# The intermediate-age open clusters Ruprecht 61, Czernik 32, NGC 2225 and 2262

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**ABSTRACT**

We present the first *BVI* CCD photometry to $V = 22.0$ of four fields centred on the region of the southern Galactic star clusters Ruprecht 61, Czernik 32, NGC 2225 and 2262 and of four displaced control fields. These clusters have never been studied before, and we provide for the first time estimates of their fundamental parameters, specifically radial extent, age, distance and reddening. We find that the four clusters are all of intermediate age (around 1 Gyr), close to the Sun and possess lower than solar metal abundance.

**Key words:** open clusters and associations: general – open clusters and associations: individual: Ruprecht 61 – open clusters and associations: individual: Czernik 32 – open clusters and associations: individual: NGC 2225 – open clusters and associations: individual: NGC 2262.

## 1 INTRODUCTION

This paper continues a series dedicated to the study of open clusters in the third Galactic Quadrant, and aims at addressing fundamental questions like the structure of the spiral arms in this quadrant, and the precise definition of the Galactic disc radial abundance gradient outside the solar circle. A more detailed illustration of the motivations of this project are given in Moitinho (2001) and Baume et al. (2004). Here we concentrate on four intermediate-age clusters (about the age of the Hyades – 600 Myr – or older) Ruprecht 61 (VdB-Hagen 32), Czernik 32 (VdB-Hagen 11), NGC 2225 and 2262, for which we provide the first photometric data and try to clarify their nature and to derive estimates of their fundamental parameters.

In Table 1 we list the cluster coordinates, which we redetermined from Digital Sky Survey (DSS) maps on a visual inspection basis.

The layout of the paper is as follows. Section 2 illustrates the observation and reduction strategies. An analysis of the geometrical structure and star counts in the field of the clusters is presented in Section 3, whereas a discussion of the colour–magnitude diagrams (CMDs) is performed in Section 4. Section 5 deals with the determination of the reddening, distance, metallicity and age of the clusters and, finally, Section 6 summarizes our findings.

## 2 OBSERVATIONS AND DATA REDUCTION

CCD *BVI* observations were carried out with the CCD camera onboard the 1.0-m telescope at Cerro Tololo Interamerican Observa-

tory (CTIO, Chile), on the nights of 2004 December 13 and 15. With a pixel size of 0.469 arcsec, and a CCD size of $512 \times 512$ pixel, each pointing samples a $4 \times 4.1$ arcmin field on the sky.

The details of the observations are listed in Table 2 where the observed fields are reported together with the exposure times, the average seeing values and the range of air-masses during the observations. Figs 1–4 show $I = 600$ s images obtained in the area of Ruprecht 61, Czernik 32, NGC 2225 and 2262, respectively. Together with the clusters, we observed three control fields 15-arcmin apart from the nominal cluster centres to deal with field star contamination. Exposure of 600 s in $V$ and $I$ were secured for these fields.

The data have been reduced with the IRAF[1] packages CCDRED, DAOPHOT, ALLSTAR and PHOTCAL using the point spread function (PSF) method (Stetson 1987). The two nights turned out to be photometric and very stable, and therefore we derived calibration equations for all the 130 standard stars observed during the two nights in the Landolt (1992) fields SA 95-41, PG 0231+051, Rubin 149, Rubin 152, T phe and SA 98-670 (see Table 2 for details).

The adopted calibration equations are of the form

$$b = B + b_1 + b_2 X + b_3(B - V)$$
$$v = V + v_1 + v_2 X + v_3(B - V)$$
$$v = V + v_{1,i} + v_{2,i} X + v_{3,i}(V - I)$$
$$i = I + i_1 + i_2 X + i_3(V - I),$$

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**Table 1.** Basic parameters of the clusters under investigation. Coordinates are for J2000.0 equinox.

| Name | RA (hh:mm:ss) | Dec. (° ′ ″) | $l$ (°) | $b$ (°) |
|---|---|---|---|---|
| Ruprecht 61 | 08:25:14 | −34:08:31 | 253.48 | +2.08 |
| Czernik 32 | 07:50:30 | −29:50:36 | 245.86 | −1.74 |
| NGC 2225 | 06:26:37 | −09:38:07 | 218.78 | −9.86 |
| NGC 2262 | 06:39:39 | +01:08:30 | 210.57 | −2.10 |

**Table 2.** Journal of observations of Ruprecht 61, Pismis 7 and Czernik 32 and standard star fields (2004 December 13 and 15).

| Field | Filter | Exposure time (s) | Seeing (arcsec) | Airmass |
|---|---|---|---|---|
| Ruprecht 61 | B | 120,1200 | 1.2 | 1.00–1.10 |
| | V | 30 600 | 1.3 | 1.00–1.10 |
| | I | 30 600 | 1.2 | 1.00–1.10 |
| NGC 2262 | B | 120,1200 | 1.2 | 1.15–1.30 |
| | V | 30 600 | 1.3 | 1.15–1.30 |
| | I | 30 600 | 1.2 | 1.15–1.30 |
| NGC 2225 | B | 120 1200 | 1.2 | 1.15–1.30 |
| | V | 30 600 | 1.3 | 1.15–1.30 |
| | I | 30 600 | 1.2 | 1.15–1.30 |
| Czernik 32 | B | 120,1200 | 1.2 | 1.25–1.40 |
| | V | 30 600 | 1.3 | 1.25–1.40 |
| | I | 30 600 | 1.2 | 1.25–1.40 |
| SA 98-670 | B | 3 × 120 | 1.2 | 1.24–1.26 |
| | V | 3 × 40 | 1.4 | 1.24–1.26 |
| | I | 3 × 20 | 1.4 | 1.24–1.26 |
| PG 0231+051 | B | 3 × 120 | 1.2 | 1.20–2.04 |
| | V | 3 × 40 | 1.5 | 1.20–2.04 |
| | I | 3 × 20 | 1.5 | 1.20–2.04 |
| T Phe | B | 3 × 120 | 1.2 | 1.04–1.34 |
| | V | 3 × 40 | 1.3 | 1.04–1.34 |
| | I | 3 × 20 | 1.3 | 1.04–1.34 |
| Rubin 152 | B | 3 × 120 | 1.3 | 1.33–1.80 |
| | V | 3 × 40 | 1.2 | 1.33–1.80 |
| | I | 3 × 20 | 1.2 | 1.33–1.80 |
| Rubin 149 | B | 3 × 120 | 1.1 | 1.21–1.96 |
| | V | 3 × 40 | 1.2 | 1.21–1.96 |
| | I | 3 × 20 | 1.2 | 1.21–1.96 |
| SA 95-41 | B | 3 × 120 | 1.2 | 1.05–1.48 |
| | V | 3 × 40 | 1.2 | 1.05–1.48 |
| | I | 3 × 20 | 1.1 | 1.05–1.48 |

where $BVI$ are standard magnitudes, $bvi$ are the instrumental ones and $X$ is the airmass; all the coefficient values are reported in Table 3. The standard stars in these fields provide the colour coverage $-0.6 \leqslant (B-V) \leqslant 2.2$. The final rms of the calibration are 0.031, 0.024 and 0.023 for the $B$, $V$ and $I$ filters, respectively. We generally used the third equation to calibrate the $V$ magnitude in order to get the same magnitude depth both in the cluster and in the field. Photometric errors have been estimated following closely Patat & Carraro (2001, appendix A), which the reader is referred to for all
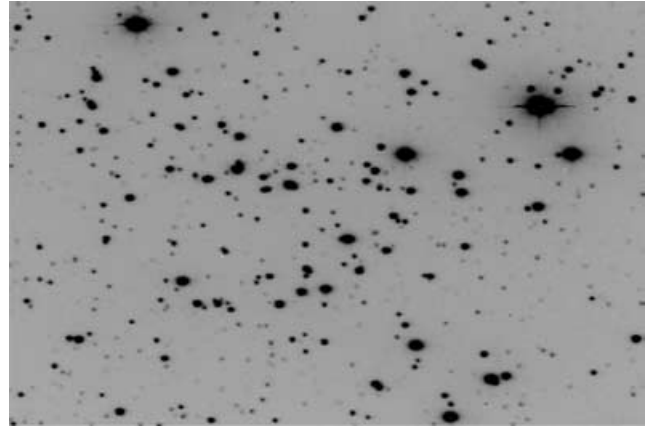


**Figure 1.** Deep I image (600 s) of the open cluster Ruprecht 61. North is up, east on the left, and the covered area is 4.1 × 4.1 arcsec.
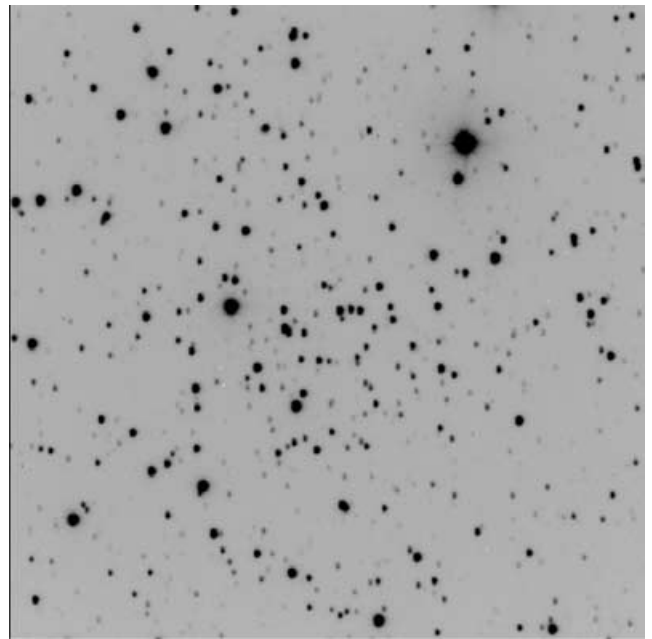


**Figure 2.** Deep I image (600 s) of the open cluster Czernik 32. North is up, east on the left, and the covered area is 4.0 × 4.1 arcsec.

the details. It turns out that the global photometric errors amount to 0.03, 0.05 and 0.20 at $V = 12$, 16 and 21.5 mag, respectively.

The final photometric catalogues for Ruprecht 61, Czernik 32, NGC 2225 and 2262 (coordinates, $B$, $V$ and $I$ magnitudes and errors) consist of 1166, 1047, 869 and 925 stars, respectively, and are made available in electronic form at the WEBDA[2] site maintained by J.-C. Mermilliod.

## 3 STAR COUNTS AND SIZES OF CLUSTERS

As we will show in this Section, our photometry covers entirely the area of each cluster allowing us to perform star counts to obtain improved estimates of the size of the clusters. In fact these clusters are generally very faint, poorly populated and compact (see Figs 1–4) and therefore could well fit within the CCD area.
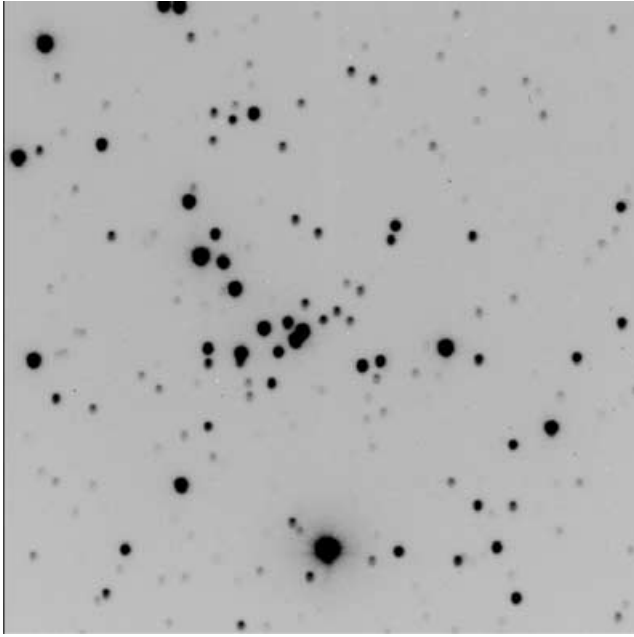
[2] http://obswww.unige.ch/webda/navigation.html

**Figure 3.** Deep I image (600 s) of the open cluster NGC 2225. North is up, east on the left, and the covered area is $4.1 \times 4.1$ arcsec.
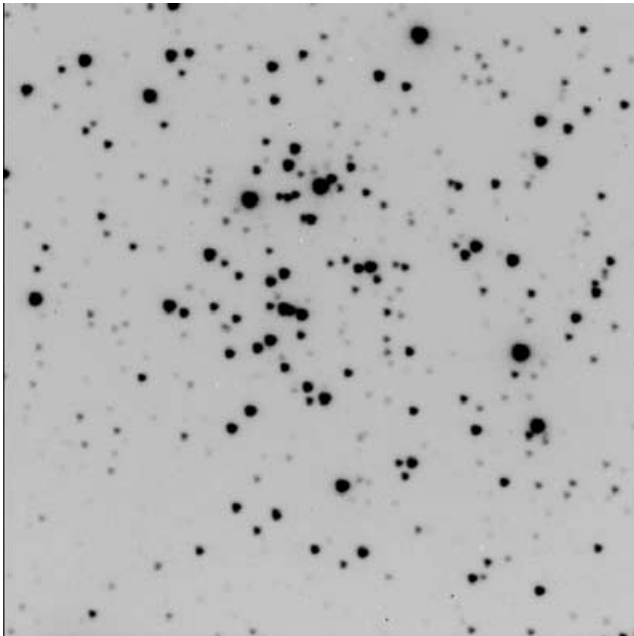


**Figure 4.** Deep I image (600 s) of the open cluster NGC 2262. North is up, east on the left, and the covered area is $4.1 \times 4.1$ arcsec.

We derived the surface stellar density by performing star counts in concentric rings around the nominal centres of the clusters (see Table 1) and then dividing by their respective areas. Poisson errors have also been derived and normalized to the corresponding area. The field star contribution has been derived from the control field which we secured for each cluster, and the errors have been computed in the same way as for the cluster field.

**Ruprecht 61.** The radial density profile for Ruprecht 61 is shown in Fig. 5 as a function of the *V* magnitude. Clearly, the cluster does not appear very concentrated, and it is deficient of bright stars. The

**Table 3.** Coefficients of the calibration equations.

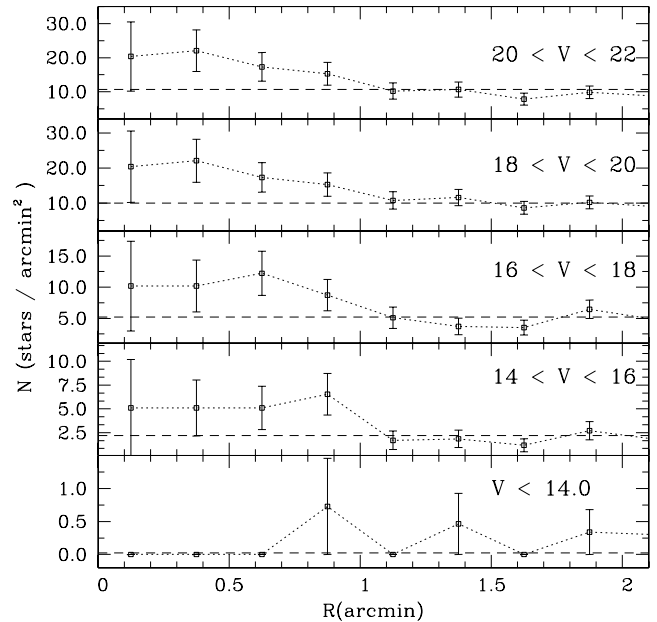| | | |
|---|---|---|
| $b_1 = 3.465 \pm 0.009$ | $b_2 = 0.25 \pm 0.02$ | $b_3 = -0.145 \pm 0.008$ |
| $v_1 = 3.244 \pm 0.005$ | $v_2 = 0.16 \pm 0.02$ | $v_3 = 0.021 \pm 0.005$ |
| $v_{1,i} = 3.244 \pm 0.005$ | $v_{2,i} = 0.16 \pm 0.02$ | $v_{3,i} = 0.009 \pm 0.005$ |
| $i_1 = 4.097 \pm 0.005$ | $i_2 = 0.08 \pm 0.02$ | $i_3 = 0.006 \pm 0.005$ |



**Figure 5.** Star counts in the area of Ruprecht 61 as a function of radius and magnitude. The dashed lines represent the level of the control field counts estimated from the accompanying control field.

cluster seems to emerge from the background in the magnitude range $16 \leqslant V \leqslant 22$. In this magnitude range the radius is not larger than 1.0 arcmin. We shall adopt the value of 1.0 arcmin as the radius of Ruprecht 61 throughout this paper. This estimate is in perfect agreement the value of 2.0 arcmin reported by Dias et al. (2002) for the cluster diameter.

**Czernik 32.** The radial density profile for Czernik 32 is shown in Fig. 6 as a function of the *V* magnitude. The cluster shows a clear lack of bright stars and it is mostly populated by stars of magnitude in the range $18 \leqslant V \leqslant 22$. In this magnitude range the radius is not larger than 1.0 arcmin. In conclusion, we are going to adopt the value of 1.0 arcmin as the Czernik 32 radius throughout this paper. This estimate is in reasonable agreement with the value of 3.0 arcmin reported by Dias et al. (2002) for the cluster diameter.

**NGC 2225.** The radial density profile for NGC 2225 is shown in Fig. 7 as a function of the *V* magnitude. Also this cluster exhibits a deficiency of bright stars ant it is mostly populated by stars of magnitude in the range $16 \leqslant V \leqslant 22$. In this magnitude range the radius is not larger than 1.2 arcmin.

This estimate is in reasonable agreement with (a bit smaller than) the value of 4.0 arcmin reported by Dias et al. (2002) for the cluster diameter.

**NGC 2262.** The radial density profile for NGC 2262 is shown in Fig. 8 as a function of the *V* magnitude. This cluster is composed mainly by stars of magnitude in the range $16 \leqslant V \leqslant 22$,
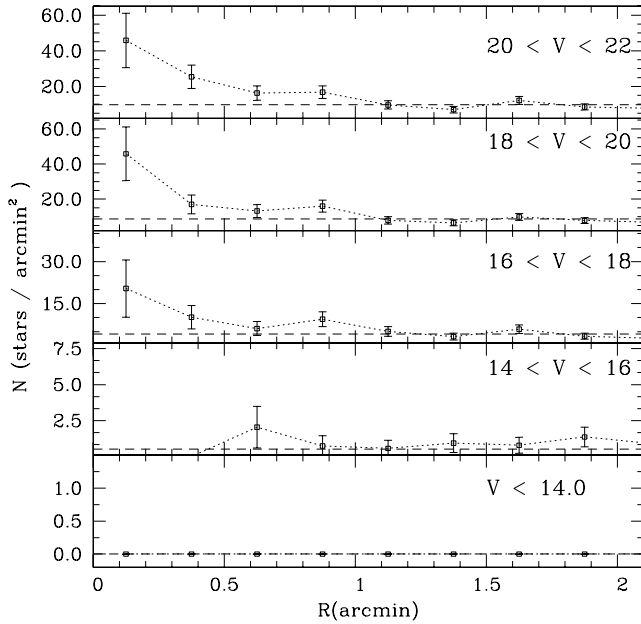
**Figure 6.** Star counts in the area of Czernik 32 as a function of radius and magnitude. The dashed lines represent the level of the control field counts estimated from the accompanying control field.
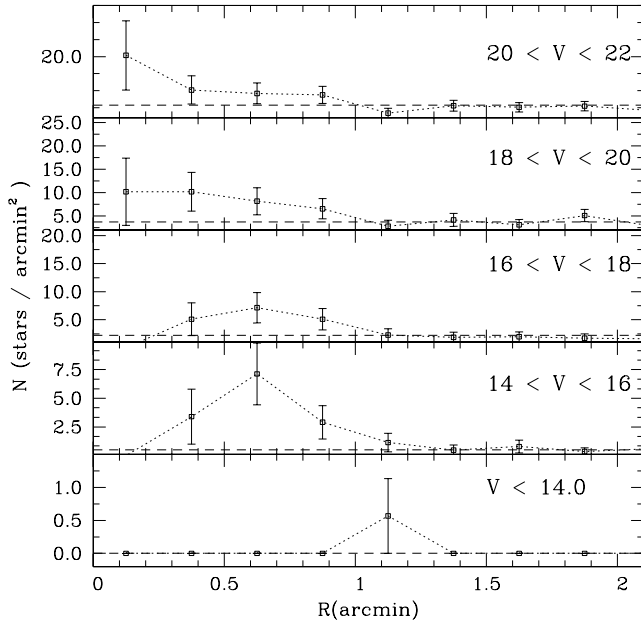


**Figure 7.** Star counts in the area of NGC 2225 as a function of radius and magnitude. The dashed lines represent the level of the control field counts estimated from the accompanying control field.



**Figure 8.** Star counts in the area of NGC 2262 as a function of radius and magnitude. The dashed lines represent the level of the control field counts estimated from the accompanying control field.

where the radius is around 1.0 arcmin. In conclusion, we are going to adopt the value of 1.0 arcmin as the radius of NGC 2262 throughout this paper. This estimate is much smaller than the value of 5.0 arcmin reported by Dias et al. (2002) for the cluster diameter.

The estimates we provide for the radius, although reasonable, must be taken as preliminary. In fact, the size of the CCD is probably too small to derive conclusiv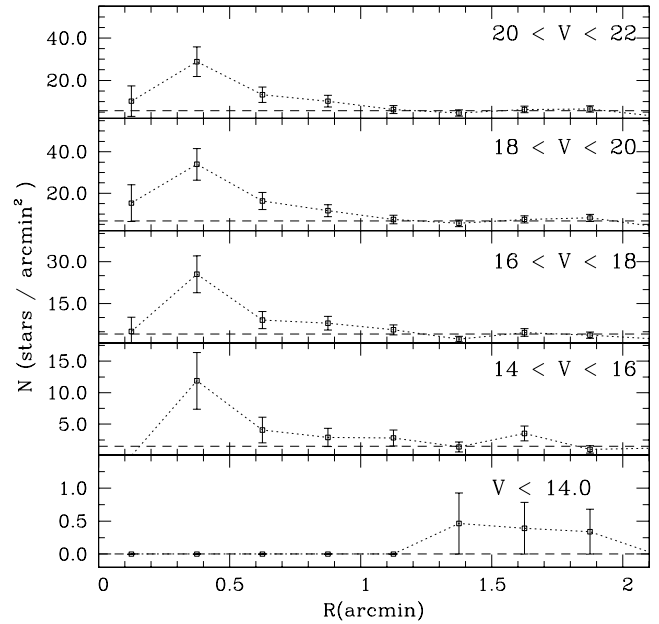e estimates of the cluster sizes, that due to dynamical evolution and mass segregation tend to be normally underestimated. Larger and deep field coverage is necessary to derive firmer estimates of the clusters radii.

## 4 THE COLOUR–MAGNITUDE DIAGRAMS

In Fig. 9 we present the CMDs obtained for the observed fields of the four clusters under investigation. All the stars observed in each field have been plotted (not only those within the derived cluster radii). In this figure, the open cluster Ruprecht 61 is shown together with the corresponding control field in the lower panels, Czernik 32 and NGC 2225 are presented in the middle panels, while finally NGC 2262 is presented in the upper panels. The control fields help us to better interpret these CMDs, which are clearly affected by strong foreground star contamination.

**Ruprecht 61**. This cluster is presented in the lower panels of Fig. 9. It exhibits a main sequence (MS) extending from $V = 15$–15.5, where the turn-off point (TO) is located, down to $V = 21.5$. This MS is significantly wide, wider than photometric error at a given magnitude (see Section 2). We ascribe this to field star contamination, and to the presence of a sizeable binary star population, which mainly enlarge the MS toward red colours. However, the reality of this cluster seems to be secured by the shape of the MS with respect to the control field MS, whose population sharply decreases at $V = 17$. Also, the cluster MS is significantly bluer and more tilted than the field MS, which derives from the superposition of stars of different reddening located at all distances between the cluster and the Sun. Another interesting evidence is the possible presence of a clump of stars at $V = 14.5$, which does not have a clear counterpart in the field, and which implies a cluster of intermediate age. In fact if we use the age calibration from Carraro & Chiosi (1994), for a $\Delta V$ (the magnitude difference between the red clump and the TO) of 0.5 mag, we infer an age around 1 Gyr. This estimate does not take into account the cluster metallicity, and therefore is simply
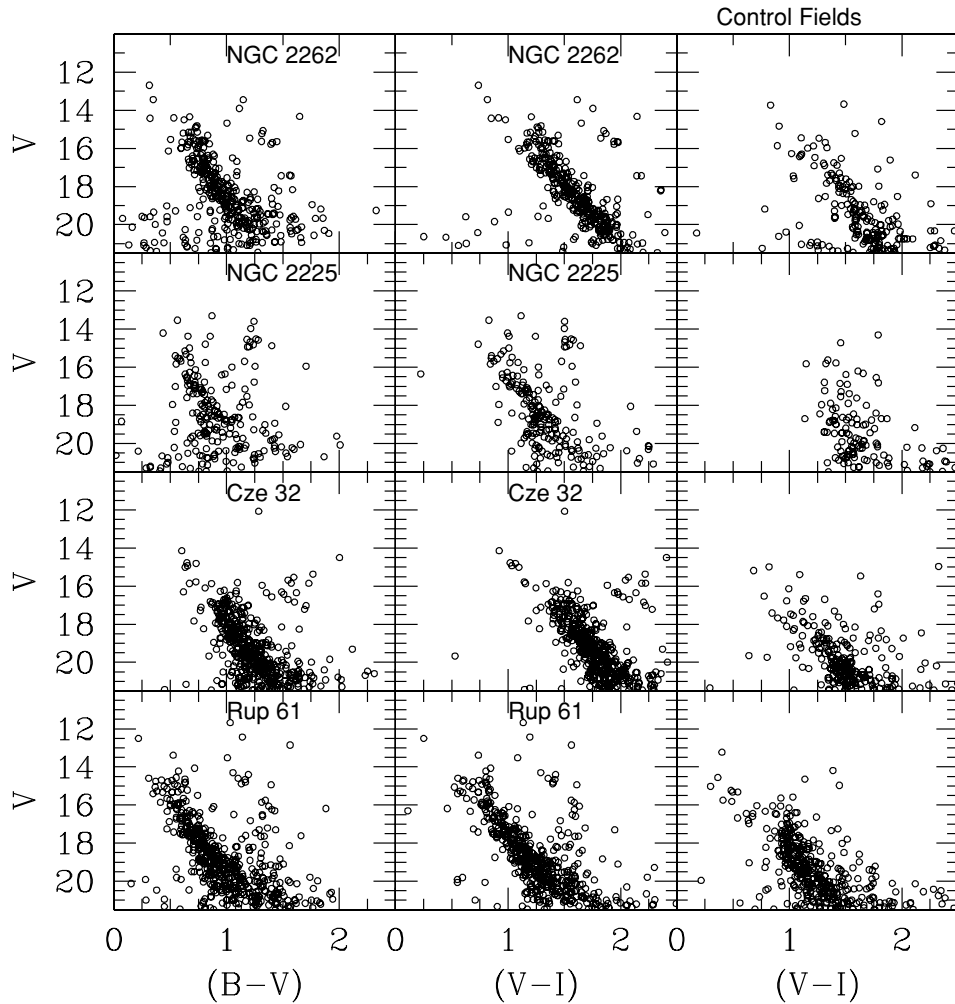
**Figure 9.** $V$ versus $(B - V)$ (left panels) and $V$ versus $(V - I)$ (middle panels) CMDs of Ruprecht 61, Czernik 32, NGC 2225 and 2262 and corresponding control fields (right panels). We include all stars in each field.

**Table 4.** Fundamental parameters of the studied clusters. The coordinates system is centred on the Sun, with the $X$ and $Y$ axes lying on the Galactic plane and $Z$ perpendicular to the plane. $X$ points in the direction of the Galactic rotation, being positive in the first and second Galactic quadrants; $Y$ points toward the Galactic anticentre; and $Z$ indicates the north Galactic pole (Lynga 1982).

| Name | Radius($'$) | $E(B - V)$ | $E(V - I)$ | $(m - M)$ | $d_\odot$ | $X$(kpc) | $Y$(kpc) | $Z$(kpc) | $R_{GC}$ (kpc) | Age (Gyr) | Metallicity |
|------|-------------|------------|------------|-----------|-----------|----------|----------|----------|----------------|-----------|-------------|
| Ruprecht 61 | 1.0 | $0.30 \pm 0.1$ | $0.41 \pm 0.1$ | $13.85 \pm 0.2$ | 3.9 | $-3.8$ | 1.1 | 0.19 | 9.4 | $1.3 \pm 0.2$ | $0.008 \pm 0.002$ |
| Czernik 32 | 1.0 | $0.85 \pm 0.1$ | $1.08 \pm 0.1$ | $15.70 \pm 0.2$ | 4.1 | $-1.7$ | 3.7 | $-0.12$ | 10.8 | $1.0 \pm 0.3$ | $0.008 \pm 0.002$ |
| NGC 2225 | 1.2 | $0.35 \pm 0.1$ | $0.50 \pm 0.1$ | $13.60 \pm 0.2$ | 3.2 | $-1.9$ | 2.5 | $-0.55$ | 11.2 | $1.3 \pm 0.2$ | $0.008 \pm 0.003$ |
| NGC 2262 | 1.0 | $0.55 \pm 0.1$ | $0.72 \pm 0.1$ | $14.50 \pm 0.2$ | 3.6 | $-1.8$ | 3.1 | $-0.13$ | 11.7 | $1.0 \pm 0.2$ | $0.008 \pm 0.004$ |

a guess. In the following section we shall provide a more robust estimate of the age through a detailed comparison with theoretical isochrones.

**Czernik 32**. The open cluster Czernik 32 is presented in the lower-mid panels of Fig. 9. The TO located at $V \approx 17$, and a prominent clump at $V \approx 16$ with no counterpart in the field CMD are readily seen, yielding an estimated age of around 1.0 Gyr. The overall morphology of the CMDs is in this case very different from the field CMD leaving no doubt that Czernik 32 is a bona-fide intermediate-age open cluster.

**NGC 2225**. The open cluster NGC 2225 is presented in the upper-mid panels of Fig. 9. Again, the overall morphology of the cluster CMDs, with a TO and an evident red clump, is very different from the field CMD. Indeed, the field sequence is much less populated and stops at $V \approx 16.5$, giving a first impression that this is a bona-fide intermediate-age open cluster. The TO located at $V \approx 16$, and red clump at $V \approx 15$, allow to estimate an age of around 1.0 billion years, confirming the first impression that NGC 2225 is an intermediate-age cluster.

**NGC 2262**. The open cluster NGC 2262 is presented in the upper panels of Fig. 9. The CMD of the cluster reveals a TO is located at $V \approx 16$, and a possible clump at $V \approx 16$ as well, which provide a rough estimate of around 0.5 Gyr for the age of NGC 2262. The overall morphology of the CMDs is also in this case very different from the field CMD confirming that this is a bona-fide intermediate-age open cluster.
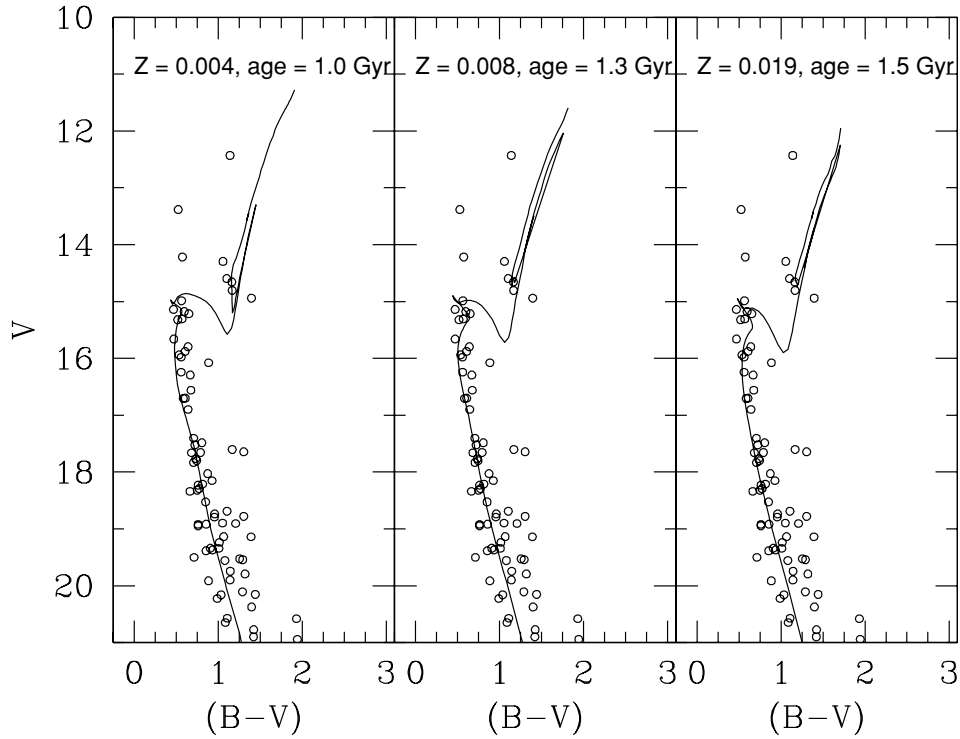
**Figure 10.** Hunting for the best-fitting isochrone solution. The CMD of Ruprecht 61 is shown together with three different isochrones. The isochrones are for the age of 1 Gyr and metallicity $Z = 0.004$ in the left panel, for the age of 1.3 Gyr and metallicity $Z = 0.008$ in the middle panel, and, finally, for the age of 1.5 Gyr and metallicity $Z = 0.019$ in the right panel.
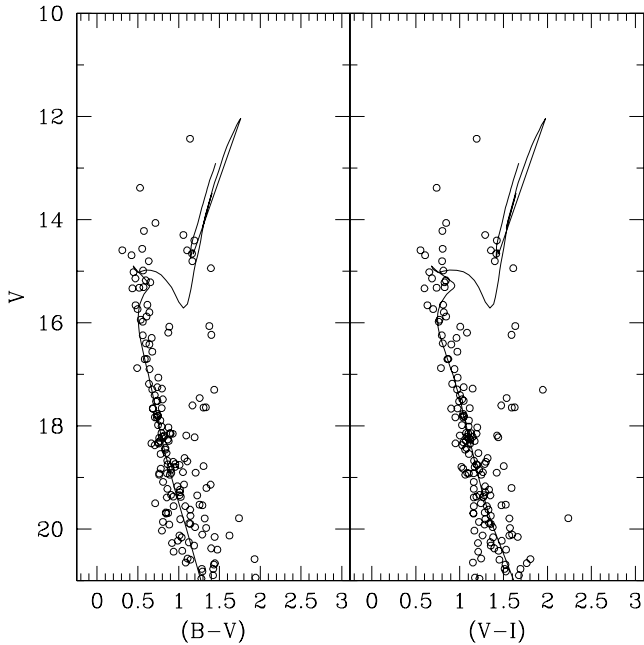


**Figure 11.** Isochrone solution for Ruprecht 61. The isochrone is for the age of 1.3 Gyr and metallicity $Z = 0.008$. The apparent distance modulus is $(m - M) = 13.85$, and the reddening $E(B - V) = 0.30$ and $E(V - I) = 0.41$. See text for more details. Only stars within the derived radius are shown.
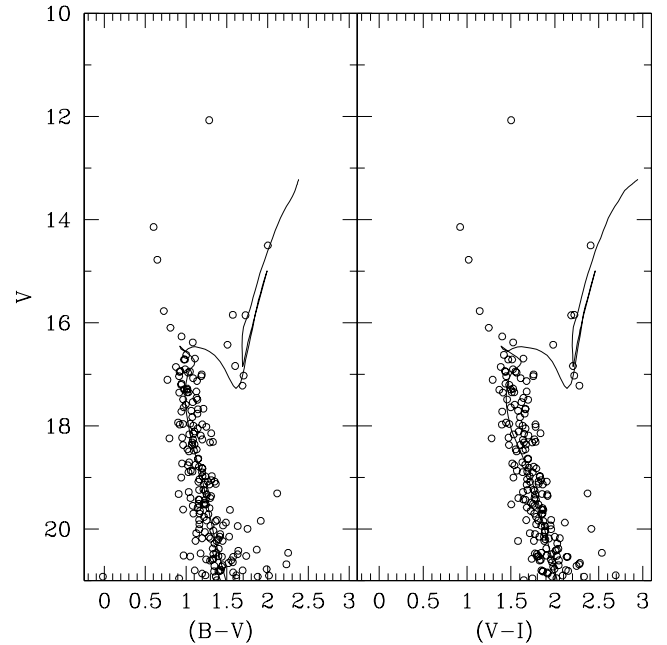


**Figure 12.** Isochrone solution for Czernik 32. The isochrone is for the age of 1 Gyr and metallicity $Z = 0.008$. The apparent distance modulus is $(m - M) = 15.7$, and the reddening $E(B - V) = 0.85$ and $E(V - I) = 1.08$. See text for more details. Only stars within the derived radius are shown.

## 5 DERIVING FUNDAMENTAL PARAMETERS OF CLUSTERS

In this section we are going to perform a detailed comparison of the star distribution in the CMDs of the clusters with theoretical isochrones. For this study, we adopt in this study the Padova library from Girardi et al. (2000). This comparison is clearly not an easy exercise. In fact, the detailed shape and position of the various features in the CMD (MS, TO and clump basically) depends mostly on age and metallicity, and then also on reddening and
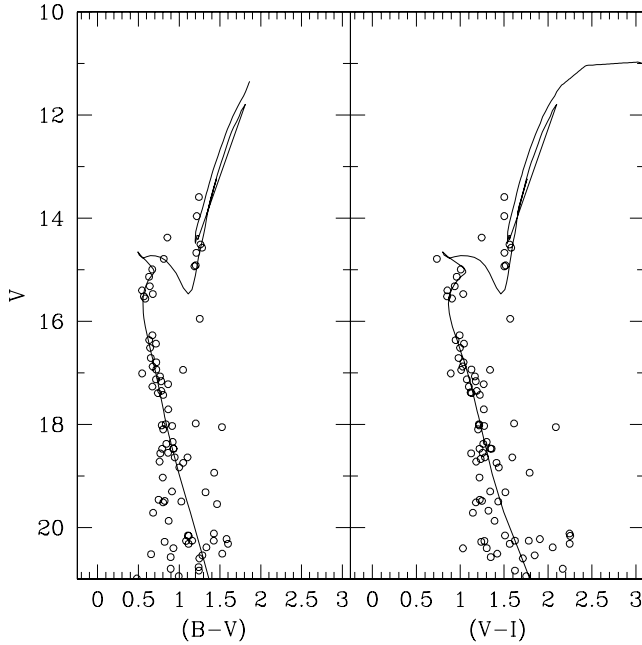
**Figure 13.** Isochrone solution for NGC 2225. The isochrone is for the age of 1.3 Gyr and metallicity $Z = 0.008$. The apparent distance modulus is $(m - M) = 13.5$, and the reddening $E(B - V) = 0.35$ and $E(V - I) = 0.56$. See text for more details. Only stars within the derived radius are shown.
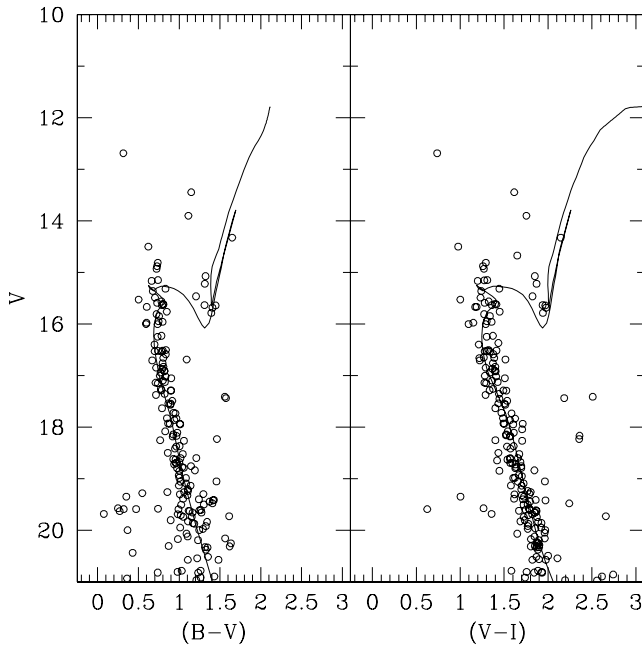


**Figure 14.** Isochrone solution for Czernik 32. The isochrone is for the age of 1 Gyr and metallicity $Z = 0.008$. The apparent distance modulus is $(m - M) = 14.5$, and the reddening $E(B - V) = 0.55$ and $E(V - I) = 0.72$. See text for more details. Only stars within the derived radius are shown.

distance. The complex interplay between the various parameters is however well known, and we refer to Chiosi, Bertelli & Bressan (1992) and Carraro (2005) as nice examples of the underlying technique.

Our basic strategy is to survey different age and metallicity isochrones in an attempt to provide the best fit of all the CMD features both in the V versus $(B - V)$ and in the V versus $(V - I)$ CMD.

To further facilitate the fitting procedure, by increasing the contrast between the cluster and the field population, we shall consider only the stars which lie within the cluster radius as derived in Section 3.

Finally, to derive the distances of the clusters from reddening and apparent distance modulus, a reddening law must be specified. In this study we shall adopt the normal reddening law $Av = 3.1 \times E(B - V)$ in deriving the distances of the clusters.

In addition to finding the best fit, we also estimated the uncertainties in the basic parameters. These uncertainties simply reflect the range of parameters that yields a reasonable fit to the clusters CMDs. The errors are reported in Table 4, and an example of the procedure is shown in Fig. 10 for the case of Ruprecht 61. The best fit for all the clusters, achieved simultaneously in the V versus $(B - V)$ and in the V versus $(V - I)$ planes, are shown in Figs 11–14.

**Ruprecht 61**. The fitting procedure and the isochrone solution for this cluster are shown in Figs 10 and 11. We obtained the best fit for an age of 1.3 Gyr and a metallicity $Z = 0.008$ (see middle panel of Figs 11 and 12). In fact, the shape of the TO in the left panel of Fig. 11 (for the $Z = 0.004$ isochrone) is clearly different from the underlying cluster sequence, and the same can be noticed for the $Z = 0.019$ isochrone (right panel), where the red hook shows a shape which does not fit very well the star distribution in the cluster. In details, the red hook is too red and somewhat faint with respect to the $Z = 0.008$ isochrone and the actual stars distribution. To get a bluer and brighter red hook, one should use a younger isochrone, which will, however, possess a too red clump and Red Giant Branch (RGB), when fixed to the TO.

The inferred reddening and apparent distance modulus are $E(B - V) = 0.30$ [$E(V - I) = 0.41$, right panel in Fig. 12] and $(m - M) = 13.85$, respectively. As a consequence, the cluster possesses a heliocentric distance of 3.9 kpc, and is located at a Galactocentric distance of 9.4 kpc, assuming 8.5 kpc as the distance of the Sun to the Galactic Centre.

**Czernik 32**. The isochrone solution for this cluster is displayed in Fig. 12. We obtained the best fit for an age of 1 Gyr and a metallicity $Z = 0.008$. The inferred reddening and apparent distance modulus are $E(B - V) = 0.85$ [$E(V - I) = 1.08$] and $(m - M) = 15.7$, respectively. These values situate the cluster at a heliocentric distance of 4.1 kpc, which corresponds to a Galactocentric distance of 10.8 kpc. The overall fit is also good in this case, the detailed shape of the MS and TO are nicely reproduced, as well as the colour of the clump.

**NGC 2225**. The isochrone solution for this cluster is presented in Fig. 13. We obtained the best fit for an age of 1 Gyr and a metallicity $Z = 0.008$, which reproduces the sharp cluster sequence extremely well. The inferred reddening and apparent distance modulus are $E(B - V) = 0.35$ [$E(V - I) = 0.50$] and $(m - M) = 13.6$, respectively. Therefore the cluster has a heliocentric distance of 3.2 kpc, and is located at a Galactocentric distance of 11.2 kpc.

**NGC 2262**. The isochrone solution for this cluster is shown in Fig. 14. We obtained the best fit for an age of 1 Gyr and a metallicity of $Z = 0.008$. The inferred reddening and apparent distance modulus are $E(B - V) = 0.55$ [$E(V - I) = 0.72$] and $(m - M) = 14.5$, respectively, which put the cluster at a heliocentric distance of 3.6 kpc, or at a Galactocentric distance of 11.7 kpc.

## 6 CONCLUSIONS

We have presented the first CCD *BVI* photometric study of the star clusters Ruprecht 61, Czernik 32, NGC 2225 and 2262. Through a

star count analysis we have refined previous estimates of the coordinates and apparent radii of the cluster. A detailed comparison of the CMDs of the clusters with theoretical isochrones has allowed us to infer the basic parameters of the aggregates and their uncertainties, which are summarized in Table 4.

In detail, the fundamental findings of this paper are as follows:

(i) the best-fitting reddening estimates support within the errors a normal extinction law toward the four clusters;

(ii) all the clusters turn out to be of intermediate age, and not far from the Sun toward the anti-centre direction; and

(iii) the photometric estimates of the metallicity are lower than solar, as expected for clusters located between 9 and 11 kpc from the Galactic Centre (Carraro, Ng & Portinari 1998).

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