Pulsational Pair Instability

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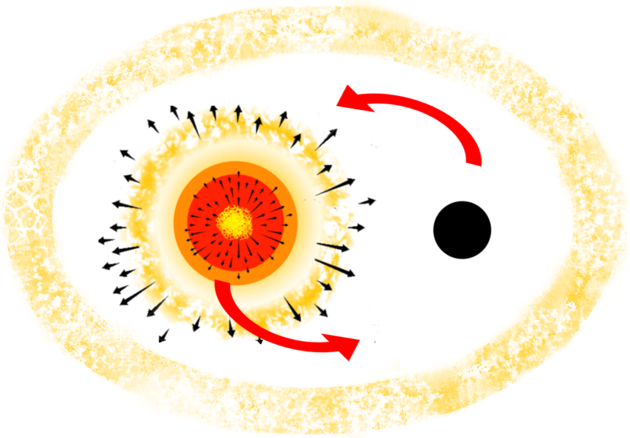
effects on CSM and binary orbits



Mathieu Renzo

Collaborators: R. Farmer, P. Marchant, S. E. de Mink, Y. Götberg, E. Zapartas, E. Laplace, S. Justham

BinCosmos

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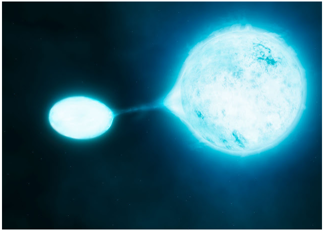
Mass loss influences the life and fate of massive stars

Stellar Winds

Mauron & Josselin 11, Meynet *et al.* 14,

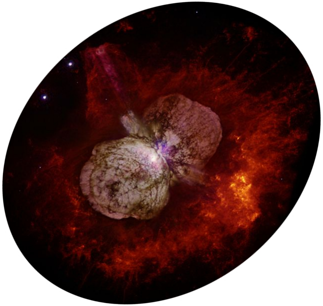
Smith 14, Renzo *et al.* 17



Binary Interactions

Kippenhahn & Weigert 67,

Podsiadlowski *et al.* 92, Götberg *et al.* 17, 18



Dynamical Instabilities

Smith 14, Rakavy & Shaviv 67,

Woosley 17, Fuller 17,

Marchant, Renzo *et al.* arXiv:1810.13412

Very roughly speaking

For each *massive* *non-merging* binary ⇒ One SNII and one stripped SN (IIb/Ib/Ic)

Eldridge *et al.* 11, 18, Zapartas *et al.* (incl. Renzo, M.) 17b, Zapartas *et al.* (incl. Renzo, M.) 18a, 18b *to be subm.*

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Conclusions

Radiation dominated:

$$P_{\mathrm{tot}} \simeq P_{\mathrm{rad}}$$

$$M_{\mathrm{He}} \gtrsim 32\, M_{\odot}$$

Woosley 2017,

Marchant, Renzo *et al.* arXiv:1810.13412,

Renzo, Farmer *et al.*, to be submitted

see also:

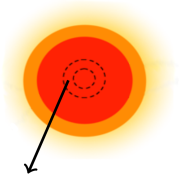
Barkat *et al.* 67,

Rakavy & Shaviv 67

Fraley 68

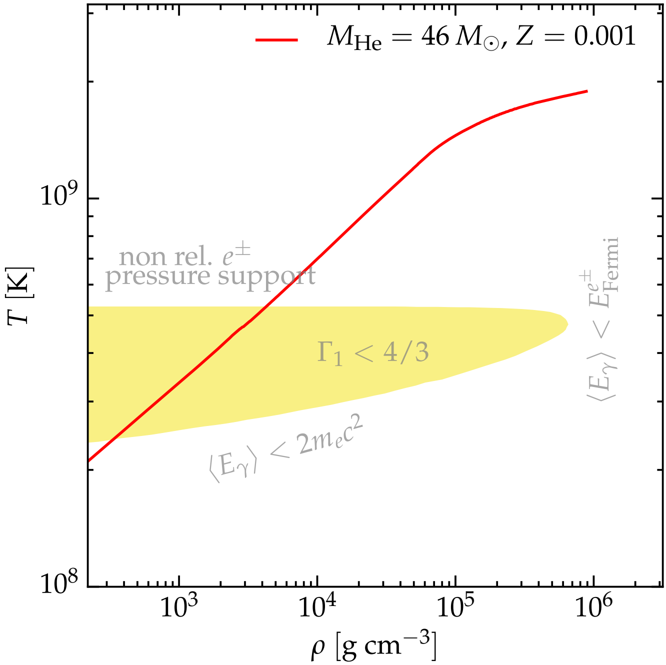
Woosley *et al.* 07

...



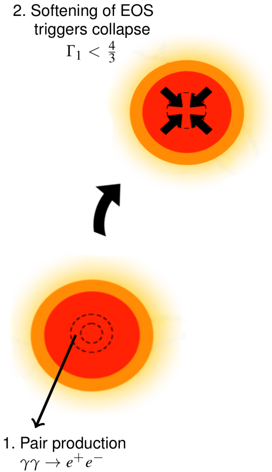
1. Pair production
$\gamma\gamma \rightarrow e^{+}e^{-}$

$$\Gamma_1 \stackrel{\mathrm{def}}{=} \left(\frac{\partial \ln P}{\partial \ln \rho}\right)_s$$



He core computed with MESA

Renzo, Farmer, *et al.*, to be submitted

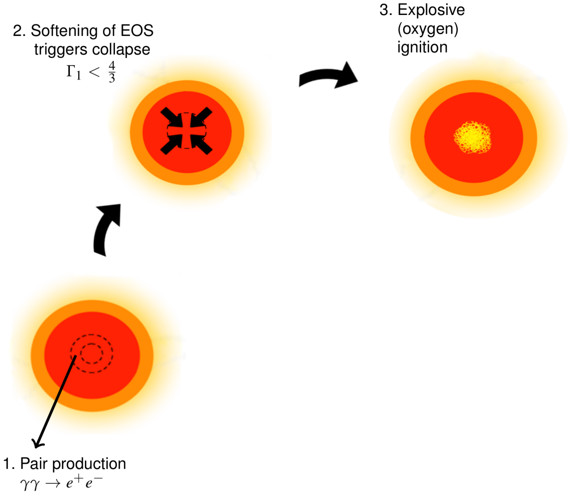


Thermal timescale

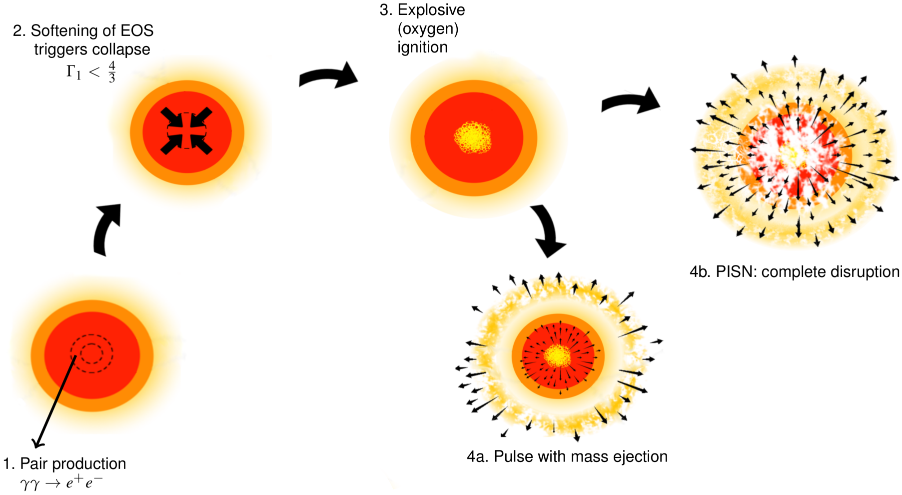
$$\tau \propto \frac{GM_{\mathrm{He}}^2}{RL_\nu} \quad , \quad L_\nu \gg L$$

(Fraley 68)

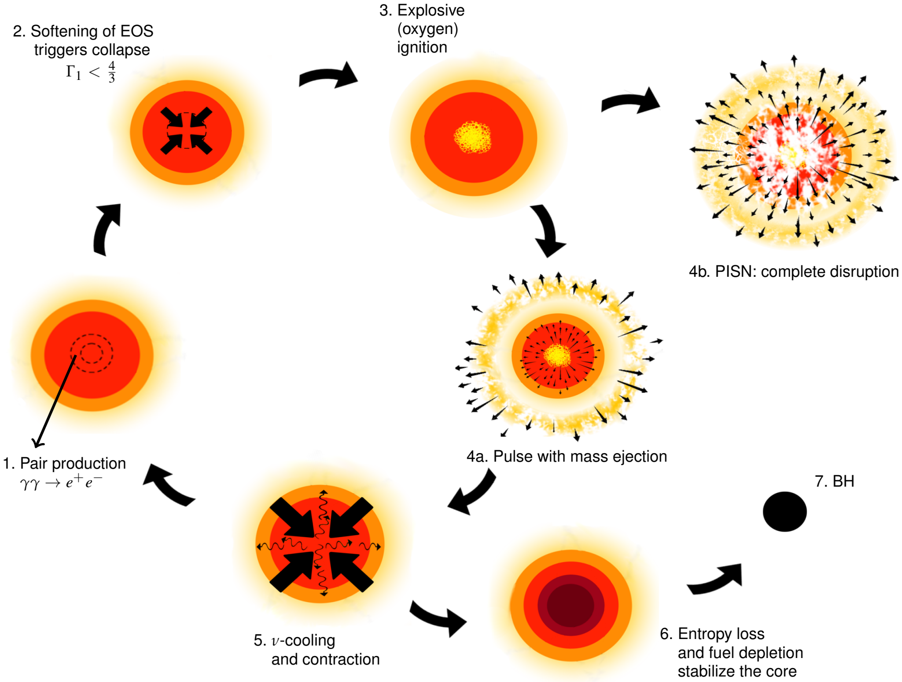
Renzo, Farmer, *et al.*, to be submitted



Renzo, Farmer, *et al.*, to be submitted

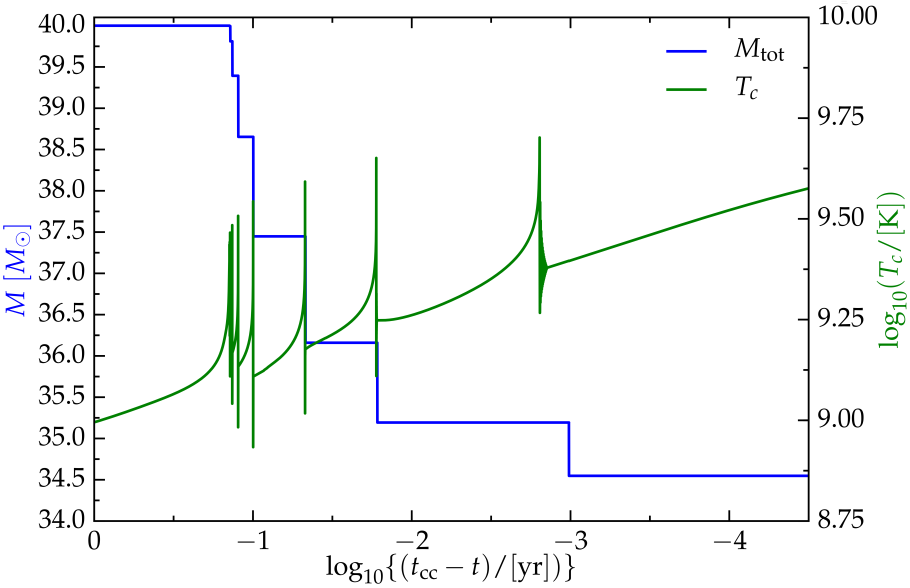


Renzo, Farmer, *et al.*, to be submitted



Renzo, Farmer, *et al.*, to be submitted

Example: 40 $M_\odot$ He core



Log Time to core-collapse

Example: 40 $M_\odot$ He core

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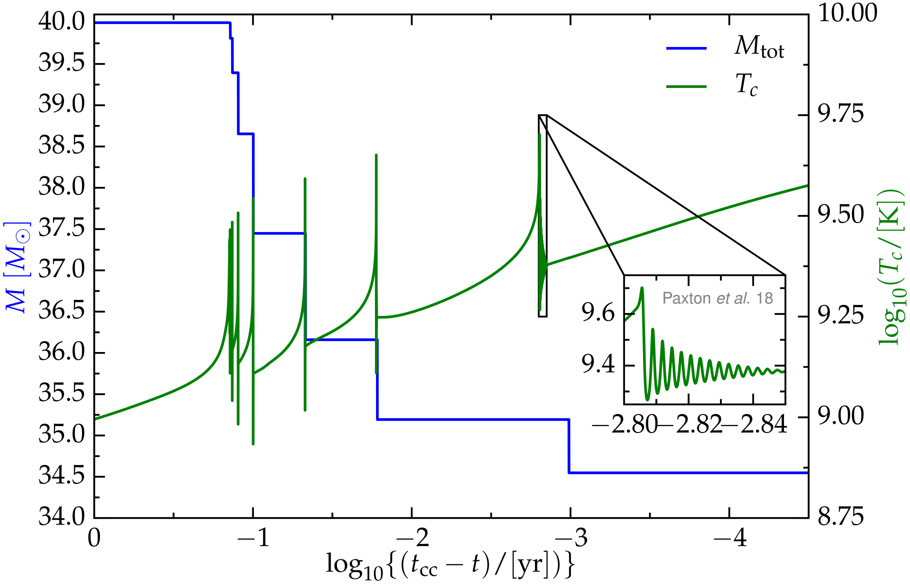

Log Time to core-collapse

Renzo, Farmer *et al.*, to be submitted

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Conclusions

How many pulses?

- as a function of He core mass

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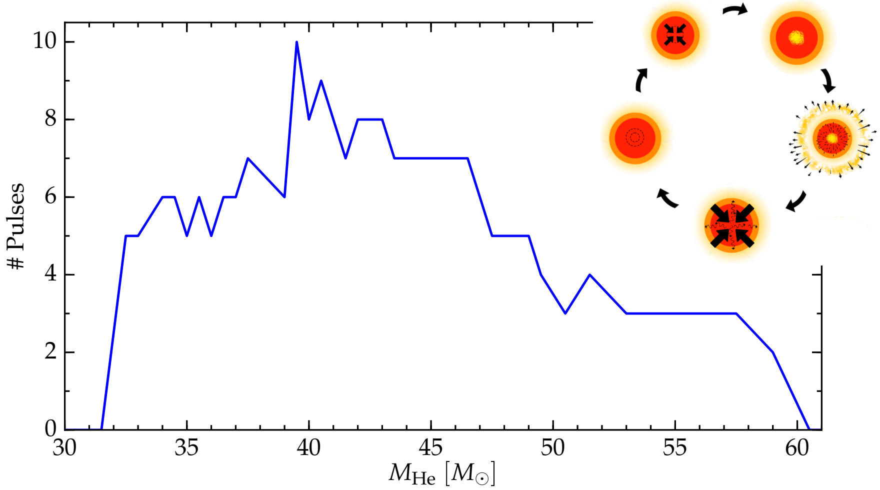
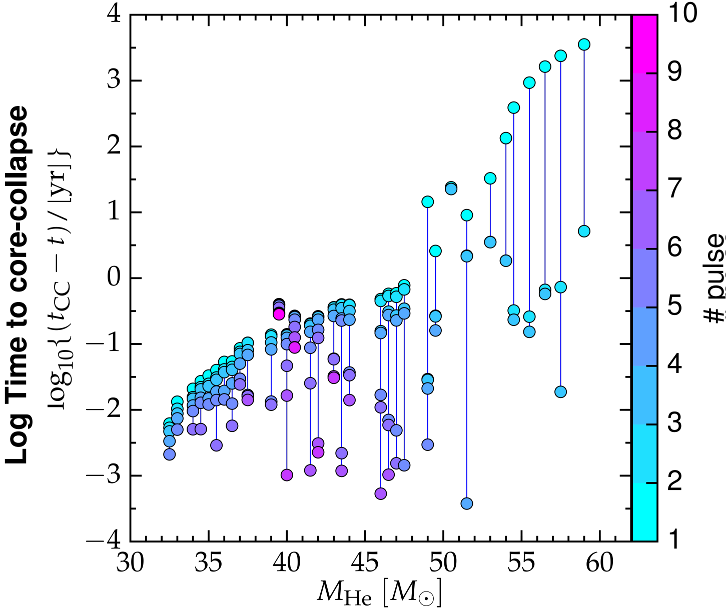


One pulse = One mass ejection

When do they pulsate?

- as a function of He core mass

Pulses timing



Renzo, Farmer *et al.*, to be submitted

Pulses timing

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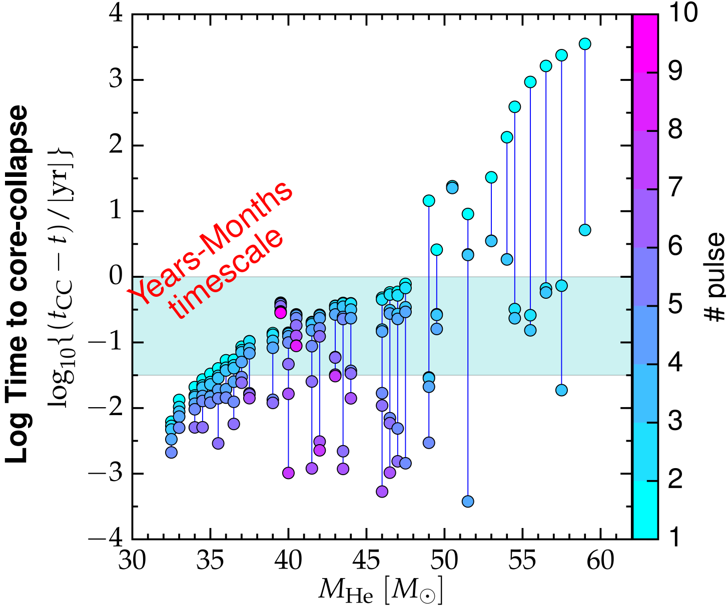

How much mass is ejected per pulse?
How much mass is ejected in total?

- as a function of He core mass

Mass lost per pulse

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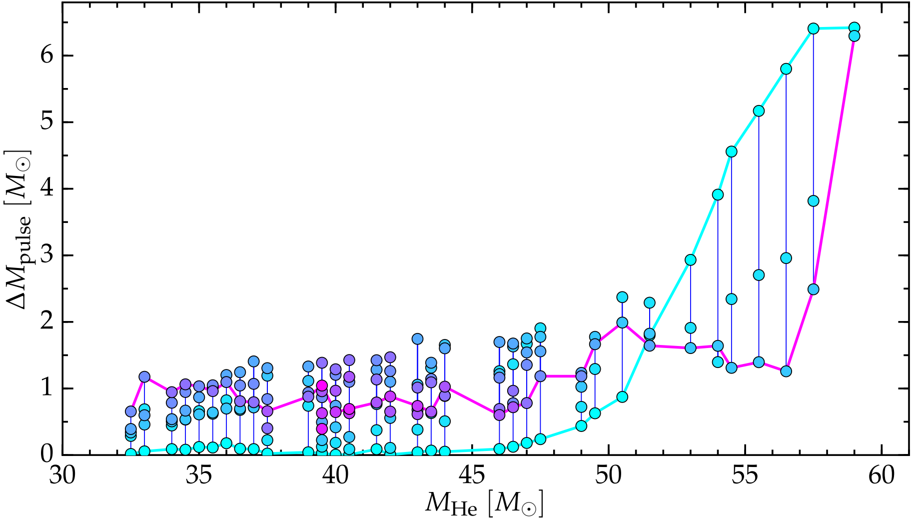

Renzo, Farmer *et al.*, to be submitted

Total mass lost

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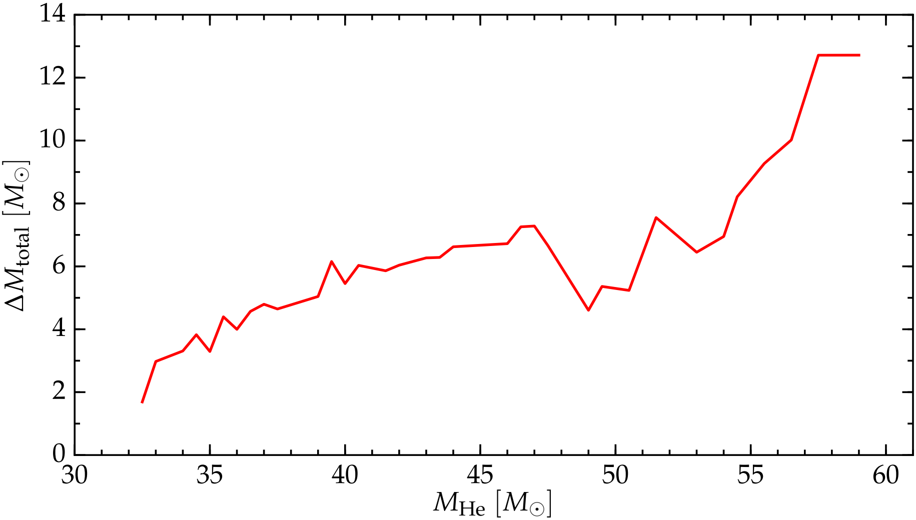
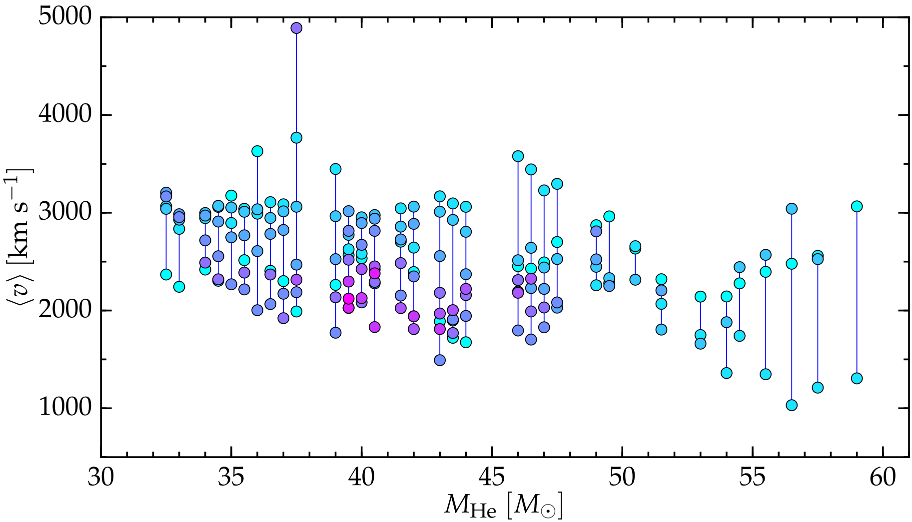


How fast are the ejected shells?

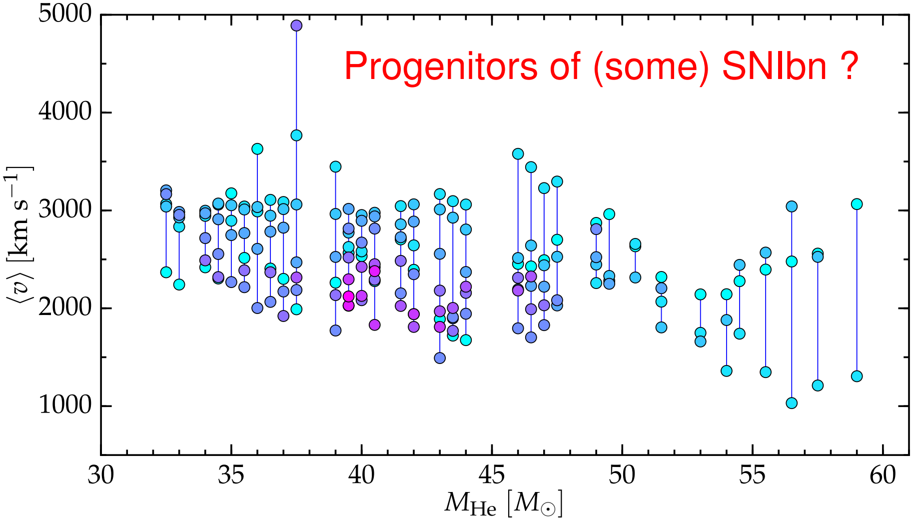
- as a function of He core mass

Center of mass velocity



Renzo, Farmer *et al.*, to be submitted

Center of mass velocity



Renzo, Farmer *et al.*, to be submitted

Can the mass shell collide?

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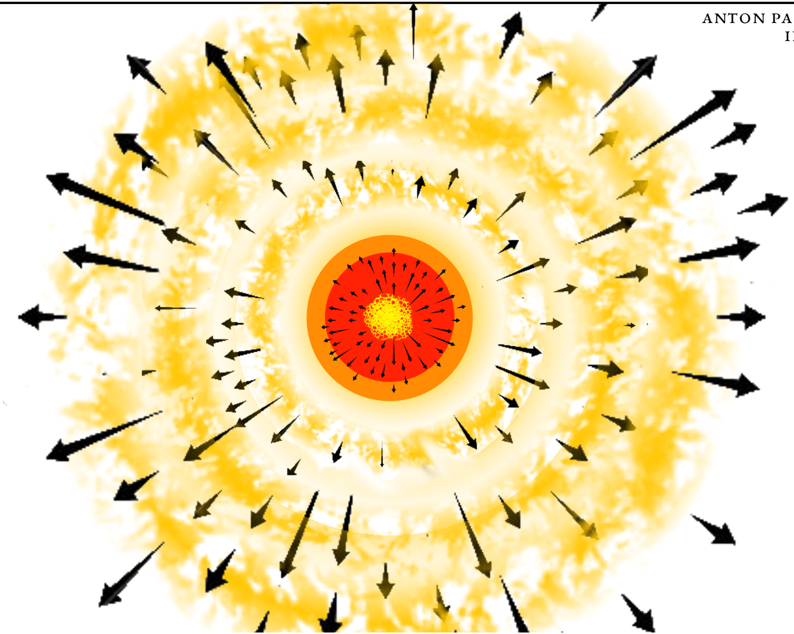

Woosley *et al* 07, Chen *et al.* 14, Woosley 17, Renzo, Farmer *et al.*, to be submitted

Can the mass shells collide?

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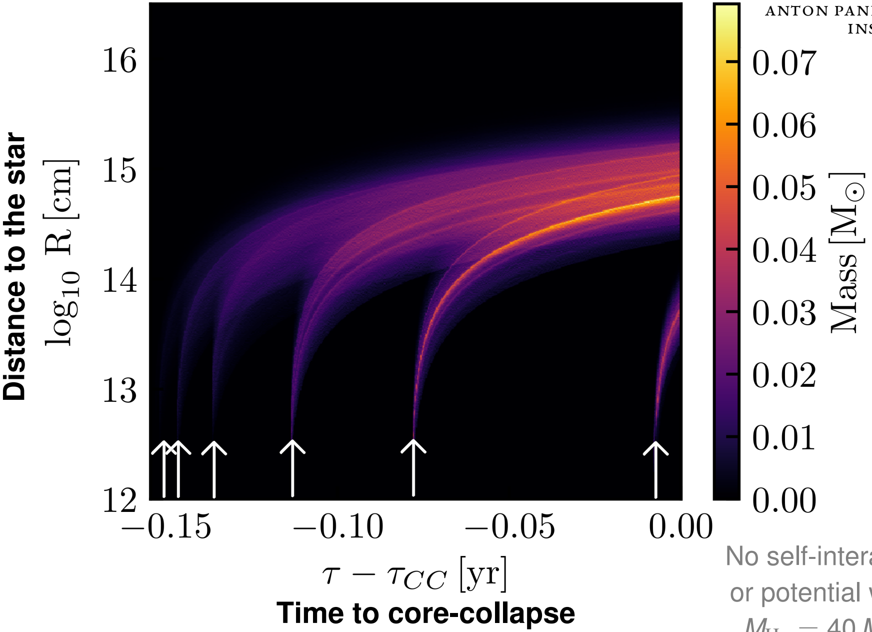

No self-interaction or potential well

$M_{\mathrm{He}} = 40\,M_\odot$

Renzo, Farmer *et al.*, to be submitted

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Conclusions

The origin of very massive BHs

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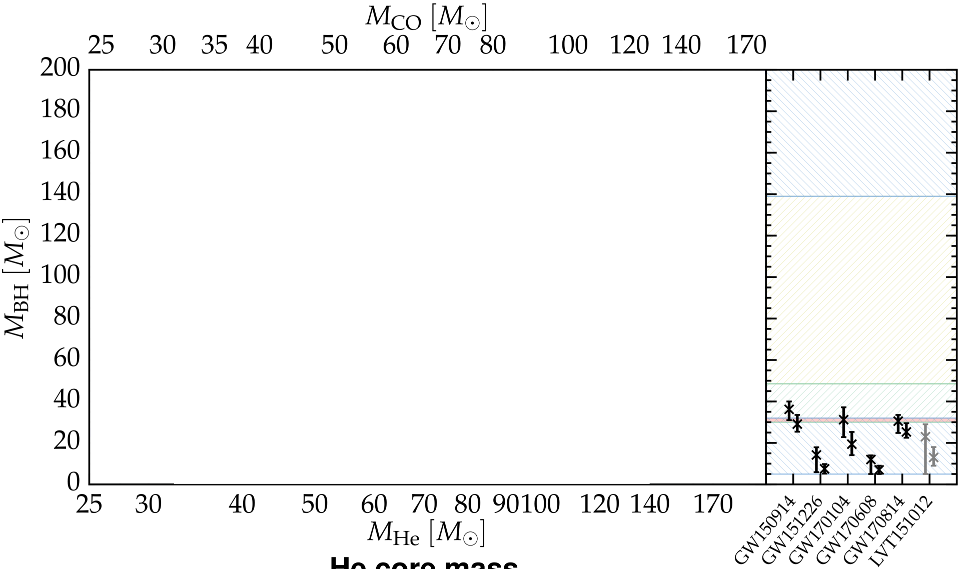
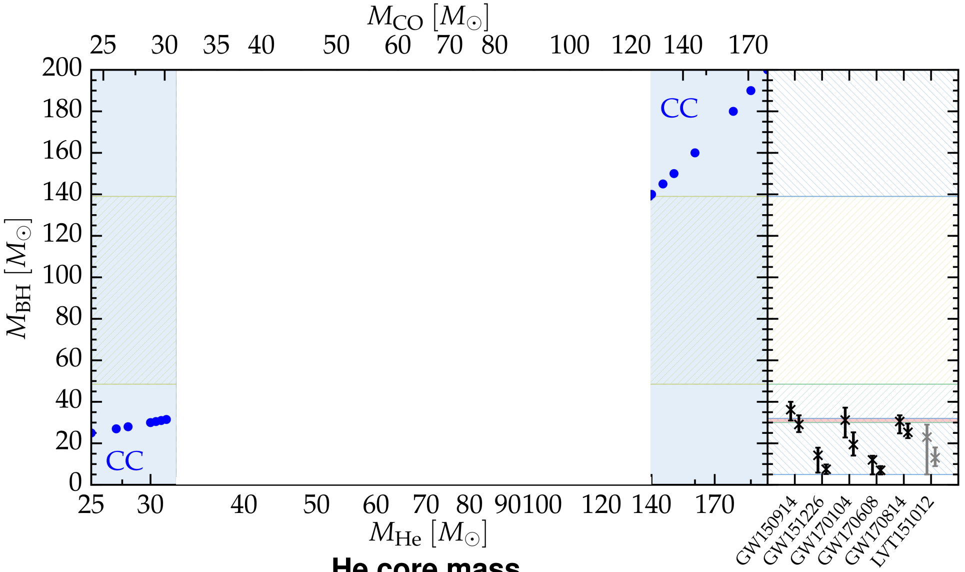


He core mass

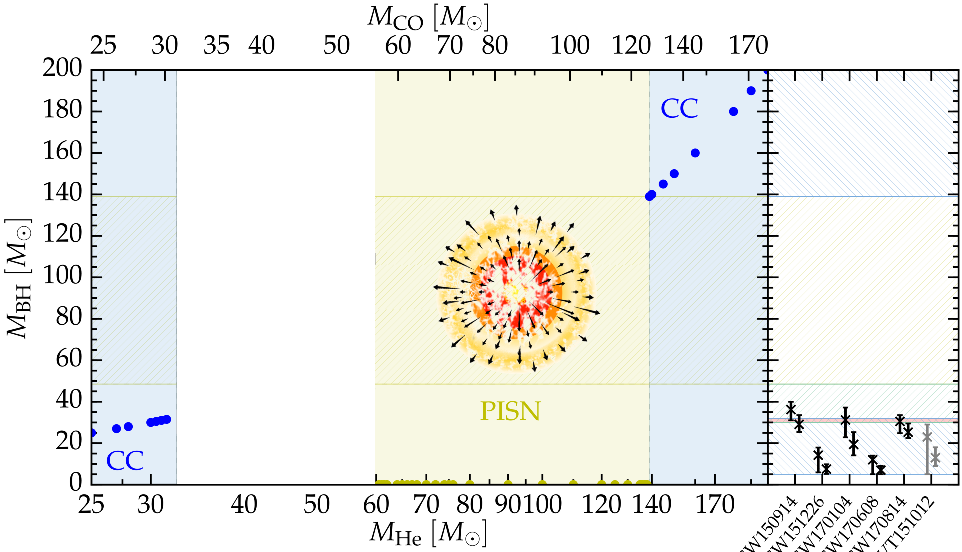
The origin of very massive BHs



He core mass

Renzo, Farmer *et al.*, to be submitted

The origin of very massive BHs



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The origin of very massive BHs

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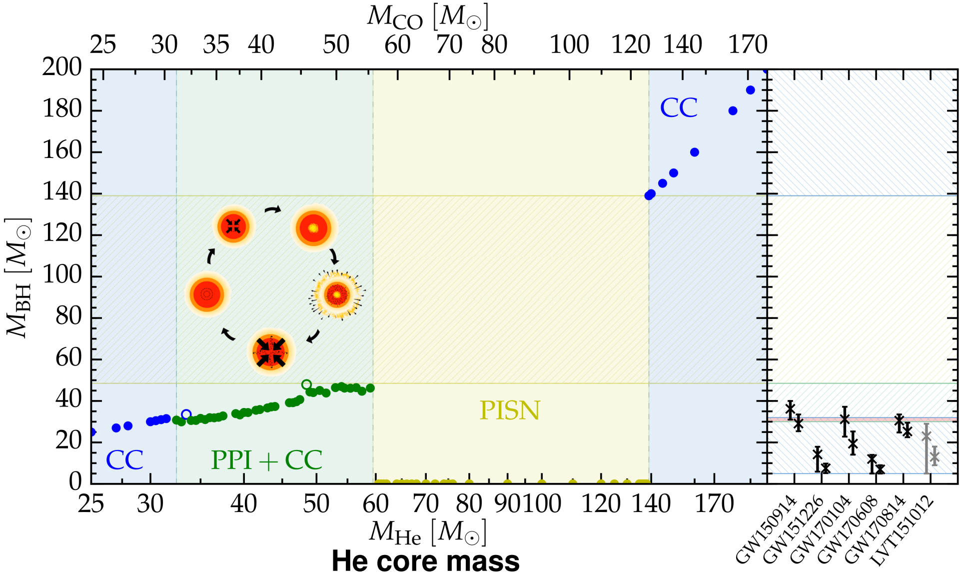
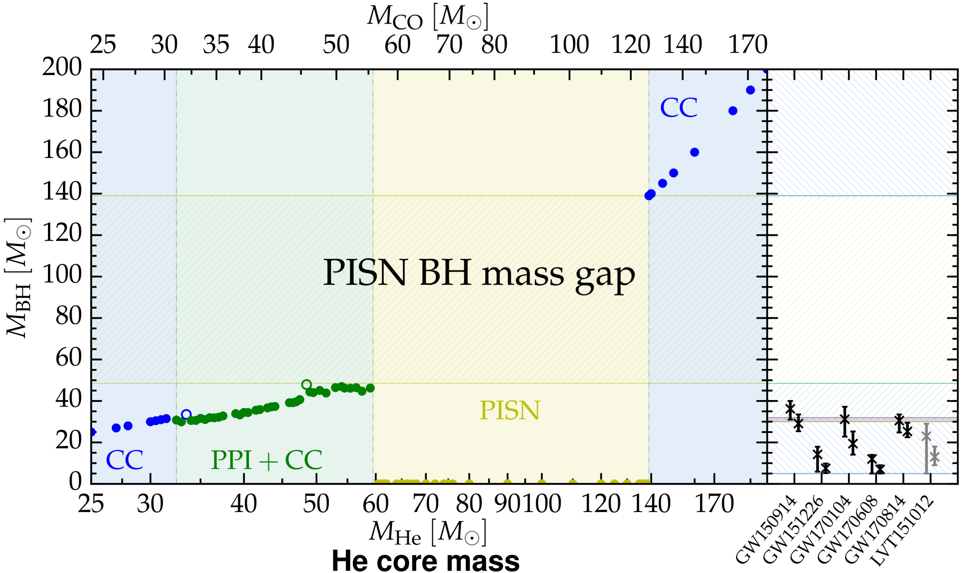


He core mass

Renzo, Farmer *et al.*, to be submitted

The origin of very massive BHs



He core mass

Renzo, Farmer *et al.*, to be submitted

BH mass function

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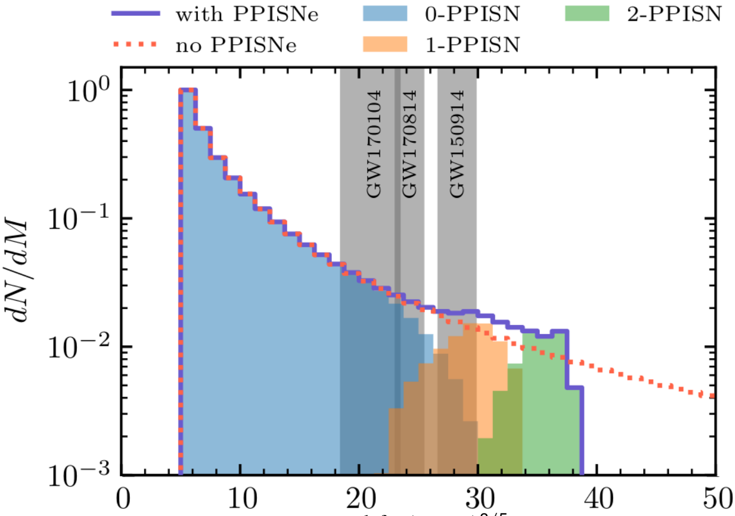

$M_{\mathrm{chirp}} \stackrel{\mathrm{def}}{=} \frac{(M_1 M_2)^{3/5}}{(M_1+M_2)^{1/5}}\ [M_\odot]$

Chirp Mass

$$\frac{dN}{dM_{\mathrm{BH}}} \propto M_{\mathrm{BH}}^{-2.35}$$

$$q \geq 0.5$$

(motivated by LVC 2016)

Marchant, Renzo, *et al.*, submitted, arXiv:1810.13412

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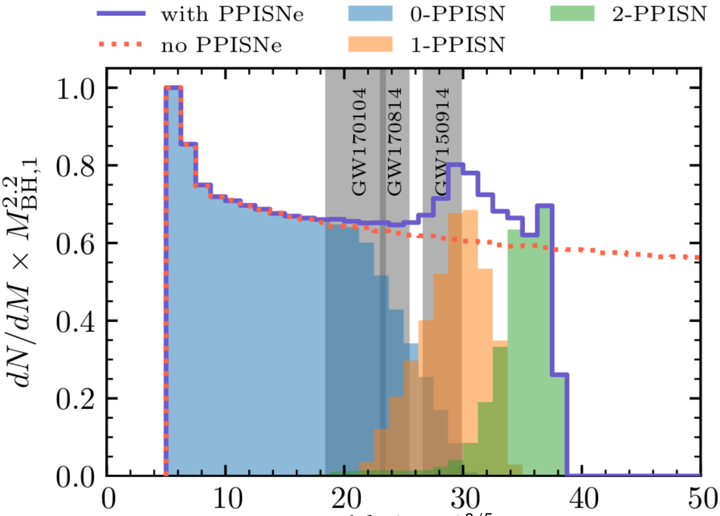
(Fishbach & Holtz 2017)



$$M_{\mathrm{chirp}} \stackrel{\mathrm{def}}{=} \frac{(M_1 M_2)^{3/5}}{(M_1+M_2)^{1/5}} \ [M_\odot]$$

Chirp Mass

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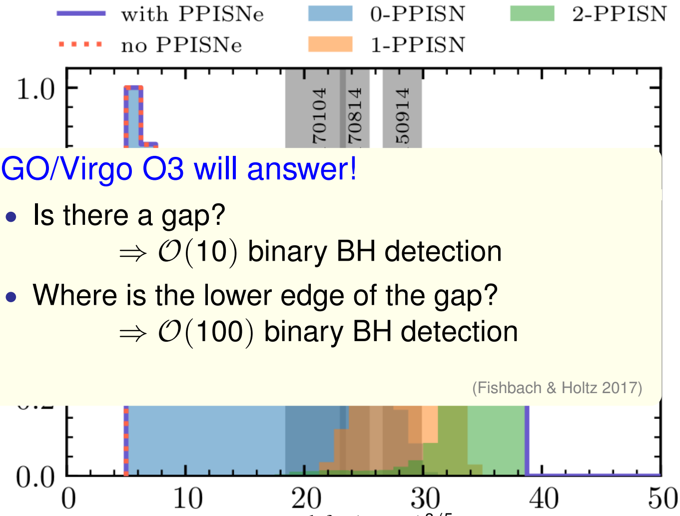

(Fishbach & Holtz 2017)

LIGO/Virgo O3 will answer!

- Is there a gap?
  $\Rightarrow \mathcal{O}(10)$ binary BH detection
- Where is the lower edge of the gap?
  $\Rightarrow \mathcal{O}(100)$ binary BH detection

(Fishbach & Holtz 2017)

$$M_{\rm chirp} \stackrel{\rm def}{=} \frac{(M_1 M_2)^{3/5}}{(M_1+M_2)^{1/5}} \ [M_\odot]$$

Chirp Mass

$$\frac{dN}{dM_{\rm BH}} \propto M_{\rm BH}^{-2.35}$$

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(motivated by LVC 2016)

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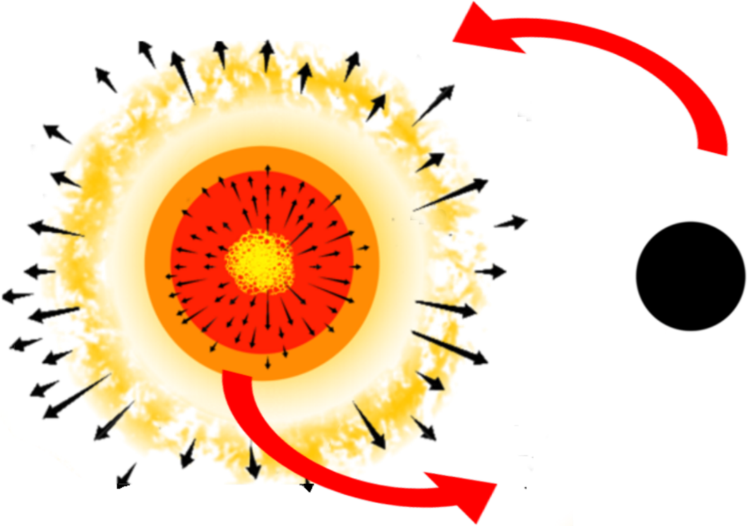
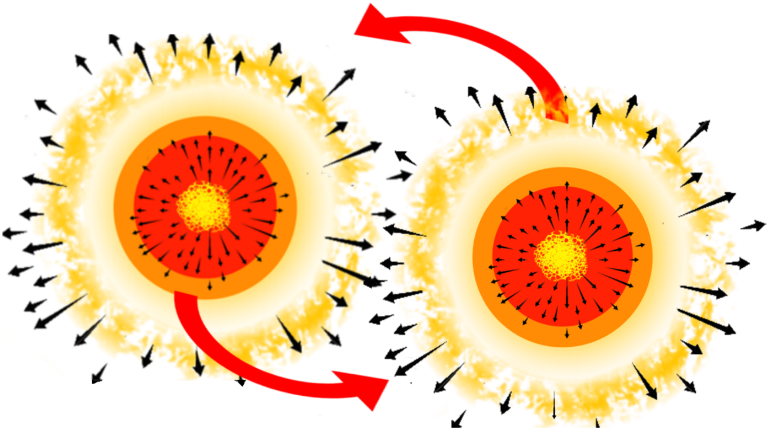
PPI in a binary



$$\Delta e = \frac{\Delta M}{M_1 + M_2 - \Delta M}$$

Two PPI in a binary



$$\Delta e = \frac{\Delta M}{M_1 + M_2 - \Delta M}$$

Eccentricity distribution

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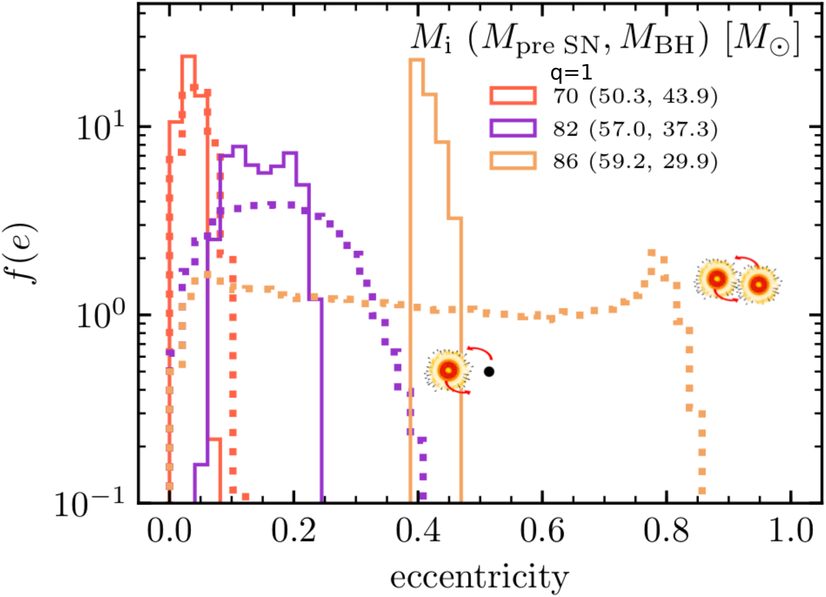

Marchant, Renzo, *et al.*, submitted, arXiv:1810.13412

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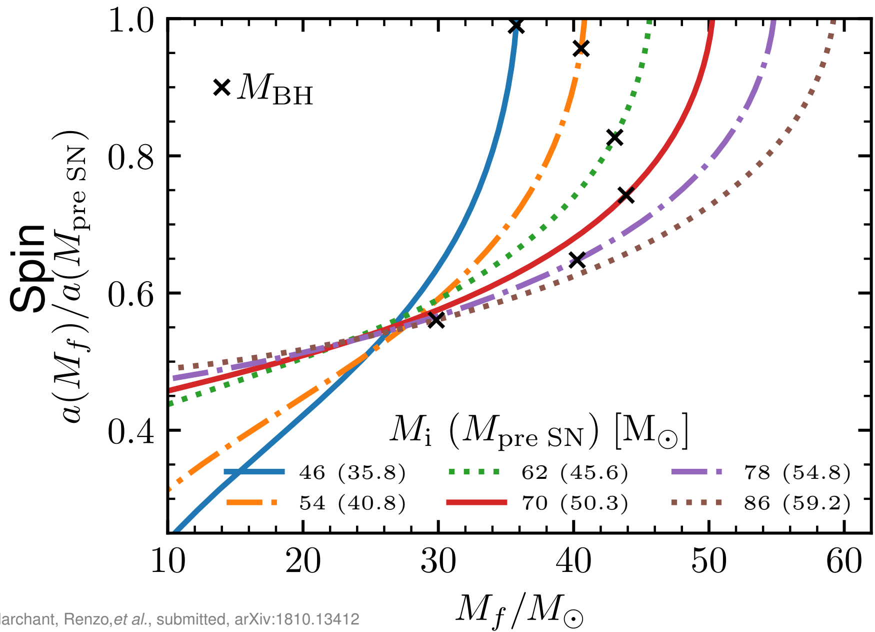
Spin down due to PPI ejecta



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Conclusions

Take home points

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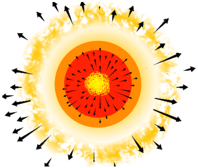
Simulations of Pulsational Pair Instability possible with MESA

including self-consistently dynamical evolution



Pulsational Pair Instability:

- **determines BH masses below** 2^{nd} **gap**
  $\Rightarrow$ LIGO/Virgo O3 will probe this process
- **can create (He-rich, "slow" moving) CSM**
  $\Rightarrow$ connection with SNIbn progenitors?
- **can modify binary orbit (and remnant spin)**
  $\Rightarrow$ Signature on gravitational wave signals?

Take home points

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Simulations of Pulsational Pair Instability possible with MESA

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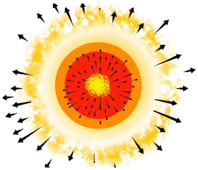

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Thank you!

Backup slides

Upper-limits in BH mass

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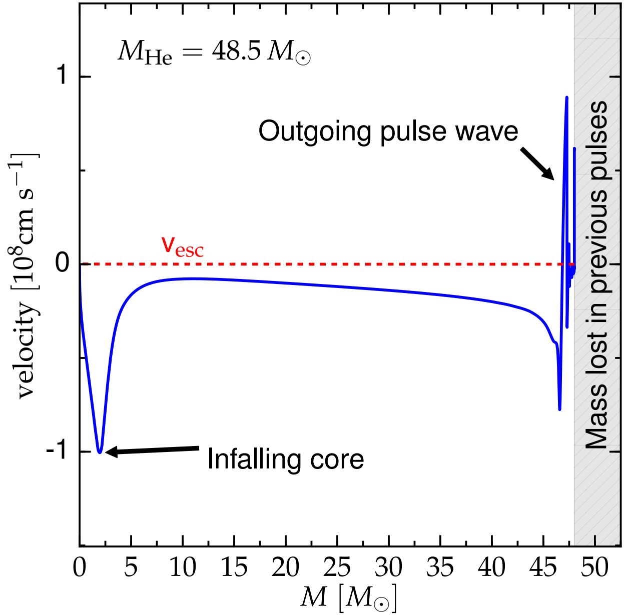
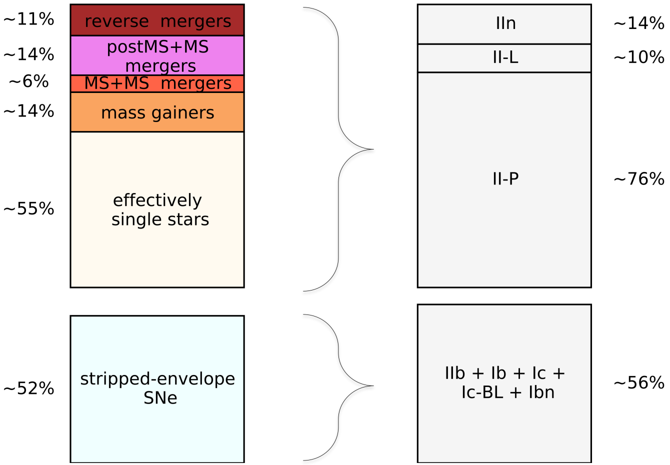


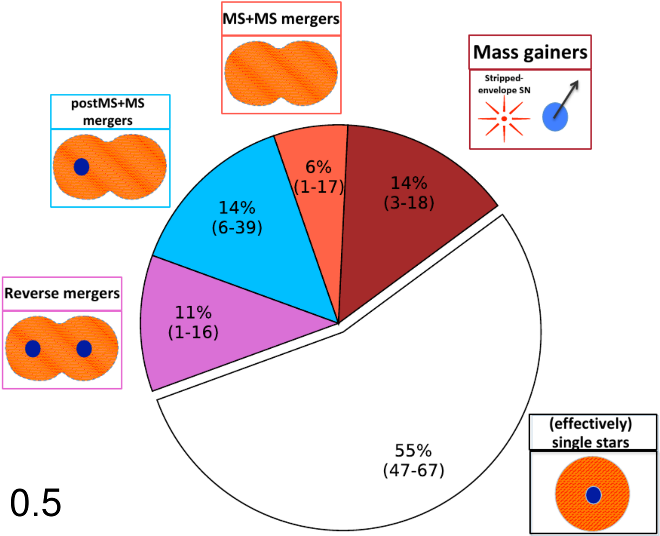
CCSN rates accounting for binarity

Model predictions | Observed fractions



Zapartas *et al.* (incl. Renzo, M.) *To be submitted*

SN type II rates accounting for binarity



$f_{\text{bin}} = 0.5$

Zapartas *et al.* (incl. Renzo, M.) *To be submitted*