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# PHOTOMETRIC STUDY OF OPEN CLUSTERS NGC 2266 AND NGC 7762

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**Abstract.** The results of photometric *UBV* monitoring of open clusters NGC 2266 and NGC 7762 are presented. 2MASS *JH* photometry is additionally used to determine the parameters of both clusters. For NGC 2266 the following parameters are obtained: the limiting radius $6.2'$, $\log(\text{age [yr]}) = 9.08 \pm 0.04$, metallicity $Z = 0.004$ ([Fe/H] $= -0.68$), interstellar reddening $E_{B-V} = 0.17$ and a distance of $2.80 \pm 0.15$ kpc. No evidence for the existence of an extended corona was found. As a result of 45 hour monitoring of 7200 stars in the cluster field, 12 were found to be variable. All of them are located outside the cluster radius. For NGC 7762 the following parameters are obtained: limiting radius $23.5'$ (including an extended corona), $\log(\text{age [yr]}) = 9.38 \pm 0.04$, interstellar reddening $E_{B-V} = 0.59$ and a distance of $0.8 \pm 0.25$ kpc; solar metallicity is accepted. The near-IR data suggest $E_{J-H} = 0.11$ and a peculiar interstellar reddening law. As a result of 55 hour monitoring of 5500 stars in the cluster field, 16 stars are found to be variable. Two of them, a short-period contact or semi-detached eclipsing system and a pulsating star of $\gamma$ Dor type – are likely members of NGC 7762.

**Key words:** open clusters: individual (NGC 2266, NGC 7762) – stars: variables: general

## 1. INTRODUCTION

The population of variable stars in the majority of known open clusters is still insufficiently studied. As the apparent diameters of the majority of open clusters studied by Maciejewski & Niedzielski (2007) were found to be much larger than the values previously accepted, we performed a dedicated CCD search for variable stars in the wider fields around the selected clusters. In this paper we present the results for two objects – NGC 2266 and NGC 7762. Additionally, deep *UBV* photometry, supported by the near-infrared *JH* data, allowed us to redetermine the basic parameters of both clusters.

NGC 2266 is a small and compact open cluster located in Gemini (J2000: $\alpha = 06^{\rm h}43^{\rm m}19^{\rm s}$, $\delta = +26^\circ\,58'$, $\ell = 187.8^\circ$, $b = +10.3^\circ$). The cluster was studied by

Kałużny & Mazur (1991) who obtained CCD photometry in the *UBV* and *Washington* systems. A foreground interstellar reddening of $E_{B-V} = 0.10$ was obtained. Their analysis of the color-magnitude diagram (hereafter CMD) indicated that the cluster has a well defined main sequence and a populous red giant clump. Its age was estimated to be close to the age of the Hyades, i.e., log (age [yr]) = 8.9. The metallicity was found to be lower than the solar: [Fe/H] = –0.26 dex from photometry of the cluster giants in the *Washington* system and [Fe/H] = –0.39 dex by comparing CMDs of NGC 2266 and NGC 1817. The obtained true distance modulus was found to be 12.95 mag, which corresponds to a distance of 3.4 kpc. The distance of NGC 2266 from the Galactic plane then is 600 pc, a relatively large value when compared with its age.

NGC 2266 was assigned to the old cluster population by Phelps et al. (1994). Ahumada & Lapasset (1995) found two candidates for blue stragglers in the cluster. Based on a morphological age indicator, Salaris et al. (2004) redetermined its age getting 870 Myr (assuming solar metallicity). Paunzen & Netopil (2006) listed NGC 2266 in the set of 72 suggested standard open clusters accepting its mean age 736 Myr. Dias et al. (2006) obtained the mean proper motion of the cluster using the UCAC2 catalogue data: $\mu_\alpha \cos\delta = -1.98$ mas/yr and $\mu_\delta = -4.32$ mas/yr. More recently, Maciejewski & Niedzielski (2007), by fitting the solar metallicity isochrone in the $V$ vs. $B$–$V$ diagram, obtained log (age [yr]) = 9.0, $E_{B-V} = 0.00$, $m$–$M$ = 12.24 and a distance of 2.8 kpc. The cluster core radius $r_{\rm core} = 1.2'$ and the limiting radius $r_{\rm lim} = 5.9'$ were determined. The cluster was found to be larger than the previous estimates have indicated. Moreover, the evidence of a mass segregation within the cluster was found.

NGC 7762 is an open cluster located in Cepheus (J2000: $\alpha = 23^{\rm h}49^{\rm m}56^{\rm s}$, $\delta = +68^\circ\,02'$, $\ell = 117.2^\circ$, $b = +5.8^\circ$). It has been a target of only a few investigations to date. The first *UBV* study of 18 stars by Chincarini (1966) resulted in the determination of $E_{B-V} = 1.02$, apparent distance modulus $m$–$M$ = 13.10, a distance of 1.0 kpc and a diameter of 3.5 pc. The first deep *BV* CCD photometry of the central part of the cluster ($4.5' \times 4.5'$) was acquired by Patat & Carraro (1995) who obtained (by fitting the solar metallicity isochrone) an age of 1.8 Gyr, $E_{B-V}$ = 0.85–0.90, the apparent distance modulus within 12.0–12.2 mag and a distance of 0.8 kpc. Moreover, these authors noted that the a distinct main sequence was seen in the CMD down to $V$ = 16.5 mag. Maciejewski & Niedzielski (2007), by fitting the solar metallicity isochrone, obtained the following parameters of the cluster: log (age [yr]) = 9.3, $E_{B-V} = 0.66$, $m$–$M$ = 11.52 and a distance of 0.8 kpc. The core and the limiting radii of the cluster were estimated to be $2.4'$ and $9.5'$, respectively. This cluster was found to be larger than previous estimates have indicated. NGC 7762 was searched for short-period variable stars by Szabo (1999): three variables were detected.

This paper is organized as follows. In Section 2 the instruments, observations and data reduction are described, in Section 3 we describe the data analysis methods and Section 4 contains the results of investigation. Section 5 gives the summary of the paper.

## 2. OBSERVATIONS AND DATA REDUCTION

The observations presented in this paper were obtained with the following instruments.

• The 2/16 m Ritchey-Chrétien-Coudé (RCC) telescope of the National Astronomical Observatory (NAO) at Rozhen (Bulgaria), operated by the Institute of Astronomy of the Bulgarian Academy of Sciences. The instrument was used in the direct imaging mode and was equipped with a VersArray 1300B CCD camera mounted at the Ritchey-Chrétien focus. The field of view was $5.8' \times 5.8'$ with a scale of $0.26''$ per pixel.

• The 90/180 cm Schmidt-Cassegrain Telescope (TSC90) of the Astronomical Observatory of Nicolaus Copernicus University located in Piwnice near Toruń, Poland. The telescope was used in the imaging mode with a 60 cm correction plate and a field-flattening lens mounted near the focal plane. A SBIG STL-11000 CCD camera (4008 $\times$ 2672 pixels $\times$ 9 $\mu$m) was used as a detector. The field of view was $72'$ in declination and $48'$ in right ascension, with a scale of $1.08''$ per pixel. $2 \times 2$ binning was used to increase the signal-to-noise ratio.

• The 70/172 cm Schmidt Telescope (ST70) of the National Astronomical Observatory (NAO) at Rozhen, operated by the Institute of Astronomy of the Bulgarian Academy of Sciences. The instrument was equipped with a 50 cm correction plate and a SBIG ST-8 CCD camera (1530 $\times$ 1020 pixels $\times$ 9 $\mu$m). The field of view of the instrument was $27'$ in declination and $18'$ in right ascension with a scale of $1.08''$ per pixel. In 2007 October the SBIG STL-11000 CCD camera was used as a detector. The field of view of the instrument was similar to that of TSC90.

CCD photometry in the *UBV* system of the central part of NGC 2266 was acquired with the RCC telescope on 2007 March 15. Two 600 s exposures were obtained in the $U$ filter, one 60 s and two 600 s exposures in $B$ and one 30 s and one 600 s exposures in $V$. Since during our observations the atmospheric conditions were not suitable for the reliable photometric calibration based on standard fields, our instrumental magnitudes were calibrated against 29 stars located in the field of the cluster, for which photometry was taken from Kalużny & Mazur (1991). The transformation equations were as follows:

$$V - v = 0.057(b - v) + 23.591 \;, \tag{1}$$

$$B - V = 1.024(b - v) - 0.618 \;, \tag{2}$$

$$U - B = 0.606(u - b) - 1.578 \;, \tag{3}$$

where $U$, $B$, $V$ are standard magnitudes and $u$, $b$, $v$ are the instrumental ones. The typical seeing during the observations was $2''$. Due to a relatively small field of view the effect of the differential atmospheric extinction was ignored. The field of NGC 2266 was searched for variable stars during two campaigns in $B$ and $V$ filters with two Schmidt telescopes. The first campaign was performed on 2006 March 22, 23, 24 and December 15, and 2007 January 15 and February 10 with the TSC90 telescope. The exposure time was set to 600 s and the typical seeing was 5–$6''$. During more than 24 hours of observations, 96 images in $V$ and 27 in $B$ were obtained. Over 7200 stars brighter than $V = 18.7$ mag were monitored. The second campaign was performed on six consecutive nights on 2007 March 14–19 with the ST70 instrument. The exposure time was set to 300 s, with a typical seeing of $3''$. During more than 21 hours of monitoring, 144 images in $V$ and 30 in $B$ were acquired. Due to smaller field of view only 2060 stars down to $V = 19.3$ mag were observed.

The *UBV* CCD photometry of the wide field centered on NGC 7762 was acquired with the TSC90 telescope on 2005 October 30. The series of two 10 s and two 600 s exposures were exposed in the three filters. The instrumental magnitudes were calibrated against 15 stars located in the field of the cluster for which photometry was taken from Chincarini (1966). The transformation equations were as follows:

$$V - v = -0.013(b - v) + 19.776 \ , \tag{4}$$

$$B - V = 1.126(b - v) + 0.011 \ , \tag{5}$$

$$U - B = 1.095(u - b) - 3.457 \ , \tag{6}$$

where $U$, $B$, $V$ are standard magnitudes and $u$, $b$, $v$ are the instrumental ones. A typical seeing during observations was $5''$. The instrumental magnitudes were corrected for the effect of differential atmospheric extinction which was monitored during each night. The field of NGC 7762 was also searched for variable stars during the two campaigns performed in $B$ and $V$ filters with the Schmidt telescopes. The first campaign with the TSC90 was performed on three consecutive nights 2005 October 30 to November 1. The exposure time was set to 600 s and a typical seeing was 5–$6''$. During 25 hours of observations 79 images in $V$ and 38 in $B$ were obtained. Over 5500 stars brighter than $V = 19.0$ mag were monitored. The second campaign with the ST70 telescope was performed on the following seven nights: 2007 August 7, 9–11, September 16 and October 4–5. The exposure time was 300 s with a typical seeing of $3''$. During 25 hours of monitoring 198 images in $V$ were acquired. Due to a smaller field of view, only 4800 stars down to $V = 19.5$ mag were observed. The campaign was also supported by observations gathered with the TSC90 instrument on the night 2007 September 6. As a result of additional 5 hours of monitoring, 17 600 s long exposures were obtained in $V$.

The collected observations were reduced with the software pipeline developed for the Semi-Automatic Variability Search[1] sky survey (Niedzielski et al. 2003; Maciejewski & Niedzielski 2005). CCD frames were processed with a standard procedure including subtraction of dark frames and flat-fielding. The instrumental stellar magnitudes were derived by means of differential aperture photometry against the selected standard stars. The aperture diameter was calculated for individual objects as $3\sigma$ of the stellar profile. The instrumental coordinates of stars were transformed into equatorial ones, based on the positions of stars brighter than 16 mag extracted from the Guide Star Catalog.

The optical data were supported with the near-infrared $JH$ photometry extracted from the 2-Micron All Sky Survey (2MASS, Skrutskie et al. 2006) [2]. The extraction radius was set to $34'$ around cluster centers.

## 3. DATA ANALYSIS

Both clusters presented in this research were analyzed in a similar way. At the first step, radial density profiles (RDPs) based on 2MASS photometry were analyzed. According to Maciejewski & Niedzielski (2007) both clusters are larger than the catalogue data indicate. It was suggested that the presented cluster sizes could be underestimated by earlier authors due to limited fields of view of their instruments. Moreover, Sharma et al. (2006) noted that open clusters appeared to be larger in the near-infrared than in the optical passbands. Therefore, near-infrared photometry from 2MASS was used to study the structure of the clusters.

[1] http://www.astri.uni.torun.pl/~gm/SAVS

[2] http://www.ipac.caltech.edu/2mass/releases/allsky

The central coordinates of the two clusters were redetermined using an algorithm proposed by Maciejewski & Niedzielski (2007). Then RDPs were constructed by counting stars inside concentric rings of the $1'$ width centered on the redetermined cluster center. Further, by least-square fitting the two-parameter King (1966) surface density profile, the central density $f_0$, the core radius $r_{\rm core}$ and the density of the background stellar field $f_{\rm bg}$ were derived. To find the limiting radius $r_{\rm lim}$, the outermost point above the maximal background density level $f_{\rm max} = f_{\rm bg} + 3\sigma_{\rm bg}$ was sought. Then $r_{\rm lim}$ was interpolated as the point where the line connecting the outermost point above $f_{\rm max}$ and the next point below $f_{\rm max}$ crosses the $f_{\rm max}$ level.

At the next step, the two-color diagrams $U$–$B$ vs. $B$–$V$ were plotted to determine interstellar reddening $E_{B-V}$ by shifting the Schmidt-Kaler (1982) main sequence along the reddening vector with a normal slope of $E_{U-B}/E_{B-V} = 0.72$. The fitting procedure was performed by the least square method with a step of $\Delta E_{B-V} = 0.01$, skipping the faintest stars to increase the reliability of the fit.

Photometric parameters, such as the distance modulus and the age of the cluster, were derived by fitting a set of theoretical Padova isochrones of metallicities $Z = 0.004$, 0.008 and 0.019 (Girardi at al. 2002) to the observed CMDs plotted for central parts of the clusters. To minimize the field star contamination, only stars lying within a radius of $2r_{\rm core}$ were taken into account. While the contamination of CMDs by the field stars appeared to be relatively small, no decontamination procedure was performed. Before applying the isochrone fitting procedure, stars with extreme values of $B$–$V$ were rejected after a visual inspection. For every theoretical isochrone of a given age, a grid of $\chi^2$ was calculated in steps of 0.01 mag for a number of observed distance moduli and a fixed reddening. The isochrone with the lowest $\chi^2$ value was taken as the final result.

The fitting procedure was repeated independently in the $J$ vs. $J$–$H$ diagram. In this case the CMD for the cluster region within $2r_{\rm core}$ was decontaminated for the contribution of field stars. Since it is impossible to identify individual cluster members from photometry alone, the field star contribution can be removed from CMD in a statistical way. The procedure applied was adopted from Maciejewski & Niedzielski (2007). Two CMDs were built: one for the cluster region and another for an offset field. The offset field was defined as a ring of the inner radius $r_{\rm lim} + 1'$ and the outer radius of $34'$. Both CMDs were divided into two-dimensional bins of $\Delta J = 0.4$ and $\Delta(J - H) = 0.1$ size. The number of stars within each box was counted. Then the cleaned cluster CMD was built by subtracting the number of stars in the offset box from the number of stars in the corresponding cluster box. The latter number was weighted by the cluster to offset field area ratio. Knowing the number of cluster stars occupying any given box in the clean CMD, the algorithm randomly excludes the required number of stars with adequate $J$ magnitude and $J$–$H$ color index from the cluster field. Finally, the list of stars in each cleaned cluster box was saved and used for constructing the decontaminated near-infrared CMD. The fixed reddening $E_{J-H}$ and distance were calculated assuming relations $E_{J-H} = 0.33\,E_{B-V}$ and $A_J = 0.282 A_V$ (Rieke & Lebofski 1985), where $A_J$ and $A_V$ are interstellar extinctions in the $J$ and $V$ passbands.

A map of scaled chi-square statistics $\Delta\chi^2$ was generated to estimate the uncertainties in $m$–$M$ and log (age). Here, $\Delta\chi^2$ was defined as

$$\Delta\chi^2 = \frac{\chi^2 - \chi^2_{\rm min}}{\chi^2_{\rm min}/\nu}\,, \tag{7}$$

where $\chi^2_{\rm min}$ is the minimum $\chi^2$ and $\nu$ is the number of degrees of freedom (equal to 2 in this case, Burke at al. 2004). The projection of the $\Delta\chi^2 = 1.0$ contour on the parameter axes was taken as the $1\sigma$ error.

The candidates for new variable stars were selected from a $V$-band database using the analysis of the variance method (ANOVA, Schwarzenberg-Czerny 1996). The search for candidates was performed on all detected stars what allowed us to find out variables with very small amplitudes, comparable to our photometric precision. All of the variable-star candidates were verified by a careful visual inspection.

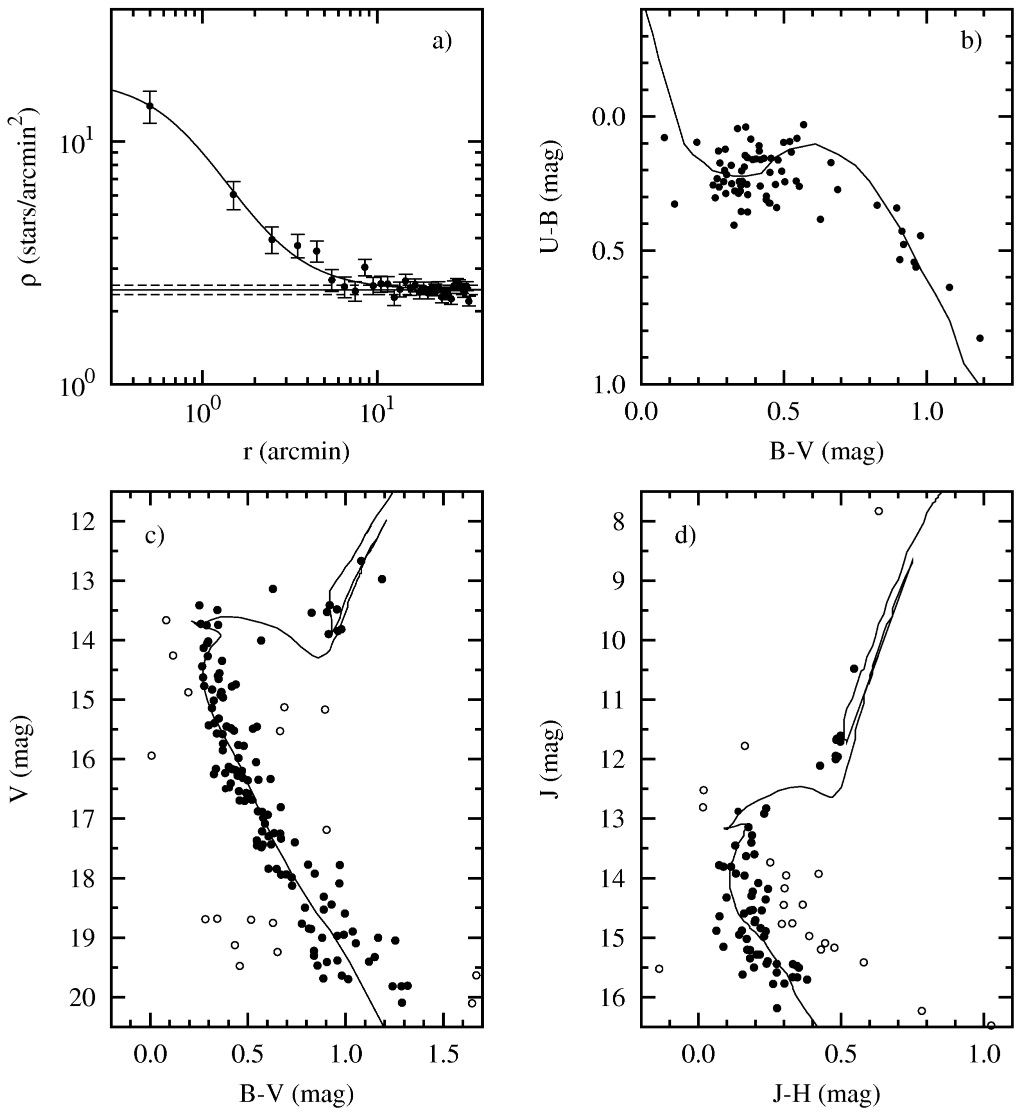


**Fig. 1.** Results of photometric analysis of NGC 2266: (a) the radial density profile, (b) the two-color diagram with the shifted Schmidt-Kaler main sequence, (c) the optical color-magnitude diagram and (d) the near-IR color-magnitude diagram. The open circles in panels (c) and (d) denote outstanding points that were manually removed before running the isochrone-fitting procedure. The best-fit isochrones with the parameters listed in Table 2 are shown.

## 4. RESULTS

### *4.1. NGC 2266*

The RDP constructed for NGC 2266 can be approximated by King's profile very well (Figure 1a). However, a noticeable star-density excess can be observed between $r = 3'$ and $5'$. Interesting enough, the cluster's apparent diameter was found to be similar in optical and near-IR bands. The value $r_{\rm lim} = 6.2'$ obtained in this study from 2MASS photometry is in good agreement with $5.9'$ obtained by optical data by Maciejewski & Niedzielski (2007). The cluster core radius, $0.85 \pm 0.04'$, appeared to be slightly smaller than the value $1.2 \pm 0.1'$ presented in the latter work. This difference, together with greater central star density from the near-IR data, can be understood as a result of the incompleteness of the optical data. The results are summarized in Table 1.

The reddening $E_{B-V} = 0.17$ was derived from the $U$–$B$ vs. $B$–$V$ diagram (Figure 1b) for the stars brighter than $V = 15.5$. This value is considerably greater than the values reported in previous investigations. As a result of independent isochrone fitting to both the optical and near-IR data sets, similar values of basic cluster parameters were derived (Table 2). Our results are consistent with the values reported in Maciejewski & Niedzielski (2007). The best fit was obtained for the isochrone of a subsolar metallicity of $Z = 0.004$ ([Fe/H] $= -0.68$) and age of $\log(\text{age [yr]}) = 9.05$–$9.10$, with the mean value $9.08 \pm 0.04$. The mean distance to the cluster is $2.8 \pm 0.15$ kpc. The CMDs with best solutions are plotted in Figures 1c and 1d.

In the field of NGC 2266, 12 short period variables were found (11 eclipsing binary systems and one pulsating star of RRC type). Their phased light curves in $V$ passband are presented in Figure 2, and the light-curve parameters are summarized in Table 3. None of them is located either within the cluster radius $r_{\rm lim}$ nor in the direct vicinity of the cluster. The nearest variable (V3) is located at a distance of $9.3'$ from the cluster center. The accuracy of our photometry was 0.025 mag for stars brighter than $V = 16$ and gradually decreased reaching 0.2 mag for the faintest stars at $V = 18.6$ and $V = 19.4$ for the observations from Piwnice and Rozhen, respectively.

### *4.2. NGC 7762*

The RDP built for NGC 7762 (Figure 3a) clearly indicates that the cluster's apparent diameter in the near-IR is greater the than values reported in previous studies. The limiting radius was estimated to be $23.5'$. By fitting the King surface density profile the core radius was found to be $3.35 \pm 0.20'$. The central star density from the near-IR data, $f_0 = 4.85 \pm 0.18$ stars/(arcmin)$^2$ compares well to the value of $5.06 \pm 0.29$ stars/(arcmin)$^2$ reported in Maciejewski & Niedzielski (2007). The structural parameters derived are given in Table 1.

The analysis of the $U$–$B$ vs. $B$–$V$ diagram (Figure 3b) gives $E_{B-V} = 0.59$ for stars brighter than $V = 14.3$. From the isochrone fitting to the optical data, the age, $\log(\text{age [yr]}) = 9.4^{+0.25}_{-0.14}$ and a distance of $0.77^{+0.19}_{-0.27}$ kpc were obtained accepting the solar metallicity. However, our attempts failed to run the fitting algorithm for the near-IR data with a fixed $E_{J-H}$ value which was calculated from $E_{B-V}$ using the ratio of color excesses for the normal extinction law. This suggests that the interstellar extinction law towards NGC 7762 may be different. Therefore, the $E_{J-H}$ parameter was let free in the fitting procedure. The solution stabilizes for

**Table 1.** Structural parameters of the investigated clusters obtained from the King profile fit.

| Cluster | Coordinates J2000 | $r_{\rm lim}$ ($'$) | $r_{\rm core}$ ($'$) | $f_0$ $\left(\frac{\rm stars}{\rm arcmin^2}\right)$ | $f_{\rm bg}$ $\left(\frac{\rm stars}{\rm arcmin^2}\right)$ |
|---|---|---|---|---|---|
| NGC 2266 | 064318+265854 | 6.2 | $0.85 \pm 0.04$ | $15.6 \pm 0.5$ | $2.45 \pm 0.04$ |
| NGC 7762 | 234953+680307 | 23.5 | $3.4 \pm 0.2$ | $4.9 \pm 0.2$ | $4.58 \pm 0.05$ |

**Table 2.** Basic parameters for NGC 2266 obtained from the isochrone fitting. $E$ denotes the color excess $E_{B-V}$ and $E_{J-H}$ in the optical and near-IR bands, respectively, $Z$ is the metallicity, $m$–$M$ is the apparent distance modulus and $d$ is the cluster distance.

| Data | $E$ (mag) | log (age) | $Z$ | $m$–$M$ (mag) | $d$ (kpc) |
|---|---|---|---|---|---|
| Optical | 0.17 | $9.05^{+0.17}_{-0.20}$ | 0.004 | $12.8^{+0.5}_{-0.8}$ | $2.9^{+0.7}_{-1.2}$ |
| Near-IR | 0.06 | $9.10^{+0.17}_{-0.18}$ | 0.004 | $12.3^{+0.7}_{-0.5}$ | $2.7^{+1.0}_{-0.7}$ |

**Table 3.** Light-curve parameters for the variable stars discovered in the field of NGC 2266. $V_{\rm max}$ is the magnitude at maximum, $B$–$V$ is the color index at maximum light, $\Delta V$ is the $V$ amplitude, $P$ is the period, $T_0$ in HDJ–2453800 is the time of primary minimum for eclipsing binaries or maximum for pulsating stars. $r_{\rm d}$ denotes the angular distance from the cluster center.

| ID | Coordinates J2000 | $V_{\rm max}$ (mag) | $B$–$V$ (mag) | $\Delta V$ (mag) | $P$ (day) | $T_0$ (day) | Type | $r_{\rm d}$ ($'$) |
|---|---|---|---|---|---|---|---|---|
| V1 | 064221+264234 | 16.38 | 16.38 | 0.57 | 0.4259 | 18.4165 | EA | 21.0 |
| V2 | 064252+272256 | 15.64 | 15.64 | 0.29 | 0.4423 | 19.5059 | EW | 24.6 |
| V3 | 064302+265035 | 15.74 | 15.74 | 0.44 | 0.5484 | 18.1306 | EB | 9.3 |
| V4 | 064313+271432 | 15.75 | 15.75 | 0.16 | 0.5812 | 18.1307 | RRC | 15.5 |
| V5 | 064334+263411 | 14.62 | 14.62 | 0.36 | 0.2942 | 17.8637 | EW | 25.1 |
| V6 | 064343+263127 | 16.17 | 16.17 | 0.38 | 0.3407 | 17.9379 | EW | 28.2 |
| V7 | 064355+263401 | 16.94 | 16.94 | 0.60 | 0.9406 | 18.6686 | EA | 26.3 |
| V8 | 064415+273025 | 15.35 | 15.35 | 0.47 | 0.3899 | 17.7495 | EW | 31.3 |
| V9 | 064430+264020 | 14.29 | 14.29 | 0.16 | 0.5048 | 18.0581 | EW | 24.5 |
| V10 | 064436+271127 | 16.94 | 16.94 | 0.26 | 0.2581 | 17.8422 | EW | 21.1 |
| V11 | 064455+271543 | 15.63 | 15.63 | 0.41 | 0.2904 | 17.6248 | EW | 27.1 |
| V12 | 064459+265902 | 15.69 | 15.69 | 0.15 | 0.9308 | 18.6921 | EA | 22.3 |

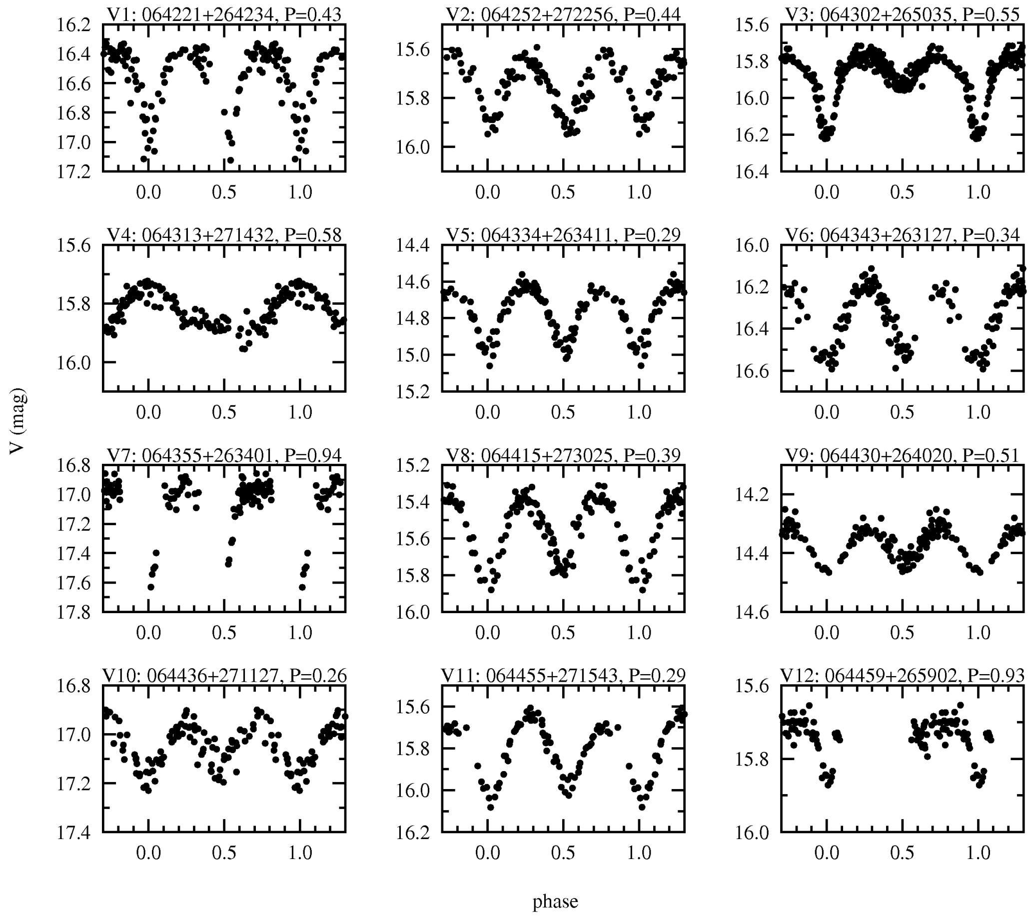


**Fig. 2.** Light curves of the variable stars discovered in the field of NGC 2266.

a solar-metallicity isochrone of log (age [yr]) = $9.35^{+0.19}_{-0.15}$, $E_{J-H} = 0.11$ and $(m{-}M)_J$ = $10.3^{+0.5}_{-0.6}$ mag. While it is not possible to transform the derived distance modulus into the true distance due to probably anomalous reddening law, the convergence of the cluster's age determinations is unequivocal. Thus, the mean age of the cluster is log (age [yr]) = 9.38±0.04. The parameters obtained are summarized in Table 4 and the CMDs with the best solutions are plotted in Figures 3c and 3d.

To verify whether the diameter of NGC 7762, reported in this study, is not overestimated, the CMD-decontamination procedure was applied for the outermost ($18.5' < r < 24.5'$) region of the cluster. The cleaned CMD for this halo ring is displayed in Figure 4a, where the best-fit isochrone is also shown. As one can see, the main sequence is well visible for $J \leq 15.0$, while for fainter stars the stellar background contamination dominates. This fact supports the large cluster radius.

As a result of 55 hours of monitoring, 16 periodic variables were detected in the field of NGC 7762. Their phased light curves in the $V$ passband are displayed in Figure 5, and the light-curve parameters are given in Table 5. Three of them, V1, V5 and V16, are not members of the cluster due to their large distance from the center. The remaining variables are located within the cluster limiting radius. To discuss their membership, they were marked by their numbers in Figure 4b. The variable V2 was initially classified as a cepheid. However, its period determination

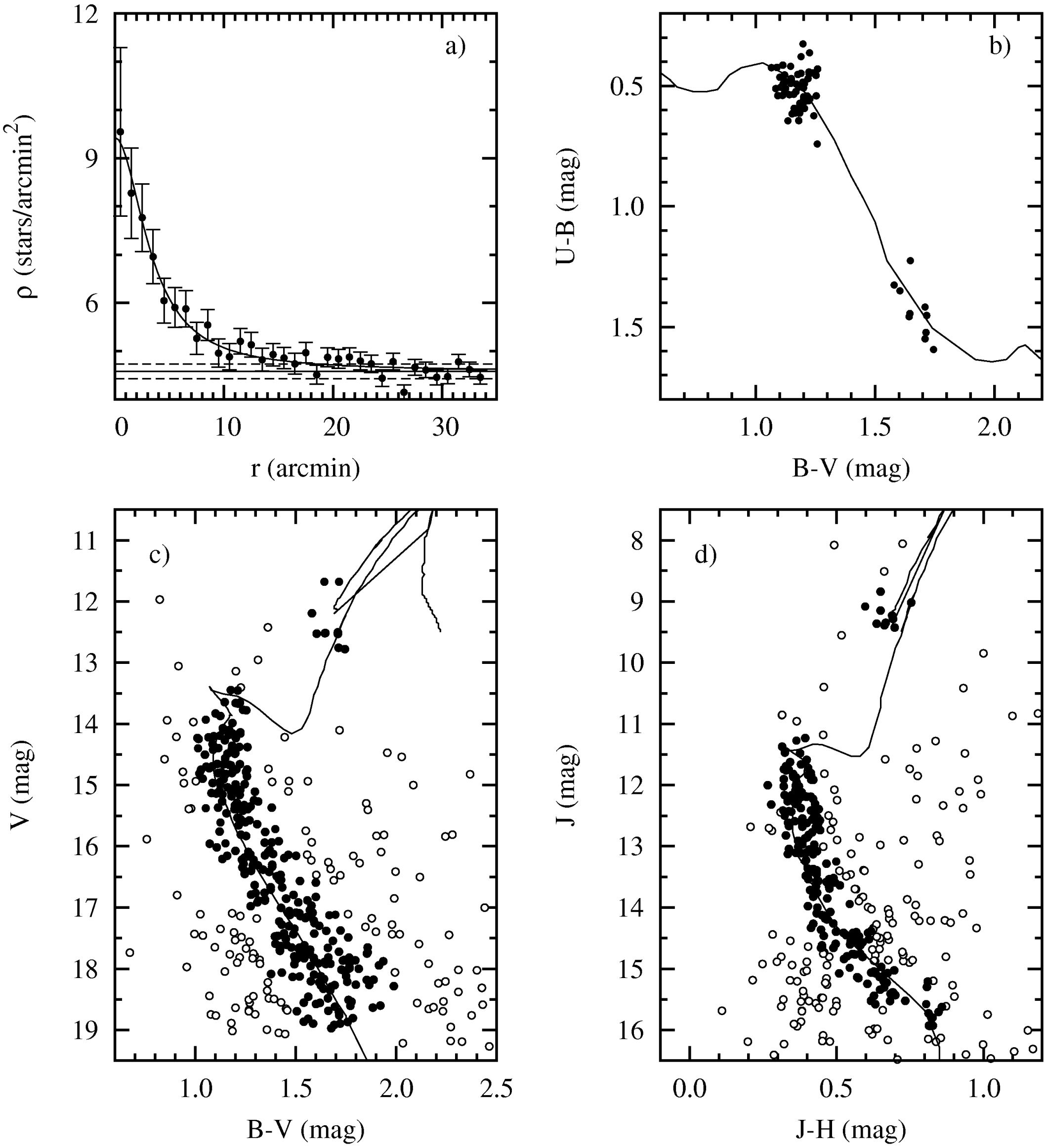

**Fig. 3.** The same as in Figure 1, but for NGC 7762. The parameters of the best-fit isochrones shown in panels (c) and (d) are given in Table 4.

**Table 4.** Basic parameters for NGC 7762 obtained from the isochrone fitting. $E$ denotes the color excess $E_{B-V}$ and $E_{J-H}$ in optical and near-IR passbands, respectively; $Z$ is the metallicity, $m$–$M$ is the apparent distance modulus and $d$ is the cluster distance.

| Data | $E$ (mag) | log (age) | $Z$ | $m$–$M$ (mag) | $d$ (kpc) |
|---|---|---|---|---|---|
| Optical | 0.59 | $9.40^{+0.25}_{-0.14}$ | 0.02 | $11.3^{+0.5}_{-0.8}$ | $0.8^{+0.2}_{-0.3}$ |
| Near-IR | 0.11 | $9.35^{+0.19}_{-0.15}$ | 0.02 | $10.3^{+0.5}_{-0.6}$ | – |

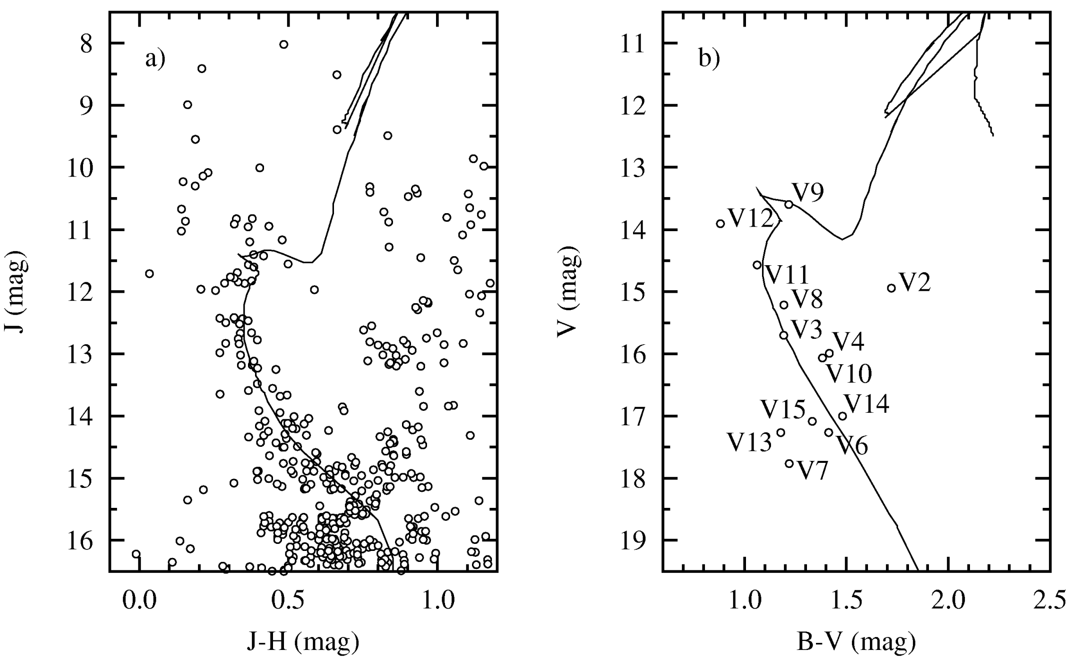


**Fig. 4.** Panel (a). The field-star decontaminated CMD for the outermost ($18.5' < r < 24.5'$) region of NGC 7762. Panel (b). Location of the variable stars detected within the cluster radius. The lines in both panels are the best-fit isochrones described in Table 4.

**Table 5.** Light-curve parameters for the variable stars detected in the field of NGC 7762. Designations are the same as in Table 3. $T_0$ is given in HDJ–2453000

| ID | Coordinates J2000 | $V_{max}$ (mag) | $B$–$V$ (mag) | $\Delta V$ (mag) | $P$ (day) | $T_0$ (day) | Type | $r_d$ (′) |
|---|---|---|---|---|---|---|---|---|
| V1 | 234725+673605 | 14.25 | 1.00 | 0.09 | 2.4752 | 681.8967 | DCEP: | 30.4 |
| V2 | 234731+681850 | 14.94 | 1.72 | 0.53 | 14.8883 | 708.2187 | DCEP: | 20.6 |
| V3 | 234803+680413 | 15.70 | 1.19 | 0.07 | 0.4852 | 675.3812 | EW | 10.3 |
| V4 | 234804+681129 | 15.99 | 1.42 | 0.27 | 0.4591 | 674.4743 | EW | 13.2 |
| V5 | 234816+672229 | 14.59 | 1.13 | 0.16 | 0.5931 | 676.3697 | EW | 41.6 |
| V6 | 234848+674628 | 17.27 | 1.41 | 0.73 | 0.6130 | 675.5504 | EA/EW | 17.7 |
| V7 | 234910+680229 | 17.76 | 1.22 | 0.86 | 0.4519 | 674.3051 | EB | 4.1 |
| V8 | 234918+680955 | 15.21 | 1.19 | 0.21 | 0.09235 | 674.41294 | DSCT | 7.5 |
| V9 | 235005+680204 | 13.60 | 1.22 | 0.04 | 0.5487 | 675.6750 | $\gamma$DOR: | 1.5 |
| V10 | 235019+680211 | 16.06 | 1.38 | 0.12 | 0.3372 | 674.4759 | EW/EB | 2.6 |
| V11 | 235028+682409 | 14.57 | 1.06 | 0.05 | 0.6905 | 676.4637 | $\gamma$DOR: | 21.3 |
| V12 | 235033+675932 | 13.90 | 0.88 | 0.23 | 4.7733 | 684.9331 | E: | 5.2 |
| V13 | 235054+680407 | 17.26 | 1.18 | 0.35 | 0.6932 | 1321.6475 | EW | 5.8 |
| V14 | 235119+682408 | 17.00 | 1.48 | 0.50 | 0.3102 | 674.9397 | EW | 22.5 |
| V15 | 235120+674506 | 17.09 | 1.33 | 0.56 | 1.4453 | 675.5850 | EB | 19.8 |
| V16 | 235315+672312 | 15.30 | 1.22 | 0.52 | 0.7288 | 675.3926 | EB | 44.2 |

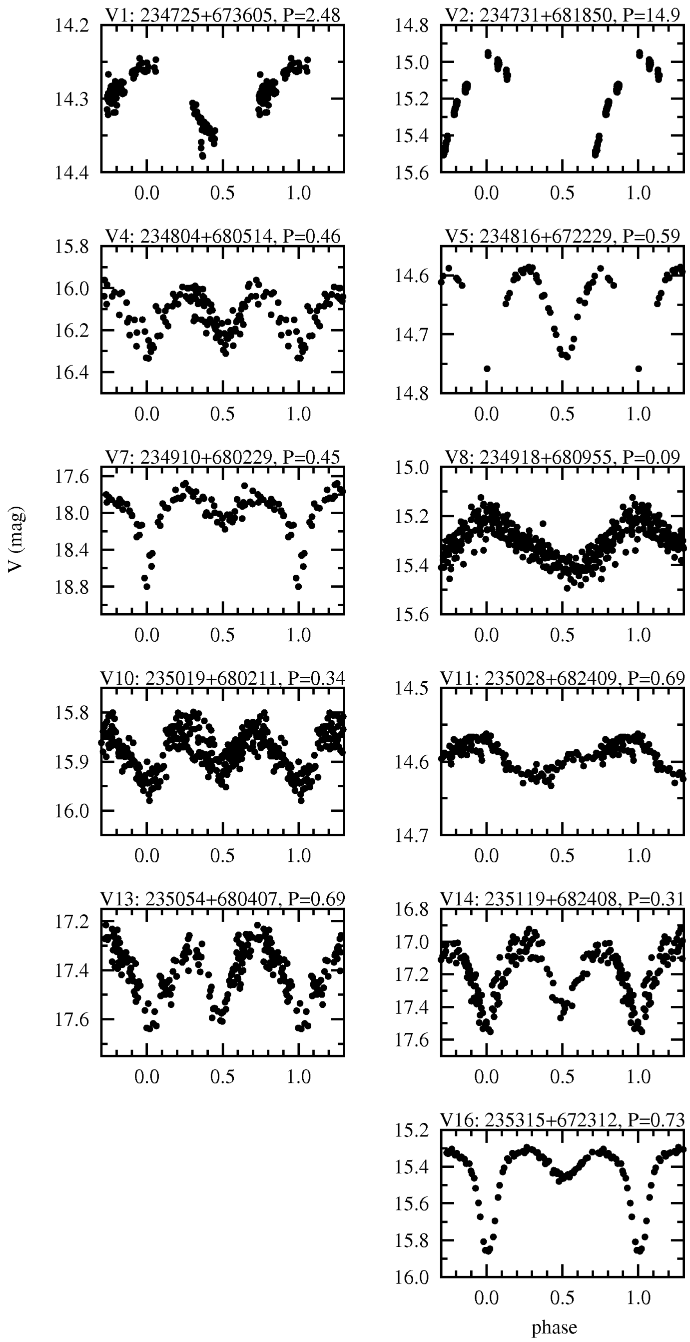


**Fig. 5.** Light curves of the variable stars detected in the field of NGC 7762.

is doubtful. Its location in the CMD clearly indicates that this star is a background object.

The variables V3, V4, V6, V10 and V14 are short period contact or semi-detached eclipsing systems the location of which in the CMD allows to treat them as the potential cluster members. To verify their membership, the absolute magnitudes were calculated in two ways under the assumption that these variables are cluster members. The absolute magnitude $M_V^{\rm iso}$ of the system may be estimated

**Table 6.** Absolute magnitudes of EW and EB systems located within the cluster radius calculated in two different ways (see the text for details).

| ID | $M_V^{\rm iso}$ (mag) | $M_V^{\rm EW}$ (mag) |
|---|---|---|
| V3 | 4.43 | 3.34 |
| V4 | 6.72 | 4.12 |
| V6 | 6.00 | 3.55 |
| V10 | 4.79 | 4.61 |
| V14 | 5.73 | 5.08 |

from its maximum brightness $V_{\rm max}$ and the cluster distance modulus $m-M$ as

$$M_V^{\rm iso} = V_{\rm max} - (m-M)\,. \tag{8}$$

On the other hand, the absolute magnitude $M_V^{\rm EW}$ can also be obtained from the empirical formula

$$M_V^{\rm EW} = -4.44 \log P + 3.02(B-V)_0 + 0.12\,, \tag{9}$$

where $P$ is the period of variation in days and $(B-V)_0$ is the dereddened color index (Ruciński & Duerbeck 1997; Ruciński 2004). If the system belongs to the cluster, both values should be identical within a typical error of 0.25 mag (Ruciński 2004). Table 6 shows that V10 is the only eclipsing system which belongs to NGC 7762. The remaining variables appear to be background-field binaries. The star V10 is located near the cluster center which is in agreement with the cluster internal dynamics (binary systems should occupy the central part of the cluster). The variability of V10 was discovered by Szabo (1999) who concluded that the shape of its light variation and position in the CMD indicated an eclipsing binary nature.

The location of the eclipsing binaries V7, V13 and V15 in the CMD below the main sequence of the cluster makes their membership very unlikely.

V9 was classified as a pulsating variable star with a period of 13 hours and the light-curve morphology typical of $\gamma$ Doradus pulsators. It is a bright star located near the cluster turn-off point. Assuming it belongs to NGC 7762, its absolute magnitude $M_V$ would be 2.33 mag what is in agreement with the values typical of $\gamma$ Dor variables (e.g., Henry & Fekel 2002). Its small distance from the cluster center also supports the membership because most massive stars are expected to occupy the inner region of the system. The variability of V9 was reported by Szabo (1999) who suggested that the star could be a $\gamma$ Doradus type variable.

The light curve of V8 reveals changes typical of $\delta$ Scuti pulsators. Assuming the star belongs to the cluster, its absolute magnitude $M_V$ would be 3.9 mag – the value too faint compared to the expected range between –2 and +2 mag (McNamara & Augason 1962). Therefore, we concluded that V8 belongs to the background.

The light curve of V11 shows variations typical of $\gamma$ Dor pulsators. Assuming that the star belongs to the cluster, its absolute magnitude $M_V$ would be 3.3 mag, what is in the range of values typical of late-type $\gamma$ Dor variables (see, e.g., Henry & Fekel 2002). However, one must note that the star is located in the outskirts of the cluster where the probability of finding the most massive stars is low due to cluster's internal dynamics. As a result we cannot definitely state that V11 is a member of NGC 7762.

We interpreted the star V12 as an eclipsing system. It is located at the extension of the cluster's main sequence where blue stragglers are expected. More observations are needed to establish the status of this star.

Light curve of GSC 4449-1434, the variability of which was reported by Szabo (1999), was found to exhibit constant brightness during our survey.

## 5. SUMMARY

The analysis of the structure of NGC 2266 resulted in the determination of the cluster limiting radius of $6.2'$ from the near-IR dataset. No evidence was found for the existence of an extended corona of the cluster. The basic parameters of the cluster such as the mean log (age yr) = $9.08 \pm 0.04$ and the mean distance $2.80 \pm 0.15$ kpc do not differ much from the previous determinations. However, interstellar reddening, $E_{B-V} = 0.17$, appears to be larger than earlier estimates. The isochrones fitting yields a self-consistent solution with a subsolar metallicity of $Z = 0.004$ ([Fe/H] $= -0.68$) which is in agreement with earlier studies. No variable stars located within the cluster radius were found, though the cluster was monitored for more than 45 hours and 12 out of over 7200 field stars were found to reveal light changes. This result, together with the observation of a well defined narrow main sequence, suggests that NGC 2266 is quite poor in binary stars.

NGC 7762 was found to be a very large stellar system with an extended corona well visible in the near-IR and extending $23.5'$ from the cluster center. The mean log (age [yr]) = $9.38 \pm 0.04$ and the distance $0.8^{+0.2}_{-0.3}$ kpc and solar metallicity, determined by the isochrone fitting, are in good agreement with the values reported in previous investigations. The interstellar reddening is found to be $E_{B-V} = 0.59$. However, the analysis of the CMD in the near-IR suggests that the interstellar extinction law in this direction can be different from normal, resulting in $E_{J-H} = 0.11$. As a result of 55 hours of monitoring of 5500 stars 16 variable stars have been found in the cluster field. Only two of them, a short-period eclipsing system and a pulsating star of $\gamma$ Dor type, were found to be likely members of NGC 7762.

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