Discovering Oscillating M Giant Stars in Eclipsing Binary Systems

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Abstract

Understanding the distances to stars is critical in being able to interpret how the Milky Way galaxy was formed and how it has evolved over time. Asteroseismology, the study of star oscillations, can be a powerful tool in determining those distances as a star's oscillation frequencies are related to its luminosity. However, the uncertainties on asterosiesmic distances to far-away M giant stars are poorly understood, and need to be calibrated. It is possible to calibrate for these asteroseismic distances using M giants in eclipsing binaries — systems in which two stars' orbital planes coincide with an observer's line of sight and periodically block light from each other. The properties of these binaries can be used to constrain the luminosities of the component stars, and therefore the distance to these systems. We intend to incorporate these two methods of measuring distances by finding oscillating M giants in eclipsing binaries using light curves obtained from two ground-based surveys: the Asteroid Terrestrial-impact Last Alert System (ATLAS) and the All-Sky Automated Survey for Supernovae (ASAS-SN). We were able to show that it is possible to recover oscillations from an M giant in an eclipsing binary that follow the period-luminosity relationship using the binary system, ASASSN21co. From the ~200 stars recovered from ATLAS and ASAS-SN, we were not able to recover stars that showed the oscillations required to provide the ability to calibrate asteroseismic distances.

Keywords: Asteroseismology, M giant stars, Ground-based astronomy, ATLAS, ASAS-SN, oscillation

1. Introduction

Understanding the structure and the evolution of the Milky Way galaxy has been one of the most sought-after answers in the field today (e.g., Miglio et al. 2012; Stello et al. 2015; Casagrande et al. 2015; Sharma et al. 2016; Rendle et al. 2019). A crucial part of the effort to understand our galaxy's structure is reliably knowing where the stars within it are. An instrument like Gaia (Gaia Collaboration et al. 2016; Gaia Collaboration et al. 2018) is able to use astrometry to measure distances up to 3 kpc, but it is incapable of determining distances for objects in the outer regions of the Milky Way and so, a new way to determine these distances is necessary (Auge et al. 2020).

Asteroseismology can be used to determine distances to bright stars far beyond the reach of Gaia, given properly calibrated distances. Asteroseismology is the study of stellar oscillations, which can be used to determine the physical properties of the stellar interior. More luminous stars produce lower oscillation frequencies or longer periods which can then be used to infer the luminosity of the star and consequently its distance. These oscillations can create fluctuations in the brightness of stars which is detectable by monitoring the relative brightness of the star over time (Auge et al. 2020). Asteroseismology can precisely constrain fundamental properties such as mass, age, and radius, which can be used as a powerful distance indicator. Mathur et al. (2016) demonstrated that the distance to high luminosity red giants observed by Kepler can be measured out to tens of kiloparsecs with a precision of a few percent. Determining the asteroseismic distances of around 3 to 10 kpc, M giants in particular, is not a suitable method without , which is why the use of eclipsing binaries is critical.

A possible solution to calibrate asteroseismic distances is to find oscillating M giant stars in eclipsing

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binaries (Torres et al. 2009). As one observes the eclipses happening, the brightness over time will experience dips, varying in size based on the parameters of each star. The primary (deeper) eclipse is when the the secondary star obscures the primary star, as the larger primary will be significantly brighter, so blocking the light will cause a greater dip. Using a well known distance-luminosity relationship, it is possible to obtain a distance which can then be compared to its asteroseismic distance and can then be calibrated.

This correction allows for determining accurate asteroseismic distances of other M giants in the Milky Way that may not be in an eclipsing binary. Photometric data from space-based missions like Kepler and TESS are suited to determine asteroseismic distances in nearby stellar populations, but they are not able to properly study the outer regions of the galaxy. The Kepler mission (Borucki et al. 2010) only covers a small section of the sky, approximately 116 square degrees, which restricts observations through only a small part of the galaxy. The Transiting Exoplanet Survey Satellite (TESS) mission (Ricker et al. 2014) covers the entire night sky with an observation window of approximately 30 days, but due to the nature of stars near the tip of the red-giant branch where they have oscillation periods longer than 30 days, TESS can only study a very small portion of them. For the purposes of this research, the use of ground-based telescopes: ATLAS (Tonry et al. 2018; Heinze et al. 2018) and ASAS-SN (Shappee et al. 2014; Kochanek et al. 2017), is necessary to be able to detect M giants. Although both telescopes have much lower precision compared to space-based telescopes, they both observe the entire night sky on a nightly basis and have been observing for over 5 years, which provides the opportunity to detect the oscillations within stars. This has been done by a previous study (Auge et al. 2020), where they were able to detect oscillating M giants using ATLAS and ASAS-SN data. The goal of our research is to locate M giants in eclipsing binaries, describe their physical properties, detect their oscillations and find their distances using asteroseismic techniques and compare them to other techniques.

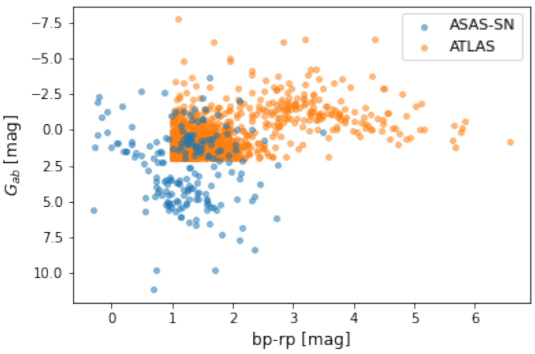

Figure 1: Color-magnitude diagram (CMD) of stars from the ATLAS and ASAS-SN variable star catalog.

2. Method

2.1. Target Selection

Using ASAS-SN's variable star database (Shappee et al. 2014), we constrain our sample to look for stars with periods greater than 50 days and which were classified as detached eclipsing binaries. The period constraint is necessary as the binary system would not be able to contain the M giant and the other component in short periods due to the size of the M giant. Figure 1 shows a color-magnitude diagram (CMD) of our selected eclipsing binary stars from ASAS-SN. To select the M giants, we used constraints on the color and the magnitude on the CMD to locate the stars where it is presumed to contained M giants. To select additional targets, we selected stars, that had the potential of being in an eclipsing binary, from the ATLAS variable stars catalog (Heinze et al. 2018) and locating M giants in a similar way as the ASAS-SN data.

2.2. Data analysis

We performed several steps for the analysis of both ATLAS and ASAS-SN, as follows:

2.2.1. ASAS-SN

- We validate the light curves that was generated using ASAS-SN Skypatrol with results from the Auge et al. (2020) paper. Using the objects target IDs, we obtained the right ascension and declination and recovered their light curves. The process of recovering the newly generated light curves from the ASAS-SN Skypatrol involves either having a Kepler ID or having the right ascension and declination of the star. Then, an amount of days that is needed to be observed is inputted to generate the light curve and the corresponding data for the star at the specified coordinates.

- Next, we look for eclipsing binary stars. Using ASAS-SN's variable star catalog, the "Eclipsing Binary" option was selected in the "Variable Type" field and inputted a minimum period of 50 days to return a list of stars that fit the requirements.
- Using the list of eclipsing binaries that was just obtained, in Figure 1, we plotted a color-magnitude diagram (CMD) and located the primary star that has the characteristics of being a M giant.
- With the list of ASAS-SN eclipsing binaries with M giant components, we visually remove the eclipse and any other outliers and calculate a Fourier transform using *LombScargle* from *astropy* (Astropy Collaboration et al. 2013; Astropy Collaboration et al. 2018) to create periodogram plot to determine if there are any detectable oscillations from the targets.
- Using the period-luminosity relationship plot that Auge et al. 2020 has found, we compared the target's oscillation period to the relationship to determine if these stars follow the trend and if it is possible to calibrate distances using these targets.

2.2.2. *ATLAS*

- Given the ATLAS targets, we compared them using their right ascension and declination to known M giants from Gaia's Early Data Release 3 (EDR3) (Lindegren et al. 2021) in the Milky Way. When the distance between the two coordinates are larger than 0.001 degrees, we assume that the star has no corresponding light curve which means that light curves from the two catalogs are not related.
- We plotted the light curve of each star and visually inspected each individual plot and kept the ones that could be processable. With the selected light curves, the list which was then constrained even more to have M giants with periods greater than a 100 days and have errors in their magnitude less than 0.05 to obtain the best possible chance of recovering the oscillations of each star.
- Same as the ASAS-SN data-set, we will visually remove the eclipses and calculate a Fourier transform using *LombScargle* to determine if there are any detectable oscillations from the targets.
- Using the period-luminosity relationship plot, the same method that has been done on ASAS-SN objects is done on the ATLAS targets to determine if these stars follow the trend and if it is possible to calibrate distances using these targets.

3. Results and Discussion

3.1. *ASAS-SN21co*

Using a paper by Rowan et al. 2021, which explores the detached eclipsing binary, ASAS-SN21co, which contains an M giant component, we wanted to prove that that period-luminosity relation is valid using this system because it would then be possible to recover distances using oscillations. In Figure 3, there is an obvious eclipse shown in the light curve. Using the method of clipping the eclipse and calculating the Fourier Transform, we were able to recover a periodogram that reveals a maximum frequency around 1.25 microhertz. ASAS-SN is able to provide the distance of the system and the apparent magnitude diagram, which were used with Eq. 1 to determine the absolute magnitude of the M giant in the eclipsing binary. Using Figure 2, we plotted the location of the M giant based on the maximum frequency found in Figure 4 and the absolute magnitude of the star which shows to follow the period-luminosity relationship found in the Auge et al. 2020 paper.

$$m - M = 5log_{10}(\frac{d}{10pc}) \qquad (1)$$

3.2. *ASAS-SN and ATLAS data catalogs*

Out of the 200 ASAS-SN detached eclipsing binary stars, we were able to recover ~30 possible candidates of stars having significant oscillations. For

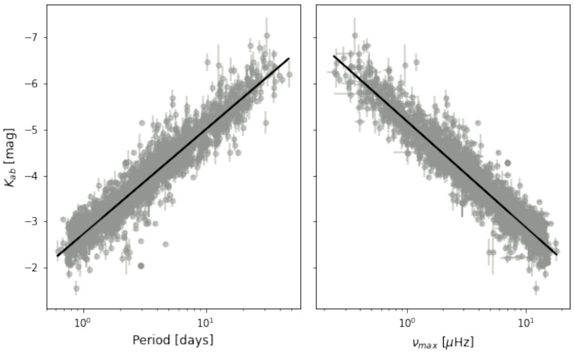

Figure 2: Left: Gaia absolute K-band magnitudes from Berger et al. 2018 as a function of the dominant period of oscillation reported by Yu et al. 2020 for a sample of red giants in the Kepler field. Right: same as the left, but using the frequency of maximum power reported by Yu et al. 2020 instead of the dominant period of oscillation

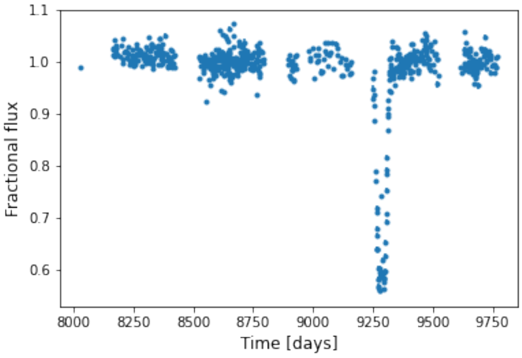

Figure 3: The light curve plot of the detached eclipsing binary of ASASSN21co.

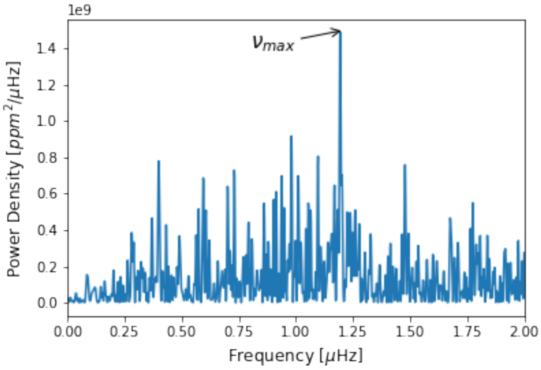

Figure 4: The periodogram of the light curve from ASASSN21co with a maximum frequency of around 1.25 microhertz.

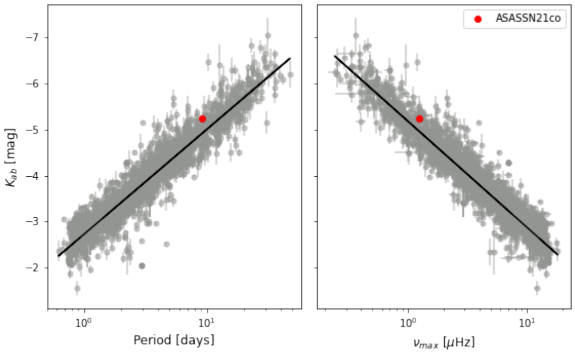

Figure 5: Period-Luminosity relationship plot with the position of ASASSN21co on M giant's absolute magnitude and the maximum frequency.

ATLAS, out of the 2000 stars, we were able to obtain approximately 30 stars that had visible light curves and fit the criteria of having periods greater than 100 days and error in magnitude less than 0.05 with a possible chance of having significant oscillations. Using the best candidates from the two telescopes, shown in Figure 6 and 7, there were significant oscillation peaks detected from both stars. We were then able to obtain the apparent magnitude and the distances to these stars, just like it has been done with ASASSN21co. These were used to calculate the absolute magnitude and by plotting it against the observed maximum frequency found in the periodograms for both stars, which the result is shown in Figure 8.

4. Conclusion

Here we presented the search for eclipsing binaries with possible oscillating M giant component using asteroseismology. This research goes along with the overall purpose of trying to create a map of the Milky Way galaxy using asteroseismology to better understand its formation and evolution. We present the results of our research:

- We have found an oscillating M giant in an eclipsing binary that does follow the trend of the period-luminosity relation which can be used to determine the distances to these systems, in particular M giants. This means that it is possible to detect these types of systems and that using the methods that we have done,

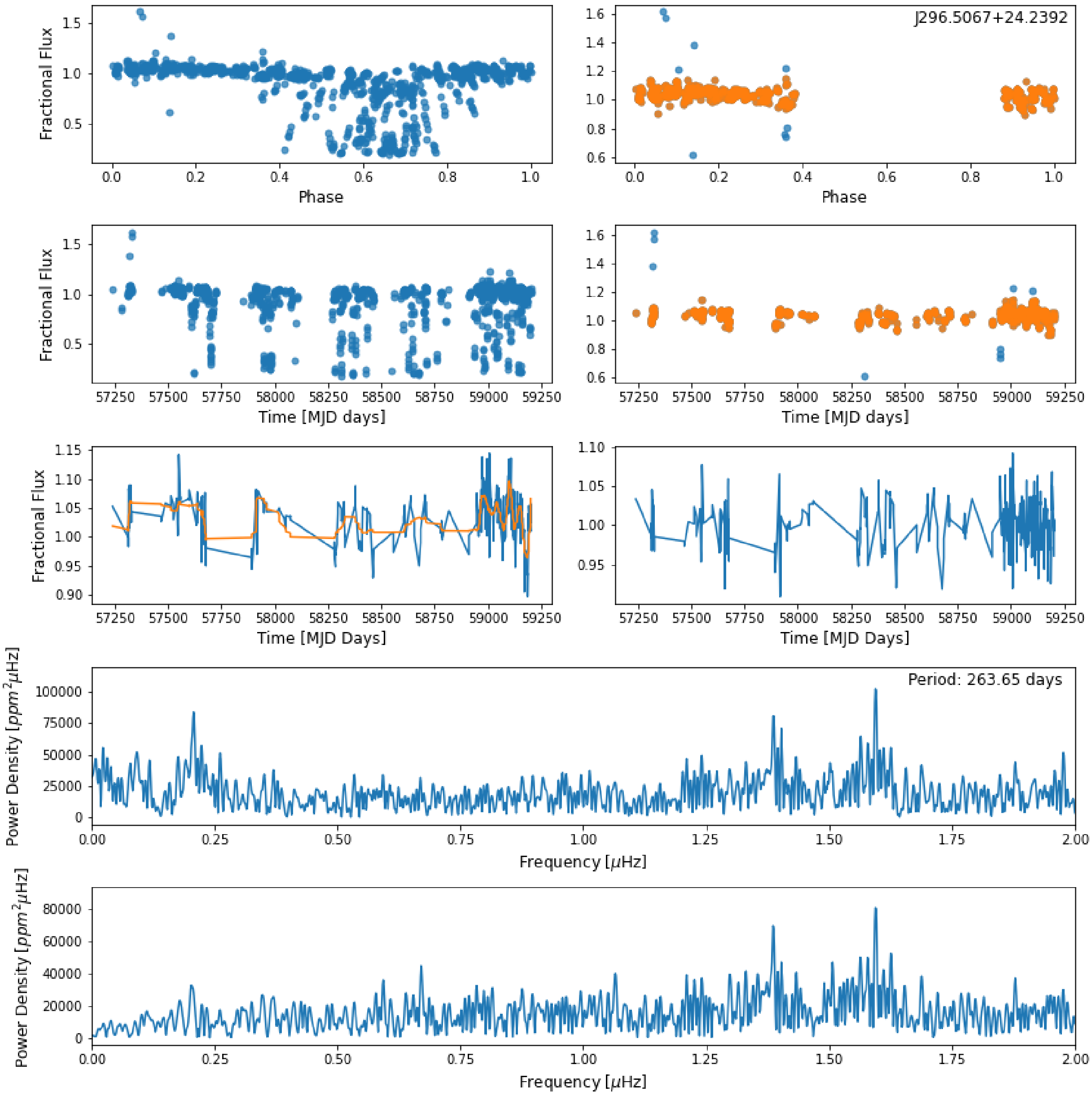

Figure 6: First Row: Phaseplot of J296.5067+24.2392 (CQ Vul) before and after clipping the eclipse. Second Row: The light curve plot before and after clipping the eclipse. Third Row: The light curve plotted against the filter of the average of the light curve at different intervals to remove the lower end noise in the periodogram. Fourth Row: Periodogram of the clipped light curve without the filter. Fifth Row: Periodogram of the clipped light curve with the filter to remove the lower end frequency noise. A maximum frequency is detected to be around 1.6 microhertz.

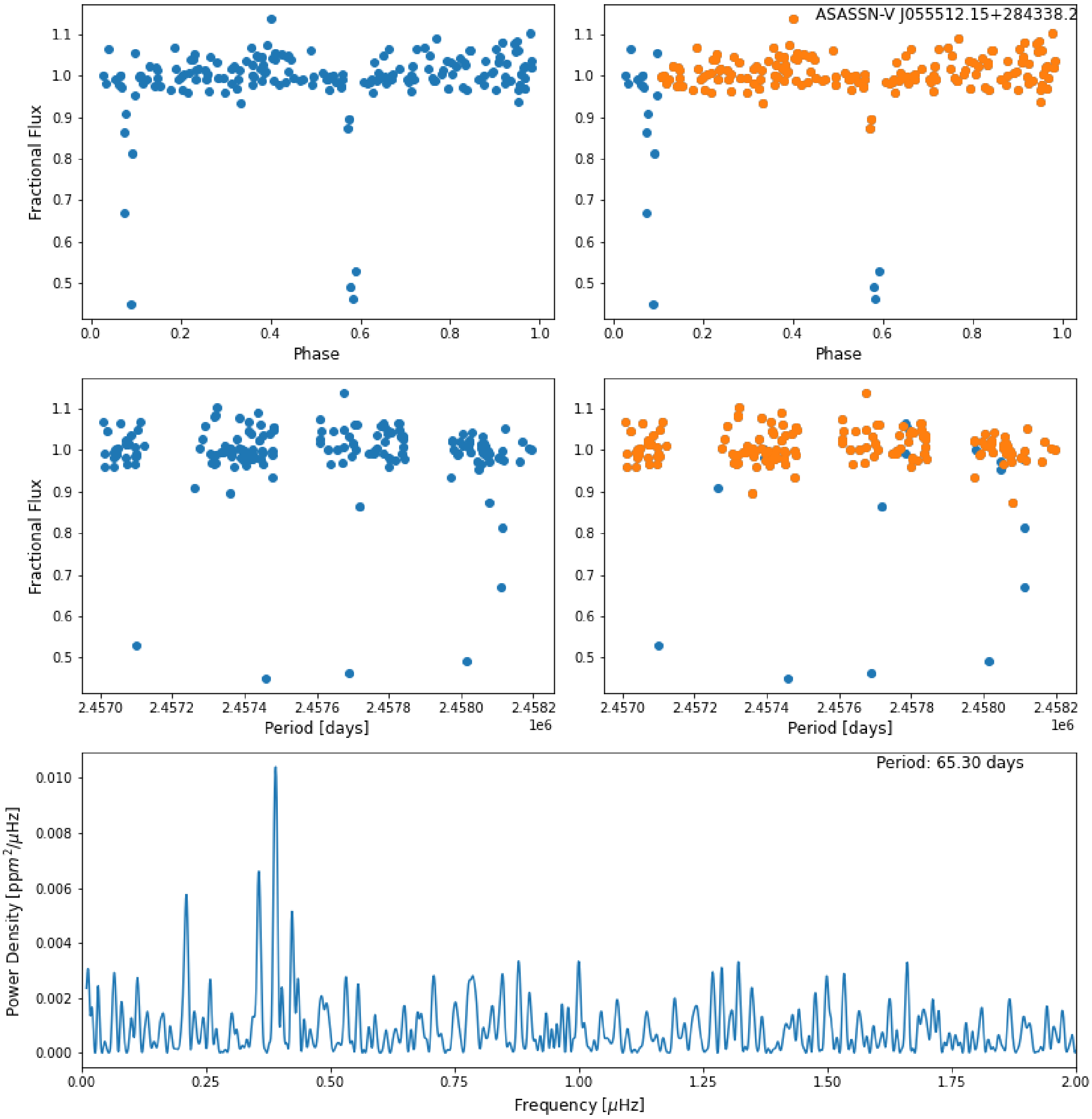

Figure 7: Top Row: Phaseplot of ASASSN-V J055512.15+284338.2 (Fy Aur) before and after clipping the eclipse. Middle Row: The light curve plot before and after clipping the eclipse. Bottom Row: Periodogram of the clipped light curve with a maximum frequency of around 0.35 microhertz

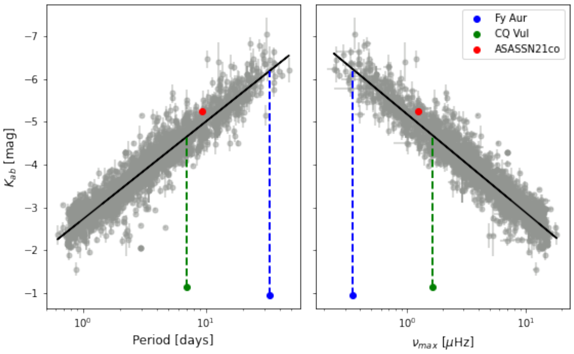

Figure 8: Period-Luminosity relationship plot with the positions of ASASSN21co, Fy Aur, and CQ Vul as points. The dotted lines correspond to where Fy Aur and CQ Vul should be based on the maximum frequency found in their periodograms.

we can apply it to other similar systems to possibly recover oscillations from the M giant in the binary system.

- From the ∼200 total targets obtained from both ASAS-SN and ATLAS, we were able to locate possible candidates of oscillating M giants in eclipsing binary systems. But, by comparing the positions of these stars based on their maximum frequency and absolute magnitude, there is no correlation between the candidates and the period-luminosity relationship, which means these are not what we are looking for in this research.
- Future work includes better orbital period limits to recover even more targets to be processed and better clipping methods of the eclipse to reduce the possibility of removing oscillations within the light curve using the current method of visually cutting them out.

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