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Stars and brown dwarfs in the σ Orionis cluster

II. A proper motion study

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ABSTRACT

Aims. I attempt to fully understand the origin of the stellar and substellar populations in the young σ Orionis open cluster, which is a benchmark for star-forming studies. Because of the very low proper motion of the cluster, late-type dwarfs with appreciable proper motion in the foreground of σ Orionis can be easily discarded as targets from expensive spectroscopic follow-up studies.
Methods. I use the Aladin sky atlas, USNO-B1, public astrometric catalogues, and photographic plate digitisations to identify stars with proper motions that are inconsistent with cluster membership in a circular area of radius 30 arcmin centred on the early-type multiple system σ Ori. Primarily because of the long time baseline of more than half a century, the errors in the measured proper motions are lower than 2 mas a^{-1}.
Results. Of the 42 stars selected for astrometric follow-up, 37 of them are proper-motion cluster interlopers. Some USNO-B1 measurements were affected by partially resolved (visual) multiplicity and target faintness. Because of their late spectral types and, hence, red colours, 24 contaminants had been considered at some point as σ Orionis members. I discuss how contamination may have affected previous work (especially related to disc frequencies) and the curious presence of lithium absorption in three M-dwarf proper motion contaminants. Finally, I classify the bright star HD 294297 as a late-F field dwarf unrelated to the cluster based on a new proper motion measurement.
Conclusions. Although proper motions cannot be used to confirm membership in σ Orionis, they can be instead used to discard a number of cluster member candidates without spectroscopy.

Key words. astronomical databases: miscellaneous – stars: late-type – open clusters and associations: individual: σ Orionis – proper motions

1. Introduction

The σ Orionis cluster ($\tau \sim 3$ Ma, $d \sim 385$ pc) in the Ori OB 1b association is a unique site for investigating the formation and evolution of stars and substellar objects from several tens of solar masses to a few Jupiter masses (Garrison 1967; Wolk 1996; Béjar et al. 1999; Caballero 2007a; Walter et al. 2008, and references therein). Although it is not as young and nearby as other star-forming regions such as the Orion Nebula Cluster, ρ Ophiuchi, or Chamaeleon I+II, σ Orionis has the great advantage of being relatively compact ($\rho_{\rm core} \sim 20$ arcmin – Caballero 2008a) and having a very low visual extinction (0.04 mag < $E(B-V)$ < 0.09 mag – Béjar et al. 2004; Sherry et al. 2008). The high spatial density and low extinction do not only facilitate the study of the initial mass function down to well below the deuterium burning limit (Zapatero Osorio et al. 2000; Béjar et al. 2001; Caballero et al. 2007; Bihain et al. 2009), but also the identification and characterisation of young stars with X-ray emission (Sanz-Forcada et al. 2004; Franciosini et al. 2006; Skinner et al. 2008; Caballero et al. 2009) or discs detected on the basis of their infrared excess (Oliveira et al. 2006; Hernández et al. 2007; Zapatero Osorio et al. 2007; Luhman et al. 2008), hydrogen recombination lines in emission (including Hα – Zapatero Osorio et al. 2002; Weaver & Babcock 2004; Kenyon et al. 2005; Caballero et al. 2006; Gatti et al. 2008; Fedele et al. 2010), or jets (Reipurth et al. 1998; Andrews et al. 2004).

Most of the works listed above compute frequencies of X-ray emitters, Hα accretors, or disc hosts, some of which are extensively used in the literature (e.g., Hernández et al. 2007). Accurate frequency determinations require a precise knowledge of the σ Orionis stellar and substellar populations. A large fraction of the cluster member candidates, especially in the inner 20 arcmin, are known to have features of extreme youth (e.g., very early spectral types, Li I λ6707.8 Å in absorption, Hα in strong broad emission, flux excess in the near- and mid-infrared, spectroscopic signatures of low gravity – Caballero 2008c). However, there is evidence that there is significant contamination by field dwarfs (Caballero et al. 2008a; Lodieu et al. 2009), apart from overlapping *young* stellar populations of the Orion Belt (e.g., Jeffries et al. 2006; Caballero 2007a; Sacco et al. 2007; González-Hernández et al. 2008) and galaxies (Caballero et al. 2007, 2008b; Hernández et al. 2007; Caballero 2008c).

The usual procedure for identifying a true σ Orionis member is the spectroscopic follow-up after photometric selection in a colour−magnitude diagram. If no spectroscopy is available and the combination of photometric band passes is not optimal, then a large number of (foreground) field dwarfs may contaminate a sample. One way of maximising the telescope time devoted to the spectroscopic follow-up of reliable cluster member candidates is to discard beforehand those that have proper motions inconsistent with cluster membership. In σ Orionis, this method of de-contamination has been applied in only a few occasions (Caballero 2007a, 2008c; Lodieu et al. 2009)[1].

[1] Besides, Zapatero Osorio et al. (2008) used the small proper motion of S Ori 70 to indicate that this object is farther away than expected if it were a single field T dwarf lying in the foreground of σ Orionis.

Depending on the accuracy of the data used, stars with proper motions larger than 10 (*Hipparcos* and Tycho-2), 20 (USNO-B1), and 30 mas a^{-1} (2MASS/UKIDSS Galactic Cluster Survey) were classified as foreground field stars. These relatively small values are due to the location of σ Orionis close to the antapex, which combined with a distance of almost 400 pc lead to a proper motion of the cluster centre of mass of only ($\mu_\alpha \cos\delta$, μ_δ) = (+2.2 ± 1.2, −0.5 ± 1.0) mas a^{-1} (Caballero 2007a); this proper motion is consistent with the value provided by Kharchenko et al. (2005).

In this work, I use Virtual Observatory tools and data archives to search for and characterise field stars in the direction of σ Orionis with relatively large proper motions, measured with accuracies superior to 2 mas a^{-1}. Most of the interloper stars seem to be of late spectral types. Because of the resemblance between their magnitudes and colours and those of young late-type stars in σ Orionis, an important fraction of the proper-motion interlopers had actually been selected as cluster member candidates in photometric surveys (Scholz & Eislöffel 2004; Sherry et al. 2004; Kenyon et al. 2005; Caballero 2006; Hernández et al. 2007).

2. Analysis

2.1. Aladin search

I used the stellar proper motions tabulated by the United States Naval Observatory USNO-B1 catalogue (Monet et al. 2003), which has a wider coverage of target magnitudes and is less affected by unresolved binarity than the most recent Positions and Proper Motions-Extended catalogue (PPMX – Röser et al. 2008). The Lick Northern Proper Motion 2 catalogue (LNPM2 – Hanson et al. 2004), which also covers the Orion region, is severely affected by systematics[2].

First, I used the Aladin sky atlas (Bonnarel et al. 2000) to cross-match the USNO-B1 and Two-Micron All Sky Survey (2MASS – Skrutskie et al. 2006) catalogues in a circle area of radius ρ = 30 arcmin centred on the Trapezium-like multiple stellar system σ Ori (Fig. 1), which is located at the centre of the σ Orionis cluster (Caballero 2008b). A total of 5421 USNO-B1 sources have a 2MASS near-infrared counterpart within 4 arcsec (in practice, I looked for the USNO-B1 counterparts of 2MASS sources). By cross-matching the two catalogues, it was possible to filter most of the numerous spurious USNO-B1 sources found in fields with high background and bright stars, as in this case. Next, I used the Aladin tool VOplot to select USNO-B1/2MASS stars with four or five detections in the USNO-B1 catalogue ($N_{\rm USNO-B1} > 3$), J-band magnitudes brighter than 15.5 mag, and proper motions $\mu_{\rm USNO-B1}$ > 40 mas a^{-1}. Very faint sources or those with detections at only two or three astrometric epochs (of a maximum of five epochs) have relatively large errors in proper motion and did not pass the previous filter. Of the 5421 USNO-B1/2MASS sources, only 42 (0.8%) objects satisfied my selection criterion. They are shown in Table A.1. The USNO-B1 proper motions of the 42 objects vary between 40 and 290 mas a^{-1}, with 31 having detections at five epochs.

I chose the 40 mas a^{-1} limit to take into account:

– the increasing dispersion in intrinsic velocity, which is proportional to the dispersion in the proper motion, with decreasing masses. In a sample of *bona fide* brown dwarfs of the well-known Pleiades cluster, Bihain et al. (2006) measured an intrinsic velocity dispersion at least four times larger than for cluster stars with masses of the order or higher than 1 $M_\odot$, as expected for a nearly relaxed cluster. Since limit values of 10 mas a^{-1} had been adopted for the most massive stars in σ Orionis (Caballero 2007a), a limit value four times larger naturally arises for low-mass cluster stars (although the σ Orionis cluster is *not* relaxed – Caballero 2008b);
– the increasing number of proper-motion interloper candidates to be followed-up for decreasing limit values. While there were 42 objects to be followed-up in the case of the 40 mas a^{-1} limit, there were 77, 161, and 492 such objects for the 30, 20, and 10 mas a^{-1} limits, respectively. Going below the 40 mas a^{-1} limit would make the target sample unmanageable;
– and the increasing number of USNO-B1 sources with spurious, incorrect, tabulated values for decreasing proper motions.

[2] For example, all LNPM2 stars in the survey area except two have very low proper motions. The two exceptions, with tabulated LNPM2 proper motions of about 10 mas a^{-1}, are an anonymous binary with true $\mu \sim 0$ and G 99–20, a high proper-motion star with true $\mu \sim 290$ mas a^{-1} (see below).

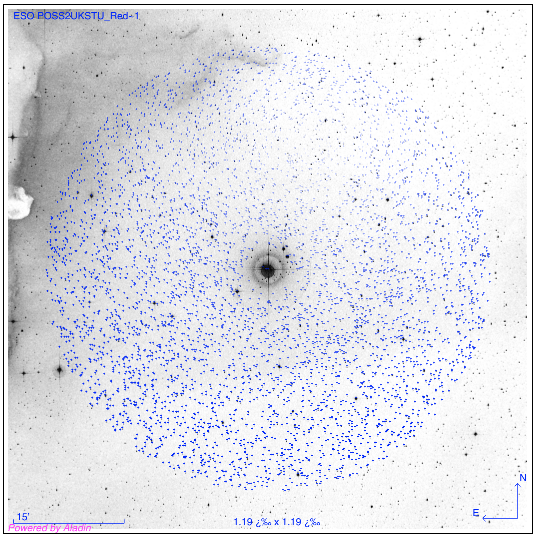

Fig. 1. Inverse-colour digitised image of the red plate (R_J) of the Digital Sky Survey II centred on the Trapezium-like σ Ori system, as shown by Aladin. Cross-matched USNO-B1/2MASS sources are marked with small (blue) crosses. Size is 70 × 70 arcmin^2, north is up, and east is to the left. Note a part of the Horsehead Nebula (Barnard 33) and the IC 434 reflection nebula to the east.

2.2. Astrometric follow-up

I followed the same methodology as Caballero (2009) in measuring high accuracy proper motions for the 42 objects. Basically, I used public data from digitised photographic plates and astro-photometric catalogues of the last half century. I gave special emphasis to the use of data from USNO-A2 (Monet et al. 1998), Guide Star Catalogues 2.2 and 2.3 (GSC2.2 and GSC2.3 – STScI 2001, 2006), 2MASS, Deep Near Infrared Survey of the Southern Sky (DENIS – Epchtein et al. 1997), Carlsberg Meridian Catalog 14 (CMC14 – Evans et al. 2002; Muiños 2006), UKIRT Infrared Deep Sky Survey (UKIDSS – Lawrence et al. 2007), and the SuperCOSMOS digitisations of plates from the United Kingdom Schmidt Telescope (UKST) and the first epoch of the Palomar Observatory Sky Survey (POSSI – Hambly et al. 2001).

The relatively poor astrometric precision of the plate digitisations, of 0.4–0.5 arcsec, was counterbalanced by the long

Table 1. Astrometric epochs for star No. 24 (G 99–20).

Date	Image
1951 Nov. 28	POSSI Red (USNO-A2.0)
1983 Nov. 28	Plate 0084 (GSC1.2/ACT)
1984 Jan. 03	UKST Blue (GSC1.2/ACT)
1990 Dec. 22	UKST Red (GSC2.2/2.3)
1996 Jan. 27	UKST IR
1998 Oct. 30	2MASS
1999 Feb. 09	DENIS
2000 Oct. 05	CMC14
2005 Oct. 06	UKIDSS K

interval between epochs. In Table 1, I show an example of the nine astrometric epochs used to compute the proper motion of star No. 24 (G 99–20). In this case, almost 54 years passed between the first and last epochs. For the other 41 objects, a typical number of astrometric epochs was also eight or nine ($\overline{N}$ = 8.14; with maxima and minima of ten and seven epochs, respectively), and they also covered about 54 years. Except for the CMC14 epochs, which have an accuracy of one day, all the tabulated astrometric epochs have a temporal precision better than 0.0001 modified Julian days. Depending on when the corresponding field was surveyed, the epochs for each dataset varied from one target to other, but remained within a narrow interval (e.g., all 2MASS measurements in the σ Orionis area were taken between J1998 and J2000). Only the epoch for the the POSSI Red (USNO-A2.0) measurement, J1951.908, remained identical for all the sources in the area.

When there was no detection by GSC2.2/2.3 and/or USNO-A2.0 (especially because of target faintness), I used instead the red optical digitisations of POSSI and UKST. Blue and infrared UKST digitisations were used in all case. Star centroid positions were measured with the IRAF environment using standard tasks. Occasionally, there was an additional, intermediate, astrometric epoch at ~J1984 from GSC1.2/ACT (Lasker et al. 1988), or double DENIS detections at different epochs between J1995 and J1999. Apart from this, the faintest objects had in general no CMC14 measurements. Of the several UKIDSS unmerged astrometric data sets, I considered those taken in the K band, which are of higher spatial resolution than to those taken in the Y, Z, J, and H bands. The astrometric accuracy for each epoch ranged between 0.06–0.07 arcsec for 2MASS (when tabulated, CMC14 accuracy was even higher) to 0.4–0.5 for USNO-A2.0 and GSC2.2/2.3 or point spread fittings of red targets in the blue UKST images.

Proper motions in right ascension $\mu_\alpha \cos\delta$ and declination μ_δ were computed independently using simple linear fits with time (i.e., possible contribution by parallax was not accounted for). Errors were estimated from the standard deviations of the differences between the observed values $\alpha(t)$ and $\delta(t)$ and the expected values $\alpha^*(t)$ and $\delta^*(t)$ from the linear regression. These errors in proper motion were always smaller than 2 mas a^{-1}, with average proper motion errors of only 0.92 and 0.97 mas a^{-1} in right ascension and declination, respectively, which are comparable to the Tycho-2 catalogue errors (Høg et al. 2000). However, the objects studied for this paper are much fainter: only nine of the 42 objects are brighter than J = 12 mag, while three objects are fainter than J = 15 mag. Because of their red colours, many targets are close to the limiting magnitude of the blue and red optical photographic plates ($B_J \sim R_F \gtrsim 20$ mag). As examples, Figs. 2 and 3 show the temporal variation in the star coordinates and the fit for the high proper-motion star No. 24 (G 99–20).

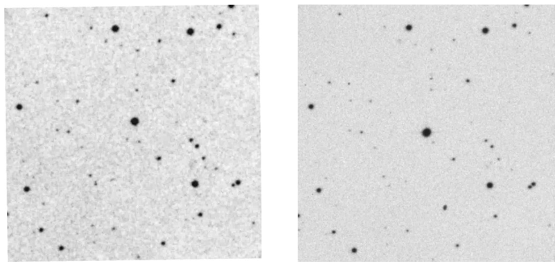

Fig. 2. Inverse-colour SuperCOSMOS digitised images of the red plates (R_J) of POSSI (J1951.9, *left*) and UKST (J1991.0, *right*) centred on the J2000 position of star No. 24 (G 99–20). Size is 5 × 5 arcmin^2, north is up, and east is to the left. During the 39 years between the two images, the star moved more than 11 arcsec.

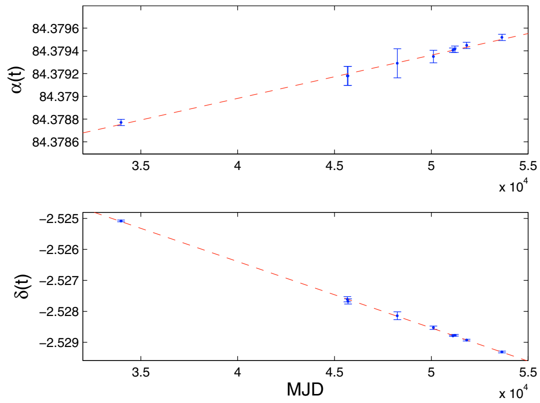

Fig. 3. Right ascension and declination as a function of modified Julian date for the star No. 24 (G 99–20). Dashed (red) lines indicate the linear fits. The largest errorbars correspond to the UKST Blue (GSC2.2/2.3) astrometric epoch.

The proper motions and number of epochs used in preparing the astrometric follow-up of the 42 objects are given in the last columns of Table A.1.

3. Results

3.1. Objects with incorrect USNO-B1 proper motions

The correspondence between the USNO-B1 proper motions and those measured in this work are in general acceptable, with variations smaller than about 10 mas a^{-1}, but a number of noticeable exceptions exist. There are 15 investigated objects whose true proper motions differ from those inferred by USNO-B1 by 30–120 mas a^{-1}. They were affected by visual multiplicity and faintness in the visible. The seven cross-matched sources with separations between the USNO-B1 and 2MASS counterparts of more than 0.9 arcsec (and up to 3.5 arcsec) are among those exceptions (the separations for the other 35 objects are of 0.6 arcsec or less).

The remaining 27 stars have reliable USNO-B1 proper motions larger than μ > 40 mas a^{-1}. Of these, six are presented here for the first time (Nos. 01, 03, 19, 25, 28, and 35) and have J-band magnitudes and proper motions in the approximate intervals 40–60 mas a^{-1} and 13–14 mag, respectively, while the other 21 stars were investigated in previous work with more or less detail.

3.1.1. Visual multiple systems

Ten investigated stars with incorrect USNO-B1 proper motions have visual companions of roughly the same optical magnitudes at separations $\rho \sim$ 4–8 arcsec, which were incorrectly resolved

Table 2. Companions in visual binary and multiple systems with incorrect USNO-B1 proper motions.

No.	ρ [arcsec]	θ [deg]	$\mu_\alpha \cos\delta$ [mas a^{-1}]	μ_δ [mas a^{-1}]	J [mag]
02[a]	7.2	242	$+3.9 \pm 0.7$	-2.3 ± 0.7	14.53 ± 0.03
04[b]	8.1	168	$+6.1 \pm 0.9$	-8.1 ± 1.2	16.08 ± 0.08
09	5.3	182	-8.2 ± 1.4	-13.6 ± 1.0	15.19 ± 0.05
12	6.0	335	$+10.5 \pm 1.3$	-7.7 ± 0.8	16.27 ± 0.08
18	6.6	292	$+5.4 \pm 1.8$	-17.2 ± 2.1	14.49 ± 0.04
20	4.8	234	-2.0 ± 1.0	-11.5 ± 1.0	15.16 ± 0.04
21	7.5	152	$+4.6 \pm 0.7$	-16.3 ± 1.1	13.07 ± 0.03
22	5.6	311	$+1.0 \pm 0.7$	-4.5 ± 0.6	14.36 ± 0.04
38	6.6	324	-9.6 ± 0.6	$+9.7 \pm 0.6$	14.47 ± 0.03
42[c]	4.5	237	$+1.3 \pm 1.9$	-10.6 ± 0.8	16.78 ± 0.03

Notes. [(a)] The visual companion to star No. 02 is appreciably brighter in the visible ($\overline{B_J}$ = 18.7 mag versus $\overline{B_J}$ = 19.8 mag) and fainter in the near infrared (K_s = 15.41 ± 0.08 mag versus K_s = 13.59 ± 0.04 mag) than the star No. 02.
[(b)] There is an additional visual companion to star No. 04. It is a faint, blue source at $\rho \sim 4.1$ arcsec, $\theta \sim 217$ deg, only resolved by 2MASS and UKIDSS ($J = 16.43 \pm 0.10$ mag), with similarly low proper motion.
[(c)] UKIDSS J-band magnitude transformed into the 2MASS one by adding the offset $J_{\rm 2MASS} - J_{\rm UKIDSS}$ measured for Mayrit 1610344. There are two additional visual companions to this star: USNO-A2.0 0825–01615246, a relatively blue star at 7.8 arcsec to the southwest and with a proper motion ($\mu_\alpha \cos\delta$, μ_δ) = (+2.9 ± 1.2, −7.6 ± 0.7) mas a^{-1}, and a faint red source at about 3 arcsec to the southeast only resolved by UKIDSS ($K \approx 16.3$ mag).

by at least one USNO-B1 astrometric epoch observation. Some properties of the visual companions to the ten stars are shown in Table 2 (stars Nos. 02 and 04 are in fact triple and quadruple systems, respectively). None have proper motions larger than 20 mas a^{-1} or consistent with membership of a physical system, and only one has ever been considered as a cluster member candidate (the visual companion to star No. 22; see below).

Three of the ten main targets in visual multiple systems have actual total proper motions larger than 70 mas a^{-1} (Nos. 02, 12, and 18) and are, therefore, high proper-motion interloper stars towards the σ Orionis cluster. The same is true of another four stars with proper motions $\mu \sim$ 20–30 mas a^{-1} (Nos. 09, 20, 21, and 22). The remaining three stars (Nos. 04, 38, and 42) have lower proper motions, of 7–12 mas a^{-1}, which are consistent with cluster membership. However, only one of them has ever been considered as a cluster member based on photometry. This star, No. 42 (Mayrit 1610344), was first identified as a (0.39-$M_\odot$, non-variable) photometric σ Orionis member candidate by Scholz & Eislöffel (2004). Afterwards, Sherry et al. (2004) and Caballero (2008c) agreed on this classification (although the first authors assigned a membership probability of only 15%), which should be adhered to until moderate-resolution visible spectroscopy is obtained. The other two low proper-motion stars (Nos. 04 and 38) have visible/near-infrared (DENIS/2MASS) colours that are inconsistent with cluster membership for their magnitudes.

Among the seven high proper-motion star contaminants in visual multiple systems, three targets merit additional descriptions.

No. 18. This was first classified as a σ Orionis member candidate by Sherry et al. (2004), who assigned it an 83% cluster membership probability. Afterwards, Hernández et al. (2007) found no infrared flux excess in its spectral energy distribution, and classified it as a "class III" young object. However, the star No. 18 has not been identified as a cluster member candidate in any other photometric survey, including the comprehensive surveys by Caballero (2008c) and Lodieu et al. (2009). Indeed, Sacco et al. (2008) measured radial velocity and lithium and Hα pseudo-equivalent widths that are inconsistent with cluster membership (No. 18 is, in addition, a spectroscopic binary). The proper motion measured here, of 78 mas a^{-1}, agrees with the Sacco et al. (2008) hypothesis that No. 18 is an M2V binary star in the foreground of σ Orionis.

No. 21. This star has been cited only once, by Hernández et al. (2007), who classified it as a "class III" young object. However, star No. 21, with a proper motion $\mu \approx 31$ mas a^{-1} and red DENIS/2MASS colours, is probably another M dwarf in the foreground of the cluster.

No. 22. The system is formed by two stars equally separated from an X-ray source detected with *XMM-Newton* by López-Santiago & Caballero (2008). On the one hand, the brightest star in the pair, which has a low proper motion, has too blue DENIS/2MASS colours for its magnitude, inconsistent with cluster membership. On the other hand, the faintest star (Table 2), which was also considered to be a cluster member candidate by Sherry et al. (2004) and Hernández et al. (2007), has a proper motion of $\mu \approx 30$ mas a^{-1} and does not belong either to σ Orionis. X-ray source [LC2008] NX 11 has hardness ratios that are unusual for young active stars in σ Orionis and is located at a relatively large separation ($\rho \sim 4$ arcsec) from the two foreground stars. The X-ray emission probably originates in an active galaxy that has yet to be detected by imaging (López-Santiago & Caballero 2008).

3.1.2. Single objects

Discarding the ten previously considered stars in visual multiple systems, there are another five objects with proper motion differences between USNO-B1 and my astrometric follow-up of $|\Delta\mu| > 12$ mas a^{-1}. These variations are ascribed to target faintness[3] (Nos. 08, 23, and 32; the three of them have $J \gtrsim 15$ mag) and high background in the visible (Nos. 29 and 36; both of them have a large separation from the cluster centre and are embedded in the IC 434 nebula, which is associated with the Horsehead Nebula – Fig. 1). Three of the stars have both colours and magnitudes that are inconsistent with cluster membership and have never been considered before in photometric surveys. However, the other two objects, which have variations of $|\Delta\mu| \gg 12$ mas a^{-1}, deserve attention.

No. 32 (Mayrit 999306). The faint brown dwarf candidate Mayrit 999306 ([BZR99] S Ori 23) was discovered by Béjar et al. (1999) and has since been identified in several other independent photometric surveys (Béjar et al. 2001; González-García et al. 2006; Caballero 2008c). Its USNO-B1 proper motion, which was based on four astrometric epochs, was severely affected by its extreme faintness in the blue optical: while Mayrit 999306 is relatively bright at 2.2 μm ($K_s \approx$ 14.0 mag), it has photographic magnitudes $B_J \gtrsim R_F \gtrsim 20$ mag. Its true proper motion, of about 14 mas a^{-1} is slightly large, but still consistent with cluster membership. Mayrit 999306 still awaits spectroscopic follow-up of moderate spectral resolution.

No. 36 (Mayrit 1493050). This young star was discovered by Scholz & Eislöffel (2004). Afterwards, Kenyon et al. (2005)

[3] The large uncertainties in the proper motions of targets fainter than $J \approx 15$ mag is an *a posteriori* justification of the limit $J < 15.5$ mag imposed in Sect. 2.1.

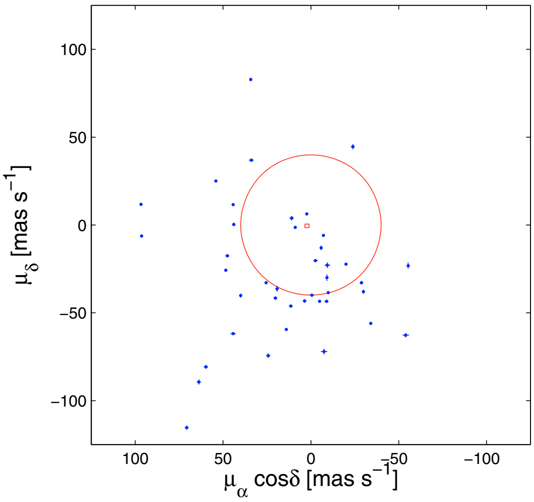

Fig. 4. Proper motion diagram of the 42 main targets. Typical errorbars are of the same size as the small (blue) dots. The (red) circle and small square close to the origin of coordinates indicate μ = 40 mas a^{-1} and the proper motion of the σ Orionis cluster centre (Caballero 2007a), respectively. Star No. 24 (G 99–20), with a proper motion of almost 300 mas a^{-1}, lies outside the limits of the figure.

found lithium in strong absorbtion and low gravity features in its spectrum, while Hernández et al. (2007) claimed that it harbours an "evolved disc" based on IRAC and MIPS *Spitzer* photometry. Maxted et al. (2008) monitored its radial velocity, which is consistent with membership and with SB2 binarity. Mayrit 1493050 is located close to an overdensity in the IC 434 nebula, which may lead to an incorrect USNO-B1 measurement, possibly in the R_F plates, where the nebula is brighter (because of the Hα emission). Its low proper motion, of only 9 mas a^{-1}, confirms the membership of Mayrit 1493050 in σ Orionis.

3.2. Cluster membership and non-membership

Table A.2 summarises the membership status of the 42 main targets (see also Fig. 4). Twenty of them were photometric cluster member candidates in the works by Scholz & Eislöffel (2004; [SE2004]), Sherry et al. (2004; [SWW2004]), and Hernández et al. (2007; [HHM2007]). However, only three objects (No. 32/Mayrit 999306, No. 36/Mayrit 1493050 – with known spectroscopic youth features –, and No. 42/Mayrit 1610344) remain as true cluster member candiates. The other 17 cluster member candidates do not belong to σ Orionis based on proper motion measurements and, in some cases, high-quality spectroscopic information from Kenyon et al. (2005), Caballero (2006), and Sacco et al. (2008). Of the other 22 stars, 15 had not been investigated in the literature and seven had been discarded as cluster members by Kenyon et al. (2005) and Caballero (2006, 2008c) based on spectroscopy and/or proper motion.

To sum up, I identify for the first time 21 proper-motion interlopers and contaminants towards the σ Orionis cluster, of which eight were previously considered as cluster member candidates based on photometry (indicated by "Yes?" in the "Previous member" column of Table A.2). Another two stars with low actual proper motion, Nos. 04 and 38, have magnitudes and colours inconsistent with cluster membership (Sect. 3.1.1). In addition, I confirm the non-cluster membership of 16 foreground stars, of which ten had never been discussed before in the literature. The data for the other six stars with proper motion measurements were tabulated by Giclas et al. (1961; No. 24), Caballero (2006; Nos. 15 and 30), and Caballero (2008c; Nos. 05, 14, and 26).

Finally, of the three objects with low proper motions and suitable magnitudes and colours for σ Orionis membership, two (Nos. 32 and 42, see above) lack spectroscopy and should be followed-up in a future spectroscopic study. The third star, No. 36, is the only *bona fide* member of cluster.

4. Discussion

4.1. Comparison to other works

Of the ten bright Tycho-2 (and *Hipparcos*) proper-motion contaminants towards σ Orionis identified by Caballero (2007a), only two had μ > 40 mas a^{-1} (HD 294269, a G0 star with lithium abundance and radial velocity inconsistent with cluster membership, and TYC 4770 924 1)[4]. In spite of the two stars being cross-matched with counterparts in the USNO-B1/2MASS search (Sect. 2.1), having similar Tycho-2 and USNO-B1 proper motions, and being detected in five USNO-B1 astrometric epochs, they did not pass the VOplot filter. It is likely that Tycho-2 stars, with mean epochs of observation 2000.0, are handled by Aladin/VOplot differently from fainter stars with USNO-B1 proper motions measured from the digitised plates (they have mean epochs of observation 1970–1980). In any case, the work of Caballero (2007a) was devoted to the brightest stars of σ Orionis and is complementary to the study presented here.

The three new stars with μ > 40 mas a^{-1} in the Mayrit catalogue (Caballero 2008c) also appear here (Nos. 05, 14, and 26). The other four non-Tycho-2 proper-motion contaminants without spectroscopy and $\mu \approx$ 20–37 mas a^{-1} in the Mayrit catalogue did not pass the VOplot filter.

Lodieu et al. (2009) tabulated eight stars with proper motions larger than 30 mas a^{-1}, of which only one, No. 16 (with spectroscopic information in Sacco et al. 2008), is presented here as a proper-motion interloper. The other seven stars are:

- S Ori 20, a faint *field* M5.5 dwarf with $N_{\rm USNO-B1}$ = 3 and with previously insufficient membership information (Barrado y Navascués et al. 2003; Kenyon et al. 2005; Caballero et al. 2007),
- three stars of proper motion μ < 40 mas a^{-1} (of which one was a photometric cluster member candidate in Sherry et al. 2004), and
- the young binary stars Mayrit 92149 AB (for which Lodieu et al. 2009 tabulated the two components) and Mayrit 1106058 AB (the X-ray star 2E 1486). The two of them have true null proper motions: spurious values of almost 400 mas a^{-1} resulted from cross-matching the (unresolved) 2MASS and (resolved) UKIDSS coordinates[5]. The two stars were first presented as binaries by Caballero (2007b) and Caballero (2008c), respectively, and exhibit incontrovertible indicators of youth.

4.2. Interloper M dwarfs with lithium?

Following Kenyon et al. (2005), "factors of 100 depletion in lithium are probably needed to reduce" values of Li I pseudo-equivalent widths, pEW(Li I)s, to about 300 mÅ or weaker in the

[4] The same can be applied to the non-Tycho-2 star HD 294276, which was recovered from the Tycho-1 catalogue.

[5] At least the following σ Orionis binary members with $\rho \sim$ 0.5–2.0 arcsec should also have very large spurious proper motion values in a 2MASS/UKIDSS cross-match: Mayrit 707162 AB, Mayrit 1564349 AB (Caballero 2006), Mayrit 1245057 AB, and Mayrit 1411131 AB (Caballero 2008c).

spectra of late-type objects. This is because the lithium is burned in the fully convective interiors of low-mass pre-main sequence stars during the first 20–140 Ma. However, the typical pEW(Li I) of T Tauri stars in σ Orionis ranges between 500 and 600 mÅ, as expected for ~3 Ma-old objects (Zapatero Osorio et al. 2002; Kenyon et al. 2005; Maxted et al. 2008; Sacco et al. 2008 – but there might be a spread in lithium abundance).

Three of the proper-motion contaminants in this work have high signal-to-noise ratio spectroscopy around Hα and Li I, taken by Sacco et al. (2008) with FLAMES at the VLT. They are the stars Nos. 11, 16, and 18, which have radial velocities and pEW(Li I)s (and Hα emission?) inconsistent with membership in σ Orionis (Table 3). Their proper motions vary between 60 and 100 mas a^{-1}, which are values much greater than expected for any cluster member. However, in spite of their late spectral type (M1.5–3.0), the spectra of these *field* dwarfs apparently display lithium in absorption, as measured with exquisite accuracy by Sacco et al. (2008). The pEW(Li I)s, of ~80–100 Å, are more than five times lower than typical σ Orionis members of the similar spectral types and magnitudes, but still appreciable. If the pEW(Li I)s were correct, then the three M dwarfs should be of the age of the Pleiades or younger ($\tau \lesssim$ 120 Ma). I instead consider the feature at the Li I wavelength that Sacco et al. (2008) found was not lithium in absorption, but a collection of lines of molecular CN (^{12}C^{14}N – Grevesse 1968; Mandell et al. 2004; Ghezzi et al. 2008). The later the spectral type of a star is, the stronger the molecular bands of lines become. In M1–3V stars, the CN features may be strong enough to contaminate the lithium region. This CN contamination might also affect the spectra of three young σ Orionis member candidates reported by Sacco et al. (2007) that exhibited lithium depletion at the level of the three field M dwarfs in Table 3.

4.3. HD 294297

For completeness, I also measured the proper motion of the late-F/early-G star HD 294297. Identified as a photometric *non-member* in the Ori OB 1b association subgroup in the early work of Warren & Hesser (1978), the measurement of a high lithium abundance in HD 294297 by Cunha et al. (1995), log ϵ(Li)$_{\rm NLTE}$ = 2.56, was in contrast used as an evidence of its youth. Furthermore, the star was one of the only two "young solar-type members of the Orion association" that were observed with STIS onboard the *Hubble Space Telescope* to investigate their boron abundance (Cunha et al. 2000). However, Caballero (2007a), who retrieved an abnormally high proper motion from the Tycho-1 catalogue (but with generous errorbars), again casted doubts on its membership in Ori OB 1b. Afterwards, González Hernández et al. (2008) derived a lithium abundance similar to that measured by Cunha et al. (1995), log ϵ(Li)$_{\rm NLTE}$ = 2.75 ± 0.18, but using a warmer effective temperature of 6450 ± 100 K (instead of 6150 K). In contrast to what is observed in the HD 294297 spectra, stars of this effective temperature barely show evidence of lithium destruction at the age of the Pleiades or even older (e.g., Soderblom et al. 1993). González Hernández et al. (2008) found that HD 294297 is overluminous in the $\mathcal{L}$ versus J diagram with respect to σ Orionis members, where $\mathcal{L}$ is the luminosity per unit of mass, normalised to this quantity in the Sun. D'Orazi et al. (2008) presented a FLAME spectrum of HD 294297, which may help ascertain the nature of the star, but they did not discuss their results.

In this work, I was able to use five astrometric epochs from UKIDSS, CMC14, 2MASS, USNO-A2, and the Astrographic Catalogue AC2000.2 (Urban et al. 1998). Since the AC2000.2 epoch of observation of HD 294297 was J1895.475, then the time interval between the first and last epochs was longer than 110 years. The measured proper motion, of ($\mu_\alpha \cos\delta, \mu_\delta$) = (+24.9 ± 1.4, −24.2 ± 1.1) mas a^{-1}, is similar to those tabulated in PPMX and UCAC3 (Zacharias et al. 2009)[6], which were not available in 2007. The proper motion is inconsistent with membership in any young association subgroup in Orion. HD 294297 is probably a late-F field dwarf at a different heliocentric distance than Ori OB 1b.

Table 3. Interloper M dwarfs with supposed lithium in absorption.

No.	[SFR2008]	Sp. type	pEW(Li I) [mÅ]	$V_{\rm r}$ [km s^{-1}]
11	S54	M 1.5	88 ± 7	+41.6 ± 0.6
16	S38	M 3.0	78 ± 5	+3.5 ± 0.5
18	S50	M 2.0	94 ± 5	+6 ± 3

4.4. Caveats

In Sect. 1, I noted the importance of a correct de-contamination before deriving any typical parameter in studies of star-forming regions. For example, special care has been applied when measuring the shape of the initial mass function in σ Orionis (see extensive de-contamination discussion in, e.g., Caballero et al. 2007; Lodieu et al. 2009; and Bihain et al. 2009). However, I warn against the incorrect use of certain parameters that were derived without a correct de-contamination:

Total number of stars. Some authors, such as Sherry et al. (2004) and Walter et al. (2008), estimated that the total numbers of stars and brown dwarfs in σ Orionis is of about 600–700 based on visible surveys without near-infrared follow-up. However, the latest comprehensive analyses (e.g., Caballero 2008c; Lodieu et al. 2009) indicate that there are no more than 400 cluster objects above the deuterium burning mass limit. The reader must not misinterpret this information and automatically apply a one-half correction factor to the works of the New York group. Part of the problem arose from incorrect assumptions about the slopes of the mass function in different mass regimes and the size of the σ Orionis cluster: the actual contamination degree can be lower than one third. Only ten proper-motion contaminants (about 25% of this full sample) were classified as cluster member candidates in the (B)VRI survey of Sherry et al. (2004).

Frequency of discs. According to Scholz & Eislöffel (2004), 5–7% of σ Orionis stars and brown dwarfs in the mass range 0.03 to 0.7 $M_\odot$ possess a circumstellar disc. This percentage interval contrasts with the values compiled by Caballero (2007a) and the widely used value of ~35% of Hernández et al. (2007) for σ Orionis stars in the mass range 0.1 to 1.0 $M_\odot$. However, the contamination in the works by Scholz & Eislöffel (2004) and Hernández et al. (2007) is significant. On the one hand, Hernández et al. (2007) considered ten proper-motion contaminants in this study to be cluster members, including the Gliese et al. (1961) high proper-motion star G 99–20; proper-motion contaminants may be a small fraction of all the contaminants in a photometric survey. On the other hand, Scholz & Eislöffel (2004) considered only five proper-motion contaminants, but

[6] Cunha et al. (1995) reported a proper motion ($\mu_\alpha \cos\delta, \mu_\delta$) = (+10.5, −1.8) mas a^{-1}.

Table 4. SIMBAD stars with USNO-B1 proper motions between 30 and 40 mas a^{-1}.

Name	α^{J2000}	θ^{J2000}	$\mu_\alpha \cos\delta$ [mas a^{-1}]	μ_δ [mas a^{-1}]	J [mag]	Remarks^a
[SWW2004] J053856.630-025702.20	084.735971	–02.950597	+28	–24	12.10 ± 0.03	...
[HHM2007] 752	084.706060	–02.832448	+16	–36	13.44 ± 0.03	...
[KJN2005] 4.03 29	084.595128	–02.758452	–22	–30	14.32 ± 0.03	No V_r in Bu05
[HHM2007] 527	084.616111	–02.699823	+30	+4	14.66 ± 0.04	...
2MASS J05392675–0233378	084.861494	–02.560502	+34	–14	11.44 ± 0.03	No μ in Ca08c
2MASS J05365466–0232069	084.227779	–02.535264	–18	+26	11.50 ± 0.02	No Li I and no μ in Ca06
2MASS J05381906–0232014	084.579439	–02.533739	–28	+16	11.99 ± 0.03	No Li I in Ca06
[HHM2007] 120	084.406798	–02.428913	–4	–32	14.66 ± 0.05	...
[HHM2007] 1242	084.962323	–02.397435	–38	–10	14.46 ± 0.04	...
[HHM2007] 998	084.833748	–02.365726	–34	–8	15.08 ± 0.03	...

Notes. $^{(a)}$ "No V_r", "no Li I", and "no μ" stand for radial velocity, pEW(Li I), and proper motion inconsistent with cluster membership, respectively. The references are Burningham et al. (2005), Bu05, Caballero (2006), Ca06, and Caballero (2008c), Ca08c.

covered only about one third of the area of the σ Orionis cluster. Most of their member candidates lacked spectroscopic information. More precisely determined frequencies of discs for different mass intervals, at about 40–60%, can be found in Luhman et al. (2008; who used the Mayrit catalogue), Caballero et al. (2007), and Zapatero Osorio et al. (2007) for stars, brown dwarfs, and planetary-mass objects, respectively.

4.5. Going further in terms of proper motion

In Sect. 2.1, I noted that there were 33 USNO-B1 sources within the survey area that have proper motions between 30 and 40 mas a^{-1} (and 119 between 20 and 40 mas a^{-1}, and 450 between 10 and 40 mas a^{-1}). With Aladin, I searched for the SIMBAD counterparts of the 33 candidate interlopers. Ten of them had been discussed in the literature (Table 4), four having been tabulated already as interlopers in the Mayrit catalogue (three of the four have spectroscopy). The other six interloper candidates were likely contaminants in the works of Sherry et al. (2004 – one interloper) and Hernández et al. (2007 – five interlopers), which casts additional doubt on, e.g., the frequencies of discs derived in those studies. We clearly require a massive astrometric follow-up of as many as possible σ Orionis member candidates that have no known features of youth.

5. Conclusions

I have used the Aladin Virtual Observatory tool to search for proper-motion contaminants towards the σ Orionis cluster. Of the 5421 USNO-B1/2MASS cross-matched sources in an area of radius 30 arcmin centred on the Trapezium-like star of eponymous name, only 42 of them had USNO-B1 proper motions larger than 40 mas a^{-1}, 2MASS J-band magnitudes brighter than 15.5 mag, and more than three USNO-B1 detections. I have astrometrically followed them up using a number of catalogues (e.g., USNO-A2, GSC2.2/2.3, 2MASS, DENIS, CMC14, UKIDSS) and photographic plate digitisations from SuperCOSMOS, and measured accurate proper motions with errorbars of less than 2 mas a^{-1}. The USNO-B1 proper motions of several targets were affected by partially resolved (visual) multiplicity or faintness in the visible.

Of the 42 investigated objects, 27 had previously been considered to be σ Orionis member candidates. The other 15 objects are reported here for the first time. I divide the 42 objects into:

- One *bona fide* cluster member of low actual proper motion ($\mu < 10$ mas a^{-1}) with known spectroscopic features of youth (No. 36/Mayrit 1493050).
- Two cluster member candidates of low proper motion, including a brown dwarf (No. 32/Mayrit 999306 and No. 42/Mayrit 1610344).
- Two previously unknown stars of low proper motion with magnitudes and colours inconsistent with cluster membership (Nos. 04 and 38).
- 37 proper-motion interlopers, of which 21 are firstly discarded for cluster membership here. In a few cases, the proper-motion measurement is supported by spectroscopic information (e.g., lack of lithium in absorption) obtained in other works.

Interestingly, 17 of the 37 proper-motion interlopers (46%) were tabulated by Scholz & Eislöffel (2004), Sherry et al. (2004), or Hernández et al. (2007) as σ Orionis member candidates, although the membership of a few of them were subsequently discarded by Kenyon et al. (2005), Caballero (2006, 2008c), or Sacco et al. (2008). The proper-motion interlopers in this work outnumber those in other comparable studies, such as Caballero (2008c) or Lodieu et al. (2009).

I discussed the curious resemblance between the pseudo-equivalent widths of the Li I λ6707.8 Å line in absoprtion of three early-M proper-motion contaminants and three "lithium-depleted young star" candidates. I also measured the proper motion of the star HD 294297 with a time baseline of more than 110 years and concluded that it is not a young F/G star, but a late-F field dwarf unrelated to Ori OB 1b. Finally, I showed some examples of studies in which de-contamination (by proper-motion interlopers) was not correctly accomplished, and the consequent implications of their results. Preliminary analyses of stars with USNO-B1 proper motions between 30 and 40 mas a^{-1} indicate that contamination by foreground interlopers could severely affect the results of some widely used works.

This analysis is a new, but necessary, step to characterise in an optimal way the stellar and substellar populations of the σ Orionis cluster, which is one of the most accesible laboratories of star formation.

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Appendix A: Long tables

Table A.1. USNO-B1 stars towards σ Orionis with $\mu_{\rm USNO-B1} > 40$ mas a^{-1}, $J_{\rm 2MASS} < 15.5$ mag, and $N_{\rm USNO-B1} > 3$: coordinates, magnitudes, and proper motions.

	2MASS			USNO-B1			This work		
No.	α^{J2000}	δ^{J2000}	J [mag]	$\mu_\alpha \cos\delta$ [mas a^{-1}]	μ_δ [mas a^{-1}]	N	$\mu_\alpha \cos\delta$ [mas a^{-1}]	μ_δ [mas a^{-1}]	N
01	084.595001	–03.064613	14.59 ± 0.03	+18	–40	5	+19.2 ± 1.0	–36.3 ± 1.7	9
02	084.425714	–03.025405	14.53 ± 0.03	–82	–62	5	–54.0 ± 1.9	–62.7 ± 1.2	8
03	084.826136	–03.013852	13.07 ± 0.02	+10	–50	5	+11.4 ± 1.1	–46.1 ± 0.9	8
04	084.539224	–03.003337	14.26 ± 0.03	+30	+28	5	+11.0 ± 1.2	+3.9 ± 1.3	8
05	084.948355	–02.983131	10.36 ± 0.03	+42	–14	5	+47.6 ± 1.1	–17.5 ± 0.9	9
06	084.850070	–02.963510	11.26 ± 0.03	+32	+80	5	+34.3 ± 0.5	+82.8 ± 1.0	9
07	084.850866	–02.924599	11.79 ± 0.03	+14	–54	5	+14.0 ± 0.7	–59.5 ± 0.5	9
08	084.642299	–02.859457	15.18 ± 0.04	+54	–52	4	+44.3 ± 1.5	–61.9 ± 0.7	7
09	084.244956	–02.819184	13.62 ± 0.04	+6	+70	4	–9.4 ± 1.6	–22.9 ± 1.6	9
10	084.369333	–02.779688	14.81 ± 0.03	–28	–36	5	–29.9 ± 0.7	–37.9 ± 1.2	7
11	084.706846	–02.757468	13.15 ± 0.03	–54	–24	5	–55.3 ± 0.9	–23.1 ± 1.8	8
12	084.533024	–02.752464	15.33 ± 0.05	+20	–36	4	–7.5 ± 1.8	–72.0 ± 1.6	7
13	084.485297	–02.732624	13.04 ± 0.03	+20	–40	5	+20.2 ± 1.1	–41.5 ± 0.9	8
14	085.152776	–02.729698	11.54 ± 0.03	+50	+10	4	+43.9 ± 0.9	+0.3 ± 1.0	9
15	085.098384	–02.718792	11.37 ± 0.03	+62	–96	5	+63.8 ± 1.2	–89.4 ± 1.5	10
16	084.730988	–02.691593	12.17 ± 0.03	+96	+8	5	+96.6 ± 0.9	+11.8 ± 0.7	9
17	084.270844	–02.684343	14.37 ± 0.03	+6	–42	5	+3.5 ± 1.0	–43.3 ± 1.0	7
18	084.523630	–02.672057	12.77 ± 0.03	–20	–40	4	+24.3 ± 1.2	–74.4 ± 1.3	8
19	085.122689	–02.651908	13.98 ± 0.03	–12	–46	5	–8.9 ± 1.2	–43.5 ± 0.5	8
20	084.472224	–02.602508	14.94 ± 0.05	+38	+30	5	–2.6 ± 1.3	–20.2 ± 0.9	8
21	085.032746	–02.598684	14.65 ± 0.04	+6	–40	5	–9.1 ± 0.7	–30.0 ± 1.9	8
22	084.346086	–02.546276	14.18 ± 0.04	–42	+0	5	–20.0 ± 0.7	–22.2 ± 0.6	8
23	084.257197	–02.544301	15.29 ± 0.07	+40	–18	4	+40.0 ± 0.7	–40.2 ± 1.1	8
24	084.379406	–02.528789	10.46 ± 0.03	+50	–282	5	+49.9 ± 0.4	–282.0 ± 0.8	9
25	085.175498	–02.516978	14.17 ± 0.03	–30	–34	5	–28.8 ± 1.0	–32.9 ± 1.0	8
26	084.815180	–02.499121	9.81 ± 0.03	+0	–42	5	–0.6 ± 1.1	–39.9 ± 0.6	9
27	084.622984	–02.479908	14.87 ± 0.03	+32	+46	5	+33.9 ± 1.4	+36.9 ± 1.0	8
28	084.353969	–02.476976	12.75 ± 0.02	–10	–40	5	–9.9 ± 0.4	–38.5 ± 0.8	8
29	085.159839	–02.451720	14.02 ± 0.03	+78	–104	4	+70.7 ± 1.1	–115.3 ± 1.2	7
30	084.665077	–02.447131	11.22 ± 0.03	+46	–18	5	+48.4 ± 0.9	–25.8 ± 0.6	10
31	084.774245	–02.437633	14.34 ± 0.03	–6	–40	5	–5.0 ± 0.3	–43.4 ± 0.6	7
32	084.462951	–02.435409	14.92 ± 0.04	+240	–210	4	–5.8 ± 0.5	–13.0 ± 1.3	7
33	084.806169	–02.397745	13.95 ± 0.03	+50	+22	5	+54.1 ± 0.5	+25.1 ± 0.4	8
34[a]	084.362205	–02.365031	11.41 ± 0.02	–18	+44	5	–23.9 ± 1.1	+44.6 ± 1.5	10
35	084.999408	–02.339369	14.59 ± 0.03	+44	+12	5	+44.3 ± 0.5	+11.6 ± 0.6	8
36	085.004221	–02.333267	13.10 ± 0.03	–12	+48	4	–7.0 ± 0.6	–5.9 ± 0.3	7
37	084.923889	–02.329536	14.22 ± 0.03	+20	–36	5	+25.5 ± 0.8	–32.8 ± 0.8	8
38	084.720246	–02.324637	14.23 ± 0.03	+70	–108	5	+8.9 ± 0.7	–1.4 ± 0.8	8
39	084.355084	–02.267993	13.80 ± 0.04	–34	–54	5	–34.1 ± 0.2	–56.0 ± 0.3	7
40	084.543043	–02.233226	13.47 ± 0.03	+104	–6	5	+96.4 ± 0.4	–6.3 ± 0.6	8
41[b]	084.969042	–02.192280	14.85 ± 0.04	+54	–82	4	+59.8 ± 1.2	–80.7 ± 1.1	8
42[c]	084.560575	–02.170903	12.48 ± 0.03	–52	–32	4	+2.4 ± 0.5	+6.3 ± 0.5	8

Notes. [(a)] Star No. 34 is a close binary, only resolved by UKIDSS ($\rho \sim 2.8$ arcsec, $\theta \sim 128$ deg, $\Delta Z \sim \Delta K \sim 3$ mag).
[(b)] Star No. 41 is a close binary, only resolved by UKIDSS ($\rho \sim 2.4$ arcsec, $\theta \sim 177$ deg, $\Delta Z \sim \Delta K \sim 3$ mag).
[(c)] The USNO-B1 proper motion values of star No. 42 actually correspond to a faint source at 4.5 arcsec to the southwest of the tabulated coordinates (see Sect. 3.1.1).

Table A.2. USNO-B1 stars towards σ Orionis with $\mu_{\rm USNO-B1}$ > 40 mas a^{-1}, $J_{\rm 2MASS}$ < 15.5 mag, and $N_{\rm USNO-B1}$ > 3: alternative names and cluster membership status.

No.	Alternative name	[SE2004]	[SWW2004]	[HHM2007]	Discarded[a]	Previous member[b]	Current member[b]
01	...	...	...	...	*This work*	Unknown	No
02	...	...	...	...	*This work*	Unknown	No
03	...	...	...	...	*This work*	Unknown	No
04	...	...	...	...	*This work*	Unknown	No
05	2MASS J05394761–0258593	...	...	...	Ca08	No	No
06	SO411068	...	202	...	Ca06	No	No
07	SO441143	...	...	...	Ca06	No	No
08	...	...	...	...	*This work*	Unknown	No
09	...	...	...	...	*This work*	Unknown	No
10	[KJN2005] 38	...	...	...	Ke05	No	No
11	[SWW2004] J053849.560–024526.94	...	101	753	Sa08	No	No
12	...	...	...	...	*This work*	Unknown	No
13	[SWW2004] J053756.467-024357.36	...	116	260	*This work*	Yes?	No
14	2MASS J05403667–0243469	...	...	...	Ca08	No	No
15	SO430116	...	...	...	Ca06	No	No
16	[SWW2004] J053855.425–024129.68	...	71	804	Sa08	No	No
17	[SWW2004] J053705.004–024103.43	...	218	...	*This work*	Yes?	No
18	[SWW2004] J053805.676–024019.36	...	88	330	Sa08	No	No
19	...	...	...	...	*This work*	Unknown	No
20	...	...	...	...	*This work*	Unknown	No
21	[HHM2007] 1354	...	...	1354	*This work*	Yes?	No
22	[SWW2004] J053723.067–023246.38	...	215	27	*This work*	No?	No
23	...	...	...	...	*This work*	Unknown	No
24	G 99–20	...	...	74	Gi61[c]	No	No
25	...	...	...	...	*This work*	Unknown	No
26	2MASS J05391564–0229568	...	...	961	Ca08	No	No
27	[HHM2007] 544	...	...	544	*This work*	Yes?	No
28	...	...	...	...	*This work*	Unknown	No
29	...	...	...	...	*This work*	Unknown	No
30	SO120908	...	...	...	Ca06	No	No
31	[SE2004] 42	42	204	...	Ke05	No	No
32	Mayrit 999306	...	...	209	...	Yes?	Yes?
33	[KJN2005] 12	...	...	...	Ke05[d]	No	No
34	SO241003	...	...	52	Ca06	No	No
35	...	...	...	...	*This work*	Unknown	No
36	Mayrit 1493050	122	...	1323	...	Yes	Yes
37	[SWW2004] J053941.738–021946.22	...	206	...	*This work*	Yes?	No
38	...	...	...	...	*This work*	Unknown	No
39	[SWW2004] J053725.220–021604.56	...	201	...	*This work*	Yes?	No
40	[SE2004] 57	57	...	...	Ke05	No	No
41	[SE2004] 112	112	...	...	*This work*	Yes?	No
42	Mayrit 1610344	6	228	...	...	Yes?	Yes?

Notes. [(a)] Work in which the cluster membership of the object was firstly discarded: Gi61, Giclas et al. (1961); Ke05, Kenyon et al. (2005); Ca06, Caballero (2006); Ca08, Caballero (2008c); Sa08, Sacco et al. (2008).
[(b)] "Yes": confirmed cluster member with signatures of youth – "Yes?": cluster member candidate based on photometry – "No?": probable non-cluster member based on photometry – "No": non-cluster member based on spectroscopy, photometry or proper motion – "Unknown": firstly presented in this paper.
[(c)] Actually, in 1961, the existence of the σ Orionis cluster had not been brought up yet.
[(d)] There is independent spectroscopic confirmation of cluster non-membership of the star No. 33, for which Sacco et al. (2008) measured lithium, radial velocity, low gravity, and Hα features inconsistent with membership.

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