STUDY OF THE HR DIAGRAM OF THE OPEN CLUSTER NGC 6866 AND ESTABLISHMENT OF ITS AGE

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Abstract

We investigate the absolute magnitudes and color indices of the stars in open cluster NGC6866 based on the images taken by Colby College's Young Telescope through differential photometry to produce the Hertzsprung-Russell (HR) diagram of the absolute magnitude M_v versus $(B\text{-}V)_o$, M_v versus$(V\text{-}R)_o$, and M_v versus $(V\text{-}I)_o$ with reasonable x and y data range. We chose star Tycho 3162-1348 in the cluster as the calibration star for the photometry whose V magnitude is 10.12, B-V color index is 0.209 to generate the properties of all other stars in the cluster. From the HR diagram we generated, we deduced that the spectra at the turn-off point is F0 and the age of the cluster is between $10^{8.85}$ years to $10^{8.95}$ years which agrees with the previous published values. The diagram of apparent magnitude V versus $(B\text{-}V)_o$ also agrees with the published graph. Overall, our result is accurate but can be improved if we can include the extinction intrinsic to the cluster itself when deducing the absolute magnitude and color indices.

Introduction

A Hertzsprung-Russell (HR) diagram is a plot of stellar surface temperature versus luminosity. By studying the HR diagram of a cluster, we can deduce many useful properties about the cluster such as its ages and the life stage of the stars in the cluster. In this investigation, we took image of open cluster NGC 6866 in B, V, I, and R photometric bands and obtain the photometry of many stars in it to produce the color-magnitude diagrams and HR diagram of it, from which we then establish the cluster's age from the main-sequence turn-off.

The open cluster NGC 6866 we chosen is 1300 pc away and has diameter 14 arcminutes (Warren & Robinson 2008). It has a V magnitude of 7.6 (Wu Z.-Y. et al. 2009) and B-V of 0.44 (Wu Z.-Y. et al. 2009). A calibration star Tycho 3162-1348 is chosen within the same field for getting the properly calibrated magnitudes of other stars in the cluster. The calibration star has a V magnitude of 10.12 (Hoe E. et al. 2000), B-V of 1.04 (Hoe E. et al. 2000) and spectral type G0 (Mermilliod J.C. et al. 2008).

As NGC 6866 is an open cluster, it exists in the Milky Way disk area and contains population I stars. The stars of open clusters are generally younger and thus, we expect the isochrone has a relatively early turn-off point which means the cluster should have a young age. Most stars should fall on the main sequence and there should also be many protostars. A few red giants may be observed on the diagram.

Observation and Data Reduction

Observation

We operated our observation at 9:00pm October 15th, 2019. The weather condition is almost photometric. Necessary information of our target cluster and calibration star is listed in Table 1.

Table 1. The information of the open cluster NGC 6866 and the calibration star Tycho 3162-1348.

Name	NGC 6866[1]	Tycho 3162-1348[2]
Right Ascension (epoch 2000.0)	20h 03m 55.099s	20h 04m 06.093s
Declination (epoch 2000.0)	+44°09’33.003’’	+44°04’54.318’’
V magnitude	7.6	10.12
B-V	0.44	1.04
Spectral Type	N/A	G0
Distance	1300pc	N/A

Data was obtained at Colby College’s Young Telescope, a Planewave 0.7m Corrected DallKirkham design with f/6.5. Images were taken using a Finger Lakes Instruments back-illuminated 2k x 2k CCD equipped with Cousins BVRI filters as specified by Bessell (1990). We used 5s exposure for V filter and I filter, 3s for R filter and 15s for B filter. The field taken is in size 25 arcminutes x 25 arcminutes. For each filter, three images were taken and used for reduction and data processing.

[1] Values obtained from software SkyX
[2] Values obtained from software SkyX

Data Reduction

To process the image for analysis, a mathematical way of producing the final processed image is shown in the following:

$$Final\ image = [(Raw\ image) - (Avg\ dark)] \times \frac{mean\ value\ of\ (Flat - Avg\ dark)}{(Flat - Avg\ dark)} \quad (1)$$

We reduce the image, firstly, by subtracting the average dark with the same exposure time as the filter. Dark is the thermal noise from free electrons moving around in the semiconductor of the CCD and the electronic noise related to reading out the detector. The dark is subtracted from the flat as well to get the normalized flat for which we used 1s exposure dark as the flat is taken in 1s. Afterwards, we divide our star images by a normalized flat. Flat frames indicate how the pixels in the detector respond to a uniform light source and can be used to correct for areas of the detector that are less sensitive than other areas, including the vignetted corners and regions where dust grains are present. Then, we register the cluster images to have the image aligned so that small telescope movements from one image to the next do not blur the resulting final images and the stars in each image are at the same x, y pixel position. The cluster in B filter after the image process is shown in Figure 1 which indicates the appearance of the cluster.

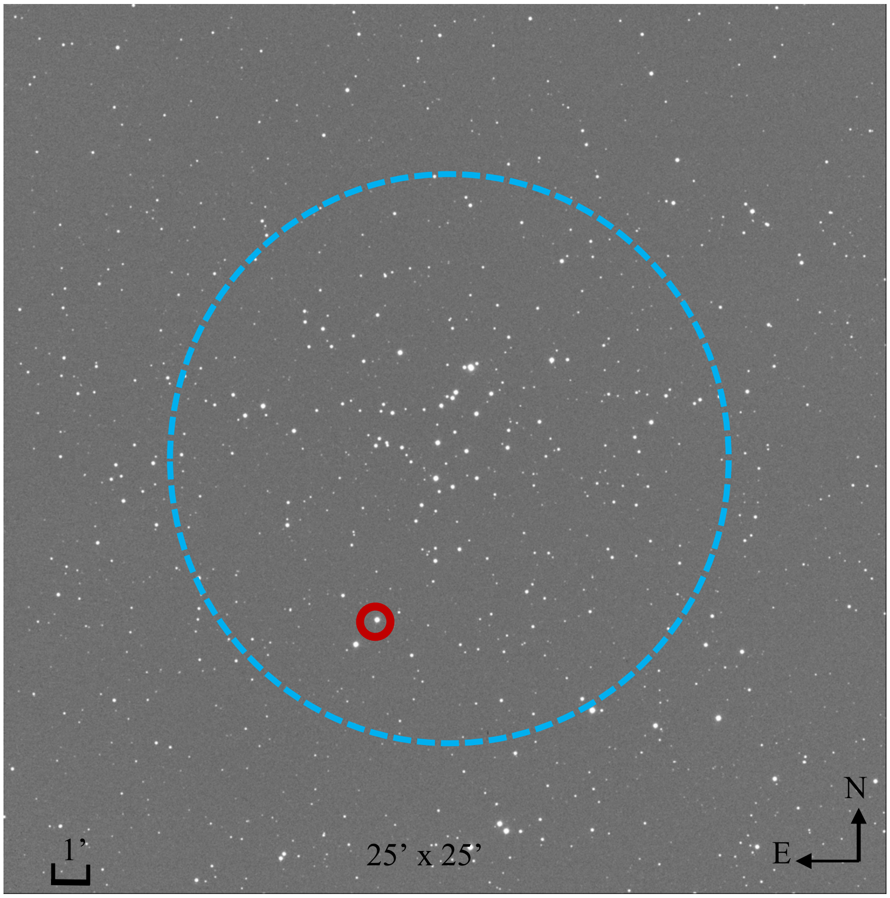

Figure 1. The reduced image of filter B with exposure time 15s. The size of the field is 25 arcminutes by 25 arcminutes. The cluster NGC 6866 is circled in blue and the calibration star Tycho 3162-1348 is circled in red. The RA of the calibration star is 20h 04m 06.093s and the declination is +44°04'54.318''. The scale is indicated on the left bottom corner and the direction is indicated on the right bottom corner.

To gain the apparent magnitudes and color indices of all stars in the cluster, we firstly obtained the apparent magnitude of our calibration star and thus the color indices. We measure the instrumental magnitude in each filter for the calibration star by setting the zeropoint to 0 and select appropriate star, buffer, and background annulus regions to include all the starlight but not include too much background sky light to define the edge of the star which is shown in Figure 2:

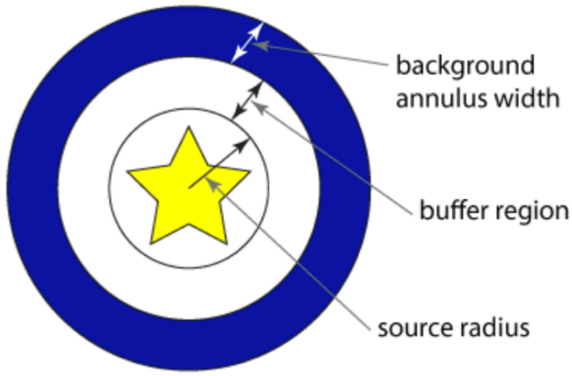

Figure 2. The graph for the aperture and annulus. The source radius is the aperture radii which is 5.36 arcsec. The buffer region is to create to buffer zone as to not have starlight in the annulus. The blue region is the annulus where the background sky level is measured.

The aperture radii (source radius) of the calibration star for all four filters is 5.36 arcsec. The total counts in the aperture contain both starlight and background sky. Therefore, we need to subtract the background sky level for which we defined an annulus around our star that is free from starlight in order to measure pure sky. From the instrumental magnitude in each filter, we deduced the calibrated magnitude for the calibration star.

As different telescopes and CCD cameras have different response to colors, we used a transformation coefficient to correct the zeropoint based on the color of our source and the response of our system. The transformation coefficients help us determine the true magnitude and color of the star. These transformation coefficients are determined for our system by Professor McGrath, by observing standard star fields over many nights. The equations for correction of zeropoint for each filter are listed below:

$$C_{vi} = (V - I) - T_{vi} \times (v - i) \qquad T_{vi} = 0.9727 \tag{3}$$

$$C_{vr} = (V - R) - T_{vr} \times (v - r) \qquad T_{vr} = 0.9832 \tag{4}$$

$$C_{bv} = (B - V) - T_{bv} \times (b - v) \qquad T_{bv} = 1.0765 \tag{5}$$

$$C_{v} = V - v - T_{v} \times (V - I) \qquad T_{v} = -0.0322 \tag{6}$$

where C is the zeropoint correction. Capital letters are the known magnitude of our star in a given filter and lowercase letters are the instrumental magnitudes from measured value without any zeropoint. T are the transformation coefficients. The result for each zeropoint C with corresponding color or color index, the apparent magnitude, and instrumental magnitude of calibration star is shown in the Table 2.

Table 2. The result of the color indices and V magnitude of the calibration star Tycho 3162-1348 and the zeropoint C with corresponding color or color index.

Color or Color Index	Apparent Magnitude or Color Index	Instrumental Magnitude or Color Index	Transformation Coefficient	Zero Point Correction, C
V-I	0.95	-0.09	0.9727	1.0415
V-R	0.50	0.57	0.9831	-0.0654
B-V	1.04	1.31	1.0765	-0.3702
V	10.12	-12.06	-0.0322	22.2107

We then performed the photometry to calibrate the colors and magnitudes and calculate proper errors on the magnitudes of the stars in the cluster which was automated.

To correct interstellar extinction, we used visual extinction coefficient, A_V=0.39 (Warren & Robinson 2008), and determine the color excess correction for each of the colors(E(B-V)), (E(V-I)), (E(V-R)) with following equations (Mathis, 2000):

$$E(B-V) = 0.32A_V \tag{7}$$

$$E(V-I) = 0.40A_V \tag{8}$$

$$E(V-R) = 0.15A_V \tag{9}$$

The filter wavelengths have been converted from the Johnson system to the Cousins system by McGrath (2019). This assumes that the extinction is solely due to interstellar dust within our galaxy along the line of sight to the cluster and ignores any extinction intrinsic to the cluster itself. We also did not make any correction to the color excess for the intrinsic color of stars.

With $A_V = 0.39$ and the distance d = 1300pc (Warren & Robinson 2008), we calculate the absolute magnitude M_V of the stars in the cluster with the following equation:

$$M_V = V - 5log(d) + 5 - A_V \tag{10}$$

Then apply the color excess correction to the experimentally measured color indices with the following equations:

$$(B - V)_o = (B - V) - E(B - V) \tag{11}$$

$$(V - I)_o = (V - I) - E(V - I) \tag{12}$$

$$(V - R)_o = (V - R) - E(V - R) \tag{13}$$

With the found values, we made "observer's H-R diagrams" plotting M_v(the absolute magnitude) versus $(B\text{-}V)_o$, M_v versus$(V\text{-}R)_o$, and M_v versus $(V\text{-}I)_o$ with reasonable x and y data range. To make it easier to see the overall trends, we restrict the stars we plot to the central region of the detector, where the cluster is densest and exclude values where photometry errors are larger than 20% in flux (0.20 in magnitude) which helps clean up the plot and eliminate the stars that do not belong to the cluster. Besides, we also create a H-R diagram of apparent magnitude V versus $(B\text{-}V)_o$.

Results and Discussion

The observer's H-R diagram of M_v versus $(B\text{-}V)_o$ is shown in figure 3 and the H-R diagram of M_v versus $(V\text{-}R)_o$ is shown in figure 4. For both figures, we chose to have three isochrones as they all fit pretty well and show the range of the result.

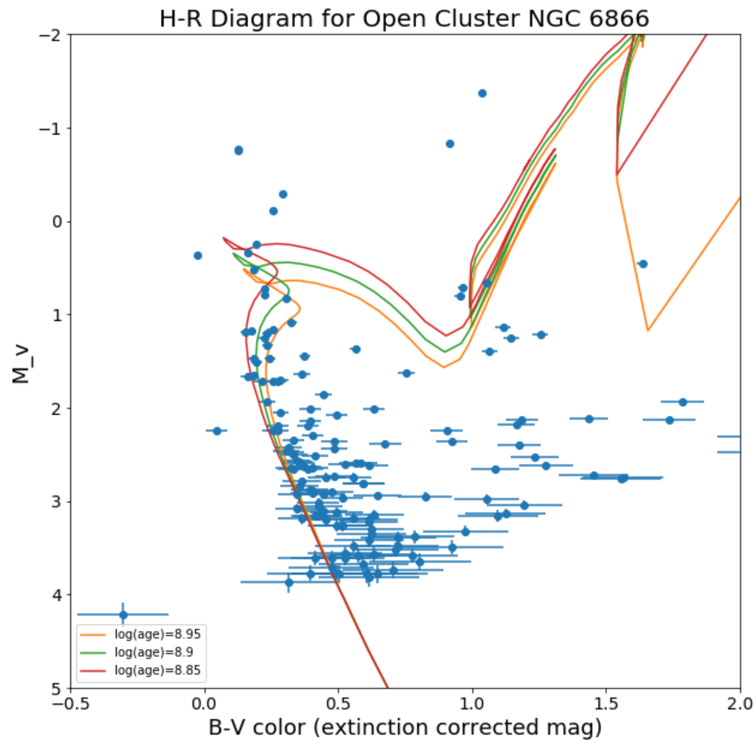

Figure 3. The observer's H-R diagram of M_v versus $(B\text{-}V)_o$ with 3 isochrones. The turn-off point has a spectra type A5 or F0 and the age of the cluster is between $10^{8.85}$ years to $10^{8.95}$ years. Most main sequence stars are on the isochrones and there are some protostars on the right bottom area and some giants or super giants on the right top area.

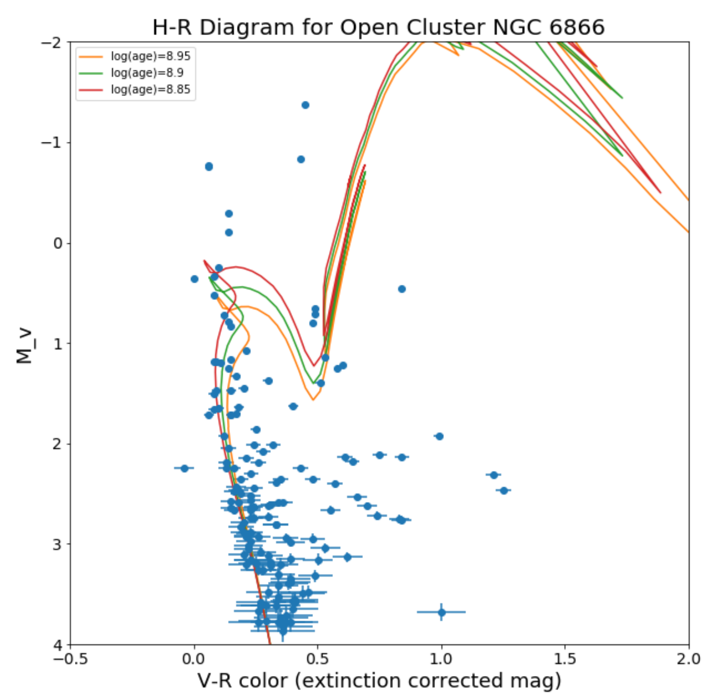

Figure 4. The observer's H-R diagram of M_v versus $(V-R)_o$ with 3 isochrones. The turn-off point has a spectra type A5, F0 or F5 and the age of the cluster is between $10^{8.85}$ years to $10^{8.95}$ years. Most main sequence stars are on the isochrones and there are some protostars on the right bottom area and some giants or super giants on the right top area of the isochrones.

From the H-R diagram of M_v versus $(B-V)_o$, we can observe the most main sequence stars fall on the isochrones near the bottom of the graph. There are some protostars moving towards the main sequence stars. Most stars are on the main sequence. There is small number of giants and super giants which are located on the top right area on the graph as they have much higher luminosities. Those on the left of the isochrones are most likely to be foreground stars. The main sequence turn-off point locates between $0<M\_v<0.5$ and $0.1<B-V<0.4$ which indicates the spectra type A5 or F0 according to Bessell (1990).

From the H-R diagram of M_v versus $(V-R)_o$, we can observe the main sequence stars fall on the isochrones near the bottom of the graph as well but with a narrower distribution range horizontally. There are also some protostars moving towards the main sequence stars with narrower errors. Most stars are still on the main sequence. Those on the left of the isochrones are most likely to be foreground stars. The graph also indicates a small number of giants and super giants after the turn-off point which locates between $0<M\_v<0.5$ and $0<V-R<0.3$. This shows that the spectra type may be A5, F0 or F5 according to Bessell (1990).

For both graphs, a small number of the main sequence stars are not on the isochrones or does not fit into the theoretical main sequence. This may be caused by the fact that when we correct the absolute magnitude, we assume that the extinction is solely due to interstellar dust within our galaxy along the line of sight to the cluster and ignores any extinction intrinsic to the cluster itself. This may lead to underestimation of the absolute magnitude of some stars.

Comparing the two H-R diagrams we got, they agree on the spectra type and the sepctra type at the turn off point is most likely to be F0 combing the two graphs. From the two graphs' turn-off points, we estimate the age of the cluster falls between $10^{8.85}$ years to $10^{8.95}$ years. Comparing to the published value $10^{8.75}$ years (Warren & Robinson 2008), 813$\pm$50 million years which is around $10^{8.91}$ years (Z.F. Bostanci et al. 2018), and $10^{8.85\pm0.10}$ years (Janes et al. 2014), the age we measured can be considered as accurate.

The observer's H-R diagram of V magnitude versus B-V is shown in Figure 5. We compared this figure with published graph of V magnitude versus B-V and they show similar distribution of the stars (Z.F. Bostanci et al. 2018). As we have a much wide range of B-V as the x-axis in our graph, compared to the published graph, we may show more protostars which are still on the process of moving to the main sequence.

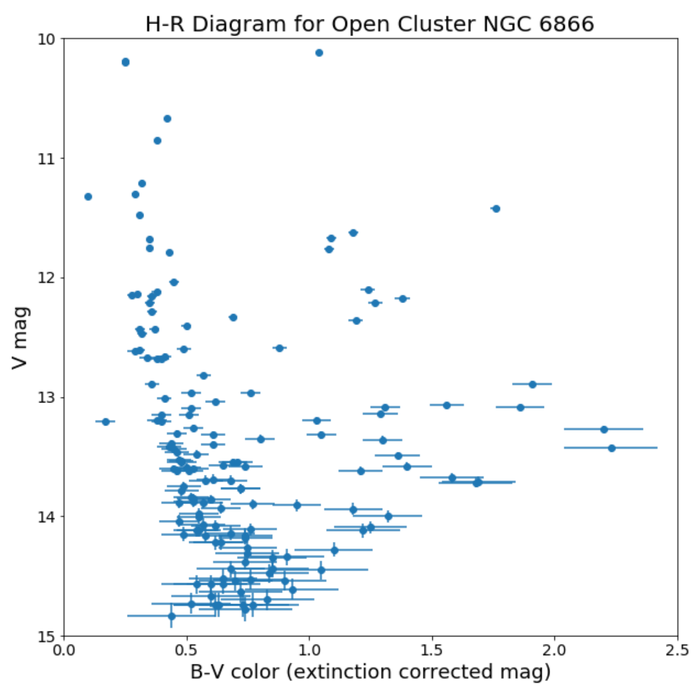

Figure 5. The observer's H-R diagram of V magnitude versus $(B\text{-}V)_o$.

Conclusion

In conclusion, we performed photometry on the stars of the cluster NGC 6866 and produced the HR diagram of M_v versus $(B-V)_o$, M_v versus$(V-R)_o$, and M_v versus $(V-I)_o$. From the diagram of M_v versus $(B-V)_o$ and M_v versus$(V-R)_o$, we deduced the spectra at the turn-off point to be F0. The age of the cluster deduced from the turn-off point is between $10^{8.85}$ years to $10^{8.95}$ years which is compared to the published values and it is considered to be accurate. We also produced a diagram of apparent magnitude V versus $(B-V)_o$ and compared it with the published diagram. They show the similar distribution of the stars which indicates that our measure meets the previous result. The overall result of our investigation meets the previous data and it can be further improved if we can include the extinction intrinsic to the cluster itself when deducing the absolute magnitude and color indices.

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