

Mekbuda: Cepheids and Photometry

Nathaniel Moore

Physics Department, The College of Wooster, Wooster, Ohio 44691, USA

(Dated: May 5, 2017)

In this paper, the star known as Zeta Geminorium (or Mekbuda) was tracked over the course of five non-consecutive nights. This star was tracked because its apparent brightness change over the course of time as it is a Cepheid. By measuring the intensity of Mekbuda I was able to fit a sine wave to the data. The amplitude was found to be within 5.4% of the agreed value and the period was found to be within 0.49% of the accepted value. This poses a confidence boosting-opportunity for future scientists to work in the Wooster Observatory to collect data.

I. INTRODUCTION

The night sky has always provided an astounding view for anyone able to see it. With the naked eye in an area with very little light pollution, from things such as city lights, a person can see thousands of stars. Due to the relatively constant movement of the Earth's spin and the Earth's rotation around the sun, the stars stay in the sky for extended periods of time. As a consequence many ancient people, such as the Greeks and Romans, used the stars for navigation.

One of the easiest ways for the ancients, and the modern person as well, to memorize these stars was to create the constellations. These constellations were made up of some of the brightest stars in the night sky, and so it made logical sense for one to utilize these stars for navigation as one could know which direction they were heading depending on their orientation in the night sky and time of year and night.

For example, a couple constellations are up constantly in the northern hemisphere like Cassiopeia and Ursa Major (better known as the Big Dipper which is part of the constellation) are always up in the northern sky. These would therefore provide a better means in which to navigate as being able to identify these two constellations could tell one the time of night and be used to find Polaris (better known as the North Star). From here, one could use the North Star to navigate the oceans.

After many observations one will notice that some stars' apparent brightness appear to change. This seems strange because the brightness of the stars seem to remain relatively constant during the night. However, after taking plenty of data there definitely is a change in their brightness over the course of several days or even years. As this reality is not necessarily the first that would come to mind without observation the question becomes, would any of our most well known stars change in their apparent brightness over the course of a few days or even years?

In fact, there are many stars in the night sky which are titled as variable stars: stars whose apparent brightness changes with time. For example, Betelgeuse of the Orion constellation, Algol of the Perseus constellation, and Eta Aquilae of the Aquilae constellation are all variable stars. There is reason to believe that the Egyptians were the

first to take notice of the variability of the stars as part of their calendar suggested a relationship to knowing that Algol's apparent brightness changed, meaning that even some of the ancients knew that the stars could change brightness [1]. The star of interest in this research was Zeta Geminorium otherwise known as Mekbuda. As the first name suggests, it is part of the Gemini constellation (more colloquially known as the Twins).

II. THEORY

A. Variable Stars: Cepheids

There is a type of variable star whose apparent brightness has a period called a Cepheid star. This means that over the course of time the apparent brightness of the star will increase and decrease at a constant rate. These stars generally have a period lasting between one and one hundred days [2]. They provide a very important service to astronomers as they can be used as sort of ruler stick that can measure the distance between us and another galaxy [3].

However, the question still remains, how and why do these stars change their brightness? The currently accepted theory is one proposed by Sir Arthur Eddington in 1917. He proposed that it was something akin to an engine. If one considers the ideal gas law, there is a build up of temperature inside the star. This increase in temperature excites the helium atoms within the star, stripping it of both of its electrons. As a consequence of this, the helium atom becomes more opaque, making the light from the star less likely to be emitted [4].

As the temperature is increasing the volume or pressure also needs to increase. However, since there is nothing to keep, other than gravity, together the star can increase its volume. That is to say that the star is surrounded by nothingness and therefore not external forces are applying pressure to the star. As the volume is increased, the temperature at the edges begins to decrease. This allows the helium atom to regain its lost electrons, decreasing its opacity. Eventually the star gets to a certain point, and the gravity of the star begins to pull the edges of the star back towards the center [4]. From this it should follow that something like a sinusoidal fit should

exist as the star does this constantly, with a near constant period.

Another way to think about this system is like a spring. Somehow it starts with either a compression or an expansion, and has been released. The way to complete this analogy is that the spring's length is the volume, while the springs position is the temperature and luminosity of the star. As we know from the mechanics of a spring, the temperature and the volume will go back and forth constantly with no loss of energy, if nothing is being taken away from the system.

B. Magnitude

In order to properly do analysis on stars, there needs to be an equation which was capable of taking out extraneous problems, such as light pollution, equitably distributed clouds, stardust, etc [5]. These are problems because they will interrupt the path of the light coming from the star. In the case of a cloud, it will absorb some of the light coming from the star, while with the light pollution it will interfere with the light's path and make other parts of the sky seem brighter. Fortunately an equation exists that can counter these problems and is presented as follows, [6]

$$m_1 - m_0 = -\frac{5}{2} \log \left(\frac{F_1}{F_0} \right), \quad (1)$$

where m_1 is the apparent magnitude of the desired star, m_0 is the apparent magnitude of the reference star, F_1 was the intensity of light coming from the desired star, and F_0 is the intensity of light coming from the reference star. As suggested by the definitions this equation requires two stars: the desired star as well as a reference star. It is ideal, for this calculation, to have the two stars be in the same photo, or relatively close to each other in the night sky.

This is because if the two stars are not in the same frame then it may be more difficult to say with certainty that the two stars were undergoing the same conditions. The fact that the equation has a Log term is a consequence of the human eye being a logarithmic detector. A more thorough description of Eqn. 1 can be found in Appendix A.

III. PROCEDURE AND APPARATUS

The College of Wooster has an observatory with a 12-inch telescope. This observatory is in a place that lacks much of the light pollution of the city of Wooster making it an ideal location for night observing.

After opening the observatory on a night with very few visible clouds, a two-star alignment needs to be performed. This process revolves around centering Polaris with the telescope followed by another star chosen by the

telescope. This star tended to be in the other half of the sky; often this would be Regulus in the Leo constellation.

Then locate another star of known coordinates, such as 55 Cancri, and write down the coordinates of that star and compare it with another program, such as in Stellarium, to check how well the two-star alignment was performed. If the coordinates were off by a couple degrees then it would be necessary to perform a second two star alignment. After this, point the telescope in the direction of the desired star, in this observational experience: Mekbuda. It could be identified as a star with another star very closely nearby. Then center the telescope on the desired star and write down the coordinates and compare it to the accepted coordinates. This is done so that if the telescope was moved to examine another part of the sky it would be easy to refind the desired star.

Remove the optical lens that allowed for the human eye to look through the telescope and replaced it with the CCD camera. This permits the CCD camera to be connected with the observatory computer and related program. Then collect pictures of Mekbuda in sets of three. Wait several minutes before taking another set of photos.

Take three photos for a single data point. Insure that the third photo is within sixty seconds from the taking of the first photo. Then wait about fifteen minutes until taking another group of three photos. After a night of observing take the photos and use CCDOps to find what the average value is for each data point.

It is difficult to determine what should be counted as a star, so center a box within CCDOps over the star, and changed the box size to fit the star. For an idea of what this looked like, please look at Fig. 1. This would have two primary consequences. First, the box excludes parts of the star which might otherwise be part of it. This is a result of the second consequence, that being that there are dark pixels within the box. Dark pixels have a lower value than the normal value for a star. If there are many dark pixels within the box, then the average for the box will go down. Therefore, sacrifice making the box fit around the primary part of the star to minimize the amount of dark pixels. This likely lost at most twenty pixels, which compared to the normal 600 pixels, is not necessarily a huge loss of light.

In order to check to make sure that the loss of light was not large, take one picture, record each value of every pixel. From here, average all the values and compared it the average value given for the star from CCDOps. The difference of average value can be seen in Appendix B. Take these differences and subtract that value from all photos of that day. Repeat the process for the reference star. Then apply Eqn. 1 and plot the data points in a program like Igor Pro.

As there is likely to be some amount of variation within each data point average together the three photos. This does not reduce the validity of the data as the photos were taken so closely together that any interesting parts of the star would not be missed as a consequence. For example, if all the data points are averaged together for the

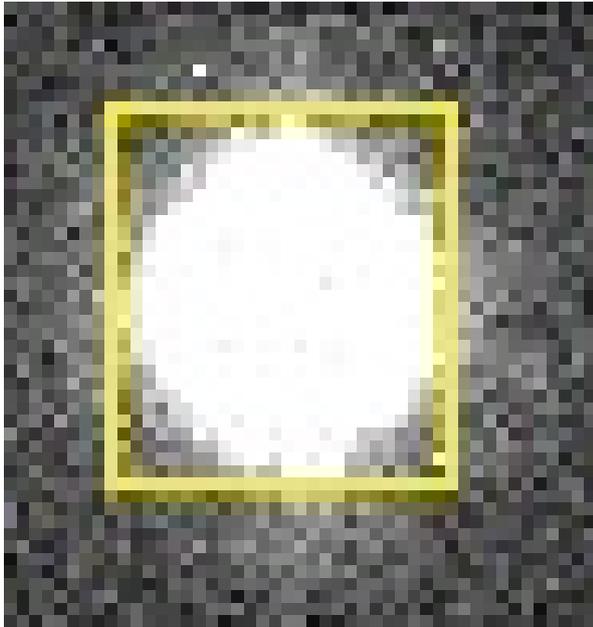


FIG. 1: This picture demonstrates the box that CCDOps would create. It would then add up the value of each pixel within that box, and divide by the number of pixels. As one can notice not all of the star is included in the box, and there is not an insignificant amount of dark pixels within that box that would be included as part of the average

day, some information may be lost; especially if the star actually has a period less than a day. However, by grouping the data points together by minute groups, it permits for the most accurate representation of the star's apparent brightness at that time. Furthermore, by averaging these data points it allows there to be a standard deviation fit which can act somewhat like error bars, which would otherwise be difficult to determine.

IV. RESULTS AND ANALYSIS

A. Results

When the data is plotted in Igor Pro, without standard deviation and error bars, the frequency of the sine wave is $0.622 \text{ Day}^{-1} \pm 0.0181$. When this is translated into a period it is approximately 10.1 days. This value, compared to the accepted value of 10.15 days [7], yields an error value of 0.49%. Igor also gave an amplitude of 0.59 magnitudes. Compared to the accepted value of 0.56 [7], this yields an error value of 5.4%. The graph of this can be seen in Fig. 2.

However, when the standard deviation of each point (recall each point is an average of three other points) is applied to the Igor plot: the period of the sine wave becomes 41.78 days, yielding a percent error of 312%, and the amplitude of the sine wave is given as -0.17 yielding a percent error of 131%. However, there appears to be a

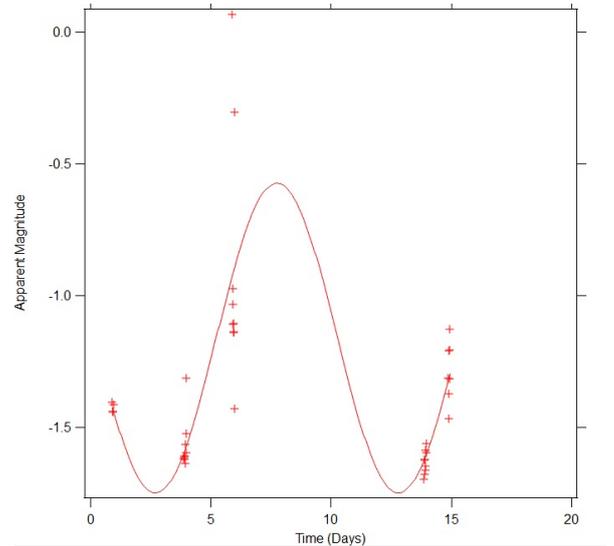


FIG. 2: This graph shows the results in Igor before application of the standard deviations bars with a fit to those data points.

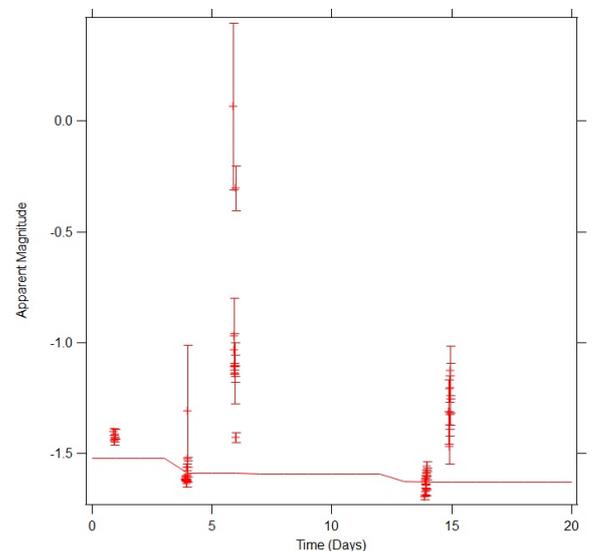


FIG. 3: As one can note from this graph, the resulting “sine” wave looks nothing like one, suggesting that perhaps something is wrong with Igor's error bar inclusion.

fit issue with these parameters as well. Igor also gave a χ^2 value of 2866.26. This plot can be seen in Fig. 3.

To check to make sure that was the lowest possible χ^2 value possible, the data was also plotted in Mathematica. When applied, the values of the period was 10.23 days and the amplitude of the function was 0.615 with a χ^2 value of 1020, which is far better than 2866.26 proposed by Igor. This suggests that something has gone wrong in Igor Pro, and that other methods should be sought out when applying error propagation. The resulting Mathematica Plot can be seen in Fig. 4.

However, when more thoroughly investigated, by creating plots with a made up sine wave, a similar situation

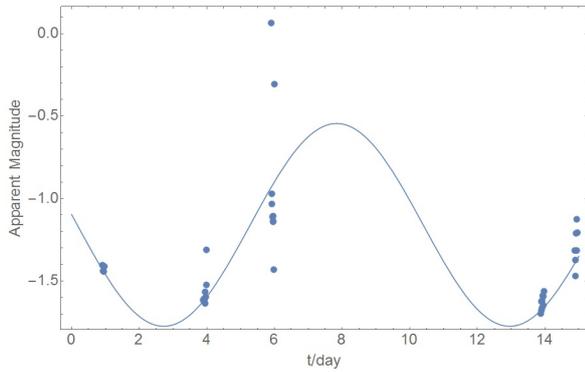


FIG. 4: When applied, the variables as described before there is a χ^2 value of 1020. There is probably a better χ^2 value with slightly other values, but this one certainly shows that the suggested values from when standard deviation were applied in Igor Pro are strange at best and perhaps even wrong.

could not be created in Igor. This suggests that the real problem may be how some of the the standard deviations related to the points plotted were too large in comparison to the majority of other points. When any point which had a standard deviation equal to or larger than 0.1 was removed and plotted in Igor, a sine wave with a period of 10.32 days and a magnitude of 0.408 was made. This yields a percent error of 1.67% on the period and 27.1% on the amplitude. A graph of this can be seen in Fig. 5

It should be noted that the points that were removed were likely affected by cloud cover and the star going behind trees. These problem points were especially prevalent at the end of a day, when the star was most likely to be behind a tree, and on the third day which had many clouds. By taking out these data points that the overall data is not compromised much, as these points likely broke some of the base assumptions of Eqn. 1.

B. Potential Areas for Error

There are a couple sources of error. First, clouds do provide quite the problem. If a cloud, which was barely visible, passed in front of one of the stars in a frame but not the other this could have affected that picture. That is to say that the amount and consistency of the object that the light would have to pass through was different breaking down Eqn. 1. Furthermore, if star was to pass behind a tree this could also have adverse effects. Both of these cases were very real possibilities in terms of the purview of this observational situation.

V. CONCLUSIONS

In conclusion it seems plausible to use the Wooster Telescope as a way to measure the period and amplitude

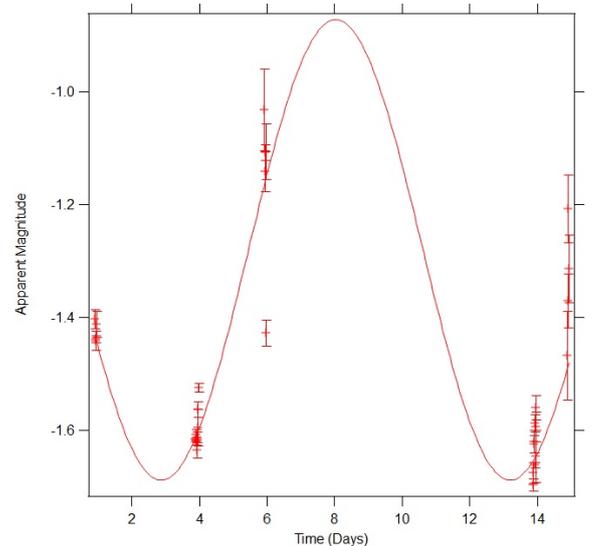


FIG. 5: This graph displays the data points with standard deviation points, with several data points removed from the graph whose standard deviation was far too high.

of Cepheid stars. When the standard deviations were not applied, the results were very close to the agreed upon values. However, when standard deviation was applied it seems to disagree with the agreed value, although the validity of those results is in question by me. By removing the points with a high standard deviation, it produced a more likely sine wave, which actually went through at least one data point a day. To reiterate the findings without standard deviation, the amplitude was found to be within 4.9% of the accepted value and the period was found to be within 0.49% of the accepted value. With standard deviation bars the error was found to be 1.67% and 27.1%.

VI. FUTURE WORK

In terms of this project, taking more data is really necessary. I am strongly confident that by taking even two more nights worth of data the results of this project will be astronomically better. Further improvement could also go into applying dark and light frames to each of the frames taken. This was not initially done as getting a light frame proved harder than expected, also if it was a cloudy night a dark frame may take out a reference star which is un-ideal if one is using Eqn. 1.

It may also be possible to increase the accuracy of the intensity by averaging over only the star instead of a box around the center of the star which includes part of space that are not the star. This however, especially for large stars, can take a very long time. However, if a program could be written the accuracy of this project could again be increased.

However, with this research as a preemptive search with the telescope it has shown that it is in fact possible

to track variable stars, and therefore may be possible to track even more complex stars than those with something akin to a sinusoid. It may even be possible to track the morphology of galaxies.

VII. ACKNOWLEDGMENTS

I would like to first thank Dr. Leary for helping me out throughout all of Junior IS. Next I would like to thank Dr. Lindner for getting me into astronomy, and also trusting me to continue in Colm Hall's footsteps in

using the observatory. Without them I would have never gotten this far in my research.

Next I would like thank Zane Thornburg for being an excellent friend and lab mate who encouraged me to continue taking data. I would also like to extend a thank you to Kyle McNickle for staying up writing this lab report and going to Taco Bell multiple times throughout this process. Finally I would like to thank Kassady Martinez-Murphy for coming out to the observatory every once and a while, which helped me maintain some semblance of my sanity.

-
- [1] Porceddu, Sebastian, and Lauri Jetsu, Tapio Markkanen, and Jaana Toivari-Viitala. "Evidence of Periodicity in Ancient Egyptian Calendars of Lucky and Unlucky Days." *Cambridge Archaeological Journal* Vol 18(3): 2008.
 - [2] Hyper Physics. "Cepheid Variables." <http://hyperphysics.phy-astr.gsu.edu/hbase/Astro/cepheid.html>
 - [3] NASA. "Cepheids." <https://starchild.gsfc.nasa.gov/docs/StarChild/questions/cepheids.html>
 - [4] Eddington, Arthur. "The Pulsation Theory of Cepheid Variables." *The Observatory*, Vol 40:1917. http://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query1917Obs...40..290E&data_type=PDF_HIGH&whole_paper=YES&type=PRINTER&filetype=.pdf.
 - [5] NASA. "Stardust Not likely to Block Planet Portraits." <https://www.nasa.gov/jpl/keck/stardust-not-likely-to-block-planet-portraits>
 - [6] Western Kentucky University "Apparent Magnitude." <http://astro.wku.edu/labs/m100/mags.html>.
 - [7] Harvard. "VizieR." <http://vizier.cfa.harvard.edu/viz-bin/VizieR-4>

APPENDIX A: APPARENT MAGNITUDES

1. Loose Derivation of the Apparent Magnitude Equation

The question of where Eqn. 1 is a prudent question. It comes from the idea that human eyes are a logarithmic detector. According to the system used during the time of Norman Robert Pogson, a change in five magnitudes was roughly a change in a factor of 100 light intensity (West Virginia University np). It should therefore follow that each magnitude is equal to

$$100^{\frac{1}{5}} \approx 2.512. \quad (\text{A1})$$

If we expand this equation to include a difference in magnitudes we find that

$$100^{\frac{m_1 - m_0}{5}} = \frac{F_1}{F_0}, \quad (\text{A2})$$

where F_1 and F_0 are the intensities or flux of the star. We can redefine $m_1 - m_0$ to be Δm , and solve for that to find Eqn. 1.

2. Defence of Using the Values as the Flux values

While I was using the CCDOps program to measure the various values of Mekbuda it was important for me to use the program's output called "Value" and "Average Value." These values were actually the amount of electrons detected by CCD camera as a result of the photons being incident on the CCD plates. There is therefore a direct proportionality between the intensity and flux of the star to the value outputted by the CCD camera.

APPENDIX B: RAW DATA

For the five nights of data, I calculated the difference in average values for one photo each night. The results

TABLE I: Average Values Mekkuda

Avg. Value	Calculated	Avg. Difference
5743.644	5611.95	131.6945
5913.657	5815.14	98.51742
3574.388	2455.61	1118.788
6474.427	6347.05	127.387
5046.804	4888.91	157.8937

TABLE II: Average Values Reference Star

Avg. Value	Calculated	Avg. Difference
1559.68	1598.799	39.119
1626.7	1626.7	338.823
1194.96	1104.47	90.49
2015.333	1658.29	357.043
1454.896	1410.8	44.096

of this can be seen in Table I. The difference would then be subtracted from all photos from that night. A similar situation was done for the reference star and can be seen in Table II.