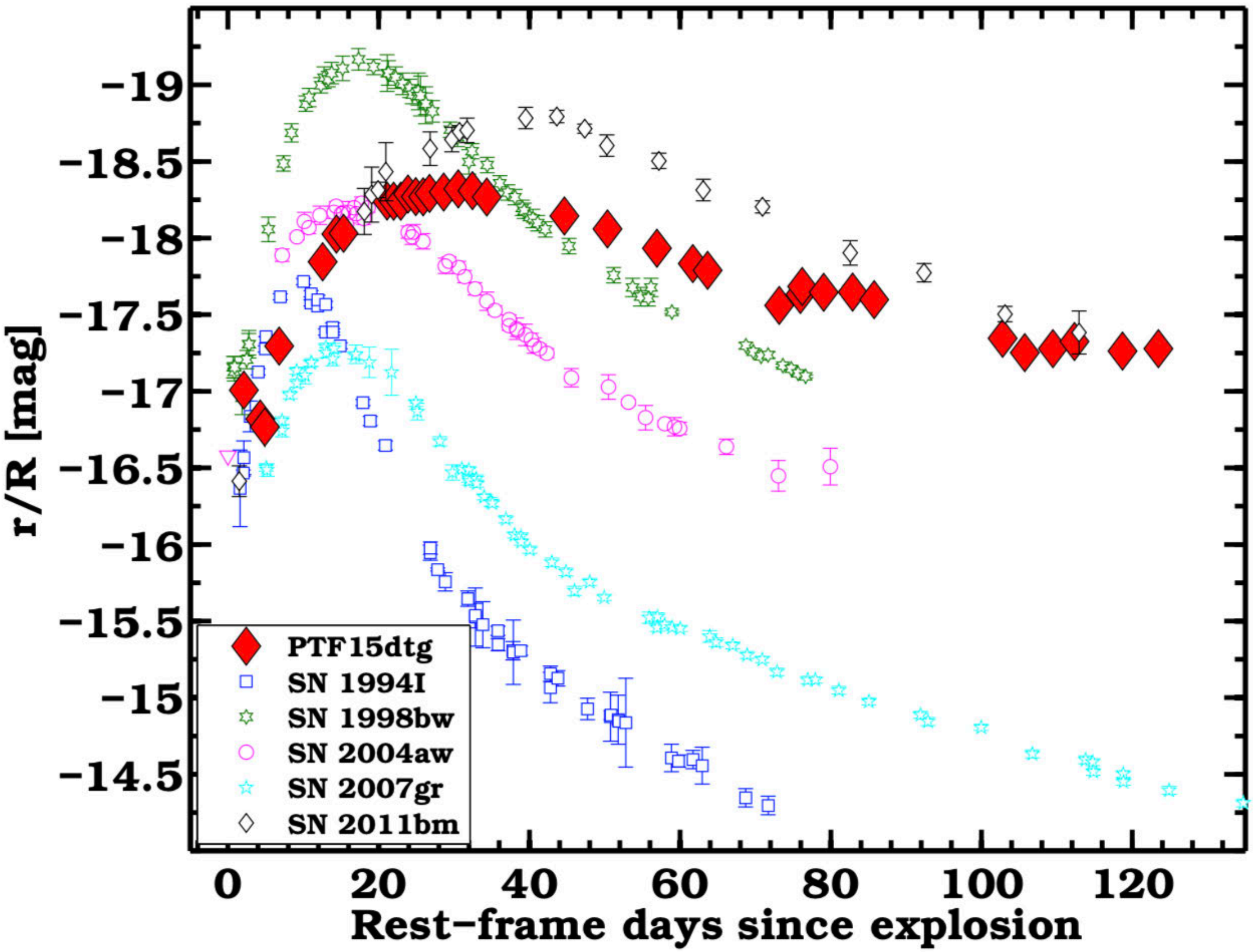
Ejecta mass estimates for stripped-envelope SNe



Lyman et al. (2016)

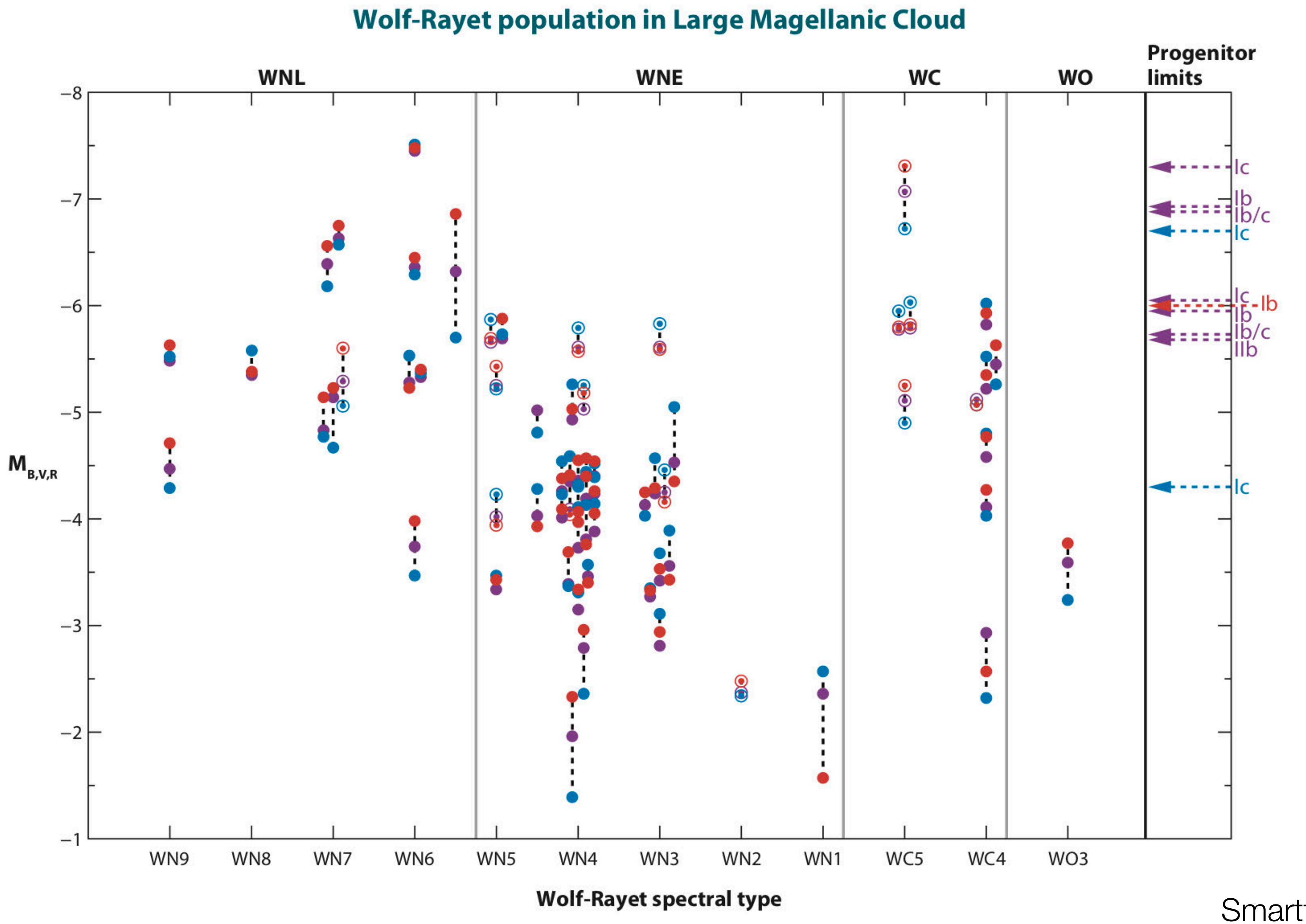
Massive WR star explosions

- PTF15dtg: a Type Ic SN with ~ 10 Msun ejecta



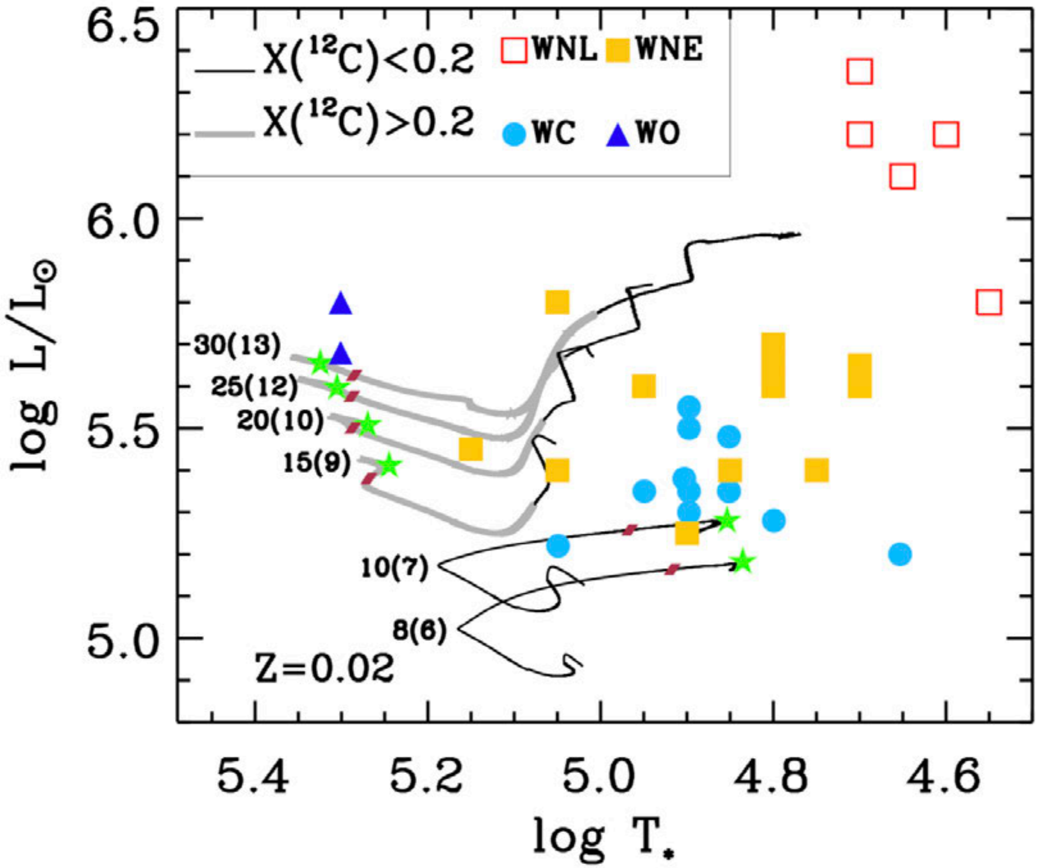
Taddia et al. (2016)

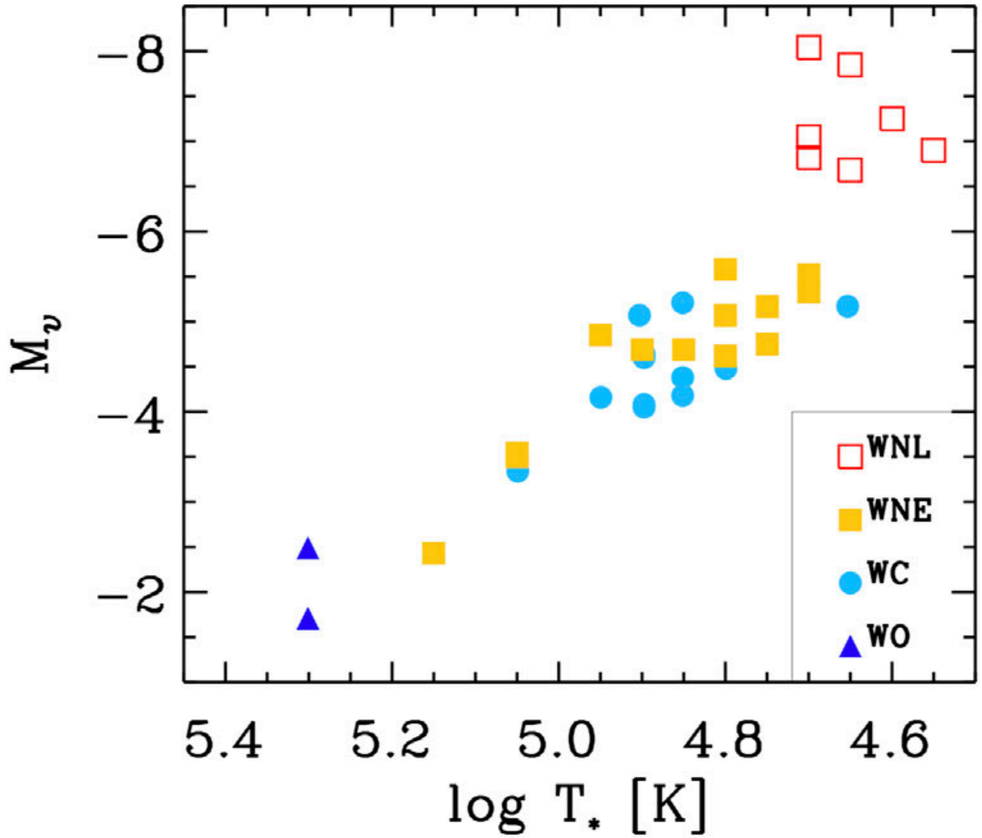
Massive WR star explosions



Smartt (2009)

Massive WR star explosions

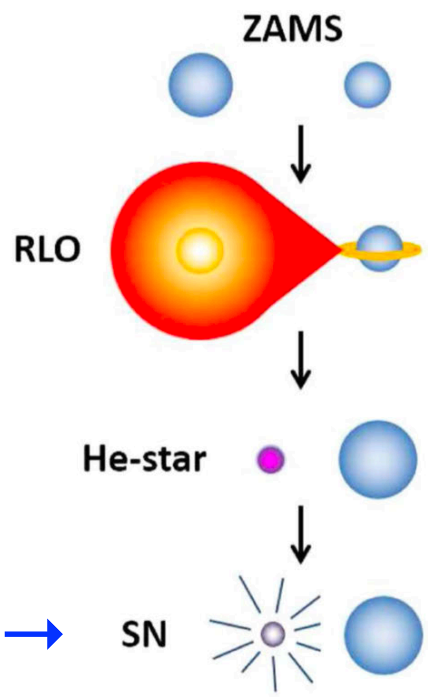




Yoon et al. (2012)

Ultra-stripped supernovae

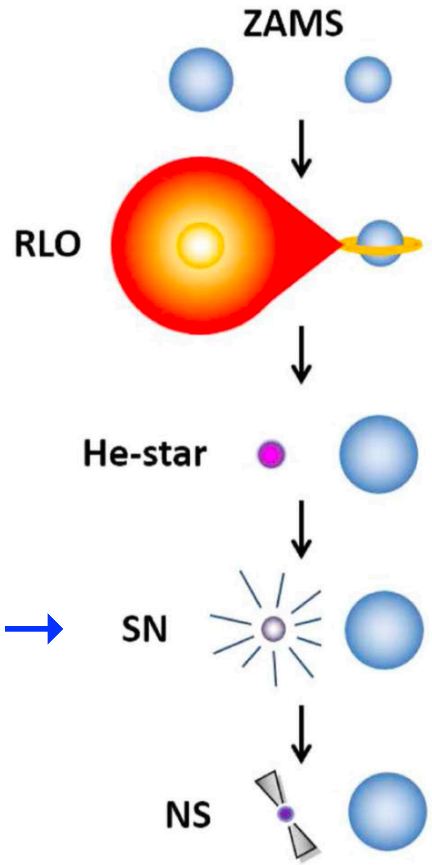
stripped SNe
Mej ~ 1 Msun →



Tauris et al. (2017)

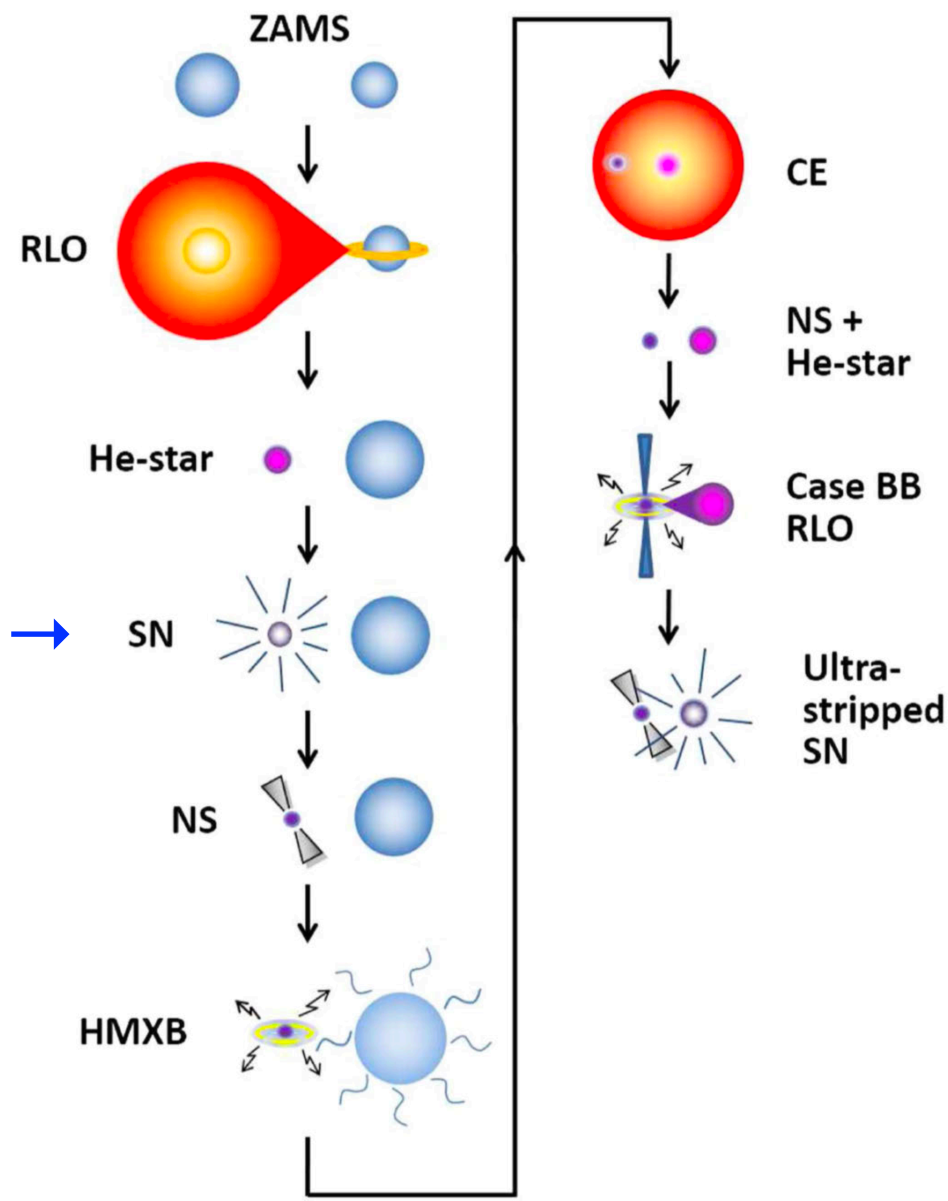
Ultra-stripped supernovae

stripped SNe
Mej ~ 1 Msun →



Tauris et al. (2017)

Ultra-stripped supernovae



stripped SNe
Mej ~ 1 Msun →

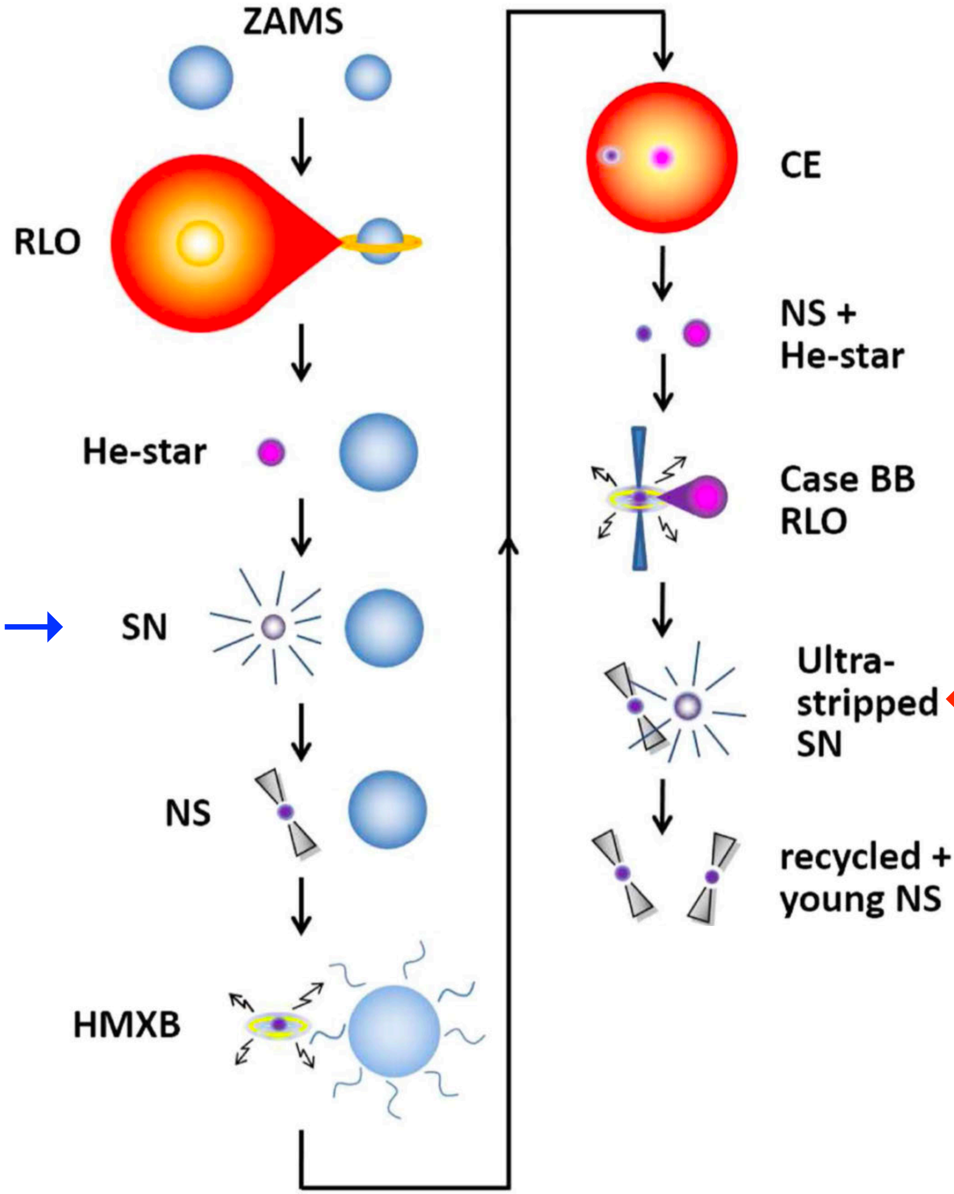
← stripped SNe with
Mej ~ 0.1 Msun
(2nd SN)

ultra-stripped SNe

Tauris et al. (2017)

Ultra-stripped supernovae

stripped SNe
Mej ~ 1 Msun →



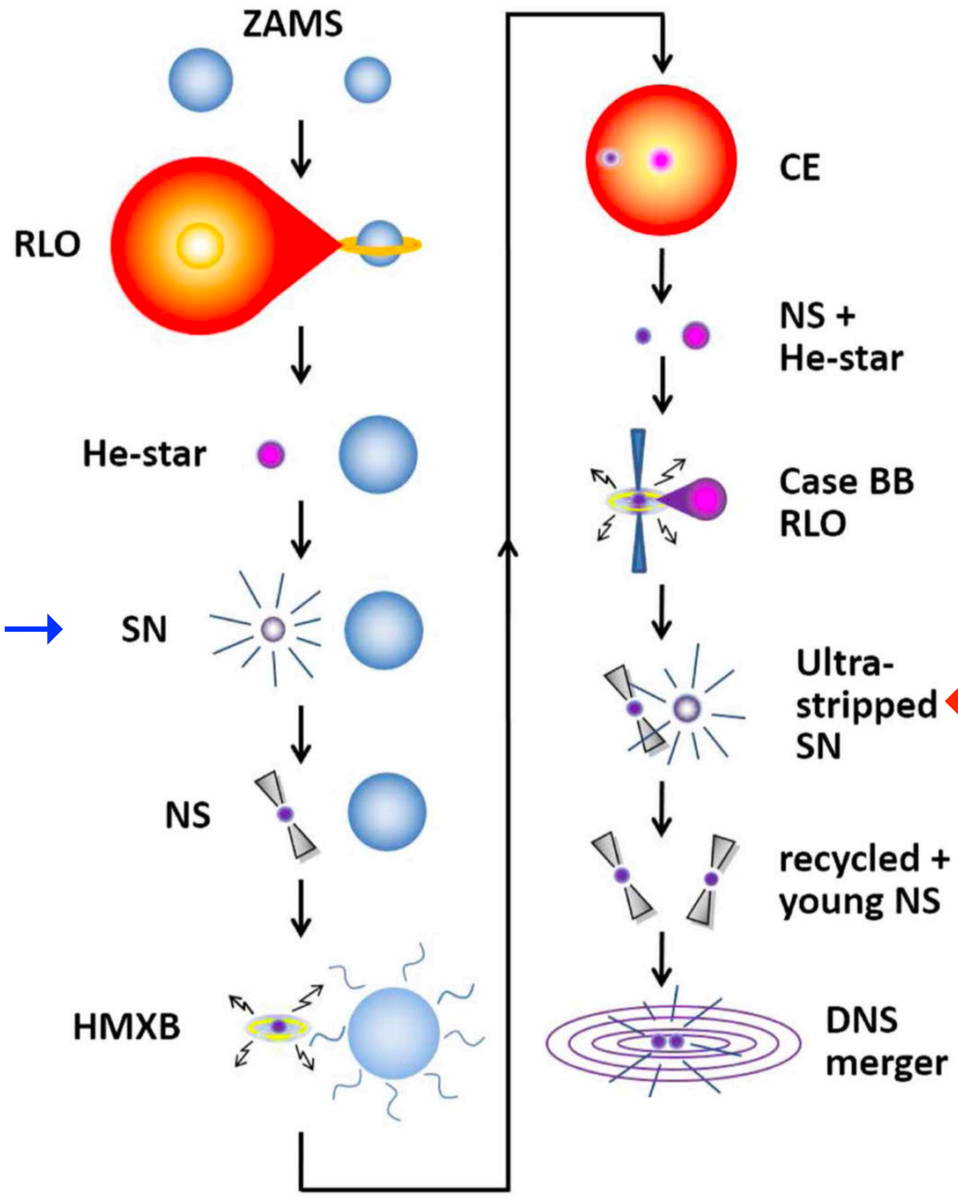
← stripped SNe with
Mej ~ 0.1 Msun
(2nd SN)

ultra-stripped SNe

Tauris et al. (2017)

Ultra-stripped supernovae

stripped SNe
Mej ~ 1 Msun



stripped SNe with
Mej ~ 0.1 Msun
(2nd SN)

ultra-stripped SNe

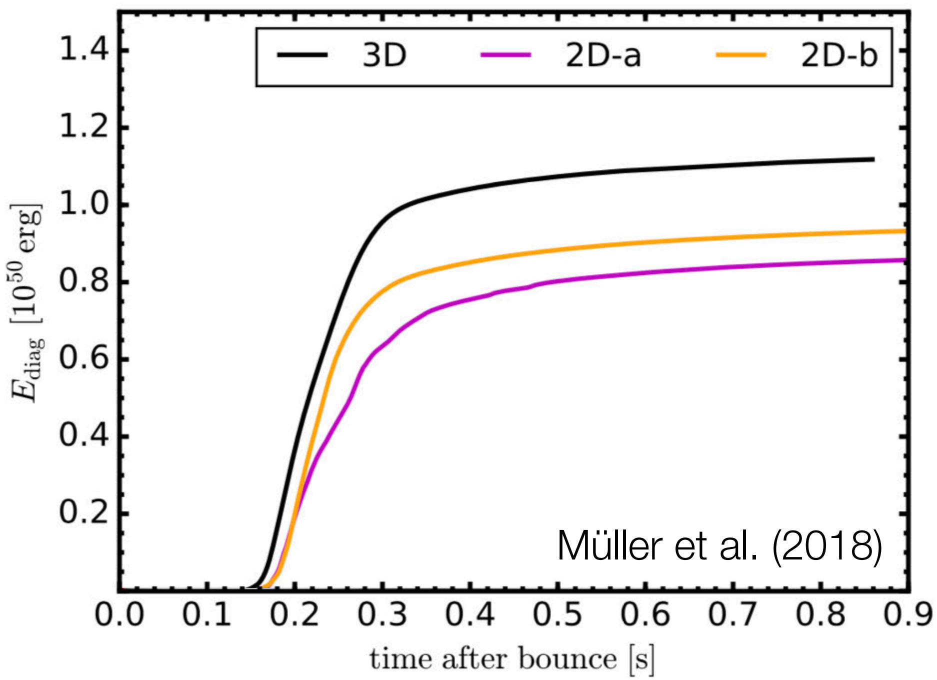
Tauris et al. (2017)

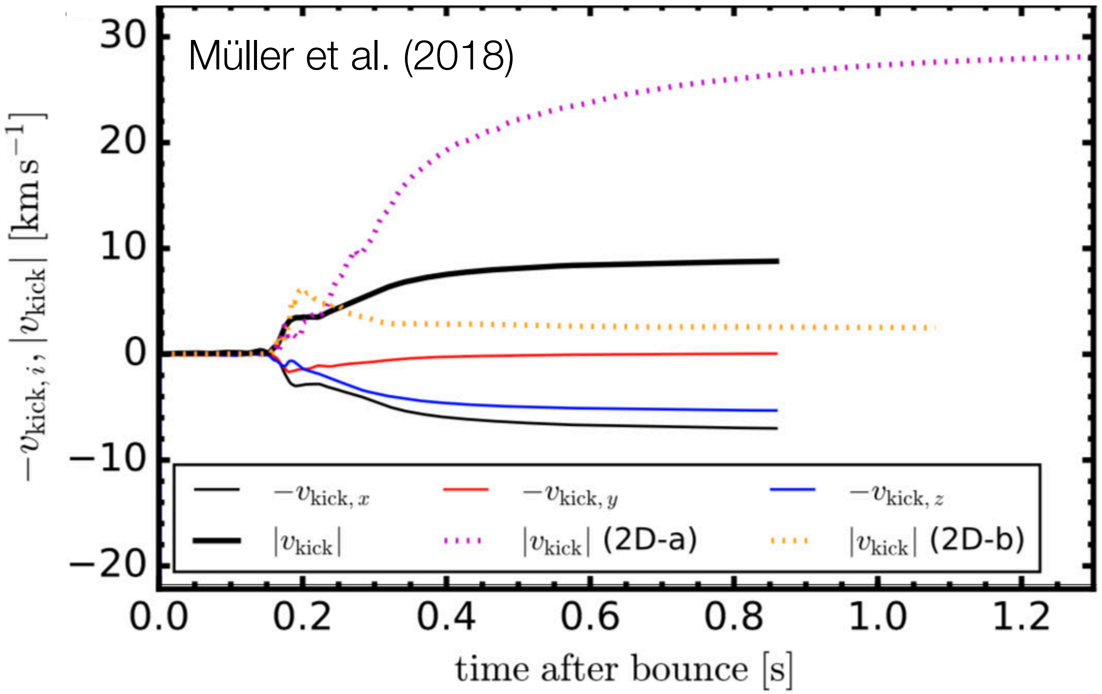
Explosion energy of ultra-stripped supernovae

- explosion energy ~ 1e50 erg

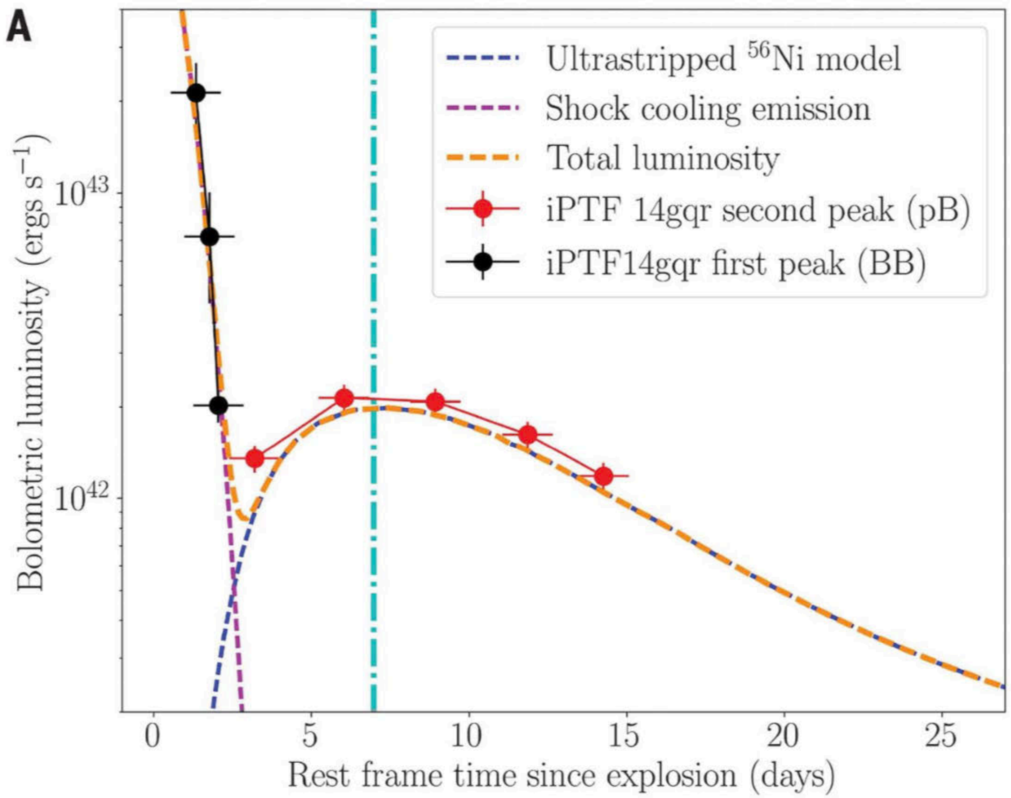
Suwa et al. (2015)

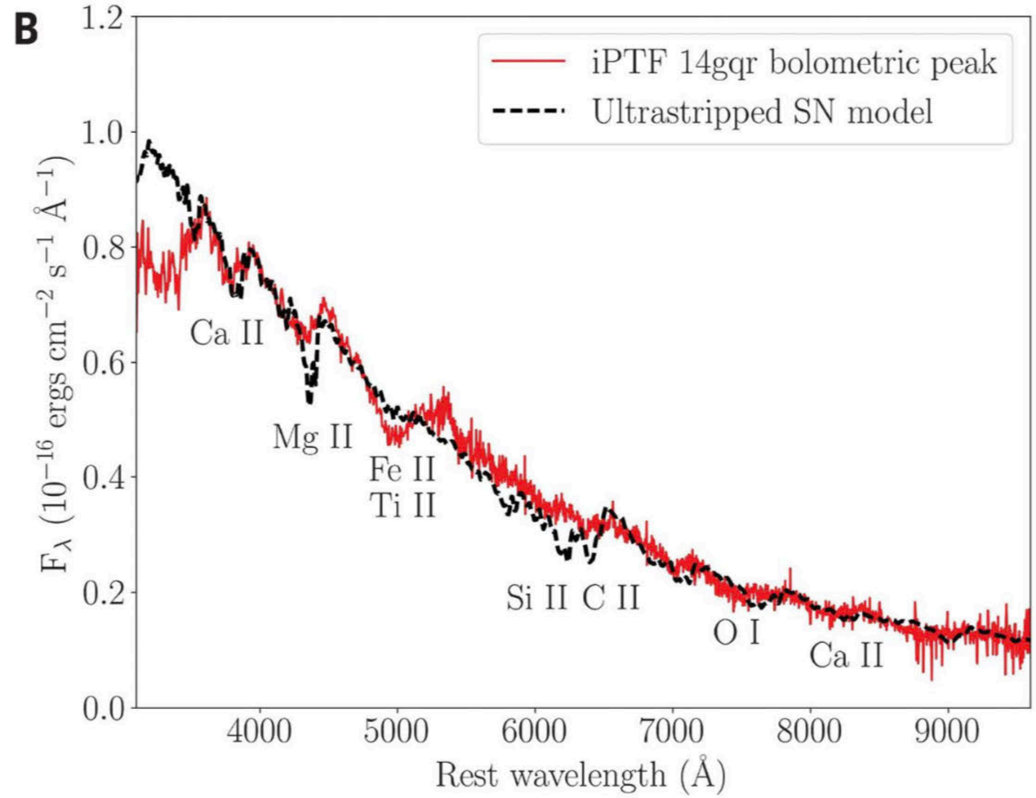
Model	$t_{\rm final}$[a] (ms)	$R_{\rm sh}$[b] (km)	$E_{\rm exp}$[c] (B)	$M_{\rm NS,\,baryon}$[d] ($M_\odot$)	$M_{\rm NS,\,grav}$[e] ($M_\odot$)	$M_{\rm ej}$[f] ($10^{-1}\,M_\odot$)	$M_{\rm Ni}$[g] ($10^{-2}\,M_\odot$)	$v_{\rm kick}$[h] (km s^{-1})
CO145	491	4220	0.177	1.35	1.24	0.973	3.54	3.20
CO15	584	4640	0.153	1.36	1.24	1.36	3.39	75.1
CO16	578	3430	0.124	1.42	1.29	1.76	2.90	47.6
CO18	784	2230	0.120	1.49	1.35	3.07	2.56	36.7
CO20[i]	959	1050	0.0524	1.60	1.44	3.95	0.782	10.5





iPTF14gqr: an ultra-stripped supernova

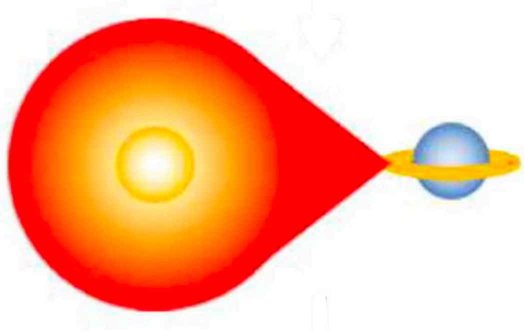




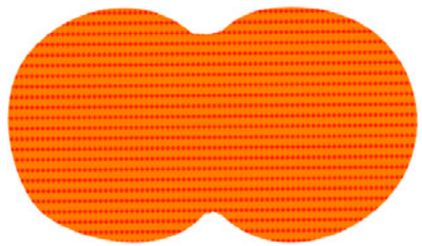
De et al. (2018)

How the companion stars affect stellar evolution?

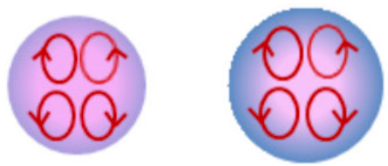
mass stripping



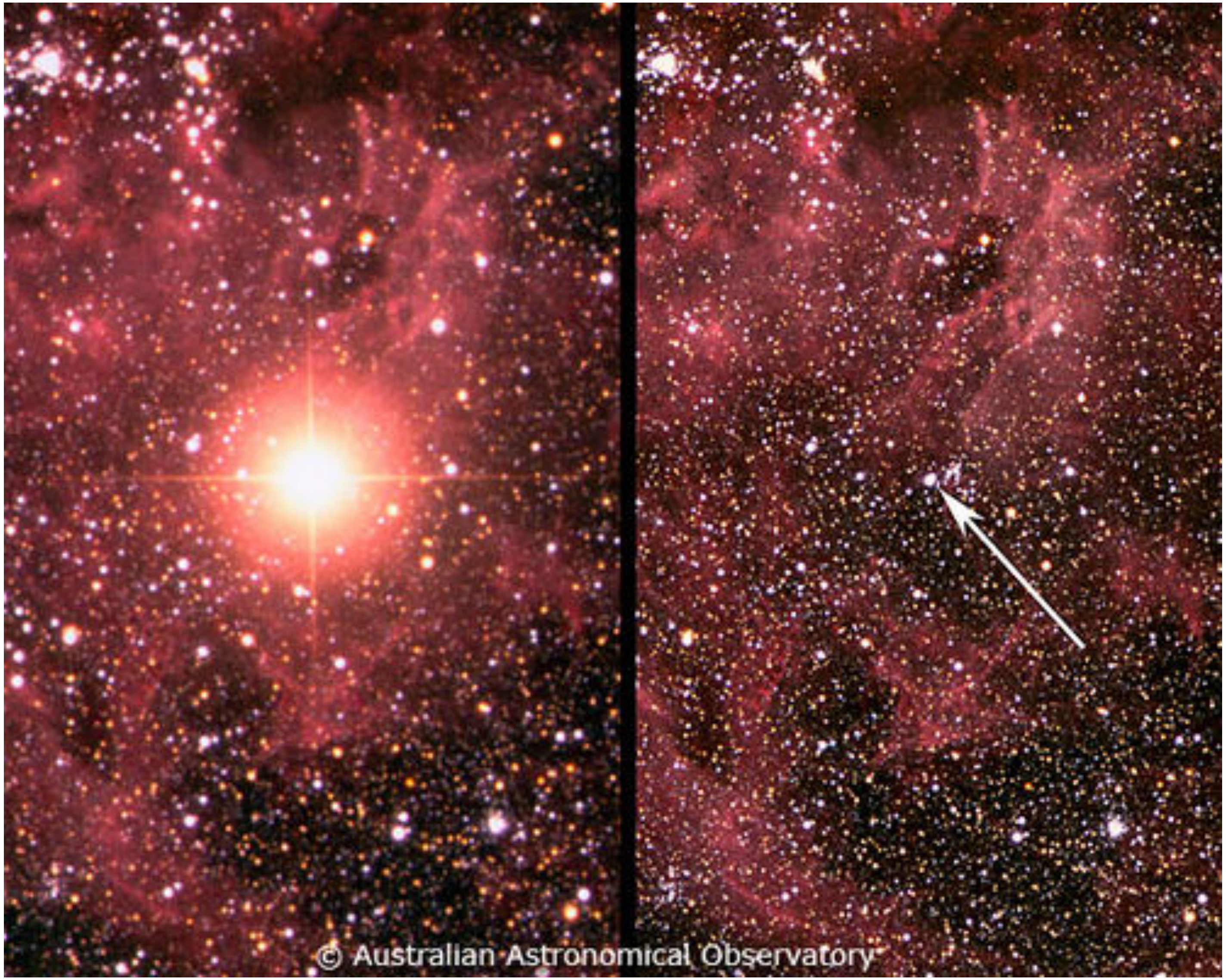
merger



rotation

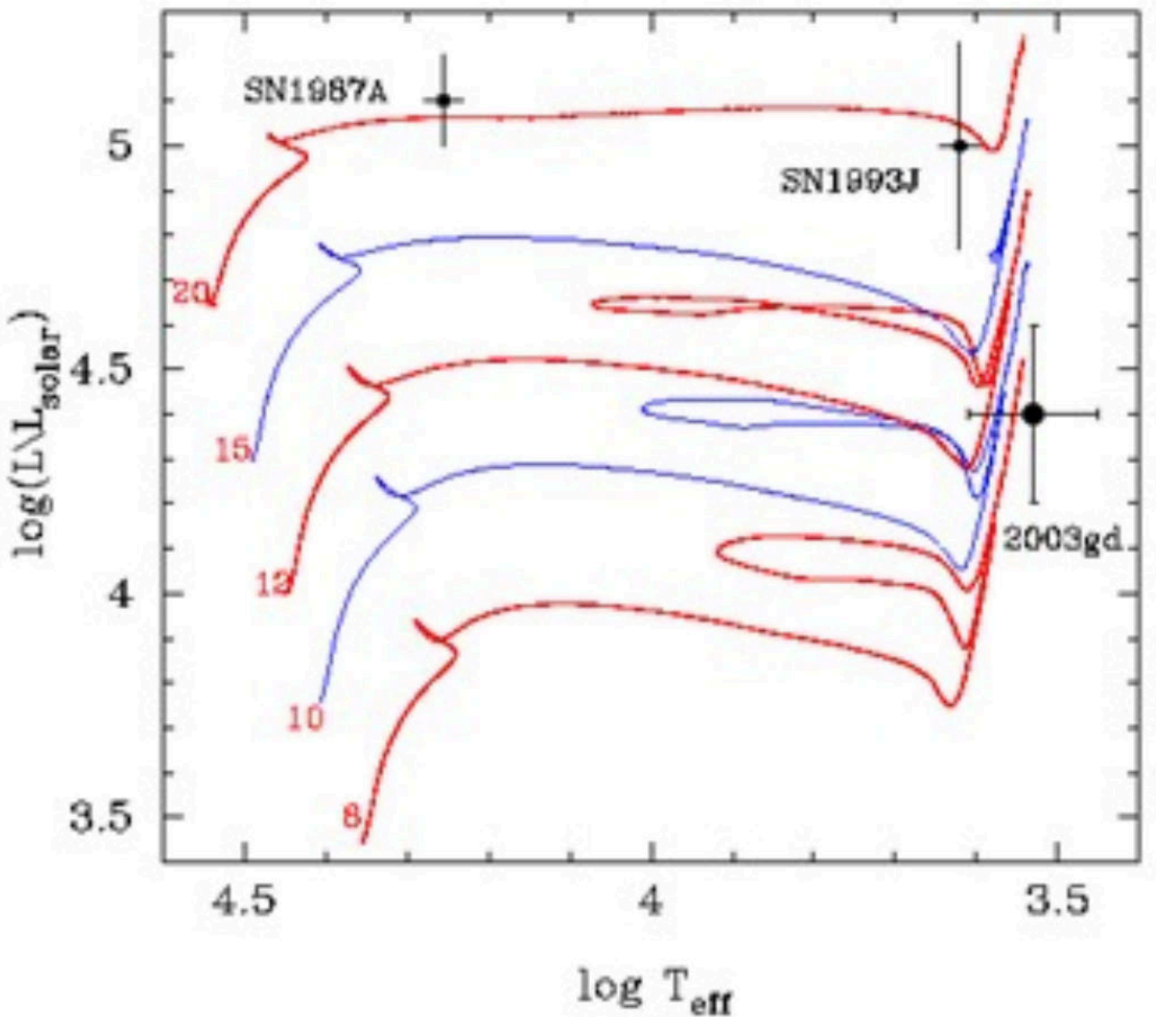


SN 1987A

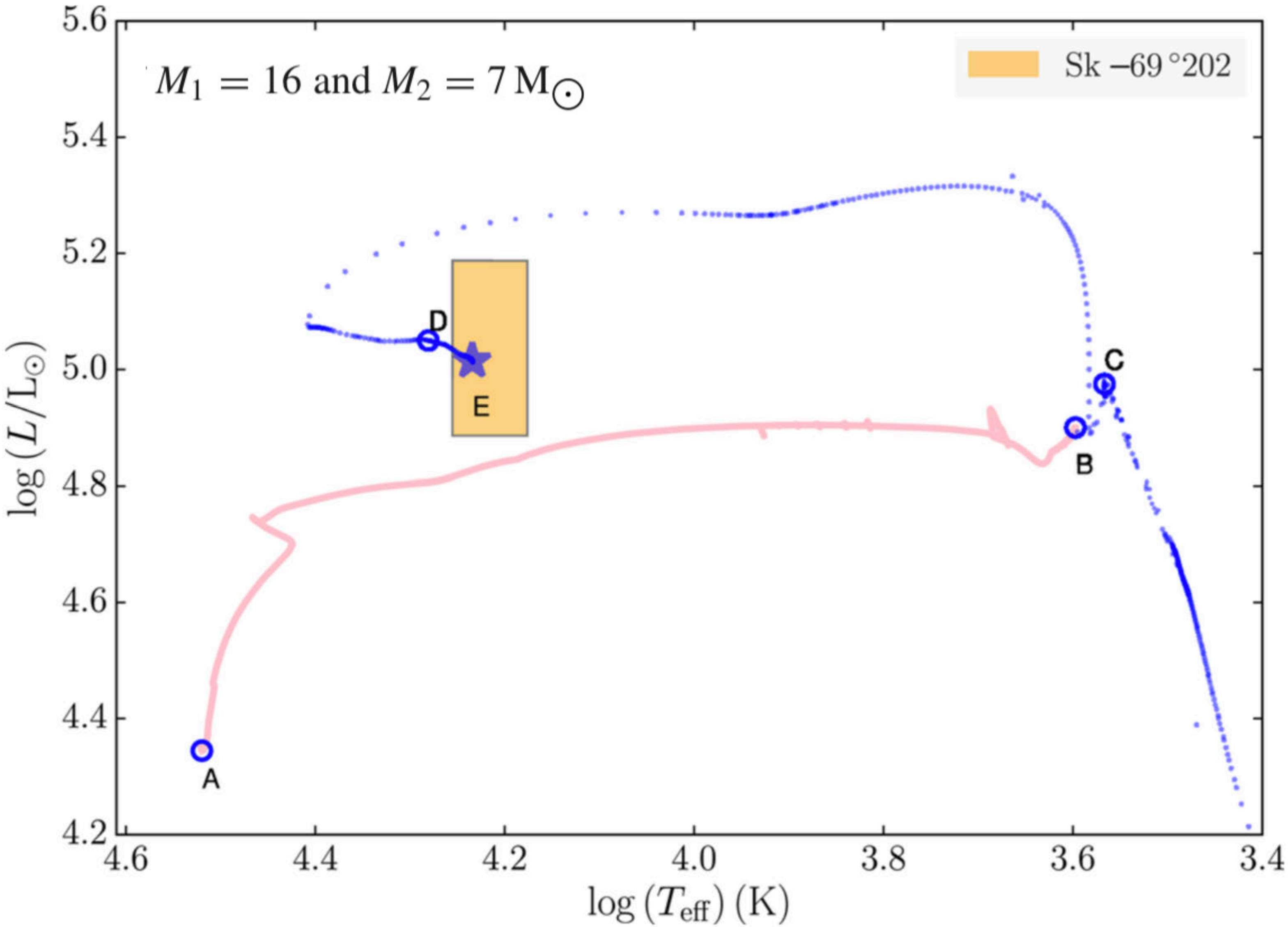


Progenitor of SN 1987A: a blue supergiant

- Sk -69º202
  - a single star progenitor with ~ 10 Msun of H-rich envelope

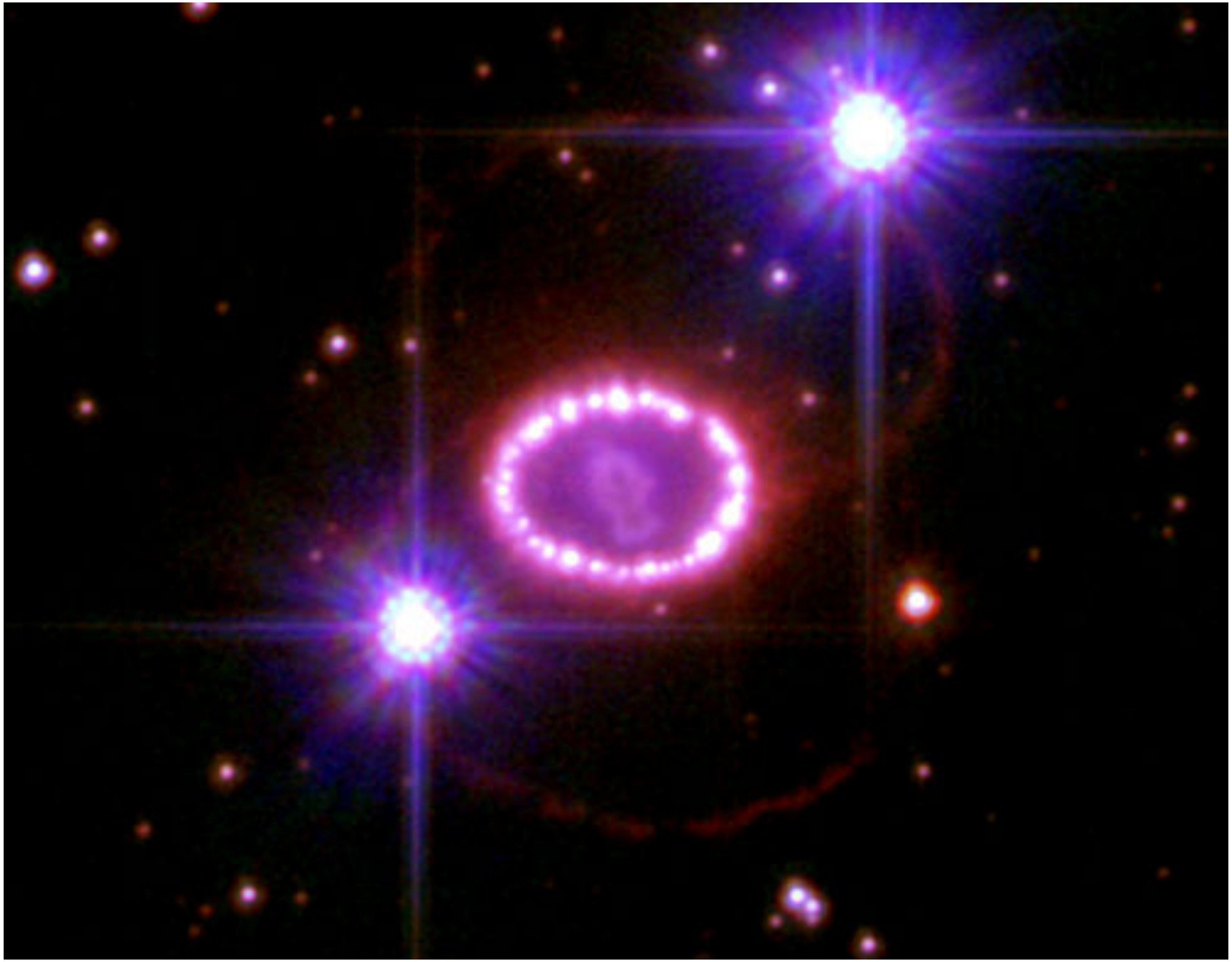


Progenitor of SN 1987A: a blue supergiant

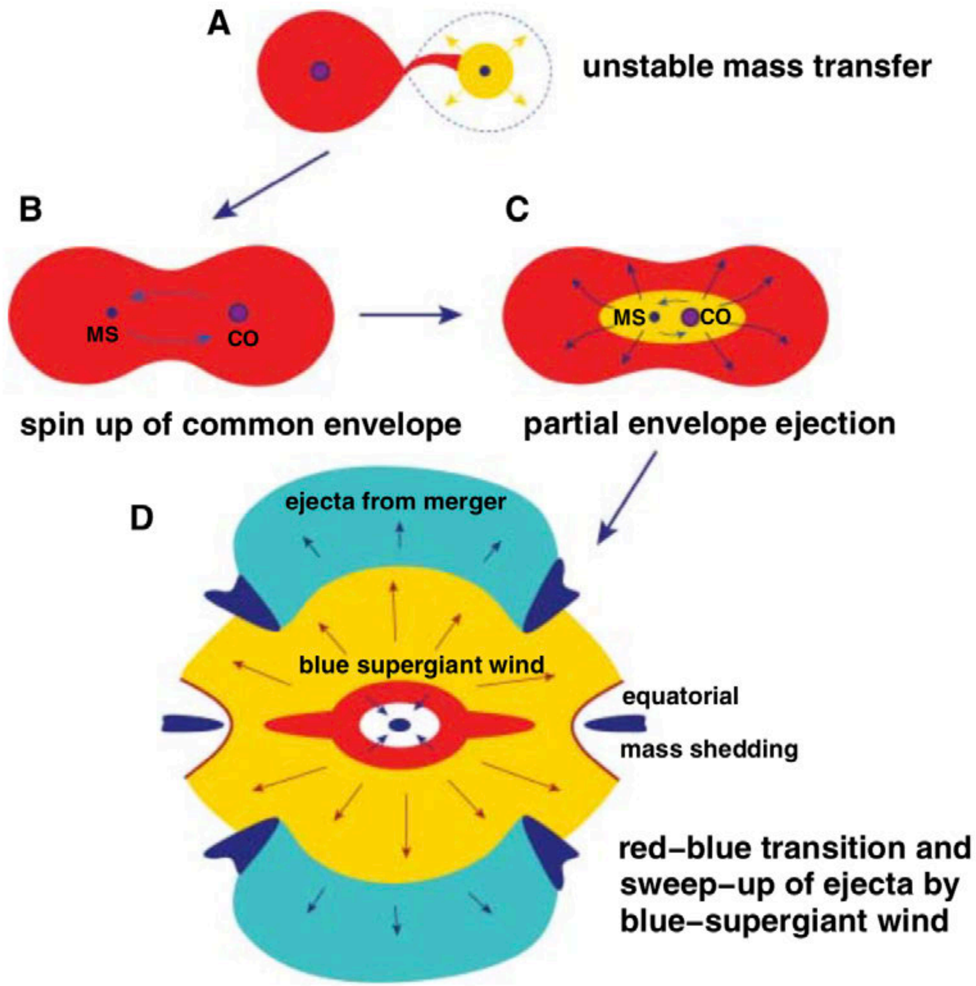


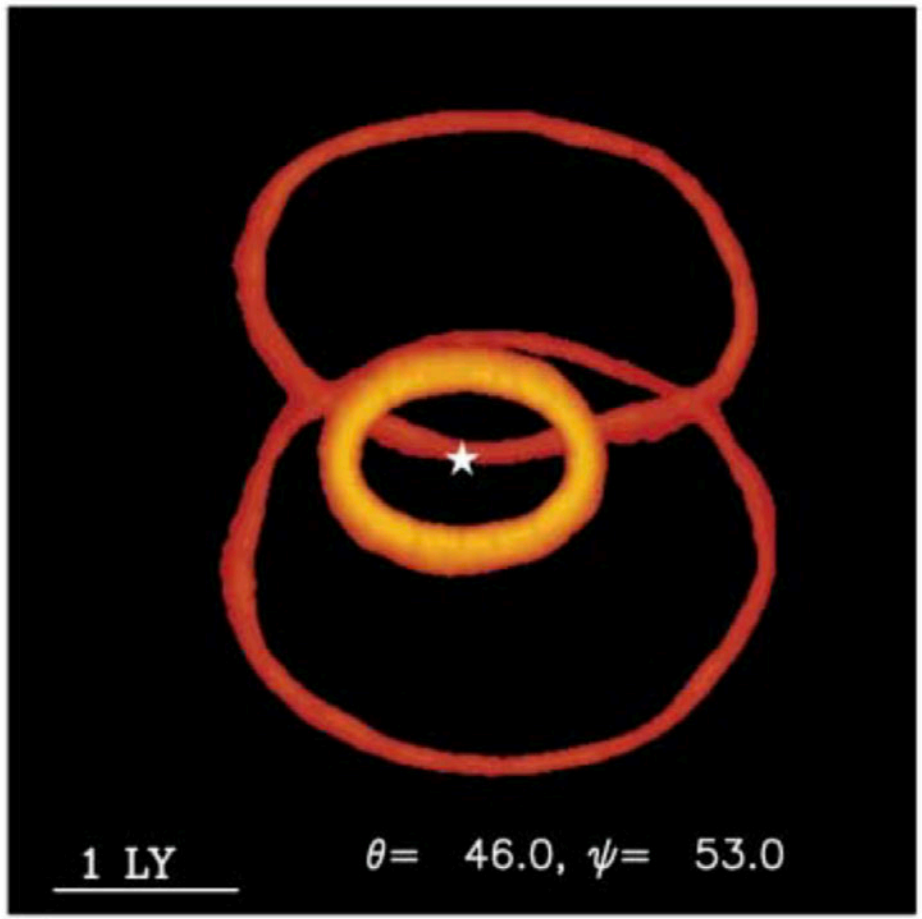
Menon & Heger (2017)

Triple rings around SN 1987A



Triple rings around SN 1987A

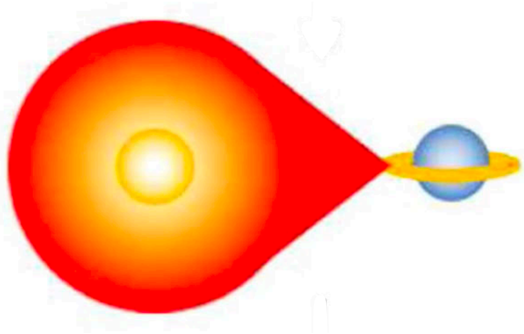




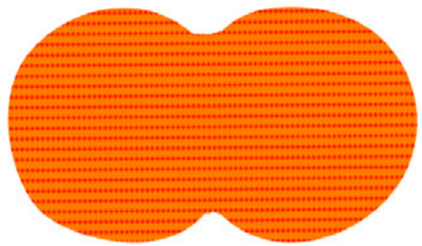
Morris & Podsiadlowski (2007)

How the companion stars affect stellar evolution?

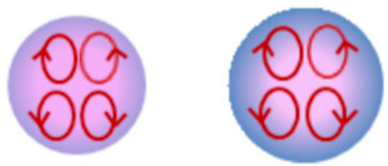
mass stripping



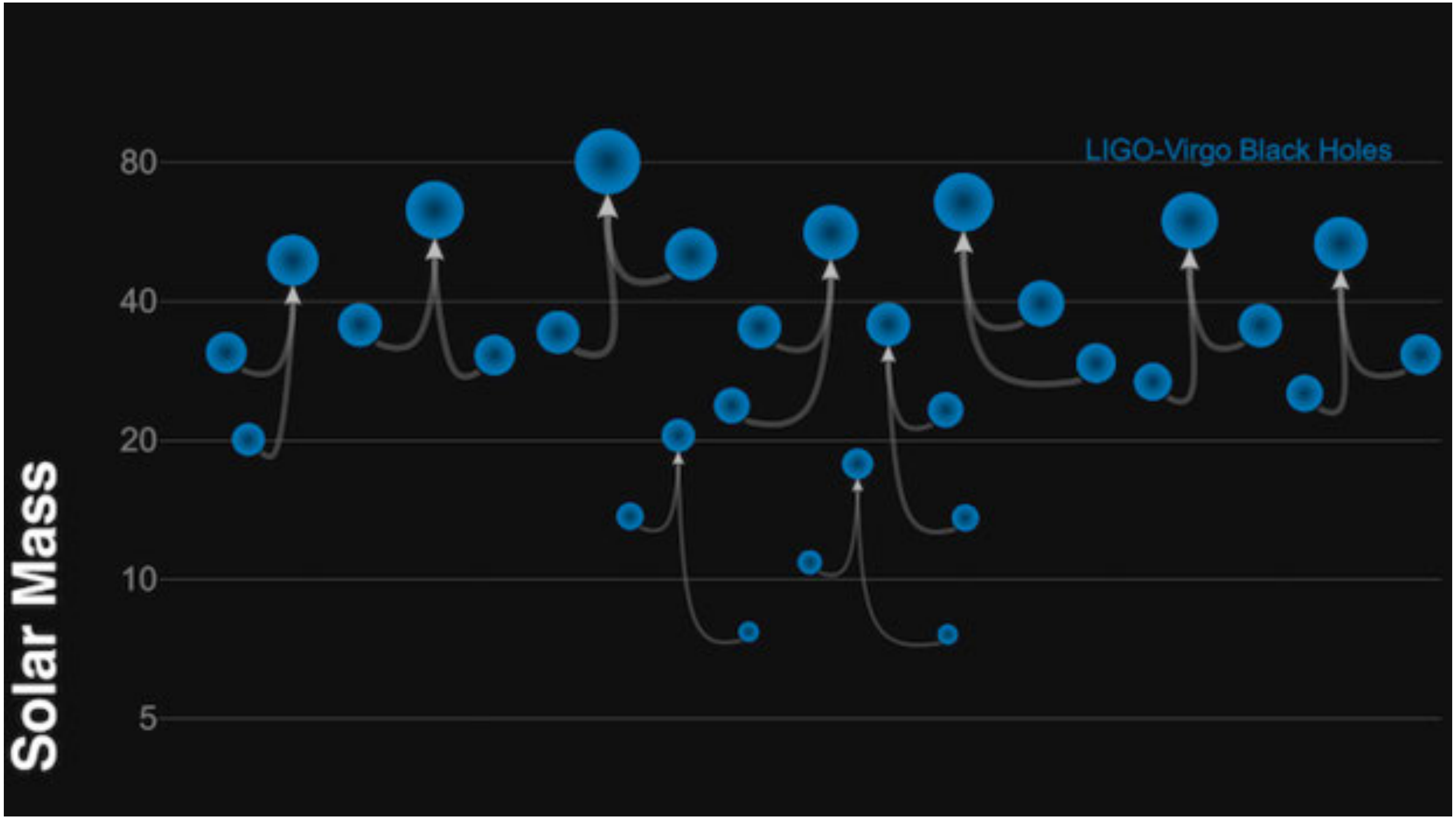
merger



rotation

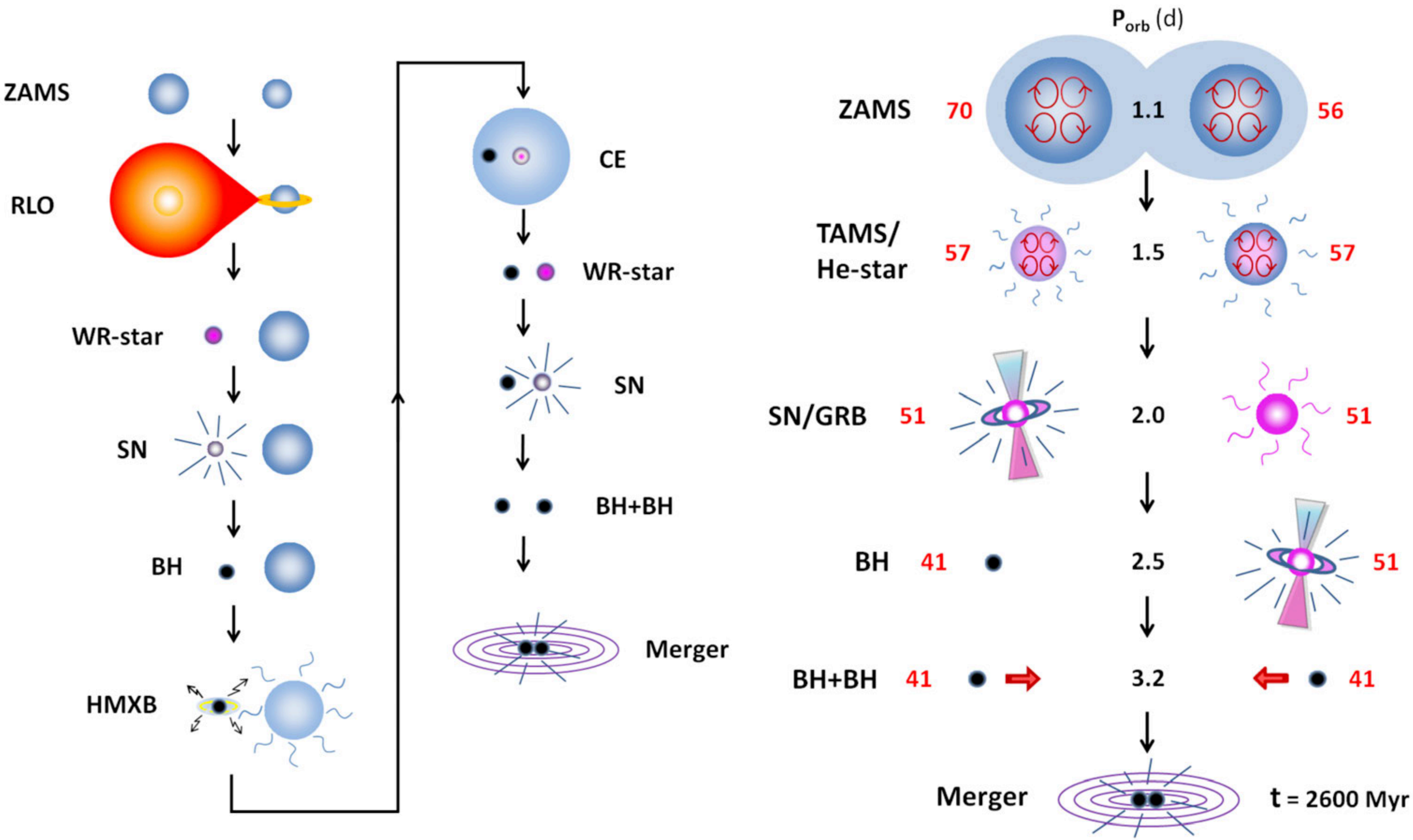


Massive binary black hole formation



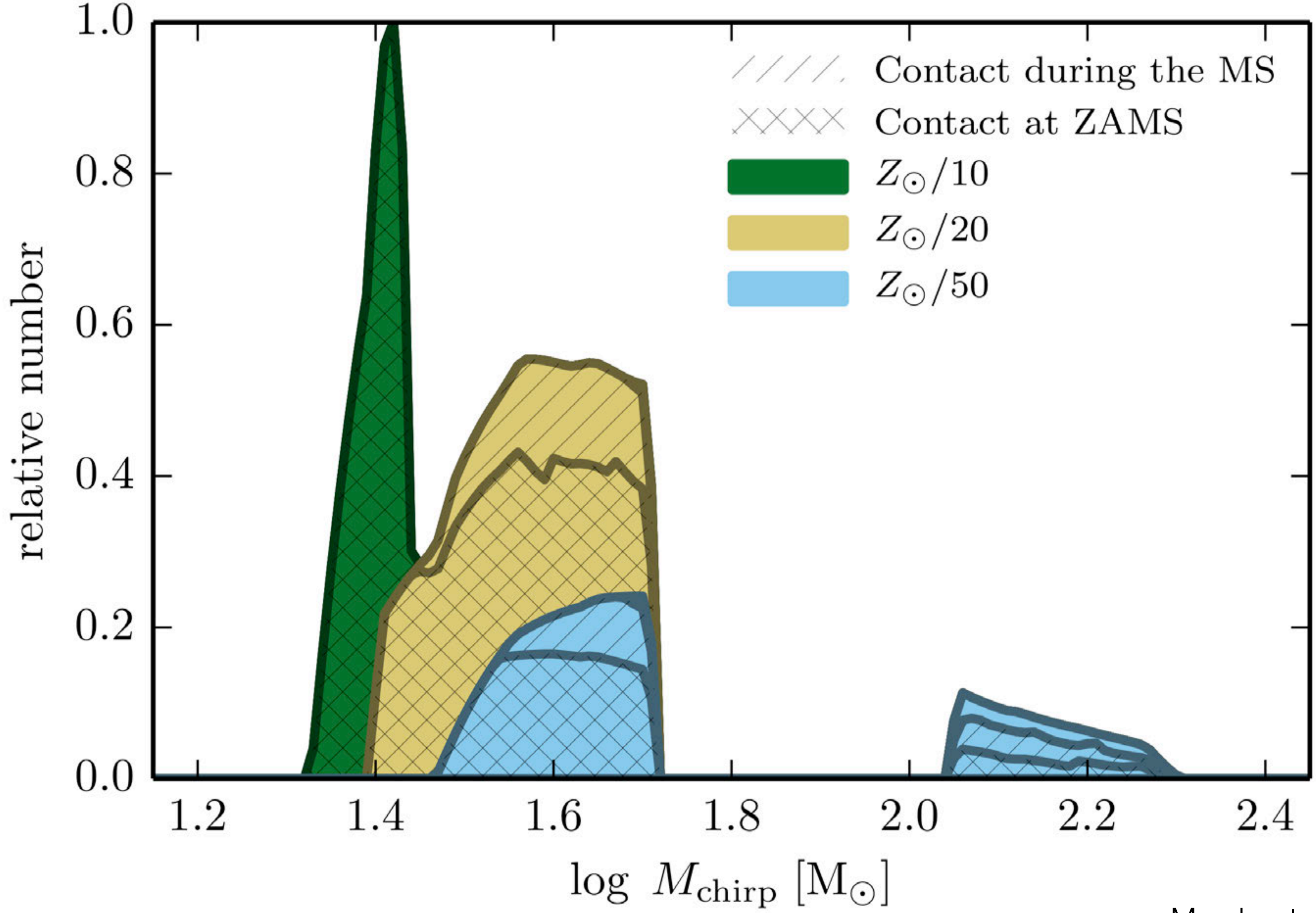
LIGO-Vergo collaboration

Massive binary black hole formation



Marchant et al. (2016)

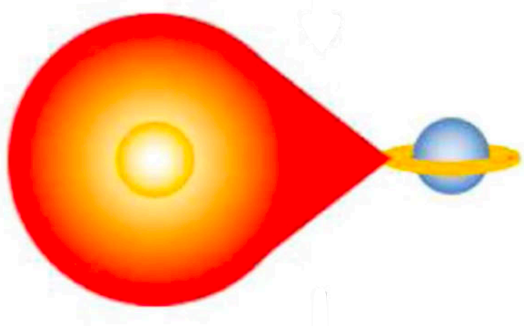
Massive binary black hole formation



Marchant et al. (2016)

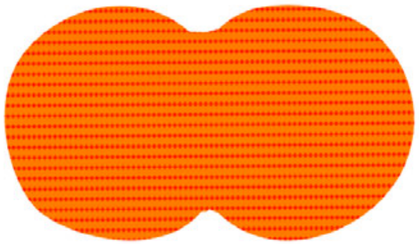
Supernova from binary: summary

mass stripping



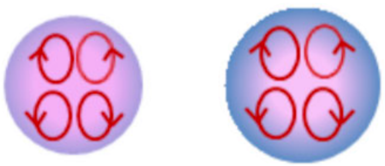
- stripped-envelope SNe are largely affected by the binary mass stripping

merger



- SN 1987A-like SN progenitors may be a product of stellar mergers

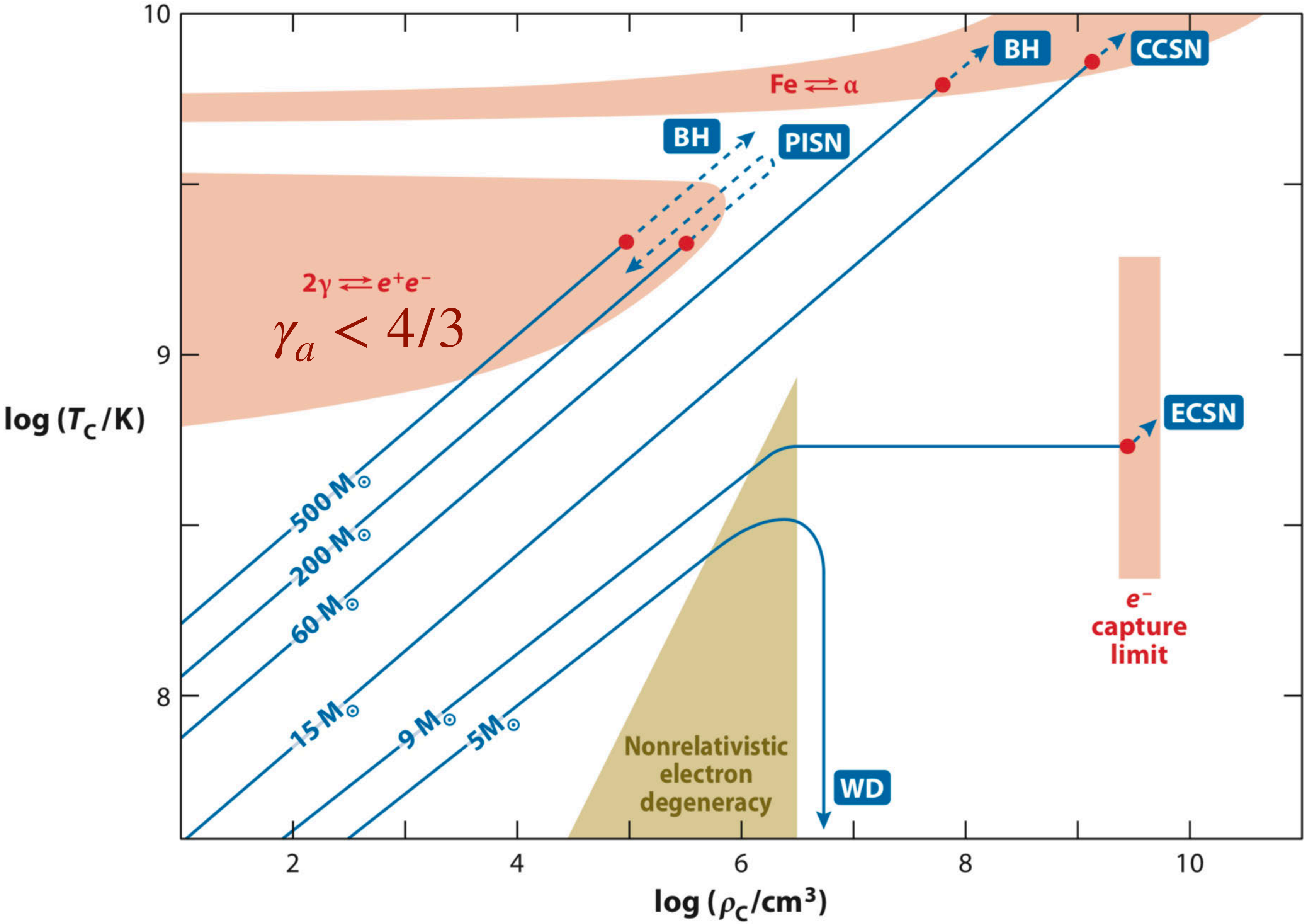
rotation



- efficient rotational mixing in binary can lead to massive black hole binary systems

Pair-instability supernovae

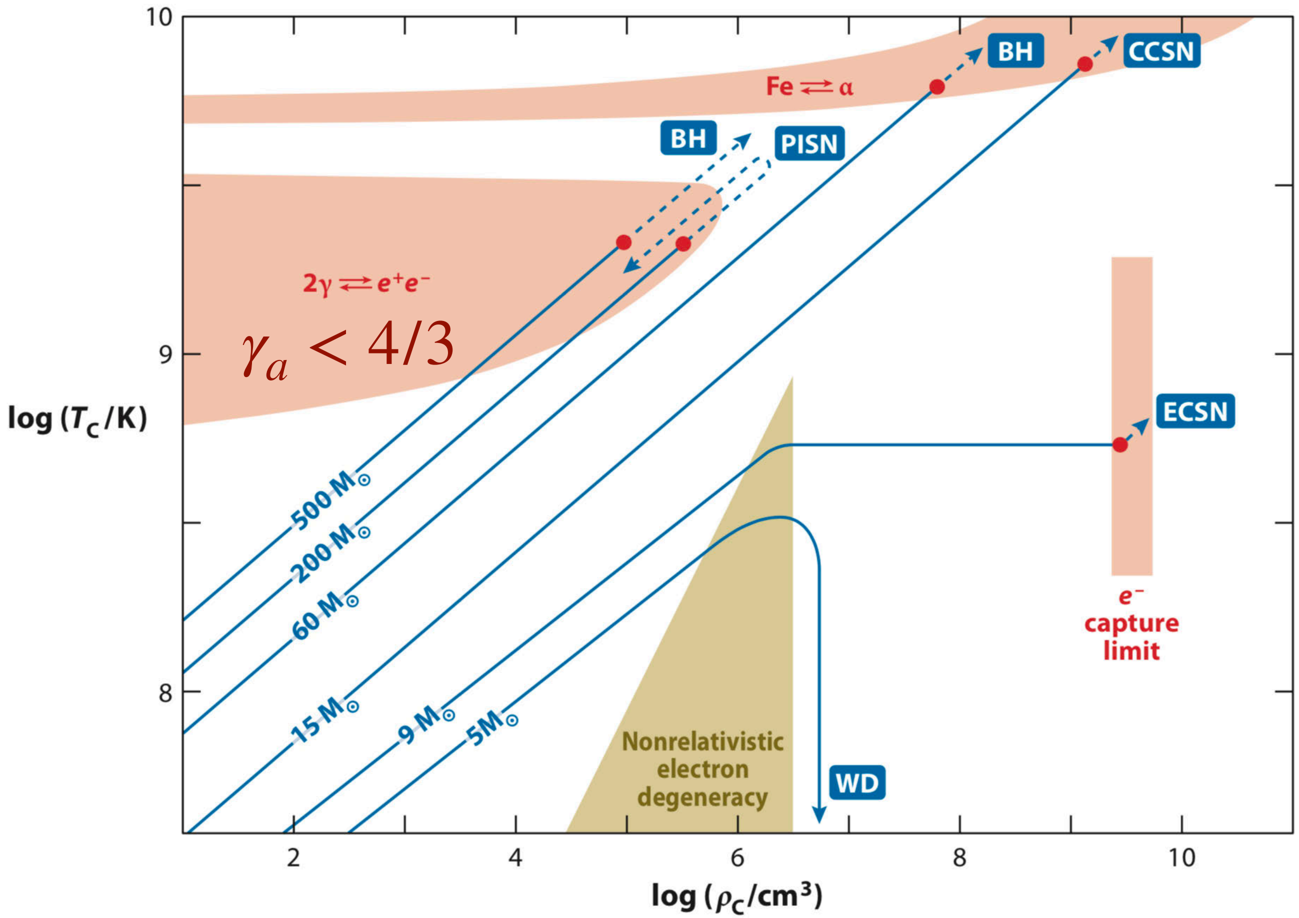
Dynamical instability by pair creation



Langer (2012)

Pair-instability supernovae

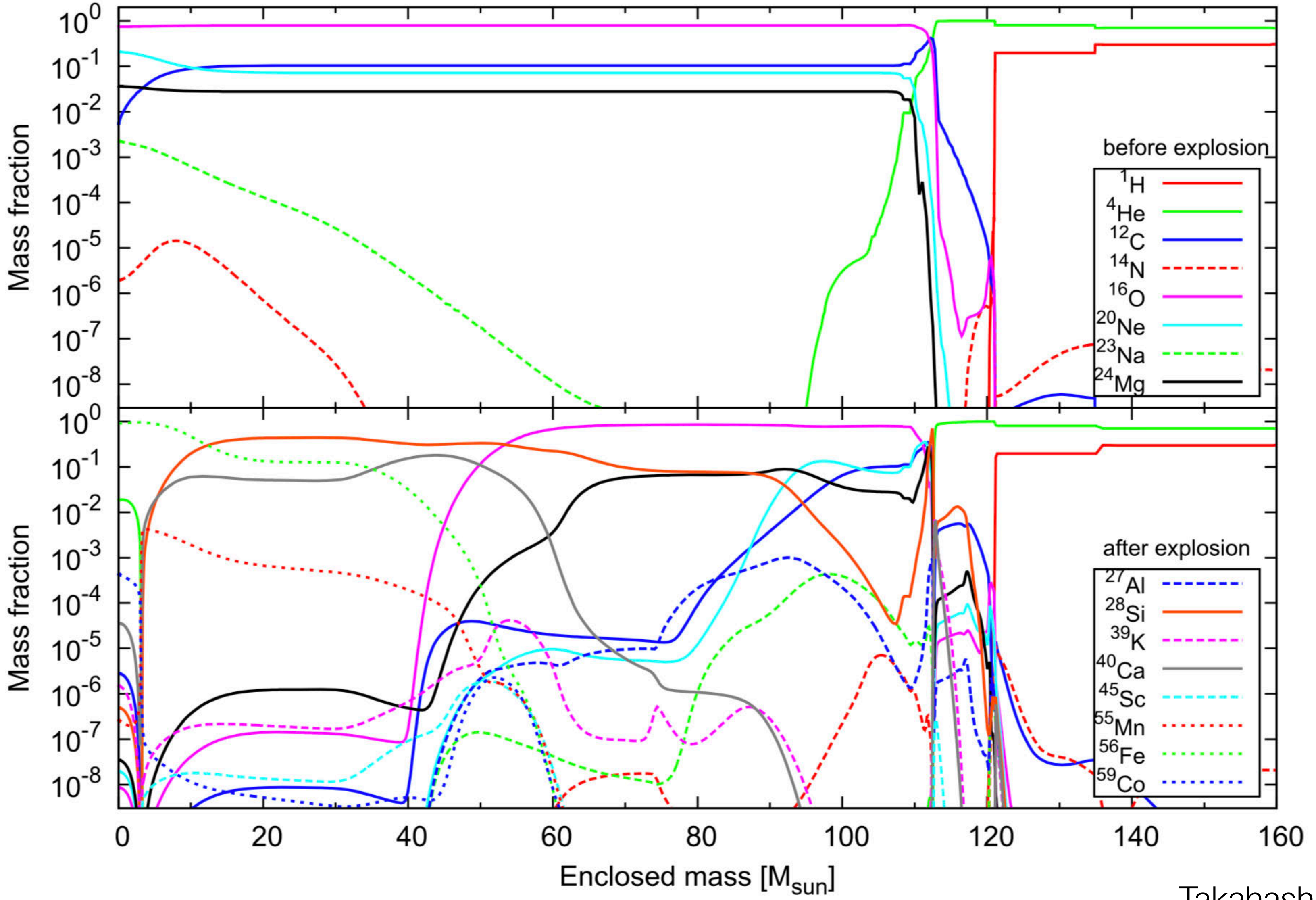
- thermonuclear explosions of very massive stars
  - ~ 150 Msun - ~ 250 Msun if there is no mass loss
  - no remnants remain!



Langer (2012)

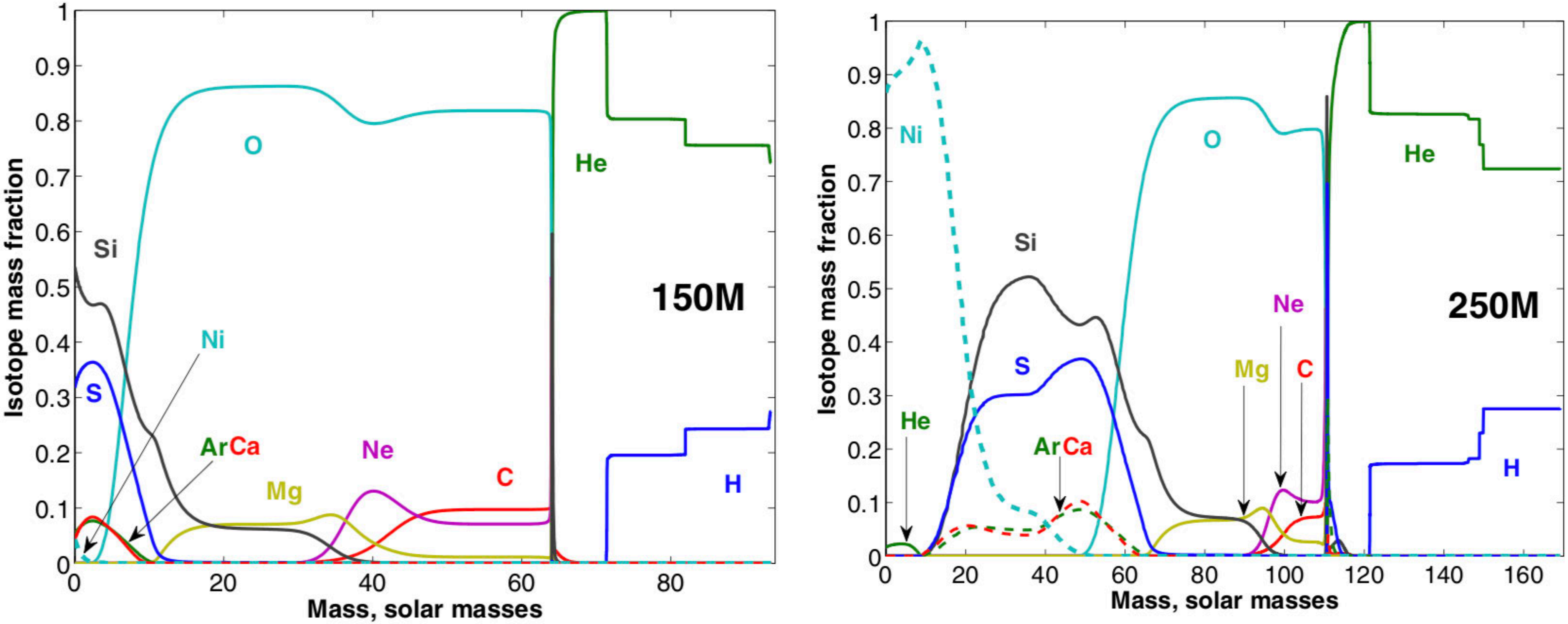
Explosive nucleosynthesis

240 Msun



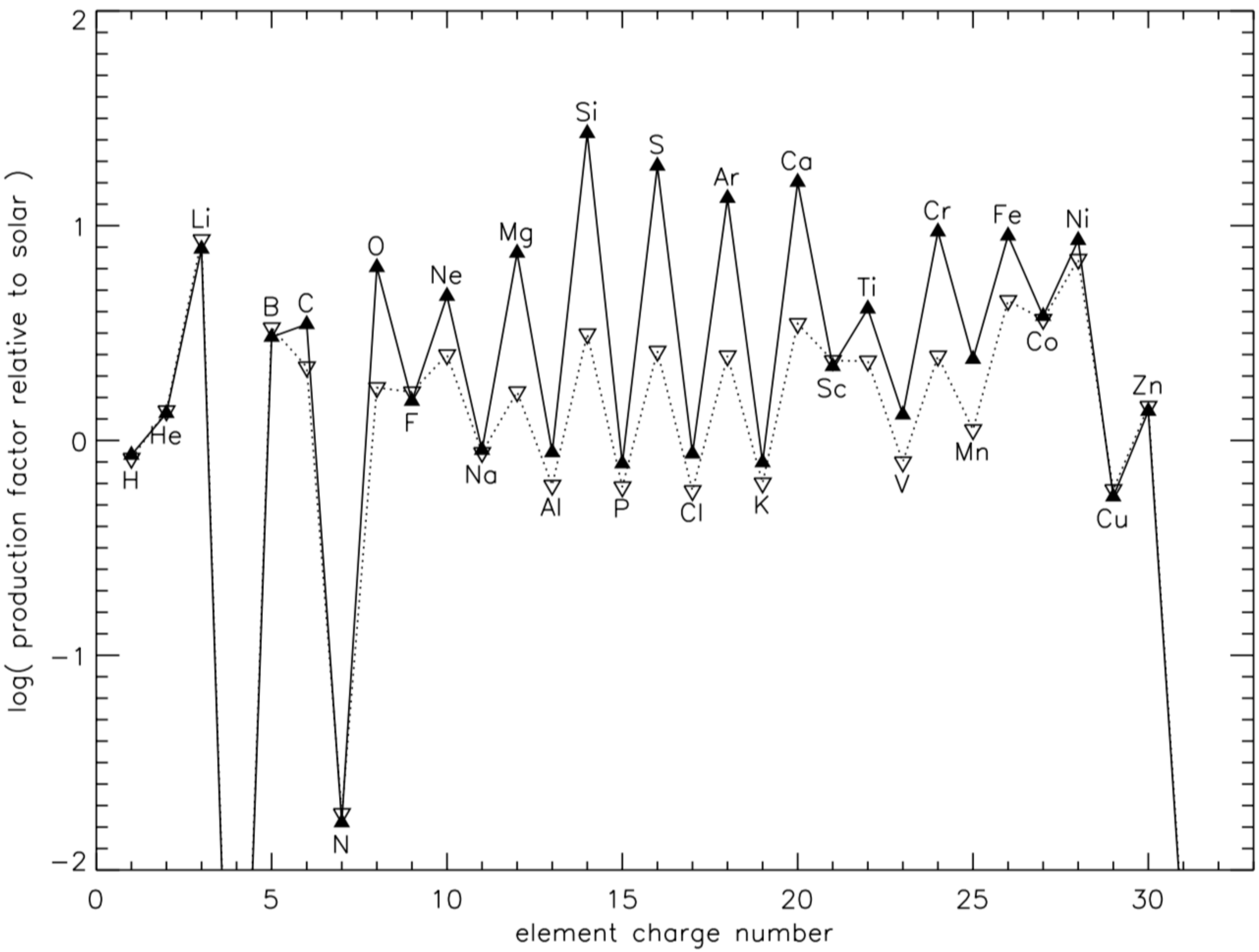
Takahashi et al. (2018)

Explosive nucleosynthesis



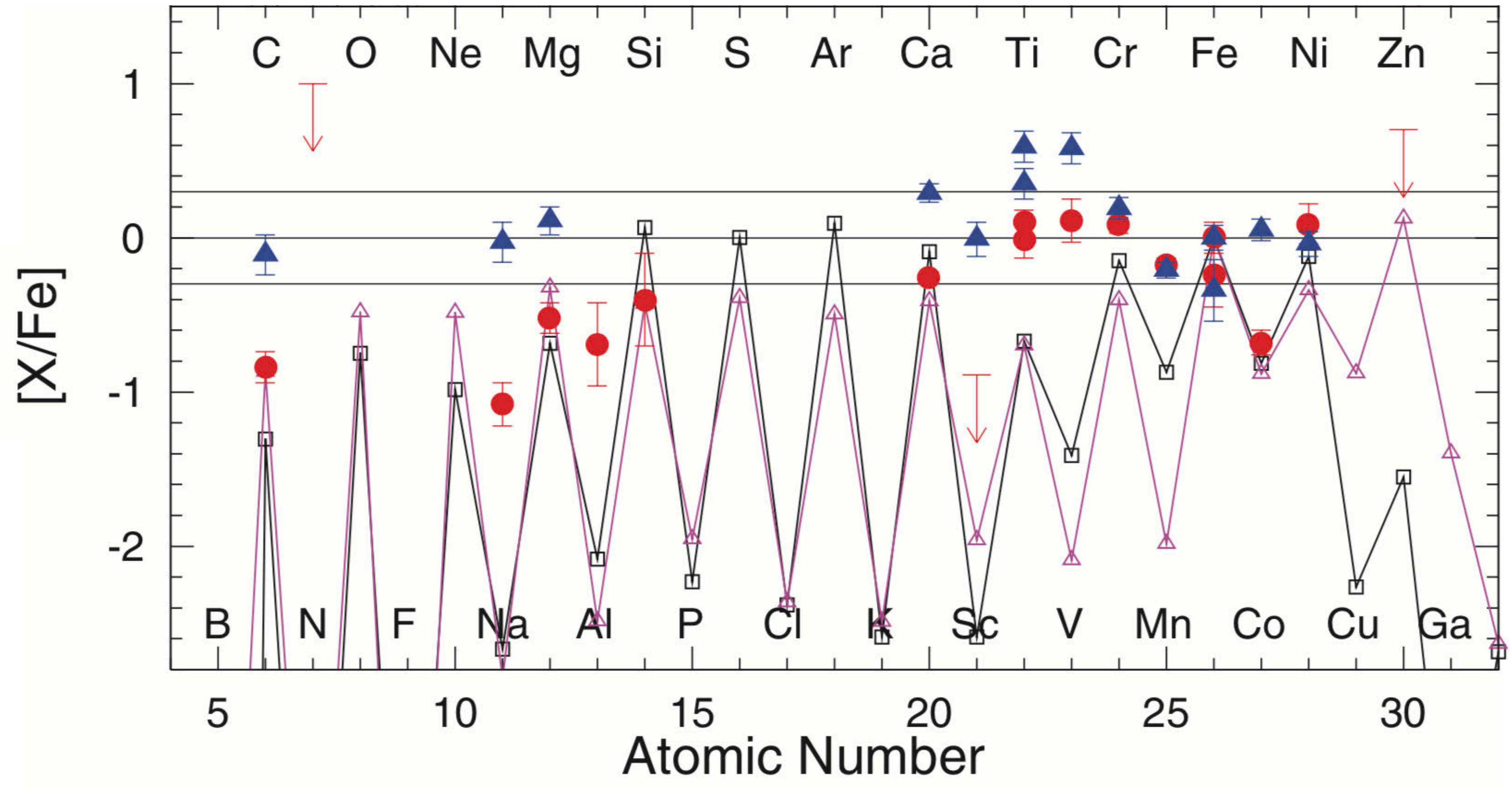
Kozyreva et al. (2014)

Explosive nucleosynthesis



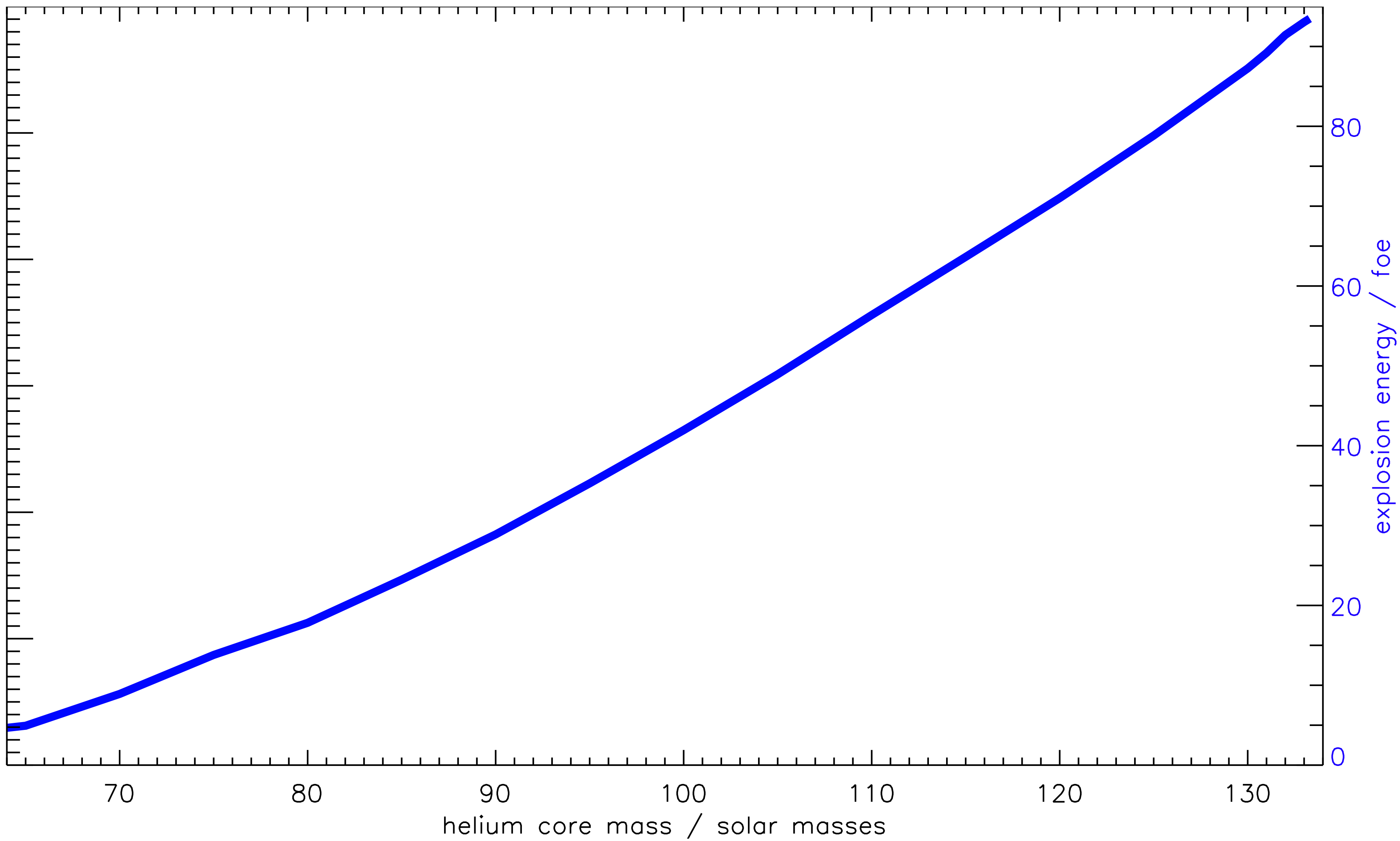
Heger & Woosley (2002)

Possible star contaminated by PISN yields



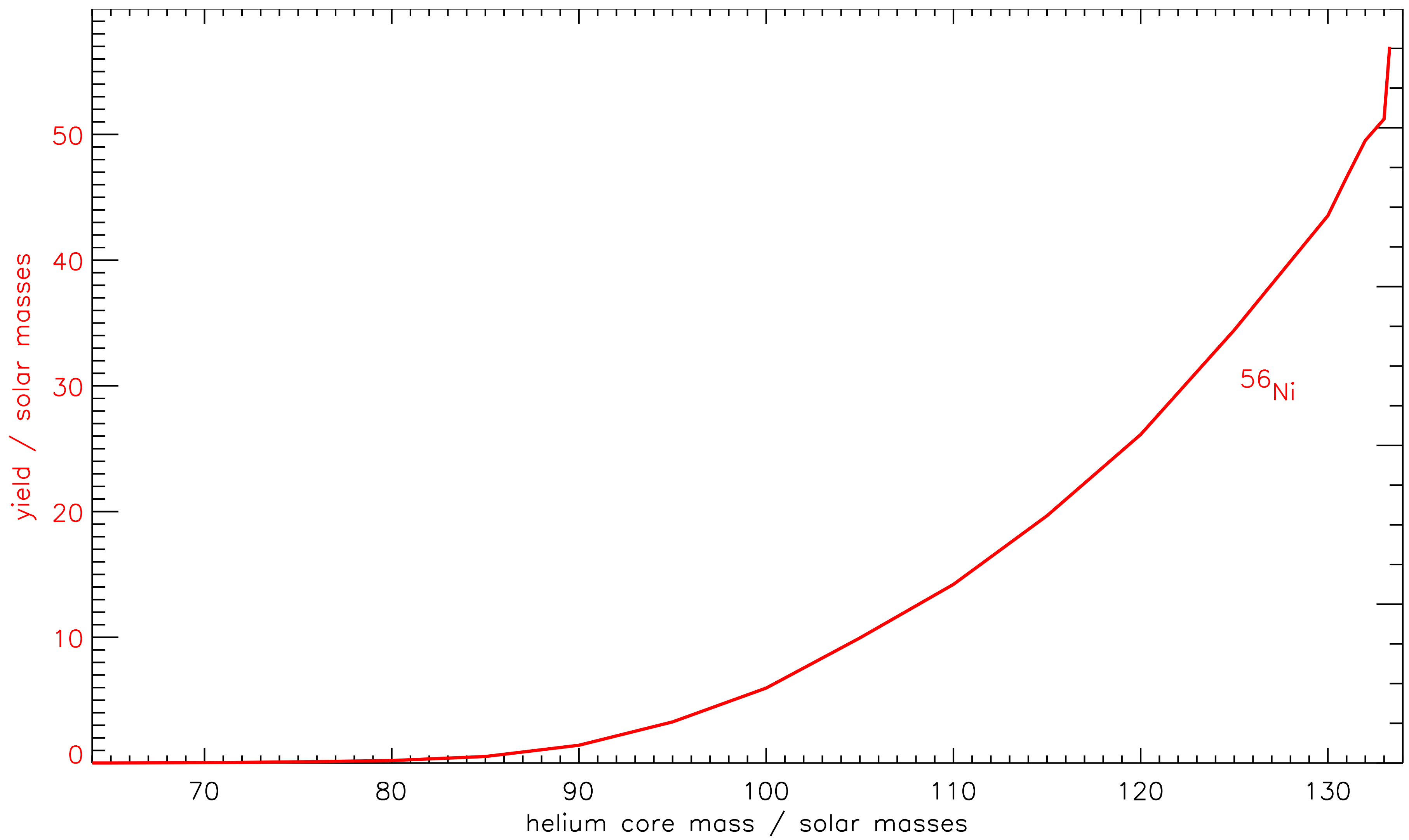
Aoki et al. (2014)

Explosion energy



Heger & Woosley (2002)

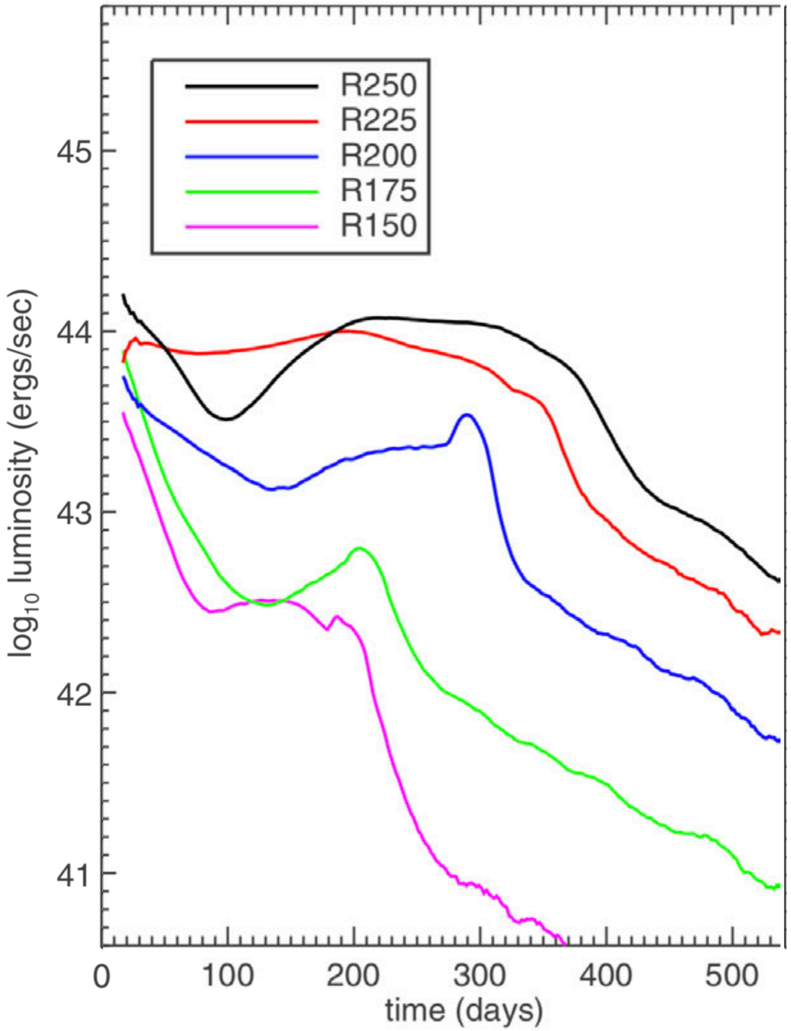
56Ni mass

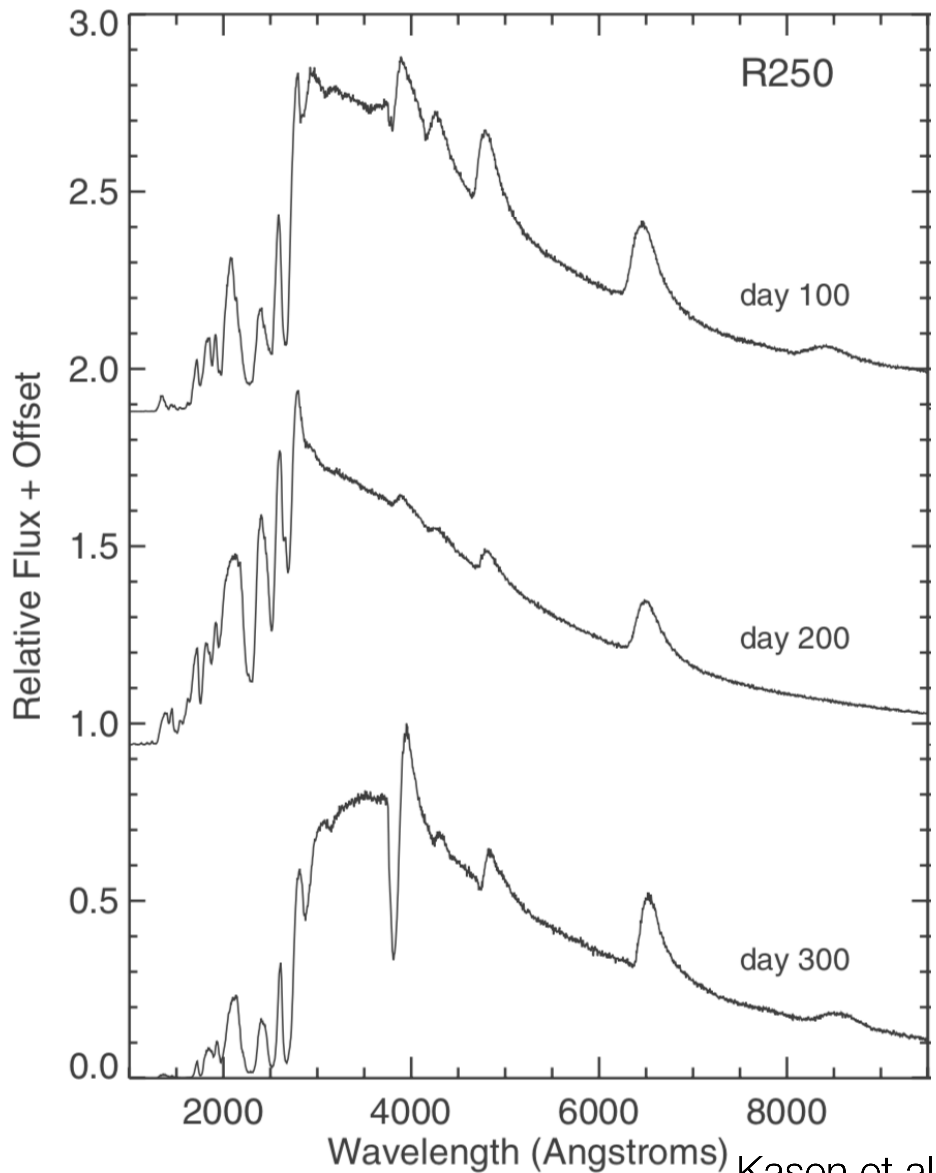


Heger & Woosley (2002)

Observational properties

- hydrogen-rich PISN explosions
  - red supergiant progenitors





Kasen et al. (2011)

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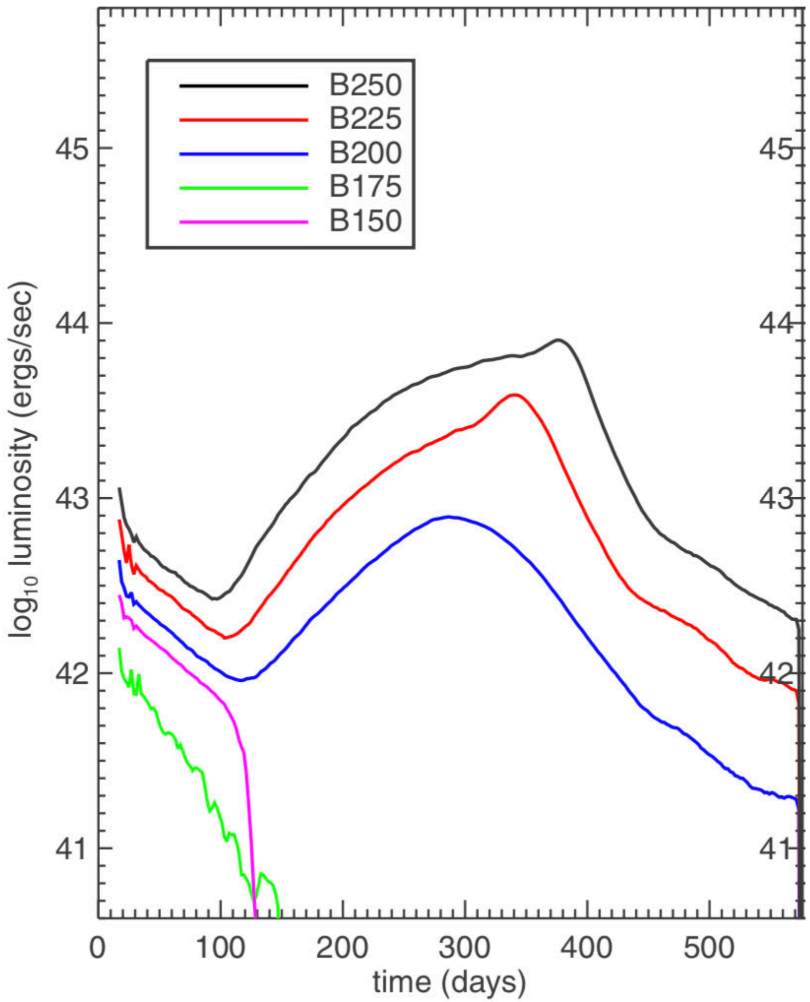
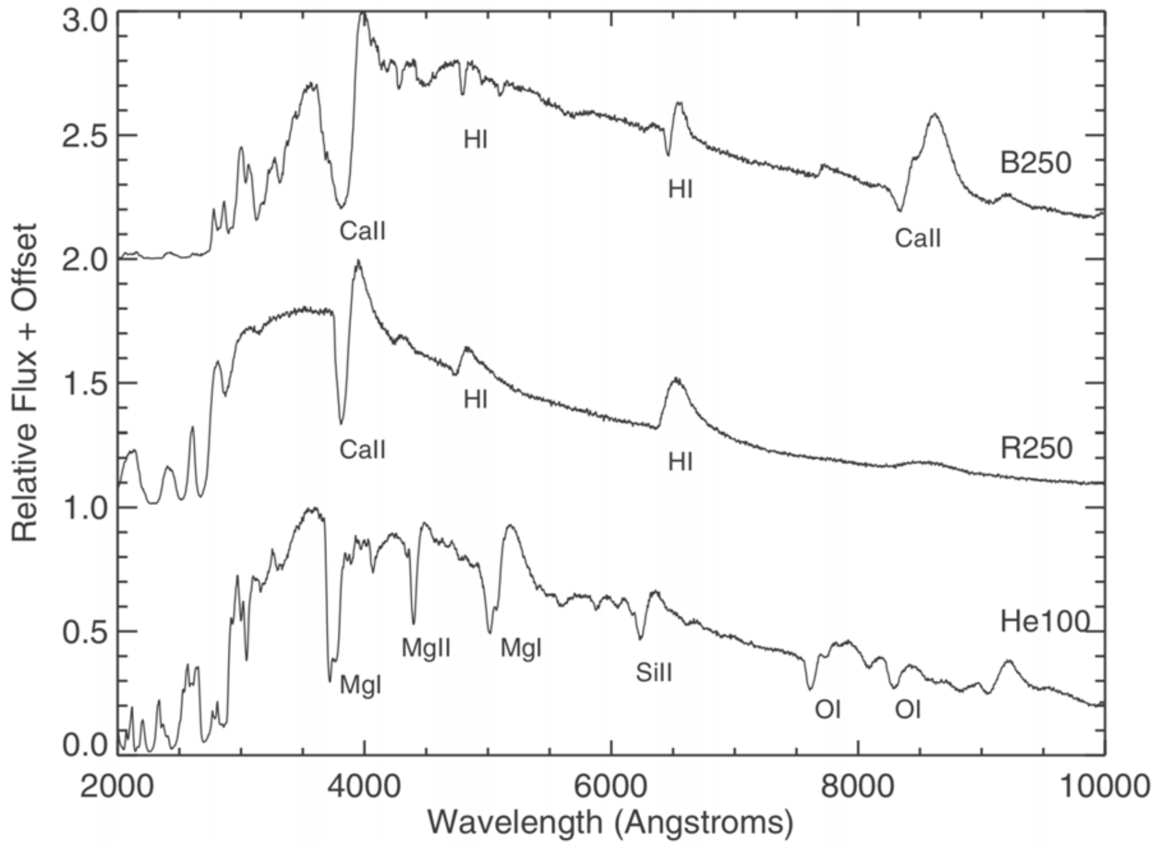
  - blue supergiant progenitors

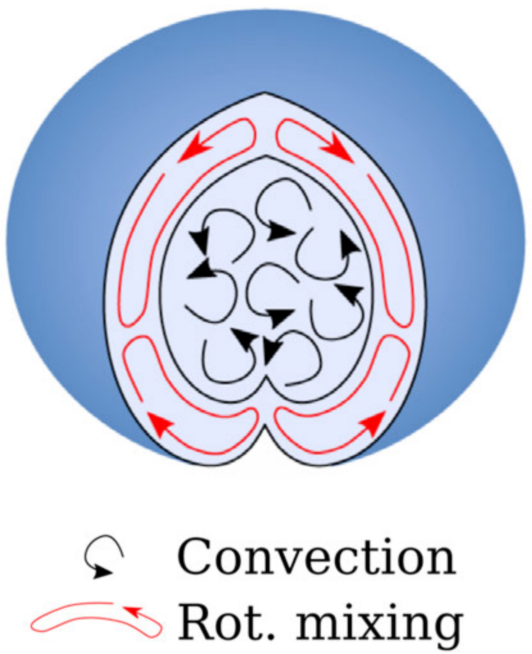




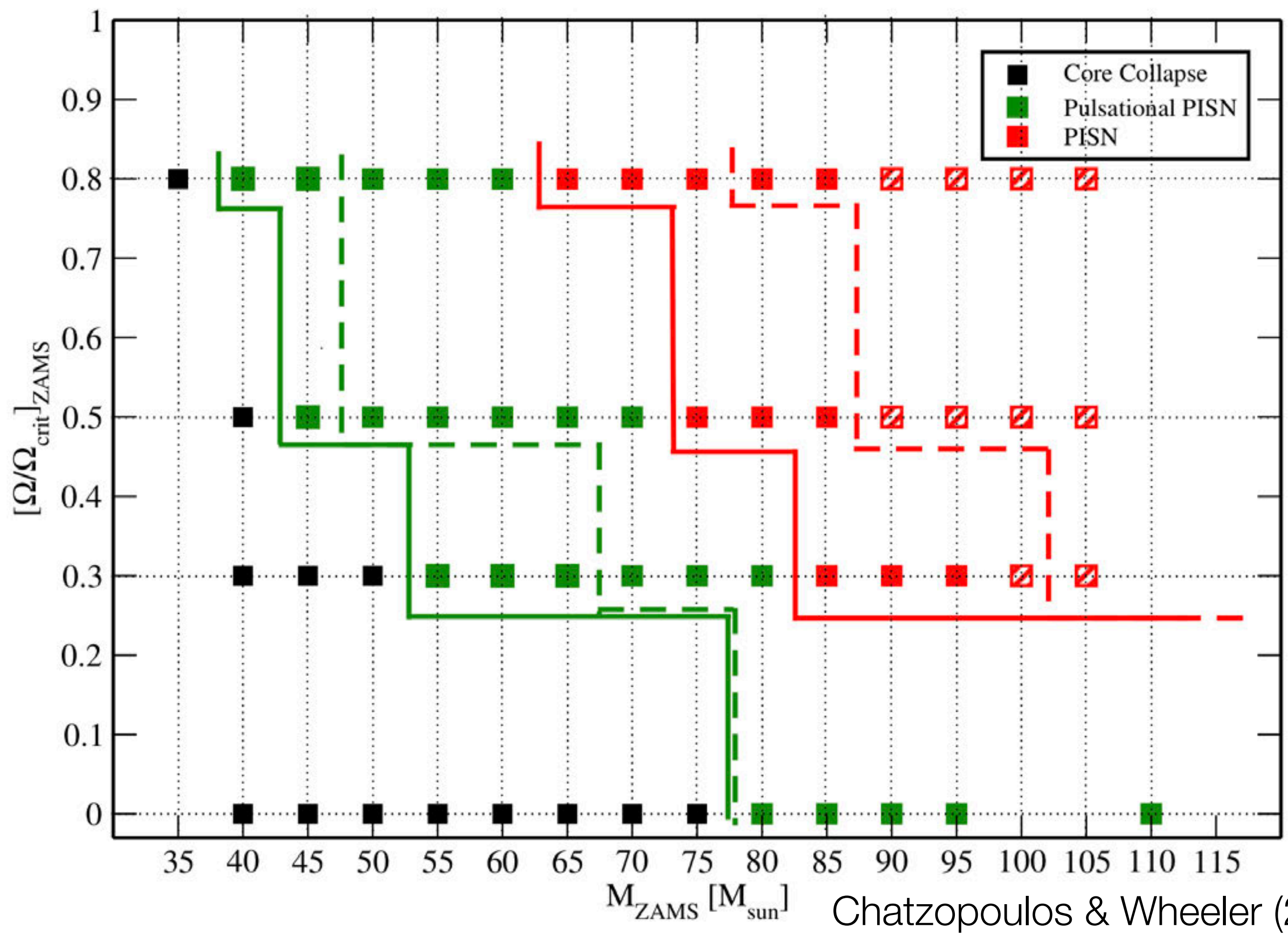
Kasen et al. (2011)

Hydrogen-free pair-instability supernovae

- no mass loss prevents hydrogen-free stars from exploding as PISNe?
  - No!
- rapid rotation can make hydrogen-free PISNe

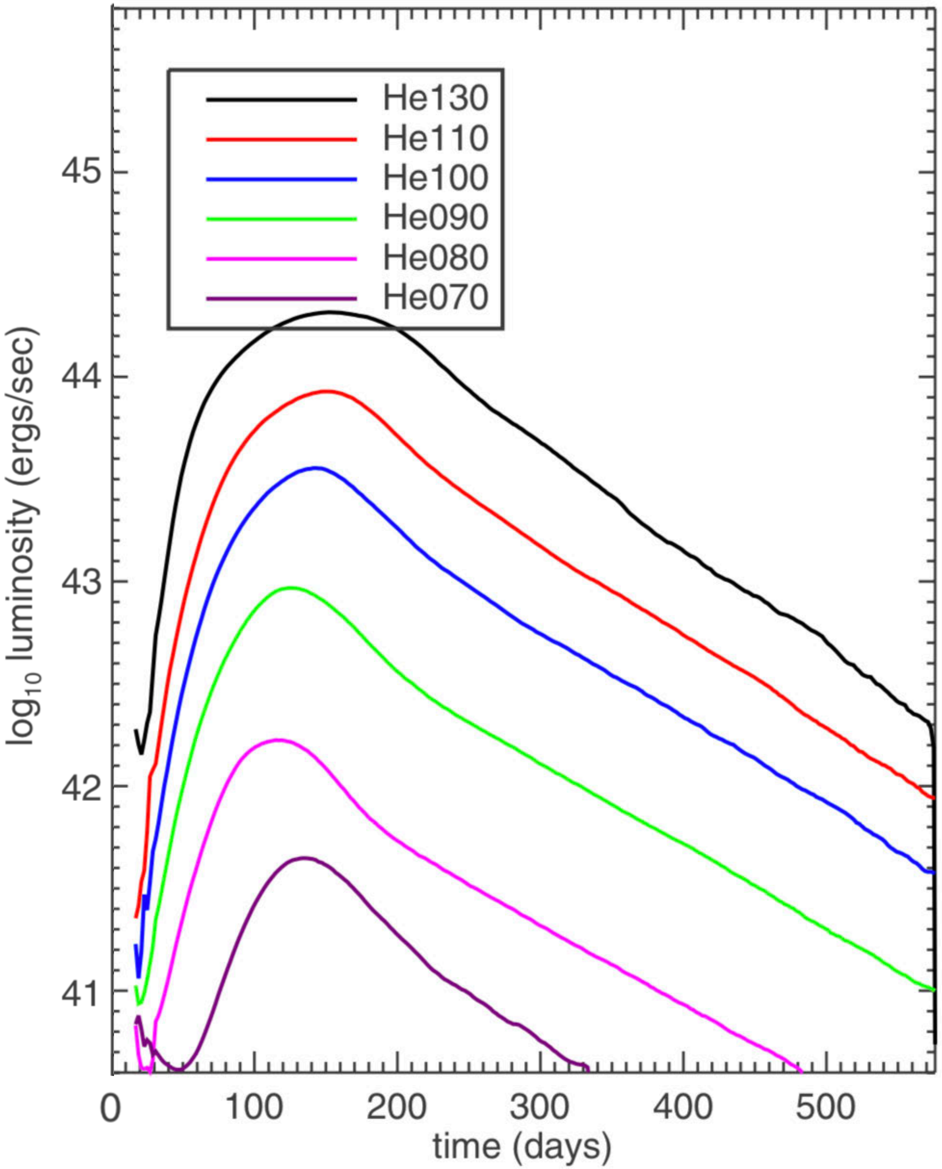


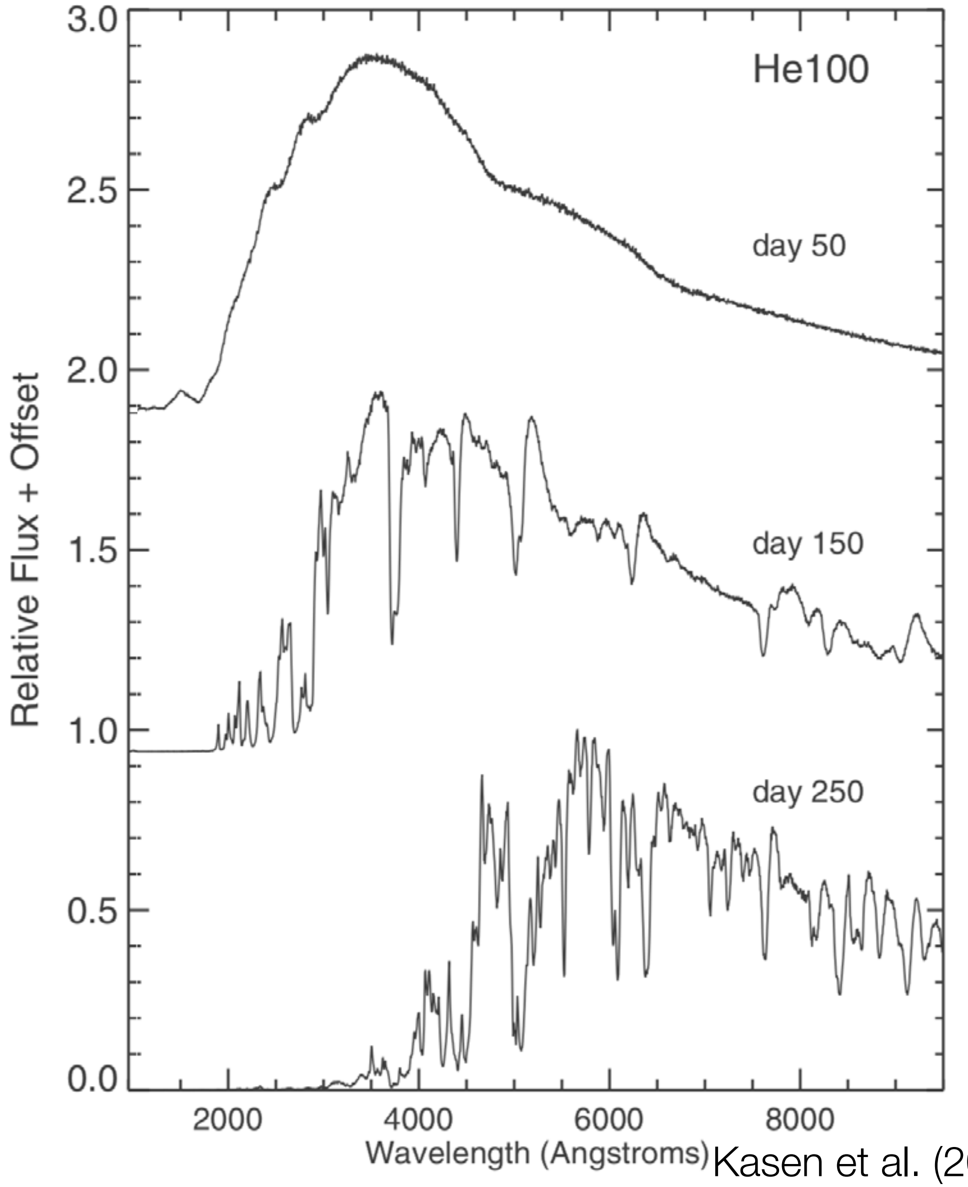
Marchant et al. (2017)



Chatzopoulos & Wheeler (2012)

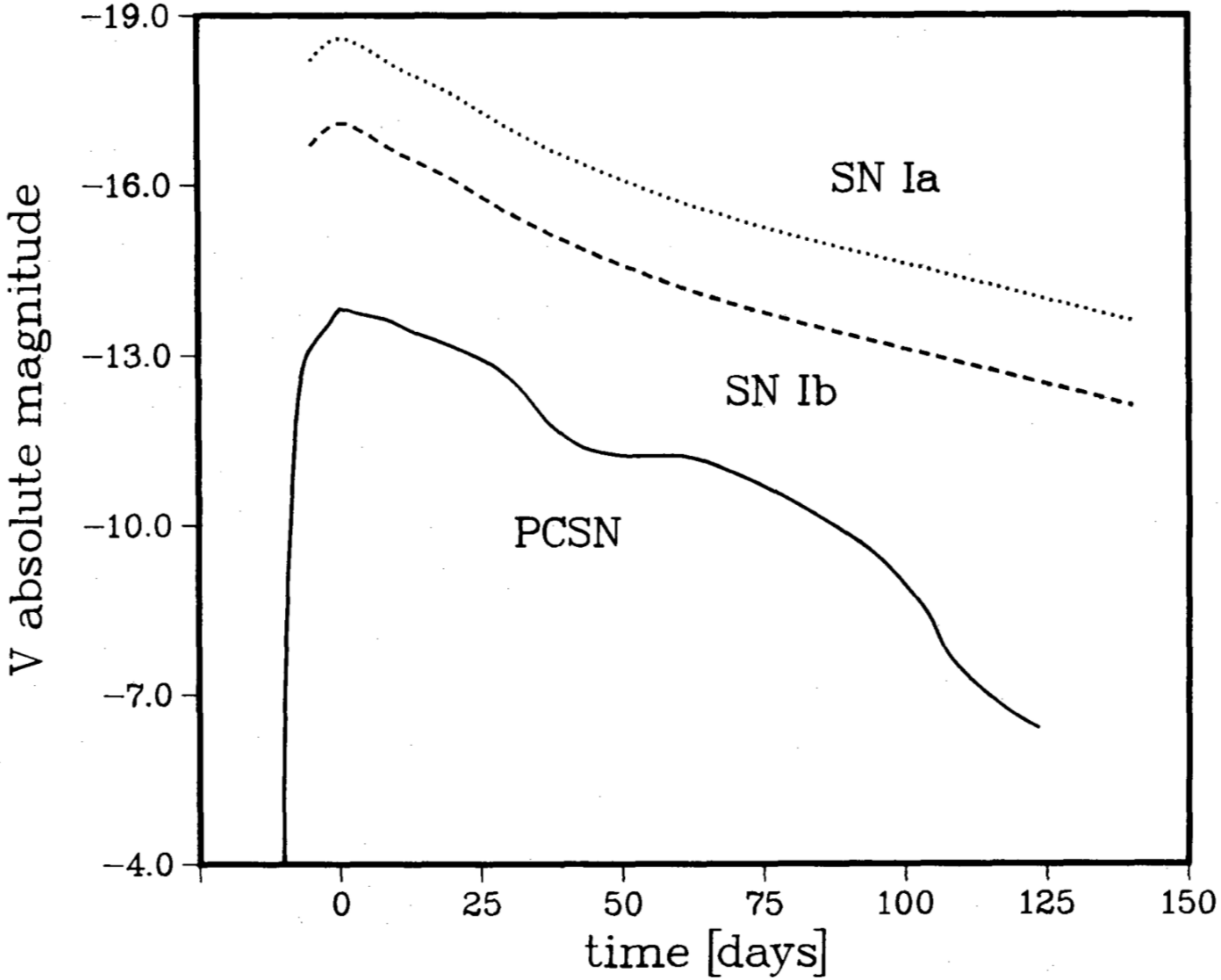
Hydrogen-free pair-instability supernovae





Kasen et al. (2011)

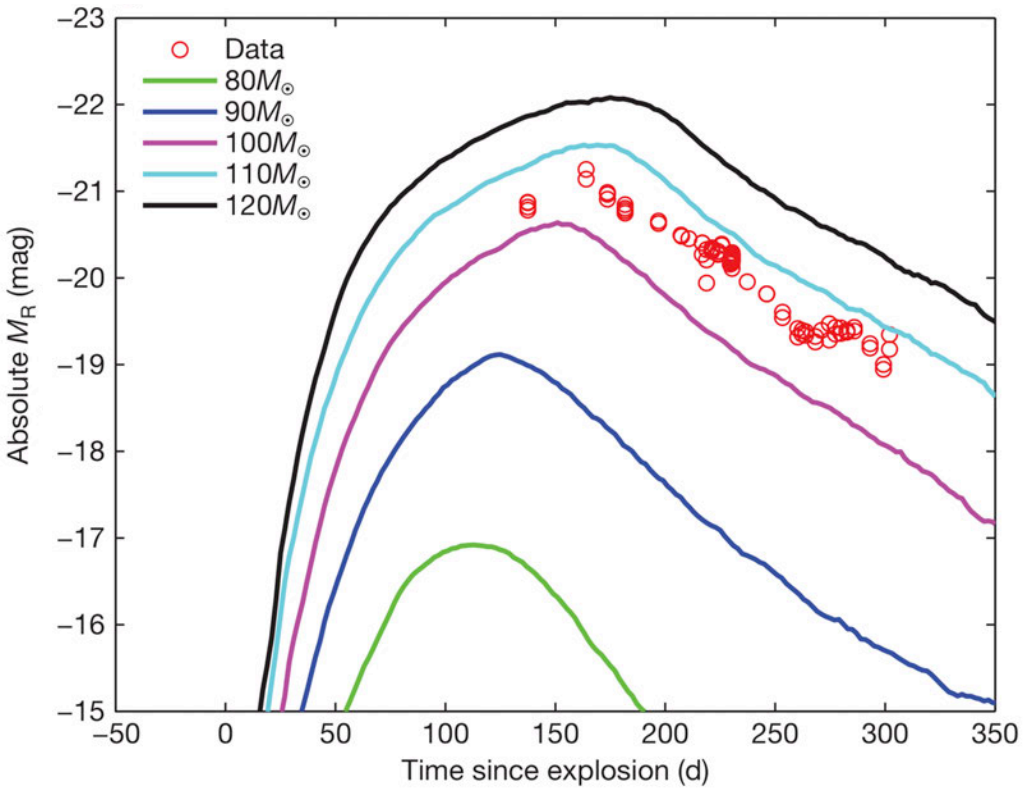
Hydrogen-free pair-instability supernovae

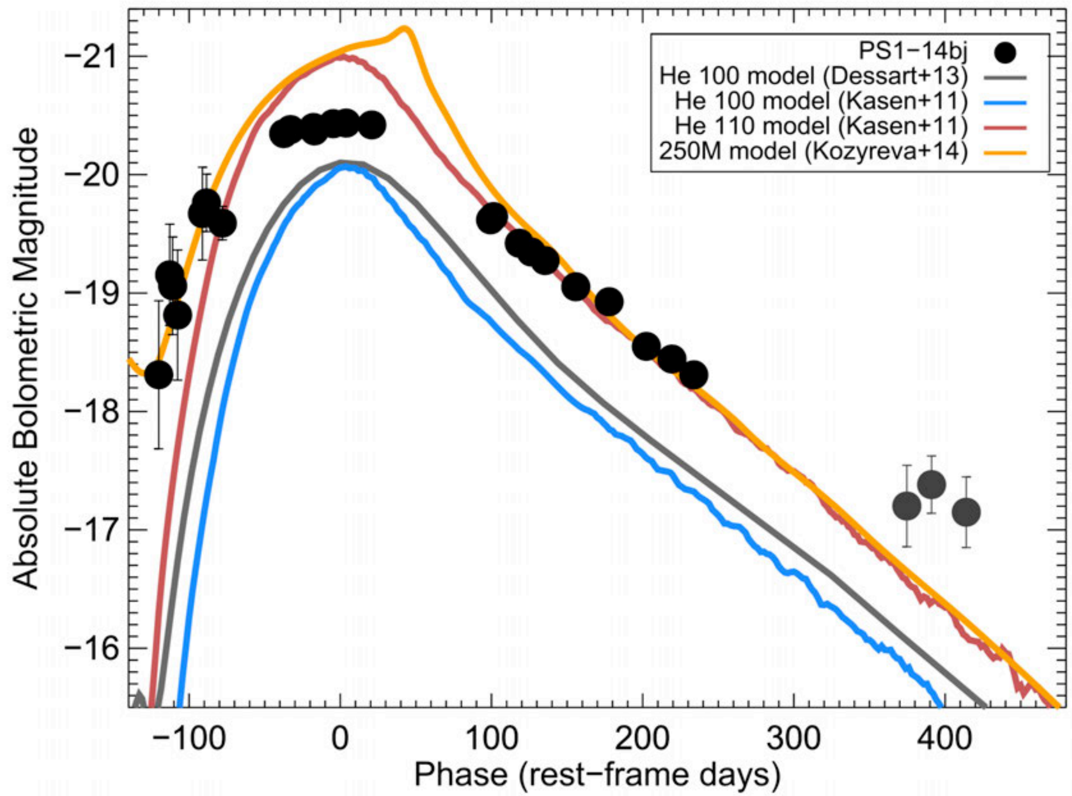


Herzig et al. (1990)

PISN candidates

- Superluminous supernovae



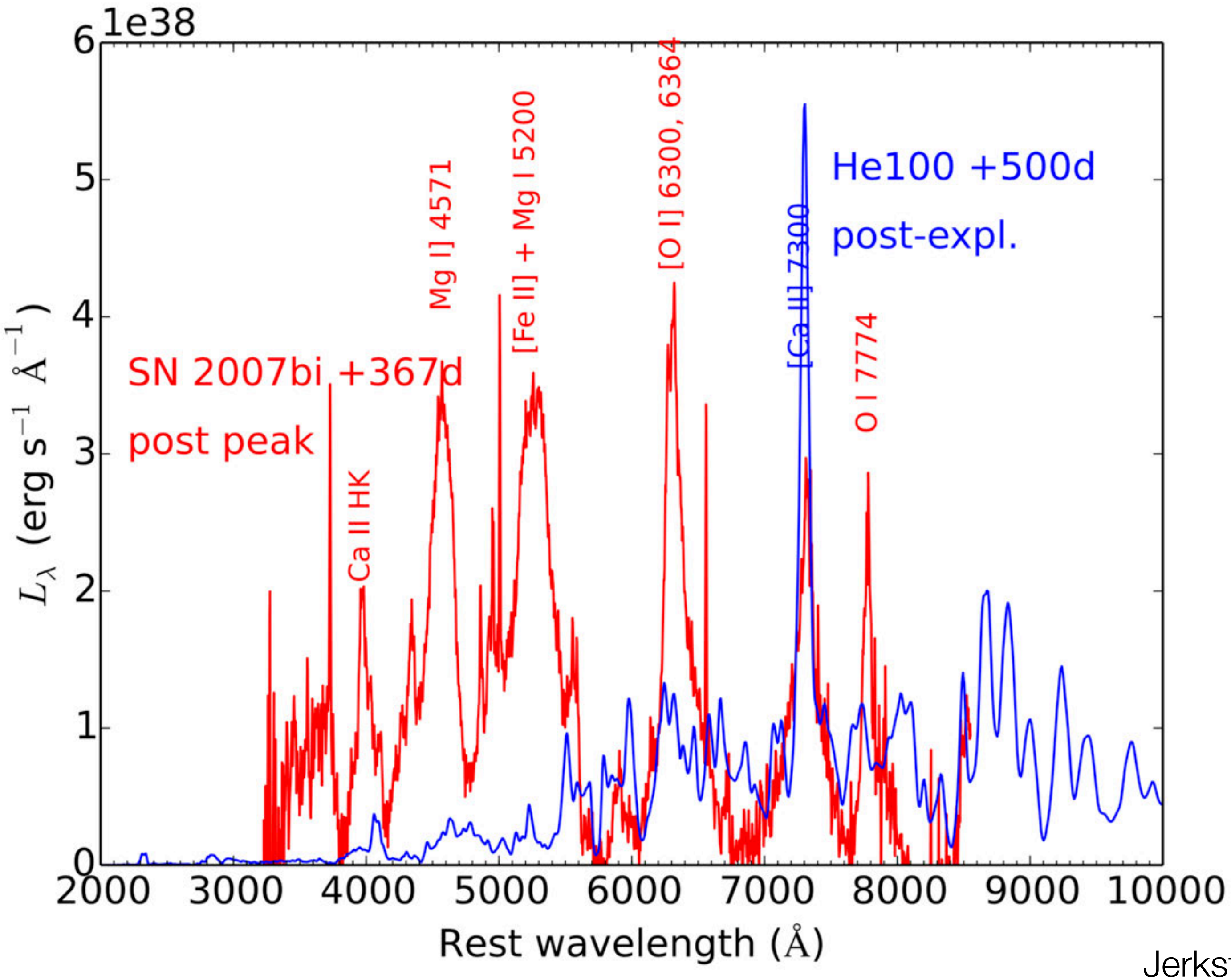


Gal-Yam et al. (2009)

Lunnan et al. (2016)

PISN candidates

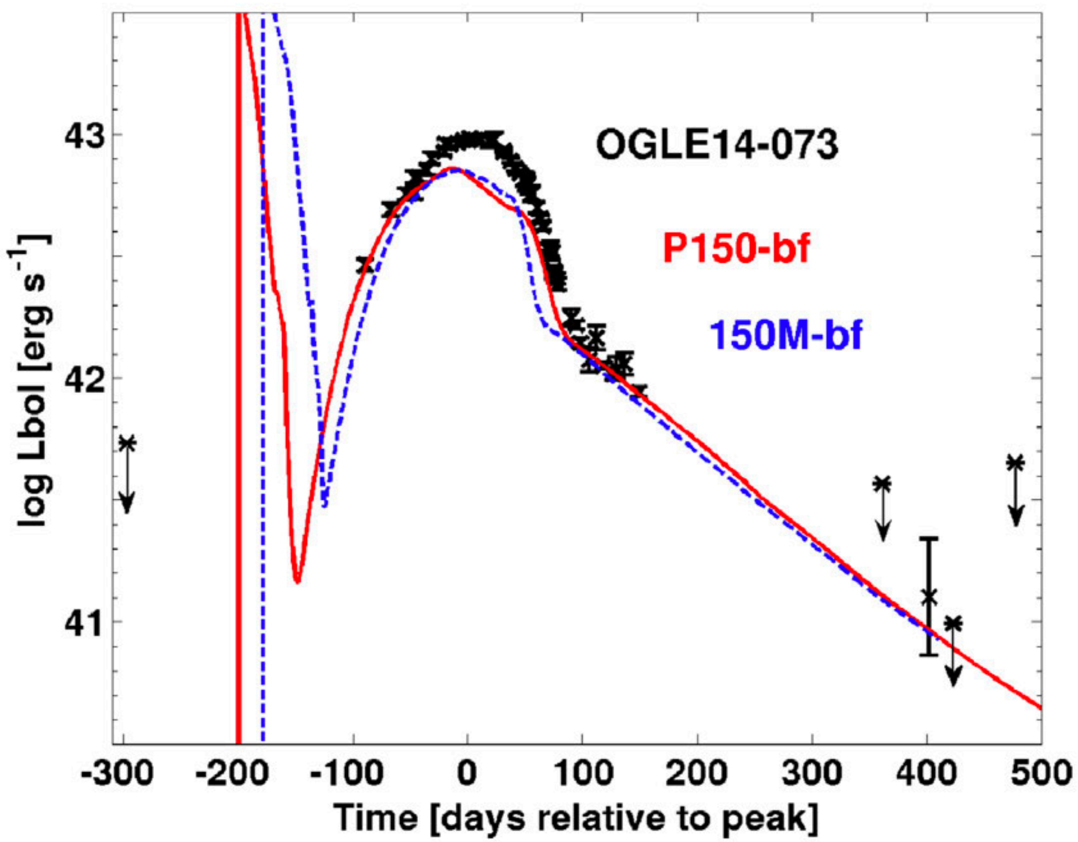
- Superluminous supernovae

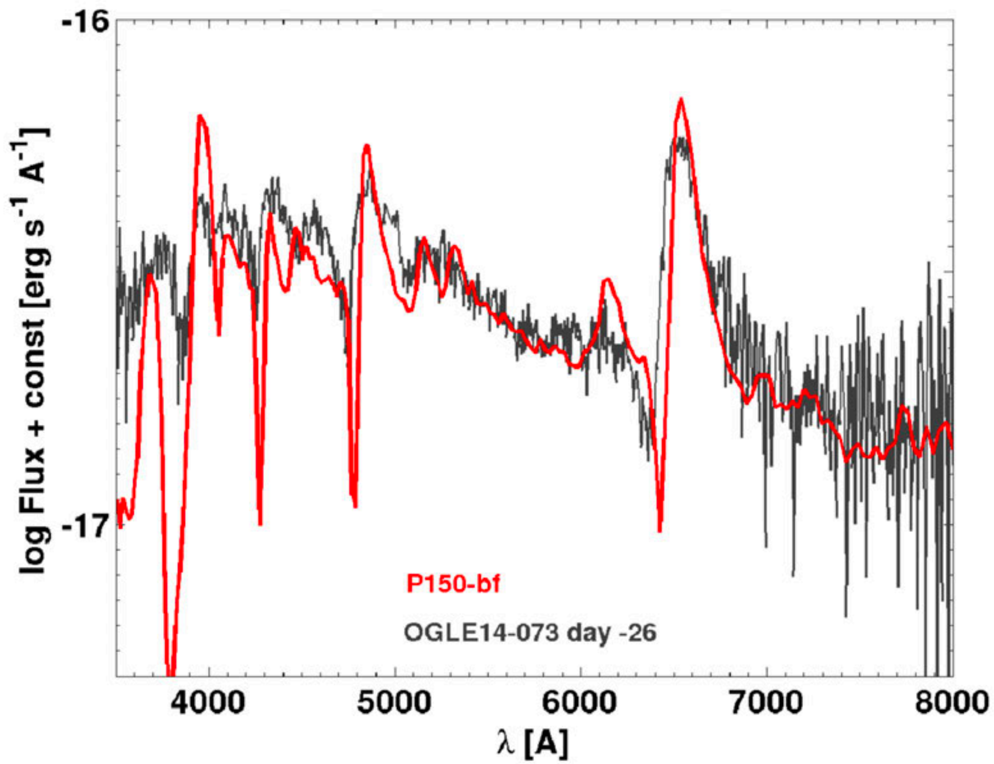


Jerkstrand et al. (2016)

PISN candidates

- OGLE14-073 (Terreran et al. 2017)

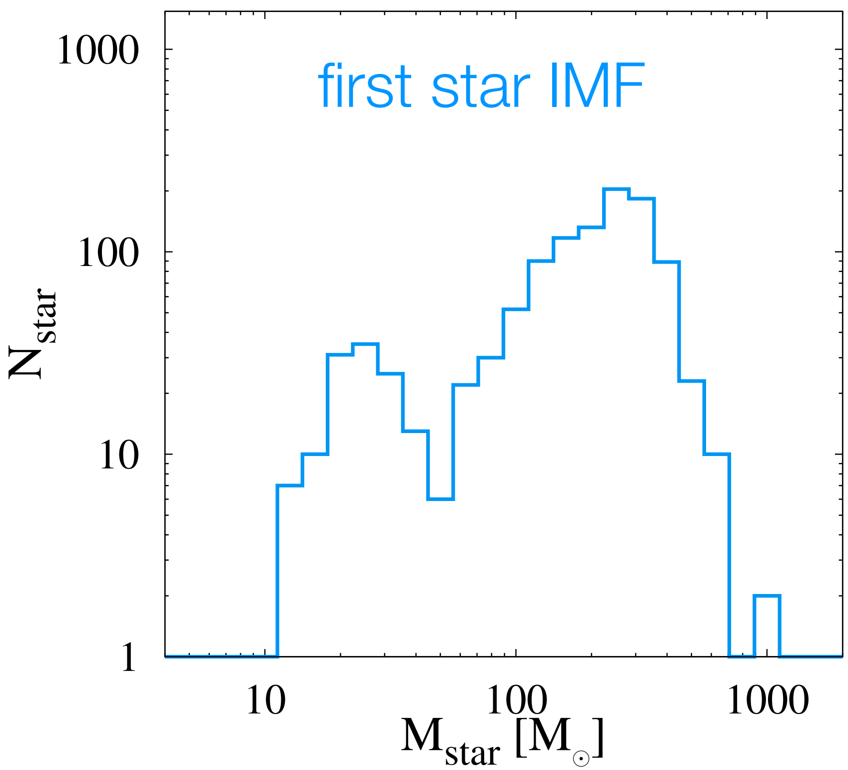




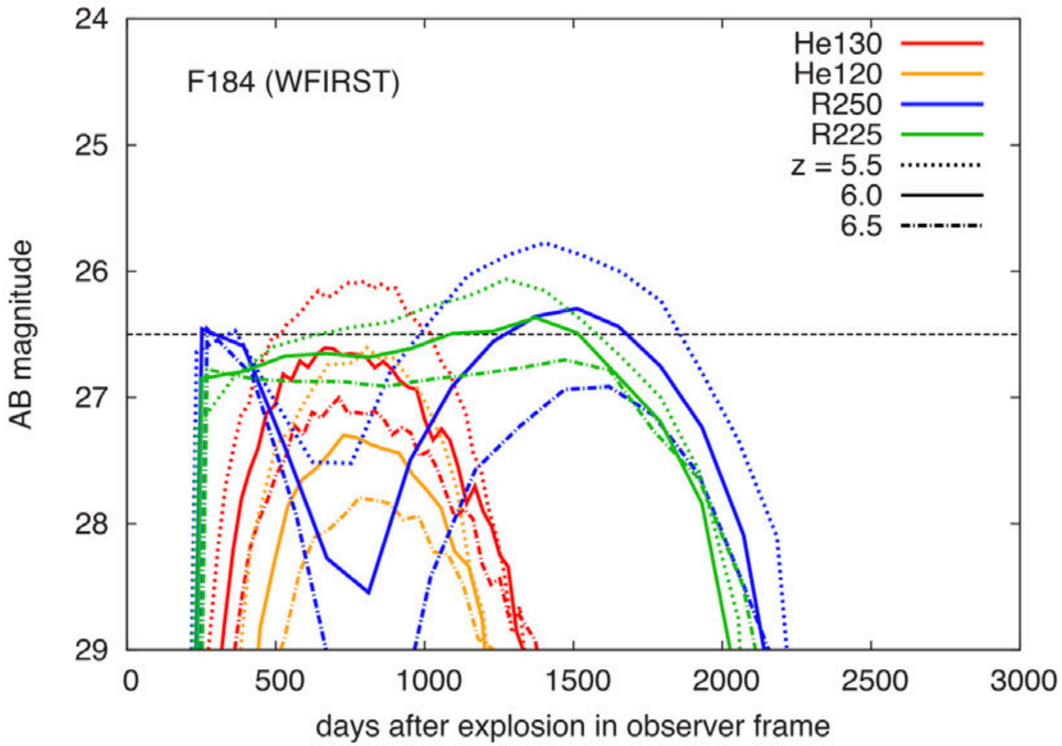
Kozyreva et al. (2018)

Pair-instability supernovae from the first stars

- many massive stars in the PISN range are predicted to form
  - ~150 Msun - ~ 250 Msun
- they can be found with coming NIR surveyors like WFIRST

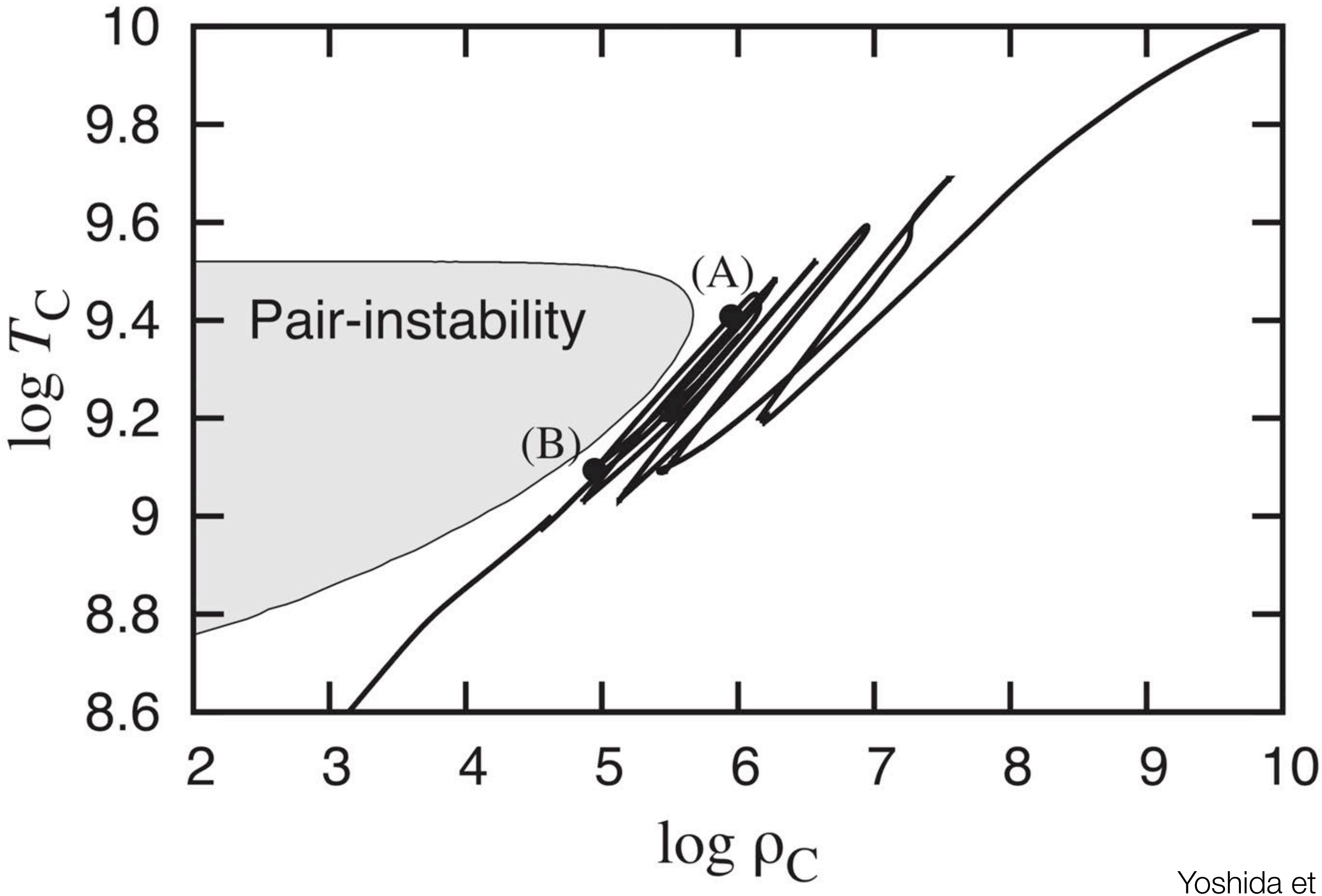


Hirano et al. (2015)



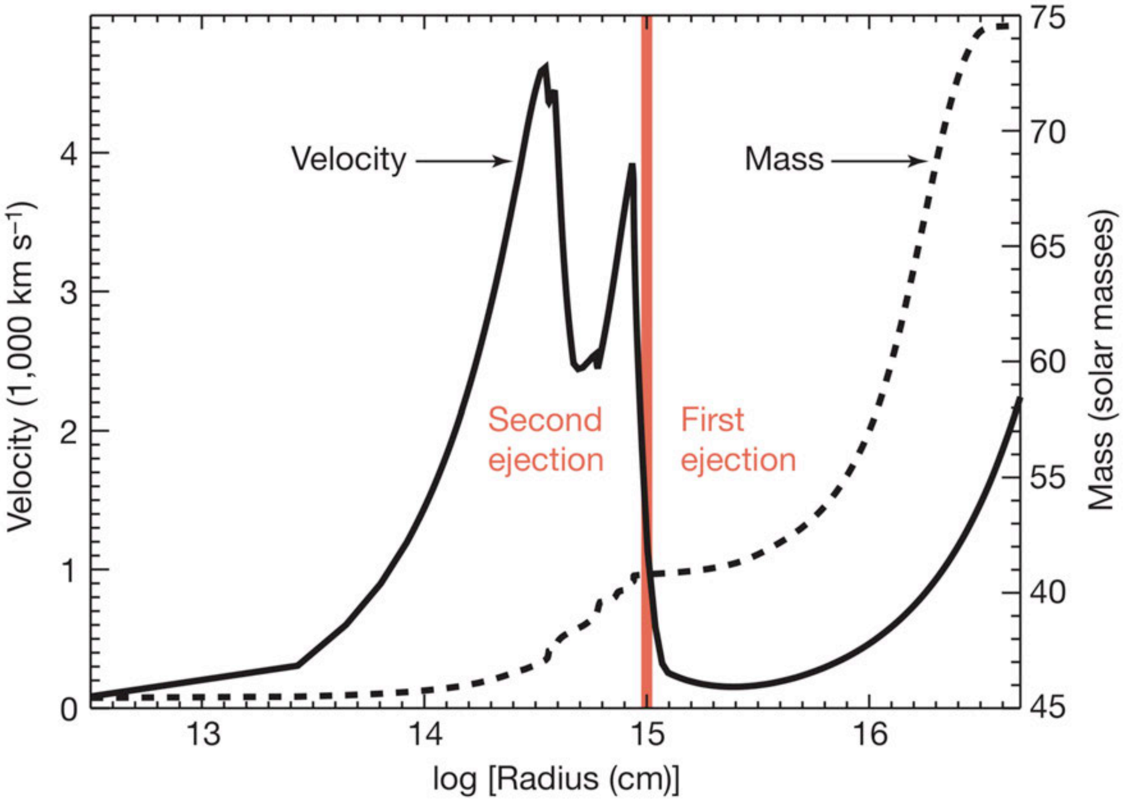
Moriya et al. (2019)

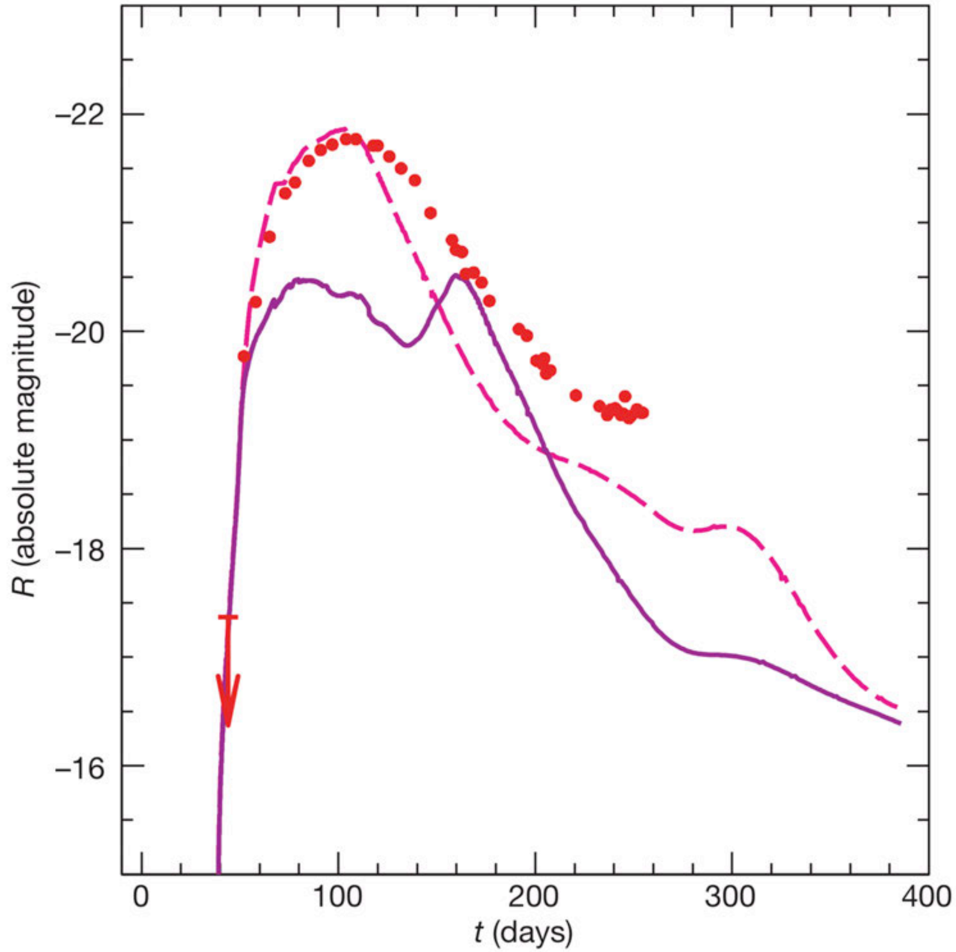
Pulsational pair-instability supernovae



Yoshida et al. (2016)

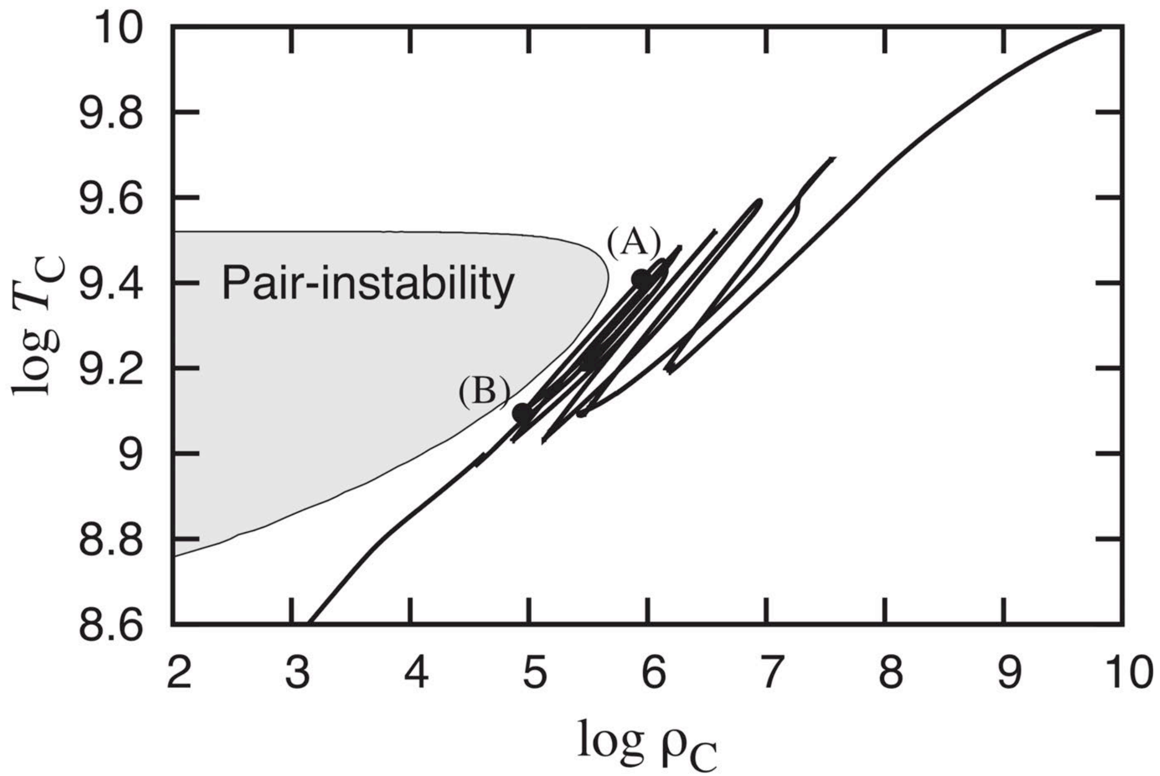
Pulsational pair-instability supernovae



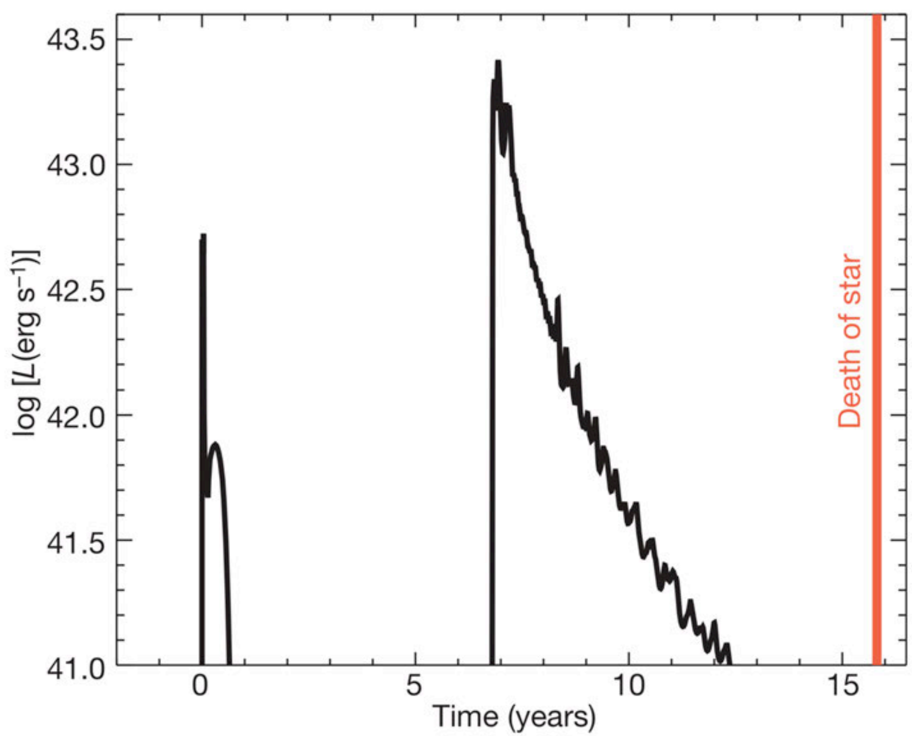


Woosley et al. (2007)

Pulsational pair-instability supernovae



Yoshida et al. (2016)



Woosley et al. (2007)

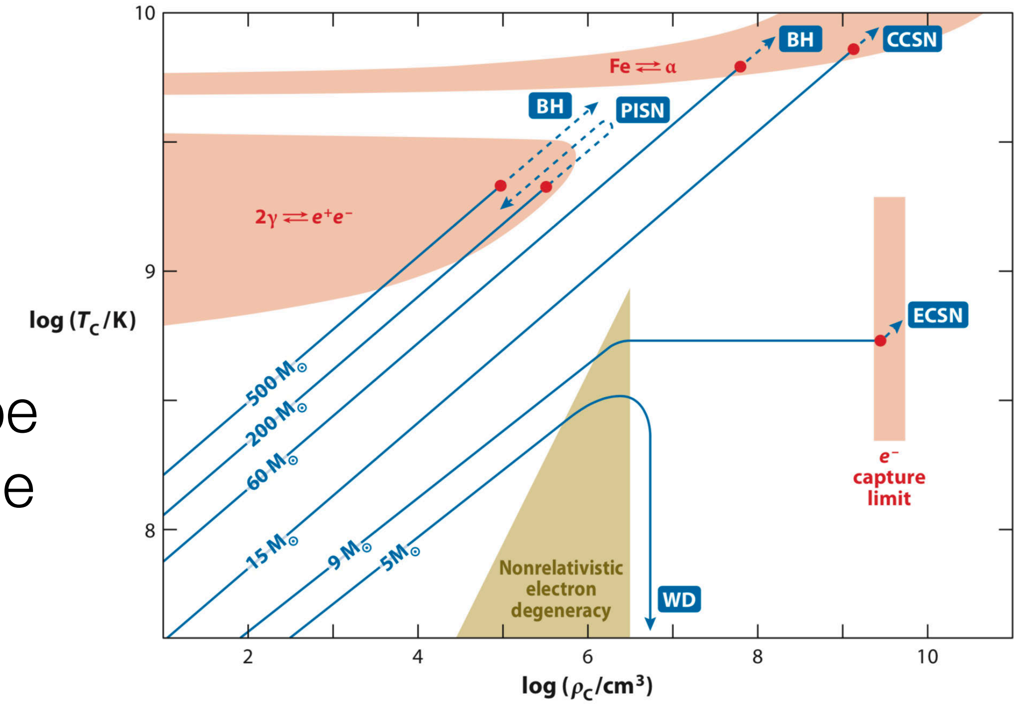
Pair-instability supernovae: summary

- thermonuclear explosions of very massive stars triggered by the dynamical instability from the pair creation

- energetic explosions
- 56Ni mass varies

- some luminous supernovae may be pair-instability supernovae but none confirmed
    - first stars?

- pulsational pair-instability also exists



Langer (2012)