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Discovery of new Milky Way star clusters candidates in the 2MASS point source catalog

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Abstract. A systematic search of the 2MASS point source catalog, covering 47% of the sky, was carried out aiming to reveal any hidden globular clusters in our Galaxy. Eight new star clusters were discovered by a search algorithm based on finding peaks in the apparent stellar surface density, and a visual inspection of their vicinities yielded additional two. They all are concentrated toward the Galactic plane and are hidden behind up to $A_V = 20$ mag which accounts for their late discovery. The majority of new clusters are associated with HII regions or unidentified *IRAS* sources suggesting that they are young, probably similar to Arches or open clusters. Only one candidate has morphology similar to a globular cluster and the verification of its nature will require deeper observations with higher angular resolution than the 2MASS data.

1. Introduction

There are about 150 known Galactic globular clusters (GC hereafter; Harris 1996). The majority of them were discovered through optical searches, biased against highly obscured objects. Since the Galaxy is estimated to have 160 ± 20 GCs (Harris 1991), a certain number of GCs may still be hidden behind the Galactic disk.

The Two Micron All Sky Survey (2MASS) offers an opportunity to carry out a systematic and unbiased search for missing GCs because it covers in an uniform way the Galactic plane in near infrared wavelengths (J, H and K_S bands) where the extinction is almost ten times smaller in comparison with the optical part of the spectrum (Bessell & Brett 1988; used throughout this letter). Using the 2MASS data base Hurt et al. (2000) found two new GCs: 2MASS GC01 and 2MASS GC02 (see also Ivanov et al. 2000). Later Dutra & Bica (2000, 2001) presented a sample of about 90 new infrared star clusters, stellar groups and candidates, mostly discovered from visual inspection of the 2MASS images. Recently, Reylé & Robin (2002) reported two new clusters discovered with DENIS. They applied a combined surface density–integrated flux–color criterion, that detected in addition 22 known clusters.

We report the first results of a systematic and objective search of new clusters in the currently released part of the 2MASS point–source catalog, covering 47% of the sky. We also give a short description of the technique, used to locate cluster candidates. The list of objects presented here is not aimed to be complete in any sense.

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2. Search algorithm

A simple and robust method, based on the apparent stellar surface density was chosen to search for obscured clusters. The first step was to divide the 2MASS point source catalog into spatial bins. We used square bins, to minimize the computational demands. Their size was a free parameter, allowing to search for structures of various scales on the sky. For each bin we stored the total number of stars, the K_S-band luminosity function, and the distribution of stars along $J - K_S$ color. Effectively, the results from the first step are two-dimensional histograms on the sky.

Next, we searched for peaks in the 2-D histogram of total number of stars in each bin. The background level and its standard deviation σ were calculated from the average number of stars in the neighboring bins. Our experiments on fields with known star clusters indicated that the most effective cluster-finding strategy was to use a two-step criterion: (i) 3σ deviation above the background, and (ii) an excess of 50 or more stars in the bin above the background. It proved to work better than the 3σ excess limit alone, probably because the value of σ is often ill-defined, especially in fields with small stellar density.

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The results presented here were obtained with parameters optimized to search for clusters with large apparent sizes on the sky since those are most likely to be discovered soon – either serendipitously or after systematic searches, such as the findings of Hurt et al. (2000) and Dutra & Bica (2000, 2001). For comparison, the median value of the half-mass radius for 141 globular clusters with known structural parameters from Harris (1996) is only 1.0 arcmin. The average is 1.3 ± 0.8 arcmin, with a maximum of 4.18 arcmin for ω Cen. Although the search for open clusters are not the main objective of this program, we ensured that they were also likely to be selected with the chosen parameters. The average size of Galactic open clusters included in the catalog of Lynga (1995) is 3.5 ± 2.0 arcmin, similar to our bin size. Of course, the lower surface density of open clusters in comparison with globulars makes them more challenging targets.

Overall, we are probing a different range of the cluster parametric space than the previous works. For example, we are sensitive to clusters with larger angular diameters, compared with the work of Dutra & Bica (2001) who found more compact objects, with median size along the large axis of only 1.8 arcmin. The objects found by Reylé & Robin (2002) are also smaller than 2 arcmin. Smaller bin sizes than 5 arcmin will constrain the search to the regime of compact clusters which are usually only partially resolved by 2MASS due to the large pixel size (1 arcsec), and therefore are not present in the point source catalog. Visual inspections or flux criteria are better suited for discovering such objects.

Clusters, larger than 5 arcmin are likely to be missed, given our choice of the bin size. However, they represent a part of the parametric space that is not likely to yield *new* candidates because such clusters would probably be relatively nearby. Therefore, they would suffer lesser extinction, and would have been easily discovered in optical.

The method was implemented as a set of C-based codes in order to carry out the process automatically. We plan to explore wider range of parameters in the future, and to shift the bin centers by half bin size, improving the completeness of the sample.

3. Results and discussion

3.1. Cluster parameters

The search yielded 247 candidates that satisfied the 3σ and 50 stars excess criteria described in the previous section. Of those, 105 were known clusters, present in SIMBAD. Incidentally, 2MASS GC01 was rejected based on insignificant peak (2.5σ), while 2MASS GC02 was not present in the released point source catalog. We inspected visually the 2MASS images of the remaining candidates, and found two more objects. No obvious objects were present in 134 cases. The basic data for the new clusters is given in Table 1. A mosaic of true color images of nine clusters is shown in Fig. 1, constructed from the 2MASS JHK_S images. It is not surprising that all candidates are situated close to the Galactic plane. This region suffers from the highest extinction which makes it easy to hide unknown clusters. All candidates are at least partially resolved, and many of them show extended emission, that might indicate ionized gas or faint population, unreachable with the 2MASS data.

The cluster coordinates are impossible to estimate by fitting of radial profiles because of the relatively low number of members. This forced us to apply an alternative method for finding the centers. We adopted a trial center, and minimized the

Table 1. Parameters of the cluster candidates. The first eight objects were identified by the automatic algorithm, and the last two were found after a visual inspection. See Sect. 3.2 for comments on individual objects.

ID CC	RA Dec (J2000.0)	l b	D $'$	K_S, $J-K_S$, $H-K_S$ mag	A_V mag
01	05:13:26 +37:27.0	169.19 −0.90	3.0	7.5 0.5 0.6	6–13
02	06:15:53 +14:16.0	196.21 −1.20	2.0	6.3 1.2 1.0	6–13
03	06:59:14 −03:55.0	217.30 −0.05	2.8	6.2 0.8 0.1	6–13
04	07:00:32 −08:52.0	221.85 −2.03	4.0	7.5 1.8 0.9	9–17
05	07:00:51 −08:56.5	221.96 −1.99	2.4	6.8 0.3 0.0	9–17
06	07:24:14 −24:38.0	238.48 −4.28	4.5	6.5 0.8 0.7	9–17
07	07:30:40 −15:18.0	230.98 +1.49	2.8	6.1 0.7 0.6	9–17
08	08:19:10 −35:39.0	254.01 +0.25	2.8	6.3 0.5 0.7	4–12
09	06:59:43 −04:04.0	217.49 −0.02	1.0	...	4–12
10	08:18:28 −35:47.5	254.05 +0.05	0.5	9.7 2.0 0.8 10.3 2.4 1.0	12–20

Fig. 1. Mosaic of true color images for nine of the new clusters listed in Table 1. The top left is CC 01, the numbers increase from left to right, and toward the lower rows. CC 09 is skipped. Blue is J, green is H, and red is K_S. North is up and East is to the left. The individual image are 4.8 × 4.8 arcmin.

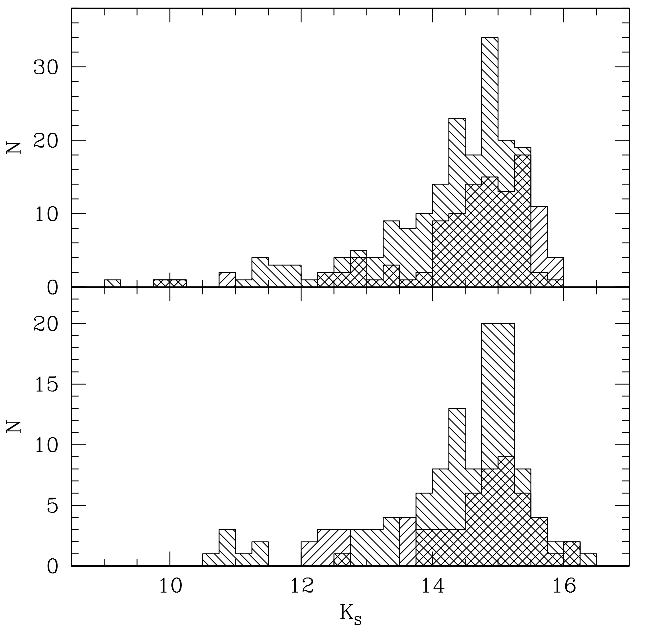

Fig. 2. Example of luminosity functions of cluster stars. The top panel is CC01. The histogram, shaded top left to bottom right refers to the stars within 3 arcmin from the cluster center. The histogram, shaded from top right to lower left includes stars from a circular annulus at about 10 arcmin from the cluster center. Both regions have the same area. The bottom panel is for CC08, the central radius is 1.5 arcmin, and the annulus is at about 5 arcmin.

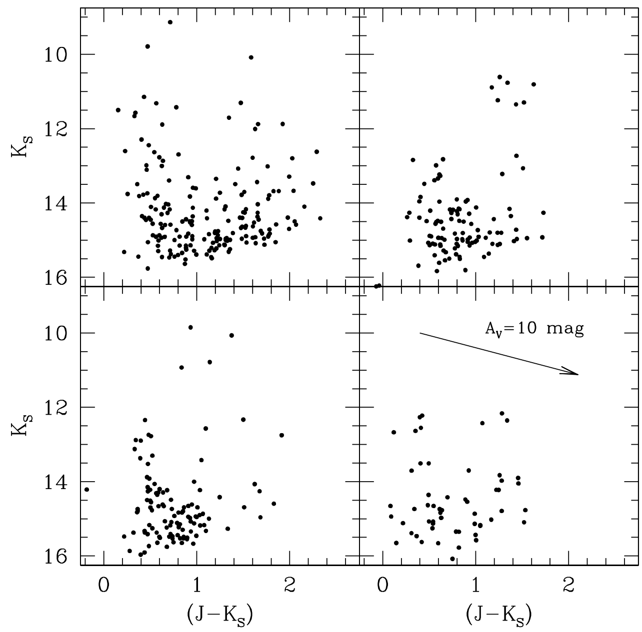

Fig. 3. Color-magnitude diagrams for CC01 (left) and CC08 (right). The top panels show all stars within 3 and 1.5 arcmin from the cluster centers, respectively. The lower panels show stars in annuli with the same areas as the central regions, at about 10 and 5 arcmin from the cluster centers, respectively. The excess of red cluster members is evident in both cases. A reddening vector, corresponding to visual extinction $A_V = 10$ mag is also shown.

sum of the distances to the point sources within 1.5 arcmin. Whenever possible, obvious non-members were excluded based on the color-magnitude diagrams. Then we moved the trial center in a rectangular grid pattern across the face of the cluster. The coordinates, presented here are accurate within 30 arcsec, and agree within this uncertainty with visual estimates. In both cases we used 2MASS world coordinates, from the point source catalog, or from the image header, respectively. The diameters were determined after visual inspection of the *K*-band images. They should be considered lower limits because some fainter stars may well be bellow the detection limit of the 2MASS atlas. The total magnitudes are obtained with aperture measurements, with diameters 100–180 arcsec. To remove the contribution from the foreground stars we subtracted the flux measured through the same aperture near the clusters from the flux measured at the cluster position. The large variations of the extinction and the apparent stellar density lead to errors of about 0.5 mag.

We carried out a thorough search for known objects near the new clusters. The majority of them were found to be associated with HII ionized regions indicating that they may be young clusters, perhaps similar to the recently discovered Arches cluster. The SIMBAD identifications are discussed in Sect. 3.2. The most promising candidate for an unknown globular cluster is CC01, based on its appearance. CC08 and CC10 possess morphologies typical of open clusters.

To verify further the nature of our candidates we constructed luminosity functions (LF hereafter) of the areas near the stellar surface density peaks, and compared them with LFs of circular regions with the same areas, well away from the objects. An example is shown in Fig. 2. The excesses of stars at the alleged cluster positions are obvious despite of the low statistics of individual bins. The color-magnitude (CMD hereafter) and color-color diagrams provide an additional test of our candidates. Figure 3 shows the CMDs of CC01 and CC04. An excess of stars is evident in both cases. However, these diagrams are of little help for unobscured or lightly obscured clusters.

The estimate of the extinction toward the clusters is a problem on its own. It is impossible to determine whether we see the tip of the main sequence or the the tip of the red giant or red supergiant branch, given the relatively shallow depth of the 2MASS point source photometry. We adopted a simple foreground screen, although it is clear that some of the clusters suffer from differential reddening. Next, we made two extinction estimates, assuming that the reddest sequence is either at $J - K_S \sim 0$ mag, typical for the blue stars, or at 0.9–1 mag, which is the usual color of the red supergiant and red giant branches. We neglected completely any metallicity effects because they are much smaller than the uncertainties in the $E(J - K_S)$ which are of order of 0.5 mag, leading to errors of ~4 mag in A_V. The results are included in Table 1. Using the stellar colors to estimate the extinction toward clusters inside our Galaxy is more reliable than far-infrared techniques (i.e. Dutra & Bica 2000), because the background dust emission can easily be confused for emission from foreground obscuring material.

3.2. Comments on individual objects

- **CC01** A rich cluster, well resolved by the 2MASS. It resembles morphologically a globular or a compact young cluster, similar to Arches. Further observations are needed to solve this ambiguity. The location of the candidate coincides with an emission nebula Min 2-58 (Minkowski 1948), clearly seen on both blue and red DSS images (while the stellar cluster is not). A radio-selected HII region within 30 arcsec was reported by Lockman (1989).
- **CC02** Resolved by the 2MASS. Extended nebulocity is present on both blue and red DSS images. There is an indication for faint stellar population on the red image. An HII region SH 2-269 B (Sharpless 1959) lies within the borders of our candidate. Water maser emission was detected by Comoretto et al. (1990) indicating that this is a young cluster embedded in a dense molecular core.
- **CC03** Partially resolved by the 2MASS. Compact ($D \sim 1$ arcmin) nebulocity is visible on the red DSS image, with no trace of the embedded stars. An HII region BFS 56, associated with a molecular cloud was found at the same position by Blitz et al. (1982). A nearby IRAS source (06567-0350) was identified by Magnier et al. (1999) as possible young stellar object. Therefore, the found cluster is likely young.
- **CC04** Well resolved on the 2MASS images. Extended nebulocity is visible on the red DSS plate, with a few bright stars that might be associated with it. Blitz et al. (1982) reported an HII region BFS 64 nearby.
- **CC05** Partially resolved by the 2MASS. A compact nebulocity ($D \sim 1$ arcmin) is visible on the red DSS image, with no associated stars. Fich & Terebey (1996) reported a cloud (221.9-2.0B) that might hide on-going star formation. Indeed, a young stellar object CPM 33 was discovered by Campbell et al. (1989), which leads as to believe that this may be a young cluster.
- **CC06** Partially resolved by the 2MASS. A patchy nebula with a few stars near the center is visible on the red DSS image. However, their association is not obvious due to heavy foreground contamination. The nebula is included in the HII region catalog of Brand et al. (1986) as BRAN 22C. CO emission, associated with this object was detected by Brand et al. (1987), suggesting the presence of a dense core.
- **CC07** Well resolved by the 2MASS. A patchy faint nebula with a few stars near the center is visible on the red DSS image. Some of the stars coincide with the brighter patches, indicating a physical association. The nebula is cataloged by Sharpless (1959) as HII region SH 2-299 B.
- **CC08** Well resolved on the 2MASS images. It is visible on the red DSS image as a loose concentration of faint stars, indicating even lower extinction than the one estimated from the near-infrared color-magnitude diagram (Fig. 3, left). The morphology suggests that this might be an open cluster.
- **CC09** Well resolved by the 2MASS. Visible on the red DSS, suggesting low extinction. We refrained from measuring the cluster brightness because of the faint apparent magnitude and the foreground contamination. Resembles an open cluster or a distant OB association.
- **CC10** Partially resolved by the 2MASS. Compact nebulocity ($D \sim 1$ arcmin) visible on the red DSS image. It is associated with IRAS 08165−3538, and appears to be a compact young cluster that does not match our search criteria for richness. It was observed in the near infrared as an unresolved source by Liseau et al. (1992) and Lorenzetti et al. (1993). Their measurements are also listed in Table 1 (last row), and agree with ours, within the uncertainties.

4. Summary

A systematic search throughout the 2MASS point source catalog yielded ten new stellar clusters. One may be a new globular, two have morphologies consistent with open clusters, and the rest are likely compact young clusters. Further analysis and deeper imaging with higher angular resolution is needed to verify their true nature.

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