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Collaborative Research of Open Star Clusters

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Abstract. Preliminary results on observations of open clusters are presented. The project has been initiated in the framework of the Uzbek–Taiwan and Taiwan–Baltic collaboration, mainly to upgrade and make use of facilities at Maidanak Observatory. We present detailed, multi-wavelength studies of the young cluster NGC 6823 and the associated complex nebulosity, to diagnose the young stellar population and star formation history in the region. In addition, 7 compact open clusters have been monitored for stellar variability. We show how observations like these could feasibly be used to look for exoplanet transit events. We also expect to join the Whole-Earth Telescope effort in future campaigns for asteroseismology.

Key words. Galaxy: open clusters and associations, general—method: observational.

1. Introduction

Open star clusters are one of the most important elemental components in the hierarchic structure of the Galaxy and of most other galaxies as well (see, e.g., Efremov 1989 and references herein). The stars forming a cluster are mainly born conjointly from the densest gas clumps in molecular clouds and therefore should have similar distances, ages, chemical composition (metallicity) and kinematics. Distributing throughout and around the Galactic disk, open star clusters are useful tools to probe the Galactic structure, dynamics and star formation history. According to the latest estimations, about 1700 open star clusters and cluster candidates are known in our Galaxy (WEBDA, Ruprecht *et al.* 1981; Lauberts 1982; Lynga 1987; Dias *et al.* 2002, 2004) but most of them are studied poorly or have not even been observed at all. At present due to the invention of more efficient two-dimensional detectors best adapted for the observations of star clusters, CCD observing is becoming the preferred technique. It replaces both the photoelectric and photographic photometry. At sites with quite good seeing conditions but equipped with small size telescopes the multicolor photometric and time-series monitoring observations of compact open clusters seems more worth pursuing than their spectroscopic surveys.

2. Observations and data processing

2.1 *NGC 6823*

The observations of complex star cluster NGC 6823 with bright nebula NGC 6820 were started in 2001 at Mt. Maidanak (Uzbekistan) on the 1.5 m and one of the 0.6 m telescopes. The Zeiss 0.6 m telescope equipped with a high sensitive water-cooled CCD-camera, Apogee AP-8e (SITe SI-003AB 1024 × 1024) was used for mosaicing photometric survey in R, I and H_α ($\lambda = 656.3$ nm; $\delta\lambda = 30$ nm) bands of the entire region. The 1.5 m AZT-22 telescope equipped with LN-cooled CCD-camera, BroCam (SITe-005 2000 × 800) was used in UBVRI and H_α for small regions that called for careful examination in the images taken by the 0.6 m telescope. The standard stars (PG 2213, SA-94, 109, 110, 114, 115, etc.) were observed for calibration each run, sometimes a few during the night.

Some spectra of the young star candidates with dispersion 50 and 200 Å/mm were obtained in 2001 and 2002 with the spectrometer on the 2.16 m telescope of Beijing Observatory in China. Besides the wide field narrow band photometry images of the entire region NGC6823/20 were obtained with Beijing 60/90 Schmidt telescope in 2002.

The data on these observations are given in Table 1. In addition to these data 5 new frames were obtained by Beijing 60/90 Schmidt telescope in red continuum around H_α in May 2004 and a few photometric images of NGC 6823 core were obtained with Lulin 1 m telescope in Taiwan in November 2004.

Table 1. NGC 6823/20 observation data.

Maidanak 0.6 m	Maidanak 1.5 m	Beijing 60/90 Schmidt	Beijing 2.16 m
Aug 12–18, 2001	Aug 08–17, 2001	Sep 05–07, 2002	Oct 27–30, 2002
146 frames	53 frames	41 frames	9 frames
RIH_α	UBVRIH_α	t, i, o	spectra

Notes: t-band = H_α; i-band = λ6660 Å and o-band = λ9100 Å.

2.2 *Time-series monitoring*

A sample has included the compact unstudied open clusters or cluster candidates extracted from Dias *et al.* (2002), which clearly show the concentration of stars to most probably be a real cluster. The observations were carried out with Zeiss 0.6 m telescope (Maidanak, Uzbekistan) equipped with CCD-camera Apogee AP-10 (Thompson Atmel THX7899 2048 × 2048) in the period from July 31st to August 23rd, 2003. We have patrolled (continuously monitored one target during all night to obtain more dense time-series) seven open clusters with the following time allocation for each: IC 4996 (5 nights), NGC 7801 (3), King 1 (4), King 13 (3), King 18 (4), King 20 (3), and Berkeley 55 (3). The R and I filters were used. The standard areas around SA 113-342 and 112-275 were observed for calibration.

2.3 *BVI photometric imaging*

These observations were made at Lulin Observatory (Taiwan) in 2003, November 08–12 in frame of Taiwan–Baltic–Uzbek collaboration and ongoing projects at National

Central University of Taiwan where the author worked as visiting scientist at that time. 1 m telescope with CCD-camera AP-8e described above was used with Johnson BVI filters. 20 poorly studied open star clusters were imaged for multi-wavelength photometry (King 1, King 16, NGC 1624, Berkeley 24, Stock 20, Skiff 1, NGC 1798, NGC 2262, Stock 21, Stock 3, NGC 1857, Berkeley 25, Dias 1, NGC 657, NGC 2126, Berkeley 75, Czernik 2, Czernik 6, NGC 2192 and Berkeley 27). We used the standards at SA – 92, 96, 98, 112, 114, RU149 to derive transformation parameters and to calibrate our photometric data.

2.4 *Data reduction and calibration*

The basic CCD-data reductions for the bias, dark and flat corrections have been done using the IRAF package routines for the NGC 6823, IC 4996, NGC 7801, King 1, King 13, King 18, King 20 and Berkeley 55 data. We have also made the proper WCS-registration of NGC 6823 frames using the scripts developed by Daisuke Kinoshita. Typical error box was not larger than $0.2''$ for each coordinate. For the extraction of sources, their analysis and photometry of stars we used the SE v2.2 by Emmanuel Bertin. The standard error of photometry (σ) in R and I bands is shown in Fig. 1.

In the case of NGC 6823 we applied all processing procedures to each frame of mosaic and analyzed every overlapped frame for consistency. The conformity of the magnitudes of stars in the overlapping areas is not larger than the standard error of photometry. This has allowed us to combine all separate catalogs of mosaic into one master catalog for each filter. The special script was written for comparison and cross-identification of catalogs. The resulting RI master catalog in the outcome consists of 3183 stars with measured R and R − I values.

3. Results, analysis and discussion

NGC 6823 is a sufficiently young, rich and compact open star cluster embedded into bright nebulosity with prominent dark trunks and globules. The core of the cluster as

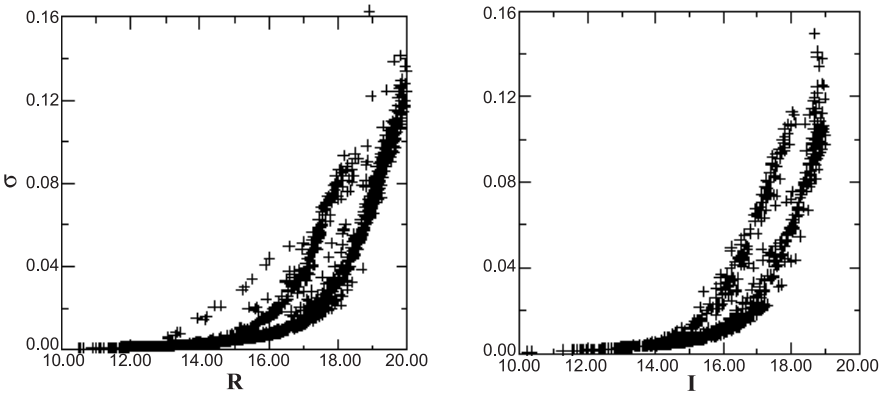

Figure 1. Standard error (σ) for R (left panel) and I (right panel) magnitudes.

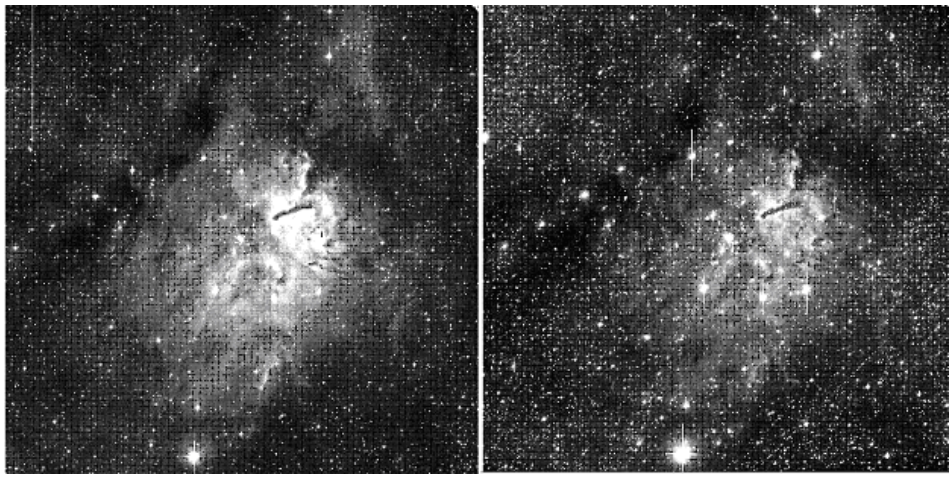

Figure 2. Left panel – the i-band ($\lambda = 6660$ Å) and right panel – the o-band ($\lambda = 9100$ Å) images of NGC 6823/6820 obtained by Beijing Observatory 60/90 Schmidt telescope. N – at the top; E – at the right. Open cluster NGC 6823 is located at the center of the images.

well as the nuclear part of giant OB stars association Vul OB1 connected with the cluster consists of a trapezium type multiple system. In common by most indicators this aggregate is very similar to the star formation complex in Orion. In Fig. 2, the narrow-band BATC image of star cluster NGC 6823 and bright HII nebula NGC 6820 is shown in o and i band passes; for more details on observational data, see Table 1. In both images the open cluster is located at the center of the picture.

Low and intermediate mass PMS stars (T Tauri stars of the late spectral type and early type Herbig emission-line stars, respectively) usually have a near-infrared (NIR) excess emission as compared to the normal stars of the same spectral types. Based on the 2MASS NIR colors and selection procedure outlined in Lee & Chen (2002) 60 young star candidates have been selected in the wide region around NGC 6823. The spectra were obtained for 9 most bright and suitable for spectral observations candidates (Table 1). Eight sources (*i.e.*, 89 per cent from the sample for which the spectral material was obtained) have been found to show clear H-alpha emission in their spectra, of which 5 are probable Herbig Ae/Be stars (HAEBES), and 3 are probable classic T Tauri stars (CTTS). The spectral energy distribution (SED) of these stars also has the shapes typical to the SED for corresponding classes of PMS stars. These young star candidates, and their 2MASS NIR magnitudes, are summarized in Table 2. These stars locate in the same parts of the entire region as known PMS stars and related objects as well as the cluster and OB association stars.

The o and i narrow band frames of NGC 6823/20 were used for photometric measurements. The instrumental magnitudes for stars were calibrated by PSF fitting. 12790 stars in i band image and 17903 stars in o band image have been extracted, and 11308 stars have both i band and o band data. The color-magnitude diagram (CMD) for o band magnitude versus o band minus i band color index is presented in Fig. 3. Only the stars with brightness fainter than 13 magnitudes were considered in o band. The bright (massive) stars in this area could not be measured for photometry because they are saturated. The presence of foreground and background stars in Fig. 3 makes the main-sequence wider.

Table 2. Some newly found young stars in the NGC 6823/6820 complex.

RA (J2000)	Dec (J2000)	Type	J	H	K_s
19 42 27.92	+23 05 14.7	CTTS	11.047	10.275	09.689
19 42 54.99	+23 24 14.8	CTTS	10.343	09.333	08.404
19 42 57.68	+23 22 52.1	CTTS	12.955	12.213	11.622
19 43 04.40	+23 18 48.7	HAeBeS	11.579	10.515	09.601
19 43 07.51	+23 26 02.9	HAeBeS	12.753	11.811	10.970
19 43 08.59	+23 25 45.7	HAeBeS	13.595	12.784	12.066
19 43 10.17	+23 25 31.1	HAeBeS	13.558	12.304	11.381
19 43 20.99	+23 19 02.3	HAeBeS	13.057	11.557	10.355

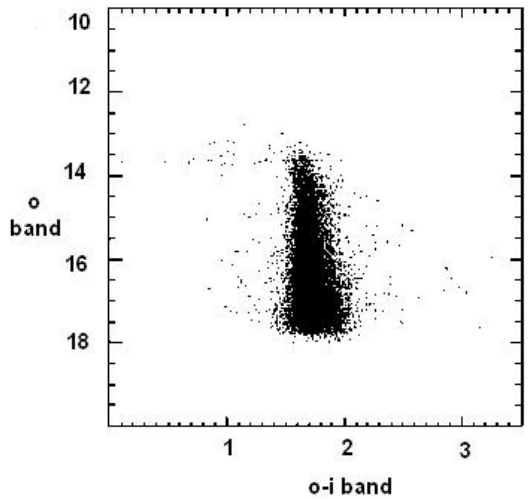

Figure 3. Color-magnitude diagram for o band and o band minus i band for stars in the region of NGC 6823/20.

According to recent estimations (see, for example, the Wilton Dias' latest statistics, Version 2.0 of June 2004, or WEBDA database) less than half of known open star clusters and cluster candidates have been studied at least photometrically to construct their CMD as well as color diagrams and derive the main parameters such as distances, reddening and ages. The kinematical or membership analysis based on radial velocities and proper motions of member stars has been made for about one tenth of the total number of open clusters. Chemical abundance ratio and [Fe/H] metallicity parameters were determined for even smaller numbers. The result of the statistical analysis is presented in Table 3.

Obviously this incompleteness points out that a large effort is still needed to improve the catalogue data. Moreover we reviewed the SIMBAD database and the literature for screening the search and study of variable stars or any kind of variability in open clusters. It turned out, that the number of such clusters is about a few dozens only and the variables in that clusters were as a rule, found accidentally. The few special

Table 3. Statistical analysis for open cluster parameters investigation.

Feature of clusters	Number	Fraction
Clusters with diameters	1688	0.999
Clusters with distances	740	0.438
Clusters with reddening	721	0.427
Clusters with ages	608	0.360
Clusters with distances, reddening and ages	594	0.351
Clusters with proper motions (PMs)	614	0.363
Clusters with radial velocities (RVs)	227	0.134
Clusters with PMs + RVs	217	0.128
Clusters with distances, ages, PMs and RVs	214	0.127
Clusters with abundances	131	0.078
Total	1690	1.000

monitoring runs were only reported on the search for variables in clusters other than the Pleiades, Coma Berencies, in Orion and so forth where the flare stars were looked for. At the same time the revealing of some kin variables in clusters will allow us to get more specific information about the cluster itself. For instance, the eclipsing binaries or cepheids make more exact the distance determinations, the discovery of PMS and flare stars – the evolutionary status and age. Consequently the monitoring of selected open clusters for variability is a worthwhile task. As a by-product of such time-series analysis the discovery of exoplanet transits might follow.

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