The Hertzsprung Russell Diagram and its Location Independency

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***Abstract*— The Hertzsprung Russell Diagram (H-R Diagram) is a diagram displaying the luminosity of stars against their temperature and is a key indicator of stellar evolution. Using the Hipparcos, Yale Bright Star and Gliese Catalogues to recreate this diagram, this visual representation of stellar evolution was analysed and interpreted. Additionally, H-R Diagrams that corresponds to each individual galactic quadrant were also compared to reveal whether the location of a star has any effect on its life cycle. This paper analyses how the H-R Diagram is an indicator only to the age and phase of a star, and its physical location in the spatial plane is not a deciding attribute to its evolution.**

I. Introduction

The creation of the Hertzsprung-Russell Diagram, often abbreviated as the H-R Diagram, by astronomers Ejnar Hertzsprung and Henry Norris Russell in the early 20th century was marked as a significant development in the field of astronomy. The H-R Diagram illustrates the luminosity of stars and their temperature by means of a two dimensional scatterplot. Although deceivingly simple, this diagram provides important vital information to astronomers by predicting the stellar evolution of different stars. Since stars in the same phases of their life tend to group together on the graph, the location at which the star is situated in the H-R Diagram gives an understanding into the type and age of the star.

In order to recreate the H-R Diagram, data from the Hipparcos Catalogue[1], Yale Bright[2] Star Catalogue and Gliese Catalogue of Nearby Stars[3] was collected and plotted. The Hipparcos Astrometric Catalogue is a compilation of data about 118,218 stars collected by the European Space Agency's Hipparcos Mission. The Gliese Catalogue of Nearby Stars features data about stars within 25 parsecs of the Sun, approximately 3800 stars in total. Finally, the Yale Catalogue is a database of 9110 stars with an absolute magnitude greater than 6.5. The

The objective behind this experiment was to investigate the relationship between the luminosity and temperature of stars and analyse the information provided by the H-R Diagram regarding the age and phase of the stars catalogued in the Hipparcos, Gliese and Yale Bright Star Catalogues (HYG Catalogue).

II. Method

The initial task was to obtain the databases from which the required data would be used. The most comprehensive and accessible database found was one compiled on the website astronexus.com[4]. A detailed description of the construction and possible errors in the HYG Database is also available on the same webpage. The database contained all data from each of the 3 aforementioned catalogues; however, for the sake of the experiment, only a few fields from the database were required and used. These were the StarID, HipparcosID, Right Ascension, Declination, Distance, Absolute Magnitude, Spectral Type, Colour Index, and each star's Cartesian Coordinates.

The StarID and Hipparcos ID fields were necessary to uniquely identify each star in the HYG catalogue and the HipparcosID respectively and therefore illustrate on the H-R Diagram the exact location of a specific star, for example, the Sun. The Right Ascension and Declination fields were kept in order to determine the exact location of the star in the spatial plane using the conventional celestial coordinate system. Similarly, the cartesian coordinates were required to position the stars in terms of the quadrant in which they exist, and therefore later produce accurate H-R Diagrams corresponding to each of the 4 quadrants. The Absolute Magnitude of a star indicates its luminosity, and therefore it was necessary to retain this information from the database in order to produce the H-R diagram, which is a plot of the stars' luminosities against temperatures. In order to plot the temperatures of the stars, each star's Colour Index was required, which then formed the x-axis of the final H-R Diagram. Additionally, the Spectral Type field was included with the purpose of being able to access the spectral type of any star (if known) in case more information about the temperature of the star is required, apart from the colour index.

Since the data was in a csv file format, it was necessary to separate the data associated with each star into individual arrays in order to make processing more manageable. To achieve this, a 2 dimensional array was created; each element of the larger array corresponded to a star in the catalogue, while the elements inside those star elements corresponded to each individual field.

At this stage, it was possible to begin representing the data in a graphical format. In order to produce the most basic version of the H-R Diagram, only 2 of the 8 chosen fields were required - Colour Index (CI) and Absolute Magnitude (AM) of each star - where CI was plotted on the horizontal x-axis and AM was plotted on the vertical y-axis. The colour index of a star provides information of the star's temperature, while its absolute magnitude gives insight into how bright the star is.

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III. Nomenclature

Additionally, some formatting was done to more accurately depict the data. Since the absolute magnitude scale describes stars which are brighter on the lower end of the spectrum and stars which are dimmer on the higher end of the spectrum, it was necessary to invert the y axis to achieve an H-R diagram which illustrated both luminosity and temperature increasing as the respective axes increased.

IV. Results

Clearly represented in Figure 1, most stars fall into specific groups in terms of their positions. It is observed that the stars fall into 4 major categories - Main Sequence Stars, Giants, Supergiants, and finally Dwarf Stars. These classifications are shown in the following Figure 2.

A vast majority of the stars appear to align themselves along the diagonal trend line on Figure 2, commonly known as the Main Sequence. Since the luminosity of a star increases with a decrease in its absolute magnitude, the negative slope of the line strongly supports the theory that there is a positive correlation between temperature and luminosity in the case of most stars. When a star is observed to be a part of the Main Sequence, it is said to be in the hydrogen burning phase of its life cycle. Brighter and hotter stars belonging to the main sequence form the top left corner of this group; whole colder hotter stars occupy the bottom right section. The majority of a star's life is spent in the main sequence as its core generates energy fusing hydrogen and helium atoms.

In the case of most stars, the depletion of the hydrogen core leads to them evolving into red giants, which is Area II on Figure 2 , or into supergiants, which is Area III on Figure 2. As represented on the diagram, these stars are inherently much brighter than those in the main sequence belonging to the same colour index. The immense mass and size of red giants allows the fusion of elements heavier than Hydrogen, such as Helium, at the cores of the stars, which allows them to produce vast amounts of energy and luminosity. Moreover, supergiants occupy a position in the H-R diagram which indicates even greater luminosity than regular red giants due to the fusion of even heavier elements at the core than their counterparts. Due to their substantial size, though, supergiants have relatively low surface temperatures.

In cases where the red giants do not possess sufficient mass to produce temperatures for the fusion of heavy elements such as Carbon, the giants will begin to shrink as the outer layers shed. Over time, a star like this continues to shrink until a point at which the electrons at the core cannot compress anymore. It forms a white dwarf - a star with extremely high density and temperature but extremely low surface area. The minimal surface area of white dwarfs prevents them from producing large amounts of power and therefore their absolute magnitude also remains low. Due to these characteristics, white dwarfs are observed in Area IV in Figure 2, below the main sequence.

V. Discussion

To accomplish one of the central goals of the experiment, the program was repeated another 4 times, with modifications being made to the parameters in each run. For each trial, only stars located in a predetermined quadrant of space were used to plot the H-R Diagram and the results are shown in the following Figure 3.

On observing the H-R Diagrams corresponding to the 4 quadrants of space, it can be easily inferred that while each figure may possess some negligible differences, they all appear to be largely similar to their counterparts. Despite the disparity in terms of their locations in the spatial plane, the stars catalogued by the Hipparcos, Yale Bright Star and Gliese Catalogues all produce predominantly comparable H-R Diagrams.

From this observation, it is possible to generalise that in order to create any H-R Diagram, the physical location of the star cluster does not play a major factor in the quality of the figure produced. Similarly, it can also be assumed that the nature of stellar evolution does not vary across different parts of the universe, and it can easily be determined with basic data about a star cluster's luminosities and temperatures. The H-R Diagram is an indicator of the temporal features of a star; i.e, its age, and is entirely independent of its spatial location.

This is an important focus and one of the main goals of creating the H-R Diagrams in this method - to analyse whether location does have an effect of stellar evolution. A key contribution that this paper provides is the understanding that the physical location of a star in space is an irrelevant factor to how the H-R Diagram for said star is formed.

VI. Conclusion

The main objective of this process was to create, interpret and explain the invaluable Hertzsprung-Russell Diagram from the Hipparcos, Yale Bright Star and Gliese Catalogues. Careful analysis of the results lead to the conclusion that the H-R Diagram is the optimal visual representation of stellar evolution, with specific areas corresponding to specific phases in a star's life cycle. Moreover, it was observed that the general rules followed by the stars in the catalogue hold true regardless of their location in the universe.

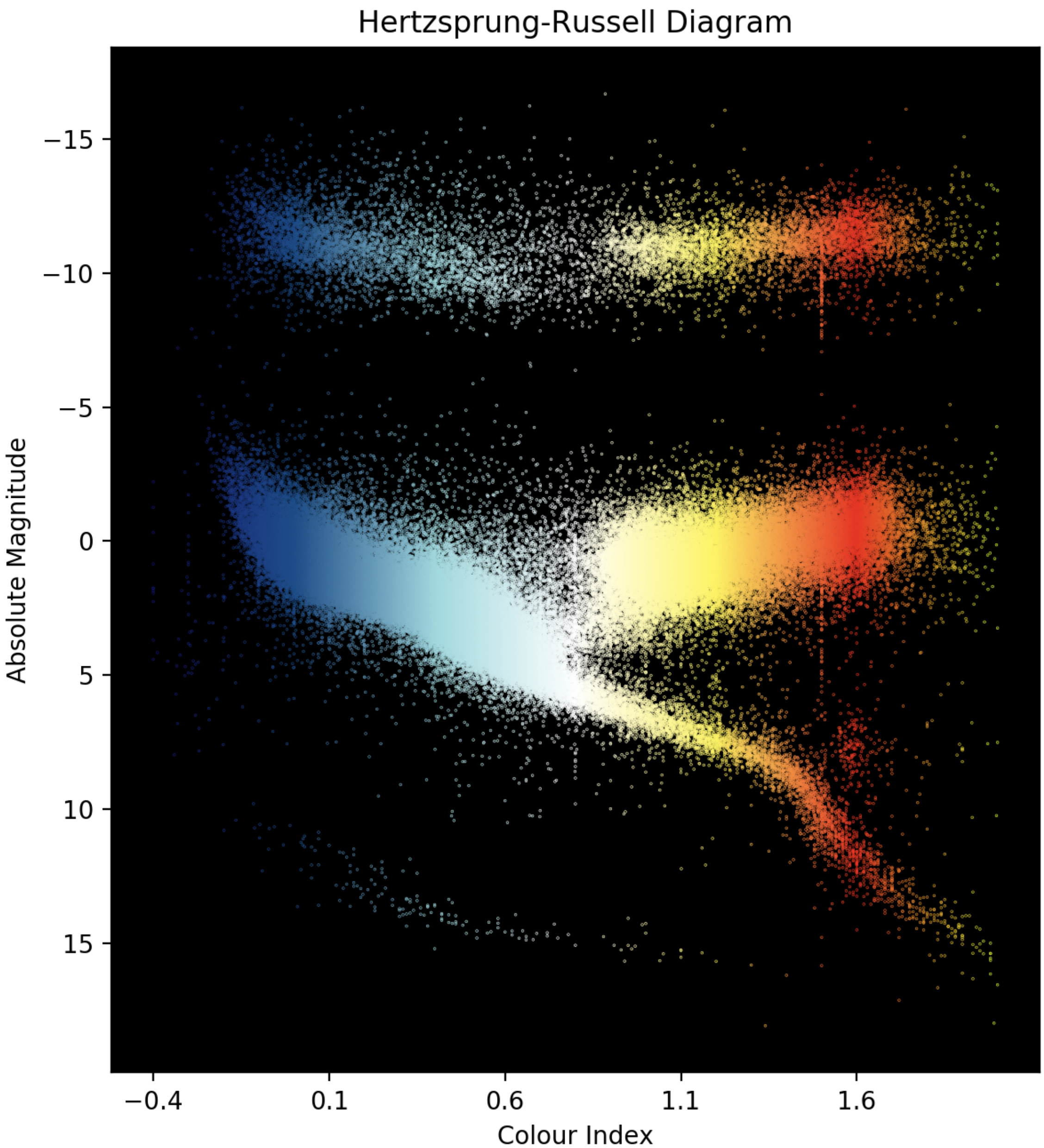

Fig. 1. Final results of Hertzsprung Russell Diagram from the Python program. Graphical representation of Absolute Magnitude (y-axis) and Colour Index (x-axis) of stars in the Hipparcos-Yale-Gliese Catalogue.s the most basic version of the H-R Diagram created, showing the luminosity of the stars (Absolute Magnitude on the y-axis) against their respective temperatures (Colour Index on the x-axis).

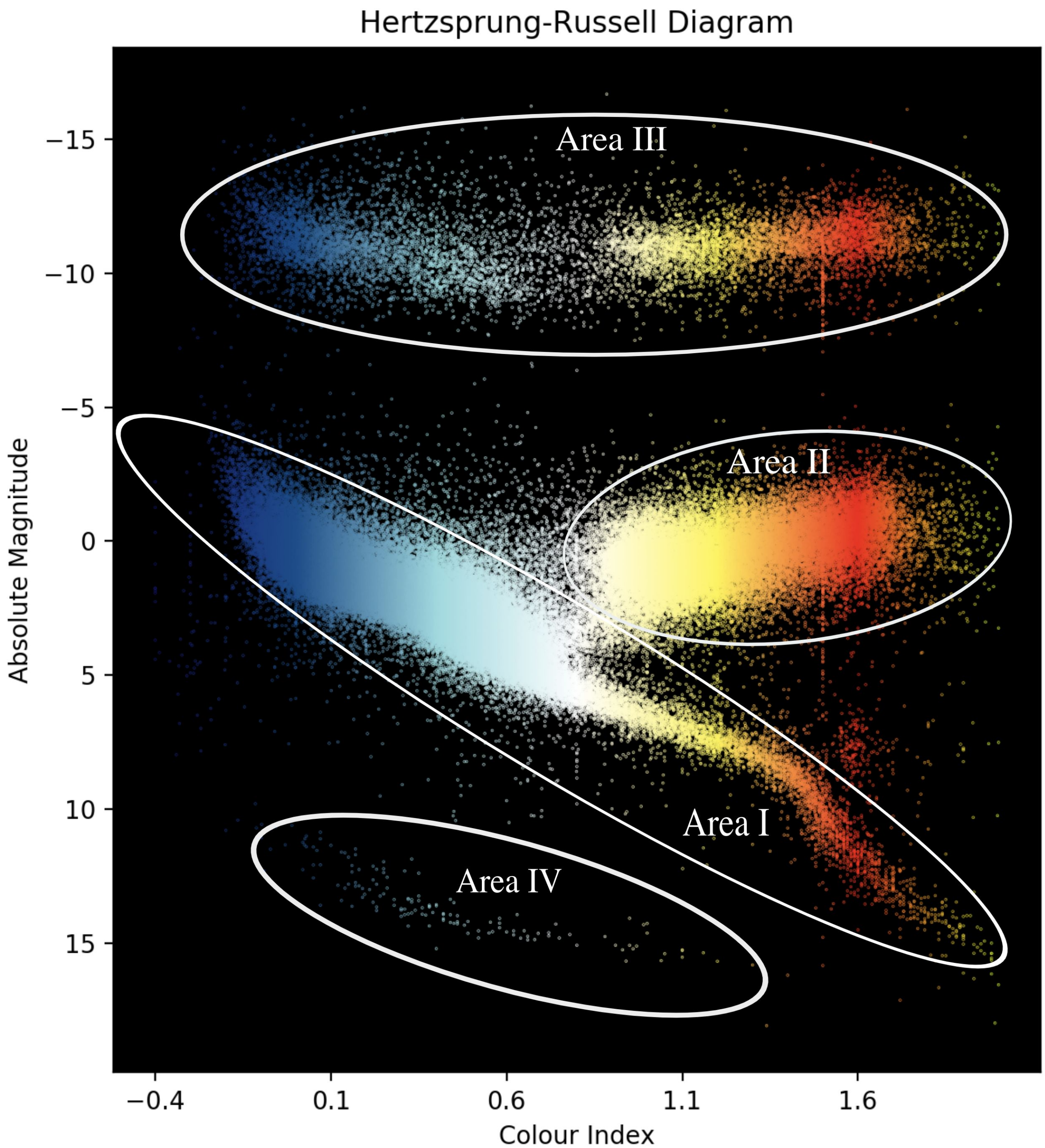

Fig. 2. Annotated Figure 1 Graphical representation of Absolute Magnitude (y-axis) and Colour Index (x-axis) of stars in the Hipparcos-Yale-Gliese Catalogue. The figure shows the 4 major classifications of stars based on their position on the diagram. Area I - Main Sequence Stars
Area II - Giants
Area III - Supergiants
Area IV - White Dwarves

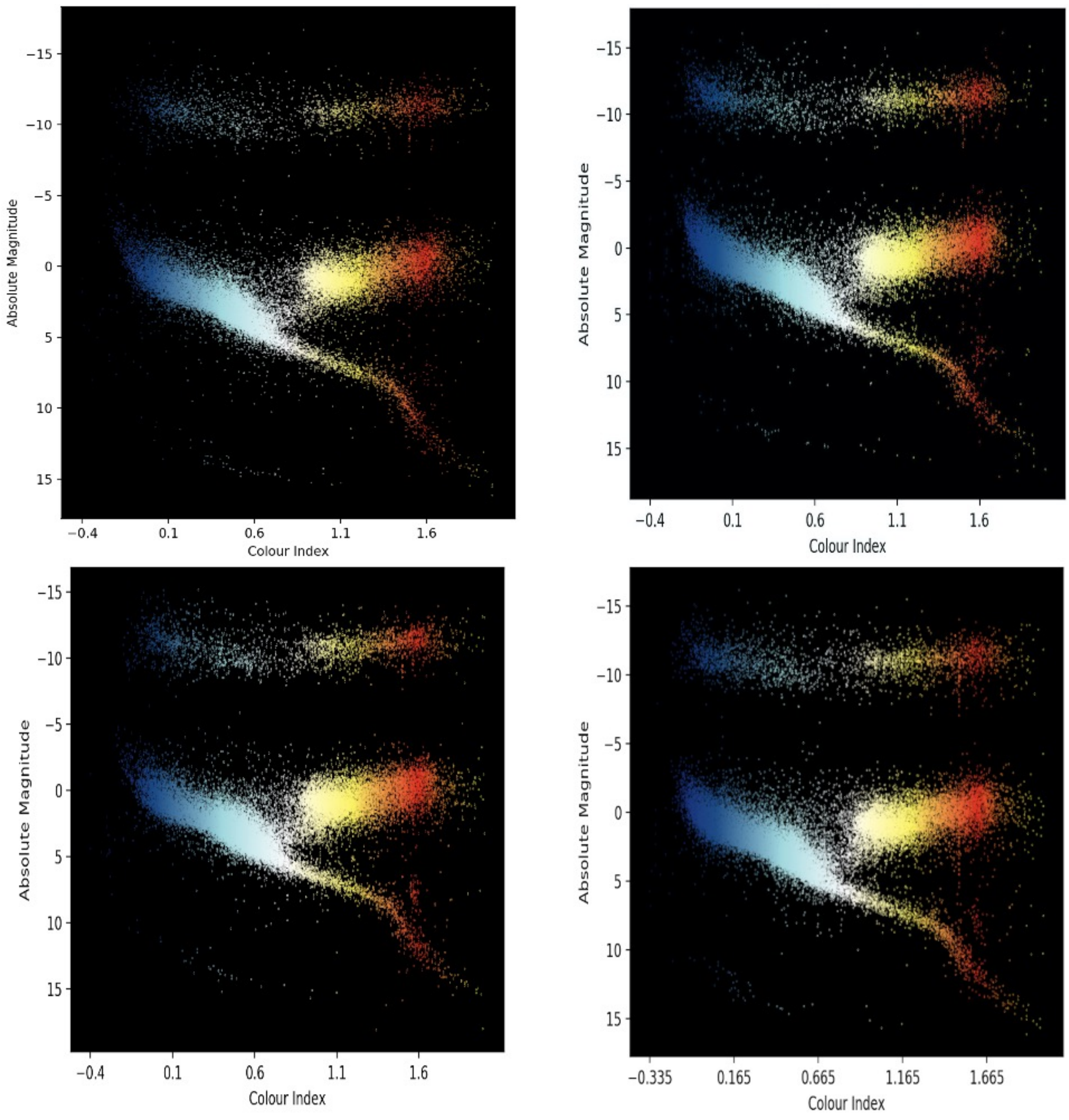

Fig. 3. Figure showing the H-R Diagrams corresponding to the 4 quadrants of the galaxy. Minimal and negligible differences between each diagram show that these figures are highly comparable. Figure 3.1 - First Quadrant (28268 stars)
Figure 3.2 - Second Quadrant (29833 stars)
Figure 3.3 - Third Quadrant (29331 stars)
Figure 3.4 - Fourth Quadrant (29966 stars)