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2MASS photometry and kinematical studies of open cluster NGC 188

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HIGHLIGHTS

- Fundamental parameters are determined.
- Apex coordinates for NGC 188 are calculated.
- Kinematical parameters of the clusters are derived.

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ABSTRACT

In this paper, we present our results for the photometric and kinematical studies of old open cluster NGC 188. We determined various astrophysical parameters like limited radius, core and tidal radii, distance, luminosity and mass functions, total mass, relaxation time etc. for the cluster using 2MASS catalog. We obtained the cluster's distance from the Sun as 1721 ± 41 pc and log (age)= 9.85 ± 0.05 at Solar metallicity. The relaxation time of the cluster is smaller than the estimated cluster age which suggests that the cluster is dynamically relaxed. Our results agree with the values mentioned in the literature. We also determined the clusters apex coordinates as (281°.88, −44°.76) using AD-diagram method. Other kinematical parameters like space velocity components, cluster center and elements of Solar motion etc. have also been computed.

1. Introduction

NGC 188 is one of the oldest known open clusters of the Milky Way belonging to the old Galactic disk population (Platais et al., 2003). The cluster's spatial location in the Galaxy ($l = 122^\circ.8$, $b = 22^\circ.4$) makes it relatively less obscured and poorly contaminated by field stars, hence, being easy to observe (Meibom et al., 2009; Wang et al., 2015; von Hippel and Sarajedini, 1998). Thus, NGC 188 has been used extensively as a classical reference to study the evolution of Galactic disk and chemical and dynamical evolution of the Galaxy. A plot of the Galactic orbit of NGC 188 is given by Carraro and Chiosi (1994). One of the reasons behind the survival of NGC 188 to this advance age may be its almost circular, highly inclined external orbit, which avoids the inner disk regions for most of the times (Bonatto et al., 2005). The cluster is known to have approximately Solar metallicity (Friel et al., 2002; Randich et al., 2003; Worthey and Jowett, 2003). The color-magnitude diagram of the cluster shows a wide giant branch (Twarog et al., 1997; Norris and Smith, 1985), blue stragglers (Leonard and Linnell, 1992; Dinescu et al., 1996) and various type of binaries (von Hippel and Sarajedini, 1998). Knowledge of accurate fundamental parameters of the open clusters is essential for many astrophysical calibrations (Fornal et al., 2007). The age of NGC 188 remains a crucial factor and surveys like 2MASS (Skrutskie et al., 1997) have enabled such studies in the near-IR bands.

Open clusters are group of stars moving in parallel direction in space on the celestial sphere. The directions of proper motions of the stars of open clusters will converge to a point called vertex (A_0, D_0) of the cluster. Proper motions can be used to calculate membership probabilities and taking the most probable cluster members for studying the kinematics of the cluster will provide more precise determination of the vertex.

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In light of the above discussion, we studied some of the basic parameters and kinematical properties of the cluster using the 2MASS catalogue in combination with other source of data which include information of proper motion and radial velocities of the cluster members. Conclusively, many parameters like limiting radius, core radius, age, distance, mass function slope and dynamical relaxation time etc. could be estimated. Our kinematical studies of the cluster provided the convergent point of the cluster, cluster's velocity and the components of space motion of the cluster. We also derived the elements of Solar motion with respect to NGC 188. The kinematical parameters derived by us will help in understanding the motion of the cluster in the Galaxy.

The structure of this article is as follows: in Section 2, we describe the data used for the present study. Section 3 explains the photometric study and the results achieved. Section 4 deals with the kinematical analysis of NGC 188. The conclusions of this paper have been given in Section 5.

2. Data used and reduction procedures

Due to the unavailability of all the required data in one general catalogue for the present study, we have compiled data from different sources. We have taken photometric data from 2MASS catalogue (Cutri et al., 2003). 2MASS uniformly scanned the entire sky in three near-infrared bands (J, H, K_s) to detect and characterize point sources brighter than 1 mJy in each band, with signal-to-noise ratio (SNR) greater than 10, using a pixel size of $2''.0$.

We combined the above photometric data with kinematical data for proper motions and radial velocities. Platais et al. (2003) presented a technique to obtain precise proper motions of stars in the region of NGC 188, using old photographic plates with assorted large aperture reflectors, in combination with recent CCD Mosaic Imager frames. They used their proper motions to determine astrometric membership probabilities down to $V=21$ in the 0.75 deg^2 area around NGC 188. For our study, we consider stars with membership probabilities higher than 50% from the catalogue given by Platais et al. (2003), which gives us 562 member stars. Geller et al. (2008) presented the results of ongoing radial velocity (RV) survey for NGC 188 by WIYN.[1] The data set observed by 3.5-m WIYN telescope on Kitt Peak in Arizona spans a time baseline of 11 years, a magnitude range of $12 \le V \le 16.5$ ($1.18 - 0.94\ M_\odot$) and covers an area of one degree diameter on the sky. For the kinematical studies, the values of radial velocity for NGC 188 stars have been taken from Geller et al. (2008).

3. Photometric analysis

3.1. Radial density profile (RDP)

To determine radial extent of the cluster, we extracted J, H, K_s magnitudes, positions and radial distance of stars from the cluster center. This data set of the cluster is taken from the Vizier webpage. The RDP were built by calculating the mean surface density in concentric rings around the cluster center, (α, δ)$_{J2000}$=($00^h47^m13^s.12$, $85°14'51''$). We calculated the mean surface density $\rho(r)$ of each ring using King model (King, 1966), i.e.:

$$\rho(r) = f_{bg} + \frac{f_0}{1+\left(\frac{r}{r_{core}}\right)^2}$$

where f_{bg} is the background surface density and r_{core} is the core radius of the cluster where the stellar density, $\rho(r)$, becomes half of its central value, ρ_0.

[1] Joint facility of the University of Wisconsin-Madison, Indiana University, Yale University, and the National Optical Astronomy Observatory.

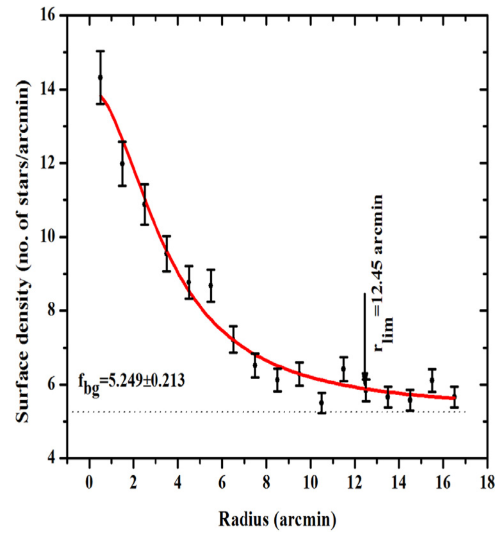

Fig. 1. The radial density profile of NGC 188. Solid line denotes the fitted density distribution and the dashed line represents the background density.

In addition, we can also define the limited radius of the cluster (r_{lim}) which represents the radius which covers the entire cluster area and reaches enough stability with the background field density (Tadross and Bendary, 2014). Mathematically, r_{lim} is defined as:

$$r_{lim} = r_{core}\sqrt{\frac{f_0}{3\sigma_{bg}} - 1}$$

Fig. 1 represents the RDP of the cluster. The background stellar density is also shown with the dotted line. Solid line represent the fitted profile of the cluster. Different radii of the clusters are derived and values are listed in Table 1. Our derived values are very similar to the values given in the literature.

3.2. Color magnitude diagram (CMD) and isochrone fitting

Many photometric parameters including reddening and distance modulus can be determined by fitting theoretical isochrones to the observed CMDs. Bonatto et al. (2004) fitted Padova isochrones to CMDs in ($J, J-H$) and ($K, J-K$) bands. We used the equations given by Carpenter (2001) to convert K_s magnitudes to K magnitudes. The fitting of isochrones with the observed CMDs are shown in Fig. 2. The visual best fit solar metallicity (Z=0.019) isochrones provide the cluster age as log(age) = 9.85.

Reddening of the cluster has been determined using Schlegel et al. (1998) and Schlafly and Finkbeiner (2011). We have the coefficient ratios $A_J/A_V = 0.276$ and $A_H/A_V = 0.176$, which are derived using absorption ratios by Schlegel et al. (1998), while the ratio $A_{K_s}/A_V = 0.118$ was derived by Dutra et al. (2002). Here we have the following results for the color excess of 2MASS photometric system by Fiorucci and Munari (2003): $E_{J-H}/E_{B-V} = 0.309 \pm 0.130$, $E_{J-K}/E_{B-V} = 0.485 \pm 0.150$; where $R_V = A_V/E_{B-V} = 3.1$. We used these formulae for the cluster under study to correct CMDs from the effect of reddening, i.e. $A_K/E_{B-V} = 0.365$ and $A_J/E_{B-V} = 0.879$. Conclusively, the distance of the cluster from the Sun can be calculated. We estimated the distance as 1721 ± 41 pc, which we will use to study the kinematics of the cluster in Section 4. This distance can also be used to determine the cluster's distance to the Galactic center (R_{gc}, the projected distance to the Galactic plane ($X_\odot$, $Y_\odot$) and the distance from the Galactic plane $Z_\odot$ (Tadross, 2012).