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A revisit to the regions of some van den Bergh open clusters using photometric and astrometric parameters

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HIGHLIGHTS

- We determine astrometric parameter and stellar members of vdB80, vdB85 and vdB130.
- vdB80 and vdB85 astrometric parameters are determined for the first time using UCAC4.
- We find that proper motion errors do not significantly affect astrometric results.
- Astrometric members are compared with the photometric ones given in the literature.

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ABSTRACT

We present results of a study that combines photometry and astrometry for the open clusters vdB80, vdB85 and vdB130. We apply a model which analyses the proper motion distribution and the stellar density to find the kinematic parameters and stellar membership in the region of the mentioned open clusters. The astrometric data are obtained from UCAC4 catalogue. For each cluster, we report the centre coordinates, the components of mean proper motion, the angular diameter and the astrometric members. They are: vdB80: $\alpha = 97^\circ.73938 \pm 0^\circ.00846$, $\delta = -9^\circ.66953 \pm 0^\circ.01177$, $\mu_\alpha cos\delta = -2.13 \pm 0.47$ mas/yr, $\mu_\delta = -0.95 \pm 0.47$ mas/yr, 12′, 15 members; vdB85: $\alpha = 101^\circ.71670 \pm 0^\circ.00808$, $\delta = 1^\circ.34392 \pm 0^\circ.01253$, $\mu_\alpha cos\delta = 0.89 \pm 0.43$ mas/yr, $\mu_\delta = 3.24 \pm 0.43$ mas/yr, 8′, 9 members; vdB130: $\alpha = 304^\circ.44001 \pm 0^\circ.01407$, $\delta = 39^\circ.32745 \pm 0^\circ.00726$, $\mu_\alpha cos\delta = -4.14 \pm 0.25$ mas/yr, $\mu_\delta = -5.15 \pm 0.25$ mas/yr, 9′, 9 members. We analyse the incidence of the proper motion errors in the determination of the cluster parameters and of the stellar membership and find that they are not significantly changed. We finally compare the astrometric members with the photometric ones given in the literature.

1. Introduction

In 1966 van den Bergh publishes a catalog of 158 reflection nebulae and remarks that several of them contain open clusters named as the reflection nebula to which they are associated. The knowledge of these embedded clusters let study the very initial phases of star formation (Bica et al., 2003).

Some of these clusters have been investigated using photometric techniques in order to determine the member stars, consequently the cluster fundamental parameters, e.g. distances, masses, ages, metallicity, mean radial velocity can be derived. An accurate knowledge of their members is therefore crucial.

Due to the fact that open cluster members share similar photometric and kinematic properties, it is worth to complete the study of the stars of the clusters field by employing astrometric methods. This analysis contributes to remove the contamination effect arised from a photometric membership determination, as Corti and Orellana (2013) demonstrate it in their investigations on the open cluster NGC 4755 and the stellar association CenOB1.

In this work we present improvements of the membership probability of the stars in the regions of the open clusters vdB80, vdB85 and vdB130, whose photometric members are given in the literature.

Open cluster vdB80: has equatorial coordinates $\alpha = 6^h30^m50^s$ and $\delta = -9^\circ 39' 18''$ ($l = 219^\circ.26$, $b = -8^\circ.93$) and is placed in Monoceros. It was first identified by van den Bergh (1966) and

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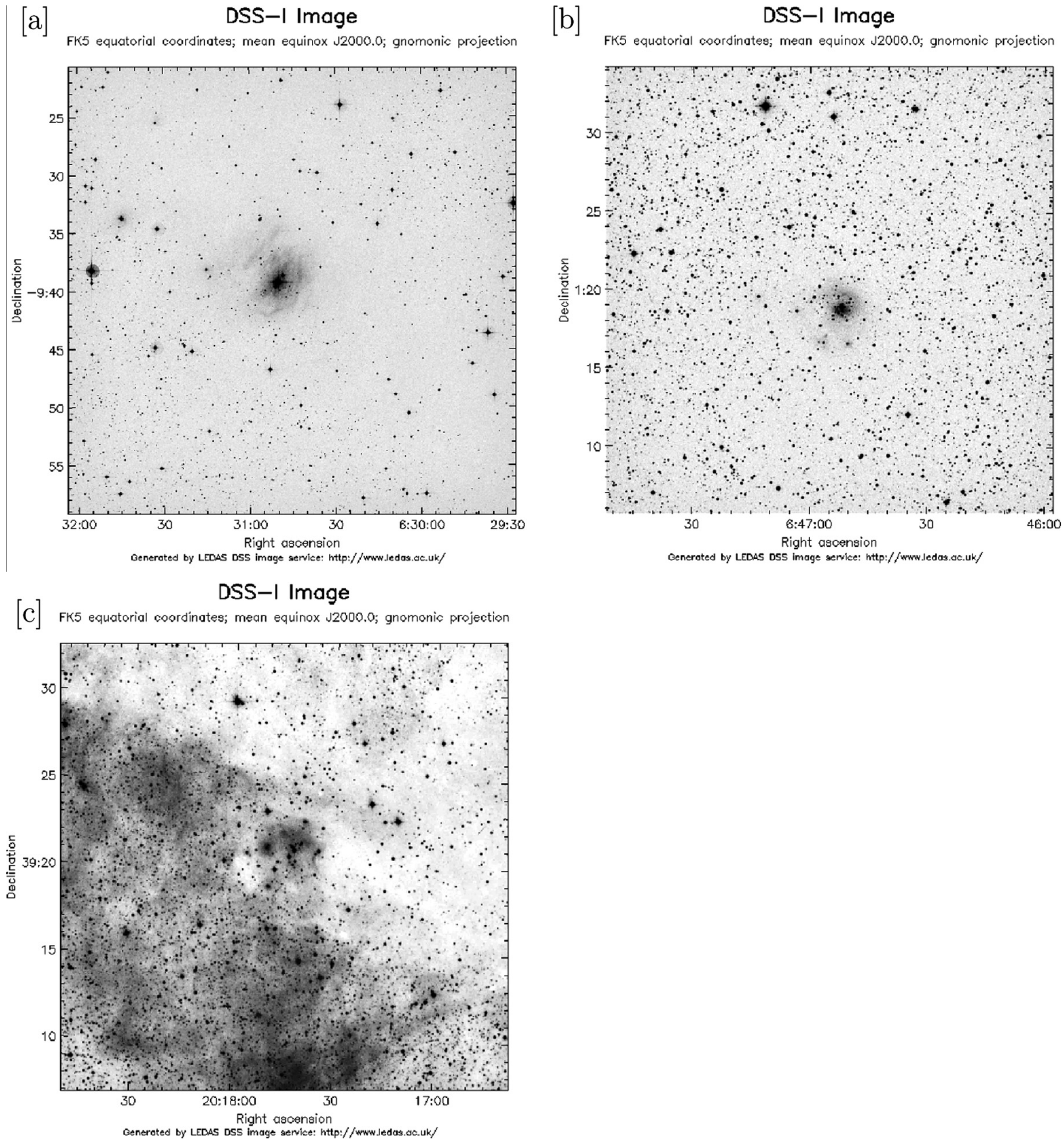

Fig. 1. Images of the optical environments of open clusters vdB80 (a), vdB85 (b), vdB130 (c). Right ascension and declination are given in the abscissa and ordinate, respectively. Orientation: north to the top and east to the left.

contains the stars BD −9 1498 (HD 46060) and BD −9 1497. Racine (1968) performed photometry and spectroscopy for 80a (HD 46060) and photometry for 80b (BD −9 1497) y 80c. In 1972 Aveni and Hunter (1972) study this compact cluster and determined spectral type and photometric data for a 24-star sample. They found seven possible members considering their spectroscopic distances and estimated the cluster age in 10^6 yr. Ahumada et al. (2001) estimate its age in $4.5 \pm 1.5 \times 10^6$ yr by an integrated spectrum indicating that it is a very young cluster. A more extensive analysis using 2MASS data is done by Bonatto and Bica (2009). They identify the members up magnitude 16 from a colour-magnitude diagram where a poorly populated main sequence and many pre-MS stars are displayed. In addition, they determine the cluster age of 5 ± 2 Myr, a distance of 2.1 ± 0.3 kpc, a mass of $95 \pm 17\ M_{\odot}$ and the analysis of the stellar density profile gives the value of $0.46 \pm 0.08'$ for core and of $5.8 \pm 0.3'$ for the cluster.

Open cluster vdB85: discovered in 1966 by van den Bergh, its is placed in Monoceros. Its equatorial coordinates are $\alpha = 06^h46^m54^s$ and $\delta = +01^{\circ}20'00''$ ($l = 211^{\circ}.2280$, $b = -00^{\circ}.4014$) and it includes the star BD + 1 1503 (HD289120). Racine (1968) makes photometric and spectroscopic observations of this star. The reflection nebula vdB-RN85 is also named as NGC 2282 in the literature. The first detailed near-infrared (JHK) imaging and photometry of the young open cluster associated to NGC 2282 is conducted by Horner et al. (1997). They investigate fundamental parameters of the cluster and the surrounding region, identify about 100 cluster members and locate the cluster at 1.7 kpc.

Open cluster vdB130: is situated in Cygnus and their coordinates are $\alpha = 20^h17^m42^s$ and $\delta = +39^{\circ}21'00''$ ($l = 76^{\circ}.9083$, $b = +02^{\circ}.0721$). It is first identified by van den Bergh in 1966 including the star BD + 38 3993 (HD228789). In 1968, Racine identifies two stars as cluster members and carries out photometric and spectroscopic observations, being HD228789 one of these stars. In 1974, he identifies 14 stars as open cluster members on the basis of their apparent connection with the nebular material and reports photometry and spectroscopy thereof. Moffat and Schmidt-Kaler (1976) review Racine's data, rederived their intrinsic properties and find a distance of 1.4 kpc for the cluster. Using UCAC4 data, Dias et al. (2014) determine mean proper motion and membership probabilities from a small sample of 62 stars in a region of radius of 4 arcmin. They obtain $\mu_\alpha \cos\delta = -3.61 \pm 3.32$ mas/yr and $\mu_\delta = -4.58 \pm 3.37$ mas/yr and find that 50 stars of the sample are cluster members.

The images of the optical environments of the three open clusters are taken from the Digital Sky Survey (DSS)[1] (Fig. 1).

2. The data

The astrometric data used in this paper, stellar position and proper motion, come from the UCAC4 Catalogue with positions over 113 million stars and 105 million of them with proper motions. The catalogue is complete to about magnitude $R = 16$ and with at least about 40 stars per square deg anywhere on the sky. The average density of this catalogue is over 2000 stars per square deg.

The UCAC4 catalogue presents very precise proper motions. They result from the combination with the re-analysis of additional 140 star catalogs, including Hipparcos/Tycho and the AC2000.2, as well as unpublished measures of over 5000 plates from other astrographs.

Errors in proper motions of the bright stars (to $R \sim 12$) run from about 1–3 mas/yr benefited by the large epoch spans involved. For the fainter stars using SPM and NPM data, typical errors are 2–6 mas/yr. The astrometry provided in UCAC4 is on the Hipparcos system, i.e. the International Celestial Reference System (ICRS), as represented by the Tycho-2 catalog. Positions in UCAC4 are given at the standard epoch of Julian date 2000.0, thus the UCAC4 is a compiled catalog. Positional errors are about 15–20 mas for stars in the 10–14 mag range. These data are supplemented by 2MASS photometric data for about 110 million stars and 5-band (B, V, g, r, i) photometry from the APASS (AAVSO Photometric All-Sky Survey) for over 50 million stars. A detailed description of the construction of UCAC4 catalogue can be found in Zacharias et al. (2013).

Data extraction has been performed using the Vizier.[2]

3. Astrometric analysis

3.1. Cluster centre coordinates

We analyse the projected stellar density of each cluster in a region around each BD or CD star associated with the reflection nebulae catalogued by van den Bergh (1966). The size and magnitude limit of the selected region depend on local characteristics. We consider the faintest magnitude up to which an overdensity can be distinguished. Up to the 15 magnitude, we examine a region sized of $15' \times 15'$ for vdB85 and another of $24' \times 24'$ for vdB130. A region of $15' \times 15'$ is chosen for vdB80 analysis considering all magnitudes.

We evaluate the observed local density at the nodes of a grid of a given size by adding the stars within a circle whose radius s_0 is weighted by a smoothing parameter following Stock and Abad's rule (Stock and Abad, 1988). The node with the highest density

Table 1
Sizes of the grid and radius selected to evaluate the local density in the region of the clusters and the approximate cluster centre coordinate (α_0, δ_0).

	Grid's size	s_0	α_0 [°]	δ_0 [°]
vdB 80	$0'.5 \times 0'.5$	$2'.2$	97.71542 ± 0.01240	−9.65500 ± 0.01222
vdB 85	$0'.5 \times 0'.5$	$3'$	101.72167 ± 0.01667	1.32333 ± 0.01667
vdB 130	$0'.5 \times 0'.5$	$1'.5$	304.43783 ± 0.01078	39.34550 ± 0.00833

is adopted as the centre of the cluster with coordinates (α_0, δ_0). It represents an approximate value of the cluster centre because it is determined only considering the spatial over-density. The grid and radius sizes depend on the local cluster regions, as shown in Table 1.

An example of the resulting projected stellar density is shown in Fig. 2.

The centre of the over-density was adopted as the position (α_0, δ_0) of the grid-point with the highest projected spatial density.

3.2. Mean proper motion and membership determination

An over-density in the sky as well as in the vector point diagram (VPD) indicates the existence of an open cluster. We adopt the mathematical model suggested by Vasilevskis et al. (1958) and the technique based upon the maximum likelihood principle developed by Sanders (1971) to detect these over-densities.

The proper motion distribution consists in the overlapping of two bivariate normal frequency functions in an elliptical subregion of the VPD:

$$\Phi_i(\mu_{xi}, \mu_{yi}, r_i) = \phi_{ci}(\mu_{xi}, \mu_{yi}, r_i) + \phi_{fi}(\mu_{xi}, \mu_{yi}), \quad (1)$$

where ϕ_{ci} is a circular distribution for cluster stars, ϕ_{fi} is an elliptical distribution for field stars; μ_{xi}, μ_{yi} are the ith star proper motion in x and y, respectively. These coordinate axes are coincident with the field distribution ones after rotating the VPD by an angle θ (Vasilevskis et al., 1965).

The model is improved using an exponential function ρ_c to describe the areal stellar density for the cluster stars (Jones and Walker, 1988).

$$\rho_c(r_i) = \rho_0 \exp(-r_i/r_0), \quad (2)$$

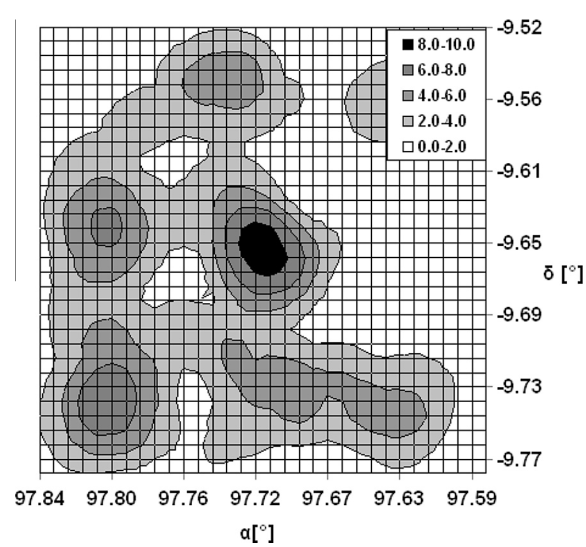

Fig. 2. Projected density map of UCAC4 stars in the region of vdB80. The scale of grey represents the different values of the density. The point with the highest density is adopted as the centre of the cluster.

[1] We thank the Leicester Database and Archive Service (LEDAS) <www.ledas.ac.uk/DSSimage/aboutdss> and the Space Telescope Science Institute (STScI) for the use of their images.
[2] <http://vizier.u.strasbg.fr/viz-bin/VizieR?-source=UCAC4>.

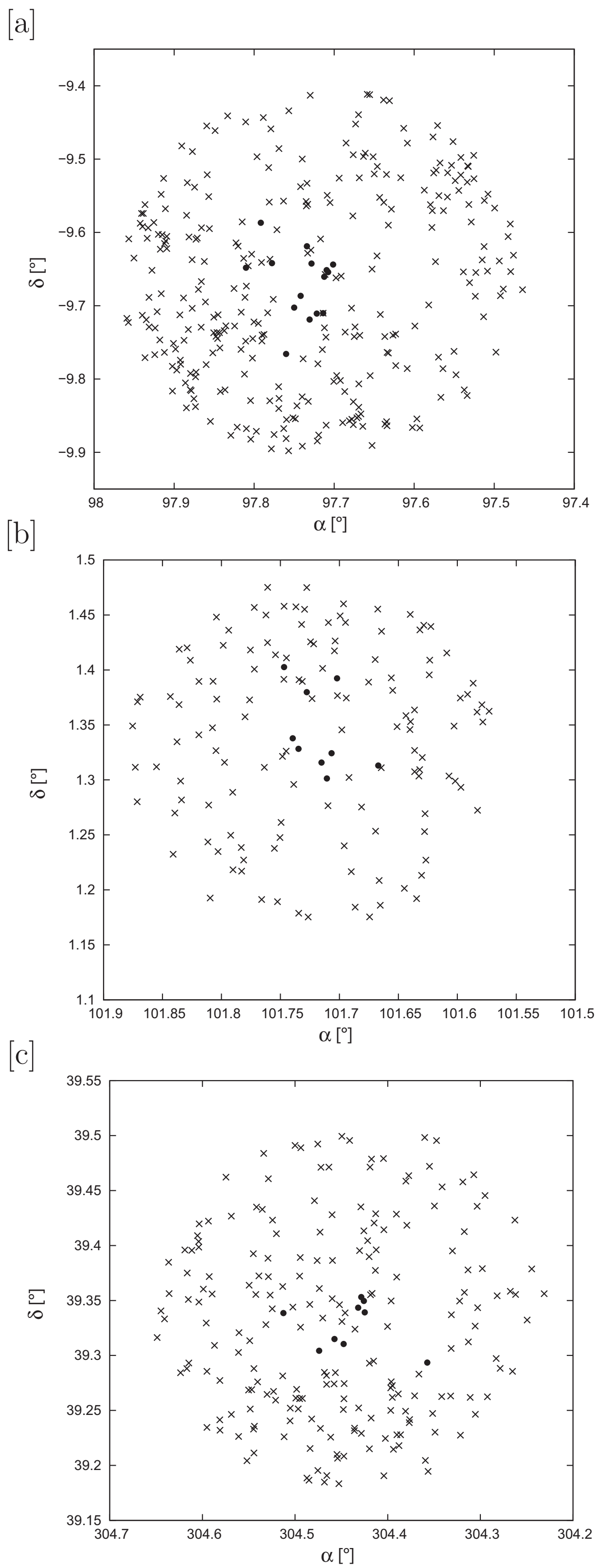

Fig. 3. Stellar positions in the region of vdB80 (a), vdB85 (b) and vdB130 (c). The black circles represent the astrometric cluster members and crosses the rest of the stars in the ellipse.

where ρ_0 is the central cluster stellar density, r_0 is the characteristic radius and r_i the distance from the cluster's centre. The function for the areal stellar density for field stars ρ_f is constant.

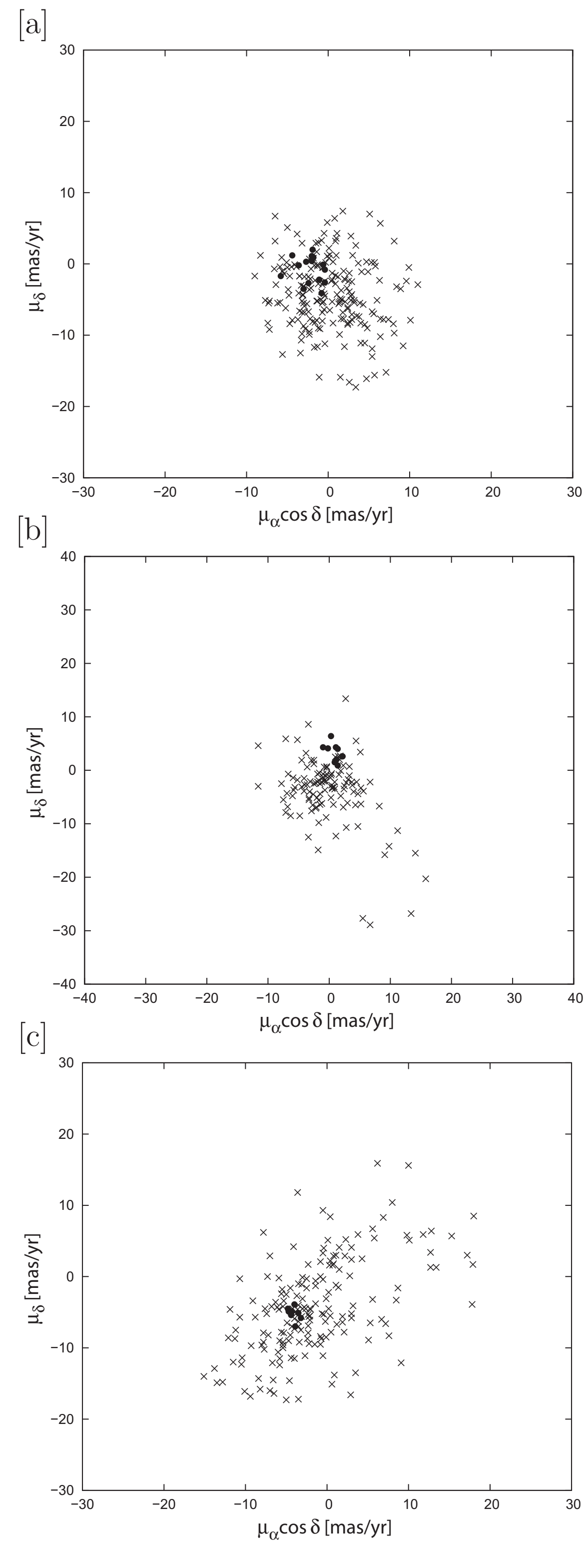

Fig. 4. Vector point diagram in the region of vdB80 (a), vdB85 (b) and vdB130 (c), proper motions are in units of mas/yr. The black circles represent the astrometric cluster members and crosses the rest of the stars in the ellipse.

The stellar radial density profile of the region is modelled by the overlapping of the functions mentioned above:

$$\rho(r_i) = \rho_c(r_i) + \rho_f. \tag{3}$$

The circular and elliptical distributions take the following form (Orellana et al., 2010).

$$\phi_{ci}(\mu_{xi},\mu_{yi},r_i) = \frac{\rho_c(r_i)}{2\pi\sigma_c^2} \times \exp\left[-\frac{(\mu_{xi}-\mu_{xc})^2+(\mu_{yi}-\mu_{yc})^2}{2\sigma_c^2}\right] \quad (4)$$

and

$$\phi_{fi}(\mu_{xi},\mu_{yi}) = \frac{\rho_f}{2\pi\sigma_{xf}\sigma_{yf}} \times \exp\left[-\frac{(\mu_{xi}-\mu_{xf})^2}{2\sigma_{xf}^2}-\frac{(\mu_{yi}-\mu_{yf})^2}{2\sigma_{yf}^2}\right], \quad (5)$$

where μ_{xf}, μ_{yf} are the field mean proper motion, σ_{xf}, σ_{yf} the elliptical dispersions for field stars, μ_{xc}, μ_{yc} the cluster mean proper motion, and σ_c its circular dispersion. These parameters are obtained after applying the method of maximum likelihood to Eqs. (4) and (5). See Orellana et al. (2010) for a detailed explanation of the method.

The probability for the ith star is calculated as

$$P_{ci}(\mu_{xi},\mu_{yi},r_i) = \frac{\phi_{ci}(\mu_{xi},\mu_{yi},r_i)}{\Phi_i(\mu_{xi},\mu_{yi},r_i)}. \quad (6)$$

A cluster member is found when $P_{ci} \geqq 0.5$.

3.3. Results

3.3.1. Open cluster vdB80

We choose the stars in a circular region of radius 15′ centred at $\alpha_0 = 97^\circ.71542 \pm 0^\circ.00833$, $\delta_0 = -9^\circ.65500 \pm 0^\circ.00833$ containing 304 stars. The proper motion data is analysed in an elliptical subregion of the VPD containing 219 stars, where $\theta = 80^\circ.26 \pm 1^\circ.63$.

The parameters $\rho_0 = 1.611 \pm 0.079$ stars/(′)^2, $r_0 = 1'.958 \pm 0'.117$ and $\rho_f = 0.272 \pm 0.011$ stars/(′)^2 adjust the function $\rho(r_i)$ to the radial stellar density profile.

After Eqs. (4) and (5) are resolved, the cluster parameters are $\mu_\alpha cos\delta_c = -2.13 \pm 0.47\, mas/yr$, $\mu_{\delta c} = -0.95 \pm 0.47\, mas/yr$, $\sigma_c = 1.84 \pm 0.33\, mas/yr$ and the field parameters $\mu_\alpha cos\delta_f = 0.19 \pm 0.35\, mas/yr$, $\mu_{\delta f} = -4.22 \pm 0.28\, mas/yr$, $\sigma_{\mu_\alpha cos\delta_f} = 4.98 \pm 0.25\, mas/yr$ and $\sigma_{\mu_{\delta f}} = 4.00 \pm 0.20\, mas/yr$.

15 stars are found to be astrometric members of the cluster. Their coordinates lead to calculate the equatorial coordinates of the centre of the cluster ($\alpha_c = 97^\circ.73938 \pm 0^\circ.00846$, $\delta_c = -9^\circ.66953 \pm 0^\circ.01177$) and a value of 6′ for radius. The location

Table A.4
vdB80 Astrometric members.

No.	UCAC4	α [°]	ϵ_α [mas]	δ [°]	ϵ_δ [mas]	$\mu_\alpha cos\delta$ [mas/yr]	$\epsilon_{\mu_\alpha cos\delta}$ [mas/yr]	μ_δ [mas/yr]	ϵ_{μ_δ} [mas/yr]	Membership probability
3	402-013693	97.7124409	17	−9.6604706	17	−2.7	3.2	0.3	1.5	0.98
4	402-013689	97.7093718	21	−9.6514173	9	−0.6	4.2	−0.1	1.9	0.96
5	402-013688	97.7075595	3	−9.6541095	3	−1.8	1.6	0.9	1.2	0.97
7	402-013686	97.7012712	22	−9.6438942	23	−0.4	1.7	−0.8	1.6	0.94
8	402-013700	97.7283609	64	−9.6424945	45	−1.9	4.7	2.0	4.9	0.93
13	402-013704	97.7339971	20	−9.6188395	20	−3.0	4.1	−3.5	4.5	0.83
14	402-013706	97.7418712	44	−9.6866170	42	−0.8	4.6	−4.1	5.0	0.65
16	402-013694	97.7137992	30	−9.7102220	30	−3.6	4.3	−0.2	4.6	0.90
17	402-013699	97.7217315	26	−9.7106406	26	−2.0	4.5	0.4	4.9	0.89
18	402-013707	97.7499574	120	−9.7025853	110	−5.8	6.1	−1.7	6.2	0.71
21	402-013710	97.7777180	176	−9.6419756	187	−2.4	7.5	−2.7	8.0	0.80
22	402-013702	97.7307018	131	−9.7188525	137	−0.4	5.5	−2.6	5.9	0.68
38	402-013724	97.8101648	137	−9.6481231	141	−1.1	5.9	−2.2	6.1	0.60
47	403-014263	97.7916030	111	−9.5868687	111	−4.4	5.2	1.2	5.4	0.54
64	402-013708	97.7600824	48	−9.7657906	40	−2.0	4.5	1.1	4.8	0.50

Table A.5
vdB85 Astrometric members.

No.	UCAC4	α [°]	ϵ_α [mas]	δ [°]	ϵ_δ [mas]	$\mu_\alpha cos\delta$ [mas/yr]	$\epsilon_{\mu_\alpha cos\delta}$ [mas/yr]	μ_δ [mas/yr]	ϵ_{μ_δ} [mas/yr]	Membership probability
7	457-022546	101.7151527	11	1.3158162	12	0.9	1.1	1.5	0.8	0.96
10	457-022567	101.7346874	25	1.3282523	24	2.2	7.2	2.6	7.4	0.97
13	457-022539	101.7066503	70	1.3242617	195	−1.0	7.7	4.3	24.5	0.94
20	457-022575	101.7395562	19	1.3378134	14	1.1	2.2	4.3	1.3	0.97
23	457-022542	101.7106306	66	1.3012903	50	0.3	9.9	6.4	4.3	0.76
51	457-022500	101.6670524	14	1.3131103	12	1.4	2.0	0.9	1.3	0.52
54	457-022562	101.7276224	13	1.3797695	15	1.4	1.0	4.0	1.4	0.88
72	457-022533	101.7020168	29	1.3923925	44	−0.2	3.6	4.1	4.7	0.68
108	458-023822	101.7469306	44	1.4025950	19	1.2	4.2	2.0	2.3	0.51

Table A.6
vdB130 Astrometric members.

No.	UCAC4	α [°]	ϵ_α [mas]	δ [°]	ϵ_δ [mas]	$\mu_\alpha cos\delta$ [mas/yr]	$\epsilon_{\mu_\alpha cos\delta}$ [mas/yr]	μ_δ [mas/yr]	ϵ_{μ_δ} [mas/yr]	Membership probability
1	647-086785	304.4318889	18	39.3434017	18	−4.4	0.9	−5.4	1.1	1.00
3	647-086776	304.4258074	12	39.3495545	11	−4.3	0.8	−4.9	0.5	1.00
4	647-086781	304.4286059	15	39.3531487	18	−4.0	3.3	−3.9	4.0	0.98
6	647-086775	304.4248483	36	39.3392048	49	−3.9	4.4	−7.0	7.0	0.91
22	647-086813	304.4574574	16	39.3149856	31	−4.4	1.9	−5.3	3.7	0.98
26	647-086802	304.4475909	65	39.3104470	26	−3.5	6.0	−5.1	2.8	0.97
38	647-086831	304.4740324	32	39.3042850	34	−3.2	4.8	−5.8	4.5	0.84
54	647-086871	304.5125998	12	39.3385159	12	−4.8	0.9	−4.5	0.6	0.84
99	647-086711	304.3572898	15	39.2935173	23	−4.7	1.3	−4.9	1.7	0.63

Table 2
Centre coordinates, mean proper motion, number of members N and diameters of the clusters.

Cluster	α_c [°]	δ_c [°]	$\mu_\alpha cos\delta$ [mas/yr]	μ_δ [mas/yr]	N	Diameter [′]
vdB80	97.73938 ± 0.00846	−9.66953 ± 0.01177	−2.13 ± 0.47	−0.95 ± 0.47	15	12
vdB85	101.71670 ± 0.00808	1.34392 ± 0.01253	0.89 ± 0.43	3.24 ± 0.43	9	8
vdB130	304.44001 ± 0.01407	39.32745 ± 0.00726	−4.14 ± 0.25	−5.15 ± 0.25	9	9

of the members in the spatial distribution and in the VPD are shown with black circles in Figs. 3a and 4a, respectively. Table A.4 gives our numbering system No., the UCAC4 number, the equatorial coordinates with their errors, the components of proper motion with their errors and the membership probability (P_{ci}).

3.3.2. Open cluster vdB85

We take 139 stars in a circular region of radius 9′.5 centred at $\alpha_0 = 101.^\circ 72167 \pm 0^\circ.00833$, $\delta_0 = 1^\circ.32333 \pm 0^\circ.00833$. The elliptical subregion of the VPD contains 127 stars and $\theta = 71^\circ.08 \pm 1^\circ.93$.

The parameters $\rho_0 = 1.416 \pm 0.339$ stars/(′)^2, $r_0 = 1'.171 \pm 0'.299$ and $\rho_f = 0.383 \pm 0.039$ stars/(′)^2 fit the function $\rho(r_i)$ to the radial stellar density profile.

Table 3
Influence of observational errors: means of the mean proper motion and of the number of members N from the 25 simulated samples for each cluster.

	$\mu_\alpha cos\delta$ [mas/yr]	μ_δ [mas/yr]	N
vdB80	−1.93 ± 0.18	−0.80 ± 0.25	15 ± 1
vdB85	0.68 ± 0.23	2.04 ± 0.25	9 ± 1
vdB130	−4.30 ± 0.20	−5.32 ± 0.21	9 ± 1

The cluster parameters take the values $\mu_\alpha cos\delta_c = 0.89 \pm 0.43$ mas/yr, $\mu_{\delta c} = 3.24 \pm 0.43$ mas/yr, $\sigma_c = 1.28 \pm 0.29$ mas/yr and the field parameters $\mu_\alpha cos\delta_f = -0.33 \pm 0.62$ mas/yr, $\mu_{\delta f} = -3.66 \pm 0.41$ mas/yr, $\sigma_{\mu_\alpha cos\delta_f} = 6.80 \pm 0.43$ mas/yr and $\sigma_{\mu_{\delta f}} = 4.52 \pm 0.29$ mas/yr.

We find 9 astrometric cluster members and then calculate the equatorial coordinates of the centre of the cluster $\alpha_c = 101^\circ.71670 \pm 0^\circ.00808$, $\delta_c = 1^\circ.34392 \pm 0^\circ.01253$ and the value of 4′ for the radius. The location of the members in the spatial distribution and in the VPD are shown with black circles in Figs. 3b and 4b, respectively. Table A.5 gives our numbering system, the UCAC4 number, the equatorial coordinates with their errors, the components of proper motion with their errors and the membership probability (P_{ci}).

3.3.3. Open cluster vdB130

The model is applied in a circular region of radius 10′ and centred at $\alpha_0 = 304.^\circ 43783 \pm 0^\circ.00833$, $\delta_0 = 39^\circ.34550 \pm 0^\circ.00833$ with 213 stars. The elliptical subregion of the VPD contains 192 stars and $\theta = 213^\circ.25 \pm 3^\circ.43$.

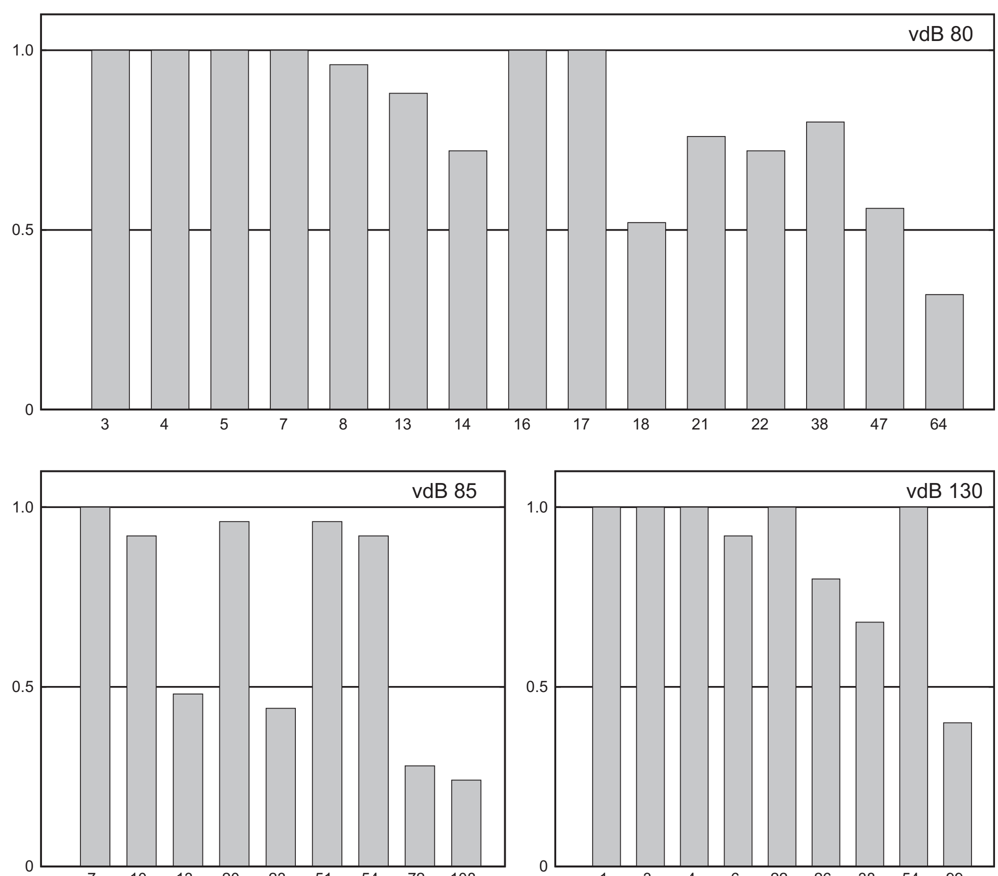

Fig. 5. Histogram showing the probability in which a cluster member previously determined keeps its membership condition throughout the 25 simulations for vdB80, vdB85 and vdB130.

The parameters $\rho_0 = 3.645 \pm 0.190$ stars/$(')^2$, $r_0 = 0'.910 \pm 0'.040$ and $\rho_f = 0.656 \pm 0.009$ stars/$(')^2$ adjust the function $\rho(r_i)$ to the radial stellar density profile. The cluster parameters take the values $\mu_\alpha cos\delta_c = -4.14 \pm 0.25\ mas/yr$, $\mu_{\delta c} = -5.15 \pm 0.25\ mas/yr$, $\sigma_c = 0.75 \pm 0.18\ mas/yr$ and the field parameters $\mu_\alpha cos\delta_f = -1.62 \pm 0.40\ mas/yr$, $\mu_{\delta f} = -4.18 \pm 0.59\ mas/yr$, $\sigma_{\mu_\alpha cos\delta_f} = 5.38 \pm 0.28\ mas/yr$ and $\sigma_{\mu_{\delta f}} = 7.99 \pm 0.42\ mas/yr$. It can be seen that these values are similar to the ones obtained by Dias et al. (2014).

Nine stars are found to be the astrometric members of the cluster. Therefore, the equatorial coordinates of the centre of the cluster and radius take the values $\alpha_c = 304^\circ.4401 \pm 0^\circ.01407$, $\delta_c = 39^\circ.32745 \pm 0^\circ.00726$ and $4'.5$ respectively. The location of the members in the spatial distribution and in the VPD are shown with black circles in Figs. 3c and 4c, respectively. Table A.6 gives our numbering system, the UCAC4 number, the equatorial coordinates with their errors, the components of proper motion with their errors and the membership probability (P_{ci}).

In summary, the centre coordinates and components of the mean proper motion of each cluster are shown in Table 2.

3.4. Proper motion errors

We analyze on the incidence of stellar proper motions errors in the determination of the cluster parameters and stellar membership. To do this, we follow the method proposed by Chen et al. (1997). For each cluster, we have generated 25 simulations by adding an increment $(\Delta\mu_\alpha cos\delta, \Delta\mu_\delta)$ to the real values $(\mu_\alpha cos\delta, \mu_\delta)$ of each star.

The increases in the proper motion components have been randomly generated from a normal distribution with mean equal to $(\mu_\alpha cos\delta, \mu_\delta)$ and standard deviation equal to the individual error. Afterwards, we apply the procedure presented in subSection 3.2 to each simulated sample and obtain the cluster parameters and the astrometrical members. For each cluster, Table 3 shows the mean value of $(\mu_\alpha cos\delta, \mu_\delta)$ and of the number of members obtained from the 25 simulations.

Comparing these results with those obtained in subSection 3.2 (see Table 2), we can see that the error does not significantly change the kinematic parameters of the studied clusters.

We also analyse the effect of the proper motion errors on the determination of cluster members for the analysed clusters. Therefore, we count the number of times in which a cluster member obtained in subSection 3.3 keeps its membership condition throughout the 25 simulations.

Fig. 5 shows these results by an histogram for each cluster, where the abscissa shows our numbering system for vdB80, vdB85 and vdB130 respectively.

It is easy to see that approximately 90% of the members maintain their condition, except the case of vdB85 where the uncertainty in the identification of the members becomes greater.

4. Discussion

We compare the cluster members of vdB80, vdB85 and vdB130 acquired by the astrometric technique with the ones obtained using photometry.

4.1. Open cluster vdB80

A notable infrared photometric analysis of vdB80 is made by Bonatto and Bica (2009) using 2MASS data in order to investigate its nature and derive its fundamental parameters. The Fig. 7 of this work shows the decontaminated $J \times (J - Ks)$ colour-magnitude diagram with the photometric members up to $J = 16$ mag.

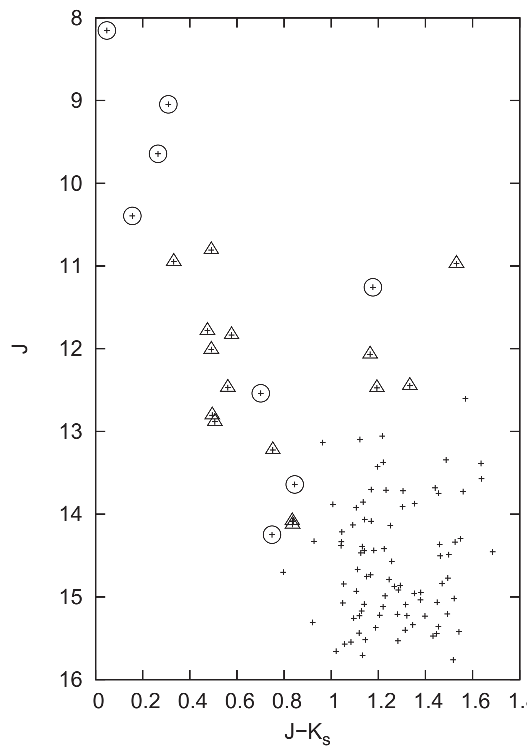

Fig. 6. Reproduction of the colour-magnitude diagram of vdB80 from Bonatto and Bica (2009). The photometric members are plotted with crosses, the astrometric members with large circles and the non astrometric members with triangles. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

We recreate the mentioned diagram in Fig. 6 and find that 23 stars of the sample are in the UCAC4 catalogue. Among these stars in common, we find that 8 stars are astrometric members and the rest 15 stars do not fulfil this condition due to their proper motions. These results are listed in Table B.7 and Fig. 6 shows Bonatto & Bica colour-magnitude diagram, where the photometric members are shown with crosses, the astrometric members with large circles and the non astrometric ones with triangles.

Taking into account that cluster members must share similar kinematic features, the VPD of the photometric members (Fig. 7) explain the reason why 15 photometric members can not be considered members of the cluster. The photometric members are plotted with crosses and the eight astrometric members with large circles.

The fact that NSV 2998 (UCAC4 402-013688) is an astrometric member supports the 5 ± 2 Myr MS cluster age obtained by Bonatto & Bica.

4.2. Open cluster vdB85

The infrared observations acquired for the study of Horner et al. (1997) were taken with specific devices on the 1.3 meter and 4 meter at Kitt Peak National Observatory and on the 1.5 meter telescope at Cerro Tololo Inter-American Observatory. They detected approximately 1121 sources at J-band (m_J <17.5), 1127 sources at H-band (m_H <16.5) and 779 sources at K-band (m_K <15.5).

Unfortunately, the only data available in the AAS CD-ROM Series, Vol. 8, 1997[3] are a list of 394 sources from the 1995 1.5 m telescope observations. These sources are located within 200″ of HD 289120 (UCAC4 457-022546). We identify 14 of them in the

[3] <http://aas.org/archives/cdrom/volume8/>.

Table B.7
vdB80. Identification of 23 photometric members determined by Bonatto and Bica (2009) in the UCAC4 catalogue.

UCAC4	J [mag]	$J-K_s$ [mag]	$\mu_\alpha cos\delta$ [mas/yr]	μ_δ [mas/yr]	Astrometric member
402-013691	10.808	0.491	5.40	−6.70	No
402-013693	10.395	0.156	−2.70	0.30	Yes
402-013689	9.046	0.309	−0.60	−0.10	Yes
402-013688	8.153	0.048	−1.80	0.90	Yes
402-013686	9.643	0.265	−0.40	−0.80	Yes
402-013700	12.539	0.701	−1.90	2.00	Yes
402-013704	11.257	1.177	−3.00	−3.50	Yes
402-013710	13.640	0.845	−2.40	−2.70	Yes
402-013709	12.069	1.165	−2.60	−5.60	No
402-013675	12.01	0.491	8.90	−3.50	No
402-013692	12.805	0.495	4.80	−9.00	No
403-014257	10.972	1.532	−3.80	4.20	No
402-013679	13.225	0.752	2.30	−3.40	No
403-014240	12.469	0.561	−2.4	13.0	No
402-013690	12.448	1.334	2.50	−2.40	No
402-013721	12.474	1.194	−14.0	−8.1	No
402-013722	11.783	0.475	−3.20	−9.80	No
403-014249	10.947	0.332	7.40	−7.80	No
402-013724	14.248	0.749	−1.10	−2.20	Yes
403-014247	11.834	0.577	−79.9	49.0	No
402-013680	12.882	0.506	−7.30	−5.50	No
403-014223	14.124	0.836	4.2	−31.5	No
403-014252	14.084	0.835	−1.60	−8.20	No

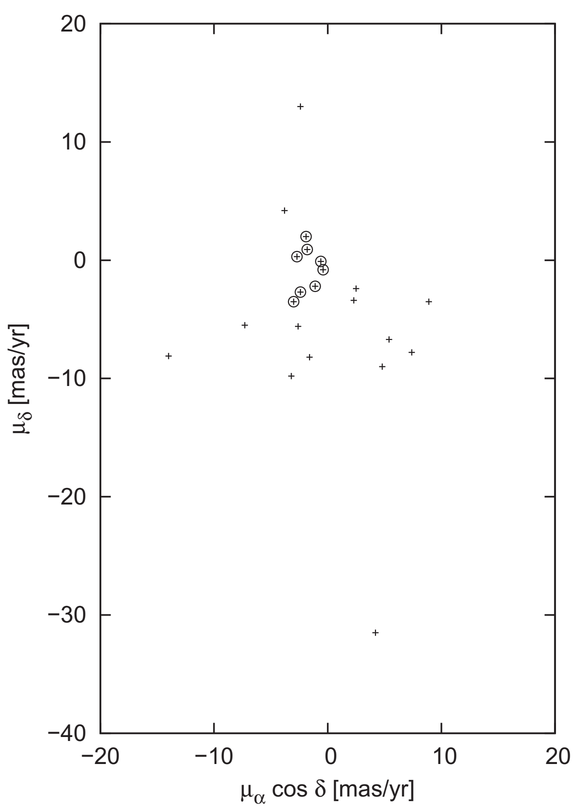

Fig. 7. VPD of 22 stars in common in the region of vdB80. The photometric members are plotted with crosses and the eight astrometric members with large circles. Star UCAC4 403-014247 is not plotted due to its large proper motion.

UCAC4 catalogue that are listed in Table B.8, where five of them are situated in a radius $r = 100''$.

In Fig. 8, we reproduce a part of Fig. 4 rigth of their work where the JHK colour-colour diagram of the photometric cluster members inside 100″ of the cluster centre is plotted. We find that four of the five sources in common are astrometric members and the other one do not fulfil this condition due to its proper motion, as seen in Table B.8. Astrometric members are shown with large circles and the non astrometric one with a triangle.

Table B.8
vdB85. Identification of 14 sources from the 1995 1.5 m telescope observations made by Horner et al. (1997) in the UCAC4 catalogue.

Horner's number	UCAC4	r [″]	$\mu_\alpha cos\delta$ [mas/yr]	μ_δ [mas/yr]	Astrometric member
177b	457-022546	1.09	0.9	1.5	Yes
120	457-022539	43.26	−1.0	4.3	Yes
144	457-022542	55.61	0.3	6.4	Yes
291	457-022567	80.86	2.2	2.6	Yes
65	457-022523	98.18	−6.9	−4.3	No
306	457-022573	111.3	−4.1	−1.5	No
328f	457-022580	113.32	−0.7	−1.8	No
309	457-022575	117.58	1.1	2.2	Yes
339	457-022583	120.93	1.1	−12.3	No
83	457-022527	122.78	−1.9	−2.2	No
137a	457-022541	144.34	7.1	−11.3	No
388	457-022593	174.23	0.3	−0.9	No
3	457-022500	174.84	1.4	0.9	Yes
33	457-022514	191.96	8.2	−6.7	No

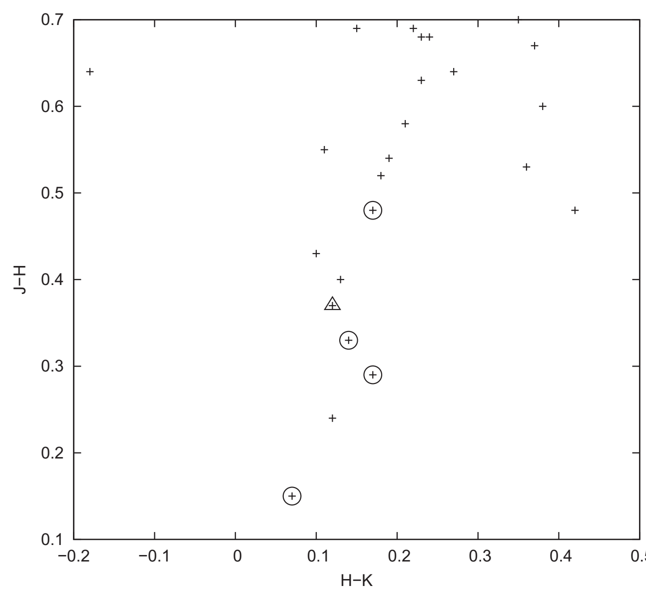

Fig. 8. vdB85. A part of the JHK colour-colour diagram of the photometric cluster members inside 100″ of the cluster centre. Astrometric members are symbolized by open circles and non astrometric member is symbolized by a triangle.

4.3. Open cluster vdB130

Racine (1974) performs UBV photometry of 14 stars identified in Plate IV (p.989) of the Palomar Sky Survey that shows the cluster's field. These stars are considered photometric cluster members due to their apparent connection with the nebular material.

Even though all these members are in the UCAC4 catalogue, six stars are astrometric members and seven ones do not fulfill this condition due to their proper motions. Racine's star No. 14 can not be evaluated by our astrometric analysis as it has no proper motion components.These results are shown in Table B.9.

Due to the fact that open cluster members have to possess similar proper motion components, the VPD (Fig. 9) of the photometric members reveals that only six of them are confirm to be cluster

Table B.9
vdB130. Identification of 14 photometric members determined by Racine (1974) in the UCAC4 catalogue.

Racine's number	UCAC4	$\mu_\alpha cos\delta$ [mas/yr]	μ_δ [mas/yr]	Astrometric member
1	647-086816	23.9	−27	No
2	647-086761	−5	−2.5	No
3	647-086871	−4.8	−4.5	Yes
4	647-086813	−4.4	−5.3	Yes
5	647-086841	−7	2.9	No
6	647-086746	53.1	34.5	No
7	647-086750	32.4	−8.5	No
8	647-086860	−6.1	−4.3	No
9	647-086849	−4.7	−9	No
10	647-086781	−4	−3.9	Yes
11	647-086776	−4.3	−4.9	Yes
12	647-086785	−4.4	−5.4	Yes
13	647-086775	−3.9	−7	Yes
14	647-086779	–	–	–

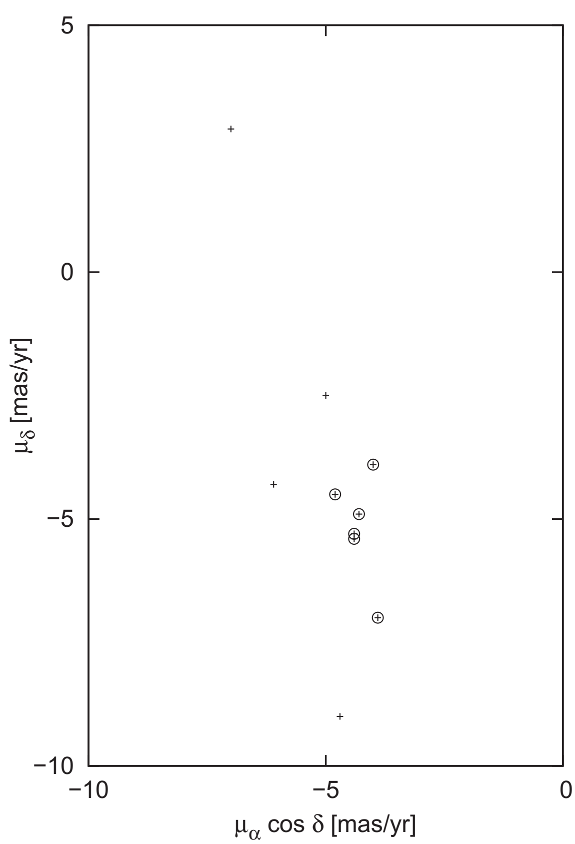

Fig. 9. VPD of 10 stars in common in the region of vdB130. The photometric members are plotted with crosses and the six astrometric members with large circles. Racine's star numbers 1, 6 and 7 are not plotted due to their large proper motion.

members. The photometric members are plotted with crosses and the six astrometric members with large circles.

5. Conclusion

As open cluster members share similar photometric and kinematic properties, this work combines astrometric and photometric results in order to reduce the uncertainty introduced by each technique individually.

We revisit the regions vdB80, vdB85 and vdB130 to determine their astrometric parameters and the stellar membership. We apply a parametric model which analyses the proper motion distribution and the stellar density to find an open cluster. The astrometric data are obtained from UCAC4 catalogue.

We report that vdB80 has $\mu_\alpha cos\delta_c = -2.13 \pm 0.47\ mas/yr$, $\mu_{\delta c} = -0.95 \pm 0.47\ mas/yr$, $\sigma_c = 1.84 \pm 0.33\ mas/yr$, 15 astrometric members, $\alpha_c = 97.^\circ 73938 \pm 0^\circ.00846$, $\delta_c = -9^\circ.66953 \pm 0^\circ.01177$ and a value of 12′ for the diameter. For vdB85, the astrometric parameters become $\mu_\alpha cos\delta_c = 0.89 \pm 0.43\ mas/yr$, $\mu_{\delta c} = 3.24 \pm 0.43\ mas/yr$, $\sigma_c = 1.28 \pm 0.29\ mas/yr$, 9 astrometric members, $\alpha_c = 101^\circ.71670 \pm 0^\circ.00808$, $\delta_c = 1^\circ.34392 \pm 0^\circ.01253$ and a value of 8′ for the diameter. In the case of vdB130, the obtained values of these parameters are $\mu_\alpha cos\delta_c = -4.14 \pm 0.25\ mas/yr$, $\mu_{\delta c} = -5.15 \pm 0.25\ mas/yr$, $\sigma_c = 0.75 \pm 0.18\ mas/yr$, 9 members, equatorial centre coordinates $\alpha_c = 304^\circ.4401 \pm 0^\circ.01407$, $\delta_c = -39^\circ.32745 \pm 0^\circ.00726$ and a diameter of 9′. It is important to remark that the astrometric parameters of vdB80 and vdB85 are determined for the first time using UCAC4 catalogue data.

We explore also the incidence of proper motion errors in the determination of the cluster parameters and of the stellar membership applying the model to 25 simulated samples of each cluster. We conclude that the observational errors do not significantly change the mean proper motion and the number of members of the studied clusters.

Finally, the comparison of our results and the photometric ones given in the literature conduct to successful membership determinations. In the case of vdB80, a detailed comparison with the photometric membership determination given by Bonatto & Bica (2009) leads to confirm that eight stars are both astrometric and photometric members. For vdB130, the comparison with the photometric members given by Racine (1974) affirms that six stars are both astrometric and photometric members. Only four stars in a region of 100″ from the centre of vdB85 adopted by Horner et al. (1997) fulfill both astrometric and photometric membership.

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Appendix A

(See Tables A.4–A.6).

Appendix B

(See Tables B.7–B.9).

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