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# The impact of a variable angular momentum loss on long-period sdB binaries

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**Abstract.** We investigated the effect of different angular momentum loss during the mass transfer of long-period sdB binaries by implementing a variable angular momentum loss efficiency parameter in MESA code. Our preliminary results show the impact on the mass ratio, orbital period, and metallicity. In particular, the number of long-period sdBs produced is reduced for higher angular momentum loss efficiency.

**Key words:** evolution – mass-loss – subdwarfs

## 1. Introduction

Hot subdwarf B (sdB) binaries with main-sequence companions are thought to be outcomes of stable mass transfer from evolved red giants. The current and typical treatment of angular momentum loss during Roche-lobe overflow is performed by using fixed mass-loss fractions. However, using a static treatment from slow mass loss until the start of a common envelope does not predict many of the observed correlations and the actual angular momentum loss is not objectively known. The change of the angular momentum loss impacts the distribution of the final orbital period, mass ratio, and ultimately the total number of produced sdBs. To investigate the effect of different angular momentum loss during mass transfer in different stellar populations, we have implemented new subroutines in MESA with a variable angular momentum loss efficiency parameter.

### 1.1. Variable angular momentum loss efficiency in MESA

We replaced the current expression for the angular momentum loss in MESA, with the following expression which considers a variation in the rate of angular momentum loss between two extreme scenarios: $\dot{J}_{min}$ and $\dot{J}_{max}$:

$$\dot{J} = (1 - \xi)\dot{J}_{min} + \xi \dot{J}_{max} \tag{1}$$

where $0 \leq \xi \leq 1$ is the degree of mixture. The minimum rate of angular momentum loss, $\dot{J}_{min}$, accordingly to Vos et al. (2020), is given by:

$$\dot{J}_{\min} = J_z \frac{q^2}{(1+q)} \frac{\dot{M}_{RG}}{M_{RG}} \tag{2}$$

where $q = M_{\mathrm{RG}}/M_{comp}$ is the mass ratio between the evolved red giant (RG), which initiates mass transfer at a rate $\dot{M}_{RG}$ through Roche-lobe overflow and the companion at the main sequence. $J_z$ is the angular momentum given by:

$$J_z = \frac{M_{RG}}{(1+q)} \frac{2\pi}{P} a^2 \left(1-e^2\right)^{\frac{1}{2}} \tag{3}$$

where $P$ is the orbital period, $a$ the binary separation, and $e$ the eccentricity of the orbit. Following Bobrick et al. (2017), we considered:

$$\dot{J}_{max} = \dot{M}_{RG} \left[ \left( \frac{q}{1+q} \right)^2 + (0.5 - 0.227 \log_{10} q)^2 \right] \frac{2\pi}{p} a^2 \left(1-e^2\right)^{\frac{1}{2}} \tag{4}$$

where $(0.5 - 0.227 \log_{10} q)$ provides an approximation for the distance between the center of the RG star to the L1 point where the mass transfer occurs, divided $a$ (Frank et al., 2002). Next, we computed binary evolution for different values of $\xi$ for the grid of models presented in Vos et al. (2020).

## 2. Simulations

We based our simulations on the grid computed by Vos et al. (2020) which was developed to study the impact of the chemical history of the Galaxy in observed binary populations. This grid encompasses a set of 2060 Galactic binaries which may potentially produce long-period composite sdB binaries forming at the present epoch. They were selected over a large population of systems representing all the binaries in the Galaxy considering detailed initial mass function, metalicities, age, and mass fraction for different population bins in modeling the Galaxy. The selection criteria for this set of binaries were the following:

- primary masses above 0.7 $M_\odot$ and below 2 $M_\odot$, to dismiss stars which remain at the main sequence and ignite the He core non-degenerately ;
- 1 $<M_{primary}/ M_{comp} < 3$;
- periods between 0.1 and 1.4 times the period corresponding to the Roche-lobe overflow at the tip of the red giant branch;
- and binaries which become sdB at the present day, i.e. in which the primary reaches the tip of the red giant branch no earlier than 300Myr before the present day and no later than 700Myr after the present day.

This set of runs produced 147 sdB binaries for $\xi = 0$, considering sdBs as those stars that reach effective temperatures above 20 000K during its core He-burning phase. In this work, we computed the same set of runs with $\xi = 0.1$ and compare the results with those for $\xi = 0$.

## 3. Results

In Fig. 1 we show the metallicity [Fe/H] vs. final orbital period, P (left panel) and the mass ratio, q vs. P (right panel), for the all sdB produced when considering $\xi = 0$ (blue circles) and 0.1 (orange circles). As mentioned in Vos et al. (2020), the maximum RG radius depends on the metallicity, therefore the final orbital periods of sdB binaries must also correlate with their initial metallicity. This strong correlation is shown in the left panel. It can also be observed that resulting orbital periods decrease when considering higher angular momentum loss. In overall, there are no major differences in these distributions for different values of $\xi$. However, the amount of resulting sdBs for both cases is different, even considering such a small change in the angular momentum loss. We obtained 132 sdBs for $\xi = 0.1$ compared with 147 for $\xi = 0$.

Fig. 2 shows the impact of different angular momentum loss efficiency for systems with the same initial parameters P, q, [Fe/H], and the sdB progenitor mass. Specifically, we considered three systems with the following initial parameters: one system with $P_1 = 430$ [d], $q_1 = 1.49$, $[\mathrm{Fe/H}]_1 = 0.367$, and 1.0 $M_\odot$; a second one with $P_2 = 349$ [d], $q_2 = 1.4$, $[\mathrm{Fe/H}]_2 = 0.1395$, and 1.2 $M_\odot$ and a third one with $P_3 = 163$ [d], $q_3 = 1.45$, $[\mathrm{Fe/H}]_3 = 0.0296$, and 1.8 $M_\odot$. For each of these systems, which are originally sdBs at $\xi = 0$, we compute a set of binary evolution models for $0 \leq \xi \leq 0.1$ with a step of $\Delta\xi = 0.01$. Colour-coding shows the values for $\xi$. Systems that result in sdB stars are marked with circles, sdA stars are marked with diamonds, while systems resulting in He-WDs or horizontal branch (HB) stars are marked with triangles and squares respectively. The diverse evolutionary pathways of binaries systems can be noticed in this $P$-$q$ diagram by the existence of the main and secondary branches. These branches, formed by observed $P$-$q$ relations, are indicated in the figure with red dashes ellipses. In this figure we can observe that for increasing values of $\xi$, the resulting orbital periods are lower. We also observed that even at low values of $\xi$, the progenitors lose a considerable amount of mass which prevents the ignition and results as He-WDs instead of sdBs.

## 4. Conclusions and future work

Our main conclusions for long period sdB binaries are summarized as follows:

– the resulting orbital period, P, decrease for higher values of $\xi$;

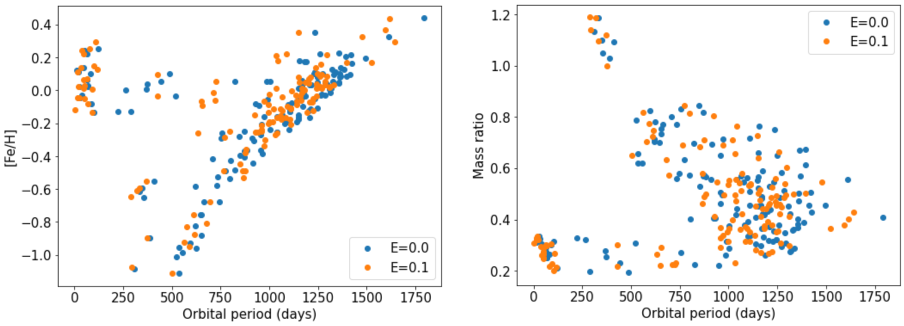


**Figure 1.** [Fe/H] vs. P and q vs. P distributions at the left and right panels, respectively, for the resulting sdBs when considering $\xi = 0$ (in blue) and 0.1 (in orange).

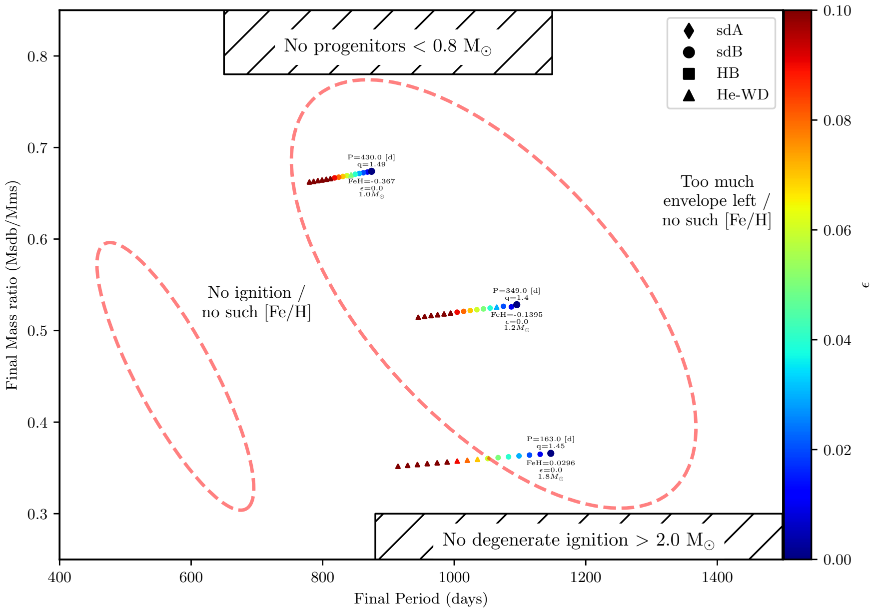


**Figure 2.** Effect of initial parameters: P, q, [Fe/H] and sdB progenitor mass on the final orbital periods and mass ratios, for small changes in $\xi$. We considered three systems with sdB progenitor masses of 1, 1.2 and 1.8 $M_\odot$, indicated in the figure along with the values for $P$, $q$, $[Fe/H]$. Systems that result in sdB stars are marked with circles, sdA stars are marked with diamonds, and systems resulting in He-WDs or HB stars are marked with triangles and squares, respectively. The locations of the main and second branches of the observed P-q relation are indicated in red dashed ellipses. Colour-coding shows the values for $\xi$ considered.

- for long-period sdB binaries, the mass fraction slightly decreases when increasing the efficiency of the angular momentum loss efficiency;
- the small changes implemented in the angular momentum loss efficiency have a little impact in the observable distribution of the sdBs in the [Fe/H] vs. P and q vs. P planes;
- these same changes, however, impact the number of resulting sdB: the higher $\xi$, the lower the number of sdB produced;
- even for values of $\xi \leq 0.1$, the progenitors lose a considerable amount of mass which prevents the ignition and results as He-WDs, instead of sdBs.

The angular momentum loss significantly impacts the evolution of binary systems forming long period sdB stars. Variations in the angular momentum loss alter mass transfer dynamics and the final configuration of these systems. The present study will be extended for $\xi \leq 1$ and compared with observed systems to retrieve reliable constraints for the angular momentum loss.

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