

BOAO PHOTOMETRIC SURVEY OF GALACTIC OPEN CLUSTERS. II. PHYSICAL PARAMETERS OF 12 OPEN CLUSTERS

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ABSTRACT

We have initiated a long-term project, the BOAO photometric survey of open clusters, to enlarge our understanding of Galactic structure using *UBVI* CCD photometry of open clusters, which have been little studied before. This is the second paper of the project, in which we present the photometry of 12 open clusters. We have determined the cluster parameters by fitting the Padua isochrones to the color-magnitude diagrams of the clusters. All the clusters except for Be 60 and NGC 1348 are found to be intermediate-age to old (0.2–4.0 Gyrs) open clusters with a mean metallicity of $[Fe/H] \approx 0.0$.

Key words: open clusters and associations: general

1. INTRODUCTION

Open clusters are an ideal tool for tackling many astrophysical problems, such as star formation processes, stellar evolution, and dynamical evolution of stellar systems. To date there are about 1200 known Galactic open clusters in the Catalog of Open Cluster Data (Lyngå 1987, hereafter COCD). Owing to the high quantum efficiency, good linearity, and large dynamic range of modern CCDs, accurate color-magnitude diagrams (CMD) of a large number of open clusters have been obtained to derive their basic physical parameters (distance, interstellar reddening, age, and metallicity). Current understanding of the Galactic disk has greatly benefited from several recent systematic CCD observations of young and old open clusters (Phelps & Janes 1993; Janes & Phelps 1994).

However, more than half of the known Galactic open clusters are as yet virtually unstudied. All that we know about the majority of the open clusters are their positions and angular diameters, which are inaccurate in many cases. To date only one-third of the known open clusters have been studied in detail to derive their basic parameters. Moreover, more than half of the well-studied clusters belong to Trumpler richness class *m* and *r*, while most of the unstudied clusters are classified as *p*. Thus, present knowledge of open clusters is considered to be heavily biased by the properties of rich open clusters.

To understand the nature of open clusters and the structure of the Galactic disk as a whole, we have started a comprehensive photometric survey of open clusters that have been little studied before, using the 1.8 m telescope at Bohyunsan Optical Astronomy Observatory (BOAO) in Korea. The primary goal of the present survey is to obtain accurate CMDs of the unstudied clusters using *UBVI* CCD photometry and to derive cluster parameters, such as distance and age. We selected 343 clusters by the declination criterion of $\delta > -20^\circ$. They comprise about half of the clusters with unknown distance and age in COCD. A more detailed description of the present survey was given by Ann et al. (1999).

This is the second paper of our survey project. Here, we present the results of the photometric survey of 12 open clusters observed during the observing runs in 1998 and 1999. In § 2, we describe the observations and data reduction. The physical parameters of the observed clusters are presented in § 3, and a brief summary and discussion are given in the last section.

2. OBSERVATIONS

We observed 12 candidate clusters of the BOAO photometric survey in 1998 December. The basic parameters of the observed clusters (COCD) are given in Table 1. The photometric observations were made using the SITE 2048 × 2048 CCD camera with Johnson-Cousins *UBVI* filters attached to the f/8 Cassegrain focus of the BOAO 1.8 m telescope. The pixel size of the CCD is 24 μm , corresponding to 0".34 on the sky. The gain and readout noise of the CCD are 1.8 electrons ADU⁻¹ and 7 electrons, respectively. We have obtained images of the central 11'.6 × 11'.6 regions of each cluster with a pair of long and short exposures for each filter. We observed several *UBVI* standard stars in Landolt's (1992) catalog for the calibration of our photometry during the observing run. However, owing to nonphotometric conditions and difficulty in transforming the *U–B* colors to the standard system, we reobserved the clusters in a short exposure with the South African Astronomical Observatory version of Landolt standard stars in the equator (Menzies et al. 1991) and blue and red standard stars (Kilkenny et al. 1998) on a photometric night during the observing run in 1999 October. The observed standard stars (or regions) are SA 112, SA 114, SA 93, SA 99, BD –11 162, Gl 876, and Gl 273. Table 2 lists the observational log.

Gray-scale maps of the *V*-band images of the clusters taken with long exposures are displayed in Figure 1. In most cases the cluster field is a small part of the observed frame. Solid circles in Figure 1 represent the angular diameters of the clusters given in the COCD, whose centers were deter-

TABLE 1
BASIC PARAMETERS OF THE 12 OPEN CLUSTERS

Cluster	R.A. (2000.0)	Decl. (2000.0)	l	b	Trumpler Class	Angular Diameter
Be 104	0 3 28.1	63 35 42.4	117.63	1.22	II 1 p	3'0
Be 60	0 17 41.4	60 57 40.3	118.85	-1.64	III 1 p	3'0
King 15	0 32 55.8	61 51 33.8	120.75	-0.95	IV 2 p	3'0
NGC 381	1 8 19.9	61 35 2.1	124.94	-1.22	III 1 m	6'0
Be 64	2 21 2.8	65 53 48.3	131.92	4.60	II 1 m	2'0
King 6	3 28 3.5	56 27 30.1	143.35	-0.07	II 2 m	10'0
NGC 1348.....	3 33 51.7	51 26 9.5	146.94	-3.71	III 2 m	5'0
Be 12	4 44 37.4	42 40 38.3	161.68	-1.99	II 1 m	4'0
Be 70	5 25 44.6	41 53 44.6	166.90	3.58	III 1 m	6'0
Be 23	6 33 28.5	20 32 47.0	192.61	5.44	III 1 m	4'0
NGC 2259.....	6 38 34.4	10 53 24.1	201.79	2.12	II 1 p	3'0
NGC 2304.....	6 55 0.9	18 1 14.1	197.17	8.87	II 1 m	3'0

mined by visual inspection of the images. We obtained photometric diagrams of the clusters for the stars located within the circles.

We have followed standard CCD reduction techniques, using IRAF/CCDRED for the preprocessing of the images obtained. This includes the subtraction of bias levels with overscan correction, trimming, and flat fielding. We used IRAF/DAOPHOT to obtain instrumental magnitudes of the stars. We applied aperture corrections to the instrumental magnitudes of cluster stars obtained from point-spread function (PSF) fitting, using the instrumental magnitudes obtained with an aperture radius of 7".

The transformation of the instrumental system to the standard system was made using the following equations (see the similar transformation for the 40 inch [1 m] telescope at Siding Spring Observatory; Sung & Bessell 2000):

$$V = v - k_V X - 0.046(B - V) + \zeta_V,$$

or

$$V = v - k_V X - 0.046(V - I) + \zeta'_V \text{ for } V - I < 1.5,$$

$$V = v - k_V X + \zeta''_V \text{ for } V - I \geq 1.5,$$

$$I = i - k_I X - 0.017(V - I) + \zeta_I \text{ for } V - I < 0.6,$$

$$I = i - k_I X + 0.083(V - I) + \zeta'_I \text{ for } V - I \geq 0.6,$$

$$B = b - k_B X + 0.112(B - V) + \zeta_B,$$

$$U = u - k_U X + f(B - V) + \zeta_U,$$

where uppercase characters, lowercase characters, k , X , and ζ represent standard magnitudes, instrumental magnitudes, extinction coefficients, air mass, and zero points, respectively. In the transformation of the U magnitude, a nonlinear function, $f(B - V)$, is involved. The function $f(B - V)$

TABLE 2
OBSERVATIONAL LOG OF THE 12 OPEN CLUSTERS

Cluster	Filter	T_{exp}	Cluster	Filter	T_{exp}
Be 104	U	200 s $\times$ 4	Be 60	U	200 s $\times$ 3
	B	200 s $\times$ 3, 50 s		B	200 s $\times$ 4
	V	100 s $\times$ 3, 10 s		V	100 s $\times$ 3, 50 s
	I	50 s $\times$ 3, 5 s		I	50 s $\times$ 3
King 15	U	200 s $\times$ 3	NGC 381	U	900 s, 90 s
	B	200 s $\times$ 3, 20 s		B	400 s, 20 s
	V	100 s $\times$ 3, 10 s		V	130 s, 10 s
	I	50 s $\times$ 3, 5 s		I	50 s, 5 s
Be 64	U	900 s	King 6	U	200 s $\times$ 3
	B	900 s		B	200 s $\times$ 3, 20 s
	V	400 s		V	100 s $\times$ 3, 10 s
	I	150 s, 30 s		I	50 s $\times$ 3, 5 s
NGC 1348...	U	200 s $\times$ 4	Be 12	U	900 s
	B	200 s $\times$ 3, 20 s		B	900 s
	V	100 s $\times$ 3, 10 s		V	400 s
	I	50 s $\times$ 3, 5 s		I	150 s, 30 s
Be 70	U	900 s	Be 23	U	200 s $\times$ 3
	B	900 s, 90 s		B	200 s $\times$ 3, 20 s
	V	400 s, 40 s		V	100 s $\times$ 3, 10 s
	I	150 s, 12 s		I	50 s $\times$ 3, 5 s
NGC 2259...	U	200 s $\times$ 3	NGC 2304...	U	900 s
	B	200 s $\times$ 3, 20 s		B	900 s, 90 s
	V	100 s $\times$ 3, 10 s		V	300 s, 30 s
	I	50 s $\times$ 3, 5 s		I	80 s, 7 s

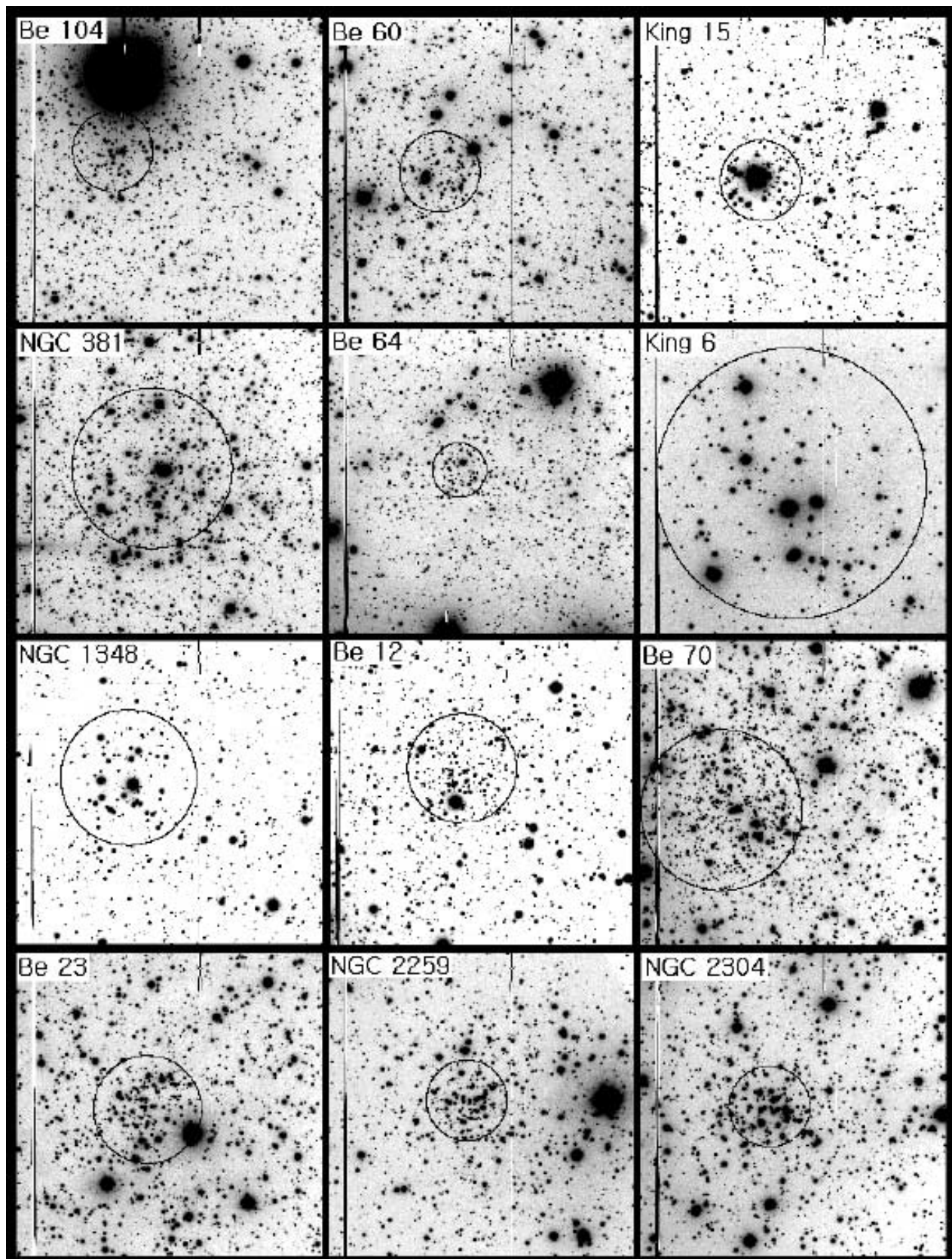


FIG. 1.—Mosaic map of gray-scale V -band images of 12 open clusters. The circles represent the angular diameters of the clusters given in COCD. The size of each box is 11.6×11.6 . North is up, and east is to the left.

allows the correction of redder ($U-B$) colors, probably due to a red leak in the U filter (M. S. Bessell 2001, private communication). It increases linearly up to $(B-V) \approx 0.8$, but shows a nonlinear increase for redder stars. This correction dominated the other factors, and we did not take into account the $U-B$ term in the U transformation. The extinction coefficients derived from standard star photometry are $k_U = 0.485 \pm 0.024$, $k_B = 0.232 \pm 0.035$, $k_V = 0.142 \pm 0.023$ and $k_I = 0.058 \pm 0.027$. The final transformation errors were between 0.021 mag in V and 0.038 mag in U . The instrumental magnitudes obtained from the observations in nonphotometric conditions during the December run were transformed to the standard system using the observations of the October run. The photometric data are available from H.B.A.

We calculate the external observational errors of the photometry of the cluster stars using the pair of exposures in the 1998 December run and the short exposures in the 1999 October run. Figure 2 shows the resulting observational errors as a function of V magnitude. The error bars in Figure 2 are the standard deviations of the observational errors for the stars in each magnitude bin. As shown in Figure 2, the observational errors for stars fainter than $V \approx 14$ increase with increasing magnitude, while the observational errors for stars brighter than $V \approx 14$ are nearly constant, with relatively large uncertainties due to the small number of stars in the magnitude bins.

3. RESULTS

We have determined the basic physical parameters of the 12 open clusters by analyzing the color-color diagrams and CMDs of the clusters. Photometric diagrams of the clusters

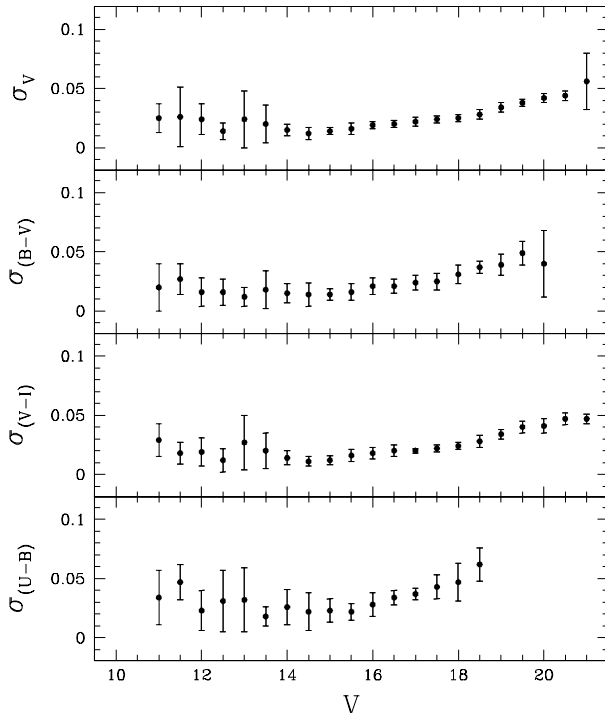


FIG. 2.—Observational errors in the present photometry. The error bars represent the standard deviations of observational errors for stars in each magnitude bin of 0.5 mag. The large error bars for the brighter stars are caused by the small number of stars in the magnitude bin.

are derived from the photometry of stars inside the angular diameters (COCD) plotted in Figure 1. To achieve improved accuracy in the derived parameters, we used stars with DAOPHOT errors less than 0.1 mag. In addition, owing to large errors in U , the $U-B$ versus $B-V$ diagrams were constructed using stars brighter than $V \approx 17$. In general, as shown in Figure 2, the total observational errors are quite large ($\sigma_v \approx 0.03$), even for the brightest stars. However, the present photometry is good enough to derive the cluster parameters using isochrone fittings.

We have estimated the reddening of the clusters from $U-B$ versus $B-V$ diagrams by comparing the theoretical zero-age main sequence (ZAMS) of the Padua isochrones (Bertelli et al. 1994) with the observed distributions of cluster stars. To do this, we assumed a slope of $E(B-V)/E(U-B) = 0.72$ (Johnson & Morgan 1953), a total to selective extinction ratio $R_V = 3.0$ and $E(V-I) = 1.25E(B-V)$ (Dean, Warren, & Cousins 1978). The advantage of using a theoretical ZAMS is the ability to take into account the metallicity effect on the stellar distribution in the color-color diagrams. Because the metallicity of clusters is not known beforehand, we assumed the solar abundance as the cluster abundance unless the stellar distributions in the color-color diagrams and CMDs cannot be described by the solar abundance isochrones.

We used the Padua isochrones (Bertelli et al. 1994) in the isochrone fittings. We put the greatest weight on the stars in the turnoff regions and giant branches, if present, since the lower main sequences are more heavily contaminated by field stars. We attempted to fit the lower envelope of the main sequence, considering the photometric errors. The best-fit solutions were obtained by visual inspections of the CMDs with the trial fittings. We present the results of the best fits in Figure 3, and the resulting cluster parameters are given in Table 3.

Since we put the greatest weight on the stars in the regions that are supposed to be the giant branches of some clusters, the memberships of these stars are crucial to the derived cluster parameters. To see whether these stars are cluster giants or not, we plotted cleaned CMDs in Figure 4. To obtain the cleaned CMDs, we statistically removed field stars from the cluster CMDs by finding stars nearest to the field stars with a photometric box of ± 0.25 in V and ± 0.1 in $B-V$. Because we did not observe the field region of each cluster, we constructed the CMDs of field stars by selecting stars randomly from the regions outside the radii that are two times larger than the cluster radii in the same CCD images, except for Be 70 for which field stars are selected from the region outside 1.5 times larger than the cluster radius due to the larger angular size of the cluster. As shown in Figure 4, giant stars are left over in the cleaned CMDs. This result strongly suggests that many stars in the red giants locus could be the members of the cluster. In the following we briefly describe the properties of the individual clusters.

3.1. Berkeley 104

Be 104 is located to the south of a very bright star, HD 225094. As indicated by its Trumpler class of IIIp, Be 104 is one of the most poorly defined clusters. Due to the paucity of members and the heavy contamination by field stars, the CMDs of Be 104 show a very broad main sequence, which is not much different from that of the field star CMDs near the

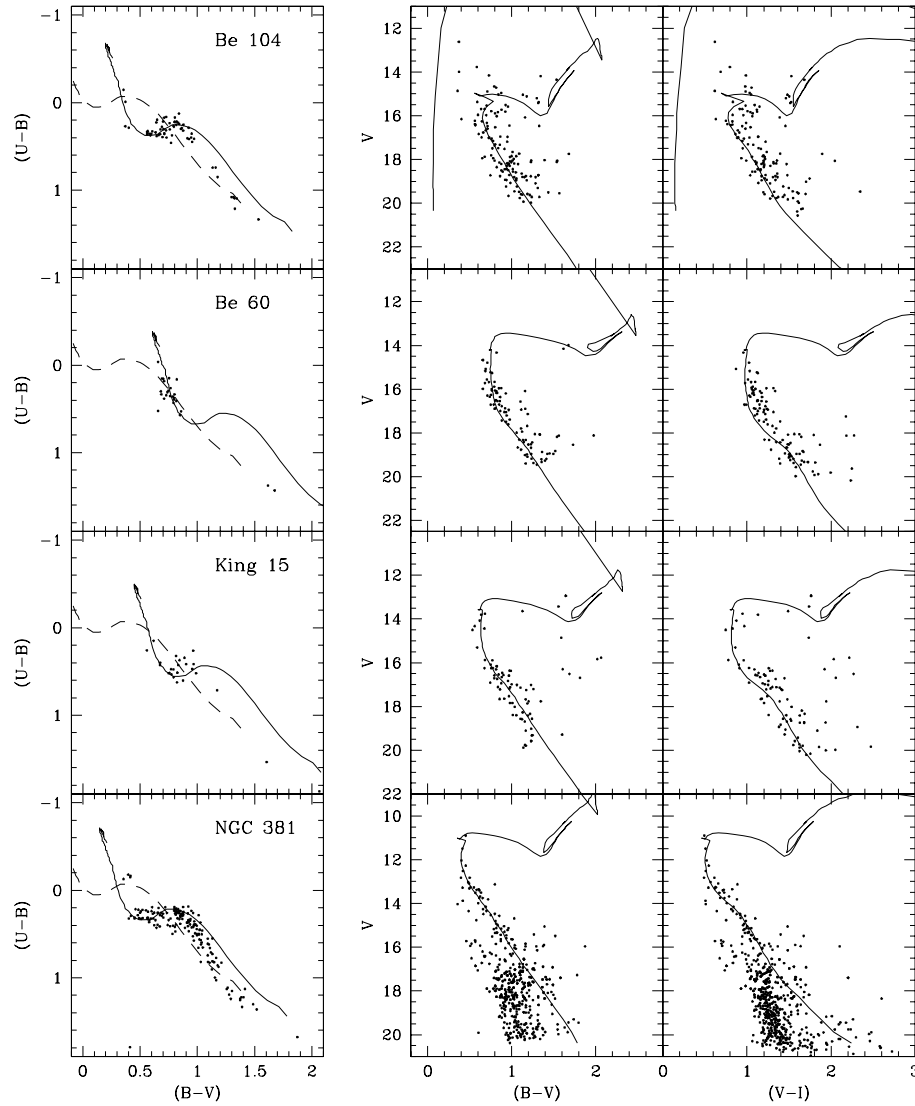


FIG. 3.—Photometric diagrams for the 12 open clusters. The dashed and solid lines in the color-color diagrams represent the theoretical ZAMS of the Padua isochrones (Bertelli et al. 1994). The solid lines in CMDs are the best-fit isochrones.

cluster. Thanks to the presence of a few giants, which are thought to be cluster members as they appear in the cleaned CMD in Figure 4, we could derive the cluster parameters by fitting the isochrones to the stellar distributions in the CMDs. The resulting cluster parameters are $(m - M)_0 = 13.2 \pm 0.2$, $E(B - V) = 0.45 \pm 0.05$, $\log(t[\text{yr}]) = 8.9 \pm 0.1$, and $[\text{Fe}/\text{H}] = 0.07$ dex. Most of the stars brighter than the turnoff point of the main-sequence stars are considered to be field stars. However, there seem also to be a few blue straggler candidates according to their positions on the CMDs.

3.2. Berkeley 60

Be 60 is also a poorly defined cluster with a Trumpler class of IIIp. As shown in Figure 1, there are several bright stars in the field of Be 60 most of which seem to be foreground stars. However, the CMDs of the stars in the central region of Be 60 show a well-defined main sequence, which permits a reasonably good isochrone fitting. The resulting best-fit isochrone

gives the cluster parameters as $(m - M)_0 = 13.2 \pm 0.2$, $E(B - V) = 0.86 \pm 0.05$, $\log(t[\text{yr}]) = 8.2 \pm 0.2$ and $[\text{Fe}/\text{H}] = 0.07$ dex. The two brightest red stars near $(B - V) = 1.6$ are not plotted in the V versus $(V - I)$ CMD due to saturation in the I image.

3.3. King 15

As shown in Figure 1, King 15 shows the typical properties of IV2p clusters, which are characterized by a small number of member stars and no central concentration. However, as can be seen in Figure 3, the stellar distributions in the CMDs of the cluster are well represented by the isochrone of $\log(t[\text{yr}]) = 8.4 \pm 0.1$ and $[\text{Fe}/\text{H}] = 0.07$ dex, with a distance modulus and reddening of $(m - M)_0 = 12.5 \pm 0.4$ and $E(B - V) = 0.70 \pm 0.12$, respectively. Phelps & Janes (1994) derived a slightly smaller distance modulus, $(m - M)_0 = 12.29$, and smaller reddening, $E(B - V) = 0.46$, for King 15. Since they had no U -band photometry, their reddening estimate was obtained by fitting the Schmidt-Kaler's (1982) ZAMS to the stellar distri-

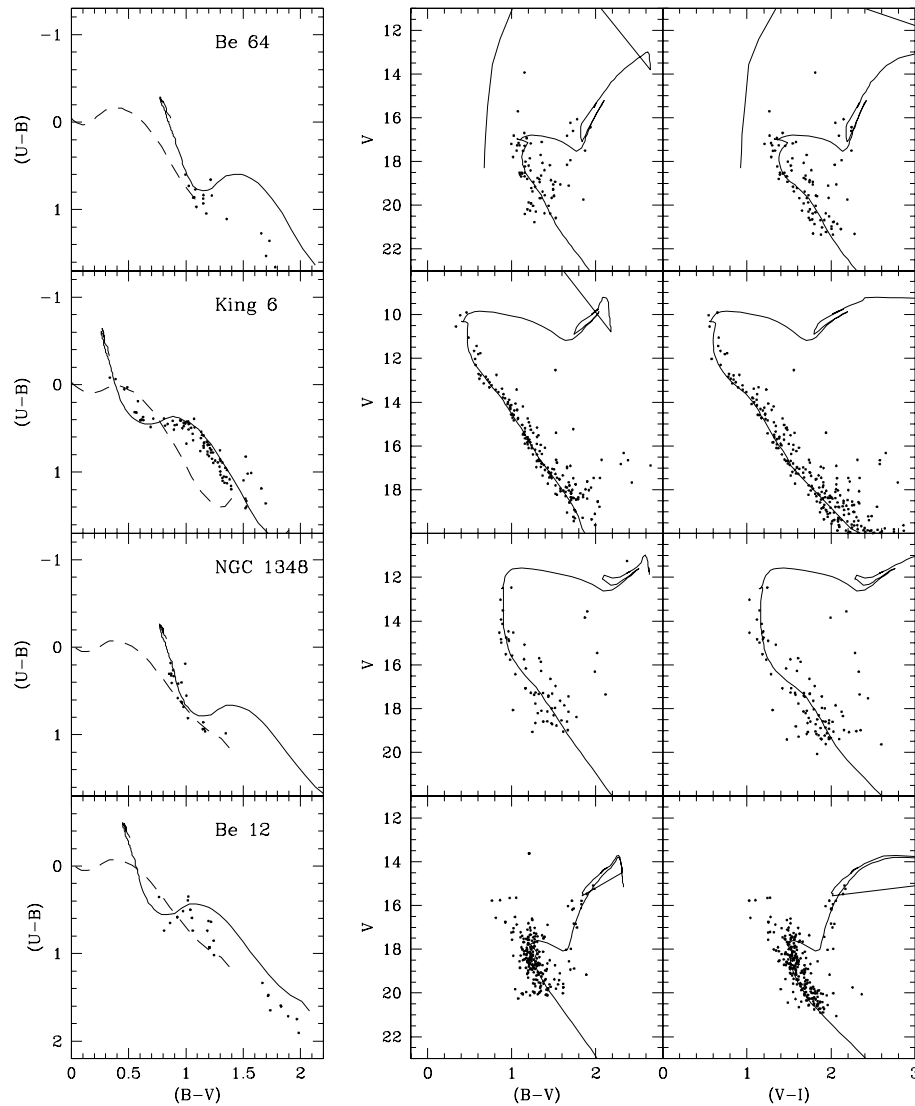


FIG. 3.—Continued

bution in the V versus $B-V$ CMD. They estimated the age of King 15 to be ~ 3 Gyr from the color of the earliest spectral type star on the main sequence $[(B-V)_0 = 0.19]$. The reason for the large discrepancy between the age derived from the isochrone fittings and that found by Phelps & Janes (1994) is due to the fact that they considered stars brighter than $V \approx 15$ to be field stars, while we consider them as cluster members according to their positions in the CMDs as well as spatial position in the cluster field.

As shown in Figure 4, the presence of stars brighter than $V \approx 15$ in the cleaned CMD support the assumption that $V \sim 14$ are cluster members. However, it is quite natural for them to believe the stars brighter than $V \approx 15$ to be field stars since their CMD is heavily populated by field stars due to the larger field compared to ours. They constructed the CMD from the stars in a field of $11'.6 \times 11'.6$, which is nearly the same field as that of the total CCD image for King 15 in Figure 1. If stars brighter than $V \approx 15$ are member stars of King 15, there is a large gap in the upper main sequence of the cluster.

3.4. NGC 381

NGC 381 is an intermediate-age open cluster with a Trumpler class of IIIIm. There seem to be no giant stars in the cluster, probably because of its small number of member stars. The main sequence of the cluster is well defined in the CMDs although there are a large number of field stars in the direction of NGC 381. Owing to the foreground and background field stars, the color-color diagram of NGC 381 is quite complicated. However, it is not difficult to determine the cluster reddening by fitting the theoretical ZAMS to the distribution of the main-sequence stars in the color-color diagram because they are well isolated from the field stars. As shown Figure 3, the isochrone of $\log(t[\text{yr}]) = 8.5 \pm 0.1$ and $[\text{Fe}/\text{H}] = 0.07$ dex fits well the stellar distribution in the CMDs of NGC 381 with a distance modulus and reddening of $(m - M)_0 = 10.3 \pm 0.3$ and $E(B-V) = 0.40 \pm 0.10$, respectively. The present estimates of the distance modulus and reddening of the cluster are in good agreement with those determined by Phelps & Janes (1994) but their age estimate of $\log(t[\text{yr}]) = 9.04$, obtained using the isochrone

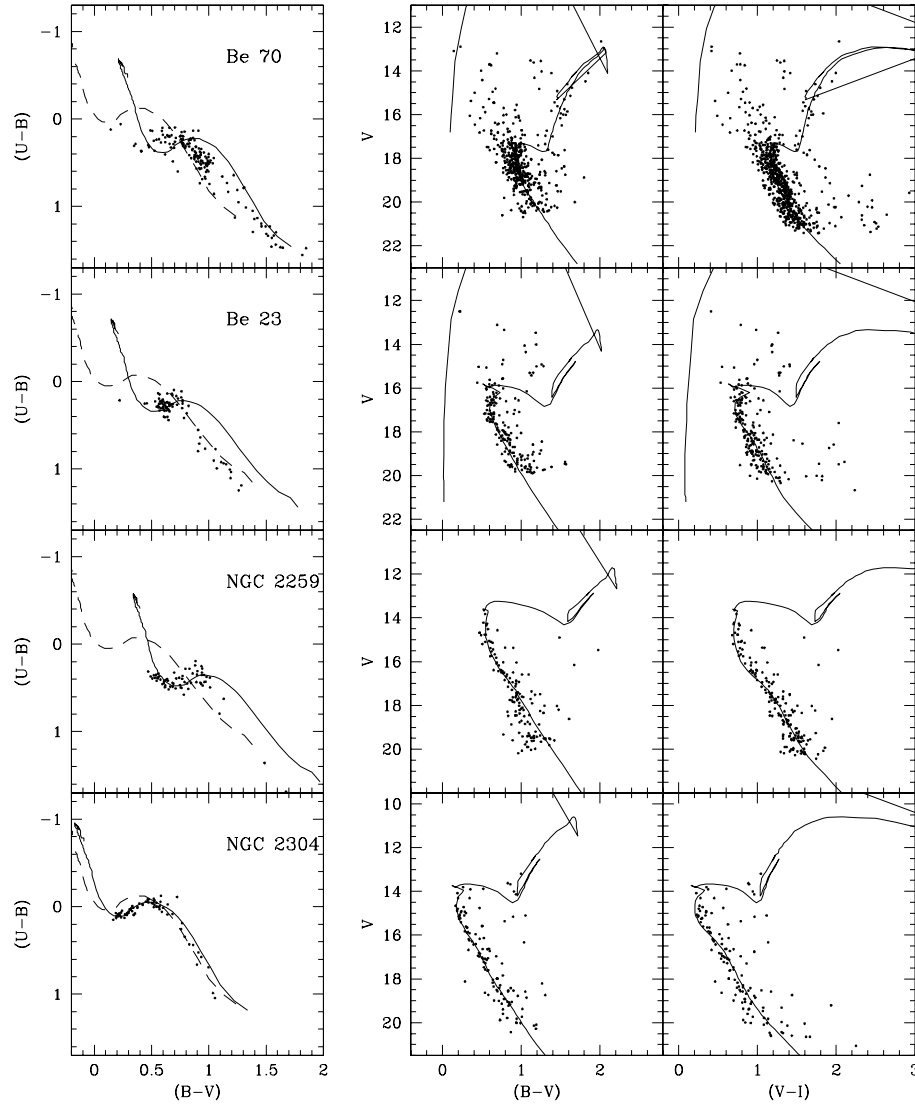


FIG. 3.—Continued

of Maeder & Meynet (1991), is about a factor of three larger than ours.

3.5. Berkeley 64

Be 64 shows the typical morphology of a Trumpler class III m cluster which is characterized by a slight concentration of member stars of similar brightness with medium richness. Because the color-color diagram does not show any clear cluster sequences because of the small number of bright stars with small photometric errors in U , we adopt $E(B-V) = 1.05$ (Pandey et al. 1997) as the cluster reddening. The CMDs of Be 64 show a quite broad main sequence due to contamination by field stars. However, the presence of giant stars, most of which are thought to be cluster members from the cleaned CMD in Figure 4, makes it possible to fit the isochrones to the stellar distributions in the CMDs unambiguously. As shown in Figure 3, the adopted isochrone of $\log(t[\text{yr}]) = 9.0 \pm 0.1$ and $[\text{Fe}/\text{H}] = -0.61$ dex with $(m-M)_0 = 13.0 \pm 0.3$ and $E(B-V) = 1.05 \pm 0.15$ fits the stellar distribution in the CMDs quite well. Our estimates of the distance modulus and age are in good agreement with those of Pandey et al. (1997).

3.6. King 6

King 6 is a nearby cluster with a Trumpler class of II 2 m. As shown in Figure 1, the angular diameter of the cluster is

TABLE 3
PHYSICAL PARAMETERS OF THE 12 OPEN CLUSTERS

Cluster	$E(B-V)$	$(m-M)_0$	$[\text{Fe}/\text{H}]$ (dex)	Age (Myr)
Be 104	0.45 ± 0.05	13.2 ± 0.2	0.07	790 ± 160
Be 60	0.86 ± 0.05	13.2 ± 0.2	0.07	160 ± 60
King 15	0.70 ± 0.12	12.5 ± 0.4	0.07	250 ± 50
NGC 381	0.40 ± 0.10	10.3 ± 0.3	0.07	320 ± 70
Be 64	1.05 ± 0.15	13.0 ± 0.5	-0.61	1000 ± 210
King 6	0.50 ± 0.10	9.7 ± 0.4	0.46	250 ± 50
NGC 1348...	1.02 ± 0.05	11.3 ± 0.3	0.07	130 ± 50
Be 12	0.70 ± 0.15	12.5 ± 0.5	0.07	4000 ± 820
Be 70	0.48 ± 0.10	13.1 ± 0.3	-0.32	4000 ± 820
Be 23	0.40 ± 0.05	14.2 ± 0.3	0.07	790 ± 160
NGC 2259...	0.59 ± 0.05	12.6 ± 0.3	0.07	320 ± 70
NGC 2304...	0.10 ± 0.02	13.0 ± 0.1	-0.32	790 ± 160

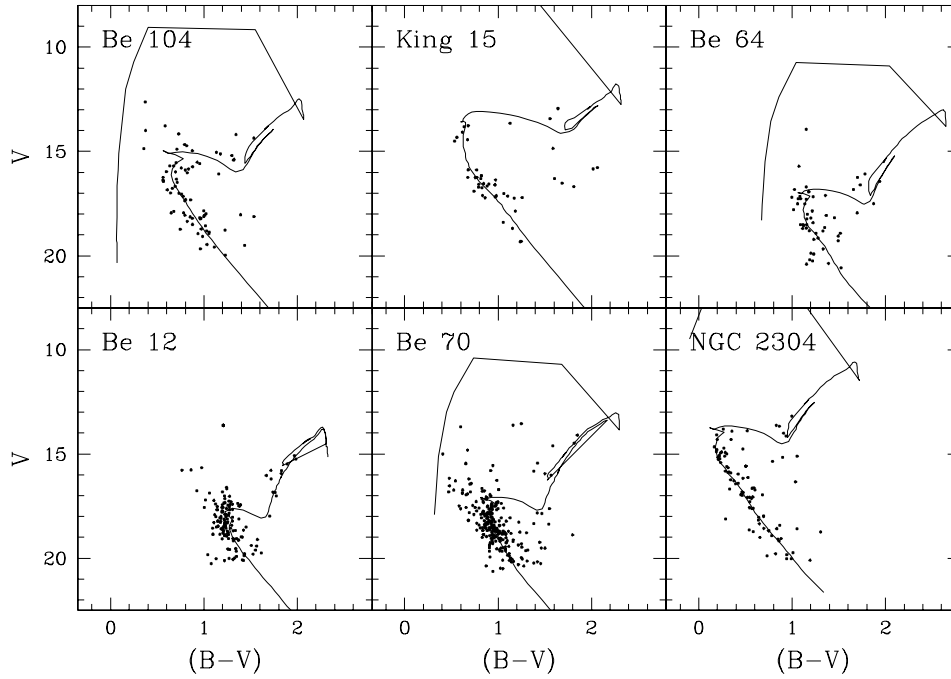


FIG. 4.—Cleaned CMDs of the six open clusters that are supposed to have giant members. The best-fit isochrones shifted according to the derived reddening and distance moduli are plotted.

comparable to the size of the observed field because of its proximity. The CMDs of King 6 show a well defined main sequence with a relatively small number of field stars, especially in the upper main sequence. However, the lower main sequence, fainter than $V \sim 18$, seems to be contaminated by field stars. Although there seems to be a clear sequence in Figure 3, the stellar distributions in the color-color diagram of King 6 cannot be fitted by the theoretical ZAMS with a single reddening value. The stars fainter than $V \sim 16$ seem to have a smaller reddening of $E(B-V) \approx 0.4$, while the stars brighter than $V \sim 13$ appear to have a larger reddening of $E(B-V) \approx 0.6$. Thus, we adopted a mean value of $E(B-V) = 0.5 \pm 0.10$ as the reddening of King 6. This is the reason why the stellar distributions in the color-color diagram show a relatively poor match with the theoretical ZAMS which is shifted by a reddening value of $E(B-V) = 0.5$. However, as shown in Figure 3, the isochrone of $\log(t[\text{yr}]) = 8.4 \pm 0.1$ and $[\text{Fe}/\text{H}] = 0.46$ dex, shifted by a distance modulus and reddening of $(m - M)_0 = 9.7 \pm 0.4$ and $E(B-V) = 0.5 \pm 0.10$, respectively, gives a pretty good match with the stellar distributions in the CMDs of the cluster. There is a slight indication of the presence of the binary sequence above the ZAMS.

3.7. NGC 1348

NGC 1348 is the youngest among the observed clusters and is relatively well recognized owing to the absence of field stars comparable in brightness to the bright members of the cluster, although the cluster stars do not show any obvious central concentration. This is the reason why NGC 1348 is classified as Trumpler class III2m. As shown in Figure 3, the color-color diagram of NGC 1348 shows a well-defined sequence, which is well matched with the theoretical ZAMS of the solar abundance shifted by $E(B-V) = 1.02$. The iso-

chrone fittings to the stellar distributions in the CMDs give the cluster parameters of $\log(t[\text{yr}]) = 8.1 \pm 0.1$, $(m - M)_0 = 11.3 \pm 0.3$, $E(B-V) = 1.02 \pm 0.05$, and $[\text{Fe}/\text{H}] = 0.07$ dex, respectively. The brightest star near $B-V = 2.4$ is saturated in the I image and is omitted in the V versus $(V-I)$ diagram.

3.8. Berkeley 12

Be 12 is an old cluster with a Trumpler class of III1m. Although Be 12 is located in the direction of a rich star field, it can be well distinguished from field stars because of the concentration of the member stars. The CMDs of the cluster show a broad main sequence caused by heavy contamination by field stars. The color-color diagram of Be 12 also shows no clear sequence, due to the lack of a sufficient number of cluster main-sequence stars that are bright enough to have small photometric errors in U as well as the contamination by field stars. The presence of blue straggler stars which are located in the bright extension of the main sequence of Be 12 may contribute to the large scatter in the color-color diagram. However, as shown in Figure 3, the isochrone of $\log(t[\text{yr}]) = 9.6 \pm 0.1$ and $[\text{Fe}/\text{H}] = 0.07$ dex fits the main sequence together with the giant branch quite well with a distance modulus and reddening of $(m - M)_0 = 12.5 \pm 0.5$ and $E(B-V) = 0.7 \pm 0.15$, respectively. The old age of the cluster supports the existence of blue straggler stars based on the presence of stars brighter and bluer than the turnoff point of the cluster main sequence because such stars are more frequently found in old open clusters (Ahumada & Lapasset 1995).

3.9. Berkeley 70

Be 70 is located in a direction toward which a large number of foreground stars are located. The CMDs of the clus-

ter show a broad main sequence due to heavy contamination by field stars. The color-color diagram appears to be complicated by the field star contamination, but we could determine the reddening of the cluster by fitting the theoretical ZAMS to the distributions of upper main-sequence stars and populous giant stars, which constitute a well-defined cluster sequence in the CMDs. The broad sequence around $B-V \approx 0.7$ in the color-color diagram is due to the field star population, whose mean reddening is much smaller than that of the cluster. The heavy contamination of field stars is apparent from the cleaned CMD of Be 70 in Figure 4. However, some of the bright blue stars above the turnoff point of the main sequence of Be 70 may be blue straggler stars from their presence in the cleaned CMD of the cluster. Owing to the well-developed giant branch and the highly populated main sequences, it is not difficult to fit the isochrones to the stellar distributions in the CMDs. The resulting cluster parameters are $\log(t[\text{yr}]) = 9.6 \pm 0.1$, $[\text{Fe}/\text{H}] = -0.32$ dex, $(m-M)_0 = 13.1 \pm 0.3$ and $E(B-V) = 0.48 \pm 0.10$.

3.10. *Berkeley 23*

Be 23 is located near the direction of the antagalactic center direction. As indicated by its Trumpler class of III1m, it shows no strong central concentration but can be identified by its relatively dense population compared to that of the field stars. Most of the brightest stars above the turnoff point are considered to be foreground stars because the CMD of a nearby field region shows similar stellar distributions. However, there is also a possibility that some of the stars that are brighter and bluer than the turnoff of the main sequence are blue straggler stars. We derived the cluster parameters by fitting the isochrone of $\log(t[\text{yr}]) = 8.9 \pm 0.1$ and $[\text{Fe}/\text{H}] = 0.07$ to the stellar distribution, especially near the turnoff, with a distance modulus and reddening of $(m-M)_0 = 14.2 \pm 0.3$ and $E(B-V) = 0.40 \pm 0.05$, respectively. The theoretical ZAMS of the solar abundance shifted by the adopted reddening of $E(B-V) = 0.40$ describes well the distribution of upper main-sequence stars in the color-color diagram. Most of the foreground stars seem to be affected by negligible reddening.

3.11. *NGC 2259*

NGC 2259 is a well-detached system of Trumpler class IIIp. Most of the bright stars in the direction of NGC 2259 are cluster main-sequence stars near the main-sequence turnoff. There seems to be little contamination by field stars in the upper main sequence but the lower main sequence is somewhat contaminated by field stars. Owing to the proximity of the cluster, the main-sequence stars bluer than $(B-V) \approx 1.0$ are bright enough to produce a clear sequence in the color-color diagram. Thus, we derived the cluster reddening by fitting the theoretical ZAMS to the distribution of bright main-sequence stars in the color-color diagram. We applied the isochrone fittings to the stellar distributions in the CMDs of NGC 2259 with the reddening derived from the ZAMS fitting. As shown in Figure 3, the isochrone of $\log(t[\text{yr}]) = 8.5 \pm 0.1$ and $[\text{Fe}/\text{H}] = 0.07$ dex with a distance modulus and reddening of $(m-M)_0 = 12.6 \pm 0.3$ and $E(B-V) = 0.59 \pm 0.05$, respectively, matches well with the stellar distributions in the CMDs of NGC 2259.

3.12. *NGC 2304*

NGC 2304 is located in the direction of the antagalactic center, slightly above the Galactic plane. It is well distinguished from the field stars. The color-color diagram shows a well defined cluster sequence which is nicely matched with the theoretical ZAMS of $[\text{Fe}/\text{H}] = -0.32$ shifted by $E(B-V) = 0.10$. However, as shown in Figure 3, the main sequence, especially the lower main sequence, is somewhat contaminated by field stars. The stellar distributions in the CMDs of NGC 2304 show the typical characteristics of intermediate-age open clusters. The stars near the giant branch seem to be cluster members since all these stars are present in the cleaned CMD of NGC 2304 in Figure 4. The isochrone of $\log(t[\text{yr}]) = 8.9 \pm 0.1$ and $[\text{Fe}/\text{H}] = -0.32$ dex with $(m-M)_0 = 13.0 \pm 0.1$ and $E(B-V) = 0.10 \pm 0.02$ fits well the stellar distribution in the CMDs of NGC 2304. There seems to be a binary sequence above the ZAMS.

4. DISCUSSION AND SUMMARY

We have determined the distances, reddenings, ages, and metallicities of 12 target clusters by isochrone fittings complemented by ZAMS fittings for the reddening estimates. To our best knowledge, no known cluster parameters were previously derived for any of the clusters except for King 15, NGC 381, and Be 64. Comparison of the cluster parameters derived from the present photometry with those found by other researchers for King 15, NGC 381, and Be 64 (Phelps & Janes 1994; Pandey et al. 1997) shows that our estimates are in good agreement with independent studies.

The mean interstellar absorption derived from the reddening of the 12 open clusters is 0.72 ± 0.51 mag kpc⁻¹, which is slightly smaller than the mean interstellar absorption of the Galactic disk, ~ 1.0 mag kpc⁻¹, derived from COCD. The smaller mean interstellar absorption reflects the general characteristics of the interstellar reddening toward the antagalactic center, and the large standard deviation is due to the inhomogeneous distribution of the interstellar clouds (Lucke 1978). Be 23 and NGC 2304, which are located in a direction very close to the antagalactic center, show extremely small interstellar absorptions of 0.17 mag kpc⁻¹ and 0.08 mag kpc⁻¹, respectively, while King 6 and NGC 1348, which are located in the direction of the Cassiopeia-Perseus region (Deutschman, Davis, & Schild 1976), show large interstellar absorptions of 1.72 mag kpc⁻¹ and 1.68 mag kpc⁻¹, respectively. The large interstellar absorption in this direction might be due to the dense interstellar cloud close to the Sun (Deutschman, Davis, & Schild 1976).

The apparent gap in the main sequence of King 15 seems to be a real feature, because the stars brighter than $V \approx 15$ are thought to be cluster members. Thus, the age of King 15 is ~ 250 Myr, which is much smaller than that suggested by Phelps & Janes (1994). However, the gap near $V \sim 14$ is not a physical gap related to stellar evolution, but is caused by random statistical fluctuations due to the small number of member stars. King 15 is too young for the cluster to have a main-sequence gap, similar to those of NGC 2420 (Anthony-Twarog et al. 1990; Lee, Ann, & Kang 1999) and NGC 2243 (Bonifazi et al. 1990), which are thought to be related to the rapid hydrogen exhausting phase of the convective core (Demarque, Sarajedini, & Guo 1994). The gap in King 15 is similar to those of Be 7, NGC 637, and Be 62

(Phelps & Janes 1993), all of which are thought to be caused by statistical fluctuations in the high mass part of the IMFs (Scalo 1986).

We have found blue straggler candidates in the four open clusters, Be 104, Be 12, Be 70, and Be 23, which have ages greater than 800 Myr. There is a tendency for older clusters to have more blue straggler stars, similar to that found by Ahumada & Lapasset (1995).

Our results for the 12 clusters presented in this study along with the results of Ann et al. (1999) are expected to be

very useful for the investigation of the open cluster system in our Galaxy. Our survey project is still in progress, and we plan to present a study of more open clusters in the near future.

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