Finding the Distance to M15 Using RR Lyrae Variable Star Magnitudes

Kyle Irby

Abstract

RR Lyrae variable stars are similar to Cepheid variables in the fact that their absolute magnitude and period are proportional to the absolute luminosity. Therefore, they are excellent for calculating distances using their apparent magnitudes, as these stars are a type of standard candle, since their absolute magnitude can be determined. Absolute magnitude, the same as luminosity, is equal to the magnitude of a star if it were only ten parsecs away from Earth. RR Lyrae stars are used for finding distances to relatively nearby objects within the Milky Way because they are far dimmer than Cepheid variables. This is why they have regularly been used to determine the distances to globular clusters; large, spherical masses of stars which orbit the center of our own Milky Way Galaxy. Specifically, M15 is known to have many RR Lyrae variable stars within the cluster. By measuring the average apparent magnitude (the midpoint between its brightest and its dimmest apparent magnitude) of several of the variables at different times, I was able to ultimately determine the distance to the star cluster. By using the equation $M = m + 5 - 5\log(d)$ when $M = 0.75$ as the absolute magnitude of an RR Lyrae, and $m = 15.83$ for the average apparent magnitude of the measured RR Lyrae stars, the measured distance resulted in 33,800 light years. The accepted distance is 32,600 light years, meaning that the measured result is not far off, and thereby supporting the idea that RR Lyrae variable stars can reliably be used to find distances to globular clusters within the Milky Way Galaxy.

Introduction

RR Lyrae variable stars are pulsating variable stars related to the Cepheids, but are intrinsically less luminous, and have shorter periods and shallower amplitudes of variability than their Cepheid cousins; however, like the Cepheid variables, their luminosity is proportional to their period. Their periods typically last between 0.5 - 1 days. Similarly to Cepheid variables, their luminosity is proportional to their period.

The period of RR Lyrae stars are short enough that one cycle can be measured in one night. Since their period and amplitude of variability are related to their absolute magnitude, it is possible to use the inverse square law of the provocation of light simply by determining the average apparent magnitude of each of the stars. This method can ultimately be used in order to find the distance to globular clusters within the Milky Way.

Using the Mark Slade Remote Observatory, I estimated the brightness of different RR Lyrae variable stars within the M15 globular cluster. By using their apparent magnitudes, as well as their absolute magnitude which was already known, it was possible to perform distance calculations on the stars. Therefore, RR Lyrae variable stars can be used as standard candles to find distances to objects within the Milky Way Galaxy.

For my observations, I used the 102 millimeter F7 apochromatic refractor of the Mark Slade Remote Observatory. The telescope is mounted on an Explore Scientific/Losmandy G11 mount using the PMC8 control system. In addition, guiding was not needed, as the telescope uses the TDM drive correction system. The imaging camera that I used on the refractor is the QHY163c OSC CMOS, a 16 megapixel camera which uses a 4,656 x 3,522 array of 3.8 x 3.8 micron pixels. This resulted in an image plate scale of 1.098 arcseconds per pixel. The facility is a small, internet accessible observatory in Wilderness, Virginia which is operated by the Rappahannock Astronomy Club and Mark Slade Remote Observatory Commission. In addition, it is supported by Explore Scientific LLC, a commercial telescope company that sells high quality instruments to the amateur astronomy community.

Procedure

My data analysis consisted of nine sets of images of M15 taken on different nights, with each set consisting of four 120 sub exposures. The images were taken on different nights and at different times in order to insure that the RR Lyrae variable stars would be at different stages of their cycles. Two of the nine final images were not analyzed because they were too far out of focus.

Once the images were collected, I used a reference image of M15, taken with a 12-inch LX200 telescope of the Mark Slade Remote Observatory. This reference image had several RR Lyrae variables identified, as well as the photometric magnitudes of several comparison stars that were determined in previous research. I used this reference image in order to annotate the collected images, marking the locations of the RR Lyrae stars and stars of known magnitude. I also blinked two of the collected images together to locate three other variable stars. Each of these stars were then found and marked on each of the seven images that would be measured.

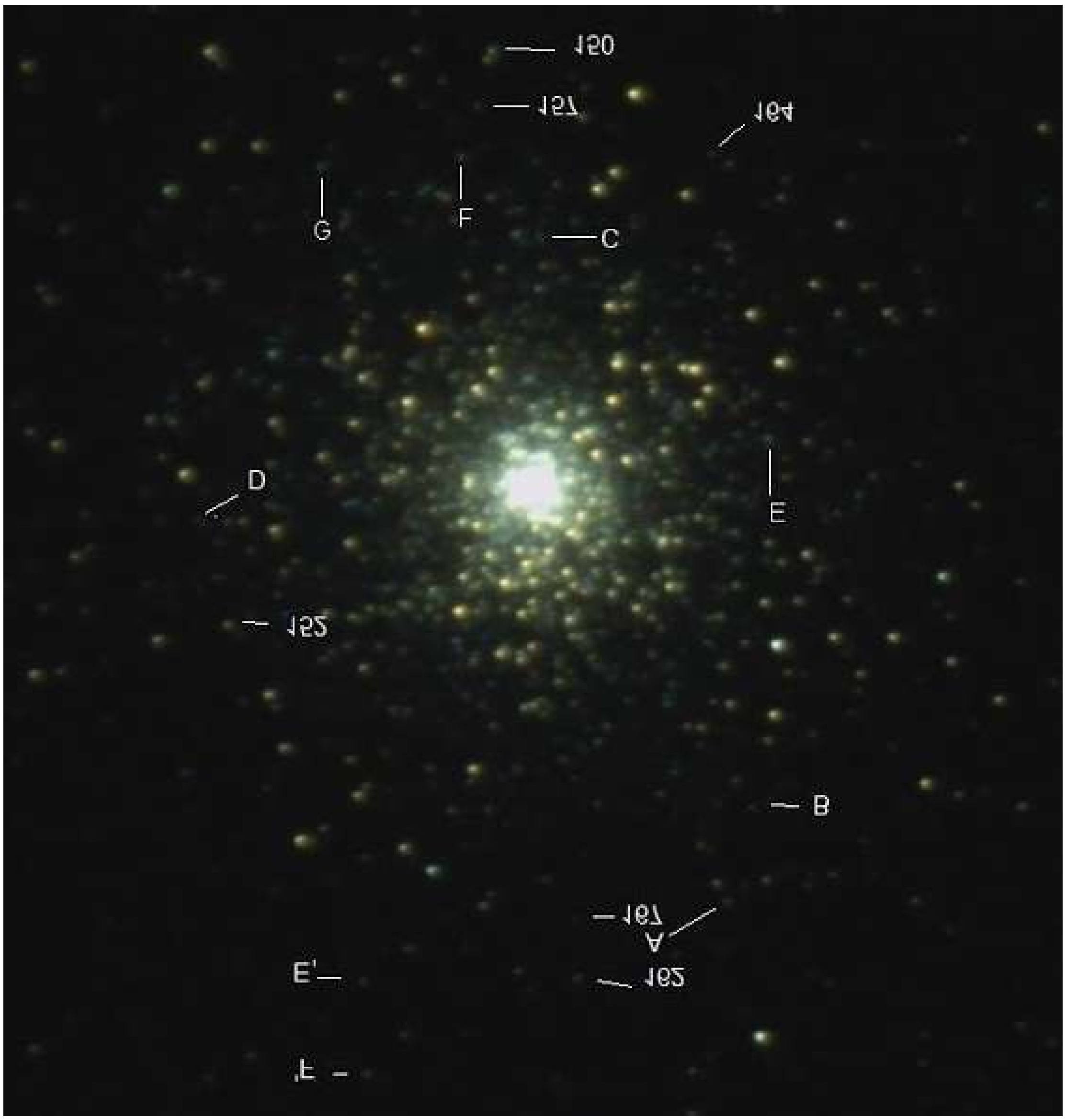
After marking the stars, I estimated the apparent magnitudes for five RR Lyrae variable stars in the cluster. These stars coincide with A, D, E, F, and G on the reference image. This was done by comparing the brightness of the RR Lyrae to the brightness of two known comparison stars in the cluster, one brighter and one dimmer. By using an arbitrary step method, I broke the difference in light levels between the two comparison stars into about five steps. I then determined which step would best match the apparent magnitude of the RR Lyrae star being measured.

Once the apparent magnitude of the RR Lyrae was determined, the value was entered into a spreadsheet. This was done for each of the five variable stars. This process was then repeated six more times, for each of the remaining images, and an average apparent magnitude was then determined for each of the five RR Lyrae stars. Finally, the average of the five RR Lyrae apparent magnitudes was determined, and was used as the value m in the equation $M = m + 5 - 5\log(d)$. In the equation, M is the absolute magnitude of RR Lyrae stars, which is 0.75, m is the average apparent magnitude of the five variable stars, and d is the distance in parsecs to the globular cluster. After getting this value of d, I converted it to light years by multiplying the value by 3.26.

Results

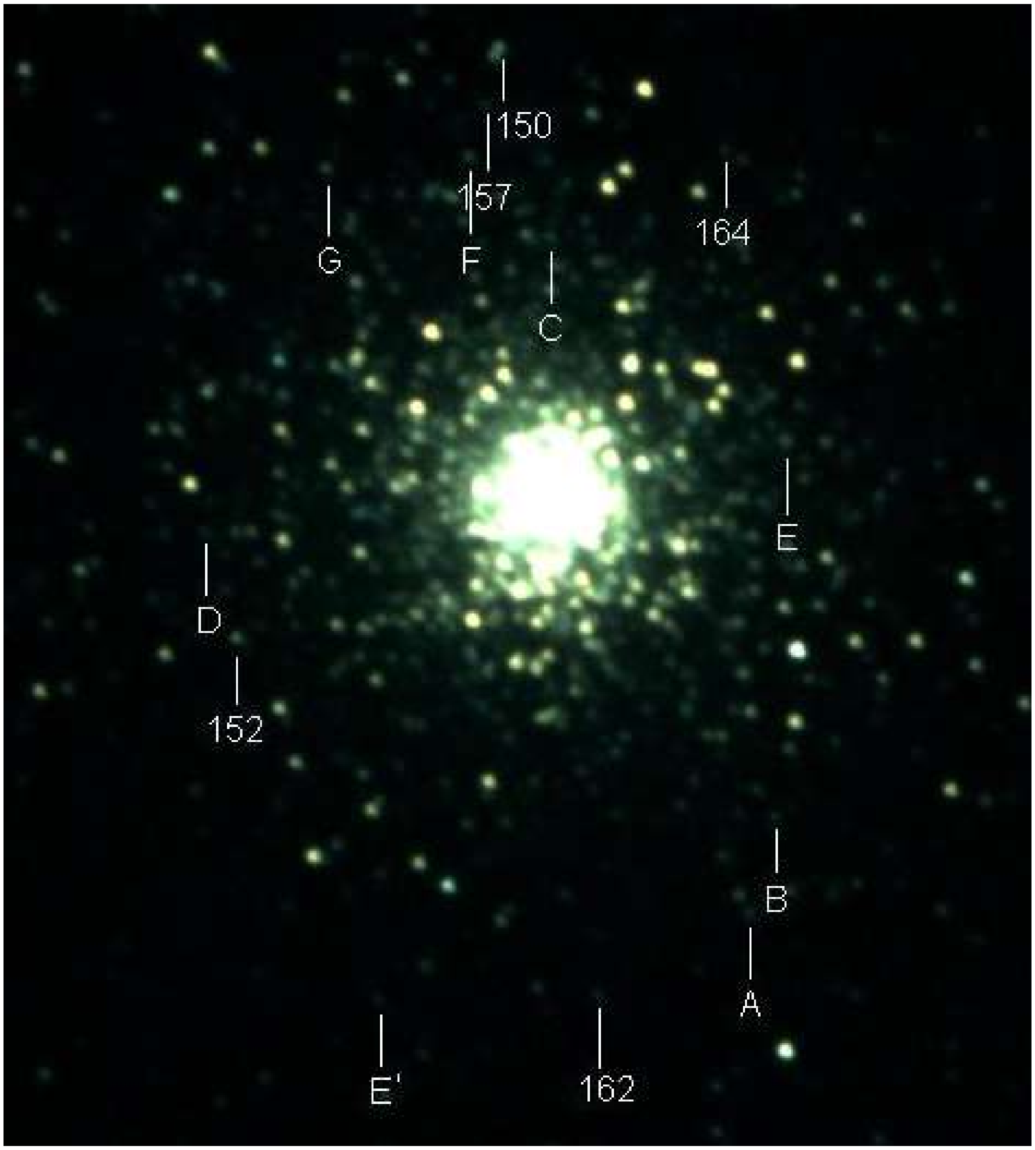
Below is the 12-inch LX200 reference image of M15 that I initially used in order to locate variables and stars of known magnitude within the cluster. Several of the markings appear upside down because the image had to be vertically flipped in order to match the orientation of the collected images.

LX200 M15 Reference Image

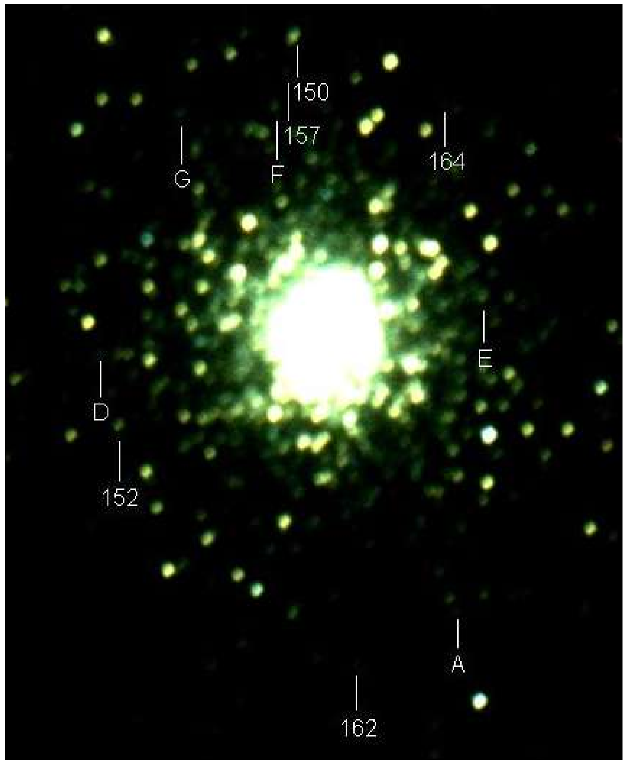


Below are each of the images that I collected and used for measurements. Round3.fit and Round5.fit were eliminated from the analysis due to poor focus, which is why they are not represented.

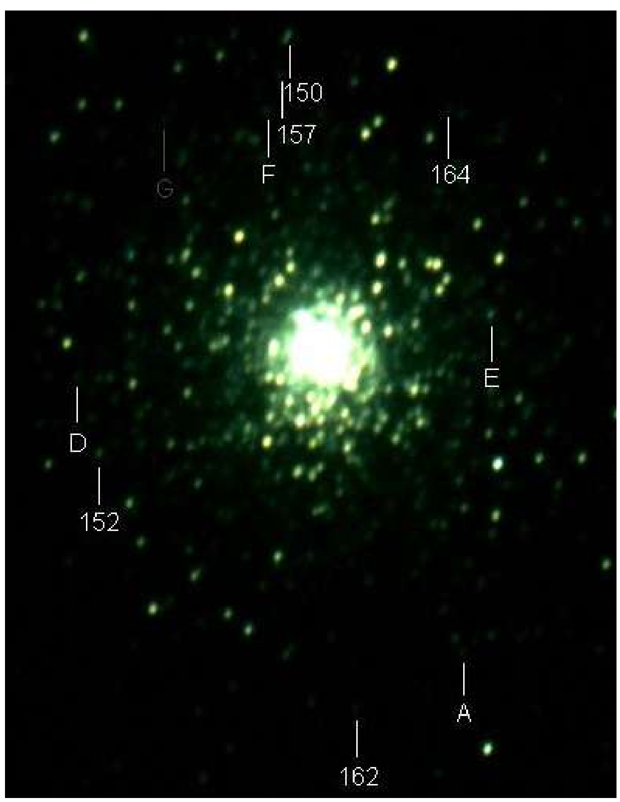
Round1.fit



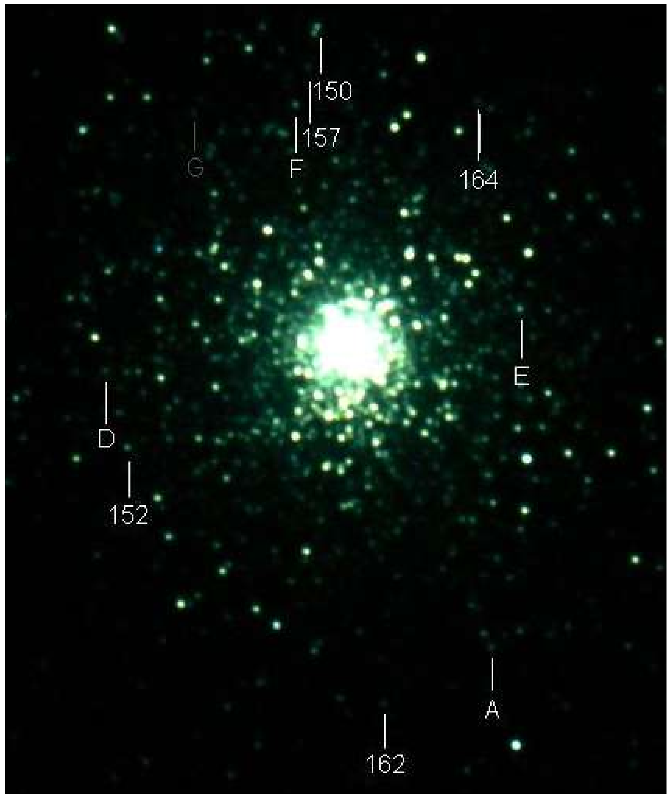
Round2.fit



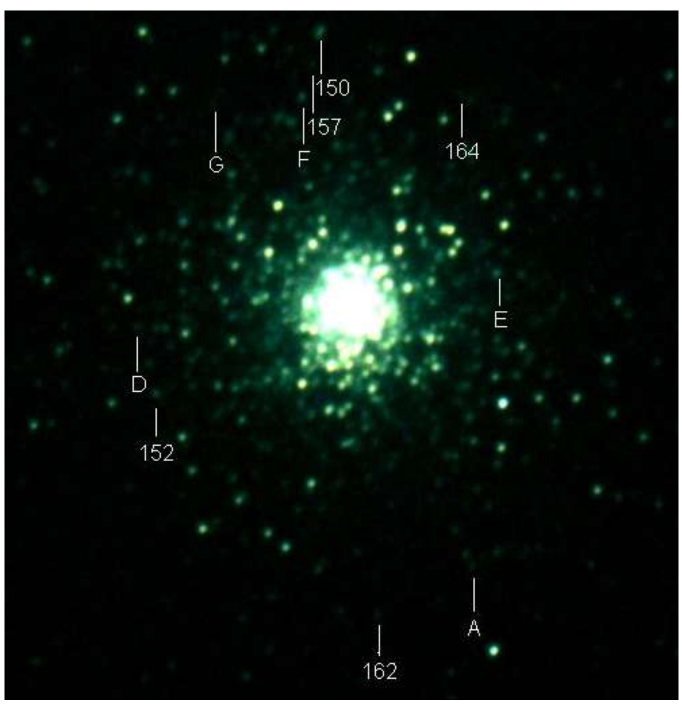
Round4.fit



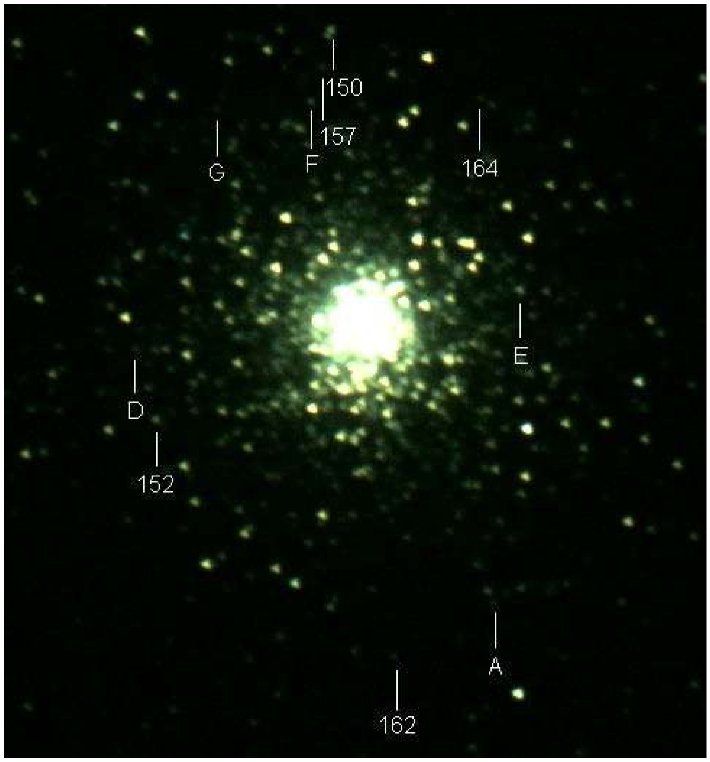
Round6.fit



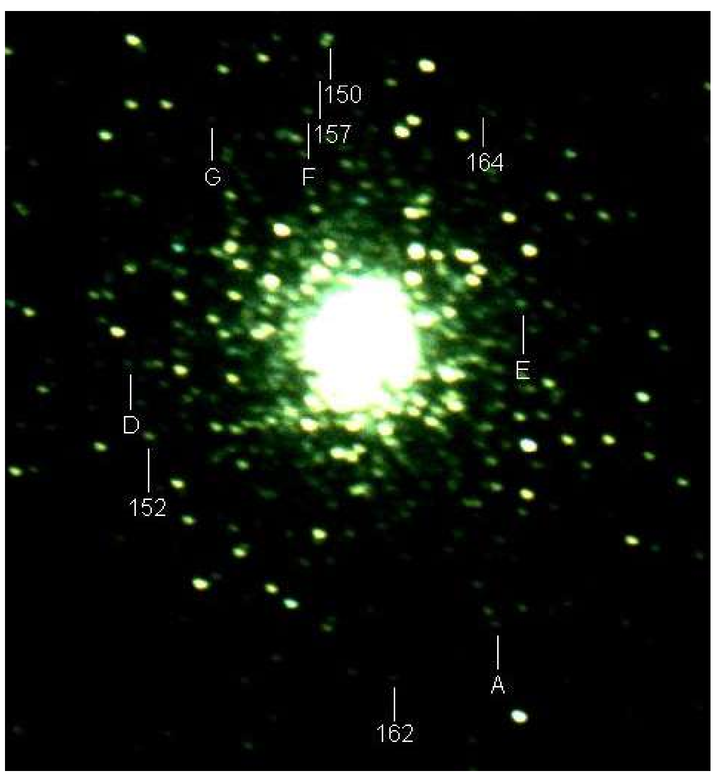
Round7.fit



Round8.fit



Round9.fit



Below is the data table which holds all of the estimated apparent magnitudes for each of the measured RR Lyrae stars. The average apparent magnitudes are in the second table.

Table 1 - Measured Apparent Magnitudes for RR Lyrae Variable Stars

Star	Round1.fit	Round2.fit	Round4.fit	Round6.fit	Round7.fit	Round8.fit	Round9.fit
A	16.2	16.2	16.1	15.4	16	16.3	15.8
D	16.4	16.2	16.3	15.6	16.1	16.2	16
E	15.4	15.3	15	14.9	14.9	15	15.3
F	15.6	15.6	16	15.3	15.2	15.4	15.7
G	16.4	15.9	16.6	16.5	16.6	16.5	16.4

Table 2 - Average Apparent Magnitudes for RR Lyrae Variable Stars

Star	Average Magnitudes
A	16
D	16.11
E	15.11
F	15.54
G	16.41
	Final Average = 15.83

Below are the equations that I used, as well as the steps taken in order to solve for the distance to M15.

M = m + 5 - 5log(d)

M = Absolute Magnitude = 0.75

m = Average Apparent Magnitude of RR Lyrae Variability = 15.83

d = Distance (Parsecs)

1 Parsec = 3.26 Light Years

$0.75 = 15.83 + 5 - 5\log(d)$

$-15.08 = 5 - 5\log(d)$

$-20.08 = -5\log(d)$

$4.016 = \log(d)$

$d = 10^{4.016}$

d = 10,375 parsecs

d = 33,800 light years

Therefore, the distance to M15 based on the measured apparent magnitude values is 33,800 light years.

Conclusion

Despite the limitations in measurement accuracy, the calculated distance to the M15 cluster was close to the accepted value of 32,600 light years. While I found it to be around 33,800 light years, this is still extremely close. The fact that the two distances are only 1,200 light years apart shows the reliability of finding distances using variable star measurements. This confirms the idea that RR Lyrae variable stars can be used as standard candles to find distances to objects within the Milky Way Galaxy.

The variance between the accepted and measured distance to M15 in this study could have been caused by several experimental errors. Firstly, there was variability due to the fact that I had to use a visual estimation method to determine the apparent magnitudes of the stars from the images. We did not have access to equipment such as measuring engines or photometric software. A second source of error in the data was due to the limited sample size. The relative small size of the telescope limited the number of RR Lyrae stars that could be detected within the images. Thirdly, we were unable to attain images from a single cycle over one night. Instead, we had to take images over several nights, hoping that enough images would allow the maximum and minimum apparent magnitude values to be recorded at some point in the imaging sequence.