

Midterm Report

Hannah Means

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1 Introduction

RR Lyrae stars are pulsating stars that occupy the horizontal branch of the Hertzsprung-Russell diagram in the instability strip. They have already lived through their main sequences and red giant phases of life, and now burn helium in their cores [2]. RR Lyrae Variables are "standard candles" in measuring galactic distances and are more often found in globular clusters. There are three main classifications: "ab," "c," and "d." Some RR Lyrae stars experience the Blazhko effect, which observes a change in amplitude and frequency over time. Sergey Blazhko noted this effect in 1907, but the cause of it has remained a mystery for 115 years. We are trying to better observe the changes from one Blazhko cycle to the next. My research being conducted this summer will focus on using data from the Transiting Exoplanet Survey Satellite (TESS) [3] to analyze and create models of these stars' pulsations in order to further understand why the Blazhko effect occurs, and what causes it to happen.

2 Procedure

The TESS data from six different RR Lyrae stars (type "c") will be used in our sample. Period 04 [5] will be used to analyze picked up frequencies (primary, harmonic, and sidebands). Models will then be created using the data from Period 04. We will also use the Fourier series, which assists in the relative analysis of the Blazhko period:

$$y(t) = Z + \sum A_i \sin(\omega_i t + \phi_i) \quad (1)$$

where Z is the zero-point offset. The Blazhko period (P_B) shifts can be measured while keeping careful note of any amplitude changes. The scattered background light will also need to be subtracted when measuring these shifts. Using the Global Astrometric Interferometer for Astrophysics (GAIA) [4], we can make more observations and measurements on different stellar parameters of these variable stars, such as luminosity. We can do this because of GAIA's high-precision, which allows us to use parallax to compute said luminosity.

The research being done this summer will mostly involve data analysis, but there may be opportunities for observational work as well. This will be conducted using the MacAdam Student Observatory to obtain light curve data from the Blazhko sample stars. To reduce and analyze this data, we will use AstroImageJ [1]. This program is useful because it allows us to check for spacial resolution. TESS data uses very large pixels (about 21 arc seconds) so neighboring celestial objects fall on the data pixel. The MacAdam data (which has a spacial resolution of about 3 arc seconds) can be used to test the contribution of the neighboring objects to light curve variations because of the high spatial resolution.

3 Period04

Period04 conducts a statistical analysis using multiple frequency fits. The Fourier series is used to calculate a primary frequency. From there, sub-harmonic frequencies can be calculated. These sub-harmonic frequencies are multiples of the primary frequency, which establishes a pattern. This allows for a better fit of the tens of thousands of data points provided by TESS. These sub-harmonic values can be further calculated until the signal-to-noise ratio (SNR) is around five. Going too low can result inaccurate data. It is important to note that these frequency fits are made for independent data sectors that are separated by time gaps. These gaps exist because there are periods where TESS is downloading data.

Once the SNR is at five (or very close to it), a model can be graphed on the scatter plot that is provided by Period 04. The more frequencies that are involved in the model, the more accurately the fit will be. From one sector to the next, we can observe that the model becomes less and less accurate, indicating a change in period and/or amplitude. This modulation is indicative of the Blazhko Effect, though stars like BV Aquarius do get out of phase over time, as shown in Figure 1 and Figure 2 below.

3.1 BV Aquarius

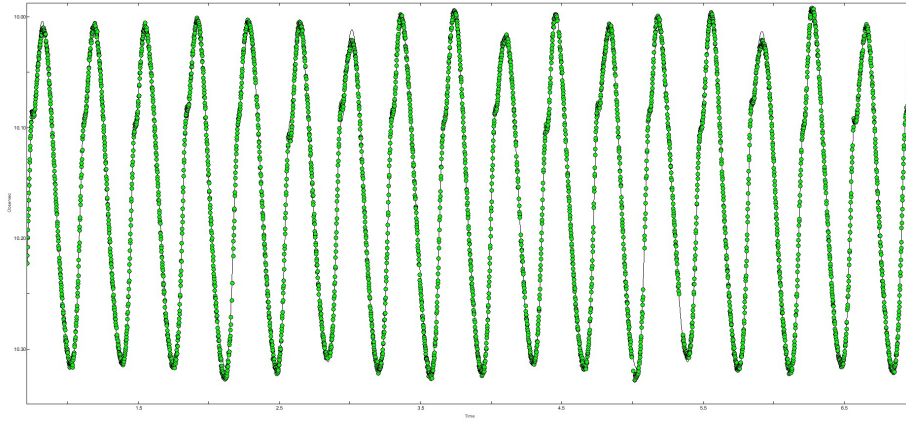


Figure 1: BV Aquarius - Sector 1

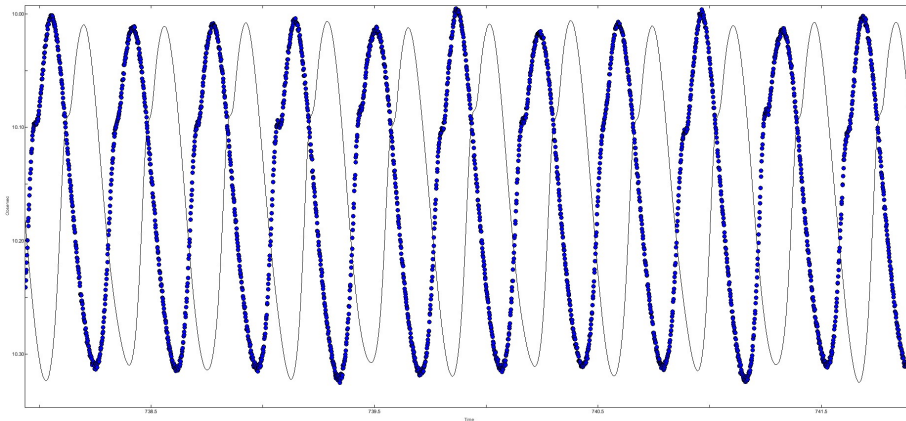


Figure 2: BV Aquarius - Sector 2

The model used in Sector 1, over time, does not accurately fit Sector 2. The pulsations become out of phase from one model to the next. This phase difference is depicted in Figure 3.

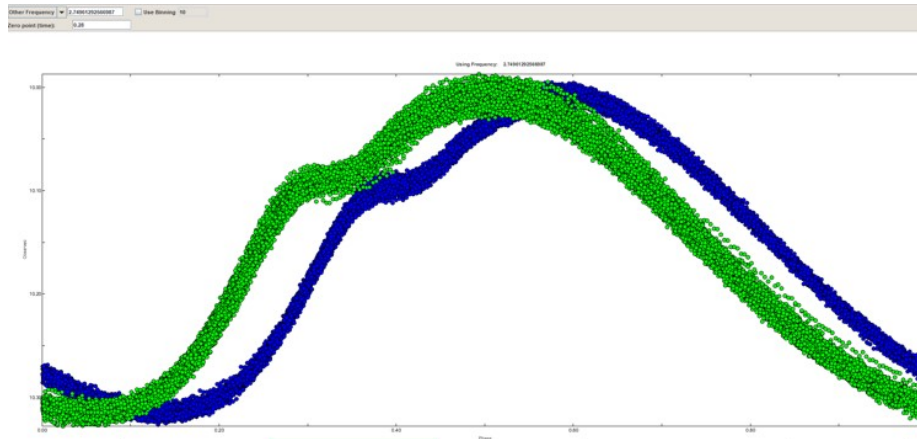


Figure 3: BV Aquarius - Phase v. Observed

4 Excel

Excel has been vital to beginning to understand where period changes begin to occur. To begin the work on Excel, two artificial data files (one from each sector) were created over the same range. It is important to note that each data point in each file was taken two minutes apart but the time step was 0.0015 between points.

Both files were adjusted to begin at the first amplitude minimum in order to create alignment. The residuals were calculated from subtracting the amplitudes from each other (Sector 1 was subtracted from Sector 2). The standard deviation of the residuals was then calculated. The shift (time from Sector 1 subtracted from Sector 2) should also be noted. From there, small time step adjustments can be made. For example, we can shift Sector 1 ahead by five time steps, and find the standard deviation again. The goal is to find where in making adjustments the standard deviation is the smallest. This will tell us where the two sectors are most closely aligned.

Time shifts from 10 steps back until 30 steps forward were made. It was expected that our first point, where the amplitude minimums were aligned, was where the standard deviation would be the smallest. However, the two sectors were aligned 20 minutes ahead of that point (10 steps forward), as shown in Figure 4. The reasoning behind this unexpected result is still unknown at this time.

Time Shift	Julian Shift (Days)	Standard Deviation
10 Back	0.117	0.057611
5 Back	0.1245	0.0447722
No Shift	0.132	0.032711
5 Forward	0.1395	0.022827
10 Forward	0.147	0.018772
15 Forward	0.1545	0.023488
20 Forward	0.162	0.033237
25 Forward	0.1695	0.044704
30 Forward	0.177	0.056765

Plotting the Julian Shift against the Standard Deviation yields the follow parabolic curve and its associated trend-line (Figure 4):

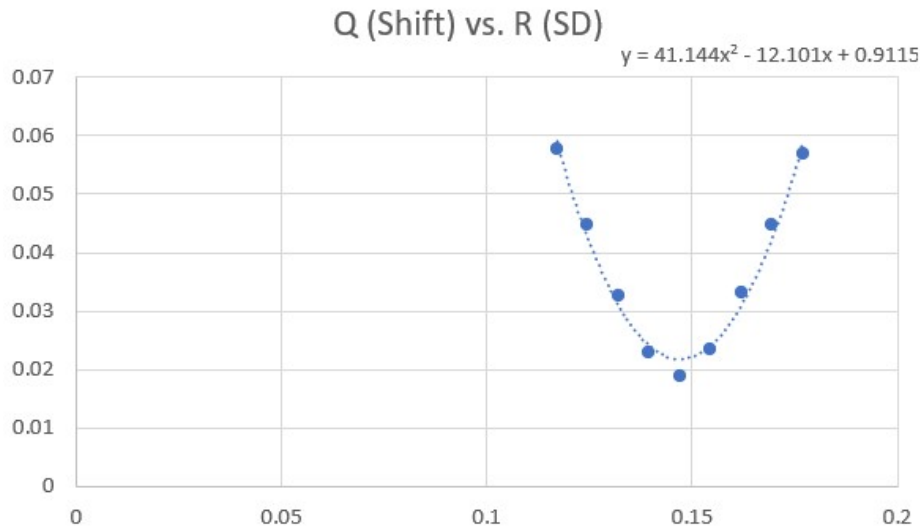


Figure 4: BV Aquarius - Julian Shift (Days) v. Standard Deviation

4.1 Using the Minimum

By taking the derivative of the equation in Figure 4, we can determine the minimum of our parabola provided by the parabolic trend-line. This yields the following value: 0.147056679. This minimum can be used to find the seconds per cycle in different parts of the sector, or even between sector. For example, a Julian Date can be converted to cycles by multiplying by the primary frequency, and then taking that result and dividing by our minimum (converted to seconds). This process can be repeated throughout a sector.

References

- [1] Karen Collins. *AstroImageJ ImageJ for Astronomy*. URL: <https://www.astro.louisville.edu/software/astroimagej/>.
- [2] Paul A. Greer. “Characterisation Of The Blazhko Effect In RR Lyrae Stars Using SuperWASP Data”. In: *PhD thesis The Open University*. (2018).
- [3] MIT. *TESS*. 2022. URL: <https://tess.mit.edu/>.
- [4] NASA. *Gaia*. 2019. URL: <https://solarsystem.nasa.gov/missions/gaia/in-depth/>.
- [5] Period04. *Homepage of Period04*. 2022. URL: <https://www.univie.ac.at/tops/Period04/>.