Revisiting the treatment of common-envelope evolution in population-synthesis codes

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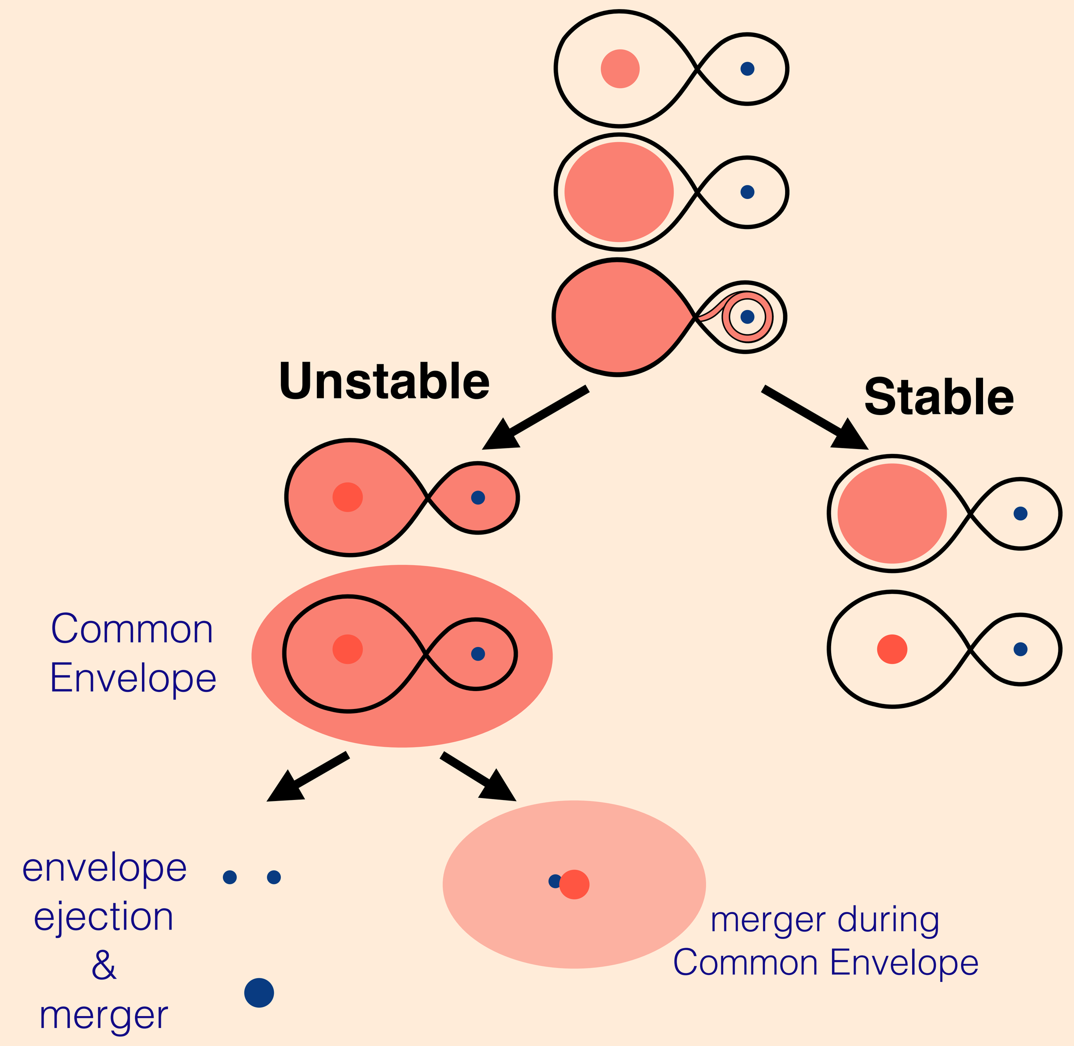
Introduction

Rapid binary population synthesis codes have been used for decades to investigate the complex evolution of compact binaries. Although these codes are widely used, they typically lack thorough calculations and prescriptions of physical processes (e.g., common-envelope, roche lobe overflow) that are crucial to accurately predict the fate of these binary systems. Many of these processes, however, have been more carefully implemented in stellar evolution codes such as MESA (Modules for Experiments in Stellar Astrophysics). Motivated by this, **we perform binary evolution simulations to compare results between a fast binary synthesis code, Binary Stellar Evolution (BSE), and MESA**. We find the BSE produces more mergers than MESA at high period binaries, such discrepancies can affect merging rates of compact binaries.

Binary Evolution



Binary Star Evolution (BSE)

A rapid binary evolution algorithm that uses detailed single star evolution models combined with algorithms that mimic binary evolution [1].

- Fast, $\lesssim$ 1 sec per model
- Most common method to compute stellar populations including binaries
- Relies on pre-computed single-star models
- similar codes: MOBSE [2], Startrack [3], COMPAS [4]

Modules for Experiments in Stellar Astrophysics

A 1-D stellar evolution code that uses physics modules to evolve simulations of single and binary stars. It solves the full stellar structure and composition equations [5].

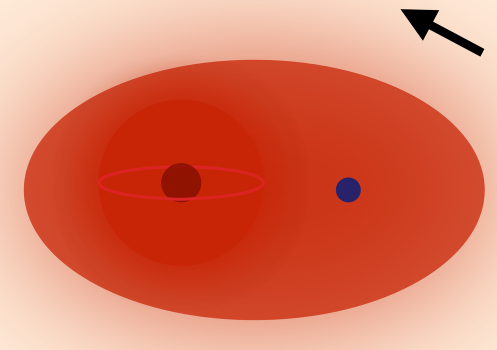
- Slower, $\gtrsim$ 1 hr per model
- Solves full stellar structure equations during binary evolution
- Up-to-date with stellar evolution theory

MESA

Common Envelope (CE)

Brief description of CE formalism and implementations

$$E_{\rm bind}(m_{\rm core}) = \alpha_{\rm CE}\Delta E_{\rm orb} \quad (1)$$



$$\frac{Gm_1 m_{1,\rm env}}{\lambda R_1} = \alpha_{\rm CE}\left(-\frac{Gm_1m_2}{2a_{\rm i}} + \frac{Gm_{1,\rm core}m_2}{2a_{\rm f}}\right)^{[6]}$$

- λ depends on core-envelope boundary [7]
- $\alpha_{\rm CE}$ is a free parameter

BSE-like implementation

The occurrence of CE evolution is determined using simple mass-ratio thresholds that depend on the stellar type.

- use fixed $\alpha_{\rm CE}\lambda$ values or
- use tabulated values for λ

MESA implementation

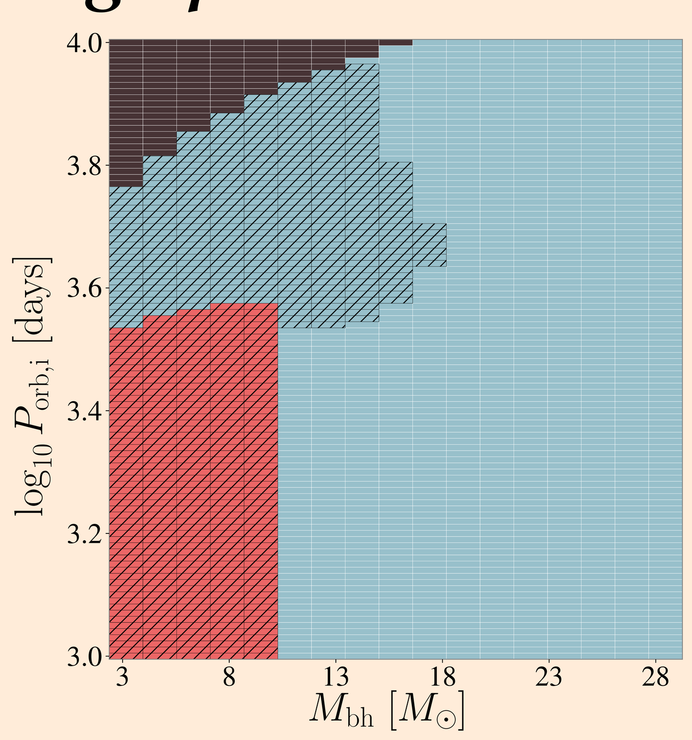
- CE begins when the mass transfer rate following Roche Lobe (RL) overflow exceeds a high threshold value (becomes unstable).
- $E_{\rm bind}(m_{\rm core})$ is calculated at the onset of dynamical instability.
- Mass is then removed by fixing a high $\dot{M}$ while updating the orbital separation (Eq 1) until $R_1 < R_{\rm RL}$

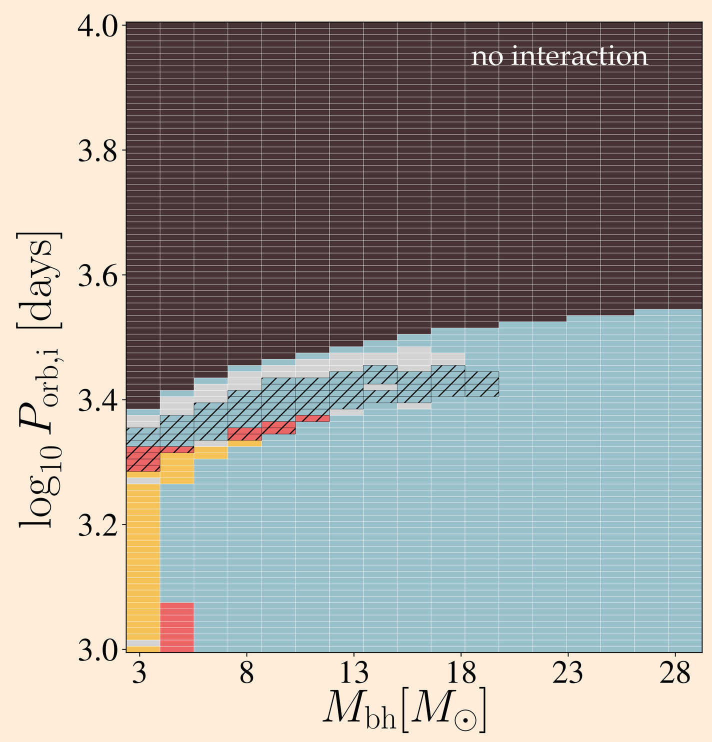
- Still requires $\alpha_{\rm CE}$
- Does not use λ and calculates $m_{1,\rm core}$

Comparison between BSE & MESA

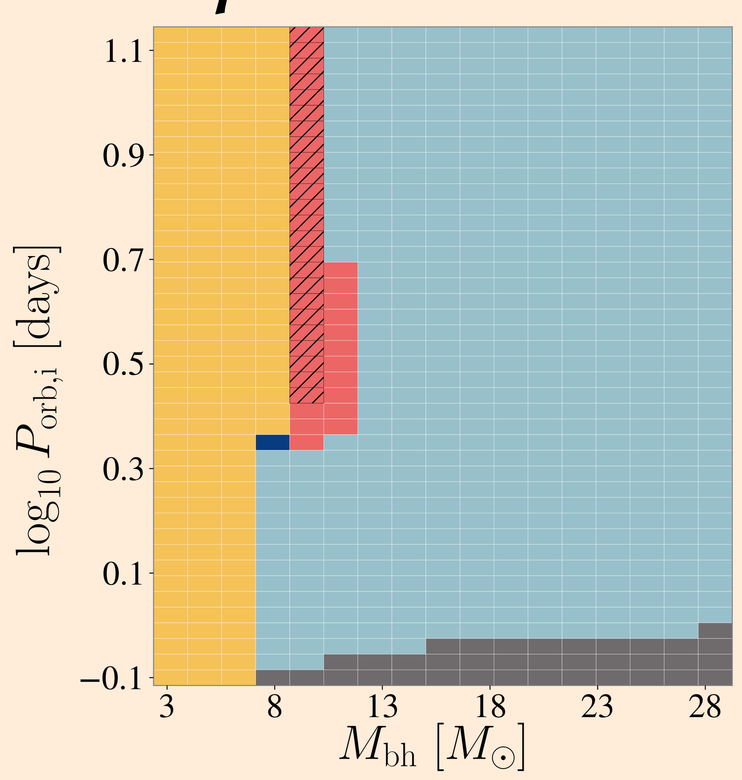
following CE | merger during CE | BBH merger | wide binary | error

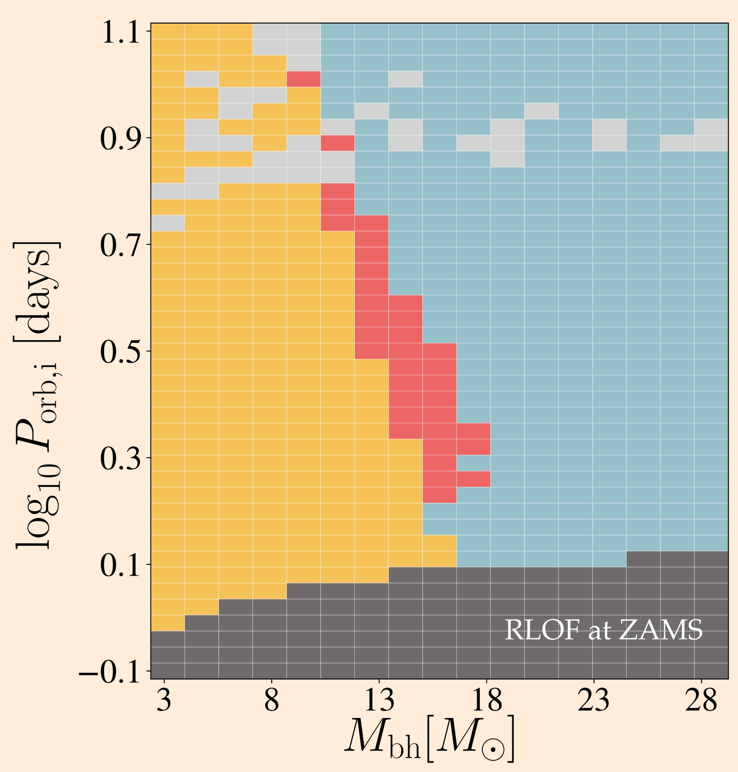
High period binaries





Low period binaries





Preliminary comparison of binary evolution calculated with BSE (left grids) to MESA (right grids). **Models are of a $30M_\odot$ low metallicity star with a companion BH of various masses and at different orbital periods.**

Differences at high orbital period:

- No interaction region begins at higher periods for BSE
- **Significantly fewer binary black hole (BBH) mergers in MESA**
- Significantly more occurrences of CE evolution in BSE calculations

Differences at low orbital period:

- Fewer systems undergoing mergers during CE
- Similar numbers of BBH mergers, but **different formation mechanisms**
- BSE produces NSBH merger

Future Work

- Identify causes of discrepancies
- Explore metallicity
- Calculate merging rates

Acknowledgements

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References

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[3] Belczynski, K et al. 2008
[4] Barrett, J et al. 2018
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[8] Breivik et. al (in prep.)