Exploring Evolutionary Track of Individual Stars with Aperture Photometry

Nusrath Jahan[1], Abantika Maytra Oishee[2], and Dibbendu Barua[3]

[1]Shahjalal University of Science & Technology, Department of Physics, Sylhet-3114, Bangladesh
[2]Hajee Mohammad Danesh Science & Technology University, Department of Physics, Dinajpur-5200, Bangladesh
[3]Notre Dame College, Dhaka-1000, Bangladesh

October 8, 2024

Abstract

This project aims to understand different stages of star evolution by constructing a model Hertzsprung-Russell Diagram. In this study, twelve target stars were particularly selected and their data were collected from the publicly available database of SDSS and we used aperture photometry for our analysis. Our results showed that most of these stars are in the main sequence phase; therefore, they are very important in the star life cycle. We also considered the effectiveness of simple aperture photometry for this kind of analysis. Since our project had to be as simple and accessible as possible, we chose methods that are easy to understand and deliberately avoided complex analyses.

Keywords: Absolute Magnitude; Color Index; Aperture Photometry; H-R Diagram; Stellar Evolution;

1 Introduction

When an image of a star is taken it includes not only the intrinsic light of stars but also the background sky light which is considered noise and so in order to distinguish the light of the stars from the background noise, a technique of photometry known as aperture photometry has been used in this project. Aperture photometry is an effective tool in studying of different stellar properties. Due to recent advancements in technology, we can now get stellar data from large surveys like the Sloan Digital Sky Survey (SDSS)[12]. This publicly available data allows to do detailed analysis of astronomical objects and understand their evolution and properties. The H-R diagram[8] graphically represents the relationship between luminosity/magnitude and color/temperature of the stars viewed in astronomy[5]. In the project, stellar evolution was studied by analyzing some selected target stars from the SDSS that are good candidates for performing aperture photometry. Further measurements about their characteristics were made, using the output obtained from aperture

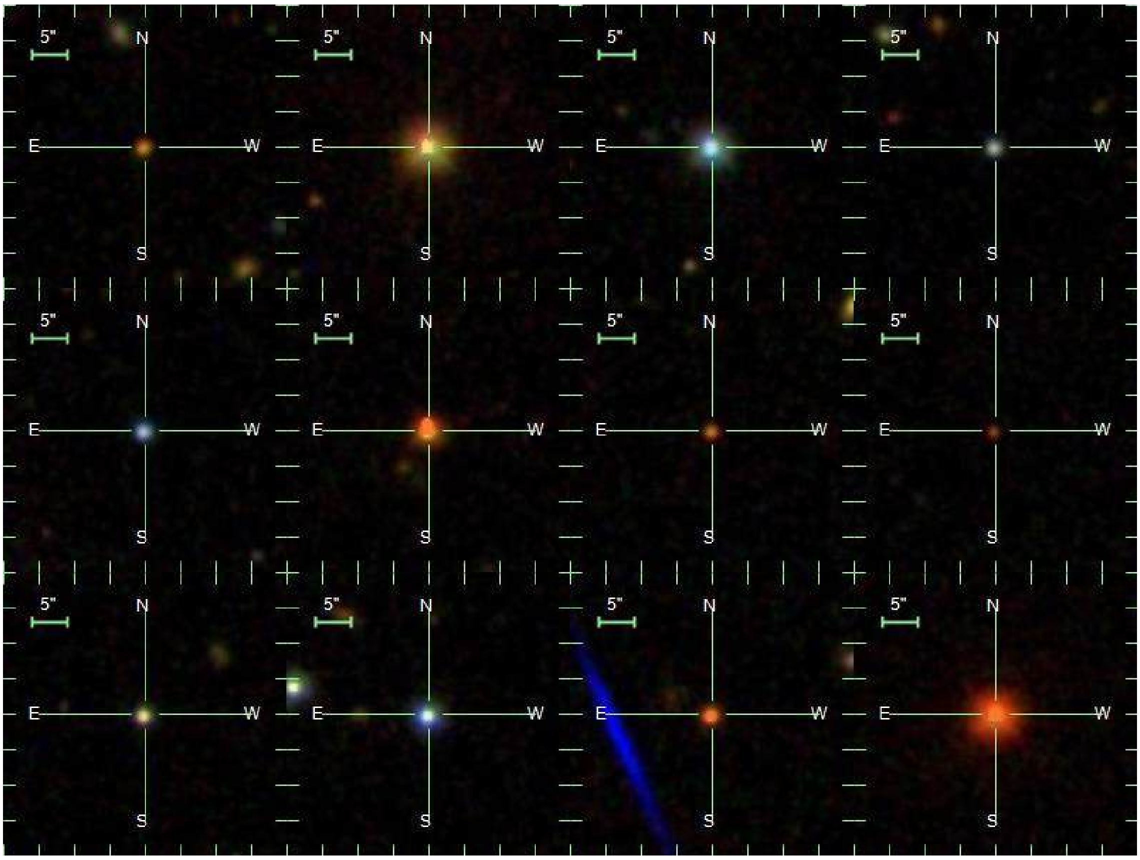

Figure 1: 12 target stars used from SDSS

photometry, and checking where they would fall in the model H-R diagram. We present results indicating that most of our target stars are in the main sequence phase.

2 Data

The data used in this project were obtained from the Sloan Digital Sky Survey (SDSS) [1] in two specific bands- g-band & r-band. These two bands are more efficient for this project to transform to B and V filters in UBV photometric system[10]. Moreover, it's easy to avoid any complexity or noise which could be made by additional bands. We have chosen our target stars such that they are located in a non-crowded field away from other bright astronomical objects to minimize contamination from overlapping light. We have also made sure that our target stars are a good fit for aperture photometry choosing small and circular, mostly concentrated star light 1 We have incorporated Vega Magnitude system in our calculation in absolute magnitude and color index which is discussed in the next section.

3 Method

We have done the aperture photometry on each star to measure its apparent flux. Next, from that apparent flux, the calculation of absolute magnitude and color index of the star is done. From those, an estimation about the approximate position of the star in the model HR diagram is possible, which enables us to infer about the star's evolutionary phase.

3.1 Aperture Photometry

We used photutils[2] to measure the flux of individual stars by defining circular apertures at their centres. The aperture photometry method[3] calculates the number of pixels within a circular aperture that detect the observed radiation from a target star. To adjust for background noise, we estimated the background sky's contribution using an annulus. The background-subtracted flux was calculated by subtracting the annulus's average background pixel value from the total flux measured within the aperture. This entire process was carried out separately for both g-filters and r-filters. Same aperture and annulus radius was used in both filters for each target star to keep uniformity. There was an offset in the center position of the star in those two bands which is accounted for by decreasing the y- coordinate of the star in r-band by 10 pixels. It is kept consistent for all target stars.

3.2 Measurement of Absolute Magnitude & Color Index

For this project, the color index and absolute magnitude were required to determine the stars' positions on the final model H-R diagram. Both the color index and absolute magnitude were derived from flux measurements, obtained through aperture photometry.

Considering Vega as the standard reference star, we have calculated the apparent and absolute flux of Vega, given that the distance of Vega from Earth is 7.68 pc [11]. The observed flux of Vega is given by[9]:

$$F_{\text{obs\_vega}} = \frac{L_{\text{vega}}}{4\pi d_{\text{vega}}^2}$$

Here, the luminosity of Vega is $L_{\text{vega}} = 47.2 L_{\odot}$.[11] The absolute flux of Vega can be obtained from the following equation[4]:

$$F_{\text{abs\_vega}} = F_{\text{obs\_vega}} \times \left(\frac{d_{\text{vega}}}{10} \right)^2$$

We have calculated the apparent magnitude of the target star using the following equation[4]:

$$m_{\text{star}} = -2.5 \times \log_{10} \left(\frac{F_{\text{obs\_star}}}{F_{\text{obs\_vega}}} \right)$$

The absolute magnitude can be calculated from the apparent magnitude using the equation[4]:

$$M = m - 5 \log \left(\frac{d}{10} \right) + 5$$

As we don't know the distance of the star, we can also write this equation as to obtain the absolute magnitude:

$$M = m + 2.5 \times \log_{10} \left(\frac{F_{\text{obs\_star}}}{F_{\text{abs\_vega}}} \right) + 5$$

After measuring the apparent magnitude of the star in the g-band and r-band, we used a transformation equation [6] to convert the magnitudes to B and V in the UBV photometric system[10]. The transformation equations are given by[7]:

$$B = g + 0.3130 \times (g - r) + 0.2271 \quad (\sigma = 0.0107)$$

$$V = g - 0.5784 \times (g - r) - 0.0038 \quad (\sigma = 0.0054)$$

where g and r are the apparent magnitudes in the g-band and r-band, respectively. The color index is obtained by the following simple equation:

$$\text{Color Index} = B - V$$

4 Results

In this section, we show the results from the model H-R diagram2 we made from bunch of different kinds of synthetic stars and positions of the target stars on it. The model H-R helps us approximately see which stellar stage each star is in. We included different types of stars: Main Sequence stars, Giants, Super giants, and White Dwarfs. We also highlighted 12 target stars to figure out what stage they are in.

Table I: Target Stars' Absolute Magnitude and Color Index

SDSS ID	**Absolute Magnitude**	**Color Index**
1237648720693691071	5.58366 ± 0.37776	1.33375 ± 0.07766
1237648720693756098	5.59716 ± 0.00517	0.99686 ± 0.00677
1237648720693690466	5.60023 ± 0.00526	0.31562 ± 0.00677
1237648720693756200	5.58991 ± 0.05944	0.37032 ± 0.02176
1237648720693756196	5.58686 ± 0.03182	0.12394 ± 0.01550
1237648720693821735	5.60044 ± 0.02918	1.26358 ± 0.01290
1237648720693822072	5.58427 ± 0.52340	1.20866 ± 0.10049
1237674649928532167	5.59502 ± 0.04068	0.67503 ± 0.01794
1237674649928597563	5.58011 ± 0.01584	0.28515 ± 0.00846
1237674649929056488	5.59721 ± 2.08978	3.05675 ± 0.03659
1237648720693756154	5.57980 ± 0.01018	1.29502 ± 0.00823
1237674649928597626	5.59977 ± 0.02625	0.66937 ± 0.01330

This model H-R diagram clearly shows regions where each of the target star types would be seen. Main Sequence stars form a long stretch, starting from low 'B-V' values and moving down as their absolute magnitude increases and thus brightness decreases. The giants are bunched up towards higher 'B-V' values, typically above 1.5. This indicates that the super giants are bright with medium to high 'B-V' values while the White Dwarfs are much dimmer and are located towards the bottom left of the diagram with lower 'B-V' values.

When we looked at the positions of the target stars, we could tell which stage they belonged to:

- **Main Sequence Stars**: 11 of the target stars fall in the area of Main Sequence stars. They hold 'B-V' values from 0.12 to 1.3 and an absolute magnitude of about 5.6. These stars are still in the main phase of their life, burning hydrogen in their cores. It is also visible that the some main sequence stars are bluer and some others are comparatively redder, that means are gradually moving on to their giant phase.

- **Giants**: Only target star that matches the Giant stage possesses a higher 'B-V' value within 1.2-1.33. This would then mean it is evolving beyond the main-sequence stage because, when it is running out of core hydrogen, they are expanding.
To sum up, we have:
11 main sequence stars, young and still burning hydrogen.
1 Giant star that is older and has started expanding.
The diagram helped us see where each target star fits in, and it shows us that different stages of a star's life. In this respect, it helps in understanding how stars change in their lifetime.

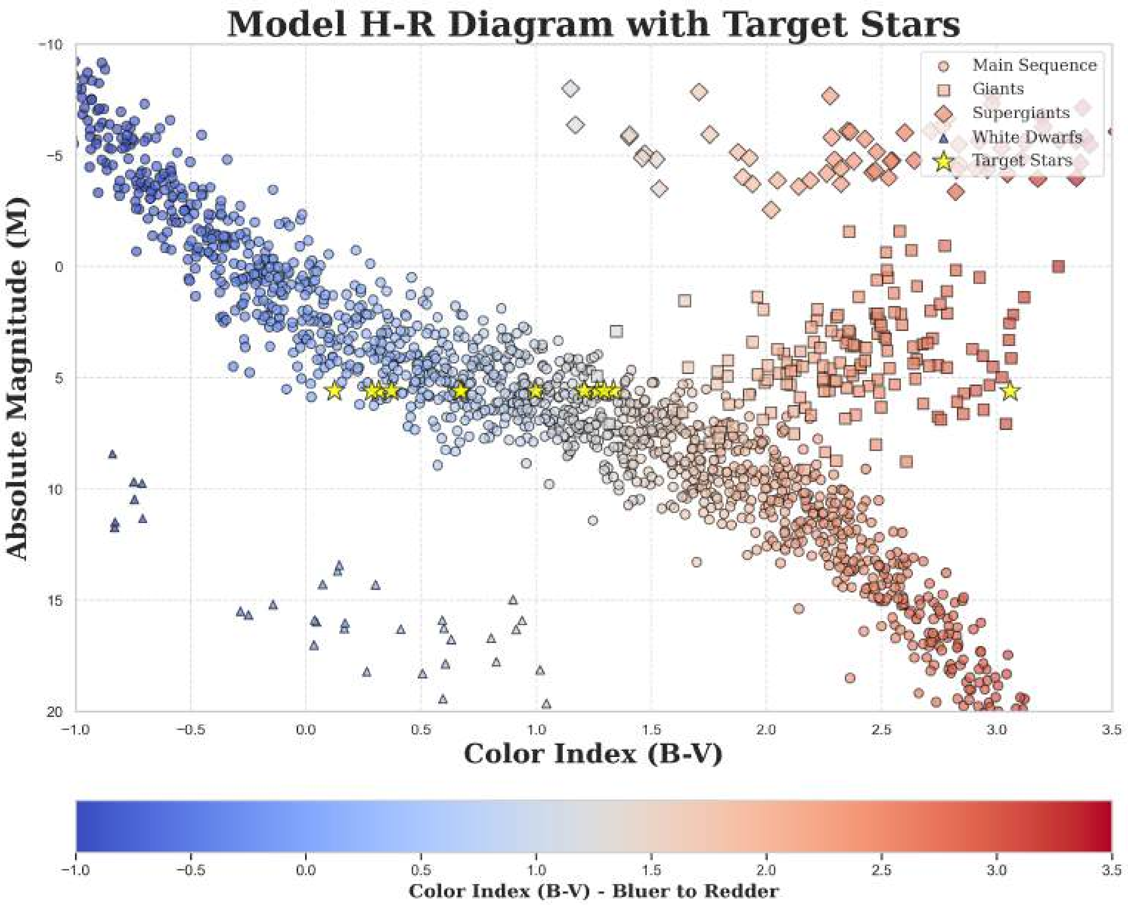

Figure 2: A model H-R diagram is created with synthetic main sequence, giant, super giant and white dwarf stars (representative points) solely based on the apparent position of different branches of theoretical H-R diagram to point out the approximate apparent positions of target stars from our measured value of absolute magnitude and color index

5 Discussion

In this project, we analyzed a few target stars using the model H-R diagram and classified them into different classes of stellar evolution, such as Main Sequence, Giants, Super giants, and White Dwarfs. A model H-R diagram gave the graphical representation of the relation between color index B-V and absolute magnitude M of a star.

These targets gave a varying of absolute magnitude and color indices. The absolute magnitudes of most of the target stars came at about 5.5, therefore probably referring to the later stages of stellar evolution. Color index value varied within the targets; whereas other targets revealed higher values showing cooler, probably older stars, other targets had a lower color index value, suggesting they were in the Main Sequence phase.

The distribution of the target stars in the model H-R diagram would suggest that they are, in general, within categories of the main sequence, with some of them probably overlapped by the giant phase. This is very well consistent with the evolution paths of stars-at a later stage, they will become brighter and cooler.

However, with the recognition that limitations do indeed happen and must be duly recognized as this project was undertaken, the error that did occur in both magnitude and color index values, as specified in the data, necessarily presented some form of doubt related to the overall study results. This could be due to background contribution, such as noise in the images, the quality of the photometric calibration, or atmospheric factors during the picture-taking process, among others. Besides, we have considered a different magnitude system from the magnitude system used by SDSS. This too introduces some error that we have not accounted for in our analysis.

6 Conclusion

This project has gone through the effectiveness of using aperture photometry with just the g and r bands in order to avoid complications as much as possible by reducing any complexity in data analysis. Still, the same approach may further be applied to larger datasets and additional bands in order to streamline the evolutionary tracks of a more inclusive range of stars. Yet, the ultimate output provides a classification that offers insight into stellar evolution. Further, in order to enhance accuracy in our stellar classifications, further studies may extend this work by considering additional data or other properties that might affect the evolution of a star.

Code & Data Availability

The code used for the analysis in this study is available at the following github repository: Astronomy Projects for Amateurs. The data utilized in this research was obtained from the Sloan Digital Sky Survey (SDSS) and can be accessed through their official website: SDSS Data Release Publications.

References

[1] M. R. Blanton et al. Sloan digital sky survey iv: Mapping the milky way, nearby galaxies, and the distant universe. *The Astronomical Journal*, 154(1):28, 2017. Data Release 13.

[2] Larry Bradley, Brigitta Sipőcz, Thomas Robitaille, Erik Tollerud, Zè Vinícius, Christoph Deil, Kyle Barbary, Tom J Wilson, Ivo Busko, Axel Donath, Hans Moritz Günther, Mihai Cara, P. L. Lim, Sebastian Meßlinger, Zach Burnett, Simon Conseil, Michael Droettboom, Azalee Bostroem, E. M. Bray, Lars Andersen Bratholm, William Jamieson, Adam Ginsburg, Geert Barentsen,

Matt Craig, Sergio Pascual, Shivangee Rathi, Marshall Perrin, Brett M. Morris, and Gabriel Perren. astropy/photutils: 1.12.0, April 2024.

[3] Photutils Developers. Photutils: Aperture photometry. https://photutils.readthedocs.io/en/stable/aperture.html, 2024. Accessed: 2024-10-05.

[4] Hannu Karttunen. *Fundamental Astronomy*, chapter 4, pages 87–104. Springer, New York, NY, 1987.

[5] R. Kippenhahn and A. Weigert. *Stellar Structure and Evolution*. Springer-Verlag, 1990.

[6] R. H. Lupton, M. Jurić, Z. Ivezić, A. Brooks, D. J. Schlegel, D. Finkbeiner, N. Padmanabhan, N. Bond, C. M. Rockosi, G. R. Knapp, J. E. Gunn, T. Sumi, and D. P. Schneider. Dissecting the Milky Way with SDSS - I: Stellar Overdensities. In *American Astronomical Society Meeting Abstracts*, volume 207 of *American Astronomical Society Meeting Abstracts*, page 133.08, December 2005.

[7] SDSS Collaboration. Sdss ubri transformations. https://www.sdss3.org/dr8/algorithms/sdssUBVRITransform.php#Rodgers2006, 2024. Accessed: 2024-10-05.

[8] Wikipedia contributors. Hertzsprung–russell diagram. https://en.wikipedia.org/wiki/Hertzsprung%E2%80%93Russell_diagram, 2024. Accessed: 2024-10-05.

[9] Wikipedia contributors. Luminosity. https://en.wikipedia.org/wiki/Luminosity, 2024. Accessed: 2024-10-05.

[10] Wikipedia contributors. Ubv photometric system — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/wiki/UBV_photometric_system, 2024.

[11] Wikipedia contributors. Vega. https://en.wikipedia.org/wiki/Vega, 2024. Accessed: 2024-10-05.

[12] Donald G. York and SDSS Collaboration. The Sloan Digital Sky Survey: Technical Summary. , 120(3):1579–1587, September 2000.