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The apparent overdensity of open clusters in the Canis Major overdensity

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ABSTRACT

The exciting debate on the existence and nature of the relatively recent discovery of the so-called Canis Major (CMa) overdensity is re-examined here based on the positions, reddenings, ages and metallicities of Galactic open clusters (OCs). The data used to carry out the current study were taken from the recently updated version of the Dias et al.'s 1776 OC catalogue. We found that only Tombaugh 2 is physically located within the main body of CMa. Even if we take into account the whole sample of catalogued OCs with unknown distances, it is statistically expected that only one additional OC could be found within the CMa region. Since the CMa overdensity appears to be quite transparent to dust, only a few OCs in that zone could have been missed. Both metallicity and age distributions of OCs located in the Galactic outer disc, including Tombaugh 2 and those projected on to CMa, are in good agreement with the paradigm of a main dispersion of age and metallicity values. There are only marginal indications for a radial abundance variation. We conclude that CMa does not contain a significant population of OCs which share its properties. This result does not favour the dwarf galaxy scenario.

Key words: open clusters and associations: general – Galaxy: structure – galaxies: dwarf.

1 INTRODUCTION

As shown by Martin et al. (2004a) and Bellazzini et al. (2004, 2006), the recently discovered Canis Major (CMa) structure appears as the strongest spatial overdensity of the whole Galactic disc in terms of either number density or statistical significance. The structure appears elongated along the tangential direction, extending from $l \approx 200^\circ$ to 280°. The evidence collected by Martin et al. (2004a,b), Martínez-Delgado et al. (2005) and Bellazzini et al. (2006) are clearly explained by the hypothesis of a disrupting dwarf galaxy in a nearly circular and planar orbit around the centre of the Galaxy.

Bellazzini et al. (2004) showed that there is a sparse population of stars younger than 1–2 Gyr that is associated with the CMa overdensity. De Jong et al. (2007) found that these young stars are at least a few hundred million years old and at most 2 Gyr. Carraro, Moitinho & Vázquez (2008) found that the spatial distribution of the stars younger than 100 Myr peaks at a heliocentric distance of $9.8^{+1.5}_{-1.0}$ kpc. They claimed that such stars are expected to be found because of the warped spiral structure of the Galactic disc in the region. They concluded that it is unnecessary to postulate the existence of an accreted dwarf galaxy in CMa to find this young stellar population (see, also, López-Corredoira et al. 2007).

Enter the open clusters (OCs) Martin et al. (2004a) searched the WEBDA data base for OCs located in the region of the CMa overdensity. They argued that since the heliocentric distances of the two young OCs - Dolidze 25 and Haffner 18 [log(age) < 8.5] – and of the old cluster Arp-Madore 2 are compatible with the distance to CMa, these three OCs could have formed as a result of an enhanced star formation activity in the disc. Bellazzini et al. (2004) reviewed their search with the aim of confirming the existence of an apparent overdensity of OCs in the surroundings of CMa. They showed that only the old and relatively metal-poor OCs Arp-Madore 2 and Tombaugh 2 have positions, ages and metallicities within the range ascribed to the main body of CMa. More recently, Bellazzini et al. (2006) determined the heliocentric distances of Tombaugh 2, Arp-Madore 2 and Haffner 11, and concluded that these three OCs are physically located within the main body of CMa. Some other recent studies of OCs have mentioned the connection between field stars observed in the cluster comparison fields and CMa (Bragaglia et al. 2006; D'Orazi et al. 2006; Moitinho et al. 2006; Carraro et al. 2007, among others). None of them have confirmed, however, that the clusters themselves belong to the CMa overdensity.

As can be seen, it is not clear at all if there exists a group of OCs belonging to CMa, and if this were so, whether they are the consequence of a strong perturbation of the disc caused by an accreted dwarf galaxy (Bellazzini et al. 2004; Martin et al. 2004a; Bellazzini et al. 2006) or by a disc warp (Moitinho et al. 2006; López-Corredoira et al. 2007; Carraro et al. 2008). In the current study we investigate these issues using as physical connection criteria, the comparison between the positions of the OCs and CMa and also between their interstellar visual absorptions, ages and metallicities. We want to make clear that in this study, we search for the presence of OCs within CMa, namely, clusters that have formed

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within the overdensity and that can be used as tracers of its properties. We are not looking for OCs formed by the strong perturbations in the Galactic disc that could result from the accretion of a dwarf galaxy. If such were the case, one would not expect the clusters to share the properties of CMa since they would have formed later than CMa stars during the accretion on to the disc. As these OCs would have formed in the disc, they should not even be expected to overlap with the body of the overdensity if CMa follows a different orbit from that of disc stars (Martin et al. 2005).

2 ANALYSIS AND RESULTS

As far as we know, Bonatto et al. (2006) have carried out the most recent thorough study of the properties of the Galactic disc based on 654 OCs distributed within a region of ∼5 kpc in radius from the Sun. Unfortunately, they could not account for the CMa overdensity, since this is located at ∼7 ± 1 kpc from the Sun. More recently, Vázquez et al. (2008) investigated the spiral structure of the Third Galactic Quadrant using a sample of OCs younger than 100 Myr, but they did not focus on the physical connection between the OC system and the CMa overdensity.

There is now a recently updated version available (2008 April) of the Dias et al.'s OC catalogue (2002). It provides information on the fundamental parameters for 1776 objects and includes the previous catalogues of Lyngå (1987) and Mermilliod (1995, included in the WEBDA data base). New objects and data, that were not present in the previous catalogues, have now been included in this one. We decided to use this catalogue to search for OCs located beyond 5 kpc from the Sun, regardless of their Galactic coordinates. With such a sample, we could not only examine the physical connection between OCs and CMa but also study the properties of the Galactic disc beyond the limits of the Bonatto et al. (2006)'s sample. In total, we found 67 OCs which fulfilled our requirement.

Fig. 1 depicts the three projected Galactic planes in which the Sun is placed at $(X, Y, Z)_\odot = (8.5, 0, 0)$ kpc. In the (*X*, *Y*) plane (upper right-hand panel), we have traced the Carina–Sagittarius, Perseus and Cygnus spiral arms according to Drimmel & Spergel (2001) and Moitinho et al. (2006). The position of the CMa main body centred at (*l*, b) = (240, − 8) (Martínez-Delgado et al. 2005) and its ascribed region according to Bellazzini et al. (2006) and Butler et al. (2007) are schematically represented by solid contours in all four panels. We have also drawn all the selected clusters with differently coloured circles.

At first glance, it seems that a few OCs lie projected on to the CMa overdensity in the different Galactic planes. Indeed, by examining the (*X*, *Y*) plane more closely, we could infer that a handful of OCs are physically located in the CMa surroundings, as were also shown by Martin et al. (2004a) after probing a smaller OC sample. However, most of the clusters projected around or inside the CMa overdensity region in the (*X*, *Y*) plane are objects belonging to the Galactic plane and not to CMa, as can be seen in the projected (*X*, *Z*) and (*Y*, *Z*) planes. For example, the concentration of clusters around the Galactic plane that we have marked with red circles, misleadingly appears to delineate the nearer boundary of the CMa overdensity in the (*X*, *Y*) plane. Note that no systematic offset is expected in the distances of the red OCs, since they come from a variety of sources (Dias et al. 2002).

A similar wrong conclusion could be drawn regarding the number of clusters related to the CMa overdensity if we only considered OCs projected on the (*l*, b) plane (Bellazzini et al. 2004, see e.g. their fig. 1). As shown in Fig. 2, five clusters, blue and magenta coloured, are within the region ascribed to CMa. However, except in the case

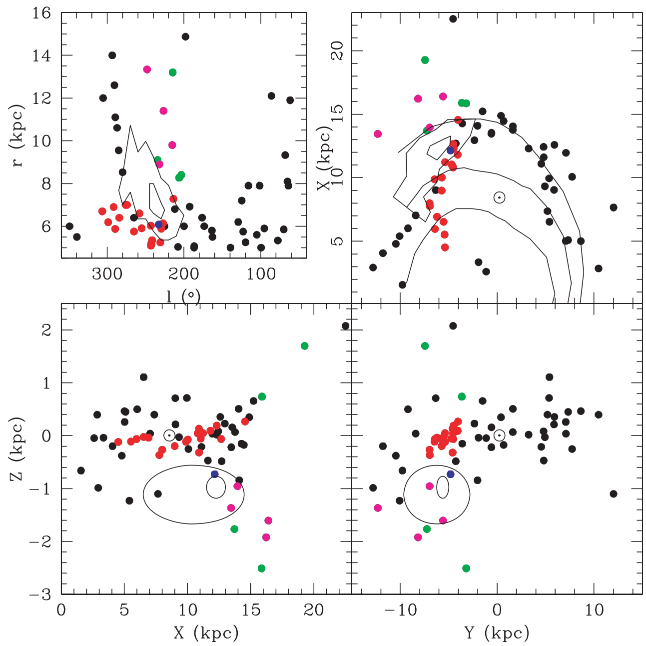

Figure 1. Relationship between the OCs heliocentric distances (*r*) and their Galactic longitudes (upper left-hand panel). The (*X*, *Y*), (*X*, *Z*) and (*Y*, *Z*) projected Galactic planes are displayed on the upper right-, lower left- and lower right-hand panels, respectively. Only OCs located beyond 5 kpc from the Sun have been plotted. The positions of the Sun and the CMa region, schematically represented according to Bellazzini et al. (2006) and Butler et al. (2007), are shown in the four panels. The Carina–Sagittarius, Perseus and Cygnus spiral arms according to Drimmel & Spergel (2001) and Moitinho et al. (2006) are also traced in the (*X*, *Y*) plane. Red circles represent Galactic plane OCs that misleadingly appear on the closer edge of CMa; green circles indicate OCs behind the CMa not projected on to it; magenta circles show OCs projected on to CMa that do not belong to it; the blue circle stands for Tombaugh 2.

of Tombaugh 2 (blue circle), the remaining clusters lie behind such stellar structure, as shown by their positions in both upper panels of Fig. 1. Conversely, there exist also OCs behind the CMa region in the (*X*, *Y*) plane (green circles) that are not in the ascribed CMa region in the (*l*, b) plane. Thus, the analysis of the positions of OCs in the three Galactic planes allows us to conclude that only Tombaugh 2 is physically located within the CMa overdensity. So, any possibility of existence of a high number of OCs in this zone should be rejected.

On the other hand, it is well known that there are many other OCs projected on to the CMa overdensity with no estimates of their distances. Dias et al. (2002) compiled in their updated catalogue a total of 83 OCs projected on to the CMa region in the (*l*, b) plane. They are distributed as follows: 39 of them have estimated distances from the Sun (*r*) smaller than 5 kpc, five of them have distances $r > 5$ kpc (magenta circles in Fig. 2) and the remaining 39 do not have distance estimates. Note that an intermediate-age OC (age ∼1 Gyr) projected on to CMa, with relatively bright clump giants ($V = 15$ mag), would be located at a distance of 14 kpc from the Sun, which is quite far from CMa. Consequently, there should not be a significant distance bias in the OCs without a distance determination. Therefore, it is unlikely that the 39 OCs with unknown distances are located at the same distance as CMa. On the contrary, bearing in mind that 89 per cent of the OCs with measured heliocentric distances are nearer than 5 kpc, we should statistically expect

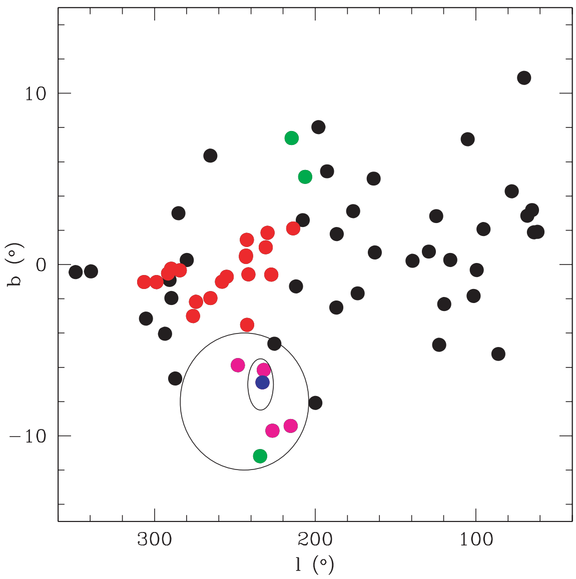

Figure 2. Distribution of OCs located beyond 5 kpc from the Sun in the (l, b) plane. Coloured circles as in Fig. 1.

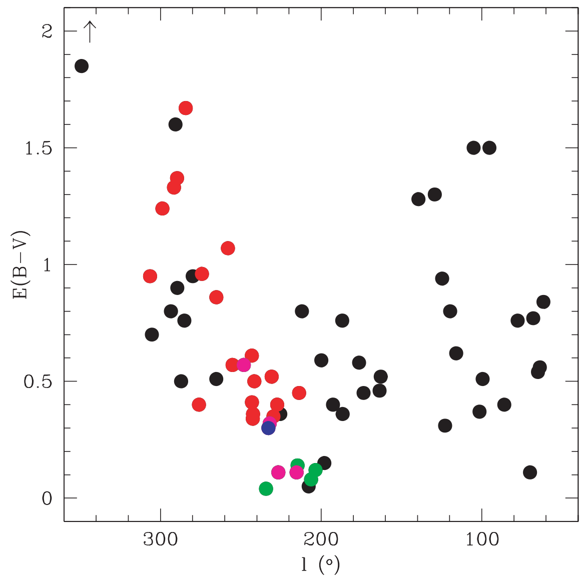

Figure 3. Relationship between the $E(B-V)$ colour excess and the Galactic longitude of OCs located beyond 5 kpc from the Sun. Coloured circles as in Fig. 1.

that approximately four OCs out of those 39 are situated beyond 5 kpc. Hence, we should expect only one additional cluster with a helicocentric distance compatible with that of the CMa overdensity. This result is supported by the fact that being the CMa region not highly reddened, OCs could be observed through it easily (see below).

We finally compared the reddenings, ages and metallicities of the OCs located beyond 5 kpc from the Sun with the fundamental parameters of the main body of CMa. For the main population of the CMa overdensity, we adopted age and [Fe/H] ranges between ∼4 and 10 Gyr and −0.3 and −0.7 dex, respectively, and $E(B-V) = 0.08 \pm 0.07$. The so-called CMa blue plume contains stars younger than 1–2 Gyr (Bellazzini et al. 2004; Martínez-Delgado et al. 2005). For our selected OCs ($r > 5$ kpc), we used the cluster parameters quoted in the Dias et al.'s (2002) catalogue (updated version).

Figs 3–5 show different relationships among the above mentioned cluster properties, where the circles keep the same colour scheme as in Fig. 1. Note that some clusters do not have determined values for all three parameters. As far as the interstellar visual absorption is concerned, Fig. 3 provides some hints about the Galactic disc structure. For example, the OCs seen through the CMa LOS along $\Delta r \sim 7.5$ kpc (blue and magenta circles) are in average affected by relatively small reddenings, in very good agreement with the $E(B-V)$ colour excess range expected for CMa (Butler et al. 2007). This means that the CMa region is fairly transparent to dust and, therefore, there should be very few OCs missing in that zone. Tombaugh 2, which has an $E(B-V)$ colour excess ∼3.5 times higher than that quoted for CMa, can be considered an exception. On the other hand, the $E(B-V)$ colour excesses reach values five to six times higher than that of Tombaugh 2's for $l \sim (100-140)^\circ$ and $(280-300)^\circ$, being up to 13 times higher towards the Galactic Centre (see also upper left-hand panel of Fig 1). In the first Galactic longitude range, the LOS crosses both the Perseus and Cygnus spiral arms ($r < 8$ kpc), while in the second one, the LOS crosses the Carina arm ($r < 7$ kpc), as can be seen in the upper right-hand panel of Fig. 1. This behaviour is more clearly visible in the red clusters, for which the larger the Galactic longitude, the higher their $E(B-V)$ colour excesses. This fact constitutes an additional proof

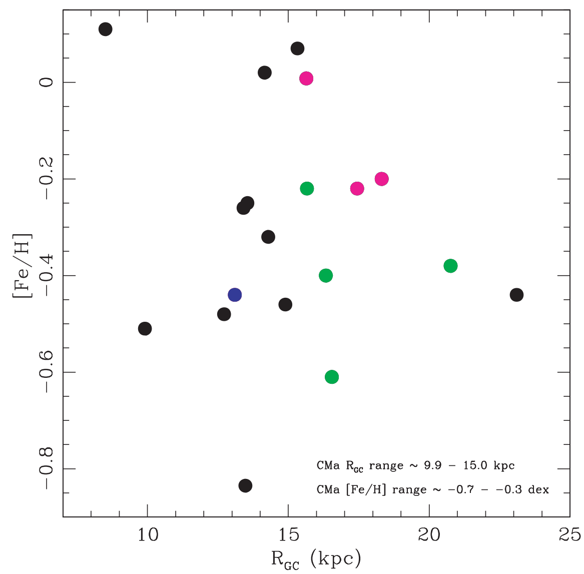

Figure 4. Relationship between the metallicity and the Galactocentric distance of OCs located beyond 5 kpc from the Sun. Coloured circles as in Fig. 1.

which reinforces the suspected lack of physical relation between these coloured red clusters and CMa.

The difficulty of studying the metallicity distribution of OCs in the outer Galactic disc has been somewhat hard to overcome because of the lack of metal abundance measurements of distant OCs. Most of the studies concerning the existence and magnitude of the radial abundance gradient have extrapolated the slope seen for Galactocentric distances R_{GC} from ∼5 up to 12 kpc towards the outermost regions of the Galactic disc (Friel et al. 2002; Chen, Hou & Wang 2003; Salaris, Weiss & Percival 2004, among others). However, more recent high-dispersion spectroscopic studies on distant old OCs have suggested that the mean metallicity of OCs beyond 12 kpc from the Galactic Centre is [Fe/H] ≈ −0.35, with

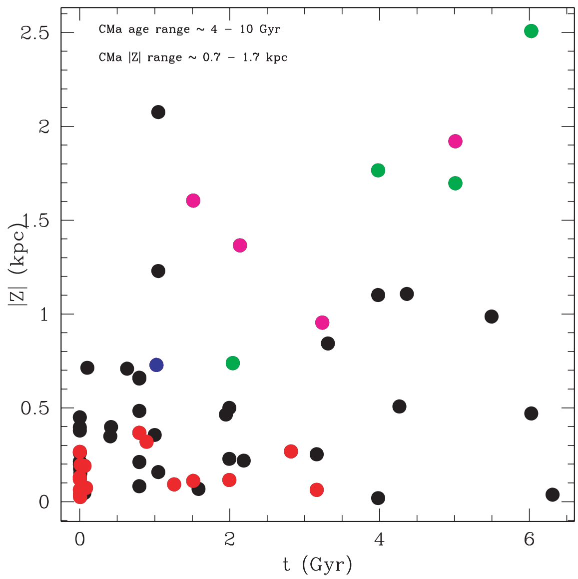

Figure 5. Relationship between the height out of the plane and the age of OCs located beyond 5 kpc from the Sun. Coloured circles as in Fig. 1.

only marginal indications for a radial abundance variation (Carraro et al. 2004; Sestito et al. 2006; Carraro et al. 2007). Yong, Carney & Teixera de Almeida (2005) found a slightly lower value for the metallicity of OCs in the outer Galactic disc towards the anticentre ($185^\circ < l < 215^\circ$; [Fe/H] ~ -0.5). Fig. 4 shows the relationship between the metallicity and the Galactocentric distance for the outermost known OCs. As can be seen, a general dispersion prevails around [Fe/H] ~ -0.35, in good agreement with a nearly constant metallicity distribution paradigm. Indeed, both the metal abundance of Tombaugh 2 and the metallicity range for the CMa overdensity lie within the expected values for the Galactic outer disc. Consequently, from the chemical enrichment point of view, we find it rather difficult that we are dealing with the population of the core of an accreted dwarf galaxy.

The stars found in the CMa region cover a wide age range, which marginally overlaps the OCs' one, as can be seen in Fig. 5. Indeed, if we bear in mind both the ranges of CMa age and height out of the plane, we find four clusters in the corresponding part of the figure; only one of them is located behind CMa (green circle). Fig. 5 also shows that Tombaugh 2 does not have a remarkably different age from that of other OCs situated at a similar height out of the Galactic plane. We are thus dealing with a statistically non-meaningful sample of clusters located within the CMa Z range, whose ages lie within the CMa age range. This result would not seem to favour the existence of a population of OCs in CMa.

Anyway, it is also necessary to keep in mind the vertical space velocities before reaching a more conclusive result. In general, the cluster velocity dispersion perpendicular to the Galactic plane in the spiral arms as well as in the Galactic plane itself is smaller than in the Galactic disc. Unless a cluster born in the Galactic plane does have a high-W space velocity perpendicular to the Galactic disc, it is bound to oscillate within a small range of Z height scales. Conversely, OCs born in the disc can either be formed at larger Z values or can reach such values as a consequence of their orbital motions (Piatti, Clariá & Abadi 1995). These OCs generally have a larger W space velocity dispersion than those born in the plane. Consequently, they also reach larger Z values. Furthermore, if these OCs were also relatively old, they must have had the chance to cross the Galactic plane several times in their lifetimes so that we could find them at any Z value. Such value can be very different from that the clusters had when they were formed. For this reason, we believe it is worth widening our knowledge of the clusters' birthplaces, particularly of those older than 4 Gyr, for a comprehensive study of their location with respect to CMa. In order to achieve this aim, it would be necessary to increase the number of OCs with mean proper motions and radial velocities accurately determined. Indeed, having these data available, it would be possible to compute their Galactic orbits backwards in time (Tecce, Pellizza & Piatti 2006).

Although no observational evidence of OCs associated to dwarf galaxies are currently available, the possibility of their existence does not have to be ruled out. In such case, the absence of OCs in CMa does not seem to favour either the dwarf galaxy scenario.

3 CONCLUSIONS

Based on the updated version of the Dias et al. (2002) OC catalogue, we analyse the distribution of OCs at large distances from the Sun to search for the presence of an overdensity of OCs that could be related to the CMa stellar overdensity. The results of this analysis lead us to the following main conclusions.

(i) There is only one known OC – Tombaugh 2 – whose Galactic coordinates (X, Y, Z) are consistent with the cluster's being within the CMa overdensity region. By considering only the (X, Y) or (l, b) Galactic planes, an apparent enhancement of OCs in that zone could be inferred. However, most of the OCs that appear projected on to CMa are situated in or around the Galactic plane.

(ii) If the whole sample of catalogued OCs with unknown distances is considered, we statistically estimate that only one additional OC could be found within the CMa region. Moreover, the CMa region appears to be quite transparent to dust, since the OCs projected on to CMa exhibit relatively low $E(B - V)$ colour excesses. Therefore, only a few OCs in that zone could have been missed.

(iii) Both metallicity and age distributions of OCs located in the Galactic outer disc, including Tombaugh 2 and those projected on CMa, show good agreement with the paradigm of a main dispersion of age and metallicity values, with only marginal indications for a radial abundance variation. We conclude that no significant population of OCs, which could be used as tracers of its properties, has formed within the CMa overdensity. The absence of OCs in CMa does not seem to favour either the idea of the CMa overdensity being an accreted dwarf galaxy.

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