NPHY 3rd Year Practicle

HR-Diagraml

Determining ages and distance of clusters NGC2243 and NGC6231 using HR-diagrams

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1 Abstract

The aims of this report is to determine the ages and distance of two clusters , NGC 2243 and NGC 6231. We used solar metallicity for cluster NGC6231 and a metallicity of 0.06899 for NGC 2243. Afterwards various isochrones with these metallicities were constructed by using an color-magnitude web application. An color magnitude diagram was constructed using the Visual magnitude and the color index (B-V) of all the isochrones. These isochrones were plotted onto the cluster data, and shifted around to compensate against interstellar reddening. The ages were determined by adjusting the isochrone's turnoff points, to match were the cluster diverges from its main sequence line. The estimated age of cluster NGC 2243 is $1e^{10}$ and NGC 6231 is $1e^{7}$. The distance was calculated using the distance modulus equation, cluster NGC2243 was determined to be 559.18 parsec away from earth,with an average apparent magnitude of 18.13 and an absolute magnitude of 9.4. Cluster 6231 was determined to have a distance of 3094 parsec away, using an average apparent magnitude of 15.053 and a absolute magnitude of 2.6.

2 Introduction

The cosmos is a still a mystery to us, but by studding the objects found within we can try to understand its origin and where it all began. The objects that helps us the most are stars, since we can determine their age by comparing various key parameters like colors and magnitudes or using stellar evolutionary models.

Stellar evolutionary models visualize how stars change over time. The stellar evolutionary is as follows, protostars are formed from molecular clouds (nebula's) that compressed due to gravitational pull to the center. This newly formed star emits its own light that is created through nuclear fission of Hydrogen within its core. This star lives for millions of years until it collapses into a supernova, which releases some of their mass back into interstellar space, which in turn causes the creation of a new star. (NSO, 2022). The abundance of elements that are left over after a star is created (heavier elements than Hydrogen and Helium) are referred to as the metallicity of that star, and this value can be used to estimate the age of a star by comparing it to the known metallicity of our sun (Spoo et al., 2022).

There are billions of stars in space, when stars group together to form a semicircular formation, we call it a cluster. There are two main types of clusters namely, open (galactic) clusters and globular clusters. The type of cluster depends on the number of contained stars and its shape. Open clusters usually contain about 100 stars and has an unsymmetrical shape, whereas globular clusters have hundreds of thousands of stars, closely packed in a symmetrical, spherical shape (Chaisson, 2022).

Open (galactic) clusters are a loosely bound gathering of young stars that moves within its own cosmic cloud (Whitt, 2020). They can contain a range of stars with different ages, but they are unstable since they don't have central mass keeping them together, therefore the stars may disperse after time. They can recognized as a concentration of stars in one area of the sky, therefore it is possible to see some clusters without instruments. The Big Dipper constellation is part of the Ursa Major Moving Group open cluster (Whitt, 2020).

Astronomers often use a plot called the Hertzprung-Russell (H-R) diagram. It compares the temperature or color index of the star against its luminosity (intrinsic brightness) (Michigan, 2019). The HR diagram is shown below (1), from this diagram there are four main classifying groups for a star or cluster. A star with a certain brightness can only lie within a certain range of colors, consequently a star with a certain color could only have a certain range of brightness. After numerous research it was concluded that the HR-diagram is a snapshot of the evolutionary states of stars (Aavso.org, 2014). Stars are therefore referred to based upon their position in the HR-diagram. The color index of the star is determined by subtracting the magnitude from two filters. This difference is called the B-V color index and the value reflects properties of the star. The smaller the index, the hotter the star (more blue) and vise versa (Uiowa.edu, 2017).

A star that is still burning Hydrogen in their core is classified as a main sequence star, and depending on their age they can be sub-dived into pre- and post-main sequence stars. Stars can evolve beyond the main sequence if their core has been converted into helium and temporally stopped nuclear reactions, this is referred to as the turnoff point.These stars have to change physically to compensate the stop of reactions, and this results in expanding its diameter, increasing brightness and lowering temperatures, thus it creates a red giant, that lies on the red giant branch (Aavso.org, 2014). Since this turnoff point indicates when the star is leaving the main sequence, it can be used to estimate the age of the cluster. This is done by constructing various stellar isochrones (same age) of the cluster's metallicity and finding the best fitting isochrone that follows the clusters data.

The observed luminosity of a star or cluster is not the actual luminosity of said cluster, since some of its photons are either absorbed or reflected by interstellar dust. Short wavelengths, which is the color blue, are the most affected by these particles, therefore the stars appear dimmer and redder than it should. This phenomenon is known as interstellar reddening and must be corrected when analyzing data (Swin.edu.au, 2022). This correction is made by subtracting the actual color index from the observed color index of the star, and this is called the color excess.

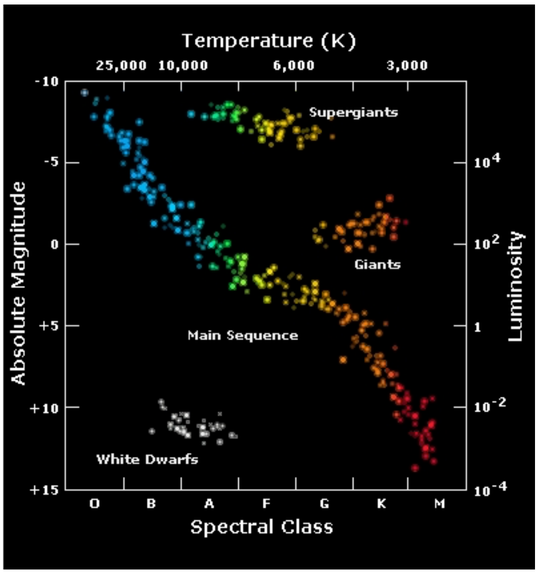


Figure 1: *This is an HR diagram, which shows how different type of stars relate to each other. It also shows the relationship between luminocity and temperature. This image was obtained from Uiowa.edu (2017)*

The two open clusters that will be observed throughout this report is New General Catalogue (NGC) 2243 and NGC 6231. NGC 2243 is part of the Canis Major constellation, and is visible from the southern hemisphere. This cluster consists of 28 stars and has an average magnitude of 10.12 with the Blue band and 9.4 in the Visual band (Theskylive.com, 2013). NGC 6231 is a bright open cluster in the Scorpius constellation and is commonly known as the 'Northern Jewel Box'. It consists of 5,700 to 7,500 pre-main-sequence stars and has a combined magnitude of 2.6. This cluster is visible without an instrument and its center consists of several blue-white super-giant stars. This cluster is estimated to be 3.2 million years old and 1 590 parsecs away from us (Reis, 2018).

There air two aims for this report, the first aim is to find estimate the age from a given metallicity of two globular clusters. The second aim is to determine the distance of both clusters.

3 Method

The two clusters used throughout this report is NGC 2243 and NGC 6321. We were given two data sets each containing the apparent magnitude of the V-filter and the magnitude difference of the Blue and Visual filters (B-V) of both clusters, which is the colour index of the cluster.

From this data we constructed a colour-magnitude (CM) diagram which will be used to estimate the age of the cluster with a certain metallicity.

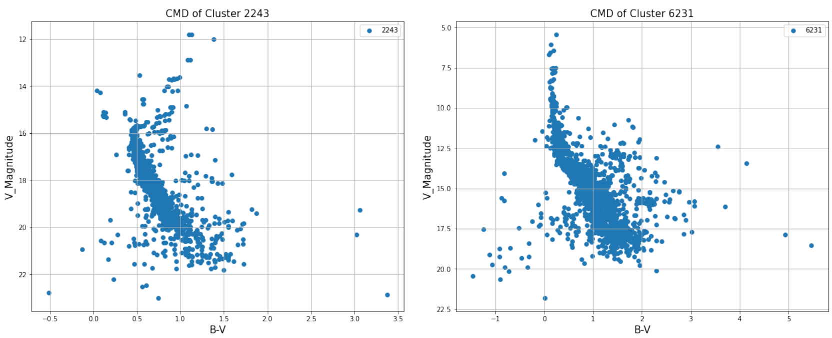


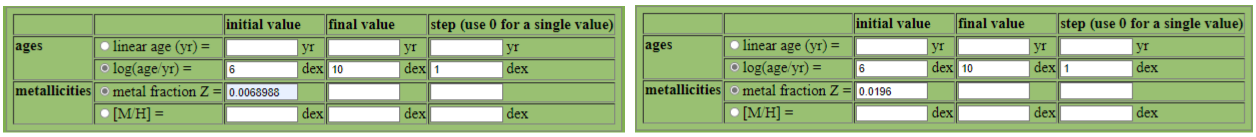
Figure 2: *The CM-diagrams of both clusters.*
Left: cluster 2243, Right: cluster 6321

To achieve our objective we used a CM diagram website (Inaf.it,2014). From the default options we only changed the circumstellar dust to no dust for both star types and the ages/metallicities tabs. For both stars we wanted an age range from $1e^6$ to $1e^{10}$. These changes can be seen in figure 9.

To determine the metallicity of a cluster, we need the metallicity of our solar system, which is $Z_0 = 0.0196$, then by using the following equation we can determine the metallicity:

$$[\frac{M}{H}] = log(\frac{Z}{Z_0})$$

For cluster NGC6231 we used solar metallicity, and for cluster NGC2243 we were given the $[\frac{M}{H}]$ = -0.44, thus the metallicity used was 0.006899.



		initial value	final value	step (use 0 for a single value)
ages	linear age (yr) =	yr	yr	yr
	log(age/yr) =	6 dex	10 dex	1 dex
metallicities	metal fraction Z =	0.0068988		
	[M/H] =	dex	dex	dex

		initial value	final value	step (use 0 for a single value)
ages	linear age (yr) =	yr	yr	yr
	log(age/yr) =	6 dex	10 dex	1 dex
metallicities	metal fraction Z =	0.0196		
	[M/H] =	dex	dex	dex

Figure 3: *The value changes for our clusters, with a age range form 5 to 10*
Left: cluster 2243, Right: cluster 6321

The CM diagram site gives us a data file with various columns, however we are only interested in the Visual- and Blue filter magnitudes columns. From these two columns we can determine the color index of the cluster, by subtracting the Visual from the Blue magnitude (B-V).

Afterwards the isochrome CM diagram is plotted ontop of the given data. However the cluster data must be shifted until it resembles a isochrome graph. This is then the estimated age of the cluster.

For the second aim of the report we use the distance modulus equation to determine the distance of the cluster:

$$(m - M) = 5log(\frac{d}{10}) \tag{1}$$

4 Results

4.1 Cluster 2243:

For this cluster we used a metallicity value of 0.006899 with the ages ranging from $1e^6$ to $1e^{10}$. The following graph is the isochromic CM diagram with this metallicity plotted over the figure 2

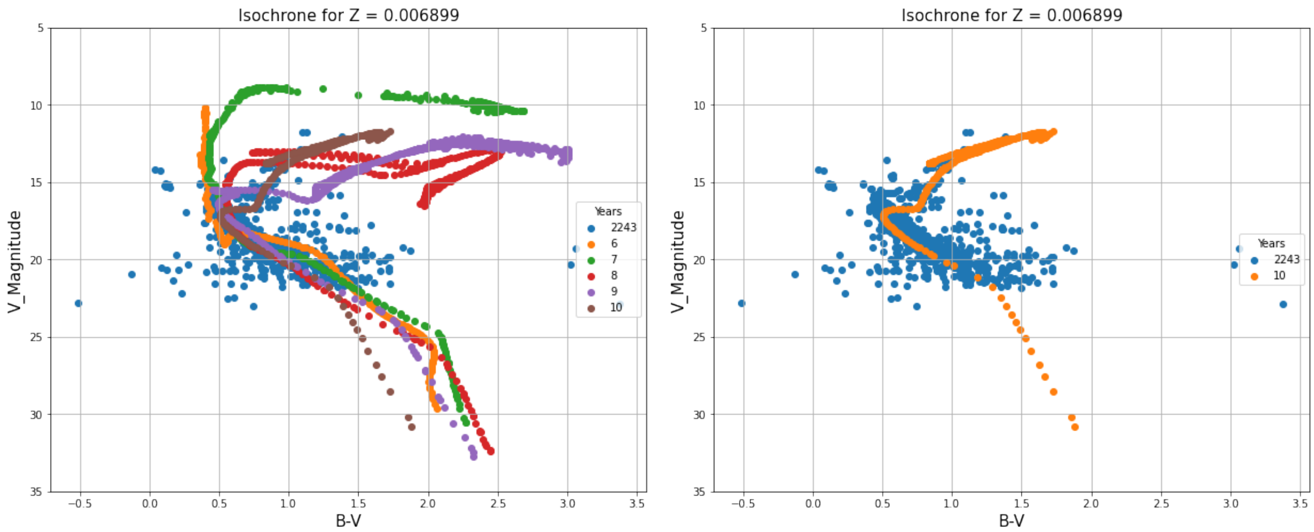


Figure 4: *HR diagram for cluster 2243 with a metallicity of 0.006899. The cluster data was altered with -13 for the V magnitude and +0.3 on the color axis. The best-fitting isochrone for this cluster is shown estimated to be* $1e^{10}$

From the left CM diagram we can easily see that the main sequence of ages 6,7 and 8 doesn't fit the data for cluster NGC 2243. With further investigation we can observe that age 10's main sequence follows the cluster more realistic, therefore we can assume the cluster is $1e^{10}$ $(10e^9)$ years old.

To determine the distance of this cluster, used the distance modulus equation:

$$(m - M) = 5log(\frac{d}{10}) \tag{2}$$

,where m_V is the average apparent magnitude of the given cluster data, with a value of 18.13, M_V is the absolute magnitude of the cluster with a value of 9.4.

$$(18.13 - 9.4) = 5log(\frac{d}{10})$$

$$d = 559.118 \quad parsec$$

4.2 Cluster 6231:

For this cluster we used solar metallicity which has a value of 0.0196, with the ages ranging from $1e^6$ to $1e^{10}$. The following graph is the isochromic CM diagram with this metallicity plotted over the figure 2:

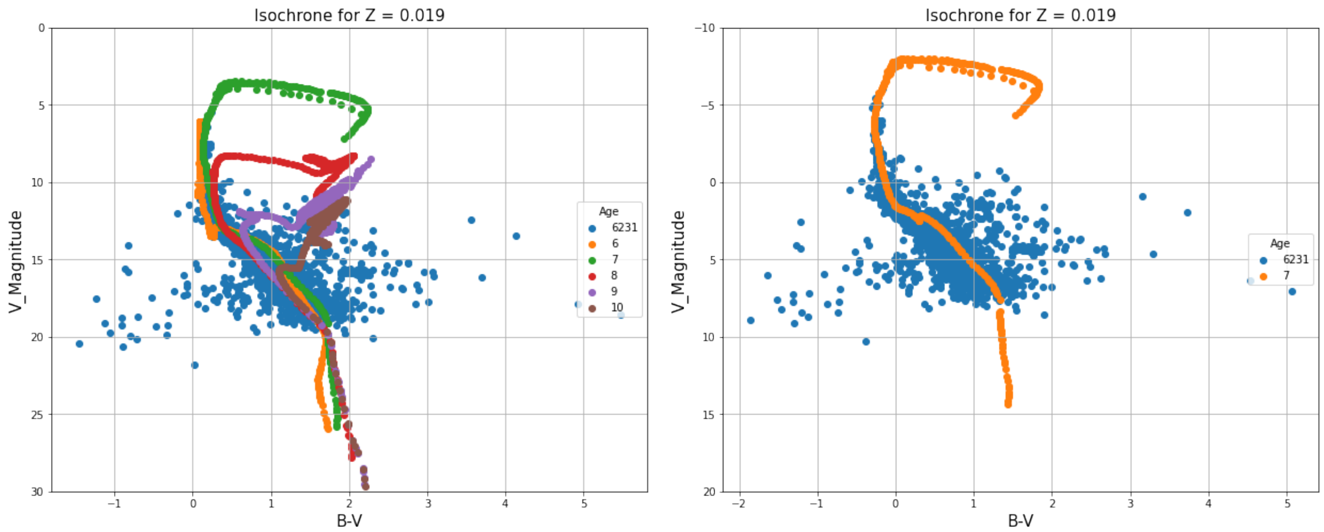


Figure 5: *HR diagram for cluster 6231 with a metallicity of 0.0196. The cluster data was altered with -11.5 for the V magnitude and by +0.4 for the color. The best-fitting isochrone for this cluster is shown estimated to be* $1e^7$ *or* $10e^9$.

From the left CM diagram in the above figure we can easily see that the main sequence of ages 10,9 and 8 are too short, therefore the cluster is $1e^7$ ($10e^6$)years old. However, with further investigation we can observe that age $1e^7$'s main sequence follows the cluster more realistic. Therefore the estimated age for this cluster is $1e^7$ years old.

To determine the distance of this cluster, used the distance modulus equation (2), where m_V is the average apparent magnitude of the given cluster data, with a value of 15.053, M_V is the absolute magnitude of the cluster with a value of 2.6.

$$(15.053 - 2.6) = 5log(\frac{d}{10})$$

$$d = 3094.657 \quad parsec$$

5 Discussion and Conclusion

As mentioned in the introduction there are various ways to estimate the age of a cluster using an HR diagram. In this report we determined it by graphing various isochrones with the same metallicity as our clusters on the same figure. Before we discuss the results of our clusters, let's discuss how the age of a cluster is related to its turnoff point by using the following figure:

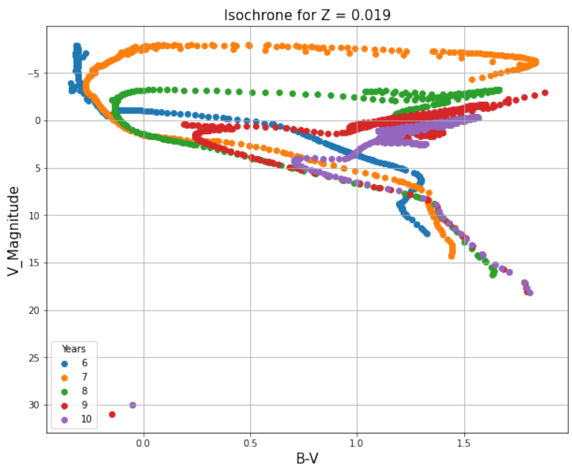


Figure 6: *The comparison between different ages with a constant metallicity of 0.019*

From the graph above we observe that a cluster with age $1e^6$ is beginning to reach its turnoff point around color index -0.3 whereas a cluster with an age $1e^{10}$ already has an turnoff point at color index 0.6. This shows that the older a star is, the cooler it gets, therefore the color index is dependant on the age of the cluster, with the same metallicity. This corresponds to what figure 1 shows us. We also see that younger stars have a brighter magnitude in the Visual band.

The metallicity of a star is an indication of the abundance of elements other than Hydrogen and Helium. In the following figure (7) various metallicities of the same age were graphed on the same axis:

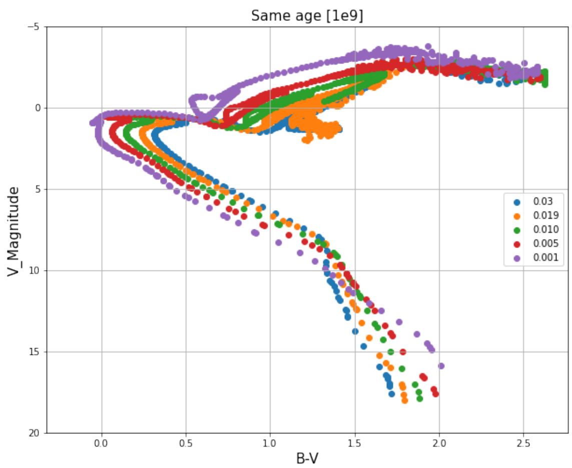


Figure 7: *The comparison between different metallicities with a constant age of* $1e^9$.

By observing figure 7 we see that a star with a metallicity of 0.03 has a turn off point around the color index value 0.4, which is about 6500K. However a star with a metallicity of 0.001 has a turnoff point at color index value 0, which is around 9000 Kelvin. With this observation we see that the lower the metallicity value is the smaller the color index becomes, and hotter the star burns.

In this report we wanted to determine the age and estimated distance of clusters NGC2243 and NGC6231. The isochrone figure for NGC 2243 with metallicity of 0.006899 is shown in figure 4. Before we could estimate the age, the isochrone data had to be shifted until it fits the data, the original (not shifted) figure is shown in addendum A, section 8. The isochrones color index was adjusted by approximately +0.6 to compensate for interstellar reddening and the Visual magnitude by approximately +15, so that the turnoff points match the given data of the clusters. After shifting the isochrones to better fit the cluster data, the age of the cluster was estimated to be $1e^{10}$ years old with a turnoff point around 0.5. This turnoff point represents a temperature of about 6300 Kelvin, thus a spectral class G. The distance of this cluster was determined to be 559.188 parsec away, however according to Ford (2018) the cluster is 4 500 parsecs away. This difference can be because I didn't take interstellar reddening into consideration.

The isochrone figure for NGC 6231 with metallicity of 0.0196 is shown in figure 5. The original (not shifted) isochrone figure of this cluster is shown in addendum A ,section 8. The isochrones color index was adjusted by approximately +0.4 to compensate for interstellar reddening and the Visual magnitude by approximately +12, so that the turnoff points match the given data of the clusters. After shifting the isochrones to better fit the cluster data, the age of the cluster was to be $1e^{7}$ years old, however it hasn't reached its turnoff point yet. The estimated turnoff point is at color index 0, which represents a temperature of 9100 Kelvin and a spectral class A. The distance of this cluster was determined to be 3094.66 parsec away, however according to Ford (2018) the cluster is 1 243 pc away. This difference can be because I didn't take interstellar reddening into consideration.

By comparing the two clusters, we can see that they differ by an age of $1e^{3}$, this difference indicates that not all star clusters are are born at the same time, and thus proves stellar evolution. This can also be seen with their metallicities, cluster NGC 2243 has a lower metallicity ,thus it has absorbed more of the abundance elements than cluster NGC6231.

6 Conclusion

The main objective of this report is to verify that it is possible to estimate the age of a cluster, with only a CM diagram and its metallicity. Throughout this report we used the Visual magnitude and color index of two clusters namely, NGC 2243 and NGC 6231. We were given the Observed color-magnitude data and used this to estimate their age, by using a metallicity of 0.06899 for cluster NGC2242 and solar metallicity (0.019) for NGC6231. With these metallicities we constructed various isochrones of color-magnitude diagrams and graphed them on top of the given CM diagrams.

The best fitting isochrone for cluster NGC2242 was estimated to be $1e^{10}$ years that is approximately 559.118 parsec (1.8 kly) away from us. The best fitting isochrone for cluster NGC6231 was estimated to be $1e^{7}$ years and is approximately 3094.65 parsec (10 kly) away from us. This difference indicates that stellar evolution is an ongoing process, therefore we can estimate the age of the cosmos if we find the oldest star clusters.

7 Bibliography

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8 Addendum

The following figure is the original CM-diagram of both clusters with an isochrone range between $1e^6$ and $1e^{10}$:

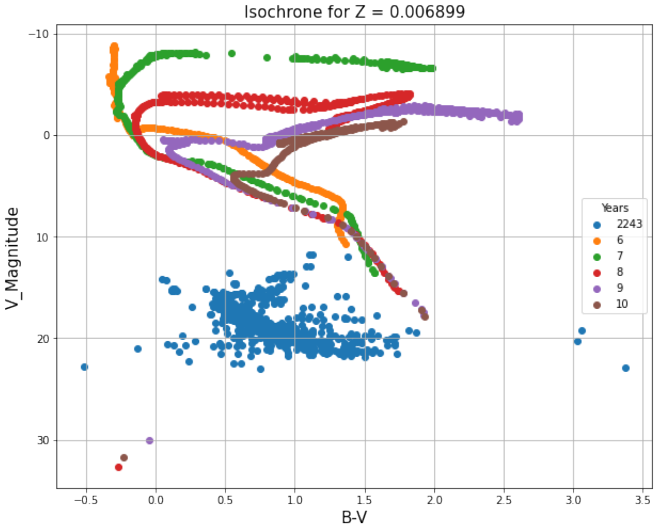

Figure 8: *The original color magnitude diagram for cluster 2243 with metallicity of 0.006899, before the compensation of interstellar reddening*

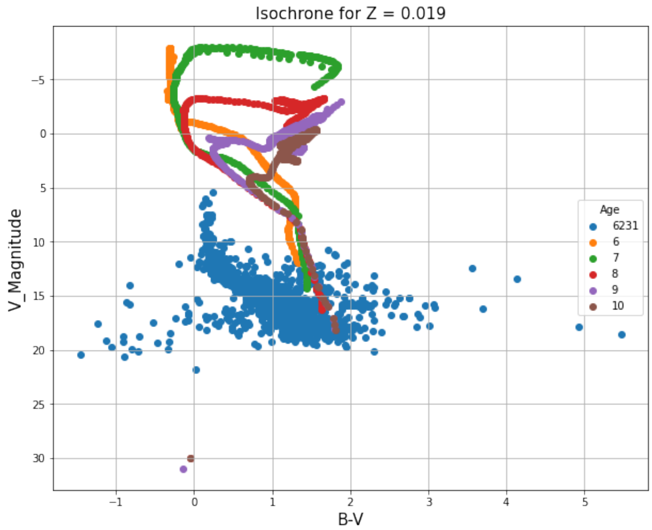

Figure 9: *The original color magnitude diagram for cluster 6231 with metallicity of 0.0196, before the compensation of interstellar reddening*