Search for blue straggler stars in open clusters from the VVV survey (preliminary result)

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Abstract. Blue straggler stars (BSS) are a group of stars that are found within some stellar clusters through their color-magnitude diagrams (CMDs). The BSS are located on the upper part of the CMD’s turn-off (TO) point along the zero-age main sequence (ZAMS) line. BSS are commonly found within intermediate-age to old stellar clusters, typically 10⁸ years. Based on the catalogue of BSS in open clusters (OCs), the OCs toward the Galactic Center (GC) that host BSS are less than the ones toward the anti-center. Using the VVV survey data in near-infrared, we plan to investigate the presence of BSS in OCs toward the GC. To reach our objectives, we generally divide the works into: (1) determine cluster membership probability, (2) fit the decontaminated CMDs with its respectable isochrones, (3) detect any stars that fall into BSS area in CMD and recheck their position in spatial diagram. Out of the 4 OCs we planned to investigate, only 1 OC had been analyzed up to its membership probability; NGC 5999. However, we found 1541 stars as the most probable members, exceeded way too many compared to the literature. We still need to refine our method in the future work to clean more field stars.

Keywords: Blue straggler stars, Open clusters, and VVV survey

1. Introduction

The discovery of blue straggler stars (BSS) back in 1953 by Allan Sandage [1] started long years of quest to understand their nature and stellar evolution in general. BSS are found through the color-magnitude diagrams (CMDs) of stellar clusters (SCs) as a sequence that resides on the upper-part of the CMD’s turn-off (TO) point along the zero-age main sequence (ZAMS) line. They are commonly found within intermediate-age to old SCs, typically around 10⁸ to 10¹⁰ years. BSS’ location on the CMD is defying the stellar evolution theory in SCs where there should be no main sequence stars that are bluer and more massive than the ones on the TO point. This implies they seem to stay longer than they should on the MS [2], raising a question towards our idea that members of SCs start their evolution together. The BSS sequence is more prominent on the CMD of old SCs such as globular clusters. It is interesting to investigate the presence of BSS in younger stellar population such as intermediate-age open clusters (OCs). In 2007, Ahumada and Lapasset published ‘New Catalogue of Blue Stragglers in Open Clusters’ (hereafter as AL07) based on their studies on large numbers of OCs in Milky Way [2]. The catalogue itself is an extended version and a revision of their previous work, AL95 [3]. However, in AL07, the OCs which are located towards the Galactic Center (GC) are less...
than the ones on the anti-center direction. This may be due to thick obscuration of ISM and the dense field. In this work, we focus on the searching for the BSS presence in OCs located towards the GC.

2. Objects and Data

2.1. The VVV Survey

Our choice to investigate the OCs toward the GC led us to make use the public data from the VISTA Variables in the Vía Láctea (VVV) Survey by European Southern Observatory (ESO). The survey was conducted in near-infrared wavelength, divided into 5 passbands: Z (0.87 μm), Y (1.02 μm), J (1.25 μm), H (1.64 μm), and Ks (2.14 μm). The survey lasted for about five years from 2010, covering 520 deg² of bulge and disc region that are divided into hundred tiles [4]. We used the data from ZYJHKs Catalogue in the Vía Láctea Version 2 (2015) where it is based from the VVV DR 2.

2.2. Objects

The objects were chosen from AL07 and ‘New Galactic star clusters discovered in the VVV survey’ [5]. Our objectives are rechecking the number of BSS in some OCs in AL07 with our own method and also analyzing OCs with unknown number of BSS. They were then cross-matched with the criteria of OCs that would most likely to host BSS [6] which are shown in table 1.

Table 1. Comparison of properties of OCs in AL07 which host BSS and the ones without

| Parameter                   | OCs with BSS | OCs without BSS |
|-----------------------------|--------------|-----------------|
| Location from Galactic Disc | Further      | Closer          |
| Average of log(age)         | 8.58         | 7.52            |
| Average of (J-H)            | 0.43 ± 0.170 | 0.19 ± 0.185    |
| Average of (H-Ks)           | 0.11 ± 0.074 | 0.09 ± 0.084    |
| Average of (J-Ks)           | 0.54 ± 0.235 | 0.23 ± 0.270    |
| Average of J                | -5.29 ± 1.061| -4.59 ± 1.072   |
| Average of H                | -5.71 ± 0.984| -4.78 ± 1.019   |
| Average of Ks               | -5.83 ± 0.098| -4.77 ± 1.020   |
| Ratio of number density     | 1.47 ± 0.201 | 1.39 ± 0.193    |
|                            |              |                 |

The next part is matching the OCs that fall into criteria with the VVV data. This is because not every OCs inside VVV survey region was observed. We decided to analyze four OCs; NGC 5999, Pismis 18, VVV CL008, and VVV CL070.

Table 2. The chosen OCs’ properties

| Parameter           | NGC 5999 | Pismis 18 | VVV CL008 | VVV CL070 |
|---------------------|----------|-----------|-----------|-----------|
| RA(J2000.0)         | 15h 52m 8.64s | 13h 36m 55.92s | 11h 55m 28.99s | 16h 21m 48.00s |
| DE(J2000.0)         | -56° 28’ 22.12” | -62° 03’ 54.00” | -63° 56’ 24.00” | -51° 44’ 11.00” |
| Galactic longitude   | 326.016° | 308.233° | 296.833° | 332.406° |
| Galactic latitude    | -1.923° | 0.337° | -1.733° | -1.329° |
| Log(age)             | 8.4      | 8.6      | 8.6      | 8.8      |
| Apparent diameter    | 3’       | 4’       | 1’ 14”  | 52”      |
| Nmembers             | 65       | 150      | 25       | 30       |
| Distance (kpc)       | 1.629    | 2.309    | 1.400    | 2.000    |
| NBSS                 | 4        | 3        | unknown  | unknown  |

We also added some constrains before requesting the data for each objects. We only picked data points with the flag “stars” and gave range of values for each magnitudes to make sure there is no empty value within the data set requested. The chosen data points are plotted spatially and the OCs which have cropped or incomplete spatial distributions were singled out.
3. Cluster Membership Analysis

Before going further to isochrones fitting and finding the BSS, we need to separate the stars that are members of the clusters and the ones belong to the back- and foreground. This step is very important because the objects lie toward a crowded region. The objects, too, are located near the Galactic disc where star formation activity is high. For the cluster membership analysis, we followed the algorithm explained by Froebrich, et al [7].

The first step is to define the cluster region \( (A_{cl}) \) and a control field region \( (A_{con}) \) around the cluster’s center coordinate. For this step, we made use the value of core radius in Milky Way Star Cluster (MWSC) Catalogue by Kharchenko, et al [8]. Stars that are located nearer than 3 times the cluster core radius belong to the cluster region \( A_{cl} \). All stars farther away than 5 times the cluster core radius up to the limit of the frame requested belong to control field \( A_{con} \). This step is illustrated in figure 1.

We then applied the decontamination procedure that makes full use of the photometric data. For each stars within each OCs’ respective frames, we only requested the magnitudes in J, H, and Ks, hence each stars have their own CCM coordinates in color-color-magnitude (CCM). For each star \( i \) with the apparent magnitude \( J_i, H_i, \) and \( Ks_i \), color \( H_i - Ks_i = HKs_i \), and color \( J_i - Ks_i = JKs_i \), we calculate the CCM distance, \( r_{ccm} \), to every other stars where \( j \neq i \) in the following way:

\[
r_{ccm} = \left[ \frac{1}{2} \left( Ks_i - Ks_j \right)^2 + \left( JK_i - JK_j \right)^2 + \left( JH_i - JH_j \right)^2 \right]^\frac{1}{2}
\]

The factor of \( \frac{1}{2} \) in front of the difference in \( Ks \)-band accounts for generally larger spread of values compared to colors. For each star \( i \) in \( A_{cl} \), we then listed all the tenth smallest CCM distance \( (r_{ccm10}) \) values over all stars where \( j \neq i \). We then compared the stars in \( A_{con} \) which have similar CCM coordinates with the stars in \( A_{cl} \) then we computed the number of stars in \( A_{con} \) within the CCM distance \( r_{ccm10} \) computed before \( (N_{ccm}) \). Then we computed probability of star \( i \), \( P_{ccm} \), to be a member of the cluster in the following way:

\[
P_{ccm} = 1.0 - \left( \frac{N_{ccm}}{10} \right) \left( \frac{A_{cl}}{A_{con}} \right)
\]

If \( P_{ccm} \) of a particular star is negative, then its membership probability is decided to be zero. We accept stars with \( P_{ccm} \) more than or equal to 0.8 as most probable members of the cluster.

After selecting the stars which have the highest chance to be members of the cluster, we construct a decontaminated CMD for the cluster. The decontaminated CMD will then be used to fit with the isochrones. The fitted CMD will be used to determine the area where BSS should reside. We then will detect star(s) which fall into the BSS area and recheck their spatial distribution. If there are
any BSS detected, we will recheck whether they are really located in cluster radius and towards the cluster area or they appear further away, closer to the field [9].

4. Preliminary Result
Out of four OCs we planned to analyze, we already partially analyzed NGC 5999 up to counting its membership probabilities $P_{ccm}$. We detected 5441 stars in its $A_{cl}$ and 7162 stars in $A_{con}$. The CMDs of $A_{cl}$, $A_{con}$, and the decontaminated CMD are shown below in figure 2.

![Figure 2](image-url)

**Figure 2.** Contaminated CMD of NGC 5999 in $A_{cl}$ (left, in red dots), CMD of $A_{con}$ of NGC 5999 (middle, in blue dots), decontaminated CMD of $A_{cl}$ (right, in black dots). All axes of the CMDs are in $J-K_s$ versus $K_s$.

The result of the membership analysis we conducted on NGC 5999 is we get 1541 stars as the most probable members of NGC 5999. This result draws the number of members way too many compared to AL07 (65 stars). We assume there is still contamination of field stars that made us unable to proceed in searching for the BSS. We will recheck and refine our membership determination method to clean more field stars in future work.

5. Conclusion
Blue stragglers (BSS) are unique objects that are challenging to study. BSS can be found in some stellar clusters, typically the old ones. A catalogue of OCs with BSS had been published in 2007 by Ahumada & Lapasset (AL07) where the OCs toward the Galactic Center are less studied. In this work, we focus our study in searching for BSS in OCs towards the GC. We made use the public data provided by the VVV Survey by ESO in near-infrared wavelength. The membership analysis is an important step in studying OCs, especially for OCs that are located toward GC due to the high density of projected stars on the field. We followed the algorithm by Froebrich, et al (2010) to determine cluster membership probability. We have planned to do the search for BSS up to the number of BSS determination, however, the work in this paper are still unfinished. We have analyzed only NGC 5999 up to its membership probability determination. We found 1541 stars as the most probable members out of 5441 we detected in its cluster region. This result exceeded way too many compared to AL07. We decided to refine our method of membership analysis in the future work.

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