1-M OBSERVATORY

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY (ERAU)

OBSERVING TIME REQUEST

Proposal Title: Confirming the non-radial g (gravity)-mode Pulsations in GD 358

Abstract

Pulsating white dwarfs (PWD) are at the forefront of Astronomy, in the forty years since their discovery, PWD stars have become important tools for unraveling the deep mysteries of the Universe [1]. The PWD that we want to observe is GD 358 (TIC 219074038), shown in *Figure 1,* and has oscillation frequencies, which are associated with nonradial g-mode pulsations, with periods from 422 s to 1087 s [2]. We request the ability to use the 1-meter observatory at ERAU for our data collection. We will also be using Kitt Peak's 1-meter observatory to help confirm our results. The data will be processed using AstroImageJ for calibration and differential photometry [3] with Period04 for the Fourier Analysis [4]. Through this, we will be able to confirm the oscillation frequencies associated with the pulsations out of 28 pulsation modes of GD 358 and see if these are combinatory frequencies. Testing our hypothesis that most of the 28 frequencies are combinatory by using a pre-whitening procedure to derive the potential pulsation frequencies [5]. This is the process of removing unnecessary autocorrelations from time series data before observing the object.

Observing Request Summary

Total Hours Requesting: 20 hours
Telescope & Observing Mode: 1-meter
Instrument Requesting: CCD camera
Specific Dates Requesting: Between March 26-April 10

Special Constraints

Time Critical Observations: No
Target of Opportunity Observations: No
Lunar Constraints: No
Other Constraints: 1 semester to finish

Observer Information

Observer Pseudonym: Dr. Cracker and Dr. Cheese

Science Justification

White dwarf stars mark the final phase for the majority of stars in the universe, offering insights into various fundamental aspects of stellar astronomy and astrophysics. They are important for understanding the structure, evolution, and chemical makeup of the Milky Way galaxy, providing context on its star history. White dwarfs also serve as indicators for the evolution of planetary systems and are used for studying physics beyond the standard model, almost acting as laboratories for stellar astrophysics. Recent findings, particularly in observational techniques, have allowed for significant advancements in understanding white dwarfs. Asteroseismology, the study of oscillations in stars, comparing observed pulsation periods with theoretical models, gives insights into its internal structures, such as chemical makeup and rotation profile [6]. These profiles describe the distribution of angular velocity within the star. Asteroseismology has provided valuable information on these rotation profiles.

By studying pulsations of white dwarfs, scientists can measure stellar parameters, study Type Ia supernova progenitors, and even test models of dark matter. White dwarf pulsations provide insights into the equations of state governing matter under extreme conditions [1]. The selection for this project is the white dwarf GD 358, chosen for its higher luminosity relative to other white dwarfs and its convenient observability within our allowed timeframe. In this project, our focus is on observing the light curve of GD 358. This aims to provide important details such as the rotation period, amplitude spectrum (amplitude vs. frequency) as shown in *Figure 4*, and emission mechanisms of the target. Our primary goal is to obtain a light curve that not only confirms but also enhances the rotation period that is out there.

The observed pulsation periods of GD 358 range from 422s to 1087s [5]. Additionally, there have been eight combination frequencies between 543s and 295s detected in the same study for the star [2]. The main question we seek to answer in this study is how these rotation periods found in our observations compare with the observed values already out. We're using AstroImageJ for image calibration and photometry to measure the brightness of a target star relative to comparison stars in the same field. We will use the G filter. Then, with Period04, we'll analyze the time series data from it for any periodic variations, comparing our results with the observed values of a known reference star like those in *Figure 1.* Additionally, we'll use the airmass plot in *Figure 2* to determine the optimal night for observation.

What makes GD 358 particularly special is its higher luminosity compared to other white dwarfs, making it an intriguing target for observation. This higher luminosity makes it more convenient to study within the allotted timeframe.

Technical Justification

For this project, we will be using a Charge Coupled Device (CCD) to return a light curve of GD 358. Doing this by using differential photometry with AstroImageJ [3] and Fourier Analysis with Period04 [4]. Firstly, we approximated the SNR using the light curve from a paper referenced that researched the frequencies of GD 358, shown in *Figure 5*. We took the least change in the relative flux which was 0.2%. Calculating the SNR by dividing the signal, the change of 0.002, from the mean flux value, approximated at 1. This gave an SNR of 500, giving an exposure time of around 20 seconds. Explaining the variables In *Figure 3*, the value A divides the N star value by the Signal-to-Noise Ratio and squares them. Where B has the aperture radius which is 3.5, the b dot is the electron count rate at 1.4 electrons per pixel per second, and the d dot is dark current at 3 electrons per pixel per second. C has the same variables including readout noise in RMS electrons per second. Using the quadratic equation with A, B, and C to solve for the exposure time.

Due to our star rising at 03:00 EST on February 06, between 00:30 and 01:20 EST on March 04 and 06, and March 11 EST for the days requested, we have 3-6 hours of observing per night, not including Kitt Peak. This gives around 720 images total for all of the runs, assuming good conditions. We picked days that are not affected by the moon and are projected to have good weather. Other than weather, there are no other constraints on the observations. We have until April to finish the project which is why the observations are mainly in February and March. This is our biggest constraint, but other than this and weather we have no constraints with the instruments and observatory.

Figures

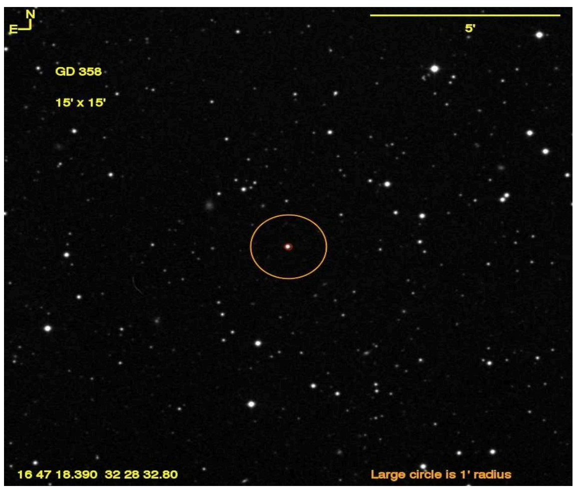

Figure 1. The Finder chart for GD 358 in the constellation Hercules, with an apparent magnitude of 13.65 and spectral type DBV [8].

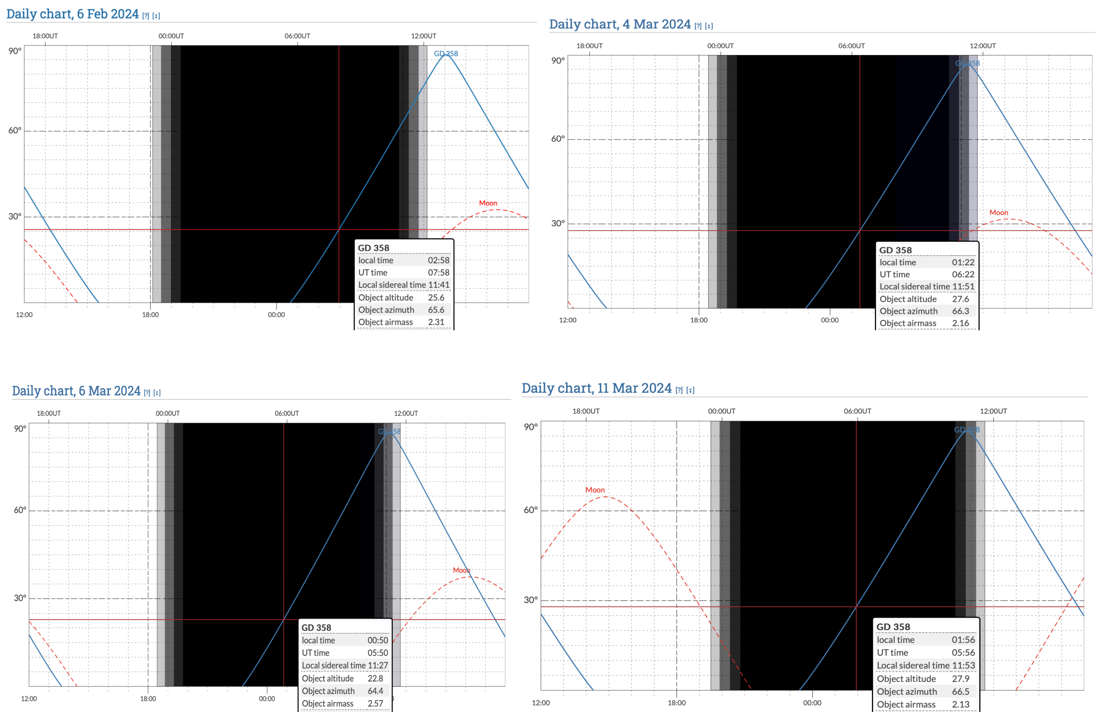

Fig 2. The Airmass plot for February 6 and March 4, 6, and 11 2024 are the dates we would like to observe with the ERAU 1-meter observatory.

Exposure Time

So,

$$A = \frac{\dot{N}_*^{\,2}}{SNR^2}$$

$$B = -\left[\dot{N}^* + n_{pix} a_b \left(\dot{b} + \dot{d}\right)\right] = -\boldsymbol{B}$$

$$C = -n_{pix} a_b \rho^2 = -\boldsymbol{C}$$

The positive root of the quadratic expression is

$$t = \frac{-B + \sqrt{B^2 - 4AC}}{2A}$$

Figure 3. The equations we used to approximate the exposure time from EP 425 by using the SNR found in Figure 5 [10].

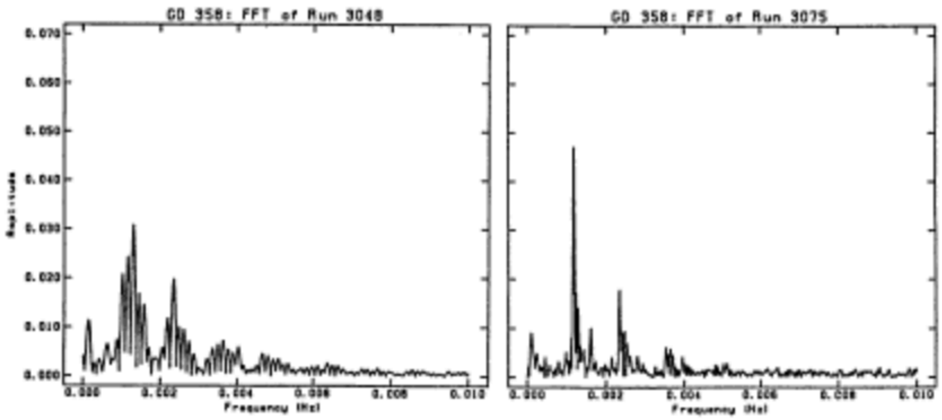

Figure 4. The Amplitude Spectrum of GD 358 we will use to compare with our data [9].

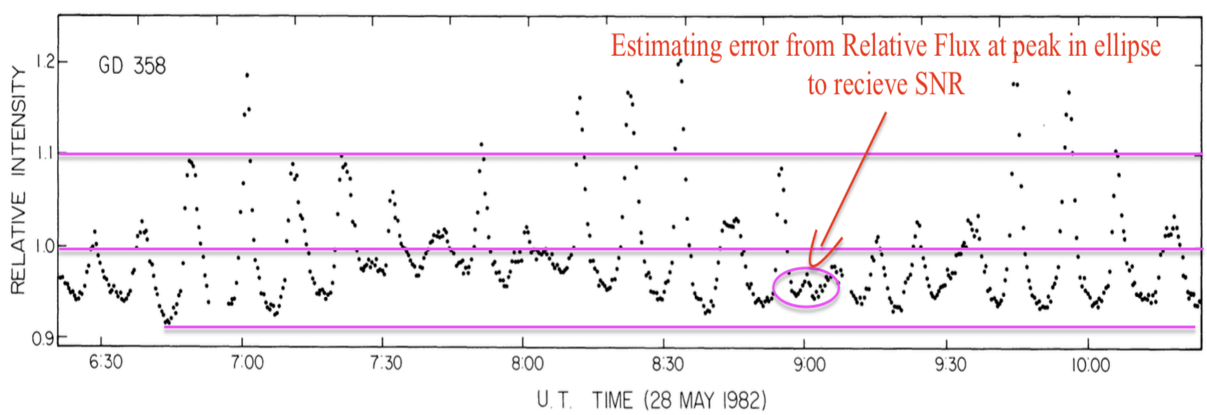

Figure 5. Light curve of GD 358 showing how the SNR was derived which was used to calculate the exposure time [5].

References

[1] Winget, D.E., and S.O. Kepler. "Pulsating White Dwarf Stars and Precision Asteroseismology." *Annual Review of Astronomy and Astrophysics*, vol. 46, no. 1, Sept. 2008, pp. 157–199, https://doi.org/10.1146/annurev.astro.46.060407.145250.

[2] Córsico, A H, et al. "Pulsating Hydrogen-Deficient White Dwarfs and Pre-White Dwarfs Observed with TESS." *Astronomy and Astrophysics*, vol. 659, 1 Mar. 2022, pp. A30–A30, https://doi.org/10.1051/0004-6361/202142153. Accessed 1 Mar. 2024.

[3] "AstroImageJ (AIJ) - ImageJ for Astronomy." *Www.astro.louisville.edu*, www.astro.louisville.edu/software/astroimagej/.

[4] "Period04 - Homepage." *www.period04.net*, www.period04.net. Accessed 1 Mar. 2024.

[5] Winget, D. E., et al. "Photometric Observations of GD 358 - DB White Dwarfs Do Pulsate." *The Astrophysical Journal*, vol. 262, Nov. 1982, p. L11, https://doi.org/10.1086/183902. Accessed 19 Jan. 2023.

[6] Córsico, A. H., Althaus, L. G., Bertolami, M. M. M., & Kepler, S. O. (2019b, June 28). *Pulsating white dwarfs: New insights*. arXiv.org. https://arxiv.org/abs/1907.00115

[7] Landolt, A. U. (1968). A new short-period Blue Variable. *The Astrophysical Journal*, *153*, 151. https://doi.org/10.1086/149645

[8] Wikimedia Foundation. (2023, December 2). *GD 358*. Wikipedia. https://en.wikipedia.org/wiki/GD_358

[9] Allen Hill, J. (n.d.). *GD 358: The Demise of Rotational Splitting*. 1987fbs..Conf..681H Page 681. https://articles.adsabs.harvard.edu//full/1987fbs..conf..681H/0000681.000.html

[10] “Course Observational Astronomy.” *Fed.erau.edu*, erau.instructure.com/courses/170028/files/37438687/download?download_frd=1. Accessed 8 Mar. 2024.