Light Curve of RR Lyrae Variable V* NR Lyr

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Abstract

The goal of this project was to use optical data to construct a light curve for the variable RR Lyrae star V* NR Lyr in the Lyra constellation. It was necessary to perform photometry on images taken over a period of time to observe the change in brightness of the variable star and make a plot of flux over time.

1 Introduction

RR Lyrae are low metallicity, low mass stars and are in the red giant stage of evolution. They are referred to as horizontal branch stars because they form a horizontal band in H-R diagrams, which conveniently makes their absolute magnitudes known. Objects that have intrinsic magnitudes can be used as standard candles—they can be used to determine distances to objects and are an essential component of the distance ladder which is used to determine increasingly larger distances. Observations of RR Lyrae stars can lead to accurate determination of distances within the galaxy and to nearby globular clusters. Before such distances are found, RR Lyrae stars must be identified and have their periods determined. To do so, stars must be observed for changes in their brightness. In this project, V* NR Lyr in the Lyra constellation was observed and the light curve was plotted. Typical RR Lyrae have periods of under a day, so it is reasonable to expect to see changes in brightness over the course of the observations. V* NR Lyr has a previously measured period of .6820 days.

In this project, the light curve for only a single variable star was plotted, however, repeating this process for many more variable stars can lead to a better understanding of the density of the Milky Way at larger distances.

2 Observations

Observations of V* NR Lyr occurred in July 2016 over the span of five observing trips, each lasting several days. There were eighteen nights of observing, with thirteen providing data on V* NR Lyr. Observations occurred at Manastash Ridge Observatory with the .75-meter telescope. The r filter was used for all observations.

In order to gather images, the CCD first had to be cooled down to a low temperature in order to minimize noise from the instrument. The telescope was slewed to the RA and Dec of the star we were observing, although images had slightly different fields each night due to the imprecision of the telescope's pointing. Tracking was turned on so the telescope remained focused on the target as the Earth rotated. Images were taken in the r filter with various exposure times. During the 13 nights with observing data, 177 images were taken of V* NR Lyr.

3 Data and Analysis

Before performing any photometry on the images collected, each image had to be corrected for CCD and telescope imperfections. Bias images are subtracted from each raw image in order to remove CCD noise. These images are short-exposure images taken with the telescope closed. The flats are taken in order to remove smudges and other telescope noise. These images are photos taken of an evenly illuminated dome or sky. Multiple flats and biases were taken each observing night. In order to remove error, a master bias and a master flat image were created by taking the mean of all calibration images. Each raw image is read in and has the master bias subtracted and is divided by the master flat image to produce the final science image. Each observing night had different flats and biases so the process of generating the master bias and flat and then performing the reduction was done separately for each round of observations. Additionally, in order to have an accurate location of the field of view of each observation, each reduced image was run through astrometry.net, which produced a WCS header. These reduced files with new headers were exported so that photometry could be done on each image. It was also found that in several nights, image headers did not contain HJD time, which was necessary to track changes of flux over time. These headers contained only UT time of observation and the HJD time had to be calculated and added to these headers.

The ultimate goal was to perform photometry on science star in each image, as well as a few good reference stars, to see how the brightness of the star of interest varies over time. The photometry data would be used to make a light curve of flux over time. The process of locating the star in each image and choosing good reference stars was challenging. The field of the telescope was changing slightly each night so the stars weren't staying in the same positions and needed to be located in each image. The general method used for locating the stars was to use the headers returned by astrometry.net to turn the images into world coordinates, and perform photometry on a set of Ra and Dec coordinates so the same stars were used in each image.

The challenge of choosing reference stars was more challenging, however. Initially, I tried to choose reference stars by hand, which was difficult because it was hard to tell if these stars wouldn't vary too much on various nights. The final method which was used to both perform photometry on V* NR Lyr and determine reference stars was to use the DAOStarFinder function to find the brightest stars in a single image from one of the nights. The function found 45 such stars, shown in Figure 1. The pixel coordinates of these 45 stars were converted to RA and Dec coordinates. In all 177 images, aperture photometry was performed on these 45 stars. Because not all stars appeared in all images due to the moving field (on such star can be seen on the bottom of Figure 1, it is already off the image), those that didn't appear in all images had to be removed. Stars that weren't present in an image returned a value on 'nan' for their flux, and were easy to remove from the list of stars. Once these stars were removed, 34 stars remained.

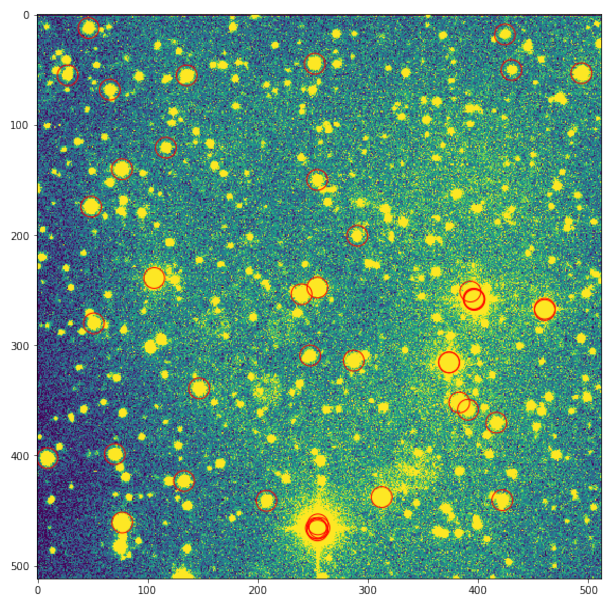

Figure 1: Initial list of stars found using DAOStarFinder function, stars are circled in red.

From this list of stars, it was necessary to choose several good reference stars and determine which star was V* NR Lyr. Since photometry was already performed on those 34 stars, it was simple to plot the flux vs time for each of the 34 stars to determine which ones had a more constant flux over time. An example of a good reference star plot is shown in Figure 2 and a poor reference star is shown in Figure 3. After going through the list of stars and choosing the 9 reference stars, it was also necessary to determine the index in the list of 34 stars of V* NR Lyr. The science star and the 9 reference stars were the only stars for which we looked at the photometry. The stars are shown in Fig 4.

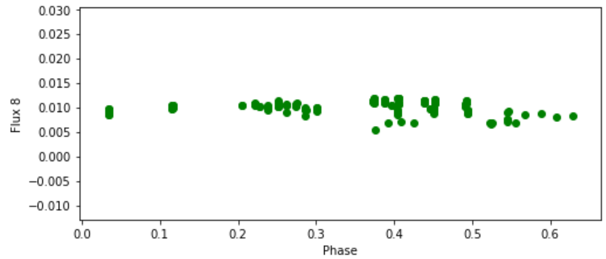

Figure 2: Plot of flux vs time for a good reference star folded over the expected period of the variable star. The y-axis label also contains the index of the star in the dictionary of all stars in Figure 1.

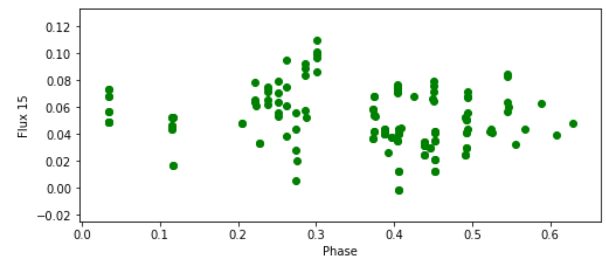

Figure 3: Plot of flux vs time for a poor reference star folded over the expected period of the variable star. The y-axis label also contains the index of the star in the dictionary of all stars in Figure 1.

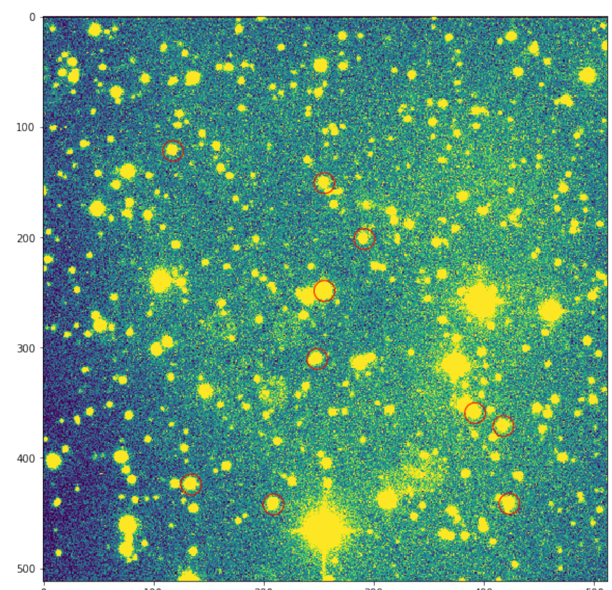

Figure 4: Final reference stars as well as V* NR Lyr circled in red.

Now that there was a list of good reference stars as well as the fluxes of each of the 10 stars of interest in the images, the flux of the variable could be adjusted by averaging the fluxes of the reference stars. This step was necessary since sky conditions changed between observing nights, and it was assumed that the reference star fluxes would remain constant for all nights. The variable star fluxes were divided by the averaged fluxes of the reference stars and Figure 5 shows the plot of flux vs time. Since the observations were spaced out over a month, to see the expected light curve of the star, the plot was folded over the expected period of the variable star: 0.6818 days. The fluxes were converted to magnitudes and two periods of the star were plotted. It was found that the outliers found in the plot were all from the same 3 nights, so it was assumed that observing conditions were poor that night and these nights were omitted from the data set. The resulting plot is shown in Figure 6.

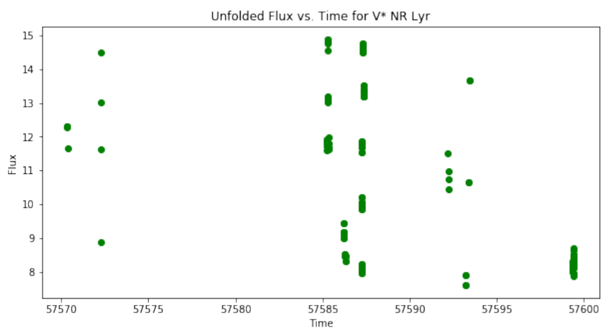

Figure 5: Unfolded light curve of flux vs time for V* NR Lyr.

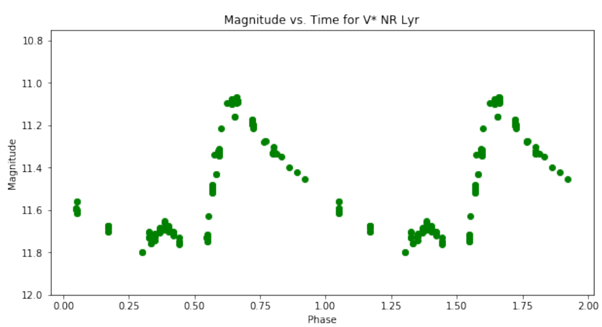

Figure 6: Folded light curve of magnitude vs phase for V* NR Lyr with a period of 0.6818 days, plotted with two periods.

4 Results

The final light curve of V* NR Lyr is shown in Figure 6. It was possible to determine the accuracy of the data collected from the previously collected data Kepler had on the star. The plot of Kepler data in the r filter is shown in Figure 7. Over-plotting the Kepler dataset and the light curve in Figure 6 produces the graph shown in Figure 8. The match between the space telescope data and the data collected at MRO are nearly perfect.

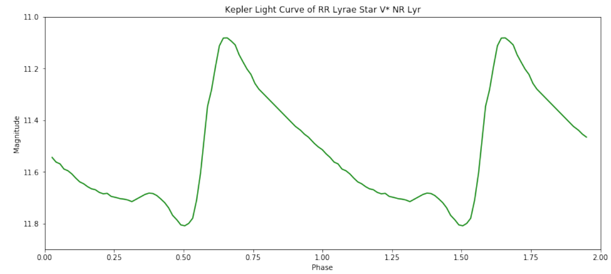

Figure 7: Kepler light curve for V* NR Lyr.

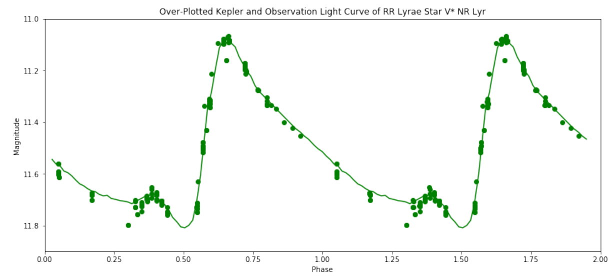

Figure 8: Over-plotted datasets.

Once it was confirmed that the light curve from the data and the Kepler curve matched up well, I used the LombScargle function to confirm the period I had been using. Figure 9 shows the plot of power vs. frequency for the data. The graph looks pretty noisy, and the highest peak, which should give the period of the data gives the incorrect period. The second highest peak gives a period of 0.6814 days for the data, which is closer to the period I had been using (0.6818 days) and the period Kepler found (0.6820 days). It is not clear why the data didn't produce a clear period.

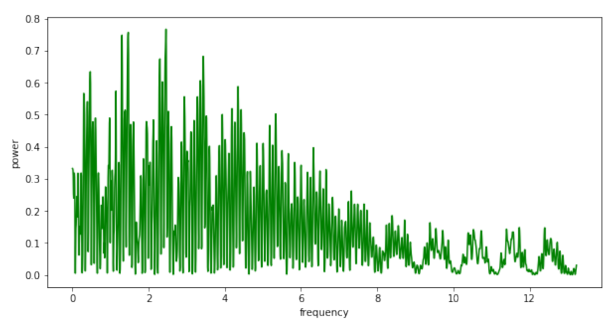

Figure 9: Power vs. frequency graph for the data determined using the LombScargle function.

5 Conclusion

While there were several nights of poor observing data omitted from the final dataset, the final light curve matches incredibly well with the light curve produced by Kepler. The error was certainly small, considering the observations used took place from a small ground-based telescope. The Kepler period and the period found using the second highest peak of the LombScargle graph were close to several decimal points. It would be interesting to consider why the curve-fitting function produced such a noisy graph of power vs. period. This could possibly be attributed to the large gaps of time between observing nights, but another round of data collection would have to occur to confirm this.

6 References

Kepler homepage @ Konkoly Observatory. (2008, December 12). Retrieved from https://konkoly.hu/kepler/