

Multiwavelength study of the Carina–Sagittarius Arm

I. Astrometric and photometric search for new open clusters in the $320^\circ \leq l \leq 325^\circ$ region

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ABSTRACT

Aims. Our main goal is to determine whether the lower stellar density observed in the Carina–Sagittarius Arm region ($320^\circ \leq l \leq 325^\circ$, $|b| \leq 1^\circ$) is an intrinsic structural feature of the spiral arm or a consequence of high interstellar reddening and extinction along the line of sight.

Methods. We performed a systematic search for new open clusters using the HDBSCAN algorithm on *Gaia* DR3 astrometric data. The physical reality of the candidates was validated through a multiwavelength analysis, integrating *Gaia* photometry with the near-IR photometry of the 2MASS catalog, the mid-IR photometric information of the WISE catalog to identify young stellar objects (YSOs), and the radio continuum emission at 843 MHz with the SUMSS survey to identify and associated interstellar material.

Results. We report the discovery of five new open clusters, the *ESFERA* sample. Our analysis reveals four young systems (10–50 Myr), with *ESFERA* 3 hosting YSOs, while *ESFERA* 5 is identified as a 2 Gyr old cluster. Although the region lacks massive star-forming complexes, these clusters trace active star formation within the region, although at a lower efficiency.

Conclusions. Our results suggest that this region represents an intrinsic star formation valley or low-density node (the string in a morphology of beads on a string) and is not an effect of extinction. The discovery of these clusters demonstrates that while the local surface density is below the critical threshold for massive complexes, star formation persists in isolated small-scale pockets throughout the arm.

Key words. parallaxes – proper motions – ISM: general – open clusters and associations: general – Galaxy: stellar content – Galaxy: structure

1. Introduction

Young open clusters (OCs) constitute primary tracers of the Milky Way spiral structure, offering a detailed sampling of the star formation history in the Galactic disk. As intrinsically bright systems that host massive early-type stars (O and B), they offer a distinct advantage for Galactic studies, as their young ages ensure that they remain close to their birthplaces in the spiral arms. Furthermore, their abundance throughout the disk provides a valuable and widely distributed sample based on which the Galactic disk properties can be studied. This complements other tracers such as Cepheids and masers (Efremov 1998; Vázquez et al. 2008; Choi et al. 2014; Molina Lera et al. 2018; Dias et al. 2021).

Crucially, distances to OCs can be determined with significantly higher precision than those of individual stars. By leveraging the photometry and kinematics of multiple cluster members, it is possible to mitigate individual measurement uncertainties. This collective analysis provides a more accurate distance estimate based on the statistical consensus of all member stars. Recent studies have highlighted an intriguing anomaly in the spatial distribution of young stellar tracers. Specifically,

large-scale surveys of OCs and OB stars (e.g., Chen et al. 2019; Liu et al. 2025) have revealed a noticeable gap or scarcity of detections within the Carina–Sagittarius Arm. This persistent lack of tracers at certain Galactic coordinates and the distance ranges raises fundamental questions regarding the continuity and local structure of this spiral arm, suggesting that our current census of the region remains incomplete.

This work bridges this observational gap by conducting a systematic search for new open clusters within the Carina–Sagittarius Arm, specifically, by targeting the region $320^\circ \leq l \leq 325^\circ$. While the number of cataloged OCs has grown significantly with the advent of the *Gaia* mission (Gaia Collaboration 2016), many candidates lack robust astrometric and physical confirmation. A major challenge in current Galactic studies are spurious entries, including duplicate records and chance alignments of field stars (asterisms) that do not constitute true clusters. Such inaccuracies can bias our understanding of the spiral structure. Consequently, we applied a rigorous membership analysis to identify genuine clusters to ensure a reliable census for the local structure of this arm.

The initial validation of OC candidates is as critical as the subsequent astrophysical analysis. To ensure maximum reliability, we adopted a multiwavelength approach that extends beyond optical observations. This involved a high-precision astrometric analysis using data from the *Gaia* Data Release 3 (*Gaia* DR3),

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specifically, parallaxes and proper motions, to confirm the common distance and kinematic coherence of the candidate stars. Furthermore, we integrated optical photometry with near- and mid-infrared (NIR and MIR) data to mitigate the effects of interstellar extinction and derive robust stellar parameters, such as age and distance. This comprehensive approach allowed us to rigorously cross-validate each stellar aggregate, ensuring that only physically genuine open clusters were used to map the Carina–Sagittarius Arm.

The paper is structured as follows. In Sect. 2, we describe the observational data and the various catalogs and services we used to obtain the astrometric and astrophysical parameters. Section 3 details the candidate selection process, including the astrometric and astrophysical constraints we applied. The analysis and results for each identified open cluster are presented in Sect. 4. Finally, the discussion and conclusions are provided in Sects. 5 and 6, respectively.

2. Observational data

2.1. Astrometric data

We used the astrometric and photometric parameters from the *Gaia* DR3 astrometric catalog (Gaia Collaboration 2023). Released on 13 June 2022, it consists of more than 1.81×10^9 sources with a limiting magnitude of $G \sim 21$ and a bright limit of $G \sim 3$. It contains some 585 million sources with five-parameter astrometry: position (α , δ), proper motion ($\mu_\alpha \cos \delta$, μ_δ), and parallax ϖ . It has about 882 million sources with six-parameter astrometry, including an additional pseudo-colour parameter. The astrometric solution is accompanied with some quality indicators, such as the renormalized unit weight error (RUWE).

2.2. Photometric data

The comprehensive study of OCs necessitates an astrometric analysis to identify cluster members, an estimate of the distances using parallax data, and a photometric analysis across a wide range of wavelengths. Consequently, in addition to the astrometric data of each stellar member, we used the optical photometric data (G , G_{BP} , G_{RP}) bands provided by *Gaia* DR3. The magnitudes are given for more than 1.80×10^9 in the G band (330–1050 nm), for more than 1.54×10^9 sources in the G_{BP} band (330–680 nm), and for more than 1.55×10^9 sources in the G_{RP} band (640–1050 nm). The photometric uncertainties supplied by the catalog are conservatively constrained to $\sigma_G \leq 0.01$ mag and $\sigma_{(BP-RP)} \leq 0.1$ mag. The color–magnitude diagram (CMD) serves as the primary tool for estimating the essential photometric characteristics of a star cluster. For our analysis with the *Gaia* data, we employed the Padova stellar isochrones from the PARSEC v1.2S models¹. These models, based on the stellar evolutionary tracks by Bressan et al. (2012), were computed for a scaled solar composition following the $Y = 0.2485 + 1.78Z$ relation, adopting a solar metallicity of $Z = 0.0152$.

To investigate the reddened stars and young stellar object (YSO) candidates within each cluster, we incorporated NIR photometry (JHK bands) from the Two Micron All-Sky Survey (2MASS)² (Skrutskie et al. 2006). The photometric uncertainties provided by the 2MASS catalog are typically $\sigma_{(JHK)} \leq 0.05$ mag. Additionally, we included mid-infrared (MIR) photometric data from the Wide-field Infrared Survey Explorer

(WISE) catalog³ (Wright et al. 2010). This MIR information covers the 3.4, 4.6, 12, and 22 μm bands (W_1 , W_2 , W_3 , and W_4) respectively.

Knowledge of the interstellar medium (ISM) is vital when studying a stellar formation region. To investigate the potential existence of an HII region and an HI shell and their connection with the star clusters, we used data from the Sydney University Molonglo Sky Survey (SUMSS) (Bock et al. 1999). SUMSS provides radio continuum emission data at 843 MHz. The synthesized elliptical beam of the survey is $45'' \text{ csc } |\delta| \times 45''$. This information was specifically used to search for interactions between the stellar population and the surrounding gas structures.

To manage and analyze the astronomical data, we used several standard software tools as listed below.

- Data management and analysis: we employed the Virtual Observatory software TOPCAT (Tool for Operations on Catalogs and Tables) (Taylor 2011) for efficient management and analysis of the astronomical tables.
- Image visualization: to analyze the images, we primarily used two visualization tools:
 - KVIS (Gooch 1996), which is part of the KARMA (A Virtual Reality Toolkit for Astronomers) astronomical visualization toolkit⁴, and
 - SAOImage DS9, which is developed and maintained by the Smithsonian Astrophysical Observatory (SAO) as an essential component of its astronomical visualization toolkit (Joye et al. 2025).
- Catalog access: to search and access a comprehensive collection of published astronomical data catalogs across various wavelengths, we consulted the VizieR tool⁵.

3. Data sources and membership

We searched for open clusters in the Carina–Sagittarius Arm region, more precisely, in the region $320^\circ \leq l \leq 325^\circ$, $-1^\circ \leq b \leq +1^\circ$. Figure 1 shows the distribution of OCs (from the UCC catalog Perren et al. 2023) in a section of the Carina–Sagittarius Arm. Figure 2 presents a histogram of the OCs shown in Fig. 1 to provide a quantitative view of the region we selected. The data display a clear lack of open clusters; this anomaly makes it a particularly compelling sector to investigate.

We used *Gaia* DR3 astrometric data (positions, proper motions, and parallaxes) for sources with a standard error in proper motion of $\leq 0.3 \text{ mas yr}^{-1}$ to minimize the errors arising from this parameter (Rizzo et al. 2025); the quotient parallax divided by its standard error must be ≥ 5 ($\text{parallax_over_error} \geq 5$) to reduce the errors in the transformation of mean weighted parallax to distance (Paíz et al. 2025); and the local RUWE threshold was determined using the GaiaUnlimited Python package (Castro-Ginard et al. 2024) to identify and discard potential binary systems and sources with unreliable astrometric solutions. The final sample consisted of 247 296 sources. These stringent astrometric quality cuts naturally limited the sample to stars typically brighter than $G \approx 18$ mag, which ensured that the membership analysis and subsequent isochrone fitting were based on high-precision data. Although these criteria exclude the lower main sequence, the sampled population (turn-off and RGB) remains sufficient for a robust characterization of the physical cluster parameters.

³ <http://irsa.ipac.caltech.edu/Missions/wise.html>

⁴ <https://www.atnf.csiro.au/computing/software/karma/>

⁵ <https://vizier.cds.unistra.fr>

¹ <http://stev.oapd.inaf.it/cgi-bin/cmd>

² <http://www.ipac.caltech.edu/2mass/>

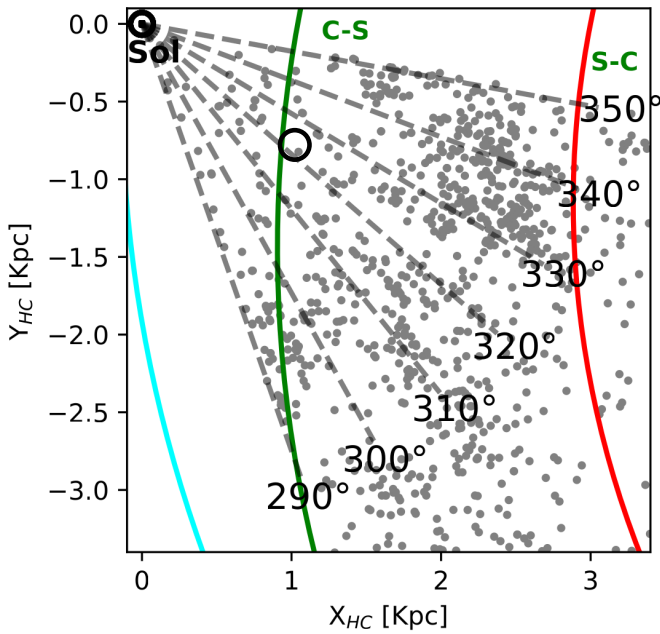


Fig. 1. Spatial distribution in heliocentric Galactic coordinates (X_{HC} , Y_{HC}) of known open clusters (gray points) from the UCC catalog (Perren et al. 2023). The plot covers the region $290^\circ < l < 350^\circ$ and $-1^\circ < b < 1^\circ$, corresponding to a prominent section of the Carina-Sagittarius Arm. The colored curved lines represent the Hou & Han (2014) spiral structure of the MW. The thick black circle highlights the specific region we investigated, centered at $l = 322^\circ$, which is characterized by a noticeable lack of known clusters and limited prior deep exploration.

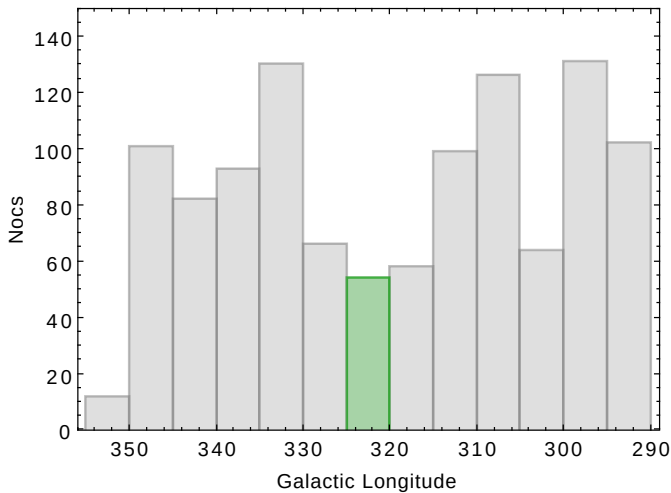


Fig. 2. Number of open clusters per 5° interval in Galactic longitude. This distribution highlights the density variations within the section of the Carina-Sagittarius Arm.

3.1. Candidate selection

We normalized the five astrometric data (α , δ , $\mu_\alpha \cos \delta$, μ_δ , and ϖ) through RobustScaler in the scikit-learn package (Pedregosa et al. 2011); for example, it removes the median and can scale the data according to the interquartile range. After this, the membership selection was performed using the HDBSCAN clustering algorithm (Campello et al. 2013) on the

five normalized astrometric parameters using its hyperparameters `min_samples` and `min_cluster_size` set to the same value (as recommended by Campello et al. 2013). To do this, we explored the range 5–100 to ensure cluster stability and discovery; the selection method (`cluster_selection_method`) can be excess of mass (eom) to select one or two of the largest clusters and some smaller clusters, or leaf to select several small and more homogeneous clusters (Santos-Silva et al. 2021). We chose leaf to prioritize the detection of small, homogeneous, and dense groupings; and with `metric=euclidean`, we used the standard euclidean metric to measure the five-dimensional distance between points.

We considered as astrometric members of a group stars with an HDBSCAN probability greater than or equal to 0.5. When HDBSCAN found groupings, we evaluated whether they corresponded to real clusters or false positives. We considered them false positives when they did not fulfill some of the following conditions by Cantat-Gaudin & Anders (2020) and Hunt & Reffert (2021):

(a) the dispersion of the total proper motion of the group members must satisfy

$$\sqrt{\sigma_{\mu_\alpha \cos \delta}^2 + \sigma_{\mu_\delta}^2} \leq \begin{cases} 1 \text{ mas yr}^{-1} & \text{if } \varpi \leq 0.67 \text{ mas} \\ 1.49 \cdot \varpi \text{ mas yr}^{-1} & \text{if } \varpi > 0.67 \text{ mas}; \end{cases} \quad (1)$$

(b) the radius containing half of the group members (r_{50}) must be smaller than 20 pc;

(c) the group must be denser than a surrounding set of 100–500 field stars. To compare densities in the five-dimensional space of normalized astrometric data, we computed the euclidean distance from each star to its ninth nearest neighbor in the group because we assumed that open clusters consist of at least ten members, and the ninth neighbor is free of contamination from binary or multiple star systems.

In this way, we divided the region we studied into five subregions of two square degrees. Out of the hundreds of groups initially identified by HDBSCAN in all subregions, 26 passed the astrometric filters (conditions a, b, and c), and 5 of them were confirmed as new open clusters with the isochrone fitting. This means that we detected a total number of 5 groupings representing new open clusters, and we call them *ESFERA 1*, *ESFERA 2*, *ESFERA 3*, *ESFERA 4*, and *ESFERA 5*. Fig. 3 shows the spatial distribution of the *ESFERA* open cluster members with their proper motions in Galactic coordinates calculated with the formulae of Poleski (2013).

3.2. Estimating the physical parameters

Building upon the sample of cluster member stars identified via the astrometric analysis described in Sect. 3.1, and adopting the cluster distances derived from their respective parallaxes, we initiated the photometric analysis for each open cluster by studying their CMDs using data from the *Gaia* DR3 survey. To determine the visual absorption for each cluster, we used the theoretical Schmidt–Kaler principal sequence (Landolt-Bornstein & Bursa 1982) in conjunction with coefficients derived from the polynomial fittings in the color–color diagram, using the Johnson–Cousins passbands (Jordi et al. 2010). These fittings are described by Eqs. (2) and (3). The standard deviation of the residuals of the fit was adopted as the σ value. The described theoretical curve was fitted to the *Gaia* photometric observations of the possible cluster members using A_v values constrained by the range proposed by Joshi (2025) (see their Fig.4) for

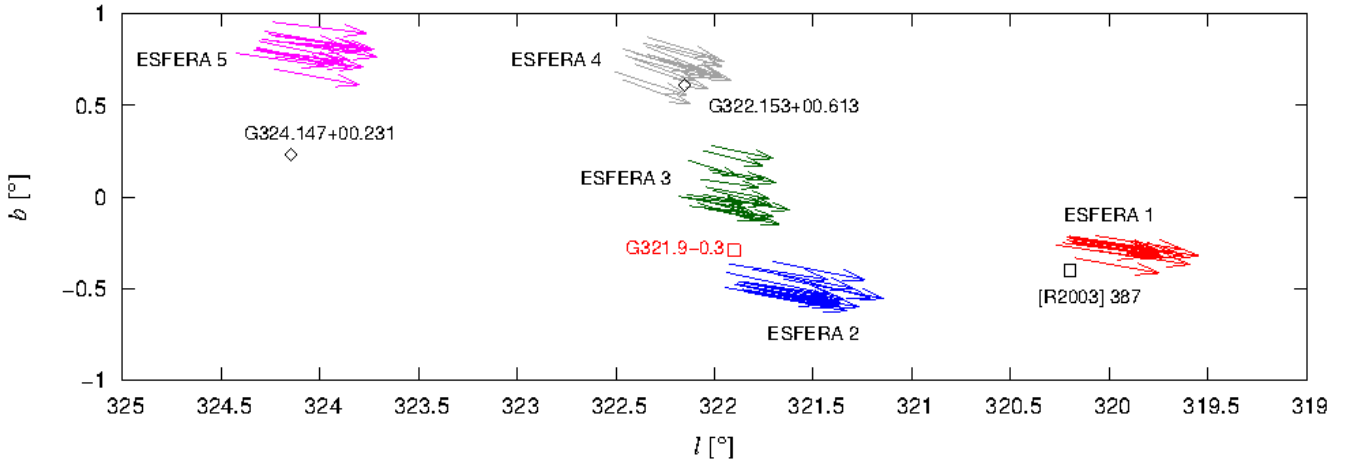


Fig. 3. Spatial distribution of the *ESFERA* open cluster members with their proper motions in Galactic coordinates. The different symbols represent HII region [R2003] 387 (Murray & Rahman 2010) (black open square), G 321.9–0.3 SNR (Ball et al. 2025) (open red square), and HII regions G 322.153+00.613 (Anderson et al. 2014) and G 324.147+00.231 (Anderson et al. 2014) (black diamonds). The proper motion components in Galactic coordinates were calculated with the formulae by Poleski (2013). The background is intentionally kept clear to maximize the contrast and visibility of the proper motion vectors.

$$300^\circ \leq l \leq 350^\circ,$$

$$G_{BP} - G_{RP} = 0.0981 + 1.429(B - V) - 0.0269(B - V)^2 - 0.0061(B - V)^3; \sigma = 0.43 \quad (2)$$

$$G = V - 0.0424 - 0.0851(B - V) - 0.3348(B - V)^2 - 0.0205(B - V)^3; \sigma = 0.38. \quad (3)$$

After we estimated the A_v value for each open cluster, we fitted the PARSEC v1.2S isochrones to their G versus $G_{BP}-G_{RP}$ photometric diagrams to determine the respective cluster ages. For this purpose, we applied the reddening law $A_G = 0.83627 A_v$, $A_{BP} = 1.08337 A_v$, and $A_{RP} = 0.63439 A_v$. Since age estimates derived from broadband photometric surveys and small member counts are inherently uncertain, we fitted the cluster by prioritizing the alignment of the most probable cluster members with the zero-age main sequence (ZAMS) and the identified early-type stars. Crucially, the metallicity was constrained to solar ($Z = Z_\odot$) in all these fitting attempts, as previously discussed in Sect. 2.2. As one stellar formation region clearly exhibited differential reddening, we needed a method to distinguish between reddening caused by dust and the inherent color of a star. Our protocol was to cross-reference the optical *Gaia* data (for stars confirmed as cluster members) with NIR photometric data from the 2MASS survey (*JHK*). We used a strict maximum angular distance of $1''$ for this matching process. Subsequently, to avoid any confusion arising from the intrinsic degeneracy between reddening and spectral type, we calculated the reddening-free photometric parameter $Q_{NIR} = (J - H) - 1.7 \times (H - K)$ (Negueruela et al. 2007). Our star classification was substantiated by the guidelines provided by Borissova et al. (2012) and Messineo et al. (2012), according to whom $-0.3 < Q_{NIR} < 0.5$ values are indicative of early main-sequence stars, $Q_{NIR} < -0.3$ values are indicative of pre-main-sequence stars (PMS) or young stellar objects (YSOs), and $0.5 < Q_{NIR}$ values are indicative of late reddening stars. Following this classification, potential YSO candidates ($Q_{NIR} < -0.3$) were further investigated by cross-matching them with the WISE catalog. This was done with the aim of confirming their YSO nature and subsequently classifying them according to the criteria established by Koenig &

Leisawitz (2014). The interstellar extinction vector, derived from the reddening law defined by Wang & Chen (2019), was superimposed on each CMD. This vector represents the reddening correction required to align the observed data with the intrinsic (dereddened) position of the theoretical isochrone, especially for the hotter and more luminous stellar populations. Based on this analysis, we estimated the spectral types of the cluster members and performed a classification using four categories: O⁻, O⁺, B⁻, and B⁺. In this nomenclature, the letters O and B denote the corresponding spectral types, and the minus (−) and plus (+) signs indicate early-type and late-type stars within each class, respectively.

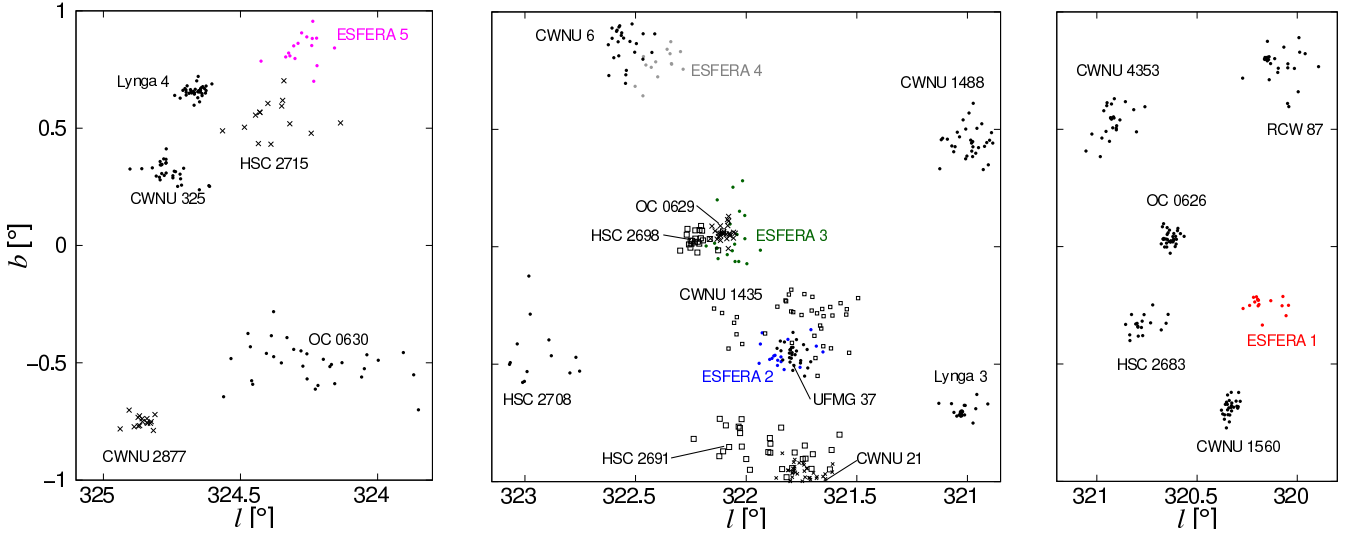
To complete the study about the redder stars, we analyzed the $(J - H)$ versus $(H - K)$ color-color diagram to distinguish different stellar populations. In our procedure, we adopted the MS calibrations given by Landolt-Bornstein & Bursa (1982), Dean et al. (1978), and Koornneef (1983). Their locations were computed using the adopted distances and visual absorption presented in Table 1 and a normal reddening law, which allowed us to use the absorption ratios ($r_X = A_X/A_v$) given by Rieke & Lebofsky (1985) and Carpenter (2001). Candidate members for each cluster were ordered by increasing *Gaia* source ID in all tables. This provided us with a uniform reference across astrometric and photometric datasets, ensuring that specific stars were easily identified and cross-referenced throughout the study.

Finally, the flux density at 843 MHz was estimated for each source located in the vicinity of each *ESFERA* open cluster. Using the task TVSTAT within the AIPS⁶ package, we determined the average background flux density (S_{bg}) in units of Jy beam^{−1}. This was achieved by calculating the mean flux density value at three different positions adjacent to each source. The root mean square (rms) of S_{bg} was then used as the detection threshold to distinguish the signal from the noise. Subsequently, the measured flux density value of each source was obtained, and the corresponding S_{bg} value was subtracted to yield the net emission. The spectral index α ($S \sim \nu^{-\alpha}$) is a key parameter that indicates the origin of the emission (either thermal radiation or nonthermal synchrotron radiation). It can be calculated from the flux densities measured at two different frequencies, ν_1 and ν_2 ,

⁶ <http://www.aips.nrao.edu/index.shtml>

Table 1. Open clusters *ESFERA* we discovered in the Galactic region $320^\circ \leq l \leq 325^\circ$, $-1^\circ \leq b \leq +1^\circ$.

ID	GLON	GLAT	α	δ	$\mu_\alpha \cos \delta$	μ_δ	Dist _{pl}	A_v	AGE
	($^\circ$)	($^\circ$)	($^\circ$)	($^\circ$)	(mas yr ⁻¹)	(mas yr ⁻¹)	(pc)	(mag)	(Myr)
1	320.167±0.017	-0.246±0.008	227.323±0.028	-58.427±0.011	-3.46±0.04	-2.86±0.03	2452±59	4.0±0.4	30±5
2	321.833±0.020	-0.456±0.012	230.220±0.036	-57.737±0.013	-3.59±0.04	-3.50±0.03	1907±32	3.5±0.3	50±5
3	322.065±0.013	0.045±0.023	230.079±0.032	-57.189±0.020	-2.22±0.05	-2.15±0.04	1939±34	2.5±0.2	10±2
4	322.387±0.018	0.776±0.016	229.860±0.038	-56.399±0.011	-2.43±0.03	-3.01±0.05	1648±24	2.5±0.2	20±5
5	324.274±0.015	0.838±0.015	232.601±0.029	-55.306±0.013	-3.27±0.07	-3.15±0.04	2417±49	3.4±0.3	2000±400

**Fig. 4.** Spatial distribution of *ESFERA 1* (red), *ESFERA 2* (blue), *ESFERA 3* (green), *ESFERA 4* (gray), and *ESFERA 5* (magenta) and local open clusters known in the literature (black) detected in this study.

with the mathematic expression $\alpha = \frac{\log(S_1/S_2)}{\log(v_2/v_1)}$. The determination of this spectral index is beyond the scope of this paper and will be addressed in a future study.

4. Analysis and results

In this section, we present the detection and characterization of five new open cluster candidates, hereafter designated as the *ESFERA* sample. Our analysis successfully identified these stellar aggregates alongside several previously catalog clusters, confirming the robustness of our selection criteria. Figure 4 illustrates the spatial distribution of these new candidates in relation to known open clusters in the literature (Cantat-Gaudin et al. (2020); Hao et al. (2022); Hunt & Reffert (2023); Cavallo et al. (2024)). While the known clusters served to validate the performance of the HDBSCAN algorithm in this region, their detailed multiwavelength analysis will be addressed in a future study.

4.1. *ESFERA 1*

Within the subregion defined by $320^\circ \leq l \leq 321^\circ$ and $-1^\circ \leq b \leq +1^\circ$, we analyzed a sample of 53 076 stars. Using the HDBSCAN algorithm with `min_samples = min_cluster_size = 10`, we identified an open cluster comprising 16 members. The mean astrometric parameters for this cluster are $\bar{\alpha} = 227.323 \pm 0.028$, $\bar{\delta} = -58.427 \pm 0.011$, $\overline{\mu_\alpha \cos \delta} = -3.46 \pm 0.04$ mas yr⁻¹, $\overline{\mu_\delta} = -2.86 \pm 0.03$ mas yr⁻¹, $\overline{\varpi} = 0.39 \pm 0.01$ mas, and $\bar{d} = 2452 \pm 59$ pc.

For *ESFERA 1*, we found $\sqrt{\sigma_{\mu_\alpha \cos \delta}^2 + \sigma_{\mu_\delta}^2} = 0.41$ mas yr⁻¹ and $r_{50} = 2.08$ pc. Figures 5a and b show the spatial distribution in Galactic coordinates and the Vector Point Diagram (VPD) of the candidate members. Figure 5c shows that the members of *ESFERA 1* are more densely grouped than a subset of 500 local field stars. They thus fulfill the three conditions described in Section 3.1.

The stars of this open cluster identified as 1 and 2 in Figs. 5d-e correspond to *Gaia* DR3 5880039205832933632 and *Gaia* DR3 5880038862235534720, respectively. Their Q_{NIR} values of 0.45 and 0.30 suggest that they are both likely early-type stars. By dereddening these stars using the $A_G/A_V = 0.789$ reddening law (Wang & Chen 2019), we placed accurately on the 30 Myr isochrone. Their derived mass and temperature values are consistent with spectral types B⁺, and possibly, B3 V and B4 V, respectively. While these two potential members of *ESFERA 1* appear significantly reddened, their positions in the IR color-color diagram (see Fig. 5e) are consistent with normally reddened stars. The other 14 potential members of the *ESFERA 1* open cluster, based on their placement along the isochrone, appear to be early-type stars ranging from B⁺ to A⁺. However, the Lyman-continuum photons emitted by these stars lack the necessary flux to ionize the interstellar medium and generate the HII region observed in this area. Furthermore, while the [R2003] 387 HII region (Murray & Rahman 2010) appears to be spatially coincident with *ESFERA 1*, its distance remains unknown. Another HII region, G 320.252–00.332, was also investigated, but its near-kinematic distance of 4.7 kpc

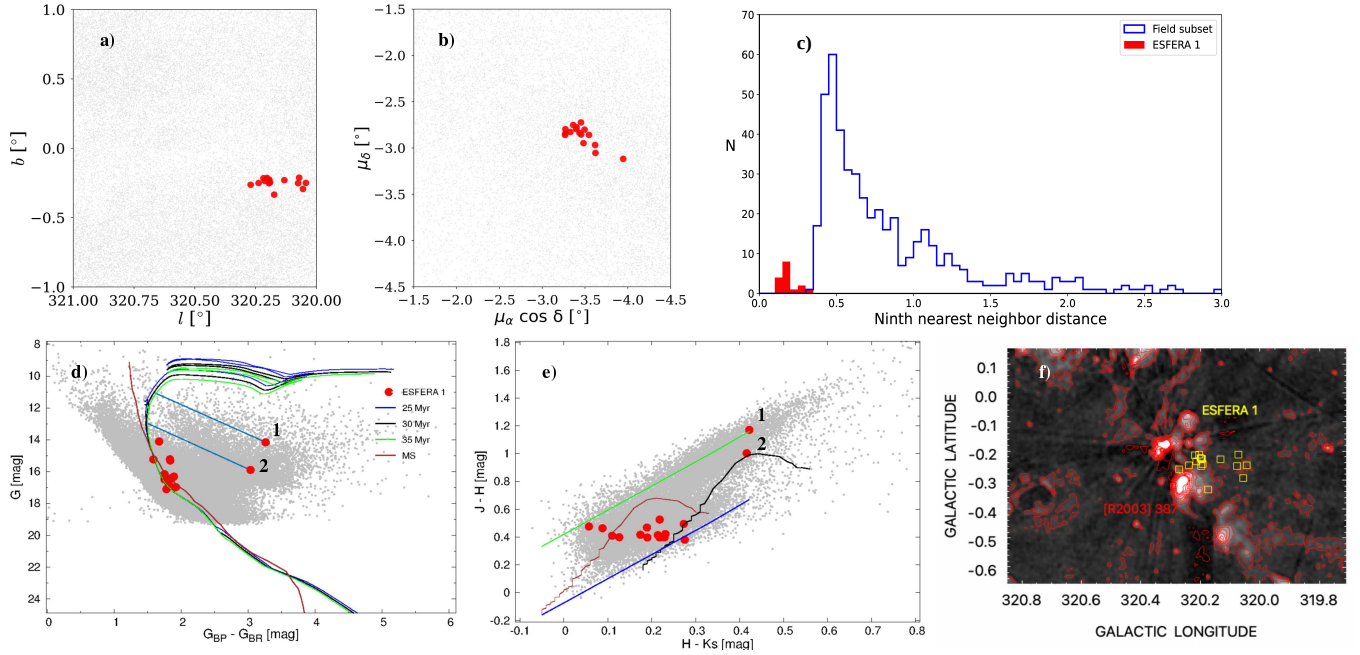


Fig. 5. Multiparametric analysis of the open cluster *ESFERA 1*. (a) Spatial distribution in Galactic coordinates and (b) VPD of the candidate members (filled red circles) compared to the field population (light gray dots). (c) Histogram of the ninth-nearest neighbor distances for *ESFERA 1* members (red) and a control subset of 500 local field stars (blue). (d) Optical CMD. The brown curve represents the MS fitted to a distance of 2452 pc and $A_V = 4$ mag. The black curve denotes the best-fit PARSEC v1.2S isochrone, and the blue and green curves represent the $\sim 15\%$ age uncertainties. (e) NIR CMD, where the black and brown curves indicate the MS shifted according to the adopted distance, with and without interstellar reddening, respectively. (f) Spatial projection of candidate members onto the SUMSS 843 MHz radio image. The red contours trace the HII emission of [R2003] 387 (Murray & Rahman 2010), and the contour levels are 5 ($\sim 5\sigma_{\text{rms}}$), 10, 50, 100, 150, 200, 250, and 300 mJy beam $^{-1}$.

(Anderson et al. 2014) confirmed that it is not physically associated with the cluster. An average visual extinction of $A_V = 4.0$ mag was adopted for the cluster, as discussed in Sect. 3.2. The complete list of members for *ESFERA 1*, including their astrometric parameters and multiwavelength photometry, is provided in Tables A.1 and B.1, respectively.

4.2. ESFERA 2

Within the subregion defined by $321^\circ \leq l \leq 322^\circ$ and $-1^\circ \leq b \leq +1^\circ$, we analyzed a sample of 51 327 stars. Using `min_samples = min_cluster_size = 10`, we identified an open cluster comprising 17 members. Its mean astrometric parameters are $\bar{\alpha} = 230^\circ 220 \pm 0^\circ 036$, $\bar{\delta} = -57^\circ 737 \pm 0^\circ 013$, $\overline{\mu_\alpha \cos \delta} = -3.59 \pm 0.04$ mas yr $^{-1}$, $\overline{\mu_\delta} = -3.50 \pm 0.03$ mas yr $^{-1}$, $\overline{\varpi} = 0.52 \pm 0.01$ mas, and $\bar{d} = 1907 \pm 32$ pc. For *ESFERA 2*, we obtained a proper motion dispersion of $\sqrt{\sigma_{\mu_\alpha \cos \delta}^2 + \sigma_{\mu_\delta}^2} = 0.51$ mas yr $^{-1}$ and a half-mass radius of $r_{50} = 2.16$ pc. As shown in Fig. C.1c, *ESFERA 2* is significantly denser than a representative subset of 500 local field stars, confirming its cluster nature.

The stars identified as 1 and 2 in Figs. C.1d-e correspond to *Gaia* DR3 5883123679555965184 and *Gaia* DR3 5883127935846172416, respectively. Star 1 yields a Q_{NIR} value of 0.32, which initially suggests an early-type main-sequence star. However, its position relative to the fitted isochrone in the CMD indicates that it has already evolved past the main-sequence turn-off point. Consequently, the appropriate luminosity class for this source is likely that of a giant (LC III) or supergiant (LC I). This classification is consistent with the estimated cluster age of 50 Myr, derived from the evolutionary analysis of its probable members. Star 2, as shown in

Fig. C.1e, is located to the right of the reddening vector for O-type dwarf stars and yields a Q_{NIR} value of -0.23 . This region of the *JHK* diagram is typically populated by YSOs, such as Herbig Ae/Be and T Tauri stars, which exhibit near-infrared excess emission due to circumstellar disks (Lada & Adams 1992). To investigate this YSO candidate, we cross-matched the source with the WISE catalog to analyze its photometric flux according to the classification scheme described by Koenig & Leisawitz (2014). However, *Gaia* DR3 5883127935846172416 was not detected in the WISE survey, leaving its YSO status unconfirmed. Finally, star 3 (Figs. C.1d-e) corresponds to *Gaia* DR3 5883133128483745408. It presents a Q_{NIR} value of 0.31, nearly identical to that of star 1. In the infrared color-color diagram, it is similarly positioned near the giant reddening vector. In the *Gaia* CMD, star 3 appears to be highly reddened, suggesting that it is likely an evolved late-type B star. The visual extinction for the cluster was estimated at $A_V = 3.5$ mag (see Sect. 3.2). The supernova remnant G 321.9–0.3 (Green 2019) is also located in the vicinity of *ESFERA 2* (see Fig. C.1f). However, multiple factors suggest that this is a line-of-sight coincidence. A detailed discussion of this topic is provided in Sect. 5. The complete list of members for *ESFERA 2*, including their astrometric parameters and multiwavelength photometry, is provided in Tables A.2 and B.2, respectively.

4.3. ESFERA 3

Within the subregion $322^\circ \leq l \leq 323^\circ$ and $-1^\circ \leq b \leq +1^\circ$, we analyzed a sample of 45 535 stars. Setting `min_samples = min_cluster_size = 10`, we identified an open cluster with 20 members. Its mean astrometric parameters are $\bar{\alpha} = 230^\circ 079 \pm 0^\circ 032$, $\bar{\delta} = -57^\circ 189 \pm 0^\circ 020$, $\overline{\mu_\alpha \cos \delta} = -2.22 \pm 0.05$ mas yr $^{-1}$,

$\overline{\mu_\delta} = -2.15 \pm 0.04$ mas yr⁻¹, $\overline{\omega} = 0.50 \pm 0.01$ mas, and $\overline{d} = 1939 \pm 34$ pc.

For *ESFERA* 3, we obtained a proper motion dispersion of $\sqrt{\sigma_{\mu_\alpha \cos \delta}^2 + \sigma_{\mu_\delta}^2} = 0.52$ mas yr⁻¹ and a half-mass radius of $r_{50} = 3.57$ pc. As illustrated in Fig. C.2c, *ESFERA* 3 is more densely populated than a representative subset of 500 local field stars, supporting its classification as a physical cluster. *ESFERA* 3 is the youngest open cluster in our sample, with an estimated age of only 10 Myr. In Fig. C.2e, the presence of reddened stars is clearly evident, specifically, stars 1 (*Gaia* DR3 5883216622652247808), 2 (*Gaia* DR3 5883215003418857472), and 3 (*Gaia* DR3 5883219440150823424). Stars 1 and 3 are recorded in the 2MASS catalog with a quality flag (Q_{fl}) of AAU. This indicates that while the J - and H -band detections are of high photometric quality, the K_s -band measurement is an upper limit, likely due to undefined photometric errors in that filter. In the CMD (Fig. C.2d), these stars are positioned close to each other on the fitted isochrone, allowing us to derive spectral types of F⁻ for star 1 and A⁺ for star 3. Star 2 presents a Q_{NIR} value of -0.47 , and its position in the IR color-color diagram exhibits a significant near-infrared excess. Our investigation of the WISE survey with the classification scheme by Koenig & Leisawitz (2014) identified this source as a Class II YSO. These objects are typically characterized by a protoplanetary disk where circumstellar dust reprocesses stellar radiation, creating an infrared excess, even as the primordial envelope begins to dissipate (Allen et al. 2004). The position of star 4 (*Gaia* DR3 5883232359411945472) in the CMD (see Fig. C.2d) relative to the fitted isochrone corresponds to temperature and mass values consistent with an A⁺ spectral type. However, its placement in the IR color-color diagram (see Fig. C.2e) is likely an artifact of the poor photometric quality, as indicated by its Q_{fl} flag of AUU. This flag denotes that the H and K_s magnitudes are upper limits, rendering its infrared colors unreliable. Star 5 (*Gaia* DR3 5883194941656356480) is the most highly reddened star in Fig. C.2d. It presents a Q_{NIR} value of 0.15, characteristic of an early main-sequence star, and its position in the Fig. C.2e is consistent with a late spectral type (with a high-quality Q_{fl} of AAA). This source was identified as a Class II YSO, cataloged as AGAL G321.934-00.006 in the ATLASGAL survey of massive cold dust clumps (Wienen et al. 2015). It has a reported heliocentric distance of 2.14 kpc, which closely agrees with the estimated distance for *ESFERA* 3. We independently verified this classification through an analysis of the WISE catalog, and the two YSOs are indicated in the allWISE color image Fig. 6. Finally, the stars spatially coincident with the HI emission (a possible HII region) possess spectral types A⁻, F⁻, and B⁺. Consequently, none of these stars provides sufficient ionizing flux to ionize the surrounding interstellar medium. The complete list of members for *ESFERA* 3, including their astrometric parameters and multiwavelength photometry, is provided in Tables A.3 and B.3, respectively.

4.4. *ESFERA* 4

In addition to *ESFERA* 3, within the same subregion ($322^\circ \leq l \leq 323^\circ$, $-1^\circ \leq b \leq +1^\circ$) and using `min_samples` = `min_cluster_size` = 10, we identified another open cluster consisting of 14 members. Its mean astrometric parameters are $\overline{\alpha} = 229^\circ 860 \pm 0^\circ 038$, $\overline{\delta} = -56^\circ 399 \pm 0^\circ 011$, $\overline{\mu_\alpha \cos \delta} = -2.43 \pm 0.03$ mas yr⁻¹, $\overline{\mu_\delta} = -3.01 \pm 0.05$ mas yr⁻¹, $\overline{\omega} = 0.59 \pm 0.01$ mas, and $\overline{d} = 1648 \pm 24$ pc. For *ESFERA* 4, we found a proper motion

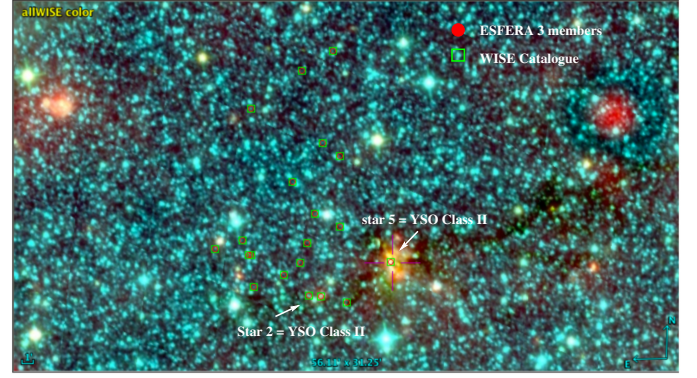


Fig. 6. AllWISE color-composite image of the *ESFERA* 3 region ($l = 320^\circ 0$, $b = 0^\circ 0$). The red circles identify the cluster members, and the green squares represent cataloged YSOs. Two probable Class II YSO members of the *ESFERA* 3 cluster are indicated.

dispersion of $\sqrt{\sigma_{\mu_\alpha \cos \delta}^2 + \sigma_{\mu_\delta}^2} = 0.61$ mas yr⁻¹ and a half-mass radius of $r_{50} = 1.90$ pc. As shown in Fig. C.3c, *ESFERA* 4 is denser than a representative subset of 500 local field stars.

Stars 1 (*Gaia* DR3 58863349440504533248) and 2 (*Gaia* DR3 58863363386248420736) possess a 2MASS photometric Q_{fl} of AAU, indicating that their resulting infrared colors are unreliable, similar to star 4 in *ESFERA* 3. The calculated Q_{NIR} values of 1.34 and 0.76 for sources number 1 and 2 are likely unphysical artifacts. When plotted on the 20 Myr isochrone, the positions of these two stars suggest that they are late-type objects, with estimated spectral types of F⁻ and F⁺, respectively. Stars 3 (*Gaia* DR3 58863257425123101568) and 4 (*Gaia* DR3 58863352429801298816) are the oldest members of *ESFERA* 4, both characterized by a G⁻ spectral type. Regarding their 2MASS JHK_s fluxes, the former has a Q_{fl} of AAU and a Q_{NIR} of -0.19 , while the latter has a Q_{fl} of AAA and a Q_{NIR} of 0.00. The positions of the two stars in the IR color-color diagram are typical of their respective spectral types. Star 5 (*Gaia* DR3 58863352567240269312) is the most highly reddened member of the cluster. By fitting the isochrone with the $A_G/A_V = 0.789$ reddening law, we derived a most probable spectral type of B⁺. Interestingly, its placement in the IR color-color diagram is somewhat anomalous, as it lies within the region that is typically occupied by late-type main-sequence stars. However, because the photometric quality in all three bands is excellent (AAA) and the Q_{NIR} value is 0.08 (consistent with a standard stellar atmosphere), this displacement is likely a result of the high extinction affecting the source and not an intrinsic near-infrared excess. Regarding the interstellar medium (see Fig. C.3f), this open cluster is located in proximity to the HII region G322.153+00.613, although their spatial positions do not overlap. The complete list of members for *ESFERA* 4, including their astrometric parameters and multiwavelength photometry, is provided in Tables A.4 and B.4, respectively.

4.5. *ESFERA* 5

Within the subregion $324^\circ \leq l \leq 325^\circ$ and $-1^\circ \leq b \leq +1^\circ$, we analyzed a sample of 52 417 stars. By increasing the clustering threshold to `min_samples` = `min_cluster_size` = 15, we identified an open cluster consisting of 16 members. Its mean astrometric parameters are $\overline{\alpha} = 232^\circ 601 \pm 0^\circ 029$, $\overline{\delta} =$

-55.721 ± 0.013 , $\overline{\mu_\alpha \cos \delta} = -3.27 \pm 0.07$ mas yr $^{-1}$, $\overline{\mu_\delta} = -3.15 \pm 0.04$ mas yr $^{-1}$, $\overline{\varpi} = 0.40 \pm 0.01$ mas, and $\overline{d} = 2417 \pm 49$ pc. For *ESFERA 5*, we obtained a proper motion dispersion of $\sqrt{\sigma_{\mu_\alpha \cos \delta}^2 + \sigma_{\mu_\delta}^2} = 0.41$ mas yr $^{-1}$ and a half-mass radius of $r_{50} = 2.41$ pc. As illustrated in Fig. C.4c, *ESFERA 5* is more densely populated than a representative subset of 500 local field stars

This is a particularly noteworthy open cluster. At 2 Gyr, it is significantly older than the other clusters we identified. Furthermore, it alone of the **five** discovered clusters contains potential blue straggler stars (BSS) among its probable members. These candidates, labeled 1 (*Gaia* DR3 5883844512499441280) through 6 (*Gaia* DR3 5883838911861950720), are located above and blueward of the main-sequence turn-off point. They represent a population of rejuvenated stars, whose presence indicates an interesting dynamical history that is further analyzed in Sect. 5. Stars 7 (*Gaia* DR3 5883837915429150592) and 8 (*Gaia* DR3 5883841832439453056) are the only sources fitted on the main sequence with a luminosity class V (see Fig. C.4d). The remaining sources, numbered 9 (*Gaia* DR3 5883845165334464256) through 16 (*Gaia* DR3 5883837086485049088), are potential giants; in Fig. C.4e, stars 9, 10 (*Gaia* DR3 5883844100182546944), 11 (*Gaia* DR3 5883840698568446208), and 13 (*Gaia* DR3 5883844375059980800) occupy the region typical of late-type stars, and stars 14 (*Gaia* DR3 5883843992792751232), 15 (*Gaia* DR3 5883844993535795840), and 16 are consistent with the giant branch. Notably, star 4 (*Gaia* DR3 5883842210396958720) has no reported magnitudes in the near-infrared *J*, *H*, *K* bands, and star 12 (*Gaia* DR3 5883840732928203776) has a Q_{fl} of AUU. The last result likely explains its significant displacement from the sequence on which stars with standard interstellar extinction are expected to lie. The complete list of members for *ESFERA 5*, including their astrometric parameters and multiwavelength photometry, is provided in Tables A.5 and B.5, respectively.

5. Discussion

Our analysis revealed that some diverse population of OCs traces the Carina-Sagittarius Arm within $320^\circ \leq l \leq 325^\circ$. We found a diversity in morphology, with structures varying from compact, such as *ESFERA 4* ($r_{50} < 2$ pc), to more extended, such as *ESFERA 3* ($r_{50} > 3.5$ pc). Furthermore, the clustering algorithm effectively separated structures projected along the same line of sight, but located at different distances, such as *ESFERA 3* (~ 1.9 kpc) and *ESFERA 4* (~ 1.6 kpc), providing a clearer view of the stellar distribution at different depths of the spiral arm. Figure 2 reveals the density drops by more than 50% compared to adjacent regions. The discovery of the five *ESFERA* clusters in this specific gap significantly improves the census of the stellar population in this undersampled section of the Galactic disk. The robustness of our method stems from the ability of the HDBSCAN algorithm to operate in a high-dimensional parameter space, which allowed us to effectively segregated stellar populations that appear to be blended in traditional proper motion or spatial projections. By simultaneously processing five-dimensional astrometric data ($\alpha, \delta, \mu_\alpha \cos \delta, \mu_\delta$, and ϖ), our approach successfully identified distinct stellar groups that share nearly identical proper motions, but are clearly separated by their parallax values. This high-dimensional clustering capability is critical for minimizing field star contamination and enables the

detection of sparse clusters that would remain hidden in traditional 2D or 3D searches, particularly within the high-density and high-extinction environments of the Galactic plane.

5.1. *ESFERA 1*

The estimated age of 30 Myr for *ESFERA 1*, derived from the isochrone fitting, strongly supports the conclusion that the cluster is not physically associated with the HII region [R2003] 387. At an age of 30 Myr, any massive O-type stars, which are essential for providing the ionizing Lyman-continuum flux required to maintain an HII region, would have already evolved off the main sequence or ended their life cycles as supernovae. The most massive members we identified, classified as B $^+$ (probably B3 V and B4 V spectral types), are perfectly consistent with a 30 Myr population, but their ionizing photon rate ($\log N_{LyC}$) is several orders of magnitude below the threshold needed to sustain the observed radio emission in the region. Furthermore, while stars 1 and 2 exhibit significant reddening, their alignment with the standard reddening vector in the *JHK_s* IR color-color diagram suggests that this extinction is primarily interstellar and not circumstellar. This indicates that *ESFERA 1* has already cleared its natal gas and dust, a process that is typically completed within the first 10 Myr of the life of a cluster. Consequently, the spatial coincidence between *ESFERA 1* and the [R2003] 387 HII region is likely a chance alignment along the line of sight. This is analogous to our findings for G320.252–00.332, where the near-kinematic distance of 4.7 kpc (Anderson et al. 2014) clearly places it at a different Galactic location, further confirming that *ESFERA 1* is an independent stellar population.

5.2. *ESFERA 2, 3, and 4*

The spatial proximity of these new candidates to interstellar features provides further insights into their evolutionary history. For *ESFERA 2*, the identification of star 2 as a potential YSO candidate based on its *JHK_s* color excess presents a chronological discrepancy. While this excess suggests the presence of a circumstellar disk, such structures typically dissipate within 5–10 Myr, which is significantly shorter than the estimated age of 50 Myr of the cluster. Since the source lacks a WISE counterpart to confirm a mid-infrared excess, its position in the IR color-color diagram might instead be explained by extreme localized extinction, or alternatively, it might be a background YSO that is unrelated to the cluster. Another possibility is that star 2 is a classical Be star, where the infrared excess originates from a gaseous decretion disk rather than a primordial pre-main-sequence disk (Zorec & Briot 1997), which would be more consistent with the evolved nature of the cluster. Another relevant aspect regarding this cluster is its possible relation with the SNR G321.9–0.3. Previous estimates placed this remnant at a distance of approximately 5.5 kpc (Case & Bhattacharya 1998), which differs from the distance we derived for the cluster. More importantly, the SNR is associated with the X-ray binary Circinus X-1, a system originating from a very massive progenitor. Because *ESFERA 2* is 50 Myr old, any such massive star would have exploded tens of millions of years ago. The presence of a visible SNR today (which typically lasts only $\sim 10^5$ years) clearly indicates a much more recent supernova event unrelated to the cluster evolution.

A similar environmental analysis was conducted for *ESFERA 3*, focusing on its association with local gas. It is noteworthy that while stars 1, 3, and 4 (spectral types A and F) of this OC are located in regions with detectable HI emission, star

2 is not. This contrast reinforces the classification of star 2 as a more primordial or less evolved object than the other members. The A- and F-type stars, despite their young age, appear to have already emerged from the densest molecular cores, whereas star 2 remains tied to a region that has not yet transitioned to a diffuse atomic phase.

The cluster *ESFERA 4*, as noted in Sect. 4.4, is located in proximity to the HII region G322.153+00.613, although their current spatial positions do not overlap. Furthermore, an analysis of the member proper motions suggested that their locations were also not coincident at the time of cluster formation; since their motion is oriented toward the HII region (see Fig. 3), it is unlikely that they share a common origin or that triggered star formation occurred between them.

5.3. *ESFERA 5*

The open cluster *ESFERA 5* has an estimated age of ~ 2 Gyr, which is highly atypical for an open cluster situated near the Galactic plane. Open clusters in this region are generally expected to be rapidly dynamically disrupted [Janes & Phelps \(1994\)](#) by frequent encounters with giant molecular clouds (GMCs) [Spitzer \(1958\)](#) and strong Galactic tidal forces [Wielen \(1985\)](#). The longevity of this specific cluster, however, suggests a distinct survival mechanism. Its persistence up to 2 Gyr, despite being close to the disk, is further supported by the presence of BSS among its members. The stellar membership of *ESFERA 5* was robustly established via an astrometric analysis of *Gaia* DR3 data. Following this, the BSS population was identified from the CMD by their position significantly above and blueward of the main-sequence turn-off point, consistent with a rejuvenation of stars more massive than the cluster turn-off mass. The astrometric solution for these BSS candidates indicates a low RUWE value, which might initially suggest a lack of close binary activity. We must account for the fact that the sensitivity of RUWE to binarity decreases significantly at distances of ~ 2.5 kpc ([Penoyre et al. 2022](#); [Castro-Ginard et al. 2024](#)). Consequently, we consider two potential formation channels for the BSS population in *ESFERA 5*. First, if these stars are indeed single objects, as the astrometric solution suggests, their formation would likely be driven by direct stellar collisions in a high-density core environment. This would imply that *ESFERA 5* was significantly more massive and compact in its early stages. Alternatively, given the distance-related limitations of RUWE, we cannot rule out the mass transfer channel in primordial binary systems ([Rain et al. 2024](#)). The presence of such a significant BSS population (regardless of the specific formation mechanism) remains a compelling indicator of the complex dynamical cluster evolution over its 2 Gyr lifetime. Furthermore, the 2 Gyr age of *ESFERA 5* denotes an evolved stellar population that lacks the capacity to ionize or mechanically disrupt the local interstellar medium. The HII region G324.147+00.231 ([Anderson et al. 2014](#)) indicated in Fig. C.4f is located at an angular distance of $\sim 38'$, which is approximately four times the estimated cluster radius. This significant spatial offset, combined with the fact that its population cannot generate such HII region, confirms that G324.147+00.231 is a non-associated object, likely projected along a similar line of sight. Old open clusters are typically not considered primary tracers of recent star formation within spiral features, but we included *ESFERA 5* in our analysis due to its unique characteristics and its absence from previous catalogs.

The detection of *ESFERA 5* ($\log t \approx 9.3$, $A_V > 3$, $b = 0^\circ.8$) is particularly consistent with the selection functions described by [Hunt et al. \(2025, see their Fig. 3\)](#). According to their analysis,

clusters in this age and extinction regime within the Galactic plane have a recovery probability below 15%, highlighting the effectiveness of our high-purity regional search in identifying older sparse populations that often elude global automated algorithms. Despite its estimated age of 2 Gyr, this cluster is particularly noteworthy for hosting a population of blue straggler stars among its members. The identification of such a mature system, containing clear evidence of stellar interactions, provides valuable insights into the dynamical history and the long-term stellar population of the Carina–Sagittarius region.

The findings in the current $320^\circ \leq l \leq 325^\circ$ sector are consistent with but distinct from previous investigations in the neighboring Carina region. Specifically, at $l = 316^\circ.8$, a multi-wavelength approach revealed a population of three embedded clusters associated with early-type stars and different classes of YSOs ([Corti et al. 2023](#)). The presence of these objects at $l = 316^\circ.8$ provides a direct point of comparison for the *ESFERA* sample, marking the transition from the active star-forming complexes of the Carina arm toward a more quiescent sector. The region spanning $l \in [320^\circ, 325^\circ]$ exhibits a significant deficit of young star-forming tracers compared to the $l \approx 316^\circ$ area. We propose that this sector represents a clear observational example of a star formation valley (or gap) resulting from the periodic fragmentation of the interstellar medium, as modeled by the magneto-gravitational instability [Elmegreen \(1982\)](#); [Kim & Ostriker \(2002\)](#).

In the context of the morphology of beads on a string described by [Efremov \(2010\)](#), our study area appears to function as the string, or the low-density node connecting two major star forming complexes (the beads): the dense Carina region at $l < 310^\circ$ and the Centaurus complex at $l > 330^\circ$. This spatial distribution suggests that large-scale gravitational and magnetic forces have effectively channeled gas away from this segment to feed the adjacent massive complexes. Consequently, the local surface density in this region has fallen below the critical threshold required to trigger collapse, maintaining it in a quiescent state compared to its immediate Galactic surroundings. In this context, the discovery of the *ESFERA* sample provides a crucial contribution to this scenario of beads on a string. While the region $320^\circ \leq l \leq 325^\circ$ lacks the massive star-forming complexes found in Carina or Centaurus, our identification of five new open clusters (particularly the youngest system, e.g., *ESFERA 3* with its associated YSOs) demonstrates that star formation is not entirely suppressed in this string segment. Instead, it occurs in smaller, more isolated pockets where the local gas density exceeds the collapse threshold. This suggests that the valley is not a void, but rather a region of lower-efficiency star formation that requires high-precision surveys such as ours to be fully characterized.

6. Conclusions

We bridged a significant observational gap in the Carina–Sagittarius Arm, specifically, within the region $320^\circ \leq l \leq 325^\circ$, by conducting a systematic search for previously uncatalogued open clusters. To achieve this, we performed a comprehensive multiwavelength analysis, integrating astrometric and photometric data from *Gaia* DR3 with near- and mid-infrared photometry from 2MASS and WISE and radio continuum data from SUMSS (843 MHz). This approach led to the discovery of five OCs, all located within the Galactic plane ($-1^\circ \leq b \leq 1^\circ$). Our sample is primarily composed of four young systems with ages ranging between 10 and 50 Myr. Additionally, we identified *ESFERA 5* as a significantly older system,

with an estimated age of 2 Gyr, highlighting the presence of evolved populations and the existence of BSS members in this Galactic sector.

The *ESFERA* sample reveals a clear evolutionary sequence of young stellar populations. *ESFERA 3* stands out as the youngest system in our census, with an age of 10 Myr and confirmed YSOs, indicating a very recent star formation event. The remaining young sample (with ages of 20, 30, and 50 Myr) completes this age distribution, providing a comprehensive snapshot of the star formation history in this sector of the Carina–Sagittarius arm.

The implementation of the HDBSCAN clustering algorithm on *Gaia* DR3 astrometry proved to be a powerful tool for isolating these systems from the dense Galactic field. By combining this with a multiwavelength validation (visual to radio), we were able to confirm the physical reality of these candidates, effectively overcoming the high extinction levels and stellar crowding characteristic of the Carina–Sagittarius sector. Our analysis of the interaction between the clusters and their environment revealed that spatial proximity does not necessarily imply a common origin. Stellar populations of different ages and evolutionary stages indeed frequently overlap along the same line of sight within the spiral arm, highlighting the complex structural assembly of the Carina–Sagittarius region. This complexity underscores the need for a systematic census, which is continued in the second part of this study.

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Appendix A: Astrometric results

Table A.1: Probable members of open cluster *ES FERA* 1 from astrometric analysis.

<i>GAIA – DR3</i>	α	δ	ϖ	ϵ_{ϖ}	$\mu_{\alpha}\cos\delta$	$\epsilon_{\mu_{\alpha}\cos\delta}$	μ_{δ}	$\epsilon_{\mu_{\delta}}$
58800...	[$^{\circ}$: ' : '']	[$^{\circ}$: ' : '']	[<i>mas</i>]	[<i>mas</i>]	[<i>mas yr</i> ⁻¹]	[<i>mas yr</i> ⁻¹]	[<i>mas yr</i> ⁻¹]	[<i>mas yr</i> ⁻¹]
26973766044928	227:11:07.0	-58:31:28.6	0.317	0.053	-3.618	0.052	-2.968	0.072
27798399504896	227:25:12.3	-58:29:59.6	0.507	0.060	-3.267	0.061	-2.860	0.070
29378947544832	227:21:49.2	-58:24:55.1	0.374	0.029	-3.622	0.029	-3.054	0.039
29413307278848	227:22:33.7	-58:25:07.0	0.460	0.078	-3.495	0.081	-2.802	0.101
29516386509824	227:23:16.1	-58:23:43.6	0.421	0.057	-3.482	0.056	-2.948	0.064
29619465728256	227:21:02.2	-58:23:54.4	0.418	0.020	-3.329	0.019	-2.827	0.026
29619465729152	227:21:13.9	-58:23:46.0	0.412	0.063	-3.271	0.064	-2.797	0.083
29619470340480	227:21:11.4	-58:23:33.2	0.434	0.080	-3.398	0.078	-2.796	0.103
29756904691200	227:22:44.9	-58:22:32.0	0.408	0.053	-3.271	0.050	-2.842	0.062
29791264429696	227:21:10.7	-58:22:51.2	0.391	0.072	-3.454	0.072	-2.855	0.094
38862235534720	227:07:24.1	-58:29:33.5	0.372	0.047	-3.946	0.049	-3.118	0.057
39205832933632	227:10:40.6	-58:28:41.1	0.382	0.027	-3.546	0.027	-2.859	0.036
39549430334336	227:07:59.2	-58:26:46.0	0.375	0.030	-3.436	0.030	-2.838	0.040
40855100166784	227:15:02.6	-58:25:51.7	0.356	0.032	-3.400	0.033	-2.776	0.041
52193818076672	227:26:41.3	-58:23:43.2	0.348	0.054	-3.453	0.052	-2.724	0.063
52262534093312	227:30:39.2	-58:23:23.5	0.387	0.050	-3.362	0.050	-2.752	0.056

Table A.2: Probable members of open cluster *ES FERA* 2 from astrometric analysis.

<i>GAIA – DR3</i>	α	δ	ϖ	ϵ_{ϖ}	$\mu_{\alpha}\cos\delta$	$\epsilon_{\mu_{\alpha}\cos\delta}$	μ_{δ}	$\epsilon_{\mu_{\delta}}$
58831...	[$^{\circ}$: ' : '']	[$^{\circ}$: ' : '']	[<i>mas</i>]	[<i>mas</i>]	[<i>mas yr</i> ⁻¹]	[<i>mas yr</i> ⁻¹]	[<i>mas yr</i> ⁻¹]	[<i>mas yr</i> ⁻¹]
17048125978624	230:09:20.4	-57:49:33.5	0.551	0.087	-3.618	0.089	-3.359	0.084
22923616738560	230:16:45.3	-57:47:41.8	0.513	0.057	-3.631	0.057	-3.529	0.055
23022399628544	230:16:02.0	-57:45:33.7	0.498	0.096	-3.273	0.094	-3.428	0.092
23335958552320	230:18:32.2	-57:45:50.0	0.481	0.069	-3.656	0.068	-3.447	0.066
23439037784960	230:17:06.3	-57:44:46.4	0.453	0.023	-3.655	0.023	-3.470	0.023
23507732445696	230:20:19.0	-57:43:25.0	0.533	0.040	-3.592	0.041	-3.453	0.040
23576476750208	230:19:04.8	-57:43:31.2	0.566	0.045	-3.398	0.045	-3.540	0.046
23679555965184	230:14:50.9	-57:44:31.9	0.553	0.023	-3.696	0.022	-3.460	0.025
23748275451136	230:17:38.8	-57:43:15.3	0.548	0.045	-3.582	0.044	-3.528	0.043
23748275452288	230:16:56.7	-57:43:19.1	0.534	0.022	-3.659	0.021	-3.294	0.022
24328068894592	230:25:51.3	-57:42:41.4	0.508	0.072	-3.592	0.074	-3.435	0.068
25500622168576	230:20:19.3	-57:38:44.1	0.528	0.089	-3.703	0.086	-3.801	0.087
27935846172416	229:55:34.4	-57:49:35.4	0.517	0.087	-3.711	0.086	-3.644	0.079
29658150063488	229:56:53.0	-57:47:22.0	0.466	0.026	-3.294	0.025	-3.627	0.025
33128483745408	229:55:00.3	-57:43:01.6	0.487	0.020	-3.446	0.019	-3.378	0.020
36117781323776	230:07:19.0	-57:41:46.5	0.521	0.074	-3.769	0.070	-3.663	0.075
37590927975040	230:16:37.4	-57:36:35.9	0.482	0.080	-3.762	0.075	-3.439	0.080

Table A.3: Probable members of open cluster *ES FERA* 3 from astrometric analysis.

<i>GAIA – DR3</i>	α	δ	ϖ	ϵ_{ϖ}	$\mu_{\alpha}\cos\delta$	$\epsilon_{\mu_{\alpha}\cos\delta}$	μ_{δ}	$\epsilon_{\mu_{\delta}}$
5883...	[$^{\circ}$:':"]	[$^{\circ}$:':"]	[mas]	[mas]	[mas yr $^{-1}$]	[mas yr $^{-1}$]	[mas yr $^{-1}$]	[mas yr $^{-1}$]
194941656356480	229:56:14.8	-57:18:33.4	0.396	0.044	-2.368	0.045	-2.173	0.045
214526707667072	230:05:26.7	-57:19:29.5	0.429	0.049	-2.309	0.052	-2.391	0.050
214973385226112	230:08:17.9	-57:17:50.0	0.581	0.042	-2.546	0.041	-2.152	0.044
215003418857472	230:09:51.0	-57:17:17.6	0.530	0.033	-2.345	0.034	-2.224	0.035
216210335393536	230:05:36.8	-57:13:30.6	0.406	0.055	-2.421	0.059	-2.212	0.061
216622652247808	230:11:22.8	-57:14:40.3	0.517	0.063	-1.925	0.067	-2.377	0.068
216863170424576	230:16:16.2	-57:14:10.7	0.522	0.019	-2.319	0.020	-1.854	0.021
217172408108160	230:14:01.6	-57:11:47.2	0.480	0.027	-2.142	0.026	-2.065	0.030
217172408111232	230:14:16.3	-57:11:40.4	0.528	0.040	-2.202	0.041	-1.756	0.044
217412926228736	230:08:15.5	-57:14:34.2	0.506	0.065	-1.930	0.068	-2.269	0.070
218031401599744	230:13:51.9	-57:10:21.6	0.575	0.039	-2.213	0.037	-2.019	0.044
219057869997952	229:59:54.0	-57:13:47.9	0.573	0.106	-2.072	0.111	-2.254	0.109
219440150823424	230:02:08.3	-57:11:45.4	0.451	0.046	-2.355	0.040	-2.235	0.047
221020698860928	230:02:25.8	-57:08:29.2	0.458	0.070	-2.260	0.063	-1.963	0.077
223151002640256	230:18:06.9	-57:09:42.9	0.590	0.054	-2.430	0.052	-2.359	0.063
232221972981504	229:54:05.5	-57:08:47.5	0.426	0.057	-2.391	0.052	-2.174	0.060
232359411945472	229:55:15.3	-57:07:05.9	0.493	0.040	-2.066	0.037	-1.919	0.044
234524076184960	230:01:42.8	-57:01:24.5	0.459	0.052	-1.656	0.052	-2.060	0.060
235344386772224	229:51:56.2	-57:00:58.9	0.457	0.067	-2.140	0.069	-2.335	0.078
236826178920448	229:46:16.3	-57:00:58.9	0.472	0.028	-2.263	0.028	-2.270	0.033

Table A.4: Probable members of open cluster *ES FERA* 4 from astrometric analysis.

<i>GAIA – DR3</i>	α	δ	ϖ	ϵ_{ϖ}	$\mu_{\alpha}\cos\delta$	$\epsilon_{\mu_{\alpha}\cos\delta}$	μ_{δ}	$\epsilon_{\mu_{\delta}}$
5886...	[$^{\circ}$:':"]	[$^{\circ}$:':"]	[mas]	[mas]	[mas yr $^{-1}$]	[mas yr $^{-1}$]	[mas yr $^{-1}$]	[mas yr $^{-1}$]
257425123101568	229:43:21.2	-56:28:16.7	0.586	0.076	-2.476	0.086	-2.956	0.091
348100474124800	230:06:36.5	-56:28:09.0	0.489	0.095	-2.181	0.093	-2.990	0.105
349440504533248	230:07:29.8	-56:24:58.2	0.550	0.051	-2.363	0.054	-3.003	0.062
350643094839552	229:55:46.6	-56:26:12.8	0.593	0.045	-2.388	0.049	-3.067	0.056
351364649407360	229:46:52.6	-56:25:31.7	0.653	0.020	-2.545	0.023	-3.099	0.024
351429059257984	229:46:50.1	-56:25:22.8	0.576	0.014	-2.519	0.015	-2.927	0.017
352429801298816	229:56:06.5	-56:23:14.1	0.569	0.063	-2.622	0.063	-2.946	0.065
352567240269312	229:57:45.4	-56:21:57.5	0.481	0.068	-2.243	0.068	-3.093	0.070
353220075304320	229:52:54.0	-56:22:41.4	0.618	0.056	-2.451	0.060	-2.964	0.065
353769831159936	229:56:37.7	-56:19:46.8	0.500	0.048	-2.366	0.046	-2.971	0.051
363287478678016	229:44:56.3	-56:23:02.1	0.577	0.061	-2.364	0.061	-3.460	0.068
363386248420736	229:40:06.7	-56:24:05.8	0.593	0.094	-2.444	0.103	-2.627	0.115
363871594262144	229:45:03.2	-56:21:38.7	0.589	0.023	-2.653	0.022	-3.169	0.027
364318270911360	229:41:39.7	-56:20:32.6	0.596	0.038	-2.374	0.037	-2.841	0.049

Table A.5: Probable members of open cluster *ES FERA* 5 from astrometric analysis.

<i>GAIA – DR3</i>	α	δ	ϖ	ϵ_{ϖ}	$\mu_{\alpha}\cos\delta$	$\epsilon_{\mu_{\alpha}\cos\delta}$	μ_{δ}	$\epsilon_{\mu_{\delta}}$
58838...	[$^{\circ}$:':"]	[$^{\circ}$:':"]	[mas]	[mas]	[mas yr $^{-1}$]	[mas yr $^{-1}$]	[mas yr $^{-1}$]	[mas yr $^{-1}$]
37086485049088	232:35:41.2	-55:23:40.5	0.355	0.031	-3.329	0.029	-2.987	0.031
37915429150592	232:25:37.4	-55:22:08.2	0.397	0.077	-3.263	0.073	-3.182	0.076
38911861950720	232:40:44.8	-55:26:33.2	0.431	0.048	-3.077	0.047	-3.197	0.050
40698568446208	232:40:51.0	-55:19:25.7	0.416	0.069	-3.300	0.064	-3.341	0.070
40732928203776	232:41:47.2	-55:18:14.3	0.364	0.066	-3.189	0.062	-3.010	0.067
41832439453056	232:52:12.3	-55:15:44.0	0.394	0.067	-3.286	0.071	-3.130	0.073
42210396958720	232:43:22.6	-55:17:55.6	0.383	0.030	-3.293	0.029	-3.055	0.033
43992792751232	232:38:00.4	-55:16:36.6	0.363	0.041	-3.174	0.039	-3.449	0.040
44100182546944	232:32:14.5	-55:18:46.8	0.372	0.055	-3.781	0.051	-3.101	0.057
44375059980800	232:30:16.1	-55:17:22.2	0.373	0.044	-3.789	0.042	-3.540	0.045
44409419719040	232:28:49.0	-55:17:50.0	0.408	0.050	-3.204	0.047	-3.113	0.051
44512499441280	232:31:34.4	-55:16:21.4	0.412	0.014	-3.297	0.014	-3.066	0.016
44649938394624	232:36:00.1	-55:16:36.8	0.415	0.024	-3.369	0.022	-3.083	0.024
44993535795840	232:32:12.7	-55:14:51.8	0.391	0.032	-2.753	0.030	-2.795	0.033
45165334464256	232:41:27.4	-55:17:29.1	0.427	0.049	-2.633	0.046	-3.084	0.050
91825860877184	232:25:42.7	-55:13:49.0	0.369	0.033	-3.575	0.034	-3.192	0.033

Appendix B: Photometric results

Table B.1: Probable members of open cluster *ES FERA* 1 from photometric observations.

<i>GAIA – DR3</i>	<i>GLON</i>	<i>GLAT</i>	<i>G</i>	<i>G_{BP} – G_{RP}</i>	<i>J</i>	<i>H</i>	<i>K_s</i>	<i>Q_{NIR}</i>	<i>S pT</i>
58800...	[° :':"]	[° :':"]	[mag]	[mag]	[mag]	[mag]	[mag]		
26973766044928	320:03:19.7	-00:17:38.1	16.17	1.75	13.84	13.36	13.31	0.38	B ⁺
27798399504896	320:10:25.9	-00:20:03.4	16.50	1.78	14.04	13.51	13.29	0.16	A ⁻
29378947544832	320:11:27.9	-00:14:46.8	15.24	1.58	13.10	12.68	12.51	0.12	B ⁺
29413307278848	320:11:42.0	-00:15:08.9	17.11	1.78	14.72	14.31	14.20	0.22	A ⁺
29516386509824	320:12:43.3	-00:14:08.1	16.50	1.75	14.15	13.75	13.63	0.18	A ⁻
29619465728256	320:11:37.2	-00:13:42.0	14.12	1.67	11.89	11.50	11.31	0.07	B ⁺
29619465729152	320:11:46.7	-00:13:37.9	16.77	1.81	14.32	13.92	13.70	0.01	A ⁻
29619470340480	320:11:52.1	-00:13:26.2	16.99	1.91	14.53	14.06	13.97	0.31	A ⁺
29756904691200	320:13:05.2	-00:12:58.1	16.41	1.85	13.96	13.54	13.33	0.05	B ⁺
29791264429696	320:12:12.9	-00:12:49.7	16.98	1.92	14.36	13.87	13.60	0.03	A ⁻
38862235534720	320:02:36.7	-00:15:00.1	15.90	3.03	12.18	11.18	10.76	0.30	B ⁺
39205832933632	320:04:31.8	-00:15:06.2	14.16	3.26	10.27	9.10	8.68	0.45	B ⁺
39549430334336	320:04:16.5	-00:12:44.3	15.23	1.83	12.82	12.44	12.16	-0.09	B ⁺
40855100166784	320:07:55.4	-00:13:48.6	15.31	1.83	12.94	12.54	12.32	0.03	B ⁺
52193818076672	320:14:16.3	-00:15:02.0	16.44	1.85	14.01	13.54	13.35	0.15	B ⁺
52262534093312	320:16:13.8	-00:15:48.1	16.32	1.89	13.77	13.35	13.12	0.03	B ⁺

Table B.2: Probable members of open cluster *ES FERA* 2 from photometric observations.

<i>GAIA – DR3</i>	<i>GLON</i>	<i>GLAT</i>	<i>G</i>	<i>G_{BP} – G_{RP}</i>	<i>J</i>	<i>H</i>	<i>K_s</i>	<i>Q_{NIR}</i>	<i>S pT</i>
58831...	[° :':"]	[° :':"]	[mag]	[mag]	[mag]	[mag]	[mag]		
17048125978624	321:45:22.8	-00:30:47.5	17.35	2.25	14.48	13.89	13.69	0.26	A ⁺
22923616738560	321:49:42.6	-00:31:21.5	16.58	1.87	14.11	13.57	13.35	0.16	A ⁺
23022399628544	321:50:32.5	-00:29:12.2	17.57	2.49	14.49	14.02	13.76	0.02	A ⁺
23335958552320	321:51:31.0	-00:30:01.8	16.97	1.98	14.32	13.82	13.55	0.05	F ⁻
23439037784960	321:51:26.9	-00:29:00.0	14.74	1.53	12.69	12.37	12.21	0.04	B ⁺
23507732445696	321:53:37.5	-00:28:47.3	15.83	1.77	13.51	13.06	12.89	0.17	A ⁻
23576476750208	321:53:07.9	-00:28:31.8	16.15	1.76	13.79	13.43	13.26	0.07	A ⁺
23679555965184	321:50:33.9	-00:28:08.8	10.24	2.71	6.85	5.92	5.56	0.32	CLIII-I
23748275451136	321:52:30.8	-00:27:52.7	16.12	1.98	13.58	13.07	12.88	0.18	A ⁻
23748275452288	321:52:09.8	-00:27:43.8	14.47	1.61	12.32	11.94	11.79	0.11	B ⁺
24328068894592	321:56:30.3	-00:29:46.8	17.05	2.53	13.74	13.31	13.08	0.03	B ⁺
25500622168576	321:56:09.8	-00:24:51.5	17.41	2.12	14.64	13.97	13.67	0.16	F ⁻
27935846172416	321:39:11.0	-00:26:52.5	17.09	2.65	13.71	12.92	12.31	-0.23	B ⁺
29658150063488	321:40:57.9	-00:25:22.4	14.93	1.63	12.72	12.39	12.22	0.02	B ⁺
33128483745408	321:42:26.9	-00:21:10.4	14.37	2.43	11.25	10.49	10.22	0.31	B ⁺
36117781323776	321:48:40.1	-00:23:39.2	16.89	1.94	14.44	14.04	13.75	-0.09	F ⁻
37590927975040	321:55:39.2	-00:21:59.1	17.22	1.86	–	–	–	–	F ⁻

Table B.3: Probable members of open cluster *ES FERA 3* from photometric observations.

<i>GAIA – DR3</i>	<i>GLON</i>	<i>GLAT</i>	<i>G</i>	<i>G_{BP} – G_{RP}</i>	<i>J</i>	<i>H</i>	<i>K_s</i>	<i>Q_{NIR}</i>	<i>S pT</i>
5883...	[° :′ :″]	[° :′ :″]	[mag]	[mag]	[mag]	[mag]	[mag]		
194941656356480	321:56:08.3	-00:00:52.8	15.85	2.99	12.06	11.13	10.67	0.15	YSO II
214526707667072	321:59:49.4	-00:04:20.3	16.29	1.90	13.80	13.40	13.20	0.05	F [−]
214973385226112	322:02:00.9	-00:03:46.3	15.29	2.35	12.06	11.48	11.19	0.10	B ⁺
215003418857472	322:03:00.7	-00:03:46.2	15.37	2.03	12.57	11.67	10.87	-0.47	YSO II
216210335393536	322:03:07.3	00:00:39.2	16.39	2.62	13.19	12.64	12.35	0.06	B ⁺
216622652247808	322:05:07.4	-00:02:00.5	16.78	1.76	14.58	14.05	12.82	–	F [−]
216863170424576	322:07:37.0	-00:03:01.4	14.14	1.50	12.07	11.74	11.59	0.08	B ⁺
217172408108160	322:07:53.2	-00:00:21.3	14.90	1.28	13.11	12.83	12.71	0.09	A [−]
217172408111232	322:08:03.6	-00:00:19.8	15.88	1.52	13.66	12.89	12.51	0.12	A ⁺
217412926228736	322:03:45.3	-00:01:00.7	16.74	2.44	13.70	13.11	12.82	0.09	A [−]
218031401599744	322:08:35.0	00:00:53.6	15.88	1.81	13.54	13.03	12.88	0.24	A [−]
219057869997952	322:00:21.5	00:02:04.4	17.63	2.10	15.04	14.21	13.71	-0.02	F ⁺
219440150823424	322:02:28.7	00:03:08.6	16.04	1.70	13.75	13.37	12.88	–	A ⁺
221020698860928	322:04:22.2	00:05:48.8	16.92	2.39	13.98	13.43	13.25	0.22	A [−]
223151002640256	322:10:52.3	00:00:11.5	16.31	2.50	12.91	12.07	11.77	0.35	B ⁺
232221972981504	322:00:23.4	00:07:59.2	16.63	2.63	13.40	12.70	12.37	0.13	B ⁺
232359411945472	322:01:49.9	00:09:04.6	15.85	1.45	13.83	12.41	11.93	0.61	A ⁺
234524076184960	322:07:50.9	00:11:59.5	16.33	2.55	13.09	12.16	11.77	0.28	B ⁺
235344386772224	322:03:35.3	00:15:12.5	16.52	1.84	14.17	13.63	13.43	0.20	F [−]
236826178920448	322:00:58.9	00:16:51.5	15.10	2.27	12.20	11.45	11.17	0.28	B ⁺

Table B.4: Probable members of open cluster *ES FERA 4* from photometric observations.

<i>GAIA – DR3</i>	<i>GLON</i>	<i>GLAT</i>	<i>G</i>	<i>G_{BP} – G_{RP}</i>	<i>J</i>	<i>H</i>	<i>K_s</i>	<i>Q_{NIR}</i>	<i>S pT</i>
5886...	[° :′ :″]	[° :′ :″]	[mag]	[mag]	[mag]	[mag]	[mag]		
257425123101568	322:17:06.0	00:21:00.7	16.9	1.8	14.4	14.2	13.9	-0.2	G [−]
348100474124800	322:28:00.7	00:34:00.6	17.2	1.8	15.0	14.5	14.2	0.0	G [−]
349440504533248	322:30:08.3	00:59:00.7	16.1	1.6	14.0	12.0	11.6	1.3	F [−]
350643094839552	322:42:00.4	00:25:00.7	16.0	1.5	14.0	13.6	13.5	0.2	F [−]
351364649407360	322:20:13.0	00:38:00.8	13.6	1.1	12.0	11.8	11.7	0.0	B ⁺
351429059257984	322:20:16.6	00:46:00.8	12.0	1.1	10.6	10.4	10.3	-0.1	B ⁺
352429801298816	322:25:45.5	00:50:00.8	16.7	1.8	14.0	13.2	12.8	0.0	G [−]
352567240269312	322:27:12.9	00:25:00.8	16.9	2.8	13.5	12.9	12.5	0.1	B ⁺
353220075304320	322:24:33.1	00:15:00.8	16.6	1.6	14.1	13.7	13.4	0.1	F ⁺
353769831159936	322:27:51.4	00:36:00.8	16.3	1.6	14.3	13.7	13.5	0.2	F [−]
363287478678016	322:20:38.6	00:19:00.8	16.5	1.6	14.3	13.8	13.7	0.3	F ⁺
363386248420736	322:17:49.0	00:51:00.8	17.1	1.8	14.6	13.2	12.8	0.8	F ⁺
363871594262144	322:21:26.4	00:27:00.8	14.3	1.2	12.6	12.4	12.2	0.0	A [−]
364318270911360	322:20:26.4	00:23:00.9	15.7	1.5	13.7	13.3	13.2	0.2	F [−]

Table B.5: Probable members of open cluster *ES FERA* 5 from photometric observations.

<i>GAIA</i> – <i>DR3</i>	<i>GLON</i>	<i>GLAT</i>	<i>G</i>	<i>G_{BP}</i> – <i>G_{RP}</i>	<i>J</i>	<i>H</i>	<i>K_s</i>	<i>Q_{NIR}</i>	<i>S pT</i>
58838...	[° :′ :″]	[° :′ :″]	[mag]	[mag]	[mag]	[mag]	[mag]		
37086485049088	324:13:15.1	00:45:59.2	12.98	3.41	9.06	7.95	7.55	0.44	CLIII-I
37915429150592	324:09:25.2	00:50:30.0	17.23	1.94	14.77	14.29	14.03	0.02	F [−]
38911861950720	324:13:58.5	00:41:59.1	16.28	1.92	13.87	13.32	13.09	0.16	BSS
40698568446208	324:18:05.0	00:47:48.3	16.95	2.86	13.72	13.12	12.88	0.19	CLIII
40732928203776	324:19:12.0	00:48:28.8	16.78	3.02	12.91	12.33	11.51	−0.80	CLIII
41832439453056	324:25:30.1	00:47:08.8	16.93	2.04	14.41	13.95	13.75	0.12	F [−]
42210396958720	324:20:07.3	00:48:13.2	15.29	1.84	–	–	–	–	BSS
43992792751232	324:18:21.6	00:51:02.7	15.50	2.77	12.14	11.22	10.96	0.48	CLIII
44100182546944	324:14:25.5	00:51:07.6	16.39	2.49	13.42	12.94	12.64	−0.02	CLIII
44375059980800	324:14:18.1	00:52:55.5	16.06	2.67	12.96	12.48	12.18	−0.02	CLIII
44409419719040	324:13:21.5	00:53:00.8	16.28	1.82	13.93	13.50	13.42	0.28	BSS
44512499441280	324:15:29.4	00:53:20.2	13.12	1.58	11.09	10.77	10.54	−0.07	BSS
44649938394624	324:17:25.1	00:51:41.5	14.58	1.59	12.53	12.21	12.01	−0.01	BSS
44993535795840	324:16:38.2	00:54:21.6	15.34	2.54	12.19	11.31	10.99	0.34	CLIII
45165334464256	324:19:28.6	00:49:12.4	16.35	2.25	13.64	13.17	12.94	0.09	CLIII
91825860877184	324:14:10.8	00:57:19.5	15.39	1.76	13.12	12.79	12.55	−0.07	BSS

Appendix C: Additional figures

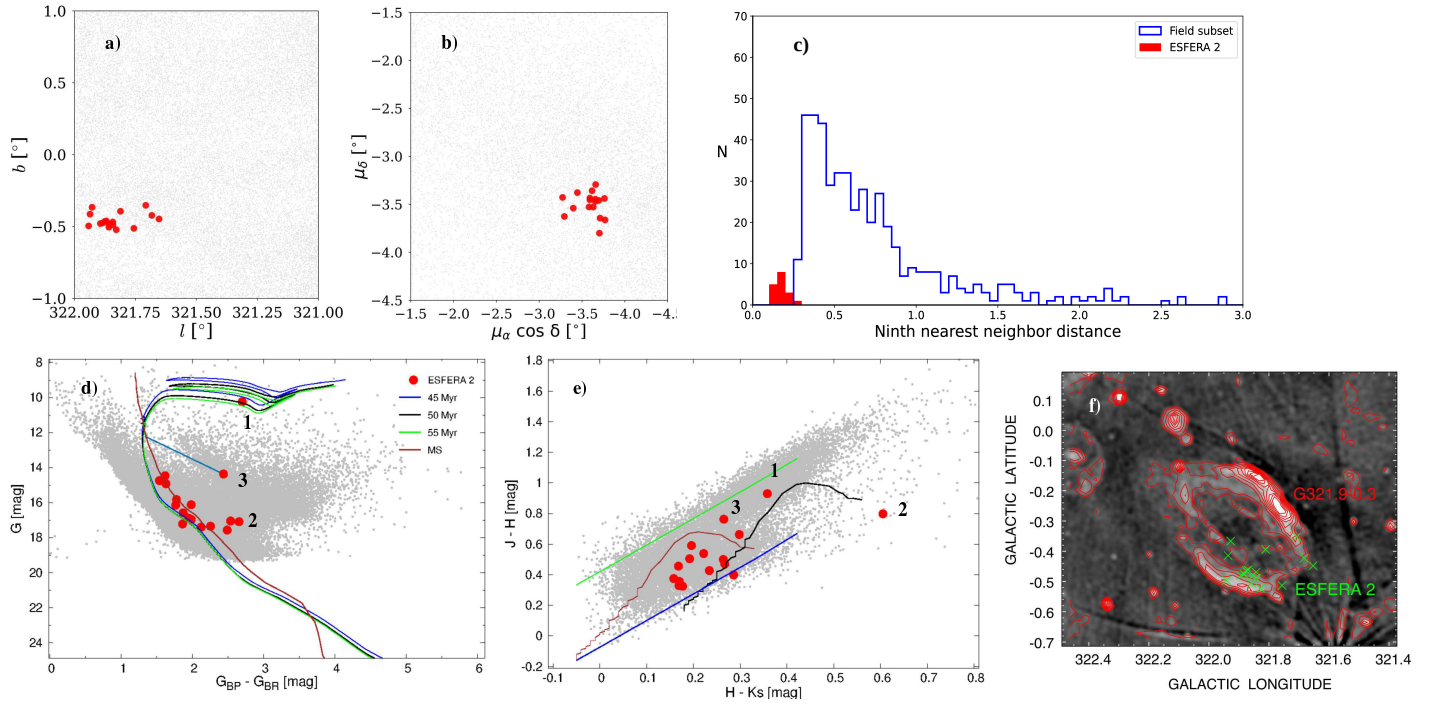


Fig. C.1: Multiparametric analysis of the open cluster *ESFERA 2*. Symbols as in Fig 5. In Fig (d) the MS is fitted to a distance of 1907 pc and $A_V = 3.5$ mag; (f) Red contours trace the HII emission of G321.9–0.3 SNR (Ball et al. 2025); contour levels are 2 ($\sim 3\sigma_{\text{rms}}$), 5, 10, 15, 20, 25, 30, 35 and 40 mJy beam $^{-1}$.

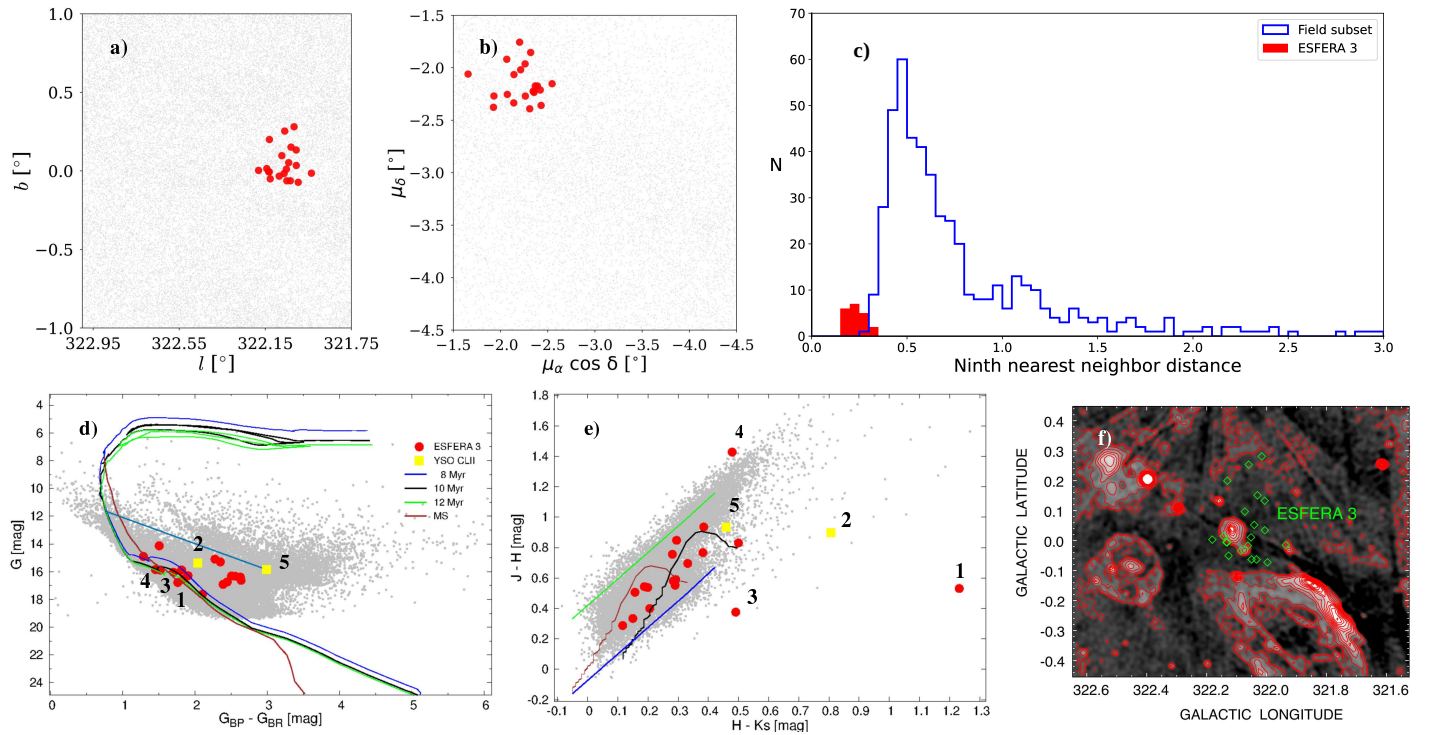


Fig. C.2: Multiparametric analysis of the open cluster *ESFERA 3*. Symbols as in Fig 5 and yellow square for Class II YSO. In Fig (d) the MS is fitted to a distance of 1939 pc and $A_V = 2.5$ mag; (f) Red contours trace the same levels of Fig. C.1 f).

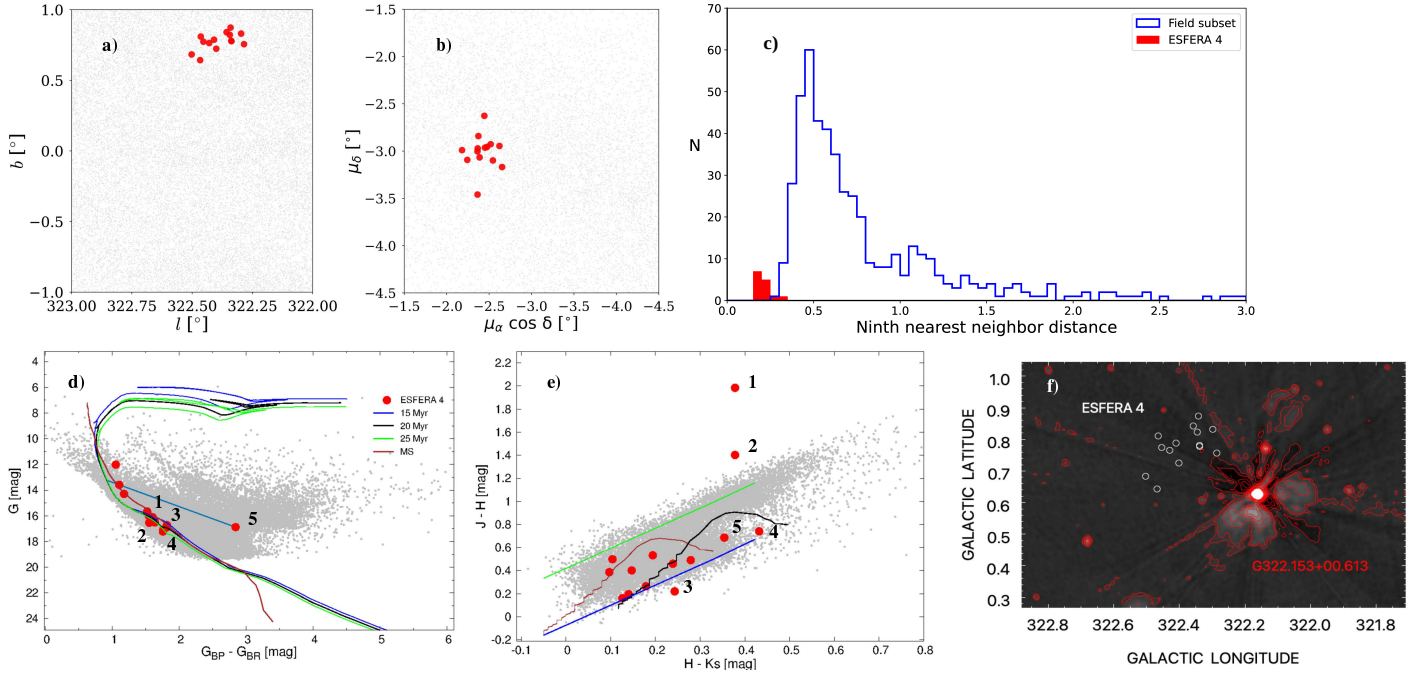


Fig. C.3: Multiparametric analysis of the open cluster *ESFERA 4*. Symbols as in Fig. 5. In Fig (d) the MS is fitted to a distance of 1648 pc and $A_V = 2.5$ mag; (f) Red contours trace the H II emission of G 322.153+00.613 (Anderson et al. 2014), contour levels are: -60, -40, -20 and -10 mJy beam $^{-1}$ for the negative emission and 5 ($\sim 3\sigma_{\text{rms}}$), 10, 30, 50, 70, 100, 150, 200, 250 and 300 mJy beam $^{-1}$ for the positive emission.

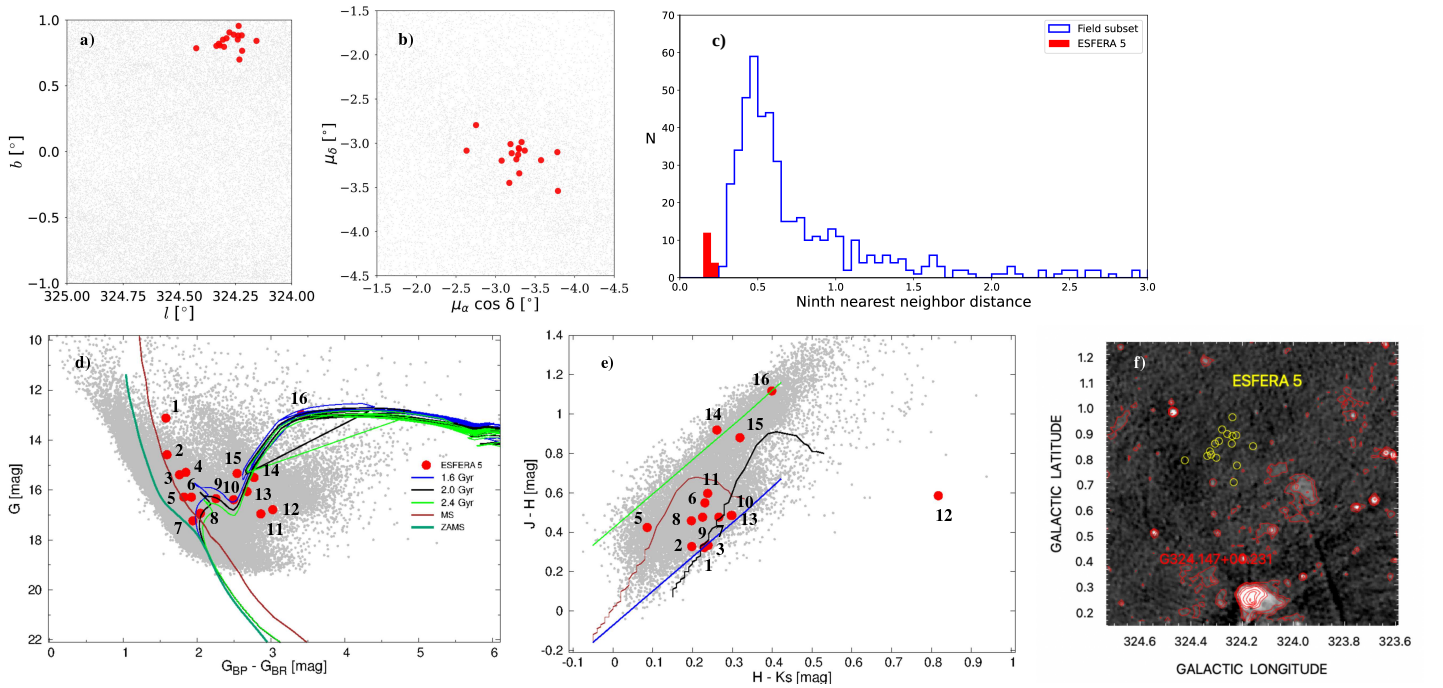


Fig. C.4: Multiparametric analysis of the open cluster *ESFERA 5*. Symbols as in Fig 5. In Fig (d) the MS is fitted to a distance of 2417 pc and $A_V = 3.4$ mag; (f) Red contours indicate the H II emission of G324.147+00.231 (Anderson et al. 2014). Contour levels are 2 ($\sim 5\sigma_{\text{rms}}$), 5, 10, 30, 50, 100, 150, 200, 250 and 300 mJy beam $^{-1}$.