NPHY 3rd Year Practicle

Atm-Ext Practical

Calculating the distance to variable star V703 Sco

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Contents

1 Abstract

The aim of this report is to determine the distance from Earth to the δ Scuti variable star, V703 Sco, that is on the border of the Scorpion constellation. We start by calculating the difference in apparent magnitude of the B-filter and V-filter, from this we saw that the star has a pulsating period of 80 minutes (0.05621 decimal hour), and a temperature range between 4950K and 7341.6K. The absolute bolometric magnitude of the V-filter was calculated, by using the theoretical model for the period luminosity relation for Scuti stars, to be 2.4338 and with the bolometric correction it is 2.557. This bolometric magnitude and the real apparent magnitude of 7.85 was used in the distacne modulus formula, to get a distance of 114.432 parsec, or 373.23 light years away form Earth.

2 Introduction

By observing the night sky stars can appear to change in brightness over time, some only change for a period of time, while others appear to have constant brightness. The stars that do change are called variable stars, and there are two main groups of variable stars, intrinsic and extrinsic. Intrinsic variables change in brightness due to a change within the star, such as Cepheid's (pulsing stars) and extrinsic variables change due to some external process acting on the star (Briggs,2021).

Cepheid stars are periodically expanding or contracting, this includes a change in its size or its effective temperature. Pulsating stars are distinguished by the period of pulsation, the shape of its light curve or change in magnitude. The change in magnitude can range from decimal magnitude values to 20 magnitudes (Space,2015). There are more than 2 million variable stars in the universe, but there are suspected to be more, our own Sun is also a pulsating variable star, however its magnitude change is about 0.1% of its magnitude over a period of 11 years.

In the early 1900's astronomer Henrietta Swan Leavitt discovered a direct relationship between the rate the a Cepheid's changes its brightness and its luminosity (absolute brightness). This relationship is extremely helpful in astrophysics, since we can determine the distance of the star,if the apparent magnitude and pulsating period is known, no matter how far away from us it is. Luminosity is the amount of light that an objects emits, and it is independent of the distance to the object. It is usually referred in units of solar luminosities, that is one solar luminosities is equal to the luminosity of our Sun (Gregersen, 2022).

Delta Scuti variable stars are a subclass of Cepheid stars and are the second most common pulsating stars. They are still relatively young stars, less than a billion years old. They have spectral types ranging from A0 to F5, and primarily located in the lower part of the Cepheid's instability strip in the Hertzsprung-Russell (H-R) diagram (Rodríguez, López-González and P. López de Coca, 2000). They have pulsation periods between 18 minutes and 8 hours with apparent magnitude change range between 0.003 and 0.9 (John, 2020). They are divided into two subgroups according to their pulsation amplitudes namely, Low Amplitude Delta Scuti stars (LADS) and high Amplitude Delta Scuti stars (HADS). The first period luminosity relation was made in 1912 by Leavitt and Pickering, and this is still used today.

Photometry, in astronomy,is the measurement of light intensity of stars and other celestial objects, and this is done by using a charge-coupled device (CCD). There are two types of photometry - differential and absolute (Ttu.edu, 2022). In differential photomerty the observed object is compared to nearby stars to get more 0accurate values, whereas with absolute photometry only the observed object is studies. When importing a CCD into an appropriate application, like FitsView or SaoImageDS9, a cirlcle is drawn over the star. The application then determines the amount of electrons that are within the cirlce, this is usually called the 'counts' of the star(Las Cumbres Observatory, 2022).

Throughout this report we will mainly work with intrinsic variable stars, more specifically Cepheid stars. The star we will be observing is V703 Sco that is on the border of the Scorpion constellation. The observed color is blue-white, which relates to a effective temperature of 6728 Kelvin (John, 2015).

This star is spectral type A9V and is an RR Lyr type (pulsating) variable star. These are pulsating stars just evolving off the Main Sequence, and they obey the period-luminosity relation, so can be used as distance indicators (Halprin and Moon, 1982). The aim of this report is to determine the distance of a variable star, by using the magnitude defence of two filters. .

3 Method

The variable star observed throughout the report was V703 Sco, the observations was made at Nooitgedacht in Potchefstroom over a period of about two and a half hours, starting at 18h00 and ending at approximately 20h30. This report was done in two separate parts, the first part is obtaining the difference in apparent magnitudes for the B and V filters. The second part is estimating the distance by using the calculated temperature, by using the difference between the apparent magnitudes of the first part.

3.1 Week 1: Gathering Time-series Data

Before we can begin with the report, we need to verify that the observed star is truly a varying star, this can be done by comparing it to surrounding stars, that we will call reference stars. The figure below (1) was obtained from the SIM-BAD site and was imported into FitsView,a application that can gather the necessary information for us. From FitsView we want the measured star and background flux of the varying star as well as three reference stars.

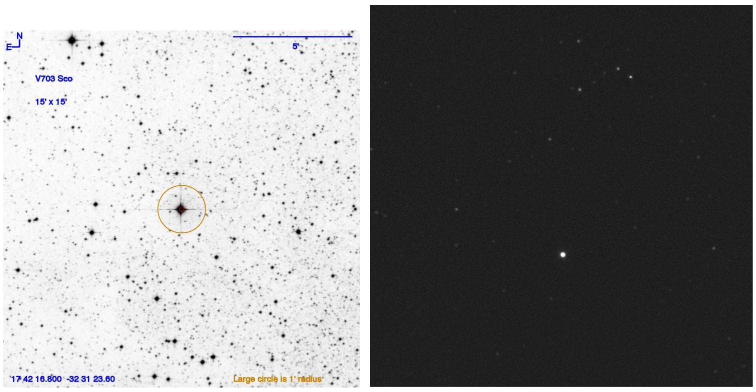

Figure 1: The image in the left is the SIM-BAD image, also knonw as a star map, its for locating the correct star. The right image is the CCD used to obtain the counts of each star.

The average background flux is then subtracted from our variable star, to determine the apparent magnitude of the target star. This calculated apparent magnitude for both filters is then graphed on the same axis, this is only to visualize the difference in apparent magnates of the two filters. Afterwards the difference between the two filters is calculated and also graphed. This is the final step before we can start the distance calculations.

3.2 Week 2: Determining Distance

In this section the apparent magnitudes for both the B and V-filter was given. This given data was imported into the NASA Exoplanet Archive (Caltech.edu, 2022), where a periodigram was plotted for us by using the Lomb Scargle method (VanderPlas, 2018). Both periodigrams are shown in results as figure 4 and 5, from these periodigram we are only interested in the maximum period of each filter. The maximum period will be used in equation 3.

The next step is to use the three magnitude differences, (maximum, average and minimum difference)from week one, to calculate three effective temperatures. However we will only use the average magnitude difference to calculate the bolometric magnitude of our target star (eq 3).

The effective temperature can be estimated via two methods, by either using the main sequence data from Johnson (1966) or by using an equation (2) that can be found in Reed (1998), both methods use the difference in filter magnitudes. The first method only gives an estimate temperature, whereas using the equation we can get a more accurate value, therefore the temperature will be calculated.

With the effective temperature known we calculated the bolometric magnitude of the star, by comparing the its variables to our Sun, for which all variables are known. The bolometric correction for our magnitude difference can be found in Johnson 1966 for the main sequence stars. This bolometric magnitude and the bolometric correction will then be used to calculate the real magnitude of only the V filter.

The final step is to calculate the distance to our star by using the distance modulus formula, by relating the calculated apparent magnitude and the real apparent magnitude.

4 Results

4.1 Week 1: Gathering Data

The following table includes some of the data gathered from the FitsView application, this table includes the counts for both the target star and the reference stars, both with their respective background counts. The full table can be seen in the appendix as table 3.

Decimal day	$R1_{count}$	$R1_{Error}$	$B1_{count}$	$B1_{Error}$	$R2_{count}$	$R2_{Error}$	$B2_{count}$	$B2_{Error}$	T_{count}	T_{Error}	T_{BG}	T_{Error}
23.74	11,471.68	68.27	4,542.57	20.63	8,629.77	44.37	5,478.74	22.70	135,825.10	1,294.42	4,619.86	20.51
23.75	10,576.90	77.73	3,726.60	21.65	7,364.70	45.02	4,077.32	21.54	144,060.99	1,481.37	4,024.91	21.55
23.75	11,570.72	86.73	4,322.71	22.60	7,952.08	50.25	3,783.09	20.72	168,018.68	1,804.24	4,237.19	22.47
23.76	8,680.19	53.57	4,010.53	21.62	6,535.87	37.85	4,030.17	21.12	100,759.99	975.06	4,030.02	22.12
23.76	9,344.53	60.08	3,356.45	19.77	7,002.03	44.20	3,812.62	20.52	127,133.39	1,309.17	4,201.84	22.06
23.77	10,171.26	71.97	3,790.64	20.24	7,273.95	45.77	3,849.92	20.96	160,315.78	1,570.78	4,223.40	22.54
23.77	9,748.54	67.33	3,666.87	20.95	7,472.76	44.05	3,902.43	21.73	164,703.30	1,732.11	4,083.61	21.77

Table 1: *The gathered data of the B-filter using FitsView , this table consists of the counts of two reference stars background counts, as well as the target star (V703 Sco)*

The average background is calculated form table 1 and then subtracted from both the target star's and the reference star's count. The results are shown in the table below (2, 4). With these values and the known average apparent magnitudes of the reference stars, we can calculate the target stat's apparent magnitude, by using equation 1 , the results is also shown in table 2:

$$M_{Target} = M_{ref} - 2.5log(\frac{N_{Target_{counts}}}{N_{Ref_{count}}}) \tag{1}$$

Target		Refence		
count	**rms**	**count**	**rms**	M_{target}
131,008.98	1,273.91	4,599.34	29.88	8.753
140,185.74	1,459.82	4,647.14	36.20	8.691
163,944.71	1,781.77	5,099.23	40.53	8.622
96,808.92	952.94	3,261.87	21.23	8.709
123,461.31	1,287.11	4,158.32	28.66	8.708
156,465.82	1,548.24	4,619.57	34.77	8.565
160,837.35	1,710.34	4,266.66	30.15	8.449
136,109.81	1,383.52	3,931.62	27.25	8.542
129,223.43	1,314.99	3,548.46	27.01	8.487
122,098.07	1,267.79	3,262.93	22.52	8.457

Table 2: *The the full data of reference and target flux counts without background, and the calculated apparent magnitude of the target star.*

Graphing the calculated apparent magnitudes of the B-filter and V-filter against the decimal days, we can visually see how the magnitudes of the same star can differ.

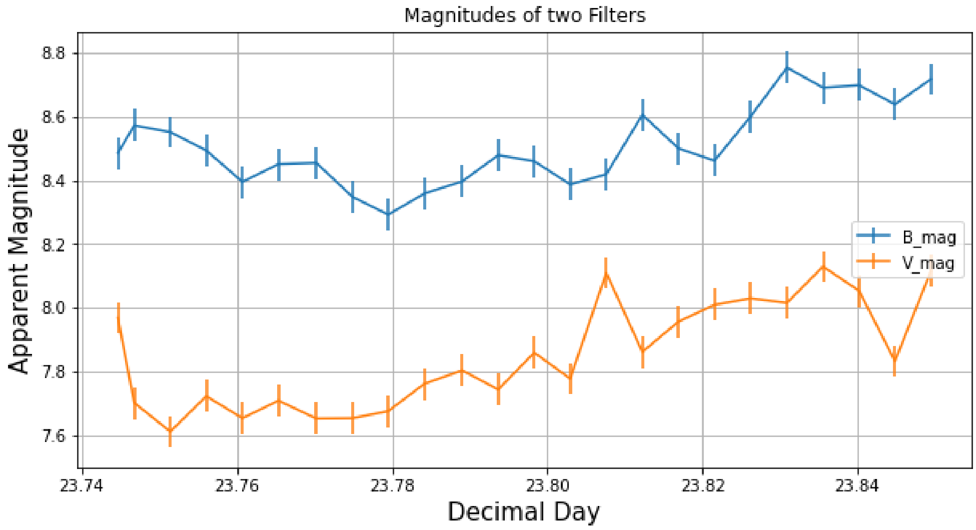

Figure 2: *Given apparent magnitudes in both V and B filter of V703 Sco, with error values. The duration was for about 3 hours.*

However we need the difference between the two apparent magnitudes to calculate the effective temperature. This difference ($B_{mag} - V_{mag}$) is shown in the graph (3) below.

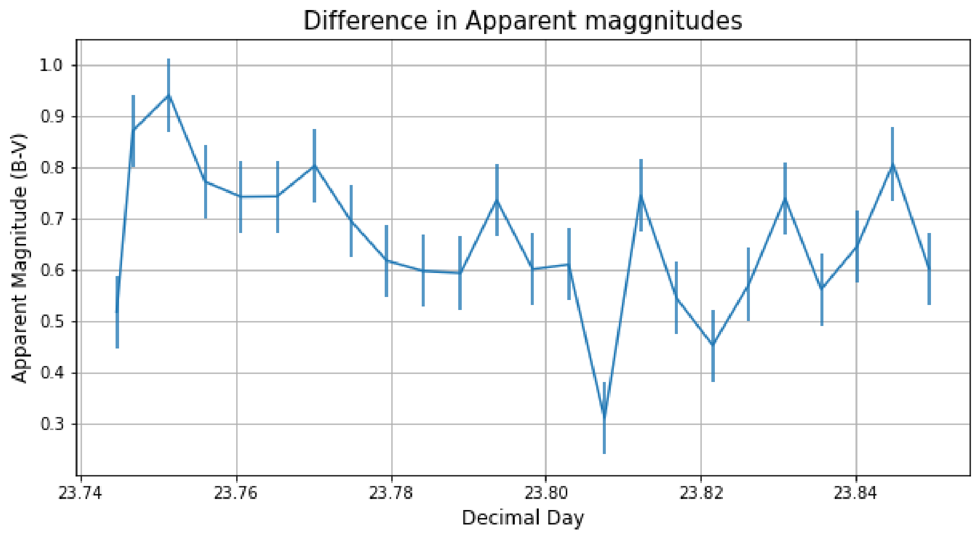

Figure 3: *The apparent magnitude difference between the B and V filter. The maximum difference is 0.94, average difference is 0.659 and the minimum difference is 0.309.*

From this graph we are only interested in three values, namely, the maximum, the average and the minimum difference. This is important since we want to calculate the effective temperature range of our variable star.

4.2 Week 2: Determining Distance

To achieve the aim of this section, we first need to know the maximum period of the star, the average difference between the two filters used (B-V), the estimated effective temperature, the bolometric magnitude and lastly the apparent magnitude of our star.

The first thing to do is importing the data into the NASA site and graphing the respective periodigram for both filters.

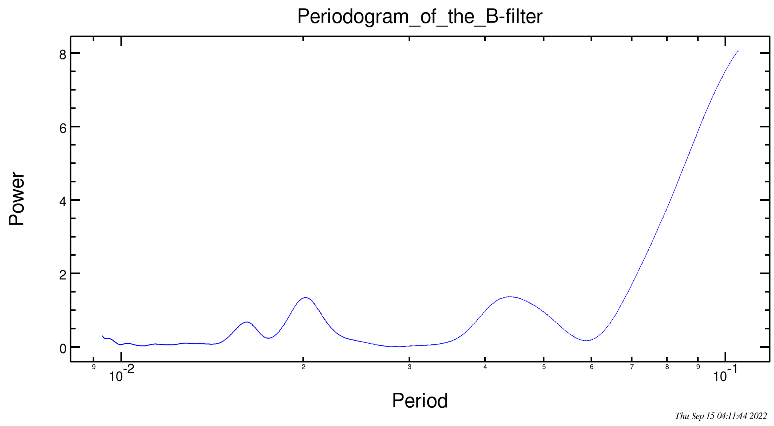

Figure 4: *Periodigram of the B-filter over a time of two hours. The maximum period is 0.10483 and the minimum period is 0.0093*

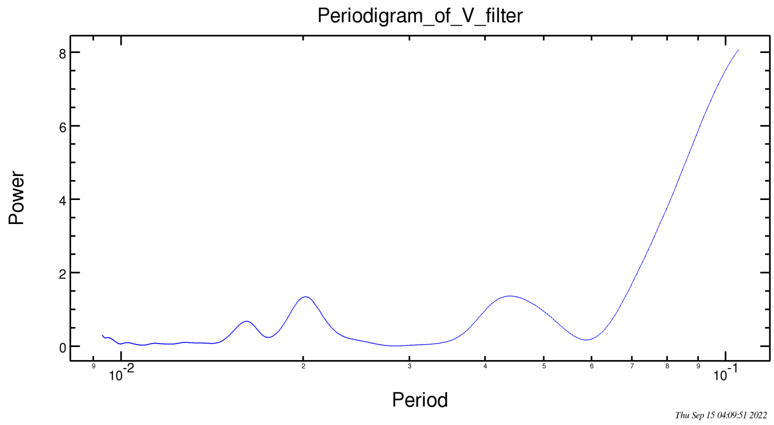

Figure 5: *Periodigram of the V-filter over a time of two hours. The maximum period is 0.10483 and the minimum period is 0.0093*

The maximum period for both filters are identical with a value 0.10483. This period value will used in the calculation for the star's theoretical bolometric equation.

The maximum, minimum and average effective temperature was calculated using equation 2, however only the average temperature will be used in the bolometric equation.

$$B - V = -3.684log(T_{eff}) + 14.551 \tag{2}$$

The method used in this report was by using equation 2. The following graph is the data obtained with this equation:

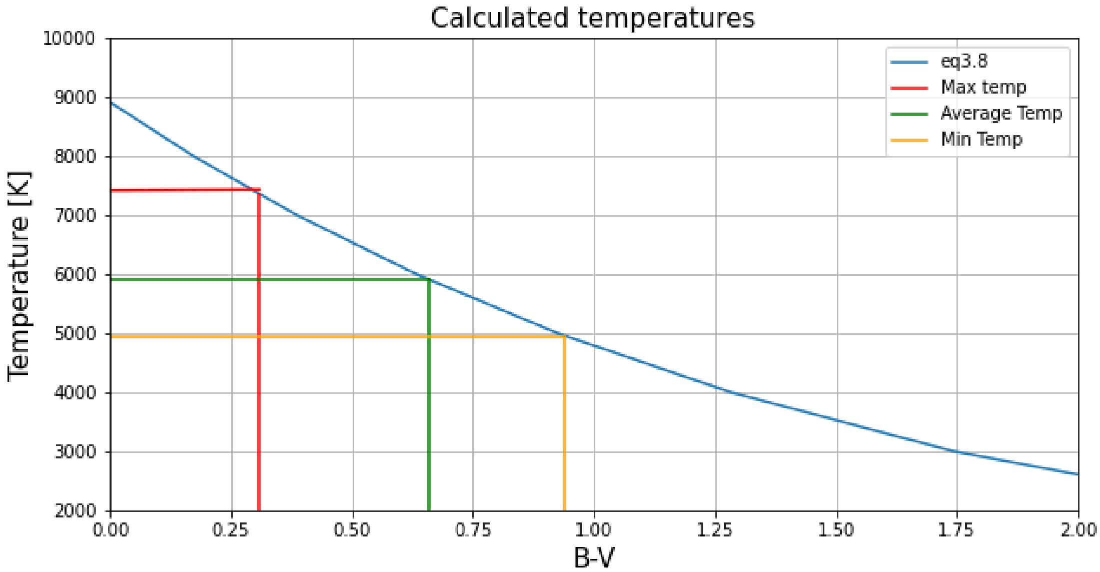

Figure 6: *The calculated temperatures using equation 2, against the difference in magnitudes. This graph also includes the temperature range of the star.*

Calculating a more precise temperature value:

$$log(T_{eff}) = \frac{14.551 - (B - V)}{3.684}$$
$$T_{avr_{eff}} = 5902.26 \ \ Kelvin$$

The estimated temperature of the star is ranges from 7341.632 Kelvin to 4950.199 Kelvin, with a average temperature of 5902.26 K. The average temperature will be used to calculate the absolute bolometric magnitude of the star, by using the theoretical model for the period luminosity relation for δ Scuti stars ,eq 3:

$$M_{bol} = -3.33log(P) + 3.33log(Q) - 10log(\frac{T_{eff}}{T_{sun}}) - 1.67log(\frac{M}{M_{sun}}) + M_{sun_{bol}} \tag{3}$$

,where P is the maximum period of graph 4 with a value 0.10483, Q the pulsation constant with a value of 0.033 days, the effective temperature of the sun as 5700K and the bolometric magnitude of the sun 4.75. The mass radio between V703 sco and our Sun is estimated to be 1.9 (Cox, Hodson and King, 1979). By using these varibles in equation 3, we calculate the absolute bolometric magnitude of V703 Sco:

$$M_{bol} = 2.433855$$

Before be can calculate the apparent magnitude of the V-filter we need the correction value from our bolometric magnitude. This correction value can be estimated from the graph 7. This graph is made by using data of main sequence stars acquired from Johnson 1996.

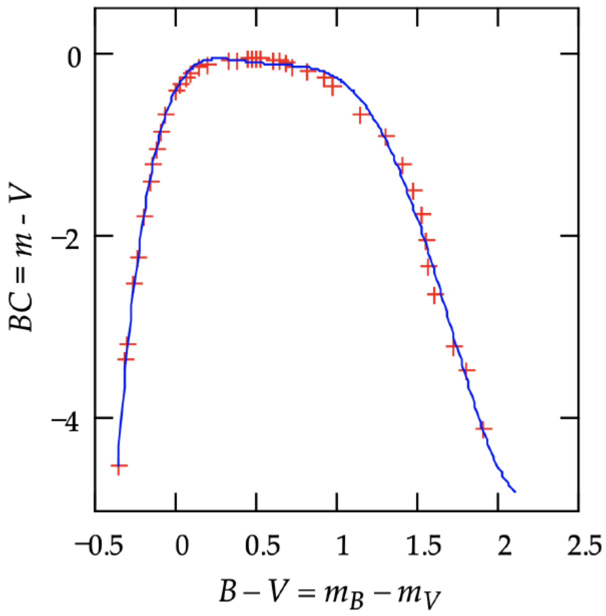

Figure 7: *Bolometric correction as a function of color index B - ´V, from Johnson 1966 for main sequence stars. Here is data from their table II plotted. The color index for V703 Sco is 0.6586 and has a correction value of -0.02.*

The penultimate calculation of this report is to find the real apparent magnitude of the star, this is calculate by subtracting the bolometric correction from the absolute bolometric magnitude.

$$M_V = M_{bol} - BC_V \tag{4}$$

$$M_V = 2.43385 - (-0.02)$$

$$M_V = 2.557$$

All the necessary calculations needed to calculate the distance are complete. Therefore we can determine the distance of the star with the distance modulus,

$$m_v - M_V = 5log(\frac{d}{10}) \tag{5}$$

$$d = 10^{\frac{(m_V - M_V + 5)}{5}}$$

where m_V is the average apparent magnitude of the V-filter, with a value of 7.85. Finally the estimated distance to the star is determined to be:

$$d_{avr} = 114.432 \ pc$$

5 Discussion

In this report we wanted to determine if star V703 Sco is a variable star, and if it was we want to know its distance. For a star to be classified as a variable star, its luminosity must change over a period of time. In the first part of the report we observed V703 Sco for a duration of about two and a half hours and with two different filters. The apparent magnitude was then determined with equation 1, and plotted against the duration in figure 2. From this graph we can see that this star is brighter in the V spectrum, therefore we can assume this star is older and cool. However we need the difference between the two filters to calculate the temperature, this difference is shown in figure 3.

This figure (3) gives us a better understanding of how the star pulsates over time. The star has a maximum magnitude difference of 0.94 at 9 minutes into the observations and has a minimum difference of 0.309 after 90 minutes. This indicates that the star has a pulsation period of about 80 minutes (1hour 20 min). Within this pulsation period the the magnitude difference decreases,hence getting the star is brighter and therefore is getting hotter and therefore is growing in size, however the star starts shrinking afterwards.The period was determined on the NASA web site, with the Lomb Scargle method, and shown in figure 4. This figure has a maximum period of 0.10483 and this corresponds to the the time we observed V703 Sco.

The effective temperatures of V703 was calculated at the start, middle and end of its pulsation period using equation 2. The effective temperature at the start was 4950.2 K and increased to 7341.6 K at the end of the pulsation period. This increase in temperature during the pulsing period corresponds with the increase of brightness. According to John (2015), the effective temperature of V703 Sco is 6728 K.

The bolemetric apparent magnitude of V703 Sco was calculated to be 2.4338, whereas the sun's bolometric magnitude is 4.75. According to Johnson 2016, the bolometric correction for our star is -0.02 and this can be seen in figure 7.From this graph we observe that stars with magnitude differences between zero and one almost doesn't need to be corrected, however the correction value increases as the difference gets either smaller than zero or larger than one. After applying the correction value we have the real apparent magnitude of V703 Sco that is 2.557.

The distance to V703 was calculated with the distance modulus formula (Johnson, 1966), and it was determined to be 114.432 parsecs or 373.23 light years away, however according to John 2015, in 1997 the distance to the star was measured to be 255.75 parsecs, and then in 2007 the distance decreased to 170.65 parsecs.When comparing the calculated distance to the distances found by John (2015), we observe that the distance decreases. This decrease in distance can be due to the astronomy technology increase.

6 Conclusion

As mentioned in the introduction the aim of this report was to determine the distance of the V703 Sco δ Scuti star. To achieve this aim we needed to know the absolute bolometric magnitude of the star M_{bol}, therefore we need to know its pulsating period, the apparent difference magnitude between two filters and the average temperature as well as its real average apparent magnitude.

In conclusion the distance of any variable star can be calculated if the these mentiond varibles are known.

7 Bibliography

Briggs, A. (2021). EarthSky | What is a variable star? [online] EarthSky | Updates on your cosmos and world. Available at: https://earthsky.org/astronomy-essentials/what-is-a-variable-star/ [Accessed 15 Sep. 2022].

Cox, A.N., Hodson, S.W. and King, D.S. (1979). Theoretical periods and masses of double-mode dwarf Cepheids. The Astrophysical Journal, 228, p.870. doi:10.1086/156912.

Gregersen, E. (2022). luminosity | astronomy | Britannica. In: Encyclopædia Britannica. [online] Available at: https://www.britannica.com/science/luminosity [Accessed 10 Sep. 2022].

John (2020). What is a Delta Scuti Variable Star ? (SX Phoenicis AI Velorum Variables). [online] Universe Guide. Available at: https://www.universeguide.com/fact/deltascutivariables [Accessed 15 Sep. 2022].

John (2015). V703 Scorpii Star Facts (Type, Distance, Magnitude, Age, Colour, Luminosity, Location more). [online] Universe Guide. Available at: https://www.universeguide.com/star/86650/v703scorpii [Accessed 14 Sep. 2022].

Johnson, H.L., 1966. Astronomical measurements in the infrared. Annual Review of Astronomy and Astrophysics, 4, p.193.

Las Cumbres Observatory (2022). Introduction to Photometry. [online] Lco.global. Available at: https://lco.global/spacebook/telescopes/what-is-photometry/ [Accessed 16 Sep. 2022].

Morgan, S. (2022). Mathematical Applications. [online] Uni.edu. Available at: https://sites.uni.edu/morgans/astro/course/Notes/section3/math11.html [Accessed 15 Sep. 2022].

Rodríguez, E., López-González, M.J. and P. López de Coca (2000). A revised catalogue of Sct stars. Astronomy and Astrophysics Supplement Series, [online] 144(3), pp.469–474. doi:10.1051/aas:2000221.

Space (2015). Types of Variable Stars: Cepheid, Pulsating and Cataclysmic. [online] Space.com. Available at: https://www.space.com/15396-variable-stars.html [Accessed 10 Sep. 2022].

Ttu.edu. (2022). Photometry Methods. [online] Available at: http://www.phys.ttu.edu/ ozprof/honours3.htm [Accessed 16 Sep. 2022].

VanderPlas, J.T. (2018). Understanding the Lomb–Scargle Periodogram. The Astrophysical Journal Supplement Series, [online] 236(1), p.16. doi:10.3847/1538-4365/aab766.

8 Appendix A

8.1 Week one Full data

Decimal day	$R1_{count}$	$R1_{Error}$	$B1_{count}$	$B1_{Error}$	$R2_{count}$	$R2_{Error}$	$B2_{count}$	$B2_{Error}$	T_{count}	T_{Error}	T_{BG}	T_{Error}
23.74	11,471.68	68.27	4,542.57	20.63	8,629.77	44.37	5,478.74	22.70	135,825.10	1,294.42	4,619.86	20.51
23.75	10,576.90	77.73	3,726.60	21.65	7,364.70	45.02	4,077.32	21.54	144,060.99	1,481.37	4,024.91	21.55
23.75	11,570.72	86.73	4,322.71	22.60	7,952.08	50.25	3,783.09	20.72	168,018.68	1,804.24	4,237.19	22.47
23.76	8,680.19	53.57	4,010.53	21.62	6,535.87	37.85	4,030.17	21.12	100,759.99	975.06	4,030.02	22.12
23.76	9,344.53	60.08	3,356.45	19.77	7,002.03	44.20	3,812.62	20.52	127,133.39	1,309.17	4,201.84	22.06
23.77	10,171.26	71.97	3,790.64	20.24	7,273.95	45.77	3,849.92	20.96	160,315.78	1,570.78	4,223.40	22.54
23.77	9,748.54	67.33	3,666.87	20.95	7,472.76	44.05	3,902.43	21.73	164,703.30	1,732.11	4,083.61	21.77
23.78	9,738.19	62.50	3,491.86	20.54	6,948.64	41.67	4,055.89	21.35	140,148.40	1,407.63	4,680.24	24.11
23.78	9,013.15	62.98	3,876.64	21.07	6,956.88	41.84	4,339.81	22.59	133,345.10	1,338.09	4,563.65	23.10
23.78	8,376.66	58.08	3,697.89	20.74	6,818.17	37.05	4,473.37	23.25	126,261.88	1,291.13	4,590.36	23.34
23.79	9,354.62	67.89	3,546.88	20.38	7,450.51	45.19	3,751.80	21.23	157,076.26	1,651.08	3,845.36	22.45
23.79	9,452.01	64.47	3,426.63	20.87	7,193.54	42.15	4,012.95	21.23	166,789.50	1,694.31	3,965.21	21.76
23.80	9,961.83	70.14	3,814.80	21.67	7,571.54	43.70	4,116.71	22.15	156,080.58	1,576.05	3,753.40	21.57
23.80	8,765.38	58.36	3,639.90	21.27	7,203.04	40.77	3,912.57	20.74	124,104.86	1,333.15	4,174.49	22.54
23.81	10,028.15	71.08	3,967.02	21.33	7,417.94	44.72	4,286.10	23.43	149,506.42	1,580.31	3,927.37	21.44
23.81	9,393.27	68.93	4,156.41	22.40	6,711.26	39.02	4,179.95	22.12	117,202	1,205.36	4,250.94	22.68
23.81	8,932.45	59.61	3,632.43	20.45	6,690.72	38.95	4,012.11	22.49	106,168.00	1,089.82	3,697.73	21.07
23.82	8,568.98	57.52	3,697.69	21.52	6,580.71	37.04	4,336.20	22.48	96,527.38	960.63	4,080.20	22.35
23.83	8,081.66	56.01	3,567.53	20.96	6,544.39	38.43	3,677.94	20.42	98,458	965.49	3,671.50	20.25
23.83	9,393.72	61.64	3,762.65	21.90	7,364.02	42.47	4,027.60	22.15	119,793.00	1,248.62	3,746.43	21.59
23.84	9,021.59	59.21	3,917.48	22.67	6,543.62	35.65	4,301.69	22.28	92,034.35	947.26	4,300.47	22.53
23.84	9,456.98	59.79	3,937.97	22.62	7,526.58	43.08	4,042.31	22.26	102,052.95	1,000.07	3,942.76	21.48
23.85	10,288.24	71.69	3,896.91	21.84	7,463.94	41.93	3,869.42	20.97	111,699.42	1,090.35	4,052.39	22.10
23.85	9,915.58	65.81	3,741.38	21.09	7,785.11	48.45	4,166.17	22.81	124,241.07	1,222.15	4,015.07	20.64
23.86	10,211.72	67.37	3,850.79	20.66	7,990.70	44.46	4,159.52	21.59	128,960.47	1,286.13	4,222.52	22.67

Table 3: *The the full data set of of reference and target flux counts with each's respective background counts.*

Target		Refence		
count	**rms**	**count**	**rms**	Target [M_i]
131,008.98	1,273.91	4,599.34	29.88	8.753
140,185.74	1,459.82	4,647.14	36.20	8.691
163,944.71	1,781.77	5,099.23	40.53	8.622
96,808.92	952.94	3,261.87	21.23	8.709
123,461.31	1,287.11	4,158.32	28.66	8.708
156,465.82	1,548.24	4,619.57	34.77	8.565
160,837.35	1,710.34	4,266.66	30.15	8.449
136,109.81	1,383.52	3,931.62	27.25	8.542
129,223.43	1,314.99	3,548.46	27.01	8.487
122,098.07	1,267.79	3,262.93	22.52	8.457
153,312.84	1,628.63	4,152.13	31.12	8.472
162,833.36	1,672.55	3,910.51	27.40	8.341
152,166.99	1,554.48	4,320.14	31.10	8.523
120,234.96	1,310.61	3,642.57	24.67	8.593
145,433.70	1,558.87	4,239.26	31.56	8.552
113,112.60	1,182.68	3,641.78	28.38	8.660
102,341.88	1,068.75	3,474.74	23.31	8.717
92,588.92	938.28	3,302.63	22.92	8.771
94,788.03	945.24	3,282.32	23.31	8.739
115,931.26	1,227.03	4,042.91	26.34	8.746
87,828.49	924.73	3,192.14	21.75	8.791
98,127.55	978.59	4,106.80	25.26	8.944
107,744.62	1,068.25	4,335.11	30.35	8.902
120,179.25	1,201.51	4,344.20	29.77	8.785
124,997.98	1,263.46	4,676.39	30.54	8.823

Table 4: *The the full data of reference and target flux counts without background, and the calculated apparent magnitude of the target star. This*