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A third red supergiant rich cluster in the Scutum-Crux arm

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ABSTRACT

Aims. We aim to characterise the properties of a third massive, red supergiant dominated galactic cluster.

Methods. To accomplish this we utilised a combination of near/mid-IR photometry and spectroscopy to identify and classify the properties of cluster members, and statistical arguments to determine the mass of the cluster.

Results. We found a total of 16 strong candidates for cluster membership, for which formal classification of a subset yields spectral types from K3–M4 Ia and luminosities between log(L/L⊙) ~ 4.5–4.8 for an adopted distance of 6 ± 1 kpc. For an age in the range of 16–20 Myr, the implied mass is 2–4×104 M⊙, making it one of the most massive young clusters in the Galaxy. This discovery supports the hypothesis that a significant burst of star formation occurred at the base of Scutum-Crux arm between 10–20 Myr ago, yielding a stellar complex comprising at least ~104 M⊙ of stars (noting that since the cluster identification criteria rely on the presence of RSGs, we suspect that the true stellar yield will be significantly higher). We highlight the apparent absence of X-ray binaries within the star formation complex and finally, given the physical association of at least two pulsars with this region, discuss the implications of this finding for stellar evolution and the production and properties of neutron stars.

Key words. stars: supergiants – Galaxy: open clusters and associations: individual: Scutum-Crux arm – stars: late-type

1. Introduction

The vigorous star formation that characterises starburst galaxies results in the production of extended complexes of young massive stellar clusters, which span hundreds of parsecs but appear to have formed over a limited time-frame (<20 Myr; Bastian et al. 2005). With masses >104 M⊙, analogues of such constituent clusters had been thought to be absent from our own Galaxy. However near-IR observations revealed that the Galactic Centre hosts 3 such young massive clusters (Figer et al. 1999, 2002, 2004), while detailed study of Westerlund 1 suggests a mass of the order of 105 M⊙ (Clark et al. 2005). Such discoveries raise the exciting prospect of directly determining such fundamental properties as their (Initial) Mass Function; currently impossible for unresolved extragalactic examples.

Furthermore, their presence in the Galaxy permits the detailed investigation of massive stellar evolution, since their high mass yields significant numbers of rare spectral types in a co-eval setting of uniform metallicity. With ages <5 Myr, Westerlund 1 and the Galactic Centre clusters provide valuable insights into the properties and evolutionary pathways of massive (>40 M⊙) stars. Recently, studies by Figer et al. (2006, F06) and Davies et al. (2007, 2008; D07 and D08 respectively) have revealed two further massive clusters dominated by red supergiants (RSGs) at the base of Scutum-Crux arm – RSGC1 (12 ± 2 Myr; M_initial ~ 3 ± 10^4 M⊙) and RSGC2 (17 ± 3 Myr; M_initial ~ 4 ± 10^4 M⊙). Collectively, both clusters sample a somewhat lower range of stellar masses, hosting 40 RSGs with M_initial ~ 14–20 M⊙; of particular interest since such stars are thought to be type II SNe progenitors (Smartt et al. 2008).

In this paper we report the discovery of a third massive, RSG dominated cluster, RSGC3, also located at the base of the Scutum-Crux arm. Identified visually in GLIMPSE/Spitzer mid-IR images (Benjamin et al. 2003) as a concentration of bright stellar sources at ~l = 29°2, b = −0°2, we utilised near-IR photometry to identify potential cluster members, a subset of which were subsequently observed spectroscopically to provide a firm classification. Finally, a synthesis of these data were used to constrain the bulk properties of the cluster and individual stars within it, enabling a comparison to RSGC1 and 2 and a characterisation of the star forming environment they delineate.

2. The RSG candidate sample

As can be seen from the near IR images of RSGC1–3 (F06, D07, Figs. 1 and 2) it is extremely difficult to determine a physical extent for such (putative) clusters since, with the exception of the RSGs, no other cluster population is readily visible as an overdensity with respect to the stellar field population. If kinematic

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information is available, it is possible to identify a co-moving, physical association of RSGs, in order to discriminate between cluster and field stars (e.g. D07). However, the spectroscopic data presented here are of insufficient resolution to extract the radial velocity of cluster members, while, unlike RSGC1 and 2 (F06; D07), we find no maser emission from any cluster members which would also provide kinematic constraints (Verheyen et al. in prep.); thus we are forced to utilise photometric data to construct a list of candidate cluster members.

Based on the spatial concentration of bright red stars, we start by taking 2MASS photometry for stars within \( r \leq 3' \) of the position of Star 1 (RA: 18h 45m 23.60s, Dec: -03° 24' 13.9''), selecting only stars with quality flags “AAA” and error \( \Delta K_S \leq 0.05 \). The ten bright stars defining the spatial concentration form a well-separated group in the \((J - K_S)/K_S\) diagram (Fig. 3), around \((J - K_S) \approx 3.0\). This grouping is also present in the \((H - K_S)/K_S\) diagram, centred around \((H - K_S) = 0.95\). We then calculate the reddening-free parameter \( Q_{IR} = (J - H) - 1.8 \times (H - K_S)\). Early-type stars have \( Q_{IR} = 0.0\), while most bright field stars have \( Q_{IR} = 0.4 - 0.5\), corresponding to red giants (Indebetouw et al. 2005; Negueruela & Schurch 2007). All ten stars form a clearly separated grouping in this diagram, with values 0.2 - 0.4, typical of supergiants. There is one more star in this clump, S14, which has redder \((J - K_S)\) and \((H - K_S)\). The only other star of comparable \( K_S \) in the field, S28, has \( Q_{IR} = 0.08\), typical of an early-type star. Considering the large number of bright stars in the field and the spatial extent of other starburst clusters in the area (e.g. F06, D07), we extended the search to \( r \leq 7'\). The group in the \((J - K_S)/K_S\) and \((H - K_S)/K_S\) diagrams, which we consider to comprise prime cluster members now includes S11, S12, S13 and S15 (Table 1).

A number of objects - S14 (found in the cluster core), S15-16 and S18-22 - have \( Q_{IR} \) similar to the above, but with redder \((J - K_S) \approx 3.7\) - colours; the separation between these stars and the main plume of red giant stars in terms of \( Q_{IR} \) is not as well defined as that for the prime cluster candidates. We identify these as likely cluster members, with the difference in colours potentially due to excess reddening with respect to the core members (noting that significant differential reddening is also observed for RSGC2; D07). Finally, for completeness, with the inclusion of S23 and S27, these stars form a well defined
We also provide the dereddened cluster member and treat it as such in the text. Co-ordinates and near-IR magnitudes are from 2MASS, with mid-IR (RSG identified by spectroscopy and included for completeness. Note that based on spectroscopy, we also consider it likely that star S16 is a circumstellar dust (and hence proxy for mass loss) and the spectral type of the stars, where available (Sect. 3).

Table 1. Summary of RSG candidates and their properties. Top panel: the core group of 15 photometrically selected stars regarded as prime cluster candidates; second panel: likely cluster members; third panel: stars of interest, as defined in Sect. 2 and fourth panel: likely foreground RSG identified by spectroscopy and included for completeness. Note that based on spectroscopy, we also consider it likely that star S16 is a circumstellar dust (and hence proxy for mass loss) and the spectral type of the stars, where available (Sect. 3).
ages and initial masses of 16–20 Myr and a total mass of 2–4 $M_\odot$.

We find a mean value of $A_K \sim 2.1$ per kpc, an upper limit to the distance to RSGC3 of $(\log(D/\text{kpc}))_{RSGC3} \leq 7$, from which we may infer $D_{RSGC3} \sim 6$ kpc. 12, 16 and 20 Myr isochrones (D07) to estimate the initial mass of the cluster from the number of RSGs currently present. For ages of 16–20 Myr this yields masses of $(2\times10^4) M_\odot$. If our second tier of RSG candidates are confirmed as cluster members, the mass estimate would increase by $\sim 30\%$, noting that this would not be altered by increasing the distance to a maximum of 7 kpc as implied by the reddening.

Finally, since stellar evolutionary codes predict a spread in intrinsic RSG luminosities for even co-eval clusters, the observed range of log $(L_{\text{bol}}/L_\odot) \sim 4.5$–4.8 for cluster members should not be interpreted as implying non-coevality.

4. Discussion and concluding remarks

With an age of 16–20 Myr and a total mass of $2–4 \times 10^4 M_\odot$, RSGC3 appears to be a close counterpart to RSGC1 and 2 (D08), while the properties of the constituent stars in terms of spectral types, luminosities and circumstellar environments are also directly comparable to the members of those clusters. As such RSGC3 belongs to an increasing population of hitherto unsuspected young massive clusters within the Galaxy. With ages ranging from 2–3 Myr for the Arches to 16–20 Myr for RSGC2 and 3 they also provide a fertile testbed for constraining the lifecycle of stars of $\sim 14 M_\odot$ and above.

Additionally, the proximity of RSGC3 to both RSGC1 and 2 – projected distances of $\sim 400$ pc and $\sim 300$ pc respectively for

Fig. 4. Montage of low (Campo Imperatore; black) and medium resolution (UKIRT; red) spectra of selected photometric targets, revealing the prominent CO bandhead absorption.

Table 2. Summary of the stellar properties of the 8 RSGs for which accurate spectral classification was possible, assuming a cluster distance of 6 kpc.

<table>
<thead>
<tr>
<th>ID#</th>
<th>$T_{\text{eff}}$ (K)</th>
<th>Spec type</th>
<th>$A_K$</th>
<th>$M_K$</th>
<th>log $(L_{\text{bol}}/L_\odot)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3605 ± 147</td>
<td>M3</td>
<td>1.20 ± 0.12</td>
<td>−9.34 ± 0.39</td>
<td>4.51 ± 0.14</td>
</tr>
<tr>
<td>3</td>
<td>3535 ± 25</td>
<td>M4</td>
<td>1.47 ± 0.08</td>
<td>−10.09 ± 0.37</td>
<td>4.79 ± 0.13</td>
</tr>
<tr>
<td>4</td>
<td>3605 ± 147</td>
<td>M3</td>
<td>1.44 ± 0.12</td>
<td>−10.12 ± 0.39</td>
<td>4.82 ± 0.14</td>
</tr>
<tr>
<td>5</td>
<td>3660 ± 130</td>
<td>M2</td>
<td>1.43 ± 0.07</td>
<td>−8.96 ± 0.37</td>
<td>4.73 ± 0.13</td>
</tr>
<tr>
<td>7</td>
<td>3790 ± 130</td>
<td>M0</td>
<td>1.40 ± 0.11</td>
<td>−9.11 ± 0.38</td>
<td>4.48 ± 0.13</td>
</tr>
<tr>
<td>8</td>
<td>3840 ± 175</td>
<td>K5</td>
<td>1.60 ± 0.04</td>
<td>−9.23 ± 0.36</td>
<td>4.54 ± 0.12</td>
</tr>
<tr>
<td>9</td>
<td>3790 ± 130</td>
<td>M0</td>
<td>1.53 ± 0.11</td>
<td>−9.14 ± 0.38</td>
<td>4.49 ± 0.13</td>
</tr>
<tr>
<td>10</td>
<td>3790 ± 130</td>
<td>M0</td>
<td>1.60 ± 0.11</td>
<td>−9.09 ± 0.38</td>
<td>4.47 ± 0.13</td>
</tr>
</tbody>
</table>

Finally, the observed range of the dereddened [8]–[12] colour index – MSX $(A - C) \sim 0.85–1.44$ (Table 1) – for the 7 (candidate) cluster members for which it may be determined is directly comparable to that found by D07 for RSGC2. Sampling the broad silicate emission feature, this provides a measure of the mass loss rate via the dust content of the circumstellar environment. It is therefore of interest that both of the stars with discrepant $(J - K_S)$ colours show excesses (S17 and S12; Fig. 3), suggesting that a build-up of circumstellar material due to enhanced mass-loss affects their near-IR properties, such as is observed in RSGC2–49 (D07).

Following the methodology pioneered by F06, we utilise Monte Carlo simulations, employing rotating stellar models (D07) to estimate the initial mass of the cluster from the number of RSGs currently present. For ages of 16–20 Myr this yields masses of $(2\times10^4) M_\odot$. If our second tier of RSG candidates are confirmed as cluster members, the mass estimate would increase by $\sim 30\%$, noting that this would not be altered by increasing the distance to a maximum of 7 kpc (as implied by the reddening). Finally, since stellar evolutionary codes predict a spread in intrinsic RSG luminosities for even co-eval clusters, the observed range of log $(L_{\text{bol}}/L_\odot) \sim 4.5$–4.8 for cluster members should not be interpreted as implying non-coevality.
and Bird et al. (2007) to search for any relativistic sources as-

Halpern 2008) we examined the catalogues of Liu et al. (2006)

Given a potential SNe rate of one every 40–80 kyr (F06), and the

give support for the hypothesis that this region has been

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Note added in proof. Shortly after acceptance we became aware of the co-discovery of this cluster by Alexander et al. (2009).

References


References


$\varnothing = 6$ kpc – at the base of Scutum-Crux arm ($l \sim 25–29^\circ$) pro-

vides strong support for the hypothesis that this region has been

subject to a recent burst of star formation (Gaztún et al. 1997, D07), yielding an extended stellar cluster complex such as those observed in external galaxies such as M51 (Bastian et al. 2005). If correct, the “starburst” has yielded a total of $>9 \times 10^5 M_{\odot}$ of stars just considering the 3 clusters. However, D07 report the presence of an additional population of RSGs in the vicinity of RSGC2, while Gaztún et al. (1997) and López-Corredoira et al. (1999) also report a significant “diffuse” field population of cool supergiants within the region delineated by RSGC1–3, suggesting that the true total may be significantly higher.

Consideration of the near-IR images of RSGC1–3 emphas-

ises this possibility; the clusters are only identifiable as such due to their significant RSG populations, as no other overdensity of (less evolved) stars is apparent. However, such stars are intrinsi-

cally short lived and consequently rare, and so only signpost the

location of clusters for which the (unresolved) stellar population is unresolvable against the field for a narrow range of cluster masses and ages. For instance, for clusters with masses of the order of $10^3 M_{\odot}$ (so comparable to the Orion cluster) one would only expect the presence of $\sim 1$–3 RSGs at any given epoch on statistical grounds, suggesting that such clusters would be dif-

ficult to identify in a near-IR survey (a problem even affecting more massive clusters for ages $<10$ Myr; D07).

Likewise, for clusters with ages of over 20 Myr, while one would expect a large number of red evolved stars to be present, their lower intrinsic luminosity will make them more difficult to discriminate against the field in any search for cluster candidates. Furthermore, the rapid dissolution of clusters due to ejection of the intercluster medium by stellar winds and SNe (Goodwin & Bastian 2006) exacerbates this problem, reducing the spatial density of any RSGs within clusters. An additional result of this process is that the velocity dispersion of cluster members will increase, in turn magnifying the uncertainty in the identification of a physical association via kinematic means.

Therefore, while the presence of RSGC1–3 points to an

episode of enhanced star formation 10–20 Myr ago, from the methodology employed in this work it is difficult to determine whether there was significant activity before this date or indeed what the total stellar yield of this “starburst” was. An analogous argument applies to determining the star formation history for ages $<10$ Myr, although the lack of Giant H II regions within this putative complex (Conti & Crowther 2004) implies that no mas-

sive clusters are currently forming.

We caution that these limitations will manifest themselves in any other near-IR searches for stellar clusters in regions of the disc with a high (projected) stellar density, likely leading to significant incompleteness in any Galactic cluster mass function determined via such a methodology.

4.1. Association with X-ray binaries and post SNe compact objects

Given a potential SNe rate of one every 40–80 kyr (F06), and the

likely association of two pulsars with RSGC1 (F06, Gotthelf & Halpern 2008) we examined the catalogues of Liu et al. (2006) and Bird et al. (2007) to search for any relativistic sources associated with RSGC3, but found none. Motivated by the hypothesis that RSGC1–3 delineate a star forming complex, we extended this search to this region ($l = 25–30^\circ, b = \pm 1^\circ$), but again found no accreting X-ray binaries within it for a distance of $6\pm1$ kpc. Given the increasing evidence for a high binary fraction amongst massive stars (e.g., Clark et al. 2008), the absence of any Be/X-ray binaries – systems consisting of a B0–3 V–IIIe primary and a neutron star accretor – is surprising, since one would expect them to be active at such an epoch (10–20 Myr; e.g., Portegies Zwart & Verbunt 1996). Nevertheless, one might suppose that a combination of their transient nature plus a SNe kick sufficient to either disrupt or rapidly eject a surviving binary from the complex may explain their lack of detection.

However, we note with interest the location of the Anomalous X-ray Pulsar (AXP) AX J1841.3–0455; $l = 27^\circ 39$, $b = -0^\circ 006$. Durant & van Kerkwijk (2006) estimate a lower limit of $>5$ kpc to AX J1841.3–0455, while Vasisht & Gotthelf (1997) provide an upper limit of 7 kpc from its association with the SNR Kes 73. Taken together they raise the possibility that it could be physically associated with the putative star forma-

tion complex, with AX J1841.3–0455 located ~equidistantly between RSGC2 and 3, and directly within the region identi-

fied by Gaztún et al. (1997) and López-Corredoira et al. (1999) as showing a significant overdensity of “field” RSGs. The expected rate of SNe for such a complex would be fully consistent with the relative youth expected of magnetars (Thompson et al. 2000), while SGR 1900+14 demonstrates that their progenitors can have masses as low as $\sim 15 M_{\odot}$ (Clark et al. 2008; Davies et al. in prep.), also consistent with the current RSG population at the base of the Scutum Crux arm.

Definitively associating AX J1841.3–0455 with the same burst of star formation that yielded RSG1–3 would imply a progenitor mass of $<20 M_{\odot}$, and hence provide additional evidence that the hypothesis that high-mass stars are required to produce magnetars is incorrect. Moreover, consideration of SGR 1900+14, AX J1838.0-0655 (the young pulsar associated with RSGC1) and potentially AX J1841.3–0455 suggests that despite having progenitors of comparable mass (~15–18 $M_{\odot}$; Clark et al. 2008, D08, Davies et al. in prep.), the surface magnetic fields of the resultant neutron stars can differ by over two orders of magnitude (Gotthelf & Halpern 2008, Kouveliotou et al. 1999; Vasisht & Gotthelf 1997), presumably reflecting differences in the properties of their progenitors other than, or being directly dependant on, stellar mass (such as magnetic field or rotational velocity).