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Proper motions of open clusters within 1 kpc based on the TYCHO2 Catalogue⋆,⋆⋆

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Abstract. We present mean absolute proper motions of 112 open clusters, determined using the data from the Tycho2 Catalogue. For 28 clusters, this is the first determination of proper motion. The measurements made use of a large number of stars (usually several tens) for each cluster. The total number of stars studied in the fields of the 164 open clusters is 5016, of which 4006 were considered members. The mean proper motions of the clusters and membership probability of individual stars were obtained from the proper motion data by applying the statistical method proposed by Sanders (1971).

Key words. Galaxy: open clusters and associations: general – astrometry

1. Introduction

The open clusters constitute a system of young objects of great value for the study of the dynamics of the Galaxy, because they span a relatively wide range of ages, and their age can be determined with higher precision than any other spiral arm tracer, with the help of the HR diagram. They are key objects to understand the motion of spiral arms and of the moving groups of stars, to derive the rotation curve and to distinguish between star formation processes. To investigate the orbits of this system, it is essential to have at our disposal accurate proper motion and radial velocities.

Many works containing observations of proper motion of open clusters can be found in the literature. However, most measurements performed in the past were *relative* proper motions. Only recently, after the Hipparcos mission (ESA 1997; Kovalevsky 1998), has a reference frame for absolute proper motion become available, and according to the IAU General Assembly, the Hipparcos Catalogue is considered as the realization of the ICRS at optical wavelengths. It is not clear whether the previous measurements can be corrected in a straightforward manner. The recent works of Platais et al. (1998), De Zeeuw et al. (1999), Robichon et al. (1999) and of Baumgart et al. (2000, hereafter BDW) are examples of measurements of proper motions of large samples of open clusters in the Hipparcos system. All these works are based on data directly taken from the Hipparcos Catalogue. Among these, Platais et al. focus on nearby and extended clusters, while BDW exclude clusters closer than 200 pc. The cluster proper motions derived by BDW are based on only a few stars in most cases, due to the restriction in magnitude of the Hipparcos data.

On the other hand, positions and proper motions of large sets of faint stars have been determined in the Hipparcos system, using ground-based observations, e.g., the Tycho-2 (Hog et al. 2000) and UCAC1 (Zacharias et al. 2000) Catalogues. These Catalogues have allowed various small field investigations to be performed in the new system (e.g., Dias et al. 2000; Teixeira et al. 2000).

In the present work, we determine proper motions of open clusters based on the Tycho2 Catalogue. We explore clusters up to a distance of 1 kpc, using the statistical method of Sanders (1971) to derive probable membership, in order to obtain the mean proper motion based on relatively large samples of stars for each cluster. We are aware, however, that it is possible to find open clusters at larger distances ($d \geq 1$ kpc) with detectable proper motion. Examples are Westerlund 02, Rupretch 49 and Pismis 11, among others. The clusters more distant than 1 kpc will be addressed in a forthcoming paper (Dias et al. 2001).

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⋆ Based on observations of the ESA Hipparcos satellite.

⋆⋆ Tables 1, 2 and 5 to 117 are only available in electronic form at the CDS via anonymous ftp to
cdsarc.u-strasbg.fr (130.79.128.5) or via
http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/376/441

2. Observational data

We selected in the BDA database[1] (Mermilliod 1995) clusters with distance less than 1 kpc as explained above.

For extended clusters, the basic hypothesis of the statistical method, that all the stars of a cluster have about the same proper motion, may not be valid. Other methods, like the convergence point method, would be preferable. In addition, for extended regions, a too large a number of field stars would have to be considered. For this reason, we excluded clusters more extended than about 2 degrees, like those studied by Platais et al. (1998).

We searched for the selected clusters in the Tycho2 Catalogue, using the central coordinates and the radius taken from the database. In many cases the central coordinates of the cluster are different from those given in the ESO Catalogue (Lauberts 1982); in these cases we opted to use the ESO coordinates. All the stars situated within the limits of the clusters were investigated. For open clusters with an apparent diameter less than $15'$ we searched for stars in an area 4 times the cluster area and if $D \geq 15'$ we used an area covered by the cluster.

In Table 1 (available in electronic form at the CDS) are given the other clusters for which the statistical method was unable to provide accurate proper motions. From a total of 168 clusters initially selected, we obtained satisfactory results for 112.

The Tycho2 Catalogue is based on the original Tycho Catalogue (ESA 1997); it contains accurate photometry and astrometry of about 2.5 million stars. For the faintest stars in common with Tycho1, Tycho2 has better positional and photometric accuracies. This is because the new method of reduction applied to Hipparcos data uses photon superposition for each star, for the ensemble of observations made during the entire mission, instead of treating each observation separately.

The Tycho2 Catalogue presents very precise proper motions. The internal or random errors are generally between 1 and 3 mas/yr. Tycho2 proper motions are in the Hipparcos system; there are no significant systematic differences between the proper motions of the two catalogues, as shown by Urban et al. (2000). The systematic errors, under 0.5 mas/yr, are typically 10% of the random errors, and are about equal to the formal errors for the rotation of the Hipparcos proper motion with respect to the ICRS, estimated to be 0.25 mas/yr (Kovalevsky et al. 1997). More details on the construction of the Tycho2 Catalogue are given by Hog et al. (2000). The high quality of the Tycho2 proper motions and their agreement with the Hipparcos set allow the determination of mean proper motions and memberships of open clusters.

3. Membership and mean proper motion determination

In a sample of field stars in which an open cluster is present, a number of characteristics reveal the stars that are members of the cluster. These include the distance parameters (the members of the cluster are within a limited volume), the kinematics parameters (the cluster members present similar spatial velocities), or photometric parameters (the members have the same ages and same chemical composition). With the proper motion provided by the Tycho2 Catalogue it is possible segregate the members of the clusters simply using the knowledge that the stars of a cluster have similar spatial velocities (in our case, we use only the proper motion data).

It is important to note that in this kind of investigation, the dispersion of proper motions of field stars is larger than that of the cluster. This happens because the dispersion of proper motions of field stars results from the dispersion of secular parallaxes, differential galactic rotation, peculiar motions and from observational errors, while the dispersion of proper motions of the cluster stars occur practically only due the observational errors, since the internal expansion of the cluster is negligible.

When the proper motion distribution is almost bimodal in both coordinate axes, the statistical method is efficient to segregate the members of the clusters and is able to discover new members. Based on these considerations, we applied statistical methods to the Tycho2 data of individual stars in the regions of clusters to determine the probability of membership of each star. The methods were those described by Vasilevskis & Rach (1957) and Sanders (1971), also discussed by Slovak (1977). The method of Vasilevskis and Rach was used to estimate the initial values of the parameters used in the method of Sanders.

Following the suggestion of Zhao et al. (1982), proper motions different from the mean by more than three times the standard deviation were discarded.

In Table 2 (available in electronic form at the CDS) we present the parameters provided by the method of Sanders. The mean proper motions of the clusters $(\mu_\alpha \cos\delta, \mu_\delta, \sigma)$ and the results of the two-dimensional Gaussian fit to the population of field stars are given. With the frequency function parameters we could determine the individual probability of the membership of each star of the cluster. The number of stars of the clusters presented in Table 2 are the values that give the best results for the searched parameters, and correspond to membership probability greater than 51%. Tables 5 to 117, only available in electronic form at the CDS, list the stars in the limits of each cluster, with the membership probabilities calculated by our method. The distances of the clusters are also given in Table 2.

4. Discussion of the results

As we already mentioned, our results cannot be easily compared with those in the literature previous to the Hipparcos mission, since they use a different system. Glushkova et al. (1997) presents proper motion measurements for 181 clusters (and 21 open clusters in Glushkova et al. 1996). The differences found are compatible with our estimated errors. Note that although Glushkova et al. claim that they determine absolute proper motion, they

[1] see also `http://obswww.unige.ch/webda/`.

do not refer to the Hipparcos system. Actually, the transformation from the 4M Catalogue (Gulyaev & Nesterov 1992) has to be done via the PPM Catalogue (Röser & Bastian 1991). We performed a quick comparison between the results of Glushkova et al. and those of BDW (187 objects in common), and we found a relative standard deviation of about of 5 mas/yr in both directions. This is larger than we would expect from the errors estimated in the two papers.

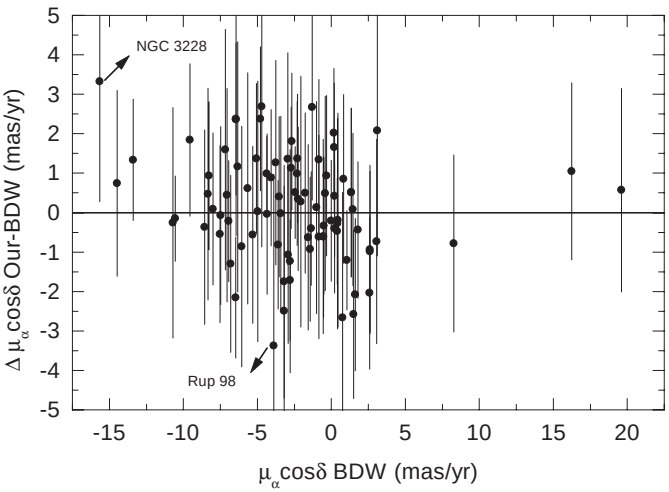

Fig. 1. Comparison of our mean proper motions with BDW in $\mu_\alpha \cos\delta$.

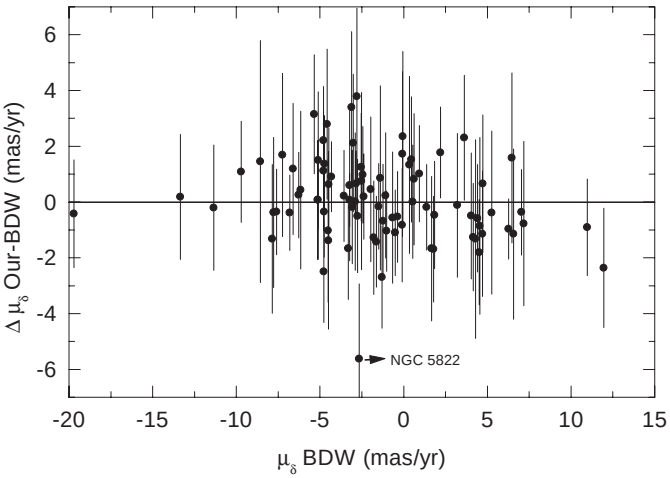

Fig. 2. Comparison of our mean proper motions with BDW in μ_δ.

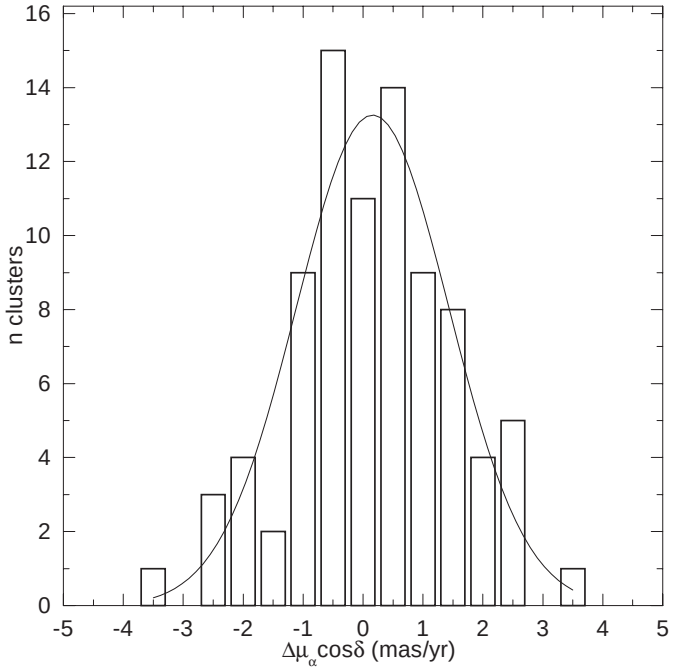

Fig. 3. Histogram of the mean proper motion differences of 86 common clusters with BDW in $\mu_\alpha \cos\delta$.

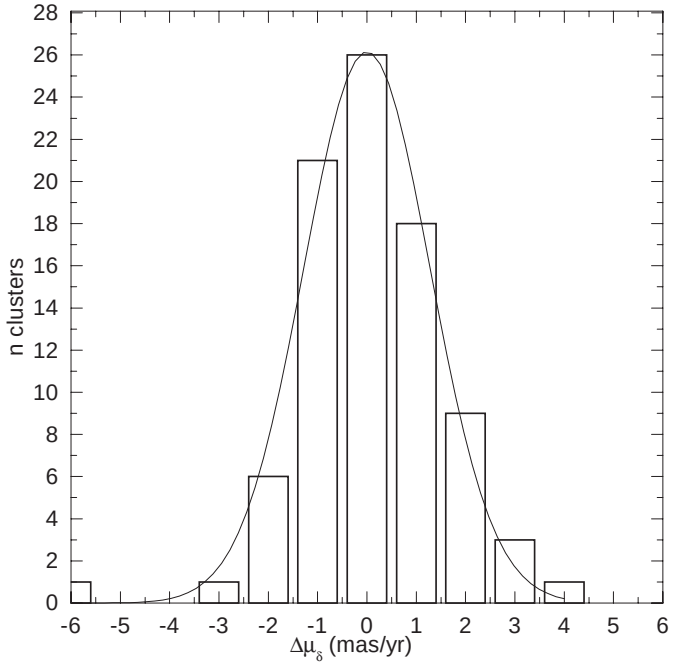

Fig. 4. Histogram of the mean proper motion differences of 86 common clusters with BDW in μ_δ.

Our results can be compared with those of BDW, that were directly taken from the Hipparcos Catalogue. We present the differences for 86 common objects in Figs. 1 and 2. Gaussian fits to the histogram of differences (Figs. 3 and 4) give the mean proper motion differences of 0.1 mas/yr in $\mu_\alpha \cos\delta$ and 0 mas/yr in μ_δ; the root mean square differences are 1.2 mas/yr in $\mu_\alpha \cos\delta$ and 1.3 mas/yr in μ_δ.

The differences between BDW and our work are within the precision of our measurements, in most cases. The mean of the differences show that there is no systematic trend, and the small value of the mean square difference assures that both sets of measurements are in agreement.

However, for 3 clusters, commented below, larger differences where found. In Fig. 1 we can see two discordant points and in Fig. 2 one discordant point, that present

differences of about 3 mas/yr. The points refer to the clusters NGC 3228, Rup 98 and NGC 5822, respectively.

4.1. Ruprecht 98

One point that differs from BDW in Fig. 1 refers to Rup 98. For this cluster the proper motion of BDW was determined based on one star only (HIP 58432). This star is present in the Tycho 2 sample and our analysis shows that this star has a high membership probability ($P = 93\%$). The difference obtained is due to the difference between Tycho2 ($\mu_\alpha \cos\delta = -6.40$ mas/yr and $\mu_\delta = -9.30$ mas/yr) and Hipparcos ($\mu_\alpha \cos\delta = -3.88$ mas/yr and $\mu_\delta = -8.57$ mas/yr) proper motion.

Our statistical analysis confirms the membership of HIP 58432, but suggests that our proper motion determination, based on a large number of stars, is the correct one.

4.2. NGC 3228

We obtain a mean proper motion different from that of BDW. In this case, the proper motion given by BDW is based on 4 Hipparcos stars, and interestingly, 3 stars are present in our sample and were selected by our method. It seems that for this cluster our method is unable to distinguish the members from the background, which has approximately the same proper motion. We can see in Table 2 that the average proper motion of the background stars is quite different from zero. This cannot be explained by the reflex solar motion, since distant stars are expected to present negligible proper motion. Since the cluster is in the direction of the Carina spiral arm of the galaxy, it is possible that in the field studied, the population of stars belonging to the arm dominates over the more distant stars, and we get a biased background.

Based on this analysis, and considering the direction of the cluster and its small distance (529 pc), we expect NGC 3228 to present a large proper motion, and in this case, the result of BDW is probably correct.

4.3. NGC 5822

We could not find the origin of the problem for NGC 5822. In this case, many more stars were used in our statistical analysis and the Hipparcos proper motions agrees with the Tycho2 ones, for the two stars used by BDW. The selection of membership in our results is not reliable because there is no conspicuous separation of two populations in the investigated field.

It is possible that in this case, the large difference with respect to BDW could be explained by the large scattering of proper motions in μ_δ. The BDW mean proper motion of NGC 5822 may not express the real proper motion of the centroid of the cluster. A more detailed investigation using faint stars could be helpful to solve this doubt.

4.4. The analyses of the stars in Collinder 399 and Roslund 5

Two controversial objects (Col 399 $\alpha = 19^{\rm h}25^{\rm m}$; $\delta = +20^{\rm o}11'$ and Ros 5 $\alpha = 20^{\rm h}10^{\rm m}$; $\delta = +33^{\rm o}46'$ in J2000), discussed by Baumgardt (1998, hereinafter B98) were investigated with the help of Tycho2 proper motions.

An area of two times the area covered by the clusters (centered on the coordinates below) was examined and no clear concentration of stars in the vector proper motion diagram (VPD) of Col 399 were found (see Fig. 5). Although the statistical solution could be compatible with the existence of an open cluster, the VPD and the large standard deviation in mean proper motion indicate that Col 399 is only a concentration of bright stars and not a real cluster, as suggested by B98.

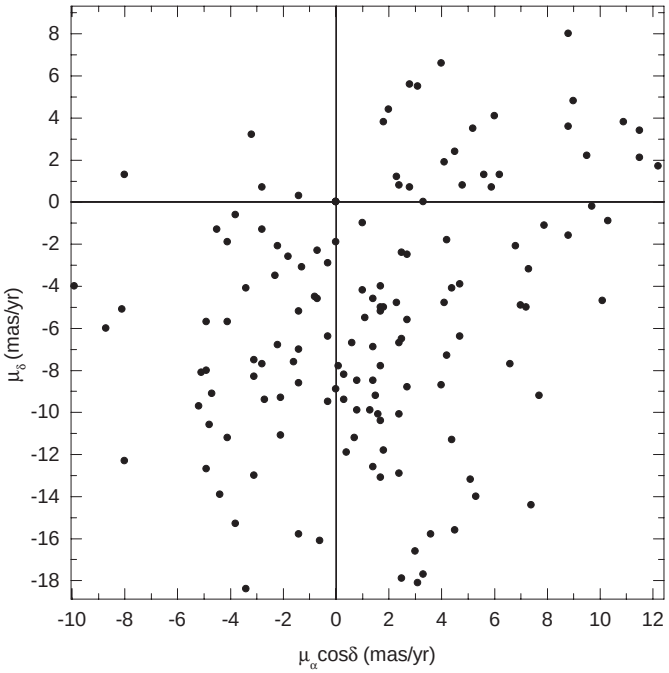

Fig. 5. Vector proper motion diagram of the stars in the region of the Collinder 399.

Also in the case of Ros 5, we do not see two separated populations. Tycho2 proper motions suggest the existence of a loose concentration of stars at $\mu_\alpha \cos\delta = 2.5$ mas/yr and $\mu_\delta = -1.5$ mas/yr.

B98 gives some arguments that corroborate the real existence of Ros 5. It is important to keep in mind that the Ros 5 is situated relatively far from the galactic plane ($b = +71.4^{\rm o}$) corresponding to $Z = 160$ pc for a distance of 500 pc. This distance to the plane may seem surprising for a young cluster ($\log t = 7.8$ years); a possible explanation could be star formation by the impact of a high-velocity cloud with the gas of the galactic plane (Lépine & Duvert 1994).

Table 3. Comparison between our results of mean proper motions of the clusters (Cols. 2 and 3) and those obtained in the literature (Cols. 4 and 5). Note that in the both sets the values are in the Hipparcos system, in mas/yr. In less two columns are given the difference (in modulus) that shows the coincidence of the results. To the clusters Col 135, Col 132 and Ros 5 the paper gives only the values of the concentration of proper motions in VPD. The references are given in text.

Cluster	$\mu_\alpha \cos\delta$	μ_δ	$\mu_\alpha \cos\delta$	μ_δ	$\Delta\mu_\alpha \cos\delta$	$\Delta\mu_\delta$	REF
Bla 1	20.2 ± 2.6	3.1 ± 2.6	19.2 ± 2.0	2.8 ± 2.0	1.0	0.3	a
Bla 1	20.2 ± 2.6	3.1 ± 2.6	19.15 ± 0.50	3.21 ± 0.27	1.0	0.1	c
Col 121*	-5.7 ± 3.2	3.7 ± 3.2	-5.1 ± 0.1	-1.5 ± 0.1	0.6	5.2	e
Col 121	-5.7 ± 3.2	3.7 ± 3.2	-3.88 ± 0.16	4.35 ± 0.19	1.8	0.6	c
Col 132	-2.0 ± 3.6	3.0 ± 3.6	-3.57 ± 0.24	4.16 ± 0.31	1.6	1.2	c
Col 132	-2.0 ± 3.6	3.0 ± 3.6	-3.0	4.0	1.0	1.0	d
Col 135	-10.7 ± 1.1	5.3 ± 1.1	-10.5	6.0	0.2	0.7	d
Col 140	-7.3 ± 1.8	2.7 ± 1.8	-8.52 ± 0.22	4.60 ± 0.28	1.2	1.9	c
IC 2391	-25.0 ± 1.2	22.8 ± 1.2	-24.6 ± 1.1	23.2 ± 1.1	2.5	0.2	a
IC 2391	-25.0 ± 1.2	22.8 ± 1.2	-25.06 ± 0.25	22.73 ± 0.22	0.1	0.1	c
NGC 1662	-1.9 ± 1.2	-2.2 ± 1.2	-3.2 ± 0.6	-1.6 ± 0.6	1.3	0.6	b
Pleiades (Mel 22)	19.9 ± 1.7	-45.0 ± 1.7	20.0 ± 1.8	-45.1 ± 1.8	0.1	0.1	a
Pleiades (Mel 22)	19.9 ± 1.7	-45.0 ± 1.7	19.15 ± 0.23	-45.72 ± 0.18	0.7	0.7	c
Ros 5	2.3 ± 2.7	-1.5 ± 2.7	3.0	1.0	0.7	2.5	d
Sto 2	17.3 ± 2.3	-13.2 ± 2.3	17.1 ± 4.6	-12.9 ± 4.6	0.2	0.3	a
Sto 2	17.3 ± 2.2	-13.2 ± 2.2	15.97 ± 0.75	-13.56 ± 0.54	1.3	0.4	c
Tru 10*	-14.5 ± 1.5	-3.4 ± 1.5	-14.3 ± 0.2	-4.9 ± 0.2	0.2	1.5	e
Tru 10	-12.1 ± 1.5	6.7 ± 1.5	-13.29 ± 0.25	7.32 ± 0.24	1.2	0.6	c
Tru 37	-1.6 ± 2.7	-1.8 ± 2.7	-3.75 ± 0.35	-3.48 ± 0.33	2.1	1.7	c

a) Sanner & Geffert (2001), A&A, 2001, 310, 87; **b)** Dias et al. (2000), A&A, 357, 149; **c)** Robicon et al. (1999), A&A, 345, 471; **d)** Baumgardt (1998), A&A, 340, 402; **e)** De Zeeuw et al. (1999), AJ, 117, 354

* Mean proper motions are in ($\mu_l \cos b$, μ_b)

Table 4. Hipparcos data of the stars in the region of the cluster Rup 147, Sto 10, VDBH 23, VDBH 34 respectively. In Cols. 1 and 2 are given the equatorial coordinates in J2000. Then are given: Hipparcos number, visual magnitude, the parallax (in mas) the proper motion in $\mu_\alpha \cos\delta$ and μ_δ (in mas/yr), the parallax error (in mas), $B-V$, and the membership probability obtained using our data (in %).

α_{2000}	δ_{2000}	num HIP	V	parallax(π)	$\mu_\alpha \cos\delta$	μ_δ	σ_π	$B-V$	P
19 15 26.117	−16 05 57.07	94635	7.43	3.57	−1.98	−27.84	1.01	1.259	100
19 17 23.845	−16 04 24.35	94803	7.65	3.75	−2.00	−27.33	1.04	1.396	100
05 39 04.270	+37 58 35.90	26585	7.51	3.74	−1.88	−1.27	0.99	0.043	69
05 39 36.800	+37 59 20.00	26632	6.96	2.60	−2.20	−0.81	0.99	0.015	87
05 41 31.090	+38 11 18.00	26803	8.18	2.68	−0.93	−3.05	1.16	0.308	80
08 12 50.710	−36 13 41.34	40218	7.62	3.20	−7.62	7.40	0.69	−0.129	92
08 13 18.194	−36 20 30.26	40255	7.32	2.67	−6.77	7.21	0.61	−0.120	92
08 13 22.654	−36 18 37.50	40268	7.34	2.51	−7.59	7.18	0.63	−0.143	92
08 13 29.517	−35 53 58.26	40274	4.78	3.33	−7.30	10.07	0.51	−0.110	36
08 13 58.312	−36 19 20.21	40321	5.09	2.77	−8.66	7.89	0.54	−0.184	85
08 13 58.700	−36 20 26.80	40324	6.11	2.20	−7.21	7.69	0.55	−0.185	75
08 15 58.823	−35 54 11.49	40485	6.15	1.72	−8.11	6.59	0.55	1.549	90
08 16 12.582	−35 52 55.74	40506	7.29	13.15	15.24	35.14	0.68	0.890	0
08 16 24.995	−36 12 09.35	40519	7.18	2.83	−10.50	7.03	0.65	−0.137	84
08 29 51.237	−44 44 36.40	41684	8.72	1.55	−1.42	2.81	0.84	0.042	76
08 30 39.230	−44 44 14.35	41737	6.30	1.46	−9.65	4.90	0.67	−0.007	69

4.5. Comparison with other astrometric studies

Some open clusters in our sample are in common with other individual astrometric studies. In this comparison we use only results of mean proper motion of the clusters given in the Hipparcos system. Comparison between the selected members with others selected by photometric criteria will be presented in a forthcoming paper.

Using recent positions obtained by meridian circle observations combined with other astrometric Catalogues, Dias et al. (2000) determined accurate mean proper motions of stars with $V \leq 15$ in the region of the open cluster NGC 1662. The membership determination was obtained

applying the Zhao & He (1990) method. Our present results are in agreement with Dias et al. (2000), the small difference being within the errors of our study.

We have in common with the work of De Zeeuw et al. (1999) the open clusters Trumpler 10 and Collinder 121. In that paper the proper motions are given in galactic coordinates ($\mu_l \cos b$, μ_b), and we transformed our mean proper motions to galactic coordinates ($\mu_l \cos b$, μ_b). We can see that our mean proper motions are in agreement with those of de Zeeuw et al., both results being different from those of BDW.

The nature of a number of open clusters was investigated by B98 using the Hipparcos data. In many cases B98 gives the values of proper motion of the concentration of the stars in the VPD. If we use these values as the mean proper motion of the clusters, it is possible to compare them with our results (Table 3), in spite of the small distances of these objects. Except for the difference of 2.5 mas/yr in Ros 5, our results are in good agreement with the literature. The difference are still within our errors and may be caused if the value of B98 (based only in two stars) does not well represent the real mean proper motion of the centroid of the cluster.

In another study, Robichon et al. (1999, hereinafter RAMT) determined the mean astrometric parameters of nearby ($d \leq 500$ pc) open clusters using data from the Hipparcos Catalogue. In this study two different member selections were applied to distinguish members from the field stars. For all clusters closer than 300 pc (and for 8 clusters closer than 500 pc) the parallaxes and proper motions of the stars were used and for the other clusters (farther than 500 pc or with less than 8 members in Hipparcos) the preselected stars in the Hipparcos Imput Catalogue (HIC) (Turon et al. 1992) were taken into account.

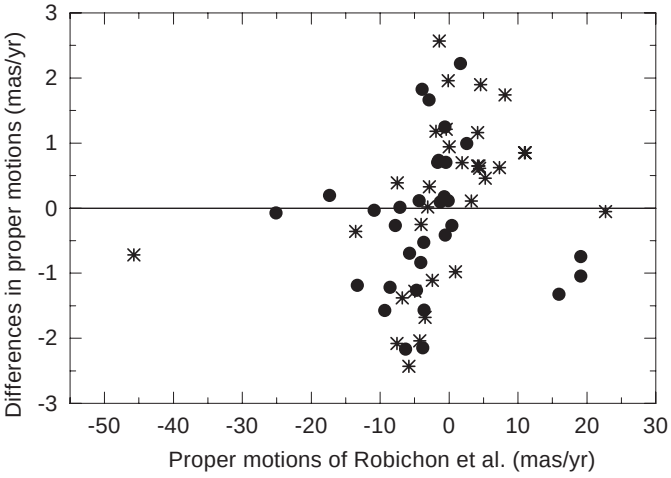

Fig. 6. Comparison of our results of mean proper motions with those provided by Robichon et al. (1999). The differences as a function of the Robichon et al. results are presented. Note that • represents the values in $\mu_\alpha \cos\delta$ and $*$ in μ_δ.

Our sample and that of RAMT have 32 objects in common and using this set we checked the quality of our mean proper motions. We determined the differences of each result (see Fig. 6) and the mean square difference in $\mu_\alpha \cos\delta$ and μ_δ (0.2 mas/yr). Clearly, no large differences can be seen and all of the differences are within 2.5 mas/yr, the typical error of our study.

4.6. Mean parallaxes of 4 clusters obtained from membership determination

We investigated the open clusters Ruprecht 147 ($\alpha = 19^{\rm h}16^{\rm m}$; $\delta = -16^{\rm o}17'$; J2000, Stock 10 ($\alpha = 05^{\rm h}39^{\rm m}$; $\delta = +37^{\rm o}56'$; J2000, vdB-Hagen 23 ($\alpha = 08^{\rm h}14^{\rm m}$; $\delta = -36^{\rm o}23'$; J2000) and vdB-Hagen 34 ($\alpha = 08^{\rm h}31^{\rm m}$; $\delta = -44^{\rm o}30'$; J2000) that have no distance determined. The identification of the members of the cluster allows us to use the data from the Hipparcos Catalogue to derive the distance of these objects (see Table 4). The parameters obtained from the Sanders method for these clusters are given in Table 2; using 2 stars for Rup 147, 3 stars for Sto 10, 7 stars for VDBH 23 and 2 star for VDBH 34 we derive the mean parallax of 3.7 ± 0.2, 3.0 ± 0.6, 2.6 ± 0.5 and 1.5 ± 0.05 respectively. We can see that these clusters are within 1 kpc with distances of roughly 250 pc, 333 pc, 384 pc and 666 pc, respectively.

This constitutes the first estimation of the distance of these clusters but a more rigorous photometric investigation is of interest to confirm these values.

5. Summary

Mean proper motions of 112 open clusters from all over the sky and within 1 kpc were determined using the data provided by the Tycho2 Catalogue. Applying the statistical method of Sanders (1971) we asserted the membership of 4006 stars and we determined for the first time mean proper motions of 28 clusters.

A comparison of our results with those of BDW showed that both sets are in agreement. In a few cases with discrepant results, we could show that the differences were real differences between Tycho2 and Hipparcos, or due to the too small numbers of stars considered by BDW. Similar conclusions were obtained from comparisons with other studies involving smaller number of clusters in the literature. These comparisons make us confident that the proper motions derived for the first time are correct, and provide a useful confirmation of BDW results, using a larger sample of stars.

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