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NGC 4337: an over-looked old cluster in the inner disc of the Milky Way *

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ABSTRACT
Galactic open clusters do not survive long in the high density regions of the inner Galactic disc. Inside the solar ring only 11 open clusters are known with ages older than one Gyr. We show here, basing on deep, high-quality photometry, that NGC 4337, contrary to earlier findings, is indeed an old open cluster. The cluster is located very close to the conspicuous star cluster Trumpler 20, as well mis-classified in the past, and that has received so much attention in recent years. NGC 4337 shows a significant clump of He-burning stars which was not detected previously. Its beautiful color-magnitude diagram is strikingly similar to the one of the classical old open clusters IC 4651, NGC 752, and NGC 3680, and this suggests similar age and composition. A spectroscopic study is much needed to confirm our findings. This, in turn, would also allow us to better define the inner disc radial abundance gradient and its temporal evolution.To this aim, a list of clump star candidates is provided.

Key words: (Galaxy): open clusters and associations: general – (Galaxy): open clusters and associations: individual: NGC 4337

1 INTRODUCTION

Recent studies have consolidated a picture of a dual Milky Way disc. The co-rotation radius roughly divides the disc in two regions, the anti-center and the inner regions, that appear to have experienced very different chemical enrichment histories. Among the others, Magrini et al. (2010) and Frinchaboy et al. (2013) provided plenty of new data that lend strong support to the earlier findings by Twarog et al. (1997) that the radial abundance gradient is not monotonic over the whole disc extent. In agreement with observations in external spiral galaxies (Bresolin et al. 2012), at about co-rotation, the radial abundance gradient flattens out in the anti-center region, while being quite steep in the inner regions. Most of these evidences come from studies of Galactic open clusters, especially the oldest ones (Friel 1995). These clusters are of invaluable importance since they allow us to trace the chemical properties of the disc since its very early assembly. Ideally, by using these clusters, one would be able to understand, e.g., how the abundance gradient built up and changed with time.

However, as widely known, they are very few in number, and mostly located in the disc periphery, where star clusters can survive longer. In the inner disc only 11 old open clusters are known, whose ages are larger than 1.0 Gyr (see Table 1). We caution the reader that this number is much smaller than what one can blindly extract from public catalogs, like for instance the WEBDA database[1]. We restricted ourselves to clusters with a solid determination of the age, located between $l=0^o$ and $l=85^o$ in the first quadrant, and from $l=275^o$ and $l=360^o$ in the fourth quadrant, and within a Galacto-centric distance smaller than the Sun value (8.5 kpc). For most clusters listed on WEBDA as older than 1 Gyr either the available data or the analysis are poor (see the discussion, e.g. in Paunzen et al. 2010), and their age cannot be considered reliable enough.
This table contains also NGC 6791, one of the oldest and more metal rich old open clusters in the Milky Way. Its membership to the disc, however, has been questioned, since overall its parameters bear more similarity to the stellar populations in the Galactic bulge (Carraro 2013).

The most recent member of this restricted family is Trumpler 20. Originally mis-classified as a young cluster, Trumpler 20 was then correctly found to be a rare example of a rich, old open cluster in the inner parts of the Milky Way disc (Platais et al. 2008, Seleznev et al. 2010). This triggered many follow-up studies (Donati et al. 2014, Carraro et al. 2014, and references therein).

We report here on another very similar case: the old open cluster

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[1] http://www.univie.ac.at/webda

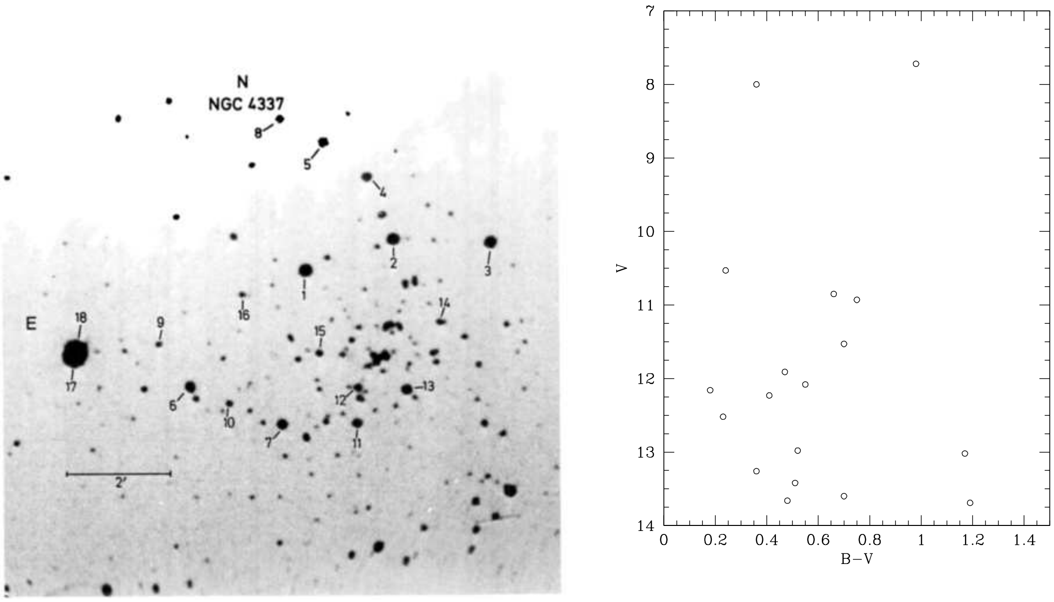

Figure 1. Leff panel: Image of NGC 4337 from Moffat & Vogt(1973). Numbers refer to observed stars, as described in the text. **Right panel:** The CMD derived from Moffat & Vogt (1973) photometry.

Table 1. Star clusters in the inner disk older than 1.0 Gyr

Cluster	l	b	Age	[Fe/H]	d_{GC}	reference
	[deg]	[deg]	Gyr		kpc	
NGC 6583	9.28	-2.53	1.0	+0.37	6.5	Carraro et al. 2005
Berkeley 44	53.21	+3.35	1.3		7.6	Carraro et al. 2006a
Berkeley 52	67.89	-3.13	2.0		8.1	Carraro et al. 2006a
NGC 6791	69.96	+10.90	8.0	+0.40	8.0	Carraro et al. 2006b
NGC 6819	73.98	+8.48	3.0	+0.09	8.2	Carraro et al. 2013
NGC 3680	286.77	+16.92	1.85	-0.03	8.3	Anthony-Twarog & Twarog
Trumpler 20	301.47	+2.22	1.5	+0.09	7.3	Carraro et al. 2014
Collinder 261	301.68	-5.53	7.0	+0.13	7.5	Gozzoli et al. 2006
NGC 6005	325.78	-2.98	1.2		6.5	Piatti et al 1998
NGC 6253	335.46	-6.25	3.0	+0.40	7.0	Piatti et al. 1998
IC 4651	340.01	-7.91	1.7	+0.11	8.0	Meibom 2000

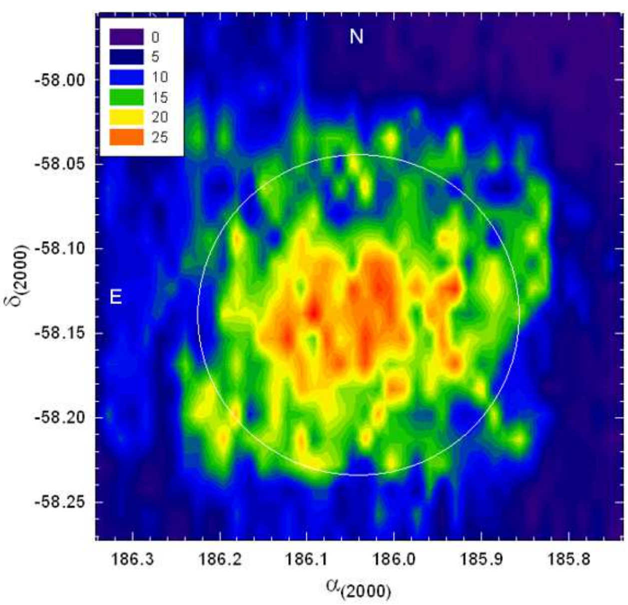

Figure 2. A density contour map in the area of NGC 4337. The map is 20 arcmin on a side, North is up, East to the left. The white circle indicates the estimate cluster area, the radius being 6 arcmin.

NGC 4337.
This cluster has 2000. equinox equatorial coordinates RA= $12^h24^m04^s$, Dec $=-58^o07'24''$, while its Galactic coordinates are l= $299^o.313$, b=$4^o.556$. It is therefore located very close to Trumpler 20 in longitude, but significantly higher onto the Galactic plane.

As a part of their southern sky search for star clusters, Moffat & Vogt (1973) describe NGC 4337 with the following words: *In spatial order, the stars 9, 6, 10, 7, 11, 13, 14, 2,4,5 and 8 appear to form an open arc, revealing some similarity to the "stellar rings" of Issestedt(1968). However the photometry shows no physical connection among these stars; they most likely represent a random arrangement of field stars. The actual cluster may be a small group (diameter ~ 2′) of stars located between nos. 14 and 15, which are too faint to be reached by the 61 cm telescope except for the possible members 12, 13, 14, 1 and 15, the photometry of these also shows no physical association.*

To help the reader, Moffat & Vogt (1973) map is reproduced in the left panel of Fig 1, while the right panel shows the color-magnitude diagram (CMD) one can derive from their stars. This CMD gives full justice to their preliminary conclusions. Clearly no hints are visible of the presence of a physical group, at odds with the photographic plate which gives the clear impression of some star concentration.

This latter evidence motivated us to acquire new CCD data. We briefly describe the observations in Section 2 of this paper, and use the photometric data-set to probe the cluster structure in Section 3. Section 4 is devoted to the analysis of the CMDs of NGC 4337. Some conclusions are given in Sections 5.

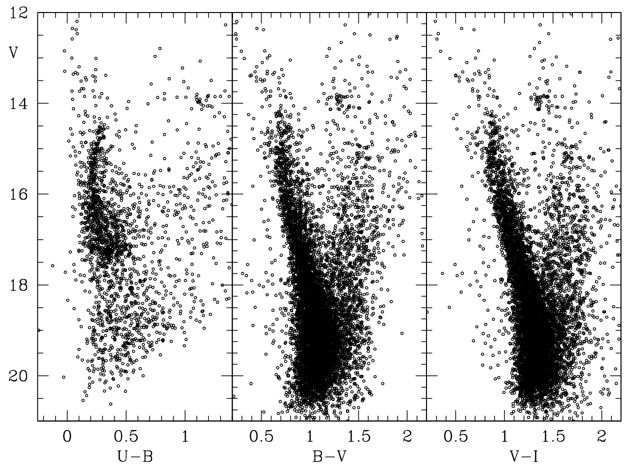

Figure 3. CMDs for all the stars observed in the field of NGC 4337.

2 OBSERVATIONS

We took UBVI images of NGC 4337 in a 20×20 squared arcmin area during two observing runs, on 2010 Feb 14 and 2010 Mar 11, at Cerro Tololo Inter-American Observatory, using the 0.9m and the 1.0m telescope. The first night (at the 0.9m) was not photometric, and therefore we tied all the images to the second night (at the 1.0m), which was photometric. During this second night, we took multiple images of the standard star fields PG 1047 and SA98, covering an airmass range 1.15−2.2. Five frames per filter, with exposures ranging from 20 to 2400 secs (U), 5 to 1800 secs (B), 5 to 1200 secs (V and I) were obtained, to avoid bright star saturation and at the same time to get deep enough to unravel the cluster main sequence. These observations were part of a long term project aimed at collecting high-quality data for a large open cluster data-set. We refer the reader to previous publications (e.g. Carraro & Costa 2007, and Carraro & Seleznev 2012) for all the details of data reduction and photometric calibration. The final catalog, cross-correlated with 2MASS, contains 8198 entries, and is made available at the CDS database. An excerpt of the catalog is presented in Table 2, which lists the clump star candidates.

3 CLUSTER STRUCTURE AND RADIUS

In Fig. 2 we show a contour plot in the area of NGC 4337, derived from our photometry. Star counts have been performed using a grid, and density inside each field computed via a suitable kernel estimate (see Vázquez et al. 2010 for more details). The cluster has quite an irregular shape, but certainly appears as a prominent overdensity. The density peak (~ 65 stars/arcmin^2) is offset with respect to the center of the field, which was chosen according to the cluster nominal center. A visual inspection of Fig 2 provides us with an estimate of the cluster radius of ~ 7 arcmin (see the super-imposed white circle), larger than visual inspection on the DSS (Dias et al. 2002).
Our quantitative star counts analysis fully supports Moffat & Vogt (1973) visual impression that NGC 4337 is clearly a star overdensity with respect to the surrounding field.

4 ANALYSIS OF THE PHOTOMETRIC DIAGRAMS

The CMD for all the stars in the observed field is shown in Fig. 3. This strikingly resembles the CMD of an intermediate-age/old open cluster. Although field star contamination is significant, a turn off point (TO) can be easily identified at V ~ 15.50, together with a prominent clump of stars at V ~ 14.0, U-B ~ 1.10, B-V ~ 1.30 , and V-I ~ 1.35. This diagram, in tandem with start counts, confirms beyond any reasonable doubt that NGC 4337 is indeed a physical star cluster.

To alleviate field star contamination we make use of the previous section results, and consider in the following only stars within 5 arcmin from the cluster center. The resulting CMD in the V/B-V plane is presented in Fig. 4. The cluster main features emerge very neatly, and should immediately remind the reader the CMD of the more famous old open clusters IC 4651 and NGC 3680 (see Table 1), or NGC 752. The TO is located at V = 15.50, and the MS extends down to V = 19, in spite of some residual field star contamination. A scattered sequence of binary stars is visible to the right of the MS. The binary sequence intersects the MS at V ~15.1. We cannot exclude the presence of a few blue straggler stars.
Interestingly enough, the MS TO region has a curved shape, typical of intermediate-age/old clusters. Finally, the Hertzsprung gap is quite evident, together with the red giant clump, made of a dozen stars.

We stress also the fact that NGC 4337 CMD is much cleaner than Trumpler 20 CMD (Seleznev et al. 2010).

To infer for the first time the cluster basic parameters, we superimposed on the cluster CMD the ridge line of IC 4651 (red dashed line), taken from Anthony-Twarog et al. (1988) study. IC 4651 seems o be the best choice, being a classical old open clusters, with an age around 1.7 Gyr (Anthony-Twarog et al. 1998, Meibon 2000, Anthony-Twarog et al. 2009), and a metallicity [Fe/H] =+ 0.11 (Carretta et al. 2004). This is slightly super-solar, as expected for clusters in the inner disc.

The fit has been performed by shifting IC 4651 ridge line by 2.6 mag in magnitude and 0.14 mag in color. The fit is really impressive as far as the MS is concerned. The only difference is in the magnitude of clump, since IC 4651 mean clump magnitude is ~ 0.3 mag. brighter than NGC 4337. Since the fit is very convincing, we conclude that the two clusters most probably share the same metallicity, but NGC 4337 would be somewhat younger than IC 4651. IC 4651 reddening and apparent distance modulus are 0.12 and 10.40 mag, respectively, according to the recent study by Anthony-Twarog et al. (2009). This implies that NGC 4337 has a reddening E(B-V) ~ 0.26 and an apparent distance modulus of ~13.00. From these figures we derive a preliminary cluster helio-centric distance of 2.8 kpc, which, in turn, implies a distance of ~ 7.5 kpc from the Galactic center.

5 SUMMARY AND CONCLUSIONS

In this work we have revisited the star cluster NGC 4337, previously considered as a random arrangement of field stars. One of the main feature of the cluster CMD is an extremely well defined MS TO region, resembling closely IC 4651, NGC 752, and NGC

Table 2. An excerpt of the photometric data presented in this paper. The full table is posted at the CDS archive. The table lists all the clump star candidates

ID	RA(2000.0	Dec(2000.0)	V	σ_V	(B-V)	$\sigma_{(B-V)}$	(U-B)	$\sigma_{(U-B)}$	(V-I)	$\sigma_{(V-I)}$
	[deg]	[deg]	mag	mag	mag	mag	mag	mag	mag	mag
90	186.06567	-58.14727	13.804	0.002	1.275	0.003	1.101	0.005	1.311	0.004
91	186.16358	-58.13047	13.827	0.002	1.308	0.002	1.199	0.006	1.404	0.003
99	186.16451	-58.22229	13.853	0.002	1.304	0.004	1.254	0.010	1.406	0.004
100	185.86345	-58.04729	13.861	0.009	1.347	0.020	9.999	9.999	1.449	0.024
106	186.01314	- 58.11106	13.867	0.002	1.277	0.002	1.007	0.005	1.348	0.004
107	186.02449	-58.12087	13.868	0.002	1.273	0.003	1.095	0.005	1.336	0.004
110	185.98837	-58.12068	13.908	0.002	1.275	0.003	1.127	0.004	1.322	0.004
114	186.03714	-58.11592	13.928	0.002	1.284	0.002	1.101	0.005	1.336	0.004
115	185.98609	-58.12367	13.933	0.002	1.320	0.003	1.180	0.005	1.365	0.005
117	185.96857	-58.11566	13.961	0.002	1.291	0.003	1.123	0.006	1.332	0.003
118	185.98385	-58.11050	13.966	0.002	1.294	0.003	1.115	0.005	1.353	0.004
121	186.03666	-58.03773	13.977	0.002	1.311	0.003	1.101	0.010	1.378	0.004
124	186.13244	-58.13392	14.017	0.001	1.280	0.002	1.135	0.006	1.321	0.003
128	186.18727	-58.03610	14.056	0.004	1.332	0.006	1.155	0.014	1.436	0.006
130	186.02041	-58.08607	14.061	0.002	1.330	0.003	1.190	0.008	1.365	0.004

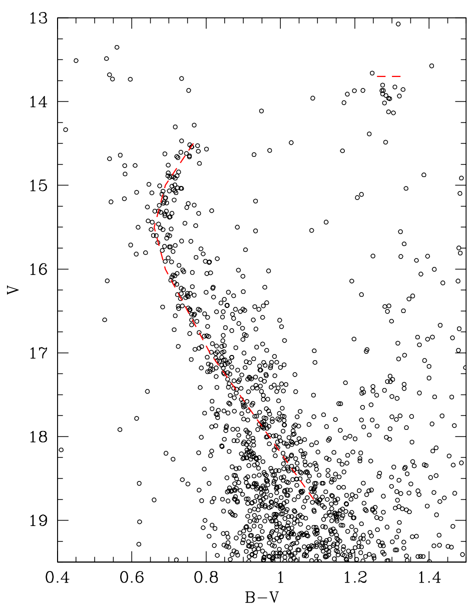

Figure 4. CMDs for all the stars within NGC 4337 radius. The red line is IC 4651 ridge line offset by 0.14 in color and 2.6 in magnitude

3680, all extremely well-known textbook intermediate-age old open clusters. NGC 4337 harbors a dozen clump stars, which would make it as massive as IC 4651, and most probably in the same dynamical stage (Meibom 2000). In fact, we do not see any manifestation of low mass stars depletion, as for NGC 3680 and NGC 752.

The cluster is therefore a rare example of an old open cluster in the inner disc. According to our preliminary estimates of the cluster parameters, its Galacto-centric distance would make NGC 4337 one of the more distant cluster from the Sun among the well known old open clusters located inside the solar ring. This is a privileged location to establish in a more solid way the slope of the inner disc radial abundance gradient (Magrini et al. 2010), and its evolution with time. We expect this study to prompt a spectroscopic campaign to derive its metal abundance, and better constrain its fundamental parameters.

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