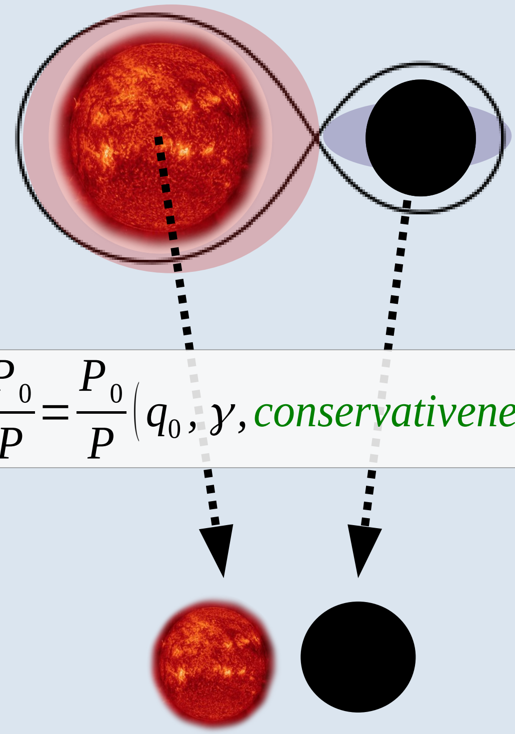
Forming Merging Double Compact Objects with Stable Mass Transfer

Annachiara Picco, Pablo Marchant,
Hugues Sana, Gijs Nelemans

Stable Mass Transfer

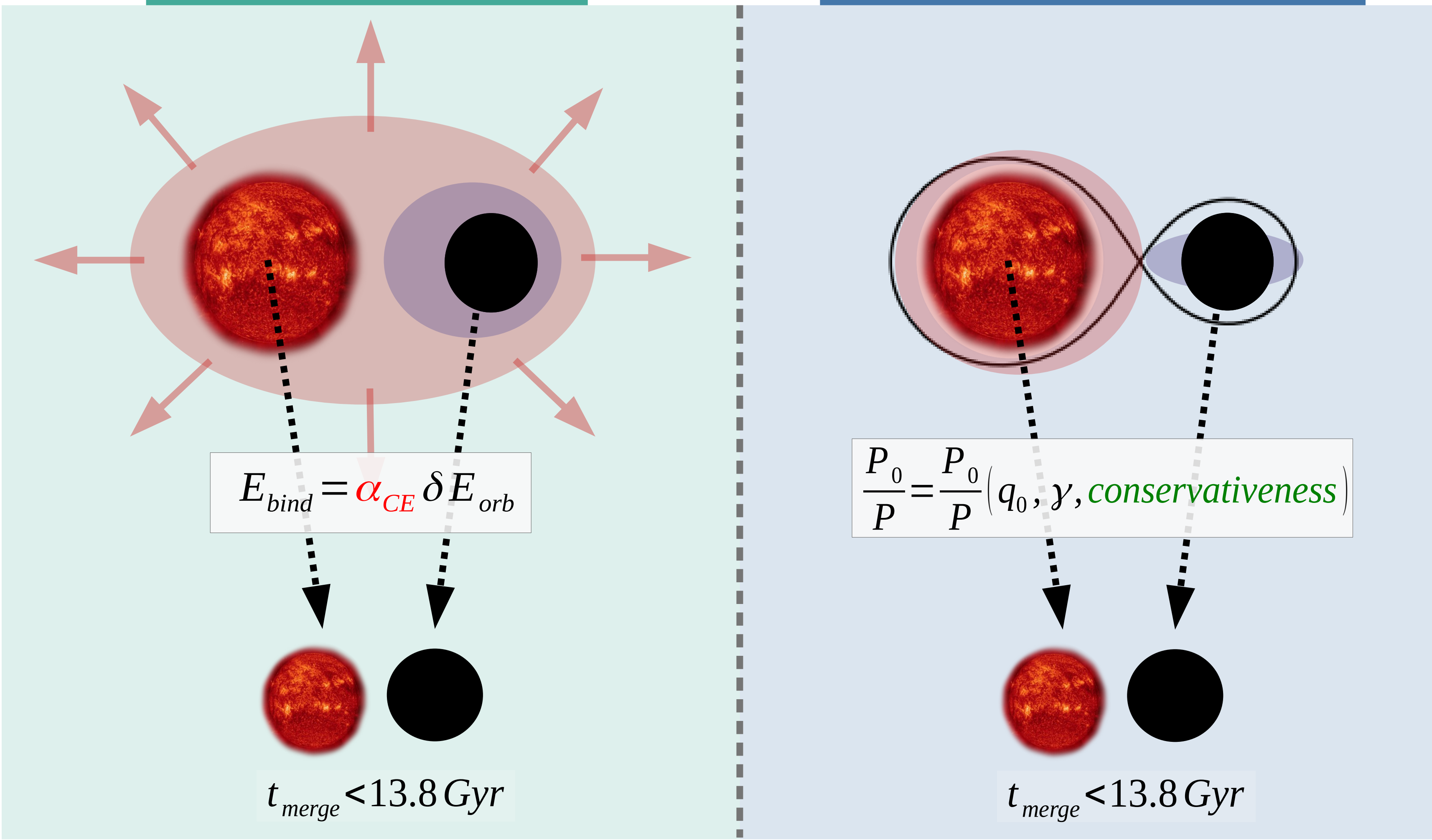


$$\frac{P_0}{P} = \frac{P_0}{P}\left(q_0, \gamma, \text{conservativeness}\right)$$

$$t_{merge} < 13.8\,Gyr$$

Common Envelope

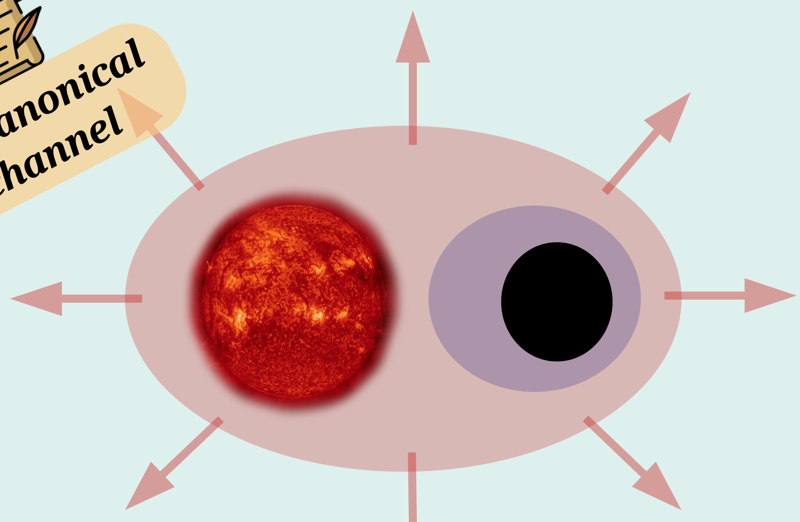
Stable Mass Transfer



Ivanova (2011, 2020)

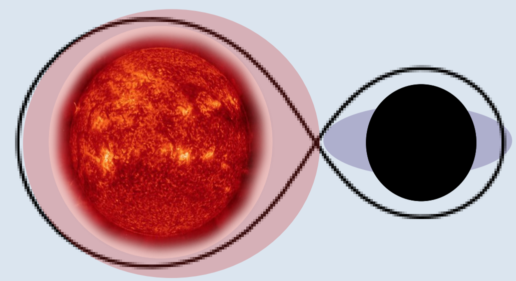
Common Envelope	Stable Mass Transfer

the **canonical channel**



$$E_{bind} = \alpha_{CE} \, \delta E_{orb}$$

- ✓ Efficiently tightens the orbit
- ✓ Can produce LVK-like mass ratios
- ✗ α_{CE} is assumed, uncertain



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Common Envelope

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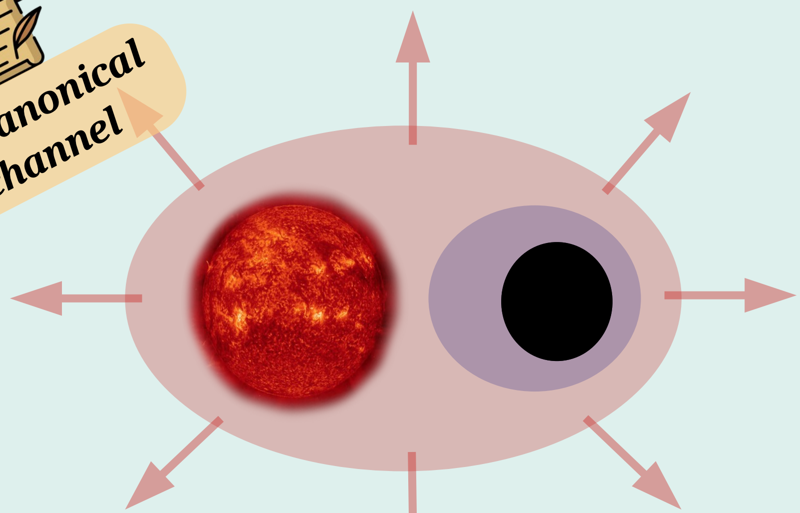

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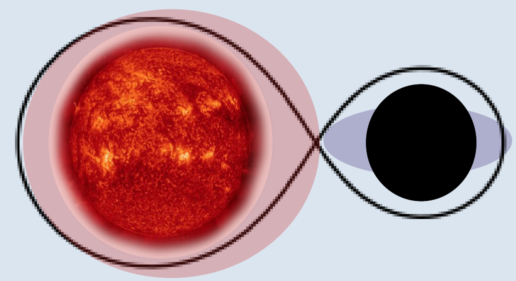
Stable Mass Transfer

more recently...



$$\frac{P_0}{P} = \frac{P_0}{P}\left(q_0, \gamma, \textit{conservativeness}\right)$$

- ✓ Efficiently tightens the orbit
- ✓ Can produce LVK-like mass ratios
- ! *Conservativeness* is a free parameter of the theory

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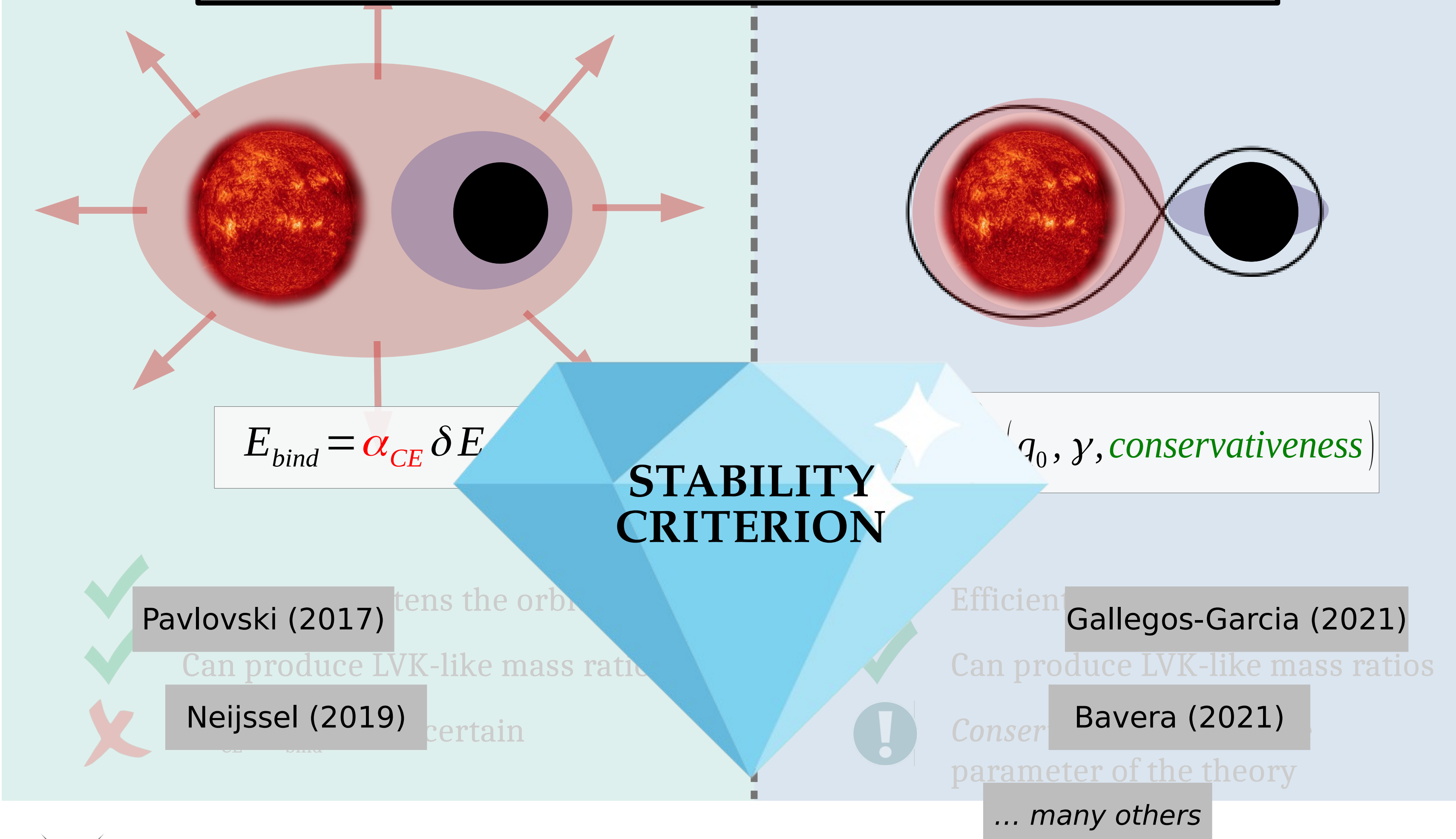
van de Heuvel et al. (2017)

BOTH CHANNELS ARE VIABLE WAYS to GRAVITATIONAL WAVES SOURCES !



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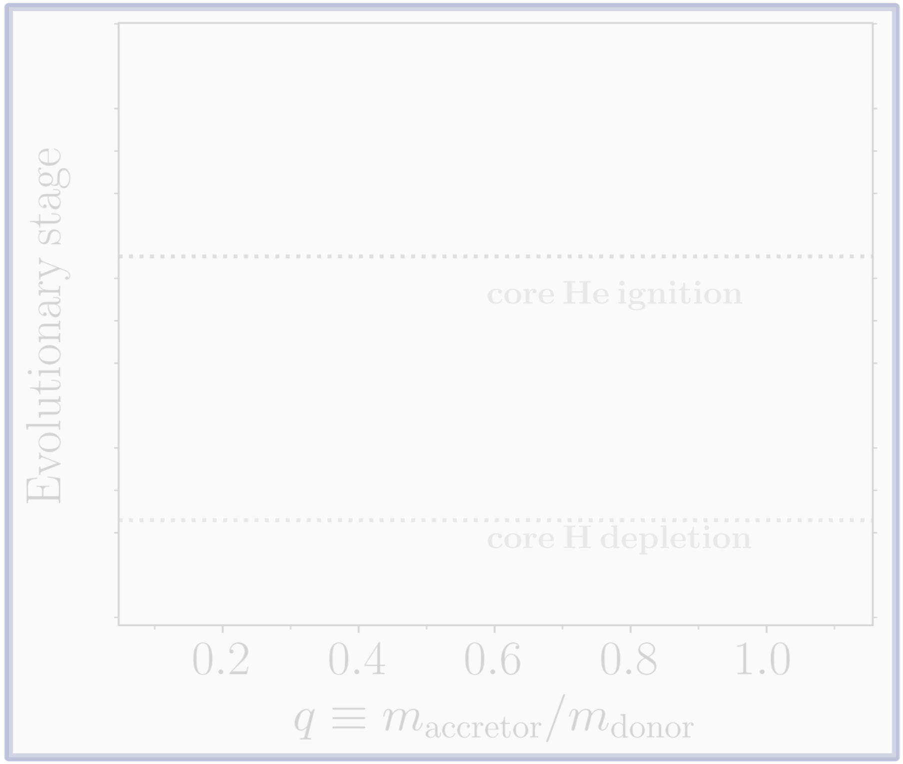
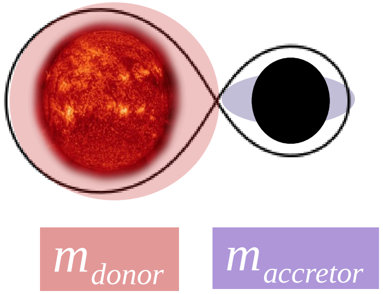
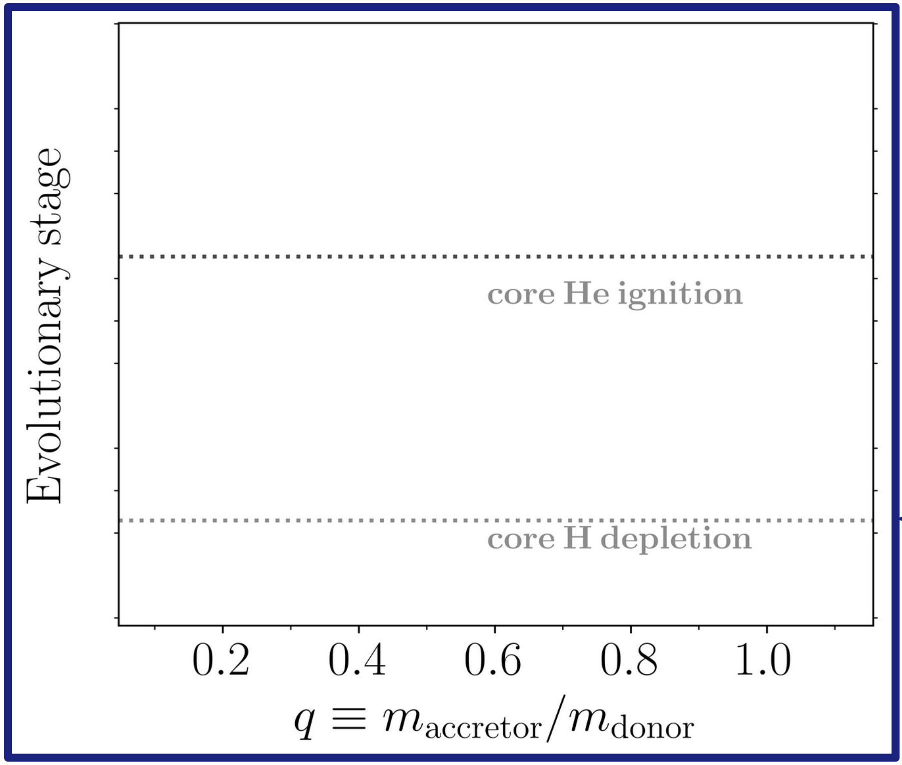
THE SIMPLEST STABILITY CRITERION for POPULATION SYNTHESIS CODES

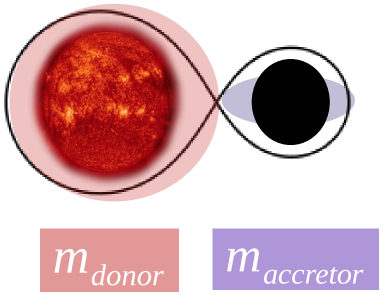




$$q < q_{critical} \Rightarrow CE$$

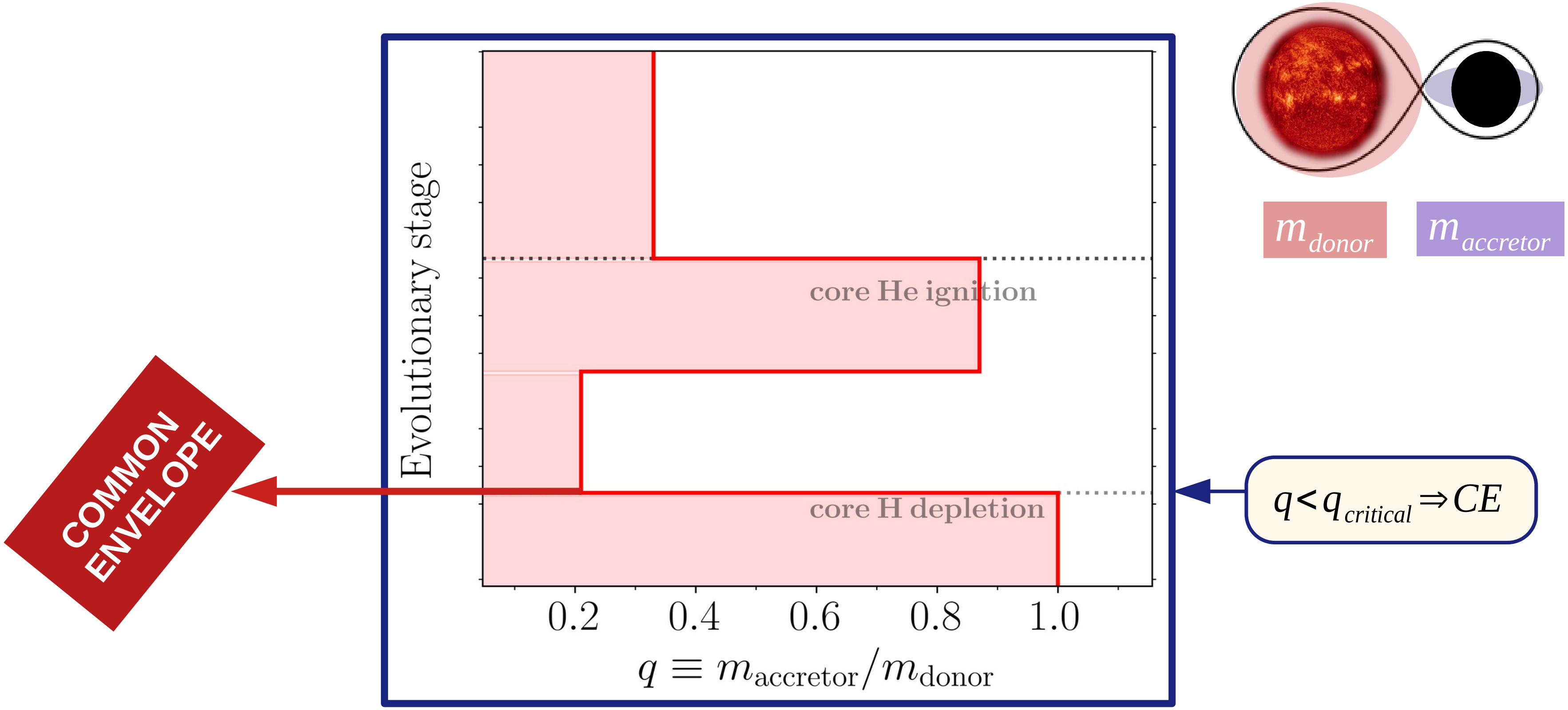
THE SIMPLEST STABILITY CRITERION for POPULATION SYNTHESIS CODES





$q < q_{critical} \Rightarrow CE$

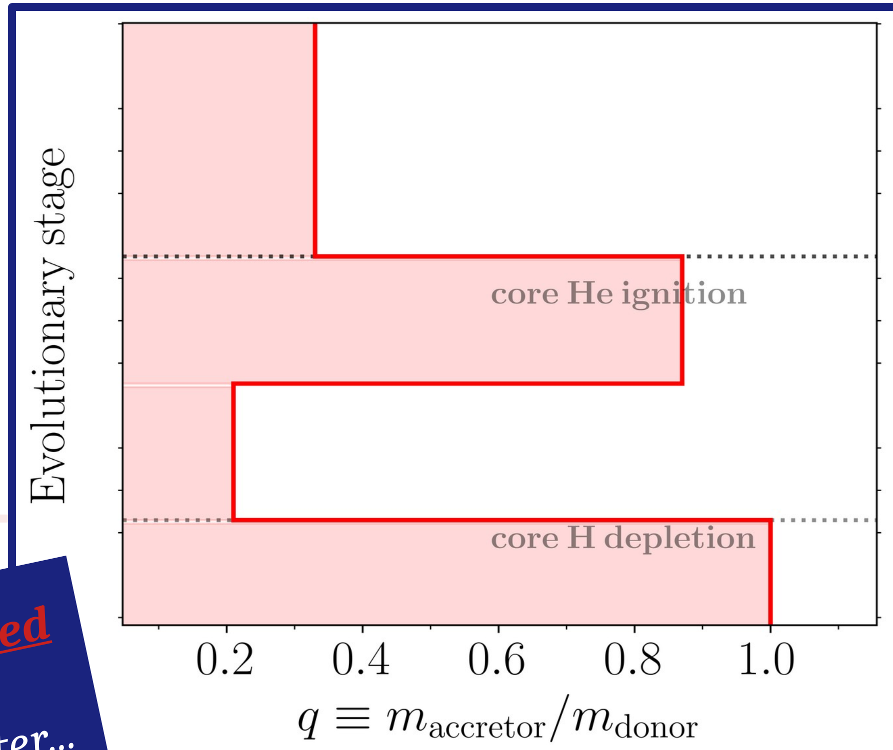
The Simplest Stability Criterion for Population Synthesis Codes

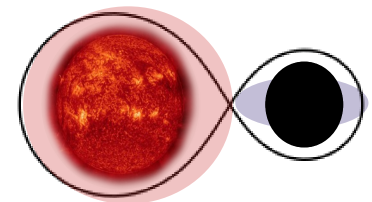


Clayes et al. (2014)

The Simplest Stability Criterion for Population Synthesis Codes

Tailored detailed models can inform better...





m_{donor} $m_{accretor}$

$q < q_{critical} \Rightarrow CE$

Detailed Single Stars Models of Unstable Mass Loss

Ge et al. (2010,2015,2020)

Stability criterion
based on
mass-radius exponents ζ

$$\zeta \equiv \frac{d\,\log R}{d\,\log M}$$

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$$\zeta_{crit} \overset{!}{=} \zeta_{RL}(q, \text{conservative}) \Leftrightarrow q = q_{crit}$$

Already implemented in some pop synth codes!

$$\zeta \equiv \frac{d \log R}{d \log M}$$

Full parameter space,
many **donor masses** and **periods**

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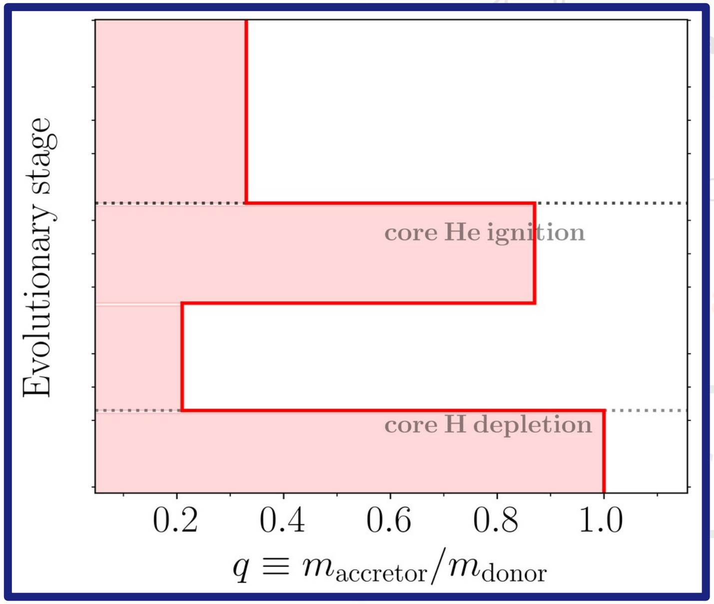
Any m_{donor}



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$\text{onservative}) \Leftrightarrow q=q_{crit}$

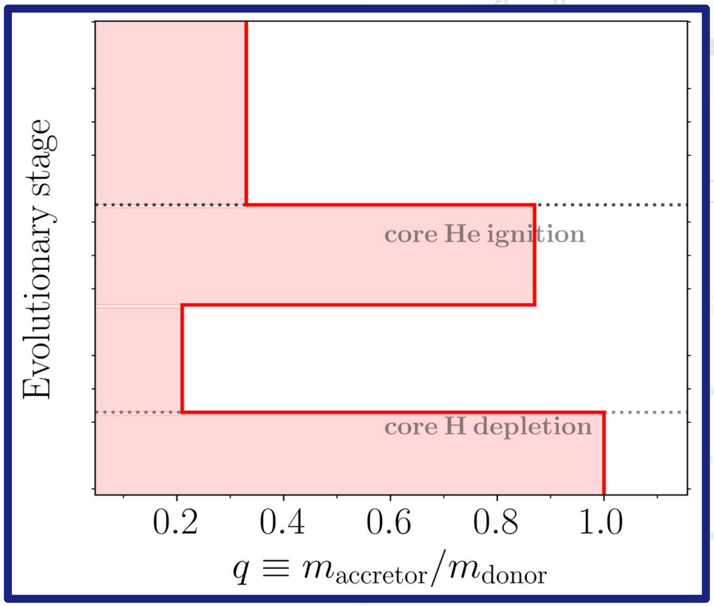
Already implemented in some pop synth codes!

$$\zeta \equiv \frac{d\log R}{d\log M}$$

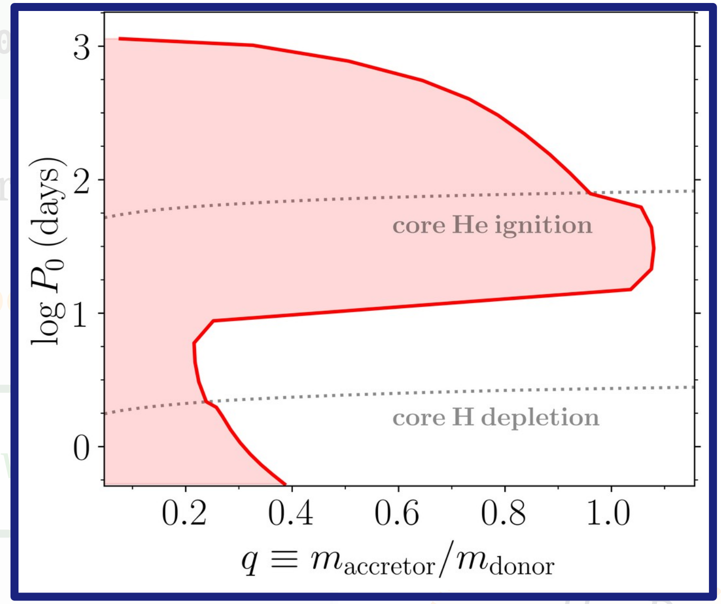
FIXED $\alpha_{overshooting}, Z, winds\ldots$

Refined Stability Criterion with Detailed Single Stars Models

Any m_{donor}



$m_{donor} = 3.2\,M_{\odot}$



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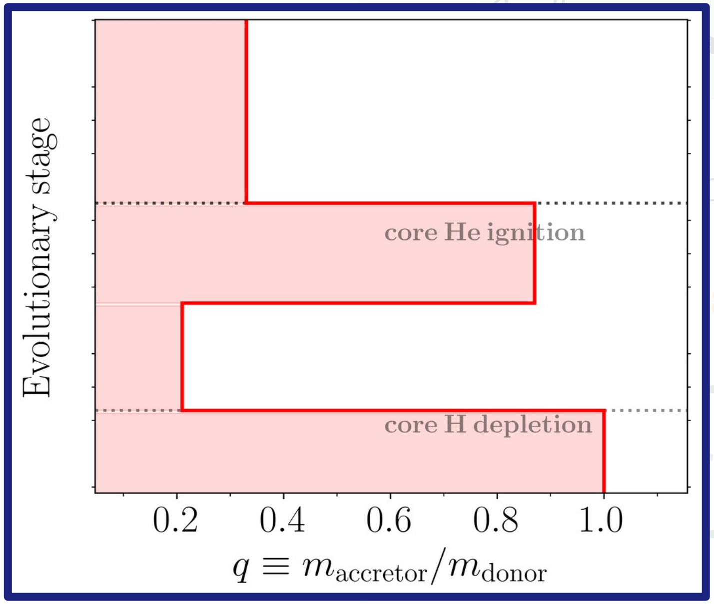
REFINED STABILITY CRITERION with DETAILED SINGLE STARS MODELS

Any m_{donor}



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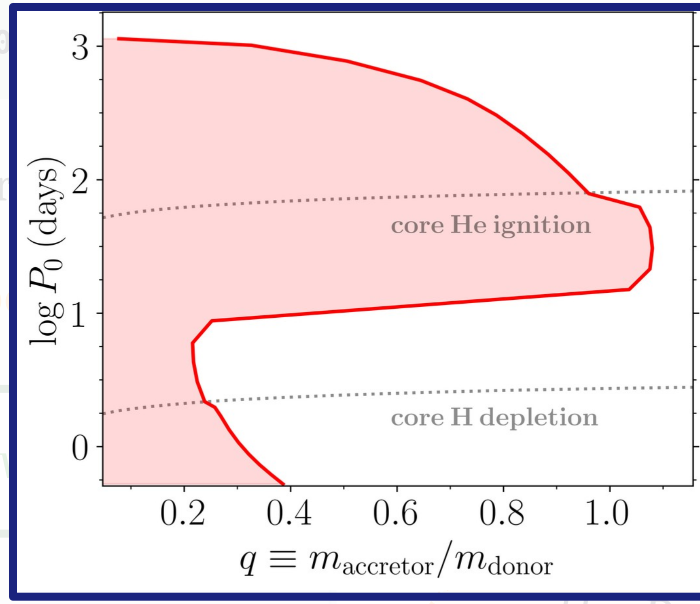

FIXED $\alpha_{overshooting}, Z, winds\,...$

+ conservativeness assumption...

Refined Stability Criterion with Detailed Single Stars Models

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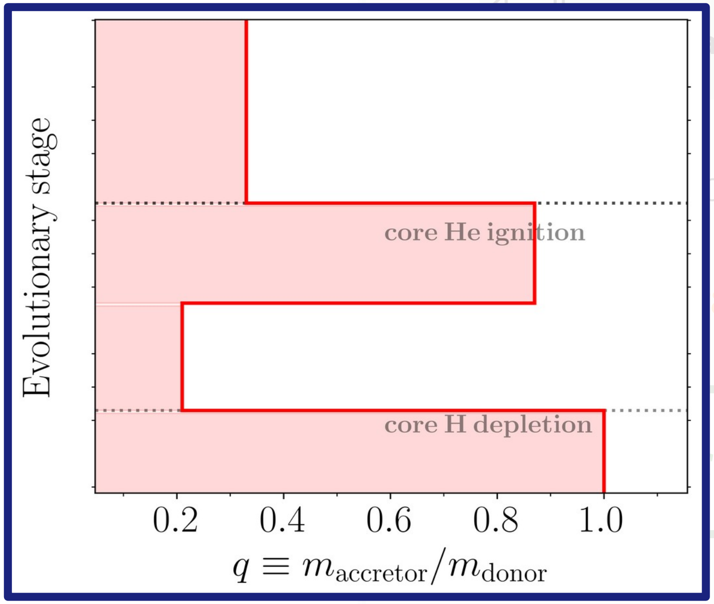

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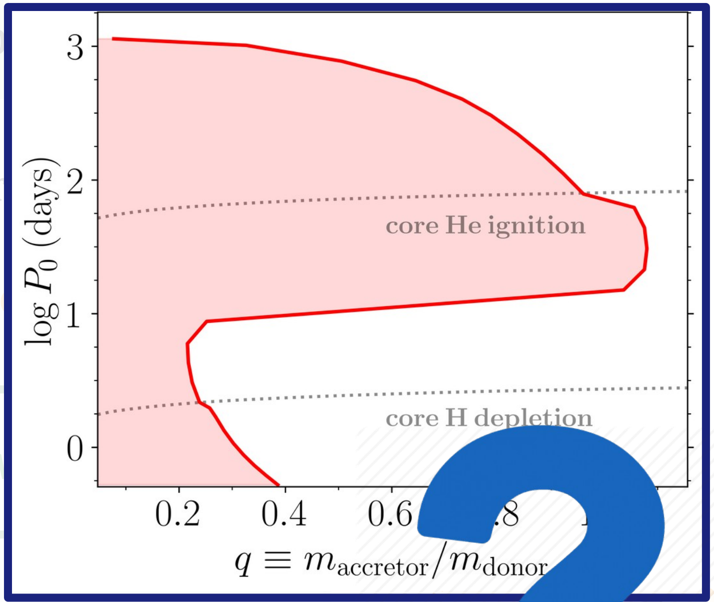

FIXED $\alpha_{overshooting}$, Z, *winds* ...

+ conservativeness assumption...

Does the stability boundary change? How...?

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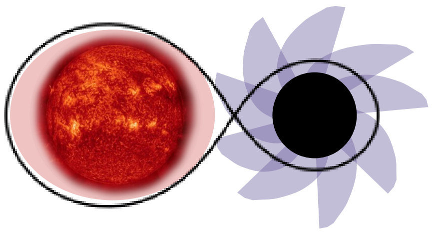
Impact of the conservativeness assumption

SEMI-ANALYTICAL

$$\zeta_{crit} \stackrel{!}{=} \zeta_{RL}(q, \text{non conservative}) \Leftrightarrow q = q_{crit}$$

NO MASS is accreted



$m_{donor} = 32\,M_\odot$

$m_{accretor}$

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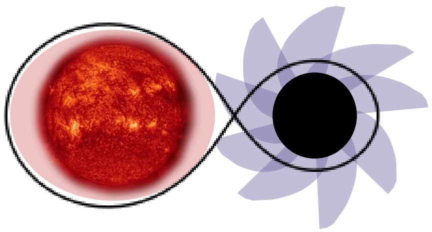

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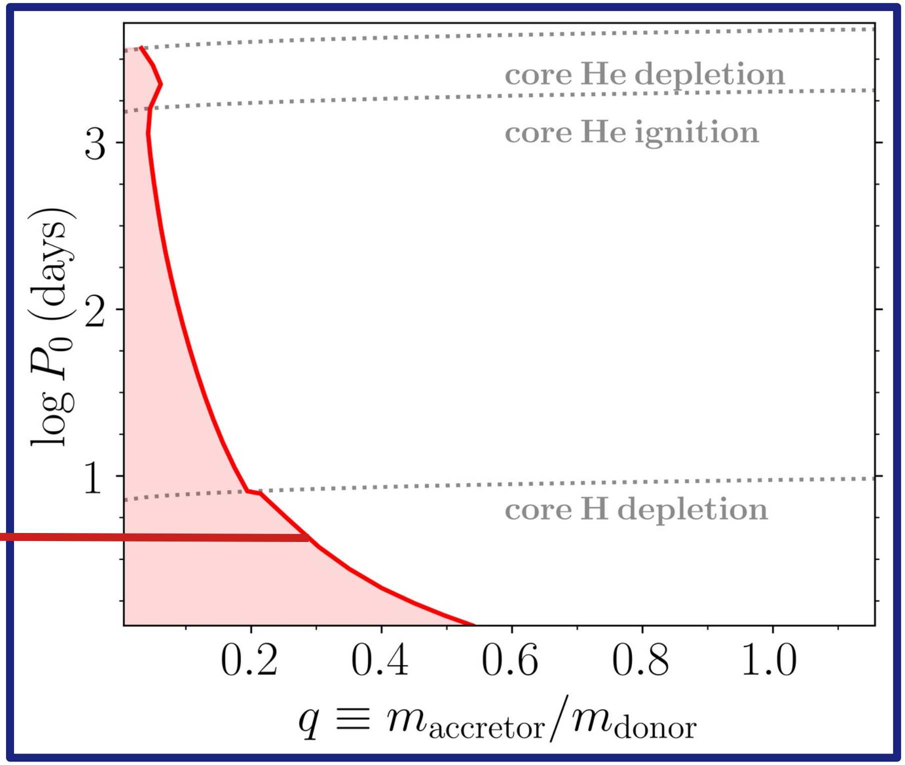
COMMON ENVELOPE



Impact of the conservativeness assumption

$t_{merge} > 13.8\,\mathrm{Gyr}$

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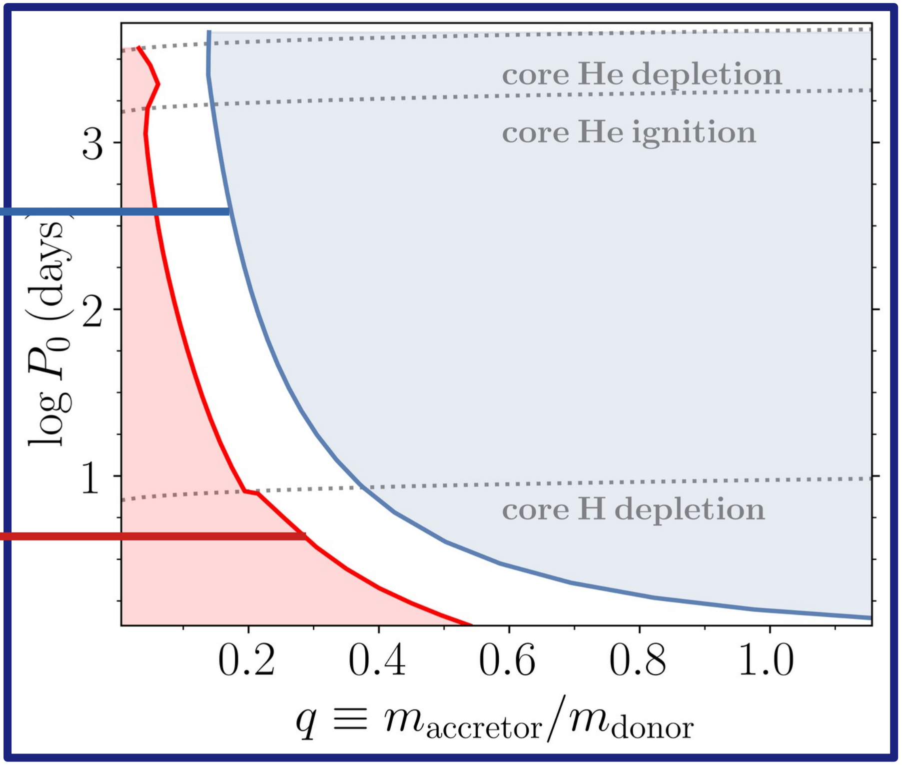

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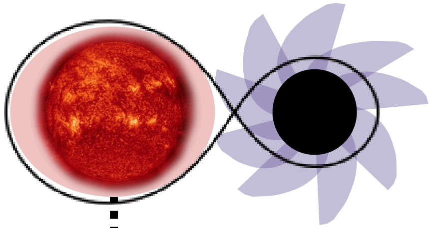

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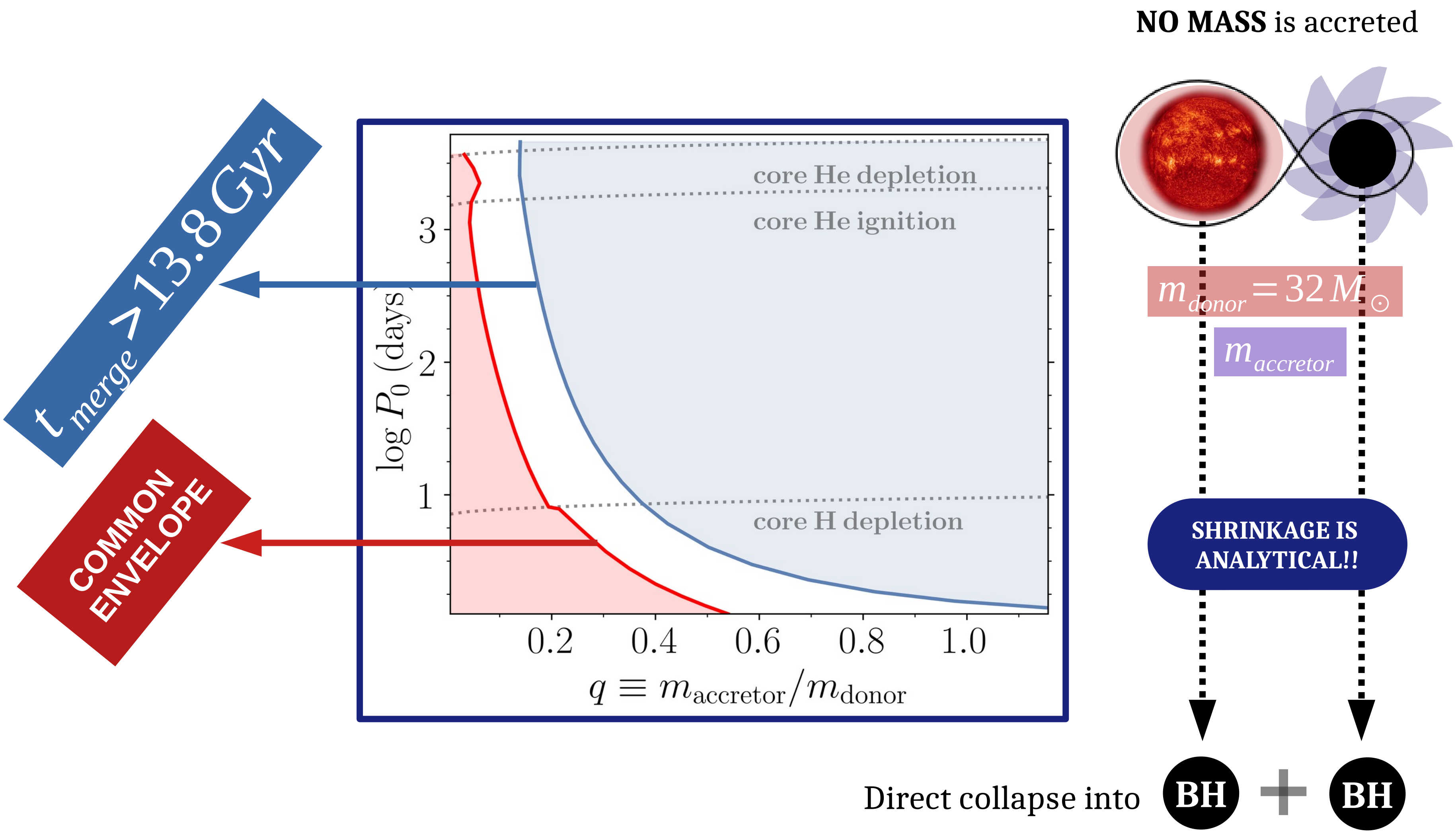
SHRINKAGE IS ANALYTICAL!!

Direct collapse into **BH**

MERGING DOUBLE BHs!



Merging Double BHs!

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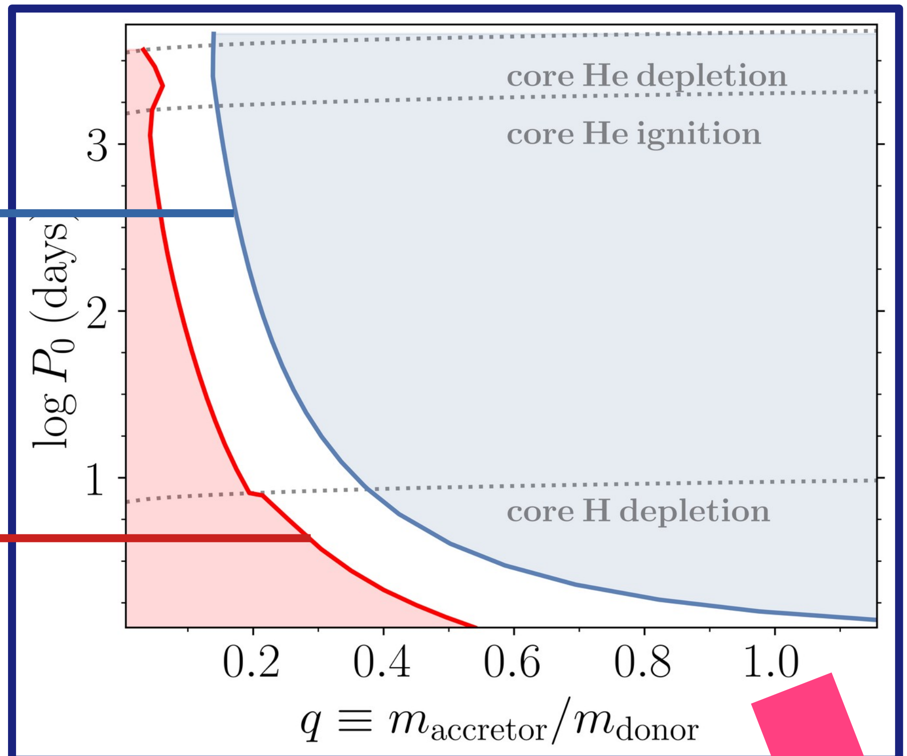
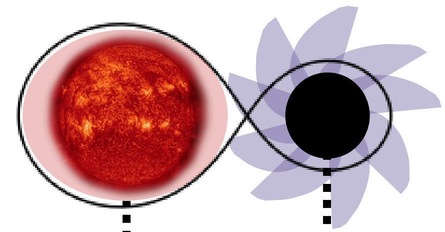


NO MASS is accreted



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SHRINKAGE IS ANALYTICAL!!

Direct co… e into **BH** + **BH**

Impact of the conservativeness assumption

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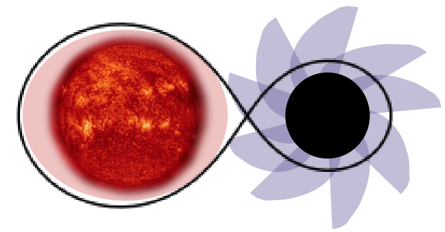
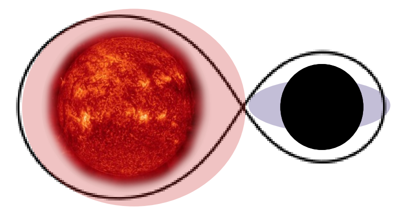


$\neq$



ALL MASS is accreted

Impact of the conservativeness assumption

$t_{merge} > 13.8\,\mathrm{Gyr}$

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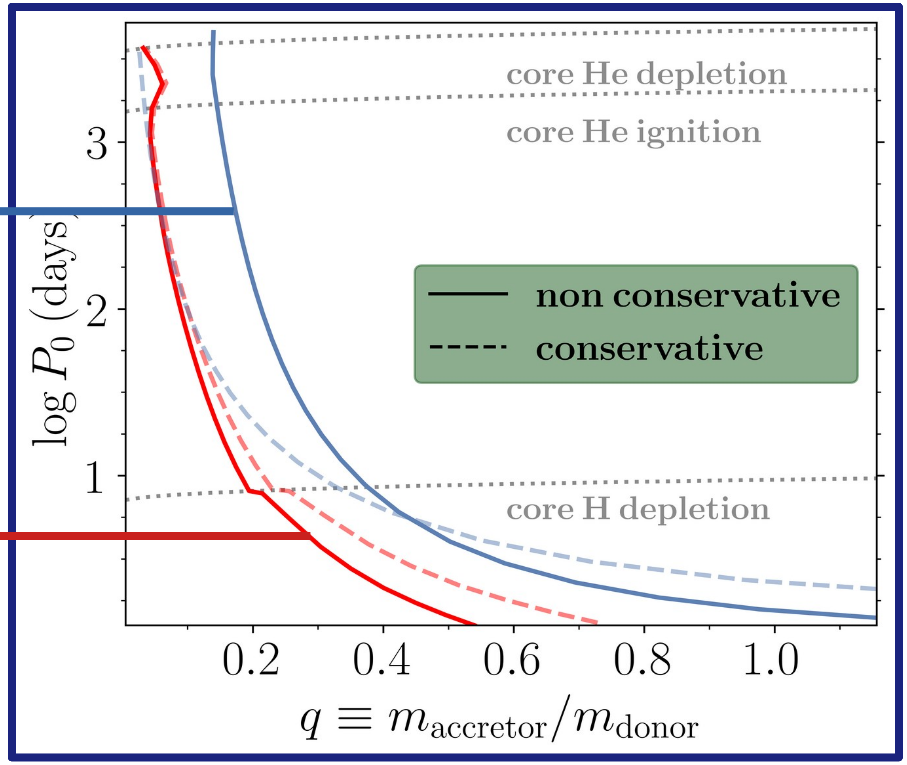

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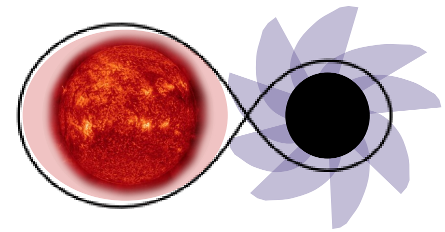

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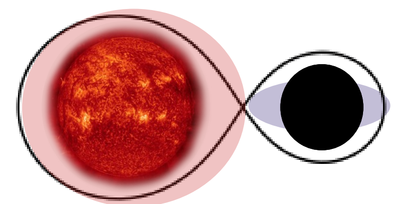

ALL MASS is accreted

MESA MODELS

fixed $Z = Z_{\odot}/10$

$\alpha_{overshooting}$

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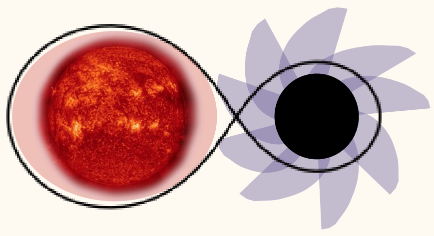
1 **CONSERVATIVENESS** determined by **EDDINGTON LIMIT**

$m_{donor} = 30\, M_{\odot}$

$m_{accretor}$



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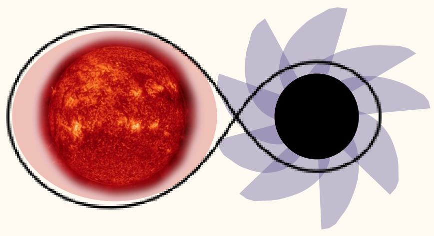
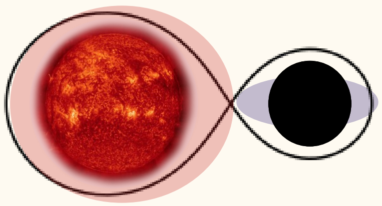


NO MASS is accreted

2 Manually set the system to be **CONSERVATIVE**



ALL MASS is accreted

MESA MODELS

1 **NO MASS** is accreted

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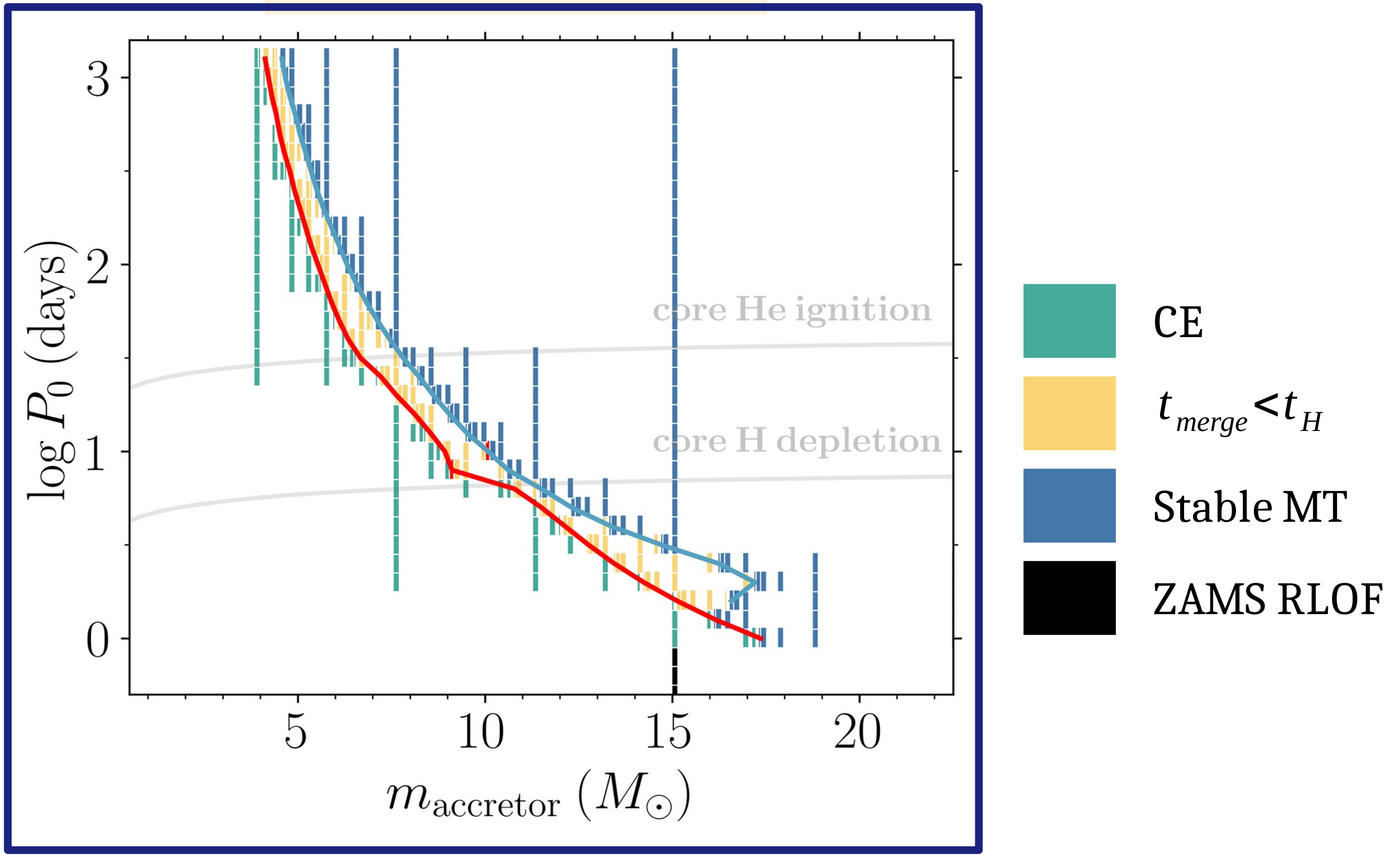


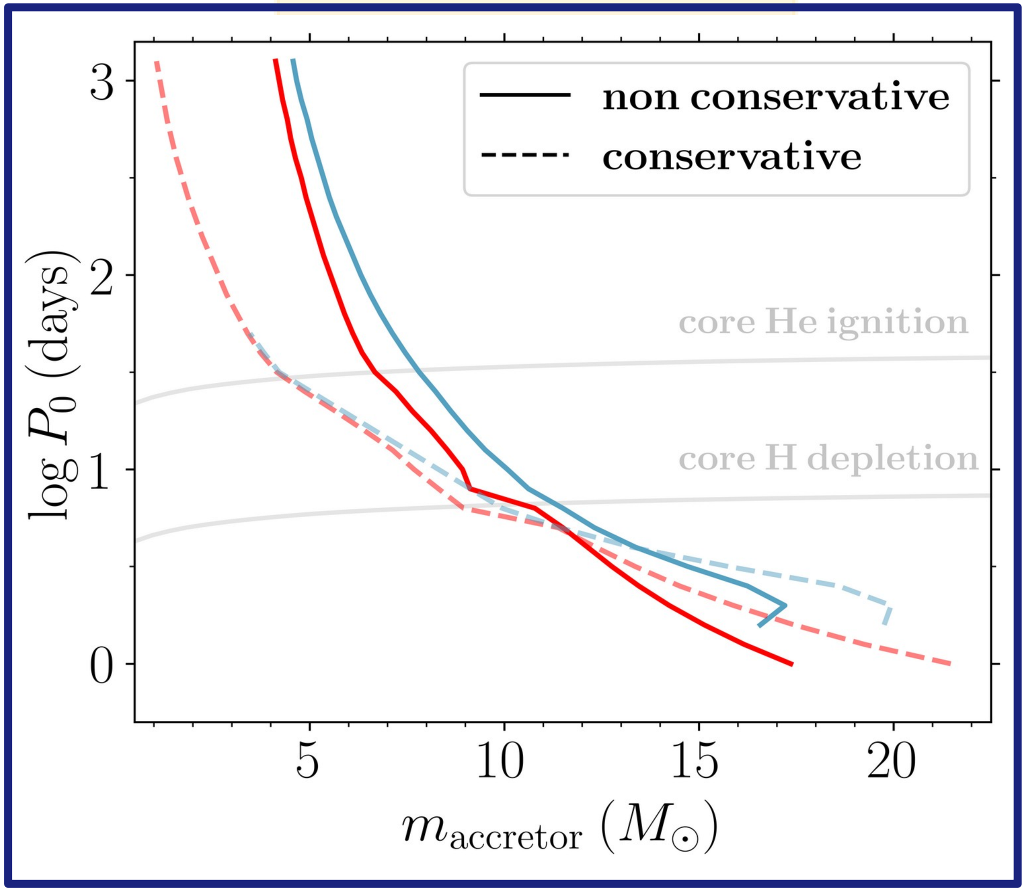
Target precision

$\delta q = 0.001$

MESA MODELS

1 2

$m_{donor} = 30\,M_\odot$



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Picco et al. (in prep)

MESA MODELS

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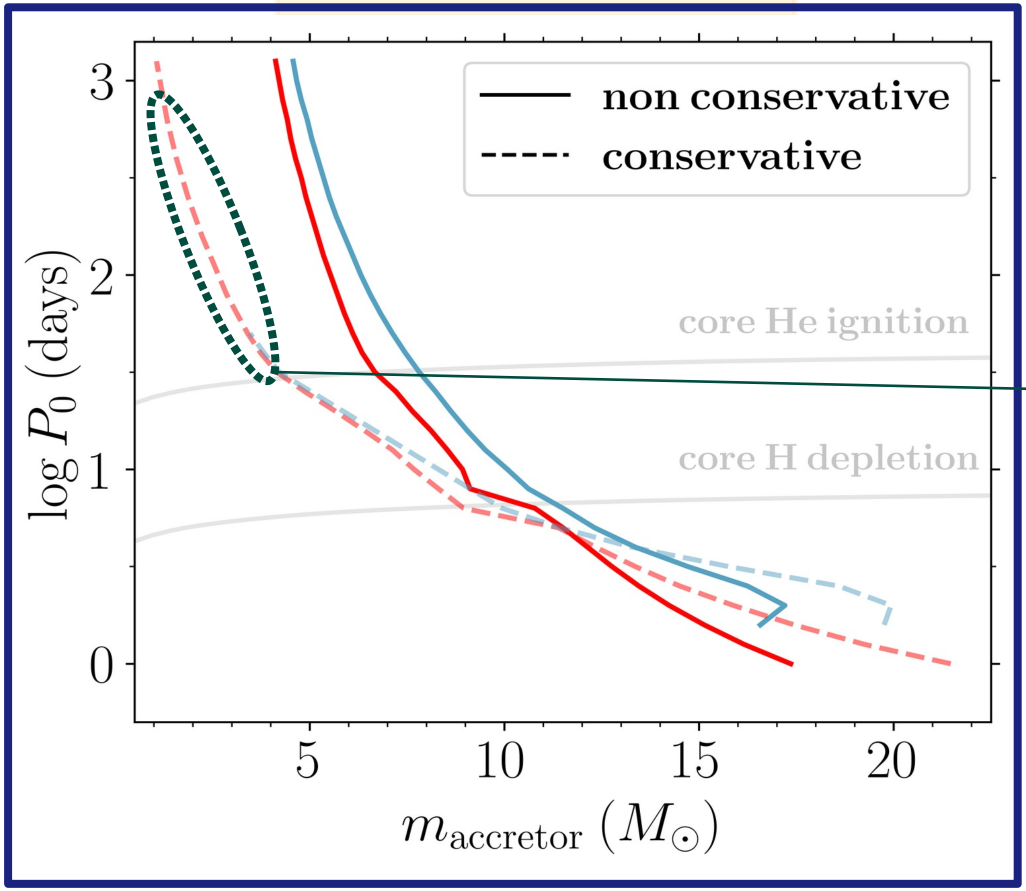


Large P_0 tail is gone...

SET YOUR BOUNDARIES WISELY!

Target precision

$\delta q = 0.001$

Impact of the overshooting parameter

RATIO of CORE TO ENVELOPE MASS

From calibrations,
usually assumed fixed to
$\alpha_{overshooting}$=0.335

MESA MODELS

fixed $Z = Z_{\odot}/10$

$\alpha_{overshooting} = 0.1, 0.3, 0.4$

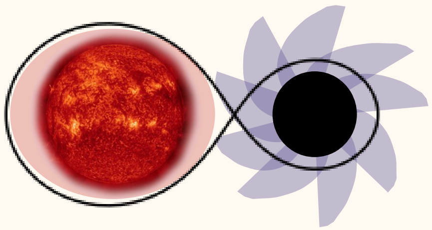
CONSERVATIVENESS determined by

EDDINGTON LIMIT

Impact of the overshooting parameter

$m_{donor} = 30\, M_{\odot}$

$m_{accretor}$



NO MASS is accreted

Marchant et al. (2021)

MESA MODELS

Impact of the overshooting parameter

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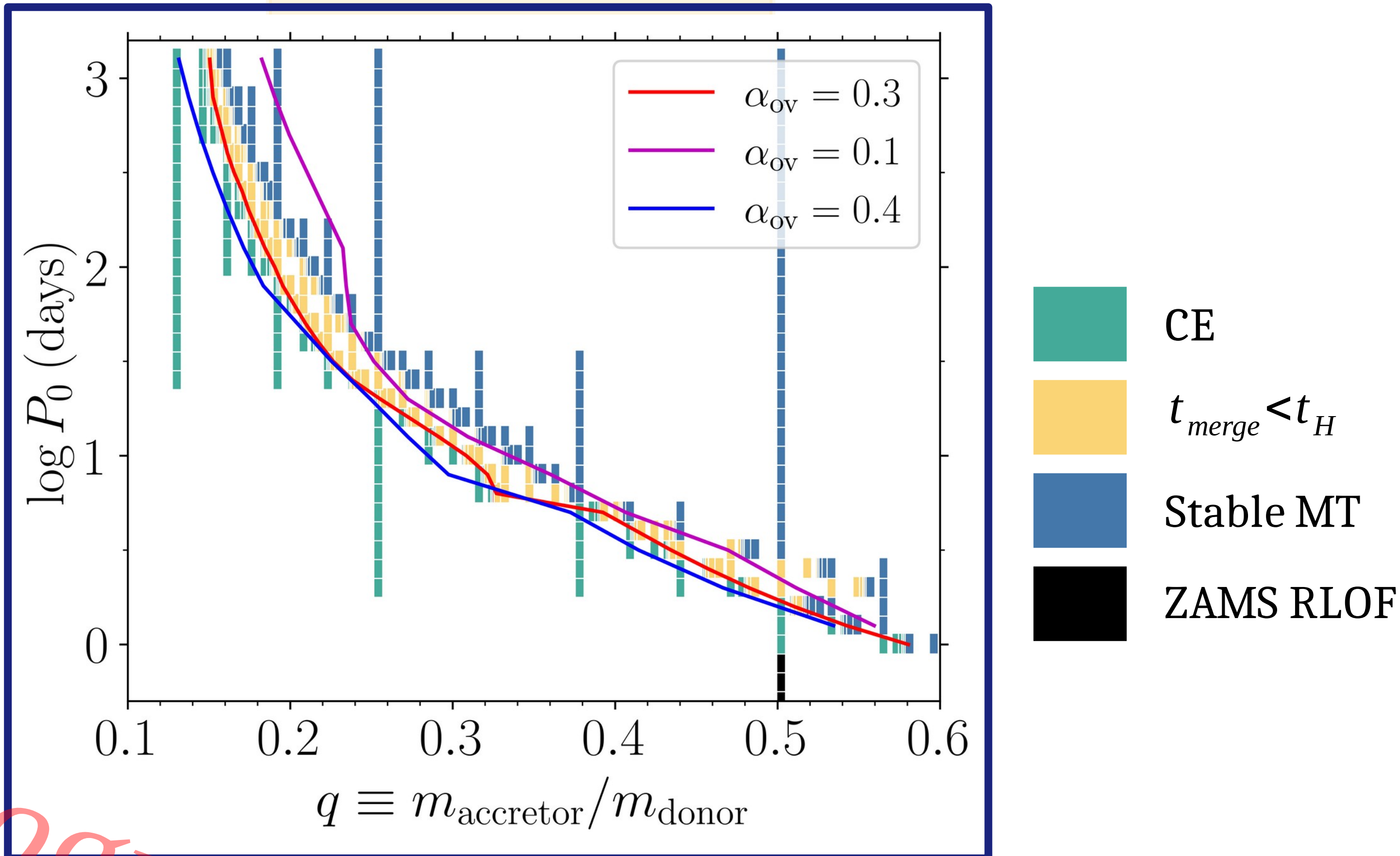

in progress

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Picco et al. (in prep)

SUMMARY

Your boundaries matter…
The stability criterion determines
the parameter space for merging **CO+CO** from stable MT

… and they shift!
Behind critical mass ratios from detailed models there is fixed input physics and assumptions, and they are influential

Future work:
Full grid detailed models to try and build a reliable stability criterion independent on these uncertainties

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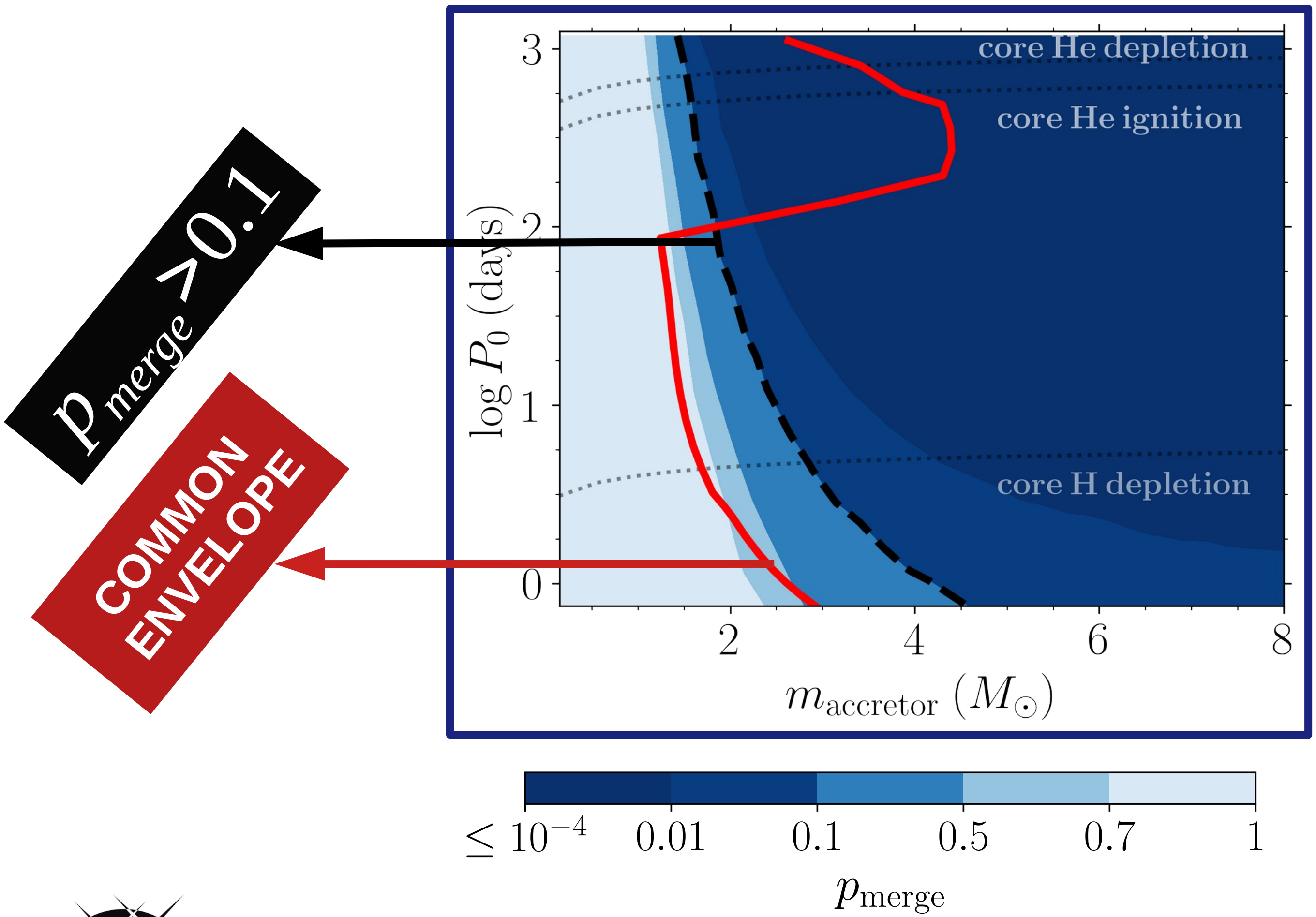
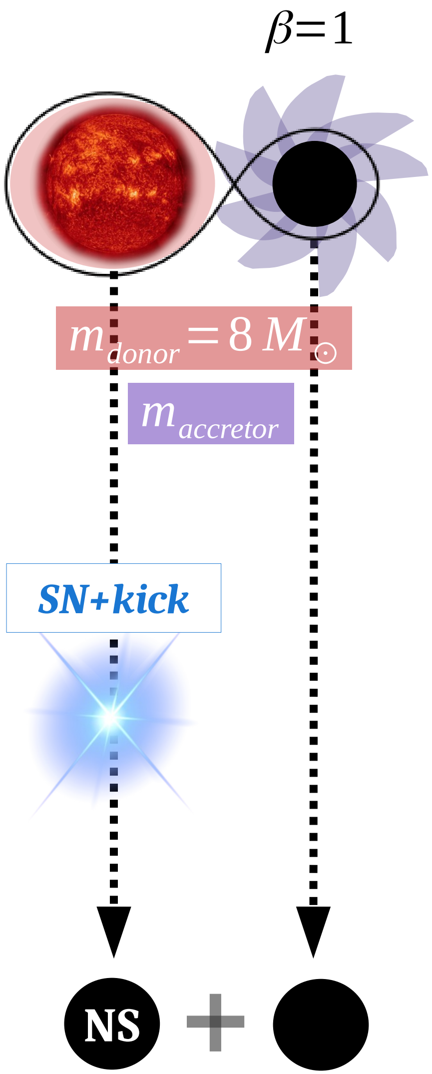
Thanks for the attention!

BACKUP

MERGING DOUBLE COs: BNS, BBH!





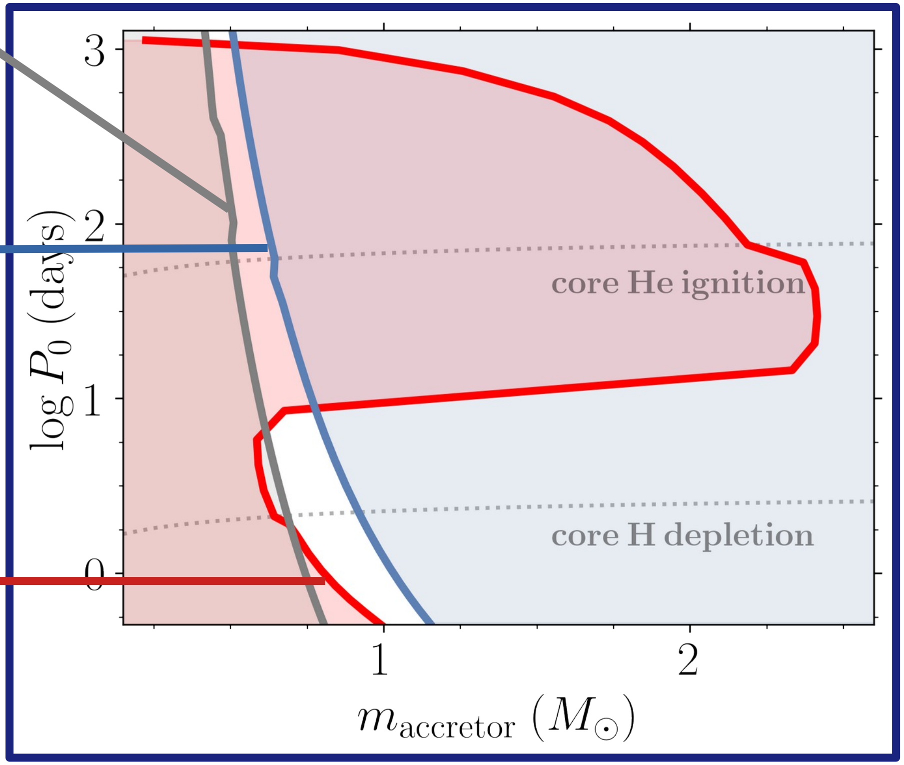
BACKUP

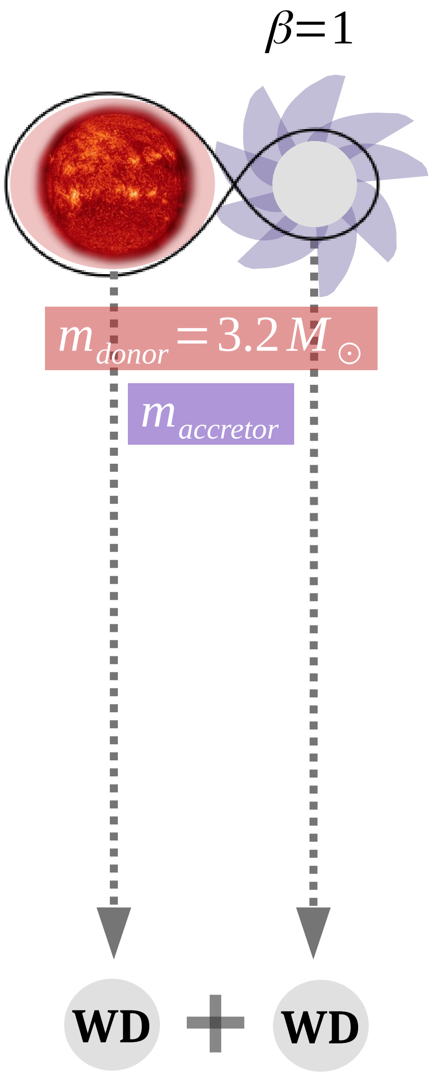
Merging Double WDs!

$R_{RL} > R_{donor}$

$t_{merge} > 13.8\,\mathrm{Gyr}$

COMMON ENVELOPE





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