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UBVI CCD PHOTOMETRY OF OPEN CLUSTER NGC 2324

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ABSTRACT

UBVI CCD photometry of open cluster NGC 2324 is presented. C-M diagrams of this cluster show well-defined main sequence with a red giant clump centered at $B-V$=1.05, V=13.45. We derived the major cluster characteristics; $E(B-V)$=0.17±0.12 from color-color diagram and mean color of red giant clump stars, $(m-M)_0$=13.1±0.1 from zero age main sequence fitting, and [Fe/H]~−0.32 from comparison the theoretical model developed by Bertelli et al. (1994) to the observed C-M diagrams. We estimate the age of NGC 2324 to be log t~8.8 by applying isochrone fitting and morphological age index method.

Key words : Hertzsprung-Russell(HR) diagram, CCD observation, open cluster, NGC 2324

I. INTRODUCTION

Open clusters give us important information for the dynamical and chemical evolution of the Galactic disk. In addition to serving as probes of the evolution of the Galactic disk, open clusters provide information regarding stellar evolution. In particular, since intermediate-age and older clusters have well populated giant branch and red giant clumps, they can be used to constrain theoretical models. In order to be useful for any of these, however, we need good age estimates for open clusters.

In spite of its importance, only a small number of open clusters have been observed with CCD. To date, most open cluster data are from old photographic studies. Rich old open cluster NGC 2324 is one of them.

NGC 2324 (RA(1950) : 7^h 01^m, Dec : 1° 07′) is located in the direction of Galactic anti-center (l_{II} = 213.45, b_{II} = 3.31). The *UBV* photometry of Hoag et al. (1961) gave $E(B-V)$=0.10 despite its very small galactic latitude. Furthermore, Janes(1979) found [Fe/H]=−0.39 from ultra-violet excess using Hoag et al. (1961)'s data and DDO photometry. Geisler et al. (1992) derived its metallicity [Fe/H] ~ −1.01 from Washington photometry of nine giant stars. This value is completely unexpected for a cluster of its age and location (Janes & Phelps 1994). Mermilliod et al.(2001) presented radial velocities and photoelectric *UBV* photometry for 73 red giant candidates in NGC 2324. And they derived log t=8.90, [Fe/H]=+0.07, $E(B-V)$=0.02 and $(m-M)$=12.95 using only red giant data and isochrone fitting method.

No *UBVI* CCD data have been published so far for NGC 2324. The primary goals of this paper are to present new CCD observation of the open cluster NGC 2324 and to determine its basic physical parameters

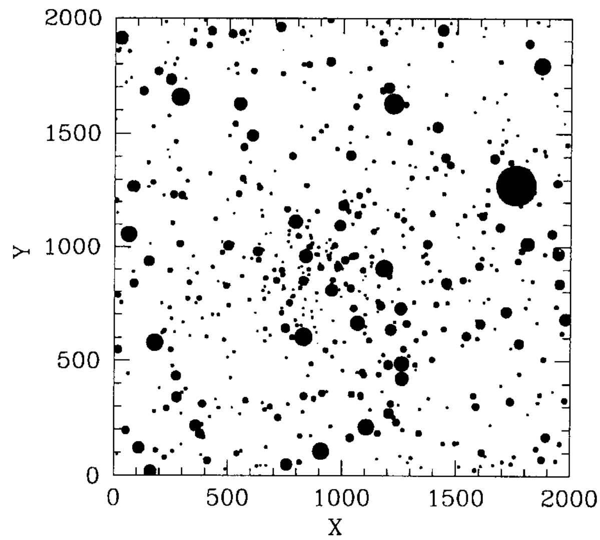

Fig. 1.— CCD observation field(20′ × 20′) in V frame of NGC 2324. Stars with V<16 are shown. East is up, North is right. The X- and Y-axes are in pixels and 1 pixel corresponds to 0.″60.

including reddening, distance modulus, age and metallicity. This paper is a partial result of our extensive study of old open clusters in both optical and near-IR wavelengths. In Section II, we describe the observation and data reduction process. We then present the main features of color magnitude diagram (CMD) of NGC 2324 in Section III. In Section IV, we derive reddening and distance modulus of NGC 2324. The age and metallicity are derived in Section V using Bertelli et al. (1994)'s isochrone. Section VI summarizes our results.

Table 1. Observation log

Date	Filter	Short Exp.(sec)	Long Exp.(sec)	FWHM(arcsec)
	U		500	2.8
Dec. 1	B	100	400	2.0
1998	V	50	250	2.5
	I	30	100	2.0

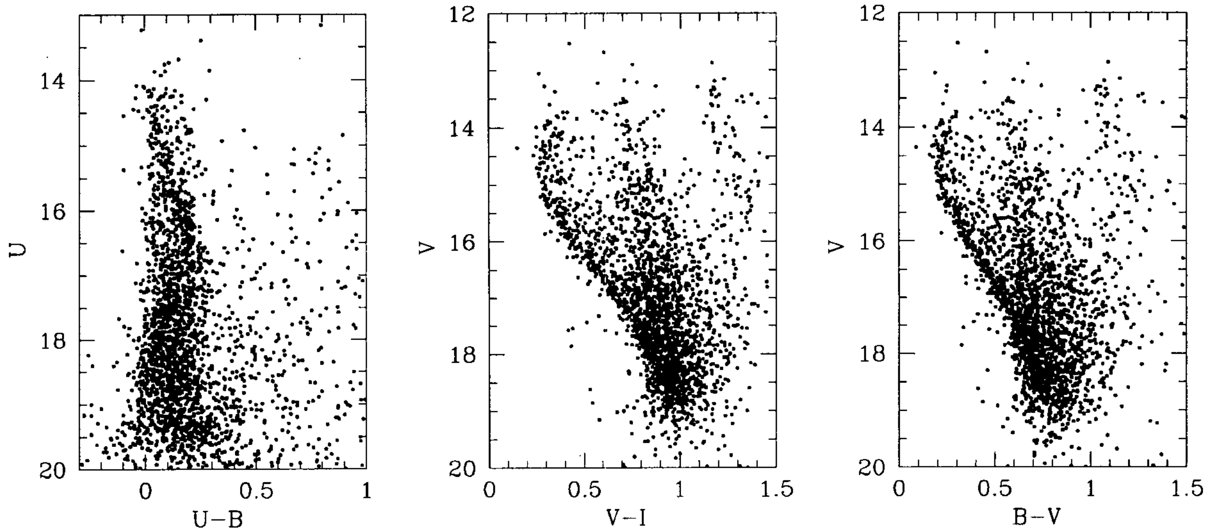

Fig. 2.— Color-magnitude diagrams of all recovered stars. No attempt was made to remove field stars.

II. OBSERVATION AND DATA REDUCTION

CCD photometry for the open cluster NGC 2324 was obtained during a five night observing program using the 40-inch telescope and SITe 2048 × 2048 CCD(24μm) of Siding Spring Observatory in December, 1998. The pixel scale was 0.″60 pixel^{-1} giving the total field of view 20.5 × 20.5 arcmin^2 at the Cassegrain focus of f/8. The gain and readout noise are respectively 1.25 e$^-$/ADU and 12 electrons. The detailed observation log is given in Table 1.

We observed the cluster using U, B, V, I filters. For B, V, I filters, we obtained both long and short exposure frames to correct the intensity saturation and nonlinearity range of bright stars. The CCD images were flattened after overscan correction and bias subtraction; all the preprocess were done using IRAF data reduction package CCDRED (Tody 1986).

Fig. 1 shows the observed CCD field of 20′ × 20′ in size. Instead of presenting the raw images, we used V band photometry data to reconstruct the stellar distribution of NGC 2324. It is seen from the figure that this cluster is indeed a populous one, with a center clearly identifiable from the stellar distribution.

We used the point spread function(PSF) fitting packages of DAOPHOT II and ALLSTAR for the stellar photometry. Stars of different frames were matched by DAOMATCH/DAOMASTER routines (Stetson 1992). For each frame, a number of isolated unsaturated stars are used to construct a good model PSF. Due to optical distortion at the focal plane, it was necessary to allow the shape of model PSF to vary quadratically with position in each frame. Finally, aperture corrections were made using the program DAOGROW(Stetson 1990) for which we used the same stars used in the PSF construction.

The resulting instrumental magnitudes were transformed into the standard $UBVI$ filter system using 120 standard star frames obtained throughout our observing run. Our standard stars were selected from Landolt (1992). The transformation equations are as follows.

$$m_B = B + 1.708 + 0.283X_B + 0.013(B-V)$$
$$m_V = V + 1.573 + 0.172X_V - 0.117(B-V)$$
$$m_I = I + 2.003 + 0.085X_I - 0.055(V-I)$$
$$m_U = U + 3.578 + 0.599X_U - 0.206(U-B)$$

where m represent instrumental magnitude and the upper case symbols indicate standard magnitude. X is

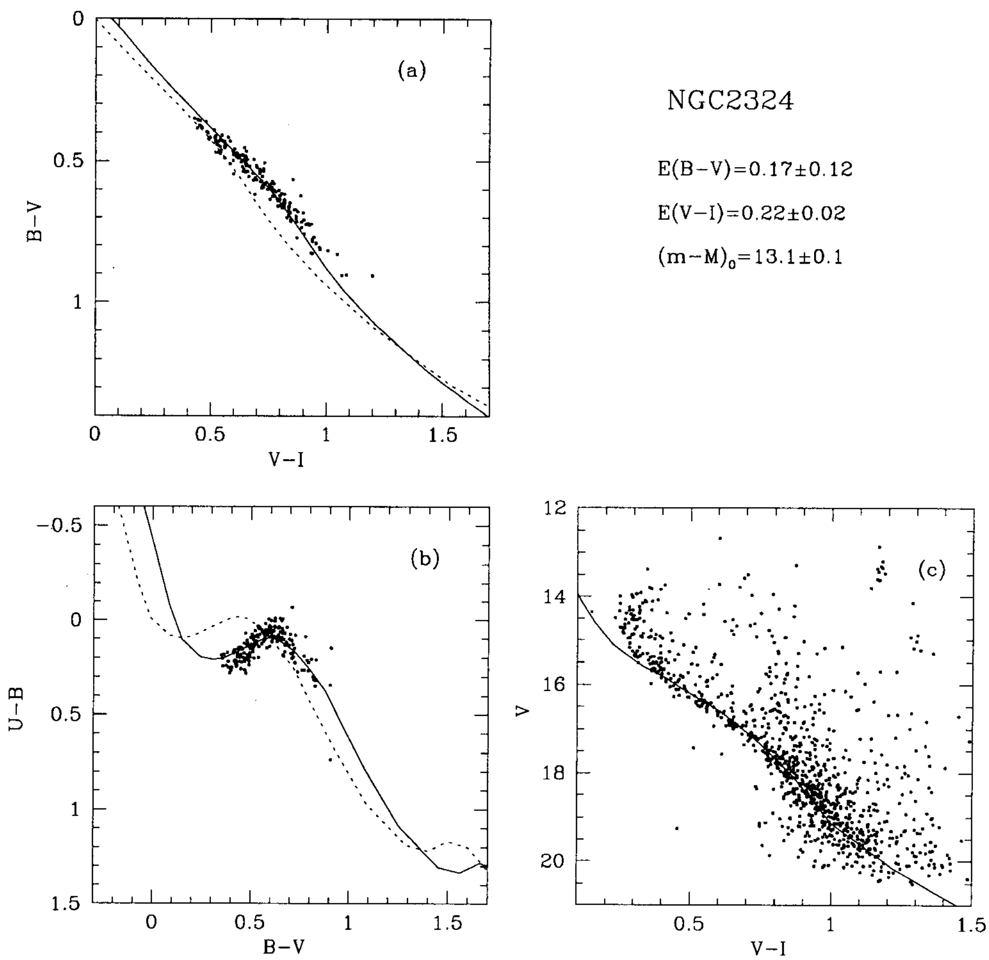

Fig. 3.— Color-color diagrams (a) $(B-V, V-I)$, (b) $(U-B, B-V)$, and (c) ZAMS fitting of $(V, V-I)$ CMD. The dashed lines in (a) and (b) represent the unreddened ZAMS line given by Sung & Bessell (1999). In (a) and (b), we plot only those stars with observational error smaller than $0^m.03$ and located within radius of R=5 arcmin.

airmass. No other trends, such as UT dependence, in the residuals were noticeable. The residuals of standard star calibration were 0.028, 0.028, 0.059, and 0.046 mag for B, V, I, and U filter respectively.

III. CMD FEATURES

New CMDs were plotted using our data in Fig. 2. A total of 2,457 stars appeared in all passband. Most earlier photometric data for this cluster were photographic or photoelectric(Cuffey 1941, Hoag et al. 1961, Becker et al. 1976, Mermilliod et al. 2001). So we cannot compare the average difference in the photometry with previous one but our photometry extends nearly 3 magnitudes fainter than other data. There is substantial field star contamination, and the field is blended with the cluster sequence near V ~17.5. Specifically, the vertical branch near $V-I$=0.8 ~ 1.0 in $(V, V-I)$ CMD and $B-V$=0.7 ~ 0.8 in $(V, B-V)$ CMD are attributed to field interloper in the Galactic plane. The scatter associated with main sequence is probably the result of binary population.

CMDs of this cluster show well-defined main sequence and red giant clump except in $(U, U-B)$ CMD, in which $U-B$ fails to represent the stellar temperature properly. The mean magnitude and color of red giant clump stars, which is in stage of the core helium burning phase, is located at $B-V$=1.05 and V=13.45. It can be shown that the red clump stars are mainly concentrated in the central region of the cluster.

IV. CLUSTER PARAMETERS

The open cluster NGC 2324 is relatively populous one, and as can be seen from the stellar distribution given in Fig. 1, there is significant central concentration of member stars. It is estimated that cluster stars dominate the general background within the central area with radius of 5 arcmin. For the following

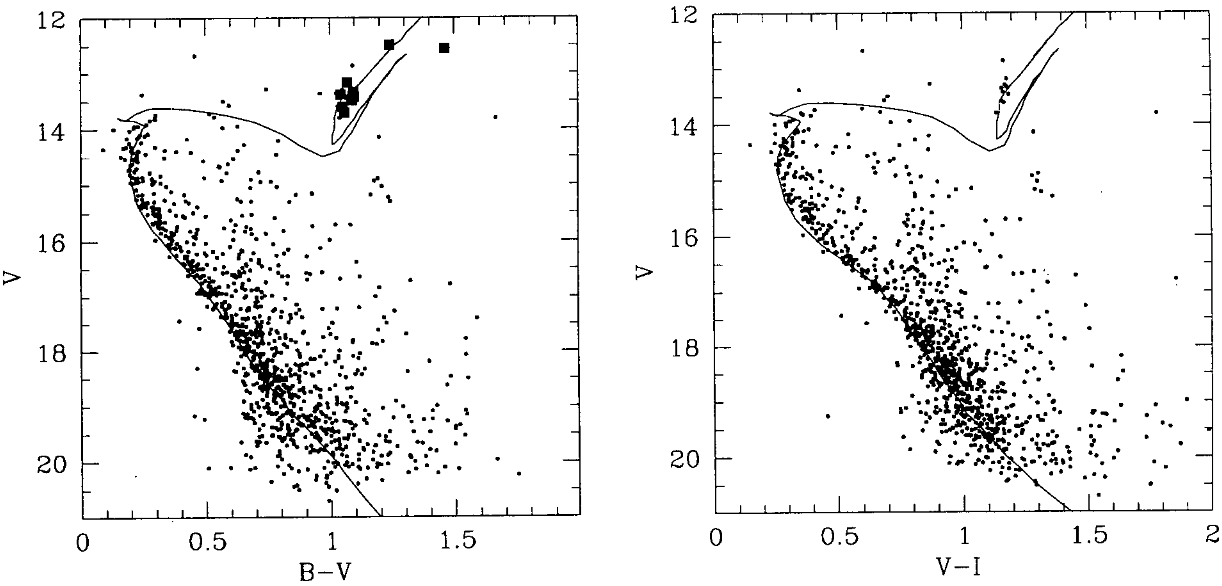

Fig. 4.— The best isochrone fittings to CMDs of NGC 2324. We used $E(B-V)$= 0.17±0.12, $(m-M)_0$=13.1±0.1, log t=8.8 and [Fe/H]=−0.32. Filled squares mean stars verified as member star or spectroscopic binary through radial velocity observation(Mermilliod et al. 2001).

analysis, therefore, we use only the stellar data located within this radius.

(a) Reddening

The prevailing method for the determination of cluster reddening is to de-redden the (U-B, B-V) colors using the following equation.

$$E_{U-B} \;/\; E_{B-V} \;=\; 0.72 \;+\; 0.05E_{B-V}$$

In order to estimate the reddening, we fit our data to the corrected ZAMS color-color curve having solar metallicity (Sung & Bessell 1999). In case of $E(V-I)$, we rederived the color excess from the $(B-V, V-I)$ two color diagram, instead of using the relationship ($E(V-I) = 1.25E(B-V)$) given by Dean et al. (1978). This new value allows the ZAMS line to be fitted to the observational $(V, V-I)$ CMD better.

Above all, we obtained $E(B-V)$= 0.16±0.03, $E(V-I)$=0.22±0.02 from the two color diagram. Fig. 3 shows our two color diagram fitting result well. For this analysis, we used stars with magnitude error less than 0.03 mag and located at R<5 arcmin.

Next the reddening can be estimated from the mean color of the red giant clump. It is known that the magnitude and color of the red giant clump in open clusters show only a small variation. Janes & Phelps(1994) determined the magnitude and color of red giant clump as M_V=0.59±0.46 and $B-V$=0.87 ±0.12 statistically for old open clusters having δV<1.0, which is defined as the magnitude difference between the main sequence turn-off and red giant clump(this value will be used to derive an age of cluster as a morphological age index) in $(V, B-V)$ CMD. The mean $B-V$ color of NGC 2324 red clump is 1.05±0.02. From this value we obtained its reddening as 0.18±0.12

Our estimates of the reddening using above two methods are mutually consistent, and the average is $E(B-V)$=0.17±0.12. We note that this value is significantly smaller than Janes & Phelps(1994)'s 0.28 and larger than Mermilliod et al.(2001)'s 0.02.

(b) Distance Modulus

Since $(B-V)$ color is affected by cluster metallicity(Sung & Bessell 1999), we use $(V, V-I)$ plane as shown in Fig. 3(c) to derive distance modulus. The uncertainty of derived distance modulus is obtained from the rms fitting error of the data within 1σ of the apparent main sequence fiducial line. Although we used the semi - empirical relation described in VandenBerg & Poll(1989) for the ZAMS fitting, the result is not much different. Adopting $E(B-V)$ value found in previous section, we derived the distance to this cluster as $(m-M)_V$=13.6±0.1. With R_V = 3.1, this value becomes $(m-M)_0$=13.1±0.1.

V. ISOCHRONE FITTING

There exist a few different approaches to age determination for open clusters. One is to compare the observed CMD with theoretical stellar evolutionary models by converting the latter into a set of isochrones. Another method is to find the differences in magnitude and color between the main sequence turn-off and positions along the giant branch (Janes & Phelps 1994).

We compared a set of isochrones against the cluster CMD to establish the possible age range of the cluster. This method for comparing isochrones involves the investigator's judgment in choosing which models compare better to an observed CMD. Isochrones are shifted to match the turnoff and the upper main sequence line in the cluster CMDs. Acceptability was based on how well the isochrones described the turnoff region, the slope along the length of visible lower main sequence, and also the location of red giant clump. But the clump region was less emphasized in the comparison because of an anomaly noted by Mermilliod et al. (1998).

We selected Bertelli et al. (1994) isochrones. Their models are preferred because models with convective overshooting appeared to be more suitable in describing open clusters (Carraro et al. 1993, 1994). We initially chose the ages ranging from $\log t \sim 8.4 - 9.5$ and metallicity subsets of four [Fe/H] values. By employing the reddening and distance modulus estimated in previous sections, we then performed more detailed comparison between CMDs and isochrones. Fig. 4 shows the fitting result very well. Our best estimate is an age of $\log t \sim 8.8$ (approximately 0.9 Gyrs) and metallicity of $[Fe/H] \sim -0.32$.

Our metallicity compares well with published values −0.39 (Hagen 1970), −0.31 (Janes & Phelps 1994) but not consistent with Geisler et al. (1992)'s value of −1.01 and Mermilliod et al.(2001)'s solar value.

We also tried to make an isochrone-free age estimate by using the method of Phelps et al. (1994) and Janes & Phelps (1994), called morphological age index (MAI). MAI is a measure of δV. The MAI is given by $MAI = 0.73 \times 10^{[0.256\delta V + 0.0662\delta V^2]}$. In case of NGC 2324, we measure $\delta V = 0.33$ and therefore its age is estimated to be around 0.9 Gyrs ($\log t \sim 8.8$). This is consistent with the isochrone determination.

VI. SUMMARY

The primary goal of this study is to derive physical parameters of the rich open cluster NGC 2324 using our CCD photometric data. From the CMD analysis, we derived cluster fundamental parameters, which are summarized in Table 2.

We note that this cluster previously had very conflicting metallicity estimates ranging from [Fe/H] of −1 to +0.07. Our CCD study is very close to Janes(1979)'s value, which is much more consistent with its relative young age of 0.9 Gyrs.

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Table 2. Basic parameters of NGC 2324

Parameter	This paper	Previous studies
$(m-M)_0$	13.1	$12.95^1, 12.3^6$
$E(B-V)$	0.17	$0.02^1, 0.10^2, 0.11^6, 0.28^4$
$\log t$	8.8	8.9^1
Metallicity	−0.32	$+0.07^1$, -0.31^4, -0.39^3, -1.01^5

1. Mermilliod et al.(2001), photoelectric and red giant stars; 2. Hoag et al.(1961) photographic; 3. Janes(1979), DDO data; 4. Janes & Phelps(1994) 5. Geisler et al.(1992), Washington photoelectric; 6. Hagen(1970)

REFERENCES

Becker, W., Svolopoulos, S. N., & Fang, C. 1976, Kataloge photographisher und photoelektrisher, Helligkeiten von 25 galaktischen Sternhaufen im RGU und UBV$_c$ System, (Basel)

Bertelli, G., Bressan, A., Chiosi, C., Fagotto, F., & Nasi, F. 1994, A&A 106, 275

Carraro, G., Bertelli, G., Bressan, A., & Chiosi, C. 1993, A&AS 101, 381

Carraro, G., Chiosi, C., Bressan, A., & Bertelli, G. 1994, A&AS 103, 375

Cuffey, J. 1941, ApJ, 94, 55

Dean, J.F., Warren, P. R., & Cousins, A. W. 1978 MNRAS, 183, 569

Geisler, D., Claria, J. J., & Minniti, D. 1992, AJ, 104, 1892

Hagen, G. L. 1970 Pub. David Dunlop Obs., 4, 1

Hoag A. A., Johnson H. L., Iriarte B., Mitchell R. I., Hallam K. L., & Sharpless S. 1961 Publ. US. Nav. Obs. 17, 341

Janes, K. A. 1979, ApJS, 39, 135

Janes, K. A., & Phelps, R. L. 1994, AJ, 108, 1773

Landolt, A. U. 1992, AJ, 104, 340

Mermilliod, J.-C., Mathieu, R. D., Latham, D. W., & Mayor, M. 1998, A&A, 339, 423

Mermilliod, J.-C., Claria, J. J., Anderson, J., Piatti, A. E., & Mayor, M, 2001, A&A, 375, 30

Phelps, R. L., Janes, K. A., & Montgomery, K. A. 1994, AJ, 107, 1079

Stetson, P. B. 1990, PASP, 102, 932

Stetson, P. B. 1992 IAU Colloq. 136, Stellar Photometry, Current Techniques and Future Development, eds by C. J. Butler & I. Elliot(Cambridge University Press : Cambridge) p. 291

Sung, H., & Bessell, M. S. 1999 MNRAS, 306, 361

Tody, D. 1986 IRAF User Manual, NOAO

VandenBerg, D. A., & Poll, H. E. 1989, AJ, 98, 1451