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Supernova progenitors from binary stars

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With Philipp Podsiadlowski and Bernhard Müller

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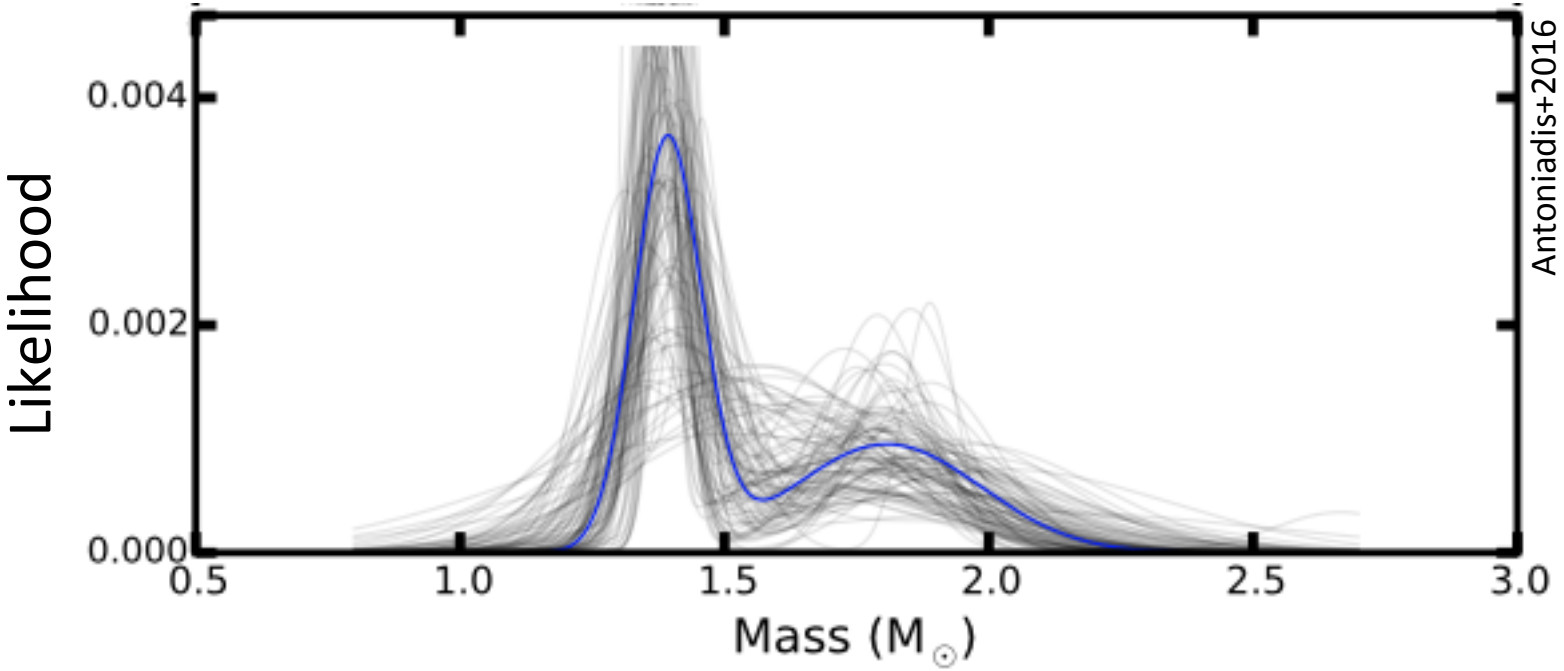
Ringberg Castle, 25th July 2017

Motivation: NS mass distribution

- Antoniadis+2016: **bimodal/asymmetric distr. of millisecond-pulsar masses** (see also Schwab+2010, Kiziltan+2013 etc.)



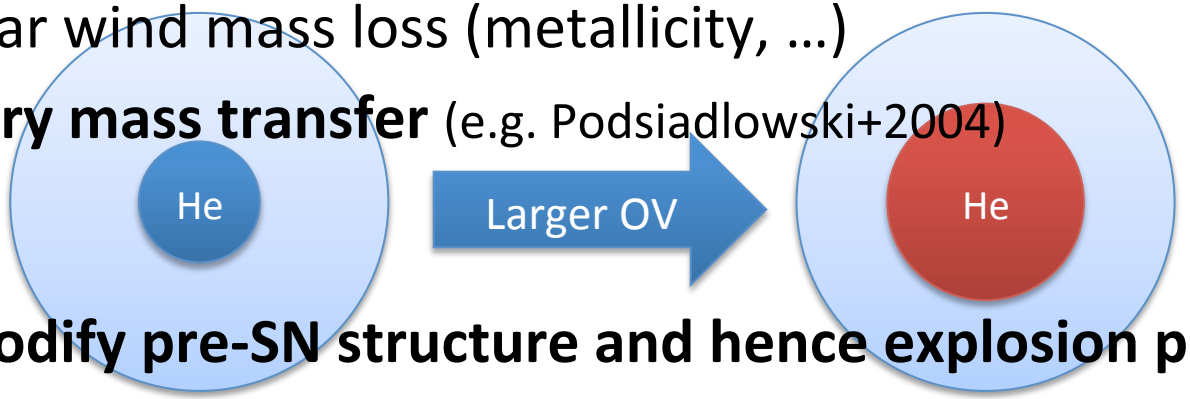
- MSPs recycled, i.e. accreted mass, but some **likely born massive** (e.g. PSRJ1614-2230; Lin+2011, Tauris+2011)

What determines the shape of the NS distribution?

Key physics governing SN explosions

1. **Supernova explosion physics:**
   - Iron core collapse vs. electron capture supernovae (e.g. Nomoto 1987, Podsiadlowski+2004)
   - Neutrino driven: location of gain radius, fallback, … (e.g. Timmes+1996, Fryer & Warren 2002, Janka+2007, Müller+2016)
   - …

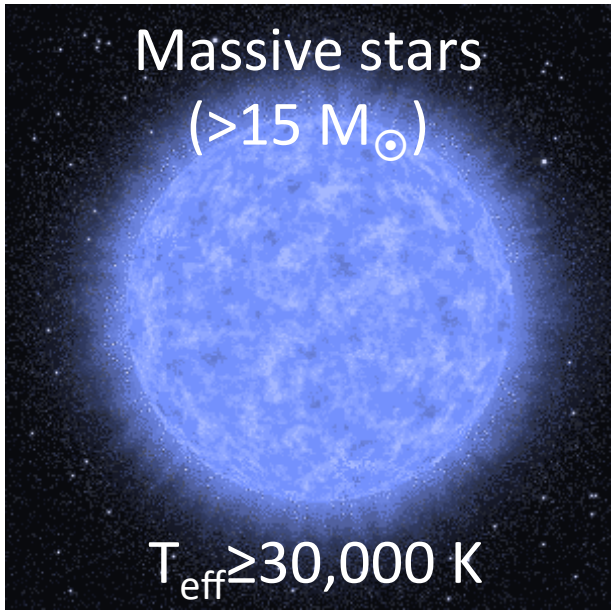
2. **Supernova progenitor evolution:** (e.g. Woosley+2002, Langer 2012)
   - Convective (core) overshooting (+ other mixing processes)
   - Stellar wind mass loss (metallicity, …)
   - **Binary mass transfer** (e.g. Podsiadlowski+2004)
   - …

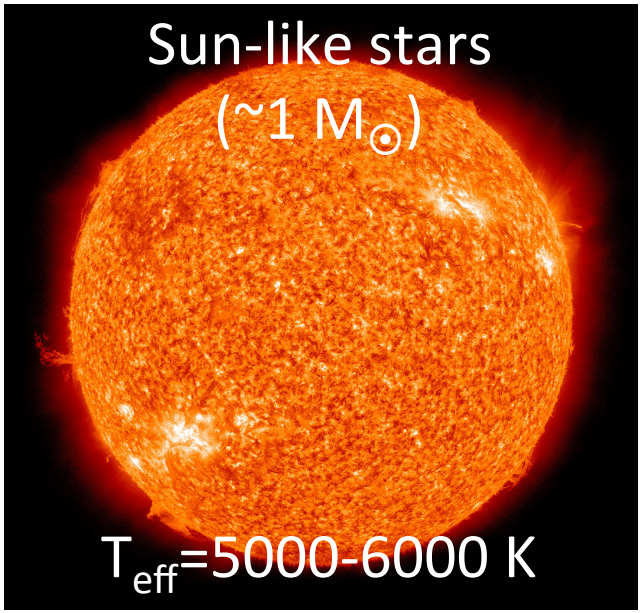


➔ **Modify pre-SN structure and hence explosion properties**

Binary stars

- Binaries are **numerous** and **everywhere** (e.g. Proxima Centauri)





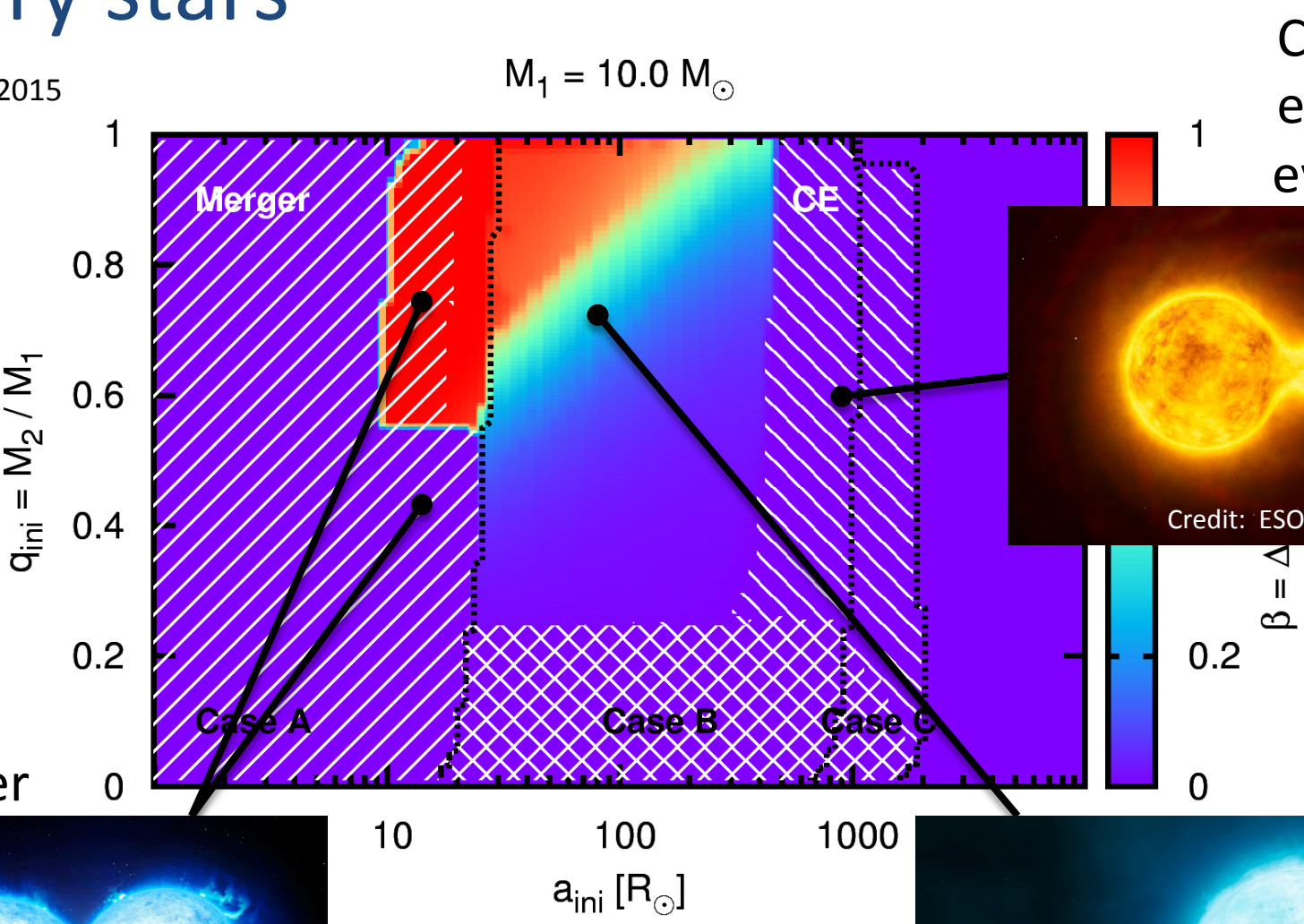
- Spectral Type: O B A F G K M

  Binary Fraction: 100% (?) 60% 30%

  (e.g. Bastian et al. 2010)

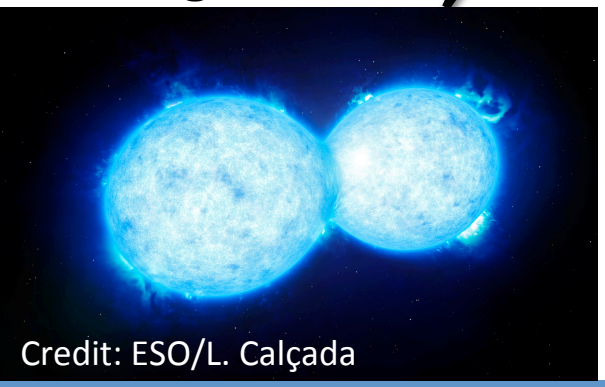
Binary stars

Schneider+2015



Common envelope evolution

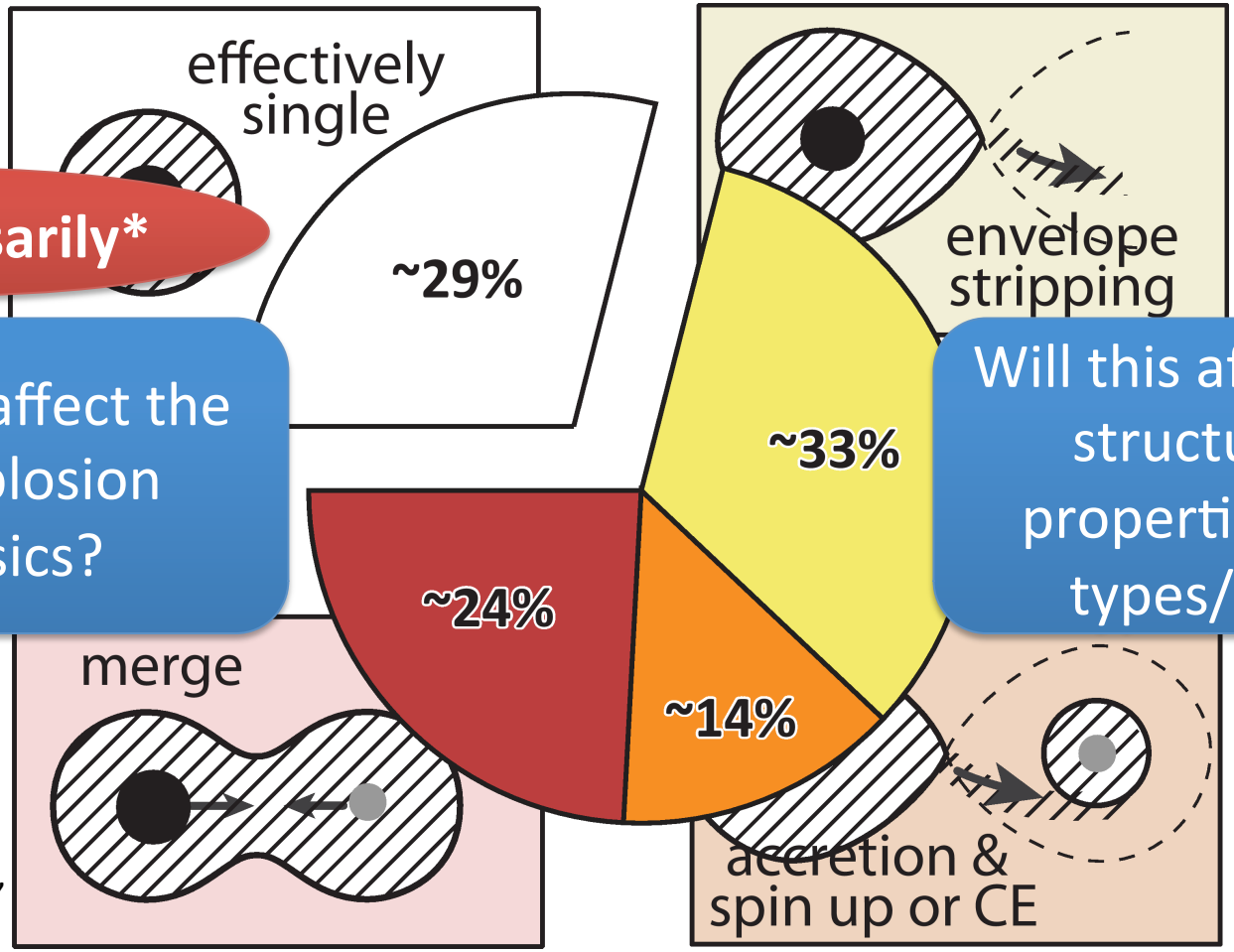
Merger



Stable mass transfer

Binary stars

- Sana+2012 (Science): >70% of all SNe from O stars affected by past binary mass exchange



Not necessarily*

Will this affect the SN explosion physics?

Yes

Will this affect pre-SN structures, SN properties and SN types/modes?

* However, some explosion modes/ types (rapid rotation, certain engines, …) may only be realised in binaries

Credit: S.E. de Mink

For more implications: e.g. talk by M. Zapartas

Binary stars

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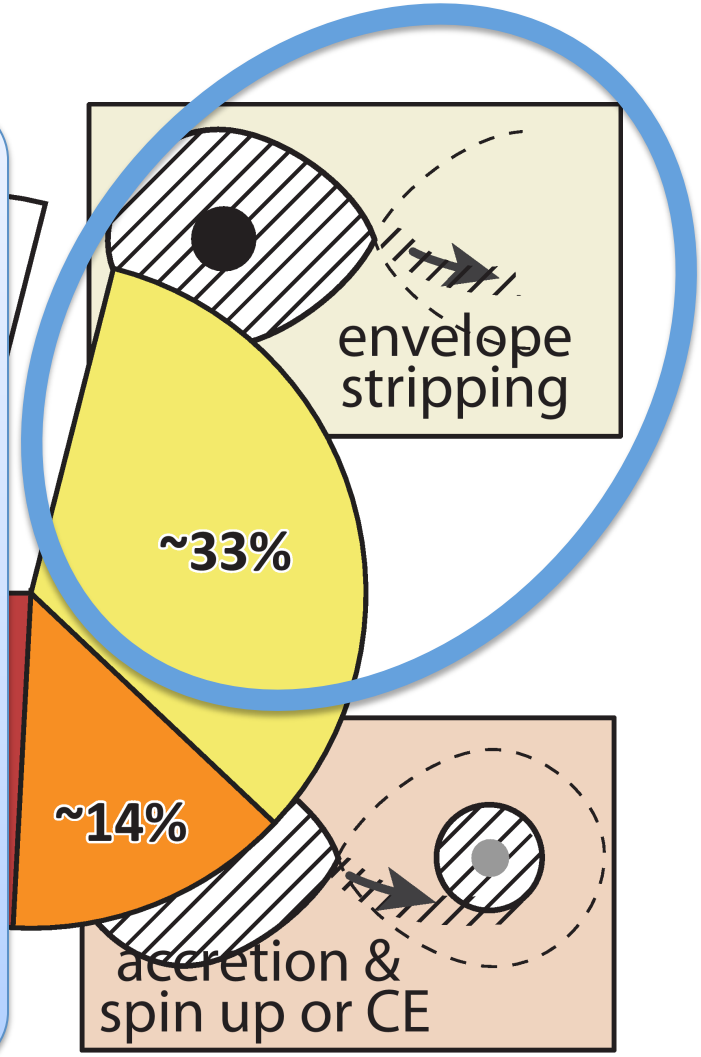
Focus on envelope stripping:

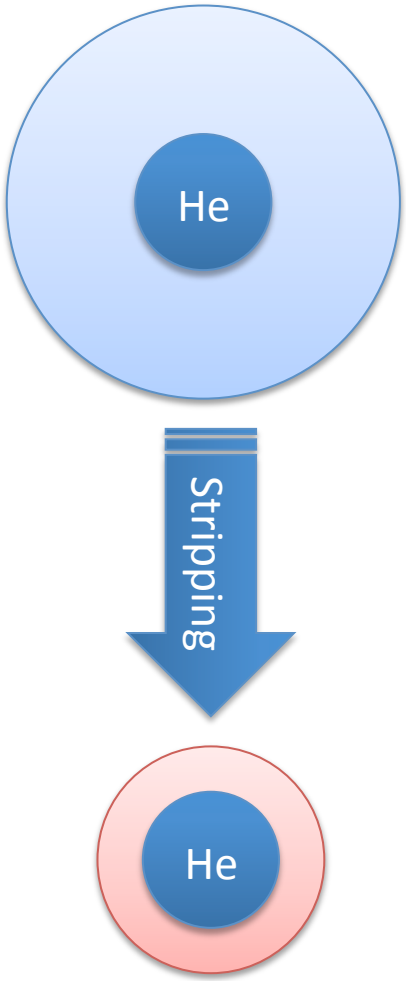
- ~1/3 of all Sne
- Highly relevant for (first) NSs and BHs in compact binaries (***all*** such progenitors stripped off their envelope)
  → NS & BH mass distributions

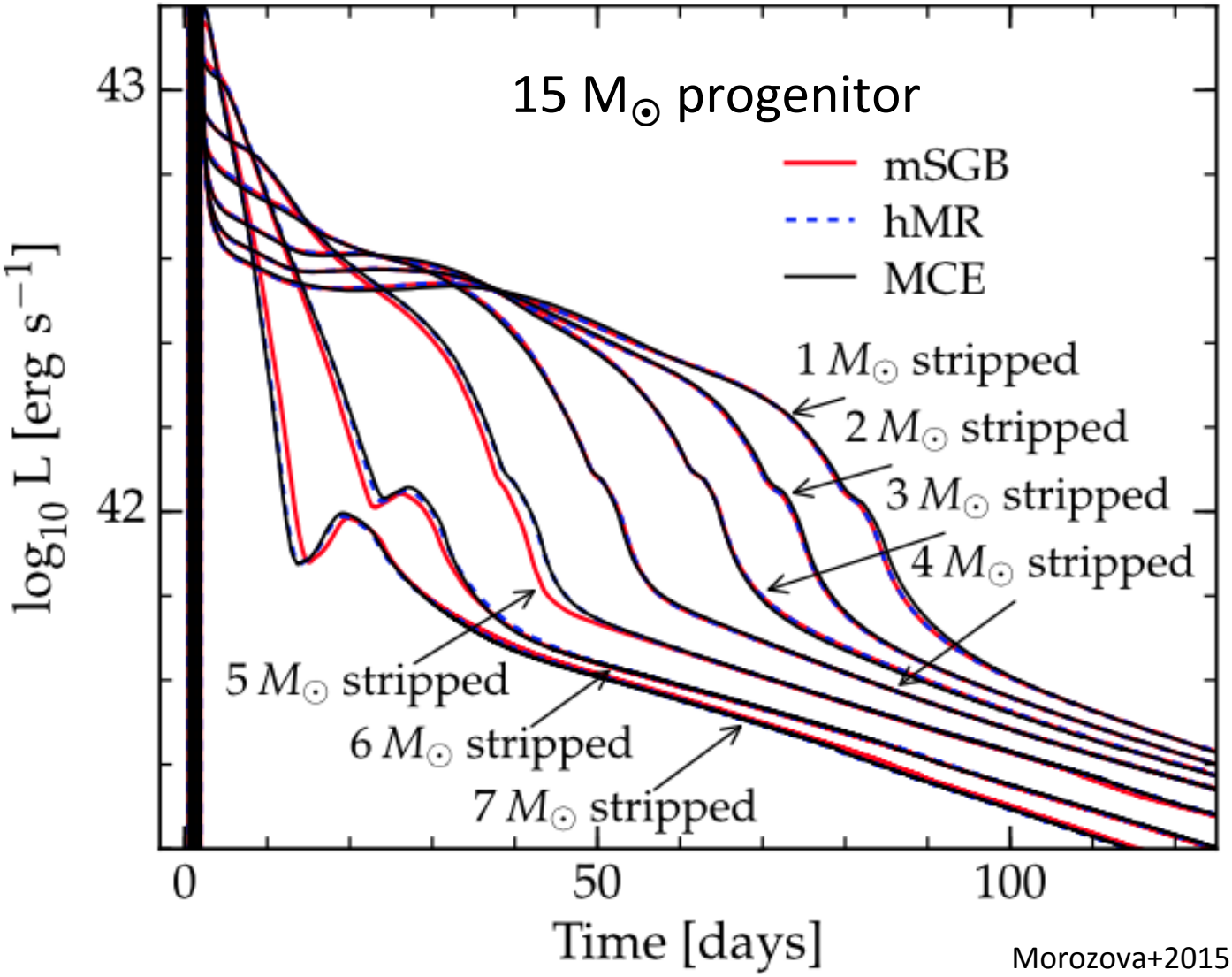


Credit: S.E. de Mink

Envelope stripping: SNII lightcurves

- Envelope stripping reduces mass that radiation has to penetrate





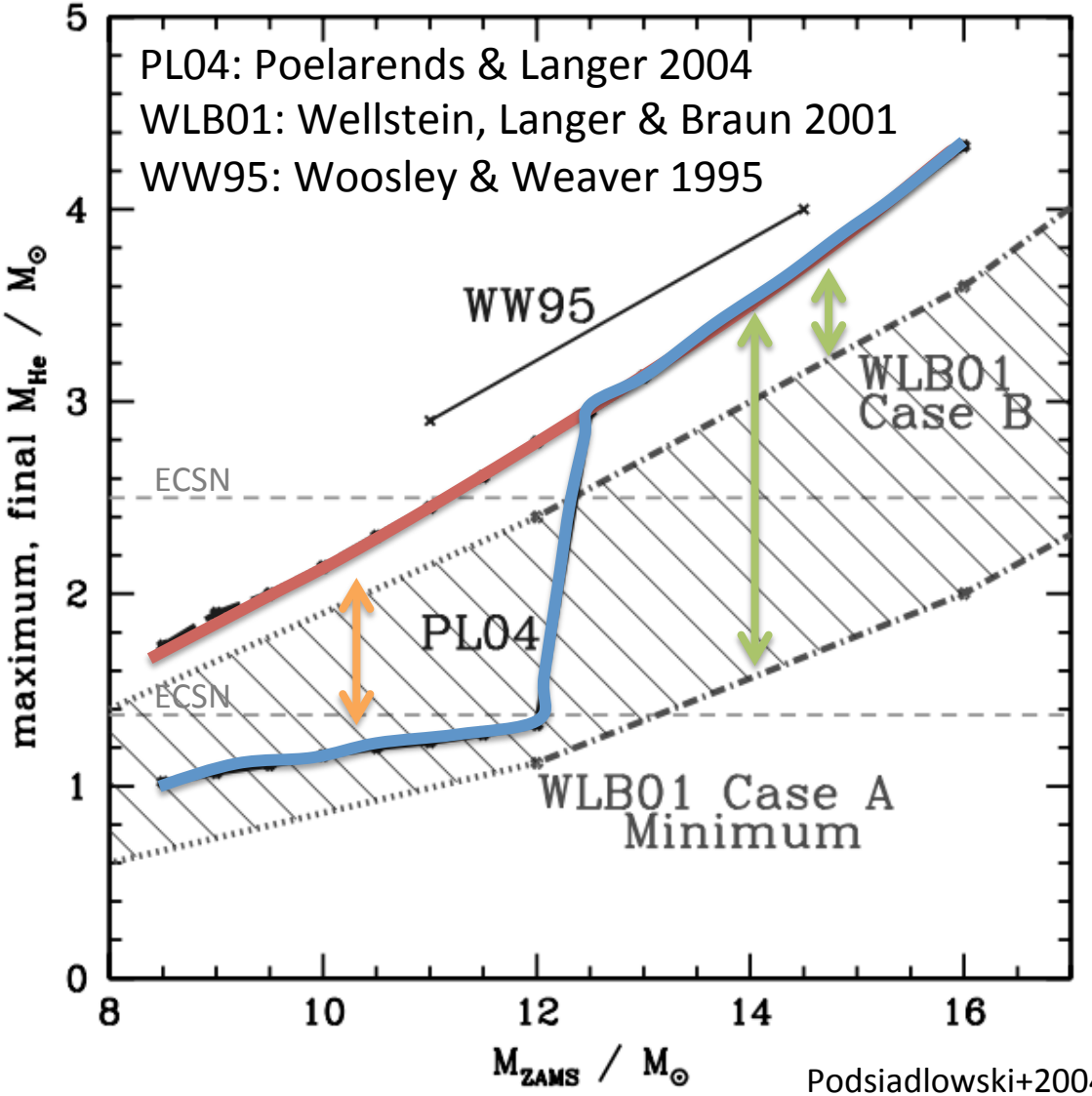
Morozova+2015

Envelope stripping: core properties

What are the consequences of loss of hydrogen-rich envelope?

1. No hydrogen-shell burning that adds helium to layers beneath
2. No 2nd dredge-up

Dredge-up can significantly reduce helium core mass during AGB phase (Iben 1974);
→ not without envelope!



Podsiadlowski+2004

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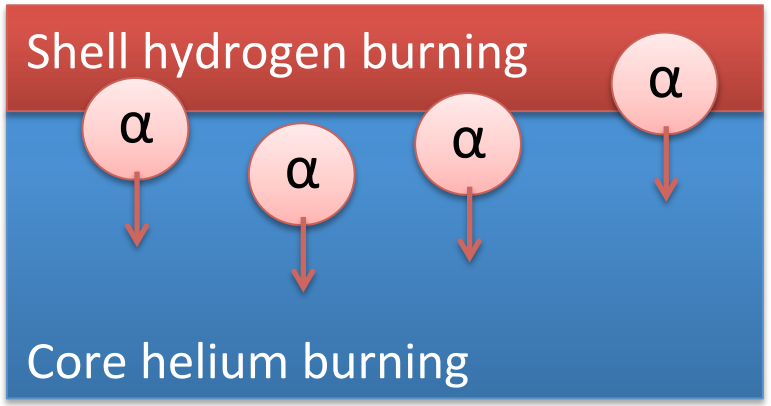


Core helium burning via triple α reaction; once carbon produced, **$^{12}C(\alpha, \gamma)^{16}O$** destroys carbon (lower C/O ratio)

Without hydrogen shell, smaller helium cores and thus larger carbon abundance and larger C/O ratio (Timmes+1996, Brown+1996, Brown+2001, Fryer+2001, Podsiadlowski+2004, …)

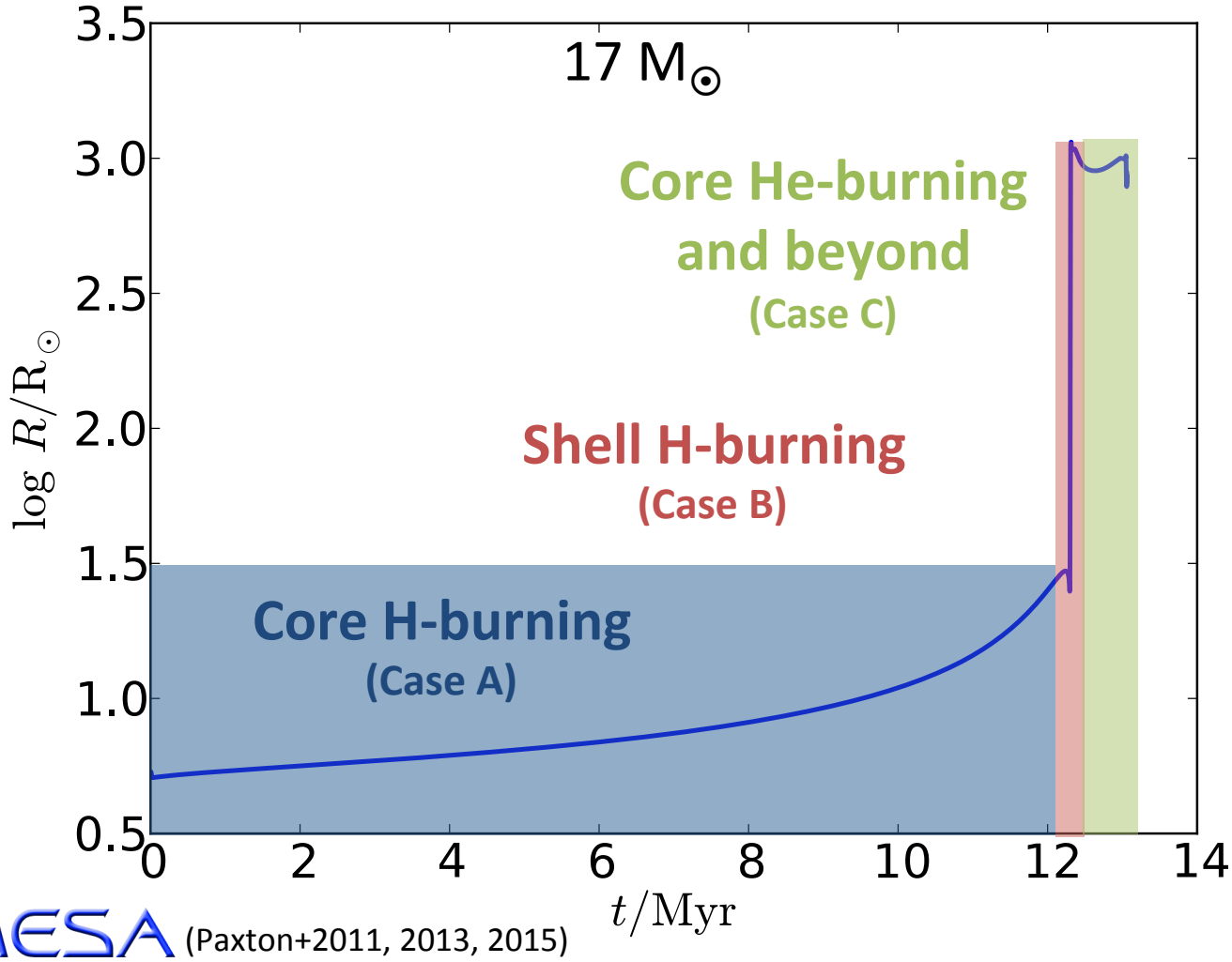
→ affects strength of carbon and other burning phases

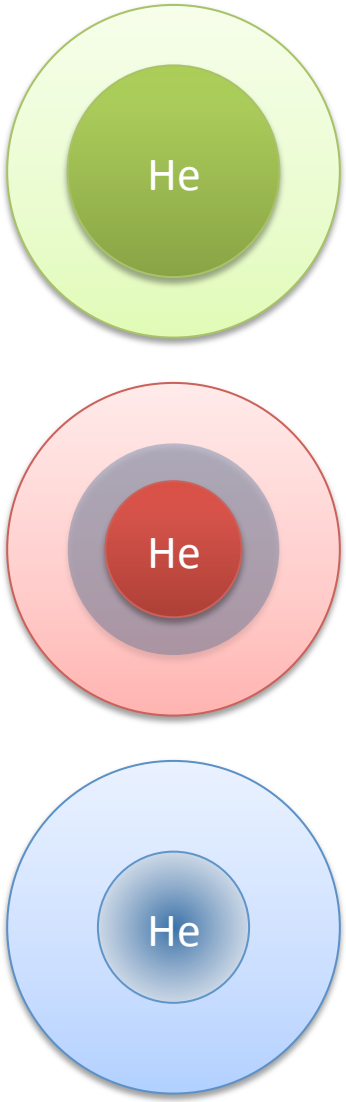
→ smaller iron cores, steeper density gradients

→ stars explode easier, changing NS-BH transition

Envelope stripping: core properties

- Also core evolution affected by binary mass loss
  → outcome depends on **when** envelope is lost





MESA (Paxton+2011, 2013, 2015)

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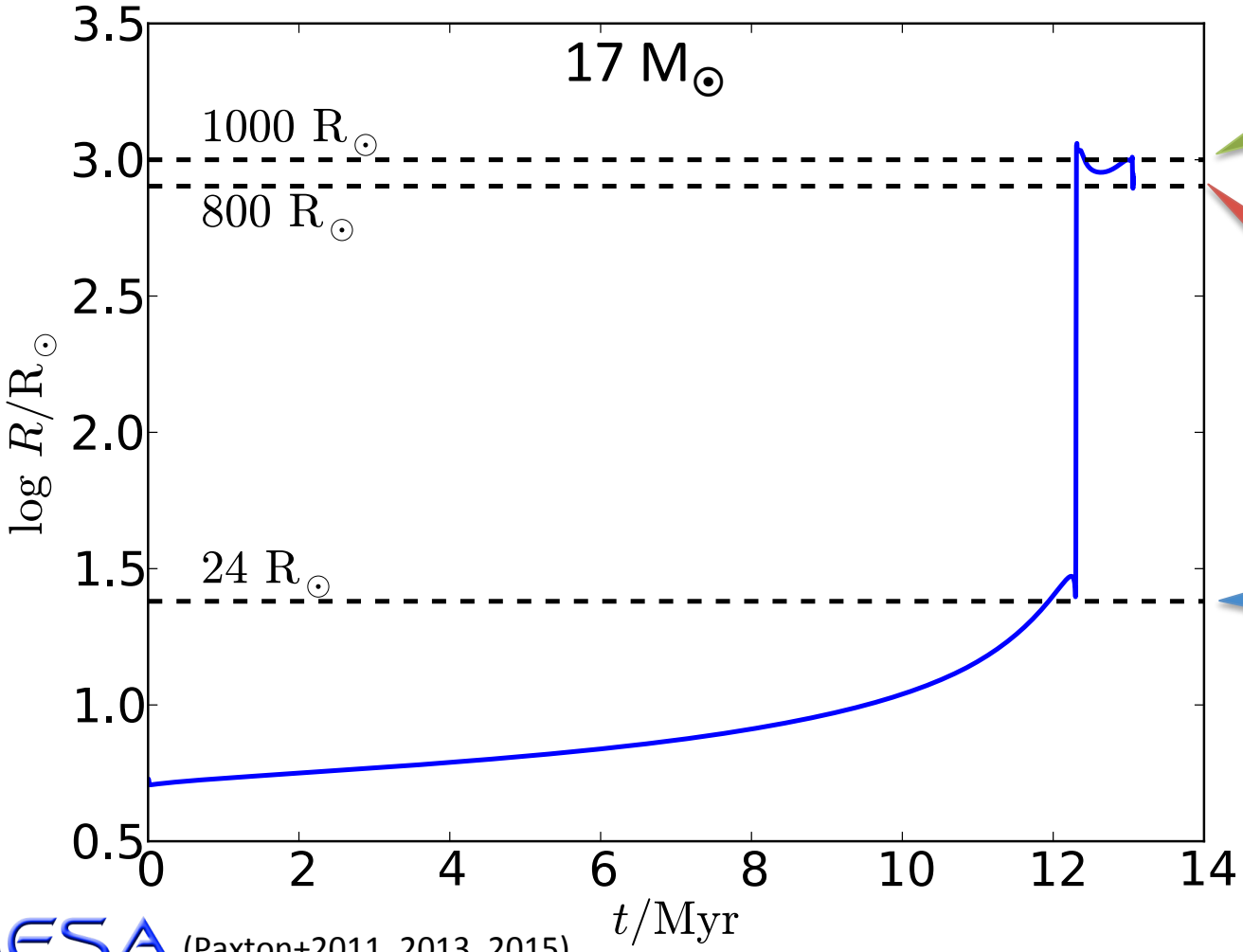


Case C
(Core He exh.)

Case B

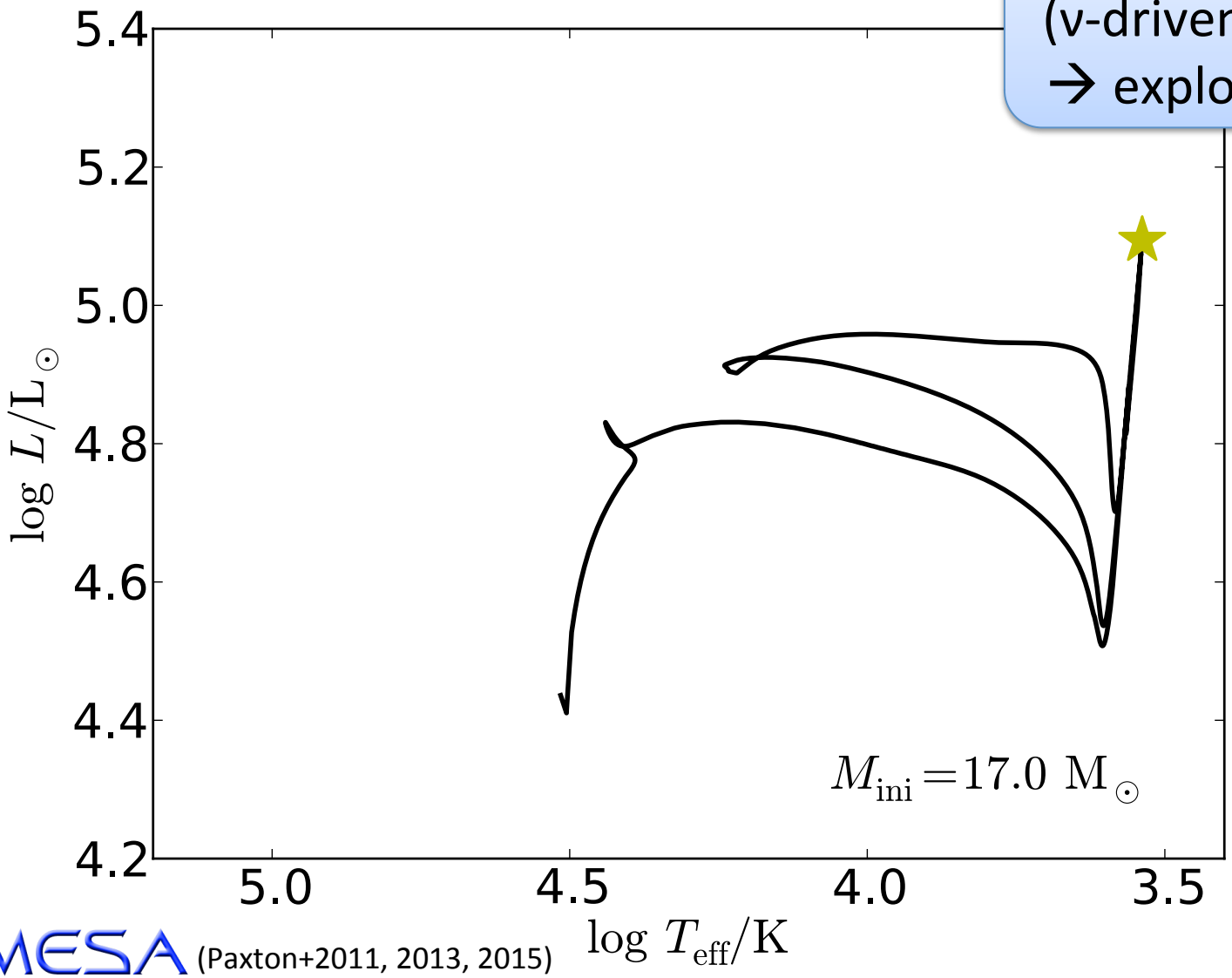
Case A
($X_c < 0.05$)

MESA (Paxton+2011, 2013, 2015)

Hertzsprung–Russell diagram

Parametric SN model
(ν-driven; Müller+2016)
→ explosion properties

E_{expl}=1.07 B
M_{ej}=14.3 $M_\odot$
M_{NS}=1.5 $M_\odot$
…



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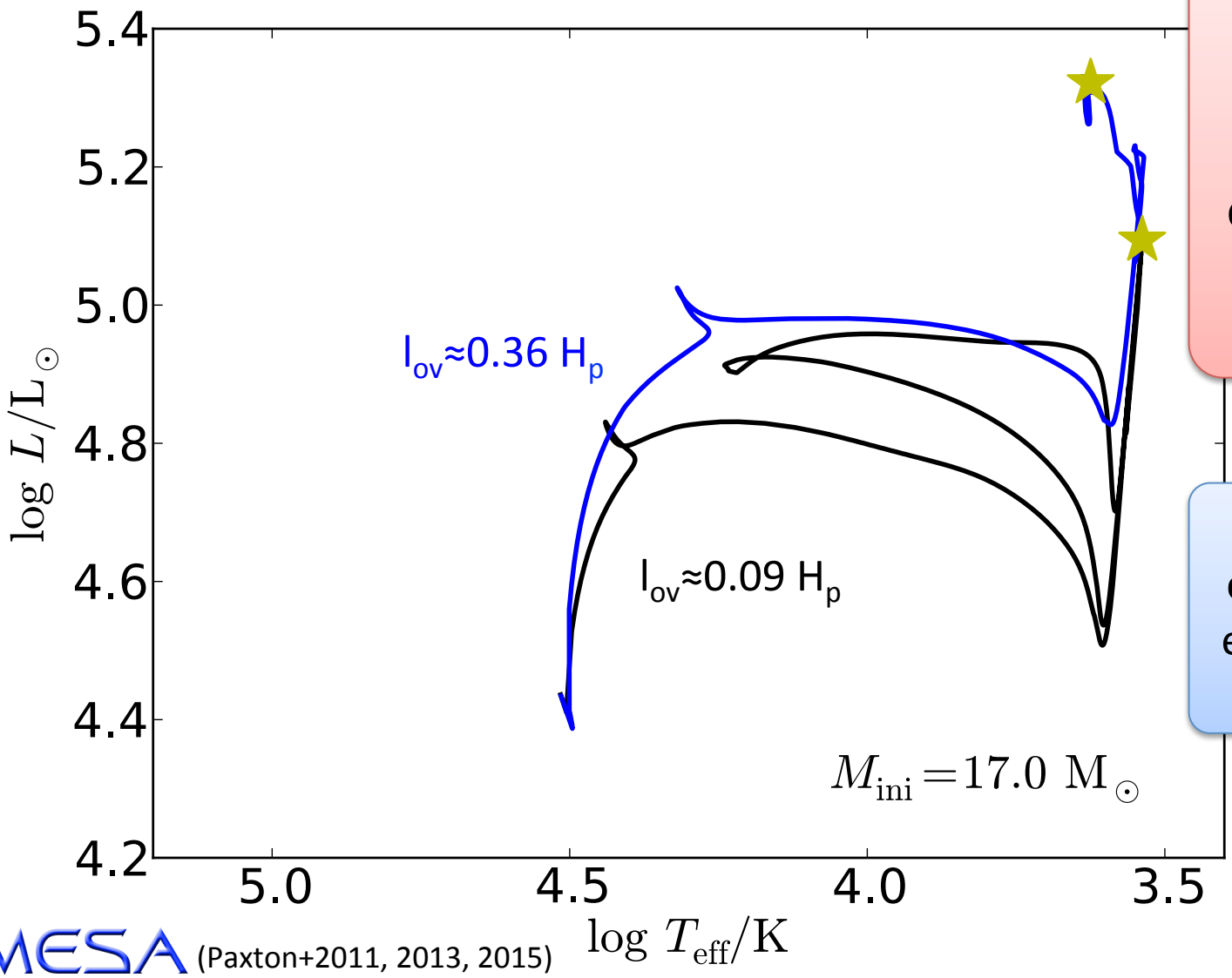
Hertzsprung–Russell diagram

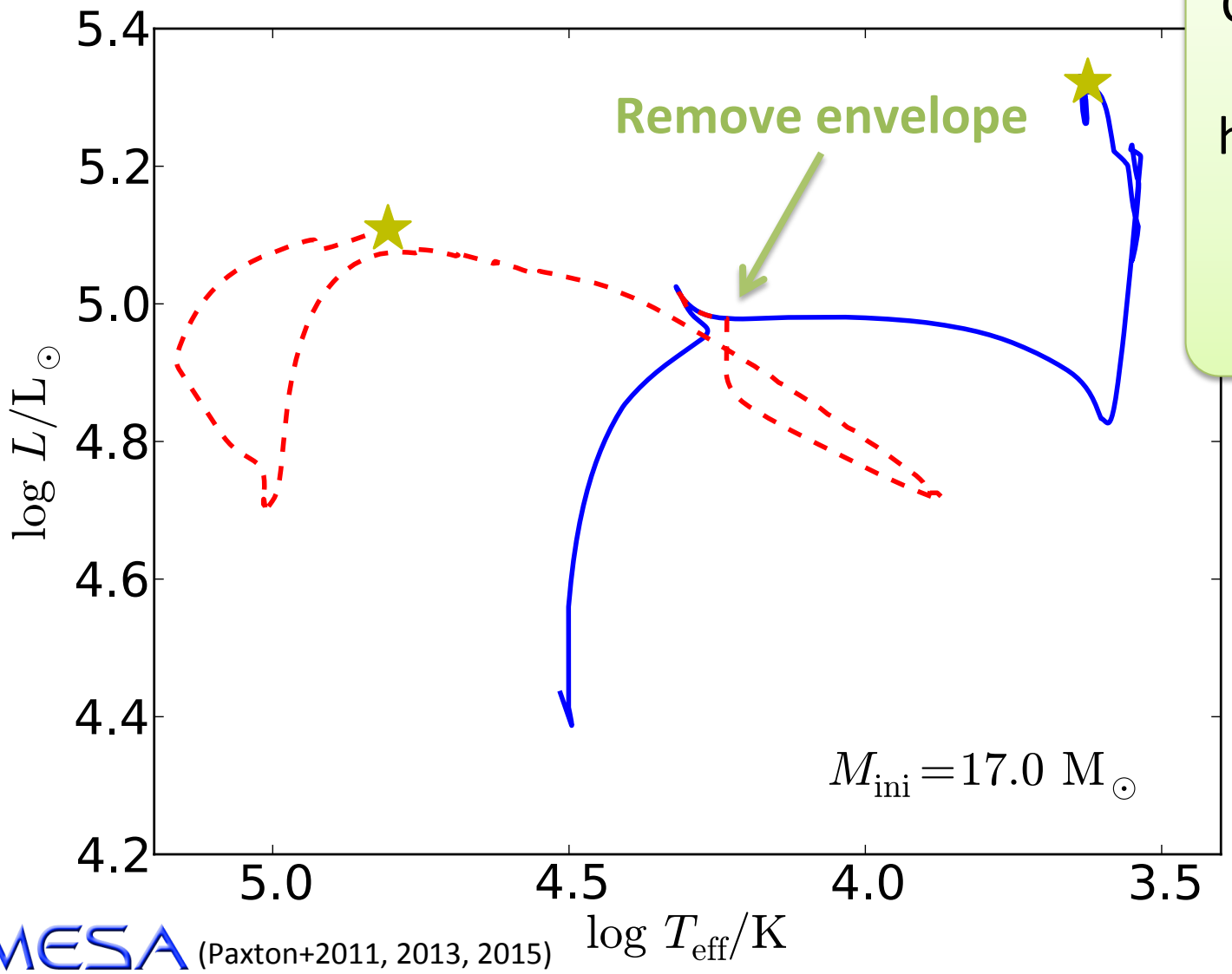


Conv. core overshooting larger than often assumed (e.g. Brott+2011, Castro+2014)

(Exponential) OV calibrated against empirical TAMS of Castro+2014

MESA (Paxton+2011, 2013, 2015)

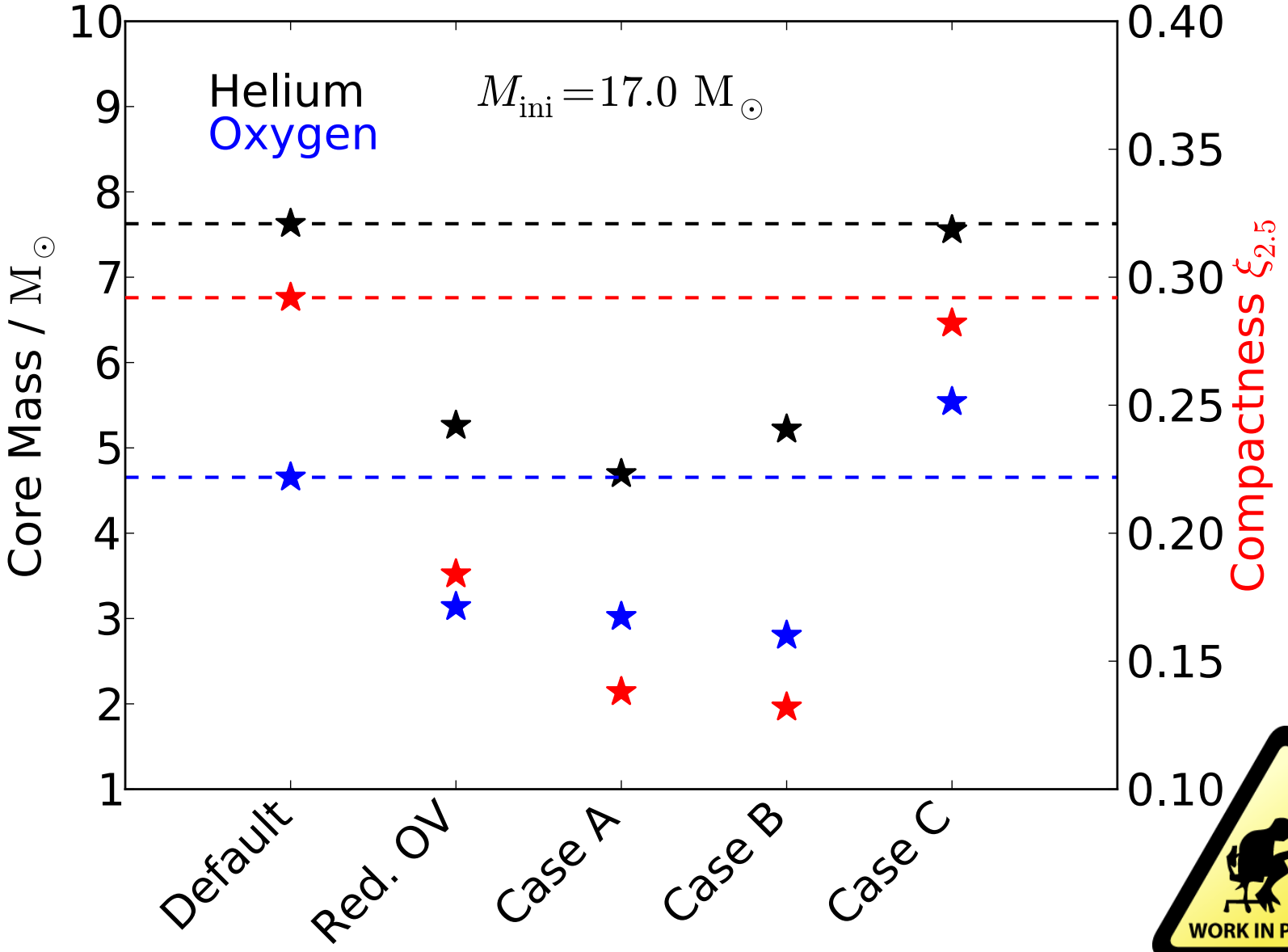
Hertzsprung–Russell diagram



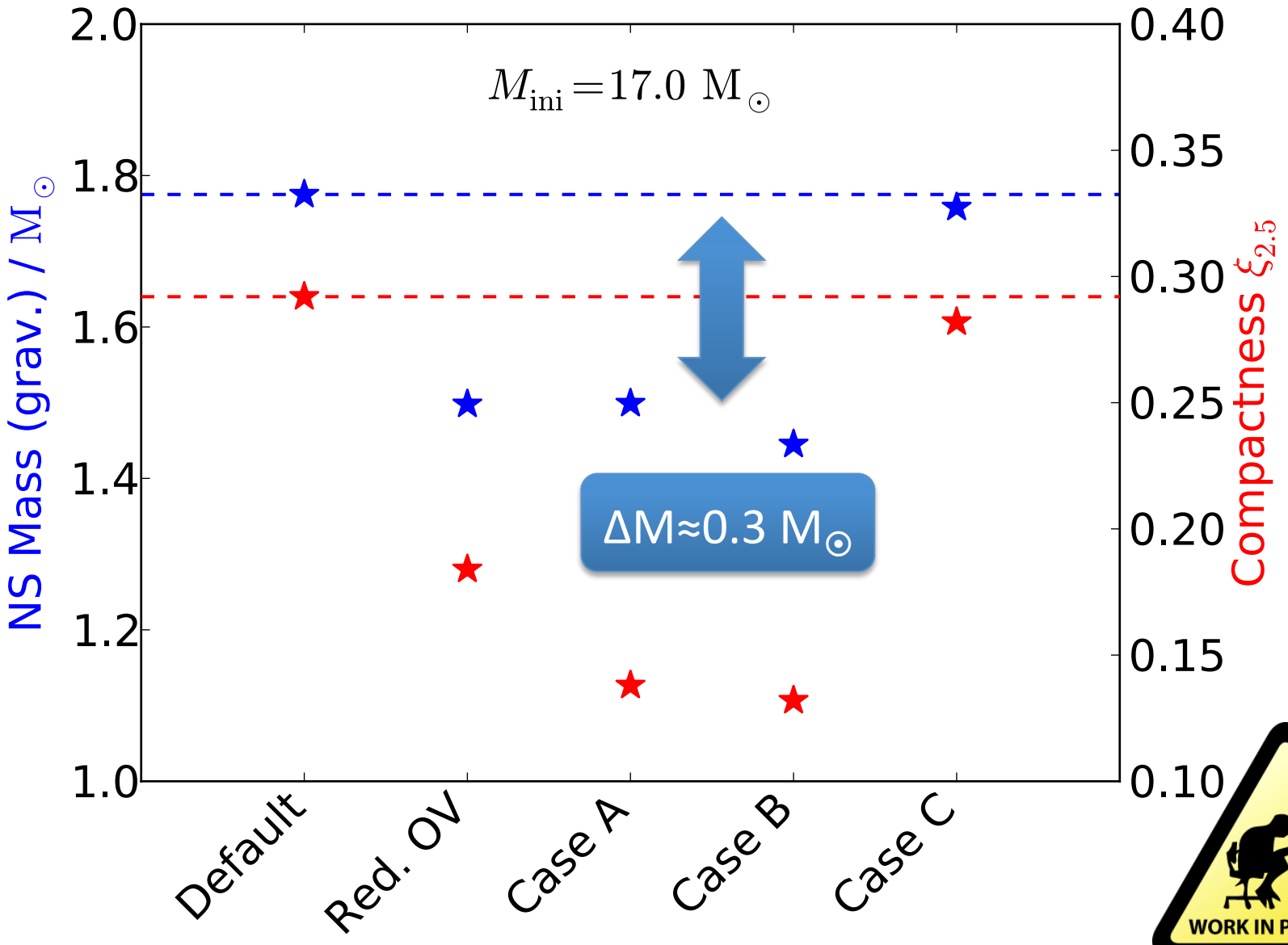
Converted into WR (SN Ib/c), heavily altering structure, evolution and final fate

MESA (Paxton+2011, 2013, 2015)

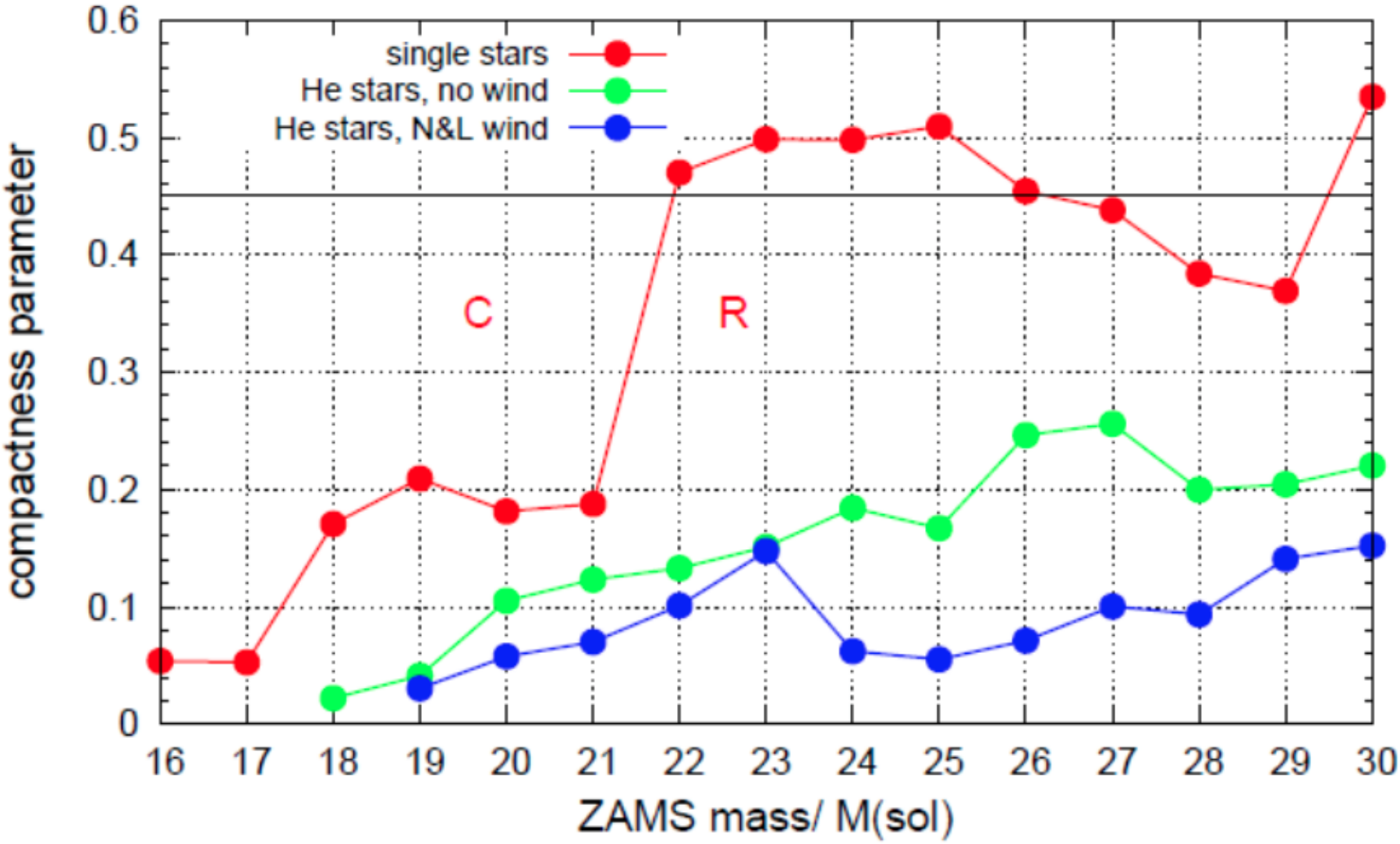
Pre-SN core masses (17 $M_\odot$)



Neutron star masses (17 $M_\odot$)

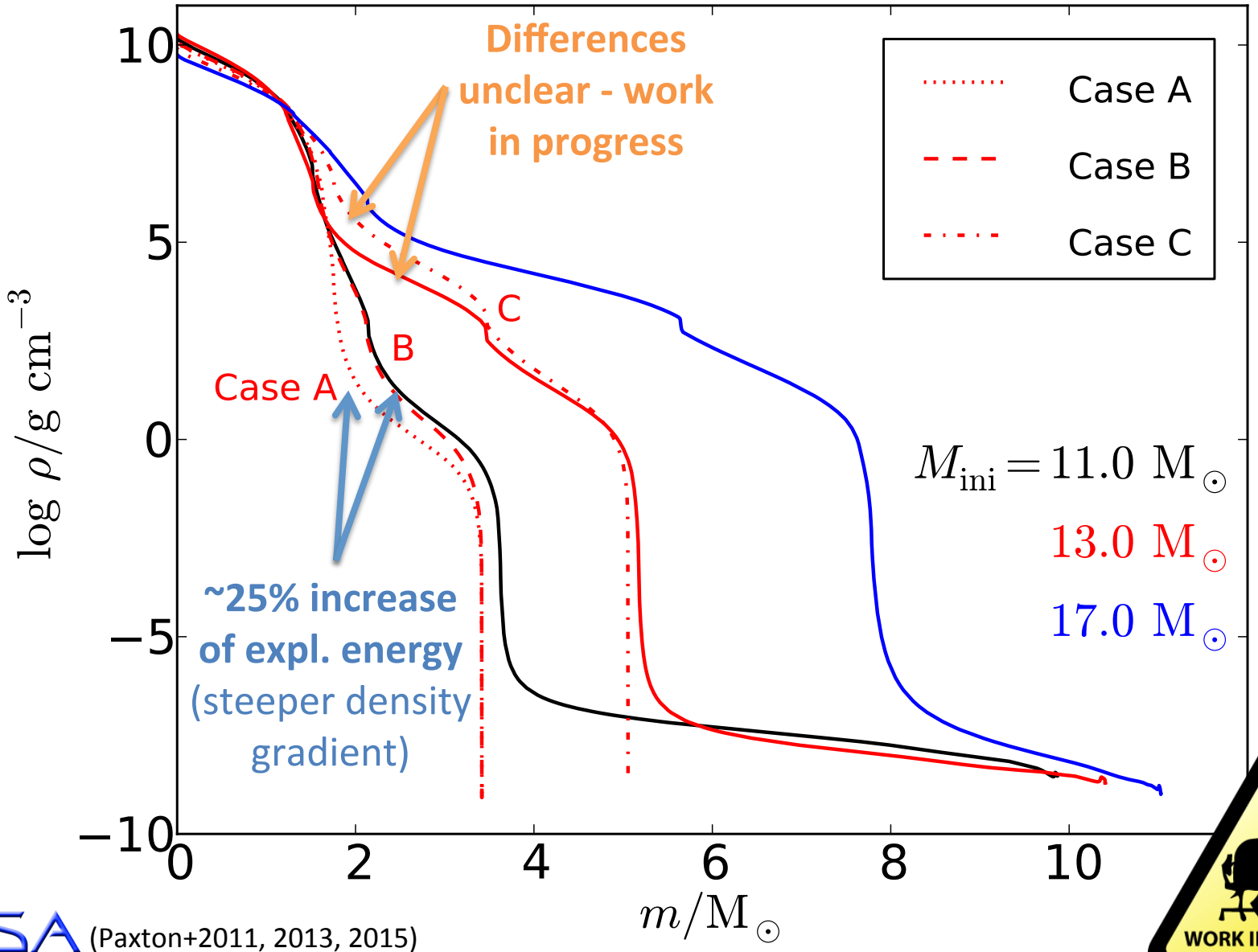


Compactness



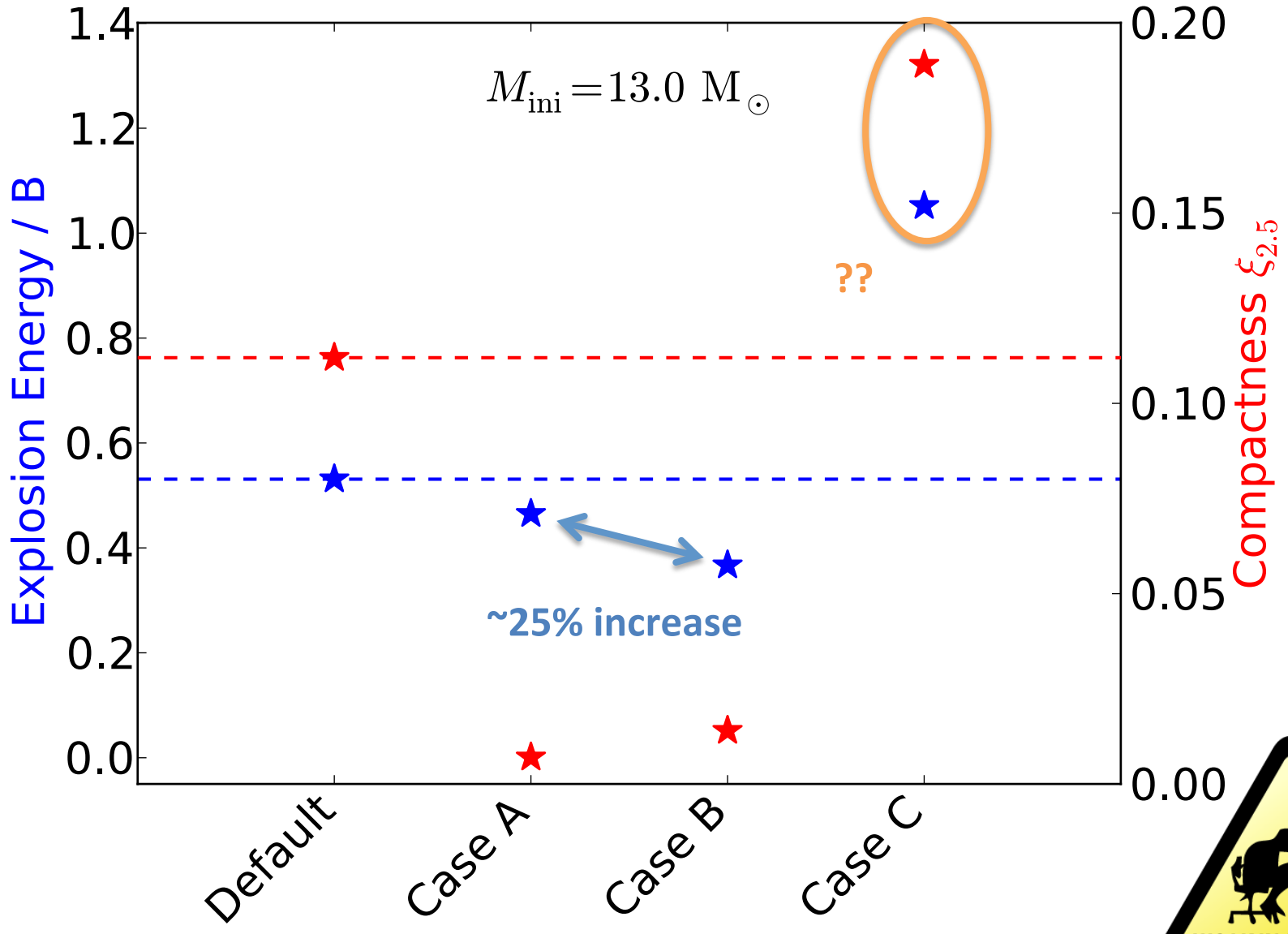
Petermann, Langer and Podsiadlowski (private communication)

Pre-SN structures



MESA (Paxton+2011, 2013, 2015)

Explosion energies (13 $M_\odot$)



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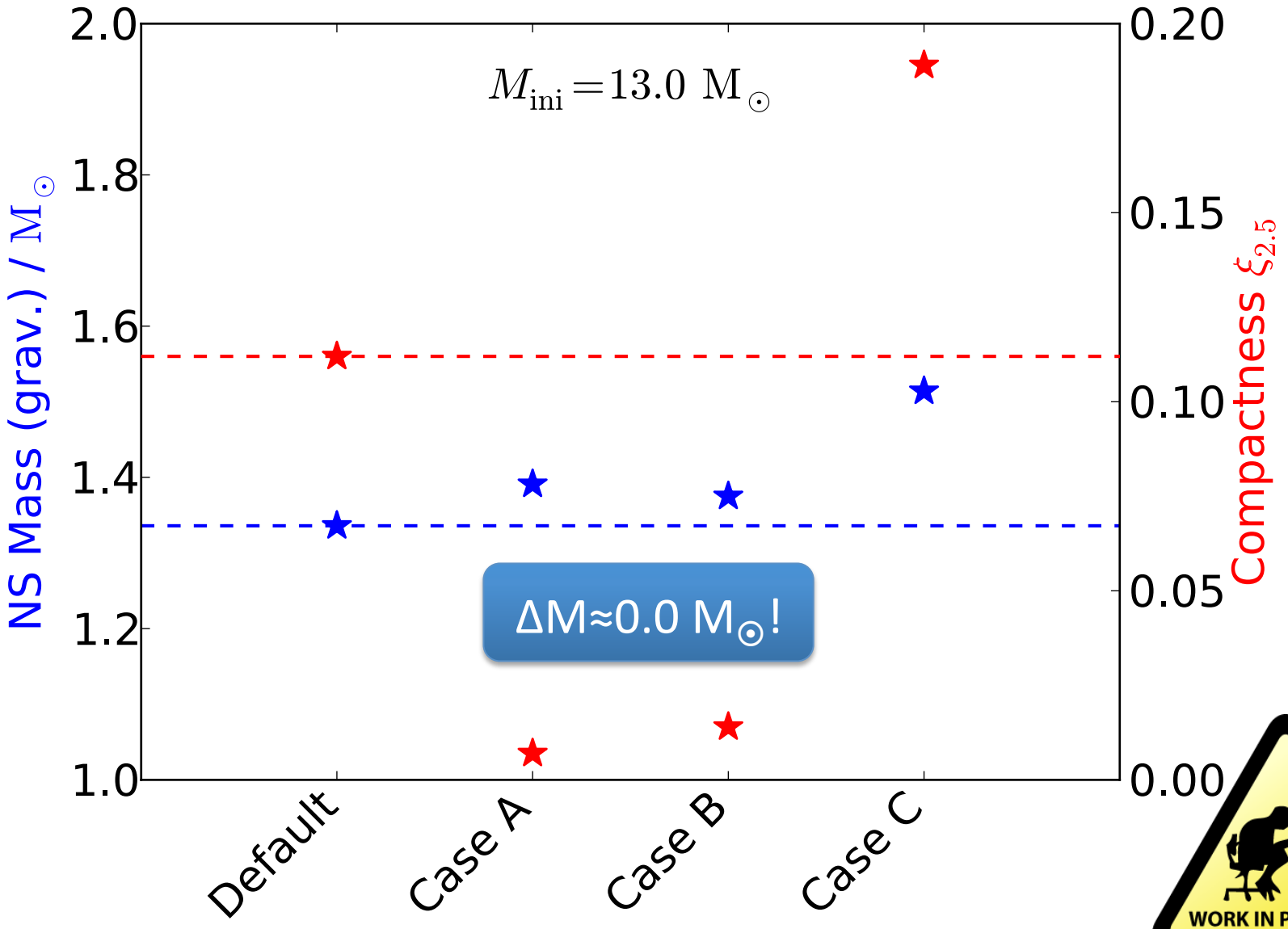

Summary

- **>70% of all SNe from binary mass-exchange products**
- **~1/3 stripped-off their envelopes** (e.g. *all* first NSs in compact binaries)
  → affects helium & CO core masses and C/O ratio
  - **Case A:** transform star in lower mass equivalent
  - **Case B:** stars evolve without hydrogen envelope
  - **Case C:** core structure already established, no big differences expected
- Overall, envelope stripping results in:
  - Less compact cores → easier to explode
  - Steeper density gradients
  - Smaller NS masses
  - Smaller explosion energies

Credit: ESO/M. Kornmesser/S.E. de Mink


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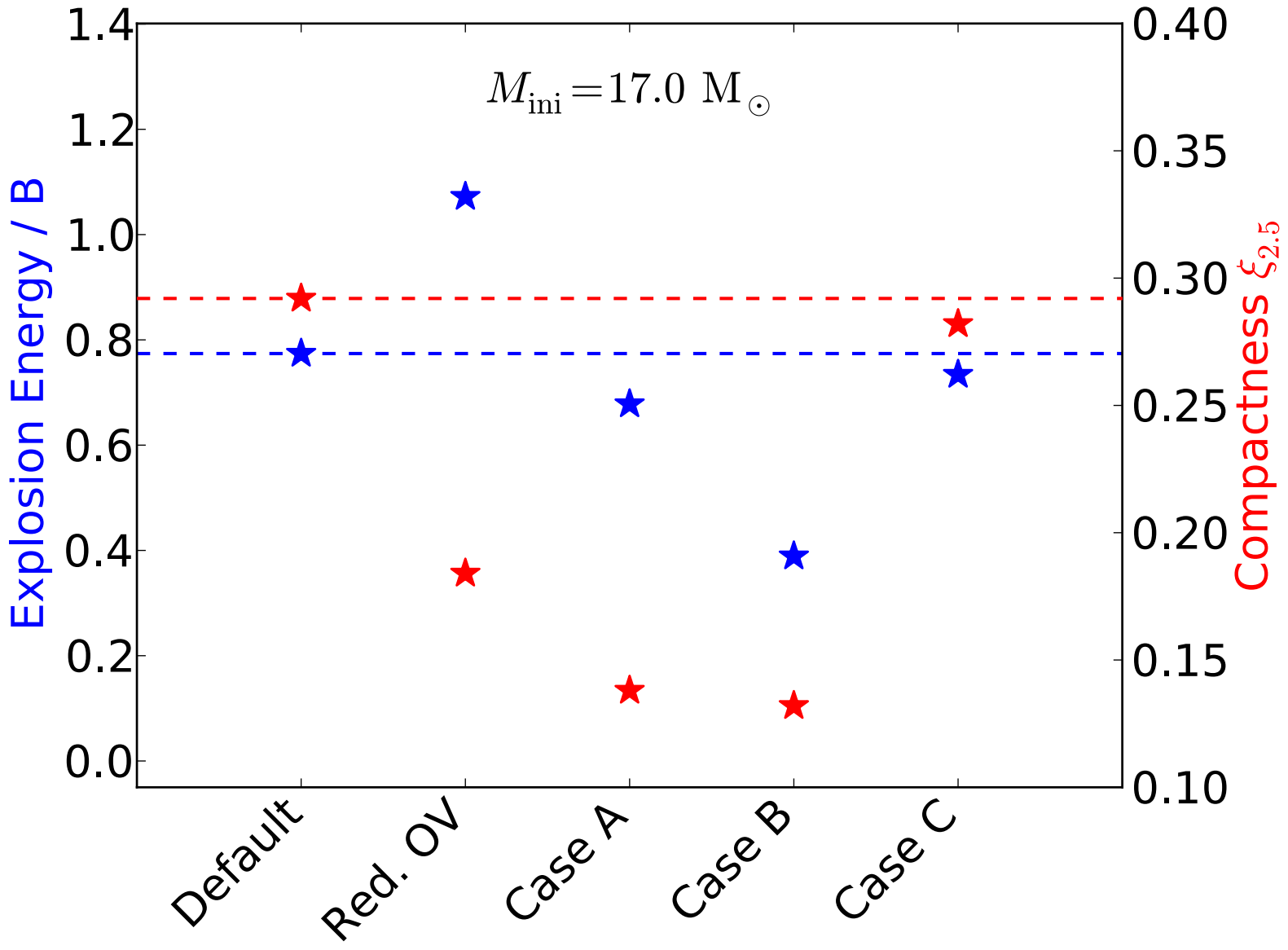
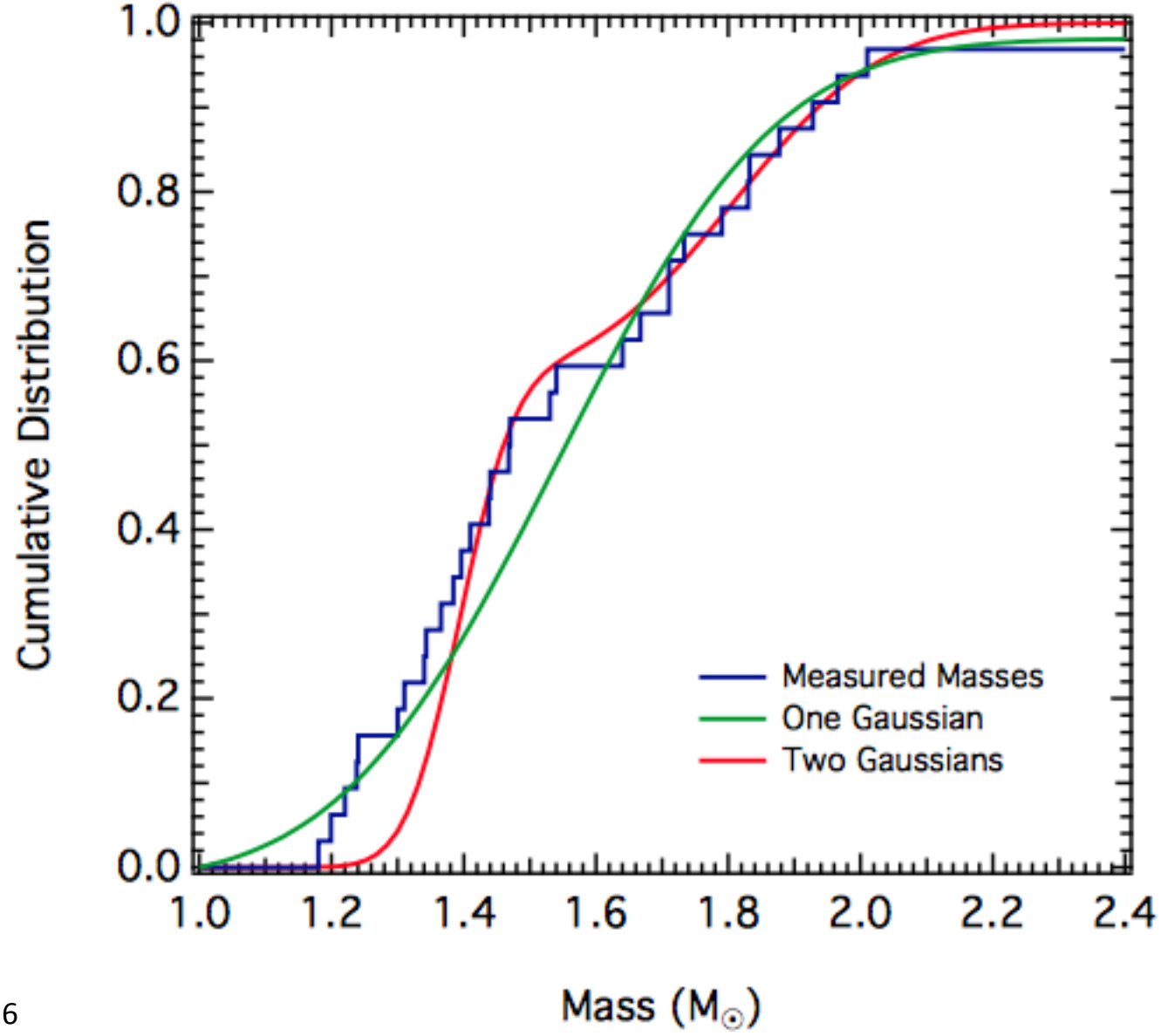
Thank you for your attention!

APPENDIX

Explosion energy



MSP masses cumulative



Antoniadis+2016