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Membership Determination of van den Bergh Open Clusters vdB92, vdB146 (NGC 7129) and vdB150

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Abstract

In this paper we study some van den Bergh open clusters combining photometry and astrometry. A model which analyses the proper motion distribution and the stellar density is applied to find the kinematic parameters and stellar membership in the region of the open clusters vdB92, vdB146 (NGC 7129) and vdB150. The astrometric data are obtained from UCAC4 catalogue. The centre coordinates, the components of mean proper motion, the angular diameter and the astrometric members are reported, taking the following values: for *vdB*92: $\alpha = 105.97281^{\circ} \pm 0.13113^{\circ}$, $\delta = -11.57814^{\circ} \pm 0.10575^{\circ}$, $\mu_{\alpha}\cos\delta = -3.46 \pm 0.19$ mas/yr, $\mu_{\delta} = 1.27 \pm 0.19$ mas/yr, 34', 60 members; for *vdB*146: $\alpha = 325.78423^{\circ} \pm 0.15297^{\circ}$, $\delta = 66.13575^{\circ} \pm 0.02907^{\circ}$, $\mu_{\alpha}\cos\delta = -2.71 \pm 0.25$ mas/yr, $\mu_{\delta} = -3.32 \pm 0.25$ mas/yr, 9', 5 members; and for *vdB*150: $\alpha = 332.22519^{\circ} \pm 0.06074^{\circ}$, $\delta = 73.40232^{\circ} \pm 0.0.07789^{\circ}$, $\mu_{\alpha}\cos\delta = 3.07 \pm 0.90$ mas/yr, $\mu_{\delta} = 4.65 \pm 0.90$ mas/yr, 15', 7 members. The incidence of the proper motion errors in the determination of the cluster parameters and of the stellar membership is analysed and it is found that they do not significantly change. We finally compare the astrometric members with the photometric ones given in the literature.

Keywords

(Galaxy:) Open Clusters and Associations: General, (Galaxy:) Open Clusters and Associations: Individual (vdB92, vdB146, vdB150), Astrometry

1. Introduction

The study of embedded clusters can provide the key to a better understanding of

a number of fundamental problems in astrophysics, e.g. distances, masses, ages, Metalicity. Moreover, the analysis of the complex gravitational interactions of their individual members contributes to the study of stellar dynamics.

Several of these clusters have been investigated using only photometric techniques to determine the members. As open cluster members share similar photometric and kinematic properties, it is useful to complete the study of the stars of the cluster region by employing astrometric methods. Recently, Corti and Orellana [1] and Orellana *et al.* [2] combine astrometric and photometric membership results in order to reduce the uncertainty introduced by each technique individually.

In this work we improve the membership probability of the stars in the regions of van den Bergh open clusters vdB92, vdB146 and vdB150.

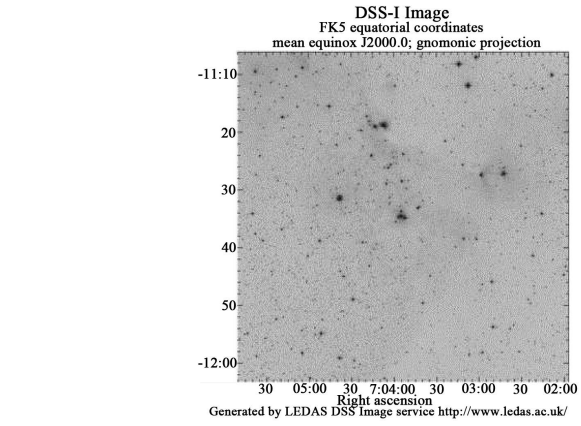
*Open cluster vdB*92: has equatorial coordinates $\alpha_{J2000} = 7^h03^m56.4^s$ and $\delta_{J2000} = -11^\circ34'57.7''$ $\left(l = 224.66^\circ, b = -2.52^\circ\right)$ (Bonatto and Bica [3]) and is placed in Canis Major. It was first identified by van den Bergh [4] and contains the stars BD-11 1763 (UCAC4 393-021223) and BD-11 1761 (UCAC4 393-021212). Racine [5] performed photometry and spectroscopy for 92b (UCAC4 393-021223) and photometry for 92a (UCAC4 393-021212) and for 92c (UCAC4 393-021222). Soares and Bica [6] employ 2MASS photometry to study the brighter sequences and derive the cluster age of 5-7 Myr and a distance of 1.5 kpc. Froebrich *et al.* [7] list the cluster as FSR 1188 and derive a core radius of 1.1', a tidal radius of 24' and 297 stars as members based on *H* photometry. A more extensive analysis up to 2MASS fainter magnitudes is done by Bonatto and Bica [3]. They derive the fundamental parameters from a colour-magnitude diagram characterized by a poorly populated main sequence and a dominant fraction of pre-MS stars. They obtain $E\left(B-V\right) = 0.22 \pm 0.13$, $A_v = 0.7 \pm 0.4$, $\left(m-M\right)_0 = 10.71 \pm 0.41$ giving a distance of 1.38 ± 0.26 kpc, a value of $\alpha_{J2000} = 105.98500^\circ$, $\delta_{J2000} = -11.58186^\circ$ for the central coordinates and $20 \pm 0.2'$ for the cluster radius. Dias *et al.* [8] employ the UCAC4 catalogue to determine the mean proper motion and stellar membership in a region centred in $\alpha_{J2000} = 105.97500^\circ$, $\delta_{J2000} = -11.53333^\circ$ containing 36 stars up to magnitude 17. They find a value of ($\mu_\alpha \cos\delta = -2.10$, $\mu_\delta = 3.87$) mas/yr, a radius of 2.5' and 26 cluster members.

*Open cluster vdB*146: is situated in Cepheus and its coordinates are $\alpha_{J2000.0} = 21^h42^m59^s$ and $\delta_{J2000.0} = 66^\circ06'48''$ $\left(l = 105.4044^\circ, b = 9.8852^\circ\right)$ (Dias *et al.* [9]). When van den Bergh [4] catalogues the reflection nebula, he remarks that stars BD + 65 1637 (UCAC4 781-037984) and BD + 65 1638 (UCAC4 781-037989) are in a small clustering. The reflection nebula vdB-RN146 is also named as NGC 7129 in the literature. In 1968 Racine identifies two stars more as cluster members: LkHα234 (UCAC4 781-037993) and vdB146d (UCAC4 781-037976). Aveni and Hunter [10] perform photometry and spectropscopy of 30 stars in the cluster as a part of their observational studies relating to star formation. They determine 9 cluster members, a distance modulus 10.5 and a total mass of 120 $M_\odot$.

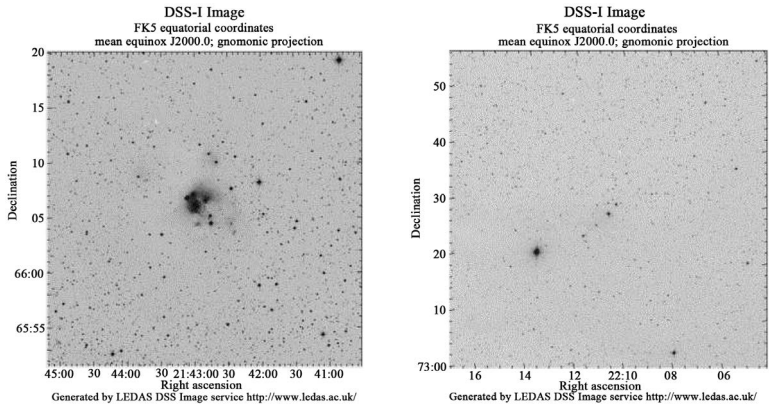
More recently, an important investigation of vdB146 and the dust cloud where it is embedded is made by Straižys *et al.* [11] using medium-band seven color photometry of 159 stars in the region and determining the spectral and luminosity classes for half of them. They locate the cloud and the cluster at 1.15 ± 0.08 kpc, and calculate the cluster age between 3.1 and 0.20 Myr employing six cluster members of spectral clases B3 to A1.

*Open cluster vdB*150: discovered in 1966 by van den Bergh, it is placed in Cepheus and its coordinates are $\alpha_{J2000.0} = 22^h12^m48^s$ and $\delta_{J2000.0} = 73^\circ20'00''$ $\left(l = 112.0625^\circ, b = 13.9057^\circ\right)$ (Dias *et al.* [9]). van den Bergh [4] finds a reflection nebula associated with the star BD +72 1020 (UCAC4 817-026634), to which Racine [5] performs photometry and spectroscopy to determine a distance modulus of 8.5. Aveni and Hunter [10] analyse a sample of 19 stars in the area and report the possible existence of a widespread group at a distance modulus of 7.5.

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



(a)



(b) (c)

Figure 1. Images of the optical environments of open clusters vdB92 (a); vdB146 (b) and vdB150 (c). Right ascension and declination are given in the abscissa and ordinate, respectively. Orientation: north to the top and east to the left. We thank the Leicester Database and Archive Service (LEDAS) http://www.ledas.ac.uk/DSSimage/aboutdss and the Space Telescope Science Institute (STScI) for the use of their images.

2. The Data

We perform our investigation taken the stellar position and proper motions from the UCAC4 Catalogue, which has 113 million stars and 105 million of them with proper motions. The catalogue is complete to about magnitude $R = 16$ having an average density over 2000 stars/( )^2.

Positional errors are about 15 to 20 mas for stars in the 10 to 14 mag range. Errors in proper motions of the bright stars (to $R \sim 12$) run from about 1 to 3 mas/yr, typical errors of the fainter stars using SPM and NPM data are at the level of 2 to 6 mas/yr.

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.* [12].

Data extraction has been performed using the Vizier[1].

3. Astrometric Analysis

3.1. Cluster Centre Coordinates, Mean Proper Motion and Membership Determination

Astrometrically, the existence of an open cluster is pointed out by an overdensity in the sky as well as in the Vector Point Diagram (VPD). The identification of members of the cluster with respect to field stars is done by evaluating both overdensities simultaneously.

The projected stellar density of each cluster is analysed in a region whose size and magnitude limit depend on local characteristics. We consider the faintest magnitude up to which an overdensity can be distinguished. Up to the 14 magnitude, we examine a region sized of $30' \times 30'$ for vdB92. Up to the 15 magnitude, we examine another of $24' \times 24'$ for vdB146. A region of $15' \times 15'$ is chosen for vdB150 analysis up to magnitude 13.

The observed local density is evaluated 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 [13]). The node with the highest density 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**.

The analysis is continued by adopting the proper motion distribution of Vasilevskis-Sanders (Vasilevskis *et al.* [14]-Sanders [15]) for cluster and field stars. The inclusion of an exponential function describing the areal stellar density for cluster stars and a constant one for field stars (Jones and Walker [16])
$\rho(r_i) = \rho_0 \times \exp(-r_i/r_0) + \rho_f$ improves the model.

The proper motion distribution for the i-th star takes the form:

[1]http://vizier.u-strasbg.fr/viz-bin/VizieR-3?-source=I/322A/out

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 [°]
vdB92	0.5′×0.5′	2.2′	105.97917 ± 0.01248	−11.56889 ± 0.01222
vdB146	0.5′×0.5′	2.2′	325.71247 ± 0.03016	66.09753 ± 0.01222
vdB150	0.5′×0.5′	2.2′	332.41250 ± 0.04279	73.404167 ± 0.01222

$$\Phi_i\left(\mu_{xi},\mu_{yi},r_i\right)=\frac{\rho_0\exp\left(-r_i/r_0\right)}{2\pi\sigma_c^2}\times\exp\left[-\frac{\left(\mu_{xi}-\mu_{xc}\right)^2+\left(\mu_{yi}-\mu_{yc}\right)^2}{2\sigma_c^2}\right]+\frac{\rho_f}{2\pi\sigma_{xf}\sigma_{yf}}\times\exp\left[-\frac{\left(\mu_{xi}-\mu_{xf}\right)^2 2\sigma_{xf}^2-\left(\mu_{yi}-\mu_{yf}\right)^2}{2\sigma_{yf}^2}\right] \quad (1)$$

where μ_{xi}, μ_{yi}, r_i are components of proper motion in *x* and *y* and the distance from the approximate cluster's centre for the i-th star, ρ_0 is the central cluster stellar density, r_0 is the characteristic radius, ρ_f is the constant areal stellar density for field stars, 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 for cluster stars. These parameters are obtained after applying the method of maximum likelihood to Equation (1).

The probability for the i-th star is calculated as

$$P_{ci}\left(\mu_{xi},\mu_{yi},r_i\right)=\frac{\dfrac{\rho_0\exp\left(-r_i/r_0\right)}{2\pi\sigma_c^2}\times\exp\left[-\dfrac{\left(\mu_{xi}-\mu_{xc}\right)^2+\left(\mu_{yi}-\mu_{yc}\right)^2}{2\sigma_c^2}\right]}{\Phi_i\left(\mu_{xi},\mu_{yi},r_i\right)} \quad (2)$$

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

3.2. Results

*Open cluster vdB*92:

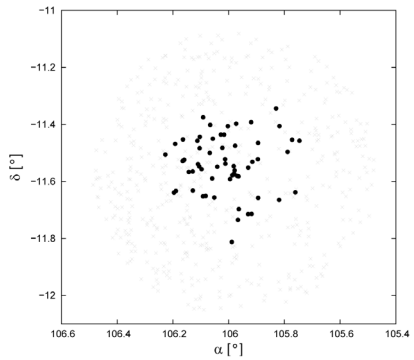
We choose the stars in a circular region of radius 30′centered at the $\left(\alpha_0,\delta_0\right)$ given in Table 1 which contains 569 stars. The proper motion data are analysed in an elliptical subregion of the VPD containing 523 stars.

The parameters $\rho_0=0.640\pm0.066$ stars$/(')^2$, $r_0=4.102'\pm0.820'$ and $\rho_f=0.169\pm0.024$ stars$/(')^2$ adjust the function $\rho\left(r_i\right)$ to the radial stellar density profile.

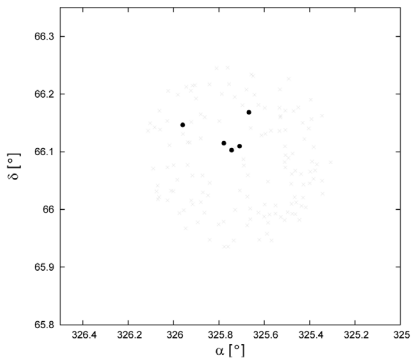
After Equation (1) is resolved, the cluster parameters are
$\mu_\alpha\cos\delta_c=-3.46\pm0.19$ mas/yr, $\mu_{\delta_c}=1.27\pm0.19$ mas/yr,
$\sigma_c=1.44\pm0.13$ mas/yr and the field parameters
$\mu_\alpha\cos\delta_f=-1.56\pm0.33$ mas/yr, $\mu_{\delta_f}=1.01\pm0.24$ mas/yr,
$\sigma_{\mu_\alpha\cos\delta_f}=7.03\pm0.23$ mas/yr and $\sigma_{\mu_{\delta_f}}=5.26\pm0.17$ mas/yr.

60 stars are found to be astrometric members of the cluster. Their coordinates lead to calculate the equatorial coordinates of the centre of the cluster $\alpha_c = 105.97281^\circ \pm 0.13113^\circ$, $\delta_c = -11.57814^\circ \pm 0.10575^\circ$ and an amount of 17.11' for the radius, in good agreement with Bonatto and Bica's value.

The location of the members in the spatial distribution and in the VPD is shown with black circles in **Figure 2(a)** and **Figure 3(a)**, respectively. **Table 2** 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}).



(a)



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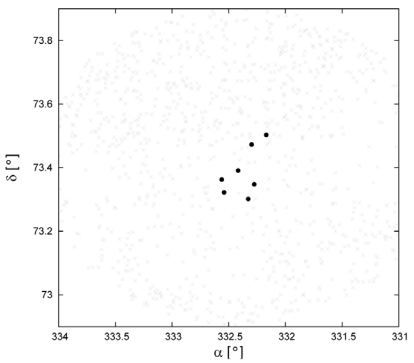


(c)

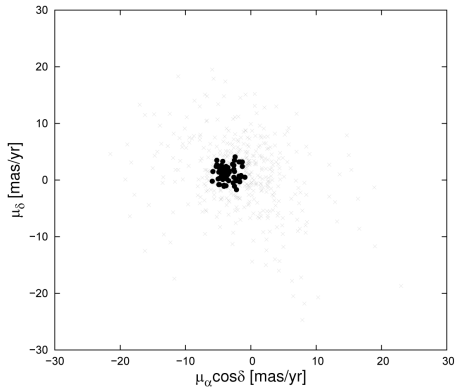
Figure 2. Stellar positions in the region of vdB92 (a); vdB146 (b) and vdB150 (c). The black circles represent the astrometric cluster members and crosses the rest of the stars in the ellipse.

Table 2. vdB92 astrometric members.

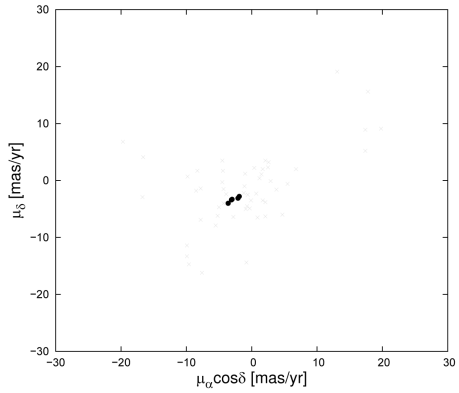
No.	UCAC4	α [°]	ϵ_α [mas]	δ [°]	ϵ_δ [mas]	$\mu_\alpha \cos\delta$ [mas/yr]	$\epsilon_{\mu_\alpha \cos\delta}$	μ_δ [mas/yr]	ϵ_{μ_δ}	P_{ci}
1	393-021227	105.9809748	17	−11.5727017	17	−3.9	2.7	0.4	2.6	0.98
2	393-021223	105.9785765	13	−11.5761306	13	−4.7	2.1	2.1	1.8	0.98
3	393-021222	105.9785174	15	−11.5614681	20	−5.0	1.3	2.4	1.8	0.97
6	393-021237	105.9868448	16	−11.5782645	16	−4.3	1.6	0.1	1.6	0.98
9	393-021212	105.9687412	25	−11.5810700	41	−4.7	1.4	2.2	1.6	0.97
10	393-021207	105.9646874	16	−11.5821648	16	−4.5	1.6	0.7	1.6	0.98
14	393-021229	105.9818480	23	−11.5463681	17	−1.3	1.6	3.2	1.6	0.87
16	393-021252	105.9950262	17	−11.5919895	23	−3.8	1.6	−1.0	2.2	0.94
27	393-021276	106.0118339	16	−11.5376506	16	−5.2	1.6	2.7	1.6	0.93
33	393-021175	105.9298500	3	−11.5517245	3	−5.2	1.4	3.5	1.6	0.85
44	393-021278	106.0127642	33	−11.5219553	16	−5.9	3.2	-0.2	1.5	0.85
56	393-021313	106.0408306	33	−11.5482892	23	−4.1	2.9	−1.1	2.5	0.88
70	393-021163	105.9150692	15	−11.5312978	16	−2.2	1.4	−1.7	1.5	0.68
90	393-021335	106.0592459	16	−11.5895948	17	−3.5	2.0	1.0	2.2	0.96
127	393-021221	105.9767768	13	−11.4748273	20	−4.2	1.3	1.9	1.8	0.94
131	393-021156	105.8952642	18	−11.5221453	19	−1.6	3.1	0.5	3.7	0.86
135	393-021292	106.0225950	14	−11.4822689	15	−5.8	1.2	1.5	1.3	0.85
179	393-021348	106.0677624	45	−11.4999575	17	−2.7	5.2	-0.5	2.0	0.85
182	392-020650	106.0514348	16	−11.6563784	17	−2.4	1.4	4.1	1.6	0.62
191	393-021393	106.0970439	18	−11.5571039	19	−2.6	1.5	2.6	1.6	0.87
217	392-020512	105.8942362	17	−11.6575553	18	−1.7	2.1	-0.3	2.4	0.75
237	393-021409	106.1058277	17	−11.5471642	17	−3.8	6.6	2.4	6.7	0.89
250	392-020551	105.9635974	18	−11.6968653	18	−1.6	2.2	3.2	2.2	0.66
254	392-020688	106.0825609	53	−11.6506845	188	−4.1	5.2	-0.9	19.5	0.78
259	393-021418	106.1100442	17	−11.5392295	17	−3.6	1.5	0.9	1.5	0.91
265	393-021155	105.8945630	16	−11.4648164	37	−1.3	1.4	2.4	3.5	0.70
287	393-021286	106.0164024	17	−11.4360525	17	−4.3	1.3	3.3	1.5	0.76
289	392-020697	106.0921245	27	−11.6519084	28	−1.8	1.6	0.7	1.6	0.81
300	393-021330	106.0568768	17	−11.4501334	16	−4.9	1.9	-0.8	2.1	0.71
301	393-021299	106.0279209	16	−11.4356939	18	-0.9	1.5	0.5	2.3	0.61

Continued

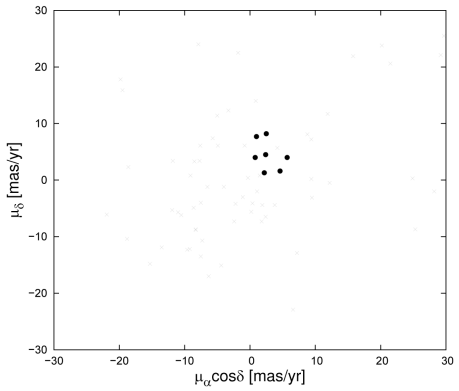
328	393-021447	106.1290406	16	−11.5650778	29	−2.5	1.5	−1.1	2.8	0.64
342	393-021406	106.1041883	16	−11.4835395	16	−3.4	1.6	-0.1	1.5	0.84
362	392-020527	105.9301680	17	−11.7145245	17	−1.5	1.4	0.8	1.5	0.73
378	392-020519	105.9179180	28	−11.7136909	23	−1.8	2.8	3.2	2.2	0.6
391	392-020759	106.1285603	24	−11.6316039	17	−2.6	2.1	1.9	1.6	0.84
401	393-021466	106.1429036	40	−11.5667806	51	−4.8	4.7	-0.8	4.1	0.66
421	393-021260	106.0029971	17	−11.4062206	16	−4.8	2.3	0.3	2.1	0.79
432	392-020556	105.9666474	20	−11.7345720	21	−1.7	1.9	0.7	2.0	0.72
456	394-020286	105.9729062	27	−11.3974145	29	−5.3	3.2	2.4	3.6	0.68
457	393-021421	106.1122303	15	−11.4573417	16	−3.7	1.5	0.2	1.5	0.82
480	393-021405	106.1035562	18	−11.4436020	17	−2.5	2.6	3.5	1.5	0.58
535	393-021497	106.1595942	100	−11.5240609	100	−2.8	8.0	2.8	8.0	0.72
537	393-021500	106.1603709	30	−11.5253356	30	−2.8	2.5	2.8	2.5	0.71
544	392-020478	105.8189924	19	−11.6645889	17	−2.2	2.0	-0.1	1.8	0.67
557	394-020263	105.9193250	27	−11.3920539	31	−3.9	2.6	0.4	3.0	0.79
559	393-021504	106.1649495	17	−11.5283389	108	−5.0	2.2	0.2	10.2	0.70
568	393-021345	106.0661868	17	−11.4015603	38	−4.5	1.4	1.3	3.2	0.79
636	393-021093	105.7886430	16	−11.4965078	12	−2.6	2.1	0.5	1.5	0.73
728	393-021503	106.1640180	15	−11.4527612	24	−3.3	1.5	1.4	2.3	0.75
731	392-020848	106.1893774	16	−11.6331556	24	−4.1	1.7	1.0	2.3	0.74
778	394-020364	106.0915403	24	−11.3749025	16	−3.5	2.7	2.2	1.5	0.69
781	392-020854	106.1961348	16	−11.6389848	16	−3.9	2.6	1.0	3.4	0.72
793	392-020451	105.7608103	32	−11.6379198	17	−2.5	3.8	1.5	1.6	0.67
806	393-021119	105.8177209	17	−11.4058306	16	−2.3	4.6	0.1	5.2	0.56
836	393-021540	106.1919289	18	−11.4683867	19	−3.9	2.0	1.8	2.2	0.69
844	393-021084	105.7723095	22	−11.4539595	19	−4.5	3.7	2.6	4.0	0.56
903	391-021627	105.9887286	16	−11.8123475	16	−4.8	6.0	2.1	6.0	0.55
957	393-021586	106.2271024	14	−11.5058823	24	−4.9	2.2	1.4	2.5	0.55
987	393-021075	105.7460736	15	−11.4571648	15	−3.9	1.5	1.4	1.5	0.62
1095	394-020201	105.8297924	18	−11.3439367	19	−3.3	6.1	1.6	7.4	0.57



(a)



(b)



(c)

Figure 3. Vector point diagram in the region of vdB92 (a); vdB146 (b) and vdB150 (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.

Dias *et al.* [8] published an astrometric research using UCAC4 catalogue. They analysed a small region of diameter 3' centred at $\alpha_{J2000} = 07^h03^m54^s$, $\delta_{J2000} = -11^\circ32'00''$ and detected an open cluster whose components of mean proper motion are $\mu_\alpha \cos\delta = -2.10$ mas/yr and $\mu_\delta = 3.87$ mas/yr having 26 members. The area considered in their investigation does not include the cluster members observed by Racine [5] and the ones mentioned by Bonatto and Bica [3].

*Open cluster vdB*146:

We take 63 stars in a circular region of radius 10' centered at $\alpha_0 = 325.71247^\circ \pm 0.03016^\circ$, $\delta_0 = 66.09753^\circ \pm 0.01222^\circ$. The elliptical subregion of the VPD contains 59 stars.

The parameters $\rho_0 = 2.681 \pm 0.184$ stars$/(')^2$, $r_0 = 0.841' \pm 0.045'$ and $\rho_f = 0.128 \pm 0.007$ stars$/(')^2$ fit the radial stellar density profile.

The cluster parameters take the values $\mu_\alpha \cos\delta_c = -2.71 \pm 0.25$ mas/yr, $\mu_{\delta_c} = -3.32 \pm 0.25$ mas/yr, $\sigma_c = 0.56 \pm 0.18$ mas/yr and the field parameters $\mu_\alpha \cos\delta_f = -0.49 \pm 1.47$ mas/yr, $\mu_{\delta_f} = -0.83 \pm 0.71$ mas/yr, $\sigma_{\mu_\alpha \cos\delta_f} = 10.79 \pm 1.04$ mas/yr and $\sigma_{\mu_{\delta_f}} = 5.21 \pm 0.50$ mas/yr.

We find five astrometric cluster members and then calculate the equatorial coordinates of the centre of the cluster $\alpha_c = 325.78423^\circ \pm 0.15297^\circ$, $\delta_c = 66.13575^\circ \pm 0.02907^\circ$ and the value of 4.31' for the radius. The location of the members in the spatial distribution and in the VPD is shown with black circles in **Figure 2(b)** and **Figure 3(b)**, respectively. **Table 3** 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}).

*Open cluster vdB*150:

The model is applied in a circular region of radius 30' and centered at $\alpha_0 = 332.412^\circ \pm 0.043^\circ$, $\delta_0 = 73.404^\circ \pm 0.012^\circ$ with 84 stars. The elliptical subregion of the VPD contains 77 stars.

The parameters $\rho_0 = 0.409 \pm 0.0163$ stars$/(')^2$, $r_0 = 2.421' \pm 0.124'$ and $\rho_f = 0.024 \pm 0.002$ stars$/(')^2$ adjust the radial stellar density profile.

The cluster parameters take the values $\mu_\alpha \cos\delta_c = 3.07 \pm 0.90$ mas/yr, $\mu_{\delta_c} = 4.65 \pm 0.90$ mas/yr, $\sigma_c = 2.39 \pm 0.64$ mas/yr and the field parameters $\mu_\alpha \cos\delta_f = -0.69 \pm 1.83$ mas/yr, $\mu_{\delta_f} = 1.09 \pm 1.23$ mas/yr, $\sigma_{\mu_\alpha \cos\delta_f} = 15.32 \pm 1.29$ mas/yr and $\sigma_{\mu_{\delta_f}} = 10.29 \pm 0.87$ mas/yr.

Seven stars are found to be the astrometric members of the cluster, three of them are fainter than 13 mag. Therefore, the equatorial coordinates of the centre of the cluster and radius take the values $\alpha_c = 332.22519^\circ \pm 0.06074^\circ$, $\delta_c = 73.40232^\circ \pm 0.07789^\circ$ and 7.25' respectively.

The location of the members in the spatial distribution and in the VPD is shown with black circles in **Figure 2(c)** and **Figure 3(c)**, respectively. **Table 4** 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 5**.

3.3. Proper Motion Errors

We analyse the incidence of stellar proper motions errors in the determination of the cluster parameters and stellar membership. We follow the method proposed

Table 3. vdB146 astrometric members.

No.	UCAC4	α [°]	ϵ_α [mas]	δ [°]	ϵ_δ [mas]	$\mu_\alpha \cos\delta$ [mas/yr]	$\epsilon_{\mu_\alpha \cos\delta}$	μ_δ [mas/yr]	ϵ_{μ_δ}	P_{ci}
4	781-037984	325.7090821	14	66.1097712	12	−3.6	0.6	−4.0	0.7	1.00
6	781-037989	325.7441039	24	66.1029014	23	−2.1	1.0	−3.1	0.9	1.00
12	781-037993	325.7783568	28	66.1150281	27	−1.9	1.0	−2.8	2.4	0.99
23	781-037976	325.6679480	22	66.1686000	36	−3.1	1.3	−3.4	2.0	0.94
65	781-038012	325.9598056	24	66.1465675	14	−3.0	0.9	−3.3	1.1	0.55

Table 4. vdB150 astrometric members.

No.	UCAC4	α [°]	ϵ_α [mas]	δ [°]	ϵ_δ [mas]	$\mu_\alpha \cos\delta$ [mas/yr]	$\epsilon_{\mu_\alpha \cos\delta}$	μ_δ [mas/yr]	ϵ_{μ_δ}	P_{ci}
1	817-026634	332.4172003	3	73.3909014	3	5.7	1.2	4.0	1.4	1.00
18	817-026638	332.5618659	23	73.3626687	38	2.4	1.6	4.5	3.5	0.99
22	817-026624	332.2750918	76	73.3474664	71	4.6	5.0	1.6	5.2	0.97
24	818-027029	332.2982621	22	73.4727898	21	0.8	5.0	4.0	6.9	0.98
33	817-026636	332.5407018	135	73.3221962	80	1.0	5.2	7.7	4.7	0.95
54	817-026629	332.3280112	111	73.3015528	110	2.2	5.2	1.3	5.5	0.93
67	818-027020	332.1690986	88	73.5030850	93	2.5	12.1	8.2	6.2	0.90

Table 5. Centre coordinates, mean proper motion, number of members N and diameters D of the clusters.

Cluster	α_c [°]	δ_c [°]	$\mu_\alpha \cos\delta$ [mas/yr]	μ_δ [mas/yr]	N	D [′]
vdB92	105.97281 ± 0.13113	−11.57814 ± 0.10575	−3.46 ± 0.19	1.27 ± 0.19	60	34
vdB146	325.78423 ± 0.15297	66.13575 ± 0.02907	−2.71 ± 0.25	−3.32 ± 0.25	5	9
vdB150	332.22519 ± 0.06074	73.40232 ± 0.07789	3.07 ± 0.90	4.65 ± 0.90	7	15

by Chen *et al.* [17]. 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 in the region of each cluster. After this, we apply the procedure presented in Subsection 1 to each simulated sample and obtain the cluster parameters and the astrometric members. We then calculate the mean value of $(\mu_\alpha \cos\delta, \mu_\delta)$ and the mean number of members, as shown in **Table 6**.

Comparing these results to those obtained in Subsection 3.2 (see **Table 5**), it is easy to see that the error does not significantly change the kinematic parameters of the studied clusters.

In addition, the effect of the proper motion errors on the determination of cluster members for each cluster is examined. Therefore, we count the number

Table 6. 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
vdB92	−3.41 ± 0.04	1.26 ± 0.04	57 ± 1
vdB146	−2.60 ± 0.04	−3.39 ± 0.07	4 ± 1
vdB150	3.37 ± 0.30	4.40 ± 0.21	7 ± 1

of times in which a cluster member obtained in Subsection 3.2 keeps its membership condition throughout the 25 simulations.

Figure 4 shows these results by a histogram for each cluster, where the abscissa shows our numbering system for vdB92, vdB146 and vdB150 respectively.

It is easy to see that between 80% and 90% of the members maintain their condition, despite the proper motion errors.

4. Discussion

We compare the stellar astrometric membership condition in the regions of vdB92, vdB146 and vdB150 with the photometric one given in the literature.

*Open cluster vdB*92:

In 2010, Bonatto and Bica made an infrared photometric analysis using 2MASS data and derived fundamental parameters. We take these parameters to plot the CMD of the 60 astrometric members (**Figure 5**). Up to 13 magnitude, we compare their distribution with the one of the photometric members drawn in **Figure 6** right of Bonatto and Bica [3]. We find that three astrometric members shown with a triangle in **Figure 5** are not photometric members.

In their investigation, Bonatto and Bica [3] calculate the average spectroscopic distance of five photometric members using SIMBAD data, in excellent agreement with the photometric value. It is important to remark that four of these stars-HRW14 (UCAC4 393-021237), BD-11 1763 (UCAC4 393-021223), HIP 34133 (UCAC4 393-021497) and NSV 3364 (UCAC4 393-021345)-are astrometric members.

*Open cluster vdB*146:

We analyse the astrometric membership condition of the nine cluster members obtained by Aveni and Hunter [10]. Only five members fulfil both astrometric and photometric condition, they are stars No. 1 (UCAC4 781-037989), No. 2 (UCAC4 781-037993), No. 4 (UCAC4 781-037984), No. 7 (UCAC4 781-038012) and No. 10 (UCAC4 781-037976). The other ones are not astrometric members for different reasons: star No. 3 (UCAC4 781-037991) cannot be evaluated by our astrometric analysis as it has no proper motion components, stars No. 23 (UCAC4 782-037014) and No. 24 (UCAC4 780-039381) are located outside the cluster radius and finally star No. 9 (UCAC4 781-037982) does not fulfil the condition due to the value of its proper motion. These results are shown in **Table 7**.

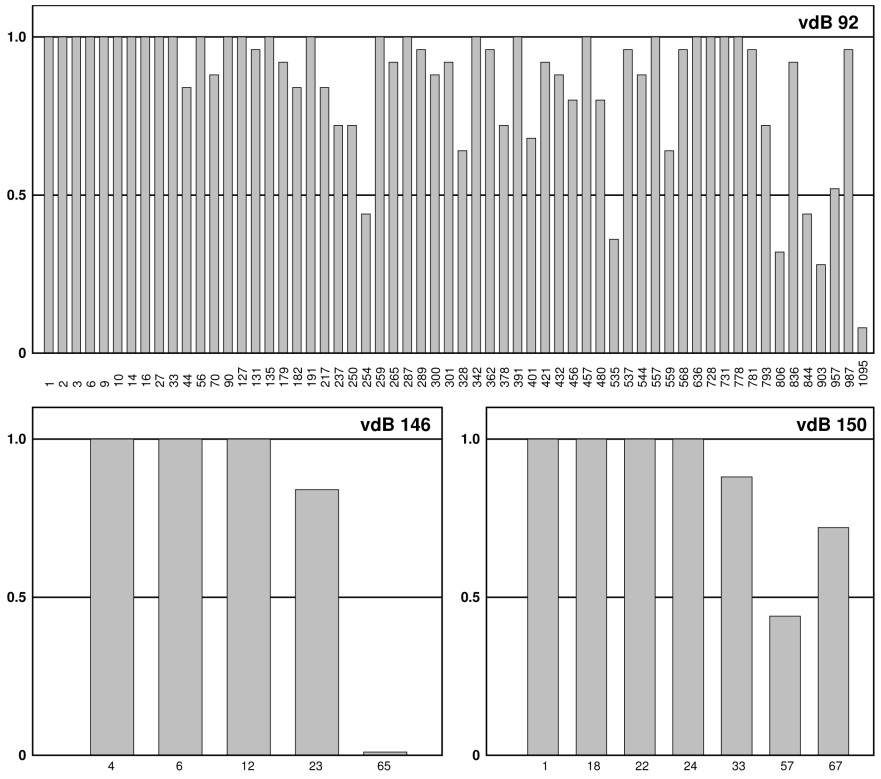


Figure 4. Histogram showing the probability in which a cluster member previously determined keeps its membership condition throughout the 25 simulations for vdB92, vdB146 and vdB150.

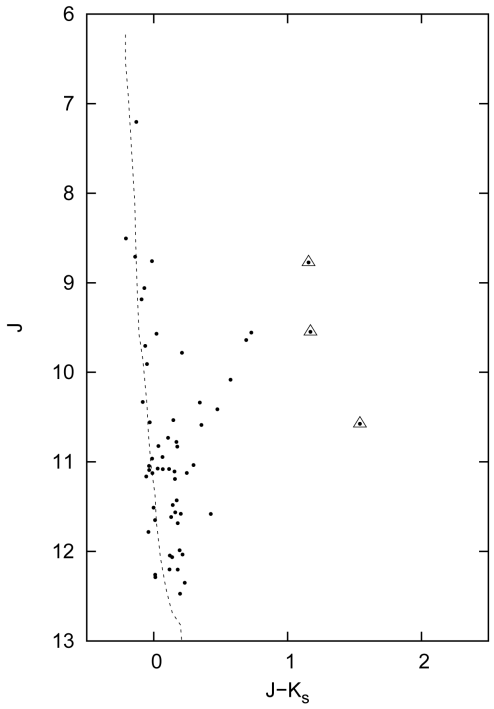


Figure 5. Colour-magnitude diagram of vdB92 astrometric members using Bonatto and Bica (2010) parameters. The ones symbolized by a triangle are not photometric members according to **Figure 6** right of the mentioned article.

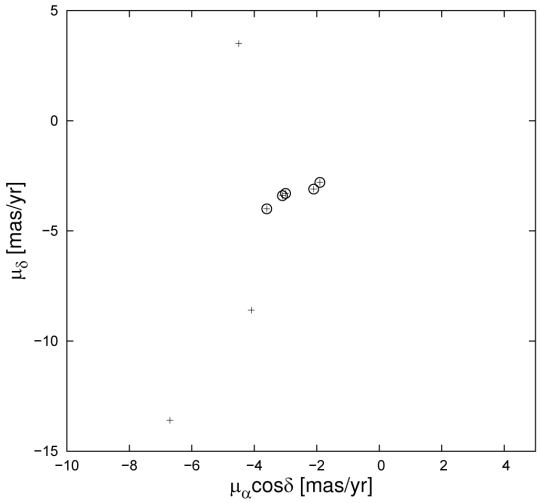


Figure 6. VPD of the eight Aveni and Hunter's photometric members for vdB146 plotted with crosses, while the five astrometric members are plotted with large circles.

Taking into account that cluster members must share similar kinematic features, the VPD of the photometric members (**Figure 6**) explains the reason why stars No. 9, No. 23 and No. 24 cannot be considered members of the cluster. The photometric members are plotted with crosses and the five astrometric members with large circles.

Straižys *et al.* [11] find that the young age of the cluster makes that only six cluster members are located close to the main sequence and the majority of stars are on the pre-main-sequence. These stars are BD + 65 1637 (UCAC4 781-037984), BD + 651638 (UCAC4 781-037989), LkHα234 (UCAC4 781-037993), No. 96 (UCAC4 781-037976), No. 105 (UCAC4 781-037982) and No. 154 (UCAC4 781-038012). Note that the former five stars are members for Aveni and Hunter [10].

While comparing our results with these six cluster members, it can be seen that only star No. 105 (UCAC4 781-037982) does not fulfil the astrometric membership condition due to its proper motion. These results are shown in **Table 7**.

*Open cluster vdB*150:

Aveni and Hunter [10] examine a sampling of 19 stars in the area surrounding the reflection nebula vdB-RN150 in order to interpret the nature of the loose group of stars. They suggest that this group, except star BD +72 1018 (UCAC4 815-027807) which belongs to nebula vdB149, is a cluster centred about star No. 1 (UCAC4 817-026634) and is located at a distance modulus of 7.5.

Even if the Aveni and Hunter's stellar membership criterion of the sampling indicates an uncertainty for all the 18 stars, our study shows that four of these stars are astrometic members, 10 do not fulfil this condition due to the values of their proper motions, two are excluded of the analysis as they have no proper motion and two are located further than 30' of the adopted centre. These results are shown in **Table 8**. Among the astrometric members, star No. 1 (UCAC 4817-026634) has a parallax of 3.31 mas (302.11 pc) as it belongs to the Hipparcos

Table 7. vdB146. Identification of 9 photometric members determined by Aveni and Hunter (1972) in the UCAC4 catalogue.

Aveni and Hunter's number	UCAC4	V [mag]	$B-V$ [mag]	$\mu_\alpha \cos\delta$ [mas/yr]	μ_δ [mas/yr]	astrometric member
1	781-037989	10.26	0.44	−2.1	−3.1	yes
2	781-037993	12.19v?	0.88	−1.9	−2.8	yes
3	781-037991	13.26	0.72	-	-	-
4	781-037984	10.09	0.39	−3.6	−4.0	yes
7	781-038012	12.35	0.61	−3.0	−3.3	yes
9	781-037982	13.25	0.45	−4.5	3.5	no
10	781-037976	12.38	0.57	−3.1	−3.4	yes
23	782-037014	10.62	1.26	−6.7	−13.6	no
24	780-039381	10.66	0.31	−4.1	−8.6	no

catalogue (HIP 109389). This distance is in good agreement with the location of the cluster at 316.2 pc determined by Aveni and Hunter [10]. As cluster members must have similar kinematic parameters, the VPD of the uncertain photometric members (**Figure 7**) explain the reason why some possible photometric members should not be considered members of the cluster. The possible photometric members are plotted with crosses and the four astrometric members with large circles.

5. Conclusions

Taking profit that open cluster members share similar photometric and kinematic properties, astrometric and photometric results are combined in this work to reduce the uncertainty introduced by each technique individually.

We report that vdB92 has $\mu_\alpha \cos\delta_c = -3.46 \pm 0.19$ mas/yr, $\mu_{\delta_c} = 1.27 \pm 0.19$ mas/yr, $\sigma_c = 1.44 \pm 0.13$ mas/yr, 60 astrometric members, $\alpha_c = 105.97281^\circ \pm 0.13113^\circ$, $\delta_c = -11.57814^\circ \pm 0.10575^\circ$ and a value of 34' for the diameter. In the case of vdB146, the obtained values of these parameters are $\mu_\alpha \cos\delta_c = -2.71 \pm 0.25$ mas/yr, $\mu_{\delta_c} = -3.32 \pm 0.25$ mas/yr, $\sigma_c = 0.56 \pm 0.18$ mas/yr, 5 members, equatorial centre coordinates $\alpha_c = 325.78423^\circ \pm 0.15297^\circ$, $\delta_c = 66.13575^\circ \pm 0.02907^\circ$ and a diameter of 9'. In the case of vdB150, the obtained values of these parameters are $\mu_\alpha \cos\delta_c = 3.07 \pm 0.90$ mas/yr, $\mu_{\delta_c} = 4.65 \pm 0.90$ mas/yr, $\sigma_c = 2.39 \pm 0.64$ mas/yr, 7 members, equatorial centre coordinates $\alpha_c = 332.22519^\circ \pm 0.06074^\circ$, $\delta_c = 73.40232^\circ \pm 0.07789^\circ$ and a diameter of 15'. It is worthy to mention that the astrometric parameters of vdB146 and vdB150 are determined for the first time using UCAC4 data.

The incidence of proper motion errors in the determination of the cluster parameters and of the stellar membership is evaluated by applying the model to 25 simulated samples of each cluster. We conclude that the observational errors do

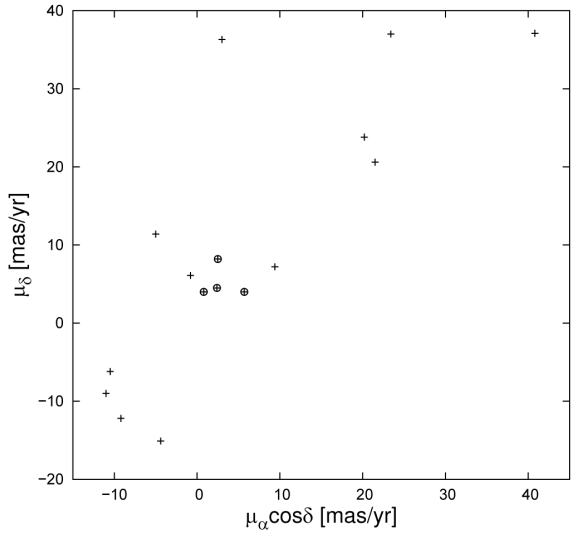


Figure 7. VPD of the 16 Aveni and Hunter's possible photometric members for vdB150 plotted with crosses, while the four astrometric members are plotted with large circles.

Table 8. vdB150. Identification of 18 possible photometric members determined by Aveni and Hunter (1972) in the UCAC4 catalogue.

Aveni and Hunter's number	UCAC4	V [mag]	$B-V$ [mag]	$\mu_\alpha \cos\delta$ [mas/yr]	μ_δ [mas/yr]	astrometric member
1	817-026634	8.38	0.09	5.7	4.0	yes
2	815-027770	8.11	1.18	−5.0	11.4	no
3	817-026679	5.96v?	1.00	21.5	20.6	no
4	817-026677	8.49	0.16	20.2	23.8	no
5	819-026990	8.12	0.43	40.8	37.1	no
6	814-028129	6.95	1.93	−11.0	−9.0	no
8	816-027561	12.09	0.98	−0.8	6.1	no
9	816-027570	11.13	0.62	−10.5	−6.2	no
10	816-027578	11.42	0.62	−9.2	−12.2	no
11	817-026638	11.51	0.91	2.4	4.5	yes
12	817-026648	10.02	1.67	9.4	7.2	no
13	818-027034	9.23	0.28	−4.4	−15.1	no
14	818-027020	10.61	0.59	2.5	8.2	yes
15	818-027055	12.12	1.70	-	-	-
16	818-027029	12.41	0.79	0.8	4.0	yes
17	818-027035	12.47	0.81	23.4	37.0	no
18	818-027036	12.46	1.20	-	-	-
19	818-027043	12.48	1.36	3.0	36.3	no

not significantly change the mean proper motion and the number of members of the examined clusters.

Finally, we compare our membership results and the photometric ones given in the literature to lead to a successful membership determination. In the case of vdB92, we take Bonatto and Bica [3] fundamental parameters and realize that 57 stars are astro-photometric members. For vdB146, the comparison with the photometric members given by Aveni and Hunter [10] affirms that five stars are both astrometric and photometric members. For vdB150, our analysis shows that four stars considered as possible photometric members by Aveni and Hunter [10] are astrometric members. In addition, the parallax of one astrometric member is in good agreement with the location of the cluster determined by Aveni and Hunter [10].

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References

[1] Corti, M.A. and Orellana, R.B. (2013) Members of Centaurus OB1 and NGC 4755: New Spectroscopic and Astrometric Studies. *Astronomy and Astrophysics*, **553**, Article ID: A108. https://doi.org/10.1051/0004-6361/201220743

[2] Orellana, R.B., De Biasi, M.S. , Paz, L.G., Bustos Fierro, I.H. and Calderón, J.H. (2015) A Revisit to the Regions of Some van den Bergh Open Clusters Using Photometric and Astrometric Parameters. *New Astronomy*, **36**, 70-79. https://doi.org/10.1016/j.newast.2014.10.005

[3] Bonatto, C. and Bica, E. (2010) The Fate of the Pre-Main Sequence-Rich Clusters Collinder 197 and vdB 92: Dissolution? *Astronomy and Astrophysics*, **516**, Article ID: A81. https://doi.org/10.1051/0004-6361/201014146

[4] van den Bergh, S. (1966) A Study of Reflection Nebulae. *Astronomical Journal*, **71**, 990-998. https://doi.org/10.1086/109995

[5] Racine, R. (1968) Stars in Reflection Nebulae. *Astronomical Journal*, **73**, 233-245. https://doi.org/10.1086/110624

[6] Soares, J.B. and Bica, E. (2003) The Embedded Star Clusters in the Nebulae vdB-RN 92 and Gy 3-7 in Canis Majoris R1. *Astronomy and Astrophysics*, **404**, 217-222. https://doi.org/10.1051/0004-6361:20030485

[7] Froebrich, D., Scholz, A. and Raftery, C.L. (2007) A Systematic Survey for Infrared Star Clusters with b < 20˚ Using 2MASS. *Monthly Notices of the Royal Astronomical Society*, **374**, 399-408. https://doi.org/10.1111/j.1365-2966.2006.11148.x

[8] Dias, W.S., Monteiro, H., Caetano, T.C., Lépine, J.R.D., Assafin, M. and Oliveira, A.F. (2014) Proper Motions of the Optically Visible Open Clusters Based on the UCAC4 Catalog. *Astronomy and Astrophysics*, **564**, A79. https://doi.org/10.1051/0004-6361/201323226

[9] Dias, W.S., Alessi, B.S., Moitinho, A. and Lépine, J.R.D. (2002) New Catalogue of Optically Visible Open Clusters and Candidates. *Astronomy and Astrophysics*, **389**, 871-873. https://doi.org/10.1051/0004-6361:20020668

[10] Aveni, A.F. and Hunter, J.H. (1972) Observational Studies Relating to Star Formation, III. *Astronomical Journal*, **77**, 17-23. https://doi.org/10.1086/111239

[11] Straižys, V., Maskoliūnas, M., Boyle, R.P., Prada Moroni, P.G., Tognelli, E., Zdanavičius, K., Zdanavičius, J., Laugalys, V. and Kazlauskas, A. (2004) The Distance to the Young Cluster NGC 7129 and Its Age. *Monthly Notices of the Royal Astronomical Society*, **438**, 1848-1855. https://doi.org/10.1093/mnras/stt2334

[12] Zacharias, N., Finch, C.T., Girard, T.M., Henden, A., Bartlett, J.L., Monet, D.G. and Zacharias, M.I. (2013) The Fourth US Naval Observatory CCD Astrograph Catalog (UCAC4). *The Astronomical Journal*, **145**, 44. https://doi.org/10.1088/0004-6256/145/2/44

[13] Stock, J. and Abad, C. (1988) The Unification of Astrometric Catalogues. *Revista Mexicana de Astronoma y Astrofsica*, **16**, 63.

[14] Vasilevskis, S., Klemola, A. and Preston, G. (1958) Relative Proper Motions of Stars in the Region of the Open Cluster NGC 6633. *Astronomical Journal*, **63**, 387-395. https://doi.org/10.1086/107787

[15] Sanders, W.L. (1971) An Improved Method for Computing Membership Probabilities in Open Clusters. *Astronomy and Astrophysics*, **14**, 226-232.

[16] Jones, B.F. and Walker, M.F. (1988) An Improved Method for Computing Membership Probabilities in Open Clusters. *Astronomical Journal*, **95**, 1755-1782. https://doi.org/10.1086/114773

[17] Chen, B., Asiain, R., Figueras, F. and Torra, J. (1997) Identification of Moving Groups from a Sample of B, A and F Type Stars. *Astronomy and Astrophysics*, **318**, 29-36.