Confirming RCB IR Excess with AllWISE and 2MASS Observations

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Abstract: This study confirms that an IR Excess has been observed in all known R Corona Borealis (RCB) stars. We extract the 3 IR bands from 2MASS (J, H, and K), the 4 IR bands from AllWISE (W1, W2, W3, and W4), and the V-band magnitude from APASS DR-9 for the 166 RCB stars identified in the AAVSO VSX database, the 76 RCB stars identified by Tisserand and Clayton, and 200 randomly selected stars. We compare the V-band magnitude to the IR band magnitudes between the RCB stars and the random stars to demonstrate that an IR excess has been observed in all stars that have been assigned to the RCB classification in the J, H and K bands.

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1. Introduction

R Corona Borealis (RCB) stars are rare, carbon-rich, hydrogen deficient stars with sudden declines in brightness at irregular intervals. Only 166 RCB stars have been identified in the AAVSO VSX database, while it is predicted that there are about 5,000 RCB stars in the Galaxy (Clayton 2012). Many stars are identified as RCB stars by means of their light curves or variations in light in photometric observations; however, stars could have similar light curves and not be an RCB star. Clayton found that RCB stars can be distinguished from other stars by observing their excess IR brightness at different IR wavelengths compared to non-RCB stars (Clayton 2012). This IR excess is simply the increased brightness in certain IR bands compared to a non-RCB star. A more recent paper studies the near infrared (NIR) spectrum of suspected RCB stars (Karambelkar 2021) but does not compare them to randomly selected stars. And (Chen 2021) compares NIR-NIR color indexes as insight into choosing stellar models but does not confirm IR excess in NIR or far infrared (FIR) bands.

In our study, we surveyed the IR data of 166 RCB stars from the VSX database and the 76 stars from (Clayton 2012) and (Tisserand 2020) using the 2MASS and AllWISE databases. We surveyed the visible magnitudes for the two sets of RCB stars using the APASS-DR9 database. Additionally, we chose a random sample of 200 stars that are included in 2MASS, AllWISE, and APASS-DR9. We retrieved their IR and visible magnitude data. We compared the visible magnitude data with the IR magnitude data between the RCB stars and the random sample to prove Clayton's hypothesis that every known RCB star has an IR excess.

2. Data Collection and Representation

2.1 RCB Stars

We queried for the 166 RCB stars in the VSX database and the 76 stars in the Tisserand/Clayton paper. We obtained each star's name, AAVSO AUID, equatorial coordinates, associated constellation, and its range of magnitudes. With this data, we ran 242 single object searches on the IRSA 2MASS All-Sky Point Source Catalog using each star's equatorial coordinates. We used the cone search method with a radius of 10 arcseconds. If the search engine returned multiple results, we reduced the radius until we narrowed the search down to one star. With each search, we recorded each star's right ascension, declination, J band selected default magnitude (1.235 μm), H band selected default magnitude (1.662 μm), and K band selected default magnitude (2.159 μm). We ran a similar search for the 242 objects in the AllWISE database and recorded for each star the band 1 (3.4 μm), band 2 (4.6 μm), band 3 (12 μm), and band 4 (22 μm) instrumental profile-fit photometry magnitudes. Using the CSV file, we submitted the list of targets to the Vizier catalog of the APASS-DR9 as a source of visual magnitude data. We chose to use the APASS-DR9 instead of the newer APASS-DR10 because photometric errors are noted to be worse in DR10 than in DR9. Using a search radius of 37.1 arcseconds, we recorded for each star the Johnson V band magnitude. After retrieving all the data, we noticed that all but seven stars from the Tisserand-Clayton list overlapped with the RCB stars in the VSX database. We originally found that only about 40 stars overlapped between the two sources. This increase in the overlap between the two data sets came from the work to identify the stars by sky position rather than relying on star designations.

2.2 Random Sample

We gathered a random sample of 200 non-RCB stars to compare their infrared excess with the RCB stars. Choosing a random sample took several attempts to find a truly random sample of non-RCB stars. The 2MASS database has a sequential ID element; however, the ID is used for both the Point Source Catalog and the Extended Point Source Catalog. The ID element was not evenly distributed within the Point Source Catalog, making it an invalid option for making a random selection. The AllWISE database also had a sequential ID element; however, not all the IDs ($1 < ID < 747634026$) had a corresponding object, making it another invalid option. We discovered another database, the SEIP Source List, that contained a sequential ID and data elements directly from the 2MASS and AllWISE databases. We used Random.org to generate 500 random ID numbers and gathered the right ascension and declination for the 500 stars. We used those 500 right ascension and declination points to search the 2MASS and AllWISE database and included the first 200 stars that were in both 2MASS and AllWISE. We recorded for each of the 200 stars their J band, H band, K band, AllWISE band 1, band 2, band 3, and band 4 magnitudes. Then, we used the right ascension and declination for these 200 stars to obtain the Johnson V band magnitude from the APASS-DR9 database.

2.3 Data Representation

We constructed six CSV files containing one each of the two populations (RCB and Random) and one each of the three IR-Excess databases (2MASS, AllWISE, and APASS-DR9). We coded a Python script that uses NumPy, Pandas, SciPy, and Matplotlib to analyze the six CSV files and to construct seven scatterplots that compare both the RCB and Random stars' visual band magnitude to each IR-band magnitude (2MASS J, H, K bands and AllWISE bands 1, 2, 3, and 4). In each scatterplot we grouped the three RCB star populations together (RCB stars only in VSX, RCB stars only in Tisserand/Clayton, RCB stars in both populations) represented as a square and plotted the randomly selected star population as a circle. We calculated the centroid of each group and plotted the centroids as a square for RCB stars and a circle for randomly selected stars.

Band Name	Band Center (Microns)
J	1.235
H	1.662
K	2.159
Band 1	3.400
Band 2	4.600
Band 3	12.000
Band 4	22.000

Table 1. Center wavelength of IR bands in microns.

3. Analysis

3.1 Scatter Plot Descriptions

The visual band magnitudes ranged from the mag 6 magnitude to mag 18, with almost every star ranging between the mag 10 and mag 17 with roughly uniform scatter.

The strongest evidence for the hypothesis that all RCB stars identified in the VSX catalog, and the Tisserand/Clayton paper (Clayton 2012) show IR excess are in the scatter plots comparing V mag to IR J, H and K bands. The centroids of the randomly sampled population of stars and the centroids for the RCB stars are clearly showing IR brightness greater for RCB stars than for randomly selected stars for these three bands. In the W1, W2, W3 and W4 bands, there is no difference, or the IR brightness is greater for the randomly selected stars, an indication that the dust is emitting more strongly in the shorter infrared wavelengths.

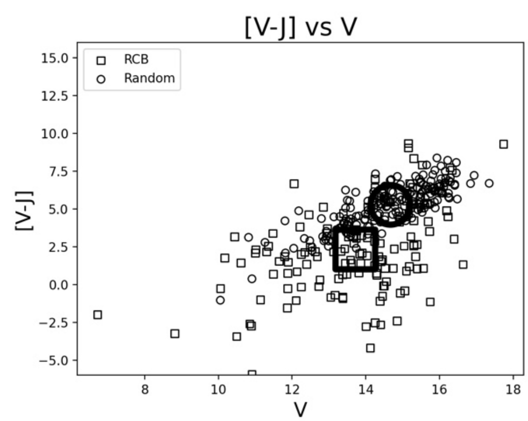

Figure 1. V vs J-V scatter plot of RCB stars and random selection of stars. In each scatter plot, the small squares and circles are individual data points. The large square and circle are the centroid of the respective data point set. Distance between centroids is 3.10 mag.

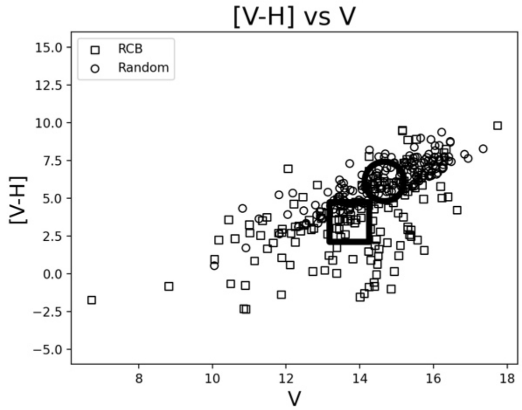

Figure 2. V vs H-V scatter plot of RCB stars and random selection of stars. Distance between centroids is 2.85 mag.

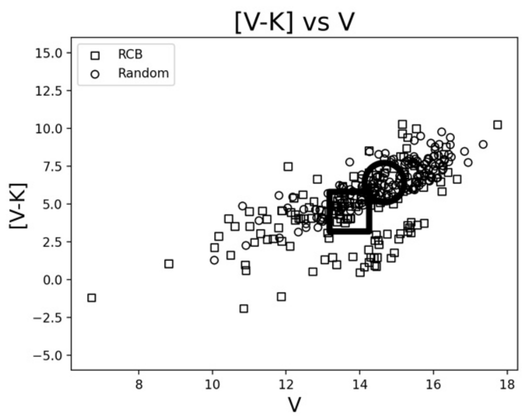

Figure 3. V vs K-V scatter plot of RCB stars and random selection of stars. Distance between centroids is 2.14 mag.

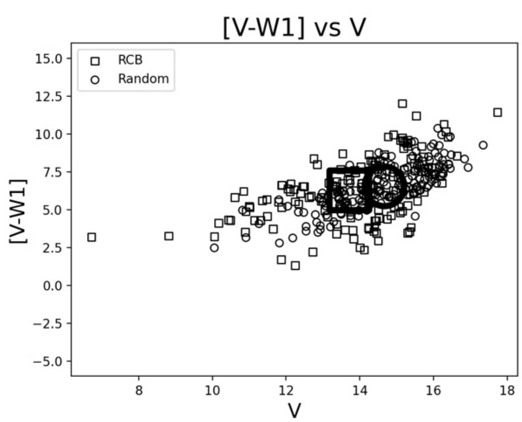

Figure 4. V vs W1-V scatter plot of RCB stars and random selection of stars. Distance between centroids is 0.99 mag.

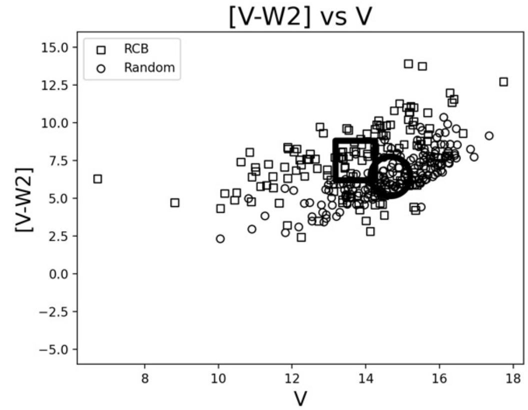

Figure 5. V vs W2-V scatter plot of RCB stars and random selection of stars. Distance between centroids is 1.42 mag.

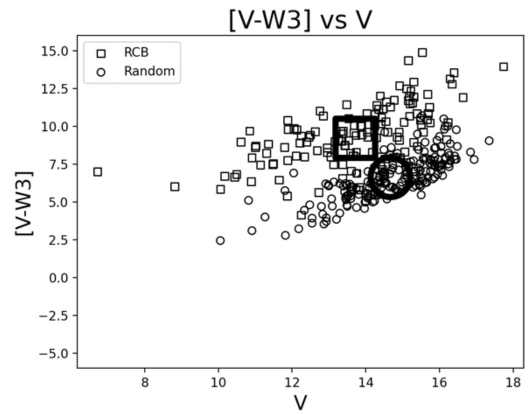

Figure 6. V vs W3-V scatter plot of RCB stars and random selection of stars. Distance between centroids is 2.75 mag.

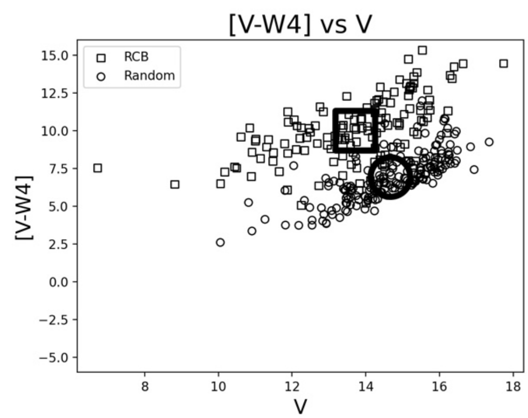

Figure 7. V vs W4-V scatter plot of RCB stars and random selection of stars. Distance between centroids is 3.21 mag.

3.2 IR Brightness Distribution

The difference between RCB stars and randomly selected stars in their IR brightness is also demonstrated in Figures 8 and 9 showing boxplots of the distribution of the two populations compared to their visual magnitudes. The RCB stars in the J, H and K bands are brighter than randomly selected stars with similar V band brightness. It is also interesting to note that the RCB stars drop off in brightness as the bands increase in wavelength (W1 through W4) as compared to randomly selected stars.

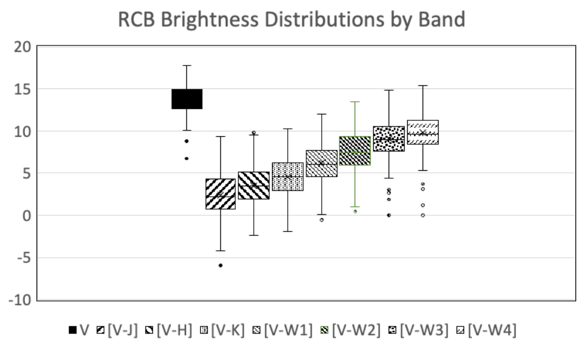

Figure 8. Boxplots of the distribution of V and IR band brightness of RCB stars studied. Note the significant increased brightness of the RCB stars in the J, H and K bands, especially compared to the randomly selected stars in Figure 9.

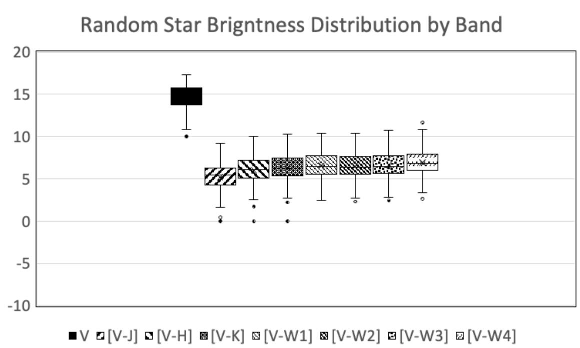

Figure 9. Boxplots of the distribution of V and IR band brightness of randomly selected stars.

4. Conclusion and Potential Projects

4.1 Conclusion

Our study confirms Tisserand and Clayton's hypothesis that RCB stars can be identified by their IR excess. An RCB star's IR excess can almost certainly be distinguishable from other stars when using the AllWISE magnitude for J, H and K bands.

4.2 Potential Projects

Using the data gathered through this study, we hope to build a classifier app using Python that can identify possible RCB stars using the IR excess as described in this paper. Follow up observations of the light curves both in full brightness descent and in the steady state pulsations could be used to confirm the RCB classification to improve the classifier model.

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This research has made use of the International Variable Star Index (VSX) database, operated at AAVSO, Cambridge, Massachusetts, USA.

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