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Optical and near-infrared photometric study of NGC 6724

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Abstract *BVRI* CCD photometry of the poorly studied open cluster NGC 6724 has been carried out down to a limiting magnitude of $V\sim20$ mag. The stars of the cluster have been observed using the Newtonian focus ($f/4.84$) of the 74-inch telescope at Kottamia Astronomical Observatory in Egypt. Also, the 2MASS - *JHK* system is used to confirm the results we obtained. The main photometric parameters have been estimated for the present object; the diameter is found to be 6 arcmin, the distance is 1530±60 pc from the Sun and the age is 900±50 Myr. The optical reddening $E(B-V)=0.65$ mag, while the infrared reddening is $E(J-H)=0.20$ mag. The slope of the mass function distribution and the relaxation time estimations indicate that cluster NGC 6724 is dynamically relaxed.

Key words: Milky Way — open clusters and associations: individual (NGC 6724) — optical photometry — IR photometry — color-magnitude diagrams

1 INTRODUCTION

Study of the structure and evolution of the Milky Way system mainly depends on accurate information about its components regarding their chemical compositions, distances, ages and their dynamical properties. One of the important components is open clusters (OCs), more than two thousand of which have been detected and cataloged. Although many of these objects are newly discovered and need photometric investigations, some others need confirmation of their physical nature, verifying if they are real star clusters or just some random groupings.

NGC 6724 is a poorly studied cluster located in the constellation Aquila (the Eagle), with J2000.0 coordinates $\alpha = 18^{\rm h}56^{\rm m}47^{\rm s}$, $\delta = +10°25'\,43''$, $\ell = 42.8292°$, $b = 3.5622°$, which was discovered by J. Herschel in 1828 using his 7-ft equatorial telescope. At that time, there was some confusion about an accurate position of its center. In this work, we present the first real photometric study of NGC 6724 in the optical *BVRI* bands observed by the 74-inch telescope at Kottamia Astronomical Observatory (KAO) in Egypt; for more details about KAO, see Azzam et al. (2010). In addition, we use near infrared (NIR) photometry of the Two Micron All Sky Survey (2MASS)[1] catalog of Skrutskie et al. (2006) to confirm the main photometric parameters.

Many different photometric parameters (distance, age, reddening, diameter, etc.) have been estimated. This paper is arranged as follows: Observation material and data reduction are given in Section 2. Radial density profile is described in Section 3. Color-magnitude diagram (CMD) analysis is performed in Section 4. Luminosity and mass functions with the dynamical status of the cluster are estimated in Section 5. Finally, the conclusion of the present study is provided in Section 6.

2 OBSERVATIONAL MATERIAL AND DATA REDUCTION

The *BVRI* CCD photometric observations of NGC 6724 that are used for this study were carried out with the 74-inch telescope at KAO in Egypt. The observations were acquired at the Newtonian focus with a plate scale of 22.53 arcsec mm^{-1} and field area of 10×10 arcmin^2 on the nights 2012 June 13–14. Various characteristics of the CCD camera used at KAO are listed in Table 1.

[1] *http://vizier.cfa.harvard.edu/viz-bin/VizieR?-source=II/246*

Table 1 Characteristics of the CCD Camera used in the Observations

Type	EEV CCD 42-40
Version	Back-illuminated with Basic Processes Broadband Coating (BPBC)
Format	2048×2048 pixel^2
Pixel size	13.5×13.5 μm^2
Grade	0
Dynamic range	30:1
A/D converter	16 bit
Imaging area	27.6×27.6 mm^2
Readout noise @20 KHz	3.9 e$^-$/pixel
Gain	2.26 e$^-$/ADU (Left amplifier) and 2.24 e$^-$ /ADU (Right amplifier)

Table 2 *BVRI* CCD Observations of NGC 6724 and Landolt SA 110

Object	Filter	Exp. Time (s)	No. of frames	Date
	B	120, 240, 360	3	
NGC 6724	V	360, 360	2	2012 June 13–14
	R	360, 360	2	
	I	360, 360	2	
	B	360, 360, 360	3	
Landolt SA 110	V	60, 360, 360, 360	4	2012 June 13–14
	R	400, 400	2	
	I	360, 360	2	

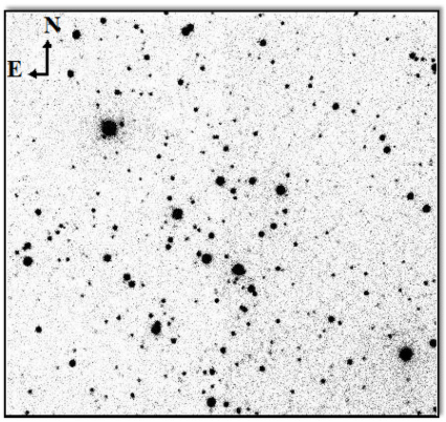

Fig. 1 The CCD B-image of OC NGC 6724 as observed by the 74-inch telescope at KAO, Egypt. North is up, east on the left.

For calibration purposes, the standard sequence Landolt (1992) SA 110 has been observed in the *BVRI* filters during the same nights, from which extinction coefficients could be obtained.

Table 2 summarizes the different *BVRI* observations of NGC 6724 and the standard sequence SA 110 ($\alpha = 18^{\rm h}40^{\rm m}51^{\rm s}$, $\delta = +00°02' \, 23''$) while Figure 1 presents an image of NGC 6724 in B-band.

The observed CCD frames were treated for bias and flat field corrections using the IRAF Software and photometry was carried out using a DAOPHOT package (Stetson 1987, 1993). The magnitude errors in each band are displayed in Figure 2. The numbers of observed stars in the B, V, R and I bands are 368, 1772, 2576 and 3910 stars respectively. The mean error for each band is found to be 0.039, 0.027, 0.024 and 0.023 mag respectively.

To obtain the instrumental magnitudes of stars in the observed field, the point spread function (PSF) of Stetson (1987) has been used. For the calibration process, the standard field SA 110 of Landolt (1992) was observed during the same nights. The frames have been treated and corrected using aperture photometry to obtain instrumental magnitudes of the standard stars. The extinction coefficients and the zero point for each color have been calculated to standardize the instrumental magnitudes of the cluster stars by applying the transformation equations

$$\begin{aligned} b &= B + Z_b + K_b X + a_b(B-V), \\ v &= V + Z_v + K_v X + a_v(B-V), \\ r &= R + Z_r + K_r X + a_r(V-R), \\ i &= I + Z_i + K_i X + a_i(V-I), \end{aligned}$$

where b, v, r and i are the instrumental magnitudes; B, V, R and I are the standard magnitudes; while values for Z, K and a are the zero points, the extinction coefficients and the color coefficients in *BVRI* bands respectively. These values are listed in Table 3. At low Galactic latitudes, the clusters are not sufficiently more promi-

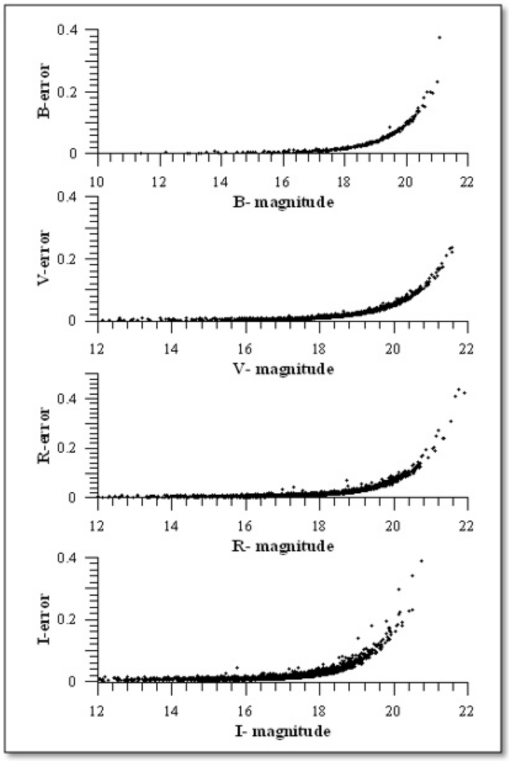

Fig. 2 *BVRI* errors of the observed magnitudes for the stars in NGC 6724.

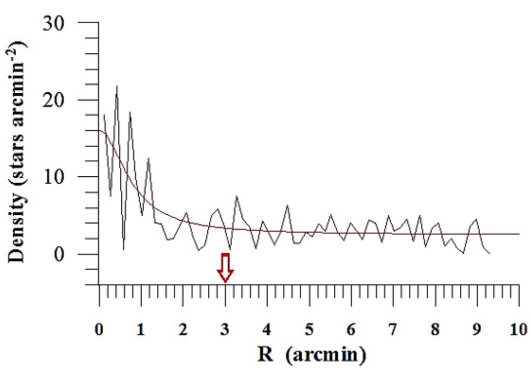

Fig. 3 The radial stellar density profile of NGC 6724, after subtracting the offset field density. The model curve of King (1966) has been applied.

nent than background field stars, so it is difficult to easily identify the cluster members. Because we did not have a comparison field in our *BVRI* observations, the photometric criterion for excluding field stars is applied. A star is regarded as a member if it lies inside the cluster limited area and, at the same time, only falls within the photometric envelope (close to the main sequence curve), i.e. about ± 0.15 mag along the abscissa (color-axis).

Table 3 The Obtained Values of the Zero Points, Extinctions and Color Coefficients

Sp. band	Z	K	a
B	3.240	0.26	0.004
V	2.755	0.16	0.002
R	2.650	0.09	0.001
I	3.108	0.05	–0.003

On the other hand, the JHK_s photometric data are extracted from published data of the 2MASS survey from Skrutskie et al. (2006). 2MASS included an area of 10 arcmin centered on the cluster. The raw data on the cluster were acquired using the VizieR[2] tool. To avoid oversampling, the completeness limit has been taken at $J < 16.5$ mag (Bonatto et al. 2004). To improve the photometric quality, stars with magnitude errors ± 0.2 mag have been excluded. Applying the completeness limit to the cluster stars, we noticed that field contamination is reduced. Therefore, the probable members are found to be 565 stars, and we used this number to estimate the astrophysical parameters of NGC 6724. 2MASS uniformly scanned the entire sky in three NIR bands $J(1.25\,\mu\text{m})$, $H(1.65\,\mu\text{m})$ and $K_s(2.17\,\mu\text{m})$ with two highly automated 1.3-m telescopes equipped with a three-channel camera. Data in each channel were acquired with a 256×256 array of HgCdTe detectors. The photometric uncertainty of the data is less than 0.155 mag with $K_s \sim 16.5$ mag photometric completeness. At a given magnitude, the errors affect the K_s band (Soares & Bica 2002), so raw data from J and H bands, with small errors, are used to probe the fainter stars of NGC 6724.

To reduce the background contamination to some extent, the field density distribution is derived for an offset field sample as follows. The offset field sample here is a ring, which has the same interior area as the cluster, but lies one degree away from the cluster's center in declination coordinate towards the noth direction. To avoid spatial variations from numerous faint stars, which can generate large errors (Bonatto et al. 2004), the cutoff $J < 16.0$ mag is applied to both the cluster and offset field stars. The field density distribution of the offset sample is found to be 16 stars per arcmin^2.

3 RADIAL DENSITY PROFILE

Subtracting the mean field density value, which is estimated from the offset sample, from the corresponding

[2] *http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=2MASS*

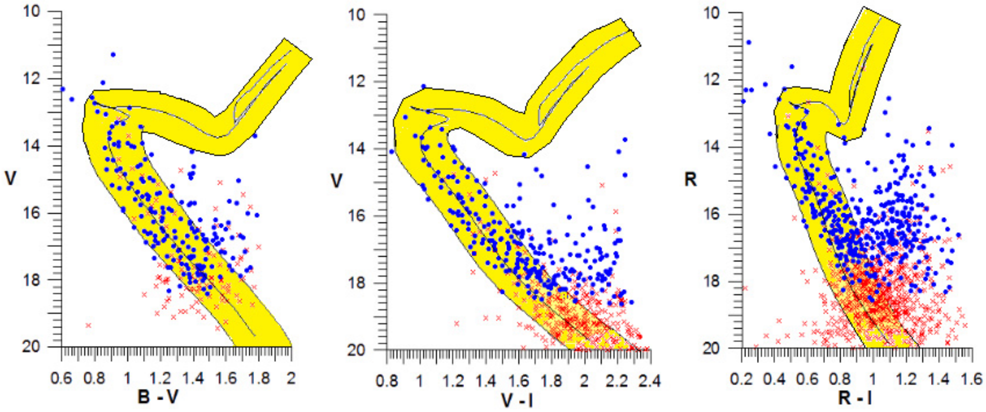

Fig. 4 The observed CMDs of NGC 6724 fitted to the theoretical isochrones of Girardi et al. (2010). The distance modulus is found to be 10.88±0.1 mag, and the reddening values are found to be of $E(B-V) = 0.65$ mag, $E(V-I) = 0.84$ mag and $E(R-I) = 0.42$ mag. The blue dots refer to stars lying within the cluster edges, while the red crosses represent the stars outside. The yellow areas represent the photometric envelopes along the main sequence curves, i.e. ±0.15 mag around the color-axis.

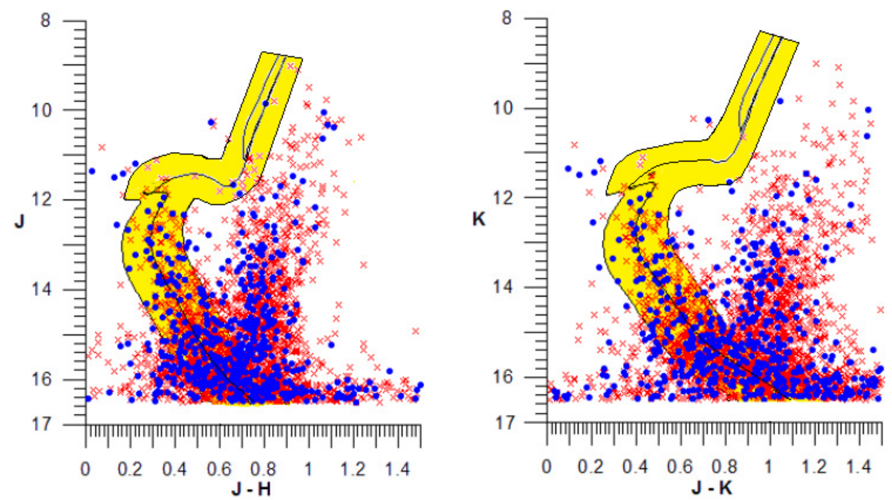

Fig. 5 The 2MASS CMDs of NGC 6724 fitted to the theoretical isochrones of Girardi et al. (2010). The distance modulus is found to be 10.97±0.1 mag, and the color excesses are found to be $E(J-H) = 0.20$ mag and $E(J-K) = 0.31$ mag. The blue dots refer to stars lying within the cluster edges, while the red crosses represent those from the offset field background sample. The yellow areas represent the photometric envelopes along the main sequence curves, i.e. ±0.15 mag around the color-axis.

one of the cluster's area outward provides an equal increment radius of 0.1 arcmin.

Figure 3 presents the radial density distribution of the cluster, where the mean stellar density in each ring is plotted against the corresponding mean radius. The cluster border is taken as the limit which contains the whole cluster area and yields sufficient stability with respect to background field density, i.e. the point where the cluster stars dissolve into the background field ones; for more details see Tadross (2005). Applying the empirical King's Model (King 1966), the density function $\rho(r)$ can be represented as

$$\rho(r) = f_{\rm bg} + \frac{f_0}{1+(r/r_c)^2}\,, \qquad (1)$$

where $f_{\rm bg}$, f_0 and r_c are background and central star densities, and the core radius of the cluster respectively. For the present photometry $f_{\rm bg} = 2.5\,\mathrm{star\,arcmin}^{-2}$, $f_0 = 13.5\,\mathrm{star\,arcmin}^{-2}$ and $r_c = 0.78'$. The limit for the angular diameter is found to be $3'$, which is in good agreement with Tadross (2011).

4 COLOR MAGNITUDE DIAGRAM ANALYSIS

The CMDs for the observed stars in NGC 6724, where $V \sim (B-V)$, $V \sim (V-I)$ and $R \sim (R-I)$, are plotted in Figure 4. The blue dots refer to stars lying within the cluster limited edges, while the red crosses represent the stars outside. These observed CMDs have been compared to many theoretical Padova isochrones (Girardi et al. 2010) with different ages, having solar metallicity $Z = 0.019$. Applying the normal fitting method for the three plots, the best fit is obtained at the mean distance modulus of 12.9±0.1 mag, age of 900±75 Myr and reddening of $E(B-V) = 0.65$ mag, $E(V-I) = 0.84$ mag and $E(R-I) = 0.42$ mag. Adopting the ratio $A_V/E(B-V)$ to be 3.1 (Garcia et al. 1988), the true distance modulus is found to be 10.88±0.1 mag.

On the 2MASS CMDs, $J \sim (J-H)$ and $K \sim (J-K)$ are plotted for the cluster NGC 6724 as shown in Figure 5. The blue dots refer to stars lying within the cluster edges, while the red crosses represent the sample from the offset field background. Using theoretical isochrones of Girardi et al. (2010) at the same age, the best fit is obtained at a distance modulus of 11.6±0.1 mag. The color excesses are found to be $E(J-H) = 0.20$ mag and $E(J-K) = 0.31$ mag. Therefore, the true distance modulus is found to be 10.97±0.1 mag, which is in good agreement with Tadross (2011). For absorption transformation between the *BVRI* and *JHK* systems, we used the ratios $A_J/A_V = 0.278$, $A_H/A_V = 0.176$ (Schlegel et al. 1998) and $A_K/A_V = 0.118$ (Dutra et al. 2002).

According to the observed and NIR CMDs of the cluster NGC 6724, the mean distance is calculated to be 1530±60 pc. Correspondingly, the mean linear radius, the distance from the Galactic center, the distance from the Galactic plane, and the distances X and Y from the Sun on the Galactic plane are 1.3 pc, 7.2 kpc, 95 pc, -1120 pc and 1038 pc respectively.

5 LUMINOSITY, MASS FUNCTIONS AND THE DYNAMICAL STATUS

The luminosity and mass functions mainly depend on membership of the cluster. The stars, which lie within the cluster edges and close to the photometric envelope of the main sequence curves within a photometric error ±0.15 mag, are considered as probable members. Accordingly, 565 stars in the cluster region have been counted inside the limited border of the cluster.

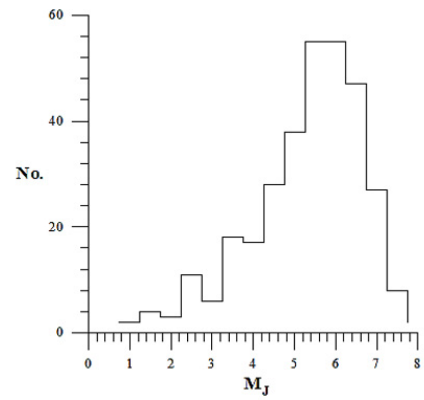

Fig. 6 The luminosity distribution of NGC 6724.

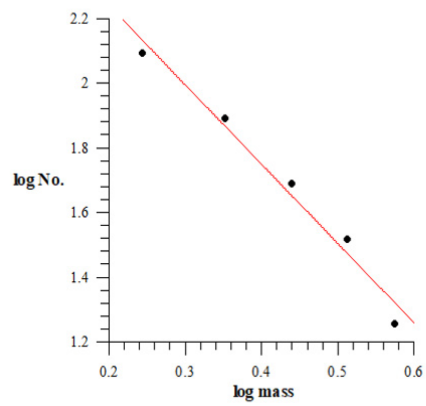

Fig. 7 The mass function of NGC 6724.

The J mag of each star has been transformed to absolute magnitude using the obtained distance modulus. The absolute magnitude has been divided into bins of 0.5 mag for each. The counted number of stars in each bin has been used in constructing the luminosity function as shown in Figure 6. The mass of each probable member in NGC 6724 has been estimated using a polynomial equation derived from the raw data of Padova isochrones tracks from Girardi et al. (2010) at the cluster's age (absolute magnitudes vs. actual masses). The mass function is constructed as shown in Figure 7. The initial mass function (IMF) can be represented by

$$\frac{dN}{dM} \propto M^{-\alpha}, \tag{2}$$

where $\frac{dN}{dM}$ is the number of stars of mass interval (M: $M + dM$) and α is the slope of the mass function. Applying the linear fit to the mass function distribution, the slope of the relation is found to be -2.48, which to some extent agrees with Salpeter (1955). The cluster's total mass is calculated by integrating the masses of all the probable members, which is found to be 995 $M_\odot$.

Following Spitzer & Hart (1971), the dynamical relaxation time (T_R) could be obtained from the relation

$$T_R = \frac{8.9 \times 10^5 \sqrt{N} \times R_h^{1.5}}{\sqrt{m} \times \log(0.4N)}, \tag{3}$$

where N is the number of cluster members, R_h is the radius containing half of the cluster mass in parsecs and m is the average mass of the cluster in solar units, assuming that R_h equals half of the cluster radius in pc. Applying the previous equation, the relaxation time is found to be 3.7 Myr (less than the cluster's age). This means that the cluster NGC 6724 is quite dynamically stable and relaxed.

6 CONCLUSIONS

The poorly studied OC NGC 6724 has been observed using the optical CCD-*BVRI* passband of the 74-inch telescope at KAO in Egypt. All the astrophysical parameters of the cluster have been estimated photometrically for the first time and confirmed by the 2MASS-*JHK* system. It is noted that calculation of the cluster limited diameter using the 2MASS database allows us to obtain reliable data for large areas outside of clusters. From the CMDs, it is apparent that this cluster has a clear main sequence branch, which confirms its nature as a physical cluster and not a random grouping of stars. Also, the mass function distribution verified that NGC 6724 is a mature cluster in that its IMF slope agrees to some extent with Salpeter (1955).

In addition, the relaxation time of the cluster compared to its age indicates that it is indeed a dynamically relaxed cluster.

References

Azzam, Y. A., Ali, G. B., Ismail, H. A., Haroon, A., & Selim, I. 2010, Astrophysics and Space Science Proceedings, eds. H. J. Haubold, & A. M. Mathi (Berlin: Springer), 20, 175

Bonatto, C., Bica, E., & Girardi, L. 2004, A&A, 415, 571

Dutra, C. M., Santiago, B. X., & Bica, E. 2002, A&A, 381, 219

Garcia, B., Clariá, J., Levato, H. 1988, Ap&SS, 143, 377

Girardi, L., Williams, B. F., Gilbert, K. M., et al. 2010, ApJ, 724, 1030

King, I. R. 1966, AJ, 71, 64

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

Salpeter, E. E. 1955, ApJ, 121, 161

Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525

Skrutskie, M. F., Cutri, R. M., Stiening, R., et al. 2006, AJ, 131, 1163

Soares, J. B., & Bica, E. 2002, A&A, 388, 172

Spitzer, Jr., L., & Hart, M. H. 1971, ApJ, 164, 399

Stetson, P. B. 1987, PASP, 99, 191

Stetson, P. B. 1993, in IAU Colloq. 136: Stellar Photometry - Current Techniques and Future Developments, eds. C. J. Butler, & I. Elliott, 136, 291

Tadross, A. L. 2005, Astronomische Nachrichten, 326, 19

Tadross, A. L. 2011, Journal of Korean Astronomical Society, 44, 1