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Progenitors of LGRBs: Are single stars enough?

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Introduction

Massive stars, with initial masses greater than $8M_{\odot}$, are the cosmic engines that drive the evolution of galaxies. The evolution of these stars is influenced by factors such as *initial chemical composition*, *wind mass loss*, *rotational mixing*, and *binary interaction*.

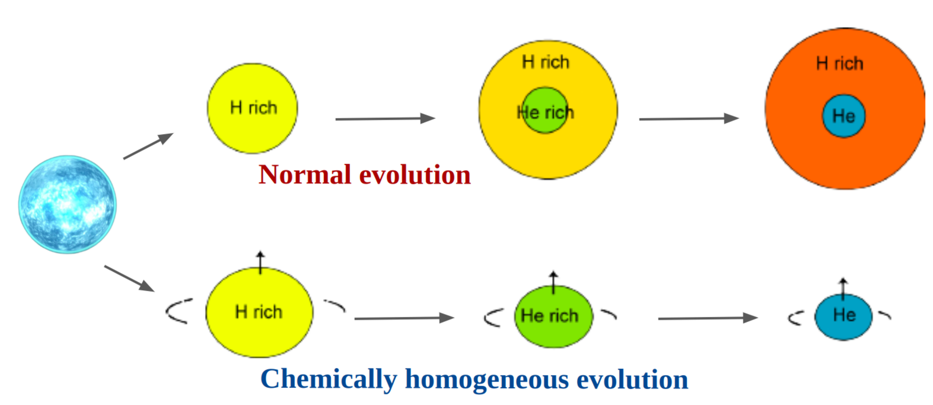

Figure 1: The evolution of a core hydrogen-burning star, with slow rotators forming a core-envelope structure and fast rotators evolving quasi-chemically homogeneously [1].

Illustrated in Figure 1, the evolution of massive stars bifurcates into two pathways, normal and chemically homogeneous [2]. In ***normal evolution***, the star evolves with a gradient of chemical composition from the core to the surface, while ***chemically homogeneous evolution*** results in a uniform chemical composition throughout the star [3]. The fate of massive stars depends on their evolutionary pathway, with normal evolution leading to core-collapse supernova explosions and compact remnants, and chemically homogeneous evolution leading to collapsars. In the ***collapsar model***, a fast-rotating massive iron core is collapsing into a compact object, while the stellar envelope stays in orbit forming an accretion disc. In the two emerging jets along the poles, ***gamma rays*** are emitted by the accretion of material onto the newly formed black hole or magnetized neutron star [4, 5, 6]. This process can happen in both ***single*** and ***binary systems***, and since the rotation rate is metallicity-dependent, it can provide valuable insights into the evolution of massive stars. The recent detections of ***black hole mergers*** by the ***gravitational wave*** observatories imply that a fraction of the observed black holes might be originating from the evolution of massive stars in low metallicity environments.

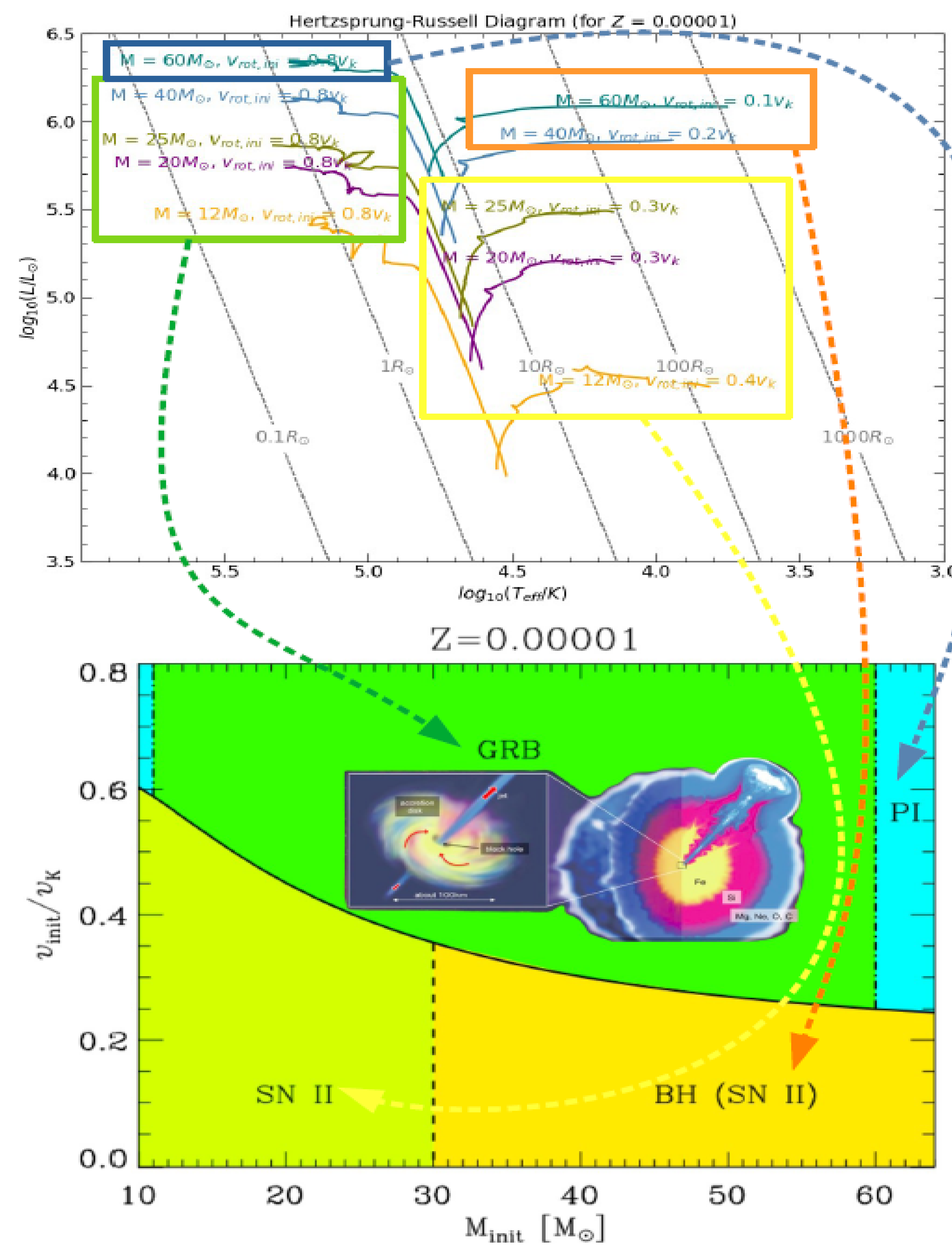

Figure 2: The Hertzsprung-Russell (HR) diagram in this figure shows the stellar evolutionary tracks of massive stars with the initial masses ranging from $12M_{\odot}$ to $60M_{\odot}$ and varying initial fraction of the Keplerian value of the equatorial rotational velocity for $Z = 0.00001$. These models are then contrasted with Figure 3 of [7] to determine the fate of rotating massive star models.

Key outcomes

Single-star models alone are insufficient to explain the observed LGRBs. Therefore, scrutinizing diverse input physics for both single and binary stellar populations against observational data is necessary.

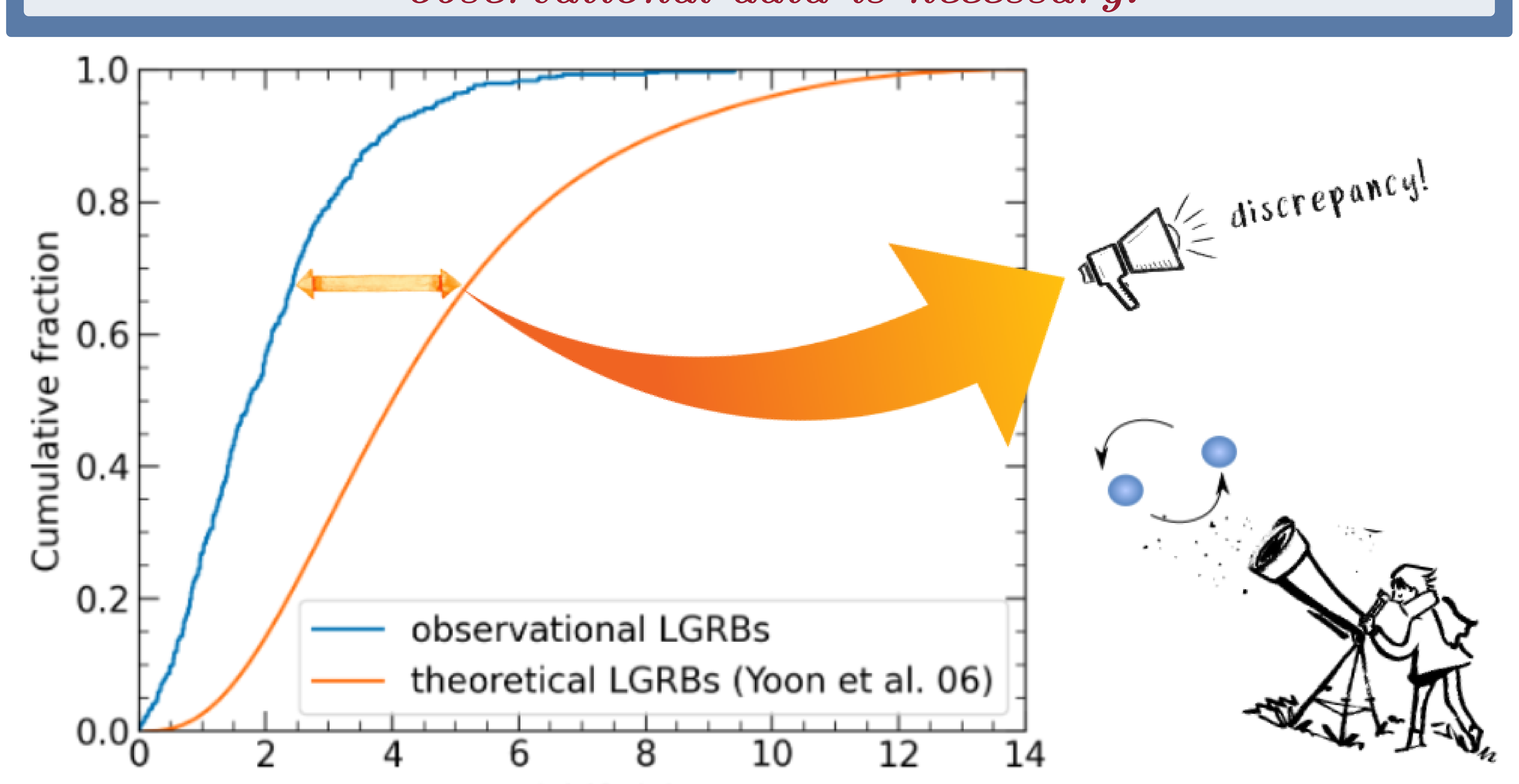

Figure 3: In this figure, I plotted theoretical predictions of LGRBs based on the theoretical single-star population from [7] with the observational data set [9].

Method

Our objective is to evaluate and expand upon the findings of [7], taking into account the latest observational data. Utilizing the Bonn code, Yoon et al. (2006) constructed single stellar models that are presented here in Figure 2 on the ***Hertzsprung-Russell (HR) diagram***. These models are then compared with Figure 3 of [7], which divides the parameterspace into areas of different final fates. Primarily, this comparison helps us establish a connection between the fates and the rotating massive star models at four different metallicities.
Additionally, we compared the observational data set of ***long-duration gamma-ray bursts (LGRBs)*** (also cf. [8]) to the theoretical population synthesis (for single-star systems) of LGRBs from Yoon et al. (2006).

Future work

The next step will be to post-process ***MESA models*** of single stars. Although the predicted rate of LGRBs has been established, it does not coincide with the observational data. This discrepancy might stem from the observational fact that the majority of massive stars exist as binaries. Thus, it is essential to produce comparable predictions for binary star populations. Our primary objective is to provide meaningful advancements to the expanding domains of ***LGRBs*** and ***gravitational-wave progenitors*** through our improved analysis.

References

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