Draft version January 20, 2022
Typeset using LaTeX default style in AASTeX63

Literature Review: Man shoot at something, nothing sure to hit it. A review of Open Clusters, associated CCD Photometry Methodology and their contribution to Stellar and Galatic Evolution

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(Received January 20, 2022)

Submitted to Dr. Antonio Martin-Carrillo

ABSTRACT

Open clusters are an integral instrument in an astronomers toolbox. They have proven to be one of the most valuable tools in determining the structure and evolution in the Milky Way, acting as stellar and galactic laboratories. They provide insight into astronomical phenomenon such as nuclear synthesis to stellar composition. In this review, basic background information and context is provided to illustrate open clusters place in astronomy. This review also details the methods and means by which science can be performed—using photometry to obtain colour-magnitude diagrams (CMDs) to analyse and survey missing for three open clusters of varying age in the Open Star Cluster Survey and WEBDA catalogues.

Completing a survey of an open cluster can be defined as a cluster classification by determination of reddening, distance and metallicity of clusters. This can be done by means of fitting theoretical isochrones to CMDs to obtain these parameters accurately. This will allow for discussion about the stellar evolution in a given cluster. In the case of an older observed cluster, an investigation into the mass function of white dwarfs can be conducted. In the case of younger clusters, an inquiry can be made into the convection overshooting among the stellar population.

In a circumstantial case, profiling of the sampled clusters spatial distribution would allow for an observation on galactic tracing as open clusters are commonly used as path-finders to find the shape of the Milky Way.

1. INTRODUCTION & BACKGROUND

Clusters of stars are one of the most readily available 'laboratories' to give insight into many Astrophysical phenomena. Study and analysis of clusters lend themselves to the development of theories in the stellar and galactic evolution, along with an insight into the stellar composition and nuclear synthesis but have been used across many fields in astrophysics.

Open clusters are classified based on their sparseness with some distinction about their core, with a higher density usually observed towards their centre, with subcategories within classified open clusters. (Trumpler 1930) Presently, there are about 3000 open clusters in known catalogues with much larger projection for open cluster discoverers on account of Gaia's observations. (Castro-Ginard et al. 2020) This review intends to briefly explain the use of open clusters in explaining stellar evolution and how this can be furthermore extended to galactic evolution. It will also outline some specific details about the questions photometry of open clusters can answer.

2. USING OPEN CLUSTERS AS STELLAR LABORATORIES

Cluster's form the perfect environment for large scale laboratories. This initially became prevalent when examining the colour-magnitude diagrams of open clusters. Stars in the same cluster were found to often have similar properties across the populations (Trumpler 1930) allowing for details of the molecular cloud to hold true for detailed observations. So when an HR diagram is plotted for an open cluster, the stellar population will mainly reside along the main sequence. The use of HR diagrams is how information about stellar evolution is inferred from observational data and, as we will later see, how photometry can be used to make further contributions to stellar and galactic evolution.

2.1. *Colour Magnitude Diagram*

Colour magnitude diagrams (CMDs) are imperative to the study of open clusters. They reveal the evolutionary state of the cluster and information about its stellar constituents. Such as the frequency of binaries, the existence of anomalous stars and the nature of a cluster's mass and luminosity functions. It also provides the reddening, distance and metallicity of clusters. An example of a CMD of an open cluster is illustrated in figure 1, where the main sequence and evolutionary track are distinct.

2.2. *Theoretical Isochrones*

Stellar Isochrones are commonly used date open clusters as the stellar population is around the same age. If the initial mass function of a cluster is well described, the entire observed population can be used to see how the population will evolve over time, given the calculation of isochrone at varying dates (i.e Gyr isochrone in steps of about 0.5 Gyr)[1]. Over the years, many databases have been built up for varying types of clusters. An example of such a database is provided by the Spanish Virtual Observatory[2] with many theoretical isochrones are fed data from near-infrared surveys like 2MASS[3] and UKIDSS[4] to provide more accurate results when comparing to experimental data. See Janes et al. (1988) §II and III for a well-illustrated use of a theoretical isochrone to enhance photometric data. The power of theoretical isochrone is also illustrated in figure 1 where a modified 5 Gyr isochrone is used to estimate the age of Messier 67 (M67).

2.2.1. *Implication of using CMDs on Open Clusters*

The use of CMDs does not come without its challenges, especially when looking at the extremes of the age distributions of open clusters as this project intends to do. When looking at open clusters, especially older ones, the spatial profile can be quite sparse. Due to this, the main sequence, when plotted on a CMD, can be subjected to masking or 'confusion' due to a popular field population. Gozzoli et al. (1996) came up with a remedy for this by means of limiting the field to the most central regions of the cluster. In doing this, further clarity was found in the main sequence. Even in doing this, the main sequence is dominated by the field in comparison to the cluster. Method of de-convolution can be used to resolve this issue further but is noted to be extremely difficult. It involves statistical subtraction by sampling the nearby field that can be used as a comparison against the sample set. This method has its own limitations, mainly that open clusters have distant members from their centre by definition. Once again, there is a commonly used solution to solve this issue by simulating the clusters evolutionary sequence and then comparing theoretical isochrones with the synthetically simulated CMD. (Gozzoli et al. 1996)

The very young open clusters do not get away from their own challenges in obtaining CMDs. As many stars are just entering the main sequence, there can be quite a broad foot on the approach from brighter luminosities. There can also be variable reddening as stars leave the main sequence, which must be subsequently accounted for during analysis. For very young clusters for decent data collection, multiple wavelength observations are required, mainly infrared (IR) and Hα wavelengths are commonly used. (Slesnick et al. 2002) Young clusters also fall victim to embedded nebulosity[5] which lead back into the aforementioned issue with sparsity as seen with older clusters.

In all cases, classification of sparse clusters can be quite difficult unless precise data can be calculated on radial velocity and motion.

3. USING OPEN CLUSTERS FOR GALACTIC TRACING

Observing the Milkyway's shape has always been difficult as the only observation point is from within it. Open clusters are commonly used as path-finders, especially when trying to determine the evolution of the galactic core. Open clusters are of use for determining attributes of the galaxy based on their properties and spatial distribution. It can provide context for a given point or trajectory in galactic evolution. van den Bergh (1958) found that cluster age and location correlated, that the older clusters in the sample size were at a greater distance from the galactic plane from younger, more conventional clusters. This was further added upon in studies by van den Bergh & McClure (1980) where larger sample size was used to determine that clusters with age greater than 1 Gyr were found primarily in the galaxy anti-centre compared to the younger populations of clusters. As time progressed and further studies

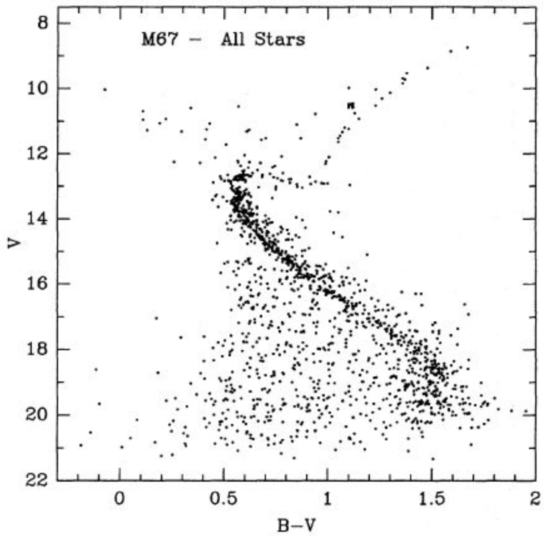
[1] *Note:* Steps used to illustrate point this usually isn't the case.

[2] http://svo2.cab.inta-csic.es/theory/iso3/

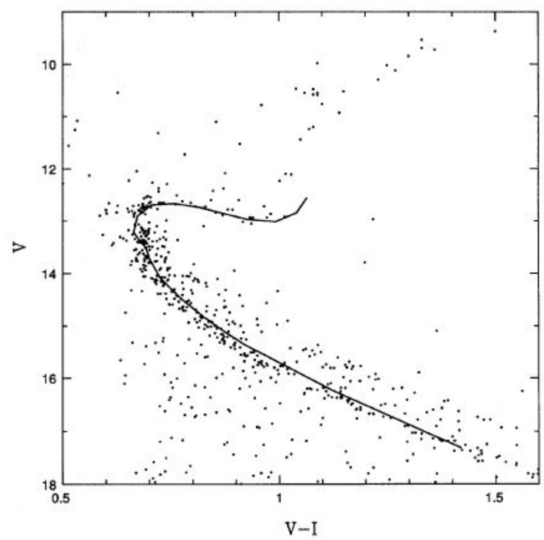
[3] https://irsa.ipac.caltech.edu/Missions/2mass.html

[4] https://www2.le.ac.uk/departments/physics/research/xroa/astronomical-facilities-1/ukidss

[5] 'Nebulosity' is a term used to describe when a cluster has similar to a nebula such as cloud-like properties.



(a) V vs $B-V$ color magnitude diagram of all M67 stars brighter than 12. This CMD exhibits a clear main sequence track.



(b) V vs $V-I$ color magnitude diagram of all M67 stars with a distance modulus greater than 9.6. Fitted with a 5 billion year old isochrone for comparison.

Figure 1: Example color magnitude diagrams of of open cluster Messier 67 (M67) produced through photometry by Montgomery et al. (1990). M67 is considered a prime exampled of an 'old' super-cluster with an estimated age of just over ≈ 4 billion years.

were complete, it became apparent that the age of the clusters would see towards the anti-centre of the galactic core. Recent studies in tandem with Gaia data release 2 (DR2) have been using Galactic tracing to infer information about the shape of the Milky Way, specifically the spiral arms. This had been extensively studied by Castro-Ginard et al. (2021). Studies involving galactic tracing require larger sample sizes of clusters in specific locations in the galactic plane, but if target clusters are chosen with the current databases in mind, further precision on cluster parameters can help improve established models and provide an extension to the data garnered by the project.

4. INTENDED PHOTOMETRY METHODOLOGIES

4.1. *Classification of Open Clusters*

When performing analysis, it is important to know the classification of an open cluster. The most common system for doing this was coined by Robert Trumpler, who determined that an open cluster could be classified based on three factors. ***(a)*** Range of brightness, ***(b)*** degree of concentration and ***(c)*** star population in a cluster.

Range of Brightness	**Degree of Concentration**	**Cluster population**
1 - Majority of stellar objects show similar brightness.	I - Strong central concentration (Detached)	p - Poor ($n < 50$)
2 - Moderate brightness ranges between stellar objects.	II - Little central concentration (Detached)	m - Medium ($50 < n < 100$)
3 - Both bright and feint stellar objects	III - No disenable concentration	r - Rich ($n > 100$)
	IV - Clusters not well detached (Strong field concentration)	

Table 1: Details relating to the classification of open clusters as described by the Trumpson classification system. Where n denotes the amounts the stellar population in a given cluster. For example Pleiades is a I3rn cluster and Hyades is a II3m cluster. Where the 'n' flag on a classification relates if the cluster shows nebulosity. (Trumpler 1930; Nilakshi et al. 2002)

4.2. *Photometry*

When approaching photometry regarding open clusters, there is a common theme in methodology with small variations depending on the specific outcomes of a given project. Generally, most open clusters can be sufficiently observed with a telescope around 1 m with observations using U, B, V and I required. Typically exposures in the U, B, V and I are around 600, 600, 300 and 120 seconds, respectively, but the source determines this number and other variables such as weather, so detailed discussion is not possible until further in the project. Typically more frames are taken towards the cluster's core as the stellar objects are less discernible from each other and require more observation to ensure correct classification. Crawford & Perry (1966) and subsequent studies outline in detail the methodology for observing open clusters using photometry with only distinguishable revisions coming in the form of data-analysis and correction methods.

From a practical standpoint, observations will need to be taken over the course of three nights as described by Kalirai et al. (2003) with accumulative combined exposures. CCD image reduction will need to be performed as traditionally done with photometry inclusive of flat-fields, bias and darks. The data will also need to be transformed to calibrate the data (see §§ 5.1 and 5.2 of ??). It will also be imperative to estimate the zero points of observed targets and ensure that estimated uncertainties are in line with that of used catalogues throughout observations.

4.3. *Existing Catalogues & Survey's*

There have been many initiatives to catalogue open clusters throughout the years. In the case of cataloguing open clusters, the conditions for membership must be well defined and understood as they directly change ideas about stellar and galactic evolution. As time progresses, the realms in which these conditions are defined become less transparent. The catalogue of interest in the context of this project will be WEBDA[6]

5. PROPOSED OBSERVATIONS & SCIENTIFIC RELEVANCE

During this project, an ideal case would be to obtain at least three open clusters at the extremes of their lifespan. One rich young open cluster. One open cluster in the middle of its lifespan which exhibits a detached centre with a medium to rich population and one older cluster with at least moderate brightness and distinction about the core. The reason for this desiring targets of these parameters is for many reasons. Mainly due to consideration of the points outlined in **??** section 2. While observing targets on the extremes of their ageing spectrum, it is important to balance the issues this carries. Having a CMD of an open cluster in its infancy may be perfect in theory for analysis on various related problems but is no good if the main sequence cannot be clearly and accurately distinguished within this project's scope.

5.1. *Convective Overshooting*

The inner convective zone and the outer radiative zone can often be subjected to boundary overshooting in stars that are of masses of $2 - 2.5$ $M_\odot$. The implication of this is that the mass of the core of the stellar object can increase substantially. In turn, this can cause a distinct change in morphology of the produced HR diagram of open clusters surveys outlined that this can happen in clusters from around 600 Myr to several Gyr. This, in turn, causes overestimation in the parameters inferred from CMDs. Thus it's another factor that should be considered when modelling and deriving stellar evolution and cluster age. The effect this had on data obtained from M67 is in-depth discussed in VandenBerg & Stetson (2004).

5.2. *White Dwarfs and the Initial–Final Mass Function*

An attractive faucet for older open cluster observations is their insight into the behaviour of white dwarfs. Open clusters have been used to constrain ranges of parameters of white dwarfs further. Mainly their cooling ages and their upper mass limits in the production of white dwarfs. This provides information about mass loss during the process of stellar evolution and, in turn, lends itself to the study of models that describe galactic chemical evolution and the chemical enrichment of the interstellar medium. Surveys and studies by Kalirai et al. (2003) to present has explored these factories in great depth and provided production of white dwarfs found in the observed old cluster the data could be fitted to proposed models.

[6] https://webda.physics.muni.cz/

5.3. *Aims & Desires*

As with any field in astronomy, the study of open clusters is disadvantaged by a lack of data. Observing and storing raw data for each cluster is a cumbersome task. Furthermore, accurately cataloguing and determining these attributes can be a time-intensive task with many open clusters lacking appropriate observation time with present technology. The versatility and implications of the study of open clusters have been briefly touched on throughout this review. A survey of open clusters in itself can be a career-long undertaking, and the study of stellar and galactic evolution from this even more so. A project that adequately surveys a set of open clusters that may have an inconcise or incomplete parameter database by lack of consideration of implications, as mentioned earlier, would be the overall aim. Any extensions or investigations into stellar or galactic evolution as described above would be a welcome addition.

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