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Photometric study of five open star clusters

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HIGHLIGHTS

- The paper presents *UBVRI* CCD photometry of five open clusters.
- The fundamental parameters like reddening, distance and age have been derived.
- The spatial structure, mass function and mass segregation have also been studied.

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ABSTRACT

UBVRI photometry of the five open clusters Czernik 4, Berkeley 7, NGC 2236, NGC 7226 and King 12 has been carried out using ARIES 104 cm telescope, Nainital. Fundamental cluster parameters such as foreground reddening $E(B-V)$, distance, and age have been derived by means of the observed two colour and colour-magnitude diagrams, coupled to comparisons with theoretical models. $E(B-V)$ values range from 0.55 to 0.74 mag, while ages derived for these clusters range from ~10 to ~500 Myr. We have also studied the spatial structure, mass function and mass segregation effects. The present study shows that evaporation of low mass stars from the halo of the clusters increases as they evolve.
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1. Introduction

Open clusters (OCs) are excellent tools to understand star formation and evolution because their stars emerge from the same molecular cloud and have a mass spectrum that can be used to study the initial mass function (IMF). Poorly populated OCs do not survive longer than a few hundred Myr, whereas rich ones may survive longer (e.g. Pandey and Mahra, 1986; Theuns, 1992; Tanikawa and Fukushige, 2005; Carraro et al., 2005; Bonatto et al., 2012). OCs are also one of the best tools to probe the age and abundance structure of the Galactic disk. As clusters evolve through dynamical effects (internally and by interactions with the Galactic tidal field), a significant fraction of the cluster stars is gradually lost to the field. Mass segregation and evaporation of low-mass members are the main effects of dynamical interactions (de la Fuente Marcos, 2001; Andersen and Nordström, 2000; Patat and Carraro, 1995; Carraro, 2006). Hence, to understand cluster evolution it is necessary to study the dense central region (the core) as well as the expanded and sparse region (the halo or corona) (Pandey et al., 1988; Maciejewski, 2009). In addition, study of the structure of OCs also gives the opportunity to understand how external environments and internal stellar encounters affect OCs. The morphological structure, or shape, of the young OCs can be governed by initial conditions in the molecular clouds and by internal gravitational interactions and external tidal perturbations as the cluster evolves (Chen et al., 2004; Sharma et al., 2006, 2008). Based on N-body simulations, de la Fuente Marcos, 1997 finds that the total disruption time for a cluster also depends on its richness. The studies of dynamical properties of the OCs are difficult in the absence of kinematical data. However, some information about the dynamical evolution of open clusters can be drawn from statistical analysis of the spatial distribution of the probable cluster members and their mass function (Kang and Ann, 2002; Ann and Lee, 2002).

In order to continue our efforts to study the dynamical evolution of OCs using the photometric properties, we carried out photometric observations of OCs Czernik 4 (Cz 4), Berkeley 7 (Be 7), NGC 2236, NGC 7226 and King 12, which cover a wide range in age and are relatively poorly studied. The basic parameters of these clusters available in the literature are listed in Table 1. Additionally, since these clusters are of intermediate to old age, they may present observable consequences of mass segregation.

The paper is organised as follows. We describe observations and data reduction technique in Section 2. Section 3 deals with spatial

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Table 1
Basic parameters of the target clusters taken from the WEBDA.

Cluster	RA (2000) (hh:mm:ss)	Dec (2000) (°: ′:″)	l (°)	b (°)
Cz 4	01 35 24	+61 16 00	128.179	−0.945
Be 7	01 54 12	+62 22 00	130.138	0.376
NGC 2236	06 29 39	+06 49 48	204.370	−1.699
NGC 7226	22 10 26	+55 23 54	101.405	−0.596
King 12	23 53 00	+61 58 00	116.124	−0.130

structure of the cluster. Section 4 describes basic parameters of clusters using the two colour diagram and colour-magnitude diagram obtained in the present study. We study luminosity and mass function in Section 5. In Section 6 we put our effort in describing dynamical evolution of clusters by means of their MF and structural parameters. Finally, we summarise our results in Section 7.

2. Observations and data reduction

The *UBVRI* CCD observations of open clusters Cz 4, Be 7, NGC 2236, NGC 7226 and King 12 were carried out using the 104 cm ARIES Telescope. A 2k × 2k CCD was used as a detector. The field of view is $\sim 13' \times 13'$ and the plate scale is $\sim 0.76''$/pixel in 2×2 pixel binning mode. The log of the observations is given in Table 2. The observed *V*-band images of the clusters are shown in Fig. 1. The typical seeing (estimated from the FWHM of the point spread function; PSF) of the images was found to be $1.5''$–$2''$. Bias and twilight flats were also taken along with the target field. The preprocessing of the CCD images was performed by using the IRAF[1], which includes bias subtraction, flat field correction and removal of cosmic rays. The instrumental magnitude of the stars were obtained using the DAOPHOT package provided by Stetson (1987, 1992). Both aperture and PSF photometry were carried out to get the magnitudes of the stars. The PSF photometry yields better results for crowded regions. The standardization of the cluster fields was carried out by observing the standard field SA 98 (Landolt, 1992). Instrumental magnitudes were converted to standard magnitudes using the following transformation equations

$$v = V + q_1 + p_1(V - I) + k_v X$$

$$b = B + q_2 + p_2(B - V) + k_b X$$

$$i = I + q_3 + p_3(V - I) + k_i X$$

$$r = R + q_4 + p_4(V - R) + k_r X$$

$$u = U + q_5 + p_5(U - B) + k_u X$$

In the above equations $u,\ b,\ v,\ r$ and i, obtained after time and aperture corrections are the instrumental magnitudes while $U,\ B,\ V,\ R$ and I are the standard magnitudes; $p_1,\ p_2,\ p_3,\ p_4$ and p_5 are the colour coefficients; $q_1,\ q_2,\ q_3,\ q_4$ and q_5 are the zero point constants; $k_v,\ k_b,\ k_u,\ k_r$ and k_i are the extinction coefficients in $V,\ B,\ U,\ R$ and I filters, respectively, and X is the airmass. The values of the coefficients for each observing night are listed in Table 3. The typical DAOPHOT errors at brighter level ($V \approx 16$ mag) are $\leqslant$0.01 mag, whereas for fainter end ($V \approx 20$ mag) the errors become larger ($\approx$0.05 mag). The entire *UBVRI* CCD photometric data for the cluster under present study is available in electronic form at the WEBDA open cluster data base website at http://obswww.unige.ch/webda/. It can also be obtained from the authors.

[1] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA) under cooperative agreement with the National Science Foundation.

Table 2
Log of CCD observations.

Region	Filters and Exposure time × no. of frame (in seconds)	Date
Cz 4	U 1200 × 2; B 900 × 3; V 500 × 3; R 200 × 3; I 200 × 3	24 Dec 2008
	U 300 × 3; B 150 × 3; V 30 × 3; R 30 × 5; I 30 × 4	08 Dec 2007
SA 98	U 300 × 7; B 100 × 7; V 60 × 7; R 60 × 7; I 60 × 7	08 Dec 2007
Be 7	U 300 × 3; B 180 × 3; V 120 × 3; R 60 × 3; I 60 × 3	23 Jan 2006
SA 98	U 300 × 5; B 180 × 5; V 120 × 5; R 60 × 5; I 60 × 5	23 Jan 2006
NGC 2236	U 1500 × 2; B 900 × 3; V 500 × 3; R 300 × 3; I 300 × 3	05 Dec 2007
	U 300 × 2; B 120 × 2; V 90 × 2; R 60 × 2; I 60 × 2	20 Feb 2009
SA 98	U 300 × 2; B 150 × 2; V 90 × 2; R 60 × 2; I 60 × 2	20 Feb 2009
NGC 7226	U 1200 × 2; B 600 × 2; V 500 × 4; R 200 × 3; I 200 × 3	11 Nov 2007
	U 300 × 2; B 100 × 2; V 90 × 3; R 50 × 3; I 40 × 3	11 Nov 2007
SA 98	U 300 × 9; B 180 × 9; V 120 × 9; R 60 × 9; I 60 × 9	11 Nov 2007
King 12	U 300 × 2; B 180 × 3; V 120 × 3; R 60 × 3; I 60 × 3	04 Nov 2005
SA 98	U 300 × 10; B 120 × 10; V 60 × 10; R 30 × 10; I 30 × 10	04 Nov 2005

2.1. Comparison with previous photometry

Barring the cluster Cz 4 all the other clusters have already been studied partially either photoelectrically or photographically. A comparison of the present photometries for clusters Be 7, NGC 2236, NGC 7226 and King 12 with the photometries available in the literature has been carried out. In Fig. 2 we plot $\Delta V,\ \Delta(U - B)$ and $\Delta(B - V)$ (in the sense, present data minus literature data) for the common stars as a function of V magnitude.

2.1.1. Be 7

Phelps and Janes (1994) carried out CCD photometry of Be 7 in the area of 11.68×11.68 arcmin^2 for the first time and reported 722 stars down to $V \sim 21$ mag. The comparison shows that the present V magnitude and $(B - V)$ colour are in fair agreement with those obtained by Phelps and Janes (1994), whereas in the case of $(U - B)$ colours there seems to be a some trend in $\Delta(U - B)$.

2.1.2. NGC 2236

The photographic observations for NGC 2236 were first carried out by Babu; 26 stars (1991) and Orekhova and Shashkina; 434 stars (1987). Babu (1991) also presented *UBV* photoelectric data for the region containing the cluster NGC 2236. Comparison has been made between the present data and those available in the literature. In Fig. 2 open circles and triangles represent present data minus photographic data given by Babu (1991) and Orekhova and Shashkina (1987) respectively, whereas filled circles represent present data minus photoelectric data given by Babu (1991). There seems to be a large scatter in the $\Delta V,\ \Delta(B - V),\ \Delta(U - B)$ without any trend. However, the V magnitude and $(B - V)$ colour made photoelectrically (see Fig. 2 filled circles) by Babu (1991) seem to match with those obtained in present study.

2.1.3. NGC 7226

The CCD photometric observations in an area of 7.9×7.9 arcmin^2 were presented by Viskum et al. (1997). They reported photometry for 499 stars down to $V \sim 18$ mag. The present V magnitudes and $(B - V)$ colours are in fair agreement with those obtained by Viskum et al. (1997).

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