

BOAO PHOTOMETRIC SURVEY OF GALACTIC OPEN CLUSTERS. III. CZERNIK 24 AND CZERNIK 27

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ABSTRACT

We present *BV* CCD photometry for the open clusters Czernik 24 and Czernik 27. These clusters have never been studied before, and we provide, for the first time, the cluster parameters; reddening, distance, metallicity and age. Czernik 24 is an old open cluster with age 1.8 ± 0.2 Gyr, metallicity $[\text{Fe}/\text{H}] = -0.41 \pm 0.15$ dex, distance modulus $(m - M)_0 = 13.1 \pm 0.3$ mag ($d = 4.1 \pm 0.5$ kpc), and reddening $E(B - V) = 0.54 \pm 0.12$ mag. The parameters for Czernik 27 are estimated to be age $= 0.63 \pm 0.07$ Gyr, $[\text{Fe}/\text{H}] = -0.02 \pm 0.10$ dex, $(m - M)_0 = 13.8 \pm 0.2$ mag ($d = 5.8 \pm 0.5$ kpc), and $E(B - V) = 0.15 \pm 0.05$ mag. The metallicity and distance values for Czernik 24 are consistent with the relation between the metallicity and the Galactocentric distance of other old open clusters. We find the metallicity gradient of 51 old open clusters including Czernik 24 to be $\Delta[\text{Fe}/\text{H}]/\Delta R_{gc} = -0.064 \pm 0.009$ dex kpc^{-1} .

Key words : open clusters and associations: individual (Czernik 24 and Czernik 27) — Galaxy: disk — Galaxy: stellar content — Galaxy: structure — Hertzsprung-Russell diagram

I. INTRODUCTION

Open clusters (OCs) are an excellent probe for the study of the structure and evolution of the Galactic disk (Friel 1995). While Lyngå (1987) has published some parameters for over 1200 OCs and Dias et al. (2002, <http://www.astro.iag.usp.br/~wilton/>, version 2.5, 2005 October 3) have presented data for 1753 OCs, only about a few hundreds of OCs have photometry good enough for the estimation of the physical parameters of the clusters (Friel 1993; Phelps, Janes, & Montgomery 1994). Ann et al. (1999) and Ann et al. (2002) have presented the results from the BOAO (Bohyunsan Optical Astronomy Observatory) photometric survey of Galactic OCs which is aimed at observing clusters with few, if any, previous studies, and this paper is the third in this series.

The OCs Czernik 24 and Czernik 27 were first identified by Czernik (1966), and there have been no photometric study for either of these two clusters. The preliminary results presented in a conference proceed-

ings (Park et al. 2001) are superseded by this paper. In this paper we present the first photometric study of Czernik 24 and Czernik 27, and provide the basic parameters. Section II describes the observations and data reduction. Section III and IV present the analysis for Czernik 24 and Czernik 27, respectively. Section V discusses the results and a summary and conclusions are given in Section VI.

II. OBSERVATIONS AND DATA REDUCTION

(a) Observations

BV CCD images of Czernik 24 and Czernik 27 were obtained using the SITE 2048 \times 2048 CCD camera ($24\mu\text{m}$ pixel) at the BOAO 1.8 m telescope on 2000 December 26. The journal of observations of Czernik 24 and Czernik 27 is given in Table 1. The field of view of the CCD image is 11.7×11.7 and the pixel scale is 0.34 pixel $^{-1}$ at the f/8 Cassegrain focus of the telescope. The gain and readout noise are, respectively, 1.8 electrons per ADU and 7 electrons.

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TABLE 1.
OBSERVATION LOG

Cluster	Filter	T_{exp}	Seeing
Czernik 24	<i>B</i>	300 s, 30 s	1.''7
	<i>V</i>	150 s, 12 s	1.''8
Czernik 27	<i>B</i>	300 s, 30 s	2.''0
	<i>V</i>	150 s, 15 s	1.''9

Color maps of Czernik 24 and Czernik 27 are illustrated in Figure 1, which shows that both objects are loose clusters. The centers of Czernik 24 and Czernik 27 are estimated approximately to be at R.A.(2000) = $05^h 55^m 27^s$ and Decl.(2000) = $+20^\circ 52' 59''$ ($X = 444$ pixel and $Y = 1107$ pixel) and R.A.(2000) = $07^h 03^m 22^s$ and Decl.(2000) = $+06^\circ 23' 47''$ ($X = 617$ pixel and $Y = 898$ pixel), respectively. The approximate radii of Czernik 24 and Czernik 27 are estimated to be 290 pixels ($\sim 99''$) and 520 pixels ($\sim 177''$), respectively.

(b) Data Reduction

The original CCD images were bias subtracted and flat-fielded using the standard CCDPROC task within IRAF*. Instrumental magnitudes of the stars in the CCD images were obtained using the digital stellar photometry reduction program IRAF/DAOPHOT (Stetson 1987; Davis 1994). The resulting instrumental magnitudes were transformed on to the standard system using the standard stars (Landolt 1992) observed on the same night. The night of observation was considered partly semi-photometric, so we secured our photometry using a secondary method as following. OC Berkeley 29 was observed on the same night we obtained images of Czernik 24 and Czernik 27. We derived standard *BV* magnitudes for stars in our Berkeley 29 field and compared with those of Kaluzny (1994)[†] as shown in Figure 2. Using stars in the range $15.0 < B_{BOAO} < 19.0$ and $14.5 < V_{BOAO} < 18.0$, we computed offsets of $\Delta B = 0.276 \pm 0.021$ and $\Delta V = 0.212 \pm 0.013$ (this study - Kaluzny). Finally, these magnitude offsets were applied to our photometry of Czernik 24 and Czernik 27 fields.

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[†]We note that the *BVI* magnitudes of Kaluzny (1994) and Tosi et al. (2004) are in excellent agreement (see Figure 3 of Tosi et al. 2004).

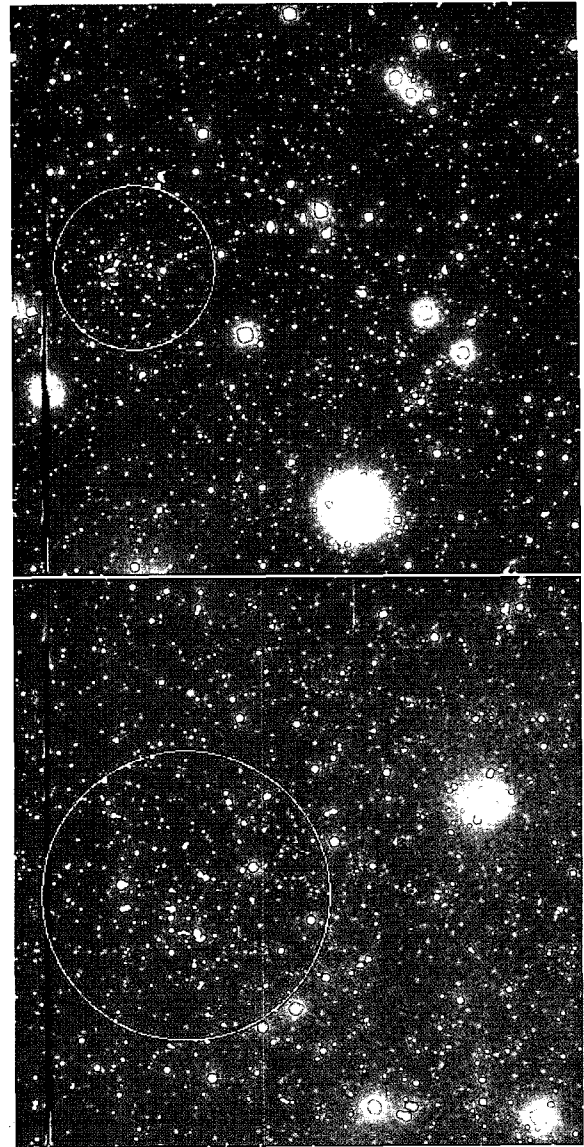


Fig. 1.— Color images of Czernik 24 (upper panel) and Czernik 27 (lower panel). The approximate sizes of the clusters are denoted as circles with radius of $\sim 99''$ and $\sim 177''$ for Czernik 24 and Czernik 27, respectively. North is at the top and east is to the left. The size of each field is $11'.7 \times 11'.7$.

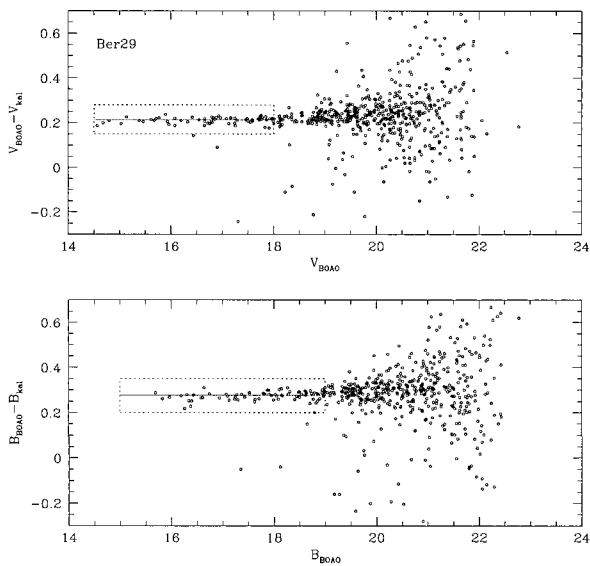


Fig. 2.— Comparison of our B, V photometry with the one in Kaluzny (1994). The differences of the two studies were estimated to be $\Delta B = 0.276 \pm 0.021$ and $\Delta V = 0.212 \pm 0.013$ (this study – Kaluzny) from the box regions of dotted lines.

III. ANALYSIS FOR CZERNIK 24

(a) Color-Magnitude Diagrams

Figure 3 shows the $V - (B - V)$ color-magnitude diagram (CMD) of the measured stars in the observed region in Czernik 24. The CMD of the central region (lower panel) consists mostly of the members of Czernik 24 with some possible contamination of field stars. Some noticeable features seen in the CMDs of Czernik 24 are: (i) a well-defined main sequence, the top of which is located at $V \approx 16.5$ mag; (ii) a gap at $V \approx 17.7$ mag in the main sequence; (iii) a few red giant clump (RGC) stars on the red giant branch sequence around $(B - V) \approx 1.4$ and $V \approx 15.5$ mag, which is noted by a square in Figure 3; and (iv) few stars along the locus of the red giant branch.

(b) Reddening

Since Czernik 24 is located at low Galactic latitude ($b = -2.^\circ 21$), it is expected that the interstellar reddening toward Czernik 24 could be significant. We have estimated the reddening toward Czernik 24 using the mean color of the RGC stars. It is known that the magnitudes and colors of the RGC stars in old open clusters show small variations (Cannon 1970; Janes & Phelps 1994). Janes & Phelps (1994) estimated the mean color and magnitude of the RGC in old open clusters to be $(B - V)_{0,RGC} = 0.87 \pm 0.12$, and $M_{V,RGC} = 0.59 \pm 0.46$, when the V magnitude difference between the RGC and the main-sequence turn-

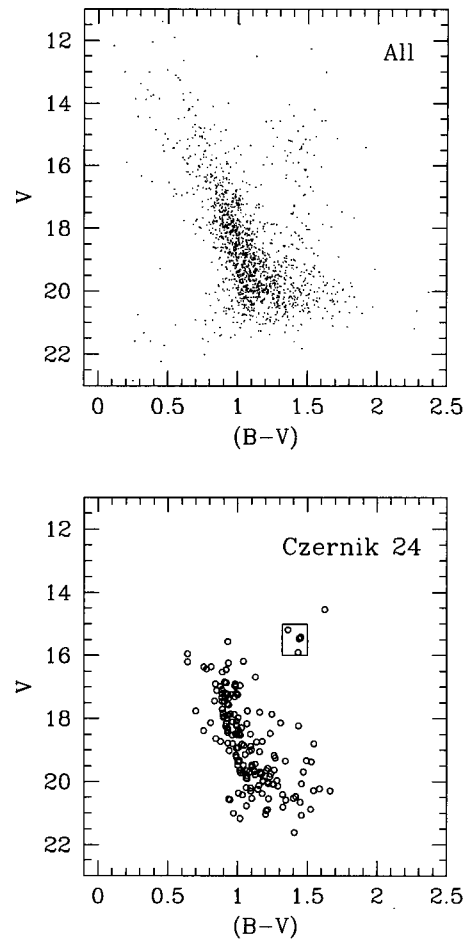


Fig. 3.— $V - (B - V)$ color-magnitude diagrams of Czernik 24. Upper panel is for the entire region, and lower panel is for the central region of Czernik 24 denoted as a circle in Figure 1 ($r < 100''$). The square represents the position of the red giant clump.

off of the clusters, δV , is less than one. The mean color and the mean magnitude of the RGC of Czernik 24 are estimated to be $(B - V)_{RGC} = 1.41 \pm 0.01$ and $V_{RGC} = 15.50 \pm 0.05$ mag, respectively, while the main-sequence turn-off magnitude and δV are estimated to be 16.4 ± 0.1 mag 0.9 ± 0.2 mag, respectively. Therefore, the resulting reddening value is estimated to be $E(B - V) = (B - V)_{RGC} - (B - V)_{0,RGC} = 0.54 \pm 0.12$.

(c) Isochrone Fitting

We derive the cluster parameters by fitting the theoretical isochrones given by the Padova group (Girardi et al. 2000). Figure 4 shows the best matched isochrone, which gives age = 1.8 ± 0.2 Gyr, $[\text{Fe}/\text{H}] = -0.41 \pm 0.15$ dex, and the true distance modulus $(m - M)_0 = (V - M_V) - 3.1 \times E(B - V) = 13.1 \pm 0.3$

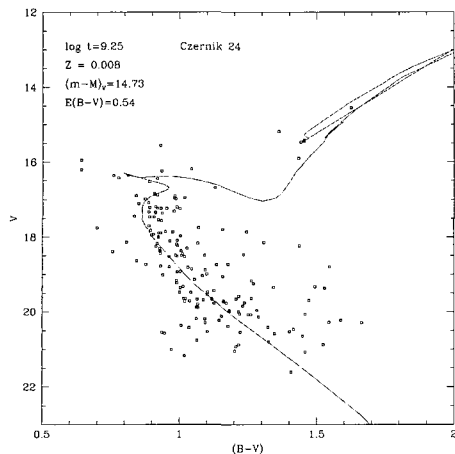


Fig. 4.— Isochrone fitting for Czernik 24 in the $V - (B - V)$ color-magnitude diagram. The solid line represents the Padova isochrone for age = 1.8 Gyr, $[\text{Fe}/\text{H}] = -0.41$ dex, shifted according to the reddening and distance of Czernik 24.

($d = 4.1 \pm 0.5$ kpc). The derived age is consistent with the presence of RGC, confirming that Czernik 24 is a cluster consisting of stars that evolved away from the main sequence.

IV. ANALYSIS FOR CZERNIK 27

(a) Color-Magnitude Diagrams

Figure 5 shows the $V - (B - V)$ CMD of the measured stars in the observed region in Czernik 27. The CMD of the central region (lower panel) consists mostly of the members of Czernik 27 with some possible contamination of the field stars. Some noticeable features seen in the CMDs of Czernik 27 are: (i) a well-defined main sequence, the top of which is located at $V \approx 14.8$ mag; (ii) a gap at $V \approx 16.2$ mag in the main sequence; and (iii) only a few stars along the locus of the red giant branch. The four stars above the top of the main sequence could be blue stragglers or foreground field stars, which needs further study to clarify.

(b) Isochrone Fitting

Since Czernik 27 is also located at low Galactic latitude ($b = +5.56^\circ$), it is expected that the interstellar reddening toward Czernik 27 could be significant. Unlike in the case of Czernik 24 where there are RGC stars, it is not possible to use the same method to estimate the reddening toward Czernik 27 since there are no RGC stars.

We derive the cluster parameters by fitting the theoretical isochrones given by the Padova group (Girardi et al. 2000). Figure 6 shows the best matched isochrone, which gives age = 0.63 ± 0.07 Gyr, $[\text{Fe}/\text{H}] = -0.02 \pm 0.10$ dex, the true distance modulus $(m - M)_0 = (V - M_V) -$

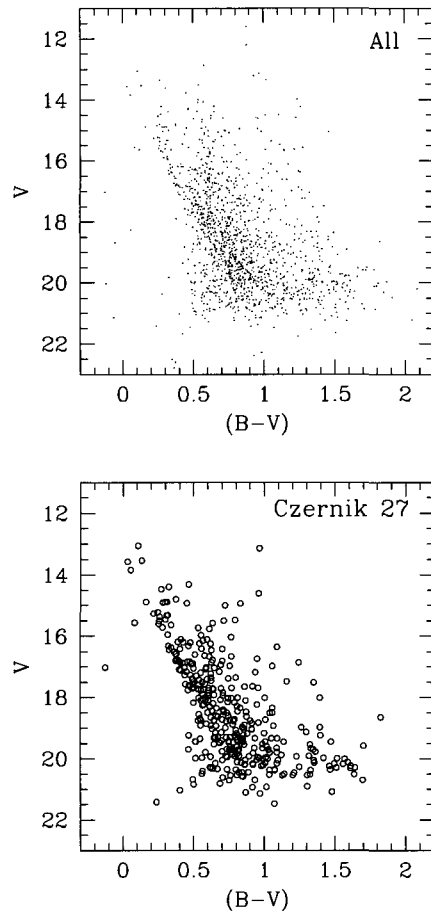


Fig. 5.— $V - (B - V)$ color-magnitude diagrams of Czernik 27. Upper panel is for the entire region, and lower panel is for the central region of Czernik 27 denoted as a circle in Figure 1 ($r \leq 177''$).

$3.1 \times E(B - V) = 13.8 \pm 0.2$ ($d = 5.8 \pm 0.5$ kpc), and the reddening $E(B - V) = 0.15 \pm 0.05$. The rather younger age of Czernik 27 than that of Czernik 24 is consistent with the fact that Czernik 27 has no evolved stars like RGC stars and has only a few stars along the red giant branch. If the four stars above the top of the main sequence are members of the main sequence, then the age might be still younger.

V. DISCUSSION

It is generally believed that the old open clusters in the Galactic disk show metallicity gradient of decreasing metallicities along the Galactocentric distances. It is also supported by the studies of other metallicity tracers such as H II regions, bright blue stars, red giants, and planetary nebulae (Portinari & Chiosi 1999; Hou, Prantzos, & Boissier 2000). Various estimates of

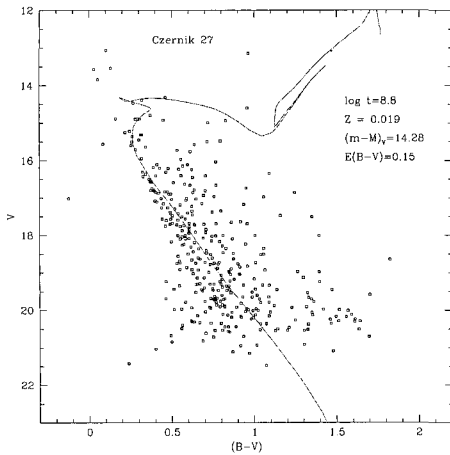


Fig. 6.— Isochrone fitting for Czernik 27 in the $V - (B - V)$ color-magnitude diagram. The solid line represents the Padova isochrone for age = 0.63 Gyr, $[\text{Fe}/\text{H}] = -0.02$ dex, shifted according to the reddening and distance of Czernik 27.

TABLE 2.
SLOPE OF THE GALACTOCENTRIC RADIAL $[\text{Fe}/\text{H}]$
GRADIENT

Paper	$\Delta[\text{Fe}/\text{H}]/\Delta R_{gc}$ (in dex kpc^{-1})
Friel (1995)	-0.091 ± 0.014
Carraro, Ng, & Portinari (1998)	-0.09
Park & Lee (1999)	-0.086 ± 0.011
Friel (1999)	-0.06 ± 0.01
Friel et al. (2002)	-0.059 ± 0.010
Chen, Hou, & Wang (2003)	-0.063 ± 0.008
Kim & Sung (2003)	-0.064 ± 0.010
Salaris, Weiss, & Percival (2004)	-0.055 ± 0.019
Carraro et al. (2004)	-0.03 ± 0.01
Mean value	-0.066 ± 0.019

the metallicity gradient from previous studies on open clusters are summarized in Table 2. From a sample of 69 young OB stars, Daflon & Cunha (2004) have obtained a similar metallicity gradient of -0.042 ± 0.007 dex kpc^{-1} .

Friel et al. (2002) have suggested a hint of slight steepening of the abundance gradient with increasing cluster age, while Salaris et al. (2004) have obtained the opposite trend. As noted by Salaris et al. (2004), it is necessary to increase the cluster sample size with $[\text{Fe}/\text{H}]$ and distance on a homogeneous scale for a better determination of the dependency of the radial metallicity gradient on age. Twarog, Ashman, & Anthony-Twarog (1997) have suggested a sharp discontinuity in the radial metallicity distribution at $R_{gc} = 10$ kpc, which is still in debate (e.g., Bragaglia et al. 2000).

Using the data of 50 old open clusters compiled in

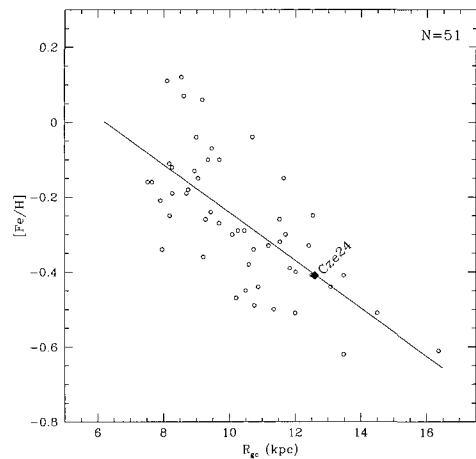


Fig. 7.— Radial abundance gradient for 51 old open clusters. The solid line is a least-squares fit to the data that yields an abundance gradient of $\Delta[\text{Fe}/\text{H}]/\Delta R_{gc} = -0.064 \pm 0.009$ dex kpc^{-1} . Filled square is the position of Czernik 24 based on the parameters obtained in this study.

Kim & Sung (2003, references therein) and those of Czernik 24[‡] obtained in this study, we have plotted the open cluster metallicity $[\text{Fe}/\text{H}]$ versus Galactocentric distance in Figure 7. We adopted the Galactocentric distance of the Sun to be 8.5 kpc. Czernik 24 is shown as a filled diamond in this plot, based on the parameters obtained in this study. The solid line represents a least-squares fit to the data that yields an $[\text{Fe}/\text{H}]$ gradient of $\Delta[\text{Fe}/\text{H}]/\Delta R_{gc} = -0.064 \pm 0.009$ dex kpc^{-1} . This value is in good agreement with the values obtained in other studies (see Table 2), and we find that the metallicity and the Galactocentric distance of Czernik 24 are consistent with the general trend obtained from the studies on old open clusters.

VI. SUMMARY AND CONCLUSIONS

We have presented the analysis of the photometry of the old open clusters Czernik 24 and Czernik 27 using the BOAO 1.8 m telescope and BV CCD imaging data. Since there have been no previous photometric study for these two clusters, we have determined, for the first time, the reddening, distance, metallicity, and age for these clusters and summarized them in Table 3. Czernik 24 is found to be an old open cluster with age 1.8 ± 0.2 Gyr, metallicity $[\text{Fe}/\text{H}] = -0.41 \pm 0.15$ dex, distance modulus $(m - M)_0 = 13.1 \pm 0.3$ mag ($d = 4.1 \pm 0.5$ kpc), and reddening $E(B - V) = 0.54 \pm 0.12$ mag. The parameters for Czernik 27 are estimated to be age = 0.63 ± 0.07 Gyr, $[\text{Fe}/\text{H}] = -0.02 \pm 0.10$ dex, $(m - M)_0 = 13.8 \pm 0.2$ mag ($d = 5.8 \pm 0.5$ kpc), and $E(B - V) = 0.15 \pm 0.05$ mag. The metallicity and distance of the old open cluster Czernik 24 obtained

[‡]Note that Czernik 27 is not an old open cluster.

TABLE 3.
BASIC INFORMATION OF CZERNIK 24 AND CZERNIK 27

Parameter	Czernik 24	Czernik 27	Reference
Other names	C0552+208, OCL 472, Lund 200	C0700+064, OCL 526, Lund 284	Lyngå 1987
α_{2000}	$05^h 55^m 27^s$	$07^h 03^m 22^s$	This study
δ_{2000}	$+20^\circ 52' 59''$	$+06^\circ 23' 47''$	This study
l	$188.^\circ 06$	$208.^\circ 58$	This study
b	$-2.^\circ 21$	$+5.^\circ 56$	This study
Trumpler class	III 1 m	III 1 p	Lyngå 1987
Reddening, $E(B - V)$	0.54 ± 0.12 mag	0.15 ± 0.05 mag	This study
Distance modulus, $V_0 - M_V$	13.1 ± 0.3 mag	13.8 ± 0.2 mag	This study
Distance, d	4.1 ± 0.5 kpc	5.8 ± 0.5 kpc	This study
Galactocentric distance, R_{gc}	12.6 ± 0.5 kpc	13.9 ± 0.5 kpc	This study
Metallicity, $[Fe/H]$	-0.41 ± 0.15 dex	-0.02 ± 0.10 dex	This study
Age, t	1.8 ± 0.2 Gyr ($\log t = 9.25$)	0.63 ± 0.07 Gyr ($\log t = 8.80$)	This study

in this study are consistent with the general trend of the metallicity gradient along the Galactocentric distance derived from the photometric data of 51 old open clusters, which is found to be $\Delta[Fe/H]/\Delta R_{gc} = -0.064 \pm 0.009$ dex kpc $^{-1}$.

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