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Mass function study of open star clusters Haffner 11 and Czernik 31

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HIGHLIGHTS

- We determine luminosity function and initial mass function for Haffner 11 and Czernik 31.
- Mass function slopes of these clusters are in agreement with Salpeter value.
- We have found mass segregation effect for these clusters and they are dynamically relaxed.

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ABSTRACT

We analysis *VI* CCD data of two open clusters Haffner 11 and Czernik 31 in order to determine their luminosity function, mass function and mass-segregation for the first time. The observed luminosity function is corrected for both data incompleteness and field star contamination. Theoretical stellar evolutionary isochrones are used to convert luminosity function into mass function. The Mass function slopes are derived as 1.22 ± 0.42 and 1.55 ± 0.38 for Haffner 11 and Czernik 31 respectively. They agree with the Salpeter value (x =1.35) within the errors. The effect of mass segregation are observed in both the clusters. The estimated dynamical relaxation time is less than age of the clusters. This indicates that they are dynamically relaxed. The cause of relaxation may be due to the dynamical evolution or imprint of star formation or both.

1. Introduction

The study of mass function is fundamental to understand star formation processes and related astrophysical problems. Observations show that most of the stars in the Milky Way galaxy form in groups or clusters (Kroupa, 2011). Being systems of coeval and equidistant stars with the same chemical composition, open clusters are key objects to investigate the mass function. Determination of mass function of open clusters can however be challenging because of the contamination from field stars (Prisinzano et al., 2003).

Mass function is the frequency distribution of stellar masses that form in one star formation event. The mass function at the time when cluster stars were formed, is called initial mass function (IMF). Many studies indicate that star formation process is a gradual process for a period of about 15–20 Myr (Pandey et al., 2000 and references therein). So in case of young age open star clusters we can estimate only the present day mass function (PDMF). In case of old star clusters mass function changes with time due to stellar as well as dynamical evolution effect. The origin of the stellar IMF and its universality are among some of the most challenging issues in the present time.

Colour-magnitude diagram of star clusters can be fairly used to derive observed luminosity function (LF). Using theoretical isochrones, LF can be converted into the mass function. The mass function of open star clusters may tell star formation theories and early evolution of star clusters (Elmegreen, 1999, 2000; Richtler, 1994).

In the literature various mass function studies are present but the universality of IMF is still a big question for all the researchers. Scalo (1986); Scalo et al. (1998) and Kroupa (2002) have deduced uniform IMF using different populations. Observations by Elmegreen et al. (2007) and Dib et al. (2010) suggest that the universality of IMF in every environments is subject to doubt due to small variations in different mass intervals. Then they found no systematic trend with these variations.

The study of mass segregation in open star clusters provides a clue about the spatial distribution of high and low mass stars within the cluster regions. It is found that high mass stars are more centrally concentrated in comparison to lower mass stars. In case of young star clusters it may be the imprint of star formation

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Table 1
Fundamental parameters for the clusters Haffner 11 and Czernik 31. These parameters are taken from Bisht et al. (2013).

Name	Radius (arcmin)	$E(B-V)$ (mag)	Distance (kpc)	Age (Myr)
Haffner 11	3.5	0.50 ± 0.05	5.8 ± 0.5	800 ± 100
Czernik 31	3.0	0.48 ± 0.05	3.2 ± 0.3	160 ± 40

process, whereas in case of old star clusters it may be due to dynamical evolutionary effects.

In the present study, we considered two open clusters Haffner 11 and Czernik 31 with the aim to investigate their luminosity function, mass functions and mass segregation. To our knowledge, this type of studies are not available using optical CCD data in the literature. The descriptions about data acquisition and derivation of fundamental parameters of these two clusters are provided in Bisht et al. (2013). The derived parameters for both the clusters are listed in Table 1. The radius is ∼ 3.0 arcmin while reddening is ∼ 0.5 mag for both the clusters. Table 1 also shows that Haffner 11 is older while Czernik 31 is intermediate age clusters.

The structure of the article is as follows. Data description is given in Section 2. Completeness of the CCD data and luminosity function are described in Section 3 and Section 4 respectively. Initial mass function and mass segregation of star clusters are given in Section 5 and Section 6 respectively. Conclusions and results are summarised in Section 7.

2. Data used

To obtain LF and MF of the star clusters Haffner 11 and Czernik 31, we have used *VI* CCD data taken by us (Bisht et al., 2013). The data were acquired using the 2k × 2k CCD system at the *f*/13 Cassegrain focus of 104-cm Sampurnanand telescope of ARIES, Nainital, India. The 0.36 arcsec pixel^{-1} plate scale resulted in a total field-of-view of 12.3 × 12.3 arcmin^2. The readout noise and gain of the CCD were 5.3 e$^-$ and 10 e$^-$ ADU^{-1} respectively. The global photometric (DAOPHOT+Calibration) errors are 0.06 mag at $V \sim 19th$ mag for V and I filters. The fundamental parameters are derived by using colour-magnitude and colour-colour diagrams of the clusters.

3. Completeness of the CCD data

It is not possible to detect all the cluster members present in the CCD frame due to stellar crowding as well as inefficiency of data reduction programmes. For the estimation of true luminosity function, it is very essential to calculate completeness factor of CCD data. In order to avoid appreciable increase in the crowding, we randomly added only 10 to 15% of actually detected stars of known magnitude and position into the original frames. We performed experiments with artificial stars using **ADDSTAR** routine in **DAOPHOT II**. Detailed description about this experiment is given by Yadav and Sagar (2002) and Sagar and Griffiths (1998). We have adopted the method given by Sagar and Griffiths (1998). Artificial stars with known magnitude and position were added in the original V frames. These images are re-reduced using the similar method adopted for the original images. The ratio of recovered to added stars in different magnitude bins gives the completeness factor. The completeness factor derived in this way are listed in Table 2 for the clusters Haffner 11 and Czernik 31. This table indicates that the completeness factor is ∼ 70% at 19 mag for both the clusters. The completeness factor of field region is assumed to be 100%.

Table 2
Frequency distribution of the stars in the $V, (V-I)$ diagram of the cluster and field regions. N_S denote the number of stars in a magnitude bin along the cluster sequence while N_F is for the field region. The number of stars in the field regions are corrected for area differences. N_C (difference between the N_S value of cluster and N_F value of field regions) denotes the statistically expected number of cluster members in the corresponding magnitude bin.

	Haffner 11			Czernik 31		
Mag	Cluster region N_S	Field region N_F	N_C	Cluster region N_S	Field region N_F	N_C
14 – 15	–	–	–	11	2	9
15 – 16	–	–	–	11	2	9
16 – 17	30	7	23	20	7	13
17 – 18	43	10	33	56	25	31
18 – 19	51	28	23	60	48	12
19 – 20	85	52	33	55	40	15

4. Luminosity function

Luminosity function (LF) is defined as the relative number of cluster members in per magnitude bin. LF can be obtained by using colour magnitude diagram (CMD) of the clusters. We have used V versus $(V-I)$ CMD for the LF estimation of these clusters. Scattering is much higher towards the fainter end of main sequence stars. This may be due to the photometric errors in magnitude estimation and contamination of field stars.

To find the true luminosity function of star clusters, it is necessary to have information about cluster membership. It is very difficult to separate cluster members from its field region stars only on the basis of main sequence stars. So, in the absence of proper motion and radial velocity data, we have use photometric criteria to select the possible member of the clusters. A brief explanation of the method adopted for the clusters Haffner 11 and Czernik 31 are given below.

The apparent $(V, V-I)$ colour magnitude diagrams (CMDs) for the cluster stars as well as the field region stars are plotted and shown in Fig. 1. We selected members for clusters by assuming blue and red envelope around MS in $V, (V-I)$ CMD of the cluster and field region as shown in Fig. 1. A star is assumed as non member if it lies outside the envelope. Stars are counted within this envelope for the cluster and field region CMDs. Difference between the counts in two fields after accounting for the difference in area between the cluster and field region will give luminosity function for the clusters. In Table 3 we have listed the expected number of field region stars and cluster members. Using this table we can estimate the number of cluster members in different parts of the colour magnitude diagram. These cluster members may be fairly used to determine the luminosity and mass function of the clusters.

For the construction of LFs, first we have converted the apparent V magnitudes into the absolute magnitudes by using the distance modulus of the clusters. Then we have built the histogram of LFs for the clusters, which are shown in Fig. 2. We included a reasonable number of cluster members in each absolute V magnitude bin for the best counting statistics. The histogram shows that the luminosity function for the cluster Haffner 11 rises steadily. For the cluster Czernik 31 a dip is found at $M_v = 4.5$ mag and then its rises.

5. Mass function of the clusters

In case of star clusters, mass of stars is a very important factor as it decides its luminosity, effective temperature and evolutionary stages. It is important to know how many stars of particular