

The *Gaia*-ESO Survey: projected rotational velocities of B stars in the Carina Nebula

W. Santos¹,^{1,2}★ S. Daflon,¹ J. V. Sales Silva,¹ K. Cunha,^{1,3} R. Blomme,⁴ T. Morel,⁵ A. Herrero^{6,7},
J. Maiz Apellániz⁸, L. Mahy⁹,^{4,5,9} S. R. Berlanas,^{6,7} T. Bensby,¹⁰ A. Bragaglia,¹¹ F. Damiani,¹²
A. Frasca¹³,¹³ G. Gilmore,^{14,15} V. Kalari,¹⁶ A. Lanzafame,¹³ S. Randich,¹⁷ S. Van Eck,¹⁷ S. Zaggia¹⁸,
L. O. Kerber² and O. J. Katime Santrich¹⁸

¹Observatório Nacional (ON)-MCTI, Rua José Cristino, 77, 20921-400 Rio de Janeiro, RJ, Brazil

²Universidade Estadual de Santa Cruz – UESC, Rodovia Ilhéus/Itabuna, km 16, 45662-900 Ilhéus, BA, Brazil

³Steward Observatory, University of Arizona, Tucson, AZ 85721, USA

⁴Royal Observatory of Belgium, Ringlaan 3, B-1180 Brussels, Belgium

⁵Space Sciences, Technologies, and Astrophysics Research (STAR) Institute, Université de Liège, Quartier Agora, Bât B5c, Allée du 6 août, 19c, 4000 Liège, Belgium

⁶Instituto de Astrofísica de Canarias, E-38200 La Laguna, Tenerife, Spain

⁷Departamento de Astrofísica, Universidad de La Laguna, E-38206 La Laguna, Tenerife, Spain

⁸Centro de Astrobiología (CSIC-INTA), ESAC campus, Camino bajo del castillo s/n, E-28 692 Villanueva de la Cañada, Madrid, Spain

⁹Instituut voor Sterrenkunde, KU Leuven, Celestijnenlaan 200D, Bus 2401, 3001 Leuven, Belgium

¹⁰Lund Observatory, Division of Astrophysics, Department of Physics, Lund University, Box 118, SE-22100 Lund, Sweden

¹¹INAF – Osservatorio di Astrofisica e Scienza dello Spazio di Bologna, via P. Gobetti 93/3, 40129 Bologna, Italy

¹²INAF – Osservatorio Astronomico di Palermo, Piazza del Parlamento 1, I-90134 Palermo, Italy

¹³INAF – Osservatorio Astrofisico di Catania, Via S. Sofia 78, 95123 Catania, Italy

¹⁴Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK

¹⁵Institute of Astrophysics, FORTH Cert, N. Plastira 100, GR-70013 Vassilika Vouton, Crete, Greece

¹⁶Gemini Observatory/NSF's NOIRLab, Casilla 603, La Serena, Chile

¹⁷INAF – Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, 50125 Firenze, Italy

¹⁸INAF – Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio 5, 35122 Padova, Italy

Accepted 2025 May 27. Received 2025 May 24; in original form 2025 March 13

ABSTRACT

The Carina Nebula is an active star-forming region with several open clusters rich in massive OB stars, thus making it an optimal target for studying stellar properties such as rotation for large samples of these early-type stars. We studied a sample of early-type stars probable members of the eight open clusters in the Carina Complex. The observational data consist of high-resolution spectra from the *Gaia*-ESO public Spectroscopic Survey. Astrometric and photometric data from *Gaia* EDR3 and radial velocities measured from the observed spectra are used to confirm the cluster members. The projected rotational velocities of 330 early-type stars of Carina are derived from the widths of He I lines at 4388 and 4471 Å. The reported $V \sin i$ values are the first estimates for 222 early-type stars. The $V \sin i$ distribution for the Carina clusters peaks at ~ 100 – 150 km s^{-1} , consistent with the distributions for B stars in Galactic clusters. $V \sin i$ estimates for stars members of the clusters Trumpler 15, Collinder 228, Collinder 232, and Bochum 11 are presented for the first time in the literature. For a subsample of stars with earlier spectral types from B0 to B3, we find a bimodal distribution, with a third, small peak towards the upper values of $V \sin i$. When the full sample is split according to the parent cluster, we find that the oldest cluster in our sample, NGC 3293, presents a higher concentration of rapidly rotating stars. In contrast, Collinder 228 presents a larger number of stars with lower $V \sin i$.

Key words: stars: early-type – stars: rotation – open clusters and associations: individual: Carina Nebula.

1 INTRODUCTION

The *Gaia*-ESO Survey (GES; Gilmore et al. 2012, 2022; Randich et al. 2022) performed one of the largest high-resolution spectroscopic surveys of the Galaxy, aiming to characterize the kinematics

and abundances of the Milky Way through a sample of 10^5 stars observed in the different components of the Galaxy (bulge, thin and thick discs, and halo). This extraordinary sample includes the Carina Nebula, which is a region with a high concentration of gas and dust, providing an ideal interstellar medium to trigger and maintain star formation processes, as shown by Rebolledo et al. (2020). The Car OB1 association is a large, very active star-forming region in the Carina–Sagittarius spiral arm, and its stellar population is split into

* E-mail: wjsantos@uesc.br

several open clusters (Lim et al. 2019). The Carina Nebula and its associated clusters have been studied in detail in a large number of photometric studies, such as those by Feinstein, Marraco & Muzzio (1973), Cudworth & Martin (1993), Massey & Johnson (1993), and Hur, Sung & Bessell (2012).

Carina has been the target of many spectroscopic studies, including the analysis of cool stars by Damiani et al. (2017). Based on X-ray data, Damiani et al. (2017) investigated new possible low-mass candidate members in Carina obscured by the dark nebula. The non-uniform reddening in Carina is remarkable due to the presence of significant dust lanes throughout the nebula: the inner region presents a larger ratio of $E(V - I)/E(B - V)$ in comparison with the outskirts. More recently, Maíz Apellániz & Barbá (2018) determined that the extinction across the Carina Nebula is variable not only on the amount of extinction [$E(4405-5495)$] but also on its type [R_{5495}], revealing the existence of different environments along the line of sight of different stars. This issue had previously caused significant discrepancies in the historical measurements of the distance to the Carina nebula (see Maíz Apellániz et al. 2020 for a review). The interstellar medium in Carina has already been discussed by Walborn & Hesser (1982) and Walborn et al. (2002).

The Villafranca project (Maíz Apellániz et al. 2020, 2022) is producing a census of Galactic stellar clusters with OB stars, including some of the clusters and subassociations in the Car OB1 association. More recently, a third paper of the project (Molina Lera et al. in preparation) has analysed the whole Car OB1 association. In those papers, it was found that Trumpler 14 and Trumpler 15 are likely real (i.e. bound) clusters and that Trumpler 16 can be divided into two subregions (Trumpler 16 W and Trumpler 16 E) that are separating from each other as a result of an overall expansion. On the other hand, Collinder 228, Collinder 232, and Bochum 11 are not clearly defined clusters but instead are regions (subassociations) of the Car OB1 association. Other parts of the association are located farther away. One of them, NGC 3293, is an independent massive cluster somewhat older than the previously mentioned ones.

Stellar rotation is fundamental to understanding the formation and evolution of early-type stars, considering that the distribution of rotational velocities as a function of spectral types reaches its maximum at early-B stars (Stauffer & Hartmann 1986). Moreover, models of stellar evolution including rotation show that this parameter alters the duration of the main sequence (MS) and induces mixing processes (Evans et al. 2005). Some spectroscopic studies have analysed the physical parameters of stars in the Carina Nebula, including projected rotational velocities ($V \sin i$). Estimates of stellar parameters and rotational velocities based on spectroscopic analysis are available in the literature for stars in Trumpler 14 and Trumpler 15 (Hanes, McSwain & Povich 2018) and Trumpler 16 and NGC 3293 (Huang & Gies 2006a, b). NGC 3293 is part of the sample studied by Wolff et al. (2007) to investigate the relation between stellar rotation and environment. More recently, based on the Fourier transform, Berlanas et al. (2023) obtained rotational velocities for a sample of O stars in Carina. Nevertheless, approximately two-thirds of the sample studied in this sample still lack rotational estimates, which are provided for the first time in this paper.

In this paper, we present measurements of radial velocities and estimates of $V \sin i$ derived from the widths of He I lines for a sample of main-sequence early-type stars. We also analyse for the first time the $V \sin i$ distributions of the open clusters in central region of the Carina Complex. This paper is organized as follows: in Section 2, we describe the observational data; in Section 3, we present a short description of the membership analysis and the adopted criteria for target selection; in Section 4, we explain the methodology used

to obtain the $V \sin i$ values. In Section 5, we discuss our $V \sin i$ results in terms of the cluster distributions and comparison with previous results from the literature. In Section 6, we summarize our conclusions.

2 DATA

This paper presents the results of a spectroscopic analysis for a sample of early-type stars belonging to open clusters in the Carina region. The study has been conducted by one of the working groups of the GES collaboration, located at the Observatório Nacional, Brazil (so-called ON Node), based on its sixth Data Release (DR6). The sample of stars was defined from a photometric analysis based on colour-magnitude diagrams (CMDs) to select targets with a high probability of being cluster members, as described in Blomme et al. (2022) and Bragaglia et al. (2022).

The spectra analysed in this paper have been obtained with the GIRAFFE multifibre spectrograph coupled to the UT2 of the Very Large Telescope (VLT) at ESO, Chile. The GIRAFFE set-ups used by GES are optimized to detect important features in the spectra of early-type stars: HR03, with spectral coverage $\lambda\lambda$ 4033–4201, contains H δ and Si II lines; HR04, which covers from $\lambda\lambda$ 4188 to 4392, contains the H γ line, an important log g indicator; HR05A has He I and Si III lines and runs from $\lambda\lambda$ 4340 to 4587; and HR06 covers $\lambda\lambda$ 4538–4759 and presents some important lines for T_{eff} diagnosis, such as C III, O II, Si III, and Si IV lines. The observed spectra were normalized by the ROBGrid node (Blomme et al. 2022) and have a nominal resolution typically higher than 20 000 (Gilmore et al. 2022; Randich et al. 2022). Examples of the observed spectra of the B-type star ALS 15 861 are shown in the four panels of Fig. 1. The spectral ranges correspond to the four instrumental configurations HR03, HR04, HR05A, and HR06, from top to bottom. Relevant absorption features are identified in the panels.

The signal-to-noise ratio (SNR) analysis provides a valuable assessment of the spectrum quality and the reliability of subsequent studies. The SNR measurement of the observed spectra was conducted in the continuum region around $\lambda\lambda$ 4455, using the IRAF task *splot*. The measured SNR values are listed in column 4 of Table B1 and the histogram of the SNR results is shown in Fig. 2. Most of the analysed spectra have an SNR of at least ~ 50 , with an average of 112.

The GES obtained GIRAFFE spectra with the blue gratings for 2112 stars in the direction of the Carina Nebula, providing a sample covering different spectral types and luminosity classes. The entire extent of Carina has not been covered by GES observations due to the observational limitation of the survey (Bragaglia et al. 2022). Since our analysis focuses on early-type stars, we used the preliminary temperatures provided by GES as an initial criterion to select stars with $14\,000 < T_{\text{eff}}(\text{K}) < 33\,000$ to form our sample. Stars with spectra showing asymmetric or duplicated lines (indicative of double-lined spectroscopic binary stars) and strong emission profiles in the hydrogen lines (evidence for strong winds or discs)¹ have been discarded from our sample, since these features may introduce additional constraints not included in the methodology adopted in this study. Potential single-lined spectroscopic binaries (SB1) in our sample were not flagged, as the GES observations were not specifically designed for binary analysis. Morel et al. (2022) conducted a detailed examination of the spectra of stars in NGC

¹ Stars with at least one Hydrogen line free of emission in their spectra were kept in the sample.

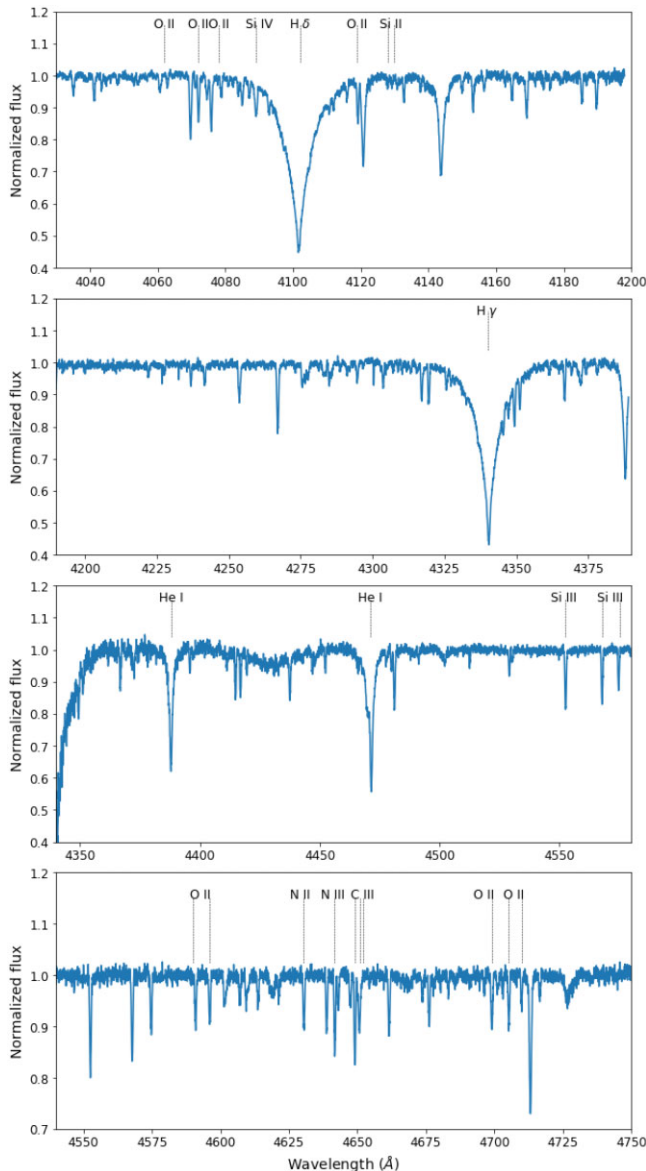


Figure 1. Examples of observed spectra for the B1 star ALS 15861, corresponding to the four GIRAFFE configurations HR03, HR04, HR05A, and HR06. Relevant absorption features are identified in the panels.

3293, obtained with different instrumental configurations and at different epochs. Their study reported a lower-than-expected binary fraction for typical early-type star samples, likely due to the survey design. Consequently, in our analysis, SB1 candidates and single stars were treated using the same methodology. Furthermore, a few stars exhibiting either extremely weak or absent diagnostic lines – due to very low SNR or exceptionally high $V \sin i$ – were excluded from the sample. As a result, our analysis begins with a selection of 347 single-lined, early-type stars associated with open clusters in the Carina Nebula.

3 MEMBERSHIP

The Carina nebula is a very complex region due to its numerous nebular and stellar components, including the clusters Trumpler 14, Trumpler 15, Trumpler 16 E, Trumpler 16 W, Collinder 228, Collinder 232, Bochum 11, and NGC 3293. The gas in this region

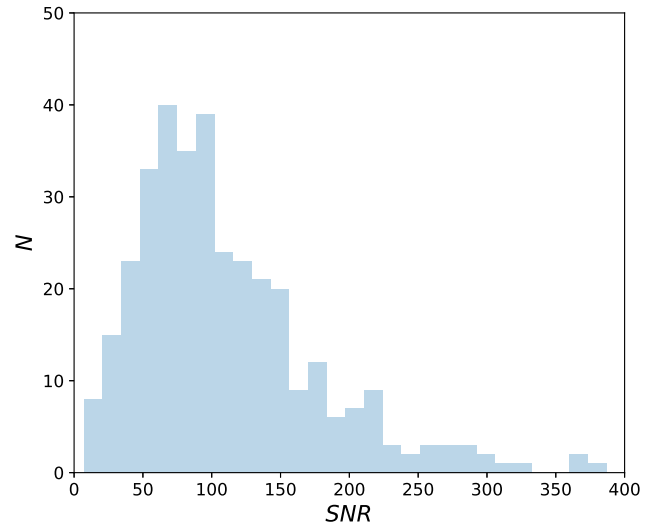


Figure 2. Distribution of SNRs measured in spectra from the sample of 347 stars of spectral types B5 to O9.5 obtained through the HR5 set up.

exhibits an intense temperature variation, ranging from cold (Yonekura et al. 2005) to hot (Seward et al. 1979; Townsley et al. 2011). Carina remains a highly active star-forming region, featuring dense pillars of dust and bright emission from H II regions (Povich et al. 2011). The clusters are embedded in molecular clouds that produce significant extinction, with $A_v \sim 15$ mag (Damiani et al. 2016). A CO-rich molecular cloud with V-shaped dust lanes can be seen in the centre of the OB association Car OB1 (Rebolledo et al. 2016). This dust lane likely plays an important role in the differential extinction observed in the Carina Nebula (Maíz Apellániz & Barbá 2018). A recent census of OB stars in the Carina Nebula (Berlanas et al. 2023) discussed the completeness in the region, considering the high extinction observed. Their associated catalogue lists 316 OB stars in Carina, representing an almost threefold increase in the number of previously known stars.

Since the targets of interest are located very close to the Galactic plane ($b \sim 0.06^\circ$ – 0.07°) and the fraction of contaminants may be significant (~ 20 per cent; Bragaglia et al. 2022), we performed an additional analysis of the astrometric and kinematic properties of targets observed by the *Gaia* mission and radial velocities estimated by us through GES spectra.

To determine the stars of each open cluster in Carina, we used the same procedure for membership analysis as applied by other GES groups for cooler stars. Astrometric and photometric data from *Gaia* EDR3 (Gaia Collaboration 2021) were used to define the members of each cluster. We selected stars from the *Gaia* EDR3 catalogue (Gaia Collaboration 2020) within a radius of 10 arcmin centred on the studied clusters and cross-matched them with our list of stars observed with GES. We used the Renormalized Unit Weight Error (RUWE) measurement to discard stars with poor astrometric solutions. The RUWE value represents the goodness of fit, with <1.0 indicating a good astrometric source. RUWE values between 1.0 and 1.4 may indicate an astrometric binary, a (partially) resolved binary or multiple stars, or even a problematic source (Lindgren 2020). Approximately 62 per cent of the stars in our sample have $\text{RUWE} < 1.0$; for ~ 27 per cent of the stars in our sample, RUWE measurements are within the range 1.0–1.4. Finally, for less than ~ 11 per cent of our sample, RUWE is larger than 1.4, which may indicate problems with the processing of astrometric measurements

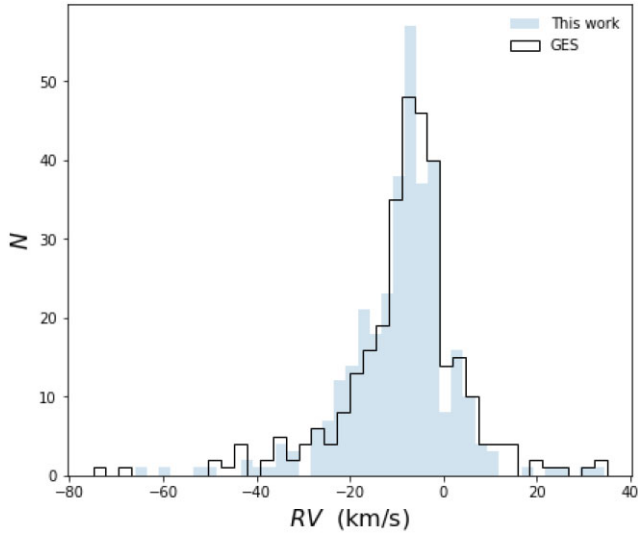


Figure 3. Comparison between the distributions of radial velocities obtained in this work (light blue histogram) and the values from other GES nodes (black-lined histogram).

or a poorly behaved solution. Stars with $\text{RUWE} > 1.4$ have been discarded from our analysis. As an additional parameter for a good astrometric solution from *Gaia*, we also considered precise parallax (ϖ) measurements, with $\sigma_{\varpi} \sim 10$ per cent.

The parallax ϖ has been corrected by the zero point ZEDR3, following Lindegren et al. (2021), to obtain the corrected parallax, ϖ_c . We followed the procedure described in Maíz Apellániz,

Pantaleoni González & Barbá (2021) and Maíz Apellániz et al. (2022) to correct the internal parallax, in case of possible underestimates. The corrected parallaxes are slightly larger than the original results, representing small variations $\delta\varpi < 0.03$ mas for the clusters studied in this paper. In general, these corrections produce small offsets in the parallax results, leading to more accurate distances.

The radial velocities were determined through cross-correlations between synthetic spectra at rest reference and the observed spectra of the target stars. This task was accomplished using the absorption lines of He I at $\lambda\lambda 4388$ and 4471 and Si III at $\lambda\lambda 4552$, 4567 , and 4574 present in the HR05A spectra. The measured radial velocities are listed in Tables B1 and C1. The distribution of the RV results for our sample stars is shown in Fig. 3 as a blue histogram, in comparison with the distribution of RV measurements obtained by other GES nodes (Hourihane et al. 2023) for Carina (black-lined histogram). The two distributions are consistent, with the distribution of RVs provided by GES presenting a slightly higher dispersion.

Fig. 4 presents the astrometric and photometric data provided by *Gaia* EDR3 for stars in the cluster Trumpler 14. The left panel shows the distribution of proper motions in right ascension and declination. The black small triangles represent the cluster members listed by Cantat-Gaudin et al. (2018). Blue open circles represent cluster members while red open circles depict non-members. The open triangles with the same colour code refer to the stars selected for the abundance analysis, which will be presented in a forthcoming paper. The side histograms are colour-coded according to the open circles and the dashed line depicts the mean value for our sample. The upper middle panel shows the distribution of measured radial velocities whereas the distribution of parallax colour-coded for probable members (blue) and probable non-members (red) is shown

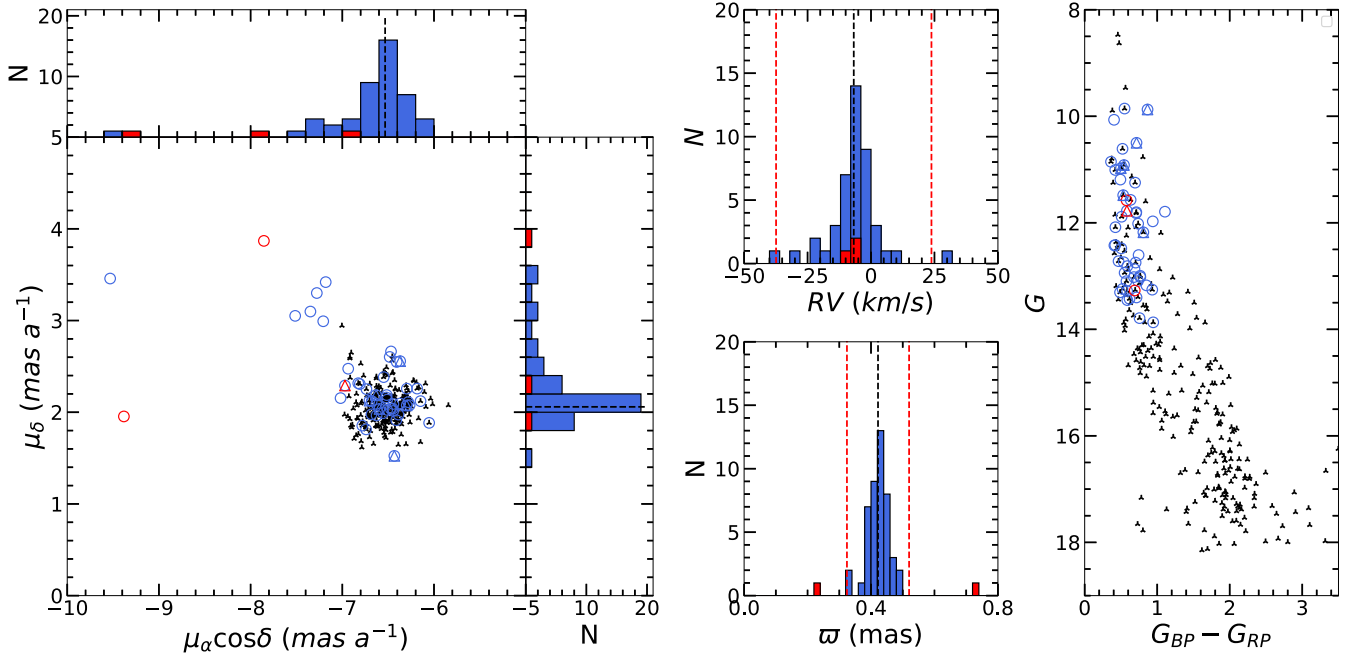


Figure 4. *Gaia* EDR3 astrometric and photometric data for the cluster Trumpler 14. Blue symbols represent stars that are cluster members, while red symbols highlight non-members. The open circles represent stars with $V \sin i$ measurements, while those stars selected for abundance analysis are represented by open triangles. The black small triangles represent the other cluster members by Cantat-Gaudin et al. (2018). *Left panel:* the distribution of proper motions in right ascension and declination. The side histograms are colour-coded according to the symbols and the dashed line depicts the mean value for our sample; *upper middle panel:* radial velocity distribution of the cluster stars; *lower middle panel:* the distribution of parallax colour-coded for probable members (blue) and probable non-members (red). The black dashed line is the mean value for our sample while the red dashed lines represent the 3σ limits; and *right panel:* the CMD for the cluster, using *Gaia* magnitudes.

in the lower middle panel. In these two histograms, the black dashed lines are the mean value for the sample while the red dashed lines represent the 3σ limits. Finally, in the right panel, we present the CMD $(G_{RP} - G_{BP}) \times G$. As expected, the selected sample of early-type stars occupies the upper left part of the CMD. Figures from A1 to A7 are presented in the Appendix A, for the clusters Trumpler 15, Trumpler 16 E, Trumpler 16 W, Bochum 11, Collinder 228, Collinder 232, and NGC3293, respectively, and using the same symbols and colours as in Fig. 4. The CMDs shown in Fig. 4 and Appendix A are not corrected for extinction.

To define our final sample of stars in each cluster, we adopted a conservative selection criterion based on a 3σ deviation in the parallax, similar to Göppel & Preibisch (2022) and Shull, Darling & Danforth (2021). Stars with $\delta\varpi < 3\sigma$ or negative ϖ are classified as background probable non-members, while stars with $\delta\varpi > 3\sigma$ are classified as foreground probable non-members.

The mean parallax for Trumpler 14 is 0.422 ± 0.032 mas. Three stars deviate more than 3σ from the cluster mean value; however one star is not shown in Fig. 4 because its parallax value is negative and out of interval shown in the figure. The star ALS 15 864 has a parallax relatively close to the threshold value, and its radial velocity is consistent with the cluster mean value, so we decided to keep this star in the sample, marked as red open triangles in Fig. 4. Berlanas et al. (2023) also marked this star as a probable member. ALS 15 206 is reported in different sources in the literature either as a member of Trumpler 14 or Trumpler 16. Our analysis is more consistent with ALS 15 206 being a member of Trumpler 14, in agreement with the conclusion of Berlanas et al. (2023).

The mean parallax of Trumpler 15 is 0.425 ± 0.031 mas, and the parallaxes of six stars are outside the 3σ limit. Two stars, ALS 15 860 and GES 10451811–5924277, have parallax very close to the threshold value and were kept in the final sample for the chemical analysis. The rich cluster Trumpler 16 E has a mean parallax of 0.430 ± 0.023 mas, with two stars outside the 3σ limit (one of them is not shown in the histograms of Fig. A2 because its parallax value is off-scale). Trumpler 16 W has a mean parallax of 0.430 ± 0.027 mas, and the parallaxes of all stars fall well within the threshold limit. NGC 3293 is the most populated cluster of our sample, with a mean parallax of 0.420 ± 0.031 mas. One star’s parallax is outside the threshold, and it is considered a probable non-member.

Bochum 11 has a mean parallax of 0.432 ± 0.028 mas, and one star, ALS 16082, may be considered a probable non-member, according to the 3σ criterion. Collinder 228 is the cluster of our sample with the highest dispersion in parallax: 0.415 ± 0.051 mas. Ten stars fall outside the 3σ limit in parallax, although their radial velocities are consistent with the cluster distribution. Five of these stars, which are very close to the threshold, are good candidates for chemical analysis so we decided to keep them in the sample. The star 2MASS J10442909–5948207 was marked as a member of Collinder 228 while ALS 1853 was considered a background object by Berlanas et al. (2023). The mean parallax of the cluster Collinder 232 is 0.436 ± 0.013 mas, and all stars are probable members according to the 3σ criterion.

Based on the analysis of the Figs 4 and A1–A7, we found 23 background and foreground objects likely to be contaminants and those are listed in Table C1. However, we decided to keep in our sample eight of these stars that present parallax slightly outside the 3σ limit but have radial velocity and proper motion still consistent with the mean value of the parent cluster and are good candidates for the chemical analysis. At this stage, our sample comprises 332 stars that are probable members of the studied clusters: 46 stars in Trumpler 14, 40 stars in Trumpler 15, 71 stars in Trumpler 16 E, 9

stars in Trumpler 16 W, 19 stars in Collinder 232, 22 stars in Bochum 11, 59 stars in Collinder 228, and finally, 66 stars in NGC 3293.

4 PROJECTED ROTATIONAL VELOCITIES

The projected rotational velocity $V \sin i$ becomes an important broadening mechanism at $V \sin i$ greater than 100 km s^{-1} and significantly affects the moderate to weak metallic lines present in the spectra of early-type stars. However, Helium lines can still be identified and measured in the observed spectra of rapidly rotating stars. The two panels of Fig. 5 show the effect of $V \sin i$ on the Helium lines at 4388 (right panel) and 4471 Å (left panel) of three stars with different rotational velocities: ALS 1808 with $V \sin i = 35 \text{ km s}^{-1}$, ALS 17 541 with $V \sin i = 114 \text{ km s}^{-1}$, and ALS 1827 with $V \sin i = 250 \text{ km s}^{-1}$.

One of the aims of this analysis is to present $V \sin i$ estimates for a sample of B stars in the Carina Complex, based on the widths of Helium lines. We used the methodology described by Daflon et al. (2007), based on the full width at half-maximum (FWHM) measurements of synthetic profiles of three He I lines at 4026, 4388, and 4471 Å, to estimate $V \sin i$. However, our spectra cover only the lines 4388 and 4471 Å. Thus, the $V \sin i$ estimates are derived through the interpolation of the measured FWHM of these two Helium lines in the grid of synthetic widths. This grid was built from measurements of the widths of non-LTE synthetic He I profiles computed with LTE model atmospheres for solar abundance (ATLAS9; Kurucz 1993) combined with non-LTE line formation (DETAIL; Giddings 1980); (SURFACE; Butler & Giddings 1985). The grid covers T_{eff} from 15 000 to 30 000 K, in steps of 5000 K, and constant values of surface gravity ($\log g = 4.0$, typical of young B stars) and microturbulent velocity (5 km s^{-1}). The synthetic spectra have been convolved with instrumental broadening corresponding to $R \sim 10\,000$ and $50\,000$, and rotational profiles ranging from $V \sin i = 0$ to 400 km s^{-1} , in steps of 50 km s^{-1} . The computations also included limb darkening using a linear limb-darkening law with a coefficient of ~ 0.3 , typical for early-type stars (Wade & Rucinski 1985). Daflon et al. (2007) investigated the impact of surface gravity variations on $V \sin i$ estimates and found that differences in $V \sin i$ are negligible for changes in $\delta(\log g) = \pm 0.3$ but can increase to 10–15 per cent for variations of $\delta(\log g) = \pm 0.5$ dex. They concluded that, although the grid has been computed for a fixed value of $\log g = 4.0$, it can be safely used for stars with $\log g = [3.7\text{--}4.3]$.

Upon examining the CMDs of the clusters in Figs 4 and A7, we observe that most of the studied stars, indicated by blue circles or triangles, are either on the MS or have recently evolved from it. To further investigate, we analysed the observed hydrogen line profiles of six seemingly evolved stars – four from Trumpler 16 E and one from Trumpler 16 W. The width of the hydrogen line wings did not provide evidence of low surface gravity, suggesting that these stars may not be as evolved as their positions on the CMDs imply. This suggests that their surface gravities ($\log g$) likely fall within the expected range for such evolutionary stages. Finally, two stars in Trumpler 15 and four in Collinder 228 that appear to have evolved away from the MS and are marked with red symbols, have been classified as non-members.

Daflon et al. (2007) did not account for gravitational darkening and macroturbulence in their calculations, which can lead to underestimations of $V \sin i$ by 12 per cent–33 per cent, depending on the spectral type and the rotational regime. As a sanity check, they also derived $V \sin i$ values from the synthesis of weak metal lines for a subset of sharp-lined stars in their sample, finding excellent agreement with

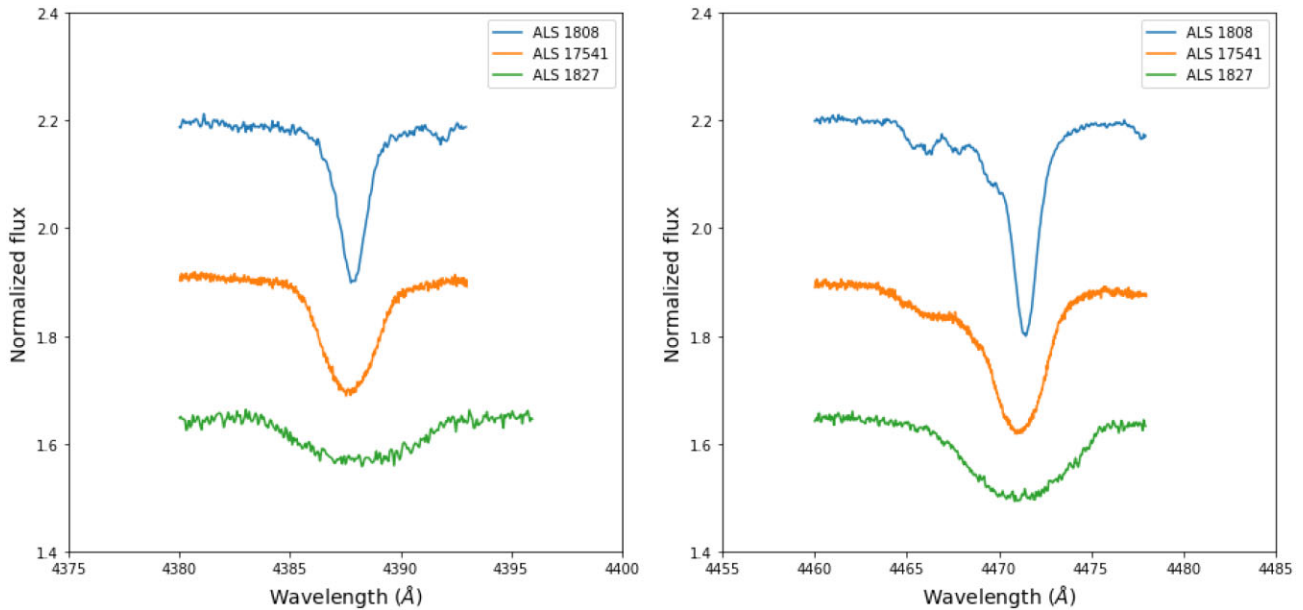


Figure 5. The effect of $V \sin i$ on the observed profiles of He I lines at 4388 Å (right panel) and 4471 Å (left panel). The $V \sin i$ values corresponding to each example spectrum are, from top to bottom, 35 km s^{−1} (blue line, star ALS 1808), 114 km s^{−1} (orange line, ALS 17541), and 250 km s^{−1} (green line, ALS 1827).

those obtained from the widths of He I lines. The mean difference between the two methods was -0.4 ± 7.7 km s^{−1}, suggesting that this method can be safely used to obtain first estimates of rotational velocities.

Following the recommendation of Daflon et al. (2007), we considered that the grid is adequate for our sample since most of the stars in our sample are on the MS. The input parameters necessary to interpolate in the grid and obtain $V \sin i$ are the effective temperature and the line widths measured from the observed spectra. The widths of the He I lines 4388 and 4471 Å were measured using the task `splot` of the reduction package IRAF. This tool allows the manual fit of a Gaussian or Voigt profile to spectral lines and automatically computes the FWHM from the fit parameters. The quality of the fit is influenced by the spectral SNR (S/N), line depth, and blending with neighbouring features. In our analysis, we adopted Gaussian fits for the He I lines, and we verified consistency through repeated measurements. Based on the typical S/N (>50) in our spectra and comparisons between multiple lines per star, we estimate that the uncertainty in the FWHM measurements is in the range of 5–10 percent. For spectra with S/N below ~40, the uncertainties may increase significantly due to continuum placement errors and poor line contrast.

At this point of our analysis, the adopted effective temperatures are those values recommended by GES. This approach is justified since the T_{eff} value has a small impact on the derived $V \sin i$. For example, considering the line He I 4388 Å with FWHM = 3.0 Å the obtained $V \sin i$ is 107 km s^{−1} for $T_{\text{eff}} = 20\,000$ K and 105 km s^{−1} for $T_{\text{eff}} = 15\,000$ K. Fig. 6 illustrates the effects of $V \sin i$ (left panel) and T_{eff} (right panel) on the synthetic profiles of the line He I 4471 Å.

The estimation of $V \sin i$ was not possible for those stars of our sample with very broad or very sharp lines, implying that $V \sin i$ is likely higher than 400 km s^{−1} or close to zero, respectively, the limits of the adopted grid. These constraints led us to discard only two stars from the sample: 2MASS J10461906–5957543, with $V \sin i \sim 0$, and ALS 15248, with $V \sin i > 400$ km s^{−1}. Our final sample comprises 330 stars probable members with $V \sin i$ estimates. In Table B1, we present the FWHM of the two He I lines, and the

corresponding $V \sin i$ values obtained from the interpolation in the grid. The last column shows the average $V \sin i$ value and the corresponding dispersion computed from the $V \sin i$ obtained from the individual lines.

5 DISCUSSION

5.1 Comparisons with the literature

Our initial sample comprises 330 stars from eight open clusters in Carina. Some early-type stars of the studied open clusters have published results of previous spectroscopic analysis. Among these, 108 stars (~33 percent) have at least one $V \sin i$ measurement available in the literature, while 222 stars (~67 percent) lack such data. Consequently, this study provides the first $V \sin i$ measurements for approximately two-thirds of the sample.

Huang & Gies (2006a, b) obtained the stellar parameters T_{eff} , $\log g$, and $V \sin i$ for a large sample of early-type stars in 19 open clusters, including Trumpler 14 and Trumpler 16, based on a method that combines fits of synthetic profiles of Balmer lines and He I lines. Hanes et al. (2018) obtained T_{eff} , $\log g$, and $V \sin i$ for a sample of hot stars in Carina using non-LTE synthesis of the He I lines at $\lambda\lambda 4026$, 4388, and 4471.

NGC 3293 is a well-studied cluster with a larger number of stars having previous spectroscopic analysis. McSwain et al. (2009) obtained stellar parameters T_{eff} , $\log g$, and $V \sin i$ from non-LTE synthesis based on the grid of Non-LTE models BSTAR2006, combining fits of synthetic profiles of H γ and He I lines at $\lambda\lambda 4388$, 4471 and Mg II $\lambda 4481$. The method of Hunter et al. (2009) to obtain the parameters T_{eff} and $\log g$ for stars in NGC 3293 uses silicon ionization balance (Si II and Si III) and hydrogen lines, while $V \sin i$ is estimated based on He I and metal lines. Morel et al. (2022) studied 160 stars with spectral types B1 to B9.5 in the cluster NGC 3293 in the context of the GES, based on GIRAFFE and UVES spectra. They obtained T_{eff} , $\log g$, and $V \sin i$ using a global least-square minimization to derive the stellar parameters.

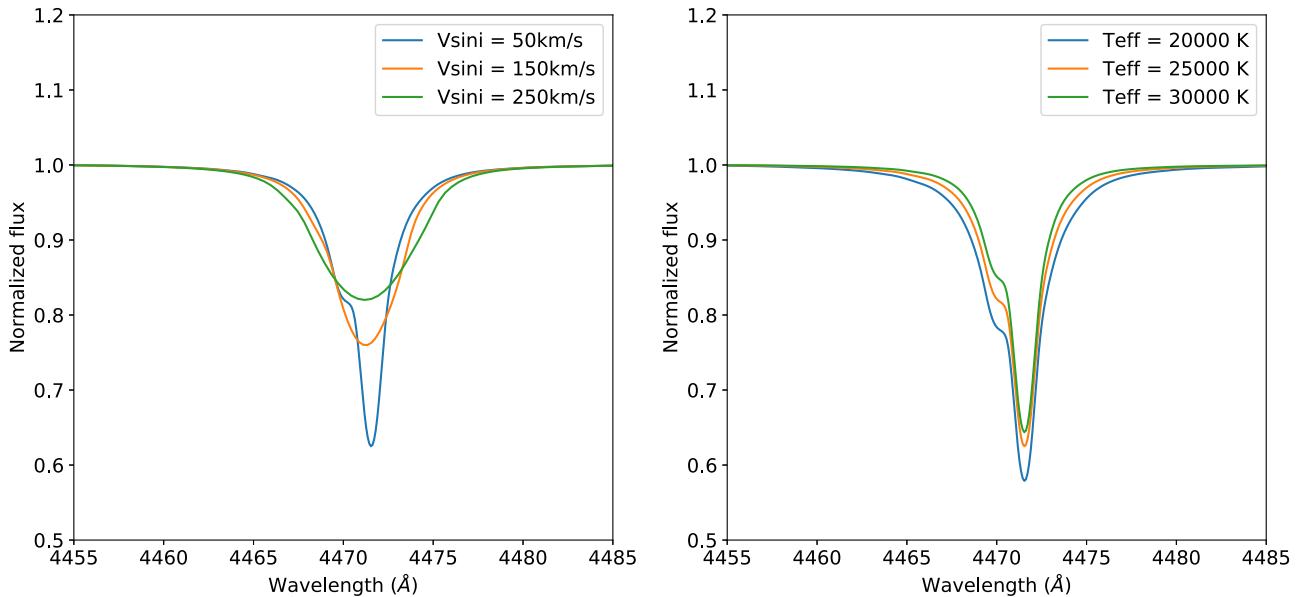


Figure 6. The effect of three different $V \sin i$ (left panel) and of three different T_{eff} (right panel) on the synthetic profiles of He I line 4471 Å.

Other working groups of the *Gaia*-ESO Collaboration also determined $V \sin i$ using different methods, such as a combined Fourier transform plus a goodness-of-fit methodology (The IAC Node) and non-LTE spectral synthesis (The Liège Node). Fig. 8 of Blomme et al. (2022) shows the comparison between the $V \sin i$ values obtained by different nodes of the *Gaia*-ESO Collaboration, including our node (ON Node). There, such a comparison was done for a sample of stars in common in the different studies including benchmark stars and other stars not belonging to the Carina region. The comparison between the $V \sin i$ values derived by the ON Node and those from the IAC and Liège Nodes shows good agreement. Berlanas et al. (2025) obtained rotational velocities for a sample of 38 O9-type and 27 B0-type stars in Carina, using *iacob-broad* (Simón-Díaz & Herrero 2007), based on a method that combines Fourier transform and the goodness-of-fit to determine the $V \sin i$ from diagnostic lines, such as He I or metal lines.

In Fig. 7, we compare our $V \sin i$ results for each star with those found in the literature and results from other nodes of the GES Collaboration. The top left panel shows the comparison with the results based on the widths of He I lines. The points are colour-coded according to the reference: results from Huang & Gies (2006b) are represented as blue circles and orange pentagons are from Hanes et al. (2018). The average difference in $V \sin i$ between our results and the results of Huang & Gies (2006b) and Hanes et al. (2018) obtained from the He I lines is $-3.9 \pm 25.2 \text{ km s}^{-1}$. The comparison between our results and those based on the fitting of metal and helium lines is shown in the top right panel. The averaged differences between our results and those of Hunter et al. (2009; red triangles) and McSwain et al. (2009; purple diamonds) are 1.9 and 3.2 km s^{-1} , respectively, in excellent general agreement within the uncertainties. The results obtained by Morel et al. (2022; black squares) present different behaviour according to the regime of stellar rotation: for $V \sin i < 200 \text{ km s}^{-1}$, results by Morel et al. (2022) are systematically lower than ours by a factor of 4 percent, while for $V \sin i > 200 \text{ km s}^{-1}$, Morel's results are ~ 12 percent larger than ours. This behaviour may be due to the relative importance of other broadening effects considered in the computation of the synthetic metal lines, as suggested by Daflon et al. (2007).

The bottom-left panel compares our $V \sin i$ estimates with those obtained by Berlanas et al. (2025) for 14 O9 stars (grey squares) and 22 B0 stars (yellow circles) that overlap with our sample. The $V \sin i$ results for the B0-type stars are consistent with our estimates within the uncertainties, while the results for the O9 stars show slightly higher dispersion. Finally, the bottom-right panel of Fig. 7 shows the comparison between our $V \sin i$ estimates and those values obtained by other GES Nodes, considering only the stars in the Carina Nebula. The average difference between the two data sets is $1.8 \pm 24.8 \text{ km s}^{-1}$. The $V \sin i$ values of most of the stars agree well within the uncertainties, with a few discrepant values, and the error bars tend to be larger for the higher $V \sin i$, which is expected and consistent with uncertainties expressed in relative difference.

5.2 Stellar rotation and cluster age

Huang & Gies (2006a) examined a sample of 496 early-type stars in 19 open clusters with varying ages, ranging from 6 to 72 Myr, with a median age of 12.5 Myr. They obtained an average value of $< V \sin i > = 147 \pm 26 \text{ km s}^{-1}$, which matches the average $V \sin i$ for our sample, $< V \sin i > = 159 \pm 91 \text{ km s}^{-1}$. In contrast to the sample of Huang & Gies (2006a), the clusters in our study are younger, with a narrow range of $\log(\text{age})$ between 6.678 and 7.139, as listed in Table 1. The adopted ages for the clusters Trumpler 14, Trumpler 15, Trumpler 16, Bochum 11, and NGC 3293 are from Dias et al. (2021a), obtained by fitting theoretical isochrones to *Gaia* DR2 photometric data, as described in Monteiro et al. (2020). The ages of the clusters Collinder 228 and Collinder 232 are from Loktin & Popova (2017), based on 2MASS photometric data.

In Fig. 8, we plot the average $V \sin i$ of young clusters as a function of the cluster age. Results of Huang & Gies (2006a) for fourteen well-sampled clusters are represented by orange triangles. Our median $V \sin i$ values for the Carina clusters are represented by the blue circles: dark blue circles represent the adopted ages listed in Table 1 while light blue circles represent the different ages found in the literature for the studied clusters, connected by the horizontal lines. The youngest Carina cluster of our sample is Trumpler 16, which

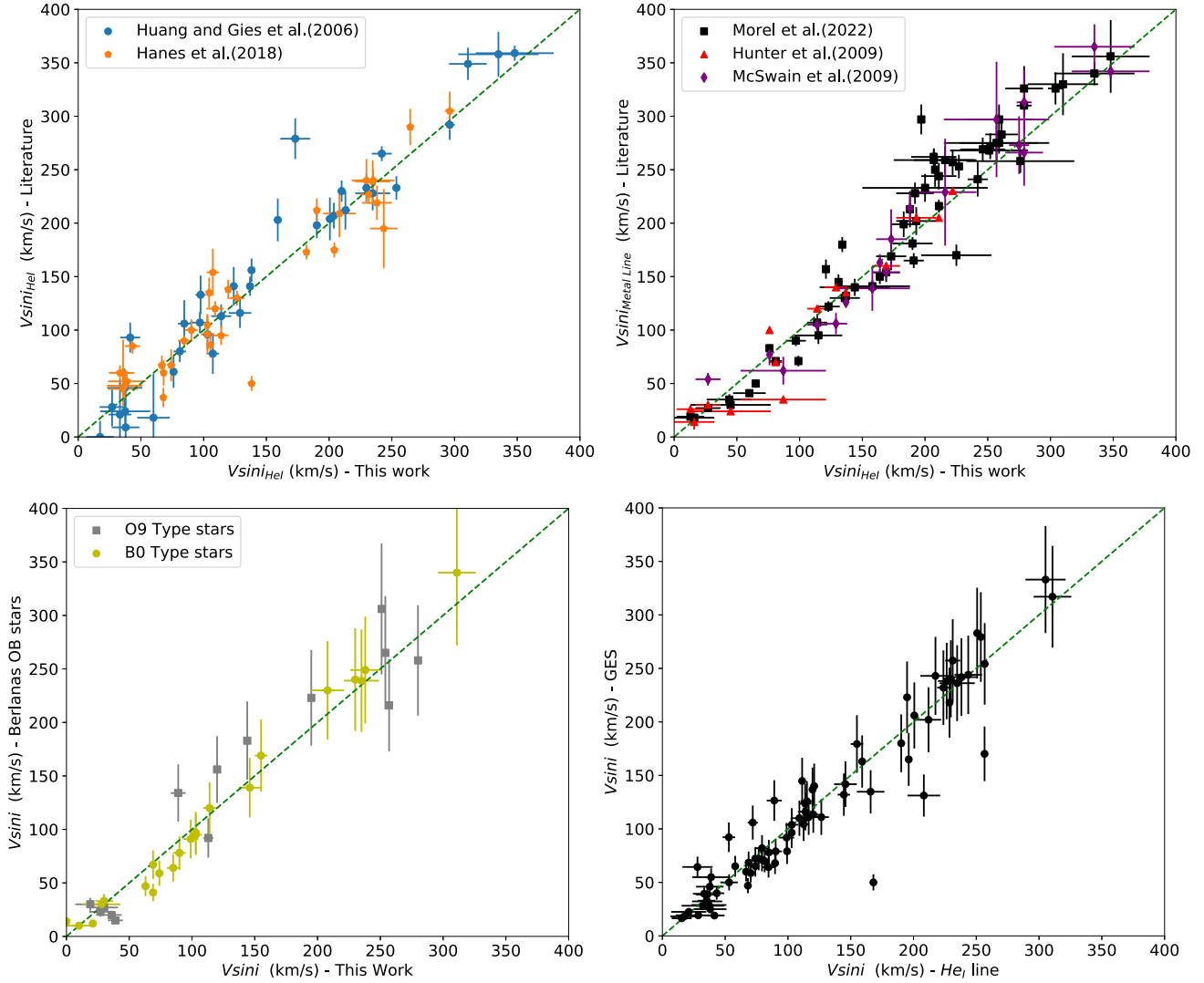


Figure 7. Comparison of $V \sin i$ values obtained in this study with literature results. The top-left panel presents published $V \sin i$ values derived from the widths of He I lines by Huang & Gies (2006b; blue circles) and Hanes et al. (2018; orange pentagons), showing an average difference of $-3.9 \pm 25.2 \text{ km s}^{-1}$ relative to our measurements. The top-right panel displays $V \sin i$ values obtained from spectral fits of helium and metal lines by Hunter et al. (2009; green triangles) and McSwain, Huang & Gies (2009; purple diamonds), with average differences of 1.9 and 3.2 km s^{-1} , respectively. Additionally, Morel et al. (2022; black squares) reported $V \sin i$ values that are systematically lower than ours by 4 per cent for $V \sin i < 200 \text{ km s}^{-1}$ and approximately 12 per cent higher for $V \sin i > 200 \text{ km s}^{-1}$. The bottom-left panel compares our results with those of Berlanas et al. (2025), where $V \sin i$ values for O9 stars (grey squares) exhibit slightly higher dispersion, while those for B0 stars (yellow circles) remain consistent with our estimates within the uncertainties. Finally, the bottom-right panel shows $V \sin i$ values obtained by other Nodes of the *Gaia*-ESO Collaboration, with an average difference of $1.8 \pm 24.8 \text{ km s}^{-1}$ relative to our results. In all panels, the dashed line represents the one-to-one correlation ($x = y$).

Table 1. The clusters ages.

Cluster	$\log(\text{age})$	Ref.
Trumpler 16 E/W	6.678 ± 0.053	Dias et al. (2021a)
Bochum 11	6.721 ± 0.101	Dias et al. (2021a)
Trumpler 14	6.726 ± 0.006	Dias et al. (2021a)
Trumpler 15	6.814 ± 0.068	Dias et al. (2021a)
Collinder 228	6.865 ± 0.032	Loktin & Popova (2017)
Collinder 232	6.874	Loktin & Popova (2017)
NGC 3293	7.139 ± 0.016	Dias et al. (2021a)

generally is not split into E and W components in the literature. The age of Trumpler 16, as one cluster, varies from $\log(\text{age}) = 6.90$ (Conrad et al. 2017) to 7.13 (Cantat-Gaudin et al. 2020), which are all greater than the age we adopted, from Dias et al. (2021b). Two clusters of our sample have scarce age estimates in the literature: the age of Bochum 11 obtained by Cantat-Gaudin et al. (2020), $\log(\text{age}) = 6.80$, is quite consistent with the age we adopted in our analysis, while the age of Collinder 232 obtained by Preibisch et al. (2011) is ~ 0.4 dex smaller than the value we list in Table 1. The logarithm of the ages of Trumpler 14 are consistent in many studies, for example, 6.67 (Conrad et al. 2017), and 6.81 (Hunt & Reffert 2023). On the other hand, the $\log(\text{age})$ of Trumpler 15 obtained by Dias et al. (2021a) is smaller than other values from the literature,

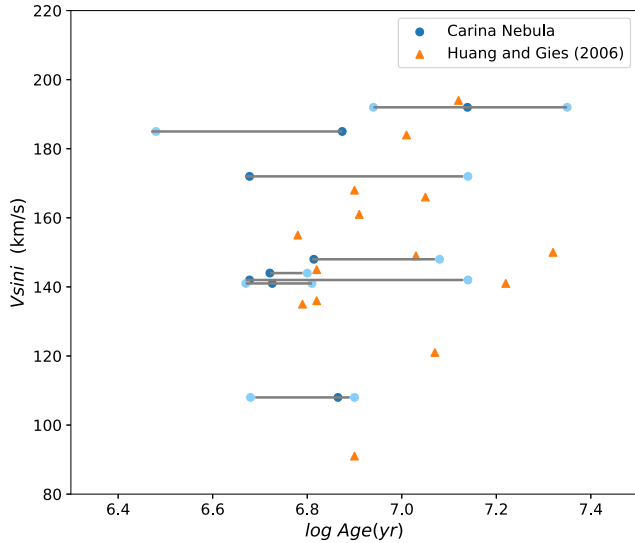


Figure 8. The median $V \sin i$ of our open clusters as a function of the cluster age. The blue circles represent the data for the Carina clusters studied in this paper (dark blue for ages listed in Table 1 and light blue for different ages available in the literature) and the orange triangles represent the 14 open clusters studied by Huang & Gies (2006a).

such as 6.95 (Cantat-Gaudin et al. 2020) and 7.08 (Conrad et al. 2017; Hunt & Reffert 2023). Conversely, the age of Collinder 228 listed by Loktin & Popova (2017) is greater than 6.68 by Conrad et al. (2017) and 6.85 by Hunt & Reffert (2023). The oldest Carina cluster of our sample is NGC 3293, with ages varying from $\log(\text{age}) = 6.94$ (Conrad et al. 2017) to 7.35 (Hunt & Reffert 2023). The analysis of Morel et al. (2022) reported an age of 20 Myr for NGC 3293, which corresponds to $\log(\text{age}) = 7.30$.

The discrepancy between the various age estimates of the studied clusters hampers the analysis of any possible trend of averaged $V \sin i$ with age. Furthermore, our sample is unsuitable for this study, since all studied clusters are of very similar age, considering the uncertainty. Nevertheless, the largest number of fast-rotating stars is found in the oldest cluster of our sample, NGC 3293.

5.3 $V \sin i$ distributions

The distribution of $V \sin i$ for the sample of 330 probable members of the Carina region is shown as the light blue histogram in Fig. 9, with an average value of $\langle V \sin i \rangle = 159 \pm 91 \text{ km s}^{-1}$. The distribution of $V \sin i$ has a peak between 100 and 150 km s^{-1} , which is a typical value for early-type stars (Wolff et al. 2007; Wolff, Edwards & Preston 1982; Huang & Gies 2006a, 2006b). The distribution is consistent with the histogram of $V \sin i$ for early-type stars in clusters (dark blue line; Huang & Gies 2006b). Approximately 70 per cent of the stars in our sample present $V \sin i$ values higher than 100 km s^{-1} . On the other hand, the distributions of $V \sin i$ for the field stars, represented by the orange and purple lines, Abt et al. (2002) and Huang & Gies (2008), respectively, have an excess of slowly rotating stars when compared to the stars in clusters.

In Fig. 10, we show the cumulative distribution functions (CDF) of $V \sin i$ for our sample (blue line), as well as the CDFs for stars in clusters (black: Huang & Gies 2006a) and for field stars (orange: Abt et al. 2002 and purple: Huang & Gies 2008). The differences in the steepness of the curves provide insights into the rotational velocity distributions across different studies and regions. A steeper curve

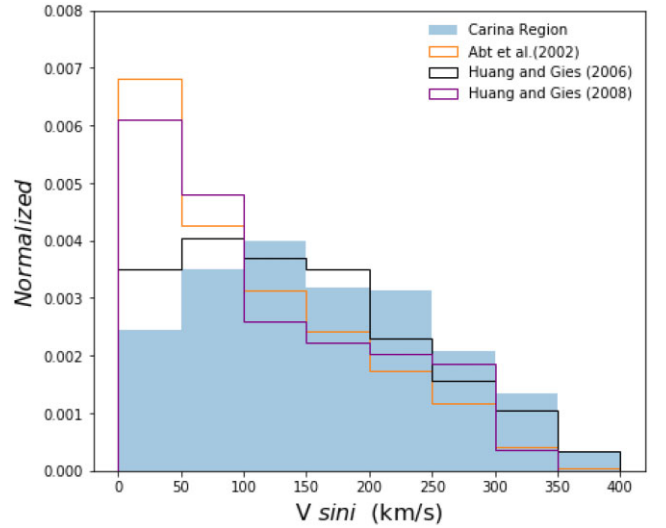


Figure 9. Distribution of $V \sin i$ obtained for 330 probable members of the Carina region (light blue histogram), compared to the distributions of $V \sin i$ of early-type stars in clusters (dark blue line; Huang & Gies 2006a), and for field stars (Huang & Gies 2008; purple line) and in the field (orange line; Abt, Levato & Grosso 2002).

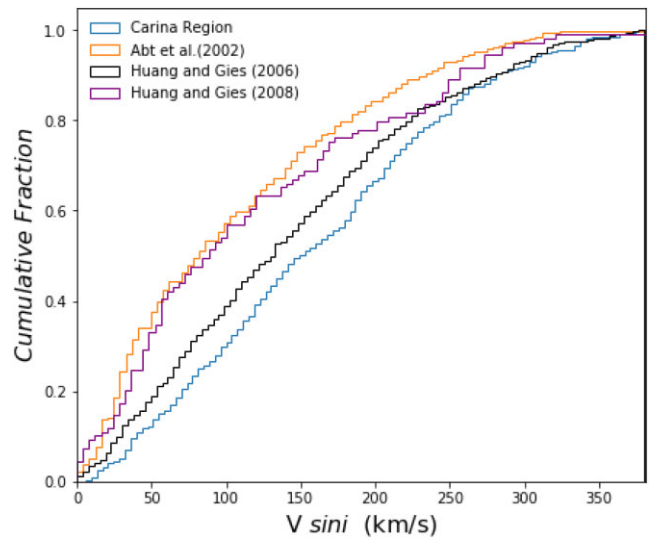


Figure 10. The cumulative fraction of stars as a function of $V \sin i$ for different data sets of stars in clusters (blue: Carina, this work; black: Huang & Gies 2006a) and in the field (orange: Abt et al. 2002 and purple: Huang & Gies 2008).

indicates a data set with more stars having similar, lower $V \sin i$ values. A more gradual curve indicates a broader range of rotational velocities, suggesting a more diverse population in terms of $V \sin i$. The two CDFs for field stars are similar and both increase more steeply, particularly in the range of 0 to 200 km s^{-1} . This suggests a higher concentration of stars with lower $V \sin i$ values compared to the Carina Region. The curves for field stars reach the cumulative fraction of 1 more quickly, indicating fewer high-velocity stars. A K-S test between our sample in Carina and the samples of field stars rejects the null hypothesis, assuming a confidence level of 95 per cent. The CDF for stars in Carina increases more gradually compared to the other data sets, indicating a wider spread of $V \sin i$ values. The CDF for stars in clusters by Huang & Gies (2006a) displays a similar

trend as the one for stars in Carina, although the former distribution is steeper than the Carina curve.

These results align with the conclusions presented by Wolff et al. (2007) and Huang & Gies (2006b) that early-type stars in clusters tend to show higher $V \sin i$ values when compared to field stars. Analyses by Abt et al. (2002) and Huang & Gies (2006b) suggested that the lower concentration of slow-rotating OB stars in different density scenarios could be related to evolutionary processes.

Field stars are generally older than stars in young clusters, as they may represent remnants of dissolved clusters (Gies & Huang 2004; Bragança et al. 2012). Over time, processes such as magnetic braking (Stępień 2000), stellar wind-driven mass-loss (Maeder & Meynet 2000), and tidal interaction in close binaries (Zahn 1977) can reduce stellar rotation rates. These mechanisms may contribute to the lower $V \sin i$ values observed in field populations. This supports the interpretation of field stars having, on average, slower rotation due to their more advanced evolutionary stage and cumulative angular momentum loss.

However, Wolff et al. (2007) suggests that this relationship is not the most appropriate, proposing that star clusters that survive the bound cluster formation process likely originate from dense environments. These OB stars typically exhibit characteristics such as a high average accretion rate during stellar formation, short core collapse times, and early disc disruption through photoevaporation. These factors may contribute to the emergence of rapid rotators within denser clusters. Conversely, objects that form in unbound associations are thought to originate from regions with lower surface density and shorter accretion times. Lower surface density can result in weaker interactions with neighbouring objects, making these stars less susceptible to early disc disruptions. This could help preserve a higher stellar rotation rate.

Wolff et al. (2007) investigated the influence of environmental density on the $V \sin i$ distribution in clusters. This study included eight clusters formed in high-density regions, seven low-density clusters, and field stars, suggesting that denser environments tend to produce more fast-rotating stars. Bragança et al. (2019) studied the rotation of 350 B-type stars located in different environments of the Galactic disc, including field stars and OB associations. Their results suggest that the distribution of $V \sin i$ of the field stars exhibits a significant concentration at lower values ($V \sin i < 50 \text{ km s}^{-1}$). Conversely, the peak of the $V \sin i$ distribution for stars in OB associations is shifted towards higher values, between 50 and 100 km s^{-1} . In the context of Bragança et al. (2019)'s study, our results suggest that there is a general trend of finding more rapidly rotating stars in the open clusters in Carina when compared to field OB stars (Abt et al. 2002; Huang & Gies 2008), which is consistent with the trend previously identified by Wolff et al. (2007) and Bragança et al. (2019).

To better understand the relationship between the density of the clusters in Carina and their rotation rates, it would be necessary to estimate the density of the clusters. However, significant reddening in the Carina region, which deeply affects the completeness in the region (Section 3), prevents a study of $V \sin i$ in terms of the densities of the Carina clusters.

Dufton et al. (2013) studied a sample of O9.5-B3 stars in the 30Dor region, in the context of the VLT-FLAMES Tarantula Survey for a sample of 334 young OB stars. They used the Fourier transform method to derive $V \sin i$ and their obtained distribution is bimodal, with ~ 25 percent of the sample presenting $V \sin i < 80 \text{ km s}^{-1}$. Following Dufton et al. (2013)'s approach, we segregate those stars in Carina from our sample with spectral types between B0 and B3. The adopted spectral types of the sample stars come from different

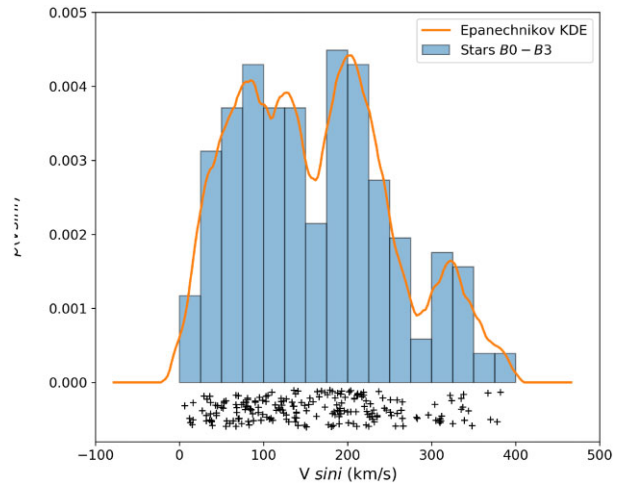


Figure 11. Distribution of $V \sin i$ for 206 B0–B3 stars of our sample. The PDF obtained with a Epanechnikov kernel is represented by the orange line and the black symbols at the bottom represent the $V \sin i$ estimates in each bin. The vertical scatter of points is artificial to avoid overlap and does not carry any quantitative meaning. The distribution is bimodal, with a third, smaller peak at high $V \sin i$.

sources listed in the SIMBAD data base. When spectral subtype was not available, we used the effective temperature and the relative intensity of key metal lines as a rough estimate of the spectral subtype. Fig. 11 presents a histogram of $V \sin i$ for this subsample of 206 B0–B3 stars, showing the frequency distribution of the $V \sin i$ estimates, represented by the black crosses at the bottom. The vertical scatter of points is artificial to avoid overlap and does not carry any quantitative meaning. Overlaid on the histogram, the orange line represents the overall probability density function (PDF) for $V \sin i$, fitted using an Epanechnikov kernel. The bandwidth was chosen according to the *rule of thumb* (Silverman 1986). The distribution shows two prominent peaks, suggesting a bimodal distribution of $V \sin i$ among the B0 to B3 stars. The first peak is centred around 100 km s^{-1} and the second peak is centred around 200 km s^{-1} . There are few stars with $V \sin i$ values above 350 km s^{-1} , indicating these extreme velocities are rare in this sample. A similar statistical analysis was performed using a combination of Gaussian distributions, confirming the bimodality of the $V \sin i$ distribution.

In Dufton et al. (2013), the bimodal distribution has been interpreted as an indication of two different populations of stars within these spectral types, resulting from different formation conditions, stellar ages, or even the presence of nearby companions. However, Dufton et al. (2013) found no evidence of a correlation between the stars's rotation and their relative positions in the 30Dor region. The OB stars of our sample have been formed in clusters within the large complex of Carina association, with similar ages and distances (Göppl & Preibisch 2022). The full comprehension of the big picture in Carina still lacks more information about the stellar populations, such as chemical composition, that could be obtained from a detailed spectroscopic analysis.

Morel et al. (2022) studied approximately 160 stars in NGC 3293, with spectral types between B1 and B9.5. They derived stellar parameters, $V \sin i$, and chemical abundances based on non-LTE synthesis. The $V \sin i$ measurements were convolved with synthetic spectra for all GIRAFFE configurations and the best fits were chosen using χ^2 . The distribution of the apparent $V \sin i$ for their sample is Gaussian, with a peak at $V \sin i$ around 250 km s^{-1} . Morel et al. (2022) found no evidence of a bimodal structure in the $V \sin i$

distribution of NGC 3293 and they suggest this may be because their sample includes stars cooler than B3. Our analysis of NGC 3293, based on a sample of 66 stars with earlier spectral types, between O9.5 and B6, also results in a Gaussian $V \sin i$ distribution, although its peak is shifted towards slightly lower $V \sin i \sim 200 \text{ km s}^{-1}$.

At the age range of the oldest open cluster of our sample, NGC 3293, binary interaction may be responsible for the enhanced rotational velocity distribution. As shown by McSwain & Gies (2005), many Be stars are spun up through binary mass transfer mechanisms. The larger number of fast rotators in NGC 3293 may thus reflect evolutionary processes in close binaries that have had enough time to operate. This interpretation aligns with the observed peak in $V \sin i$ distribution and supports the idea that Be stars emerge preferentially in slightly older stellar populations due to post-interaction spin-up effects. We note, however, that the census of Be stars in the sample clusters was not an objective of this work.

Berlanas et al. (2023) studied the population of OB stars in the same Carina clusters studied in this paper, but not NGC 3293. Their sample comprises stars with spectral types earlier than B2 in the case of dwarfs, earlier than B5 in the case of giants, and all spectral types in the case of supergiants. The spectra of the B stars are mainly from GES while the data for the O stars are from the GOSSS project (Maíz Apellániz et al. 2016, and references therein). Berlanas et al. (2023) discussed the distribution of stellar rotation in terms of a rotation index that qualitatively indicates the line broadening, from slight to severe. For this sample of O and early-B types stars, they obtained a distribution that peaks at the bin $200\text{--}250 \text{ km s}^{-1}$, suggesting their sample presents a higher concentration of rapidly rotating stars compared to the distributions of the clusters studied in this work. This may result from the fact that our sample includes stars with spectral types between B3 and B6 that are not present in Berlanas' sample.

Stellar rotation is believed to play a crucial role in the formation of circumstellar discs observed around B-type stars with emission lines in their spectra – commonly known as Be stars (Rivinius, Carciofi & Martayan 2013). Some stars in our sample exhibit emission lines in their observed spectra. However, as mentioned in Section 3, the Carina region is embedded in dense molecular clouds, so some central emissions may have a nebular origin.

The observed emission lines are classified based on visual inspection of their profiles and measurements of the FWHM. Narrow, single-peaked lines are classified as nebular emission, and the corresponding sources are considered non-Be stars. In contrast, broad emission lines – sometimes displaying double peaks or P-Cygni profiles – are likely formed in circumstellar discs. Based on this classification approach, 73 stars in our sample were identified as Be stars, and 257 as non-Be stars (including those with probable nebular emission lines).

We note however the number of stars classified as Be stars may be overestimated, especially in Trumpler 14 and Trumpler 16W, as some of the detected emission lines could originate from nebular rather than from a rotating circumstellar disc. A detailed analysis to confirm the origin of these emission profiles is beyond the scope of this paper.

Fig. 12 shows the $V \sin i$ distributions for non-Be stars (blue histogram, average $V \sin i = 151 \pm 88 \text{ km s}^{-1}$) and Be stars (orange histogram, average $V \sin i$ of $187 \pm 99 \text{ km s}^{-1}$). Be stars, in particular, tend to rotate more rapidly, with a higher concentration of fast rotators and a distribution peak shifted slightly toward higher $V \sin i$ values. These results are consistent with previous studies indicating that Be stars are generally rapid rotators, often approaching their critical rotational velocities. It is important to note that $V \sin i$

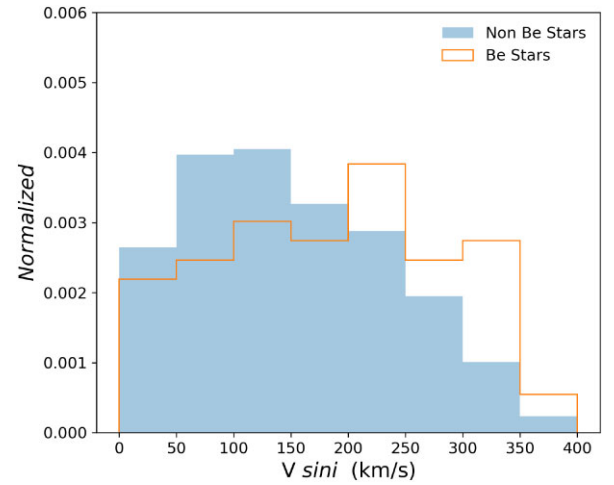


Figure 12. Distributions of $V \sin i$ for 73 Be (orange) and 257 non-Be (blue) stars in Carina. The peak of the $V \sin i$ distribution for the Be stars is shifted towards higher values.

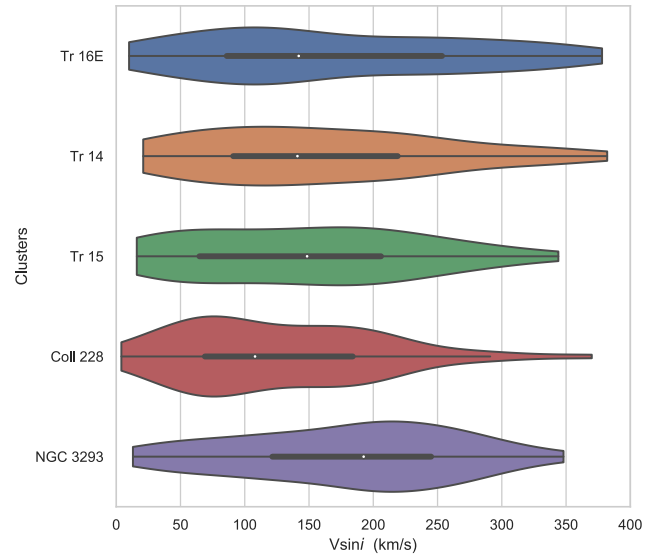


Figure 13. Violin distributions of $V \sin i$ of early-type stars of the open clusters Trumpler 16 E (blue), Trumpler 14 (orange), Trumpler 15 (green), Collinder 228 (red), and NGC 3293 (purple). The distributions are arranged according to increasing cluster ages, from top to bottom. White dots in the plots indicate the median, while the thick bars represent the IQR and the thin bars show the 95 percent confidence interval. Broader regions of the distribution represent a higher probability that a star will have that $V \sin i$ value.

represents the projected rotational velocity along the line of sight; thus, the true equatorial velocities are likely higher, especially for stars observed at lower inclination angles.

Fig. 13 presents a violin plot showing the distribution of $V \sin i$ values of open clusters with more than 40 stars: Trumpler 14, Trumpler 15, Trumpler 16 E, Collinder 228, and NGC 3293.² This type of plot is useful for comparing data distributions across multiple

²The distributions of $V \sin i$ in the clusters Trumpler 16 W, Bochum 11, and Collinder 232 are not discussed here due to the small number of stars in these three clusters.

groups simultaneously. A coloured violin plot represents each cluster in the figure, a combination of a box plot and a kernel density plot. They show the distribution of the data across different values: the width of the violin plot at different values of $V \sin i$ indicates the density of stars with those velocities; the white dot in the centre of the black bar represents the median value of $V \sin i$ for that cluster. The black bar in the centre of each violin represents the interquartile range (IQR), which contains the middle 50 per cent of the data, and the thin black line extending from the black bar represents the range of the data, excluding outliers.

The violin plot for Trumpler 14 shows a median $V \sin i$ of $141 \pm 95 \text{ km s}^{-1}$, and a fairly symmetric distribution, with moderate spread, indicating a balanced distribution of rotational velocities. The median $V \sin i$ for Trumpler 15 is $148 \pm 88 \text{ km s}^{-1}$ and the distribution is narrower compared to Trumpler 14, indicating less variations in rotational velocities within this cluster. The distribution of $V \sin i$ for Trumpler 16 E is quite narrow with a lower spread, showing a high concentration of stars with similar rotational velocities and the median value is $142 \pm 104 \text{ km s}^{-1}$. Collinder 228 has a wider spread compared to previous clusters, indicating higher variability in rotational velocities, and the median $V \sin i$ is $108 \pm 77 \text{ km s}^{-1}$. Finally, NGC 3293 presents the highest median $V \sin i$ among the clusters, $192 \pm 84 \text{ km s}^{-1}$, and the distribution is wide and asymmetric, with a long tail towards higher velocities, indicating a significant number of stars with high rotational velocities.

The violin plots for Trumpler 15 and Trumpler 16 E show less variation in $V \sin i$, indicating more homogeneous populations in terms of rotational velocity. In contrast, NGC 3293 has a broader and skewed distribution, suggesting a more diverse population with many stars rotating at higher speeds. The purple violin in Fig. 13 suggests that it might have a relevant contribution of NGC 3293 stars at the peak at $V \sin i \sim 200 \text{ km s}^{-1}$ in Fig. 11. Collinder 228 also shows considerable variability in rotational velocities. Our results suggest that, in general, stars in Collinder 228 tend to have lower $V \sin i$ than the stars in NGC 3293.

6 CONCLUSIONS

We analysed high-resolution spectra for a sample of O9.5-B6 stars members of eight open clusters in the Carina Nebula: Trumpler 14, Trumpler 15, Trumpler 16 E, Trumpler 16 W, Collinder 228, Collinder 232, Bochum 11, and NGC 3293. The observational data was provided by the *Gaia*-ESO Survey, a large public spectroscopic survey that used UVES and GIRAFFE spectrographs. The cluster members have been confirmed based on the distributions of astrometric and photometric data from *Gaia*, and radial velocities measured from helium and silicon lines.

Projected rotational velocities ($V \sin i$) were derived from the widths of He I lines for a sample of 330 early-type stars that are probable members of the Carina clusters. For 222 of these stars, $V \sin i$ values are reported for the first time. Additionally, this study presents the first $V \sin i$ estimates in the literature for members of the clusters Trumpler 15, Collinder 228, Collinder 232, and Bochum 11. The distribution of $V \sin i$ for the full sample has a peak in the bin $100\text{--}150 \text{ km s}^{-1}$, which is consistent with typical distributions of $V \sin i$ of stars in clusters, but differs from the distributions of field B stars, which generally show an excess of low $V \sin i$ values. For a sub-sample of stars with earlier spectral types between B0 and B3, the $V \sin i$ distribution turns into a bimodal distribution, with peaks at 100 and 200 km s^{-1} , plus a third, small peak at 350 km s^{-1} .

The $V \sin i$ distributions of each cluster, considering only those clusters with more than 40 analysed stars, are slightly different in

terms of the median $V \sin i$ values and the distribution shape and symmetry. For example, the oldest cluster of our sample, NGC 3293, presents a wide, asymmetric distribution, with the highest median $V \sin i$ among the clusters, suggesting this cluster has a larger number of rapidly rotating stars. On the other hand, the distribution for Trumpler 16 E is quite narrow, indicating that the stars' $V \sin i$ have a lower dispersion. Collinder 228 presents the lowest median $V \sin i$ among the Carina clusters, $126 \pm 77 \text{ km s}^{-1}$.

ACKNOWLEDGEMENTS

We thank the referee for carefully reading our manuscript and for the constructive comments and suggestions. My sincere thanks to my wife, F. Carine, for her constant partnership and support throughout the development of this research. WS acknowledges financial support from CAPES and FAPERJ for PhD fellowships. SD acknowledges CNPq/MCTI for grant 306859/2022-0 and FAPERJ for grant 210.688/2024. TM acknowledges financial support from Belspo for contracts PRODEX *Gaia*-DPAC and PLATO mission development. SRB and AH acknowledge funding from the Spanish Ministry of Science and Innovation (MICINN) through the Spanish State Research Agency through grant PID2021-122397NB-C21, and the Severo Ochoa Programme 2020–2024 (CEX2019-000920-S). SRB also acknowledges financial support by NextGeneration EU/PRTR and MIU (UNI/551/2021) through grant Margarita Salas-ULL. JMA acknowledges support from the Spanish Government Ministerio de Ciencia e Innovación and Agencia Estatal de Investigación (10.13039/501100011033) through grant PID2022-136640 NB-C22 and from the Consejo Superior de Investigaciones Científicas (CSIC) through grant 2022-AEP 005.

Based on observations collected at the ESO telescopes under programme 188.B3002, 193.B-0936, and 197.B-1074, the *Gaia*-ESO Public Spectroscopic Survey. These data products have been processed by the Cambridge Astronomy Survey Unit (CASU) at the Institute of Astronomy, University of Cambridge, and by the FLAMES/UVES reduction team at INAF/Osservatorio Astrofisico di Arcetri. These data have been obtained from the GES Data Archive, prepared and hosted by the Wide Field Astronomy Unit, Institute for Astronomy, University of Edinburgh, which is funded by the UK Science and Technology Facilities Council. This work was partly supported by the European Union FP7 programme through ERC grant number 320360 and by the Leverhulme Trust through grant RPG-2012-541. We acknowledge the support from INAF and Ministero dell' Istruzione, dell' Università e della Ricerca (MIUR) in the form of the grant "Premiale VLT 2012". The results presented here benefit from discussions held during the *Gaia*-ESO workshops and conferences supported by the ESF (European Science Foundation) through the GREAT Research Network Programme.

DATA AVAILABILITY

The GES spectra analysed in this paper are available at the GES Science Archive (<http://ges.roe.ac.uk/>).

REFERENCES

- Abt H. A., Levato H., Grosso M., 2002, *ApJ*, 573, 359
- Berlanas S. R. et al., 2023, *A&A*, 671, A20
- Berlanas S. R. et al., 2025, preprint (arXiv:2501.16508)
- Blomme R. et al., 2022, *A&A*, 661, A120
- Bragaglia A. et al., 2022, *A&A*, 659, A200

- Bragança G. A., Daflon S., Cunha K., Bensby T., Oey M. S., Walth G., 2012, *AJ*, 144, 130
- Bragança G. A. et al., 2019, *A&A*, 625, A120
- Butler K., Giddings J., 1985, Newsletter on the Analysis of Astronomical Spectra, No. 9, Univ. College London
- Cantat-Gaudin T. et al., 2018, *A&A*, 618, A93
- Cantat-Gaudin T. et al., 2020, *A&A*, 640, A1
- Conrad C. et al., 2017, *A&A*, 600, A106
- Cudworth K., Martin S., 1993, in Cassinelli J. P., Churchwell E. B., eds, ASP Conf. Ser. Vol. 35, Massive Stars: Their Lives in the Interstellar Medium. Astron. Soc. Pac., San Francisco, p. 266
- Daflon S., Cunha K., de Araújo F. X., Wolff S., Przybilla N., 2007, *AJ*, 134, 1570
- Damiani F. et al., 2016, *A&A*, 591, A74
- Damiani F. et al., 2017, *A&A*, 603, A81
- Dias W. S., Monteiro H., Moitinho A., Lépine J. R. D., Carraro G., Paunzen E., Alessi B., Vilella L., 2021a, *VizieR Online Data Catalog*, p. J/MNRAS/504/356
- Dias W. S., Monteiro H., Moitinho A., Lépine J. R. D., Carraro G., Paunzen E., Alessi B., Vilella L., 2021b, *MNRAS*, 504, 356
- Dufton P. L. et al., 2013, *A&A*, 550, A109
- Evans C. J. et al., 2005, *A&A*, 437, 467
- Feinstein A., Marraco H. G., Muzzio J. C., 1973, *A&AS*, 12, 331
- Gaia Collaboration, 2020, *VizieR Online Data Catalog*, p. I/350
- Gaia Collaboration, 2021, *A&A*, 649, A1
- Giddings J. R., 1980, PhD thesis, Univ. College London, United Kingdom
- Gies D. R., Huang W., 2004, in Maeder A., Eenens P., eds, IAU Symp. 215, Stellar Rotation. Astron. Soc. Pac., San Francisco, p. 57
- Gilmore G. et al., 2012, *The Messenger*, 147, 25
- Gilmore G. et al., 2022, *A&A*, 666, A120
- Göppel C., Preibisch T., 2022, *A&A*, 660, A11
- Hanes R. J., McSwain M. V., Povich M. S., 2018, *AJ*, 155, 190
- Hourihane A. et al., 2023, *A&A*, 676, A129
- Huang W., Gies D. R., 2006a, *ApJ*, 648, 580
- Huang W., Gies D. R., 2006b, *ApJ*, 648, 591
- Huang W., Gies D. R., 2008, *ApJ*, 683, 1045
- Hunt E. L., Reffert S., 2023, *A&A*, 673, A114
- Hunter I. et al., 2009, *A&A*, 496, 841
- Hur H., Sung H., Bessell M. S., 2012, *AJ*, 143, 41
- Kurucz R., 1993, ATLAS9 Stellar Atmosphere Programs and 2 km/s grid. Kurucz CD-ROM No. 13, Cambridge
- Lim B., Nazé Y., Gosset E., Rauw G., 2019, *MNRAS*, 490, 440
- Lindgren L., 2020, *A&A*, 633, A1
- Lindgren L. et al., 2021, *A&A*, 649, A4
- Loktin A. V., Popova M. E., 2017, *Astrophys. Bull.*, 72, 257
- Maeder A., Meynet G., 2000, *A&A*, 361, 159
- Maíz Apellániz J., Barbá R. H., 2018, *A&A*, 613, A9
- Maíz Apellániz J. et al., 2016, *ApJS*, 224, 4
- Maíz Apellániz J., Crespo Bellido P., Barbá R. H., Fernández Aranda R., Sota A., 2020, *A&A*, 643, A138
- Maíz Apellániz J., Pantaleoni González M., Barbá R. H., 2021, *A&A*, 649, A13
- Maíz Apellániz J., Barbá R. H., Fernández Aranda R., Pantaleoni González M., Crespo Bellido P., Sota A., Alfaro E. J., 2022, *A&A*, 657, A131
- Massey P., Johnson J., 1993, *AJ*, 105, 980
- McSwain M. V., Gies D. R., 2005, *ApJS*, 161, 118
- McSwain M. V., Huang W., Gies D. R., 2009, *ApJ*, 700, 1216
- Monteiro H., Dias W. S., Moitinho A., Cantat-Gaudin T., Lépine J. R. D., Carraro G., Paunzen E., 2020, *MNRAS*, 499, 1874
- Morel T. et al., 2022, *A&A*, 665, A108
- Povich M. S. et al., 2011, *ApJS*, 194, 14
- Preibisch T. et al., 2011, *A&A*, 530, A34
- Randich S. et al., 2022, *A&A*, 666, A121
- Rebolledo D. et al., 2016, *MNRAS*, 456, 2406
- Rebolledo D. et al., 2020, *ApJ*, 891, 113
- Rivinius T., Carciofi A. C., Martayan C., 2013, *A&AR*, 21, 69
- Seward F. D., Forman W. R., Giacconi R., Griffiths R. E., Harnden F. R. J., Jones C., Pye J. P., 1979, *ApJ*, 234, L55
- Shull J. M., Darling J., Danforth C. W., 2021, *ApJ*, 914, 18
- Silverman B. W., 1986, *Density Estimation for Statistics and Data Analysis*. Chapman and Hall, London
- Simón-Díaz S., Herrero A., 2007, *A&A*, 468, 1063
- Stauffer J. R., Hartmann L. W., 1986, *PASP*, 98, 1233
- Stepień K., 2000, *A&A*, 353, 227
- Townsley L. K. et al., 2011, *ApJS*, 194, 15
- Wade R. A., Rucinski S. M., 1985, *A&AS*, 60, 471
- Walborn N. R., Hesser J. E., 1982, *ApJ*, 252, 156
- Walborn N. R., Danks A. C., Vieira G., Landsman W. B., 2002, *ApJS*, 140, 407
- Wolff S. C., Edwards S., Preston G. W., 1982, *ApJ*, 252, 322
- Wolff S. C., Strom S. E., Dror D., Venn K., 2007, *AJ*, 133, 1092
- Yonekura Y., Asayama S., Kimura K., Ogawa H., Kanai Y., Yamaguchi N., Barnes P. J., Fukui Y., 2005, *ApJ*, 634, 476
- Zahn J. P., 1977, *A&A*, 57, 383

APPENDIX A: PHOTOMETRIC AND ASTROMETRIC DATA

In this appendix, we present through Figs A2 and A7 the distributions of astrometric and photometric data from *Gaia* EDR3, as well as radial velocities measured from the observed spectra, for the clusters Trumpler 15, Trumpler 16 E, Trumpler 16 W, Bochum 11, Collinder 228, Collinder 232, and NGC 3293.

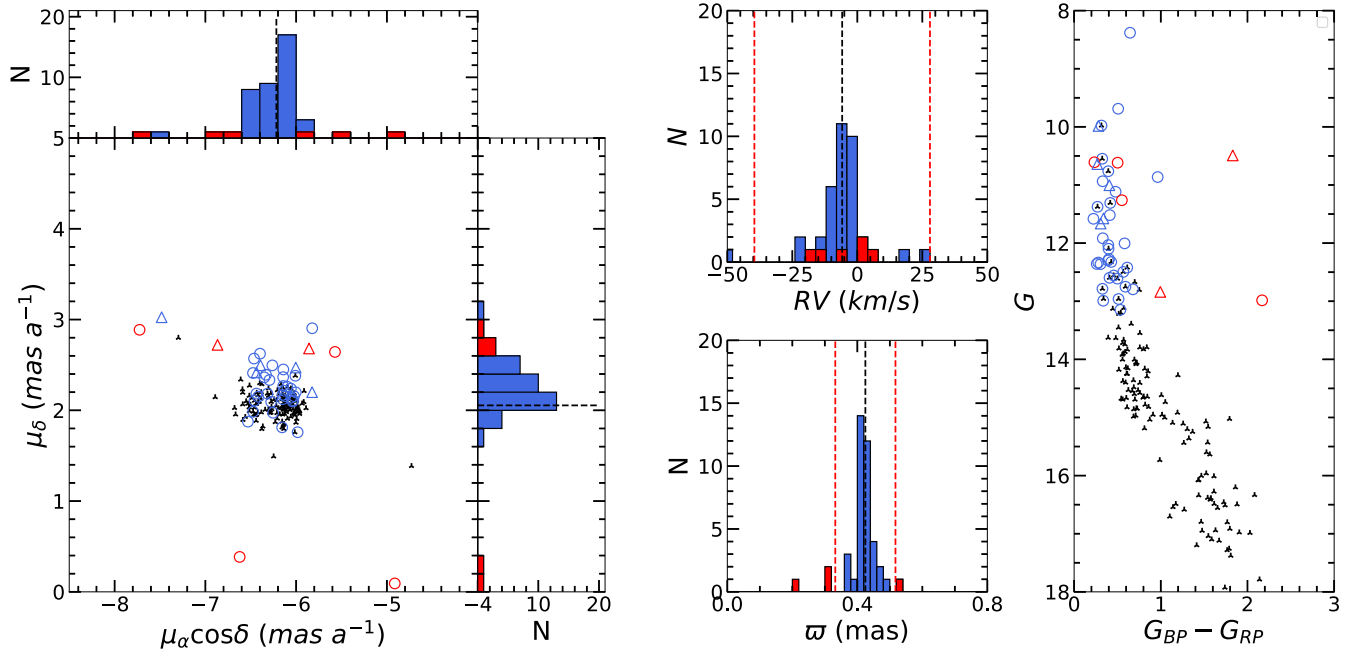


Figure A1. *Gaia* EDR3 astrometric and photometric data for the cluster Trumpler 15. The small black triangles represent the cluster members by Cantat-Gaudin et al. (2018). Open symbols represent early-type stars with $V \sin i$ measurement, with the blue circles representing the cluster members and the red circles representing non-members. The open triangles with the same colour code refer to the stars selected for the abundance analysis, which will be presented in a forthcoming paper. *Left panel:* the distribution of proper motions in right ascension and declination. The side histograms are colour-coded according to the symbols and the dashed line depicts the mean value for our sample. The middle panels show the distributions of the sample stars' radial velocities (upper) and parallax (lower), colour-coded according to the open circles. The black dashed lines are the mean values while the red dashed lines represent the 3σ limits for the sample stars. The right panel presents the colour $\times$ magnitude diagram using *Gaia* magnitudes.

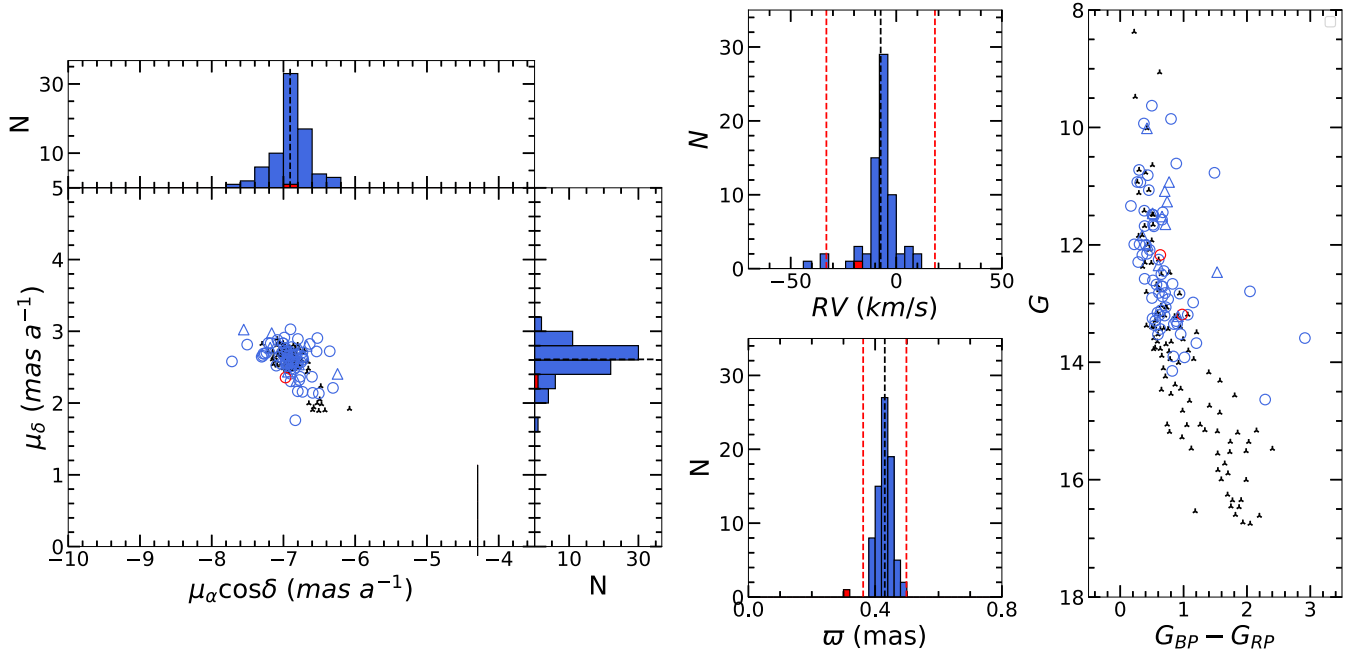


Figure A2. Same as Fig. A1 for the cluster Trumpler 16 E.

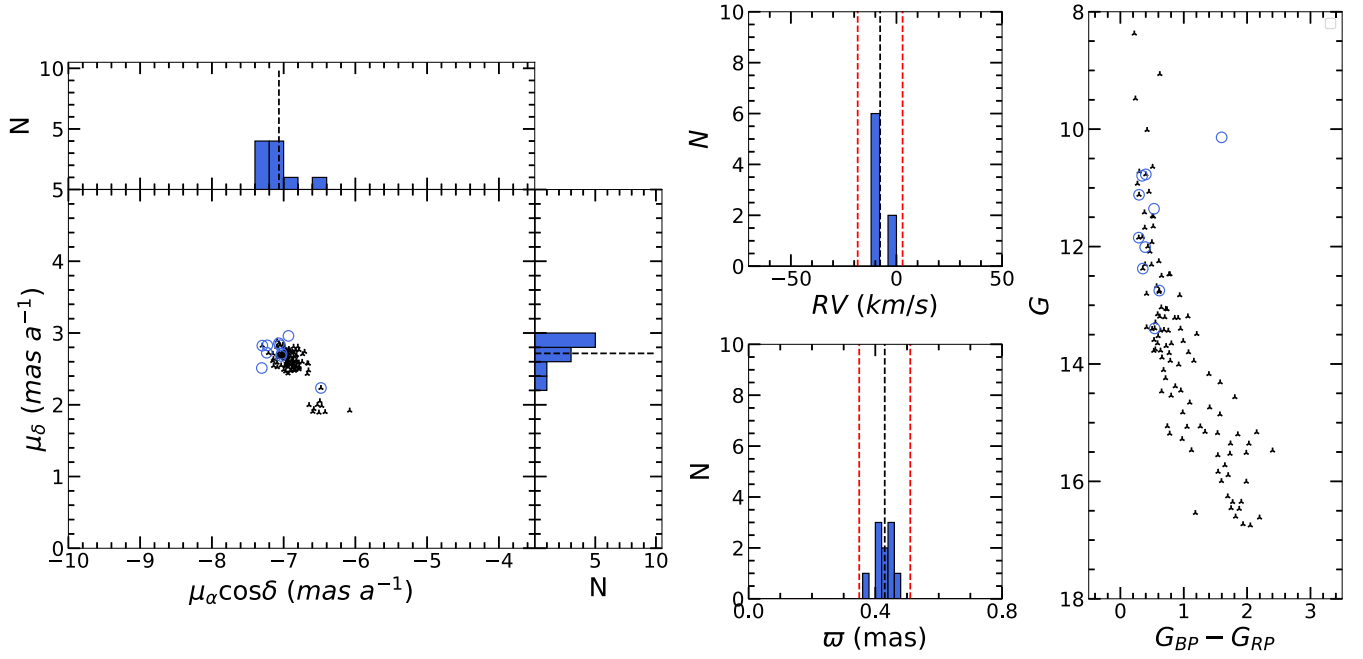


Figure A3. Same as Fig. A1 for the cluster Trumpler 16 W.

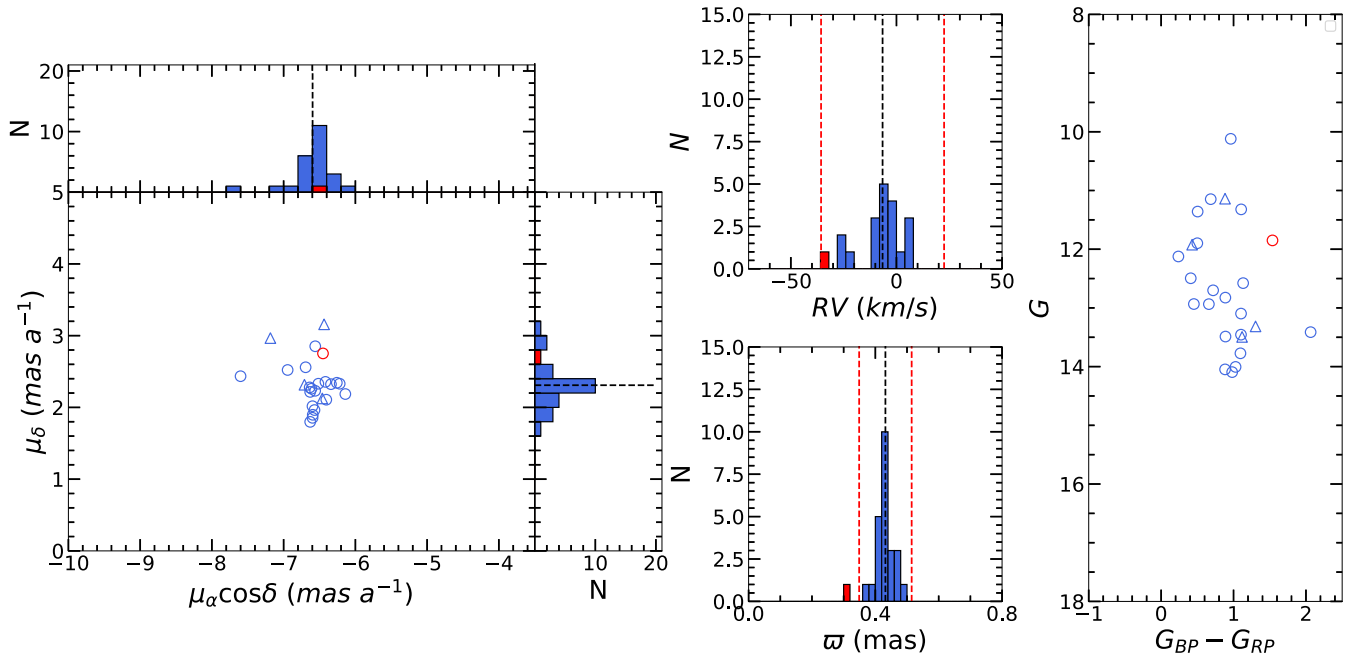


Figure A4. Same as Fig. A1 for the cluster Bochum 11.

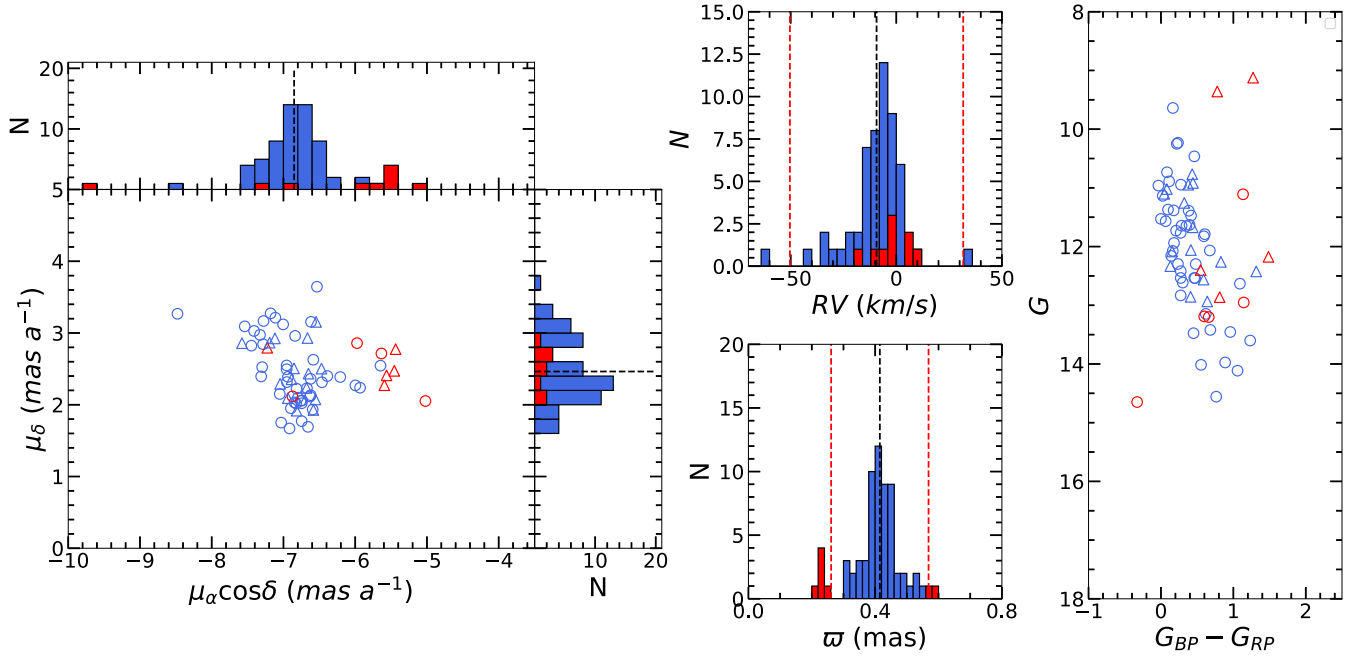


Figure A5. Same as Fig. A1 for the cluster Collinder 228.

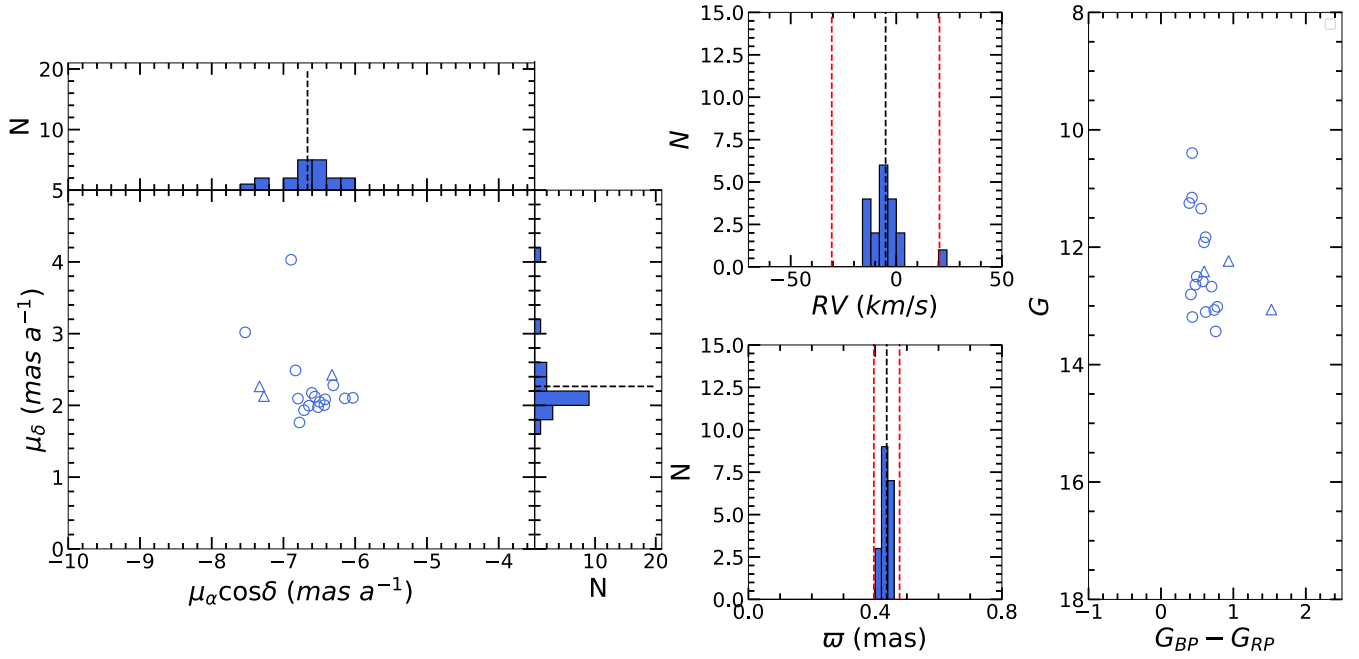


Figure A6. Same as Fig. A1 for the cluster Collinder 232.

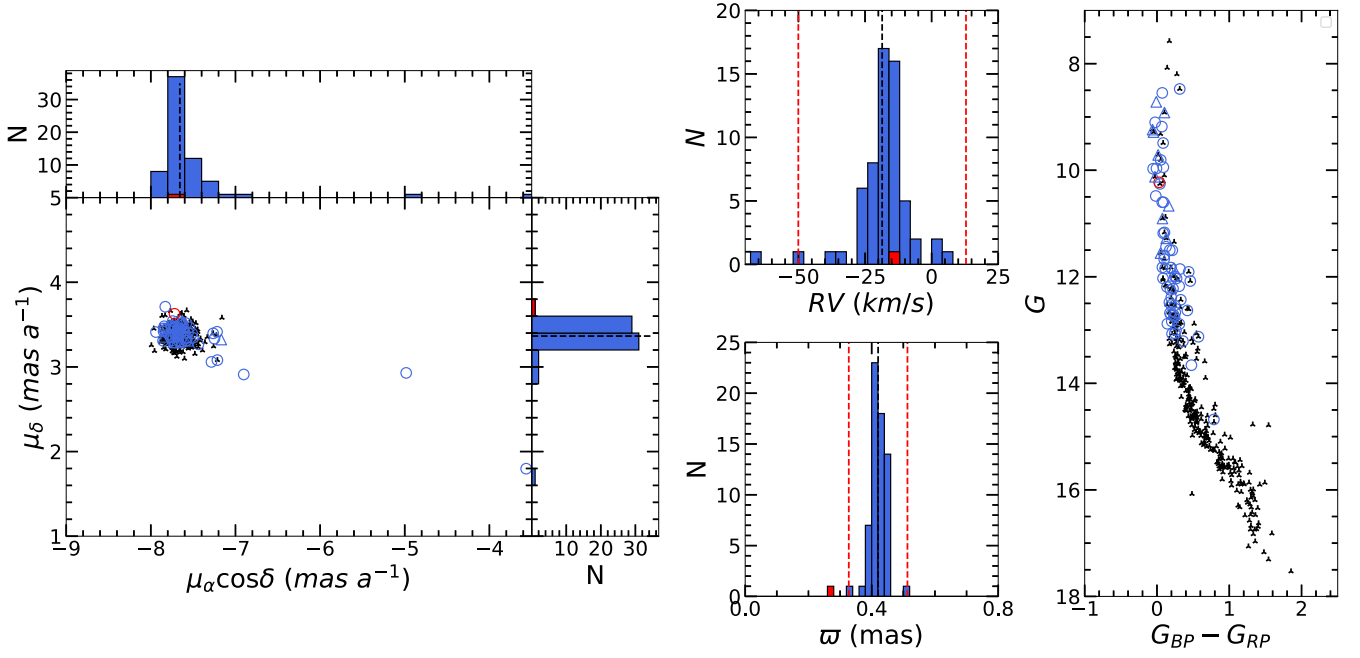


Figure A7. Same as Fig. A1 for the cluster NGC 3293.

APPENDIX B: MEASUREMENTS OF FWHM AND ESTIMATES OF PROJECTED ROTATIONAL VELOCITIES

In this Appendix, we list the main results for the stars analysed in this paper: GES ID, others names, the radial velocities measured

from He and Si lines, SNR of the observed spectra, FWHM ($\text{\AA}$) measurements of the He I lines 4388 and 4471 $\text{\AA}$, the $V \sin i$ estimates derived through the interpolation of the measured FWHM, and the average $V \sin i$ values from He I lines, with the corresponding dispersion. According to the analysis described in Section 3, the stars are separated by cluster.

Table B1. FWHM and $V \sin i$ estimates for the sample stars.

GES ID	Other ID	V_r (km s^{-1})	SNR	FWHM ($\text{\AA}$)		$V \sin i$ (km s^{-1})		
				4388 $\text{\AA}$	4471 $\text{\AA}$	4388 $\text{\AA}$	4471 $\text{\AA}$	Average
Trumpler 14								
10435522–5933147	ALS 15 229	$+2 \pm 1$	79	–	1.26	–	21	21
10435847–5933016	ALS 19 738	-11 ± 3	175	5.96	5.99	247	223	235 ± 17
10435580–5932520	[HSB2012] 1498	-12 ± 1	104	3.47	4.52	135	148	141 ± 9
10435902–5933197	2MASS J10435902–5933196	-21 ± 3	140	4.74	5.23	195	196	196 ± 0
10435650–5932498	2MASS J10435649–5932497	-7 ± 2	167	5.37	5.91	227	235	231 ± 6
10435366–5933006	2MASS J10435365–5933006	-23 ± 2	144	2.86	3.32	112	111	111 ± 0
10435756–5933385	ALS 15 224	-10 ± 2	101	2.84	3.46	110	117	114 ± 5
10435724–5932412	[HSB2012] 1550	-4 ± 2	86	4.66	4.93	185	174	179 ± 8
10435952–5932316 ^e	ALS 19739	-8 ± 3	142	2.67	3.26	98	101	99 ± 2
10435208–5932401	2MASS J10435207–5932401	-3 ± 3	47	3.56	4.46	136	146	141 ± 7
10435230–5932361 ^e	2MASS J10435230–5932360	$+2 \pm 1$	110	3.46	3.93	129	129	129 ± 0
10435953–5932227	2MASS J10435953–5932227	$+30 \pm 1$	93	1.88	2.57	67	73	70 ± 4
10435090–5933506	ALS 19 733	-5 ± 2	171	4.92	5.69	205	219	212 ± 10
10440432–5932478 ^e	2MASS J10440432–5932478	-1 ± 2	70	5.12	5.74	206	211	209 ± 4
10434798–5933591 ^e	2MASS J10434798–5933590	-12 ± 2	83	5.35	4.84	219	219	219 ± 0
10440063–5931524 ^e	2MASS J10440063–5931524	-5 ± 3	73	5.12	5.66	206	207	207 ± 1
10435603–5934410	ALS 19 735	-10 ± 1	137	3.06	3.77	117	123	120 ± 4
10440867–5933488 ^e	2MASS J10440866–5933488	-7 ± 3	95	8.13	8.60	339	350	344 ± 8
10440384–5934344	2MASS J10440384–5934344	-4 ± 2	76	4.23	5.42	169	176	173 ± 5
10434478–5934158 ^e	2MASS J10434478–5934158	-2 ± 5	99	7.16	7.44	294	292	293 ± 1

Table B1 – *continued*

GES ID	Other ID	V_r (km s ⁻¹)	SNR	FWHM (Å)		$V \sin i$ (km s ⁻¹)		
				4388 Å	4471 Å	4388 Å	4471 Å	Average
10434356–5934035	ALS 17 185	+4 ± 1	79	1.54	1.55	23	36	29 ± 9
10434580–5934359	2MASS J10434580–5934359	–6 ± 8	66	7.79	8.63	323	351	337 ± 20
10441215–5933512 ^e	2MASS J10441215–5933511	–1 ± 0	102	5.91	6.33	245	240	242 ± 3
10441283–5933322 ^e	2MASS J10441282–5933321	–6 ± 2	50	4.15	4.82	162	168	165 ± 4
10440583–5935117 ^e	ALS 15 227	–12 ± 2	371	2.31	3.05	87	93	90 ± 5
10433597–5933179	2MASS J10433596–5933179	–8 ± 1	80	1.90	1.79	43	45	44 ± 1
10433866–5934444	2MASS J10433865–5934444	–5 ± 1	106	8.86	9.29	377	388	382 ± 8
10435502–5936242	2MASS J10435501–5936242	–10 ± 2	81	3.80	4.79	157	161	159 ± 3
10440684–5936116	2MASS J10440683–5936116	–8 ± 1	82	7.59	7.81	313	311	312 ± 2
10435131–5928598	Cl* Trumpler 14 Y 586	–15 ± 2	58	–	2.64	–	94	94
10433085–5929239	HD 303 312	+9 ± 3	223	4.05	4.55	170	172	171 ± 1
10431695–5937534	2MASS J10431694–5937534	–9 ± 1	67	1.86	1.85	60	56	58 ± 2
10432367–5925595	–	–39 ± 1	55	2.17	2.10	65	66	65 ± 1
10432183–5924227 ^e	ALS 16 078	–28 ± 4	68	5.33	5.91	217	220	219 ± 2
10440093–5935459	CPD-58 2625	–8 ± 1	163	1.39	1.51	23	38	30 ± 11
10441536–5936043 ^e	2MASS J10441535–5936042	–3 ± 0	88	5.74	6.55	237	250	244 ± 10
10435540–5926553	2MASS J10435539–5926551	–2 ± 3	45	3.50	3.88	131	130	131 ± 1
10440248–5929368	ALS 1827	–2 ± 1	204	5.89	6.19	250	251	251 ± 0
10440828–5929594	ALS 15 233	–8 ± 2	121	2.56	3.24	95	103	99 ± 6
10440509–5933413	ALS 19 740	–6 ± 2	125	2.94	3.65	103	111	107 ± 5
10435177–5935451	2MASS J10435176–5935450	–7 ± 3	40	–	7.85	–	309	309
10433335–5935111	ALS 1808	–6 ± 2	298	1.49	1.60	18	39	28 ± 15
10434124–5935530	ALS 15203	–17 ± 2	49	3.44	3.96	140	139	139 ± 1
10434743–5931265 ^e	2MASS J10434743–5931264	–6 ± 1	104	1.53	1.11	30	23	26 ± 5
10440576–5927079	2MASS J10440576–5927078	+6 ± 0	51	1.96	1.92	50	53	52 ± 2
10435796–5933537 ^b	ALS 15 864	–4 ± 2	146	2.18	2.38	74	72	73 ± 2
Trumpler 15								
10444236–5922029	2MASS J10444235–5922029	–3 ± 1	68	4.63	5.10	186	180	183 ± 4
10444212–5922305	CPD-58 2655	–9 ± 2	144	4.22	4.85	175	179	177 ± 3
10444278–5921383	2MASS J10444278–5921383	+25 ± 4	44	5.25	5.71	213	210	212 ± 2
10444178–5921330	ALS 15856	–11 ± 1	116	2.86	3.45	104	105	104 ± 0
10444946–5922192	2MASS J10444948–5922191	–9 ± 5	96	6.95	7.26	286	284	285 ± 1
10444058–5921138	ALS 15 855	–5 ± 2	124	4.87	5.62	202	206	204 ± 3
10443514–5921220	Cl Trumpler 15 24	0 ± 0	75	1.71	1.57	26	38	32 ± 8
10443511–5923282	2MASS J10443510–5923281	–7 ± 0	95	2.00	1.93	55	54	55 ± 1
10443075–5921263	ALS 15 861	–2 ± 1	149	1.53	1.57	18	36	27 ± 12
10443592–5923356	2MASS J10443591–5923356	–6 ± 2	92	5.54	6.25	227	236	232 ± 7
10443267–5920385	Cl Trumpler 15 25	–8 ± 2	98	2.20	2.29	68	68	68 ± 0
10445073–5920234	2MASS J10445073–5920233	–9 ± 0	100	7.69	7.54	314	297	305 ± 12
10445869–5922228	2MASS J10445869–5922228	–3 ± 4	65	4.85	5.14	193	183	188 ± 7
10445733–5920476	2MASS J10445733–5920476	–5 ± 1	84	2.89	3.17	102	104	103 ± 2
10450531–5919349	2MASS J10450531–5919347	–2 ± 2	103	4.53	5.22	182	186	184 ± 3
10445081–5918004	2MASS J10445080–5918005	–7 ± 1	53	3.49	3.94	131	123	127 ± 6
10444209–592635 ^e	2MASS J10444208–5926353	–3 ± 0	79	8.14	8.70	336	353	344 ± 12
10440517–5921165	2MASS J10440516–5921165	–2 ± 1	63	4.86	5.18	197	189	193 ± 6
10440328–5919498	2MASS J10440327–5919498	+6 ± 1	74	1.99	2.16	52	58	55 ± 3
10441729–5917154	2MASS J10441729–5917154	–4 ± 1	68	3.38	3.67	125	117	121 ± 6
10440793–5917271	2MASS J10440789–5917267	–8 ± 1	54	3.27	3.74	120	121	120 ± 0
10452045–5917062	HD 303300	–16 ± 1	156	3.81	4.62	158	173	166 ± 11
10435355–5918466	2MASS J10435347–5918457	–8 ± 3	30	6.14	6.34	255	240	248 ± 10
10435416–5918244	2MASS J10435413–5918244	–6 ± 1	72	5.30	5.99	216	224	220 ± 6
10444398–5913590	–	+18 ± 2	49	1.21	1.33	5	29	17 ± 17
10454824–5922042	2MASS J10454824–5922041	–21 ± 2	63	6.32	6.87	261	267	264 ± 4
10435328–5916011	–	+3 ± 6	58	4.27	4.63	167	161	164 ± 4
10440062–5925493	ALS 1822	–49 ± 1	216	2.16	2.27	76	72	74 ± 3
10443022–5926130	TYC 8626-2506-1	–2 ± 2	128	4.61	5.01	196	194	195 ± 1
10432015–5917582	2MASS J10432014–5917582	–22 ± 1	59	1.97	1.83	51	49	50 ± 1
10432557–5919175	2MASS J10432556–5919175	–15 ± 1	59	3.29	3.99	121	123	122 ± 1
10444234–5923038	ALS 1855	–11 ± 1	166	3.41	4.15	140	152	146 ± 9
10444448–5921327	ALS 15 854	–5 ± 2	221	5.57	6.31	234	237	235 ± 2
10442912–5920049	ALS 1842	–2 ± 1	126	1.37	1.43	4	28	16 ± 18

Table B1 – continued

GES ID	Other ID	V_r (km s ⁻¹)	SNR	FWHM (Å)		$V \sin i$ (km s ⁻¹)		
				4388 Å	4471 Å	4388 Å	4471 Å	Average
10443766–5923073	2MASS J10443766–5923073	-1 ± 0	45	–	6.85	–	265	265
10444065–5922285	ALS 15 859	-4 ± 1	105	3.71	4.42	149	153	151 ± 3
10444652–5921538	CPD-58 2662	-5 ± 1	76	2.65	3.28	91	97	94 ± 4
10441935–5917026	GES J10441935–5917026	-8 ± 3	62	–	2.03	–	50	50
10443636–5924203 ^b	ALS 15 860	$+5 \pm 0$	73	1.90	2.06	49	57	53 ± 5
10451811–5924277 ^b	HD 93 342	$+3 \pm 1$	75	1.40	1.07	23	21	22 ± 2
Trumpler 16 W								
10443049–5941406 ^e	ALS 15 215	-9 ± 2	141	5.36	5.83	227	232	230 ± 3
10442897–5942343 ^e	ALS 19 742	-10 ± 2	146	3.03	3.83	110	118	114 ± 6
10443139–5944080 ^e	2MASS J10443139–5944080	-9 ± 1	110	2.96	3.82	105	115	110 ± 7
10442895–5943473 ^e	2MASS J10442894–5943473	-9 ± 1	103	6.34	6.91	262	268	265 ± 5
10442377–5941065 ^e	2MASS J10442376–5941064	-4 ± 1	82	1.80	1.40	44	39	42 ± 4
10441969–5943079 ^e	2MASS J10441968–5943078	-1 ± 4	46	4.32	4.95	169	175	172 ± 4
10442251–5939258	ALS 15 230	-12 ± 1	165	6.86	7.43	294	299	296 ± 4
10441320–5943103	ALS 15 210	-8 ± 3	173	3.06	2.97	115	110	113 ± 4
10443290–5940261	ALS 15 211	-9 ± 4	203	5.30	6.12	220	238	229 ± 13
Trumpler 16 E								
10450180–5942014 ^e	[HSB2012] 3314	-5 ± 3	53	5.46	5.92	223	220	222 ± 2
10450216–5942010 ^e	ALS 15 220	-10 ± 2	124	2.65	3.29	99	106	103 ± 5
10450523–5941426 ^e	ALS 19 746	-10 ± 1	94	2.51	3.16	88	92	90 ± 3
10450673–5941565	ALS 15200	-6 ± 0	228	1.36	1.44	20	33	27 ± 9
10450636–5942357	ALS 15249	-1 ± 1	135	2.16	2.45	73	75	74 ± 1
10445478–5941239 ^e	[HSB2012] 3100	-7 ± 4	56	3.42	3.70	127	123	125 ± 3
10445408–5941294	ALS 15 216	-7 ± 3	177	7.09	7.81	300	321	311 ± 15
10450790–5941341 ^e	HSB2012 3482	-6 ± 0	40	8.90	9.21	376	381	378 ± 4
10445796–5941031 ^e	[HSB2012] 3192	-23 ± 1	119	5.12	5.66	208	208	208 ± 0
10450990–5942139 ^e	HSB2012 3545	-9 ± 2	90	7.26	7.91	302	318	310 ± 12
10450977–5942192	HSB2012 3540	-41 ± 2	94	3.31	3.92	122	127	124 ± 3
10450520–5940574	[HSB2012] 3397	-7 ± 1	100	6.06	6.49	255	259	257 ± 3
10450933–5941283 ^e	HSB2012 3526	-7 ± 2	55	4.11	4.79	162	165	163 ± 2
10445991–5943149	ALS 19744	-5 ± 1	149	5.63	6.35	236	251	244 ± 11
10450590–5940546	HSB2012 3424	-7 ± 1	138	2.12	2.45	65	69	67 ± 3
10450974–5942572 ^e	ALS 15246	-9 ± 2	122	2.72	3.29	102	104	103 ± 2
10451120–5941113	ALS 15209	-6 ± 3	223	5.33	6.15	225	245	235 ± 14
10451170–5941163	ALS 15213	-8 ± 0	60	6.07	6.58	252	252	252 ± 0
10450023–5943345 ^e	ALS 19 745	-10 ± 1	133	3.58	4.31	136	140	138 ± 3
10451400–5941420 ^e	HSB2012 3648	-7 ± 1	34	7.70	7.91	315	314	314 ± 0
10451265–5942488	ALS 15228	-13 ± 1	133	2.06	2.43	67	73	70 ± 5
10450020–5940052 ^e	[HSB2012] 3263	-3 ± 0	37	8.48	9.34	345	382	366 ± 23
10451622–5941412 ^e	2MASS J10451622–5941411	-12 ± 5	65	4.72	5.20	187	186	187 ± 1
10450968–5940088 ^e	ALS 19747	-10 ± 2	117	5.40	6.05	220	227	224 ± 5
10451355–5943318 ^e	2MASS J10451355–5943318	$+7 \pm 1$	34	–	8.47	–	341	341
10451499–5943233	ALS 15245	-15 ± 1	186	3.69	4.40	151	159	155 ± 5
10445846–5939437 ^e	[HSB2012] 3211	0 ± 1	27	2.33	2.74	78	77	78 ± 1
10451894–5942184 ^e	2MASS J10451894–5942184	-5 ± 1	62	1.69	1.77	23	43	33 ± 14
10451670–5943141	ALS 15247	-5 ± 1	96	2.95	3.65	112	118	115 ± 5
10450588–5944189 ^e	ALS 15238	-6 ± 2	145	4.65	5.26	190	191	190 ± 1
10452057–5942213	2MASS J10452056–5942212	-8 ± 1	46	7.65	7.35	315	329	322 ± 10
10452057–5942513	ALS 1878	-6 ± 1	228	3.01	3.50	119	120	120 ± 0
10451656–5939571 ^e	ALS 15223	-12 ± 2	130	5.10	6.04	216	236	226 ± 14
10450310–5944568 ^e	[HSB2012] 3344	-4 ± 0	29	–	7.11	–	277	277
10452416–5942314 ^e	2MASS J10452415–5942313	-7 ± 0	79	7.75	8.20	320	330	325 ± 7
10443822–5943056 ^e	2MASS J10443822–5943056	-6 ± 5	102	8.11	8.25	336	333	335 ± 3
10450793–5939012	2MASS J10450792–5939011	-10 ± 2	106	5.62	6.05	230	227	229 ± 2
10451272–5939066	2MASS J10451271–5939066	-3 ± 0	79	3.33	3.82	123	119	121 ± 3
10451943–5939374 ^e	ALS 19748	-8 ± 1	126	3.26	4.08	122	131	127 ± 6
10450837–5938475	2MASS J10450836–5938475	-32 ± 2	45	3.98	4.57	157	151	154 ± 5
10452314–5940034	2MASS J10452314–5940033	$+1 \pm 0$	83	3.42	4.14	127	133	130 ± 4
10452846–5941555 ^e	2MASS J10452846–5941555	-20 ± 1	18	–	3.73	–	122	122
10445394–5945240	2MASS J10445393–5945240	-3 ± 1	62	2.38	2.67	78	81	79 ± 2
10452521–5940011 ^e	2MASS J10452520–5940011	-6 ± 2	88	7.80	7.40	304	297	301 ± 5
10453134–5941133	2MASS J10453134–5941133	-9 ± 1	103	3.26	3.98	122	126	124 ± 3

Table B1 – *continued*

GES ID	Other ID	V_r (km s ⁻¹)	SNR	FWHM (Å)		$V \sin i$ (km s ⁻¹)		
				4388 Å	4471 Å	4388 Å	4471 Å	Average
10452311–5944458	2MASS J10452310–5944458	+10 ± 2	95	3.85	4.49	150	148	149 ± 2
10453255–5942359	2MASS J10453254–5942359	–5 ± 0	55	8.26	8.28	343	334	339 ± 6
10450823–5946070 ^e	CPD-59 2629	–10 ± 2	170	1.53	1.60	35	43	39 ± 6
10452190–5945249	2MASS J10452190–5945249	–3 ± 1	66	2.22	2.41	66	68	67 ± 2
10451297–5946060	2MASS J10451297–5946059	–6 ± 1	56	5.00	5.52	202	201	202 ± 1
10444609–5946057	2MASS J10444609–5946056	–6 ± 1	84	2.54	2.84	87	83	85 ± 2
10453820–5942157	2MASS J10453819–5942157	+9 ± 1	24	–	8.94	–	367	367
10445364–5946595	2MASS J10445363–5946595	–1 ± 1	76	1.33	1.10	13	16	15 ± 2
10452214–5937385 ^e	ALS 15244	–6 ± 1	191	1.50	1.50	17	37	27 ± 14
10453808–5944095	2MASS J10453807–5944095	–8 ± 2	63	1.26	1.36	11	28	19 ± 12
10454365–5939540	2MASS J10454365–5939540	–2 ± 1	91	1.40	1.28	21	18	20 ± 2
10453368–5947148	2MASS J10453367–5947147	–4 ± 1	121	2.75	3.08	94	101	98 ± 4
10454061–5937042	2MASS J10454060–5937041	–2 ± 1	71	6.37	6.93	263	270	266 ± 5
10452228–5950471	[ARV2008] 206	+3 ± 0	102	2.48	2.62	93	85	89 ± 6
10461505–5940192	Cl* Trumpler 16 MJ 676	–18 ± 1	22	–	4.25	–	139	139
10445351–5951541	2MASS J10445351–5951541	–7 ± 1	148	3.71	4.32	141	148	145 ± 5
10443719–5940015	ALS 15 242	–8 ± 1	145	2.28	2.81	81	88	85 ± 5
10444098–5940104	ALS 19 743	–5 ± 1	152	1.17	1.21	2	17	10 ± 11
10445376–5937483	ALS 15 236	–19 ± 2	142	1.62	1.69	9	37	23 ± 20
10463082–5944176	2MASS J10463081–5944175	–7 ± 2	90	2.93	3.03	103	98	101 ± 4
10444711–5939202	2MASS J10444710–5939201	–6 ± 1	71	6.36	6.88	262	267	265 ± 4
10450579–5945196	ALS 1870	+6 ± 0	327	5.94	6.25	253	254	254 ± 0
10450584–5943077	ALS 15 197	–35 ± 1	200	1.48	1.57	31	41	36 ± 8
10453661–5944111	2MASS J10453660–5944110	+5 ± 2	46	6.00	6.32	256	257	257 ± 1
10445602–5938530	2MASS J10445602–938530	–6 ± 2	45	4.49	5.26	181	189	185 ± 5
Collinder 228								
10443687–6001116	ALS 15957	–5 ± 1	246	8.45	9.16	358	381	370 ± 17
10442198–5959351	2MASS J10442207–5959351	–5 ± 1	138	3.74	4.62	152	150	151 ± 1
10441496–6000057	ALS 1836	+34 ± 2	499	2.30	2.56	84	79	81 ± 4
10441444–6001270	ALS 15 958	–10 ± 1	144	3.69	4.52	145	153	149 ± 6
10443829–6005450	2MASS J10443829–6005449	–60 ± 2	84	3.57	4.17	135	135	135 ± 0
10443174–6005449 ^e	ALS 16 054	–6 ± 1	139	4.62	5.23	189	191	190 ± 1
10441513–6007509	CPD-59 2569B	–3 ± 1	169	1.86	1.99	44	53	48 ± 7
10440078–6006012 ^e	CPD-59 2554	–16 ± 1	139	4.53	5.11	181	181	181 ± 0
10440104–6006378	2MASS J10440105–6006377	–2 ± 1	95	2.13	2.19	63	64	64 ± 1
10435479–6006208 ^e	2MASS10435478–6006207	–1 ± 2	95	2.41	2.84	79	86	83 ± 5
10435238–6001175 ^e	–	+3 ± 1	90	6.77	7.70	279	304	291 ± 18
10434797–6001201 ^e	2MASS J10434797–6001201	+2 ± 1	92	4.44	5.02	176	176	176 ± 0
10434887–6006437 ^e	2MASS J10434886–6006437	+6 ± 1	126	5.11	5.74	206	212	209 ± 4
10434679–6008264 ^e	CPD-59 2539	+2 ± 1	130	2.45	2.84	81	87	84 ± 4
10434887–6009009	ALS 18775	–26 ± 2	156	4.54	5.14	183	181	182 ± 1
10435198–6010368 ^e	2MASS J10435127–6010386	+3 ± 3	86	6.24	6.76	258	261	259 ± 2
10433156–6003160 ^e	2MASS J10433154–6003159	–3 ± 1	254	3.01	3.44	107	109	108 ± 1
10432030–6013015	2MASS J10432028–6013014	–6 ± 1	107	4.80	3.77	179	119	149 ± 42
10424533–6012063	2MASS J10424532–6012063	–32 ± 1	144	2.51	3.15	86	91	88 ± 4
10425717–6007414	CPD-59 2510	–4 ± 1	182	1.75	1.74	20	38	29 ± 13
10425445–6002595	2MASS J10425444–6002594	–41 ± 2	96	2.13	1.90	62	62	62 ± 0
10425898–6000242	2MASS J10425900–6000240	–11 ± 2	108	3.61	4.17	137	136	136 ± 1
10424616–6000576	CPD-59 2504	–3 ± 3	138	5.21	5.90	211	219	215 ± 6
10422722–6000052	2MASS J10422722–6000052	–16 ± 3	84	3.74	4.45	144	146	145 ± 1
10423616–5959262	ALS 15956	–12 ± 1	260	2.92	3.54	104	106	105 ± 1
10424804–5953371	–	–14 ± 2	131	4.27	4.61	167	159	163 ± 6
10421831–6001553	–	–14 ± 4	104	2.27	2.21	70	70	70 ± 0
10422123–5957156	–	–22 ± 2	177	3.84	4.08	148	136	142 ± 8
10420759–5956249	–	–16 ± 1	140	1.68	1.38	38	38	38 ± 0
10415981–5955075	HD 305439	–23 ± 1	159	3.01	3.72	107	115	111 ± 6
10434882–6000366 ^e	ALS 15 962	–6 ± 2	114	4.86	6.01	204	228	216 ± 17
10440371–5948141	2MASS J10440371–5948141	–10 ± 1	93	2.21	2.74	76	83	79 ± 5
10434303–5945334	2MASS J10434303–5945333	–10 ± 1	70	3.61	4.31	138	137	138 ± 0
10434813–5950443	Cl* Trumpler 14 MJ 137	–3 ± 2	117	2.24	2.51	72	70	71 ± 1
10435010–5947025 ^e	2MASS J10435009–5947024	–13 ± 2	53	4.82	5.09	193	180	187 ± 9
10435088–5950308	2MASS J10435088–5950307	+10 ± 4	59	4.08	4.41	158	151	155 ± 6

Table B1 – continued

GES ID	Other ID	V_r (km s ⁻¹)	SNR	FWHM (Å)		$V \sin i$ (km s ⁻¹)		
				4388 Å	4471 Å	4388 Å	4471 Å	Average
10440071–5949519	2MASS J10440071–5949518	-3 ± 2	128	1.94	1.64	52	51	52 ± 1
10440237–5952047	2MASS J10440236–5952046	-17 ± 1	108	1.69	1.49	23	33	28 ± 7
10441456–5954492 ^e	2MASS J10441455–5954492	-17 ± 1	39	–	5.19	–	186	186
10441879–5951490 ^e	2MASS J10441879–5951490	-32 ± 5	90	4.80	5.39	199	203	201 ± 3
10444512–5954114 ^e	2MASS J10444512–5954114	-10 ± 2	44	2.96	3.05	105	104	105 ± 1
10445041–5955450	ALS 1864	-2 ± 1	267	1.99	2.17	68	70	69 ± 2
10445392–5956134	Gaia DR3 5350302097055370496	-8 ± 2	39	4.66	5.27	188	188	188 ± 0
10450602–5956512	2MASS J10450601–5956512	-8 ± 2	52	1.22	0.99	1	6	4 ± 3
10451073–5957548	2MASS J10451072–5957547	-5 ± 1	51	6.57	7.53	271	297	284 ± 18
10451338–5957538	HD 305533	-5 ± 2	214	4.69	5.49	199	217	208 ± 13
10451341–6000589	CPD-59 2638	-9 ± 1	105	2.74	3.11	95	95	95 ± 0
10451672–5954458	HD 305528	$+2 \pm 0$	117	2.16	2.25	65	69	67 ± 3
10433443–5943265 ^e	2MASS J10433443–5943264	-2 ± 1	92	1.42	1.47	26	35	30 ± 7
10443008–5952141	ALS 15 222	-6 ± 1	178	1.13	1.22	4	15	10 ± 8
10445734–6000467	ALS 1866	-5 ± 1	157	2.06	2.21	68	68	68 ± 1
10445053–5957227	2MASS J10445053–5957227	$+1 \pm 0$	46	2.37	2.87	81	82	81 ± 1
10444551–5952538	2MASS J10444550–5952537	-9 ± 3	30	5.48	5.59	226	209	217 ± 12
10435403–5946106	2MASS J10435403–5946105	-12 ± 1	21	–	5.69	–	193	193
10413434–5958474 ^{b, e}	2MASS J10413434–5958474	-20 ± 1	94	2.22	2.51	77	77	77 ± 0
10421033–5958009 ^b	HD 305439	-11 ± 2	282	2.06	2.41	69	75	72 ± 4
10425293–6003478 ^{b, e}	2MASS J10425293–6003478	-3 ± 1	62	2.06	2.23	63	63	63 ± 0
10443676–5954249 ^b	ALS 1853	$+6 \pm 1$	105	1.61	1.76	7	41	24 ± 24
10442910–5948207 ^f	2MASS J10442909–5948207	-7 ± 0	60	1.98	2.22	67	72	69 ± 3
Collinder 232								
10444614–5933041 ^e	2MASS J10444614–5933041	-6 ± 3	56	6.09	6.54	252	250	251 ± 1
10445838–5932063 ^e	2MASS J10445837–5932062	-7 ± 1	67	6.67	7.36	275	290	283 ± 10
10445036–5934469	2MASS J10445036–5934468	-12 ± 1	39	–	3.60	–	119	119
10452417–5932358	2MASS J10452417–5932357	-1 ± 1	85	3.60	3.87	136	126	131 ± 8
10444734–5926595 ^e	Gaia DR3 5350388683629610752	-6 ± 1	99	6.15	6.51	253	249	251 ± 3
10451589–5929564	2MASS J10451588–5929563	-14 ± 4	78	7.34	7.67	308	310	309 ± 2
10451925–5929522 ^e	2MASS J10451925–5929522	$+2 \pm 0$	79	1.36	1.47	8	32	20 ± 17
10452876–5930038	2MASS J10452875–5930037	$+3 \pm 1$	19	1.18	1.28	6	16	11 ± 7
10442518–5928160	ALS 15 232	-8 ± 2	89	4.72	5.33	204	204	204 ± 0
10442886–5928166	2MASS J10442885–5928165	-2 ± 1	72	1.26	1.25	7	12	9 ± 4
10444727–5928155	2MASS J10444727–5928155	-2 ± 1	93	4.65	5.19	186	184	185 ± 1
10450616–5931231	ALS 15237	$+22 \pm 2$	148	4.37	5.27	176	189	182 ± 9
10442549–5933093	ALS 15 235	-16 ± 2	110	2.87	3.68	104	114	109 ± 7
10442848–5932229	2MASS J10442848–5932228	-1 ± 1	61	4.33	4.76	170	167	168 ± 2
10442946–5933438	2MASS J10442945–5933437	-6 ± 1	68	7.95	7.98	328	319	324 ± 6
10443223–5933593	2MASS J10443223–5933592	-15 ± 1	138	7.62	7.42	317	294	305 ± 16
10444650–5934134	2MASS J10444649–5934134	-8 ± 1	72	4.97	5.42	199	196	198 ± 2
10445629–5933035	ALS 15 205	-7 ± 2	158	5.40	6.10	230	246	238 ± 12
10442598–5928593 ^e	Gaia EDR3 5350387270553228928	-11 ± 2	98	2.43	3.16	93	94	94 ± 1
Bochum 11								
10452563–5958452	2MASS J10452563–5958451	-6 ± 2	27	4.74	5.46	188	198	193 ± 7
10453186–6000294	AHP2016 OBc 53	-27 ± 4	24	–	3.99	–	144	144
10454701–6000272	2MASS J10454701–6000271	-5 ± 1	96	3.53	4.42	133	145	139 ± 8
10455900–5958098	2MASS J10455899–5958098	$+2 \pm 0$	111	6.93	7.12	285	277	281 ± 5
10460116–5949420	2MASS J10460116–5949420	$+8 \pm 2$	13	–	5.17	–	187	187
10460277–5950193	2MASS J10460277–5950192	-10 ± 1	75	7.89	8.48	330	347	338 ± 12
10460291–5950259	2MASS J10460291–5950259	-3 ± 1	20	2.05	2.05	58	53	56 ± 4
10460478–5949218	2MASS J10460477–5949217	$+6 \pm 2$	120	4.94	5.46	210	216	213 ± 4
10460493–5959018	–	$+6 \pm 0$	175	1.92	2.05	44	53	48 ± 6
10460607–5956339	2MASS J10460606–5956339	-3 ± 1	123	4.78	5.33	193	191	192 ± 1
10460609–5957394	2MASS J10460608–5957394	-1 ± 1	24	–	2.69	–	82	82
10462246–5953205	ALS 1892	-15 ± 1	161	–	5.35	–	230	230
10462658–5956131	2MASS J10462657–5956131	-11 ± 0	19	–	4.10	–	127	127
10463118–5954352	2MASS J10463117–5954351	-25 ± 1	17	–	3.03	–	96	96
10463278–5952375	2MASS J10463277–5952375	-18 ± 3	8	–	2.34	–	68	68
10463643–5948049	2MASS J10463643–5948048	-8 ± 1	43	1.55	1.57	11	32	21 ± 15
10463801–5955166	2MASS J10463801–5955165	-8 ± 6	48	6.11	6.63	253	255	254 ± 1
10464887–5950410	2MASS J10464886–5950409	-10 ± 1	57	4.34	5.08	176	183	179 ± 4
10470064–5957242	2MASS J10470063–5957242	-8 ± 1	56	3.15	3.95	114	123	118 ± 7

Table B1 – *continued*

GES ID	Other ID	V_r (km s ⁻¹)	SNR	FWHM (Å)		$V \sin i$ (km s ⁻¹)		
				4388 Å	4471 Å	4388 Å	4471 Å	Average
10470436–5948281	2MASS J10470435–5948281	−2 ± 1	46	6.14	6.28	255	237	246 ± 12
10470657–5951515	2MASS J10470656–5951514	+8 ± 1	45	2.27	2.21	70	71	71 ± 1
NGC 3293								
10342068–5814107	–	+4 ± 9	77	8.4	4.2	134	134	134 ± 0
10342078–5813305	CPD-57 3450	−21 ± 2	176	3.4	3.8	129	116	123 ± 9
10344202–5815419	ALS 20075	−26 ± 2	71	3.5	3.1	129	102	115 ± 19
10344494–5809103 ^e	–	−16 ± 10	7	1.5	1.7	42	50	46 ± 6
10344774–5807274	2MASS J10344773–5807272	−22 ± 5	49	4.7	4.9	190	175	183 ± 10
10344868–5809012	V* V400 Car	−16 ± 1	41	1.9	2.2	63	68	65 ± 3
10344869–5807127	–	−11 ± 2	298	2.8	3.1	98	101	99 ± 2
10345480–5807233	ALS 20077	+1 ± 4	71	5.4	5.4	220	194	207 ± 18
10350325–5814268	ALS 20084	+1 ± 4	72	6.6	6.1	273	228	251 ± 31
10351355–5811124	2MASS 10351352–5811125	−38 ± 4	89	4.5	5.5	181	202	192 ± 15
10352272–5817081	ALS 20080	−19 ± 4	78	6.9	7.1	283	275	279 ± 6
10352410–5813284	2MASS J10352408–5813285	−14 ± 3	103	4.7	5.2	190	186	188 ± 2
10352851–5812496	2MASS J10352849–5812497	−52 ± 1	224	1.5	1.2	27	5	16 ± 16
10353007–5812080	HD 303067	−14 ± 2	291	2.8	3	103	92	97 ± 8
10353230–5815220 ^f	HD 303075	−13 ± 5	207	6.6	6.6	281	270	275 ± 8
10353289–5810162	Cl* NGC 3293 FEAS 454	−16 ± 2	51	5.7	3.9	131	131	131 ± 0
10353568–5813564	2MASS J10353565–5813566	−15 ± 5	76	3.4	4.4	128	145	136 ± 12
10353581–5813077	Cl* NGC 3293 ESL 116	−15 ± 14	84	7.5	6.5	307	246	276 ± 43
10353662–5816040	2MASS J10353660–5816042	−20 ± 2	108	4.1	4.8	163	166	164 ± 2
10353767–5812120	2MASS J10353767–5812120	−9 ± 3	148	6.7	6.3	277	240	259 ± 26
10353848–5813069	Cl* NGC 3293 ESL 73	−19 ± 3	209	4.2	3.7	164	124	144 ± 28
10354026–5813012	2MASS J10354026–5813012	−5 ± 7	133	7	6.1	287	227	257 ± 42
10354072–5812440	ALS 1671	−22 ± 1	64	1.6	2.2	51	70	60 ± 13
10354194–5811567	2MASS J10354191–5811568	−19 ± 5	550	7.3	7.4	308	300	304 ± 6
10354331–5813334	ALS 20065	−25 ± 3	153	5	5.5	210	210	210 ± 0
10354405–5813459	Cl* NGC 3293 ESL 40	−24 ± 4	129	7.9	7.4	330	291	310 ± 28
10354456–5814303	V438 Car	−19 ± 1	275	4.8	5.3	194	193	193 ± 16
10354499–5816350	2MASS J10354497–5816352	−16 ± 2	217	4.5	5.5	179	201	190 ± 16
10354530–5815280	Cl* NGC 3293 ESL 57	−17 ± 3	98	5.5	6.1	226	228	227 ± 2
10354723–5813375	ALS 15740	−17 ± 2	174	2	1.6	56	31	44 ± 18
10354752–5805130	ALS 20081	−18 ± 7	117	6.5	6.6	270	252	261 ± 13
10354822–5812329	ALS 15741	−17 ± 1	68	2.8	3.5	108	119	114 ± 8
10354901–5814541	ALS 20070	−18 ± 4	313	2	3.5	62	111	87 ± 34
10354954–5815398	2MASS J10354954–5815398	−12 ± 2	221	5.8	6.5	237	248	242 ± 8
10355051–5812126	2MASS J10355050–5812127	−26 ± 2	73	6.4	5.5	208	208	208 ± 0
10355073–5811414	2MASS J10355073–5811414	−16 ± 3	194	5.4	5.5	221	200	211 ± 14
10355129–5816179	ALS 20087	−18 ± 4	105	6.2	6.4	257	247	252 ± 8
10355174–5813392	2MASS J10355174–5813392	−16 ± 6	106	6	5.6	246	205	225 ± 28
10355301–5812168	ALS 15743	−25 ± 2	271	5.1	5.5	211	212	211 ± 1
10355312–5814260	2MASS J10355311–5814257	−27 ± 6	53	5.6	4.6	235	164	200 ± 50
10355363–5814478	ALS 15744	−18 ± 18	70	4	5.1	167	200	183 ± 23
10355397–5815047	ALS 20092	−11 ± 5	94	5.6	3.7	121	121	121 ± 0
10355422–5815267	HD 91983	−25 ± 2	101	3.1	3.8	122	135	129 ± 9
10355467–5813486 ^g	ALS 15745	−18 ± 3	125	8.8	8.1	370	326	348 ± 31
10355469–5812371	2MASS 10355469–5812371	−13 ± 2	195	6.2	5.8	257	217	237 ± 28
10355491–5812591	ALS 20064	−18 ± 3	77	6.6	7.1	276	289	282 ± 9
10355492–5806492	10355492–5806492	−15 ± 3	152	4.5	4	179	137	158 ± 30
10355539–5812197	ALS 20066	−18 ± 1	237	4	4.8	161	177	169 ± 11
10355660–5811314	ALS 15746	−22 ± 3	264	1.5	1.4	34	21	27 ± 10
10355711–5815218	Cl* NGC 3293 ESL 66	−35 ± 1	126	1.9	1.2	48	27	38 ± 15
10355781–5812213	ALS 15748	−15 ± 2	375	1.3	1.1	21	5	13 ± 11
10355836–5814411	2MASS J10355836–5814411	−25 ± 3	44	5.6	5.2	230	184	207 ± 32
10355849–5814148	ALS 15751	−28 ± 8	77	5.2	5.9	218	228	223 ± 7
10360160–5815096	HD 92007	−21 ± 1	370	2.2	2.6	75	77	76 ± 1
10360229–5812581	2MASS J10360231–5812583	−19 ± 2	73	6.3	6.2	259	234	246 ± 18
10360349–5814401	ALS 15753	−15 ± 1	198	5.4	6	221	223	222 ± 1
10360491–5810433	HD 303065	−13 ± 2	244	3.4	3.8	139	135	137 ± 2
10360525–5816455	2MASS J10360523–5816456	−66 ± 2	63	1.4	2.5	22	68	45 ± 32

Table B1 – continued

GES ID	Other ID	V_r (km s ⁻¹)	SNR	FWHM (Å)		$V \sin i$ (km s ⁻¹)		
				4388 Å	4471 Å	4388 Å	4471 Å	Average
10360595–5814270 ^e	ALS 1683	-20 ± 3	219	8.5	7.8	358	313	335 ± 32
10360656–5806551	2MASS J10360656–5806549	-19 ± 2	67	5.7	5.5	233	198	216 ± 25
10360657–5817538	ALS 20074	-10 ± 1	83	7.4	6.6	301	255	278 ± 33
10360764–5815204	ALS 20072	-18 ± 2	204	2.3	2.8	78	85	81 ± 5
10361290–5813250	2MASS J10361290–5813250	-7 ± 1	106	6.8	6.2	281	237	259 ± 31
10361348–5811207	2MASS J10361347–5811208	-24 ± 1	90	4.5	4.8	181	165	173 ± 12
10361692–5815000	ALS 20085	-22 ± 2	53	6.5	5.4	197	197	197 ± 0
10362800–5808180	2MASS J10362800–5808180	-16 ± 2	61	7.1	6.9	290	268	279 ± 15

^bProbable background star kept in the sample.^eEmission in at least one Hydrogen line.^fProbable foreground star kept in the sample.

APPENDIX C: MEASUREMENTS OF FWHM AND ESTIMATES OF PROJECTED ROTATIONAL VELOCITIES FOR PROBABLE NON-MEMBERS

In this Appendix, we list the main results for the 15 stars probable non-members analysed in this paper: GES ID, others names, the

radial velocities measured from He and Si lines, SNR (S/N) of the observed spectra, FWHM measurements of the H I lines 4388 and 4471 Å, the $V \sin i$ estimates derived through the interpolation of the measured FWHM, and the average $V \sin i$ values from H I lines.

Table C1. FWHM measurements and $V \sin i$ estimates for 15 early-type stars in the Carina Nebula marked as probable non-member.

GES ID	Other ID	V_r (km s ⁻¹)	SNR	FWHM (Å)		$V \sin i$ (km s ⁻¹)		
				4388 Å	4471 Å	4388 Å	4471 Å	Average
10442843–5934197 ^f	2MASS J10442842–5934196	-1 ± 1	124	2.85	3.48	108	113	110 ± 3
10441243–5934091 ^b	2MASS J10441242–5934091	-6 ± 2	191	6.30	6.69	260	258	259 ± 1
10441678–5920096 ^f	CPD-58 2634	-18 ± 1	176	3.02	3.42	109	101	105 ± 6
10441792–5925204 ^b	2MASS J10441791–5925204	-13 ± 1	184	4.61	5.00	181	178	180 ± 2
10443090–5914461 ^b	2MASS J10443089–5914461	-7 ± 3	27	–	2.61	–	85	85
10444276–5921511 ^f	ALS 15 857	$+3 \pm 2$	131	5.01	5.66	209	218	213 ± 7
10445888–5942231 ^b	2MASS J10445888–5942230	-19 ± 2	66	2.07	2.26	59	62	60 ± 2
10451063–5945126 ^f	2MASS J10451062–5945126	-12 ± 2	40	–	1.29	–	14	14
10420950–6002267 ^b	2MASS J10420949–6002265	-3 ± 2	69	3.00	3.65	115	118	116 ± 3
10431946–5944488 ^f	2MASS J10431945–5944488	-6 ± 2	27	–	1.44	–	32	32
10442108–5956208 ^b	2MASS J10442107–5956207	-3 ± 2	70	3.79	4.32	145	146	146 ± 0
10443239–5954458 ^f	2MASS J10443239–5954457	$+5 \pm 0$	28	–	7.20	–	281	281
10424477–6005021 ^b	[AHP2016] OBc 17	-10 ± 7	131	5.27	5.87	222	231	226 ± 7
10454461–5950411 ^b	ALS 16082	-35 ± 1	52	4.42	5.03	187	195	191 ± 6
10355661–5812407 ^b	CPD-57 3520	-15 ± 1	285	4.9	5.2	197	186	191 ± 8

^bBackground probable non-member.^fForeground probable non-member.

This paper has been typeset from a $\text{\LaTeX}$ file prepared by the author.