

Spectral and physical characterization of B-type stars in Trumpler 11

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Resumen / Realizamos un estudio exhaustivo del cúmulo abierto Trumpler 11, ubicado en la región suroeste de la nebulosa de Carina, utilizando el espectrógrafo GMOS de Gemini Sur en modo multi-objeto. Determinamos los parámetros físicos y el tipo espectral de 24 estrellas de tipo B tardío, caracterizamos el enrojecimiento en todo el campo del cúmulo y obtuvimos estimaciones precisas de su distancia y edad. Este análisis espectroscópico se complementó con fotometría de *Gaia DR3* y curvas de luz de *TESS*. Al comparar las propiedades y el estado evolutivo de Trumpler 11 con datos de los cúmulos abiertos cercanos, exploramos la estructura a gran escala y la historia de formación estelar del brazo de Carina-Sagitario.

Abstract / We performed a deep study of the open cluster Trumpler 11, located in the southwestern region of the Carina Nebula, using Gemini South GMOS spectroscopy in multi-object mode. We determined the physical parameters and spectral type of 24 late B-type stars, characterized the reddening across the cluster field, and obtained accurate estimates of the cluster's distance and age. This spectroscopic analysis was complemented with *GAIA DR3* photometry and *TESS* light curves. By comparing the properties and evolutionary status of Trumpler 11 with those of nearby open clusters, we explored the large-scale structure and star-formation history of the Carina-Sagittarius arm.

Keywords / galaxies: clusters: individual (Trumpler 11) — stars: fundamental parameters — stars: evolution — techniques: spectroscopic — techniques: photometric

1. Introduction

The Carina-Sagittarius Arm is a primary spiral arm of the inner Milky Way, characterized by complex stellar populations, massive star clusters, and the Car OB1 association, which is potentially one of the Galaxy's most massive star-forming complexes. Interestingly, the Carina arm shows an age gradient throughout its profile. Ivanov (1983) reported the decrement in the mean age of star clusters with the radial distance from the sun, in the direction from the inner to the outer part of the arm. This age gradient was regarded as the artifact of a density wave forming a spiral arm pattern. Mel'Nik et al. (1998) presented an age gradient based on OB1 and OB2 associations, suggesting younger stellar populations in the inner edge and older stars at the outer edge of the arm. These results were in general agreement with the expected residual velocity distribution due to spiral density waves within the corotation radius. While studying the structure of the Galaxy, Avedisova (1989) also reported an age gradient along and across the Carina arm, supported by the presence of several giant H II regions, molecular clouds, and tens of young open clusters in the inner part of the arm.

We performed a deep study of the open cluster Trumpler 11, located in the southwestern region of the Carina Nebula, using Gemini South GMOS spectroscopy in multi-object mode complemented with *GAIA DR3* photometry and *TESS* light curves. Through spectroscopic analysis of 24 late B/early A-type stars, we determined physical parameters, spectral types, reddening, distance, and age. By comparing the properties and evolutionary status of Trumpler 11 with nearby open clusters, we explored the large-scale structure and star-formation history of the Carina-Sagittarius arm, investigating stellar population characteristics at the outer edge of this galactic region and contributing to our understanding of sequential star formation and chemical evolution.

Section 2 gives an overview of the observational data used in this study. Section 3 describes the spectroscopic analysis conducted to determine stellar classifications and derive atmospheric parameters of 24 stellar sources. Results of our analysis were presented in Section 4. The discussion and conclusions of these findings are presented in Section 5, which places Trumpler 11 within the broader context of the region surrounding the Carina Nebula.

2. Data and Observations

The data used in this work are part of an observational Gemini proposal (Program GS-2024A-Q-212 and GS-2024A-Q-403, PI: Y. Aidelman) aimed at studying two open clusters: Ruprecht 44 and Trumpler 11. In this study, we focus exclusively on Trumpler 11. Additional data from *GAIA* and *TESS* space missions were also included. In the following sections, we outline the observations, instrumental configuration, and the data reduction procedure.

2.1. Gemini Spectroscopy

Data were acquired in queue mode at the Gemini South Observatory (Cerro Pachón, Chile). For this study, the Gemini Multi-Object Spectrograph (GMOS) was selected. GMOS is a versatile instrument installed on both the Gemini North and Gemini South 8.1-m telescopes. Its design features the on-instrument wave-front sensor (OIWFS) and active flexure compensation system, which maintain very high image quality and stability.

The observations were carried out on the night of 10th May 2024 from 00:52:16.9 UTC till 02:06:21.0 UTC. Six science observations in two fields of Trumpler 11 were obtained, each with an exposure time of 80 sec in field 1 and 150 sec in field 2. In between these observations, four flat frames of exposure 3 sec taken along with six images of the wavelength calibrator CuAr lamp with an exposure time of 40 sec were observed. The GMOS instrument was configured with two masks (named hereinafter C1 and C2) with 1-arcsec slits, a B480 grating, and a detector array of three 2048 × 4176 Hamamatsu chips arranged in a row. A spectral resolving power of $R = 1522$ was achieved, covering the spectral range 3750 – 8500 Å.

There were 45 targets observed in two masks (23 in field 1 and 22 in field 2, with 6 sources appearing in both). The spectra were reduced using GEMINI IRAF packages (v1.14)*, following the same method as the longslit case but applied to multiple slits. Initial processing included overscan correction with Legendre polynomial fits (RMS < 0.5), edge trimming, and bias correction using GBIAS and GSREDUCE tasks. Flat-field correction was applied with the GFLAT routine to account for pixel sensitivity variations. Wavelength calibration used polynomial fits to lamp line positions (RMS < 0.2) with the GSWAVELENGTH or MGSWAVELENGTH routines. Individual spectra were extracted using GSEXTRACT task, including aperture identification, background definition, and sky subtraction. Local ID numbers were assigned to targets during reduction. These reduced data were analyzed in our study, which has been discussed in Section 3.

2.2. GAIA DR3

Additionally, data from *GAIA DR3* (Gaia Collaboration et al., 2023) for the star cluster Trumpler 11 were ob-

tained using the ASTROQUERY.GAIA module (Ginsburg et al., 2019) to identify probable cluster members. We conducted a circular search centered at $\alpha = 151.248^\circ$, $\delta = -61.619^\circ$ with a radius of 10 arcmin.

2.3. TESS

The Transiting Exoplanet Survey Satellite (*TESS*), launched by NASA in 2018, searches for planets orbiting bright, close-by stars through a full-sky survey Ricker et al. (2015). The time-based data from the *TESS* High Level Science Products (HLSP) mission were obtained from the Mikulski Archive for Space Telescopes (MAST) through the STScI portal**. Pre-reduced light curves for each spectroscopic source were examined to search for eclipsing binaries.

3. Methodology

We identified typical spectral lines found in B and A-type stars and measured line center and equivalent widths using IRAF’s SPLIT task with both Gaussian fitting and bisector techniques. The center of lines was used to estimate radial velocities of the stars, and equivalent widths were utilized to determine spectral classification using the quantitative relations proposed by Didelon (1982). These spectral classifications were refined manually through visual comparison to standard stellar spectra.

Stellar parameters were derived by comparing the observed spectra with synthetic ones convolved to the observed resolution. Synthetic spectra from the BOSZ 2024 models grid (Mészáros et al., 2024) were used, for solar metallicity, with effective temperatures in the interval 6000 – 16000 K, and surface gravities with $\log g = 2 - 5$. A custom PYTHON fitting routine was used to perform this analysis. We determined the effective temperature (T_{eff}), surface gravity ($\log g$), microturbulent velocity (v_{mic}), and projected rotational velocity ($v \sin i$) for each star. A linear combination of weighted χ^2 was used to check the goodness of the fit.

Cluster members were identified using proper motions and parallaxes provided by the *GAIA DR3* release. The PYUPMASK algorithm (Pera et al., 2021) was used to estimate the cluster membership probability. Spatial parameters, *RA* and *DEC*, along with astrometric parameters, such as proper motions and parallaxes, and errors were used with default hyperparameters of the PYUPMASK algorithm. A probability was assigned to each source as an output. For this study, stars with membership probability greater than 90% were considered as cluster members.

To investigate the stellar population and evolutionary status of the sample, we employed color–magnitude diagrams (CMDs). Bressan et al. (2012) models of stellar evolutionary tracks and isochrones were used for this analysis. These models cover a wide range of ages, masses, and metallicities and are available in various

*The Gemini IRAF software is maintained and distributed by NSF’s NOIRLab, <https://iraf.noirlab.edu/>

**<https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html>

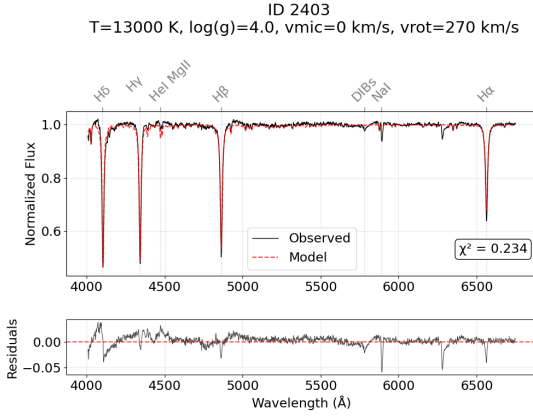


Fig. 1. Star ID 2403: example of an atmospheric model fitting with residual plot.

photometric systems. Isochrones from the *GAIA* photometric system were downloaded from the official website of Padova CMD***.

4. Results

From the atmospheric model fitting, stellar parameters like T_{eff} , $\log g$, v_{mic} , and $v \sin i$ were estimated (see Table 1). Additionally, the radial velocities, spectral and luminosity classes were determined for each star using line identification and measurements as explained in Sec. 3. Figure 1 shows stellar spectra of star ID 2403 fitted with a synthetic model along with the residual plot. We also report a Be star with clear emission in $H\alpha$ line (Fig. 2, as seen pole-on). By inspecting light curves for the spectroscopic sources in our sample, we found 3 binary star candidates exhibiting typical features of an eclipsing binary system. From which stars ID 3200 (UCAC4 142-033225) and ID 3775 (TYC 8943-1802-1) were previously reported and confirmed.

The spectroscopic Hertzsprung-Russell (sHR) diagram, introduced by Langer & Kudritzki (2014), plots $\log T_{\text{eff}}$ and $\log(\mathcal{L}/\mathcal{L}_{\odot})$, the solar normalized gravitationally weighted luminosity defined as $\mathcal{L} = T_{\text{eff}}^4/g$, and given by

$$\log(\mathcal{L}/\mathcal{L}_{\odot}) = 4 \log T_{\text{eff}} - \log g - \log \mathcal{L}_{\odot}, \quad (1)$$

where the solar gravitationally weighted luminosity is $\log \mathcal{L}_{\odot} = 10.61$. Through this sHR diagram, as shown in Fig. 3, the initial mass of the stars was constrained. These values are reposted in Table 1.

The cluster properties were determined using *GAIA* astrometric and photometric data. Using the radial density profile, the radius of Trumpler 11 was estimated to be 6 arcmin. From the *GAIA* G vs $B_p - R_p$ color-magnitude diagram and a visual comparison with isochrones (shown in Fig. 4), we estimate an age of 100 Myr, the distance modulus $(m-M)_0 = 13.15 \pm 0.30$ mag, and color excess $E(B_p - R_p) = 0.26 \pm 0.02$ mag for the open cluster Trumpler 11.

***<http://stev.oapd.inaf.it/cmd>

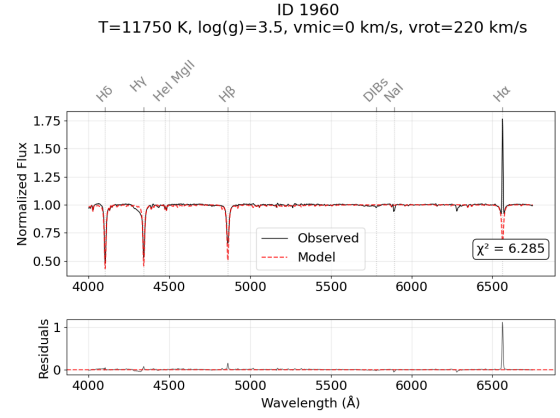


Fig. 2. Be star ID 1960: atmospheric model fitting with residual plot.

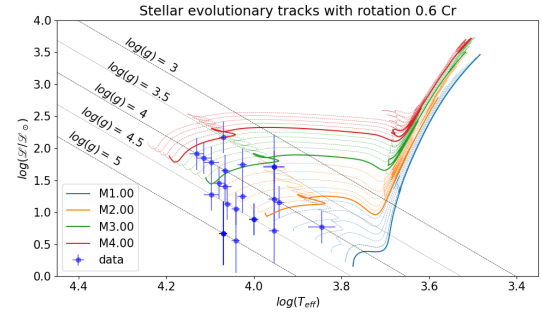


Fig. 3. Spectroscopic HR diagram with stellar evolutionary tracks for stars with initial masses ranging from 1 to $4.8 M_{\odot}$ rotating at 60% of critical rotational velocity (0.6 Cr).

5. Discussion and Conclusions

Our analysis reveals that Trumpler 11 contains a homogeneous population of AB-type main sequence stars (predominantly B7-B9, some A2, and F2 types) characterized by effective temperatures of 8000-13500 K, high surface gravities, and initial masses ranging from ~ 2.0 to $4.0 M_{\odot}$. All observed stars are fast rotators with projected velocities reaching half their critical rotation, and the cluster exhibits a systemic radial velocity of 33 ± 15 km/s. We identified a new eclipsing binary, ID 3775, from *TESS* photometry, and one classical Be star (ID 1960) displaying $H\alpha$ emission with the lowest $\log g$ value, seen pole-on. The cluster parameters indicate a radius of 6 arcmin, a distance of 4.2 ± 1.0 kpc (which is a bit larger than previously reported by Sagar & Cannon, 1994, i.e., 3.1 ± 0.3 kpc), and an age of 100 Myr. Significantly, we observe an age gradient among Carina arm clusters, with ages increasing both radially outward from the Carina Nebula and from the inner to outer spiral arm edge, providing insights into sequential star formation processes in this galactic region (shown in Fig.5).

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Table 1. Derived stellar parameters using spectral analysis. Values with ":" were estimated by extrapolation of the models. Columns 1–10 list the local identification number of the stars (*ID*), right ascension (*RA*) and declination (*Dec*) in degrees, effective temperature, surface gravity ($\log g$), projected rotational velocity ($v \sin i$), initial mass in solar masses, spectral type and radial velocity.

<i>ID</i>	<i>RA</i>	<i>Dec</i>	T_{eff}	$\log(g)$	$v \sin i$	<i>Initial mass</i>	<i>Spectral type</i>	<i>Radial velocity</i>
	[°]	[°]	[K]	[dex]	[km s ⁻¹]	[$M_{\odot}$]		[km s ⁻¹]
1216	151.26851	-61.59124	11000 ± 250	5 ± 0.5	100 ± 20	:2.5	B9 V	30 ± 9
1960	151.25688	-61.59933	11750 ± 250	3.5 ± 0.25	220 ± 20	4.0	Be8 V	-9 ± 13
2342	151.23688	-61.59839	10000 ± 250	4.5 ± 0.25	240 ± 20	:2.2	A0 V	23 ± 22
2403	151.30104	-61.60258	13000 ± 500	4 ± 0.25	270 ± 20	3.6	B7 V	42 ± 21
2684	151.23291	-61.61116	10625 ± 250	4.25 ± 0.25	155 ± 20	2.5	B9 V	62 ± 11
2792	151.26854	-61.60847	8750 ± 250	4 ± 0.25	200 ± 20	2.1	A3 V	48 ± 9
2996	151.24709	-61.61795	12000 ± 375	4.25 ± 0.25	115 ± 20	2.9	B9 V	43 ± 10
2998	151.24474	-61.61137	9000 ± 250	4.5 ± 0.5	150 ± 20	:1.8	A2 V	44 ± 16
3002	151.24414	-61.61471	11500 ± 250	4.5 ± 0.25	280 ± 20	:2.6	B9 V	26 ± 6
3084	151.32200	-61.61916	11750 ± 250	5 ± 0.5	240 ± 20	:2.7	B9 V	49 ± 10
3169	151.16191	-61.61503	11750 ± 250	5 ± 0.5	220 ± 20	:2.7	B9 V	53 ± 18
3200	151.21819	-61.61533	11625 ± 250	4 ± 0.25	180 ± 20	3.0	B9 V	35 ± 14
3249	151.17079	-61.61359	9000 ± 250	4 ± 0.5	240 ± 20	2.2	A2 V	41 ± 10
3494	151.14944	-61.62062	9000 ± 250	3.5 ± 0.25	200 ± 20	2.8	A2 V	65 ± 11
3537	151.24896	-61.62900	11625 ± 375	4.25 ± 0.25	250 ± 20	2.8	B9 V	40 ± 3
3718	151.19429	-61.62558	10625 ± 250	3.75 ± 0.25	275 ± 20	3.0	B9 V	41 ± 13
3775	151.22075	-61.62706	12500 ± 500	4 ± 0.25	200 ± 20	3.4	B8 V	37 ± 1
4149	151.36407	-61.63198	11750 ± 250	5 ± 0.5	240 ± 20	:2.7	B9 V	36 ± 18
4345	151.26395	-61.63642	13500 ± 500	4 ± 0.25	200 ± 20	3.8	B7 V	-5 ± 13
4474	151.23418	-61.63850	7000 ± 250	4 ± 0.25	200 ± 20	2.5	F2 V	20 ± 3
4906	151.27028	-61.64910	9000 ± 250	3.5 ± 0.5	150 ± 20	2.8	A2 V	43 ± 20
4919	151.26192	-61.64751	12500 ± 500	4.5 ± 0.25	130 ± 20	:3.0	B8 V	-13 ± 8
5129	151.21420	-61.64799	11000 ± 250	4.5 ± 0.25	200 ± 20	:2.4	B9 V	54 ± 27
814	151.22833	-61.57798	10000 ± 250	4.5 ± 0.25	280 ± 20	:2.2	A0 V	-3 ± 35

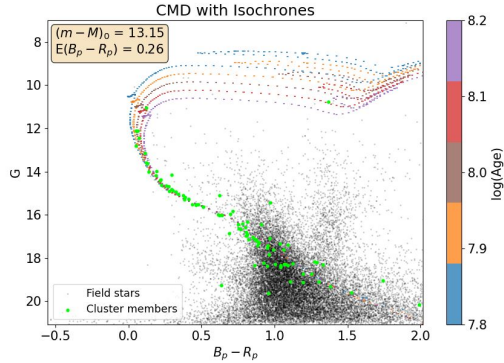


Fig. 4. GAIA color-magnitude diagram with isochrones overplotted to estimate the cluster age.

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