A possible sequential star formation in the giant molecular cloud G174+2.5

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ABSTRACT
We investigate the nature of 14 embedded clusters (ECs) related to a group of four H II regions Sh2-235, Sh2-233, Sh2-232, and Sh2-231 in the giant molecular cloud G174 + 2.5. Projected towards the Galactic anticentre, these objects are a possible example of the collect and collapse scenario. We derive astrophysical parameters (age, reddening, distance, core and cluster radii) for the ECs and investigate the relationship among their parameters. Parameters are derived with field decontaminated 2MASS colour-magnitude diagrams (CMDs) and stellar radial density profiles (RDPs). The CMDs of these young clusters are characterised by a poorly-populated main sequence and a significant number of pre-main sequence stars, affected by differential reddening. The ECs are KKC 11, FSR 784, Sh2-235 E2, Sh2-235 Cluster, Sh2-233SE Cluster, BDSB 73, Sh2-235B Cluster, BDSB 72, BDSB 71, Sh2-232 IR, PCS 2, and the newly found clusters CBB 1 and CBB 2. We were able to derive fundamental parameters for all ECs in the sample. Structural parameters are derived for FSR 784, Sh2-235 Cluster and Sh2-235E2.

Key words: (Galaxy:) open clusters and associations:general; Galaxy: stellar content, collect and collapse, and sequential star formation; Galaxy: structure

1 INTRODUCTION
Most stars form after the gravitational collapse of massive and dense gas clumps inside giant molecular clouds (GMCs), with collapsing clumps forming embedded clusters (ECs). However, supernova explosions, H II region expansion due to massive-stars, UV radiation, and stellar winds, may disrupt GMCs completely, on a timescale of a few $10^7$ yr (Elmegreen 2000; Bonnell et al. 2006). In this context, Hartmann et al. (2001) point out that stars older than $\approx 5$ Myr are not found associated with molecular gas, and Allen et al. (2007) suggest that the primordial gas of ECs disperses in $3 - 5$ Myr (Leisawitz et al. 1989; Proszkow & Adams 2009). For Lada & Lada (2003), the duration of the embedded phase is $2 - 3$ Myr. On the other hand, the parent GMCs are very disruptive environments for ECs. Lada & Lada (2003) estimate that only 4 - 7% of them survive for more than 40 Myr (infant mortality), but the appearance of bound and unbound clusters are indistinguishable for clusters younger than 10 Myr. In other words, stars are born in star clusters embedded in GMCs but, as a consequence of the disruptive mechanisms, most end up as part of the field-star population after cluster disruption.

ECs can be partially or fully immersed in embryonic molecular clouds and H II regions. The younger are located in gas clumps and the most evolved are often linked with H II regions or other nebulae (Leisawitz et al. 1989). Often, these H II regions, excited by fast winds from massive OB stars, expand into the molecular cloud triggering sequential star formation. In this sense, the collect and collapse model (Elmegreen & Lada 1977; Whitworth et al. 1994) suggests that H II regions expand accumulating material between the ionisation and the shock fronts. This material, as a consequence of the shocks, becomes unstable and fragments into several cores, triggering star formation in multiple protocluster regions. Another possible process is the “radiation-driven implosion” model, in which the expanding H II region compresses the existing molecular clumps, the density increase exceeding the critical mass and the clump collapses (Lefloch & Lazareff 1994). In both scenarios the massive stars trigger a second generation of cluster formation (see also, Fukuda & Hanawa 2001; Hosokawa & Inutsuka 2005; Deharveng, Zavagno & Canlan 2005; Dale, Bonnell & Whitworth 2007). In any case, GMC observations indicate that there often occurs a multiple cluster formation as a result of winds of OB stars or expanding H II regions (Allen et al. 2007).

Star cluster formation is the preferential mode of star formation, and ECs may be responsible for 70%-90% of all stars formed in GMCs. However, the rapid expulsion of the
Table 1. Cross-identifications of the embedded clusters in G174 + 2.5.

| Design#1 | Design#2 | Design#3 | Design#4 | Design#5 | D (') | Ref. |
|----------|----------|----------|----------|----------|-------|------|
| KKC 11   | FSR T88  | Sh2-235 East1 | -        | -        | 4.5   | 7, 8, 10 |
| FSR T84  | Koposov 7 | Sh2-235North-West | -        | -        | 3.2   | 8, 9, 10 |
| Sh2-235 E2 | -        | -        | -        | -        | 1.3   | 6    |
| Sh2-235 Cl. | CISS 11  | Sk2-235Central | -        | -        | 1.4   | 1, 10 |
| BDSB T3  | CIITW 1  | -        | -        | -        | 0.7   | 5, 8 |
| Sh2-233 Cl. | CISS 10  | Hodapp 18 | Sk2-235ABC | -        | 1.6   | 1, 2, 10 |
| BDSB T2  | -        | -        | -        | -        | 2.0   | 6    |
| BDSB T1  | -        | -        | -        | -        | 0.8   | 6    |
| Sh2-232IR | -        | -        | -        | -        | 1.0   | 10   |
| Sh2-233 SE cl. | DB2001-24 | KKC9NE | -        | -        | 1.0   | 3, 4, 7 |
| PCS 2    | -        | -        | -        | -        | 0.5   | 5, 10 |
| G173 58 + 2, 45 Cl. | IRAS 05361 + 3539 Cl. | -        | -        | -        | 0.3   | 11   |
| CBB 1    | -        | -        | -        | -        | 1.0   | 11   |
| CBB 2    | -        | -        | -        | -        | -     | -    |

Table Notes. Cols. (1−5) show cross-identification and col. (7) references for parameter determinations. The references are: 1 - Carpenter et al. (1993); 2 - Hodapp (1993); 3 - Porras et al. (2000); 4 - Dutra & Bica (2001); 5 - Shepherd & Watson (2002); 6 - Bica et al. (2003); 7 - Kumar, Keto & Clerkin (2006); 8 - Froebrich, Scholz & Raftery (2007); 9 - Koposov et al. (2008); 10 - Kirsanova et al. (2008); 11 - This work.

Figure 1. XDSS R image (30′ × 30′) of the Sh2-235 H II region. The image also shows part of the Sh2-232 HII region (top left).

primordial gas by winds of OB stars and supernova explosions disrupt most clusters very early. As a consequence of rapid gas expulsion, the stellar orbits cannot adjust to the new potential, and probably give rise to an unbound association. N-body simulations show that in this phase (10 - 30 Myr) the cluster expands in all scales reaching for virialization. The fate of a cluster is determined by the star formation efficiency (SFE). If the gas is removed slowly the cluster will remain bound as long as the SFE is higher than 30%, but if the gas is removed rapidly, the SFE needs to be higher than 50%. As a consequence of infant mortality, the number of optically detected clusters is significantly smaller than that of ECs (Lada et al. 1984; Verschueren 1990; Lada & Lada 2003; Goodwin & Bastian 2004).

In this work we investigate properties of the star clusters embedded in the GMC G174+2.5, related to a group of H II regions located in the Perseus arm towards the Galactic anticentre. A star forming complex with numerous ECs minimises uncertainties owing to the distance in common. This paper is organised as follows. In Sect. 2 we provide general data on the target clusters. In Sect. 3 we present the 2MASS photometry and introduce tools employed in the CMD analyses, especially the field star decontamination algorithm. Sect. 4 is dedicated to the cluster structure. In Sect. 5 we estimate cluster masses. In Sect. 6 we investigate the relationship among the derived parameters. Finally, in Sect. 7 we present the concluding remarks.

2 PREVIOUS STUDIES ON THE G174+2.5 STELLAR CONTENT

The H II regions Sh2-235, Sh2-233, Sh2-232, and Sh2-231 have been subject to several studies in different wavelength ranges, but astrophysical parameters for most ECs located in these regions have not been derived so far. The ECs selected for the present analysis are given in Table 1 where we adopt a chronological criterion for the literature identifications. We show in Fig. 1 an XDSS 30′ × 30′ R image of the Sh2-235 H II region. In Fig. 2 we show schematic charts for the nebulosities and clusters, and in Fig. 3 2MASS images of the ECs in the K_s band. All objects are quite obscured by interstellar dust and appear to be affected by differential reddening. Being projected close to each other, this sample of ECs may be an example of H II regions with a sequential...
Sequential star formation in G174+2.5?

star formation and the development of a collect and collapse scenario. Furthermore, the detection of far-IR sources, molecular outflows, and $H_2O$ masers in previous works indicate on-going star formation. The distance to the Sun estimated for these H II regions is in the range $d_\odot = 1.0-2.3$ kpc (Georgelin 1975). Most works use $d_\odot = 1.8$ kpc for this group of nebulosities.

Within uncertainties, Sh2-231, Sh2-232, Sh2-233 and Sh2-235 have comparable CO radial velocities (Blitz, Fich & Stark 1982). This indicates that we are dealing with a large HII-molecular complex with components located essentially at the same distance from the Sun.

2.1 Sh2-235 and surroundings
Sh2-235 is the most prominent H II region in this group. It is a diffuse optical H II region excited by a star of spectral type O9.5 V (BD+35°1201). Allen et al. (2005) identify two clusters associated with the Sh2-235 H II region, Sh2-235 Cluster and KKC 11. Kumar, Keto & Clerkin (2006) add to these objects the cluster Sh2-235 East2. Kirsanova et al. (2008) conclude that these objects are still embedded in dense clumps of the parental molecular cloud G174 + 2.5. They also argue that the Sh2-235 Cluster and Sh2-235 E2 probably started the primordial gas expulsion, but KKC 11 is less evolved.

South-west of the Sh2-235 are four small nebulae named...
Figure 3. First row panels: 2MASS 3' × 3' $K_s$ images centred on FSR 784, KKC 11 and Sh2-235E2. Second row: the same for the cluster pairs Sh2-235 Cluster and CBB 2, G173 and CBB 1, PCS 2 and Sh2-233SE Cluster. Third row: Sh2-235B Cluster, BDSB 71, and BDSB 72. Fourth row: same as row three for BDSB 73 and Sh2-232 IR Cluster. The small circle is automatically generated by the 2MASS image tool, surrounding the input coordinates. The large circle in the second row surrounds the main body of each cluster. The last panel in the fourth row shows the large background area (indicated with outer and inner brown circles) used in the statistical field decontamination of Sh2-232 IR Cluster. Note that it is huge with respect to the cluster area, for statistical purposes. The symbols are the same as in Fig. 2.
Sequential star formation in G174+2.5?

Sequential star formation is triggered by a combination between compression of pre-existing dense clumps by the shock wave, and the collect and collapse scenario. However, the clusters in Sh2-235 A, B and C appear to be embedded in primordial gas, and star formation cannot be triggered by the expansion of the Sh2-235 ionisation front (Lafon et al. 1983). On the other hand, Tokunaga & Thompson (1979) suggest that the linear disposition of these star forming regions may be the result of collect and collapse scenario.

2.2 Sh2-231, Sh2-232 and Sh2-233

Sh2-232 is an extended H II region with ≈ 40′′ diameter (Fig. 2), excited by B stars. Hodapp (1994) observed two nebulae in Sh2-233 and noticed a young infrared EC, as well as a probable Herbig-Haro object. Portas et al. (2001) identified two clusters in this region, PCS 2, located around the IRAS 05358 + 3543 source and Sh2-233 SE at a separation of 1′ (0.5 pc) from each other for an adopted distance to the Sun of 1.8 kpc. However, Chan & Fich (1992) estimated a distance of 2.3 ± 0.7 kpc, based on spectral types of stars.
in the H II region. Porras et al. (2000) detected 92 stars in JHK, but the those associated to PCS 2 is 20 and to Sh2-233 SE is 15 stars. The average extinction was $A_V = 8.44 \pm 4.77$ for Sh2-233 SE and $A_V = 15.06 \pm 3.48$ for PCS 2. The estimated ages were 6 Myr for field stars, 3 Myr for Sh2-233 SE and less than 2 Myr for PCS 2. Mao & Zeng (2004), based on cluster members (Porras et al. 2000), obtained a stellar mass of $10.7 M_\odot$ for PCS 2 with a star formation efficiency (SFE) of $\sim 4\%$, and for Sh2-233 SE a mass of $38.4 M_\odot$ with a SFE of $\sim 47\%$. They suggest that the SFE of PCS 2 was underestimated because of the upper mass completeness limit of $1 M_\odot$ estimated for PCS 2, and point out that the SFE increases with time while the cluster is embedded in a molecular cloud. The large SFE difference of the two clusters indicates that Sh2-233 SE is more evolved than PCS 2. Snell, Dickman & Huang (1990) identified a CO outflow with two lobes centred on IRAS 05358 + 3543. Jiang et al. (2001) named Sh2-233SE and PCS 2 as S233 A and S233 B, respectively. They argue that Sh2-233SE is less embedded than PCS 2. Recently, Yan et al. (2010) derived ages of 0.3, 0.5, and 1.5 Myr and masses of 45, 30, and 107 $M_\odot$ for Sh2-233 SE Cluster, PCS2 and field stars, respectively.

3 2MASS PHOTOMETRY

2MASS\footnote{The Two Micron All Sky Survey, available at \url{www.ipac.caltech.edu/2mass/releases/allsky/}} photometry (Skrutskie et al. 2006) in the $J$, $H$ and $K_s$ bands was extracted in concentric regions centred on the coordinates of the ECs (Table 2) using VizieR\footnote{http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=II/246}. Large extraction areas are essential to build RDPs (Sect. 3) with a high resulting contrast relative to the background, and for a consistent field star decontamination (Sect. 3.1).

3.1 Field-star decontamination

Field stars are conspicuous in the observed CMDs of the present ECs (Figs. 4 to 5). To uncover the intrinsic CMD morphology from the field stars, we apply a field-star decontamination procedure. The algorithm deals statistically the relative number-densities of probable cluster and field stars.

appears to be associated with a binary system near the centre of the G173.58+2.45 Cluster (hereafter G173). We discovered an additional EC, CBB 1, at an angular distance of 1’ from G173.
in cubic CMD cells that have axes along the $J$, $(J - H)$ and $(J - K_s)$ axes. These are the colours that provide the maximum discrimination among CMD sequences for star clusters of different ages (e.g. Bonatto, Bica & Girardi [2004]).

The algorithm (i) divides the range of magnitude and colours of a given CMD into a 3D grid, (ii) computes the expected number-density of field stars in each cell based on the number of comparison field stars (within 1σ Poisson fluctuation) with magnitude and colours compatible with those of the cell, and (iii) subtracts from each cell a number of stars that corresponds to the number-density of field stars measured within the same cell in the comparison field. Consequently, this method is sensitive to local variations in field star contamination in magnitude and colours. Cell dimensions are $\Delta J = 1.0$, and $\Delta (J - H) = \Delta (J - K_s) = 0.2$, which provide sufficient star-count statistics in individual cells and preserve the morphology of the CMD evolutionary sequences. The dimensions of the colour/magnitude cells can be subsequently changed so that the total number of stars subtracted in the whole cluster area matches the expected one (1σ Poisson fluctuation). We gave a brief description of the field-star decontamination procedure. For details see Bonatto & Bica [2007a] and Bica, Bonatto & Camargo [2008].

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure8}
\caption{Same as Fig. 4 for the cluster pair G173 and CBB 1. The diamond is the IRAS 05361+3539 source.}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure9}
\caption{Colour-colour diagrams for the decontaminated photometry. Siess, Dufour & Forestini (2000) isochrones and reddening vectors are compared with the PMS distribution.}
\end{figure}

### 3.2 Fundamental parameters

Usually, decontaminated CMDs of ECs are characterised by a poorly-populated MS and a significant number of PMS stars. PMS stars are usually located in the same CMD region occupied by faint red field stars and consequently one is not able to distinguish them, considering only CMD properties. In this context, the field-star decontamination procedure is essential for the identification of cluster evolutionary sequences. We adopt isochrones from the Padova group with solar-metallicity (Girardi et al. [2002]) computed with the 2MASS $J$, $H$, and $K_s$ filters, and the PMS tracks of Siess, Dufour & Forestini (2000) fitted in $J \times (J - H)$ and $J \times (J - K_s)$ decontaminated CMDs (Figs. 4 to 8) to derive the ECs’ fundamental parameters. Because of the poorly-populated MSs, the 2MASS photometric uncertainties for lower sequences, the large population of PMS stars and differential reddening, we decided for the direct comparison of isochrones with the decontaminated CMD morphology. We carry out eye fits, taking the combined MS and PMS stellar distributions as constraint, allowing for differential reddening and photometric uncertainties. The cluster sample presents a significant fraction of stars redder than the youngest PMS isochrone. Probably, the differential reddening contributed to this $(J - K_s)$ excess towards red colours, but part of it can be intrinsic and related to their evolutionary stage. The youngest stars are the reddest and with
Table 2. Derived fundamental parameters for the embedded clusters.

| Cluster    | $\alpha$(2000) | $\delta$(2000) | $\ell$ | $b$ | $A_V$ | Age | $d_0$ | $R_{GC}$ |
|------------|----------------|----------------|--------|-----|-------|-----|-------|----------|
| (1)        | (h m s)        | ($^\circ$ $'$ $''$) | ($^\circ$) | ($^\circ$) | (mag) | (Myr) | (kpc) | (kpc)    |
| KKC 11     | 5:41:30        | 35:48:49       | 173.685| 2.865| 5.5 ± 1.0 | 3 ± 2 | 2.2 ± 0.5 | 9.4 ± 0.2 |
| FSR 784    | 5:40:46        | 35:55:06       | 173.517| 2.794| 4.0 ± 1.0 | 3 ± 2 | 2.4 ± 0.5 | 9.6 ± 0.2 |
| Sh2-235 E2 | 5:41:24        | 35:52:21       | 173.624| 2.878| 4.0 ± 1.0 | 3 ± 2 | 2.1 ± 0.5 | 9.3 ± 0.2 |
| Sh2-235 Cl.| 5:41:07        | 35:49:30       | 173.634| 2.805| 3.8 ± 1.0 | 5 ± 2 | 2.0 ± 0.6 | 9.2 ± 0.2 |
| BDSB 73    | 5:40:55        | 35:44:08       | 173.688| 2.723| 3.8 ± 1.0 | 3 ± 2 | 2.1 ± 0.5 | 9.3 ± 0.5 |
| Sh2-235B Cl.| 5:40:53       | 35:42:15       | 173.712| 2.701| 3.8 ± 1.0 | 3 ± 2 | 1.9 ± 0.5 | 9.1 ± 0.5 |
| BDSB 72    | 5:40:54        | 35:40:22       | 173.740| 2.687| 3.8 ± 1.0 | 3 ± 2 | 2.1 ± 0.5 | 9.3 ± 0.5 |
| BDSB 71    | 5:40:51        | 35:38:20       | 173.763| 2.660| 3.8 ± 1.0 | 3 ± 2 | 2.0 ± 0.4 | 9.2 ± 0.4 |
| Sh2-232 IR | 5:41:06        | 36:09:00       | 173.356| 2.973| 5.0 ± 1.2 | 3 ± 2 | 1.9 ± 0.5 | 9.1 ± 0.5 |
| PCS 2      | 5:39:13        | 35:45:53       | 173.481| 2.446| 3.5 ± 1.0 | 3 ± 2 | 2.2 ± 0.5 | 9.4 ± 0.5 |
| Sh2-233 SE | 5:39:10        | 35:45:15       | 173.484| 2.432| 3.5 ± 0.8 | 3 ± 2 | 2.2 ± 0.5 | 9.4 ± 0.5 |
| G173 Cl.   | 5:39:28        | 35:40:43       | 173.581| 2.443| 3.5 ± 0.9 | 5 ± 3 | 2.5 ± 0.2 | 9.8 ± 0.2 |
| CBB 1      | 5:39:23        | 35:41:22       | 173.563| 2.434| 3.5 ± 0.9 | 5 ± 3 | 2.5 ± 0.2 | 9.8 ± 0.2 |
| CBB 2      | 5:41:11        | 35:50:10       | 173.632| 2.822| 3.8 ± 1.0 | 3 ± 2 | 2.0 ± 0.6 | 9.2 ± 0.2 |

Table Notes. Cols. 2 to 5: Optimised central coordinates; Col. 6: reddening in the cluster’s central region. Col. 7: age, from 2MASS photometry. Col. 8: distance to the Sun. Col. 9: $R_{GC}$ calculated with $R_\odot = 7.2$ kpc (Camargo et al. 2006) as the distance of the Sun to the Galactic centre. The ECs CBB 1 and CBB 2 were discovered in the present work.

Table 2 shows the CMDs of the ECs Sh2-235 B, BDSB 73, BDSB 72, BDSB 71 and Sh2-232 IR Cluster. These objects present a poorly-populated MS and a rather populous PMS.

Figs. 4 and 5 show the CMDs of cluster pairs. Fig. 6 shows the CMDs of the pair Sh2-235 SE Cluster ($R = 2.5'$ and $R = 1$') and CBB 2 ($R = 1$'). The aim of this procedure is to isolate the population of each EC and discard the possibility that we may be working with a single object. In the top-panel we present the $J \times (J - K_S)$ CMDs extracted for Sh2-235 cluster and CBB 2. In the middle panels we show the background field corresponding to a ring with the same area as the central region. In the bottom panels we give the field star decontaminated CMDs. For the ensemble we get $A_V = 3.77 ± 1.0$ mag, and a distance to the Sun $d_0 = 2.0 ± 1.0$ kpc, which agrees with previous values (Georgelin et al. 1973).

Fig. 5 shows the number-density distribution for probable stars in the decontaminated $J \times (J - K_S)$ CMDs.
that these stars are probably embedded in dense structures, which explains the larger values of $A_V$ estimated in the previous works, especially in the case of individual star analyses.

Figs. 2, 3 and 11, together with the age derived for the Sh2-235 Cluster ($\approx 5$ Myr), indicate that the O star ($\approx 1$ Myr) is not a member of this cluster. A possible explanation for the presence of the O star near this cluster is that winds from Sh2-235 Cluster, colliding with the surrounding gas, might have originated this star, CBB 2 and other clusters in the neighborhood. Assuming $v \approx 20 \ km \ s^{-1}$ for the dense gas involved in the expansion (Kirsanova et al. 2008), the Sh2-235 Cluster might be responsible for sequential star formation across a region of radius $\approx 10$ pc (Fig. 11), which includes also the clusters in a row in the southwest direction. Sequential star formation is possible also for the pairs G173 and CBB 1, and Sh2-233SE Cluster and PCS 2. Recently, Dewangan & Anandarao (2011) point out that star formation continues to occur in the Sh2-235 complex, mainly within the ECs. They identified 86 Class 0/I and 144 Class II YSOs, which reinforce the possibility of a sequential star formation event.

### 3.3 Colour-colour diagrams

Colour-colour diagrams are useful tools to investigate the nature of ECs. We show in Fig. 9 the decontaminated near-IR colour-colour diagram ($J-K_s$) vs ($H-K_s$) of the member stars, together with PMS tracks (Siess, Dufour & Forestini 2000), set with the reddening values derived above, to estimate ages. As a consequence of the presence of the PMS stars in the cluster, it is expected that some stars present near-IR excess. As expected from the CMDs of ECs (Figs. 4 to 8), a significant fraction of the stars appears to be very reddened. Most stars, specially MS stars, have ($H-K_s$) colours close to the isochrone, within the uncertainties. Besides, most of the very red PMS stars are displaced parallel to the respective reddening vectors. However, a significant fraction appears to present an abnormal excess in ($J-K_s$) and ($H-K_s$), especially Sh2-235B, which may come from PMS stars still bearing circumstellar discs. MS stars lie on the blue side of the diagrams and there occurs a gap between MS and PMS stars in the CMDs.

### 4 CLUSTER STRUCTURE

The structure of the ECs is analysed by means of the stellar radial density profile (RDP), defined as the projected num-
Figure 11. Schematic distribution of cluster positions and ages. Asterisks are O stars, and the plus sign is a B star. It also shows the nebulae Sh2-235 and Sh2-231 as reference.

Figure 12. Stellar radial densities profile (filled circles) built with colour-magnitude filtered photometry, centred in the coordinates of Sh2-235 Cluster, FSR 784 and Sh2-235E2. Solid line: best-fit King profile. Horizontal shaded region: stellar background level measured in the comparison field. Gray regions: 1σ King fit uncertainty.

The number of stars per area surrounding the cluster centre. RDPs are built with stars selected after applying the respective colour magnitude (CM) filter to the observed photometry. CM filters isolate the probable cluster sequences excluding stars with colours different from those of the cluster sequences (e.g. Bonatto & Bica 2007a, and references therein). However, residual field stars with colours similar to those of the cluster are expected to remain inside the CM filter. They affect the intrinsic stellar radial distribution profile in a degree that depends on the relative densities of field and cluster. The contribution of these residual field stars to the RDP is statistically quantified by means of comparison to the field. In practical terms, the use of the CM filters in cluster sequences enhances the contrast of the RDP with respect to the stellar field. The CM filters are shown in Figs. 4 to 8 as the shaded area superimposed on the field-star decontaminated CMDs.

To minimise oversampling near the centre and undersampling for large radii, the RDPs are built by counting stars in concentric rings of increasing width with distance to the centre. The selected number and width of rings produce RDPs with adequate spatial resolution and moderate 1σ Poisson errors. The residual background level of each RDP corresponds to the average number of CM-filtered stars measured in the comparison field.

The cluster structure was derived by means of a King-like profile, which is similar to a two-parameter King (1962) model that describes the intermediate and central regions of globular clusters. The fit was performed with a non-linear least-squares routine that uses the errors as weights. The best-fit solutions are shown in Fig. 12 for 3 relatively populous ECs as a solid line superimposed on the RDPs. The profile is expressed as \( \sigma(R) = \sigma_{bg} + \sigma_{OK}/(1 + (R/R_{core})^2) \), where \( \sigma_{bg} \) is the stellar background surface density, \( \sigma_{OK} \) is the central density relative to the background level and \( R_{core} \) is the core radius. The cluster radius (\( R_{RDP} \)) and uncertainty can be estimated by considering the RDP fluctuations with respect to the residual field. \( R_{RDP} \) is the distance from the cluster centre where RDP and comparison field become statistically indistinguishable. Small variations in the RDPs are probably due to the presence of other clusters and/or enhanced dust absorption. The derived structural parameters are given in Table 3.

In Fig. 12 we show the RDPs of Sh2-235 Cluster, Sh2-235 East2, and FSR 784. For Sh2-235 Cluster and Sh2-235 East2. Overdensities show up in their RDPs.

Fig. 13 shows the RDPs of Sh2-235B Cluster, BDSB 71, BDSB 72, BDSB 73, Sh2-232 IR Cluster, KKC11, CBB 2 and the pairs CBB 1 and G 173, PCS 2 and Sh2-233 SE. The RDPs are typical of ECs of low mass and/or initial evolutionary phases, and cannot be fitted by King’s profile (Soares et al. 2005). They present bumps and dips as compared to field stars. The depression in star counts in the central region of some ECs is possibly due to strong dust absorption, crowding or structured cores. Sh2-232 IR Cluster has a high cluster/background density contrast, but the profile is irregular. The Sh2-235B cluster profile includes several of the small clusters nearby like BDSB 71, 72 and 73. A deeper photometry is required for the analysis of the structure of these objects.

The structure of young populous ECs can be generally characterised by an RDP with multiple peaks on a large spatial scale or centrally condensed with an RDP that
can be described by a King’s law (Lada & Lada 2003), although the present objects are not virialised. However, the differential dust absorption produces conspicuous variations in the RDPs of the present objects. King profile describes the structure of clusters close to spherical symmetry and centrally concentrated. However, many young clusters are substructured or asymmetric, deviating significantly from this shape, and therefore cannot be fitted by King’s law (Cartwright & Whitworth 2004; Gutermuth et al. 2005). In Fig. [14] we show the spatial distribution of stars in the decontaminated photometry of the three ECs that follow a King-like profile (FSR 784, Sh2-235 Cluster and Sh2-235E2) and two representative cases of objects that do not (KKC 11 and BDSB 73). The former are centrally concentrated and nearly circularly symmetric. The cavities and overdensities in the stellar distribution (Fig. [14]) can be seen as bumps and dips in the RDP (Fig. [11]). On the other hand, objects like BDSB 73 that are not centrally condensed and KKC 11 with more elongated shape do not follow a King profile. The multiple peaks in the RDPs of these ECs may be a fractal effect. If these objects survive the primordial gas expulsion, they may undergo merging evolving into a relatively smooth structure.

The angular distribution of decontaminated stars (Fig. [14]), used in the CMD construction, reproduces the distribution of stars in the RDPs built with filtered photometry (Figs. [12] and [13]), supporting the consistency of our results.

5 MASS ESTIMATES

Given the poorly-populated nature of the MS, we simply counted stars in the CMDs (within the region \( R < R_{\text{RDP}} \)), and summed their masses as estimated from the mass-luminosity relation implied by the respective isochrone solution (Sect. [5.2]). The results are given in Table [4]

All the ECs clearly present distinct populations of MS and PMS stars (Figs. [4] to [8]). However, given the differential reddening, it is not possible to attribute a precise mass value for each PMS star. Thus, we simply count the number of PMS stars and adopt an average mass value for the PMS stars to estimate \( n_{\text{PMS}} \) and \( m_{\text{PMS}} \). Assuming that the mass distribution of the PMS stars also follows Kroupa’s (2001) MF, the zsc, average PMS mass - for masses within the range \( 0.08 \lesssim m(M_\odot) \lesssim 7 \) - is \( < m_{\text{PMS}} > \approx 0.6M_\odot \). Thus, we simply multiply the number of PMS stars (Table 8) by this value to estimate the PMS mass. Finally, we add the latter value to the MS mass to obtain an estimate of the total stellar mass. These values should be taken as lower limits.

6 RELATIONS AMONG ASTROPHYSICAL PARAMETERS

N-body simulations of massive star clusters that include the effect of gas removal (e.g. Goodwin & Bastian 2006) show that the phase of dramatic core radii increase may last about 10-30 Myr. Mass segregation may also lead to a phase of core contraction, with high mass stars more concentrated in the core while low mass stars are transferred to outer parts of the cluster. In this context, we suggest that most objects of our sample have not yet removed completely their primordial gas and are not in this expansion phase. As a consequence the core and cluster radii remain small. However, these ECs may be intrinsically small as well.
Table 5. Integrated colours and magnitudes.

| Cluster   | Apparent Absolute Corrected | Colours               |
|-----------|-----------------------------|-----------------------|
|           | $J$ | $H$ | $K_s$ | $J$ | $H$ | $K_s$ | $(J - H)$ | $(J - K_s)$ |
| FSR 784   | 12.9 | 9.7 | 8.8 | -0.02 | -2.8 | -4.0 | 2.82 ± 0.14 | 3.57 ± 0.14 |
| Sh2-235 E2 | 13.2 | 11.7 | 10.6 | 0.5 | -0.6 | -1.5 | 1.11 ± 0.33 | 1.99 ± 0.31 |
| Sh2-235 Cl. | 8.5 | 8.2 | 7.9 | -4.0 | -4.0 | -4.0 | -0.05 ± 0.04 | 0.01 ± 0.04 |

Table Notes. Col. 2-4: apparent magnitude. Cols. 5-7: absolute magnitude. Cols. 8-9: $(J - H)$ and $(J - K_s)$ colours.

Lada & Lada (2003) argue that the structure in ECs reflects the underlying structure in the dense molecular gas from which they formed and suggest two possible structures for these objects: those similar to classical OCs (radially concentrated that fit a King law) and those that exhibit a density profile with multiple peaks. The latter kind of ECs present a fractal-like structure with smaller substructures or mini clusters that are probably a consequence of the fact that these objects are formed in a GMC with a fractal substructure (Schmeja et al. 2008a, Lomax et al. 2010, Sánchez et al. 2010, and references therein). They evolve with time and their fates depend on the processes of dissolution, which they will undergo. If the ECs do not endure the action of the dissolution processes, they might evolve into a homogeneous distribution of stars and eventually disperse. Otherwise their fate will be a centrally concentrated distribution of stars or a bound cluster. This is possible for the lower mass ECs and cluster pairs or multiples (Figs. 4 to 8). It would also be important to have deeper observations of the less-populated clusters with irregular RDPs (Fig. 13). Probing fainter PMS stars might contribute to the construction of better sampled stellar density profiles, like those of the intrinsically populous and massive clusters in the present star-forming complex (Fig. 12).

Fig. 13. Stellar RDPs for the remaining ECs built with colour-magnitude filtered photometry.

Fig. 14. Angular distribution of the decontaminated stellar content for FSR 784, Sh2-235, Sh2-235E2, KKC 11 and BDSB 73. BD+35°1201 is indicated as an open circle around the star.

When the projected mass density of a star cluster follows a King-like profile (Bonatto & Bica 2008a), the cluster mass ($M_{\text{clus}}$) can be expressed as a function of the core radius and the central surface mass-density ($\sigma_{\text{MO}}$) according to $M_{\text{clus}} \approx 13.8 \sigma_{\text{MO}} R_c^2$ (Bonatto & Bica 2009). Fig. 15 (top-right panel) shows the distribution of our populous ECs in the plane core radius (Sect. 4) vs cluster mass (Sect. 5). Clearly, our ECs (together with the reference sample) distribute parallel to the above relation, being constrained within King-like distributions with $15 \lesssim \sigma_{\text{MO}} (M_\odot \text{pc}^{-2}) \lesssim 600$ (these limits take the uncertainties into account). This correlation between cluster mass...
and core radius is consistent with the mass-radius relation suggested by Portegies Zwart, McMillan & Gieles (2010) for massive clusters younger than 100 Myr and extended for less massive ones (Camargo, Bonatto & Bica 2010).

Since, the cluster radius and mass were computed, we compare the cluster mass density \( \rho(M_\odot pc^{-3}) \) as \( \frac{1}{3} M_{\text{clus}} R_{\text{DDB}}^3 \). The results are shown in the plane \( R_{\text{DDB}} \text{ vs. } \rho \) (Fig. 15 bottom-right panel). Despite the error bars, the density decreases with cluster radius as \( \rho \propto R_{\text{DDB}}^{-3.0 \pm 0.3} \), similarly to the cluster sample studied by Camargo, Bonatto & Bica (2010). We also show in Fig. 15 the relation between age and both \( R_{\text{core}} \) and \( [Z_{\text{GC}}] \) for the present ECs. We fit an empirical curve \( R_{\text{core}}(pc) = 0.27 \times ln(\text{age}[Myr]) - 0.25 \) (the solid line) to Galactic OCs younger than 100 Myr. The dashed line is the observed relation for M51 clusters (Bastian et al. 2008). The present clusters behave as relatively low mass ECs, as expected.

7 CONCLUDING REMARKS

In the present work we performed a field-star decontaminated 2MASS analysis of 14 ECs in the H II regions Sh2-235, Sh2-233, Sh2-232 and Sh2-231, G174+2.5, and other small nebulae in the area. We were able to derive astrophysical parameters and investigate the nature of young clusters embedded in these H II regions. Fundamental parameters were obtained for all ECs analysed, but structural parameters were derived for FSR 784, Sh2-235E2 and Sh2-235 Cluster. The decontaminated C-MDs exhibit a poorly-populated MS and a large fraction of PMS stars, and suggest some age spread, as expected for sequential star formation process. Two new ECs (CBB 1 and CBB 2) were discovered in this work.

The age, size and location of KKC 11, FSR 784, Sh2-235 Cluster, CBB 2, and Sh2-235E2 are consistent with the collect and collapse scenario. The C-MDs of Sh2-235 B, BDB 71, BDB 72, BDB 73, Sh2-232 IR Cluster, G173, CBB 1, and PCS 2 suggest that these objects are ECs. The enhanced dust absorption mainly in the innermost region indicates that deep photometry is necessary to derive their structural parameters.

The present ECs have core and cluster radii smaller than clusters at the same Galactocentric distance and age. Probably most of them have not expelled the primordial gas completely, and thus have not expanded.

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