Lab Report 5

More on Stellar Clusters, the Hertzsprung-Russell Diagram, Main Sequence Fitting and Evolutionary Tracks of Stars

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Contents

1 Experiment (IX): Investigating the HR diagram for the Pleiades and Hyades Clusters with Hipparcos Catalog, and Main Sequence Fitting.

We plot the HR diagram for the Pleiades and Hyades clusters using the Hipparcos catalog. We use the stars that are found within 2 degrees of the center of the Pleiades cluster, which turn out to be 56 stars. We use the stars within 8 degrees of the center of the Hyades cluster, and we limit ourselves to 100 stars. We use the Hipparcos catalog to obtain the apparent magnitudes and the B-V color of the stars. We plot the magnitudes (y-axis flipped since brighter stars have lower magnitudes) against the B-V color (x-axis) to generate the HR diagram for both clusters.

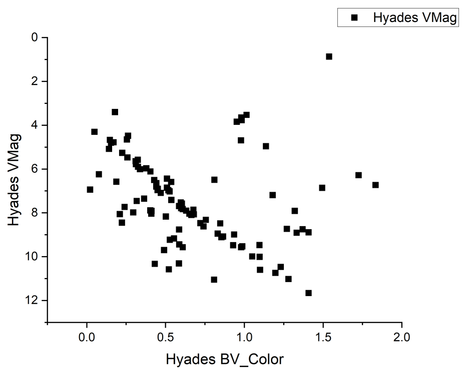

Figure 1: HR Diagram for Hyades Cluster

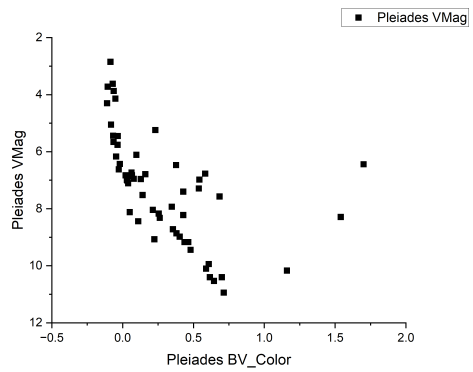

Figure 2: HR Diagram for Pleiades Cluster

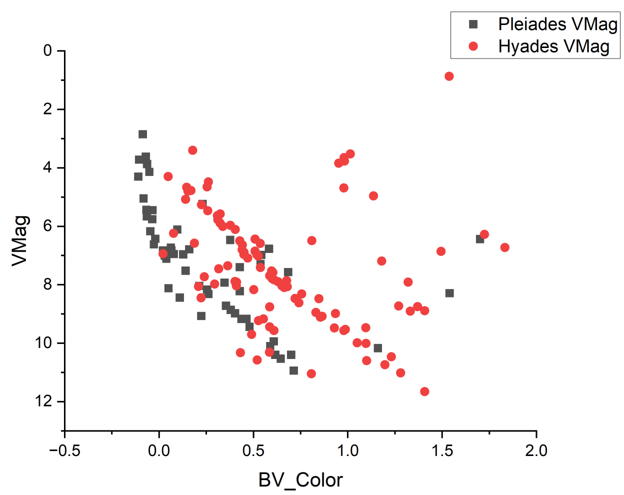

Figure 3: Combined HR Diagram for Pleiades and Hyades Clusters

1.1 Questions

1. **Which cluster older? Why?**
   Answer: The Hyades cluster is older than the Pleiades cluster. This is because many stars in the Hyades cluster have evolved out of the main sequence and went on to the red giant branch.

2. **Which cluster is closer? Why?** Answer: The Hyades cluster is closer than the Pleiades cluster. This is because the stars with the same B-V color in the Hyades cluster as the Pleiades cluster appear to be brighter in the Hyades cluster (have a lower apparent magnitude). This means that the Hyades stars are closer to us than the Pleiades stars.

3. **What does the gap between the two cluster main sequence stars represent?** Answer: The gap between the two cluster main sequence stars represents the difference in distance between the two clusters. The stars in the Hyades cluster are closer to us than the stars in the Pleiades cluster, so they appear brighter (lower apparent magnitude) than the stars in the Pleiades cluster.

4. **Is the number and arrangement of stars in your plots similar to those below? If not, why?** Answer: The arrangement of stars in my plots is similar to those below. The number of stars in my plots is different because I used a different number of stars in the sample taken from the Hipparcos catalog. I used 56 stars for the Pleiades cluster and 100 stars for the Hyades cluster.

We now want to estimate the distance to the Pleiades cluster using the distance to the Hyades cluster. We know that the distance to the Hyades cluster is 46.3 pc [1]. We can use the difference in apparent magnitude between two stars, one in each cluster, with similar B-V color to estimate the ratio between the distances to the two clusters. We use stars with similar B-V colors and on the main sequence, since the HR diagram usually indicates that they would have similar mass and luminosity if they have the same B-V color and fall on the main sequence. We can use the following equation to estimate the distance to the Pleiades cluster:

$$m_2 - m_1 = 5\log_{10}\left(\frac{d_2}{d_1}\right) \tag{1}$$

where m_1 and m_2 are the apparent magnitudes of the two stars, and d_1 and d_2 are the distances to the two clusters. We can rearrange this equation to get:

$$d_2 = d_1 \cdot 10^{\frac{m_2 - m_1}{5}} \tag{2}$$

We use the two following stars to estimate the distance to the Pleiades cluster:

- Star 1: name = HIP 20899, B-V = 0.609, m_1 = 7.83 (Hyades cluster)
- Star 2: name = HIP 17091, B-V = 0.608, m_2 = 9.94 (Pleiades cluster)

We can now plug in the values to get:

$$d_2 = 46.3 \cdot 10^{\frac{9.94 - 7.83}{5}} \approx 122.3 \text{ pc} \tag{3}$$

This value agrees really well with the values given by other experimenters using the Hipparcos catalog. The distance to the Pleiades cluster is estimated to be 120.2 ± 1.9 pc [2]. We can also calculate the percentage error of our result:

$$\text{Percentage error} = \frac{|122.3 - 120.2|}{120.2} \cdot 100 \approx 1.75\% \tag{4}$$

Which is really small, so our approach worked well.
After digging a bit, I found that the value for the distance obtained by the Hipparcos catalog is not very accurate. The true distance to the Pleiades cluster is 136.2 ± 5 pc [3]. The value is very off, and is claimed to be due to systematic errors in the Hipparcos catalog.

2 Experiment (X): A detailed study of King Cobra Open Cluster (Messier 67) and Cluster Age Estimation.

We will now study the King Cobra Open Cluster (Messier 67) and estimate its age. We will use the application by NMSU to estimate the age of the cluster from the turnoff point of the main sequence.

2.1 Choosing Appropriate Stars from the Cluster

The following is the data chart for the 12 chosen stars from the cluster:

M67 Stellar Cluster Stars

#	ID	X (%)	Y (%)	Size (")	V (mag)	B-V (mag)
1	191	81.1	52.8	36	14.34	0.58
2	183	84.4	49.3	40	13.11	0.77
3	271	19.7	85.2	52	12.28	0.48
4	211	28.7	60.2	44	12.98	0.51
5	118	33.5	23.3	52	12.49	0.86
6	121	21.1	24.5	40	13.31	0.49
7	293	20.6	93.2	28	14.87	0.72
8	273	11.4	86.8	28	15.52	0.70
9	272	93.6	83.3	32	14.82	0.63
10	299	59.6	92.7	28	15.27	0.82
11	126	22.4	27.8	28	14.69	0.60
12	147	67.5	36.3	32	14.29	0.50

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Figure 4: Data chart for the 12 chosen stars from the King Cobra Open Cluster (Messier 67)

(a) The solar-type star is #191.

(b) The 2 to 3 stars fainter and bluer than solar are #126,272.

(c) The 2 to 3 stars fainter and redder than solar are #273,293,299.

(d) The 2 to 3 stars brighter and bluer than solar are #121,211,271.

(e) The 2 to 3 stars brighter and redder than solar are #118,183.

2.2 Estimating the Age of the Cluster

The following is the HR diagram for the King Cobra Open Cluster (Messier 67) after the application by NMSU added 400 more stars based on the data chart above:

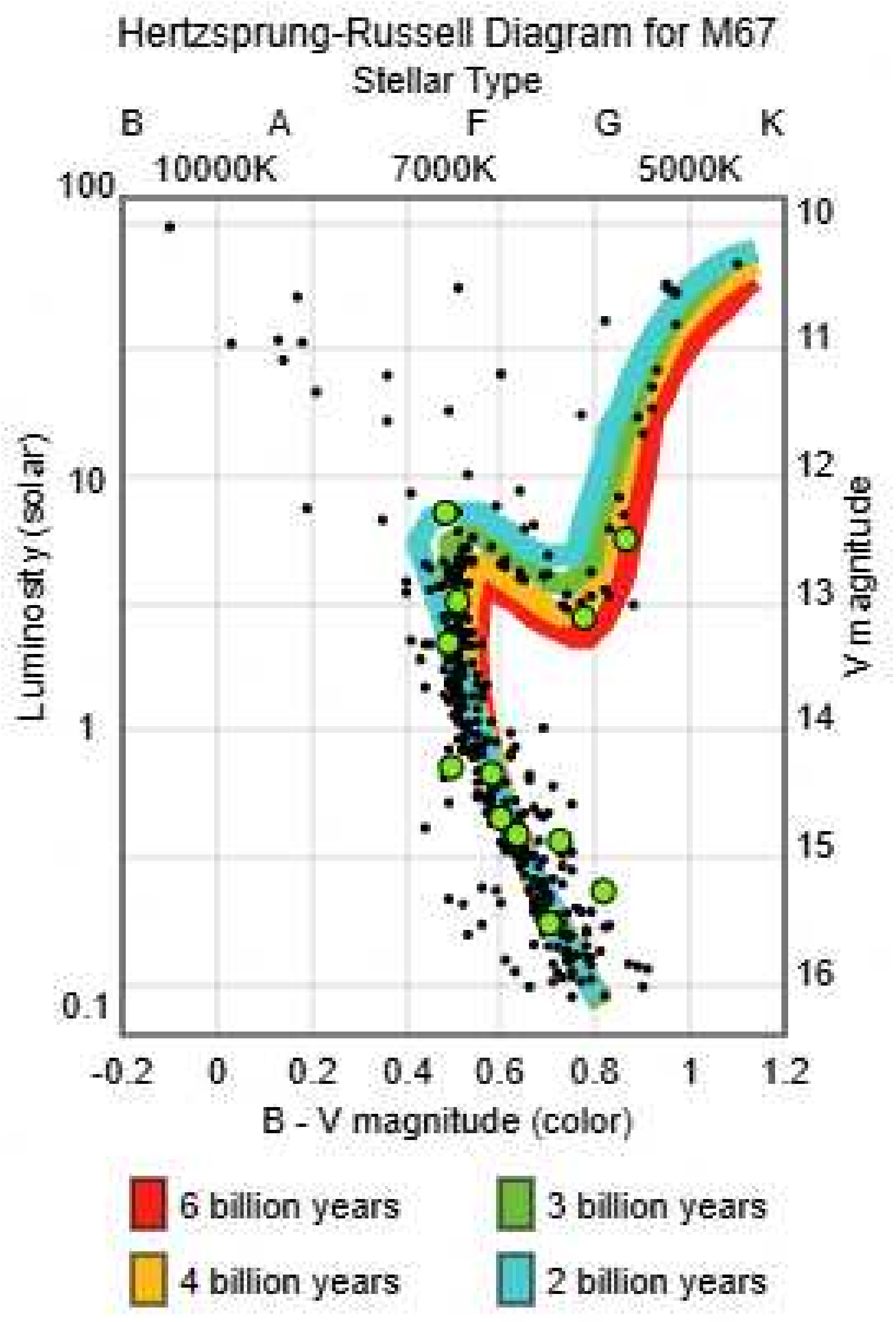

Figure 5: HR Diagram for the King Cobra Open Cluster (Messier 67)

2.3 Sources of Error

1. What happens if an aperture is too small? Where will the associated star appear on the H-R diagram, relative to its correct position?
   Answer: If an aperture is too small, it will not capture enough light from the star, and the star will move down vertically on the HR diagram, making it appear fainter than it actually is.

2. What happens if an aperture is too large? Does it matter whether the extra space is dark sky, or contains a neighboring object? Answer: If an aperture is too large, if there is a neighboring object that is brighter than the star we are trying to measure, the star will appear brighter than it actually is and might move up in the HR diagram. If the extra space is dark sky, it will not affect the position of the star on the HR diagram much.

3. What happens if the aperture is offset from the center of the star? Answer: If the aperture is offset from the center of the star, it will not capture all the light from the star, and the star will move down vertically on the HR diagram if next to it is dark space, making it appear fainter than it actually is. Unless there is a neighboring star that is brighter than the star we are trying to measure, in which case the star will appear brighter than it actually is.

4. What happens if you place an aperture directly between two stars? Answer: If you place an aperture directly between two stars, it will capture light from both stars, and shows two bumps in the counts diagram. Depending on the size of the aperture, it will indicate how much light is captured from each star.

2.4 Estimating the Age of the Cluster

The age of the cluster is estimated to be 3.5 billion years. This estimation is based on the turnoff point of the main sequence which aligns well with the model for the age being 3 billion years. The lower bump however seem to align better with the model for the age being 4 billion years. This is because the lower bump is likely to be the turnoff point for the red giant branch, which is the next stage of evolution for stars after the main sequence. Therefore, an average is made of the two ages to get a final age of 3.5 billion years for the King Cobra Open Cluster (Messier 67). The most recent estimate of the age of the cluster is 3.95 ± 0.15 billion years [3]. This is very close to our estimate.

3 References

[1] - Barbara E. McArthur et al 2011 AJ 141 172. DOI 10.1088/0004-6256/141/5/172
[2] - F. van Leeuwen 2009 A&A 497 (1) 209-242. DOI: 10.1051/0004-6361/200811382
[2] - Guillermo Abramson 2018 Res. Notes AAS 2 150 DOI 10.3847/2515-5172/aada8b
[3] - Reyes, F., Kalirai, J. S., Marigo, P., Saracino, S., & Gossage, S. (2024). A self-consistent age and helium determination of the open cluster M67. Monthly Notices of the Royal Astronomical Society, 532(2), 2860-2875. https://doi.org/10.1093/mnras/stae1650