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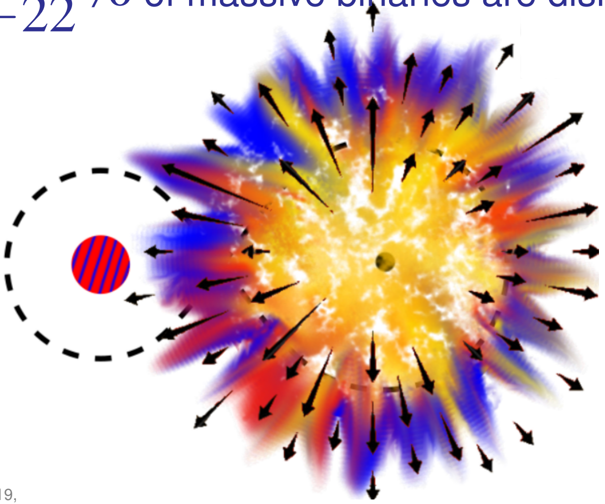
“Widowed” stars

Most massive binaries do not survive the 1st explosion

$86^{+11}_{-22}\%$ of massive binaries are disrupted



Renzo *et al.* 2019b, Kochanek *et al.* 2019, Eldridge *et al.* 2011, De Donder *et al.* 1997

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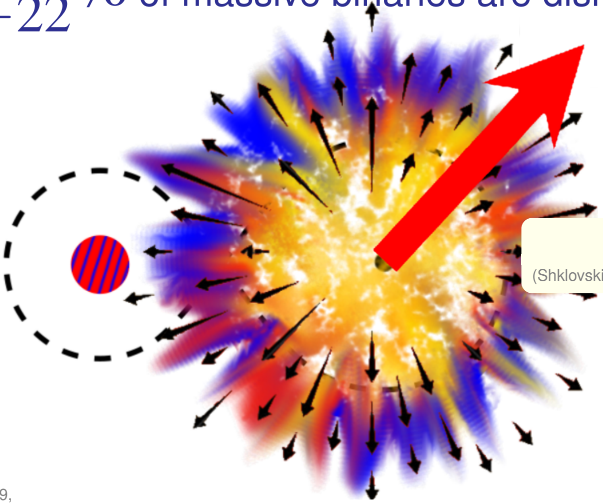

SN Natal kick

(Shklovskii 1970, Katz 1975, Janka 2013, 2017)

Renzo *et al.* 2019b, Kochanek *et al.* 2019, Eldridge *et al.* 2011, De Donder *et al.* 1997

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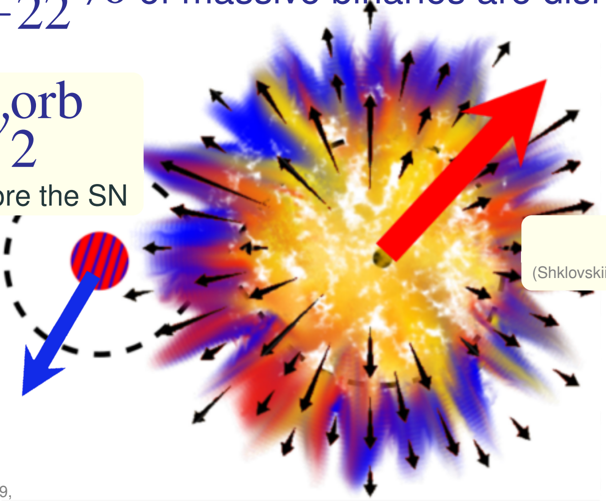
$86^{+11}_{-22}\%$ of massive binaries are disrupted

$$v_{\mathrm{dis}} \simeq v_2^{\mathrm{orb}}$$

before the SN



SN Natal kick

(Shklovskii 1970, Katz 1975, Janka 2013, 2017)

Renzo *et al.* 2019b, Kochanek *et al.* 2019, Eldridge *et al.* 2011, De Donder *et al.* 1997

Why understand widowed stars?

Stellar populations

accretors lurk in samples

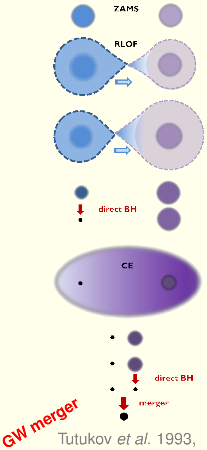
$(10 - 12\%)$ **Renzo *et al.* 2019b**

+

Oe/Be stars, stragglers

Pols *et al.* 1991, Wang *et al.* 2021

Binary interactions

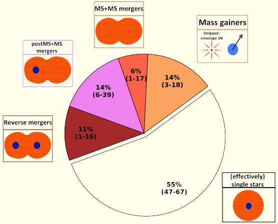


Tutukov *et al.* 1993,

Belczynski *et al.* 2016, **Renzo *et al.* 2023**

Transients

Common: H-rich SNe



Zapartas *et al.* (incl. Renzo) 2019

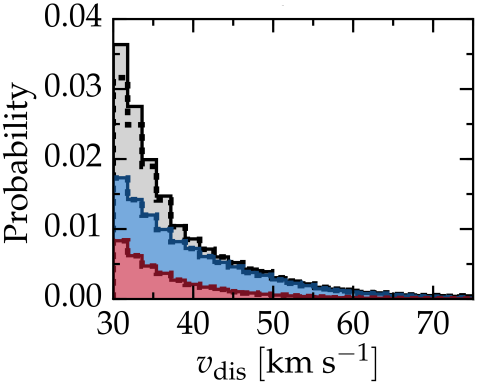
+

Uncommon: H-rich/H-poor SNe

L-GRB, LBV, SNIIn **?**

Petrovich *et al.* 2005, Cantiello *et al.* 2007

Accretor stars can be *runaways*...

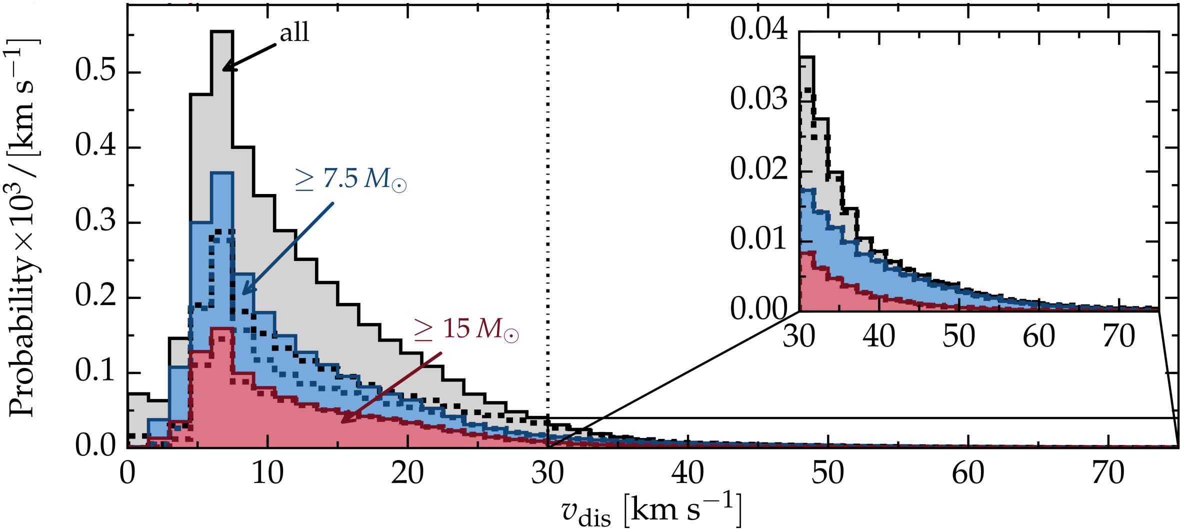


Velocity w.r.t. pre-explosion binary center of mass

Renzo *et al.* 2019b

Numerical results: http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/624/A66

...but most are only *walkaways*



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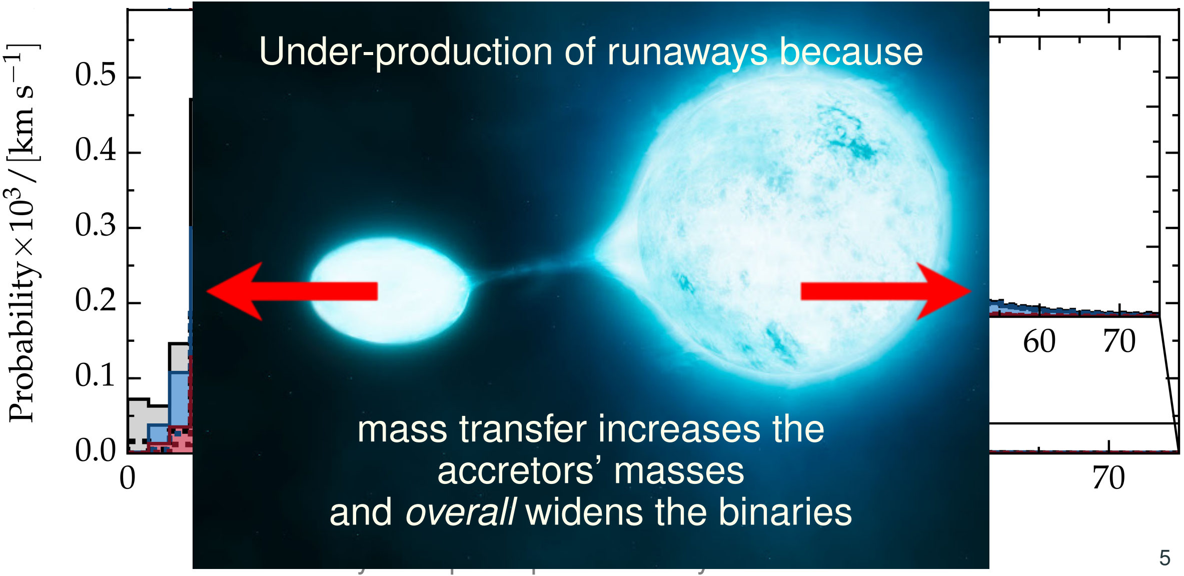


Renzo *et al.* 2019b

Numerical results: http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/624/A66

Mass transfer occurs before the 1^{st} explosion

- **Spin-up**

  Packet 1981, Cantiello *et al.* 2007, de Mink *et al.* 2013, **Renzo & Götberg 2021**

- **Pollution**

  Blaauw 1993, **Renzo & Götberg 2021**

- **Rejuvenation**

  Hellings 1983, 1985, **Renzo *et al.* 2023**

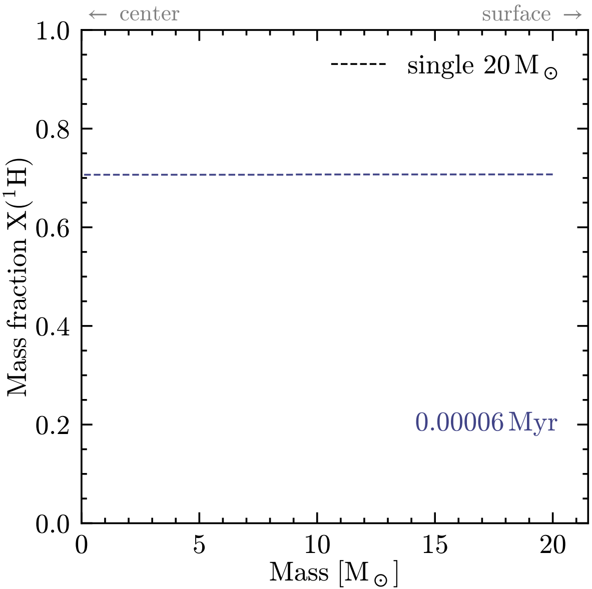
The "widowed" star carries signatures of its past in a binary

Renzo & Zapartas 2020

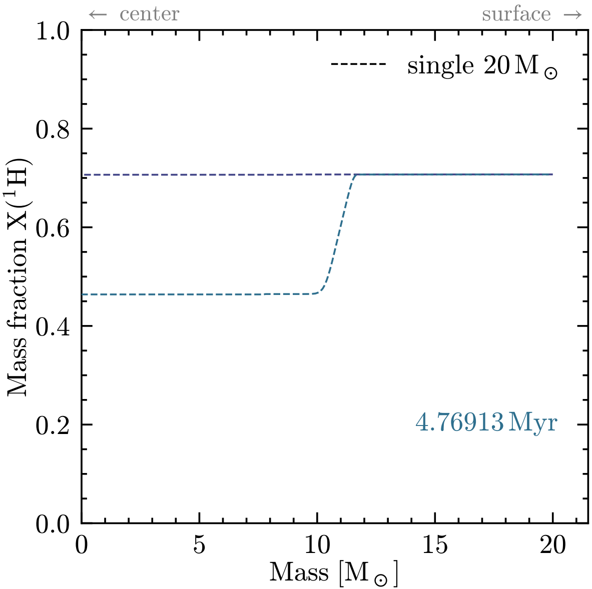
Rejuvenation:

core-envelope boundary

Refresher: formation of the helium core in single stars



Refresher: formation of the helium core in single stars



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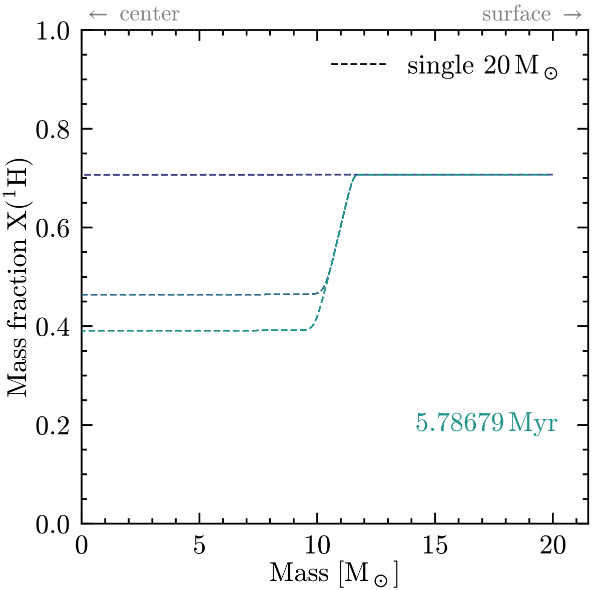

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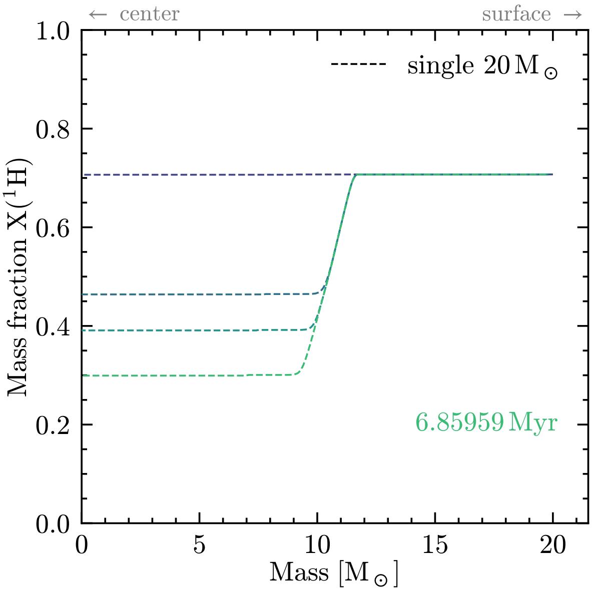

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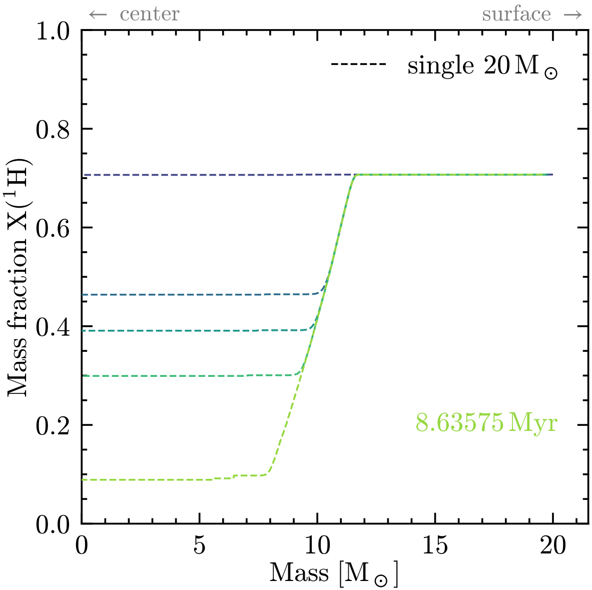

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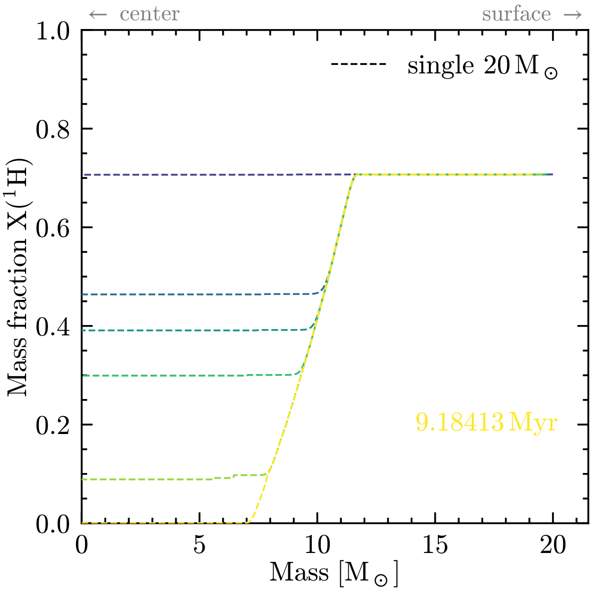
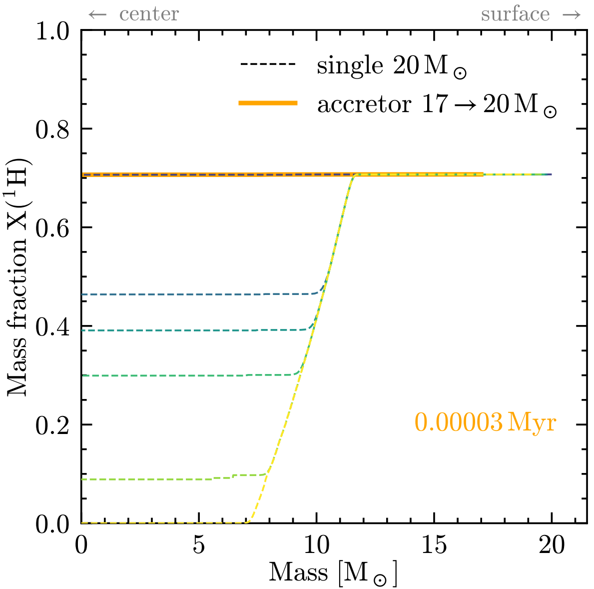


Evolution of the accretor's core through RLOF



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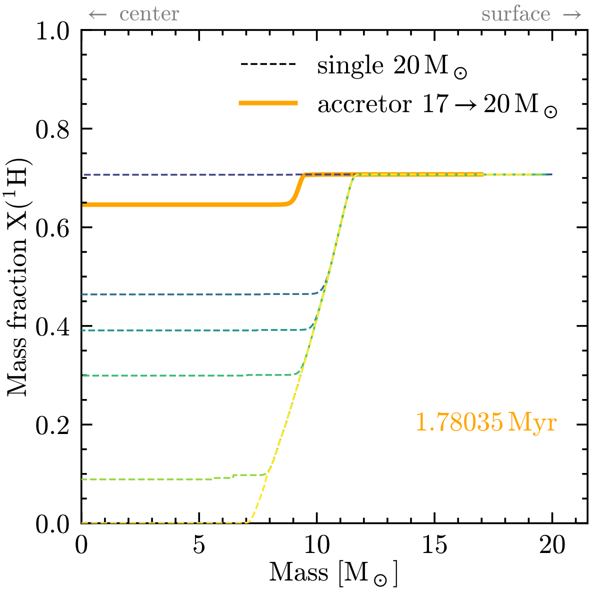

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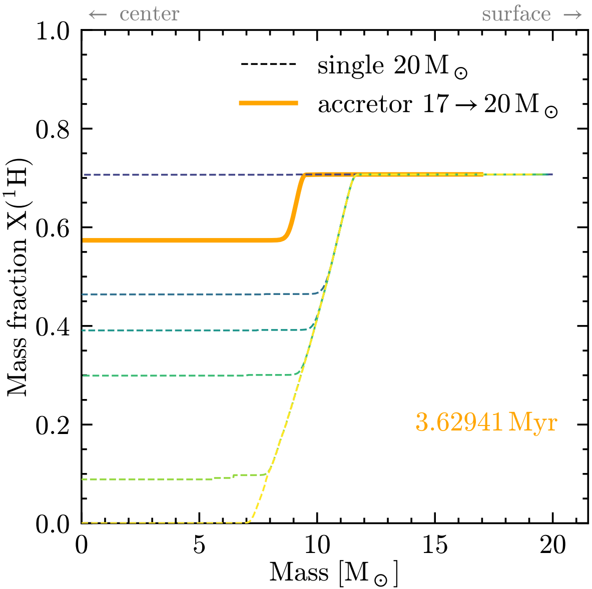

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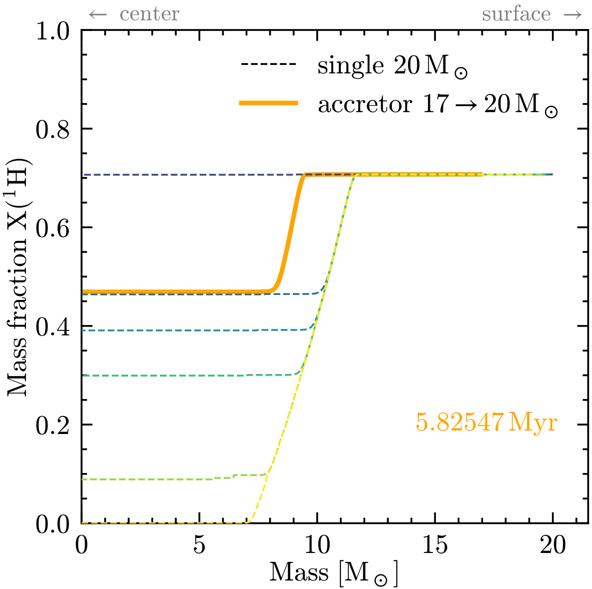

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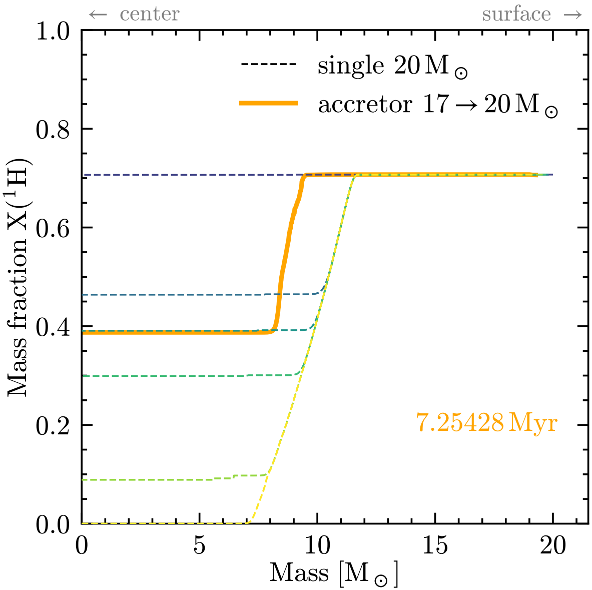

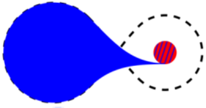

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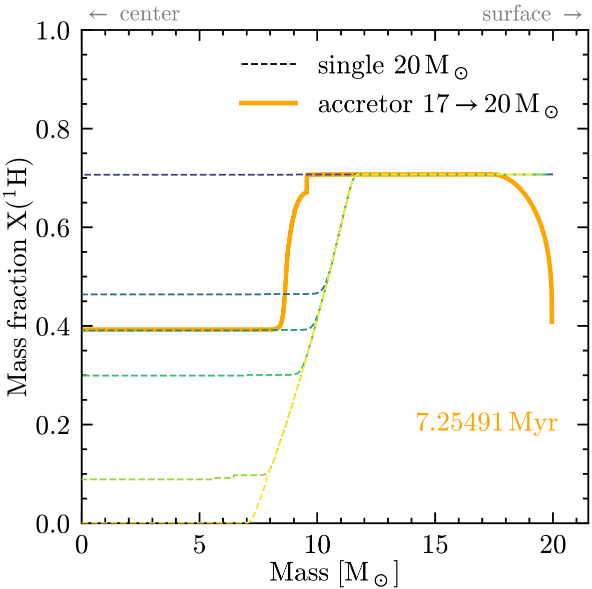

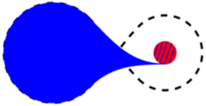

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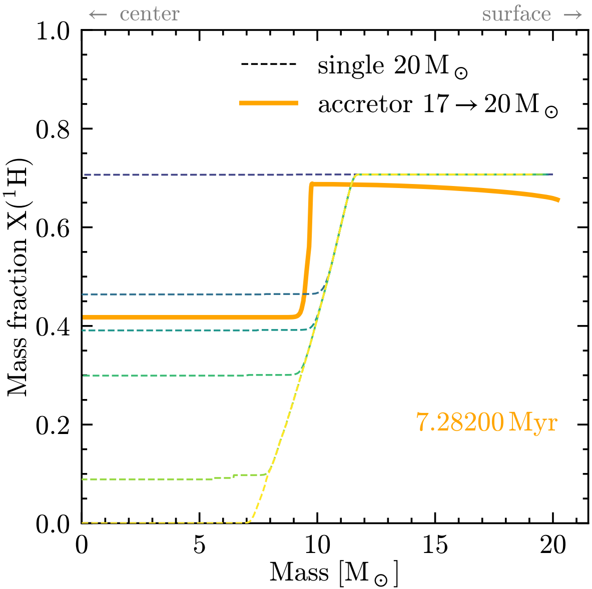

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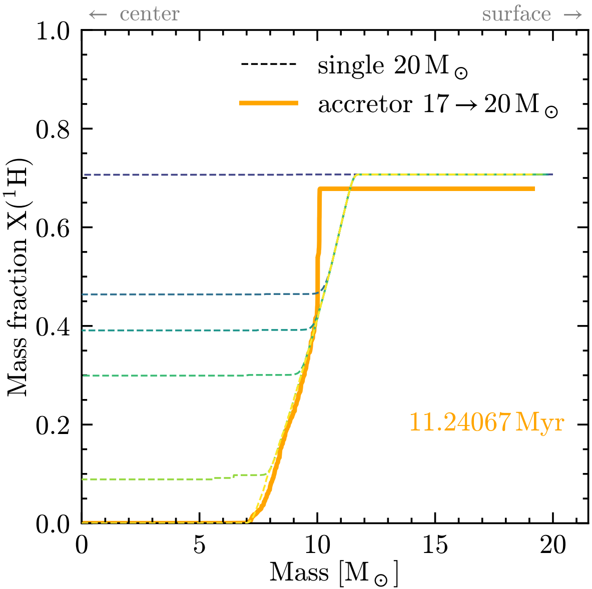
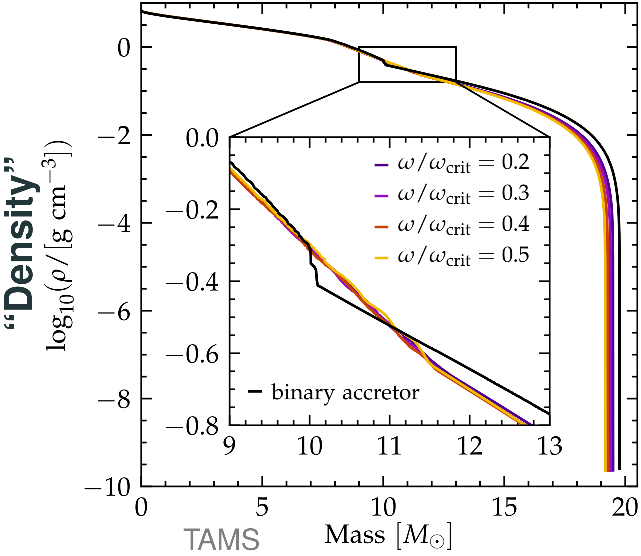
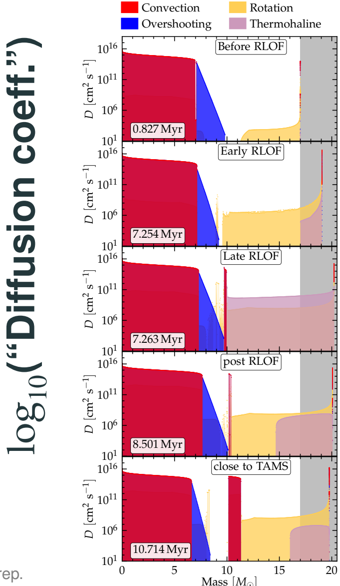


Rejuvenation changes the core/envelope boundary





Renzo & Götberg 2021, Gade Pedersen, Renzo, *et al.* in prep.

Consequences of rejuvenation

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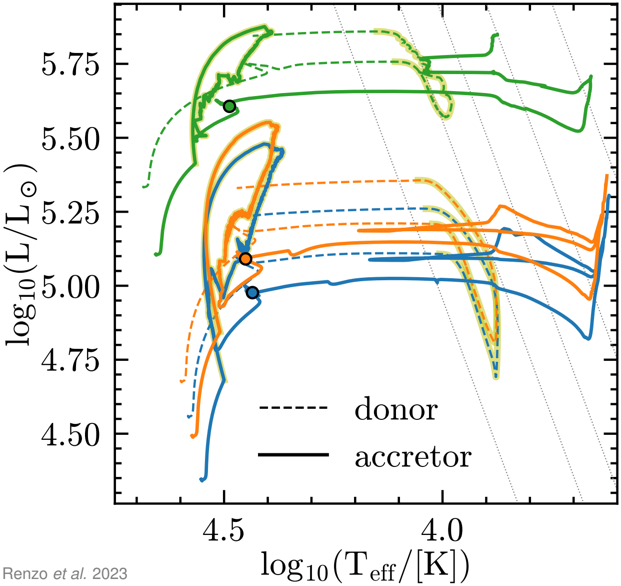
Blue loops in high-mass stars?

Low-Z massive accretors



$Z = 0.0019 \simeq Z_\odot / 10$

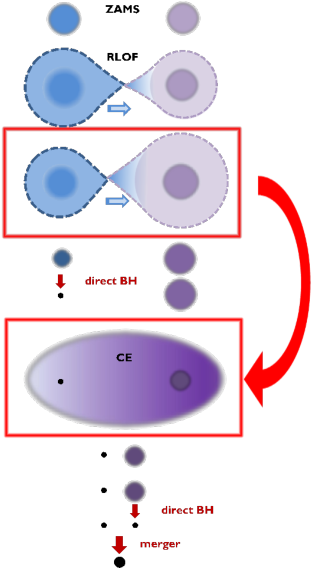
(to focus on GW merger progenitors)

Renzo *et al.* 2023

Consequences of rejuvenation

Easier to unbind the envelope

The common envelope in GW progenitors is initiated by the accretor



Belczynski *et al.* 16

Does RLOF rejuvenation impact how easy it is to remove the envelope ?

Renzo *et al.* 2023

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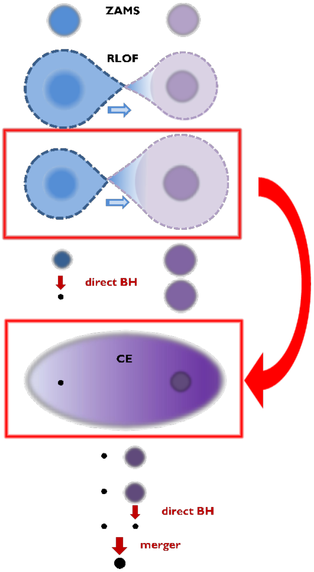


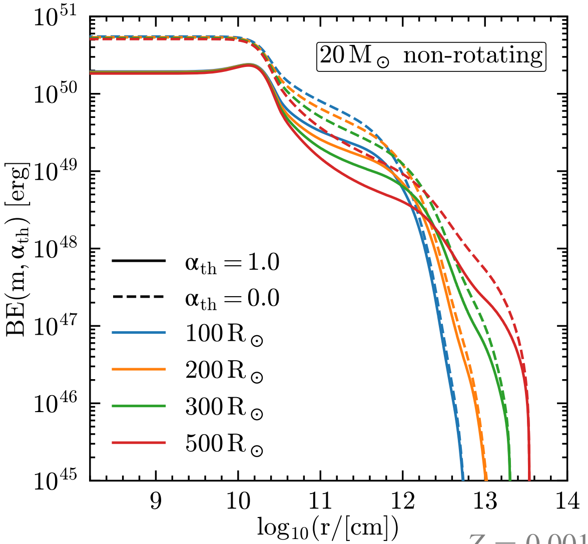
Belczynski *et al.* 16

Does RLOF rejuvenation impact how easy it is to remove the envelope ?

Renzo *et al.* 2023

1. Binary evolution until detachment
2. Continue evolution of accretors as single stars
3. Compare binding energy of accretors and single stars of same total mass at given R

The binding energy is the cost to “dig” into the star



$$BE(m,\alpha_{th}) = -\int_m^M dm' \left(-\frac{Gm'}{r(m')} + \alpha_{th} u(m')\right)$$

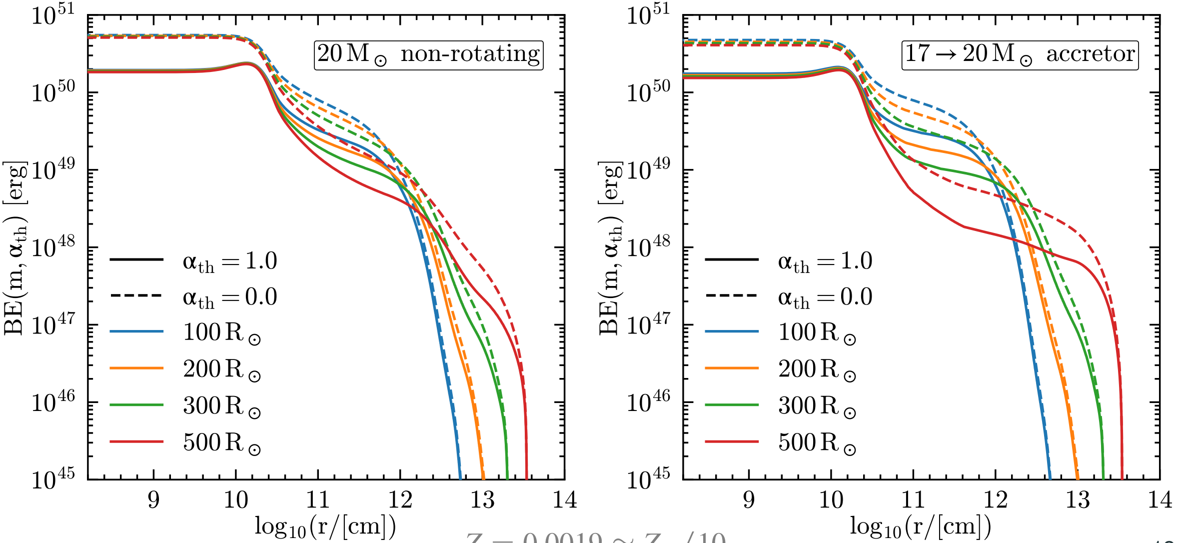
- Gravitational potential energy
- Internal energy
- α_{th} free parameter

fraction of internal energy usable to eject envelope

$Z = 0.0019 \simeq Z_{\odot}/10$

Renzo *et al.* 2023

Comparing $20\,M_\odot$ non-rotating single star vs. accretor



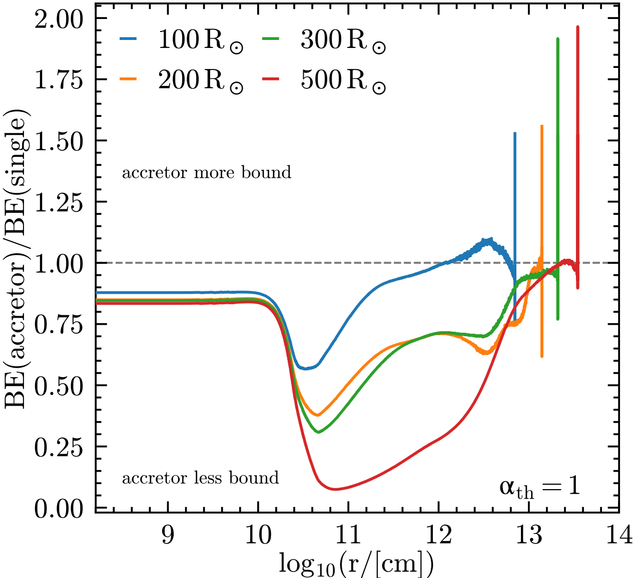
$Z = 0.0019 \simeq Z_\odot/10$

Renzo *et al.* 2023

Taking the ratio: accretors are easier to unbind

NS progenitor

$15 \rightarrow 17\, M_\odot$

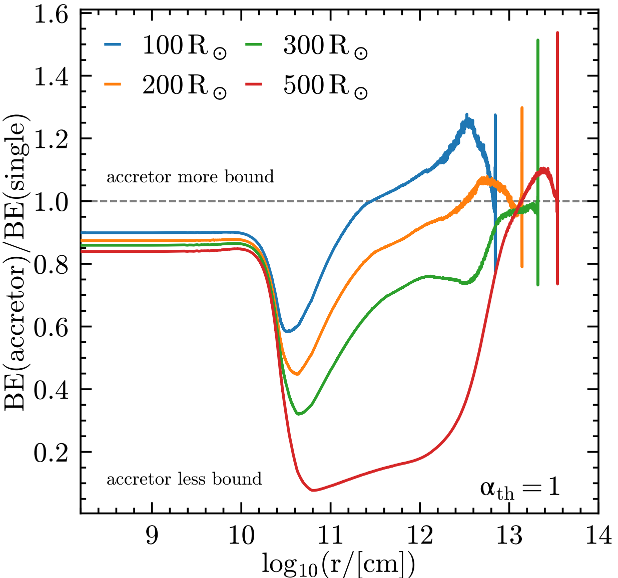


Renzo *et al.* 2023

Taking the ratio: accretors are easier to unbind

NS or BH progenitor

$17 \rightarrow 20\,M_\odot$

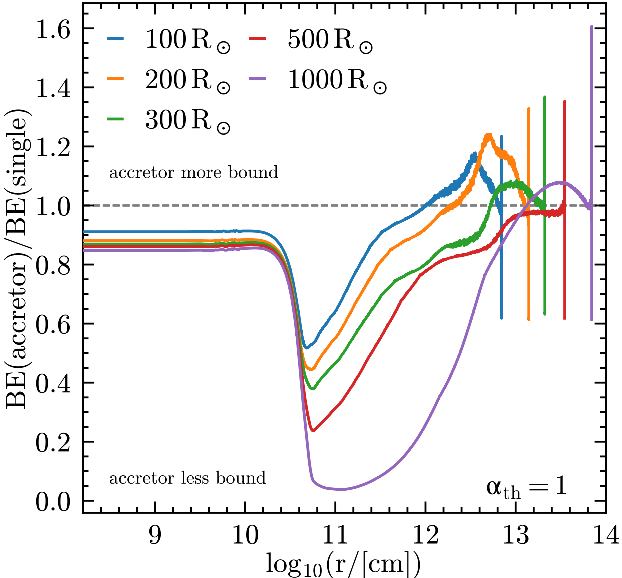


Renzo *et al.* 2023

Taking the ratio: accretors are easier to unbind

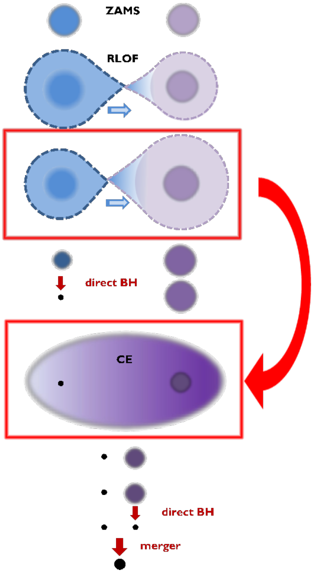
BH progenitor

$30 \rightarrow 36\,M_\odot$



Renzo *et al.* 2023

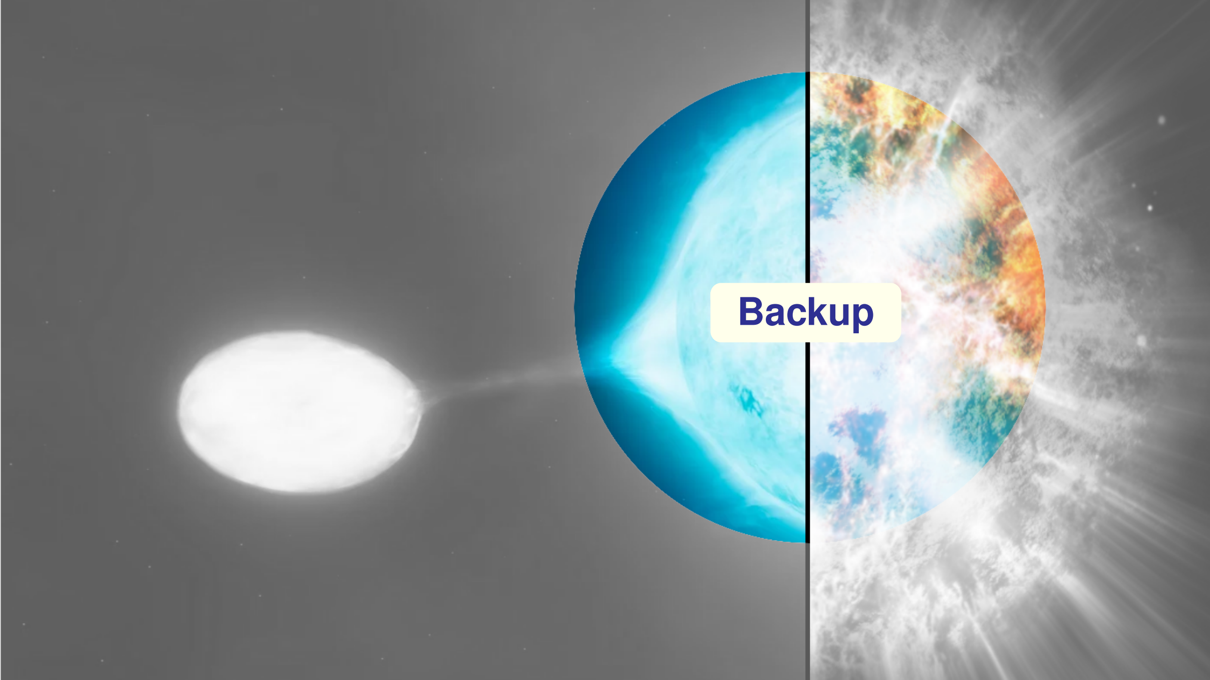
If the common-envelope donor is a former accretor



Belczynski *et al.* 16

Implications for common-envelope

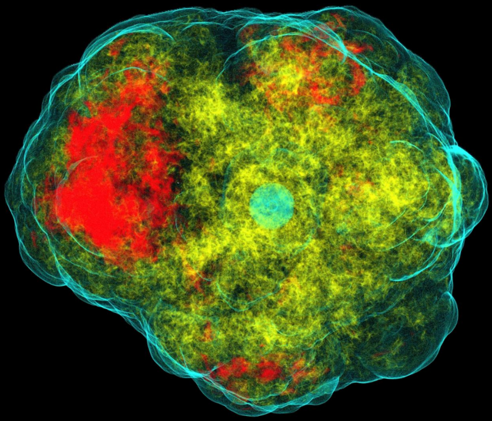
- Fewer “reverse” stellar merger
- Wider post-CE separation
- Mass-dependent (?) impact on GW merger rates


Backup

SN natal kick

Observationally: $v_{\rm pulsar} \gg v_{\rm OB-stars}$

Physically: ν emission and/or ejecta anisotropies



Credits: C. D. Ott, S. Drasco

SN natal kick

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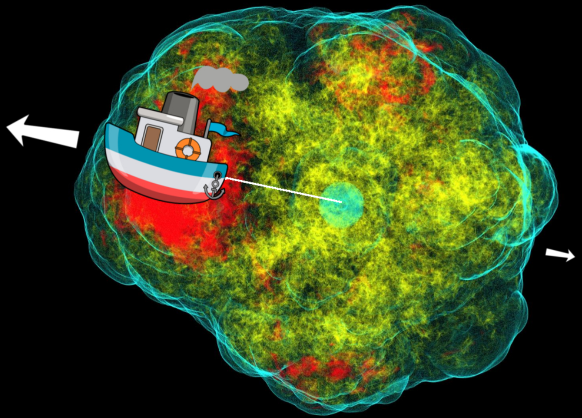

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