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Physical Characteristics and Classification of the Large Amplitude Variable Star V1719 Cygni

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Abstract

Pulsating stars are used as standard candles which are helpful in determining distances to stellar objects along with the relationship between their period and apparent luminosity. The focus of this study was the variable star, V1719 Cygni, which is often classified as a Delta (δ) Scuti star, but there exists debate that it should be classified as a RR Lyrae star due to its abnormal light curve and similar characteristics between the two variable star categories. Observational data was taken in 2019 using the Las Cumbres Observatory international telescope network. The resulting data were calibrated using comparison stars in the field of known magnitude. We performed aperture photometry in the V-, B-, i- and z- photometric bands. The period was then found using the string method which determines the most probable period. The average period was found to be 0.269 days with an error of 0.0005. The distance was calculated using the previously established period-luminosity relation for both δ Scuti and RR Lyrae stars to determine which classification fits our data best. The distance calculation was more closely aligned with previous results when using the δ Scuti relationship as compared to the RR Lyrae relationship. Based on these results, we conclude that V1719 Cygni should be classified as a high-amplitude δ Scuti variable star. It is important to note that period-luminosity relationships have not been established in all photometric bands, but the period measurements obtained in the B-, i-, and z- bands will help to establish that relationship.

Keywords: Pulsating star, δ Scuti, RR Lyrae, light curve, period-luminosity relationships

Profiles of the Authors

Ashley Lieber is a senior at the University of Arkansas. She will be graduating in May 2021 with a BS in physics with a concentration in astronomy. Additionally, she will earn minors in mathematics and STEM education. In the immediate future, she is planning to pursue a Ph.D. in Astrophysics to continue her work in astronomy research. She hopes one day to work in astronomy education outreach as part of an observatory or museum to share the great advancements and discoveries of space science with the general public. She has also conducted computational research in solar physics and will soon defend her honors thesis on the flaring activities of M dwarf host stars of Earth-like exoplanets. When she is not doing research, she enjoys immersing herself in the Fayetteville community by taking part in community attractions like the farmers' market, Crystal Bridges art museum, and the vast array of hiking trails and restaurants.

Logan Siems is a student at the University of Arkansas in the Master of Arts in Teaching program. She graduated from the University of Arkansas in the spring of 2021 with degrees in physics and mathematics. Now that she is a Noyce fellow, she is working and learning to incorporate aspects of authentic research experiences such as her own experiences in astronomy into secondary science and mathematics education. She also enjoys roller skating and buying plants that she will forget to water.

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Introduction

Pulsating stars have come to be critical objects for measuring stellar distances due to their regular, periodic changes in luminosity. The light curves that result from these stars and their accompanying period-luminosity relationships can be used to determine distances beyond the limits of parallax.

These period-luminosity relationships have been established for the multiple types of pulsating stars in many photometric bands. RR Lyrae and Delta (δ) Scuti stars are two types of pulsating stars with distinct period-luminosity relations. However, stars of these types can occasionally be hard to differentiate from each other since characteristics such as period of pulsation, temperature, and luminosity occasionally overlap. Most stars in either of these categories have distinct periods or locations on the H-R diagram that clearly establish their classifications as either a Delta Scuti or RR Lyrae star, but sometimes stars have temperatures, luminosities, and periods that do not make the categorization clear (Catelan and Smith, 2015).

One such case is the star V1719 Cygni. This star's period and temperature do not clearly fall into either classification category thus leading to the discrepancies that are present in the existing literature. V1719 Cygni was originally categorized as a RR Lyrae star by Poretti (1984), however they found the light curve to be "unstable" on longer timescales. Poretti and Antonello (1988) studied the light curve in further detail using Fourier analysis. To account for abnormalities in the star, such as its asymmetrical light curve, they proposed various physical characteristics of the star, such as microturbulence, high metallicity, and helium settling. In the 1990s, Fernley & Barnes (1997) used the data gathered by the *HIPPARCOS* satellite (Perryman, 2011) to classify the star as an RRc Lyrae due to the observed sinusoidal light curve, corresponding period of ≈ 0.25 days and low metallicity.

Other studies of V1719 Cyg were compiled and compared by Pena et. al (2001) along with their own observations. Based on this data, especially the high metallicity and larger mass, Pena et al. concluded that V1719 Cyg is a high amplitude, Delta Scuti. However, the [Fe/H] value that they used in this study was 1.020, which is a very unlikely value according to Catelan and Smith (2015). This classification as a Delta Scuti star is significant because it determines which period-luminosity relation can be used to find an accurate distance to V1719.

A period-luminosity relationship has been established in the V-band for Delta Scuti stars (Ziaali et al., 2019) and in the V, i, and z bands for RR Lyrae type stars (Catelan et al., 2004; Cáceres and Catelan 2008). In this paper, the period of V1719 Cyg was studied in the V, i, B, and z bands which was then averaged to be used in the determination of distance. The stellar distance was determined using the previously established period-luminosity relationships for both RR Lyrae and Delta Scuti for comparison purposes. Comparing these distances provides more evidence to confirm the classification of V1719 Cyg as a high-amplitude Delta Scuti star and provides more data that can be used to solidify and establish period-luminosity relations for Delta Scuti star in the V, B, i, and z bands. These period-luminosity relations are a very active field of current research which will help to more accurately establish distances to distant objects.

Methods

I. Observations

In order to investigate the behavior of the variable star V1719 Cyg, we remotely requested photometric data of the star which was carried out by the 0.4-meter SBIG (Santa Barbara Instrument Group) telescope at the Haleakalā Observatory in Hawai'i. The summit where the telescope is located operates under conditions that are optimal for making ground-based observations of the night sky such as its altitude, limited light pollution, dryness, and stillness of air. Observations were conducted through the Las Cumbres Observatory Telescope Network which consists of 23 international telescopes that work in conjunction with the Our Solar Siblings project. The coordinates at the time of this investigation were Right Ascension of

21h 04m 34.40s and Declination of +50d 47m 07.50s. Data was recorded over a time span of thirty-three days starting in November 2019 yielding a total of thirty-eight observations. The data was collected in four photometric bands: i, z, B, and V. These bands cover a broad range of the electromagnetic spectrum from infrared to visible light which were highly useful in our aperture photometry conducted later on.

II. Apparent Stellar Magnitude

The data from the observatory was preprocessed through the Our Solar Siblings (OSS) data pipeline as described in Fitzgerald (2018). Images were processed using the OSS pipeline including techniques such as image cleaning, calibration, and various aperture photometry and point-spread function photometry (PSF) algorithms. Aperture photometry methods given by the apt, sek, and apt files measure the flux inside of some circle for each object in the field and they tend to work better for more isolated stars such as V1719 Cyg. Because of this, we expected to have more success analyzing data from these files. Alternatively, point spread function (PSF) photometry methods given by the dop, dao, and psx files fits a function to each object and so it manages close objects and crowded fields better than the aperture methods (Fitzgerald 2018). Interestingly, for the i and z band we utilized the apt files, but for the B-band, we used dao and for the V-band we used sek. This was because these files proved to be more compatible with the Python script used for analysis later on.

With the optimal photometry tool determined for each band, the light curves for each observed band of data could be constructed. This was done by employing an established nine-stage pipeline of Python code. This code systematically removes any damaged or useless data that are outside a certain threshold using Astrosource. For example, if a certain image does not have clear images of the surrounding star field in order to make comparisons in relative magnitude, the image will be discarded. The code identifies stars near our target star, V1719 Cyg, to use for comparisons. These stars met the criteria of being present in every image over the data collection period while also remaining relatively constant in apparent magnitude over that same period. Then the apparent magnitude of V1719 Cyg could be compared to these stars to determine how it varied over time relative to these stars with relatively constant apparent magnitude as described in Fitzgerald (2018). These comparison stars create a baseline in magnitude to which the variations in the target star can be more accurately calibrated.

III. Light Curve and Period Analysis

The period of pulsation was then determined using the phase dispersion method (PDM) and distance method (also known as the string-length method) (Stellingwerf, 1978; Dworetsky, 1983). The PDM method tests various period candidates by using the period to compare variance of the amplitude in bins along the phase and finding the period for which the variance is minimized (Stellingwerf, 1978). The distance method also uses candidate periods and plots amplitude vs phase then finds the period with the minimum distance between consecutive points (Dworetsky, 1983). After the period was determined in each band, the variation of the target star over its phase was graphed which is known as its light curve.

The variation in V1719 Cygni's magnitude throughout its period was then graphed and is known as the star's light curve. In this study, two complete cycles were graphed in the light curve to demonstrate the repetitive nature of the star's variations in magnitude.

Results

I. Apparent Magnitude Results

The apparent magnitude of the star in each band studied is reported in Table 1 along with the uncertainty in measurements and amplitude. The value reported as the apparent magnitude is the middle

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magnitude which is the midpoint within the magnitude variation as seen in the light curves of Figures 1, 2, 3 and 4. It is interesting to note that the values for amplitude are considered high for a Delta Scuti type variable star (Catelan and Smith, 2015), which may be a contributing factor to its misclassification.

Table 1:
Stellar Magnitude and Amplitude in Each Photometric Band Studied

	z- Band	i- Band	B- Band	V- Band
Magnitude (mags)	7.67	7.67	8.093	7.849
Amplitude (mags)	0.256	0.256	0.547	0.765
Uncertainty[1]	0.02768	0.0207	0.0109	0.0207

[1]Value of uncertainty relates to the measurements themselves

Table 1: Table details the apparent magnitude, amplitude, and uncertainty of measurements resulting from this study of V1719 Cyg. Values in each band are reported. The apparent magnitude refers to the middle or mid-point magnitude across all measurements within a certain band.

II. Period and Light Curve Results

The period of V1719 Cyg was determined in each photometric band studied. Both the PDM and distance (string) methods were used to calculate these values which are reported in Table 2. In order to evaluate this calculated period in relation to previous studies, Table 3 provides a comparison of previously determined periods of V1719 Cyg to the period reported in this paper. This direct comparison shows that the period reported in this study is comparable to the previous determinations of period thus providing more evidence towards the validity of our methods and the findings. It is important to note that of the two periods obtained in each band using the two methods described, the period used for calculation purposes was chosen on the basis that it agreed with the period in the remaining bands and had a considerably low error.

These calculated periods were then used to graph the light curve of the star in each photometric band as seen in Figure 1, 2, 4, and 4. The graphs show two complete periods to show the periodic variability of this star. It should be noted that the error in the periods displayed in Table 2 are underestimated as a consequence of the instruments and code that was used (Fitzgerald, 2018).

Table 2:
Period Determinations in Each Photometric Bands

	z- Band	z- Band Error	i- Band	i- Band error	B- Band	B- Band Error	V- Band	V- Band Error
Period[1] (days)	0.21416	0.00055	0.3152	0.0015	0.2671	0.0014	0.26704	0.00084
Period[2] (days)	0.37536	0.00016	0.20344	0.0001	0.277	0.0005	0.26656	0.0008

[1] Determined using the Distance (String) Method
[2] Determined using the PDM Method

Table 2: Table details the period and period errors of V1719 Cyg in each photometric band used in this study.

Table 3: Comparison of Previous Findings of Period to this Study	
Reference	Period (days)
Padalia & Gupta 1982	0.267394
Poretti 1984	0.267298
Poretti & Antonello 1988	0.267295
Present Paper	0.27323

Table 3: Table compares the period used in calculations for this study with the period findings of previous studies.

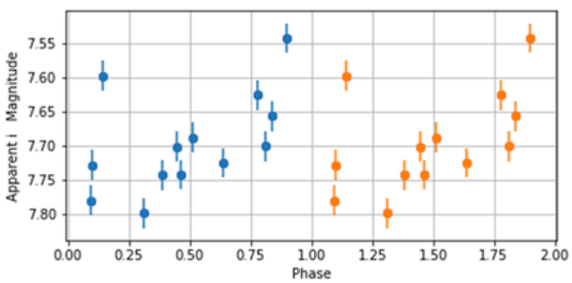

Figure 1: Light curve spanning two complete phases for V1719 Cyg in the i-band using the PDM period.

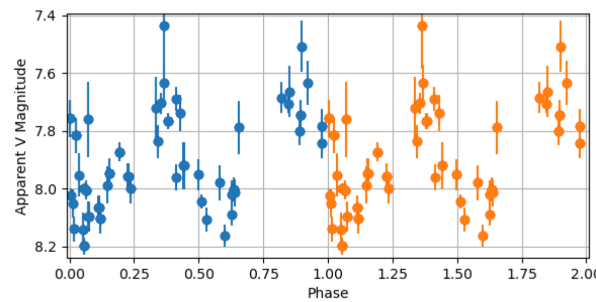

Figure 2: Light curve spanning two complete phases for V1719 Cyg in the V band using the PDM period.

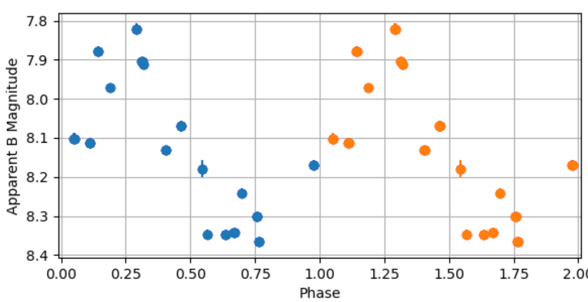

Figure 3: Light curve spanning two complete phases for V1719 Cyg in the B band using the PDM period.

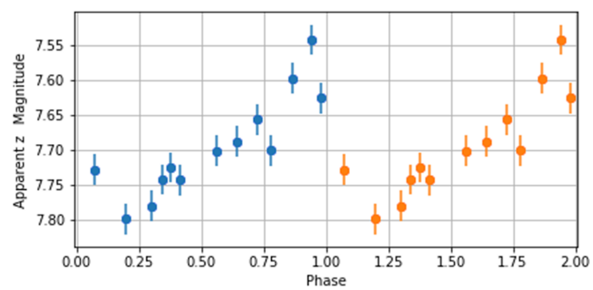

Figure 4: Light curve spanning two complete phases for V1719 Cyg in the z band using the PDM period.

III. *Absolute Magnitude and Distance Results*

Finally, the distance to V1719 was calculated using the values we established for period and apparent magnitude, in the V, I, and z bands along with the established measurement of metallicity for V1719 Cyg from Kim and Yushchenko (2011). This metallicity value [Fe/H] of 0.300 accounts for the chemical composition of the star and was converted to the logarithm of the of the metal mass fraction, log Z using the following relations from Cáceres and Catelan (2008) and an [α/Fe] value of 0.3 as suggested in Catelan et al. (2004).

$$\log Z = [\mathrm{M/H}] - 1.756$$

$$[\mathrm{M/H}] = [\mathrm{Fe/H}] + \log(0.638f + 0.362)$$

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$$\text{where } f = 10^{[\alpha/Fe]} = 10^{0.3}$$

Then, absolute magnitude, M, could be found using period-luminosity relations for RR Lyrae stars in those bands, which are shown in the equations below. The V-band relation comes from Catelan et al. (2004). The i and z band relations come from Cáceres and Catelan (2008).

$$M_v = 2.288 + 0.882 \log Z + 0.108(\log Z)^2$$

$$M_i = 0.908 - 1.035 \log P + 0.220 \log Z$$

$$M_z = 0.839 - 1.295 \log P + 0.211 \log Z$$

Then, the calculation was repeated using the relation established in 2019 for Delta-Scuti type stars in the V-band, shown in the equation below (Ziaali et al., 2019).

$$M_V = (-2.94 \pm 0.06) \log(P) - (1.34 \pm 0.06)$$

Once the absolute magnitude was found, the distance could then be calculated using the following equation

$$d = 10^{(m-M-A+5)/5}$$

where d is the distance, m is the apparent magnitude, M is the absolute magnitude, and A is the extinction factor that accounts for interstellar reddening which results from the scattering of starlight in the interstellar medium (Fitzgerald, 2018). The results of these calculations are shown in Table 4 alongside a comparison to previously published results.

Table 4:

Distance to V1719 Cyg: Comparison of Previous Findings to this Paper

Reference	Distance (pc)	Error
Gaia (2016)	392.512	±5
Joner & Johnson (1985)	158	N/A*
Johnson & Joner (1986)	325	N/A*
Alania (1987)	223	N/A*
Claret & Rodriguez (2000)	283	N/A*
Pena et al. (2001)	324	±53
Present Paper: Delta Scuti V-Band[1]	316.68	±5.6
Present Paper: RR Lyrae V-Band[2]	228.03	±14.4
Present Paper: RR Lyrae z-Band[2]	141.17	±5.7
Present Paper: RR Lyrae i-Band[2]	149.69	±6.1

[1]Using period-luminosity relation outlined in Ziaali et al (2019)

[2]Using period-luminosity relation outlined in Catelan et al. (2004) and Cáceres and Catelan (2008).

*Errors in these cases could not be found

Table 4: This table displays the results of the distance to V1719 Cyg determined in this study alongside previously published findings of distance. The corresponding errors are also reported except for the cases where errors could not be found or substantiated (these are indicated by *)

If V1719 Cyg was an RR Lyrae type star, we would expect the estimations of distance in each band using the RR Lyrae relations to agree rather closely with one another. However, as seen in RR Lyrae distance determinations in Table 4, the values vary by nearly 100 parsecs from the V-band to the z-band. This provides evidence in support of the conclusion that V1719 Cyg is not an RR Lyrae star. On the contrary, the distance determined by using the Delta Scuti relation is 316.68 $\pm$ 5.6 pc which is closer to agreeing with the distance found by *Gaia* (2016) – 392.51 $\pm$5 pc – by the parallax method, though they do not align perfectly showing a difference of 76 parsecs.

It should be noted again that the errors in the calculations of distance are yet again underestimated. One of the contributing factors for the underestimation of the errors is due to the algorithm used to analyze the photometry files itself. It is noted that the code consistently underestimates the error as it aims to calibrate the photometric images of the star that are inputted (Fitzgerald, 2018). This underestimation of the error at the period determination stage would have been propagated into the errors in the distance calculations. While refining the code is outside the scope of this project, it is always a goal to strive towards.

The differences seen in these distance calculations showcase the fact that the star V1719 Cyg is a special case to study. It's abnormal properties – temperature, metallicity, luminosity, and high amplitude – contribute to its misclassification (Peña et al., 2001). There is still much work to be done to further confirm the classification of this star and the validity of the Delta Scuti period-luminosity relation (Ziaali et al., 2019). Since a period-luminosity relation for Delta Scuti stars has not been established for bandpasses other than V, the measurements of period in the B, i, and z bands and the distance estimation using the relatively new relation in the V-band can provide useful insight on how these relations behave as future studies seek to establish them.

Conclusions

This research has determined the magnitude of the variable star V1719 Cyg in different photometric bands to be as follows, V: 7.849, B: 8.093, i: 7.67, z: 7.67. The period was also determined using the Distance Method and Phase Dispersion Method. From the values of period in these bands, an average period of 0.27323 days was found which supports the previous findings of the period for this star.

The distance calculations using the RR Lyrae period-luminosity relation are, V: 228.03 $\pm$ 14.4 pc, i: 149.69 $\pm$ 6.1 pc, z: 141.17 $\pm$ 5.7 pc. When the calculations were done using the Delta Scuti period-luminosity relationship, the V band yielded a distance of 316.68 $\pm$ 5.6 pc. These distances can be compared to the distance provided by *Gaia* which is 392.51 $\pm$5 pc (*Gaia* Collaboration, 2016). The data clearly supports the statement that the star V1719 Cyg is more accurately classified as a large amplitude Delta Scuti star rather than an RR Lyrae type star.

Throughout the course of this study, it became apparent that physical characteristics of V1719 Cyg such as its period, light curve, and calculated distances, and the methods used to study such variable stars may be the root cause for the misclassification of the star as a RR Lyrae variable star. A more detailed study into the surface gravity and metallicity of this star should be conducted to better differentiate between RR Lyrae and Delta Scuti stars. However, based on the findings in this study, we concur with recent results that V1719 Cyg should be classified as a large amplitude, Delta Scuti variable star though we recognize the need for the development of more period-luminosity relations in more bandpasses for Delta Scuti type stars.

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