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Very first approach to the lack of fast rotators in Cygnus OB2

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Abstract

Cygnus OB2, within the Cygnus X complex, is one of the most active star-forming regions of our Galaxy, hosting hundreds of O and B-type stars across different evolutionary stages. Despite extensive studies of its massive stars, Cygnus OB2 exhibits a notable absence of fast-rotating stars ($v \sin i > 200$), which challenges existing models of massive star evolution. This study aims to investigate whether some stars classified as B0 in Cygnus OB2 are in fact rapidly rotating late-O stars, which could restore the expected tail of fast rotators in this region. We generated synthetic spectra using `FASTWIND`, and broadened and degraded them with the `SpecBlur` tool to evaluate the effects of rotation and noise on spectral classification. Using spectral reclassification methods and calculating projected rotational velocities with `iacob-broad`, we found approximately 30 % of the B0 population were actually late-O stars. Our work reveals a shortage of fast rotators in Cygnus OB2, even after reclassification, suggesting possible explanations including the young age of the region, alignment of stellar axes, and the potential ejection of fast-rotating stars as runaways.

1 Introduction

Hot massive stars significantly influence the evolution of galaxies by emitting intense radiation and ejecting material into their surroundings [1]. Traditionally, stellar mass and metallicity have been considered as the main factors affecting their evolution; however, stellar rotation has also become recognized as a fundamental process, particularly in massive stars with low metallicity [2]. Observations show that most massive stars exist in binary systems [3, 4], and these interactions between massive companions introduce changes to rotation rates through processes like mass transfer, tidal forces, and mergers.

The rotational velocity distributions of massive stars generally exhibit bimodality [5, 6], with most stars rotating slowly (40–80 km/s) and a high-velocity tail extending to around 450 km/s. Binary interactions are believed to be responsible for this tail [7], yet Cygnus OB2, a young-active region of massive star formation, lacks a population of fast rotators [8]. Given the potential for rotation to alter classification, our study examines whether certain stars currently classified as B0 are, in fact, late-O types with rapid rotation, aiming to account for the missing fast rotators in Cygnus OB2.

2 Effects of rotation on spectral classification

We examined how rotation could lead to misclassification in the late-O and B-type regime, where the weak HeII 4542 line is critical for spectral classification.

To perform the analysis, we generated synthetic spectra for late-O and early-B type stars using the `FASTWIND` stellar atmosphere code [9, 10, 11, 12]. These synthetic spectra were processed using our `SpecBlur` tool, which applies controlled degradation in signal-to-noise (S/N) and rotational broadening. We created a grid of synthetic spectra that covers a range of rotational velocities ($50 - 400\,\mathrm{km/s}$) and two S/N levels (100 and 200).

Our analysis focused on the ratios between HeII 4542 and HeI 4388, which are commonly used to distinguish between late-O and early-B stars. These ratios were measured in both the synthetic and reference spectra [13], with uncertainties calculated based on standard deviations across multiple degraded spectra.

Three main results emerged from our synthetic spectra analysis:

- High-velocity B0 and late-O stars can appear similar to earlier types with lower rotational velocities.
- For B0.2 and B0.5 stars with $v \sin i > 200\,\mathrm{km/s}$ might be classified as later types due to the broadening of HeII 4542 at high rotation.
- Rapidly rotating stars in the O9.5 and O9.7 range could be confused with extremely fast B0 stars due to similar line depth ratios.

Rotational broadening and S/N degradation introduce significant challenges to accurate spectral classification in the late-O to B0 range, with a high potential for misclassifying rapidly rotating O9.5 and O9.7 stars as B0 types. This finding has direct implications for Cygnus OB2, where re-evaluating the classification of early-B stars under the consideration of rotation effects could help identify a hidden population of fast rotators.

3 Spectral reclassification of the B0 population from Cygnus OB2

We address in this work the challenges and inconsistencies in the spectral classification. Discrepancies found in the literature arise from differences in spectral resolution, signal-to-noise ratios, and classification methods. To ensure a unified classification approach, the study follows [14] criteria, which rely on the relative strengths of spectral lines such as HeII 4542, 4200, HeI 4388, 4144, and SiIII 4552.

Using the Marxist Ghost Buster (`MGB`) code [15], we performed spectral reclassification by comparing observed spectra with a grid of standard stars organized by spectral type and luminosity class. Our classification reveals that approximately 30 % of the B0 stars from Cygnus OB2 were actually late-O types., suggesting that some fast rotators may have been misclassified due to the influence of rotation on spectral features.

4 Rotational velocity distribution of Cygnus OB2

The rotational velocity distribution of Cygnus OB2 diverges significantly from expectations based on theoretical models and comparisons with other massive star-forming regions, such as 30 Doradus and Carina OB1. Despite our reclassification efforts, a tail of high-velocity rotators is clear absent in Cygnus OB2 (see Fig 1).

The comparison of rotational velocities from Cygnus OB2 with other regions shows a striking lack of stars with projected rotational velocities ($v \sin i$) exceeding 200 km/s. Probability density functions, derived from empirical studies, suggest that at least 15-20 high-velocity stars should exist in Cygnus OB2, yet only nine O-type stars are observed to have $v \sin i$ over 200 km/s. Furthermore, theoretical models predict that approximately 19 % of massive stars should achieve such speeds due to binary interactions, a frequency not observed in Cygnus OB2.

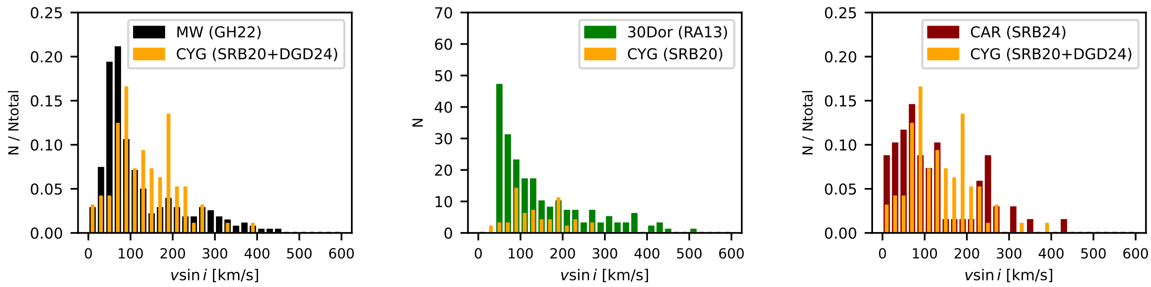

Figure 1: Distribution of projected rotational velocities for OB-type stars across different regions of the local Universe. The histograms in *black*, *green*, and *red* represent the $v \sin i$ measurements for Galactic O stars [5], O stars in 30 Doradus [16], and the the O and B0-type population of Carina OB1, respectively. The *orange* histogram displays the rotational velocities for Cygnus OB2, merging O-types from [8] and our OB sample stars.

5 Explanations for the lack of fast rotators in Cygnus OB2

5.1 Age of Cygnus OB2

The relatively young age (estimated at $1 - 6$ Myr [8]) of Cygnus OB2 may mean that only tidal interactions — active in the initial stages — have influenced stellar rotation rates. Most high-velocity rotators are typically produced by mass-transfer interactions [7], which occur later in stellar evolution (after 8 Myr), suggesting that the limited spin-up effects from tides alone could account for the lack of fast rotators.

5.2 Runaway stars

The absence of fast rotators within the core region of Cygnus OB2 might also be due to the ejection of these stars as runaways. These stars have been spun up by mass-transfer before the more massive star of the system explodes as a supernova, event that might disrupt the system, producing a fast rotator with a relatively large proper motion. Such stars would no longer reside in the core of Cygnus OB2 and may have moved outward, skewing the observed velocity distribution.

5.3 Orientation of spin axes

Another explanation for the lack of fast rotators might be in the alignment of stellar rotation axes. If the rotational axes are predominantly aligned perpendicular to the line-of-sight, only part of the actual rotational velocity would be observable. This alignment could significantly skew the $v \sin i$ measurements toward lower values, leading to an underrepresentation of fast rotators.

6 Conclusions

This study has thoroughly investigated the absence of fast-rotating stars in the Cygnus OB2 region, revealing several key findings. Our spectral reclassification indicated that approximately 30 % of the stars initially classified as B0 are, in fact, late-O stars. Despite this adjustment, the overall population of fast rotators ($v \sin i > 200$) remains significantly lower than both empirical and theoretical predictions, with only nine O-type stars exceeding this threshold.

Several potential explanations for this lack of fast rotators were considered. First, the young age of Cygnus OB2 may limit the impact of mass transfer processes, which typically enhance rotational velocities, as such interactions are expected to become significant only after 8-10 million years. Second, the alignment of stellar spin axes with respect to the line of sight could lead to an underestimation of actual rotational speeds, further skewing the observed distribution. Finally, it is plausible that fast rotators have been ejected from the core of Cygnus OB2 as runaways, contributing to the observed deficit in high-velocity stars.

Our work highlights the need for further investigations into the dynamics of massive stars in Cygnus OB2, particularly focusing on the implications of rotation and binary interactions in this rich star-forming region. Future observational campaigns, especially those utilizing high-resolution spectroscopy, may provide deeper insights into stellar populations and their evolutionary paths in Cygnus OB2.

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