NRIAG Journal of Astronomy and Geophysics (2016) 5, 16–22

National Research Institute of Astronomy and Geophysics

NRIAG Journal of Astronomy and Geophysics

www.elsevier.com/locate/nrjag

A comprehensive study of the young open star cluster NGC 6611 based on deep VRI CCD images and 2MASS data

I.M. Selim [a,b,*], **A. Essam** [a], **Y.H.M. Hendy** [a], **R. Bendary** [a]

[a] *National Research Institute of Astronomy and Geophysics, Astronomy Dept., Cairo, Egypt*
[b] *Computer Science Higher Technological Institute (HTI), Egypt*

Received 15 January 2016; revised 9 February 2016; accepted 21 February 2016
Available online 29 March 2016

KEYWORDS

Galaxy;
Open clusters and associations;
Individual;
NGC 6611

Abstract In the present study, we have used Deep CCD images of the extremely young open star cluster NGC 6611, up to a limiting magnitude of $V \sim 22.86$ mag in V, R and I passbands. The resulting color-magnitude V; $(V–I)$ diagram as well as their radial density profiles has been determined. Using 2MASS data, we confirmed the consistency between the 2MASS photometry, by fitting isochrones, the extinction $E_{(V-I)} = 0.530 \pm 0.04$ mag, $E_{(J-H)} = 0.31 \pm 0.02$, from the color magnitude diagram the cluster distance $= 2.2 \pm 0.21$ kpc and age = 3.6 Myr, based on the fitting of theoretical stellar isochrones of solar metallicity $Z = 0.019$. The distance modulus of the cluster is estimated at 12.3. The radial stellar density profiles and the cluster center have been determined by two methods. The core and cluster radii are determined from the radial stellar density profiles. Only about 40% of the cluster members are present in the core region. The cluster luminosity function has been calculated. The mass function slope of the entire cluster is $\sim -0.67 \pm 0.12$. The effects of mass segregation, most probably due to dynamical evolution, have been observed in the cluster.

1. Introduction

Studying massive young open star clusters is not only very important investigations for understanding star formation and chemical evolutionary processes in the galaxy, but also a good tool for the basic information to estimate parameters such as age, distance, metallicity and age-metallicity relationship. Open star cluster NGC 6611 is a very young and it is embedded in a star formation region. NGC 6611 is located near the external border of the Sagittarius Carina spiral arm $l = 170°$ and b $+0.8°$. Walker (1961), Sagar and Joshi

* Corresponding author at: National Research Institute of Astronomy and Geophysics, Astronomy Dept., Cairo, Egypt.
E-mail address: i_selim@yahoo.com (I.M. Selim).

Peer review under responsibility of National Research Institute of Astronomy and Geophysics.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.nrjag.2016.02.006
2090-9977

(1979) and The et al. (1985) found that the stars of the open star cluster NGC 6611 are still in the stage of evolution toward their hydrodynamically stable state of the main sequence. NGC 6611 is the massive young cluster with 2–3 Myr that ionizes the Eagle Nebula (Oliveira, 2008).

The first photometric study of NGC 6611 was carried out by Walker (1961) from photoelectric and photographic UBV observations, and he used color excesses of stars as a criterion to pick out cluster members. Sagar and Joshi (1979), The et al. (1990) and Hillenbrand et al. (1993) studied this cluster by combining CCD observations in the UBV system and infrared (JHK) photometric data. Oliveira (2008) found that the IMF of NGC 6611 is well described by a lognormal distribution. However, a lognormal distribution, the IMF of NGC 6611 seems to peak at higher masses than the Galactic field and the solar neighborhoods IMF.

Belikov et al. (1999) summarize that the NGC 6611 is known as part of a star-forming region at a distance of 2100 pc and an age of about 3 Myr. Hillenbrand et al. (1993) and Belikov et al. (2000) found that this cluster is very young, with an age of (2–3 Myr), While (Hillenbrand et al., 1993; Belikov et al., 2000; Dufton et al., 2006) considerable age for sources in the Eagle Nebula about (<1–6 Myr). Martayan et al. (2008) redetermined the age of NGC 6611 and found it is about 1.2–1.8 Myr. Hillenbrand et al. (1993) combined CCD UBV observations with near-infrared JHK ones to establish a theoretical HR diagram for the cluster, from which they conclude that NGC 6611 is actively forming 3–8$M_{\odot}$ stars. Recent distance determinations and values around 1.8 kpc are derived using spectroscopic parallaxes Dufton et al. (2006). The cluster is probably associated with the extensive bright emission nebula M 16 (The Eagle Nebula) and suffers from strong differential reddening. The massive stars in NGC 6611 are responsible for the ionization of the HII region M16, the Eagle Nebula, the higher concentration of within 4 arcmin radius central area, while the cluster members are distributed over a region of $\sim$14 arcmin radius, Belikov et al. (2000). Hillenbrand et al. (1993) and Oliveira, 2008 have found a large number of massive stars as well as a large population of pre-main-sequence stars in NGC 6611.

In this paper, we discuss new observations of NGC 6611 at optical wavelengths and we used near-IR wavelength (2MASS) data to study the cluster. This paper is organized as follows. First, we describe the observation and its reduction process by IRAF and the photometry and its calibration. This is followed by the Color Magnitude Diagram (CMD) identification, the spatial structure of the cluster and selection of candidate cluster members have been done. After that we discuss the luminosity, mass function and dynamical state of the cluster. Finally, we concluded and compare its main features to other clusters.

2. Observations and data reduction

CCD VRI images were carried out at the night of 06 June, 2013 using the EEV 42-40 CCD camera mounted at the Newtonian focus of the 188 cm telescope, located at the Kottamia astronomical observatory of NRIAG in Egypt, with pixel size of 13.5 μm × 13.5 μm and a CCD size of 2048 * 2048 pixels^2 cooled by liquid nitrogen each pointing a 10 × 10 arcmin field of view on the sky. More details about the instrument and telescope can be found in Azzam et al. (2009). A number of bias and flat frames were also taken by the target of cluster field. At least 20 flat field exposures were available in filters V, R and I, from the dome and sky illumination. To calibrate the observations, standard field SA 107 (Landolt, 1992) were observed in the same period of observation. In order to provide accurate photometric measurements for faint stars, several deep exposure frames in each filter have been taken. The journal of 78 exposure observations of the cluster is given in Table 1 and the image in filter V shown in Fig. 1.

Images were processed with the help of IRAF software package using standard procedures. Preliminary reductions of all CCD Images for the cluster and stander stars, to apply bias subtraction, flat field corrections and removal of cosmic rays, have been done with standard package in the IRAF software of CCDRED and FORTRAN program. Observations of standard field SA 107 (Landolt, 1992) in the same period of observation have been used for the corrected atmospheric extinction. Instrumental magnitudes for all measured stars were transformed into a standard system using fitting coefficients derived from observations of standard stars whose magnitudes have been well established in Landolt (1992).

The usual reduction procedure has been done with the IRAF packages of CCDRED, DAOPHOT, ALLSTAR and PHOTOCALL to get the magnitudes of the stars using the point spread function (PSF) method. The estimated magnitude has been carried out using DAOPHOT profile fitting software, as described by Stetson (1987, 1992), so that it can be determined reliably to faint levels. The stellar PSF used by DAOPHOT is evaluated from the sum of several uncontaminated stars present in each image to obtain the instrumental magnitudes; the instrumental corrections were then applied for obtaining the standard magnitudes and colors of the stars in each frame. Further processing and conversion of these raw instrumental magnitudes into the standard photometric system have been done using the procedure outlined by Stetson (1992). The adopted photometric calibration equations using the transformation coefficients between instrumental and standard magnitude are the following equations:

$$v = V + Z_v + k_v * X + a_v * (V - R)$$
$$r = R + Z_r + k_r * X + a_r * (V - R)$$
$$i = I + Z_i + k_i * X + a_i * (I - R)$$

where V, R and I are standard magnitudes and v, r and i are the instrumental magnitudes respectively, Z_v, Z_r and Z_i are the zero points in v, r and i respectively, X is the airmass for each filter and k_v, k_r and k_i are the extinction coefficients in V, R and I filters respectively. The magnitudes errors of the cluster NGC 6611 are shown in Fig. 2. The values of the zero point, the color coefficients and the extinction coefficients for each filter are listed in Table 2.

Table 1 Journal of observations.

Date	Filter	No. of exp.	Air mass range	Exp. time (s)
2013 June, 06	V	21	1.347	150
2013 June, 06	R	27	1.421	60
2013 June, 06	I	30	1.419	25