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Improved proper motion determinations for 15 open clusters based on the UCAC4 catalog

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Abstract The proper motions of 15 nearby ($d < 1$ kpc) open clusters (OCs) were recalculated using data from the UCAC4 catalog. Only evolved or main sequence stars inside a certain radius from the center of the cluster were used. The results significantly differ from the ones presented by Dias et al. (2014). This could be explained by a different approach in which we take the field star contamination into account. The present work aims to emphasize the importance of applying photometric criteria for the calculation of OC proper motions.

Key words: proper motions — Galaxy: open clusters and associations: general

1 INTRODUCTION

Open clusters (OCs) are fundamental building blocks of spiral and irregular galaxies. Studies of Galactic OCs have produced a great number of important scientific results in areas such as stellar evolution and star formation (Castellani et al. 2002; Phelps & Janes 1993). Furthermore, Galactic OCs are crucial for understanding the structure and dynamics of the Milky Way. OCs and OB associations have been used to explore local structures (de Zeeuw et al. 1999; Torra et al. 2000) as well as the large-scale structure of the Galaxy (Bobylev & Bajkova 2014; Zhu 2008). They also help trace the chemical composition throughout the Galactic thin disk (Magrini & Randich 2015).

Proper motion is a key parameter describing OCs. Proper motions, distances and radial velocities are used to derive Galactocentric velocities of OCs. The latter are of fundamental significance in studies of Galactic dynamics, e.g. determination of OC orbits (Wu et al. 2009) and rotation of the Galaxy (Dias & Lépine 2005; Zhu 2007). Another important implication of OC proper motions is the calculation of membership probabilities for individual stars (Sanders 1971; Cabrera-Cano & Alfaro 1985). It has been shown that cluster parameters based on photometric membership probabilities are consistent with those based on proper motion membership probabilities, see e.g. Wu et al. (2007).

The early history of OC proper motion determinations has been outlined by Vasilevskis (1962). Up until the end of the 20th century, proper motions of OCs were mainly derived on a case-by-case basis. The first large catalog was compiled by Glushkova et al. (1997) for 181 clusters with $\log(\text{age}) < 8.3$. Large OC proper motion catalogs were later released by Baumgardt et al. (2000) and Dias et al. (2001, 2002) using Hipparcos and Tycho-2 data respectively. The results, obtained by Loktin & Beshenov (2003), were also based on the Tycho-2 catalog, and are currently the ones cited in the SIMBAD database.

The UCAC4 catalog (Zacharias et al. 2013) contains proper motion data for more than 105 million objects (complete to $R = 16$ mag). It compiles astrometric data from over 140 catalogs, including Hipparcos and Tycho-2, for the derivation of mean positions and proper motions. The astrometry is complemented by optical and near-infrared (NIR) photometry from APASS and 2MASS. Dias et al. (2014) have used UCAC4 to obtain proper motions for 1805 Galactic OCs. We have recalculated the proper motions of 15 close ($d < 1$ kpc from the Sun) OCs via a different method and obtained results, which are significantly different from the ones by Dias et al. (2014).
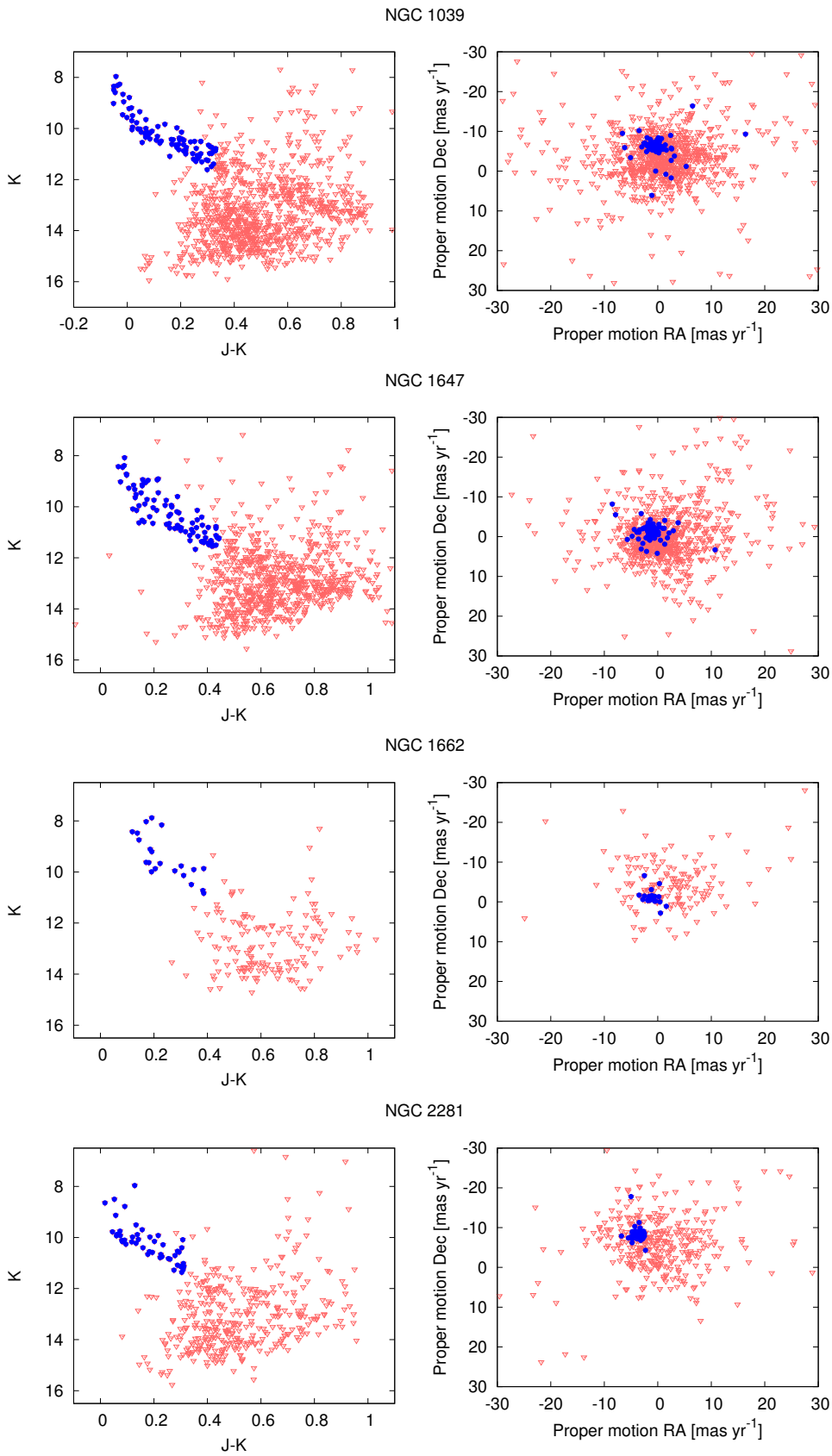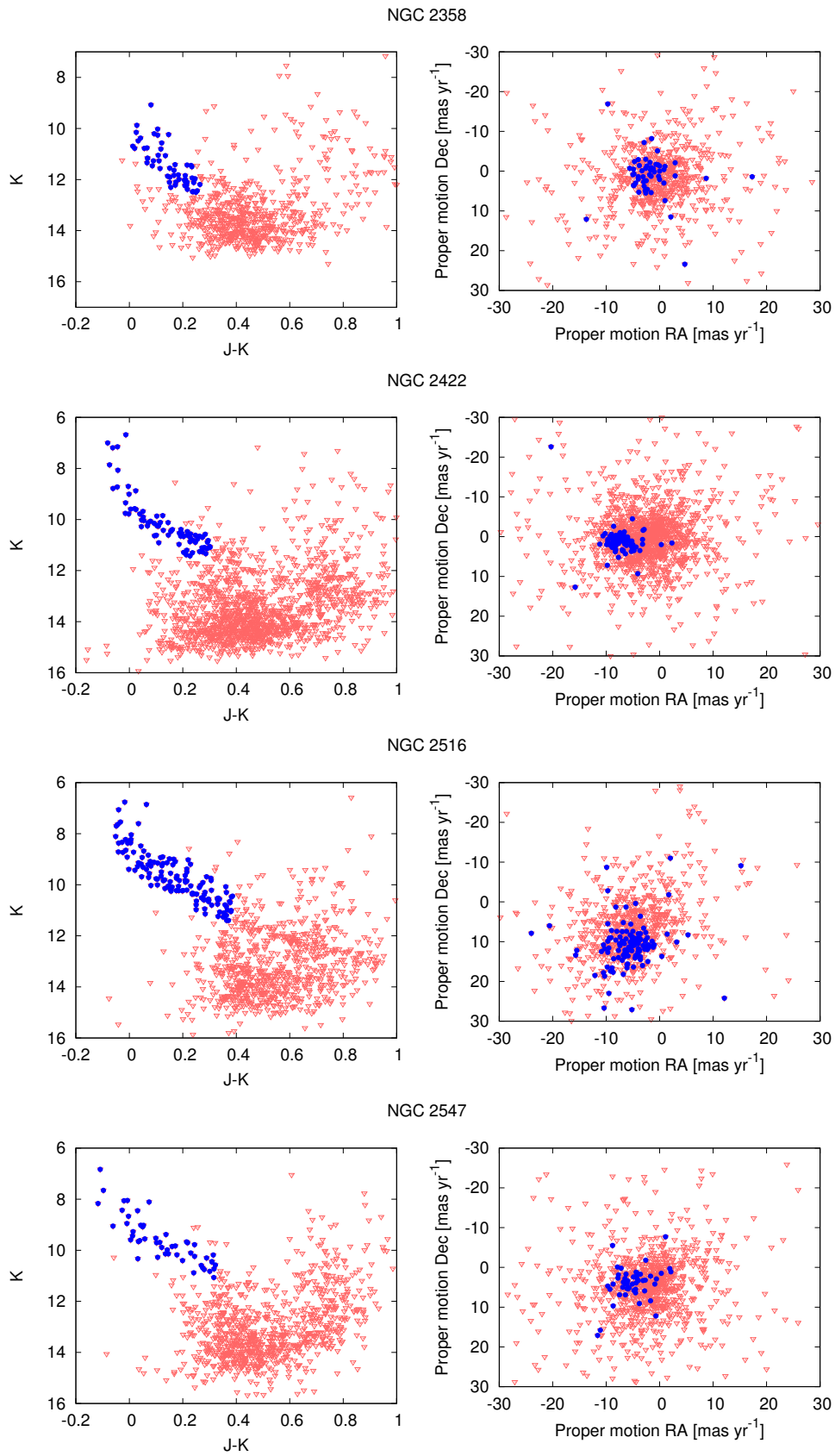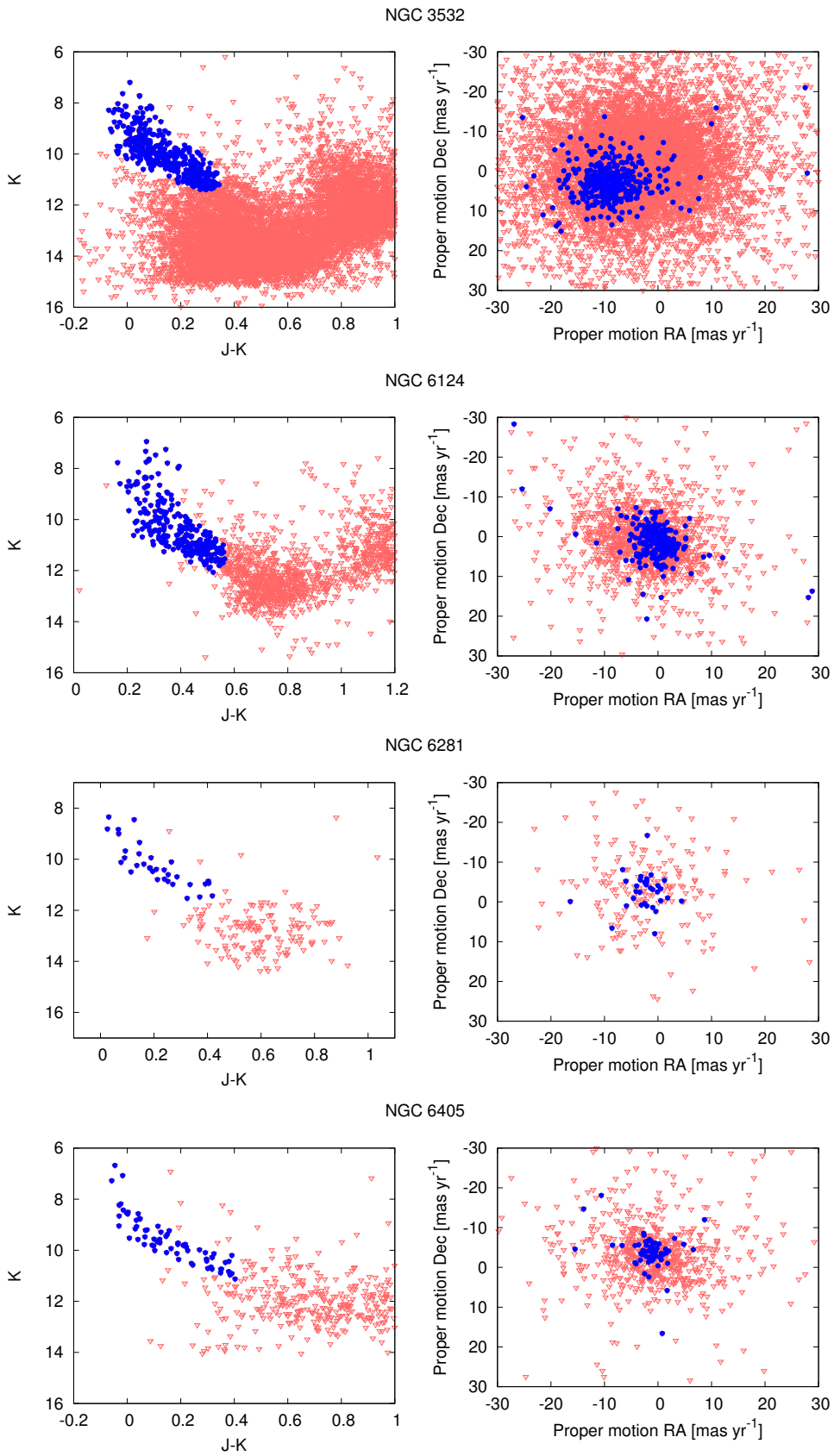
Fig. 1 *left*: NIR CMDs of all clusters considered in this study. All stars inside the search radii are plotted with red triangles. Filled blue circles represent highly probable cluster members (the N_1 subselections), used to calculate the OC proper motions after the deletion of outlying points. *Right*: All sources plotted in a $\mu_\alpha \cos \delta$ vs. μ_δ plane. Cluster members appear grouped together.

NGC 2358

NGC 2422

NGC 2516

NGC 2547

Fig. 1 — *Continued.*

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NGC 3532

NGC 6124

NGC 6281

NGC 6405

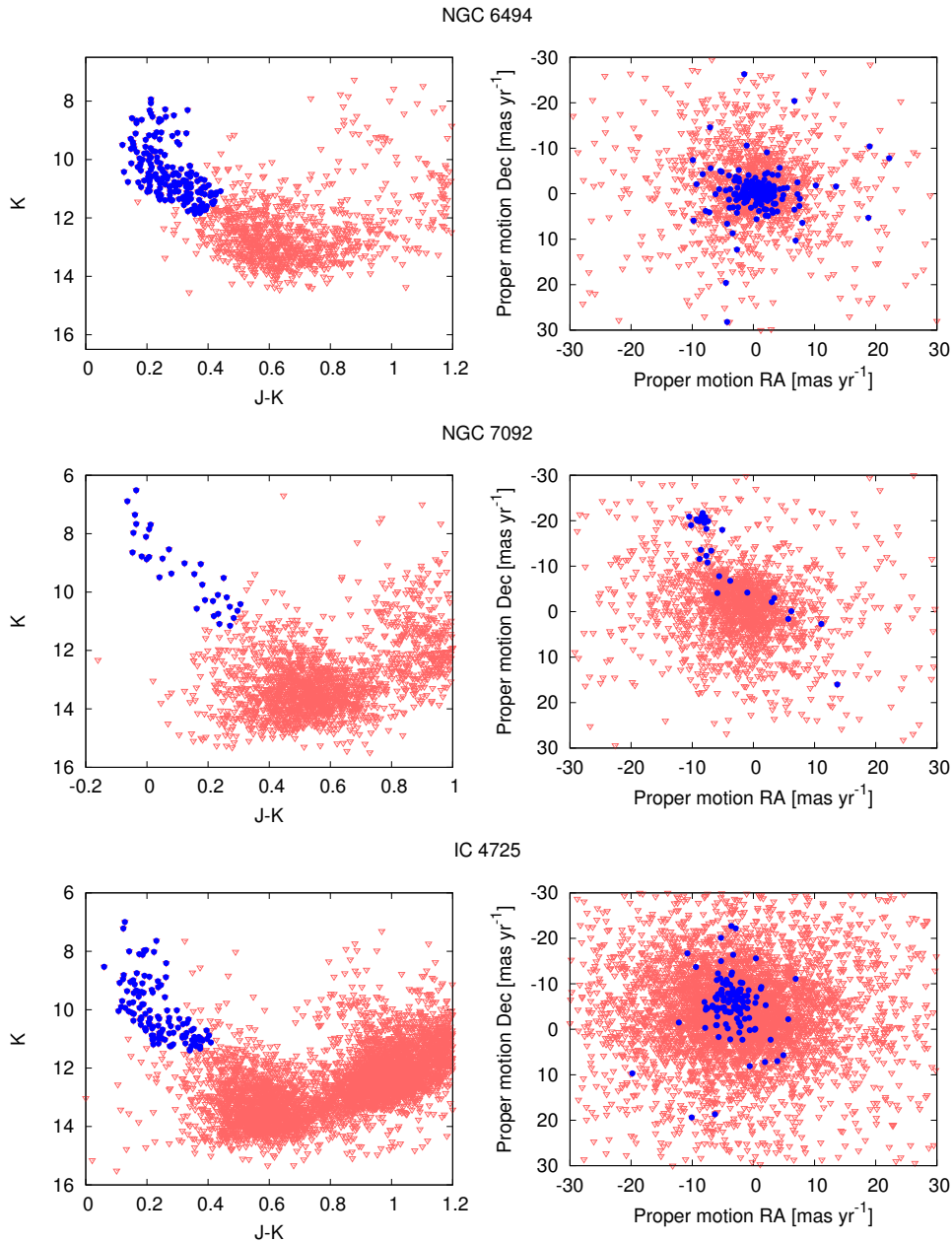**Fig. 1** — *Continued.*

NGC 6494

NGC 7092

IC 4725

Fig. 1 — *Continued.*

2 OBJECT SELECTION AND METHOD

The OCs for this work were selected from the WEBDA list[1] of close OCs ($d < 1$ kpc). Clusters closer than 300 pc were not included as there should be systematic differences between the proper motions of their members, depending on location. We chose only prominent OCs, whose color-magnitude diagrams (CMDs) exhibit typical features for OCs (main sequence (MS), turnoff point). The selected clusters are presented in Table 1.

Stars in the vicinity of each cluster were extracted by searching the UCAC4 catalog inside a given radius from the cluster center. We used the same coordinates and radii for the search as Dias et al. (2014). A 2MASS ($J - K$) vs. K diagram was built for each cluster. Out of all the N_0 stars, N_1 cases were selected as very probable cluster members based on their location on the CMD. Only stars lying on the MS or evolved ones, i.e. to the right of the MS and forming a feature along an isochrone, were included in the N_1 subselections (Fig. 1). Data selection was

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[1] See *http://www.univie.ac.at/webda/dist_list.html*

Table 1 Open Clusters Studied in the Current Work

Cluster	Alt. name	α (J2000)	δ (J2000)	l	b	Dist. [pc]	$(m-M)$	$E(B-V)$	log (age)
NGC 1039	M34	02:42:05	+42:45:42	143.658	−15.613	499	8.71	0.07	8.25
NGC 1647	–	04:45:55	+19:06:54	180.337	−16.772	540	9.81	0.37	8.16
NGC 1662	–	04:48:27	+10:56:12	187.695	−21.114	437	9.14	0.30	8.63
NGC 2281	–	06:48:17	+41:04:42	174.901	16.881	558	8.93	0.06	8.55
NGC 2358	–	07:16:55	−17:08:59	231.05	−2.30	630	9.06	0.02	8.72
NGC 2422	M47	07:36:35	−14:29:00	230.958	3.130	490	8.67	0.07	7.86
NGC 2516	–	07:58:04	−60:45:12	273.816	−15.856	409	8.37	0.10	8.05
NGC 2547	–	08:10:09	−49:12:54	264.465	−8.597	455	8.42	0.04	7.56
NGC 3532	–	11:05:39	−58:45:12	289.571	1.347	486	8.55	0.04	8.49
NGC 6124	–	16:25:20	−40:39:12	340.741	6.016	512	10.87	0.75	8.15
NGC 6281	–	17:04:41	−37:59:06	347.731	1.972	479	8.86	0.15	8.50
NGC 6405	M6	17:40:20	−32:15:12	356.580	−0.777	487	8.88	0.14	7.97
NGC 6494	M23	17:57:04	−18:59:06	9.894	2.834	628	10.09	0.36	8.48
NGC 7092	M39	21:31:48	+48:26:00	92.403	−2.242	326	7.61	0.01	8.45
IC 4725	M25	18:31:47	−19:07:00	13.702	−4.434	620	10.44	0.48	7.97

Notes: The basic parameters are retrieved from the WEBDA database.

Table 2 Proper Motions Calculated for 15 OCs

Cluster name	$r_{\rm s}$ [arcmin]	N_0	N_1	MAD (μ) [mas yr^{-1}]	N_2	$\mu_\alpha \cos\delta$ [mas yr^{-1}]	σ_α [mas yr^{-1}]	μ_δ [mas yr^{-1}]	σ_δ [mas yr^{-1}]	$N_{\rm D}$
NGC 1039	18.5	1022	86	0.92	72	–0.56	1.03	–6.26	0.82	783
NGC 1647	21.0	848	87	1.14	78	–1.13	1.35	–1.27	1.24	656
NGC 1662	11.0	173	21	0.99	19	–1.10	1.24	–0.66	1.21	151
NGC 2281	13.5	439	46	0.92	43	–3.92	0.91	–8.21	0.92	330
NGC 2358	11.0	750	55	2.83	49	–1.85	2.56	0.49	3.10	618
NGC 2422	13.5	1487	78	1.64	73	–7.29	1.87	1.38	1.79	1293
NGC 2516	16.0	941	134	2.84	117	–5.48	3.13	11.14	3.36	737
NGC 2547	13.5	960	51	2.55	48	–4.88	2.80	3.71	2.96	644
NGC 3532	26.0	11974	409	3.40	386	–8.90	3.91	2.97	3.80	8705
NGC 6124	20.5	1838	263	2.72	243	–0.18	2.49	1.19	3.16	1633
NGC 6281	5.0	280	33	2.83	30	–1.92	2.40	–2.51	3.40	207
NGC 6405	11.0	930	67	2.05	61	–1.11	2.33	–3.87	2.12	737
NGC 6494	15.5	1640	185	2.36	162	0.49	2.80	–0.27	2.37	1342
NGC 7092	15.5	2019	34	2.77	25	–8.20	1.18	–18.14	3.97	1464
IC 4725	15.5	5812	124	2.84	111	–3.46	2.55	–6.01	3.76	4458

Notes: The last column contains the number of stars used by Dias et al. (2014).

carried out using Virtual Observatory tools (Aladin[2] and TOPCAT[3]).

Outlying points in the N_1 subselections were removed using median absolute deviation (MAD), defined as:

$$\mathrm{MAD}(x) = \mathrm{median}_i(|x_i - \mathrm{median}_j(x_j)|)$$
$$\mathrm{MAD}(\mu) = \sqrt{(\mathrm{MAD}(\mu_\alpha \cos\delta))^2 + (\mathrm{MAD}(\mu_\delta))^2} \quad (1)$$

The value of MAD(μ) was calculated for each cluster. Sources with proper motion differing by more than 4MAD(μ) from the median proper motion were considered outliers and excluded from the sample, thus producing even narrower subselections consisting of N_2 stars. The

proper motions of the clusters were finally calculated by averaging the data in the N_2 subselections.

3 RESULTS

Our results are presented in Table 2. The standard deviations of the proper motions in the N_2 subselections are in the range of 0.8 mas yr^{-1}–4 mas yr^{-1}, which is comparable to the errors given by Dias et al. (2014). However, the results significantly differ from theirs ($|\Delta\mu| > 2$ mas yr^{-1} for 9 of the 15 clusters). Very large deviations are observed for NGC 7092, NGC 3532 and NGC 2422. Higher deviations from Dias et al. (2014) are generally observed at higher absolute proper motion values (Fig. 2).

We suggest that Dias et al. (2014) may have used a large number of background stars, which could have con-

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[2] See *http://aladin.u-strasbg.fr/*
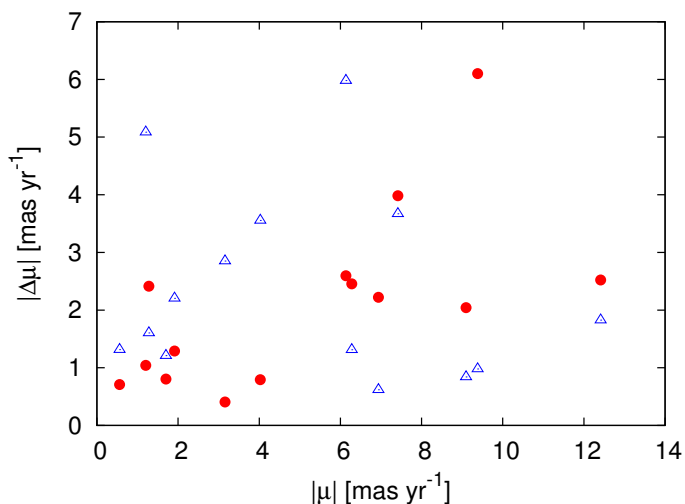[3] See *http://www.star.bris.ac.uk/ mbt/topcat/*

Fig. 2 Comparison of the calculated proper motions with the values from Dias et al. (2014) (*circles*) and Loktin & Beshenov (2003) (*triangles*). The x-axis represents absolute proper motion values, calculated in this work, while the y-axis represents absolute values of vector differences compared to previous estimates. The Dias et al. (2014) data point corresponding to NGC 7092 lies outside the plot at $(|\mu|, |\Delta\mu|) = (18.18, 17.08)$.

taminated their selections. We attempted to estimate the percentage of those background stars. For each cluster we examined four nearby fields, centered $40'$ away ($60'$ away in the case of the larger NGC 3532), and with radius r_s, equal to the search radius for the cluster (Table 2). The median number N_F of UCAC4 sources in these four fields was then calculated. The portion of field stars should be roughly $f = N_F/N_0$. For all clusters $f > 67\%$. The portion of field stars among those used by Dias et al. (2014) would be approximately $f_D = 1 - (1 - f)N_0/N_D$. The minimum and median values of f_D are 57% and 75% respectively. Although this is just a rough estimate, it shows that a considerable portion of stars used by Dias et al. (2014) are not physical members of the respective clusters.

Loktin & Beshenov (2003) have also applied photometric criteria for their selections. Our agreement with the latter is slightly better in general (median $|\Delta\mu|$ of 1.6 mas yr^{-1}) and much better in the case of NGC 7092 ($|\Delta\mu| = 1.52$ mas yr^{-1} and 17.08 mas yr^{-1} when comparing the data in Table 2 to Loktin & Beshenov (2003) and Dias et al. (2014) respectively). The proper motion diagram for NGC 7092 (Fig. 1) contains a considerable number of outlying points. The reason is that NGC 7092 is a very close cluster, located near the Galactic plane (Table 1). Most of the outliers are not in the N_2 subselection and do not affect the result as they lie farther than 4MAD (μ) from the median value.

4 SUMMARY

Proper motions are important parameters of OCs, which help us improve our understanding of Galactic dynamics. We built NIR CMDs of 15 OCs and we used them to se-

lect stars that are very probable members. After excluding the ones with an uncommon proper motion, we used those subselections to calculate the proper motions of the clusters. Our results suggest that Dias et al. (2014) may have used selections which were contaminated by background stars. Our work shows the advantage of utilizing CMDs for the calculation of OC proper motions.

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