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The old metal-poor open cluster ESO 92-SC05: accreted from a dwarf galaxy?

S. Ortolani,[1★†] E. Bica[2★] and B. Barbuy[3★]

[1]*Università di Padova, Dipartimento di Astronomia, Vicolo dell'Osservatorio 2, I-35122 Padova, Italy*
[2]*Universidade Federal do Rio Grande do Sul, Dept de Astronomia, CP 15051, Porto Alegre 91500-970, Brazil*
[3]*Universidade de São Paulo, Rua do Matão 1226, 05508-900 São Paulo, Brazil*

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ABSTRACT

The study of old open clusters outside the solar circle can bring constraints on formation scenarios of the outer disc. In particular, accretion of dwarf galaxies has been proposed as a likely mechanism in the area. We use BVI photometry for determining fundamental parameters of the faint open cluster ESO 92-SC05. Colour–magnitude diagrams are compared with Padova isochrones, in order to derive age, reddening and distance. We derive a reddening $E(B-V) = 0.17$, and an old age of ∼6.0 Gyr. It is one of the rare open clusters known to be older than 5 Gyr. A metallicity of $Z \sim 0.004$ or $[\mathrm{M/H}] \sim -0.7$ is found. The rather low metallicity suggests that this cluster might be the result of an accretion episode of a dwarf galaxy.

Key words: Hertzsprung–Russell (HR) diagram – open clusters and associations: individual: ESO 92-SC05.

1 INTRODUCTION

The population of old Galactic open clusters was reviewed by Friel (1995), where it was pointed out the importance of studies of individual clusters to better understand stellar and dynamical evolution. New objects help constrain disc abundance gradients, the chemical enrichment and mixing in the disc, and age–metallicity relation.

Dias et al. (2002)[1] reported 1537 open clusters of all ages as well as additional open cluster candidates. Both the Dias et al. study and the WEBDA (Web Base de Donees d'Amas) data base (Mermilliod 1996)[2] have compiled the basic parameters of known clusters from the literature. Janes & Phelps (1994) and Friel (1995) have defined old open clusters as those with ages older than the Hyades (∼700 Myr). Such objects are sometimes referred to as intermediate age clusters. A total of 108 confirmed old open clusters were reported in Ortolani, Bica & Barbuy (2005b), where the age distribution of open clusters was analysed.

Janes & Phelps (1994) analysed a sample of 72 old open clusters showing evidence that the Galactic disc might have been constantly disturbed by infalling material. More recently, Frinchaboy et al. (2004) suggested that the part of the outer old open clusters might have formed in an accreted dwarf galaxy. Finally, Rocha-Pinto et al. (2006) find evidence of a disrupted accreted dwarf galaxy called Argo. Bonatto et al. (2006) have shown that open clusters older than 1 Gyr in their sample reach heights up to $Z_{\mathrm{GC}} = 350$ pc. Disc heating could be efficient for thickening the disc in terms of field stars, but it is not established how old open clusters might acquire vertical velocity for such heights.

In this work, we study the open cluster ESO 92-SC05 located in the fourth quadrant, that presents an unusually low metallicity and an old age. The cluster ESO 92-SC05 was discovered in the ESO blue plates (Lauberts 1982 and references therein). It has coordinates J2000.0 $\alpha = 10^{\mathrm{h}}\,03^{\mathrm{m}}\,14^{\mathrm{s}}$ and $\delta = -64^\circ 45' 12''$ ($l = 286\overset{\circ}{.}19$, $b = -7\overset{\circ}{.}50$). In the cluster direction, Schlegel, Finkenbeiner & Davis (1998) give a reddening $E(B-V) = 0.20$.

In Section 2, the observations are described. In Section 3, the colour–magnitude diagrams (CMD) are presented. In Section 4, we derive cluster parameters and discuss possibilities for the origin of such an old and metal-poor star cluster. Concluding remarks are given in Section 5.

2 OBSERVATIONS AND REDUCTIONS

ESO 92-SC05 was observed on 2000 March 5 with the 1.54-m Danish telescope at ESO (La Silla). A Loral/Lesser CCD detector C1W7 with 2052 × 2052 pixel, of pixel size 15 μm was used. It corresponds to 0.39 arcsec on the sky, providing a full field of 13 × 13 arcmin^2. The log of observations is reported in Table 1. Fig. 1 shows a 15 min V exposure of ESO 92-SC05 for a field extraction of 6.5 × 6.5 arcmin^2 (1000 × 1000 pixel). The image suggests a core concentration of stars surrounded by a halo of fainter

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★E-mail: sergio.ortolani@unipd.it (SO); bica@if.ufrgs.br (EB); barbuy@astro.iag.usp.br (BB)

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

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

Table 1. Log of observations.

Target	Filter	Exp.	Seeing (arcsec)
ESO 92-SC05	*V*	60	1.25
	V	900	1.25
	B	60	1.25
	B	1800	1.25
	I	40	1.25
	I	600	1.25

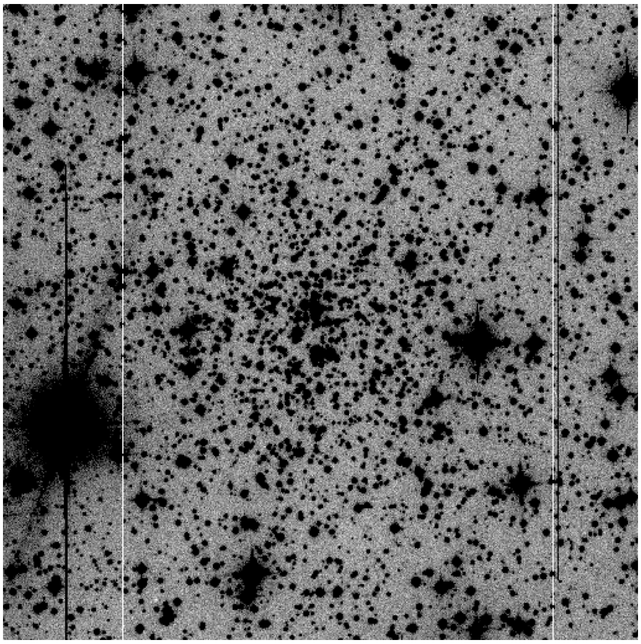

Figure 1. *V* image (15 min) of ESO 92-SC05. The field extraction size is 6.3 × 6.3 arcmin^2. North is up and east to the left.

stars. DAOPHOT II (Stetson 1992 and references therein) was used to extract the instrumental magnitudes. For calibrations, we used Landolt (1983, 1992) standard stars.

The calibration equations are

$$V = 26.46 + 0.01\ (B - V) + v,$$

$$B = 26.40 + 0.1\ (B - V) + b,$$

$$I = 24.61 - 0.01\ (V - I) + v,$$

for 10, 15 and 5 s in *B*, *V*, and *I*, respectively, at 1.1 airmasses. The cluster was observed at an airmass of 1.25. The errors in the zero-point calibration are dominated by the crowding in the transfer from aperture to convolved magnitudes, of about ±0.03 mag in each colour. The CCD shutter time uncertainty (0.3 s) gives an additional 3 per cent error. The magnitude zero-point uncertainty is around ±0.05. In Figs 2(a)–(c), the error distribution plots for the *B*, *V* and *I* photometry are shown . These figures show the standard errors, derived on the basis of statistical poissonian noise produced by DAOPHOT. For the atmospheric extinction, we applied the La Silla coefficients.[3]

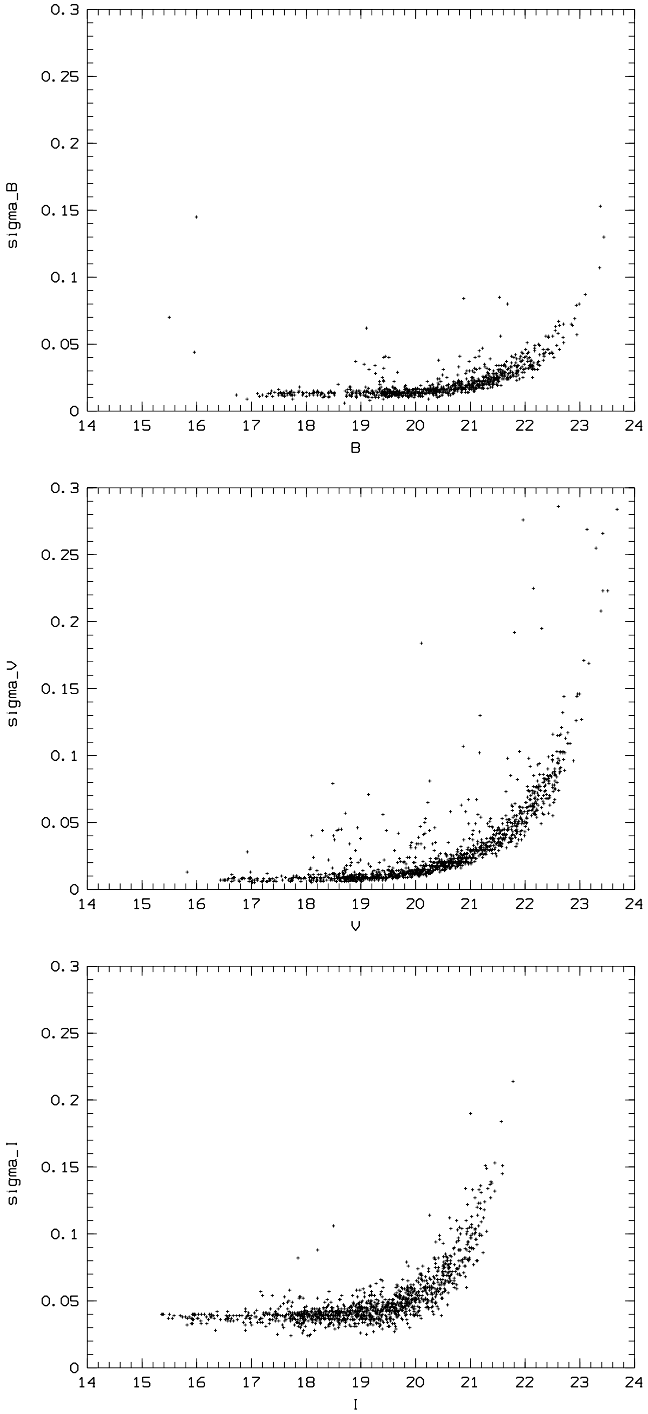

Figure 2. Error distribution plots for the *B*, *V* and *I* photometry.

3 COLOUR–MAGNITUDE DIAGRAMS

In Figs 3(a) and (b), the *V* versus $B - V$ and *V* versus $V - I$ CMDs of ESO 92-SC05 are shown for an extraction of $r < 300$ pixel ($r < 117$ arcsec).

A well-populated old turn-off (TO) is evident, as well as a clump also suggesting an old age, and possibility of a few blue stragglers. The red giant branch (RGB) is steep indicating a low metallicity. The shape of the TO and subgiant branch (SGB) suggest an intermediate or low metallicity.

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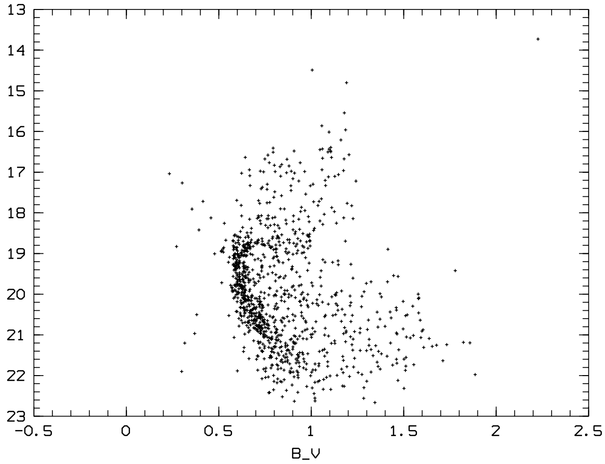
[3] http://www.ls.eso.org/lasilla/atm-ext/



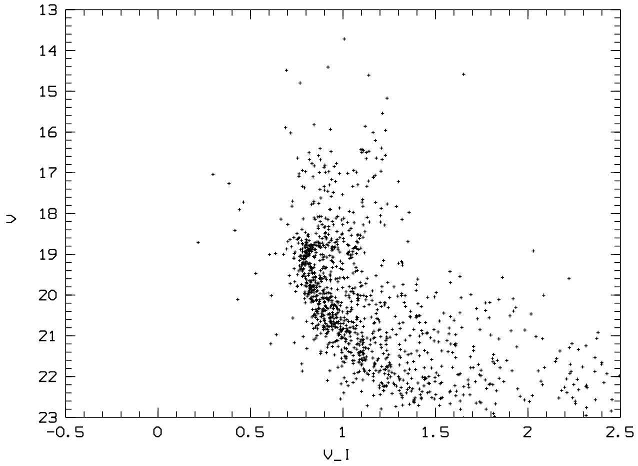


Figure 3. ESO 92-SC05: (a) V versus $B-V$; (b) V versus $V-I$ CMDs for an extraction of $r < 300$ pixel ($r < 117$ arcsec).

The clump is located at $V = 16.45$ and $B - V = 1.13$ (or $V - I = 1.18$). From the luminosity difference between the main-sequence TO at $V \approx 19.1$ and the clump, an age range between 5.0 and 6.3 Gyr is inferred by comparison with Padova isochrones (Girardi et al. 2000). The CMDs show sequences specially well defined at the level of the TO and SGB, despite the presence of field contamination. The V versus $V-I$ CMD is deeper.

4 CLUSTER PARAMETERS

Padova isochrones from Bertelli et al. (1994) and Girardi et al. (1996, 2000)[4] were used to derive cluster parameters, by fitting them simultaneously on the B, V and V, I diagrams. We adopted the relation $E(V-I) = 1.33E(B-V)$ (Dean, Warren & Cousins 1978).

Figs 4(a) and (b) show the V versus $B-V$ and V versus $V-I$ CMDs best fit with Padova isochrones of age = 6.3 Gyr and metallicity $Z = 0.004$ ([M/H] ~ -0.7). Reddening values in the range $E(B-V) = 0.17$–0.19 are acceptable from the B, V and V, I diagrams.

This result appears to be robust, as a result of a series of fits with isochrones in the age and metallicity ranges of $6.3 < t(\mathrm{Gyr}) < 5, 0.004 < Z < 0.0004$ and reddening values $0.30 < E(B-V) < 0.10$.

Note in Fig. 4(a) that the colour of the RGB clump appears redder than the isochrone, whereas the luminosity level does correspond to the isochrone. We consider that the fit in luminosity is a more reliable reference because the luminosity transformations are much more accurate than the temperature–colour transformations. The colour displacement of the RGB clump, of the order of 0.05–0.07 mag in $B-V$, is compatible with the transformation errors from theoretical to observed planes, which is a problem inherent to the presently available isochrone calculations, due to still missing opacities in the treatment of cool stars atmospheres.

From our comparisons, we concluded that, first we cannot obtain a fit for the same metallicity and a younger age because, even if the RGB colour would be closer, the luminosity of the clump, in the case of 5 Gyr, would be off by 0.2 mag in V. Secondly, by increasing the metallicity, where a closest set to our previous fit is obtained with solar metallicity (versus our $Z = 0.004$) and 5 Gyr, it reduces the discrepancy in V, but there is still a 0.15 mag discrepancy, while the colour of the RGB clump gets a good fit. In this case, the isochrones are, however, considerably redder and the colour excess (reddening) drops to zero or to slightly negative values. Furthermore, the two colours ($V-I$ and $B-V$) would give a different reddening, with $E(V-I) = 0.15$ and the whole V, I diagram is considerably off. Clearly, only a lower metallicity is suitable.

As concerns α-enhancement derived for metal-poor open clusters (e.g. Carraro et al. 2007), we found that there is no need for trying to fit α-enhanced isochrones, given that Salaris, Chieffi & Straniero (1993) showed that the α-enhancement effect on the isochrones is equivalent to metallicity-scaled isochrones. It is important to stress that the Salaris et al. results are valid for low metallicities, and fail at high ones (near-solar and above), as found by Salaris & Weiss (1998) and Salasnich et al. (2000). For [Fe/H] < -0.5, in principle solar-scaled isochrones can be safely used.

In Fig. 5, the reddening $E(B-V)$ is plotted against metallicity Z for different ages, derived from the isochrone set used. The line corresponding to the reddening of ESO 92-SC05 indicates a metallicity $Z = 0.0035 \pm 0.001$ or [M/H] ≈ -0.7. Chen, Hou & Wang (2003) presented a histogram of metallicities for 118 open clusters for which ages and metallicities are available. Typical metal-poor open clusters show [Fe/H] ≈ -0.4 (e.g. Gratton & Contarini

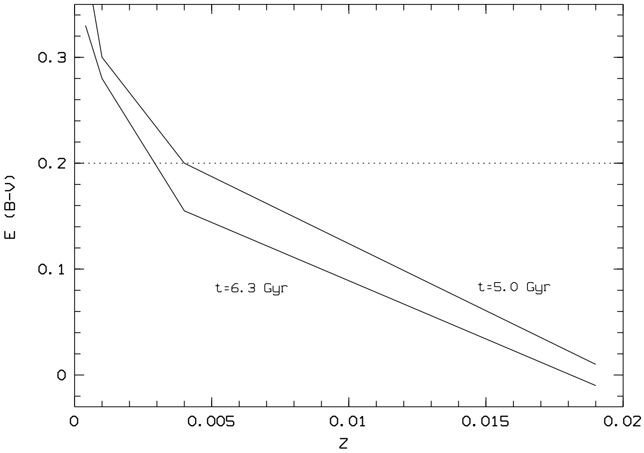


Figure 5. Reddening $E(B-V)$ versus metallicity Z for different ages. The dotted line corresponds to the reddening of ESO 92-SC05, from Schlegel et al. (1998).

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[4] http://pleiadi.pd.astro.it

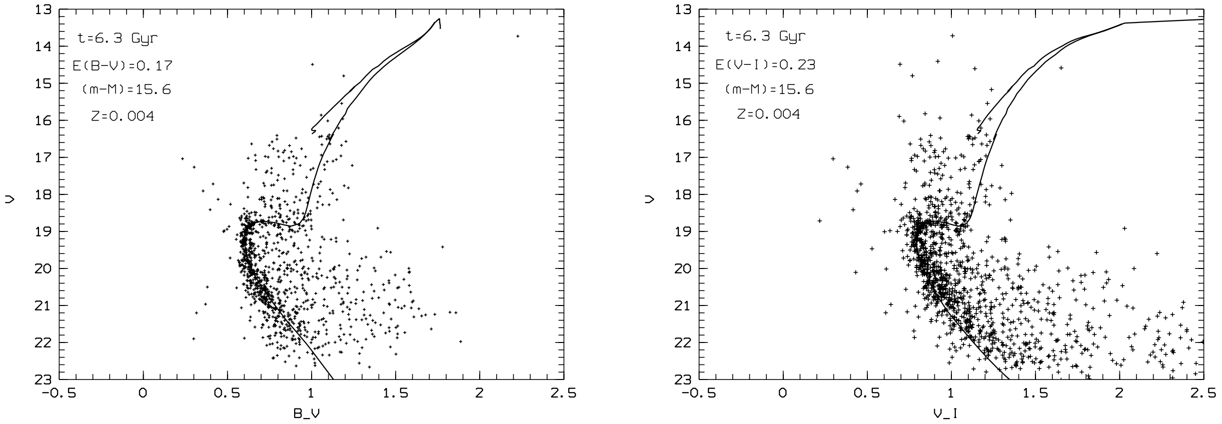

Figure 4. ESO 92-SC05: (a) V versus $(B-V)$; (b) V versus $(V-I)$ for the same extraction of Figs 3(a) and (b), with Padova isochrones for age = 6.3 Gyr and metallicity $Z = 0.004$ ([M/H] ~ -0.7) overplotted.

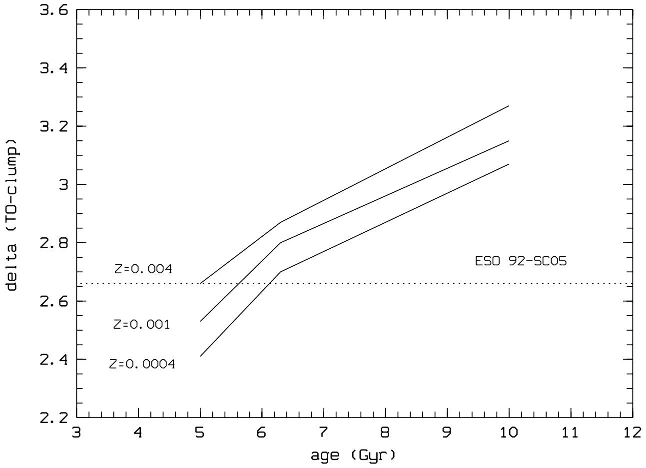

Figure 6. Magnitude difference between TO and clump ΔV (TO-clump) versus age (Gyr) for different metallicities Z. The dotted line corresponds to the ΔV (TO-clump) value of ESO 92-SC05.

Table 2. Parameters of ESO 92-SC05.

Parameters	Values
Age (Gyr)	6.0 ± 1.0
[M/H]	-0.7 ± 0.2
$(m-M)_V$	15.71 ± 0.1
$E(B-V)$	0.17 ± 0.04
A_V	0.53 ± 0.15
$(m-M)_o$	15.18 ± 0.2
$d_\odot$	10.9 ± 1.0 kpc
R_{GC}	11.4 ± 1.0 kpc
X_{GC}	4.5 ± 0.4 kpc
Y_{GC}	-10.4 ± 1.0 kpc
Z_{GC}	1.4 ± 0.2 kpc

1994), while ESO 92-SC05 is more metal-poor. Chen et al.'s fig. 4 showing the metallicity histogram indicates that open clusters with [Fe/H] < -0.5 are extremely rare. Fig. 6 shows the magnitude difference between TO and clump ΔV (TO-clump) versus age (Gyr) for different metallicities Z. The dotted line with the ΔV (TO-clump) = 2.65 value of ESO 92-SC05, indicates that its age is 5.6 ± 1.0 Gyr.

The adopted cluster parameters are given in Table 2. Until recently, the adopted distance of the Sun to the Galactic Centre was $R_{GC} = 8.0$ kpc, as reviewed by Reid (1993). Various methods have given smaller values. Eisenhauer et al. (2005) derived $R_{GC} = 7.6 \pm 0.3R$ kpc, Nishiyama et al. (2006) found $R_{GC} = 7.5 \pm 0.35$ kpc and Bica et al. (2006) found $R_{GC} = 7.2 \pm 0.3$ kpc. On the other hand, Groenewegen, Udalski & Bono (2008) obtained a longer distance ($R_{GC} = 7.94 \pm 0.37$ kpc). Recently, Nikiforov (2008) has shown that the galactocentric distance from solving for the stellar orbit around Sgr A is not as precise so far, due to systematic errors. As a compromise value, we adopt $R_{GC} = 7.5$ kpc. The Galactocentric coordinates are shown in Table 2. For $R_{GC} = 8$ kpc the results are similar.

In a CMD of the total field of ESO 92-SC05, we counted 10–15 clump stars, depending on contamination. M67 has approximately five clump stars and estimated to have 724 $M_\odot$ (Montgomery, Marschall & Janes 1993). Fan et al. (1967) found six clump stars in M67 that were kinematically selected members. They derived a total cluster mass of $M = 1270\,M_\odot$ (stars with masses larger than $0.5\,M_\odot$) for $R < 66.6(15.2\,\mathrm{pc})$. Within a comparable spatial radius ESO 92SC-05 has eight clump stars leading to a total mass $M \approx 1700\,M_\odot$. From the ratio of clump stars, we estimate a mass of $1800 \pm 400\,M_\odot$ for ESO 92-SC05. Thus, we are dealing with a massive open cluster in the outer disc.

4.1 Age distribution of old open clusters

Compilations of old open clusters are bringing progressively new objects (e.g. Frinchaboy & Phelps 2002) and a clearer picture of their spatial, age and metallicity distributions (Friel 1995; Dutra & Bica 2000; Ortolani et al. 2005b). Currently, in Dias et al. (2002) catalogue 188 open clusters are reported to be older than 700 Myr. Relative to Ortolani, Bica & Barbuy (2005a) the sample increased by about 80 per cent. In Fig. 7, we show the histogram of the 188 old open clusters presently known and now including ESO 92-SC05. It is clear from this figure that ESO 92-SC05 is among a dozen open clusters older than 6 Gyr so far known in the Galaxy.

Open clusters in general may be dissolved in a typical time-scale of 600 Myr (Bergond, Leon & Guibert 2001), whereas for massive clusters ($m \sim 10^4\,M_\odot$), the time-scale for disruption is estimated to be 2 Gyr (Gieles et al. 2006). This is compatible with the histogram,

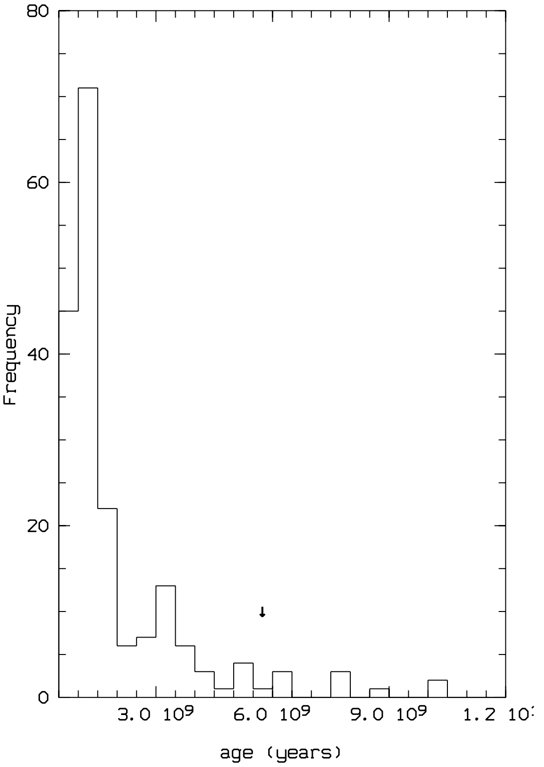

Figure 7. Age histogram for old open clusters based on Dias et al. (2002) catalogue. The arrow indicates the age bin of ESO 92-SC05.

indicating that the older clusters probably are a surviving population of initially massive clusters.

5 CONCLUSIONS

We present BVI photometry of the star cluster ESO 92-SC05. A reddening $E(B-V) = 0.17$ and a distance from the Sun $d_{\odot} = 10.9$ kpc are found. ESO 92-SC05 is one of the few distant, old open clusters studied in detail in the fourth quadrant, along with Saurer 3, ESO 92-SC18, ESO 93-SC08 and BH 144 (Dias et al. 2002).

The old age of 6.0 Gyr for ESO 92-SC05 includes it in the sample of rare Galactic open clusters known to be older than 5 Gyr (Ortolani et al. 2005a,b; see also the catalogue by Dias et al. 2002).

A low metallicity of [M/H] ~ -0.7 is found for ESO 92-SC05. Assuming the metallicity gradient of -0.06 dex kpc^{-1} over the Galactocentric distances of 7–16 kpc derived by Friel et al. (2002), and confirmed by Salaris, Weiss & Percival (2004), we get an expected value [M/H] ~ -0.34 at the distance of 11 kpc. ESO 92-SC05 is thus of lower metallicity. It appears to be among the most metal-poor open clusters in the Galaxy (Friel et al. 2002; Chen et al. 2003).

The origin of this cluster is an interesting issue. The distance from the plane of $Z_{\rm GC} = 1.4$ kpc is high. Is it a member of the outer disc that could be thick or captured from an infalling dwarf galaxy (Frinchaboy et al. 2004; Yong, Carney & Teixeira de Almeida 2005; Rocha-Pinto et al. 2006). ESO 92-SC05 shows characteristics similar to Berkeley 29 and Saurer 1, which were considered to be possible accretion products from the Galactic Anticenter Stellar Strucure (GASS) by Frinchaboy et al. (2006). In fact, ESO 92-SC05's location at (l = $286^{\circ}\!.2$, $b = -7^{\circ}\!.5$) is rather far from the proposed direction ($l = 240^{\circ}$, $b = -8^{\circ}$) and extent of the accreted dwarf galaxy Canis Major (Martin et al. 2004). Moreover, Canis Major has been argued to be part of the Galactic warp (Momany et al. 2006). On the other hand, ESO 92-SC05 projection in Carina and its distance (Table 2) match the Argo–Navis structure (Rocha-Pinto et al. 2006). Finally, ESO 92-SC05 matches the fourth quadrant extensions of GASS. It fits quite well not only spatially but also in the age–metallicity relation, occupying the lower envelope of the distribution (Frinchaboy et al. 2004).

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