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# A report on the studies of star clusters with the UPSO 104-cm Sampurnanand telescope during last 25 years

A. K. Pandey
*Uttar Pradesh State Observatory, Manora Peak, Naini Tal 263 129, India*

**Abstract.** Keeping astrophysical importance of star clusters in mind, their observations were started at the U.P. State Observatory in 1973 using the 104 - cm Sampurnanand telescope. The observations were used to determine the cluster parameters, e.g., distance, reddening, and age etc., for a large sample of open clusters. These cluster parameters were used to study the initial mass function (IMF), star formation processes, stellar evolution, spatial structure of clusters and interstellar extinction in young open clusters. The cluster parameters were also used to understand the galactic structure.

*Key words* : 104 - cm Sampurnanand telescope - open cluster studies

## 1. Introduction

Star clusters are useful to study galactic evolution, stellar evolution and galactic structure because fundamental parameters like distance, age and reddening are accurately known for them as compared to single stars. Star clusters also constitute a principal link between the theories of stellar evolution and the observable universe. For example the older galactic open clusters provide a measure of the minimum age of the galactic disk, whereas the younger open clusters provide an opportunity to study the star formation processes in molecular clouds which are considered to be the birth places of star clusters.

In the light of the above, observations of star clusters were started through 104 - cm Sampurnanand telescope in 1973 immediately after installation of the telescope. The aim of the observations was to collect the data for a large sample of star clusters; use them to obtain their fundamental parameters e.g., reddening, distance, age etc. and to study the initial mass function (IMF), star formation processes, stellar evolution, spatial structure of the clusters, interstellar extinction etc. The details of observations are given in the next section.

## 2. Observations

UBV photoelectric observations of 17 open clusters have been obtained using 104 - cm Sampurnanand Telescope of the U.P. State Observatory (UPSO). Details of the observed clusters are given in Table 1. Out of these 17 clusters, the data from 11 young open clusters have been used by Myakutin et al. (1984) to estimate the age and mass of the cluster members. The catalogue of Myakutin et al. provides a homogeneous data set, because the observations were carried out with the same instrumental set up. These photoelectric data have been used extensively in the literature.

CCD observations of star clusters started at UPSO in 1990 when we got our CCD system of the size 384 × 576 pixels (Mohan et al. 1991). In 1995, we got an improved version of a CCD camera system having a 1024 × 1024 pixels chip which provides a field of 6 × 6 arc-min$^2$. UBVRI CCD observations for 16 open clusters have been obtained so far. Details of CCD observations are given in Table 2.

## 3. Results

Some important results obtained from the observations mentioned above are given below :

### *3.1 Mass function (MF)*

The mass and age estimates of stars in 11 young open clusters, given in the catalogue of Myakutin et al. (1994) have been used by Sagar et al. (1986, 1988) and Pandey et al. (1991 a, 92) to study the MF and age distribution of star clusters. The main conclusions about the MF's are :

(i) the average value of the slope of the mass function is X = 1.4, close to Salpeter's value X = 1.35,

(ii) there is no statistically significant change in the slope of mass function from one cluster to other,

(iii) in general, the clusters under discussion do not show significant variations of mass function slope x with galactocentric distance (in the range 8.2 - 11.8 kpc), although two inner ones have a flat mass function ( x = 0.85),

(iv) effects of mass segregation have been observed in some of these clusters. In most of the clusters dynamical relaxation time is larger than the cluster age, which indicates that observed mass segregation could be due to star formation processes.

The result (iv) is important to constrain the theories related to the process of star formation in open clusters. For example, Lada et al. (1984) have studied dynamical evolution of young open clusters and concluded that some mass segregation may occur after a time > 3 × 10$^6$ yr. This time is more than the ages of some young open clusters where mass segregation is observed. Therefore, the observed mass segregation in young open clusters may be the imprint of star formation processes, and the assumption of no initial mass segregation and a uniform mass function in open clusters, may not be justified in theoretical studies of dynamical evolution of open clusters. Some theories of star formation also support the possibility that the spatial distribution of stars of different mass differ at birth (Gorti and Bhatt 1995; Podsiadlowski and Price 1992).

**Table 1.** Photoelectric Photometry.

| Cluster | R.A. (1950) | Dec (1950) | Age (Myr) | Distance (kpc) | Reference |
|---|---|---|---|---|---|
| NGC 1778 | $05^h 05^m .4$ | 36° 58' | 200 | 1.1 | Pramana 1975, 4, 160 |
| NGC 2169 | $06^h 06^m .8$ | 13° 58' | 90 | 0.8 | A&Sp. Sci. 1976, 40, 447 |
| Tr-1 | $01^h 32^m .3$ | 61° 02' | 26 | 3.3 | A&Sp. Sci. 1977, 48, 225 |
| NGC 581 | $01^h 29^m .9$ | 60° 27' | 40 | 2.7 | BASI 1978, 6, 12 |
| NGC 6530 | $18^h 01^m .7$ | -24° 20' | 2 | 1.7 | MNRAS 1978, 184, 467 |
| NGC 6611 | $18^h 16^m .3$ | -13° 52' | 5.5 | 3.2 | A&Sp. Sci. 1979, 66, 3 |
| NGC 6823 | $19^h 41^m .0$ | 23° 01' | 5 | 3.5 | A&Sp. Sci. 1981, 75, 465 |
| IC 1805 | $02^h 28^m .9$ | 61° 14' | 1 | 2.4 | JRASC. 1983, 77, 40 |
| NGC 654 | $01^h 40^m .6$ | 61° 38' | 16-63 | 2.4 | MNRAS 1983, 202, 961 |
| NGC 2264 | $06^h 38^m .6$ | 09° 56' | 5 | 0.8 | MNRAS 1983, 202, 747 |
| NGC 6913 | $20^h 22^m .1$ | 38° 22' | 0.3-1.75 | 1.5 | PASJ 1983, 35, 405 |
| King 12 | $23^h 50^m .5$ | 61° 41' | ~10 | 2.5 | A&Sp. Sci. 1984, 105, 315 |
| King 21 | $23^h 47^m .4$ | 62° 26' | ~10 | 1.9 | BASI 1984, 12, 217 |
| M 39 | $21^h 30^m .4$ | 48° 13' | 200-400 | 0.3 | MNRAS 1985, 213, 337 |
| NGC 1931 | $05^h 28^m .1$ | 34° 13' | ~10 | 2.2 | A&Sp. Sci. 1986, 120, 107 |
| St 17 | $23^h 43^m .6$ | 61° 54' | ~ 10 | 2.1 | BASI 1986, 14, 20 |
| NGC 2539 | $08^h 08^m .4$ | -12° 41' | 600 | 1.1 | BASI 1986, 14, 95 |

**Table 2.** CCD Photometry.

| Cluster | R. A. (1950) | Dec (1950) | Age (Myr) | Distance (kpc) | Reference |
|---|---|---|---|---|---|
| King 10 | $22^h 52^m .9$ | 58° 54' | 50 | 3.2 | BASI 1992, 20, 303 |
| NGC 7419 | $22^h 52^m .3$ | 60° 34' | 40 | 2 | BASI 1993, 21, 33 |
| NGC 1931 | $05^h 28^m .1$ | 34° 13' | 10 | 2.2 | BASI 1994, 22, 291 |
| NGC 366 | $01^h 03^m .3$ | 61° 58' | 25 | 2.2 | BASI 1994, 22, 369 |
| Be 64 | $02^h 17^m .1$ | 65° 40' | 1000 | 3.9 | A&AS 1997, 122, 111 |
| Be 69 | $05^h 21^m .3$ | 32° 36' | 1000 | 2.9 | A&AS 1997, 122, 111 |
| King 7 | $03^h 55^m .2$ | 51° 39' | 800 | 2.2 | BASI (in press) |
| NGC 2309 | $06^h 53^m .8$ | -7° 08' | 600 | 2.4 | BASI (in press) |
| NGC 2192 | $06^h 11^m .0$ | 39° 48' | Data reduction to be done | | |
| Ru 7 | $06^h 55^m .4$ | -13 ° 9' | | - do - | |
| NGC 1798 | $05^h 8^m .1$ | 47° 34' | | - do - | |
| Bi 9 | $06^h 55^m .1$ | 3° 7' | | - do - | |
| Be 20 | $05^h 30^m .1$ | 0° 6' | | - do - | |
| NGC 654 | $01^h 40^m .6$ | 61° 38' | | - do - | |
| Be 2 | $0^h 22^m .5$ | 60° 7' | | - do - | |

### *3.2 Interstellar Extinction*

We know that molecular clouds are the birth places for star clusters, and with time the gas and dust in these clouds will either be used up in star formation processes, or will be dispersed away by radiation pressure due to massive stars present in these systems. Therefore, in young open clusters the presence of variable amount of unused gas and dust is expected inside the cluster and consequently, a non-uniform interstellar extinction is observed. The interstellar extinction can be estimated from the (U – B) and (B – V) colour - colour diagram of the young star clusters. It is one of the most important parameters to study the star formation processes and the galactic structure.

Sagar (1987) has studied the interstellar extinction in young open clusters and concluded that the variation of reddening in one cluster is distinctly different from the others. To explain the non uniform extinction in young open clusters, a complicated physical scenario is required.

Sagar (1979) and Pandey et al. (1990) have found that the differential extinction $\Delta$ E (B–V) [=E$(B-V)_{max}$–E $(B-V)_{min}$] in open clusters, which may be due to the presence of gas and dust, decreases systematically with the age of the cluster. Consequently, we can infer that the average gas removal time is about $10^8$ yr. Using the value of average differential extinction due to interstellar matter the mass of the gas and the star formation efficiency (SFE) in star clusters are estimated. It is concluded that bound clusters are formed in low mass clouds ($M < 10^4 M_\odot$), while the unbound OB associations are formed in clouds having higher masses. Our work also supports the existence of corona around open clusters and it is concluded that the coronal regions in bound open clusters are dynamically stable in the tidal forces of the Galaxy ( cf. Pandey et al. 1990)

### *3.3 Non-coeval star formation*

Moderately young open clusters (having age ~ $5\times 10^7$ yr) are the most suitable objects to study the star formation process in star clusters. Sagar (1979) has concluded that star formation in clusters is non-coeval, prolonged, and takes place in a time interval of approximately $10^7$ - $10^8$ yrs. The observed low cluster formation rate and high space density of low mass clouds suggest that star formation in open clusters is a continuous process for about $10^8$ yr (Pandey et al. 1990).

The distribution of pre-main sequence (PMS) stars in the HR diagram of outer region of the clusters indicates that these stars are younger than the upper main sequence stars of the inner region, which indicates that the formation of less massive stars in the outer regions does not cease even after formation of most massive stars in the cluster, as generally believed in sequential star formation process (cf. Pandey et al. 1991 b).

### *3.4 CCD Observations*

UBVRI CCD observations for 15 open clusters have been obtained so far. Photometry has also been carried out for nearby fields to correct for the effects of field star contamination. In case of Be 69 and King 7, the comparison of observational colour-magnitude diagram (CMD) with the standard isochrones of Van den Berg (1985) indicates an apparent discrepancy between the shape of turnoff and isochrones. The morphological features of CMDs of old open clusters are better understood in terms of convective core overshooting (cf. Pandey et al. 1997 and Durgapal et al. 1997). Analysis of remaining clusters is in progress.

## 4. Publications

The scientific results obtained using the data on star clusters observed with the 104-cm telescope of UPSO, have been published in the form of 40 papers in various national/ international refereed journals and proceedings of conferences/workshops. In addition 4 Ph.D. theses on star clusters have been based on the data taken with the telescope.

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