Thermally Pulsing AGB Stars

Owen Johnson and Daniel Opdahl

Physics

Early Stellar Evolution

Stars are complex structures that go through many evolutions throughout their lifetimes. They can lose mass, change in brightness temperature and radius, and even explode. It is important to be able to understand these changes and how they occur in order to fully understand the complex inner workings of stars. One of the most fundamental tools that astronomers use to do this is the HR diagram.

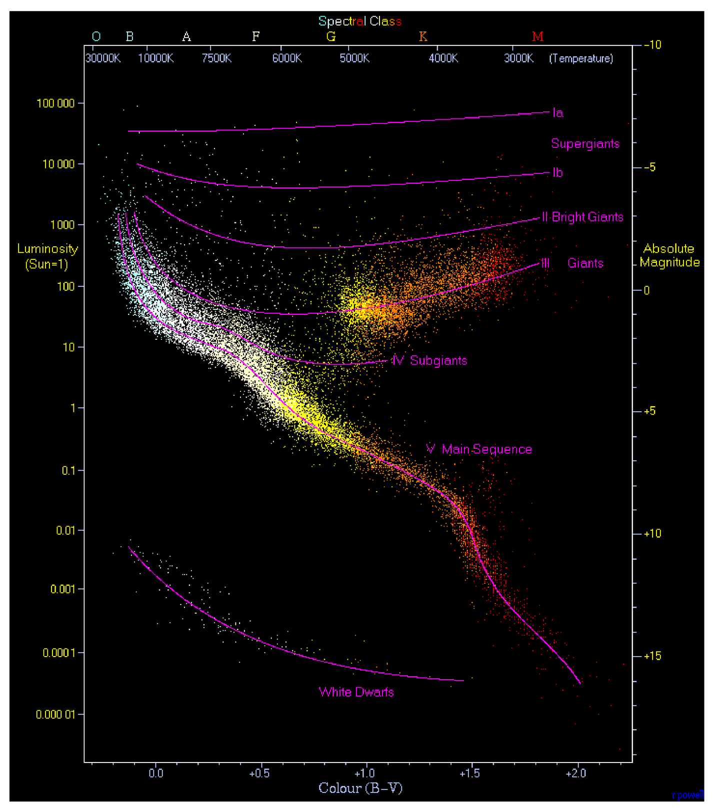

Figure 1. An example of an HR diagram, on the horizontal axis is the temperature, and the color of the star. Luminosity and magnitude are on the vertical axis. [1]

- Stars spend the majority of their lifetime, 90% of it, on the main sequence fusing hydrogen into helium.
- When the star runs out of hydrogen in it's core it begins to move off the main sequence and onto the giant branch
- Higher mass stars spend less time on the main sequence because they burn hydrogen much faster than low mass stars.
- After leaving the main sequence stars begin burning hydrogen in shells around their core causing the luminosity of the star to increase.
- As the star climes the giant branch its core temp increases until it is hot enough to initiate helium fusion. This is followed by a decreasing in luminosity and an increase in surface temperature of the star.

The Asymptotic Giant Branch

Once the star has burned all the helium in its core it begins to burn helium in shells. At this point the star has joined the asymptotic giant branch (AGB). The star behaves very similar on the HR diagram to the Giant branch stars because both branches are characterized by shell burning.

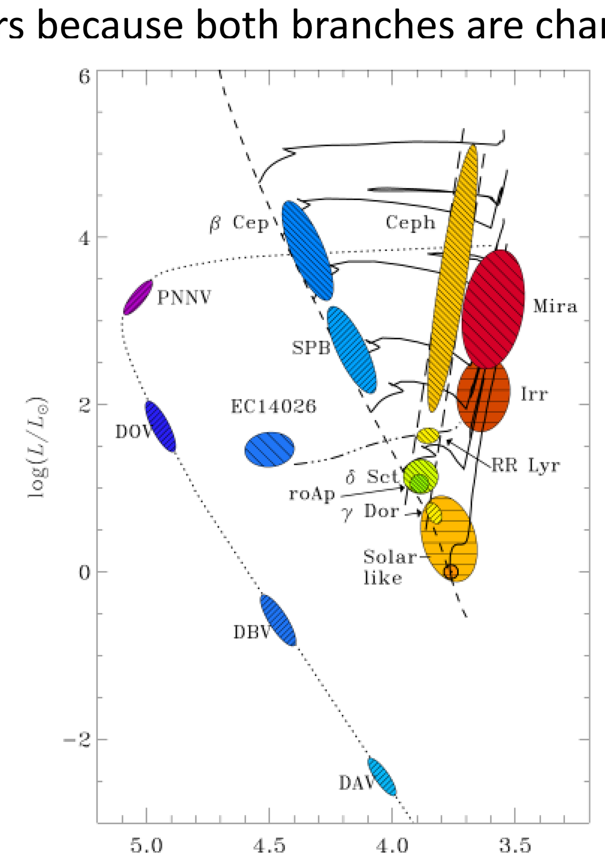

Figure 2. The evolution of a 5 solar mass star. After the star leaves the main sequence it travels up the red giant branch down the horizontal branch and back up the AGB. [2]

When a star is traveling up the AGB it will experience a large change in luminosity while actually losing temperature. This implies that the Radius of the star is growing when it is on the AGB.

When a star is on the asymptotic giant branch it has a very large radius to mass ratio. Most of it's mass is confined to a small dense core and surrounding layers.

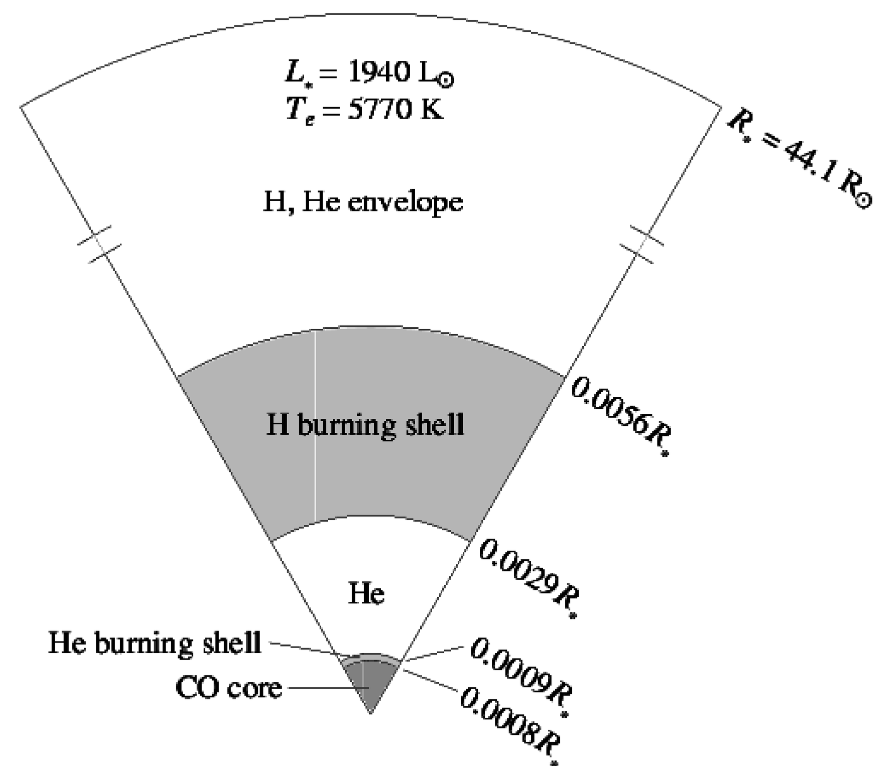

Figure 3. The structure of a 5 solar mass star on the AGB. There is a small carbon and oxygen core that extends to 0.0008 solar radii surrounded by a helium burning shell, a dormant helium shell and a Hydrogen burning shell. In all, the shell and the surrounding layers up to the Hydrogen burning shell account for roughly 1/10000 of the star's radius. [3]

The most prevalent feature of stars on the asymptotic giant branch is their pulsations. Over relatively constant time intervals, the stars on the AGB brighten and dim. These are called pulsating variable stars and there are many types of these, however, the ones that we will focus on are multi-periodic and mono-periodic long period variables (LPV). The pulsation periods of these stars range from 40 to 500 days.

Stellar Pulsations

Pulsations in LPVs occur due to an internal cycle with pressure and gravity. At every layer inside of the star, there is a gravitational force pulling that layer in and a pressure force pushing that layer out. If these forces are thrown out of balance, one force will be greater than the other and the star will begin to oscillate, illustrated by the cycle shown in Figure 4.

- The internal pressure force exceeds the force of gravity
- The star expands, causing it to become less opaque and dimmer
- The gravitational force exceeds the force of the internal pressure
- The star condenses, causing it to become more opaque and brighter

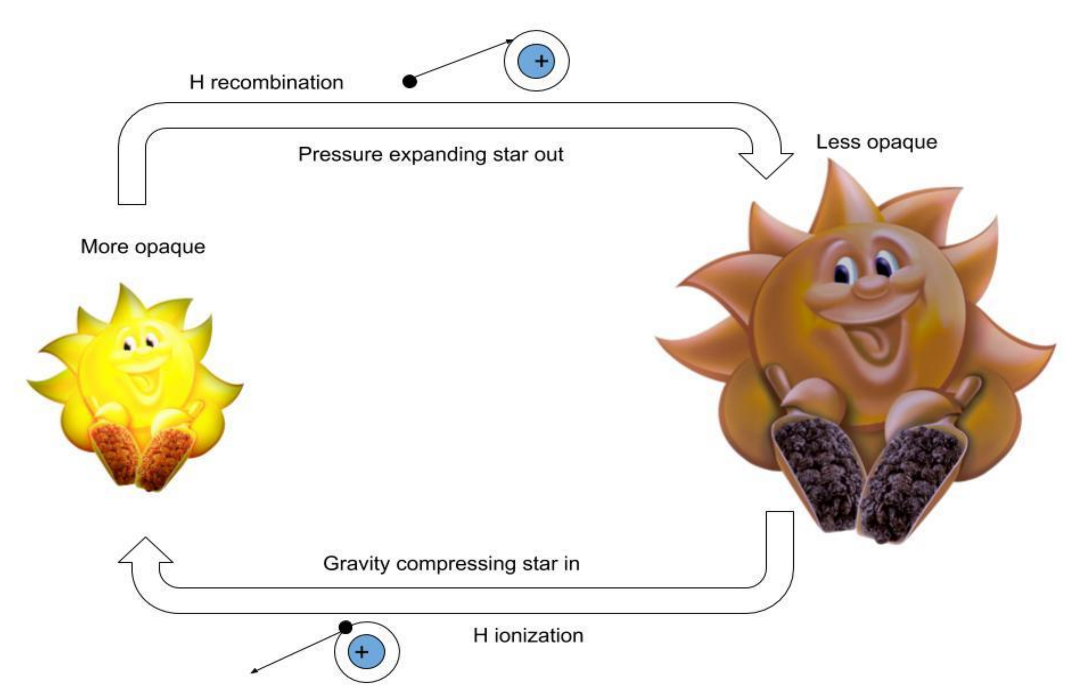

Figure 4. The driving force of stellar pulsation. When the star is at its largest diameter the force of gravity exceeds the pressure force and the star contracts. As the star contracts the pressure inside it rise causing hydrogen and helium to ionize. As the gasses ionize they become more opaque and the star appears brighter. Gas pressure then pushes the outer layers away causing the gasses to de-ionize and the cycle repeats.

Our Place in the Milky Way

Space in a galaxy is not empty. Although it is not filled with matter to nearly the density that we are accustomed to here on Earth, it is not completely empty by any means. Interstellar space is filled with pockets of gas and dust. For light from distant stars to reach us, it must travel through the galaxy. Since space in our galaxy is not a perfect vacuum, when light travels through our galaxy, it becomes red shifted from interacting with matter along the way and losing energy. To what degree light from distant stars becomes red shifted is a function of how much matter the light interacts with on its journey to Earth. If light has to travel through more dense areas of the galaxy, it will be more red shifted than if it traveled through more empty space.

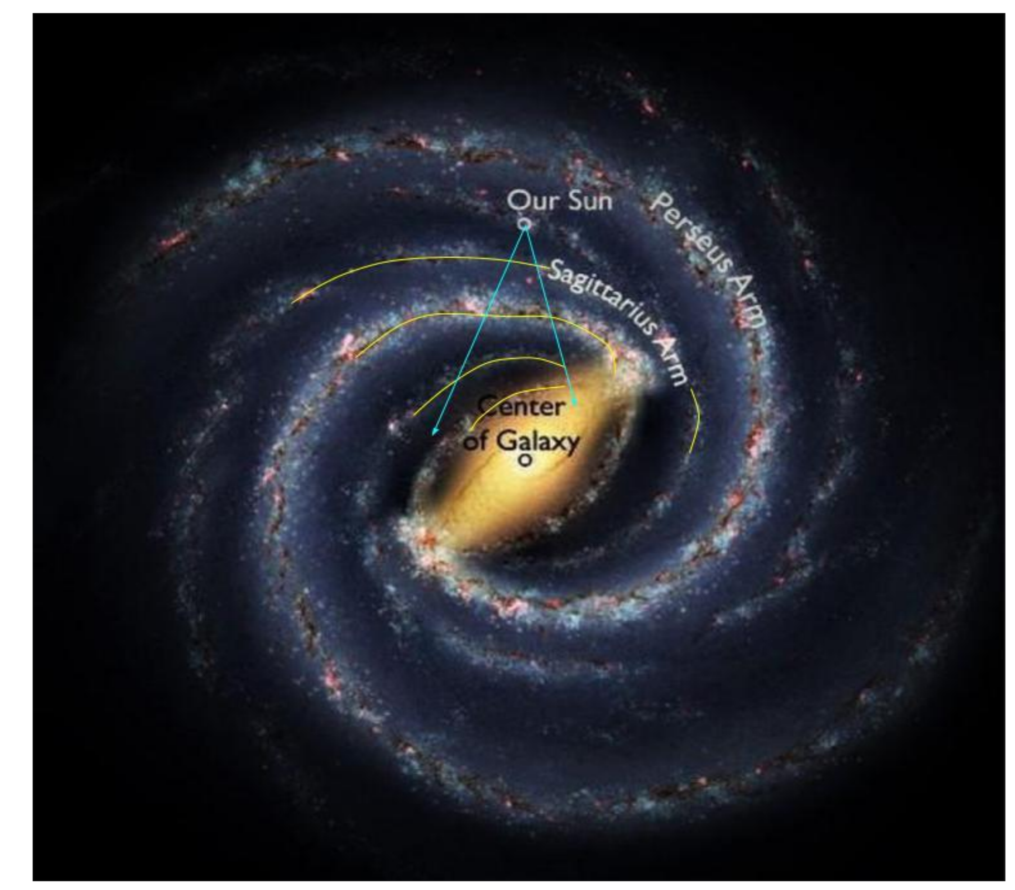

Figure 5. An artistic rendering of the Milky Way galaxy as seen from above. Our sun's approximate position in the galaxy is indicated on a small offshoot of the Sagittarius arm. Our line of sight towards the galactic center is also drawn on the image, we are looking through 4 spiral arms when we look to the center of the galaxy. [4]

Another consequence of our spiral shaped galaxy is that we would expect to see stars clustered together. The spiral arms are where we should see most stars with fewer in the space between them. When we look towards the center of the galaxy we are looking through 4 spiral arms so we would expect to see clumps of stars at 4 distinct distances.

Important vocabulary

B-V color index: Analogous to the temperature of the star

Magnitude: How bright a star is, lower numbers indicate brighter stars, on a logarithmic scale.

Absolute Magnitude: How bright a star would appear if viewed from 10 parsecs away.

Apparent Magnitude: How bright a star appears from earth.

Luminosity: Another way to measure the brightness of a star, higher luminosities indicate a brighter star.

Sources

[1]https://en.wikipedia.org/wiki/Hertzsprung%E2%80%93Russell_diagram
[2] https://www.aavso.org/vsots_rrlyr
[3]Carroll and Ostlie, An Introduction to Modern Astrophysics
[4] *MWbranch13-300x247. Our Milky Way Galaxy* (The National Radio Astronomy Observatory, 2017).
Sunny the Sun (The Kellogg Company, 1952).

Distance Evolution of AGB Stars

Owen Johnson and Daniel Opdahl

Physics

A method for Finding the Distance to LC Pulsating Stars

As light from a star travels through interstellar space on its way to be picked up by our telescopes it interacts with dust and molecules. This has two important effects on the light.

- As the light travels through the interstellar medium some of it is filtered out and does not reach the telescope. This is called extinction and affects the apparent magnitude of the star.
- Shorter wavelength light is affected more by extinction than long wavelengths, this causes a reddening of the star making it appear cooler than it actually is.

Using data from open star clusters in the same general direction as the stars that we are observing we can find an approximation for interstellar extinction and reddening as a function of distance.

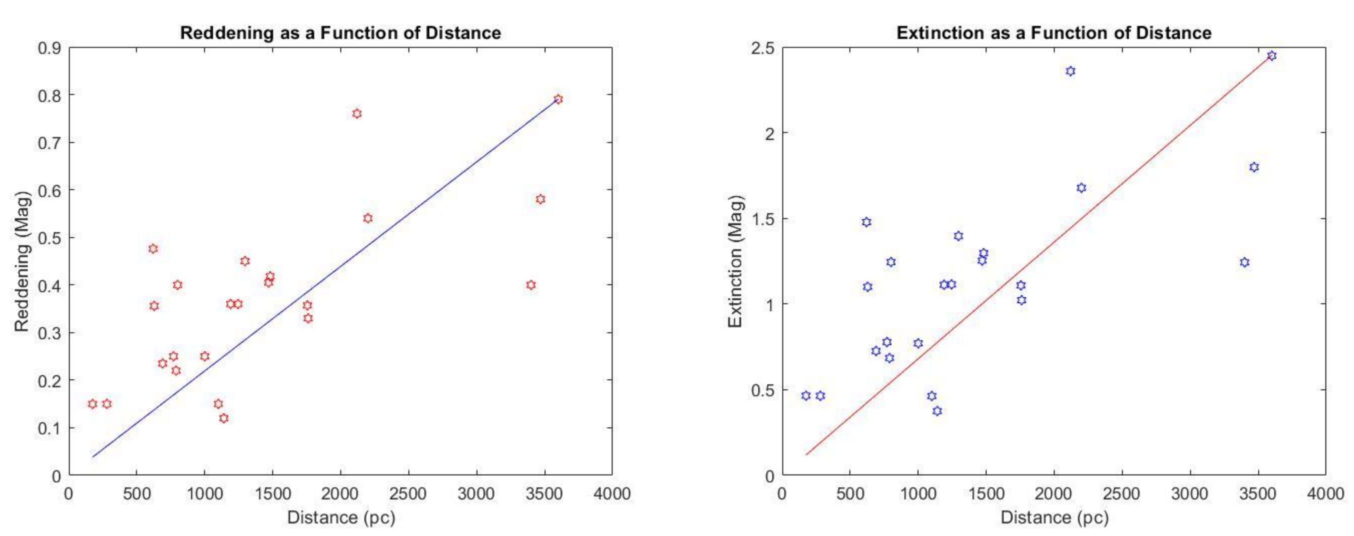

Figure 6. Reddening and extinction of light as a function of distance in the direction of the M23 star cluster. Reddening increases by 0.00021 mag per parsec and extinction increases by 0.0006808 mag per parsec.

To find the distance to our stars we found what the absolute magnitude and intrinsic B – V of our star would be if it was at different distances, and compared that to the absolute magnitude and intrinsic B – V relation we see on the Asymptotic giant branch.

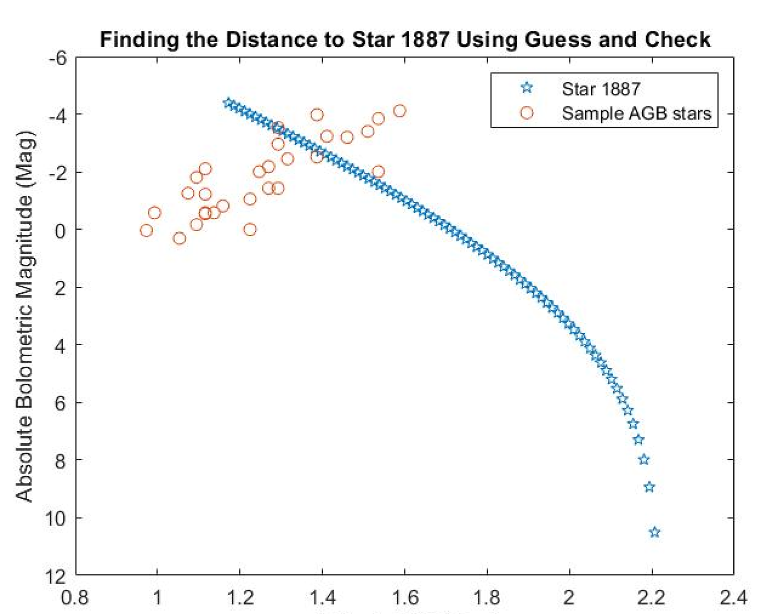

Figure 7. Using the Guess and Check method to find the distance to star 1887. each blue star corresponds to a different distance guess. The one closest to the center of the sample AGB stars is our best guess for the distance to 1887.

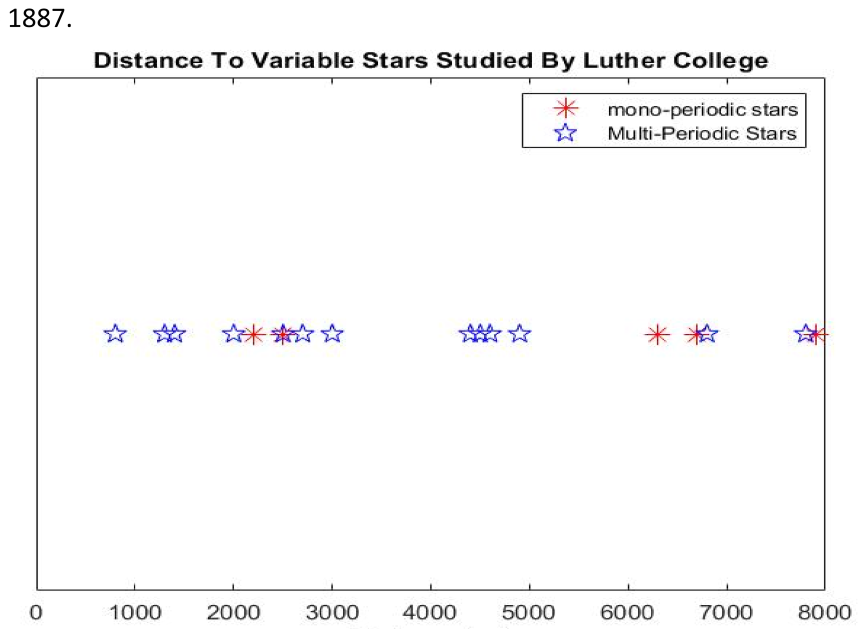

Figure 8. Distance to Variable Stars studied by Luther College. This is the distance to all the variable stars that Luther studies for which we have observed B-V data. It can be seen that there is a clear clumping of the stars. Uncertainty bars were omitted because they all overlapped and made the data messy.

The uncertainty in the distance to the clusters increased with distance, to the point that the uncertainty for the stars near 7000 pc away was on the order of 1500 pc. To test the validity of the distances we found we plotted where the stars would fall on the AGB.

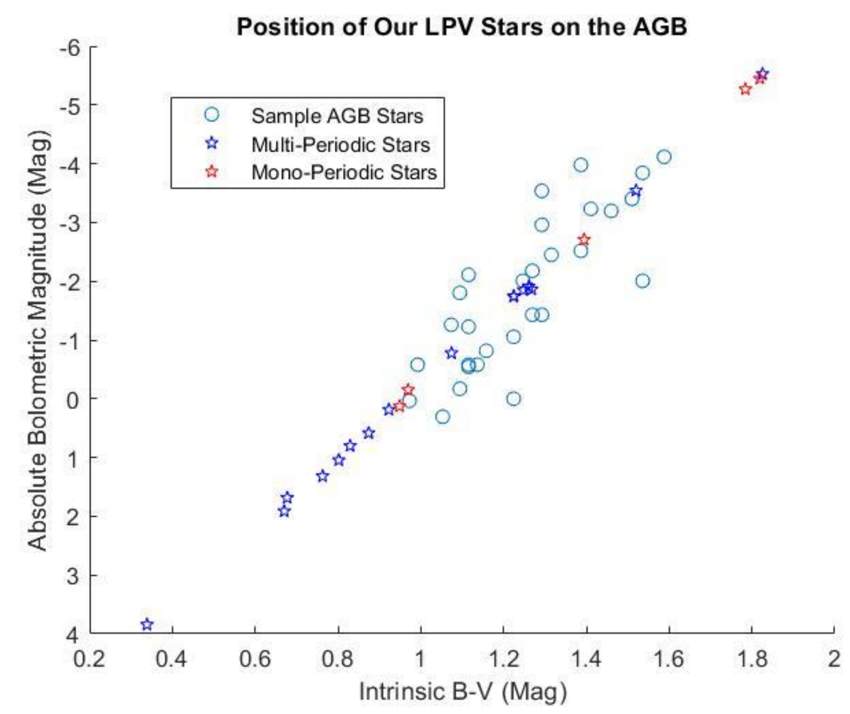

Figure 8. Position of our stars on the AGB. We would expect the mono-periodic stars to be higher on the branch than the multi-periodic stars and that is what we get if we take the average position of the them.

The Radius / Luminosity / Temperature Relationship

The luminosity of a star is directly related to the radius and temperature of said star,

$$L = \sigma 4\pi R^2 T^4.$$

The luminosity of the star is also related to its magnitude by the equation

$$L = L_0 \times 10^{-0.4M},$$

Where $L_0 = 3.0128 \times 10^{28}\ W$. The temperature of the star's surface can found using Ballesteros' formula

$$T = 4600\left(\frac{1}{0.92(B-V)+1.7} + \frac{1}{0.92(B-V)+0.62}\right)$$

These formulas can be used to find the radius of the Luther College pulsating stars using their intrinsic B – V and their absolute magnitudes. Because based on the assumption that our pulsating stares are on the asymptotic giant branch radii less than 5 times that of the sun were not used.

The Baker One Zone Model and The Density of LC LPV stars

If we assume that our LPV's have a constant density, which they do not, we can find that density using the pulsation period. This is done by linearizing the hydrostatic equilibrium equation

$$m\frac{d^2R}{dt^2} = -\frac{GMm}{R^2} + 4\pi R^2 P.$$

Linearizing this equation and solving for period we are left with the equation

$$P = \frac{2\pi}{\sqrt{4/3G\rho_0(3\gamma-4)}}$$

Using the Baker one zone model we were able to calculate the average densities of our stars to be.

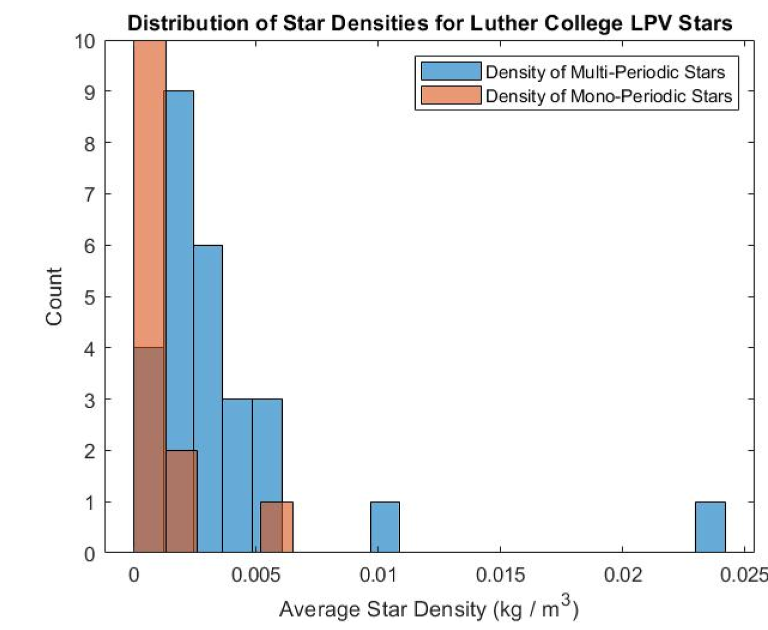

Figure 9. The density distribution for the LPV stars in the Luther college data set. All the stars have very low densities with most of them being under $1/100\ \frac{kg}{m^3}$. This is what would be expected from a AGB star as it does not gain any mass in its life time but it does swell to a much larger volume than it originally was. Mono-Periodic stars appear to have lower densities than Multi-Periodic ones.

Finding the Mass of The Stars

Finally a mass was able to be calculated for the stars for which we had enough data. This was done by using the densities and the radii of the stars

$$M = \rho_0 * R^3 \frac{3}{4}\pi.$$

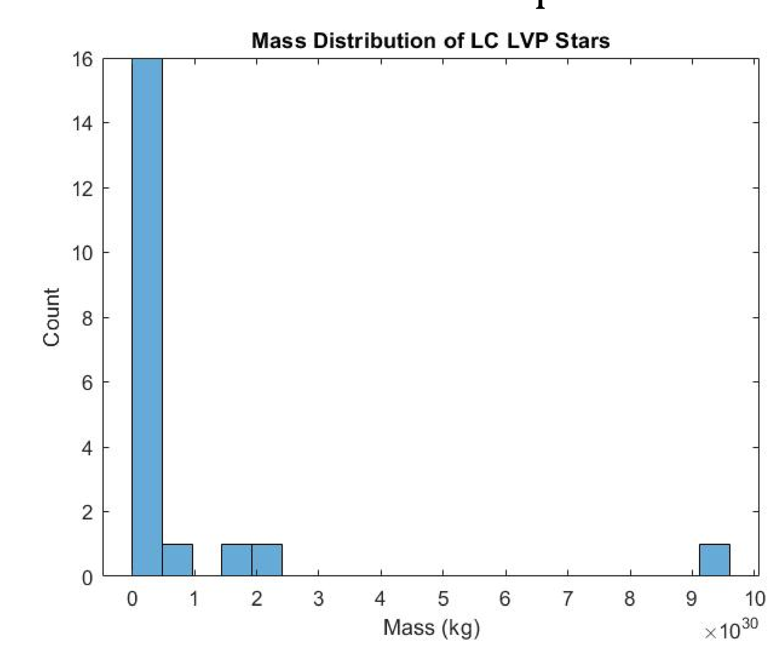

Figure 10. The mass distribution of LC LPV stars. The majority of the stars appear to have a mass less than the sun which is $1.989 \times 10^{30}\ kg$.

Most of the stars don't fall within the 0.6 to 10 solar mass range that we would expect for AGB stars. This is due to the radii being off, most of the radii were under estimated.

Conclusions

- The stars seem to be clumped together at certain distances away from the earth, this implies that they could be on the arms of the Milky Way.
- The Baker one zone model is an effective and simplified method for finding the average density of a star.
- The method that we used to find the radii of the stars was not accurate and this affected the accuracy of our mass calculations.

Future Work

- More accurate reddening and extinction model.
- A way to use R – I color index instead of B – V.
- Obtaining more nights of color data.
- Testing the accuracy of the Guess and Check method using stars of known magnitude and B-V.