CCD Astrometry of the Components of WDS 00153-2259

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Abstract

In this paper we show how WDS star 00153-2259 is an optical double using the Harshaw Statistic, a probability calculation of the radial direction, observing the star with an i-filter and r-filter. For the AB pair, we found a mean position angle of 263.6° and a mean separation distance of 7.13". For the AC pair, we found a mean position angle of 214.0° and a mean separation distance of 24.4". For the BC pair, we found a mean position angle of 199.7° and a mean separation distance of 20.4". Through our calculations and observations, we found that the star is actually an optical double even though some calculations may lead to it being otherwise.

Introduction

The objective of our research was to measure a star system to determine the gravitational nature of the system. Our research was to provide additional measurements on both the angular separation and position of the component[s] in Washington Double Star Catalog (WDS) 00153-2259 (HDO 6) assessing whether this system may be a physical or optical double. A classification as a double star can help determine the binary system's stellar mass, which is a notable factor in determining and confirming theories on the life cycle of stars. HDO 6 was chosen over multiple criteria: an angular separation between 5 and 12 arc-seconds, a delta magnitude greater than or equal to 3, a magnitude no less than 13, and a system with three components.

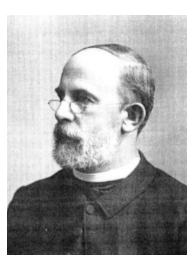

Figure 1: George Mary Searle (1839 – 1918)

The components for HDO 6 have been observed 19 times. The first observations were made by George Mary Searle, Figure 1, a prominent astronomer who made significant contributions to observations of stars. Since then, the system has been observed a further 8 times by various astronomers, with the most recent observation being made in 2018 by W.R.A. Knapp and J. Nanson.

Equipment and Methods

We used the Las Cumbres Observatory (LCO) with the Cerro Tololo telescope (Brown, 2013), located in Chile, to observe the WDS 00153-2259 (HDO 6) multi star system. We used the 0.4 meter SCICAM QHY600 camera with the SDSS-rp filter and SDSS-ip filter to get two different sets of 10 images.

Figure 2: Image of Cerro Tololo Telescope used to image HDO 6

To analyze our image, we used AstroImageJ (AIJ) (Collins, 2017) which gave us the apparent separation, delta magnitude (difference in brightness) and position angle. To make sure our data was accurate we repeated the data extraction twice for each image. Through AIJ we accessed the Gaia data which allowed us to grab the star Right Ascension, Declination, Primary Motion Right Ascension, Primary Motion Declination, and Radial Velocities used in our calculations. Figure 3 is an example of HDO 6 taken by the LCO telescope.

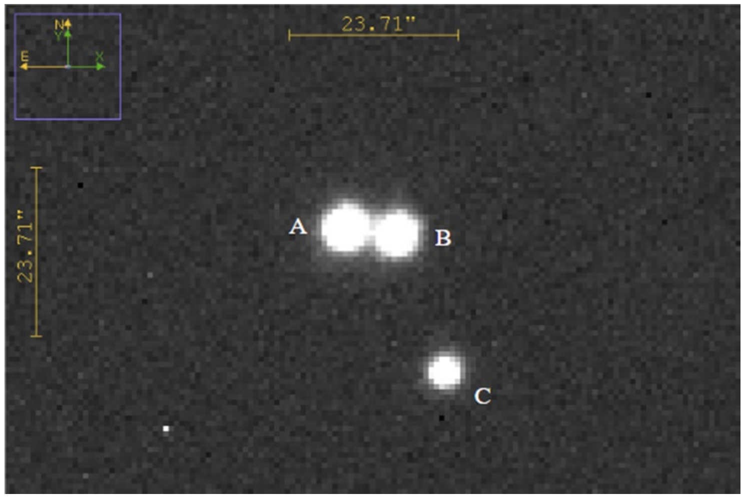

Figure 3: Image of HDO 6 taken by LCO telescope on AstroImageJ. 'A' represents star A, 'B' represents star B, and 'C' represents star C.

We then recorded these data points on Excel and calculated the mean and standard deviation of our data. We then used a Harshaw Statistic Calculator (Harshaw, 2014), provided by the Boyce Research Initiatives and Education Foundations (BRIEF), to determine the likelihood that a system is gravitationally bound.

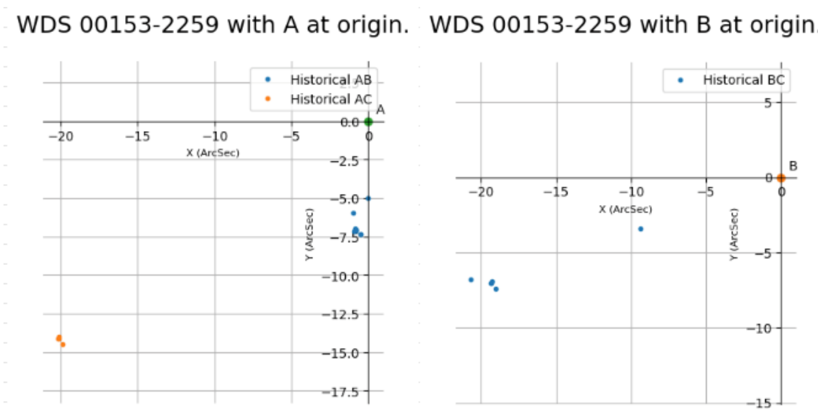

Figure 4: Historical Data Plots for WDS 00153-2259 with A at the origin (left image) and B at the origin (right image).

Data And Measurements

To create the historical data plot chart, we used the following observations from the WDS Catalog, Tables 1 - 3.

Epoch	Position Angle (θ)	Separation (ρ)
1880.09	270	5
1909.8	260.8	6.06
1920.07	262.8	7.24
1921.89	262.8	7.35
1921.89	266	7.355
1931	263	7.01
1994.619	263	7.1
1999.577	263.5	7.102
2000.6	263.4	7.16
2015	263.48	7.121

Table 1: Primary Star 'A' WDS Historical Data

Epoch	Position Angle (θ)	Separation (ρ)
1994.619	216	24.6
1999.577	215	24.58

2000.6	215	24.62
2015	214.888	24.504

Table 2: Secondary Star 'B' WDS Historical Data

Epoch	Position Angle (θ)	Separation (ρ)
1880.89	200	10
1920.07	198.2	21.76
1994.62	201.3	20.43
1999.577	200	20.566
2000.6	199.9	20.58
2015	199.786	20.501

Table 3: Tertiary Star 'C' WDS Historical Data

Using these data tables, we were able create our historical data plots, Table 4.

We compared our observations to previous data, and checked the error to be confident that our data was indeed correct. Figure 1 shows a summary of all our observations: when we took them, which observatory, which filter, and how many images we measured.

Observations				
WDS: 00153-2259			Discoverer: HDO 6	
Date	Epoch	Observatory	Filter	Measured Images
2023-12-29	2023.953	LCO Cerro Tololo	SDSS-ip	10
2023-12-29	2023.953	LCO Cerro Tololo	SDSS-rp	10
2023-12-27	2023.947	LCO Cerro Tololo	SDSS-ip	6
2023-12-27	2023.947	LCO Cerro Tololo	SDSS-rp	6

Table 4: A summary of the observations made on HDO 6

We then used our observations from 2023.953 to calculate the average Theta, Rho and Delta Magnitude for each pair of stars in HDO 6. The standard error and standard error of the mean were then checked to determine if our calculations were accurate. Tables 5 and 6 show observations taken on 2023.953, of the AB stars in HDO 6. Table 5 is the rp filter and Table 6 is the ip filter.

WDS 00153-2259 HDO 6 AB HDO 6				
Epoch	Measurement	Theta	Rho	Delta Magnitude (SDSS-rp)
2023.953	Mean Standard Deviation Standard Error of the Mean	263.627 0.13500 .04268	7.128 0.0192 0.006	0.171643 0.0062 0.001958
2015.	Last Measurement	263.4	7.121	

Table 5: Observations taken on 2023.953, of the AB stars in HDO 6 with rp filter

WDS 00153-2259 HDO 6 AB HDO 6				
Epoch	Measurement	Theta	Rho	Delta Magnitude (SDSS-ip)
2023.953	Mean Standard Deviation Standard Error of the Mean	263.626 0.1568 0.04958	7.1214 0.042 0.012	0.156868 0.009 0.0028
2015.	Last Measurement	263.4	7.121	

Table 6: Observations taken on 2023.953, of the AB stars in HDO 6 with ip filter.

Similarly, Table 7, 8 show observations taken on epoch 2023.953, of the BC stars in HDO 6. Table 7 shows the rp-filter and Table 8 shows the ip-filter.

WDS 00153-2259 HDO 6 BC HDO 6				
Epoch	Measurement	Theta	Rho	Delta Magnitude (SDSS-rp)
2023.953	Mean Standard Deviation Standard Error of the Mean	199.673 0.06664 0.02107	20.44716 0.01956 0.00618	1.37591 0.013875 0.004338
2015.	Last Measurement	199.7°	20.501	

Table 7: Observations taken on epoch 2023.953, of the BC stars in HDO 6 with rp filter

WDS 00153-2259 HDO 6 BC HDO 6				
Epoch	Measurement	Theta	Rho	Delta Magnitude (SDSS-ip)
2023.953	Mean Standard Deviation Standard Error of the Mean	199.678 0.0860 0.02720	20.475 0.0294 0.009	0.1.290833 0.007319 0.002314
2015.	Last Measurement	199.7°	20.501	

Table 8: Observations taken on epoch 2023.953, of the BC stars in HDO 6 with ip filter

Similarly, Table 9, 10 show observations taken on epoch 2023.953, of the AC stars in HDO 6. Table 9 shows the rp-filter and Table 10 shows the ip-filter.

WDS 00153-2259 HDO 6 AC HDO 6				
Epoch	Measurement	Theta	Rho	Delta Magnitude (SDSS-rp)
2023.953	Mean Standard Deviation Standard Error of the Mean	214.868 0.05564 0.01760	24.43122 0.000463 0.000146	1.547553 0.009009 0.002849
2015.	Last Measurement	214.8°	24.504	

Table 9: Observations taken on epoch 2023.953, of the AC stars in HDO 6 with rp filter

WDS 00153-2259 HDO 6 AC HDO 6				
Epoch	Measurement	Theta	Rho	Delta Magnitude (SDSS-ip)
2023.953	Mean Standard Deviation Standard Error of the Mean	214.845 0.0718 0.02272	24.4536 0.00063 0.00020	0.1447701 0.010519 0.003327
2015.	Last Measurement	214.8°	24.504	

Table 10: Observations taken on epoch 2023.953, of the AC stars in HDO 6 with ip filter

We did not use the observations from epoch 2023.947 since there were mistakes with our images and filters and we couldn't get accurate data.

Table 11 shows the Gaia Data for our star system which helped us on our calculations for our radial direction probability calculator. The radial direction probability measures the probability that the pair of stars are within one light year of distance.

Component	Gia G Magnitude	Parallax	Parallax Standard Error	RA Proper Motion	DEC Proper Motion
A	1.19E+01	2.5611	0.0418	-2.927	-15.913
B	1.21E+01	0.8312	0.4383	-3.123	-15.888
C	1.35E+01	0.6727	0.0171	2.738	-12.393

Table 11: Gaia Data of WDS Star 00153-2259

Table 12 - 14 show the Radial Direction Probability of the AC, AB, BC star pairs respectively.

Star	Mean	-1 Std. Dev	distance	Mean	+1 Std. Dev	distance	Mean SEM	
A	1272.891	1252.449	20.441	1272.891	1294.010	21.120	20.781	light years
C	4846.142	4726.008	120.135	4846.142	4972.544	126.402	123.268	light years
	SEM(A-B) =	Square Root of [	20.781	squared	123.268	squared]		
	SEM(A-B) =	**125.01**	**light years**					

Table 12: Radial Direction Probability of AC Star

Star	Mean	-1 Std. Dev	distance	Mean	+1 Std. Dev	distance	Mean SEM	
A	1272.891	1252.449	20.441	1272.891	1294.010	21.120	20.781	light years
B	3922.040	2567.940	1354.100	3922.040	8297.277	4375.236	2864.668	light years
	SEM(A-B) =	Square Root of [	20.781	squared	2864.668	squared]		
	SEM(A-B) =	**2864.74**	**light years**					

Table 13: Radial Direction Probability of AB Star

Star	Mean	-1 Std. Dev	distance	Mean	+1 Std. Dev	distance	Mean SEM	
B	3922.040	2567.940	1354.100	3922.04(	8297.277	4375.236	2864.668	light years
C	4846.142	4726.008	120.135	4846.14ż	4972.544	126.402	123.268	light years
	SEM(A-B) =	Square Root of [	2864.668 squared	123.268	squared]			
	SEM(A-B) =	2867.32	light years					

Table 14: Radial Direction Probability of BC Star

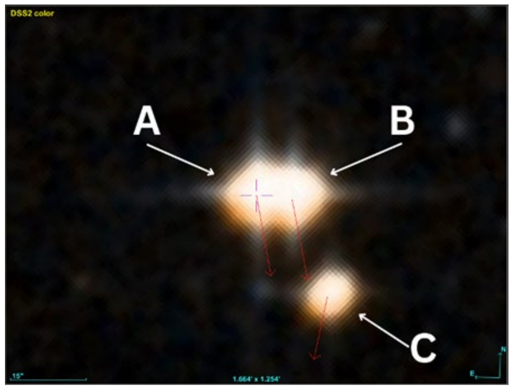

Figure 5: Proper Motion Image

Star Pair	Probability of Being Gravitationally Bound
AB	0.006103672
AC	0.23100494
BC	0.236254779

Table 15: Harshaw Statistic Probability of Each Star Pair being Gravitationally Bound to One Another

Discussion

Using the Gaia DR3 Data for our star system, we calculated the probability of the components moving in the same radial direction. All three-star pairs AB, AC, and BC had a probability 0% of being within one light year of one another, which suggests that they are likely not gravitationally bound.

The distance between the stars can be calculated using the parallax formula $d = (1/p)10^3$. The parallax distance between AB, AC, and BC which all were greater than 1 light year, as shown in Radial Direction Probability of AC, AB, BC, Tables 12, 13, 14, indicating that the stars are not gravitationally bound. These large parallax values could have been caused by high errors but the parallaxes were significant enough that these errors can be disregarded. Our conclusion is further supported by the fact that the normal distribution indicated that the stars were not gravitationally bound even while taking the errors into account.

Proper motion is used to determine whether or not multiple stars are gravitationally bound, by observing whether or not the stars share similar motion in space. The proper motion image, Figure 5, it is clear that stars A and B as labeled in the image are moving in unison, which suggests that stars A and B are gravitationally bound.

As seen in Harshaw Statistic Probability, Table 15, AC and BC had moderately low Harshaw statistic values, which suggests a plausible but still unlikely chance that the stars are gravitationally bound. For AB, on the other hand, the Harshaw statistic was low, which suggests a high probability of the stars being gravitationally bound.

The distance between each of them was well above one light year. The closest radial direction was the AC star system as seen in the Radial Direction of Probability of AC Star, Table 12. AB and BC had a similar amount of radial direction being well above the AC Star System seen in Radial Direction Probability of AB Star, Table 13, and Radial Direction Probability of BC Star, Table 14. With the normal distribution function, it came out that all combinations had a probability of 0% of being one light-year away from each other. Finally, there aren't enough observations to determine if there is apparent relative motion over time between the stars.

Conclusion

Our hypothesis was that the star system WDS 00153-2259 was not gravitationally bound. We tested our hypothesis by running the data using the Harshaw statistic calculator, Proper motion images, parallax, and a distance calculator. The data and measurements collected are inconclusive since the Harshaw statistic predicted stars AB are likely to be bound, and the proper motion of the two stars indicate the stars are moving in the same direction yet the parallax does not indicate the stars are not gravitationally bound. The distance calculator also showed that the star's had a 0% chance of the star's being gravitationally bound, supporting the parallax data. Our evidence indicates that there is a high possibility of the stars not being gravitationally bound, but more research is required to fully determine the nature of the system.

Acknowledgments:

This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory. To help find evidence of a pattern in the historical movement of the components, we used a Google Jupyter Notebook that created graphs from the Washington Double Star Catalog (WDS) created by Mary Kovic and we would like to thank her for her permission to use her Historical Data Points program. This work has made use of data from the European Space Agency (ESA) mission Gaia (https://www.cosmos.esa.int/gaia), processed by the Gaia Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement. This research has made use of the "SIMBAD

Astronomical Database," operated at CDS, Strasbourg, France, and the "Aladin Sky Atlas," also developed at CDS, Strasbourg Observatory, France.

References:

Burch, Joeseph, et. al. (2023). The Journal of Double Star Observations, 19(3), 278-283. http://www.jdso.org/volume19/number3/Burch_278_283.pdf

Harshaw, Richard W., 2018, "Gaia DR2 and the Washington Double Star Catalog: A Tale of Two Databases ", Journal of Double Star Observations, 14, 734-740.

Hewett, Alex et. al. (2019). Journal of Double Star Observations, 15(3), 332-335. http://www.jdso.org/volume15/number3/Hewitt_332_335.pdf

Collins, K, Keilkopf J., Stassun K, and Hessman, F. 2017. Arxiv, 1701.04817. https://arxiv.org/pdf/1701.04817.pdf