Uniform detection of the pre-main-sequence population in the five embedded clusters related to the H II region NGC 2174 (Sh2-252)

C. Bonatto* and E. Bica

Departamento de Astronomia, Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves 9500, Porto Alegre 91501-970, RS, Brazil

ABSTRACT

We investigate five embedded clusters (ECs) and the extended stellar group itself of the prominent H II region NGC 2174 (Sh2-252), which presents scarce and heterogeneous information coming from the optical and infrared. Considering the discrepant values of distance and age, the clusters and the H II region appear to be physically unrelated. The analysis is based on field-star-decontaminated 2MASS photometry, which allows sampling of the pre-main sequence (PMS). We find that Sh2-252A, C, E, NGC 2175s and Teu 136 are small ECs (radius within 1.0–2.3 pc) characterized by a similar age (∼5 Myr), reddening (AV ∼ 1), distance from the Sun (d⊙ ∼ 1.4 kpc) and low mass (<200 M⊙). This age is consistent with the H II region, the presence of O and B stars still in the main sequence (MS) and the dominance (≳95 per cent by number) of PMS stars in the colour–magnitude diagrams (CMDs). NGC 2175 is not a star cluster, but an extended stellar group that encompasses the ECs Sh2-252 A and C. It contains ∼36 per cent of the member stars (essentially PMS) in the area, with the remaining belonging to the two ECs. CMDs of the overall star-forming region and the ECs provide d⊙ = 1.4 ± 0.4 kpc for the NGC 2174 complex, consistent with the value estimated for the physically related association Gem OB1. Our uniform approach shows that NGC 2174 and its related ECs (except, perhaps, for Teu 136) are part of a single star-forming complex. CMD similarities among the ECs and with the overall region suggest a coeval (to within ±5 Myr) star-forming event extending for several Myr. At least four ECs originated in the event, together with the off-cluster star formation that probably gave rise to the scattered stars of NGC 2175.

Key words: open clusters and associations: general – open clusters and associations: individual: NGC 2174 (Sh2-252).

1 INTRODUCTION

A lingering question related to star formation is whether stars in associations and young stellar groups originate in clusters that dissolve rapidly (e.g. Bonatto & Bica 2010b and references therein) or are directly formed throughout the parent molecular cloud. At the bottom of this issue lies the scenario in which star formation is scale-free and hierarchical, with high-velocity turbulent gas forming large-scale structures and small clumps being formed by low-velocity compression (Elmegreen 2008). In this context, young stellar groupings would be hierarchically clustered, with the great star complexes at the largest scales and the OB associations and subgroups, clusters and cluster subclumps at the smallest (e.g. Efremov 1995).

Hierarchical patterns in extended structures have been detected in the Magellanic Clouds (MCs) and other nearby galaxies (see e.g. Bonatto & Bica 2010a, and references therein). At the few pc scale, Hubble Space Telescope (HST) and VLT-ISAAC photometry of pre-main-sequence (PMS) stars in the Small Magellanic Cloud (SMC) star-forming region NGC 346/N66 suggest hierarchical star formation, probably originating from more than one event (Sabbi et al. 2007; Gouliermis et al. 2008; Hennekemper et al. 2008). These works show that some of the PMS stars are found in subclusters (some located in the central region of the association and others at the border), with the remaining stars scattered around the association, a scenario directly related to the single or sequential star-formation issue.

Recently, our group studied the stellar content of the Sh2-132 H II region, a star-forming complex hosting at least four embedded clusters (ECs) and presenting evidence of triggered star formation and hierarchical structuring (Saurin, Bica & Bonatto 2010). However, given its rather large distance (d⊙ ∼ 3.5 kpc) and the Two-Micron All Sky Survey (2MASS)1 photometric depth, we could only sample a fraction of the PMS population. Thus, the present paper focuses

1 The Two Micron All Sky Survey, All Sky data release (Skrutskie et al. 2006).
Table 1. Star clusters or candidates in NGC 2174 (Sh2-252) identified in the literature.

<table>
<thead>
<tr>
<th>Name</th>
<th>ℓ</th>
<th>b</th>
<th>α(2000)</th>
<th>δ(2000)</th>
<th>Size (arcmin x arcmin)</th>
<th>Other designations</th>
<th>Related objects</th>
<th>References</th>
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<tr>
<td></td>
<td>(°)</td>
<td>(°)</td>
<td>(hms)</td>
<td>(°')</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Sh2-252A</td>
<td>189.76</td>
<td>0.33</td>
<td>06:08:32</td>
<td>+20:39:24</td>
<td>1.6 × 1.6</td>
<td></td>
<td>in NGC 2175, Sh2-252; Gem OB1</td>
<td>03.02</td>
</tr>
<tr>
<td>Sh2-252C</td>
<td>189.85</td>
<td>0.50</td>
<td>06:09:22</td>
<td>+20:39:33</td>
<td>2.6 × 2.6</td>
<td>KKC 16</td>
<td>in NGC 2175, Gem OB1, rel IRAS 06063+2040</td>
<td>03.02,04</td>
</tr>
<tr>
<td>Sh2-252E</td>
<td>190.05</td>
<td>0.53</td>
<td>06:09:53</td>
<td>+20:30:16</td>
<td>1.4 × 1.4</td>
<td>NGC 2174, CSS16, KKC 17</td>
<td>in Gem OB1, rel IRAS 06068+2030</td>
<td>01.03,04</td>
</tr>
<tr>
<td>NGC 2175s†</td>
<td>190.07</td>
<td>0.79</td>
<td>06:10:52</td>
<td>+20:36:45</td>
<td>3 × 2</td>
<td>OCI-475,1, Pismis 27</td>
<td>in Sh2-252</td>
<td>05.06</td>
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<td>Teutsch 136</td>
<td>190.14</td>
<td>1.05</td>
<td>06:11:58</td>
<td>+20:40:28</td>
<td>3 × 3</td>
<td>Koposov 82</td>
<td></td>
<td>07.08</td>
</tr>
</tbody>
</table>

Possible young open cluster or stellar group

| NGC 2175          | 189.94 | 0.46 | 06:09:22 | +20:33:44 | 22 × 15                | Collinder 84, OCI-476 | in Sh2-252, in Gem OB1 | 05.00      |

(†): ‘s’ refers to small. Col. 1: Adopted name. Col. 6: Optical diameter. References in Col. 9: 01: Carpenter et al. (1993); 02: these clusters were included in the Embedded Cluster Catalogue by Bica, Dutra & Barbuy (2003); 03: a cluster image is provided in the 2MASS gallery at http://www.ipac.caltech.edu/2mass/gallery; 04: Kumar et al. (2006); 05: Pismis (1970); 06: listed in DAML02; 07: Kronberger et al. (2006); 08: Koposov et al. (2008).

3 Adopted by WEBDA: http://www.univie.ac.at/webda/
4 Leicester Data base and Archive Service (LEDAS) DSS/DSS-II service on ALBION: http://ledas-www.star.le.ac.uk/DSSimage

The prominent H II region Sh2-252 was originally catalogued by Sharpless (1959), who related it to an emission nebula (NGC 2174) and a loose stellar distribution (NGC 2175). Currently, NGC 2174 refers to the whole H II region, while NGC 2175 refers to a possible young open cluster (OC) or a stellar group of scattered stars in the nebula. We will thus use NGC 2174 (Sh2-252) for the H II region and NGC 2175 for the possible stellar group.

Different designations and parameters for star clusters and candidates in the direction of NGC 2174 are available in the literature. For instance, Pismis (1970) and Dias et al. (2002, hereafter DAML02) list an OC, NGC 2175, within the H II region NGC 2174. Pismis (1970) finds a small cluster in the area, designated as NGC 2175s, where ‘s’ refers to small. DAML02 refers to NGC 2175s as Pismis 27. Pismis (1970) inferred that NGC 2175s and NGC 2175 have different reddening values ($E(B-V) = 0.70$ and 0.25, respectively), and are located at different distances ($d_⊙ = 3.5$ and 1.95 kpc, respectively). Star counts also suggest that the distribution of stars in NGC 2175 corresponds to a spherical shell. Pismis (1970) provides the fundamental parameters for the possible OC NGC 2175: $d_⊙ = 1.63$ kpc, $E(B-V) = 0.60$ and age = 9 Myr. In DAML02 they are $d_⊙ = 1.0$ kpc, $E(B-V) = 0.60$ and age = 32 Myr.

For NGC 2175s, Koposov, Glushkova & Zolotukhin (2008) derived $d_⊙ = 1.0$ kpc, $E(B-V) = 0.68$ and age < 50 Myr, while Teutsch 136 is cited as a new infrared cluster but without parameter determination. Kumar, Keto & Clerkin (2006) derived $d_⊙ = 4.52$ kpc, $A_k = 1.0$, number and mass of member stars $N = 202$ and $M = 1474 M⊙$ and effective radius $R_{eff} = 2$ arcmin for Sh2-252C; for Sh2-252E they found $d_⊙ = 1.5$ kpc, $A_k = 0.6$, $N = 68$, $M = 45 M⊙$ and $R_{eff} = 1.5$ arcmin. The remaining objects in the area (Table 1) have no parameters yet determined.

Discrepant values for the distance to the H II region have also been provided by kinematical methods. For instance, based on $UBV$ photometry and spectroscopy, Georgelin, Georgelin & Roux (1973) derived a kinematical distance of $d_⊙ = 1.48 ± 1.21$ kpc. On the other hand, the CO radial velocities of Blitz, Fich & Stark (1982) implied the distance $d_⊙ = 4.4 ± 0.4$ kpc. More recently, Reid et al. (2009) used trigonometric parallaxes to derive $d_⊙ = 2.1$ kpc and a (revised) kinematical distance of $d_⊙ = 3.3^m\pm0.4^m$ kpc. Such a difference in the kinematical distance may be accounted for by the nearly anti-Galactic direction of Sh2-252.

A few relatively bright stars mixed with nebular gas and/or dust emission are seen in the 45 arcmin × 45 arcmin $B$ image (Fig. 1, taken from the Leicester Data base and Archive Service (LEDAS)). Close-ups of the stars (and the stellar group NGC 2175) are shown in the smaller field 2MASS $K_s$ images (Fig. 2). Table 1 provides parameters found in the literature for the clusters and candidates. Cluster designations and coordinates – as derived in the present paper – are given in Table 2. Note the small differences between our coordinates and those given in the literature. This occurs because the central coordinates were recomputed with field-star-decontaminated photometry (Section 3). According to our approach, the cluster centre corresponds to the coordinates that produce the...
smoother stellar radial density profile (RDP) and, at the same time, the highest stellar density in the innermost region (Section 4).

3 DECONTAMINATED CMDS

Fig. 1 shows that the H II region NGC 2174 (and related objects) still retains part of the parent gas and dust. Thus, we employ 2MASS J, H and K, photometry to probe the photometric properties with adequate depth, especially at the faint stellar sequences. Additionally,

Table 2. Fundamental parameters derived in this work.

<table>
<thead>
<tr>
<th>Cluster</th>
<th>α(2000)</th>
<th>δ(2000)</th>
<th>l</th>
<th>b</th>
<th>Age (Myr)</th>
<th>E(B − V) (mag)</th>
<th>d⊙ (kpc)</th>
<th>ΔR⊙c (kpc)</th>
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<td>Embedded clusters</td>
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<td></td>
</tr>
<tr>
<td>Sh2-252A</td>
<td>06:08:32.2</td>
<td>+20:39:18.0</td>
<td>189.77</td>
<td>−0.34</td>
<td>~5</td>
<td>0.29 ± 0.16</td>
<td>1.4 ± 0.3</td>
<td>1.4 ± 0.5</td>
</tr>
<tr>
<td>Sh2-252C</td>
<td>06:09:21.6</td>
<td>+20:38:37.0</td>
<td>189.87</td>
<td>−0.50</td>
<td>~5</td>
<td>0.30 ± 0.16</td>
<td>1.5 ± 0.4</td>
<td>1.5 ± 0.5</td>
</tr>
<tr>
<td>Sh2-252E</td>
<td>06:09:52.7</td>
<td>+20:30:15.2</td>
<td>190.05</td>
<td>−0.54</td>
<td>~5</td>
<td>0.32 ± 0.16</td>
<td>1.4 ± 0.3</td>
<td>1.4 ± 0.4</td>
</tr>
<tr>
<td>NGC 2175s</td>
<td>06:10:54.6</td>
<td>+20:36:49.5</td>
<td>190.07</td>
<td>−0.80</td>
<td>~5</td>
<td>0.45 ± 0.10</td>
<td>1.2 ± 0.3</td>
<td>1.1 ± 0.3</td>
</tr>
<tr>
<td>Teutsch 136</td>
<td>06:11:58.1</td>
<td>+20:49:29.5</td>
<td>190.14</td>
<td>+1.05</td>
<td>~5</td>
<td>0.54 ± 0.16</td>
<td>1.8 ± 0.4</td>
<td>1.7 ± 0.5</td>
</tr>
<tr>
<td>Possible young open cluster or stellar group</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>NGC 2175</td>
<td>06:09:22.4</td>
<td>+20:33:06.5</td>
<td>189.95</td>
<td>−0.46</td>
<td>~5</td>
<td>0.35 ± 0.10</td>
<td>1.5 ± 0.4</td>
<td>1.7 ± 0.5</td>
</tr>
</tbody>
</table>

Figure 3. CMDs showing the observed photometry for representative regions (top) and the equal-area comparison fields (middle). The decontaminated CMDs are shown in the bottom panels, together with the 5-Myr Padova isochrone (for the MS) and the 0.2-, 1-, 5- and 10-Myr PMS isochrones. The isochrones have been set according to the adopted fundamental parameters (Section 5.3). Also shown is the colour–magnitude filter (shaded polygon). Reddening vectors for $A_V = 0–10$ are shown in the bottom panels.

2MASS provides the spatial and photometric uniformity required for wide extractions and high star-count statistics. The photometry for each target (Table 1) was extracted from VizieR, and only stars with errors lower than 0.1 mag are used.

Clusters that contain important fractions of faint stars and/or are projected near the Galactic equator require field-star decontamination for the proper identification and characterization of the member stars. Although projected towards the Galactic anticentre, the present clusters are found near the plane and have CMDs dominated by PMS stars (see below). Thus, we apply the decontamination algorithm first developed in Bonatto & Bica (2007) and improved in Bonatto & Bica (2010b) to minimize confusion with red dwarfs of the Galactic field.

Representative CMDs of the targets are shown in the top panels of Figs 3 and 4. For NGC 2175, we first consider a region of radius $R = 5$ arcmin, which is located outside the borders of the neighbouring Sh2-252C and Sh2-252E (Fig. 1) and thus is expected to be free from contamination by stars of both objects; a wider region will be considered in Section 5. An indication of a low age comes from comparison with the CMDs extracted from equal-area offset fields (middle panels), which is consistent with the presence of gas and dust (Figs 1 and 2).

Indeed, the decontaminated CMDs (bottom panels of Figs 3 and 4) present similar features: they are essentially characterized by stellar sequences of mildly reddened, young clusters, with a nearly vertical, developing MS and a significant population of PMS stars. Given the time-scales associated with stellar formation ($\sim 10^7$ yr for low-mass stars), very young clusters are expected to contain a population of PMS stars (e.g. Bonatto & Bica 2010b, and references therein). Thus, the assumption that the red and faint stars belong to the PMS is consistent with the $\sim 5$ Myr age of the ECs in the complex (Section 5). Internal differential reddening is implied by the colour distribution at faint magnitudes ($J \gtrsim 14$), which is wider than the spread predicted purely by PMS models. A comparison with the reddening vector (for $A_V = 0–10$) shows different degrees of differential reddening, which is lower for NGC 2175s and Teu 136 and higher for the remaining cases. If most of the colour spread is due to non-uniform reddening and not to systematic differences in the stellar content, then the upper limit to the differential reddening would be $\Delta A_V \lesssim 6$ mag.

4 STRUCTURAL PARAMETERS

Probable member stars of each cluster are selected by a colour–magnitude filter, which is wide enough to include MS and PMS stars, photometric uncertainties and binaries (Figs 3 and 4); they are used to build the projected stellar radial density profile (RDP)
erwise, the RDPs would be characterized by random fluctuations (Bonatto & Bica 2008).

The values of $R_{c}$ and $R_{bg}$ (Table 3) show that we are dealing with small-scale clusters. Indeed, compared with the core radii derived for a sample of relatively nearby OCs by Piskunov et al. (2007), the present ECs occupy the small-$R_c$ tail of the distribution.

5 THE DISTANCE TO NGC 2174 AND THE NATURE OF NGC 2175

5.1 Distance and age of NGC 2174

Evidence drawn in previous sections suggest that we are dealing with a coeval star formation in NGC 2174 that produced at least five ECs physically related to the H II region. In this sense, we can use the CMD morphology of the whole area to derive the average fundamental parameters of NGC 2174. For this purpose, we decontaminate a region of 25 arcmin in radius (Fig. 6), thus including NGC 2175 and the ECs Sh2-252A, C, E and NGC 2175s.

To derive the fundamental parameters we use the Padova isochrones (Girardi et al. 2002) computed for the 2MASS filters. For the PMS we use the isochrones of Siess, Dufour & Forestini (2000). We restrict the analysis to solar-metallicity isochrones because the clusters are expected to be young and located not far from the Solar circle (see below), a region essentially occupied by [Fe/H] $\approx$ 0. 0 OCs (Friel 1995). Reddening transformations are based on the absorption relations $A_J/A_V = 0.276$, $A_H/A_V = 0.176$, $A_Ks/A_V = 0.118$ and $A_J = 2.76 \times E(J - H)$ (Dutra, Santiago & Bica 2002), with $R_V = 3.1$, considering the extinction curve of Cardelli, Clayton & Mathis (1989).

Given the poorly populated MS, the significant population of PMS stars and the differential reddening, we estimate the fundamental parameters by eye, using the decontaminated CMD morphology (Fig. 6) as our constraint. Beginning with zero distance modulus and reddening, the MS+PMS isochrones are shifted in colour and magnitude until an acceptable fit for the blue border of the MS and PMS sequences is obtained. The rather poorly populated and nearly vertical MS accepts any isochrone of age within 1–10 Myr. Considering the differential reddening, a similar age spread results for the PMS stars, which are basically contained within the 0.2-Myr and 10-Myr isochrones. This age range is consistent with the gas- and dust-embedded ECs in the area, suggesting an age spread of ~10 Myr in the star formation.

Additionally, the presence of a few O and B stars still in the MS, some of these projected within the ECs Sh2-252E and NGC 2175s, constrains the age of the complex to a few Myr. The spectral types, coordinates (J2000) and location of these ionizing stars are O9 V ($\alpha = 06:09:40$, $\delta = +20:29:15.4$) near the west border of Sh2-252E, B1.5 V ($\alpha = 06:10:53$, $\delta = +20:36:33.8$) near the centre of NGC 2175s, B1.5 V ($\alpha = 06:10:59$, $\delta = +20:34:19.6$) slightly to the south of the latter and two B2.5 V stars ($\alpha = 06:09:50$, $\delta = +20:37:05.2$ and $\alpha = 06:09:55$, $\delta = +20:38:31.6$) located to the north-east of the centre of NGC 2175. Thus, based on the gas- and dust-embedded character of the ECs (Figs 1 and 2) and the ionizing stars, we adopt ~5 Myr as the age for the bulk of stars in NGC 2174.

The adopted solution is shown in Fig. 6, where the isochrones are set with $A_V = 0.8 \pm 0.3$ and $d_{\odot} = 1.44 \pm 0.34$ kpc. Within the uncertainty, this value is consistent with the distance of the
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1.5 kpc, the clusters −0.5 and 0.10 4.0 ± 0.25 4.5 ∼0.34 kpc. Evolutionary tracks of selected PMS masses are

42 0.35 −0.2 M R = −0.5 0.447 152 ± 42 0.35 ± 0.06 2.0 ± 0.2

clusters (Figs 3 and 4) resemble that of the wide-field CMD of NGC 2174 (Fig. 6), a similar isochrone solution is expected to apply to all ECs in the complex. Thus, we simply use the NGC 2174 solution as a fundamental-parameter template. The adopted solutions are shown in Figs 3 and 4, and the fundamental parameters are given in Table 2.

NGC II ±77 0.26 ±0.08 2.4 ±0.5 1 arcmin 0.06 2.0 ±0.2

NGC 2174, covering a region of radius R = 25 arcmin. The isochrones have been set with A V = 0.8 ± 0.3 and d⊙ = 1.44 ± 0.34 kpc. Evolutionary tracks of selected PMS masses are shown (light-dotted lines) for illustrative purposes. Filled symbols indicate MS O and B stars in the area.

Gem OB1 association (d⊙ = 1.5 − 1.9 kpc), to which NGC 2174 appears to be physically related (Dunham et al. 2010).

5.2 Nature of NGC 2175

According to the literature (Table 1), NGC 2175 encompasses the ECs Sh2-252C and Sh2-252E (Fig. 1). In fact, the decontamination shows that most of the stars (∼64 per cent) in the region belong to both ECs, with the remaining following the same CMD morphology as the ECs (Fig. 4), which might suggest an EC. However, the RDP centred on NGC 2175 (Fig. 5) is irregular and shows only a very narrow peak, followed by the excesses produced by the neighbouring ECs. This indicates that NGC 2175 is not a star cluster.

Instead, its stellar content may be (i) stars that already have escaped from the neighbouring ECs, (ii) a leftover of a disrupted EC or (iii) a result of star formation throughout the molecular cloud not related to a cluster. Perhaps, given the rather low age of the star-formation event, the first two scenarios may not apply, since the stars would have to scatter over a region of ∼6 pc in radius in less than ∼5–10 Myr. This would favour NGC 2175 as an off-cluster star formation in the molecular cloud.

5.3 Fundamental parameters of individual clusters

Since the decontaminated CMD morphologies of the individual clusters (Figs 3 and 4) resemble that of the wide-field CMD of NGC 2174 (Fig. 6), a similar isochrone solution is expected to apply to all ECs in the complex. Thus, we simply use the NGC 2174 solution as a fundamental-parameter template. The adopted solutions are shown in Figs 3 and 4, and the fundamental parameters are given in Table 2.

We find only small variations in reddening (E(B − V) = 0.29 − 0.45) and distance (d⊙ = 1.2 − 1.5 kpc) among the CMDs (Table 2). Teu 136 may be the exception, in the sense that it is somewhat more reddened (E(B − V) = 0.54) and more distant (d⊙ = 1.8 ± 0.4 kpc) than the others. Obviously, given the uncertainty in d⊙, the clusters can be said to be at the same distance. However, since Teu 136 is located beyond the east border of the H II region (Fig. 1), it may be just a young cluster projected close but not physically related to the complex. Our reddening value for Sh2-252C is about 10 per cent of that derived by Kumar et al. (2006), while our distance from the Sun is about 30 per cent of theirs. On the other hand, both works agree with respect to the distance of Sh2-252E.

Compared with the remaining cases (Figs 3 and 4), the decontaminated CMD of the dust-shrouded EC NGC 2175s presents the best constraints, in terms of stellar sequences (it contains at least 2 B1.5 V stars), for finding an independent isochrone solution. Under the same strategy applied for NGC 2174, we find E(J − H) = 0.14 ± 0.03 (E(B − V) = 0.45 ± 0.10 or A V = 1.4 ± 0.3), the observed and absolute distance moduli (m − M V )o = 10.75 ± 0.5 and (m − M)⊙ = 10.31 ± 0.51, respectively, and d⊙ = 1.2 ± 0.3 kpc. These values are consistent with those of the wide-field NGC 2174, and with the d⊙ = 1 kpc obtained by Kroupa et al. (2008). Given the ℓ and b coordinates (Table 1), NGC 2175s is located ∼1.1 kpc outside the Solar circle and ∼16 pc above the plane.

6 STELLAR MASS ESTIMATE

Followed by a developing, poorly populated MS, PMS stars are the dominant (in number) component in the CMDs of our clusters (Figs 3 and 4). Consequently, most of the cluster mass is still stored

<table>
<thead>
<tr>
<th>Cluster</th>
<th>σ⊙ (stars arcmin⁻²)</th>
<th>R⊙ (arcmin)</th>
<th>RGP⊙ (arcmin)</th>
<th>l arcmin (pc)</th>
<th>σ⊙ (stars pc⁻²)</th>
<th>R⊙ (pc)</th>
<th>RGP⊙ (pc)</th>
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</thead>
<tbody>
<tr>
<td>Pismis 27</td>
<td>19.6 ± 8.7</td>
<td>0.58 ± 0.18</td>
<td>5.5 ± 0.5</td>
<td>0.335</td>
<td>175 ± 77</td>
<td>0.19 ± 0.06</td>
<td>1.8 ± 0.2</td>
</tr>
<tr>
<td>Sh2-252 A</td>
<td>60.8 ± 37.3</td>
<td>0.21 ± 0.08</td>
<td>2.4 ± 0.4</td>
<td>0.410</td>
<td>362 ± 222</td>
<td>0.09 ± 0.03</td>
<td>1.0 ± 0.2</td>
</tr>
<tr>
<td>Sh2-252 C</td>
<td>30.3 ± 8.4</td>
<td>0.78 ± 0.14</td>
<td>4.5 ± 0.5</td>
<td>0.447</td>
<td>152 ± 42</td>
<td>0.35 ± 0.06</td>
<td>2.0 ± 0.2</td>
</tr>
<tr>
<td>NGC 2174</td>
<td>190 ± 100</td>
<td>0.15 ± 0.10</td>
<td>4.0 ± 0.5</td>
<td>0.405</td>
<td>916 ± 610</td>
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</tr>
<tr>
<td>Teutsch 136</td>
<td>27.1 ± 20.2</td>
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<td>4.5 ± 0.5</td>
<td>0.511</td>
<td>104 ± 77</td>
<td>0.26 ± 0.13</td>
<td>2.3 ± 0.3</td>
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</tbody>
</table>

Col. 5: arcmin to parsec scale.

Figure 6. Decontaminated photometry of NGC 2174, covering a region of radius R = 25 arcmin. The isochrones have been set with A V = 0.8 ± 0.3 and d⊙ = 1.44 ± 0.34 kpc. Evolutionary tracks of selected PMS masses are shown (light-dotted lines) for illustrative purposes. Filled symbols indicate MS O and B stars in the area.
in PMS stars. Thus, to estimate the cluster mass we simply consider the number of MS and PMS stars (for \( R \leq R_{\text{RDP}} \)) in the field-decontaminated photometry.

The mass of each MS star is taken from the mass–luminosity relation corresponding to the isochrone solution (Section 5.3). Summing up the values for all stars produces the total number (\( n_{\text{MS}} \)) and mass (\( m_{\text{MS}} \)) of MS stars. MS stars are detected within the range 1.7–6.5 \( M_{\odot} \) (Table 4). For the PMS, on the other hand, the presence of differential reddening precludes such an estimate of individual masses. Thus, we simply count the number of PMS stars and adopt an average PMS mass value to estimate \( n_{\text{PMS}} \) and \( m_{\text{PMS}} \). To compute the average PMS mass value we use the Kroupa (2001) initial mass function\(^7\) for PMS masses in range 0.08 \( M_{\odot} \)–7 \( M_{\odot} \). The result is \( \bar{m}_{\text{PMS}} = 0.6 M_{\odot} \). The estimated values are given in Table 4, which also gives the average mass density (\( \rho \)) of each cluster.

As anticipated by the CMDs (Figs 3 and 4) and the small sizes (Table 3), we are dealing with low-mass clusters (\(< 200 M_{\odot} \)) having poorly populated MSs and with most (\( \geq 95 \) per cent) of the stars still in the PMS. Indeed, the mass stored in the PMS stars is the dominant (\( \approx 70–90 \) per cent) component of the detected cluster mass, which is consistent with the low ages. However, given the presence of dust and gas (Figs 1 and 2), differential reddening and the 2MASS photometric limitation (which precludes detection of very low-mass PMS stars), the mass values may be somewhat higher than quoted in Table 4.

### 7 SUMMARY AND CONCLUSIONS

Previous works on the \( H\alpha \) region NGC 2174 (Sh2-252) came up with discrepant values for the age and distance from the Sun of the deeply embedded star clusters (and candidates) in the area, to the point where no physical relation among them – and with the complex – could have been inferred.

We investigate the above issue with field-star-decontaminated 2MASS photometry (to enhance CMD evolutionary sequences) and stellar RDPs, to derive fundamental and structural parameters of the five previously catalogued embedded clusters (Sh2-252A, C, E, NGC 2175s and Teu 136) and one candidate (NGC 2175).

The decontaminated CMDs are characterized by similar properties: a poorly populated and developing MS, a dominant fraction (\( \geq 95 \) per cent in number) of PMS stars, a similar foreground absorption, \( A_V \approx 1 \) mag, and some differential reddening. Taken together, the presence of gas, dust, some O V and B V stars and the MS+PMS CMD morphologies consistently constrain the age of the ECs (and the extended stellar group) to less than \( \approx 10 \) Myr (the bulk of the stars are probably \( \approx 5 \) Myr old), with a time spread of \( \approx 10 \) Myr for the star formation. The MS+PMS stellar masses are low, within \( \approx 60 M_{\odot} – 200 M_{\odot} \). Within the uncertainties, the distances from the Sun of Sh2-252A, C, E, NGC 2175s and NGC 2175 are essentially the same, \( d_{\odot} \approx 1.4 \pm 0.4 \) kpc and reddened (\( A_V \approx 1.8 \) mag) than the other objects. Since Teu 136 is beyond the north-east border of NGC 2174, it may be just an EC projected near the \( H\alpha \) region. The decontaminated wide-field CMD of NGC 2174, which is expected to reflect the average properties of the stars in the region, provides the distance \( d_{\odot} = 1.44 \pm 0.34 \) kpc, the foreground absorption \( A_V = 0.8 \pm 0.3 \).

The stellar RDPs of Sh2-252A, C, E, NGC 2175s and Teu 136 follow a King-like function characterized by small core and cluster radii, with 0.06 \( \leq R_c(\text{pc}) \leq 0.26 \) and 1.0 \( \leq R_{\text{RDP}}(\text{pc}) \leq 2.3 \), respectively. NGC 2175, on the other hand, is not a cluster, and its stars probably originated in the same star-formation event that gave rise to the ECs. Thus, NGC 2175 may be classified as a young stellar group.

What can be concluded from our uniform, near-infrared approach is that NGC 2174 and its related ECs (Sh2-252A, C, E, NGC 2175s and perhaps Teu 136) are part of a single star-forming complex located at \( d_{\odot} \approx 1.4 \) kpc from the Sun. Thus, we are dealing with a coeval (to within \( \pm 5 \) Myr) star-forming event that extended for \( \sim 10 \) Myr. Besides the scattered stars of NGC 2175 (probably an off-cluster star formation in the molecular cloud), the event gave rise to at least four ECs in the complex. Finally, the derivation of constrained distance values for star-forming complexes is important for spiral-arm structure studies (e.g. Russeil 2003), by providing a kinematically independent determination, especially for central and anticentre directions.

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\( \Delta m = m_{\text{MS}} – m_{\text{PMS}} \)

\( m_{\text{MS}} \) (stars)

\( m_{\text{PMS}} \) (stars)

\( m_{\text{MS}+\text{PMS}} \) (stars)

\( \bar{m}_{\text{MS}+\text{PMS}} \) (stars)

<table>
<thead>
<tr>
<th>Cluster</th>
<th>( \Delta m ) (( M_{\odot} ))</th>
<th>( m_{\text{MS}} ) (stars)</th>
<th>( m_{\text{PMS}} ) (stars)</th>
<th>( m_{\text{MS}+\text{PMS}} ) (stars)</th>
<th>( \rho ) (( M_{\odot} ) pc(^{-3} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC 2175s</td>
<td>1.7–6.5</td>
<td>18 ± 4</td>
<td>51 ± 12</td>
<td>108 ± 14</td>
<td>176 ± 14</td>
</tr>
<tr>
<td>Sh2-252A</td>
<td>2.7–3.8</td>
<td>2 ± 1</td>
<td>6 ± 3</td>
<td>86 ± 8</td>
<td>106 ± 8</td>
</tr>
<tr>
<td>Sh2-252C</td>
<td>1.7–6.5</td>
<td>6 ± 2</td>
<td>20 ± 9</td>
<td>289 ± 15</td>
<td>295 ± 17</td>
</tr>
<tr>
<td>Sh2-252E</td>
<td>1.7–5.5</td>
<td>6 ± 2</td>
<td>20 ± 9</td>
<td>109 ± 12</td>
<td>113 ± 15</td>
</tr>
<tr>
<td>Teu 136</td>
<td>2.7–5.5</td>
<td>4 ± 2</td>
<td>16 ± 8</td>
<td>176 ± 14</td>
<td>180 ± 15</td>
</tr>
</tbody>
</table>

\( \text{Col. 2: effective mass range of the MS, Col. 9: average mass density.} \)
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