Mapana Journal of Sciences
2018, Vol. 17, No. 1, 57–73
ISSN 0975-3303 | https://doi.org/10.12723/mjs.44.6

Methods to Identify Star Clusters in the Large Magellanic Cloud (LMC)

P. K. Nayak* and A. Subramaniam†

Abstract

The Large Magellanic Cloud (LMC) hosts a few thousand star clusters which are ideal tools to study stellar evolution, star formation history, cluster formation and dissolution processes in the galaxy. Although many surveys (like IRSF, OGLE II etc) of the LMC have been carried out, a large fraction of clusters, mainly poor ones are yet to be identified. Also, the parameters of already identified clusters are not well studied. In this context, we have tried to explore that among the available and upcoming surveys which survey (optical/NIR) can be used to efficiently detect and study the clusters in the LMC. We have found that the available OGLE-III optical data is ideal for this purpose, but only for young clusters, whereas Deeper optical data from DECAM survey, OGLE-IV and skymapper are ideal to study poor and old clusters. We have also found that one can combine the ongoing VISTA data with upcoming optical data (OGLE IV) and estimate the cluster parameters more accurately.

Keywords: Large Magellanic Cloud, star cluster, isochrone, star formation history, colour magnitude diagram

1. Introduction

The Large Magellanic Cloud (LMC) is the third nearest galaxy to the Milky Way (MW), located at a distance of ~ 50 kpc [15], hosts a large number of star clusters. The LMC is irregular type of galaxy with a prominent off-centered warp [16] stellar bar and suspected spiral arms. It is also known as a gas rich galaxy with active ongoing star

*Indian Institute of Astrophysics, Bangalore, 560034 and Research Scholar, Pondicherry University; prasanta@iiap.res.in
†Indian Institute of Astrophysics, Bangalore, 560034; purni@iiap.res.in

Received: December 2017. Reviewed: December 2017

formation [6]. The LMC has been long considered as a planar face on disk galaxy, but the studies on Cepheids [9], red clump stars (Olsen & Salyk 2002) and RGB stars [18] confirmed the inclined geometry of the disk of the LMC with an angle of inclination of the order of i $\sim$ 35 degree. Due to this proximity of the LMC we can resolve the individual members of the star clusters with ground based telescopes under good seeing conditions, which is not possible in the case of the other distant neighbouring galaxies (e. g., Andromeda, Triangulum etc.). Thus, the LMC becomes a great celestial laboratory to study the structure and evolution of external galaxies with the use of star clusters of stars in a low metallicity (Z=0.008, [12]) environment.

So far, there are many studies on identifying the star clusters and estimate their parameters in the LMC, but the most recent and estensive catalogue of $\sim$ 3000 star clusters is given by Bica et al. (2008). The catalog provides central co-ordinates (in RA and Dec), major and minor axis, position angles of star clusters. The authors suggested that the catalog is still not complete and a large number of poor clusters (mass $< 10^3 M_\odot$) are yet to be identified. Using the Magellanic Cloud Photometric Survey (MCPS) [21, 20] data, Glatt [5] presented ages and luminosities of 1194 star clusters and associations in the LMC. Pietrzynski & Udalski [11] estimated ages and reddening of 600 star clusters in the central LMC, using the Optical Gravitational Lensing Experiment II (OGLE II) data [17]. Hence, the studies suggest that only $\sim$ 50% of the cataloged clusters by Bica *et al.*[2] has the information about age and reddening.

The proper motion study of the LMC and the Small Magellanic Cloud (SMC) suggested that the SMC became a strongly interacting binary pair with the LMC only recently, suffering two strong tidal interactions $\sim$ 2 Gyr ago and $\sim$ 250 Myr ago [4, 3]. According to Besla *et al*[1], the SMC made close passages around the LMC at around 900 Myr and 100 Myr ago. These strong interactions between the Magellanic Clouds (MCs) could have triggered star formation in both the galaxies, which can be confirmed by studying formation and evolution history of star clusters in the MCs. Therefore, it is necessary to identify poor clusters to complete the catalog and then estimate age and reddening of all the cataloged clusters to get a clear picture about formation and evolution of clusters as well as the MCs. In this context, we have explored the following tasks, to identify and optimise the methods to study star clusters in the LMC.

(i) Which filter combination in the optical and NIR is ideal for accurate estimation of cluster parameters?

(ii) Which survey (optical/NIR) can be used to efficiently detect star clusters?

(iii) Compare the upcoming deeper surveys with the present surveys, to study poor clusters.

The rest of the paper is arranged as follows: In subsections 1.1, 1.2 and 1.3 we have described about star clusters, star clusters in the LMC and theoretical isochrone respectively. In the Section 2., we mentioned about the data used for this study, followed by analysis in Section 3. Section 4. presents suitability of optical and NIR data. In the Section 5. we compare deeper NIR data with optical data. Results of this study are presented in Section 6., followed by the conclusion in Section 7.

1.1 *Star Clusters*

A star cluster is a group of stars, assumed to be born from the same material at about same age and located at the same distance. This assumption is quite justified as stars within a cluster are formed from a single clump in the molecular cloud with diameter of the order of 5 pc which is small compared to the clusters distance of about hundreds of parsecs. The time scale to form a star cluster is about few million years which can be neglected for the clusters older than 50 Myr (intermediate to old clusters). The assumption of same age of star clusters is not valid for the younger clusters of ages less than 10 Myr. Interstellar absorption and reddening will be same for all the stars within a cluster as they are located at the same distance. So, the stars in a cluster can be considered as they are located at the same distance having same age and chemical compositions, but with different stellar masses.

Star clusters help us to understand the structure and evolution of the galaxies in the present universe. Also, the study of stars clusters helps us to probe the properties of each star within the cluster and their evolution. Cluster color magnitude diagrams (CMDs) are the best test beds for stellar evolutionary models. On the other hand, the use of stellar models has improved the understanding of stars in different evolutionary stages in the cluster, such as RR Lyrae stars and Cepheids and also in the determination of ages of clusters. These objects are found to have considerable information regarding the formation and evolution of the host galaxy, for example, the study of globular clusters has revolutionised the understanding of the formation of our Galaxy. Using the star clusters, we can probe the structure, formation and the evolution the external galaxies, where it is very hard to resolve the individual stars. The star clusters also help us to know about star formation history (SFH) and the recent star forming region of the host galaxy.

The star clusters are identified by the localised enhancement in the stellar number density compared to the field. Their characteristics mainly depend on the host galaxy. Star clusters are found in all the three components, halo, disk and buldge of our Galaxy. The clusters in our Galaxy can be classified into three types, based on their appearance as open clusters, globular clusters and OB associations.

1.2 *Clusters in the LMC*

The MCs contain a class of populous star clusters, with masses that are typically an order of magnitude smaller than those of the average globular clusters ($10^{5.5}$ $M_\odot$), but an order of magnitude larger than those of the most Galactic open clusters ($10^{3.5}$ $M_\odot$), this class is rare or absent in our Galaxy. The old globular clusters seen in MCs are very few and have ages greater than 10 Gyr. The mean absolute magnitude of these objects is identical to that of true globulars in M31 and our Galaxy. Studies of the populous clusters in the MCs are particularly important as they allow one to study the rapid evolutionary phases in the H-R diagram due to their richness, which is unlikely to be observed in the sparser Galactic open clusters.

1.3 *Theoretical Isochrones*

The basic understanding to the theory of stellar evolution comes from the Hertzsprung-Russell (H-R) diagrams which display the relationship between the stellar spectral types and luminosities in a two dimension plot. The most convenient form of H-R diagrams to analyse the evolutionary stages of stars is a plot of luminosity of star in units of solar luminosity vs effective temperature of the star in logarithmic scale, called as theoretical H-R diagrams, whereas the observational form of H-R diagram is the plot of magnitudes vs color index named as color magnitude diagrams. The basic property of this diagram is that it shows a specific location of stars in its different evolutionary stages in the diagrams. With the help of this plot one can say about present evolutionary stage of any star and also the age that star, once its location in CMD is known. Thus it is one of the best tool to check stellar evolutionary theory. To check the theory one has to compare the theoretical H-R diagram with one obtained observationally. For this one needs to observe many stars, find their individual value of distance, reddening, metallicity and place them in the H-R diagrams where it is very difficult to estimate those parameters for individual field stars.

The cluster CMD has a well defined main sequence (MS) extending up to an upper limit of brightness, depending upon its age. The stars brighter than this limit will go to the red giant phase. For young clusters CMDs show a few number of supergiants across a wide Hertzsprung gap and a group of M supergiant. In the intermediate age clusters, the MS terminates at a lower brightness and a RGB can be seen separated from the MS by a narrow Herzsprung gap and no supergiants. Thus a cluster CMD represents a snapshot of stellar evolution at different time scales. This is what is actually needed to test the stellar evolutionary theories, which predict the luminosities and the effective temperatures of a star of mass m, at different ages. These are called stellar evolutionary tracks. Now if we find the locus of stars with different masses having the same age, it is called an isochrone. So, the cluster CMD is nothing but an isochrone corresponding to the cluster age.

2. Data

To achieve the objective we have used the following database: (a) Optical Gravitational Lensing Experiment (OGLE) phase-III, presents data in U, B, V, I bands. (b) Infra-Red Survey Facility (IRSF) in their Magellanic Clouds Point Source Catalog (MCPSC), presents data in J, H, K bands (c) VISTA has released a part of the survey data in the region of the MCs, which has deeper coverage, presents data of stars in Y, J, K bands.

3. Analysis

The ages of star clusters are usually derived based on either optical or NIR isochrones. This is due to the fact that the data is in general, optical or NIR, not together. On the other hand, if one uses a combination of a filter in optical and another in the NIR, it will be possible to get a broader colour range and help to obtain better colour separation near the turn-off. As the ages of clusters are estimated based on the turn-off location, it is essential that this region gets large colour range for accurate estimation of age. The approach of combining optical and NIR has not been explored in detail so far.

As many deep surveys are likely to be available in the optical and NIR, it is worthwhile to explore the advantage of using optical-NIR colours for the isochrones and to derive ages. In this study, we have used Marigo *et al.* [8] isochrones. The isochrones table contains absolute magnitudes in the bands U, B, V, R, I, J, H, K. Midpoint wavelength and full width half maxima (FWHM) of these bands are given in Table 3..

Table 1: The table represents midpoint wavelength and FWHM of different bands, present in the isochrone table

Bands	U	B	V	R	I	J	H	K
Midpoint wavelength (nm)	363	445	551	658	806	1220	1630	2190
FWHM (nm)	66	94	88	138	149	213	307	390

We have plotted isochrones for ages (in log scale) 8.0, 8.3, 8.5, 8.7 and 9.0 with different combination of filters, which are listed in [8] isochrones. The plots shown here (Figure 1) are for V vs (V-I); J vs (V-J); J vs (J-H) and H vs (J-H). Additionally, we have also marked the following evolutionary stages along the isochrone:

(i) Turn-off region (TO)

(ii) Red giant branch bottom (RGBb)

(iii) Red Giant branch top (RGBt)

(iv) Begining of helium burning phase (BHeb)

(v) End of helium burning (EHeb)

These are used to assess which set of isochrones give better separation of the main-sequqnce turn-off and nearby region. We find that the J vs (V-J) and V vs (V-J) isochrones produce better separation of the main-sequence turn-off region, when compared to the other isochrones.

We infer from this analysis that a combination of optical and NIR filters can bring about better resolution of the turn-off region. This will be ideal to estimate ages of clusters and multiple population with different ages. We suggest that, if optical and NIR data are available for stellar population, it will be more efficient if we combine the data for accurate estimation of ages, instead of analysis the data separately. The prerequisite is that the data should be sufficiently deep in both the optical and NIR bands, particularly, the NIR data.

4. Suitability of Optical and NIR Data in the LMC for Cluster Studies

We considered two data sets, one each in optical (OGLE III) and NIR (IRSF-MCPSC), which have large coverage of the LMC.

The star cluster studies are biased towards the rich clusters in the LMC, but attention is also needed to be given to the large number of poor clusters as well. The aim is to compare the above two datasets to identify which data set is ideal for the study of poor star clusters. We compare using qualitative and quantitative methods. We have compared the CMDs, spatial distribution of stars and number of stars in the cluster region, for 7 clusters of different number density with different ages. The selected clusters are NGC1718, NGC1751, NGC1846, NGC1861, NGC2019, HODGE3, NGC2121, taken from the catalog by *Bica et al.* [2]. We consider the average of major and minor axis as the radius of the clusters. To get the ages of those selected cluster we have used the catalogs given by [5, 11, 13].

In the data sets, OGLE III and IRSF, the positions of stars are given in spherical co-ordinate. We change the spherical co-ordinate to cartesian co-ordinate system. Then we extract the stars located within a

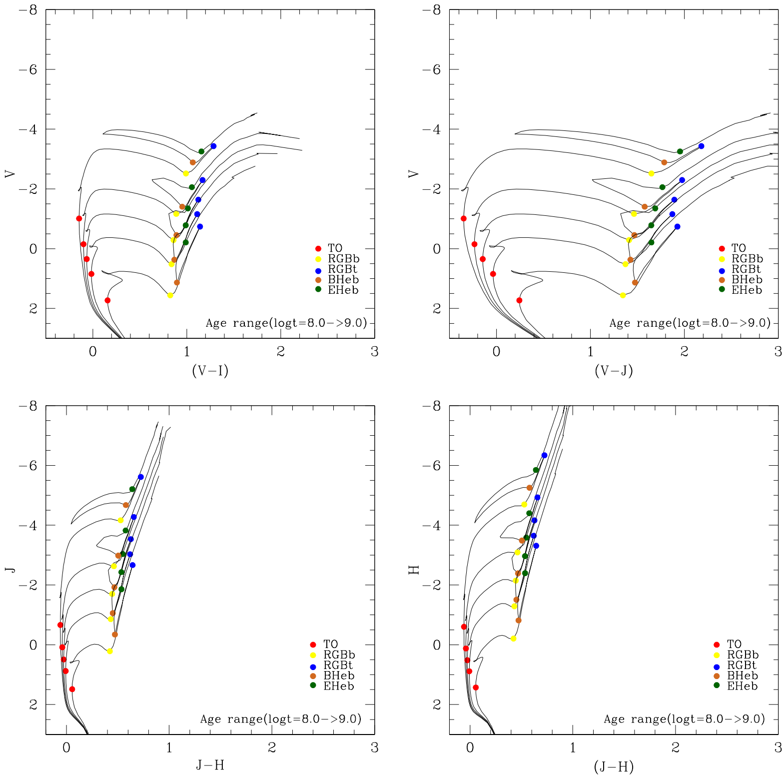

Figure 1. The Figure shows isochrones using different filter combinations in absolute magnitude scale, using Marigo *et al.* [8] isochrone table. The evolutionary stages and the age range of the isochrones are mentioned in the plots.

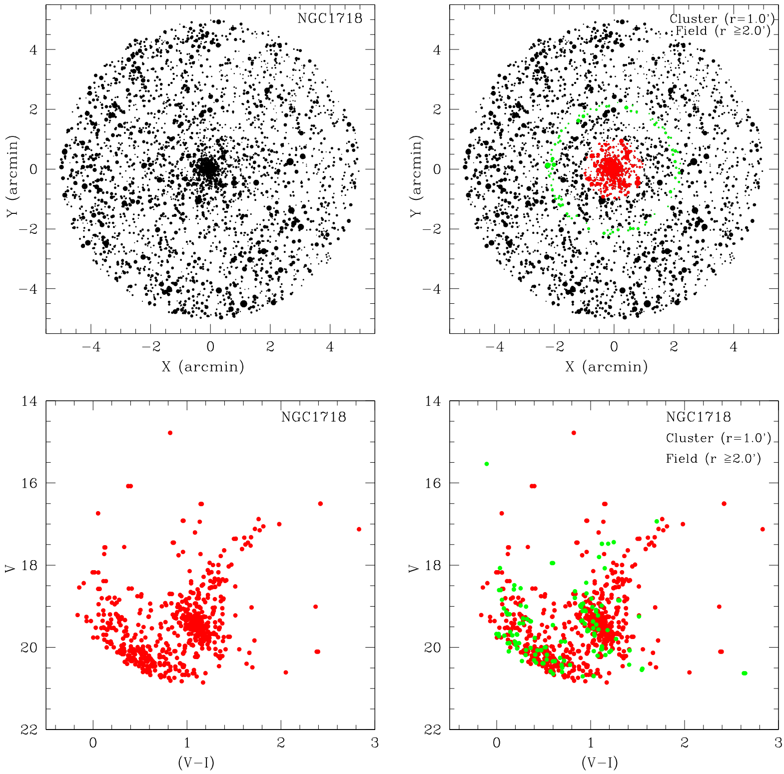

Figure 2. The top left panel shows the spatial distribution of cluster NGC1718. In the top right panel cluster and field regions are marked in red and green respectively. The bottom left panel shows the CMD (V-I vs V) of cluster region while the bottom right one shows the CMDs of both cluster and field region. The data used here is OGLE III.

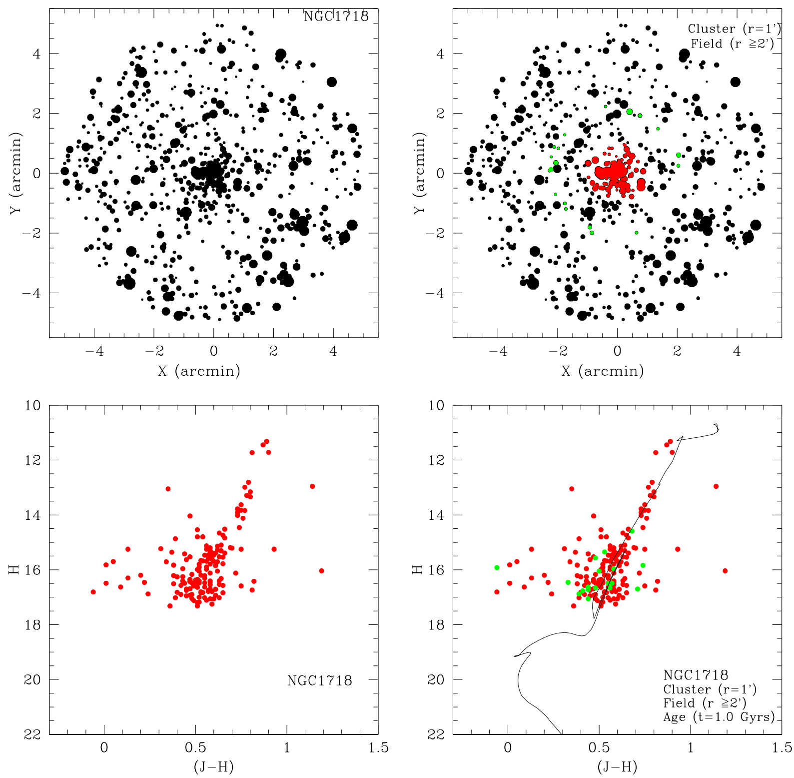

Figure 3. The Figure shows the same as Figure 2 but for IRSF data. In the bottom right panel a isochrone of 1Gyr has been overplotted to show that main sequence is not visible in IRSF data.

area of 5′ radius around each cluster with cluster center to be the center of that area. Now, we subtruct the data within the cluster radius which contains cluster stars as well as field stars, also take the annular ring around the cluster region of same area as the cluster area which gives the stellar density of the field region. Here we have assumed that fields are equally distributed within that 5′ radius. Difference of this two regions gives the stellar density of the cluster stars. The same work has been carried out for all the selected clusters with the use of two data sets and plot the CMDs and spatial distribution of stellar density for each cluster with the extracted data sets.

First we compare the cluster features such as evolutionary features in the CMD and stellar density in the spatial distribution, which are qualitative, and then we quantitatively compare the number of stars detected in both surveys.

In Figure 2, the spatial distribution of cluster NGC1718 is shown in top left panel, cluster region and field region are marked as red and green points in the top right panel using OGLE III data. The CMD of cluster region is shown in the bottom left panel and in the bottom right panel CMD of field region is overplotted on cluster CMD.

In Figure 3, spatial distribution and CMDs of cluster and field regions are shown for the same cluster NGC1718 using IRSF data. Isochrone of age 1Gyr has been overplotted on cluster and field CMDs in the bottom right panel of Figure 3, which clearly suggest that main sequence is not covered by IRSF data. So, IRSF data will not be helpful to study clusters in the LMC.

Table 2: Compare the number of cluster stars present in cluster region for OGLE III and IRSF data. The table contains name of the cluster, position (RA and Dec), radius, inner and outer radii of annular field region in columns 1-6 respectively. Columns 7-9 contain number of stars present in cluster and field region, and their difference for IRSF data. Columns 10-12 represent same as columns 7-9 but for OGLE III data.

Cluster	RA(^{o})	Dec(^{o})	r(′)	r1(′)	r2(′)	N(1)	N(2)	N	N(3)	N(4)	N′
NGC1718	73.10	-67.05	1.0	2.0	2.24	156	19	137	628	126	502
NGC1751	73.55	-69.81	0.75	2.0	2.14	206	35	171	595	112	483
NGC1846	76.90	-67.46	2.0	3.0	3.61	407	139	268	2012	661	1351
NGC1861	77.59	-70.78	0.8	2.0	2.15	87	49	38	336	168	172
NGC2019	82.99	-70.16	0.75	2.0	2.14	325	144	181	1018	679	339
HODGE3	83.33	-68.14	1.0	2.0	2.24	183	59	124	368	156	212
NGC2121	87.05	-71.48	1.2	2.0	2.33	368	107	261	867	294	573

In the Table 4., we have listed seven clusters along with their positions (RA and Dec), radius (r), inner (r1) and outer (r2) radii of the field regions, number of stars present in the cluster and field regions for both OGLE III and IRSF data. N(1) and N(3) represent the number of stars present within the cluster region in IRSF data and OGLE III data respectively. N(2) and N(4) represent the number of stars present within the annular field region in IRSF data and OGLE III data respectively. N (N(1) – N(2)) and N′ (N(3) – N(4)) are the number of cluster stars present in that cluster in IRSF data and OGLE III data, respectively.

We find that the number of cluster stars detected in the OGLE III survey is larger for all the 7 clusters. The comparison of spatial distribution suggests that the cluster is identified as a denser region in both surveys, but the density is more in OGLE III data. The CMDs suggest that the IRSF-MCPSC data do not reach the main-sequence, thus making it not appropriate for star cluster studies. Though, using this data one can study the red giants and AGB population of known and well studied star clusters. In summary, OGLE III data is found to be better to study poor star clusters, compared to IRSF-MCPSC data.

The natural question to ask at this point is, how does a deeper NIR data compare with the optical data? We address this question in the next section.

5. Comparison of Deeper NIR Data and Optical Data

VISTA survey has deeper coverage of stars for a small region in LMC and we will check whether this deeper NIR data gives any better result than IRSF data. We choose the clusters from the catalog by *Bica et al.*[2]. We consider the average of major and minor axis as the radius of the clusters. To compare the deeper data set VISTA with OGLE III we follow the same procedure as mentioned above for the comparison of IRSF and OGLE III and plot the CMDs and spatial distribution of the chosen clusters. The selected clusters are HS359, HS385, NGC2015, NGC 2091, BSDL2300. Here we have shown CMDs and special distribution of one cluster (NGC2015) as an example. VISTA survey used the filters of Y, J and K bands.

The CMDs are shown here for K vs (J-K) and V vs (V-I).

We will first compare qualitatively with the help of CMDs and the spatial distribution of stellar density of the clusters. The plots are shown in Figure 4 (for OGLE III) and Figure 5 (for VISTA).

In both the figures top left panel shows the spatial distribution of cluster NGC2015 while in the top right panel cluster and field regions are marked in red and green colours respectively. The bottom left panels shows the CMDs of cluster region and in the bottom right panel CMDs of field regions are overplotted on cluster CMDs. In the bottom right panel of Figure 5 an isochone of 16 Myr has been overplotted on CMDs. From these two Figure we can see that fields stars are more in number and spread in wide region in the CMD for VISTA data.

A quantitative comparison has been listed in the Table 5., similar to Table 4. We have used the same methods as described in section 4., to calculate the number of cluster stars present in each cluster for VISTA data (N) and OGLE III data (N′). The details of the table columns are given in the caption.

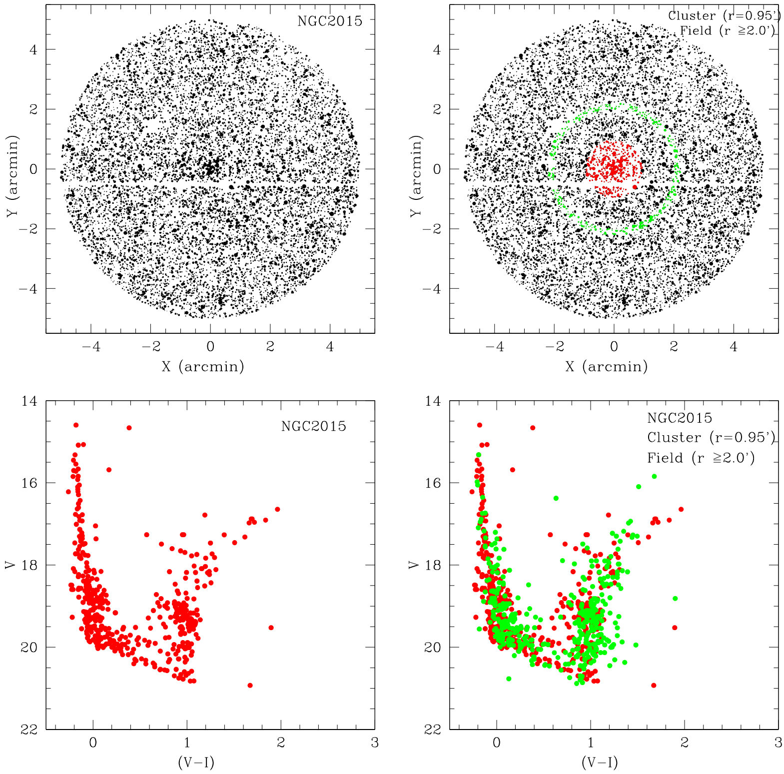

Figure 4. The Figure shows the same as Figure 2 but for the cluster NGC2015 using OGLE III data.

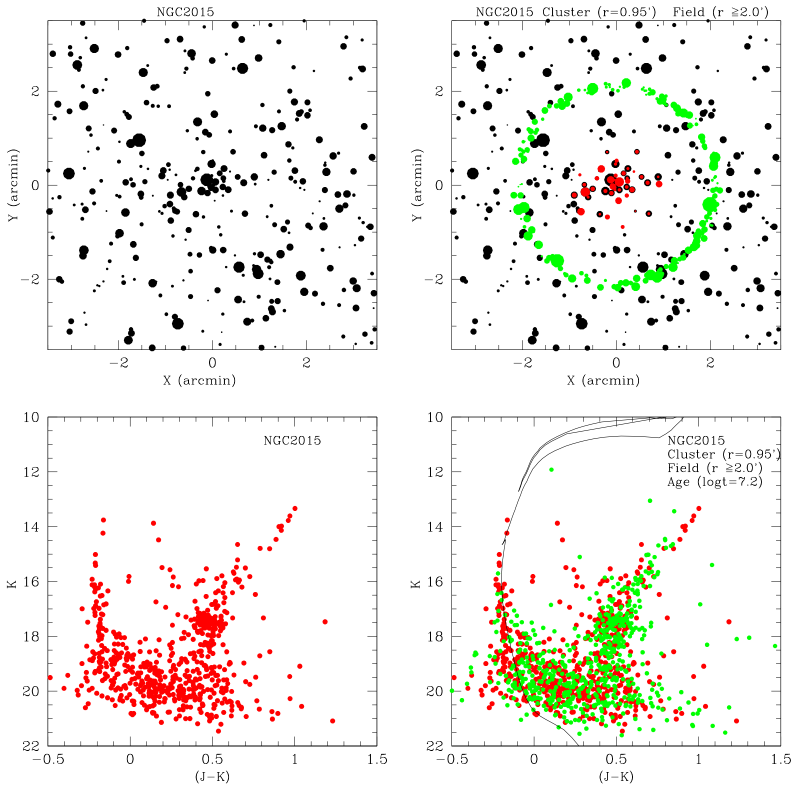

Figure 5. The Figure shows the same as Figure 2 but for the cluster NGC2015 using VISTA data. In the bottom right panel a isochrone of 16Myr has been overplotted.

Table 3: Compare the number of cluster stars present in cluster region for OGLE III and VISTA data. The table contains name of the cluster, age in log scale, position (RA and Dec), radius, inner and outer radii of annular field region in columns 1-7 respectively. Columns 8-10 contain number of stars present in cluster and field region, and their difference for VISTA data. Columns 11-13 represent same as columns 8-10 but for OGLE III data.

Cluster	Age	RA (^{o})	Dec (^{o})	r ($'$)	r1 ($'$)	r2 ($'$)	N(1)	N(2)	N	N(3)	N(4)	N$'$
NGC1718	9.05	83.68	-69.39	1.0	1.5	1.80	741	666	75	699	445	254
NGC1751		85.21	-69.55	0.75	1.5	1.68	394	368	26	269	200	69
NGC1846	7.60	83.03	-67.24	0.95	2.0	2.21	628	604	24	460	387	73
NGC1861	7.70	85.24	-69.45	1.3	1.5	1.98	1051	1040	11	636	569	67

The Table 5. indicates that the number of cluster stars observed in all the 5 clusters are very less in the VISTA survey than OGLE III survey. The table also proposes that the deeper data uncover many field stars along with the cluster stars causes the less stellar density of cluster stars. The CMDs using VISTA survey suggest that the MS, TO and RGB region are not well seen due to huge number of field stars and from the spatial plots we notice that it is hard to discover a poor cluster using VISTA survey. So going for a deeper data for better estimation of parameters is not a good option for poor clusters.

6. Results

We summarise the results below:

1. The age estimation of star clusters can be made more accurate, if the optical and NIR data are combined. The isochones in the (V-J) colour is found to be able to differentiate the turn-off region of different ages better. Hence the cluster CMDs with optical – NIR colours are suggested for accurate age estimation. On the other hand, optical data are in general deeper when compared to the NIR data, making such an effort very difficult.

2. We considered deeper NIR data to be combined with optical data. We find that the deeper NIR data produces more field stars, making the identification of cluster features in the almost impossible, in the CMDs as well as spatial distribution. We also detect less number of cluster stars, suggesting that, this method may not be good for poor clusters. This technique is likely to work for rich star clusters.

3. We find that the optical OGLE-III data is quite useful to identify star clusters and estimate the parameters. Even the poor young clusters are found to show moderate density enhancement in the spatial distribution, while the MS and TO can be identified in the CMD.

7. Conclusion

Based on the above results, we conclude that:

1. Moderately deep optical data is ideal to detect and characterise star clusters. Thus, already available OGLE-III data is ideal for this purpose, but for younger clusters. Deeper optical data from DECAM survey, OGLE-IV and skymapper will be ideal to study poor old clusters.

2. The NIR data (shallow as well as deep) is not ideal to detect poor star clusters. The ongoing VISTA survey will be good to study moderate to rich star clusters, in combination with the optical data, and estimate the cluster parameters accurately.

3. The above findings help to suggest ways to make use of the upcoming database efficiently.

References

[1] Besla, G., Kallivayalil, N., Hernquist, L., van der Marel, R.P., Cox, T.J. and Kereš, D., 2012. The role of dwarf galaxy interactions in shaping the Magellanic System and implications for Magellanic Irregulars. Monthly Notices of the Royal Astronomical Society, vol. 421, no. 3, pp. 2109-2138.

[2] Bica, E., Bonatto, C., Dutra, C.M. and Santos Jr, J.F., 2008. A general catalogue of extended objects in the Magellanic System. Monthly Notices of the Royal Astronomical Society, vol. 389, no. 2, pp.678-690.

[3] Diaz, J. and Bekki, K. Constraining the orbital history of the Magellanic Clouds: a new bound scenario suggested by the tidal origin of the Magellanic Stream. Monthly Notices of the Royal Astronomical Society, vol. 413, no. 3, pp. 2015-2020, 2011.

[4] Diaz, J.D. and Bekki, K. The tidal origin of the magellanic stream and the possibility of a stellar counterpart. The Astrophysical Journal, vol. 750, no. 1, pp. 36, 2012.

[5] Glatt, K., Grebel, E.K. and Koch, A. Ages and luminosities of young SMC/LMC star clusters and the recent star formation history of the Clouds. Astronomy & Astrophysics, vol. 517, p. A50, 2010.

[6] Harris, J. and Zaritsky, D. The star formation history of the large magellanic cloud. The Astronomical Journal, vol. 138, no. 5, p. 1243, 2009.

[7] Kato, D., Nagashima, C., Nagayama, T., Kurita, M., Koerwer, J.F., Kawai, T., Yamamuro, T., Zenno, T., Nishiyama, S., Baba, D. and Kadowaki, R. The IRSF Magellanic Clouds point source catalog. Publications of the Astronomical Society of Japan, vol. 59, no. 3, pp. 615-641, 2007.

[8] Marigo, P., Girardi, L., Bressan, A., Groenewegen, M.A., Silva, L. and Granato, G.L. Evolution of asymptotic giant branch stars-II. Optical to far-infrared isochrones with improved TP-AGB models. Astronomy & Astrophysics, vol. 482, no. 3, pp. 883-905, 2008.

[9] Nikolaev, S., Drake, A.J., Keller, S.C., Cook, K.H., Dalal, N., Griest, K., Welch, D.L. and Kanbur, S.M. Geometry of the large magellanic cloud disk: Results from macho and the two micron all sky survey. The Astrophysical Journal, vol. 601, no. 1, p. 260, 2004.

[10] Olsen, K.A.G. and Salyk, C., "A warp in the Large Magellanic Cloud disk?," *The Astronomical Journal*, vol. 124, no. 4, p.2045, 2002.

[11] Pietrzynski, G. and Udalski, A.,"The Optical Gravitational Lensing Experiment. Ages of about 600 Star Clusters from the LMC," *Acta Astron.*, vol. 50, pp. 337–354, 2000.

[12] Andrés E. Piatti and Doug Geisler, "The Age-Metallicity Relationship of the Large Magellanic Cloud Field Star Population from Wide-field Washington Photometry,"*The Astronomical Journal*, vol. 145, no. 1, pp. 17, 2013.

[13] Popescu, B., Hanson, M.M. and Elmegreen, B.G., "Age and Mass for 920 Large Magellanic Cloud Clusters Derived from 100 Million Monte Carlo Simulations," *The Astrophysical Journal*, vol. 751, no. 2, pp. 122, 2012.

[14] Mary E. Putman, Lister Staveley-Smith, Kenneth C. Freeman, Brad K. Gibson and David G. Barnes, "The Magellanic Stream, High-Velocity Clouds, and the Sculptor Group," *The Astrophysical Journal*, vol. 586, no. 1, pp. 170-194, 2003.

[15] Saha, A., Olszewski, E. W., Brondel, B., Olsen, K., Knezek, P., Harris, J., Smith, C., Subramaniam, A., Claver, J., Rest, A., Seitzer, P., Cook, K. H., Minniti, D. and Suntzeff, N. B., "First Results from the NOAO Survey of the Outer Limits of the Magellanic Clouds," *Astron. J.*, vol. 140, pp. 1719–1738, 2010.

[16] Subramanian, S. and Subramaniam, A., "An estimate of the structural parameters of the Large Magellanic Cloud using red clump stars," *Astron. Astrophys.*, vol. 520, A24, 2010.

[17] Udalski, A., Szymanski, M.K., Soszynski, I. and Poleski, R., 2008. The optical gravitational lensing experiment. final reductions of the OGLE-III Data. arXiv preprint arXiv:0807.3884.

[18] van der Marel, R.P. and Cioni, M.R.L., "Magellanic Cloud structure from near-infrared surveys. I. The viewing angles of the Large Mag," 2001.

[19] Westerlund, B.E., *The Magellanic Clouds, vol. 29*. Cambridge University Press, 1997.

[20] Zaritsky, D., Harris, J., Thompson, I.B. and Grebel, E.K., The Magellanic Clouds photometric survey: The Large Magellanic Cloud stellar catalog and extinction map. The Astronomical Journal, vol. 128, no. 4, pp. 1606, 2004.

[21] Zaritsky, D., Harris, J., Thompson, I.B., Grebel, E.K. and Massey, P., "The magellanic clouds photomtric survey: the small magellanic cloud stellar catalog and extinction map," *The Astronomical Journal*, vol. 123, no. 2, pp. 855, 2002.