Study of Stellar Hosts in NASA Exoplanet Archive through Hertzsprung–Russell Diagrams

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Abstract

The NASA Exoplanet Archive [10] contains a large amount of information pertaining to many exoplanetary stellar hosts, including host name, spectral type, effective temperature, radius, luminosity, distance, B magnitude, and V magnitude. This study creates Hertzsprung-Russell (H-R) diagrams [4] based on stellar host data from the NASA Exoplanet Archive, followed by a discussion on the results.

In this study, the H-R diagrams were created in Google Colab, with NumPy and Pandas for mathematical computation and data analysis, and Matplotlib for graph plotting.

The resulting H-R diagrams indicate that the stars found in the NASA Exoplanet Archive [10] follow the same pattern as what has been documented in many astronomy research communities. The majority of stars fall into the main sequence [9] region, groups of giants or supergiants appear near or at the top-right of the diagrams, and white dwarfs near the bottom-left corner.

1. Introduction

The Hertzsprung-Russel (H-R) diagram is a well-known scatter plot used to show the relationship between stars' absolute magnitudes or luminosities and their spectral classes, B-V color indices, or effective temperatures. Since its creation by Ejnar Hertzsprung in 1911 and Henry Norris Russell in 1913 [4], it has been an important tool for understanding stellar evolution.

This study creates H-R diagrams based on stellar host data in the NASA Exoplanet Archive [10] and explores said diagrams with analysis.

2. Data and Methodology

2.1. Data Source

Raw data of the stellar hosts in the NASA Exoplanet Archive [10] was downloaded as a csv file with the following fields:

- host name
- spectral type
- effective temperature (K)
- radius
- luminosity (in $log_{10}\frac{L_*}{L_\odot}$)
- distance (in parsec)
- B magnitude
- V magnitude

The csv file was then fed into a Google Colab notebook to generate the H-R diagrams.

2.2. Methodology

Google Colab was used to run a Jupyter notebook in this study, with the Pandas library used for data processing and analysis and Matplotlib for graph plotting. NumPy was also used for mathematical computation.

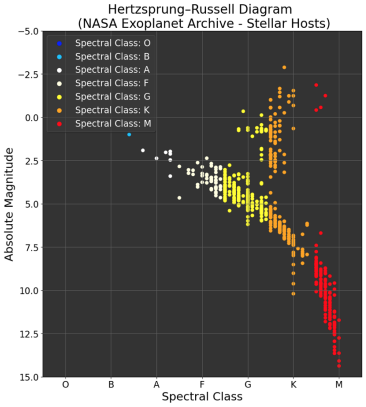
There were originally 36,381 data entries in the downloaded csv file, with each entry representing the data for a single star. Many of these data entries, however, were either duplicates or had missing fields. After removing said entries, 673 stars were plotted in the H-R diagrams (as shown in Figure 1).

If only the host name, distance, B magnitude, and V magnitude are considered, then 3,894 stars can be analyzed after removing duplicates and incomplete data entries. An H-R diagram (Figure A.3) was created based on these stars and is shown in the Appendix A section.

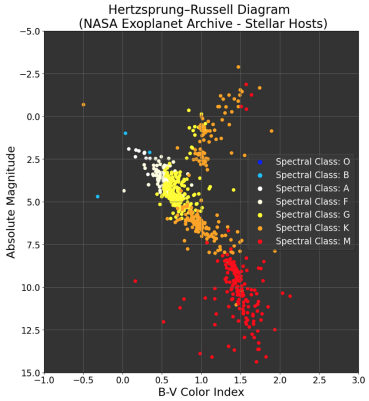
In the study, the stars' B-V color indexes were calculated by subtracting the V magnitudes from the B magnitudes. The absolute magnitude (denoted by M) was calculated from the apparent magnitude (essentially the V magnitude, denoted by m) and the distance (denoted by d, in parsec) with the following formula [1]:

$$M = m - 5log_{10}(\frac{d}{10})$$

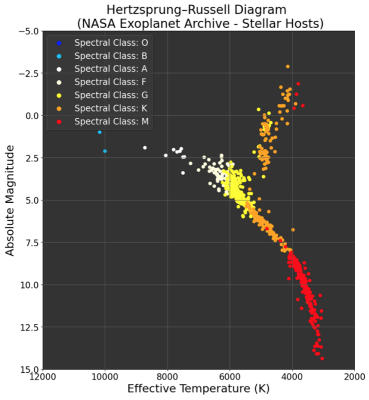
Finally, Matplotlib was used to plot H-R diagrams based on the stars' data, shown in the Results section below.



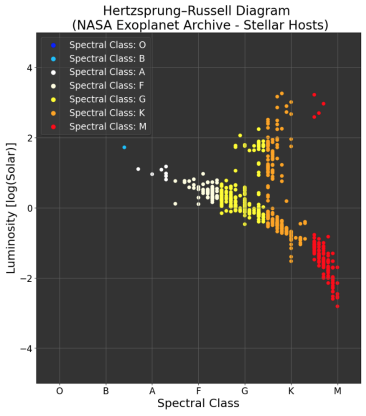
(a) Absolute magnitude v.s Spectral class



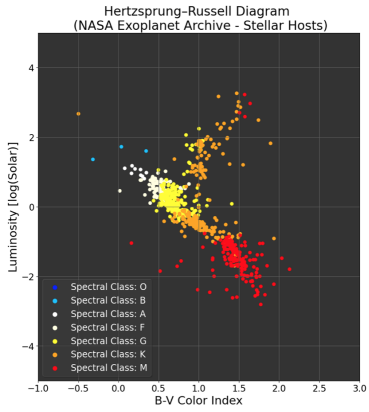
(b) Absolute magnitude v.s B-V color index



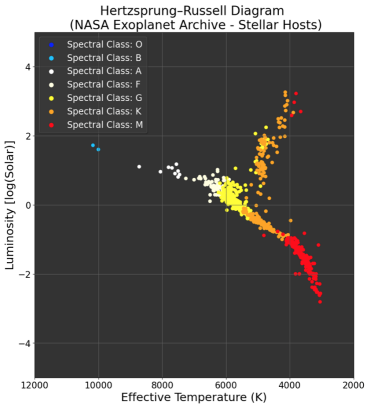
(c) Absolute magnitude v.s Effective Temperature



(d) Luminosity v.s Spectral class



(e) Luminosity v.s B-V color index



(f) Luminosity v.s Effective Temperature

Figure 1: H-R diagrams plotted based on stellar hosts data from NASA Exoplanet Archive [10]

3. Results

Figure 1 shows six H-R diagrams based on the data of the 673 stars. All six diagrams use spectral class, B-V color index, and effective temperature as the x-axis. The top three diagrams use absolute magnitude as the y-axis, while the other three use luminosity. The source code of the Google Colab notebook can be found at [6].

4. Discussion

Figures $1(a)$, $1(b)$, and $1(c)$ show the relationship between the stars' absolute magnitudes and their spectral classes, B-V color indices, or effective temperatures, while figures $1(d)$, $1(e)$, and $1(f)$ show the relationship between the stars' luminosities and their spectral classes, B-V color indices, or effective temperatures. As demonstrated in the figures, these relationships are not random but instead fall into groups, which are discussed in the following subsections.

4.1. Axes of H-R Diagrams

The y-axis in this study is either the star's absolute magnitude or luminosity (in $log_{10}\frac{L_*}{L_\odot}$). Luminosity is defined as a star's intrinsic brightness [13], while absolute magnitude is defined as the magnitude of a star when seen from a distance of 10 parsecs [2]. Both essentially measure the true brightness of a star, independent of its distance.

The x-axis in the study is either the star's spectral class, B-V color index, or effective temperature. The B-V color index essentially indicates the temperature of a star. The lower the B-V index the hotter the star, and the higher the B-V index the cooler the star. The spectral class is a classification of stars based on their spectral characteristics [12]. It classifies stars into O, B, A, F, G, K, or M, a sequence of classes from the hottest (O) to the coolest (M).

4.2. Main Sequence, Giants/Supergiants, White Dwarfs

In the H-R diagrams, a majority of the stars fall into the main sequence [9] region which follows a

band running from the bottom-right of the diagram to the top-left. There are groups of stars near or at the top-right corner (giants [3] or supergiants [14]) and a group of stars near the bottom-left corner (white dwarfs [15]). The patterns of the H-R diagrams align with what has been found and documented in many astronomy research communities.

4.3. Luminosity v.s. Effective Temperature

Figure 2 is an H-R diagram that shows the relationship between stars' luminosities and temperatures, with the sizes of circles in proportion to the radii of the stars. The bigger the star's radius, the larger the size of the star in the diagram.

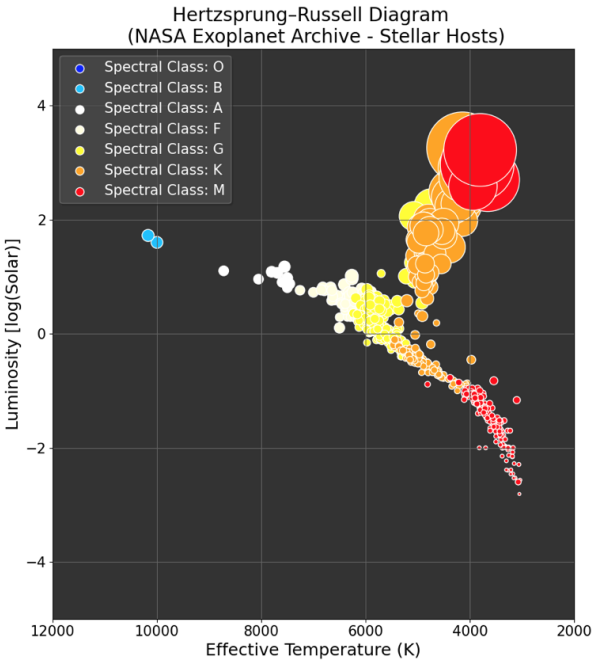


Figure 2: H-R diagram - relationship between stars' luminosities and effective temperatures

The diagram allows us to gauge more information about a star based on its other data and to see trends in star data in general. For example, there is a group of stars of spectral class B near the top-left portion of the diagram. These stars have high temperatures, giving them high luminosity. As we move further to the right, we can see that near the bottom-right corner is a group of stars with spectral class M. These stars are cool, giving them low luminosity.

An interesting group of stars occurs near the top-right corner of the graphs, where despite being cool, these K or M-class stars still have high luminosities. This is because they are gigantic in size – they are supergiants.

The luminosity of a star (the total radiative power output of star) is given by the following formula [11].

$$L_* = 4\pi R^2 \sigma T^4$$

where R is the star's radius, T is the effective temperature, and σ is the Stefan–Boltzmann constant [11]. The observations from Figure 2 match with this.

Appendix A. H-R Diagram with More Stars

In this study, any stellar data entries with missing fields were removed during the data cleaning process. This resulted in large portion of data entries being removed and only 673 stars being plotted in many of the graphs.

If only the host name, distance, B magnitude, and V magnitude data fields were considered during the data cleaning process, then 3,894 stars would be left, with more data for plotting.

Figure A.3 shows the H-R diagram based on the data of these 3,894 stars. The y-axis is the absolute magnitude and the x-axis is the B-V color index. As shown in the diagram, these 3,894 stars follow a similar pattern as what was discussed in the study. The source code of the Google Colab notebook can be found at [7].

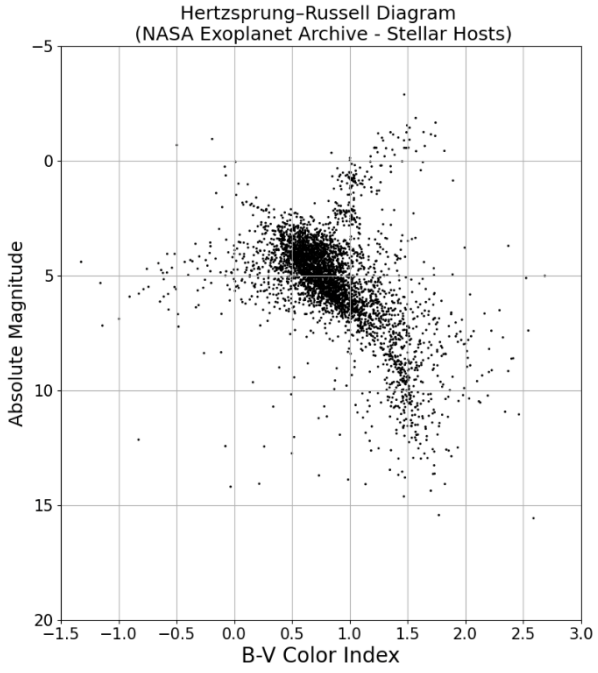


Figure A.3: H-R diagram with more stars

Appendix B. H-R Diagram for Stars from Wikipedia

A list of exoplanetary host stars (around 253 stars) can be found at Wikipedia [5]. After removing duplicates and data entries with missing fields, 156 stars can be plotted.

Figure B.4 shows the H-R diagram based on the data of these 156 stars. The y-axis is absolute magnitude and the x-axis is spectral class. As shown in the diagram, these 156 stars follow a similar pattern as what was discussed in the study. The source code of the Google Colab notebook can be found at [8].

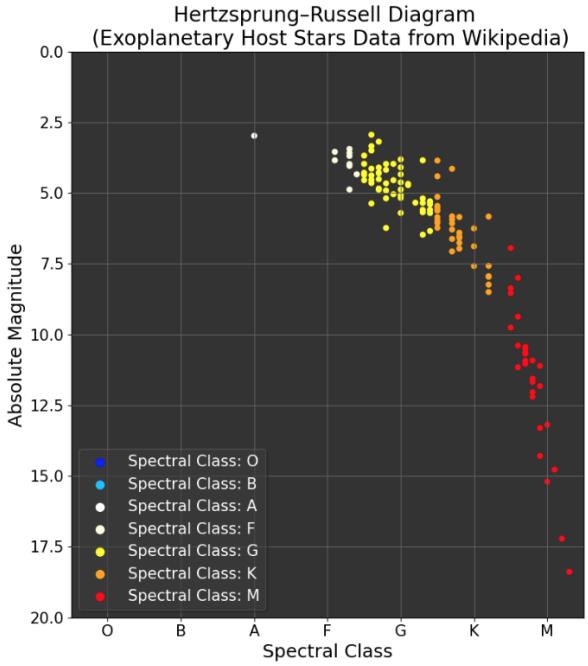


Figure B.4: H-R diagram with stars from Wikipedia

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