Point-Spread Function (PSF) Photometric Analysis of Open Clusters: Melotte 72 & NGC 2158

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ABSTRACT
Point Spread Function (PSF) photometry of open star clusters Melotte 72 and NGC 2158 was performed using *g* and *r* band data from the Sloan digital Sky Survey (SDSS) Data Release 7. Instrumental magnitudes of stars in both bands were transformed into calibrated magnitudes using standard equation. Color-Magnitude (CM) diagrams were produced and compared with the SDSS isochrones for AB stellar system for different ages and/or metallicities. The objective of this study was to determine the physical parameters (age, distance, metallicity, reddening) of open clusters from CM diagrams. The best fit isochrones were used to estimate cluster parameters. The observed parameters were then compared with the WEBDA data base.

KEYWORDS
PSF Photometry, Melotte 72, SDSS, NGC 2158, Isochrone Fitting, IRAF

1. INTRODUCTION

A stellar cluster is a collection of gravitationally bound stars having similar chemical composition, age and are at the same distance from the sun. Born at the same time and from the same molecular cloud, the members of star clusters travel together through space. They are classified as open (galactic) clusters and globular clusters. Open clusters are relatively smaller in size with hundreds to a few thousand stars contained within a diameter of about 30,000 light years across. Stars in open clusters are young (bluish) mostly presented in irregular galaxies or in the galactic plane of spiral ones. Using the techniques of photometry, the important parameters of open clusters can be determined from the light received on earth.

Open clusters are important to study as they help to understand the processes involved in stellar evolution by acting as stellar laboratories[1] and the assembly and evolution of the Milky Way thin disc.[2] Two of major variables of stellar evolution, composition and age are identical among all the stars of open clusters — thus open cluster represents a snapshot of hundreds of stars having identical ages and compositions but different masses. In short, an understanding of a star's "life story" can be patched together without having to follow a few individuals from birth to death.

The most basic tool for studying stellar clusters is the Hertzsprung-Russell diagram (HR diagram). It relates the absolute magnitude (luminosity) and temperature (spectral type) of each star in a cluster which then provides a way of looking into the evolution of clusters. Instead of temperature, when color is plotted against absolute magnitude, a Color Magnitude Diagram (CMD) is obtained. CMDs are of great importance to the theories of stellar evolution.

Isochrones are the curves showing same age stars on the HR diagram; as the stars of an open cluster are of same age, these curves can be used to estimate their age. In this research, color magnitude diagrams, obtained using Point Spread Function (PSF) photometry, have been assessed against various isochrones. The best fit isochrone helped estimate the parameters of selected clusters.

PSF photometry is a more powerful technique than traditional Aperture photometry. PSF photometry is based on the fact that there is same basic profile shape of every star (unlike galaxies or nebulae), i.e., only brightness (amplitude) is different for different stars. Stars are convolved with the telescope optics and (for ground-based telescopes) blurring by the Earth's atmosphere but they all are just images of point sources of light. Hence, a standard profile for all the stars in an image can be created which can be used to find each star's brightness by comparing the standard profile with the profile of that star.[3]

2. DATA USED

Physical parameters were estimated for two open clusters: Melotte 72 (**Figure 1**) and NGC 2158 (**Figure 2**). Melotte 72 is located at RA 07h 38m 24s and DEC –10° 41' 00" (J2000) in the Monoceros constellation with an angular size of 5'. NGC 2158 is in the Gemini constellation at RA 06h 07m 25s and DEC +24° 20' 28" (J2000) having angular size of 4'.

Figure 1. Melotte 72

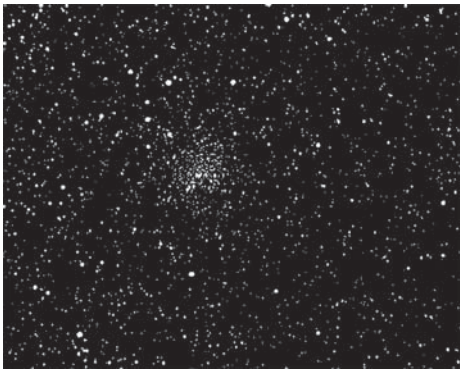

Figure 2. NGC 2158

FITS (Flexible Image Transport System) files of both clusters in *g* and *r* filters were downloaded from Sloan digital Sky Survey (SDSS) Data Release 7 FITS. SDSS used 120 megapixel Charge Coupled Device (CCD) with a 2.5-meter telescope at Apache Point in New Mexico, USA.[4] The images were obtained in *g* (characteristic wavelength = 468.6 nm) and *r* (characteristic wavelength = 616.5 nm) band of the *ugriz* photometric system. Isochrones concerning to SDSS data were obtained from *CMD 2.5 input form* at http://stev.oapd.inaf.it/cgi-bin/cmd_2.5 for different ages and metallicities.

3. METHODOLOGY

IRAF (Image Reduction and Analysis Facility) was used to process the images of both clusters using PSF photometry. This provided the *g* and *r* band instrumental magnitudes of individual stars of each cluster. Ds9 was interfaced with IRAF to visualize images while performing photometry tasks. Stars in both clusters were then cross matched using Tool for Operations on Catalogues and Tables (TOPCAT). Finally, a single file containing the instrumental magnitudes of stars in a cluster was obtained. The instrumental magnitudes were calibrated and a CMD plot was plotted between *g* and *g-r* which was then fitted with appropriate isochrones.

i. Determination of Instrumental Magnitudes using PSF

Using the *imexamine* task in IRAF, the researchers determined the Full Width Half Maximum (FWHM) of some of stars and the standard deviation of background sky in both images and calculated their average values. These values were used to set *centerpars*, *daopars*, *datapars*, *findpars*, *fitsktpars*, *photpars* in IRAF. The procedure for generating PSF is as follows:

- 25 to 50 candidate stars were selected using '*pstselect*' task
- Using '*psf*' task, among the pst starlist only those were selected having similar surface plots
- In the next step the PSF using '*nstar*' and '*substar*' tasks was refined
- '*psf*' was run again which produced final PSF
- Using '*allstar*' task, the final built psf was fitted to all the stars in the image

Figures 3 and **4** present the radial profile density and surface plot of the PSF model.

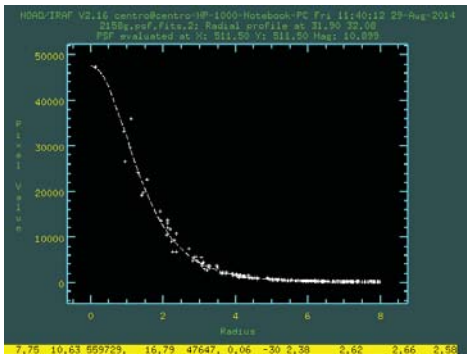

Figure 3. Radial Profile Density of PSF Model

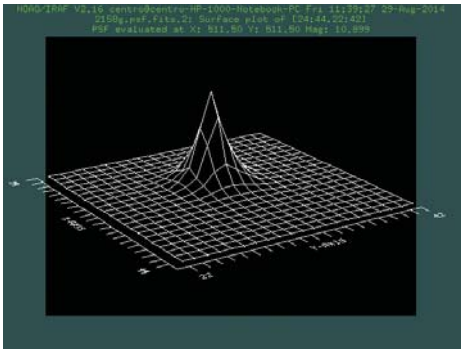

Figure 4. Surface Plot of PSF Model

Using *pdump* task, a text file containing coordinates of each star and its corresponding instrumental magnitude was obtained.

ii. Calibration

The procedure defined in the previous section was repeated separately for *g* and *r* filter FITS images of both clusters so there were two files containing the data of stars for each respective filter. As there was a difference between numbers of stars detected by both filters, cross-matching of individual stars in each band was performed to select only those stars which were detected in both bands. For this purpose TOPCAT was used which produced a single data file for each cluster.

Instrumental magnitudes of common stars in both filters of each cluster were calibrated into corresponding calibrated magnitudes using

$$m = m_0 + (m_{ins} - 25) - kx$$

where

m_0 = constant depending on the considered filter

m_{ins} = instrumental magnitude

k = atmospheric extinction coefficient

x = air mass

and 25 is a constant applied to the instrumental magnitude values to make them positive.

The values of the aforementioned parameters for both clusters have been taken from the photometry data file from SDSS and presented in **Table 1**.

	Melotte 72			NGC 2158		
	m_0	k	x	m_0	k	x
G	24.3748	0.17412	1.3907	24.5667	0.1506	1.0235
R	24.0401	1.06033	0.1068	24.5667	0.0916	1.02353

Table 1. Photometric parameters for both open clusters

iii. CMD Plotting and Isochrones Fitting

MATLAB was used to plot Color-magnitude diagrams of both open clusters which were then fitted with appropriate isochrones. Isochrone fitting was started using an educated guess based on age and metallicity ranges of open clusters. Several same age isochrones with different metallicities and vice versa were tested. Best fitted isochrones were then used to estimate the parameters of the star clusters. **Figure 5** shows the isochrones fitted color-magnitude diagram of Melotte 72 and NGC 2158.

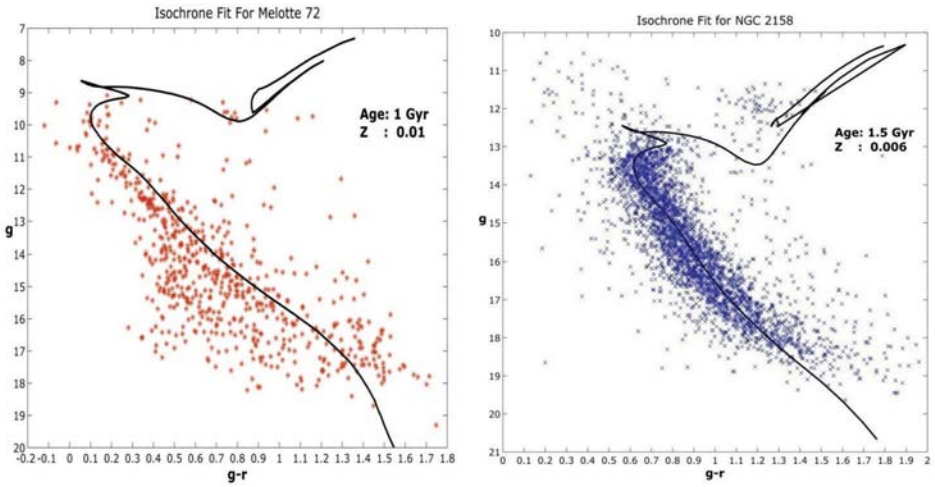

Figure 5. Isochrone fitted color magnitude diagrams of Melotte 72 and NGC 2158

iv. Calculations

Distances of both open clusters were calculated using the following equation:

$$(m\text{-}M) = 5 \log d\text{-}5$$

Where $(m\text{-}M)$ is distance modulus and d is distance in parsecs. In this case, distance modulus was the difference between g coordinates of turn-off values of cluster data and the best fit isochrones. Similarly, reddening was obtained from the difference in $g\text{-}r$ coordinate of two turn-off values. **Table 2** shows the values of distance modulus, reddening, metallicity and the distance determined for both open clusters.

	Melotte 72		NGC 2158	
	Our Findings	At WEBDA	Our Findings	At WEBDA
Age (Gyr)	1 Gyr	0.60	1.5	1.05
Metallicity (Z)	0.01	0.000	0.006	-0.023
Distance Modulus (V-M_v)	8.242	13.01	11.406	14.64
Reddening $E(V$-$B)$	0.199	0.20	0.65	0.360
Distance (pc)	445.04	3000	1910.73	5071

Table 2. Photometric parameters for both open clusters

4. RESULTS/CONCLUSIONS

Table 2 suggested a little higher values for the age of both open clusters when compared with those at WEBDA. It was 0.40 Gyr higher for Melotte 74 and 0.45 Gyr for NGC 2158. Similarly, reddening values were found acceptable for Melotte 72 while a bigger difference was seen for NGC 2158. It was noticed that we underestimated the distance of both open clusters with a larger difference.

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Muhammad Awais Mirza is a junior undergrad student at Department of Space Science, Institute of Space Technology (IST), Islamabad. He undertook this research during summer internship at SUPARCO — the national space agency of Pakistan. A space nut and an excellent team player, Awais is working as the head of Astronomy and Astrophysics wing of IST Space Society. His great passion inspires him to further engage with the topic in the framework of a professional career.

PRESS SUMMARY

Star Clusters are the collections of stars, born at same time, traveling together through space. After processing images (from a 2.5 meter telescope) of two star clusters, we obtained their color (temperature) vs. luminosity graphs. Using these graphs, we estimated the parameters like distance and age of these clusters. Finally, the estimated parameters were compared with the literature.