Impact of Binary Systems on Massive Star Evolution

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Abstract

In recent years, research on magnetars has become popular, making the search for progenitor stars of rapidly rotating compact objects an important topic. Accreting stars in binary systems can gain additional angular momentum through Roche Lobe Overflow (RLOF) from the donor star, affecting the rotation rate of the accreting star. Therefore, they are considered a way to produce fast rotating compact objects. This study uses MESA to simulate the evolution of massive binary systems and compares it with the evolution of single stars to understand how binary systems influence the progenitors of supernovae. Results show a higher initial rotation rate reduces mass accretion due to the expansion of the orbit. After RLOF, the accretor accelerates, possibly reaching critical rotation. Lower initial rotation has more mass transfer, leading to even greater acceleration. Mass transfer also alters surface helium abundance, making the accretor's composition differ from single star evolved.

Introduction

Fast rotating compact objects have become a popular topic in recent years. Identifying the progenitor stars of rapidly rotating compact objects is crucial for understanding their origins and formation mechanisms. Low metallicity allows stars to retain sufficient angular momentum, facilitating the formation of magnetars.[1]

Binary systems have a significant impact on stellar evolution. In a binary system, the more massive star (donor star) evolves first and begins mass transfer through Roche lobe overflow (RLOF). The less massive star (accretor star) gains additional angular momentum through this mass transfer. And accretor star is possible to reach critical rotation in main sequence stage.

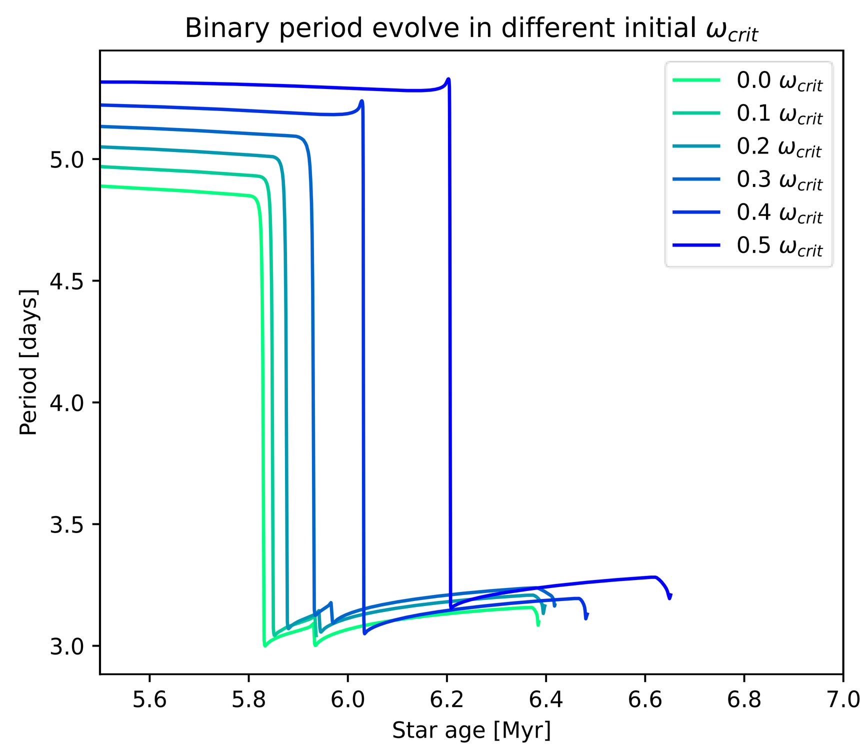
Therefore, understanding how binary system evolution affects massive stars is important.

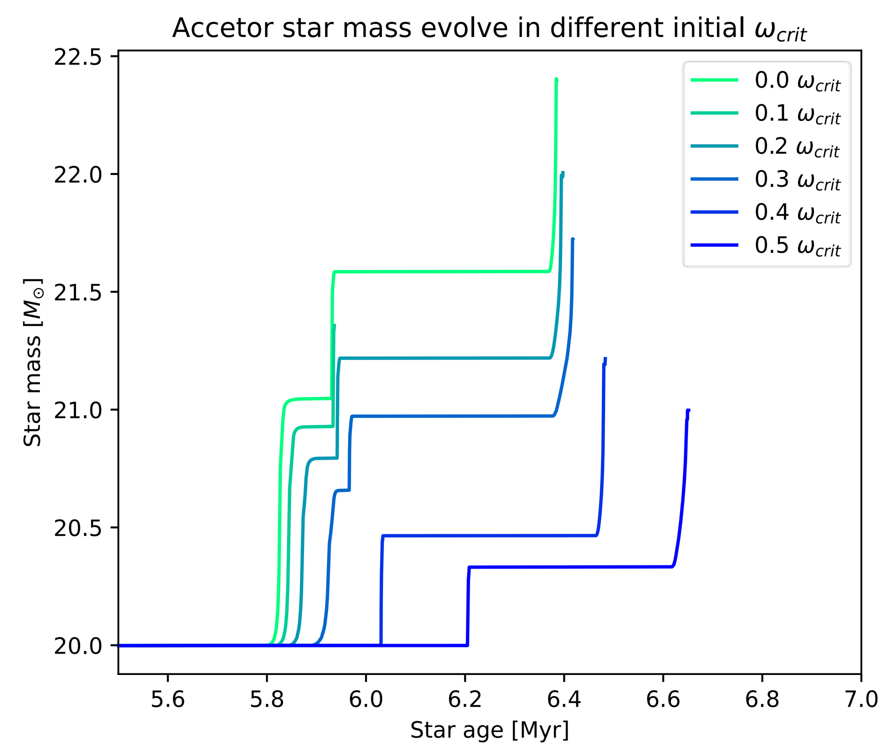
Method

- Our study uses Modules for Experiments in Stellar Astrophysics[2] (MESA) to simulate stellar evolution.
- The binary system consists of a 30 and 20 solar mass star with a metallicity of $z = 0.0001$. Other settings follow Renzo & Götberg (2021)[3] and Wang & Pan (2024)[4]
- Binary systems evolution : angular velocity (ω) is set from non-rotating to 0.5 of the critical rotation speed (ω_{crit}). The orbital period is set to 5 days.
- Single star evolution : the initial mass ranges from 20 to 24 solar masses, with rotation rates varying from non-rotating to 0.5 of the critical rotation speed.

Result

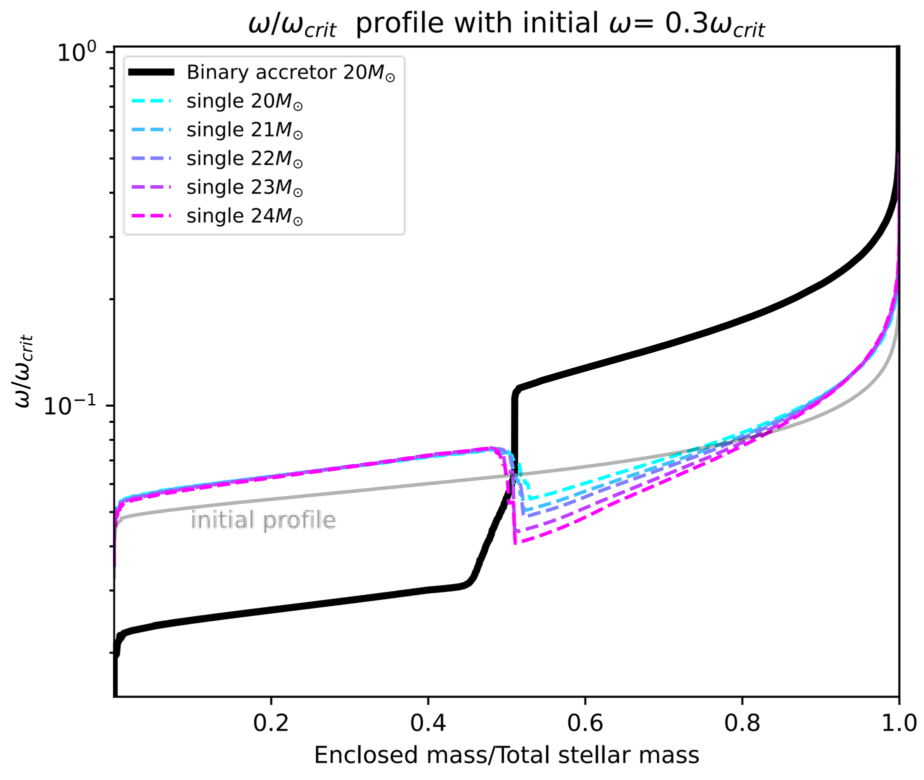
Binary Evolution

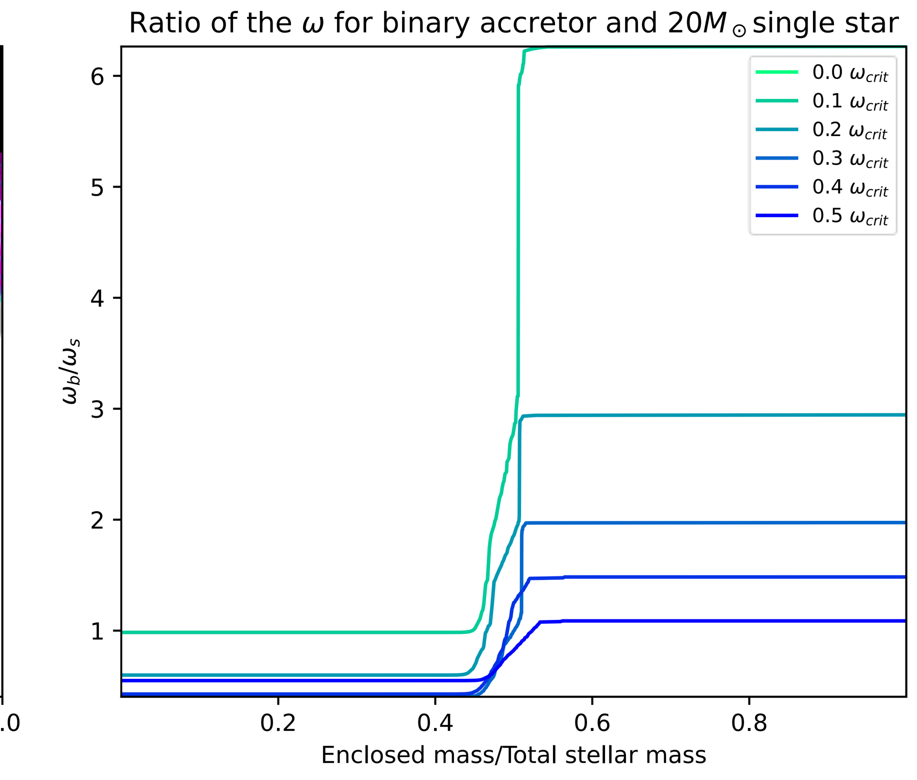




In binary systems, tidal forces cause rotational and orbital angular momentum to transfer, leading to changes in the orbital period. A longer period results in less mass accretion by the accretor star. Hence, higher rotation speeds lead to longer orbital periods (left) and lower accretor star masses (right).

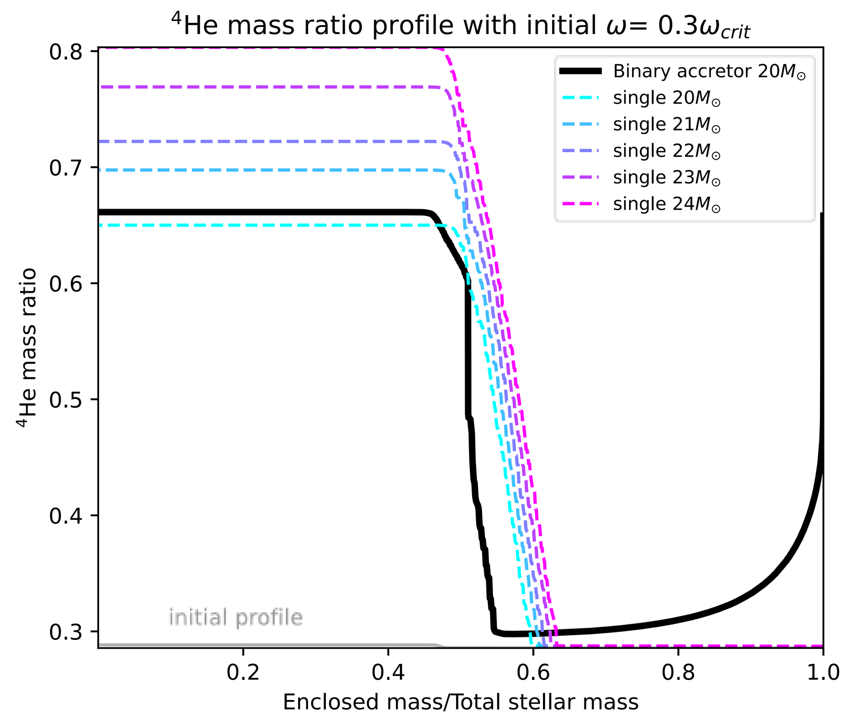
Post-RLOF stage : Angular velocity

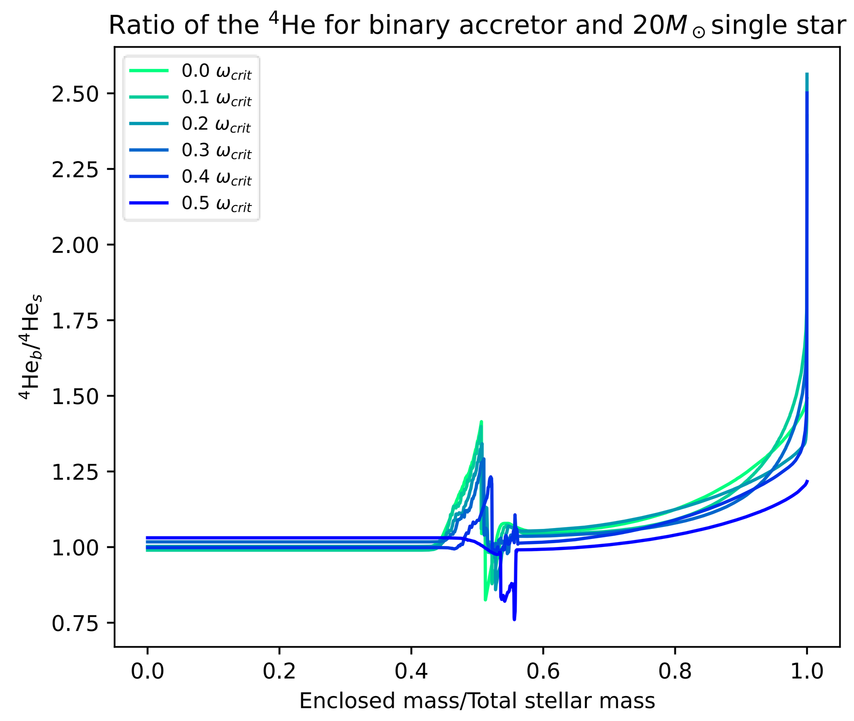




Mass transfer from RLOF provides angular momentum to the accretor star, spinning up its surface (left). Greater mass transfer results in more angular momentum gain, leading to higher spin-up. Therefore, stars with lower initial rotation are accelerated by a larger factor (right). ω_b, ω_s is the ω of the accretor star and single star, respectively.

Post-RLOF stage : ^{4}He abundance





Mass transfer from RLOF alters the elemental distribution of the accretor star. In the post-RLOF phase, the donor star has already been burning helium for some time, leading to significant ^{4}He enrichment on the accretor star's surface (left & right). ^4He_b, ^4He_s is the ^{4}He abundance of the accretor star and single star, respectively.

Conclusion

A binary star system with a higher initial rotation rate will increase orbital period due to tidal forces, resulting in less mass being accreted. In the post-RLOF phase, the accretor star is indeed accelerated, even reaching critical rotation speed. And a lower initial rotation rate allows for more mass transfer, leading to even greater acceleration.

Additionally, the surface helium abundance is altered due to mass transfer, causing the elemental distribution of the accretor star to differ from that of a single star.

Reference

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