Photometric Analysis of Messier 39

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Abstract: In this analysis, I investigated the properties and behavior of an open star cluster known as Messier 39. I used photometry and data analysis to examine the cluster and understand its properties, focusing on its Red and Blue filters. Data was acquired using AstroImageJ and further analyzed using Python to convert raw flux values into magnitudes and generate Hertzsprung-Russel (HR) diagrams. My initial findings included analysis of the data, showing important patterns and relationships within the cluster. I conducted advanced experiments, such as manipulating magnitude permutations and applying linear regression models, to gain deeper insights into the characteristics of the stellar population. The results showed consistency with theoretical expectations, emphasizing the importance of thorough data analysis in astrophysical research. Finally, I compared my HR diagram with standard references, confirming the accuracy of my observational techniques and data interpretation. This study underscores the significance of combining various data analysis methods to enhance our understanding of star clusters and their properties.

Keywords: open star cluster, HR diagram, stellar population.

Biography: Hridaya Marasini has expertise in using astronomical datasets. He is the absolute winner of the national astronomy Olympiad in his country and a finalist in the OAAO. He has participated in several summer programs related to astronomy. He conducted this research after years of experience in the field of astronomy research.

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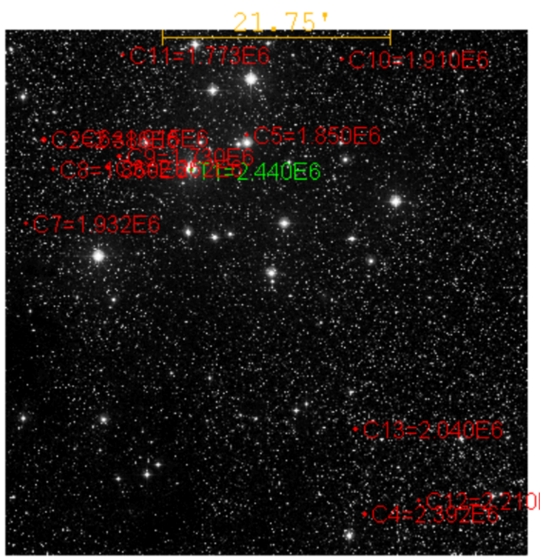
I. Introduction

This study focuses on Messier 39 (M39), an open cluster approximately 824.4 light years away It's apparent magnitude of 4.6, Right Ascension of 21^h31^m, and declination of +48° 26′ [2]. M39 is one of the closest open clusters to Earth and is estimated to be about 200-300 million years old. It contains about 1000 stars and has many main sequence stars like red giants, dwarfs. The cluster's apparent size is 32 arc minutes, making it larger than the full Moon which means it can be best observed with small telescopes and binoculars.

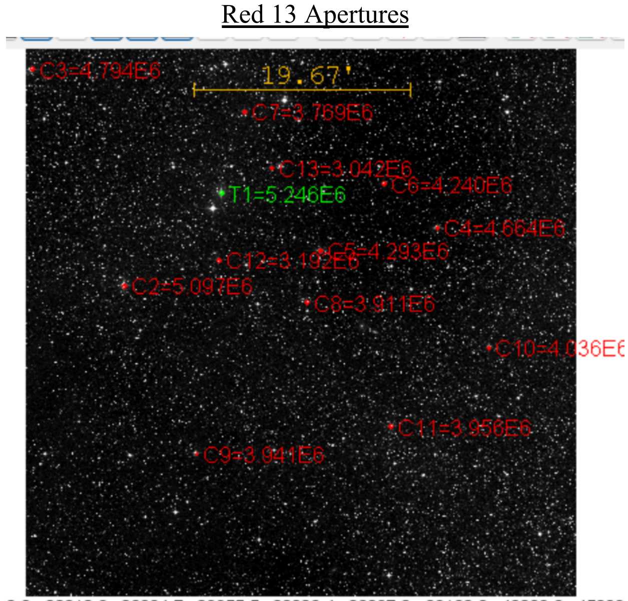
II. Methods

Data for M39 was acquired from the ESO Online Digitized Sky Survey in FITS file format. Multi-aperture photometry was performed using AstroImageJ, initially sampling thirteen of the brightest, non-overlapping stars. Flux data for these stars were extracted and converted to magnitudes using the equation $m=-2.5\log(F/F0)$, where $F0=1000$ for our purposes. This data was used to plot H-R diagrams for both the blue and red filters.

Blue 13 Apertures

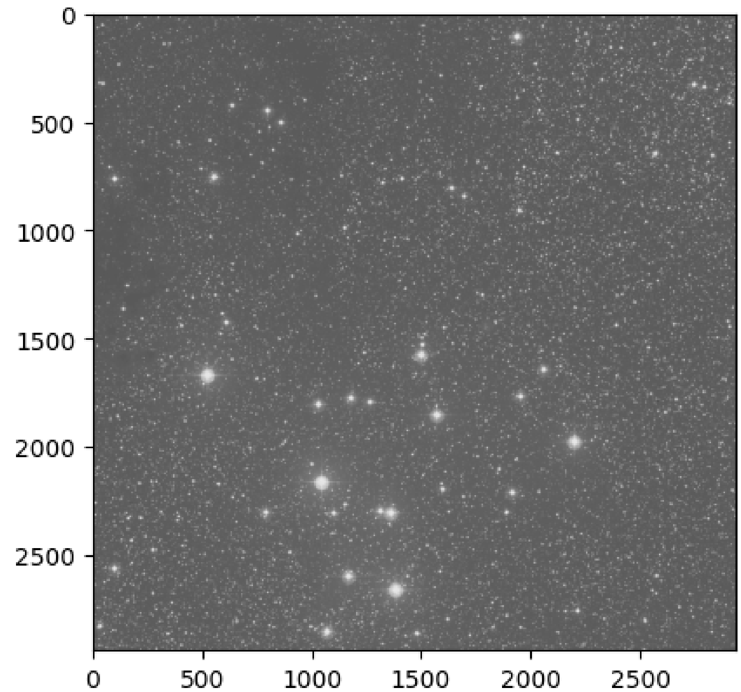


Red 13 Apertures

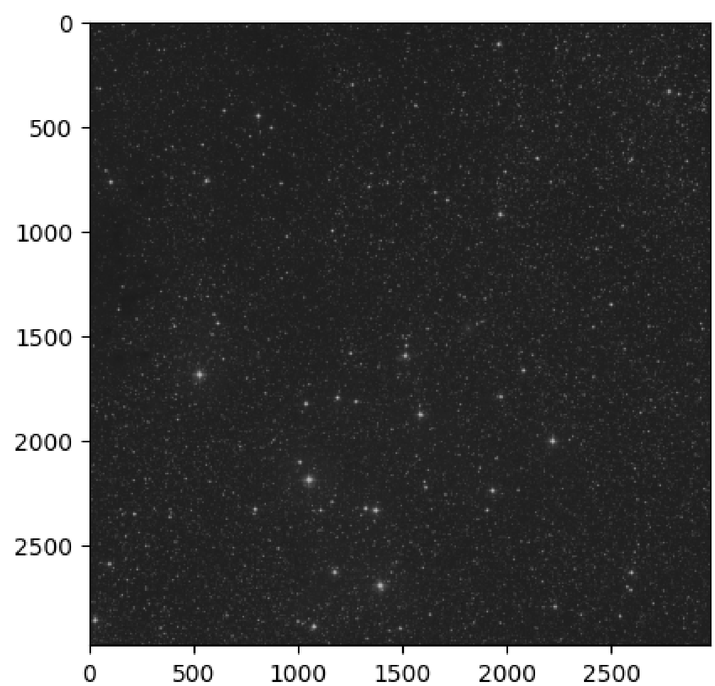


The raw photos through the FITS file was made using python:

<u>Blue Filter</u>



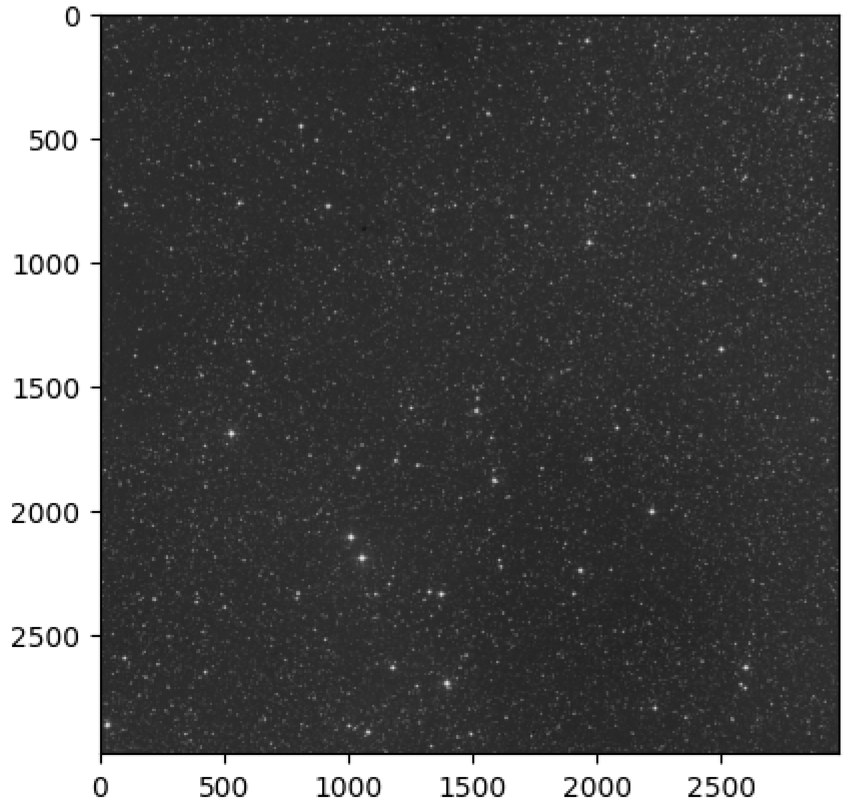
<u>Red Filter</u>



To optimize the accuracy of our results I included data from the Infrared filter. Similar to the process of extracting the fluxes and magnitudes of the blue and red filters, an Infrared FITS file was downloaded from the database ESO Online Digitized Sky Survey. Then, using the multi-aperture photometry tool from AstroImageJ, the measurements of the fluxes of 13 stars were created, by placing the previous apertures from the blue and red filter data. This ensured that we maintained the same sample size and stars as before.

With the use of Python, I also obtained the raw picture of the Infrared FITS file, which only captured around half of the image that the blue and red filters included.

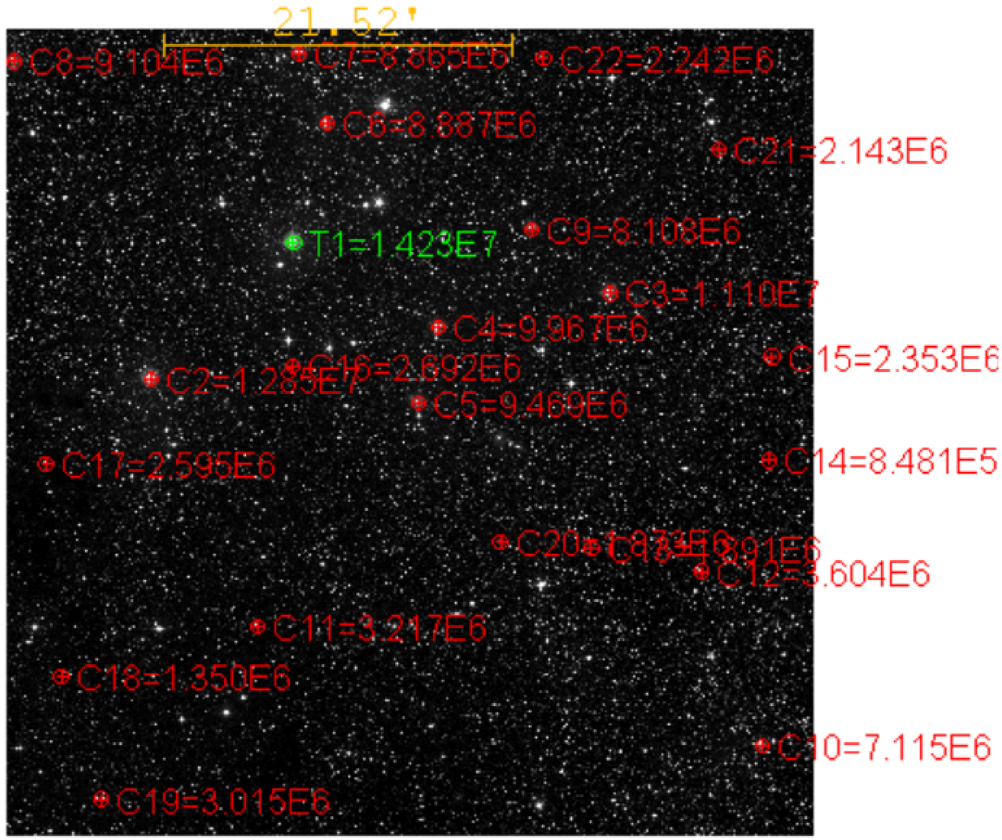
Infrared



Then, using the magnitude equation previously noted, the absolute magnitudes of each star was obtained. This output was then used to plot a H-R Diagram, with the y-axis being the absolute magnitude calculated from infrared data. Similar to the graphs and diagrams created with blue and red filters, the average value of each magnitude and the average magnitude of each star was created with the addition of Infrared data.

After, I resampled our images, this time expanding the second sample size to one including twenty-two stars. This was to account for less luminous stars in M39 that would be significant to the makeup of the cluster alongside the brighter, larger stars. I used the same process of extracting the flux from the table, calculating the magnitude and plotting the stars on an H-R diagram, only on a larger scale.

Blue 22 Apertures



From the initial sample of thirteen stars, flux values were extracted and converted to magnitudes. H-R diagrams were plotted for the blue and red filters, showing significant groupings of stars indicating the presence of hot, blue stars and dimmer red or brown stars.

Given this relationship, I calculated the magnitudes from the original sample size of 13 and using Python, computed the median of the blue filter magnitudes. Then I plotted stars close to the median amount and added a color bar to see if the stellar populations graphed on the H-R diagram could be differentiated by filter (red or blue).

Using Python, we performed various data manipulations and analyses. Linear regression models identified relationships within the data. We extracted flux values for red, blue, and infrared filters and converted them to magnitudes. H-R diagrams were plotted for each filter and the combined data, revealing relationships between magnitudes and stellar properties. Additionally, resampling and permutation analysis of an expanded dataset of twenty-two stars identified patterns and relationships. Linear regression models further explored data fit and correlation.

Machine learning techniques were applied to predict future magnitudes based on existing data. Models were trained on the current dataset to learn patterns and trends. These models enabled the prediction of future values of stellar magnitudes, enhancing our understanding of the data and providing insights for future research.

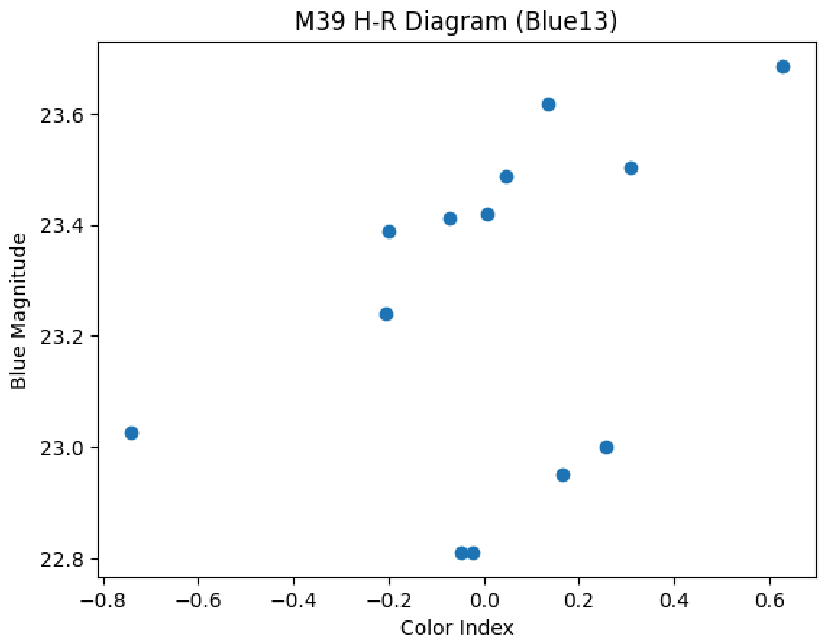
III. Figures and Tables

In my initial sample, I was able to extract the flux value of our stars from T1-C13.

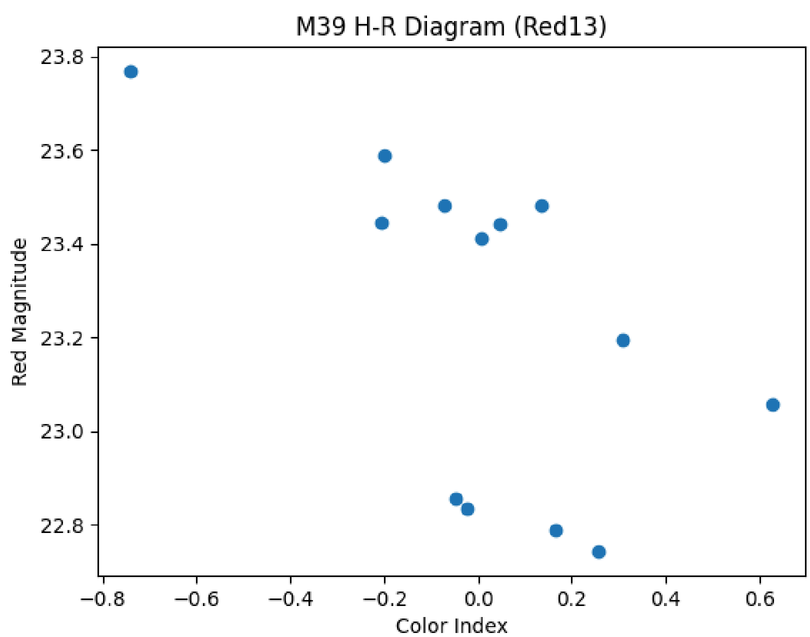
	Red Flux (photons)	Blue Flux (photons)	Uncertainty in Red Flux (photons)	Uncertainty in Blue Flux (photons)
T1	0.1123326183268304	0.100585955720815	6.16677267351E-5	1.32736819346E-4
C2	0.106582397185872	0.1090746359213184	6.23373736985E-5	1.291246057009E-4
C3	0.1101138440485922	0.1028175044700126	6.31905933528E-5	1.265743583684E-4
C4	0.1076042389440193	0.1093705020812832	6.24176853776E-5	1.292014342626E-4
C5	0.0935006227011105	0.0825609540888213	5.79152084966E-5	1.241130762538E-4
C6	0.0833428542047888	0.0856870095236888	5.49443463178E-5	1.195394217873E-4
C7	0.0798768475371538	0.086507447082542	5.45486496986E-5	1.198076769011E-4
C8	0.0846874537469976	0.0830554858531391	5.53858996676E-5	1.181897829846E-4
C9	0.0988407306104304	0.0767937766829012	5.88789608542E-5	1.168376867364E-4
C10	0.0856934523214119	0.0854462814264812	5.54212185761E-5	1.198473129062E-4
C11	0.0832603289751008	0.0788597619842706	5.47470101448E-5	1.164634801166E-4
C12	0.0742839909795159	0.1002481599991523	5.22879711147E-5	1.243745705366E-4
C13	0.0845662805290195	0.0918123107851773	5.50155198139E-5	1.22185786085E-4

Using these values, I created H-R diagram scatterplots. To differentiate between the graphs, I refer to the first two as “Blue 13” (B13) and “Red 13” (R13), based on the filter and sample size. The term “Color Index” refers to the commonly used formula Blue Magnitude - Red Magnitude, which we calculated in Python to produce the graphs.

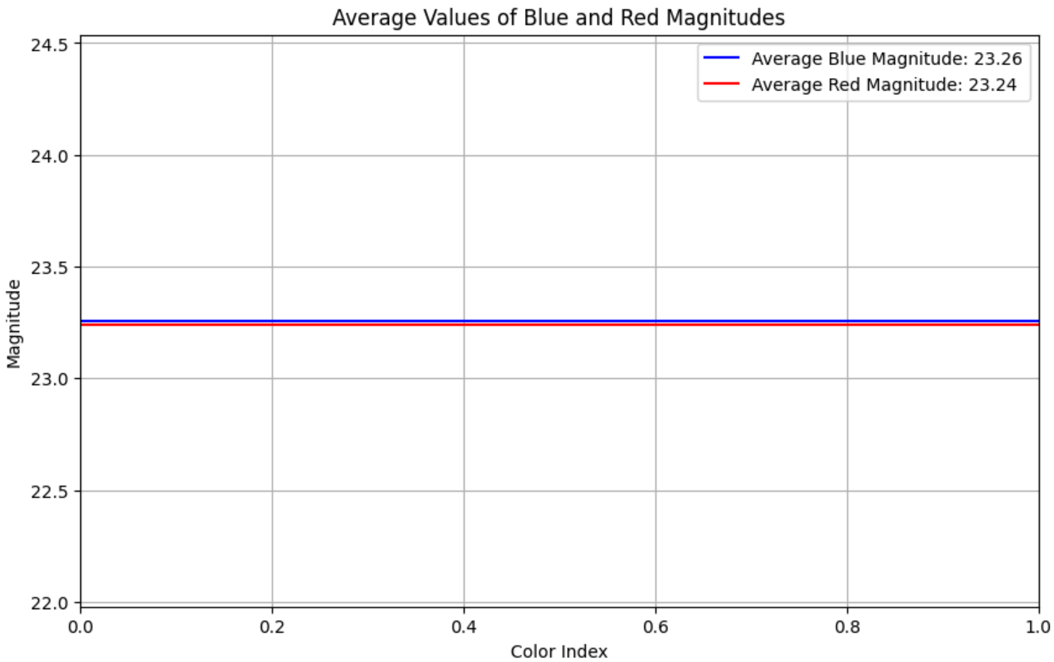
<u>Blue 13</u>



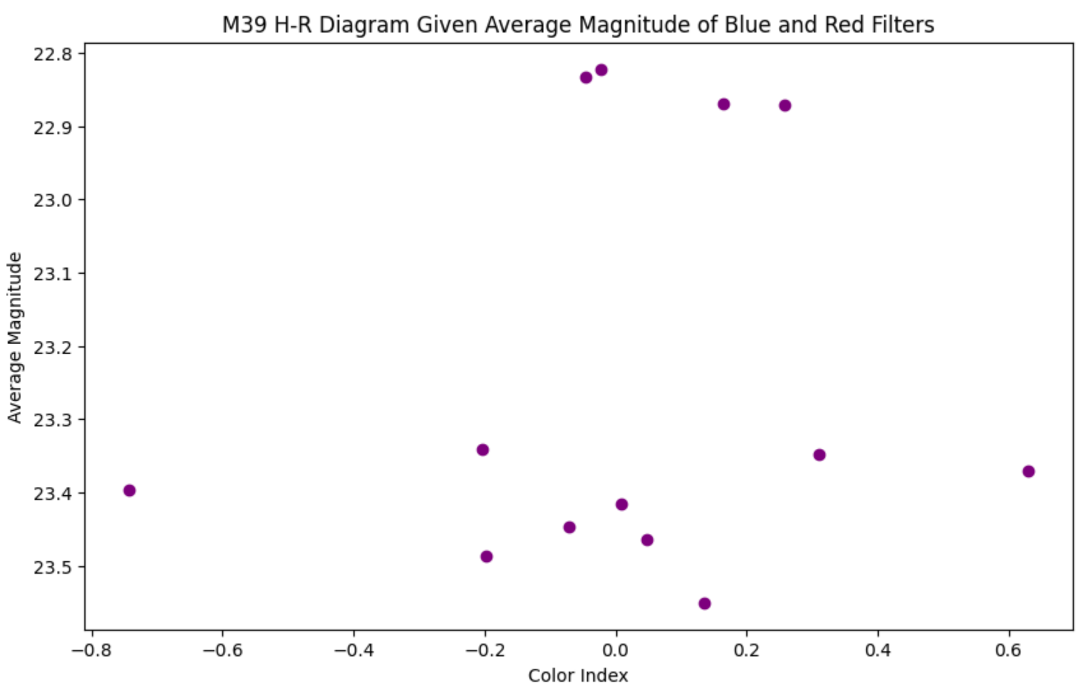
<u>Red13</u>



Average Value of Initial Magnitudes (13)



Average Magnitude of Original Sample ([B13 + R13]/2)

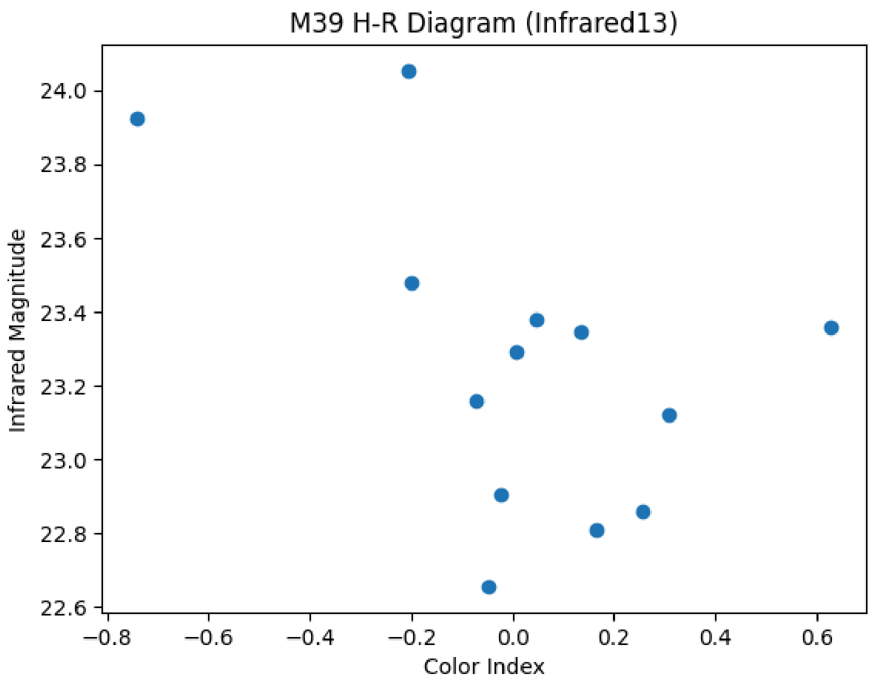


To improve the accuracy of our analysis, data from the infrared filter was also included. The fluxes of the same thirteen stars were measured using the infrared data, maintaining the same sample size.

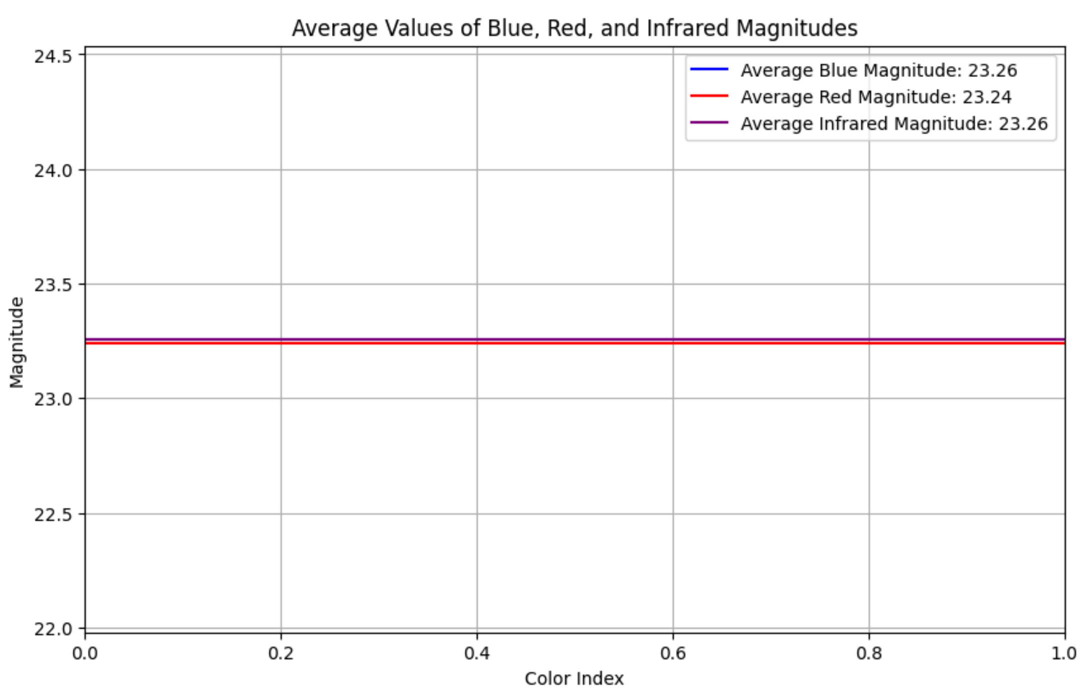
The fluxes obtained from the Infrared data were:

	Infrared Flux (Photons)
T1	0.107203332237848
C2	0.116270575843521
C3	0.1086077118333596
C4	0.1053423520614842
C5	0.0961706649734285
C6	0.0948557648313469
C7	0.0834426022450842
C8	0.0868653495510806
C9	0.0875866787264558
C10	0.0898986901273191
C11	0.0879559107079496
C12	0.0697839295498915
C13	0.0662868981876694

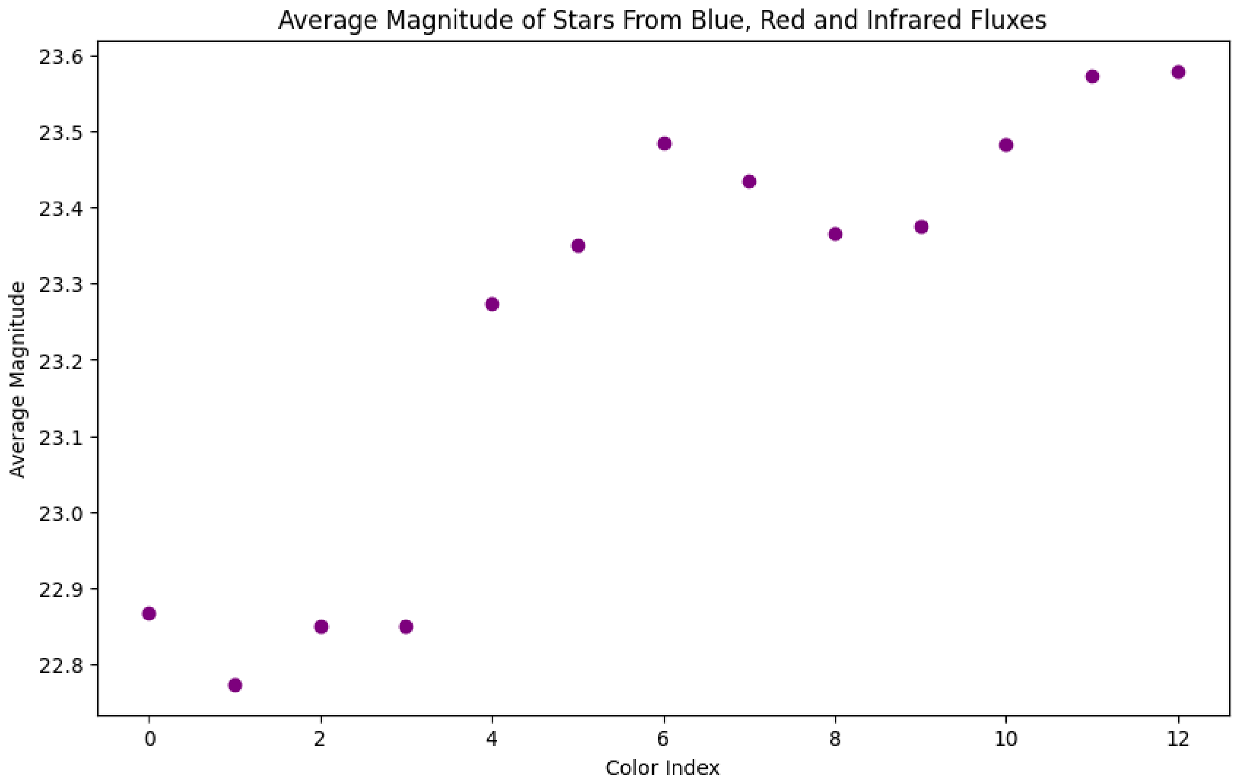
Infrared 13



Average Value of Initial Magnitudes with Infrared Data (13)



Average Magnitude of Original Sample with Infrared Data ([B13 + R13+I13]/3)



The inclusion of infrared data revealed additional dim stars, particularly hot but dim stars in the bottom left of the scatter plot. The combined average magnitudes across all three filters showed a diagonal strip indicative of main sequence stars.

With the resampled data, the new fluxes for the Red and Blue filters respectively were:

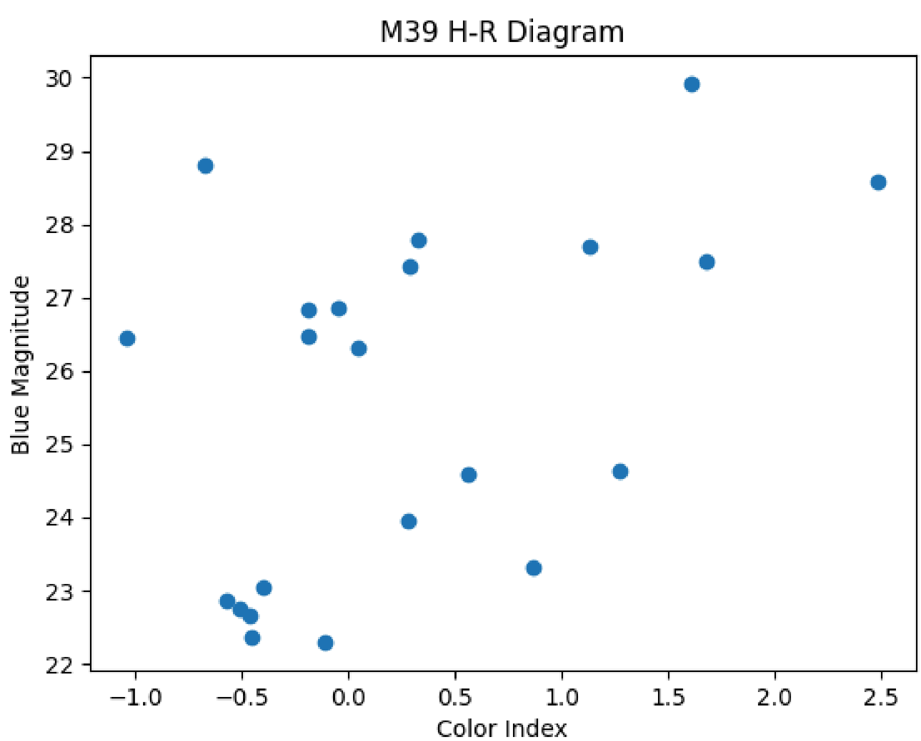
BLUE

```
[0.0891, 0.134, 0.131, 0.116, 0.112, 0.107, 0.0998, 0.0526, 0.0689, 0.0536,
0.0108, 0.0168, 0.0149, 0.009869713748, 0.02163501941, 0.01550404273,
0.02530870477, 0.00634100617, 0.02687445802, 0.02547529867, 0.01717113427,
0.02176772406]
```

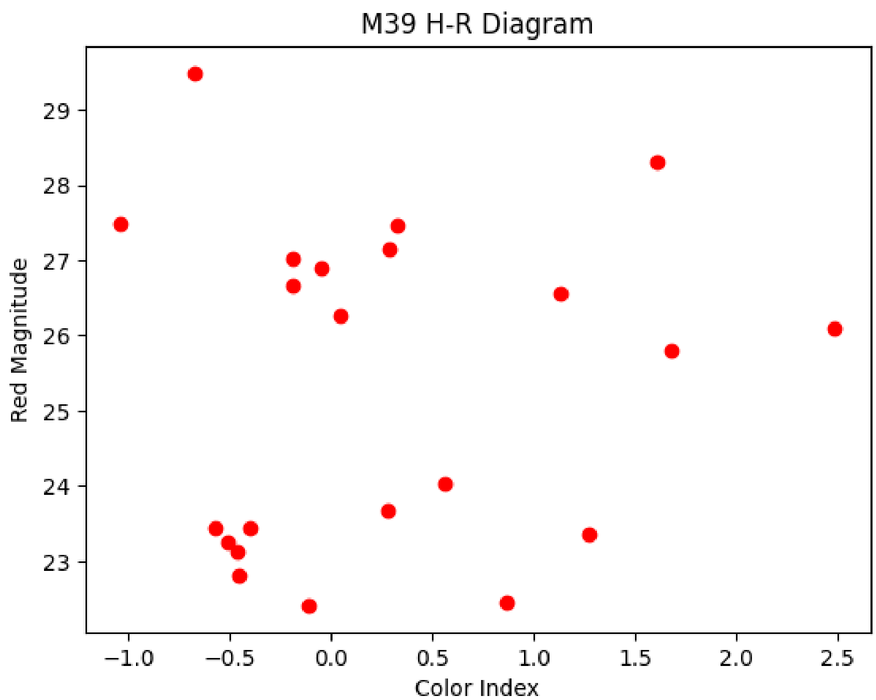
RED

```
[0.126, 0.128, 0.109, 0.0965, 0.0912, 0.0851, 0.0849, 0.0874, 0.0771, 0.067,
0.0292, 0.0329, 0.017, 0.007542510749, 0.02121219309, 0.02434319901,
0.02344270462, 0.01205905418, 0.02733954693, 0.01681408749, 0.0192803578,
0.02018913239]
```

Resampled Blue (Blue 22)

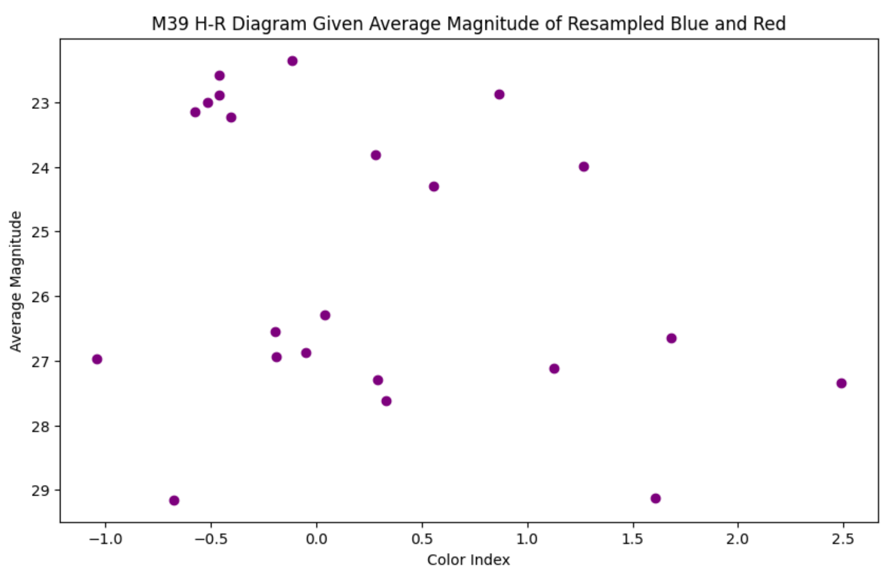


Resampled Red (Red 22)

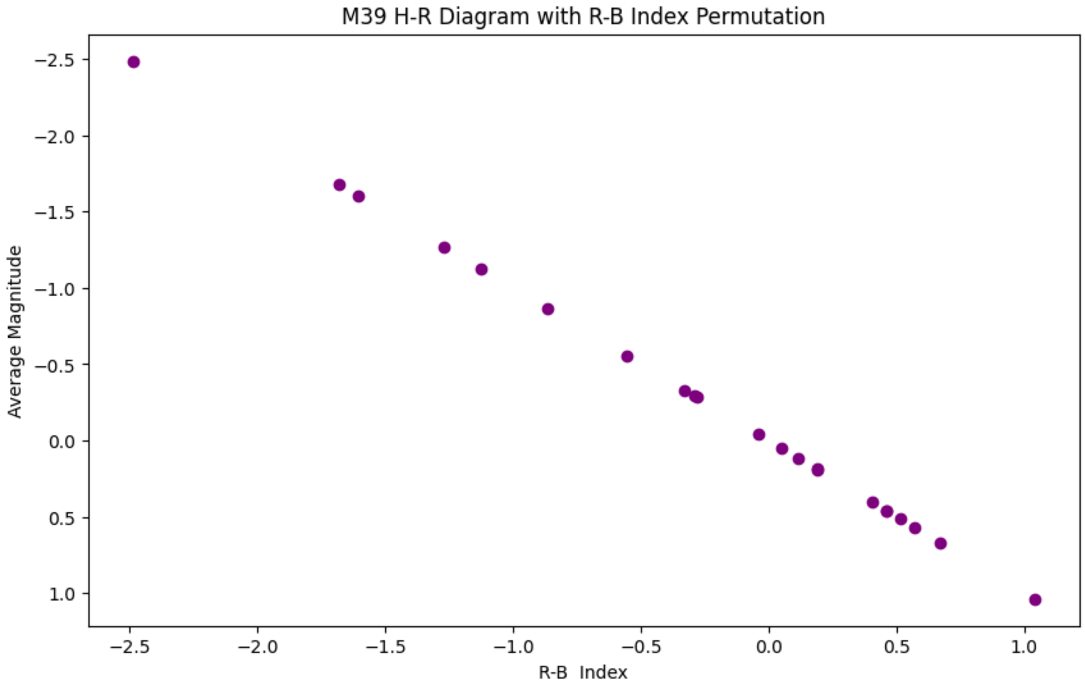


Next I performed various permutations on the resampled data.

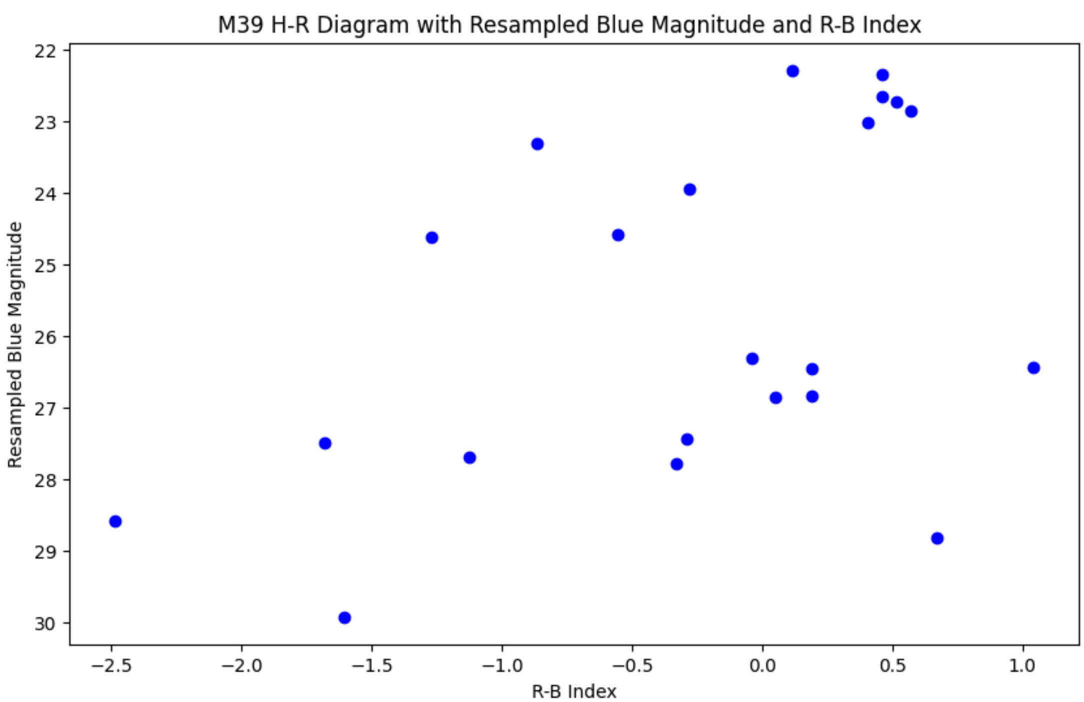
AvgM22

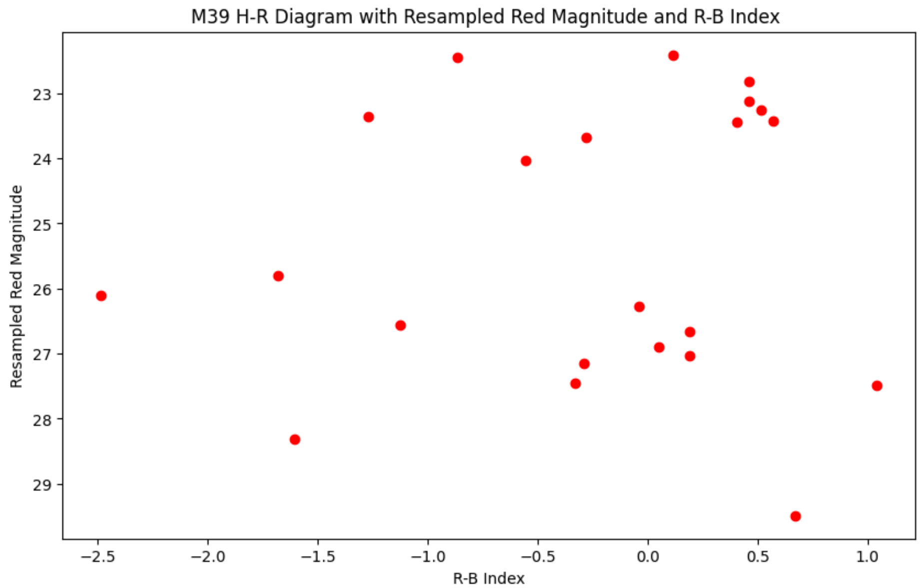


AvgM22 over R-B Index

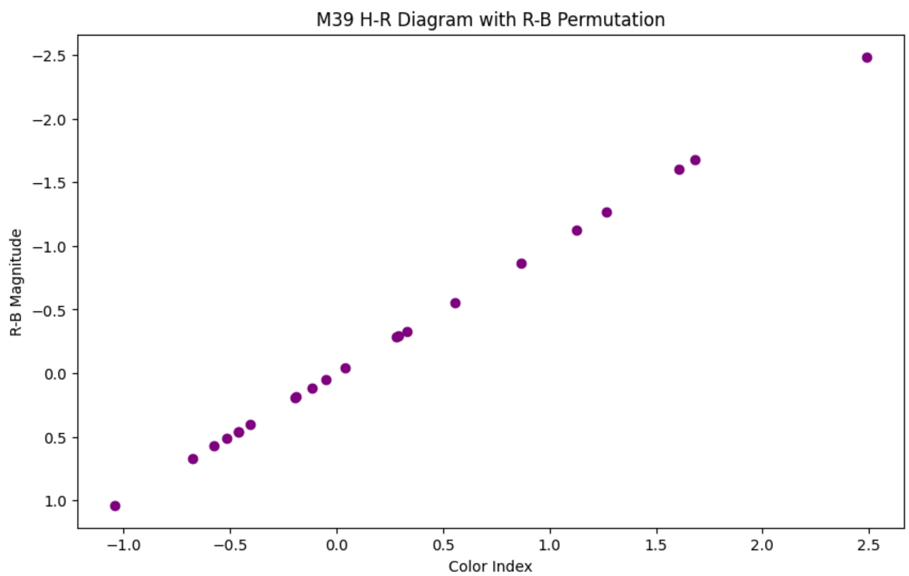


Blue22 set with R-B Index



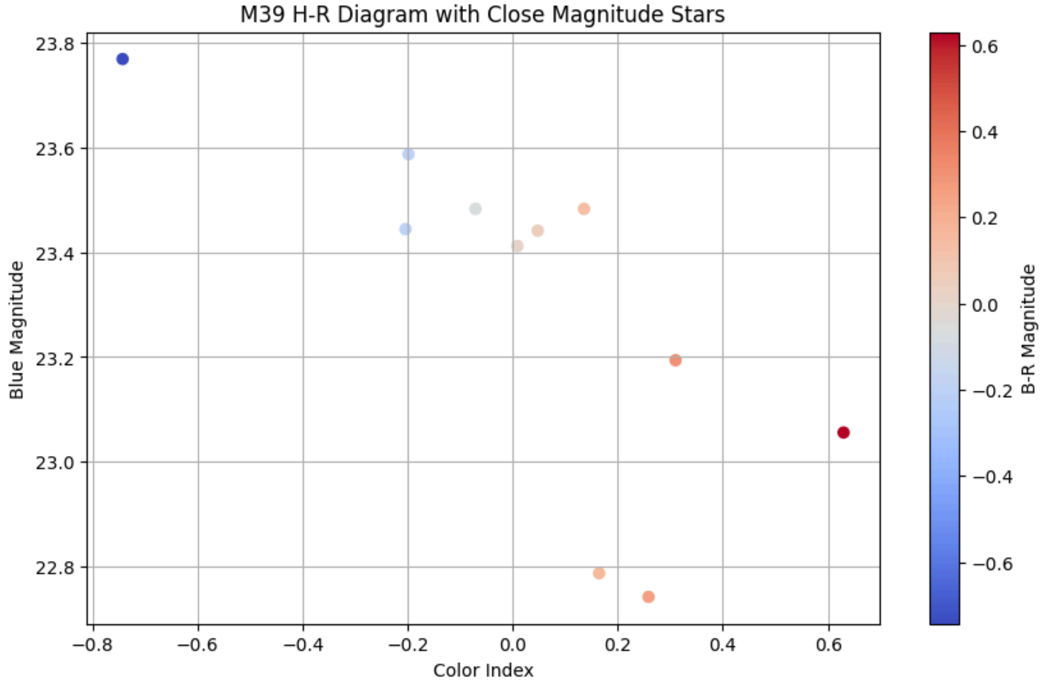


<u>R22-B22 Permutation</u>

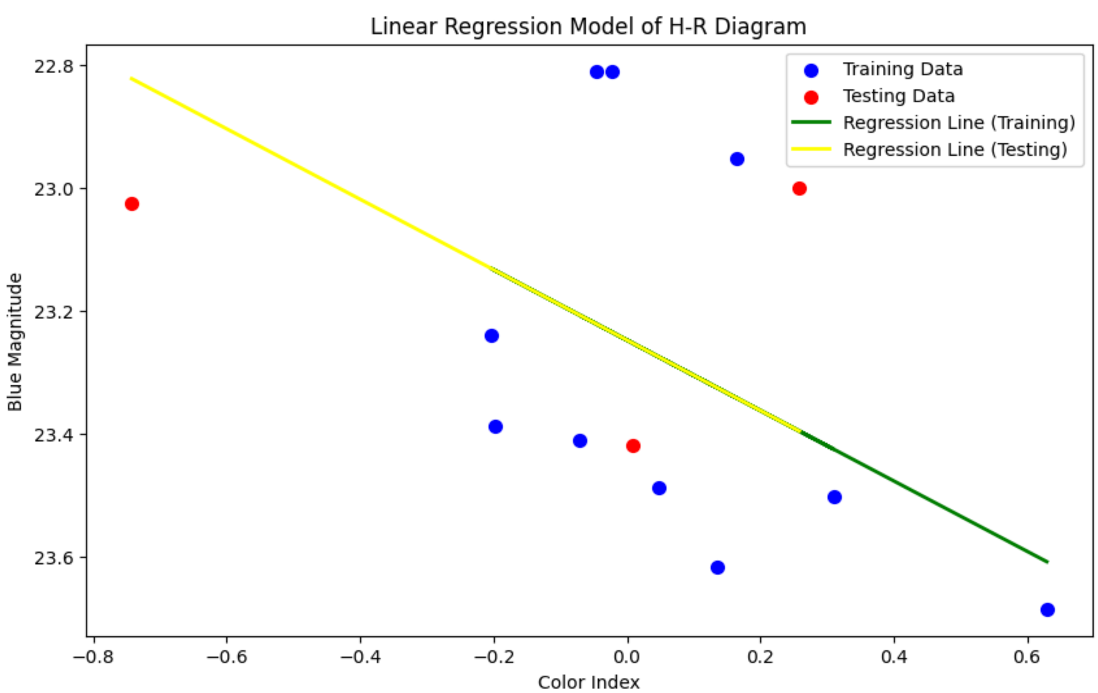


The resampled data of twenty-two stars showed a clear linear trend from the top left to the bottom right of the H-R diagram, indicating an influx of main sequence stars. Various permutations and manipulations of the data confirmed these patterns.

Close Magnitude 13



<u>Train-Test Split Linear Regression 13</u>



"R^2 1, LR1" was the r^2 value of the training data, and "R^2 2, LR1" was the value of the testing data. The r^2 values and interpretations corresponding to "Train-Test Split Linear Regression 13" were as follows:

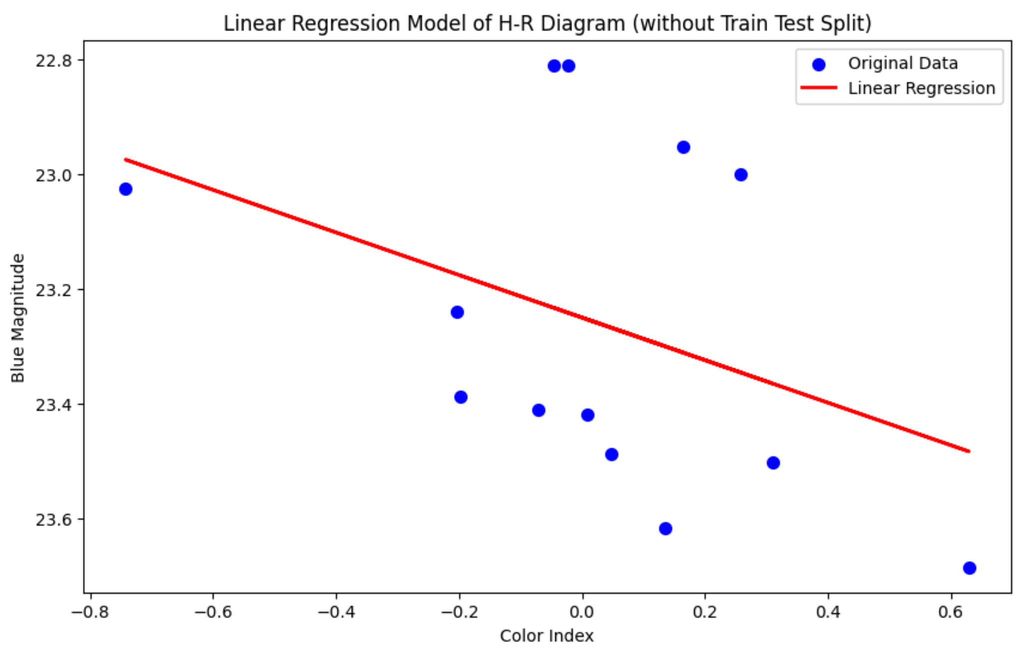
R^2 1, LR1:

```
R^2 score: 0.20
This is a poor fit.
```

R^2 2, LR1:

```
R^2 score: -1.04
This is a poor fit.
```

<u>Regular Linear Regression 13</u>



The r^2 value and interpretation corresponding to "Regular Linear Regression 13" was as follows:

R^2 3, LR2:

```
R^2 score: 0.15
This is a poor fit.
```

Here, I coded a machine learning model to predict future values of magnitudes for the blue and red filter respectively after being trained on the data of previous magnitudes. The code provided insight to potential errors and deviation from expected values, as well as the value of the magnitude itself.

Machine Learning and Blue Magnitude Predictions

```
Mean Squared Error: 1.6166058711975673
R-squared: -0.3068675897496058
Predicted Blue Magnitude: 5.727011790763683
```

Machine Learning and Red Magnitude Predictions

```
Mean Squared Error: 1.6166058711975673
R-squared: -0.1425361406240728З
Predicted Red Magnitude: 4.227011790763684
```

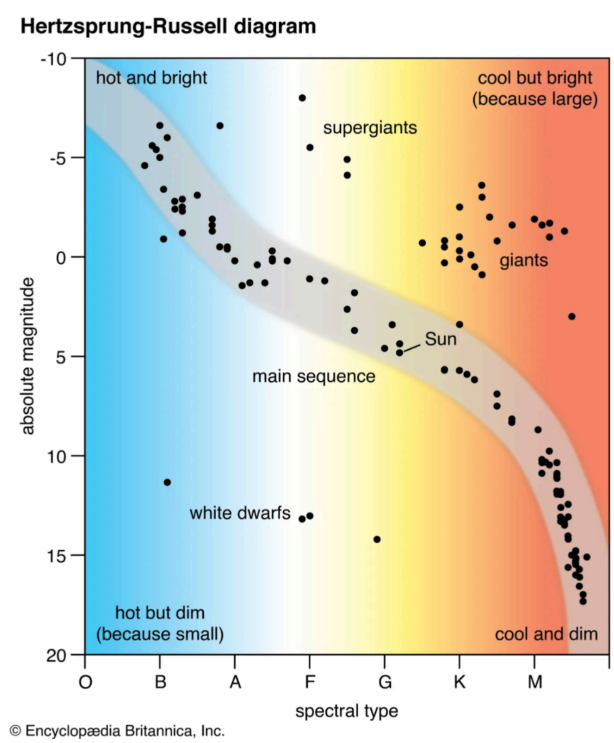
It can be noted that the R-squared value is different to the r^2 value obtained from the linear regression model. There is a possibility that this could be correlated to the sample sizes used in both models, with the linear regression model using 13 stars and the machine learning model using 22 stars.

IV. Discussion

For reference purposes, the M39 cluster, colored, and standard H-R diagram respectively look as such:

Image of M39

H-R Diagram



I chose a constant second flux value, F0= 1000, to calculate magnitudes using the formula m = -2.5 log10(F/F0). This made the x-axes of our graphs different from typical H-R diagrams, where B-R values usually range between [-1.5, 2]. Despite this difference, we can still interpret the graphs similarly, with the left side representing hotter temperatures and the right side cooler temperatures. Blue filters capture hotter stars well, while red filters are better for cooler stars. In both "Blue 13" and "Red 13" scatterplots, hotter and larger blue stars cluster in the top right, while white dwarf stars and dimmer red or brown stars appear in the bottom left and middle right. Cooler stars, which emit more in the infrared spectrum, are more visible in the "Infrared 13" plot, where many hot but dim stars are found in the bottom left.

The average magnitudes from the blue, red, and infrared filters show a pattern resembling the main sequence stars in a typical H-R diagram. The diagonal stripe from the top left to the bottom right in the "Average Magnitude of Original Sample with Infrared Data" plot suggests many main sequence stars in M39. Resampled datasets, like "Avg M22 over R-B Index," also show similar patterns, supporting the idea of an influx of main sequence stars. Additionally, the "Average Value of Initial Magnitudes with Infrared Data" graph validates our data by aligning with expected differences between blue, red, and infrared filters. The "Close Magnitude 13" plot highlights a predominance of blue stars, indicating a younger star cluster, as younger stars emit more energy and have shorter wavelengths.

The machine learning predictions of magnitudes presented some challenges. While the Mean Squared Error (MSE) and R-squared values were ideal, the predicted magnitudes for the red filter were unexpectedly more negative than those for the blue filter, which contradicted our data. This discrepancy might be due to a limited sample size or an overemphasis on bright stars. Our findings were corroborated with existing H-R diagrams of M39, and the patterns we observed, such as clusters of hot blue stars and the main sequence star strip, were consistent with these larger diagrams. This study highlights the importance of careful data analysis and provides insights into the compositions and behaviors of stars in open clusters.

V. Conclusion

In this study, I examined Messier 39 using photometry and advanced data analysis tools. I collected data with AstroImageJ and processed it using Python, converting raw measurements into magnitudes and creating detailed Hertzsprung-Russell (HR) diagrams. The analysis revealed key patterns and relationships, particularly in the stars' brightness and colors. I experimented with different analysis methods and applied linear regression models, which confirmed the reliability of our approach. Comparing our HR diagrams with standard references validated our techniques.

References

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Lecture 3: Luminosity, brightness and telescopes Luminosity and the Stefan-Boltzmann law Solid Angle Flux, brightness and intens,
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Open Cluster Messier 39 | Deep⋆Sky Corner (deepskycorner.ch)

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Messier 39 (NGC 7092) | Cygnus | Go Astronomy (go-astronomy.com)