Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **434,** 194–208 (2013) doi:10.1093/mnras/stt996
Advance Access publication 2013 July 4

NGC 1252: a high altitude, metal poor open cluster remnant*

R. de la Fuente Marcos,[1] C. de la Fuente Marcos,[1]† C. Moni Bidin,[2] G. Carraro[3,4] and E. Costa[5]

[1]*Universidad Complutense de Madrid, Ciudad Universitaria, E-28040 Madrid, Spain*
[2]*Instituto de Astronomía, Universidad Católica del Norte, Av. Angamos 0610, Antofagasta, Chile*
[3]*European Southern Observatory, Alonso de Cordova 3107, Vitacura, Santiago, Chile*
[4]*Dipartimento di Astronomia, Università di Padova, Vicolo dell'Osservatorio 2, I-35122 Padova, Italy*
[5]*Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile*

Accepted 2013 June 5. Received 2013 May 21; in original form 2013 January 9

ABSTRACT

If stars form in clusters but most stars belong to the field, understanding the details of the transition from the former to the latter is imperative to explain the observational properties of the field. Aging open clusters are one of the sources of field stars. The disruption rate of open clusters slows down with age but, as an object gets older, the distinction between the remaining cluster or open cluster remnant (OCR) and the surrounding field becomes less and less obvious. As a result, finding good OCR candidates or confirming the OCR nature of some of the best candidates still remain elusive. One of these objects is NGC 1252, a scattered group of about 20 stars in Horologium. Here we use new wide-field photometry in the *UBVI* passbands, proper motions from the Yale/San Juan SPM 4.0 catalogue and high-resolution spectroscopy concurrently with results from *N*-body simulations to decipher NGC 1252's enigmatic character. Spectroscopy shows that most of the brightest stars in the studied area are chemically, kinematically and spatially unrelated to each other. However, after analysing proper motions, we find one relevant kinematic group. This sparse object is relatively close (∼1 kpc), metal poor and is probably not only one of the oldest clusters (3 Gyr) within 1.5 kpc from the Sun but also one of the clusters located farthest from the disc, at an altitude of nearly −900 pc. That makes NGC 1252 the first open cluster that can be truly considered a high Galactic altitude OCR: an unusual object that may hint at a star formation event induced on a high Galactic altitude gas cloud. We also conclude that the variable TW Horologii and the blue straggler candidate HD 20286 are unlikely to be part of NGC 1252. NGC 1252 17 is identified as an unrelated, Population II cannonball star moving at about 400 km s^{-1}.

Key words: stars: individual: HD 20286 – stars: individual: NGC 1252 17 – stars: individual: NGC 1252 21 – stars: individual: TW Horologii – open clusters and associations: general – open clusters and associations: individual: NGC 1252.

1 INTRODUCTION

It is now widely accepted that stars are formed in some type of star cluster (see e.g. Hopkins 2013) but the vast majority of stars in any given galaxy are field stars. Understanding the details of the processes responsible for the transition of stars from star clusters (globular and open clusters, stellar associations or any other similar structure) to the field is essential to explain the observed astrometric, kinematic and chemical properties of the field populations.

In the Milky Way disc, open star clusters born within star-forming complexes are one of the sources of field stars (see e.g. Elmegreen & Lada 1977; Efremov 1978, 1979; Elmegreen & Efremov 1996; Efremov & Elmegreen 1998). In the absence of a catastrophic encounter with a giant molecular cloud (GMC), theory shows that an open cluster soon starts losing members to the field; first mainly by ejection, then by the most gradual process of evaporation. Early numerical simulations (von Hoerner 1963) found that open cluster dissolution proceeds slowly at first, then increasingly faster only to slow down when the object is barely distinguishable from the surrounding star field. This intrinsic lack of contrast against the stellar background makes observational studies of the final stages of the evolution of open clusters particularly challenging, especially in the case of the most dynamically evolved and therefore more interesting

*Based on observations collected at the European Organization for Astronomical Research in the Southern hemisphere, Chile (programme IDs 281.D-5054 and 086.D-0963).

† E-mail: nbplanet@fis.ucm.es

objects. This may explain why the final stage of the evolution of star clusters has traditionally received more attention from theoretical grounds than from the observational community. Years before the invention of computers, this topic had already attracted the interest of Rosseland (1928), Ambartsumian (1938) and Spitzer (1940). In particular, the seminal papers of Ambartsumian (1938) and Spitzer (1940) showed that star clusters cannot evaporate completely and that evaporation proceeds only until a hierarchical multiple system is formed (Spitzer 1940).

The almost final residue of the evolution of an open cluster is often called an open cluster remnant or OCR (e.g. de la Fuente Marcos 1998). From an observational perspective, OCRs are expected to consist of just a few tens of stars. This can be naively interpreted as a strong argument in favour of a scenario in which such an object should disintegrate (evaporate) within a relatively short time-scale of the order of $t_{\rm relax} \approx (0.1N/\ln N)\, t_{\rm cross}$ (actually, $t_{\rm evap} \simeq 140 t_{\rm relax}$; see e.g. Binney & Tremaine 2008), where $t_{\rm relax}$ is the cluster relaxation time, N is the cluster population and $t_{\rm cross}$ is the cluster crossing time or characteristic time-scale required for a star in the open cluster to travel a distance equal to the size of the cluster. Following this (erroneous) line of thought, OCRs should be virtually impossible to observe due to their intrinsically short lives. This reasoning is quite correct in the case of open clusters born that way, i.e. with just a few tens of stars. However, currently observable OCRs likely had many more stars in the past, perhaps as many as $N \sim 10^4$ members when they were born. At the solar circle, an open cluster that rich is expected to last several Gyr. In this case, numerical simulations predict a remnant consisting of mainly binaries and long-lived hierarchical triples (e.g. de la Fuente Marcos 1998). For the oldest systems, this population of binaries and triples is the result of several Gyr of close and distant gravitational interactions and also stellar evolution. Therefore, these are not primordial systems but the survivors of a long and highly selective contest for dynamical stability where stellar mass loss has now a very limited role. Hence, the resulting multiple system sample is highly biased towards very stable dynamical configurations. In general, a poorly populated young open cluster and an (perhaps much older) OCR may look similar in terms of membership but, dynamically speaking, they are worlds apart (see the review in e.g. de la Fuente Marcos 2002).

Traditionally ignored by the observational community for the reasons pointed out above, an early approach to the topic was considered by Lodén & Rickman (1974) and implemented by Lodén (see Lodén 1993, and references therein). From this humble beginning, the observational interest in OCRs has been steadily increasing in recent years (e.g. Bica et al. 2001; Carraro 2002, 2006; Pavani et al. 2003, 2011; Villanova et al. 2004; Bica & Bonatto 2005; Carraro et al. 2007; Moni Bidin et al. 2010). Besides their role in feeding the field populations and in the validation of computer models, the study of OCRs can also help to explain the existence of very wide binary systems (Moeckel & Clarke 2011; Reipurth & Mikkola 2012), higher order hierarchical systems (van den Berk, Portegies Zwart & McMillan 2007) and their high fraction in the field with respect to what is observed in young clusters (Kouwenhoven et al. 2010). Therefore, OCRs are not mere curiosities and, in fact, there are multiple good reasons for studying them. Unfortunately, finding good OCR candidates or, even better, confirming the OCR nature of some of them still remains elusive. Chance alignments of bright stars or asterisms often mimic the structural properties of OCRs (see e.g. Moni Bidin et al. 2010) and both kinematic and spectroscopic information are generally required to reveal the true nature of these interesting but challenging objects.

In this paper, we re-examine the possible open cluster remnant nature of NGC 1252, a sparse southern high Galactic latitude group of stars in Horologium. This controversial object has been classified both as asterism and OCR, depending on the authors (see below). The main objective of this research is to shed new light on this matter by providing a detailed study of the stellar content and kinematics of the object. To this end, we present new CCD *UBVI* photometry and two-epoch spectroscopy, which we combine with proper motions from the Yale/San Juan Southern Proper Motion SPM 4.0 (SPM4) catalogue (Girard et al. 2011) in an attempt to unravel the true nature and current dynamical status of this object, if real. This paper is organized as follows. In Section 2 we provide an extensive review of the data previously available on this object and its associated area of the sky. Observations, data reduction and overall results are presented in Section 3. In Section 4 we focus on proper motions. The relevance of the results is discussed in Section 5. In Section 6 we draw our conclusions. Some objects are further analysed in Appendix A.

2 NGC 1252: A CONTROVERSIAL OBJECT

This sparse group of stars in Horologium was first recorded by Herschel in 1834 as h 2515 (Herschel 1847). The same group of stars was included as object GC 663 by Herschel (1864) in his ‘Catalogue of Nebulae and Clusters of Stars’. The ‘New General Catalogue of Nebulae and Clusters of Stars’ (Dreyer 1888) coined the name NGC 1252 and described the object as an 8th mag star surrounded by a group of 18 or 20 stars (see Fig. 1). The object did not receive further attention until the publication of ‘The Revised New General Catalogue of Nonstellar Astronomical Objects’ (Sulentic & Tifft 1973). This catalogue is a modern, revised and expanded version of the original NGC. Besides incorporating the many corrections to the NGC found over the years, each object was verified on Palomar Observatory Sky Survey (POSS) prints and on plates for southern objects specifically taken for the purpose. In this catalogue, NGC 1252 is described as an unverified southern object, i.e. the object is regarded as doubtful. The Catalogue of Star

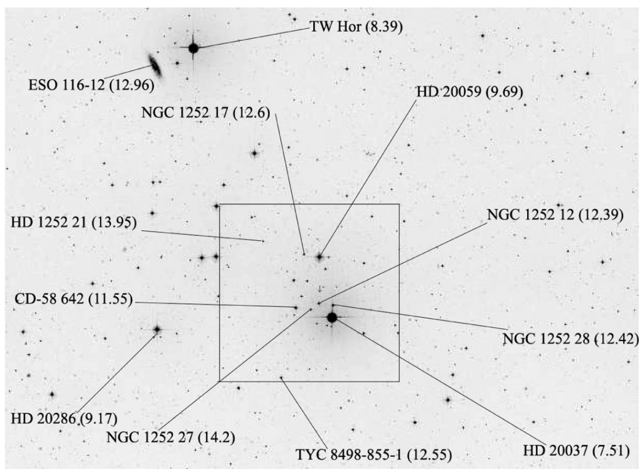

Figure 1. SERC J-DSS1 image of the neighbourhood of NGC 1252 (Epoch 1975-09-10T18:07:00, $\lambda = 468$ nm, resolution 6.8 arcsec pixel^{-1}), north is up, east to the left. A number of objects mentioned in the text are indicated, with B magnitudes in parentheses. Within the square, we have the observed 20×20 arcmin^2 stellar field (see the text for details). The original description in Dreyer (1888), an 8th mag star surrounded by a group of 18 or 20 stars, matches well what is actually observed if we assume that HD 20037 is part of the object.

Clusters and Associations (Ruprecht, Balázs & White 1981) does not include this object.

An extensive search across published literature on this object reveals over a dozen entries, several of them within the context of the OCR paradigm. The first detailed study of NGC 1252 was carried out by Bouchet & Thé (1983). They found that NGC 1252 is an open cluster of age ∼500 Myr located at a distance of nearly 470 pc with a diameter of nearly $0\overset{\circ}{.}5$ or 8 pc. They also pointed out that the carbon star TW Horologii (= HD 20234) is probably a member of the cluster (see Fig. 1 for their relative positions). In contrast, Eggen (1984) considered the existence of such a cluster unlikely and listed the variable star TW Horologii, a putative member of NGC 1252 for the previous authors, as a probable member of the Hyades supercluster. Ahumada & Lapasset (1995) identified a blue straggler candidate (HD 20286) in NGC 1252 (see Fig. 1), that they considered an open cluster based on Bouchet & Thé (1983) data. More recently, Baumgardt (1998) and Baumgardt, Dettbarn & Wielen (2000) concluded that NGC 1252 is not a real cluster but an asterism. Feeding the controversy, Pavani et al. (2001) and Bica et al. (2001) argued that NGC 1252 is not a field fluctuation but an OCR of age 3 Gyr located 640 pc from the Sun and 460 pc below the Galactic disc. Loktin & Beshenov (2003) also considered NGC 1252 an open cluster located 707 pc from the Sun and provided proper motions (see below) based on six candidate members. Following Bouchet & Thé (1983) and Pavani et al. (2001), Xin & Deng (2005) also described NGC 1252 as an extremely underpopulated open cluster with a very luminous blue straggler, HD 20286. Using United States Naval Observatory CCD Astrograph Catalogue 2.0 (UCAC2; Zacharias et al. 2004) positions and proper motions, Dias et al. (2006) classified NGC 1252 as open cluster with proper motions $(\mu_\alpha \cos\delta,\ \mu_\delta) = (14.28,\ 9.07)\,\mathrm{mas\,yr^{-1}}$. They estimated the number of members in the cluster at 25. Based on Pavani et al. (2001) and Dias et al. (2002), van den Bergh (2006) gives a value of 2.61 pc for the diameter of the cluster. Pavani & Bica (2007) reanalysed Two Micron All Sky Survey (2MASS; Skrutskie et al. 1997) photometry and UCAC2 proper motions to confirm NGC 1252 as a 2.8 Gyr old loose OCR located at a distance of 790 pc from the Sun and 610 pc below the disc. Ahumada & Lapasset (2007) ratified their 1995 results using data from Dias et al. (2002). Pavani et al. (2011) compiled previous results to conclude that NGC 1252 is a robust OCR candidate. Zejda et al. (2012) also consider NGC 1252 among open clusters, with proper motions $(\mu_\alpha \cos\delta,\ \mu_\delta) = (11.1,\ 7.5)\,\mathrm{mas\,yr^{-1}}$.

NGC 1252 (also known as ESO 116−11) is currently classified as a cluster of stars in SIMBAD.[1] Its FK5 coordinates are given as $\alpha = 03^{\mathrm{h}}10^{\mathrm{m}}49^{\mathrm{s}}$, $\delta = -57°46'00''$ (Xin & Deng 2005) with Galactic coordinates $l = 274\overset{\circ}{.}084$, $b = -50\overset{\circ}{.}831$. Its proper motion is cited as $(\mu_\alpha \cos\delta,\ \mu_\delta) = (7.98 \pm 0.60,\ 5.95 \pm 0.45)\,\mathrm{mas\,yr^{-1}}$ (Loktin & Beshenov 2003). NGC 1252 is listed as a *bona fide* open cluster in both the Open Cluster Database[2] (WEBDA; Mermilliod & Paunzen 2003) and the New Catalogue of Optically Visible Open Clusters and Candidates[3] (NCOVOCC; Dias et al. 2002). These data bases are widely used in professional open cluster studies. The current version of WEBDA (2013 March; Paunzen & Mermilliod 2013) includes coordinates identical to those in SIMBAD, distance, 640 pc, reddening, 0.02 mag, distance modulus, 9.09 mag, age, 3.0 Gyr, and diameter, 14 arcmin. Therefore, the object is located 496 pc below the Galactic plane. This is rather unusual for an open cluster and it will be discussed at length later. The 2013 January version (v3.3; Dias 2013) of NCOVOCC includes NGC 1252 as an OCR (based on Pavani & Bica 2007) with coordinates identical to those in SIMBAD and diameter, 8 arcmin, located 790 pc from the Sun (therefore, 612 pc below the Galactic plane), its colour excess is listed as 0.00 mag with an age of 2.8 Gyr and proper motions $(\mu_\alpha \cos\delta, \mu_\delta) = (7.98 \pm 0.45, 5.95 \pm 0.60)\,\mathrm{mas\,yr^{-1}}$ (Loktin & Beshenov 2003, note the switching of errors with respect to the SIMBAD data above). The NGC/IC Project[4] (Erdmann 2010), a source popular among amateur astronomers, indicates that NGC 1252 is a sparsely populated cluster of size 2 arcmin (see also Corwin 2004).

The roots of the debate on the nature of NGC 1252 can be traced back to an issue frequently overlooked: despite being an object located at high Galactic latitude and, in theory, mostly free from stellar contamination, the area of the sky around NGC 1252 is also home of two relatively close and well-studied stellar structures: the Tucana–Horologium association (e.g. Zuckerman, Song & Webb 2001) and the Hyades stream or supercluster (e.g. Eggen 1959) and, perhaps, additional relatively close moving groups (fully evaporated open clusters not OCRs). The Tucana–Horologium association contains a coeval (∼30 Myr old) stream of stars with common space motion all within ∼70 pc from the Earth (Zuckerman et al. 2011). Members of the Tucana–Horologium association in the area of NGC 1252 have heliocentric distances ∼50 pc, *V* in the range 4–16 and proper motions ∼70 $\mathrm{mas\,yr^{-1}}$. Only a few of the brightest stars in our samples are expected to be part of the Tucana–Horologium association. Far more problematic could be the role of the Hyades stream which is expected to be a main source of stellar contamination in the field of NGC 1252. The existence of the Hyades stream was first proposed by Olin J. Eggen and it was first studied in detail by Ogorodnikov & Latyshev (1968) concluding that it contained too many stars to having been supplied by the Hyades cluster alone. The debate on the true nature of the Hyades stream has only recently been settled; instead of being primarily composed of coeval stars originating from the evaporating Hyades open cluster, the structure is believed to be the result of resonant trapping induced by the Galactic spiral perturbation, specifically, scattering at a Lindblad resonance (Famaey et al. 2007; Sellwood 2010; Hahn, Sellwood & Pryor 2011; Pompéia et al. 2011). The Hyades stream contains an heterogeneous group of stars mostly within 500 pc from the Earth, their radial velocities close to 11 $\mathrm{km\,s^{-1}}$ in the area around NGC 1252 (Eggen 1984) and they can be included in an imaginary box with Galactic velocity components $\mathrm{U} \in (-50,\ -25)\,\mathrm{km\,s^{-1}}$ and $\mathrm{V} \in (-23,\ -12)\,\mathrm{km\,s^{-1}}$ (Pompéia et al. 2011).

3 OBSERVATIONS AND REDUCTION

The observations presented here were completed in three separate runs and focused on the area enclosed by the square in Fig. 1. Photometry was obtained on 2008 December at Cerro Tololo. Spectroscopy was completed in two different runs, both at La Silla, on 2008 September and 2010 December, respectively. Details of the actual observations and the data reduction procedures as well as the results are given in the following sections.

[1] http://simbad.u-strasbg.fr

[2] http://www.univie.ac.at/webda/

[3] http://www.astro.iag.usp.br/∼wilton/

[4] http://www.ngcicproject.org

Table 1. *UBVI* photometric observations of NGC 1252 and standard star fields.

Target	Date	Filter	Exposure (s)	Airmass
SA 98	2008 December 25	U	2 × 10, 2 × 150, 2 × 400	1.15–1.55
		B	2 × 10, 2 × 100, 2 × 200	1.15–1.41
		V	2 × 10, 2 × 60, 2 × 120	1.15–1.46
		I	2 × 10, 2 × 60, 2 × 120	1.15–1.35
NGC 1252	2008 December 25	B	10, 100, 1500	1.27–1.33
		V	10, 100, 900	1.34–1.36
		I	10, 60, 120, 900	1.21–1.24
SA 104	2008 December 25	U	30, 3 × 200	1.61–1.69
		B	10, 100	1.77–1.78
		V	10, 100	1.72–1.74
		I	10, 100	1.82–1.84
SA 98	2008 December 26	U	2 × 10, 2 × 150, 2 × 400	1.15–1.62
		B	2 × 10, 2 × 100, 2 × 200	1.15–1.81
		V	2 × 10, 2 × 60, 2 × 120	1.15–1.67
		I	2 × 10, 2 × 60, 2 × 120	1.15–1.72
NGC 1252	2008 December 26	U	2 × 20, 200, 2000	1.15–1.16
		B	10, 100	1.20–1.20
		V	10, 60	1.19–1.20
		I	10, 60	1.21–1.21
PG 1047	2008 December 26	U	20, 200	1.22–1.23
		B	10, 150	1.21–1.21
		V	10, 60	1.22–1.22
		I	10, 60	1.20–1.20
PG 0918	2008 December 26	U	10, 200, 400	2.00–2.11
		B	10, 200	1.77–1.79
		V	10, 100	1.88–1.90
		I	10, 100	1.82–1.83

3.1 Photometry

The region of interest (20×20 arcmin^2 area enclosed by the square in Fig. 1) was observed with the Y4KCAM camera attached to the Cerro Tololo Inter-American Observatory (CTIO) 1-m telescope, operated by the Small and Moderate Aperture Research Telescope System (SMARTS) consortium.[5] This camera is equipped with an STA 4064 × 4064 CCD[6] with 15-μm pixels, yielding a scale of 0.289 arcsec pixel^{-1} and a field-of-view (FOV) of 20×20 arcmin^2 at the Cassegrain focus of the CTIO 1-m telescope. The CCD was operated without binning, at a nominal gain of 1.44 e$^-$/ADU, implying a readout noise of 7 e$^-$ per quadrant (this detector is read by means of four different amplifiers). The quantum efficiency and other detector characteristics can be found at the OSU web site.[6] In Table 1 we present the log of our *UBVI* observations. All the observations were carried out in good-seeing, photometric conditions. Our *UBVI* instrumental photometric system was defined by the use of a standard broad-band Kitt Peak $U B V I_{\rm kc}$ set of filters.[7] To determine the transformation from our instrumental system to the standard Johnson–Kron–Cousins system and to correct for extinction, we observed 46 stars in Landolt's area SA 98 (Landolt 1992) multiple times and with different airmasses ranging from ∼1.2 to ∼1.8. Field SA 98 is very advantageous, as it includes a large number of well-observed standard stars, with a very good colour coverage: $-0.2 \le (B-V) \le 2.2$ and $-0.1 \le (V-I) \le 6.0$. Furthermore, it is completely covered by the FOV of the Y4KCAM. In addition, observations of standard star fields PG 1047, SA 104 and PG 0918 were obtained in order to have an even wider airmass coverage.

3.1.1 Reductions

Basic calibration of the CCD frames was completed using the Yale/SMARTS y4k reduction script based on the IRAF[8] package CCDRED. For this purpose, zero exposure frames and twilight sky flats were acquired every night. Photometry was then performed using the IRAF DAOPHOT and PHOTCAL packages. Instrumental magnitudes were extracted following the point spread function (PSF) method (Stetson 1987). A quadratic, spatially variable, master PSF (PENNY function) was adopted. Aperture corrections were determined making aperture photometry of a suitable number (typically 10–20) of bright, isolated, stars in the field. These corrections were found to vary from 0.160 to 0.290 mag, depending on the filter. The PSF photometry was finally aperture corrected, filter by filter.

3.1.2 Results

After removing problematic stars (blends, possible variable stars, artefacts, etc.), and stars having only a few observations (less than five) in Landolt's (1992) catalogue, our photometric solution for a grand total of 322 measurements per filter, turned out to be

$$
\begin{aligned}
U &= u + (3.080 \pm 0.010) + (0.45 \pm 0.01)\, X \\
&\quad - (0.009 \pm 0.006)\,(U - B), \\
B &= b + (2.103 \pm 0.012) + (0.27 \pm 0.01)\, X \\
&\quad - (0.101 \pm 0.007)\,(B - V), \\
V &= v + (1.760 \pm 0.007) + (0.15 \pm 0.01)\, X \\
&\quad + (0.028 \pm 0.007)\,(B - V), \\
I &= i + (2.751 \pm 0.011) + (0.08 \pm 0.01)\, X \\
&\quad + (0.045 \pm 0.008)\,(V - I),
\end{aligned}
$$

where *UBVI* are standard magnitudes, $ubvi$ are the instrumental ones and X is the airmass. The coefficients have been obtained averaging the photometric solutions of individual nights (December 25 and 26) into a single one, since the two photometric solutions turned out to be identical within the observational uncertainties. The final rms of the fitting were 0.030, 0.015, 0.010 and 0.010 in U, B, V and I, respectively.

Global photometric errors were estimated using the scheme developed by Patat & Carraro (2001, appendix A1), which takes into account the errors resulting from the PSF fitting procedure (i.e. from ALLSTAR) and the calibration errors (corresponding to the zero-point, colour terms and extinction errors). In Fig. 2 we present our global photometric errors in V, $(B-V)$, $(U-B)$ and $(V-I)$ plotted as a function of the V magnitude. Quick inspection shows that stars brighter than $V \approx 20$ mag have errors smaller than ∼0.05 mag in magnitude and lower than ∼0.10 mag in $(B-V)$ and $(V-I)$. Larger errors are found in $(U-B)$. Our final optical photometric catalogue consists of 356 entries having *UBVI* measurements down to $V \sim 22$.

3.1.3 Completeness and astrometry

Completeness corrections were determined by running artificial star experiments on the data (see Carraro et al. 2005, for details).

[5] http://www.astro.yale.edu/smarts
[6] http://www.astronomy.ohio-state.edu/Y4KCam/ detector.html
[7] http://www.astronomy.ohio-state.edu/Y4KCam/filters.html

[8] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

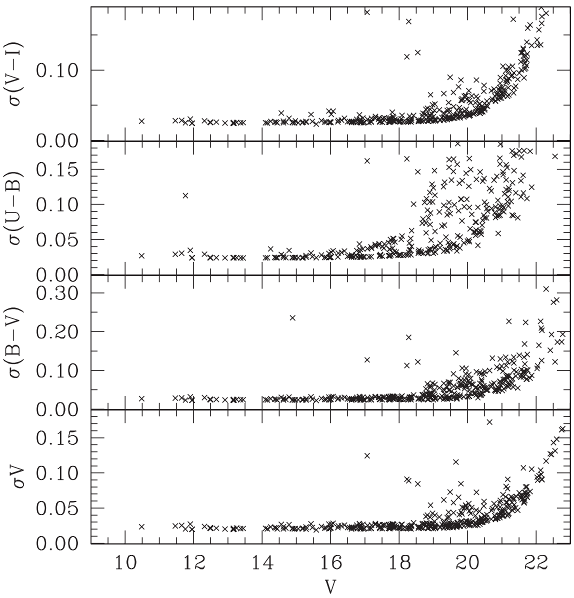

Figure 2. Photometric errors in V, $(B - V)$, $(U - B)$ and $(V - I)$ as a function of the V magnitude.

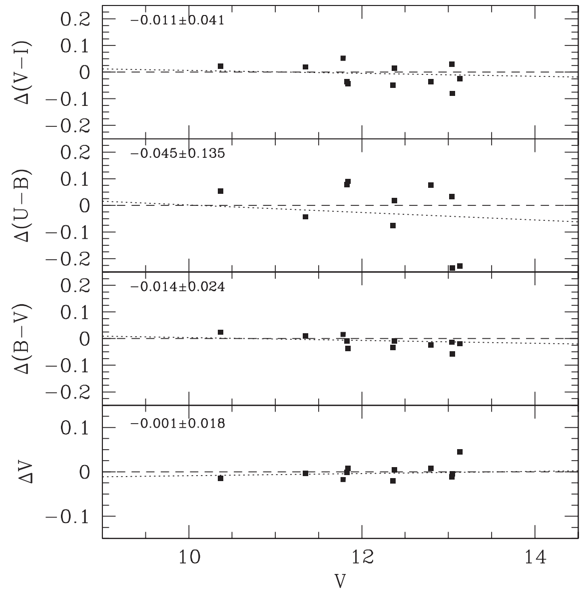

Figure 3. Comparison of our photometry with Bouchet & Thé (1983) for V, $(B - V)$, $U - B$ and $(V - I)$: our photometry minus that in Bouchet & Thé (1983). The mean differences are displayed on the top left-hand corners of the various panels.

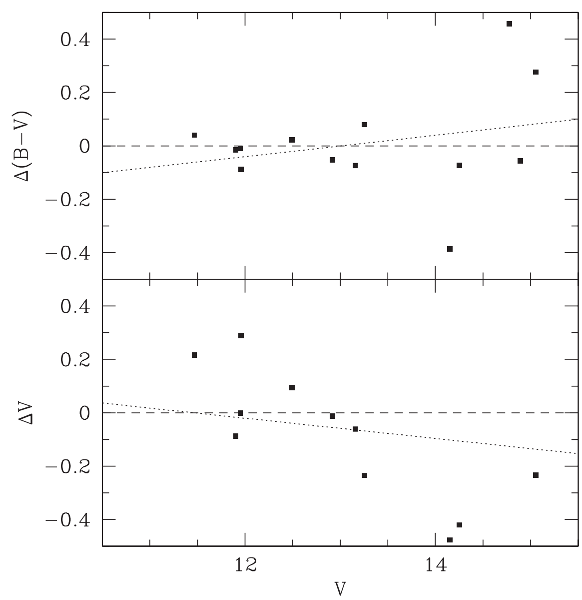

Figure 4. Comparison of our photometry with Pavani et al. (2001) for V and $(B - V)$: our photometry minus that in Pavani et al. (2001). There are unusually large differences, mainly in V. The linear fittings are displayed as dotted lines. Two points fall outside the plotting boundaries at the bottom panel.

Basically, we created several artificial images by adding artificial stars to the original frames. These stars were added at random positions, and had the same colour and luminosity distribution of the true sample. To avoid generating overcrowding, in each experiment we added up to 20 per cent of the original number of stars. Depending on the frame, between 1000 and 5000 stars were added. Then, a systematic comparison between the number of added and detected stars was carried out. In this way, we have estimated that the completeness level of our photometry is better than 50 per cent down to $V = 21.5$, that can be considered as the limiting magnitude of the present study.

Our optical catalogue was cross-correlated with 2MASS, which resulted in a final catalogue including *UBVI* and $J H K_s$ magnitudes. As a by-product, pixel (i.e. detector) coordinates were converted to RA and Dec. for J2000.0 equinox, thus providing 2MASS-based astrometry.

3.1.4 Comparison with previous photometry

We compared our photometry with that from the *UBVRI* photoelectric study by Bouchet & Thé (1983). We could only compare *UBVI*, since we did not observe in *R*. We found 13 stars in common, and the results are shown in Fig. 3, in the sense our photometry minus that in Bouchet & Thé (1983). We found that the two studies are in the same system, both in V mag, and in all the colours. The mean differences are reported on the top left-hand corners of the various panels in Fig. 3. We only notice that a small, unaccounted for, colour term (dashed line) can perhaps be present in $U - B$.

We then compare our data with the more recent CCD study in *BV* by Pavani et al. (2001), with which we have 11 stars in common. The comparison is shown in Fig. 4, in the sense our photometry minus that in Pavani et al. (2001). There are unusually large differences, mainly in V. We do not have a clear explanation for that, since Pavani et al. (2001) claim that they used stars in common with Bouchet & Thé (1983) to tie their photometry. However, a quick glance at their table 1 immediately shows that there are significant differences between them and Bouchet & Thé (1983) too. The enormous colour term in V simply demonstrates that their photometry must be, somehow, wrong.

3.1.5 Colour–magnitude diagrams

From our photometric data we construct colour–magnitude diagrams (CMDs) for several colour combinations and they are shown in Fig. 5. The CMDs for the detected stars do not exhibit an obvious, distinctive feature that can lead us to conclude that there is a normal open cluster in the area of the sky commonly assigned

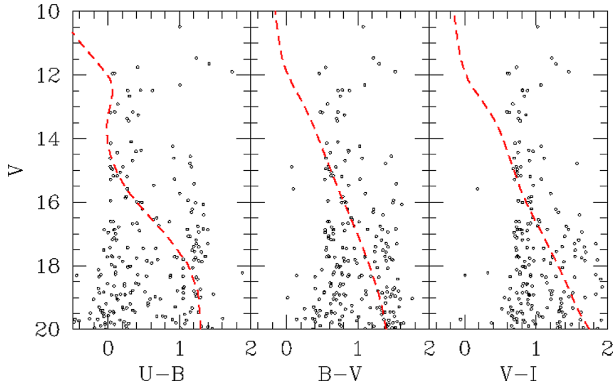

Figure 5. CMDs in various colour combinations for all the stars having *UBVI* photometry in the field of NGC 1252. A ZAMS of solar metallicity taken from the Padova data base (Girardi et al. 2000) is also included. $E(B-V) = 0.02$ and a distance of 1 kpc have been assumed.

to NGC 1252. As a guidance, a zero-age main-sequence (ZAMS) of solar metallicity taken from the Padova data base (Girardi et al. 2000) is also included. A well populated sequence in the V versus $B-V$ and V versus $V-I$ diagrams can easily be discarded. However, the existence of a real stellar grouping at the location of NGC 1252 cannot be confirmed or ruled out on the basis of photometric evidence alone.

3.2 Spectroscopy

High-resolution spectra of 13 cluster member candidates were collected at La Silla Observatory during two observing runs. In the following, 12 observed stars will be identified by means of their ID in the Bouchet & Thé (1983) photometry, while the star GSC 0849800928, not included in that catalogue, will be simply referred to as 'star A'. In other words, if a star appears as NGC 1252 1 in SIMBAD, it will be named here as BT1. The spectra of nine stars were secured with the High Accuracy Radial velocity Planet Searcher (HARPS) fibre-fed spectrograph at the 3.6-m telescope on 2008 September 18. The details on the actual observations and data reduction methodology were provided in Moni Bidin et al. (2010). A second epoch for six promising candidates, plus the spectrum of four stars not previously observed, were collected with The Fiber-fed Extended Range Optical Spectrograph (FEROS) at the ESO/MPG 2.2-m telescope, on 2010 December 17–22. Exposure times varied between 600 and 1800 s, depending on target magnitude, for a resulting signal-to-noise ratio (S/N) of 30–60, except for one spectrum of much poorer quality (S/N = 10). The spectra were de-biased, flat-fielded, extracted and wavelength calibrated by means of standard IRAF[8] routines. This procedure did not improve the spectral quality with respect to the output of the online pipeline at the telescope, which was therefore used in the analysis. The second fibre of the spectrograph was allocated to the sky during the observations, and the extracted sky background was subtracted from each target.

The radial velocities (RVs) were measured by means of a cross-correlation technique (Tonry & Davis 1979), as implemented in the FXCOR IRAF task. A synthetic spectrum of solar metallicity extracted from the library of Coelho et al. (2005) was used as template. Its temperature was fixed as the value of the grid nearest to the temperature of the target, estimated from its $(B-V)$ colour by means of the relations in Alonso, Arribas & Martínez-Roger (1999). The typical surface gravity of a red giant, subgiant or main-sequence star ($\log(g) = 2.0$, 3.5, 4.5, respectively) was adopted after determining the most likely luminosity class of the target by means of a visual inspection of its spectra. Previous investigations have shown that even relatively large mismatches between the parameters of the object and the synthetic template have only negligible effects on the measurements, although they increase the estimated uncertainties (Morse, Mathieu & Levine 1991; Moni Bidin et al. 2010, 2011). The spectral range 4800–6800 Å was used in the cross-correlation, excluding the 5250–5350 Å gap in the HARPS spectra. The results were corrected for heliocentric velocity, but no other corrections were applied. In fact, zero-point errors were found negligible in HARPS spectra (see discussion in Moni Bidin et al. 2010), and the excellent agreement between the results obtained in the two epochs indicated that FEROS data neither required correction. The results are given in Table 2. The errors were estimated quadratically summing the contribution of the most relevant sources: the cross-correlation error (0.3–0.8 km s^{-1}), the uncertainty in zero-point definition (0.1 km s^{-1}) and choice of synthetic template (0.2 km s^{-1}). The six stars observed in both epochs show no RV variation, and the two measurements agree within 0.2 km s^{-1}; this suggests that they are not binaries.

The stellar parameters (effective temperature, surface gravity and microturbulence velocity) were estimated as described in Moni Bidin et al. (2010). The results are given in Table 2. In brief, temperature and gravity were measured fitting the wings of strong lines known to be good indicators of these parameters. The actual values of the parameters were determined minimizing the χ^2 of the fitting with synthetic spectra drawn from the library of Coelho et al. (2005). The Hα Balmer line was used to derive the temperature (Fuhrmann, Axer & Gehren 1994), except for the stars BT15 and BT17, which are too cool for this method. Their $T_{\rm eff}$ was estimated from the temperature–colour relations of Alonso et al. (1999) assuming $E(B-V) = 0.02$ (Schlegel, Finkbeiner & Davis 1998), and $E(V-I) = 0.03$ by means of the Cardelli, Geoffrey & Mathis (1989) relations between reddening in different bands. Similar results are obtained using the recalibration of Schlafly & Finkbeiner (2011) ($A_U = 0.090$ mag, $A_B = 0.075$ mag, $A_V = 0.057$ mag, $A_I = 0.031$ mag, $A_J = 0.015$ mag, $A_K = 0.006$ mag). Both the $(B-V)$

Table 2. Stellar data derived from spectroscopic analysis.

ID	Run	$T_{\rm eff}$ (K)	$\log(g)$ (dex)	$[\frac{\rm Fe}{\rm H}]$ (dex)	ξ (km s^{-1})	RV (km s^{-1})	d (pc)
BT11	FEROS	4750	3.15	+0.01	1.72	−7.1 ± 0.6	380 ± 100
BT12	FEROS	6090	3.55	−0.50	1.83	21.8 ± 0.6	1000 ± 240
	HARPS	6030	3.65	−0.55	1.71	22.0 ± 0.8	830 ± 160
BT14	FEROS	5890	4.40	0.00	1.01	31.0 ± 0.5	450 ± 100
	HARPS	5860	4.35	−0.05	1.04	31.1 ± 0.5	460 ± 130
BT15	HARPS	4360	1.65	−0.75	1.51	8.6 ± 0.5	2140 ± 370
BT16	FEROS	4850	4.45	+0.05	0.61	41.1 ± 0.5	200 ± 20
	HARPS	4760	4.25	−0.05	0.63	40.9 ± 0.3	190 ± 25
BT17	HARPS	4040	0.55	−1.15	1.79	67.7 ± 0.5	6000 ± 500
BT18	FEROS	5400	3.70	−0.30	1.48	18.4 ± 0.5	770 ± 200
	HARPS	5340	3.50	−0.45	1.62	18.3 ± 0.5	960 ± 240
BT19	FEROS	5210	4.30	−0.12	0.88	14.3 ± 0.4	300 ± 50
	HARPS	5120	4.35	−0.10	0.78	14.5 ± 0.5	250 ± 50
BT21	FEROS	5470	4.40	+0.11	0.85	20.3 ± 0.6	360 ± 40
BT22	FEROS	5320	4.40	+0.15	0.82	−1.4 ± 0.6	240 ± 30
BT27	FEROS	6040	3.75	−0.35	1.62	5.2 ± 0.4	1200 ± 300
	HARPS	6180	3.65	−0.20	1.76	5.3 ± 0.5	1600 ± 400
BT28	FEROS	6050	3.40	−0.35	1.95	−4.0 ± 0.4	1300 ± 300
A	HARPS	5900	4.25	−0.25	1.10	−14.5 ± 0.4	680 ± 60
σ		85	0.15	0.07	0.25		

Table 3. SPM4 proper motions and computed kinematic data. N is the number of stars with proper motions within 3σ of those of a given star in the table (within a 20 arcmin^2 field around NGC 1252). U, V, W are the components of the heliocentric Galactic velocity of the star (see the text for details).

ID	α (^{h}:^{m}:^{s})	δ (°:′:″)	V (mag)	SPM4 ID	$\mu_\alpha \cos\delta$ (mas yr^{-1})	μ_δ (mas yr^{-1})	N	U (km s^{-1})	V (km s^{-1})	W (km s^{-1})
BT11	03:11:09.0	−57:47:38	10.41	1230000671	17.4 ± 1.5	15.9 ± 1.3	2	−41 ± 9	−5 ± 7	11 ± 6
BT12	03:10:50.1	−57:47:09	12.03	1230015455	0.7 ± 1.4	2.7 ± 1.3	4	−10 ± 6	−11 ± 5	−20 ± 4
BT14	03:11:04.4	−57:46:23	12.43	1230015464	−11.1 ± 1.4	−21.5 ± 1.3	2	53 ± 3	−22 ± 2	−19 ± 2
BT15	03:11:10.7	−57:44:38	11.44	1230000682	3.0 ± 1.4	1.7 ± 1.2	4	−31 ± 13	−19 ± 11	2 ± 9
BT16	03:10:59.9	−57:44:42	13.06	1230083288	23.8 ± 1.8	−0.8 ± 1.7	7	−10 ± 2	−41 ± 1	−20 ± 1
BT17	03:11:02.6	−57:41:49	12.29	1230015463	7.3 ± 1.4	−17.5 ± 1.3	5	305 ± 55	−380 ± 40	239 ± 33
BT18	03:10:44.9	−57:43:24	12.64	1230015452	−19.6 ± 1.6	−46.4 ± 1.5	1	204 ± 7	−35 ± 5	16 ± 4
BT19	03:10:42.3	−57:42:07	13.25	1230083276	−16.8 ± 1.8	−54.8 ± 1.7	2	72 ± 6	−23 ± 4	4 ± 3
BT21	03:11:36.1	−57:40:23	12.64	1230015481	13.4 ± 1.7	7.1 ± 1.6	14	−22 ± 4	−23 ± 3	−9 ± 2
BT22	03:11:45.4	−57:37:48	12.51	1230015490	−2.1 ± 1.5	−6.1 ± 1.3	5	7 ± 2	0 ± 1	3 ± 1
BT27	03:10:56.6	−57:47:48	14.33	1230015460	6.8 ± 1.5	13.2 ± 1.4	5	−98 ± 16	2 ± 11	−14 ± 9
BT28	03:10:38.5	−57:47:20	12.15	1230015448	9.6 ± 1.4	7.4 ± 1.3	7	−71 ± 15	−19 ± 12	16 ± 10
A	03:10:51.6	−57:49:21	14.33	1230015456	−7.6 ± 1.9	−22.5 ± 1.9	2	73 ± 9	−4 ± 6	26 ± 5

and the $(V-I)$ colours were used, and the results averaged. The Ca I line at 6162 Å (Edvardsson 1988; Katz et al. 2003), the redder line of the Mg I b triplet at 5182 Å (Kuijken & Gilmore 1989), and the Na I doublet at 5890–5893 Å were used for gravity measurements. The values given by the equations of Reddy et al. (2003) and Gratton et al. (2003) were averaged to estimate the microturbulence velocity ξ. Finally, a total of 506 Fe I lines were inspected in each spectrum, with atomic data retrieved from the Vienna Atomic Line Database[9] (VALD; Kupka et al. 2000). For each star, 30–100 lines free of blending with other lines, in the range 5000–6500 Å, with equivalent width EW = 40–80 mÅ, and next to spectral regions where a clear continuum could be defined, were selected. Their EWs were measured with a Gaussian fitting, and they were used with the previously derived temperature, gravity and ξ, to estimate the metallicity, by means of the local thermodynamic equilibrium (LTE) code MOOG[10] (Sneden 1973). The atmospheric models required for the calculation were obtained interpolating from the Kurucz (1992) grid with the overshooting option switched off (Castelli, Gratton & Kurucz 1997). The method was iterated when the final parameters, in particular the metallicity, were noticeably different from those of the synthetic spectra used to estimate temperature and gravity. The parameters were also measured with the method of the ionization/excitation equilibrium of iron lines. In this case, the temperature and microturbulence velocity were fixed removing the trend of iron abundance with the excitation potential and EW, respectively, while the gravity was determined by the requirements that the Fe I and Fe II lines returned the same iron abundance. This method was applicable only to a subset of the sample, because the low S/N of many spectra prevented us from measuring a sufficient quantity of lines. Hence, we performed it only for seven stars as a safety check on the reliability of our results. A wider range of line EWs (20–120 Å) was considered in these measurements, and for each star more than 100 lines were finally selected. The results of this alternative method were consistent with our measurements, with only slightly higher temperature and metallicity. The mean difference (in the sense our results versus ion/exc method) and rms were $\Delta(T_{\rm eff}) = -42 \pm 120$ K, $\Delta(\log(g)) = 0.01 \pm 0.19$ dex, $\Delta([{\rm Fe/H}]) = -0.1 \pm 0.08$ dex. These rms should reflect the combined uncertainties of the two methods, hence we obtained a rough estimate of the error (given in the last line of Table 2) of our results, dividing them by $\sqrt{2}$.

The position of each target in the temperature–gravity plane, independent of distance and reddening, was compared to Yale–Yonsei isochrones (Yi, Kim & Demarque 2003) of the respective metallicity. The only free parameter was age, but its incidence on the results was negligible except for subgiant stars ($\log(g) \leq 4$), for which the age of best isochrone fitting was also derived. The absolute magnitude of each star was thus calculated, which was then used to estimate its distance. The error associated with this estimate was obtained from the errors in temperature and gravity, deriving the absolute magnitude interval compatible with the 1σ box in the temperature–gravity plane. The reddening in the direction of NGC 1252 is expected to be rather negligible, $E(B-V) = 0.02$ (Schlegel et al. 1998; Pavani et al. 2001; Schlafly & Finkbeiner 2011). For this reason, we did not estimate $E(B-V)$ for each target as done in Moni Bidin et al. (2010), because this quantity does not help distinguishing cluster members from field stars in this case.

We have used the results in Table 2 and proper motions from the SPM4 catalogue (Girard et al. 2011) to calculate the Galactic space velocity of the spectroscopic targets and its uncertainty (see Table 3). The heliocentric Galactic velocity components have been computed as described in Johnson & Soderblom (1987) for equinox 2000. Our results are referred to a right-handed coordinate system so that the velocity components are positive in the directions of the Galactic Centre, U, Galactic rotation, V, and the North Galactic Pole, W. We use the value of the parallax associated with the value of the distance in Table 2 and its error. From these values, we derive the heliocentric reference frame velocity components UVW. Our spectroscopic results (see Table 2) point out an absence of obvious clustering in distance, radial velocity or metallicity among the brightest stars in the studied NGC 1252 area. There are, however, a few of them that exhibit somewhat compatible distances (BT11, BT14, BT16, BT19 and BT21) but their radial velocities are rather different and their SPM4 proper motions mutually incompatible. Another example of stars located at similar distances is the pair BT12 and BT27, again with quite different radial velocities and proper motions. In principle, our high-resolution spectroscopy indicates that among the brightest stars in the NGC 1252 area, the majority are chemically, kinematically and spatially unrelated, i.e. they appear to be part of random star field fluctuations. This

[9] http://vald.astro.univie.ac.at/∼vald/php/vald.php?docpage = usage.html
[10] Freely distributed by C. Sneden, University of Texas, Austin.

scenario is typical of an asterism not of a true open cluster. The only pair of stars with reasonably compatible properties is BT27 and BT28. BT27 is a subgiant that seems to be located 1400 ± 200 pc from the Sun. It is a relatively metal-poor star with iron abundance of −0.28 ± 0.07. Our two-epoch spectroscopy indicates that the star is single. Dias et al. (2006) give a membership probability of 55 per cent for this star. BT28 is another subgiant located 1300 ± 300 pc from the Sun and relatively metal poor with iron abundance of −0.35. Our single epoch spectroscopy for this star does not allow us to draw any conclusions with respect to its possible binarity. Its distance, metallicity and kinematic data are compatible with those of BT27 although their radial velocities are different (see Table 2) but it could be a binary member of the cluster, if real. Dias et al. (2006) give a membership probability of 69 per cent for BT28. The pair is separated by 2.4 arcmin or 0.9 pc at a distance of 1350 pc. If this pair is signalling the presence of a coherent group in the area, a sequence of stars with similar proper motions should be visible in the CMDs. That will be the subject of the next section.

4 PROPER MOTIONS: CANDIDATE MEMBER SELECTION

It is true that the brightest stars in the field of NGC 1252 do not appear to form a physical system but what if just a few of them are the brightest members of a real but faint OCR? The analysis of the proper motions of stars in the area should help to answer this critical question. In this work we use proper motions from the SPM4 catalogue (Girard et al. 2011) which contains absolute proper motions, celestial coordinates, *B*, *V* and 2MASS photometry for over 103 million stars and galaxies between the south celestial pole and −20° in declination. The catalogue is roughly complete to $V = 17.5$. We decided to use the SPM4 catalogue instead of the UCAC4 catalogue (Zacharias et al. 2011, 2013) because it has better coverage; for example, in a 20 arcmin^2 field around NGC 1252 we find 70 stars in UCAC4 but 116 (66 per cent more) in SPM4. On the other hand, we use SPM4 instead of the Positions and Proper Motions-extended Large (PPMXL) catalogue (Röeser, Demleitner & Schilbach 2010) because even if it appears to be far more complete than SPM4 or UCAC4 (1148 entries for the same 20 arcmin^2 field), the relative errors are about 50 per cent larger, rendering any analysis based on proper motions of very limited use. As an example, NGC 1252 27 has UCAC4 (162-002807) proper motions $(\mu_\alpha \cos\delta, \mu_\delta) = (6.2 \pm 1.2, 6.3 \pm 1.2)$ mas yr^{-1}, $V = 13.17$ and $B - V = 0.43$; its PPMXL proper motions are $\mu_\alpha \cos\delta = 16.7 \pm 11.0$ mas yr^{-1}, $\mu_\delta = 10.0 \pm 11.0$ mas yr^{-1}, therefore, somewhat compatible with UCAC4 or SPM4 data (see Table 3) but with very large errors. In this case, the UCAC4 μ_δ proper motion is nearly half the value quoted by SPM4. Table 3 displays the SPM4 proper motions of all the stars studied spectroscopically with *N* being the number of stars in the SPM4 catalogue sharing the proper motion – within 3σ of the values quoted – of a given star in the table. Let us assume that one of these stars is a member of NGC 1252. The only star with a relatively large cohort of candidate comoving stars is NGC 1252 21, a star of almost solar metallicity located at a distance of 360 ± 40 pc from the Sun. The proper motions of this star match well those attributed to NGC 1252 in Dias et al. (2006) and Zejda et al. (2012). Unfortunately, the CMD (see Fig. 6, right-hand panel) suggests that the candidate group is made of stars located at different distances (perhaps also of different metallicities): some as close as NGC 1252 21 but others located as far away as 1 kpc. Although the individual number of candidate comoving stars for NGC 1252 27 and NGC 1252 28 is smaller, their combined figure is close to the value of *N* found for NGC 1252 21. If, as some studies suggest (see Section 2), there is a real open cluster located at a heliocentric distance close to 1 kpc in the area of sky commonly associated with NGC 1252 and we assume that the stars NGC 1252 27 and NGC 1252 28 are among its brightest members, the 2MASS CMD in Fig. 6, left-hand panel, supports that conclusion. It also shows that some of the stars with proper motions compatible with those of NGC 1252 21 are also compatible with those of the pair NGC 1252 27 and NGC 1252 28 as their 3σ spreads overlap, even if their distances are rather different. For example, the second brightest star (the brightest is NGC 1252 28) in Fig. 6, left-hand panel, is TYC 8498−853-1 which is an F5V star located 533 pc from the Sun (Pickles & Depagne 2010); this star has a 75 per cent membership probability in Dias et al. (2006). The third brightest star in the same diagram is NGC 1252 21 itself. Both TYC 8498−853-1 and NGC 1252 21 are not part of NGC 1252, as described here. This is to be expected within the context of foreground stellar contamination, as already pointed out in Section 2. The main source of this foreground contamination could be the Hyades stream as the velocity components of NGC 1252 21 in Table 3 are very close to the range quoted by Pompéia et al. (2011). This somewhat coherent structure is not a cluster but the result of resonances.

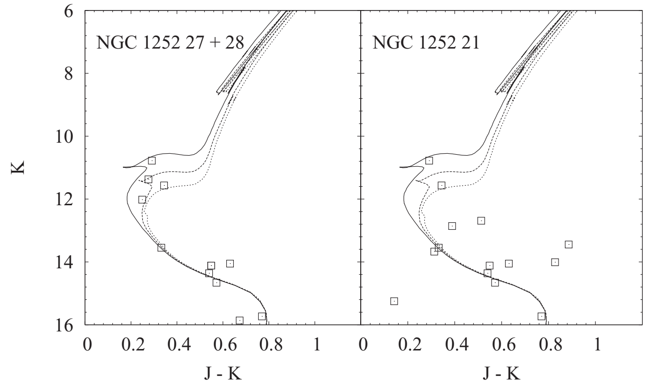

Figure 6. 2MASS near-infrared CMD for stars with proper motions within 3σ of those of the pair NGC 1252 27 and NGC 1252 28 (left-hand panel) and NGC 1252 21 (right-hand panel). The dashed isochrone is for an age of 3 Gyr, [Fe/H] = −0.35 (Bressan et al. 2012) and a heliocentric distance of 1.1 kpc. The continuous isochrone corresponds to an age of 2 Gyr and the dotted isochrone is for 4 Gyr (same iron abundance and assumed distance).

Under normal circumstances, overdensities in proper motion diagrams signal the presence of kinematically coherent structures. The usual approach followed in Carraro et al. (2007) consists in extracting proper motion components in a 20 arcmin^2 field around the object and search for statistically significant clumps. Alternatively, we can also compare with adjacent star fields looking for peculiar features that are only present in one area. Figs 7–10 show three vector-point diagrams as a function of the *K* magnitude for a 20 arcmin^2 field around NGC 1252 and eight equivalent neighbouring star fields. The top panel is restricted to stars having $K < 12$, the middle panel to stars in the range $12 \leq K < 14$ and the bottom panel to stars having $14 \leq K < 16$. Stars in the top panel for the NGC 1252 area appear to clump around $\mu_\alpha \cos\delta = 4$ mas yr^{-1}, $\mu_\delta = 3$ mas yr^{-1} but that is not observed at fainter magnitudes (see Fig. 7, three central panels). However, for stars with $12 \leq K < 14$, a group is visible centred at $\mu_\alpha \cos\delta = 12$ mas yr^{-1}, $\mu_\delta = 6$ mas yr^{-1} which are close to the values cited by Dias et al. (2006) and Zejda et al. (2012), and a more extended structure is observed at fainter magnitudes. These results, together with the analysis of Fig. 6 and

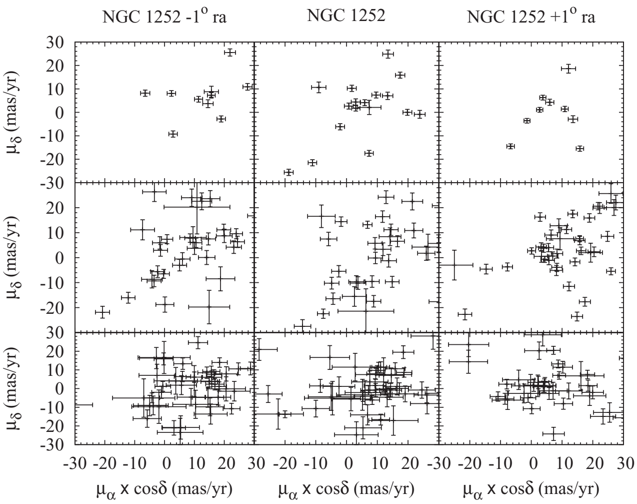

Figure 7. Proper motion analysis: proper motion components with 1σ error bars in a 20 arcmin^2 field around NGC 1252 and two equivalent fields centred at the position of NGC 1252 $\pm1°$ in right ascension. Top panel: stars brighter than $K = 12$. Middle panel: stars having $12 \leq K < 14$. Bottom panel: stars having $14 \leq K < 16$.

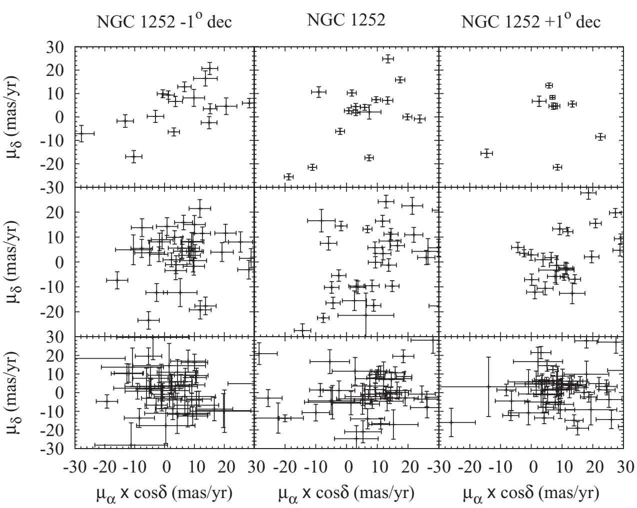

Figure 8. Same as Fig. 7 but for a 20 arcmin^2 field around NGC 1252 and two equivalent fields centred at the position of NGC 1252 $\pm1°$ in declination.

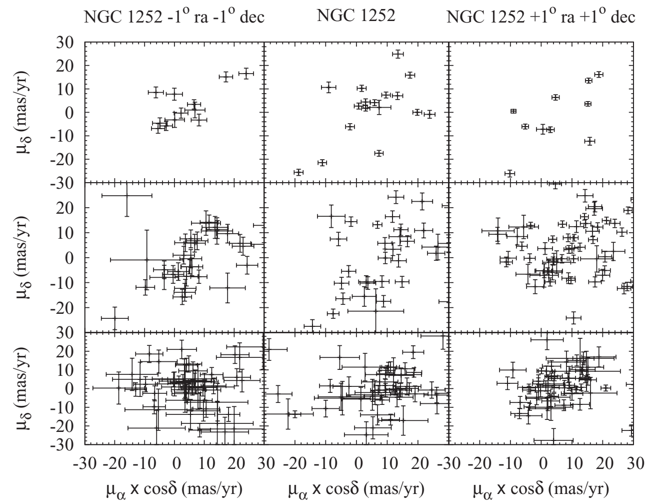

Figure 9. Same as Fig. 7 but for a 20 arcmin^2 field around NGC 1252 and two equivalent fields centred at the position of NGC 1252 $-1°$ in right ascension, $-1°$ in declination and $+1°$ in right ascension, $+1°$ in declination.

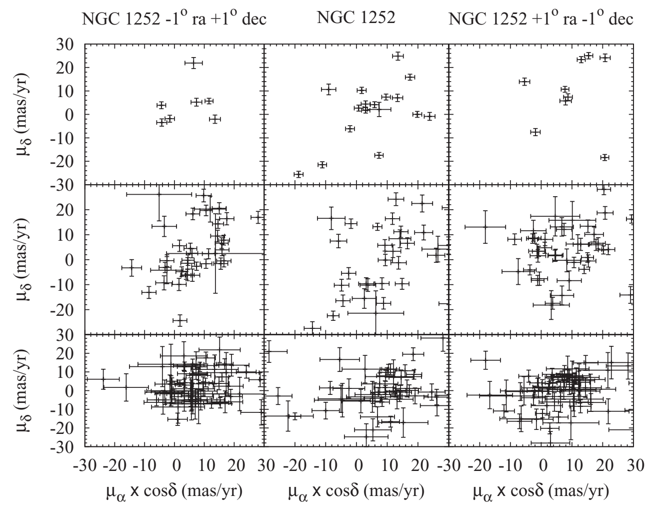

Figure 10. Same as Fig. 7 but for a 20 arcmin^2 field around NGC 1252 and two equivalent fields centred at the position of NGC 1252 $-1°$ in right ascension, $+1°$ in declination and $+1°$ in right ascension, $-1°$ in declination.

Table 3, indicate that the clump found is the result of two contributions, the ~1 kpc distant NGC 1252 and a significantly closer population that we interpret as part of the Hyades stream. Given the small number of stars involved and the tight mixture of unrelated (in terms of heliocentric distance and metallicity) populations in proper motion space, a simple statistical analysis looking for overdensities in Figs 7–10 does not draw any meaningful conclusions.

Out of all the bright stars studied spectroscopically in this work, only two appear to be kinematically consistent with membership on a possible NGC 1252 stellar group but their radial velocities are different and we cannot confirm the single nature of NGC 1252 28 as we have single epoch spectroscopy. There are 11 stars (out of a total of 116 in SPM4, ~10 per cent) with proper motions within 3σ of those of NGC 1252 27 and NGC 1252 28 in our 20 arcmin^2 field centred on the SIMBAD's coordinates of NGC 1252. The 2MASS near-infrared CMD for these suspected NGC 1252 members is seen in Fig. 6, left-hand panel. The best Padova theoretical isochrone[11] fitted corresponds to an age of 3 Gyr and abundance [Fe/H] = -0.35 (Bressan et al. 2012), assuming a heliocentric distance of nearly 1 kpc. Isochrones within an age range of 2–4 Gyr and iron abundance range of -0.20 to -0.50 are also compatible; a heliocentric distance to NGC 1252 $\gg$ 1 kpc appears to be highly unlikely. But, how significant is the group found? If we study the CMDs for stars with proper motions within 3σ of those of the pair NGC 1252 27 and NGC 1252 28 at various locations in the neighbourhood of NGC 1252, we can find out if the sequence in Fig. 6, left-hand panel, is peculiar to the area observed or shared across a wider region. Fig. 11 suggests that members of a kinematically coherent but extended structure, the associated moving group, occupy an area approximately located between right ascension 3^h10^m and 3^h15^m

[11] http://stev.oapd.inaf.it/cgi-bin/cmd

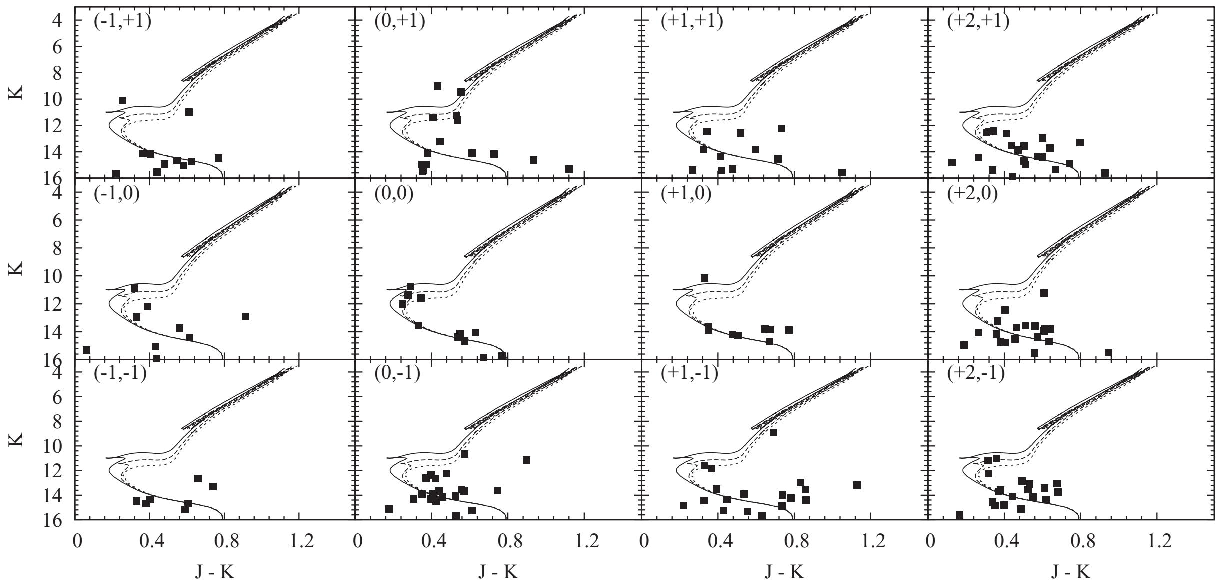

Figure 11. 2MASS near-infrared CMDs for stars with proper motions in SPM4 within 3σ of those of the pair NGC 1252 27 and NGC 1252 28 at various locations around NGC 1252. Each panel corresponds to a 20 arcmin^2 patch of sky centred at the position of NGC 1252 and shifted in right ascension and declination by the amounts indicated in parentheses (top left-hand corner). For example, (+1, −1) means that the squared patch of sky is centred at the location of NGC 1252 +1° in right ascension and −1° in declination.

with declination between −57°34′ and −57°58′; it seems to extend east of NGC 1252. In summary, the OCR that may be present in the area of NGC 1252 is relatively close (∼1 kpc), of subsolar metallicity, and probably old. In Tables 4, we have compiled relevant data for the 11 suspected NGC 1252 members plotted in Fig. 6, left-hand panel, and two other candidates (see below). Our average proper motions for NGC 1252 are $\mu_\alpha \cos\delta = 9.2 \pm 3.0$ mas yr^{-1}, $\mu_\delta = 8.8 \pm 2.8$ mas yr^{-1}. These values are consistent with those in Zejda et al. (2012). The cluster centre is found at $\alpha = 03^{\rm h}10^{\rm m}47^{\rm s}$, $\delta = -57°45'18''$.

5 NGC 1252: A HIGH GALACTIC ALTITUDE OPEN CLUSTER REMNANT

In Fig. 12, we present several optical CMDs obtained from the photometry presented in Section 3.1 and using the values of the OCR parameters constrained by the proper motion analysis carried out in Section 4. The stars with proper motions within 3σ of those of NGC 1252 27 and NGC 1252 28 are plotted as filled black squares. Our photometry is plotted as empty circles. Typical of OCRs, there is a sparse main sequence and the turn-off point is not well defined but it could be near $V = 12$. Hardly any trace of the red giant branch or red clump is observed. In principle, they could be absent because the associated stars were saturated on our images. No blue stragglers are observed but this could also be the result of image saturation. The large number of objects under the proposed main sequence is made of faint field stars, probably part of the distant halo like NGC 1252 17 (see Appendix A). The colour of the bluest of these stars is redder than the proposed location of the turn-off point of NGC 1252 so they could be older than the OCR but they could also have higher (perhaps, solar) metallicity. The isochrones from Girardi et al. (2000) correspond to a metallicity of [Fe/H] = −0.35 and ages 2, 3 and 4 Gyr; they include the post-giant evolution and the locus of the white dwarf cooling sequence. An age of 3 Gyr is favoured but differences are not very significant and they are probably well within the observational errors. An interesting feature that is glimpsed in the first two diagrams is the presence of a population of faint blue stars that appear in a sequence near $V = 22$. They could be faint unresolved galaxies but objects there could also be candidates to signal the locus of the NGC 1252 white dwarf cooling sequence. They are well below the completeness limit, however. *N*-body simulations suggest that up to 10 per cent of members of old OCRs could be white dwarfs if the population of the original cluster was larger than a few thousand stars (see fig. 3 in de la Fuente Marcos 1998). Deeper photometry is needed to confirm this tentative analysis.

In order to find additional candidates for membership in NGC 1252 and confirm the lack of red giant branch or red clump, we have searched SPM4 for objects with proper motions within 3σ of those of NGC 1252 27 and NGC 1252 28 and distance to the centre of the cluster <12 arcmin (over 3 pc at the assumed distance for the cluster). This search gives 13 objects (including the ones already discussed above) that are included in Table 4. In order to find out which objects are the most relevant members of the cluster we have to estimate a membership probability. A robust choice to estimate this probability from proper motions is a bivariate Gaussian distribution. The probability of object i being a member of a kinematic group using $\mu^*_\alpha = \mu_\alpha \cos\delta$ and μ_δ is given by

$$P_i^k = {\rm e}^{-\frac{1}{2}\left[\left(\frac{\mu^*_{\alpha i} - \langle\mu^*_\alpha\rangle}{\sigma_{\mu^*_\alpha}}\right)^2 + \left(\frac{\mu_{\delta i} - \langle\mu_\delta\rangle}{\sigma_{\mu_\delta}}\right)^2\right]}, \quad (1)$$

where $\langle\mu^*_\alpha\rangle$ (9.2 mas yr^{-1}), $\langle\mu_\delta\rangle$ (8.8 mas yr^{-1}) are the average values for the cluster, $\sigma_{\mu^*_\alpha}$ (3.0 mas yr^{-1}), σ_{μ_δ} (2.8 mas yr^{-1}) are the associated standard deviations and $\mu^*_{\alpha i}$, $\mu_{\delta i}$ are the proper motions of the ith object. The computed values are given in Table 4, last column; three stars have membership probability higher than 80 per cent. Given the uncertainty in the possible value of the radial velocity of the cluster (we do not have three or more stars with similar radial velocities), we do not compute the motion or Galactic space velocity of NGC 1252. In addition, we do not estimate its mass function or initial mass function (IMF) as we do not have enough spectroscopically confirmed members to obtain a meaningful result.

Table 4. Candidates for membership in NGC 1252 based on SPM4 proper motions. The distance from the customary centre of the cluster in arcminutes is represented by r. The entries are sorted by r.

ID	Designation		r	α	δ	$\mu_\alpha \cos\delta$	μ_δ	U	B	V	I	J	H	K	P_i^k
	SIMBAD	SPM4	(arcmin)	($^{h:m:s}$)	(°:′:″)	(mas yr^{-1})	(mas yr^{-1})	(mag)	(mag)	(mag)	(mag)	(mag)	(mag)	(mag)	(per cent)
122	NGC 1252 28	1230015448	1.93	03:10:38.5	−57:47:19	9.6 ± 1.4	7.4 ± 1.3	12.50 ± 0.04	12.41 ± 0.03	11.95 ± 0.02	11.35 ± 0.03	11.07 ± 0.04	10.87 ± 0.04	10.78 ± 0.03	87.2
176	NGC 1252 27	1230015460	2.05	03:10:56.6	−57:47:47	6.8 ± 1.5	13.2 ± 1.4	13.73 ± 0.04	13.64 ± 0.03	13.16 ± 0.02	12.57 ± 0.03	12.27 ± 0.03	12.00 ± 0.03	12.02 ± 0.03	22.5
227	–	1230083297	3.02	03:11:11.2	−57:46:34	12.1 ± 9.1	7.5 ± 9.0	18.73 ± 0.04	18.68 ± 0.03	17.97 ± 0.02	17.07 ± 0.03	16.50 ± 0.14	15.91 ± 0.17	15.73 ± 0.24	56.0
236	–	1230082026	4.36	03:11:16.2	−57:48:25	2.8 ± 7.5	11.5 ± 7.4	18.00 ± 0.04	18.06 ± 0.03	17.51 ± 0.02	16.79 ± 0.03	16.54 ± 0.13	16.15 ± 0.22	15.86 ± 0.25	06.6
192	–	1230084516	4.76	03:10:59.9	−57:41:28	11.1 ± 2.9	11.5 ± 2.9	18.08 ± 0.04	17.40 ± 0.03	16.50 ± 0.02	15.54 ± 0.03	14.90 ± 0.04	14.42 ± 0.04	14.36 ± 0.07	52.2
22	–	1230083252	6.72	03:09:58.9	−57:45:17	9.5 ± 2.9	7.9 ± 2.9	17.81 ± 0.04	17.47 ± 0.03	16.68 ± 0.02	15.79 ± 0.03	15.23 ± 0.06	14.80 ± 0.06	14.66 ± 0.10	94.2
99	–	1230015445	7.62	03:10:32.1	−57:38:43	9.2 ± 2.3	5.8 ± 2.3	15.54 ± 0.04	15.50 ± 0.03	14.95 ± 0.02	14.27 ± 0.03	13.88 ± 0.03	13.58 ± 0.03	13.55 ± 0.04	55.5
279	NGC 1252 21	1230015481	8.43	03:11:36.0	−57:40:23	13.4 ± 1.7	7.0 ± 1.6	14.23 ± 0.04	13.89 ± 0.03	13.17 ± 0.02	12.41 ± 0.03	11.91 ± 0.02	11.61 ± 0.03	11.57 ± 0.02	30.3
–	TYC 8498−853-1	1230000655	9.55	03:09:44.9	−57:50:16	5.9 ± 1.4	4.1 ± 1.3	–	–	–	–	11.65 ± 0.02	11.42 ± 0.03	11.37 ± 0.02	13.9
340	–	1230015496	10.40	03:12:04.1	−57:43:13	9.0 ± 2.3	14.5 ± 2.3	15.63 ± 0.04	15.57 ± 0.03	14.97 ± 0.02	14.24 ± 0.04	13.65 ± 0.03	13.29 ± 0.03	13.30 ± 0.05	13.3
–	–	1230081981	10.86	03:09:37.5	−57:51:14	9.9 ± 2.5	9.7 ± 2.5	–	–	–	–	14.66 ± 0.04	14.23 ± 0.04	14.12 ± 0.06	91.8
–	–	1230015446	10.92	03:10:35.3	−57:56:45	10.6 ± 2.7	4.0 ± 2.7	–	–	–	–	14.47 ± 0.03	14.21 ± 0.04	14.05 ± 0.06	21.0
335	–	1230084546	11.06	03:12:02.5	−57:40:53	10.4 ± 2.7	11.4 ± 2.7	17.55 ± 0.04	17.07 ± 0.03	16.22 ± 0.02	15.28 ± 0.03	14.68 ± 0.04	14.17 ± 0.05	14.05 ± 0.07	60.5

For the same reason, we do not try to provide a value for the cluster effective radius, the tidal radius or the concentration parameter. We can however conclude that the degree of concentration of this OCR is rather low as expected of an old and relaxed dynamical system. As for the original population of the cluster, its current population (see Fig. 12) could be ∼30 members and for such membership after 3 Gyr, the results of numerical simulations (de la Fuente Marcos 1998) suggest that the initial membership could be as high as 10^4 stars, much larger than our estimate for NGC 1901 in Carraro et al. (2007). This estimate puts the parent open cluster of the present NGC 1252 OCR among the most massive open clusters currently observable in the Milky Way. Further discussion on the possible origin of this unusual object is presented below.

How do our results compare with those obtained in past studies of this area? We agree with Bouchet & Thé (1983) that there is an actual open cluster in that region of the sky but in contrast with our own findings, their conclusions draw a picture of a younger and closer object. That picture is not supported by our current results. We disagree with Eggen (1984) as he concluded that NGC 1252 was probably not a cluster (more on this later). We cannot confirm that NGC 1252 has any blue stragglers as pointed out by Ahumada & Lapasset (1995), Xin & Deng (2005) and Ahumada & Lapasset (2007): HD 20286 is a foreground star (see Appendix A). We do not agree with the conclusions obtained by Baumgardt (1998) and Baumgardt et al. (2000): our results indicate that NGC 1252 is a real open cluster, not an asterism. We coincide with the conclusions drawn by Pavani et al. (2001) and Bica et al. (2001) regarding the presence of an OCR in the area and its age but their distance is almost half the value found in our study. As a consequence, their object is closer to the Galactic plane. This smaller value of the distance could be the result of the relatively large differences in V between our photometry and theirs as pointed out in Section 3.1.4: their stars brighter than $V = 13$ are up to 0.3 mag brighter than ours. It could also be possible that Pavani et al. (2001) and Bica et al. (2001) identified the population that we consider part of the Hyades stream as NGC 1252. These stars have a significant distance spread but they are closer than 600 pc and they are present in all the extended area around the cluster (see Fig. 11). Similar comments can be made about Loktin & Beshenov (2003), their proper motions are also slightly smaller than the values obtained here. In contrast, our proper motion results agree well with those in Dias et al. (2006) and Zejda et al. (2012). Nonetheless, we believe that these authors are mixing stars located at different distances, including many candidate members that are, in fact, part of the foreground population. As for the value of the diameter quoted in van den Bergh (2006), our results suggest a larger value as the object exhibits no concentration but, as pointed out above, more data are needed to provide a reliable figure. Finally, Pavani & Bica (2007) use 2MASS photometry and UCAC2 proper motions. This may explain the shorter distance obtained by these authors in comparison with our result. In general, the somewhat shorter distance quoted in some papers could also be the result of assuming that the cluster has solar metallicity which appears not to be the case.

Regarding the origin of NGC 1252, van den Bergh (2006) pointed out that open clusters with ages >1 Gyr appear to form a singular structure that he termed a 'cluster thick disc'. Van den Bergh considers that part of the open cluster thick disc consists of objects that were probably captured gravitationally by the main body of the Galaxy. Similar views appear in Gozha, Koval' & Marsakov (2012). This does not necessarily imply that a fully formed star cluster was captured; our Galaxy harbours a population of high Galactic altitude gas clouds which are, in some cases, similar to those found

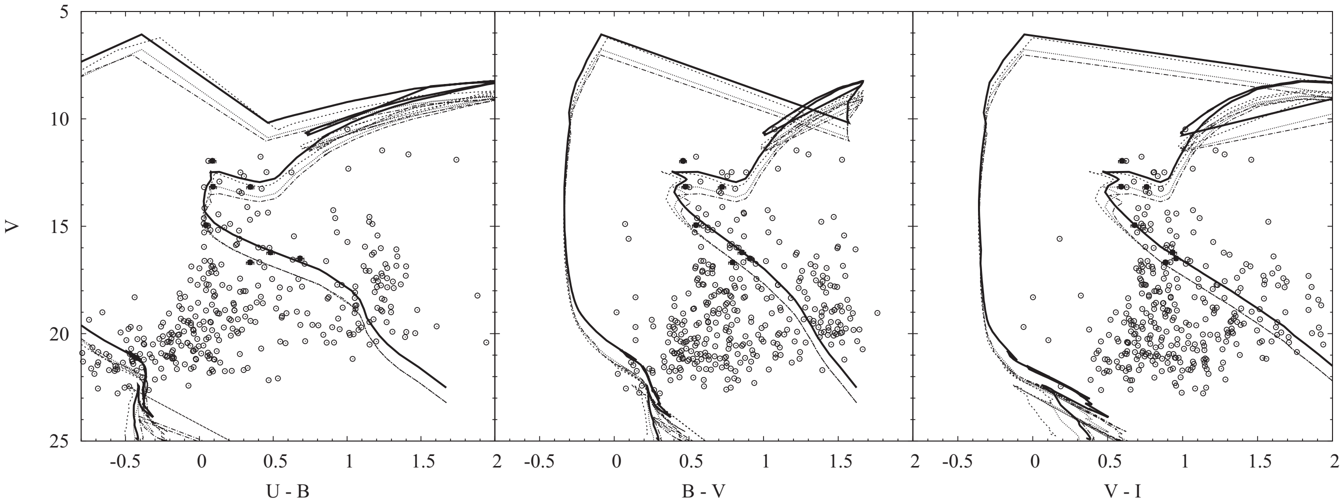

Figure 12. Optical CMDs for the photometry presented in Section 3.1 and the candidate members discussed in Section 4. In the three panels, the isochrones correspond to a metallicity of [Fe/H] = −0.35 and ages 2, 3 and 4 Gyr from models by Girardi et al. (2000) which include the post-giant evolution and the locus of the white dwarf cooling sequence. Traces of a possible white dwarf cooling sequence can be seen in the first two diagrams. The seven stars in common with those in the list of 11 suspected NGC 1252 members based on proper motions appear as solid points. A heliocentric distance of 1350 pc has been assumed but the solid, thick line is the isochrone of age 3 Gyr at a distance of 1 kpc.

in the disc. Although the disc hosts nearly 95 per cent of all known young open clusters and even a larger fraction of GMCs, a small but significant percentage of young open clusters are found far from the thin disc (de la Fuente Marcos & de la Fuente Marcos 2008). Within the disc, star formation is mainly driven by the large-scale shock induced by a spiral arm although supernovae also play a non-negligible role. However in absence of spiral shocks, what mechanism could form star clusters at high Galactic altitude? This was one of the objections pointed out originally by Eggen (1984) to conclude that NGC 1252 was probably not a cluster because it was located too far from the disc. Contrary to this old, restrictive view, star formation at high Galactic altitude is now well documented observationally (see de la Fuente Marcos & de la Fuente Marcos 2008, for details) and several mechanisms capable of explaining its existence have been suggested: supernova-triggered star formation (e.g. Williams et al. 1977), off-plane gas ejection (Martos et al. 1999) and tidal encounters (de la Fuente Marcos & de la Fuente Marcos 2008). These mechanisms can operate concurrently. Star formation far from the Galactic disc is not unusual and de la Fuente Marcos & de la Fuente Marcos (2008) already concluded that nearly 13 per cent of known open clusters are found at $|z| \geq$ 200 pc, where $z = d \sin b$, d and b are the heliocentric distance and Galactic latitude, respectively, of the object. The 2013 January version (v3.3; Dias 2013) of NCOVOCC includes 2174 open clusters; out of them, 1629 have both distance and age. Within this smaller sample, we find 293 (18 per cent) clusters of all ages with separation from the disc >200 pc. Among young clusters (age <100 Myr) the fraction of high-altitude objects is 4.7 per cent (24 out of 505 clusters). This fraction increases to 50.6 per cent (158 out of 312 clusters) for old clusters (age >1 Gyr). As expected, moving in an inclined orbit increases the survival opportunities of a star cluster. These numbers clearly vindicate the conclusions of van den Bergh (2006) pointed out above and also single out NGC 1252 among known OCRs. With a current distance below the Galactic disc of almost 900 pc, NGC 1252 is the first object that can be truly considered a high Galactic altitude OCR. The orbit of the parent GMC of NGC 1252 may have been unusually inclined perhaps as a result of the Galactic warp or a tidal interaction with another massive object. An alternative scenario is in situ formation, maybe as a result of a tidally induced star formation event at high Galactic altitude following the tidal encounter paradigm outlined by de la Fuente Marcos & de la Fuente Marcos (2008): a close encounter between a high Galactic altitude gas cloud and a globular cluster.

6 CONCLUSIONS

In this paper, we have re-examined the open cluster remnant nature of NGC 1252 in Horologium. This controversial object had been classified both as asterism (e.g. Baumgardt 1998) and OCR (e.g. Pavani et al. 2001). The main objective of this research was to shed some new light on this controversy and we believe that we have accomplished this objective as well as clarified and discussed some other important aspects related to this area of the sky. Our main conclusions can be summarized as follows.

(i) All the available evidence shows that there is a very sparse, faint open cluster or OCR in the area of sky commonly associated with NGC 1252.

(ii) This poorly populated stellar group is located at about 1 kpc from the Sun and it is 3 Gyr old.

(iii) Spectroscopy of two candidate members indicates that the group has subsolar metallicity.

(iv) We identify about a dozen candidate members but further observations are required in order to confirm membership in terms of photometry, spectroscopy and astrometry. In particular, deeper photometry and multi-epoch spectroscopy of the brightest candidate members are needed.

(v) In light of numerical simulations (de la Fuente Marcos 1998), what is observed now at the location of NGC 1252, the OCR, is compatible with an original open cluster made of perhaps as many as 10^4 stars.

(vi) With a current distance below the Galactic disc of almost 900 pc, NGC 1252 is the first open cluster that can be truly considered a high Galactic altitude OCR; an unusual object that can hint at a star formation episode induced on a high Galactic altitude gas cloud by a non-standard mechanism, perhaps a passing globular cluster (de la Fuente Marcos & de la Fuente Marcos 2008).

(vii) The carbon star TW Horologii, associated by some authors with the open cluster NGC 1252, is clearly a foreground object. Its distance and kinematic properties are incompatible with membership in NGC 1252.

(viii) The blue straggler candidate HD 20286, identified by multiple authors as a true member of NGC 1252, is a foreground object. Its status as blue straggler should be revised.

(ix) NGC 1252 21 that has been commonly associated with the centre of NGC 1252 appears to be a foreground star, unrelated to the cluster.

(x) NGC 1252 1 (HD 20059) appears to be a relatively close star, the primary of a wide binary system.

(xi) NGC 1252 17 is a background Population II star moving in a retrograde orbit at a very high speed, 403 km s^{-1}, but probably still bound to the Milky Way (see Smith et al. 2007). It could be a cannonball star (Meylan, Dubath & Mayor 1991).

As a metal poor open cluster of Gyr age, this object is of interest to studies of stellar evolution and star formation. The study of OCRs is always a challenging but rewarding endeavour; however and in the case of an object like NGC 1252, the high Galactic latitude (and, in this case, also altitude) of the object and significant foreground contamination complicate matters further. As pointed out above, deeper photometry and additional multi-epoch spectroscopy are needed in order to improve the values of the parameters of this object now that its true nature has been better established.

ACKNOWLEDGEMENTS

The authors thank the referee for his/her constructive reports and helpful suggestions regarding the presentation of this paper. RdlFM and CdlFM acknowledge partial support by the Spanish ‘Comunidad de Madrid’ under grant CAM S2009/ESP-1496. EC acknowledges support by the Fondo Nacional de Investigación Científica y Tecnológica (proyecto No. 1110100 Fondecyt), and the Chilean Centro de Excelencia en Astrofísica y Tecnologías Afines (PFB 06). In preparation of this paper, we made use of the NASA Astrophysics Data System and the ASTRO-PH e-print server. This work also has made extensive use of the SIMBAD data base and the VizieR catalogue access tool, both operated at the CDS, Strasbourg, France. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

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APPENDIX A: A FEW OBJECTS IN THE NGC 1252 FIELD

The area around NGC 1252 includes two objects that have been associated with NGC 1252 by some authors. Here we compile available data to confirm or disprove their connection to NGC 1252. We also discuss a few other objects with unusual properties.

A1 TW Horologii

TW Horologii (TW Hor; = HD 20234 = HR 977) is a naked-eye variable orange star located nearly 30 arcmin north-east of NGC 1252 (see Fig. 1 for their relative positions). It is one of the sky's brightest carbon stars normally shining at *V* magnitude 5.79 but displaying small variations of 0.6 mag with a period of 157 d (Bouchet 1984). Bouchet & Thé (1983) first suggested that TW Hor was a probable member of NGC 1252 but shortly after, Eggen (1984) contested their result by arguing that NGC 1252 was not a true open cluster but just an asterism. For Eggen (1984), TW Hor is a member of the Hyades supercluster. TW Hor is bright enough to be studied by the *Hipparcos* mission. The new *Hipparcos* reduction (van Leeuwen 2007) gives a distance of 322^{+43}_{-34} pc to TW Hor that is incompatible with our distance determination for the cluster. Proper motions, $(\mu_\alpha \cos\delta, \mu_\delta) = (18.44 \pm 0.31, 13.20 \pm 0.35)$ mas yr^{-1}, also from the new *Hipparcos* reduction, are inconsistent with membership too. The Extended *Hipparcos* Compilation (XHIP) which is based on the new *Hipparcos* reduction gives a distance of 316 ± 38 pc with $(\mu_\alpha \cos\delta, \mu_\delta) = (18.49 \pm 0.29, 13.26 \pm 0.31)$ mas yr^{-1}, that translates into a transverse velocity of 34.1 km s^{-1} (Anderson & Francis 2012). Its radial velocity is 14.3 ± 2.9 km s^{-1} (Gontcharov 2006) which is incompatible (within the error limits) with that of NGC 1252 27 or NGC 1252 28 (see Table 2). All this body of observational evidence indicates that TW Hor is not part of NGC 1252. On the other hand, both its radial velocity and distance are compatible with those of NGC 1252 19 in Table 2 but their proper motions are fully incompatible. TW Hor's radial velocity could be compatible with NGC 1252 18 in Table 2 but both distances and proper motions are incompatible. Finally, TW Hor and NGC 1252 11 have compatible distance and proper motions but their radial velocities are very different although we cannot confirm that NGC 1252 11 is not a binary. However, TW Hor and NGC 1252 21 have somewhat compatible (within 6σ) distance, radial velocity and proper motions. This clearly shows how heterogeneous the stellar populations in this area of sky are and how dangerous is to draw any conclusions without having enough data.

A2 HD 20286

HD 20286 is NGC 1252 4 in Bouchet (1984). This star is also known as CD-58 652 and it was identified as a blue straggler candidate in NGC 1252 by Ahumada & Lapasset (1995). Xin & Deng (2005) pointed out that this B9.5 V star is the only confirmed blue straggler in NGC 1252. The object is also included as blue straggler in an updated list by Ahumada & Lapasset (2007). HD 20286 is located 613^{+407}_{-174} pc from the Sun and has $(\mu_\alpha \cos\delta, \mu_\delta) = (0.93 \pm 0.63, -4.94 \pm 0.74)$ mas yr^{-1} (van Leeuwen 2007). Its SPM4 (1230000090) proper motions are $(\mu_\alpha \cos\delta, \mu_\delta) = (6.2 \pm 2.3, -7.1 \pm 1.9)$ mas yr^{-1}. Its UCAC4 (161-002935) proper motions are $(\mu_\alpha \cos\delta, \mu_\delta) = (5.4 \pm 1.0, -6.3 \pm 1.0)$ mas yr^{-1}. Even if its heliocentric distance could be compatible with our determination for NGC 1252, their proper motions are clearly incompatible. There are no stars in Table 2 with both distance and proper motions compatible with those of HD 20286. As in the previous case, observational evidence indicates that HD 20286 is not part of NGC 1252. Therefore, its status as blue straggler should be revised.

A3 HD 20059

HD 20059 is NGC 1252 1 in Bouchet (1984). This star is also known as CD-58 641. HD 20059 is located 96^{+7}_{-6} pc from the Sun and has $(\mu_\alpha \cos\delta,\ \mu_\delta) = (4.39 \pm 0.64,\ -69.81 \pm 0.78)$ mas yr^{-1} (van Leeuwen 2007). Its SPM4 (1230000086) proper motions are $(\mu_\alpha \cos\delta, \mu_\delta) = (-3.2 \pm 2.7, -63.9 \pm 2.2)$ mas yr^{-1}. The UCAC4 (162-002803) proper motions are $(\mu_\alpha \cos\delta,\ \mu_\delta) = (6.1 \pm 1.0,\ -67.5 \pm 1.0)$ mas yr^{-1}. With a spectral type of K1III/IV, this foreground star is completely unrelated to NGC 1252 and it was already classified as such by Dias et al. (2006). However, it appears to be the primary of a wide binary system with a faint ($V \sim 13$) kinematic companion at about 27 arcsec (∼2,600 au) from the primary: the star UCAC4 (162-002805) has proper motions $(\mu_\alpha \cos\delta,\ \mu_\delta) = (8.6 \pm 2.5,\ -62.2 \pm 2.5)$ mas yr^{-1} (SPM4) and $(\mu_\alpha \cos\delta,\ \mu_\delta) = (5.8 \pm 2.8,\ -64.7 \pm 2.7)$ mas yr^{-1} (UCAC4).

A4 HD 20037

HD 20037 is clearly NGC 1252 13 in Bouchet (1984) but SIMBAD does not match their coordinates for unknown reasons. It is also known as CD-58 640. It is located 167^{+10}_{-9} pc from the Sun and has $(\mu_\alpha \cos\delta, \mu_\delta) = (10.03 \pm 0.28, 4.42 \pm 0.34)$ mas yr^{-1} (van Leeuwen 2007). Its SPM4 (1230000085) proper motions are $(\mu_\alpha \cos\delta, \mu_\delta) = (7.4 \pm 3.8, 2.1 \pm 3.0)$ mas yr^{-1}. The UCAC4 (162-002893) proper motions are $(\mu_\alpha \cos\delta,\ \mu_\delta) = (10.0 \pm 1.0,\ 4.4 \pm 1.0)$ mas yr^{-1}. With a spectral type of G8III, this foreground star is not related to NGC 1252 although it is the closest projected bright star to the cluster (see Fig. 1).

A5 NGC 1252 21

NGC 1252 21 has SPM4 (1230015481) proper motions $(\mu_\alpha \cos\delta,\ \mu_\delta) = (13.4 \pm 1.7,\ 7.1 \pm 1.6)$ mas yr^{-1}. Its UCAC4 (162-002824) proper motions are $(\mu_\alpha \cos\delta, \mu_\delta) = (15.9 \pm 1.2, 7.4 \pm 1.2)$ mas yr^{-1}. It was considered a probable member of NGC 1252 by Dias et al. (2006) with a membership probability of 62 per cent (the highest being 78 per cent). Our results indicate that it is a foreground star of almost solar metallicity located at a distance of 360 ± 40 pc from the Sun (see Table 2). Its kinematic properties and distance are compatible with those of TW Hor. The proper motions of this star match those attributed to NGC 1252 in Dias et al. (2006) and Zejda et al. (2012).

A6 CD-58 642

CD-58 642 is NGC 1252 11 in Bouchet (1984), a K0III star. It was also considered a probable member of NGC 1252 by Dias et al. (2006) with a membership probability of 62 per cent. However, our results suggest that it is another foreground star of solar metallicity located at a heliocentric distance of 380 ± 100 pc. Although its SPM4 (1230000671) proper motions are $(\mu_\alpha \cos\delta,\ \mu_\delta) = (17.4 \pm 1.5,\ 15.9 \pm 1.3)$ mas yr^{-1} and its UCAC4 (162-002816) proper motions are $(\mu_\alpha \cos\delta,\ \mu_\delta) = (17.4 \pm 0.9,\ 16.2 \pm 0.8)$ mas yr^{-1}, compatible with both TW Hor and NGC 1252 21, its radial velocity is very different, -7.1 ± 0.6 km s^{-1} but it may be a binary.

A7 NGC 1252 17

NGC 1252 17 has SPM4 (1230015463) proper motions $(\mu_\alpha \cos\delta,\ \mu_\delta) = (7.3 \pm 1.4, -17.5 \pm 1.3)$ mas yr^{-1} and UCAC4 (162-002812) proper motions $(\mu_\alpha \cos\delta,\ \mu_\delta) = (7.9 \pm 1.0,\ -8.4 \pm 1.1)$ mas yr^{-1}. Our results suggest that it belongs to the background Population II (see Table 2) and it is located 6000 ± 500 pc from the Sun with [Fe/H] = −1.15. Dias et al. (2006) gave a membership probability of 19 per cent for this object so it is unlikely related to the cluster for them too. With a radial velocity of 67.7 ± 0.5 km s^{-1} and non-negligible proper motions, the velocity of this metal poor, halo star may be close to the Galactic escape velocity. Following the procedure outlined at the end of Section 3, we derive the heliocentric reference frame velocity components *UVW*, which turn out to be $U = 305 \pm 55$ km s^{-1}, $V = -380 \pm 40$ km s^{-1} and $W = 239 \pm 33$ km s^{-1}. This yields a total velocity $V_T = 543$ km s^{-1}. Taking into account the values of the solar motion and the in-plane circular motion of the local standard of rest around the Galactic centre from Schönrich, Binney & Dehnen (2010), the Galactocentric velocity components are $U = -294 \pm 55$ km s^{-1} (U is now positive in the direction of the Sun), $V = -125 \pm 40$ km s^{-1} and $W = 246 \pm 33$ km s^{-1}. NGC 1252 17 is moving in a retrograde orbit around the centre of the Galaxy as it is likely a bound star because its current speed is below the local escape speed ($498 < v_{esc} < 608$ km s^{-1}; Smith et al. 2007). On the issue of the origin of this star, we can speculate that it was formed long ago in a globular cluster. Its radial velocity is well in excess of typical values of the globular cluster escape velocity. NGC 1252 17 may have been ejected during interactions with hard binaries at the cluster core, becoming a so-called cannonball star (Meylan et al. 1991).

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

NGC 1252. Details of the photometry described in the paper (http://mnras.oxfordjournals.org/lookup/suppl/doi:10.1093/mnras/stt996/-/DC1).

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