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ABSTRACT

Common phases of mass transfer in stellar binaries are case A (during the donor's main sequence) and case B (after the donor's main sequence but before helium core depletion). For most masses, radii significantly grow after the main sequence, making case B more common. However, very massive stars ($\gtrsim 30\,M_\odot$) may already undergo significant expansion during the main sequence increasing the probability of case A mass transfer, but this depends on uncertain stellar physics. For observationally-informed convective boundary mixing, case A mass transfer dominates for donor masses $\gtrsim 75\,M_\odot$. This is not the case without convective boundary mixing or with the values assumed in rapid binary population synthesis. Therefore, case A mass transfer may be more dominant than commonly assumed, with potential impact on rates of all post mass transfer binaries.

1. MASS TRANSFER IN VERY MASSIVE BINARIES

Binary stars with a sufficiently small orbital separation undergo a mass transfer phase in which one donor star transfers mass to an accretor. For very massive stars ($\gtrsim 30\,M_\odot$), mass transfer most often occurs as case A or case B Kippenhahn & Weigert (1967).

Case B is expected more often than case A mass transfer, since stars in most mass ranges expand most prominently post-main sequence in the Hertzsprung gap (van den Heuvel 1969). However, very massive stars may already undergo a drastic expansion in radius during their main sequence. (e.g., Sanyal et al. 2015; Jiang et al. 2015; Sabhahit & Vink 2024). This may increase the rate of case A (de Mink et al. 2008), which could have significant implications on the rates of Wolf-Rayet+O-type binaries, X-ray binaries, and gravitational wave progenitors. The radius of the donor is dependent on unknown stellar parameters, including stellar winds (**?**Josiek et al. 2024), metallicity (Xin et al. 2022), close-to-super-Eddington-layers (e.g., **???**), and convective boundary mixing (Anders & Pedersen 2023; Johnston et al. 2024). Here, we illustrate this comparing the radial evolution of very massive stars varying convective boundary mixing, metallicity, and models commonly adopted in rapid binary population synthesis.

2.

We computed 60 MESA models (version 24.03.1) from $30\,M_\odot$ to $100\,M_\odot$ at metallicity $Z = 0.001, 0.0001$ following the setup from **?** with and without overshooting and compared them to the **?** models used in SSE/BSE **?** taken from COMPAS **???**. Individual models are shown in gray, and the red and blue lines in each panel of Fig. **??** denote the maximum radius during the main sequence and helium core burning phase respectively. The right axis shows orbital separations where the stellar radius meets the roche radius (**?**) considering a typical accretor-to-donor mass ratio of $q = 0.55$. The red regions denote binaries which will undergo case A mass transfer and the blue regions denote binaries which will undergo case B mass transfer. In the top left panel, donors with masses $\gtrsim 75\,M_\odot$ can only experience case A. Removing convective boundary mixing (middle) keeps main sequence radii smaller, preserving the blue region at all masses. The overshooting implementation from **?** (bottom), while nonzero, still leaves a large window for case B up to $100\,M_\odot$. At even lower metallicities (right), stars are more compact, and all models allow for case B mass transfer at all masses.

In order to demonstrate the change in ratio between instances of case A and case B mass transfer, we modelled 60 stars while varying mass ($30 - 100 M_\odot$; of $5 M_\odot$ intervals), metallicity ($Z = 0.001, 0.001$) and model of boundary mixing. The top panels of FIGURE are determined from the exponential boundary mixing model from **?** fit to the expected values from the step boundary mixing model from Brott et al. (2011). This is configured in Claret & Torres (2018). This "broad convective boundary mixing" model is compared to a model that does not consider boundary mixing. Both models were instructed to end before the carbon burning phase could commence.

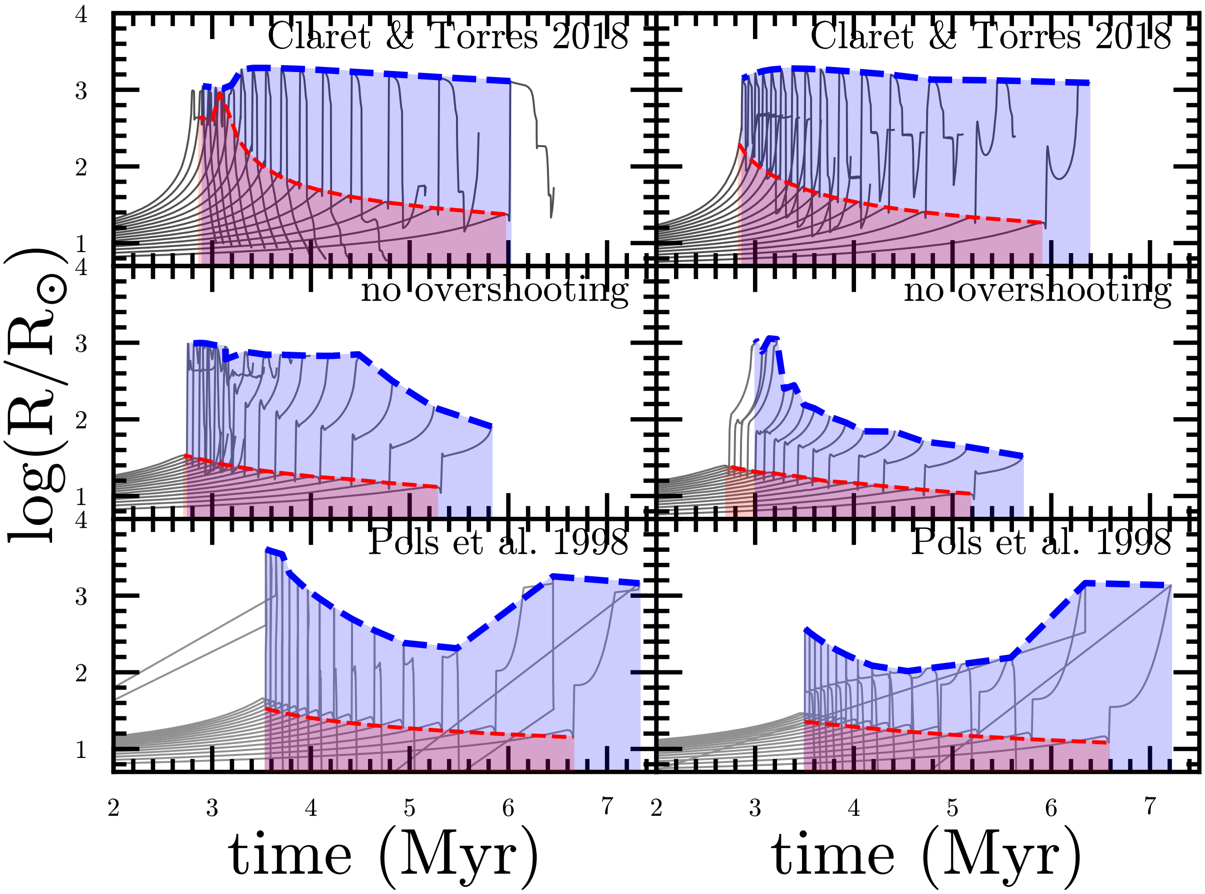

Figure 1. Each panel contain 15 stellar models spanning from a $30\,M_\odot$ star on the right to a $100\,M_\odot$ with intervals of width $5\,M_\odot$. The top panels plot models that feature broad convective boundary mixing, the middle panels plot models that do not feature overshooting, and the bottom panels plot models generated from COMPAS using data from **?**. The left panels have a metallicity $Z = 0.001$ and the right panels have a metallicity $Z = 0.0001$

In addition, 30 models generated using the rapid population synthesis code COMPAS using models generated from data gathered in **?** are plotted in the bottom panels of FIGURE. These models match the metallicities of the stellar evolution models in the other panels. These models include data until core collapse.

Convective boundary mixing has a strong effect on stellar radius Brott et al. (2011); Johnston et al. (2024), which determines Roche lobe overflow. The vast differences in the ratio of expected abundances of case A and case B mass transfer are consequentially expected. The broad convective boundary mixing models limit case B mass transfer for stars of mass ($\gtrsim 75 M_\odot$) . In contrast, omitting convective boundary mixing allows case B mass transfer to occur at a significant scale in all mass regimes such that $M < 100_\odot$. HOW TO CITE Brott's paper suggests broad convective boundary mixing models currently provide the best approximation for observed characteristics of massive stars. As a result, many rapid population synthesis softwares and other stellar mass transfer models may underestimate the abundance of case A mass transfer procedures.

Binary interactions are crucial to the formation of X-ray binaries and gravitational waves sources. in particular for BBH stable mass transfer may dominate **??**

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