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# The intermediate-age open cluster NGC 2112

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## ABSTRACT

We report on *BVI* charge-coupled device photometry of a field centred on the region of the intermediate-age open cluster NGC 2112 down to  $V = 21$ . Owing to the smaller field coverage, we are able to limit the effect of field star contamination that, in the past, hampered precise determinations of the cluster age and distance. In this way, we provide updated estimates of the fundamental parameters for NGC 2112. Having extended the photometry to the *I* pass-band, we are able to construct a colour–colour diagram, from which we infer a reddening  $E(B - V) = 0.63 \pm 0.14$  mag. The comparison of the colour–magnitude diagram with theoretical isochrones leads to a distance of  $850 \pm 100$  pc and an age of  $2.0 \pm 0.3$  Gyr. While the distance is in agreement with previous determinations, the age turns out to be much better constrained and significantly lower than previous estimates.

**Key words:** Hertzsprung–Russell (HR) diagram – open clusters and associations: general – open clusters and associations: individual: NGC 2112.

## 1 INTRODUCTION

NGC 2112 (Collinder 76, C 0551-0031, OCL 509) is a northern open cluster of intermediate age, located relatively far from the Galactic plane toward the anticentre direction ( $\alpha = 05^{\text{h}}53^{\text{m}}.9$ ,  $\delta = +00^{\circ}23'$ ,  $l = 205^{\circ}91$ ,  $b = -12^{\circ}59$ , J2000). It is classified as a II2m open cluster by Trumpler (1930), and has a diameter of about 18 arcmin, according to Lyngå (1987). It is quite a poorly studied object, but is rather interesting owing to its position in the disc and to its combination of suspected old age and low metal abundance, which would make it a noteworthy object to study within the framework of the chemical evolution of the Galactic disc (Carraro, Ng & Portinari 1998). Moreover, it remained unstudied for a long time owing mainly, we guess, to the high contamination of field stars in its direction, which prevented precise estimates of its age and distance (Richtler & Kaluzny 1989).

For these reasons, we decided to undertake a multicolour charge-coupled device (CCD) study of the cluster, as presented in the present paper, which is the fourth of a series dedicated to improving the photometry of northern intermediate-age open clusters at the Asiago Observatory. We already reported elsewhere on NGC 1245 (Carraro & Patat 1994), on NGC 7762 (Patat & Carraro 1995) and on NGC 2158 (Carraro, Girardi & Marigo 2002).

The plan of the paper is as follows. In Section 2 we summarize the previous studies on NGC 2112, while Section 3 illustrates the observation and reduction strategies. The analysis of the colour–magnitude diagram (CMD) is performed in Section 4, whereas

Section 5 deals with the determination of cluster reddening, distance and age. Section 6 is dedicated to discussing the properties of the cluster in the context of the chemical evolution of the Galactic disc. Section 7 is devoted to analysing the geometrical structure and star counts and, finally, Section 8 summarizes our findings.

## 2 PREVIOUS INVESTIGATIONS

NGC 2112 has been studied previously. The first investigation was carried out by Richtler (1985), who obtained photographic *BV* photometry for about 80 stars down to  $V = 15$ . Although he was not able to reach the cluster Turn Off (TO), he nevertheless drew attention to this probably old neglected cluster, and suggested that NGC 2112 had a reddening of about 0.5 mag, and was about 800 pc far from the Sun. By analysing additional Strömgen photometry, Richtler suggested that the cluster had to be very metal poor ( $[\text{Fe}/\text{H}] \approx -1$ ).

A more accurate and deeper analysis was performed by Richtler & Kaluzny (1989). They obtained *BV* CCD photometry for about 500 stars in a field of 200 arcmin<sup>2</sup>. Additionally, they obtained moderate resolution spectra for a handful of bright stars. Their conclusions were that the cluster was very contaminated by field stars. Nevertheless, they were able to strengthen the suggestions of Richtler (1985) by claiming that the cluster was 3–5 Gyr old, 700–800 pc far from the Sun and had a reddening of  $E(B - V) = 0.60$  mag. As for the metal abundance, they could not conclude anything, since they were not able to separate probable cluster members from non-members.

The Washington photometry reported by Geisler (1987) and Geisler, Clarià & Minniti (1991) apparently corroborated the previous suggestions that NGC 2112 was very metal poor ( $[\text{Fe}/\text{H}] \approx -1.3$ ), but this finding hardly reconciled with the age inferred by

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the previous photometries in the conventional frame of the Galactic disc evolution (Richtler & Kaluzny 1989). Only recently, however, the metal abundance of NGC 2112 was derived by means of high-resolution spectroscopy by Brown et al. (1996). They were able to select a few cluster members on the basis of radial velocity, providing in the end a much higher metal content value  $[Fe/H] = -0.15$ , only slightly lower than the solar one. These authors emphasized that the previous lower metallicity estimates were a result of the difficulty in separating cluster members and to the uncertainties in the reddening estimate. The metallicity they obtained was, however, based on only one certain member and two probable members. Clearly, as the same authors stressed, an astrometric study is urgent for this cluster in order to infer a more reliable abundance measurement.

To summarize the present situation regarding the cluster basic parameters, we note that:

- (i) as for the distance, Richtler (1985) and Richtler & Kaluzny (1989) report *preliminary* and *of the order of* estimates, respectively;
- (ii) according to Richtler (1985), the cluster is simply *very old*, whereas Richtler & Kaluzny (1989) suggest an age between 3 and 5 Gyr.
- (iii) reddening determinations are reported as indications only;
- (iv) as far as the metallicity is concerned, one might rely on the modern result of Brown et al. (1996), but we shall devote some discussion to the possibility of this cluster also being very metal poor.

In conclusion, NGC 2112 has the reputation of being a severely contaminated open cluster for which some of the fundamental parameters have proved very difficult to estimate. For these reasons we thought it worthwhile to carry out a new photometric study of this cluster.

### 3 OBSERVATIONS AND DATA REDUCTION

Observations of NGC 2112 were carried out with the AFOSC camera at the 1.82-m telescope of Cima Ekar (Asiago, Italy), on the night of 2001 November 14. AFOSC samples a  $8.14 \times 8.14$  arcmin<sup>2</sup> field in a  $1K \times 1K$  thinned CCD. The typical seeing was around 2.0 arcsec. Additionally, we provide *V* photometry of a field 10 arcmin eastward of the cluster to derive field star counts.

We also observed the Landolt (1992) standard star fields PG 1047+003, SA 93 and PG 2331+055. The details of the observations are listed in Table 1, where the observed fields, together with exposure times, seeing and airmasses are reported.

A DSS<sup>1</sup> map of the observed region is shown in Fig. 1.

The data have been reduced by using the IRAF<sup>2</sup> packages CCDRED, DAOPHOT and PHOTCAL. The calibration equations obtained are:

$$b = B + 1.407 \pm 0.022 + (0.004 \pm 0.029)(B - V) + 0.30X$$

$$v = V + 0.752 \pm 0.009 + (0.036 \pm 0.012)(B - V) + 0.18X$$

$$i = I + 1.619 \pm 0.048 + (0.011 \pm 0.052)(V - I) + 0.08X,$$

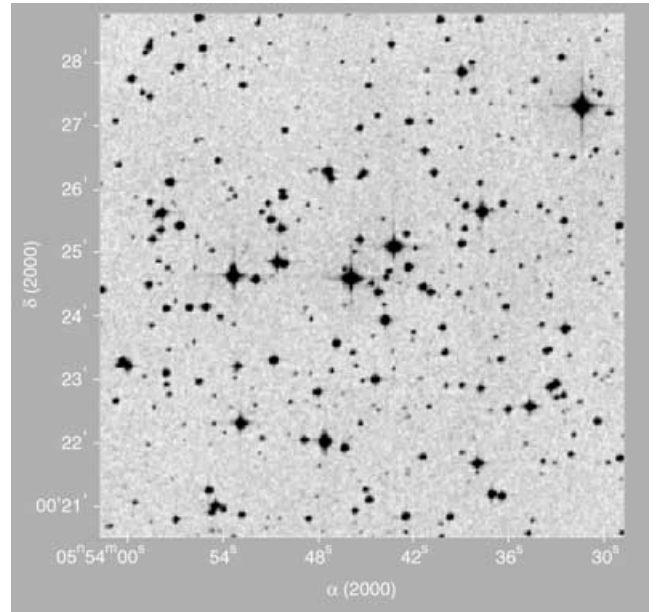
where *BVI* are standard magnitudes, *bvi* are the instrumental magnitudes and *X* is the airmass. The standard stars in these fields provided a very good colour coverage. For the extinction coefficients,

<sup>1</sup> Digitized Sky Survey, <http://www.eso.org/dss/dss>

<sup>2</sup> IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

**Table 1.** Journal of the observations of NGC 2112 and Landolt fields (2001 November 14).

Field	Filter	Integration time (s)	Seeing (arcsec)	Airmass
PG 1047+003	<i>B</i>	60, 60	2.0	1.440
	<i>V</i>	30, 30	2.1	1.450
	<i>I</i>	30, 30	1.8	1.438
NGC 2112	<i>B</i>	60, 600	2.0	1.438
	<i>V</i>	5, 15, 30, 30, 300	1.9	1.453
	<i>I</i>	2, 300	2.3	1.445
PG 2331+055	<i>B</i>	120, 120	2.0	1.308
	<i>V</i>	30, 30, 60, 60	2.1	1.307
	<i>I</i>	30, 30, 30	1.9	1.307
SA 93	<i>B</i>	60, 60	2.1	1.514
	<i>V</i>	30, 30, 30	2.0	1.500
	<i>I</i>	30, 30	2.1	1.497



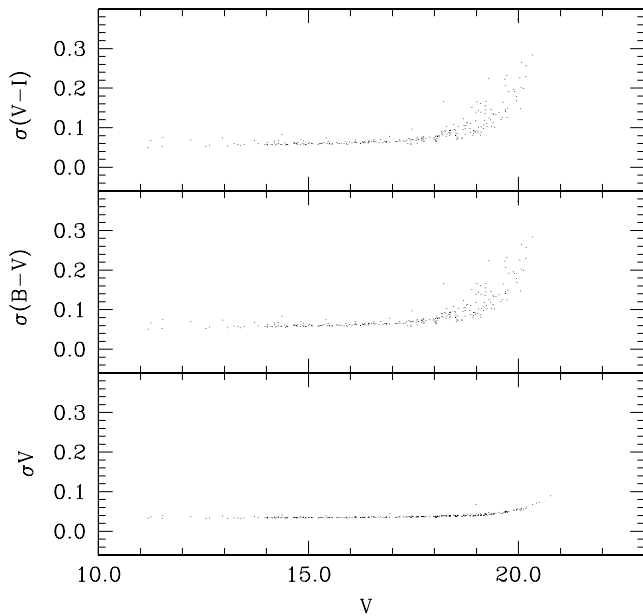
**Figure 1.** A DSS image of a region around NGC 2112 covered by the present study. North is up and east is on the left.

we assumed the typical values for the Asiago Observatory. The error affecting these coefficients is 0.03 (Desidera, Fantinel & Giro 2001).

Finally, Fig. 2 presents the run of photometric errors as a function of magnitude. These errors take into account fitting errors from DAOPHOT and calibration errors, and have been computed following Patat & Carraro (2001). It can be noticed that stars brighter than  $V \approx 20$  mag have photometric errors lower than 0.1 mag in magnitude and lower than 0.2 mag in colour. The final photometric data are available in electronic form at the WEBDA<sup>3</sup> site.

We compared our photometry with the CCD one from Richtler & Kaluzny (1989), finding a nice agreement. In fact, from the 53 stars

<sup>3</sup> <http://obswww.unige.ch/webda/navigation.html>



**Figure 2.** Photometric errors as a function of magnitude for our NGC 2112 observations.

in common brighter than  $V \approx 16.5$  mag, we obtain the following mean differences:

$$V_{\text{CBB}} - V_{\text{RK}} = -0.028 \pm 0.067(\text{s.e.})$$

$$(B - V)_{\text{CBB}} - (B - V)_{\text{RK}} = 0.034 \pm 0.047(\text{s.e.}),$$

where the subscript CBB refers to this study, whereas the subscript RK refers to the photometry of Richtler & Kaluzny (1989).

#### 4 THE COLOUR-MAGNITUDE DIAGRAMS

A comparison of our photometry with past analyses is shown in Fig. 3, from which it is evident that the present study supersedes the

previous ones. Richtler (1985) photometry (panel a) does not reach the TO, whereas the photometry of Richtler & Kaluzny (1989), panel (b), has:

(i) photometric errors amounting to  $\Delta V = 0.1$  and  $\Delta(B - V) = 0.15$  already at  $V \approx 18.0$  (see their figs 4a and b);

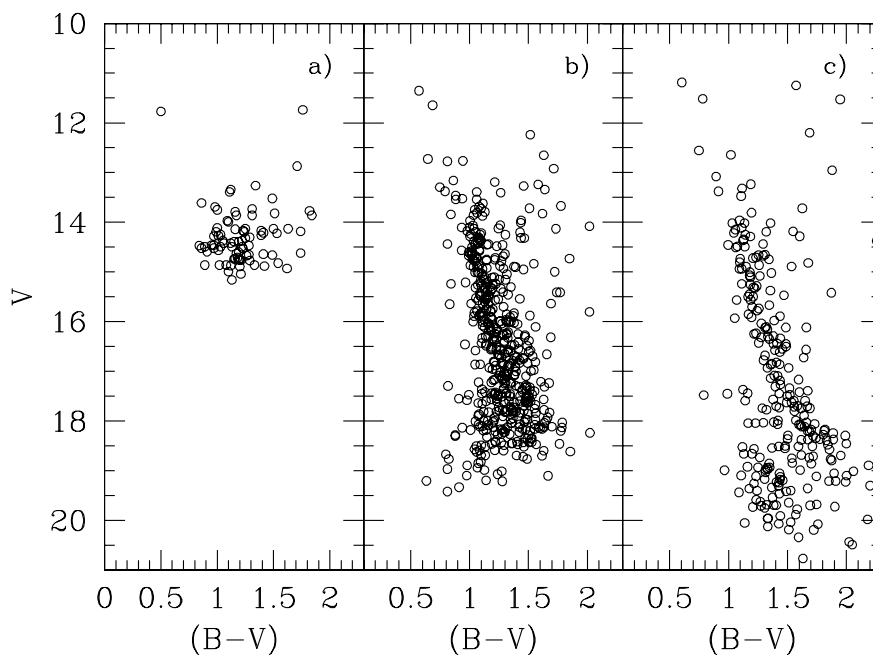
(ii) covers a very large region of the sky, enhancing the effect of the field star contamination in this way.

This is mostly evident by considering the width of the MS, which in our case (panel c) is much narrower. By inspecting these CMDs, we find that the TO is located at  $V \approx 14.5$  mag,  $(B - V) \approx 1.0$  mag and the MS is clearly visible down to  $V = 19$  mag. A binary sequence is evident on the right of the MS in both Richtler & Kaluzny (1989) and our photometry. The evolved region of the CMD is poorly populated. This is not surprising, since the cluster is not very populous. Probably this fact is the most effective one in hampering a precise age estimate. Nevertheless, the subgiant branch is sufficiently clear, and probably there are three to four stars in the red giant branch (RGB), among which are some of those used by Brown et al. (1996) to estimate the metallicity of NGC 2112. Apparently, no RGB clump stars are present.

All the blue stars above the cluster TO might be field stars located between us and the cluster, or blue straggler stars, which we know to be present in many intermediate-age open clusters (Mermilliod 1982). The field star contamination is very evident in panel (b), where the MS starts widening significantly already at  $V = 17$  mag, where the photometric errors are less than 0.1 mag (see above) and the TO region is much more contaminated by interlopers. In our photometry (panel c) the field contamination is less severe owing to the smaller field coverage. Clearly, the bulk of stars leftwards of the MS below  $V \approx 19.0$  mag are field stars.

#### 5 CLUSTER FUNDAMENTAL PARAMETERS

As we mentioned in Section 2, the fundamental parameters of NGC 2112 (age, distance, metallicity and reddening) are still poorly known (see Table 2). The cluster age estimates range from the



**Figure 3.**  $BV$  CMDs of NGC 2112. (a) Richtler (1985) photometry; (b) Richtler & Kaluzny (1989) photometry; (c) the photometry presented in this study.

**Table 2.** NGC 2112 fundamental parameters taken from the literature.

	Richtler (1985)	Richtler & Kaluzny (1989)	Geisler (1987)	Brown et al. (1996)
$E(B - V)$	0.50	0.60		0.60
$(m - M)$	9.2	9.2–9.4		
Distance (pc)	700	700–800		
Age (Gyr)	Very old	3–5		
[Fe/H]	−1.0	−1.0	−1.3	−0.15

simple statement that the cluster is very old to 3–5 Gyr, the distance from 700 to 800 pc and the reddening  $E(B - V)$  from 0.5 to 0.6 mag. None of these previously reported estimates has an error bar and we take them as first guesses only. In the next sections we are going to derive updated estimates for them.

### 5.1 Reddening

In order to obtain an estimate of the cluster mean reddening, we analyse the distribution of the MS stars with  $V < 18$  in the  $(B - I)$  versus  $(B - V)$  plane, which is shown in Fig. 4.

The linear fit to the main sequence in the  $(B - I)$  versus  $(B - V)$  plane,

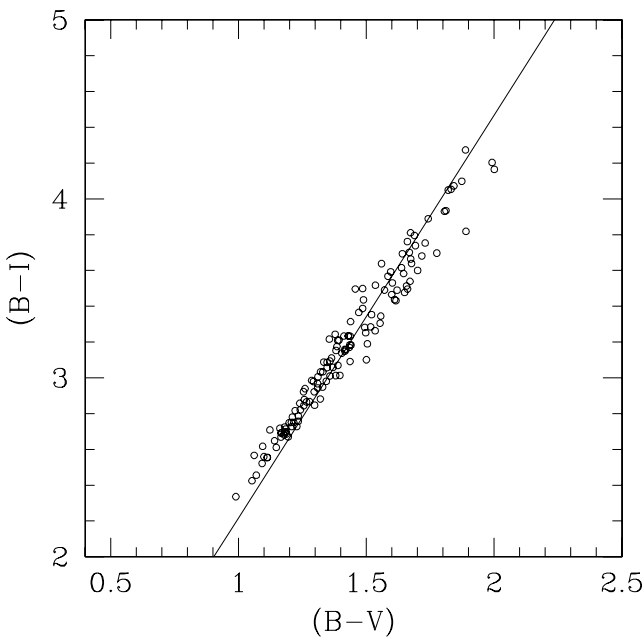
$$(B - I) = Q + 2.25 \times (B - V) \quad (1)$$

can be expressed in terms of  $E(B - V)$ , for the  $R_V = 3.1$  extinction law, as

$$E(B - V) = \frac{Q - 0.014}{0.159}, \quad (2)$$

following the method proposed by Munari & Carraro (1996).

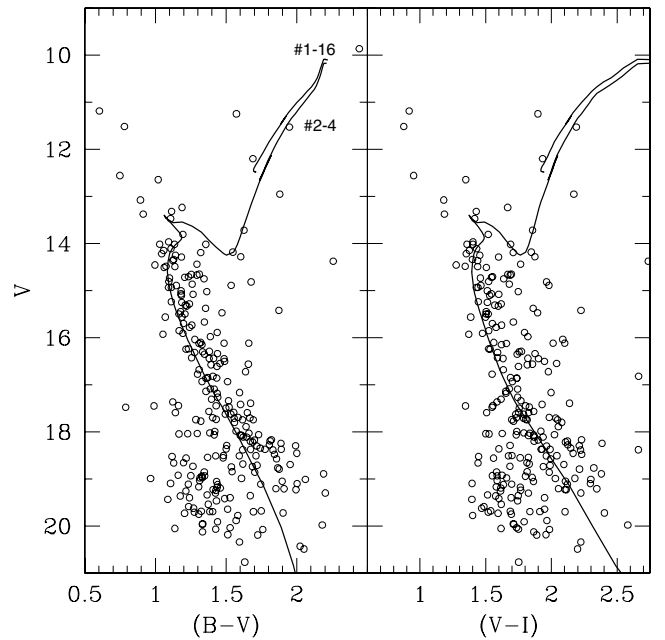
This method provides an estimate of the mean reddening and, as amply discussed in Munari & Carraro (1996), can be used only for certain colour ranges. In particular, equation (2) holds over the range  $-0.23 \leq (B - V)_0 \leq +1.30$ . MS stars have been selected by considering all the stars having  $15 \leq V \leq 18$  and  $0.9 \leq (B - V) \leq 1.7$ . A least-squares fit through all of these stars gives  $Q = 0.115$ , which, inserted in equation (2), provides  $E(B - V) = 0.63 \pm 0.14$  mag. The

**Figure 4.** NGC 2112 MS stars in the  $(B - V)$  versus  $(B - I)$  plane.

uncertainty is rather large, and is a result of the scatter of the stars in this plane, which indicates the presence of stars with different reddening, presumably a mixture of stars belonging to the cluster and to the field. Besides, also some differential reddening cannot be ruled out, as was proposed in past photometries, owing to the location of the cluster, in the eastern part of Orion, engulfed in the Barnard's loop H II region (SH2-276, Sharpless 1959).

### 5.2 Distance and age

As already mentioned, there is a considerable uncertainty in the literature among different estimates of NGC 2112 distance and age, as shown by the data reported in Table 2. We have derived new estimates for these parameters as follows. First of all we have generated isochrones from Girardi et al. (2000) by adopting the abundance determination by Brown et al. (1996). The value  $[\text{Fe}/\text{H}] = -0.15$  converts into the theoretical overall metallicity  $Z = 0.012$ . Then, we have estimated the cluster age and distance simultaneously by assuming that the reddening is that estimated in the previous section:  $E(B - V) = 0.63$  mag. The results are shown in Fig. 5. Here we consider the distribution of the stars in the  $V$  versus  $(B - V)$  plane (left-hand panel) and in the  $V$  versus  $(V - I)$  (right-hand panel). Overimposed in both diagrams is a 2.0-Gyr isochrone, which turns out to provide the best fit of the overall CMD. In performing the fit we paid attention to reproduce the TO, the subgiant region and the base of the RGB. Noticeably, an important constraint is the star no 2–4 (Richtler's numbering): this lies close to the theoretical red giant branch, and it is considered a probable member (Brown et al. 1996). On the other hand, the very red and bright star no 1–16 – considered a non-member (Brown et al. 1996) – clearly departs from the fitting isochrone.

**Figure 5.** Left-hand panel, NGC 2112 data in the  $V$  versus  $B - V$  diagram, as compared with the Girardi et al. (2000) isochrone of age  $2.0 \times 10^9$  yr (solid line), for the metallicity  $Z = 0.012$ . A distance modulus of  $(m - M)_0 = 9.65$  mag, and a colour excess of  $E(B - V) = 0.63$  mag, have been derived. Right-hand panel, NGC 2112 data in the  $V$  versus  $V - I$  diagram, as compared with the Girardi et al. (2000) isochrone of age  $2.0 \times 10^9$  yr (solid line), for the metallicity  $Z = 0.012$ . A distance modulus of  $(m - M)_0 = 9.65$  mag, and a colour excess of  $E(V - I) = 0.85$  mag, have been derived.

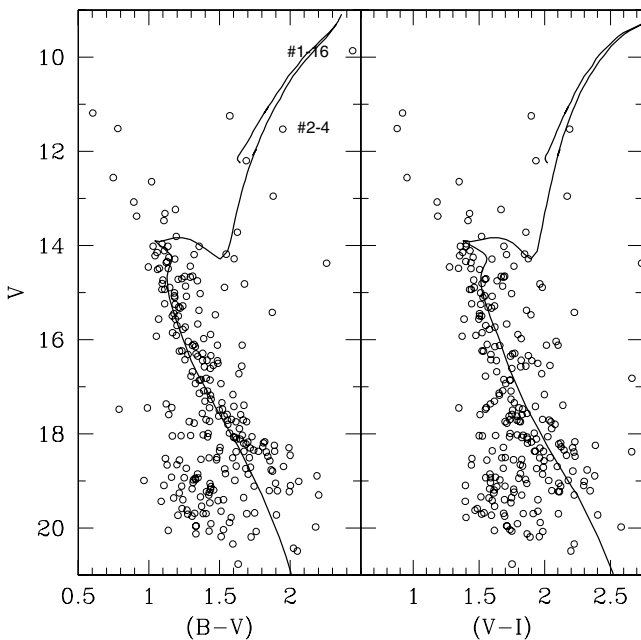
This fit has been reached by shifting the isochrone vertically by  $(m - M) = 11.60 \pm 0.30$  mag, where the uncertainty is attributable here to both the scarcely populated red giant region and the uncertainty in the reddening.

Consequently, the reddening-corrected absolute distance modulus becomes  $(m - M)_0 = 9.65 \pm 0.30$  mag and the cluster distance from the Sun is  $850 \pm 100$  pc. While the distance we infer is basically consistent with previous suggestions, the age turns out to be significantly younger. To give an estimate of the age uncertainty we tried to fit the CMD with slightly younger and slightly older isochrones, and we found that the best-fitting age was in the range 1.7–2.3 Gyr.

Finally, by assuming 8.5 kpc for the distance of the Sun to the Galactic centre, we provide for NGC 2112 the following estimates of the Galactocentric rectangular coordinates:  $X = 9.2$ ,  $Y = -0.36$  and  $Z = -0.18$  kpc, which place NGC 2112 well within the Orion spiral arm. We note, however, that the distance from the Galactic plane is larger than the scaleheight of the thin disc ( $\approx 75$  pc). This situation is not unusual, since there are several intermediate-age or old open clusters presently at large distances from the Galactic plane: NGC 6791, 2204 and 2420 for instance (see Friel 1995). Nevertheless, they are usually considered members of the old thin disc, which probably formed at fairly high  $Z$  (Carraro & Chiosi 1994); (Friel 1995).

### 5.3 Consequences of a lower metal abundance

In this section we rederive estimates of NGC 2112 basic parameters by assuming that its metal abundance is very low ( $[\text{Fe}/\text{H}] \approx -1.0$ ), as found for instance by Richtler (1985) and Richtler & Kaluzny (1989). The results are presented in Fig. 6.



**Figure 6.** Left-hand panel, NGC 2112 data in the  $V$  versus  $B - I$  diagram, as compared with the Girardi et al. (2000) isochrone of age  $2.8 \times 10^9$  yr (solid line), for the metallicity  $Z = 0.003$ . A distance modulus of  $(m - M)_0 = 9.13$  mag, and a colour excess of  $E(B - I) = 0.82$  mag, have been obtained. Right-hand panel, NGC 2112 data in the  $V$  versus  $V - I$  diagram, as compared with the Girardi et al. (2000) isochrone of age  $2.8 \times 10^9$  yr (solid line), for the metallicity  $Z = 0.003$ . A distance modulus of  $(m - M)_0 = 9.13$  mag, and a colour excess of  $E(V - I) = 1.07$  mag, have been obtained.

In this case the theoretical overall abundance  $Z$  turns out to be 0.003. By adopting this metallicity, it was not possible to derive a reasonable fit with the reddening obtained above. In contrast, a good fit has been achieved with an isochrone of the age 2.8 Gyr (15 per cent uncertainty) yielding  $E(B - V) = 0.82$  mag, and  $(m - M)_0 = 9.13$  mag. We will make two comments.

The first one is that star no 2–4, usually considered a member of NGC 2112, is clearly off the expected location of the RGB. Secondly, the reddening implied by this metallicity is significantly larger than any previous estimate. These facts seem to rule out the possibility that NGC 2112 is very metal poor.

## 6 NGC 2112 AND THE CHEMICAL EVOLUTION OF THE GALACTIC DISC

NGC 2112 is located toward the anticentre direction. As for several other clusters located in the Galactic sector between  $l = 135^\circ$  and  $225^\circ$  (Carraro et al. 2002), it is of intermediate age and has a lower than solar metal abundance ( $[\text{Fe}/\text{H}] = -0.15$ ). It is interesting to also consider this cluster in the age–metallicity relationship (AMR) and in the Galactic abundance gradient, having now at our disposal updated estimates of the distance and age. In fact, this cluster has usually not been taken into account in deriving global relationships for the Galactic disc (see Carraro et al. 1998). With an age of 2.0 Gyr, a distance from the Galactic centre of 9.2 kpc and a metal abundance of  $-0.15$  dex, NGC 2112 fits perfectly into both the age–metallicity and the distance–metallicity relationships (see Carraro et al. 1998, fig. 3). However, if the metallicity were much lower, as derived in previous studies, the cluster would place, in the AMR, close to Berkeley 21 [an old open cluster for which a very low but uncertain metal abundance has been reported (Friel & Janes 1993; Tosi et al. 1998; Hill & Pasquini 1999)], and it would deviate hugely from the mean Galactic abundance gradient, concurring to steepen it.

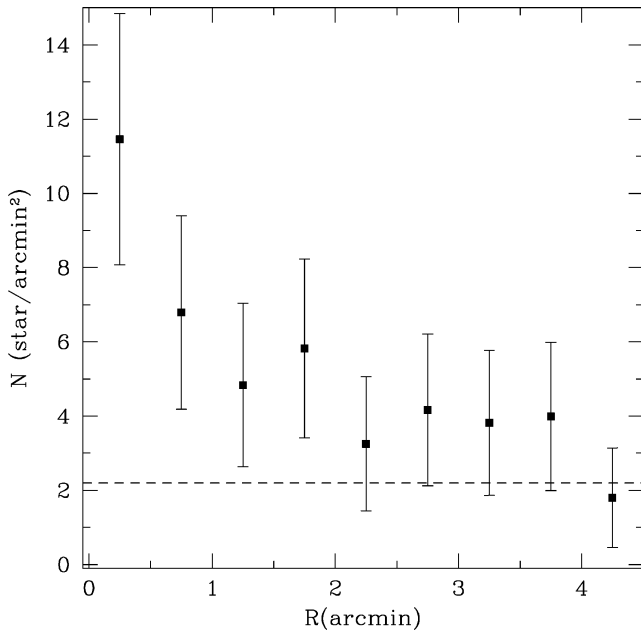
It is quite clear that NGC 2112 – as for other intermediate-age metal poor clusters – plays an important role in shaping the age–metallicity and age–distance relationships holding for the Galactic disc. Consequently, a proper motion study to better discriminate the physical members and a more constrained metal abundance determination are therefore really welcome.

## 7 STAR COUNTS AND CLUSTER SIZE

We derive the surface stellar density by performing star counts in concentric rings around stars no 1–1 (Richtler’s numbering) selected as the approximate cluster centre, and then dividing by their respective surfaces. The final density profile and the corresponding Poisson error bars are shown in Fig. 7, where we take into account all the measured stars brighter than  $V \approx 19$  mag.

The dashed line is the Galactic field number density derived from the accompanying field we observed in the  $V$  passband centred 10 arcmin eastward of NGC 2112. In this field we count 2.2 stars arcmin $^{-2}$  brighter than  $V \approx 19$  mag.

The surface density decreases smoothly over the whole region we covered, but the cluster starts to merge with the field already at about 3.5–4.0 arcmin. According to Lyngå (1987), NGC 2112 has a radius of about 9 arcmin. This means that we were able to sample the cluster core (see Fig. 1), where the contamination of field stars is minimized. However, it is very difficult to provide a precise estimate of the cluster radius. In fact, Friel & Janes (1993) identified two probable members (nos 3–16 and 3–17, Richtler’s numbering) outside the region we covered, which probably belong to the cluster envelope.



**Figure 7.** Star counts in the field of NGC 2112 as a function of the radius. The dashed line is the field number density estimate in the accompanying Galactic field.

## 8 CONCLUSIONS

We have presented a new CCD *BVI* photometric study of the intermediate-age open cluster NGC 2112. The CMDs we derive are much cleaner than previous ones, and allow us to infer updated estimates of the cluster basic parameters. In detail, we find that:

- (i) the age of NGC 2112 is 2.0 Gyr, with a 15 per cent uncertainty;
- (ii) the reddening  $E(B - V)$  turns out to be  $0.63 \pm 0.14$  mag;
- (iii) we place the cluster at about 0.85 kpc from the Sun toward the anticentre direction;
- (iv) we show that the estimate of metallicity by Brown et al. (1996) is probably the most realistic one;
- (v) combining together age, distance and metallicity, we suggest that this cluster is a genuine member of the old thin disc population.

As already noticed in the past, a proper motion study of NGC 2112 is really necessary to efficiently isolate cluster members from non-members and then derive robust estimates of the cluster chemical abundance.

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