Astrometric Measurements of WDS 06425-2314 BU 195

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Abstract
We report charge-coupled device (CCD) astrometric measurements of the double stars BU 195AB and BU195AC in the triple star system WDS 06425-2314 (BU 195) obtained using the Las Cumbres Observatory (LCO) and AstroImageJ (AIJ) software. For BU 195AB, our measurements indicate a mean position angle of 215.5° ± 0.571° and a mean separation of 5.827" ± 0.061". For BU 195AC, our measurements indicate a mean position angle of 178.693° ± 0.354° and a mean separation of 34.489" ± 0.183". Calculations involving parallax, proper motion, and distance, and comparing the prior measurements of each double star to our own measurements, suggest that BU 195AB and BU 195AC are optical doubles.

1. Introduction

This paper presents astrometric measurements of the position angle (θ) and separation (ρ) of the AB and AC components of the triple star system WDS 06425-2314 BU 195. The objectives were to add measurements to the historical database, and to determine whether the AB and AC pairs may be gravitationally bound or optical doubles.

Candidate star systems were initially determined through Stelle Doppie (Stelle 2018), the Washington Double Star Catalog (Mason 2018), and the SIMBAD Astronomical Database (Wenger 2000) based on telescopic capabilities (described below), optimal viewing based on time of year, and the following criteria: a ρ between 5 and 12 arcseconds, a primary magnitude of 10 or less, and a delta magnitude (Δmag) of less than 3.

The BU 195 system was first observed by Sherburne Wesley Burnham, an American astronomer known for his work discovering double stars. The AB component was first observed in 1874 and has been observed 15 times. The AC component was first observed in 1892 and has been observed 7 times.

2. Equipment and Methods

The BU 195 system's DEC is -23° 13' 57.4″ which necessitates a Southern hemisphere observatory to image the star system. The site used for imaging the BU 195 system was the Cerro Tololo Inter-American Observatory located in Chile, hosted by the Las Cumbres Observatory (LCO) system (Brown 2013). There are two 0.4-meter telescopes at this site, which were for imaging, Figure 1. The type of imaging used of the star system was CCD imaging through a SBIG STL-6303 with a field of view (FOV) of 29.2 x 19.5 arcminutes and a plate scale of 0.57 arcseconds. A total of 12 images were taken of BU 195AB and a total of 14 images were taken of BU 195AC, with the filters used in each image shown in Tables 1-2. When taking the BU 195AB images, there wasn't enough exposure time to capture the C component in the images. Due to this, we then took another set of images with larger exposure times to acquire the C component. As seen in Fig. 2, the larger exposure time caused the B component to appear very close to the primary star, but since the C component is very dim and far away from the A and B components, the image of the C star was not impacted by this. The number of nights in the observation of BU 195AB is

one, which the date was 2021.8378. The number of nights in the observation of BU 195AC is one, which the date was 2021.8925.

Table 1. WDS 06425-2314 BU 195AB Images.

Images taken in the SLOAN r	Images taken in the SLOAN i
6	6

Table 2. WDS 06425-2314 BU 195AC Images.

Images taken in the SLOAN r	Images taken in the SLOAN i	Images taken in the SLOAN g
8	4	2

Figure 1: Image of the 0.4 meter telescope with the SBIG STL6303 cameras, provided by Las Cumbres Observatory

The software utilized to reduce the data from the images taken of the BU 195 was AIJ. Michael Fitzgerald's Our Solar Siblings (OSS) Pipeline (Fitzgerald 2018) calibrated and plate-solved all images from Las Cumbres Observatory. With AstroImageJ, the centroids of the images were located automatically after adjusting the aperture and estimated the location of the centroid in the given star. After locating the centroid of the two components (i.e., either AB or AC), the data given to the user was Δmag,

ρ (in arcseconds), and θ (in degrees). The next step was to calculate the mean, standard deviation, and SE (standard error) of the data.

The last reported measurements of WDS 06425-2314 BU 195AB and WDS 06425-2314 BU 195AC are shown in Tables 3 and 4. The data shown in these tables are from the Washington Double Star Catalog and the SIMBAD Astronomical Database (all magnitude measurements shown in Tables 3 and 4 are in the Bessel V Filter).

Table 3. Last Reported Measurements of WDS 06425-2314 BU 195AB.

Epoch	θ	ρ	Primary Magnitude	Secondary Magnitude	Δmag
2016.0	215.4°	5.85"	7.15	9.57	2.42

Table 4. Last Reported Measurements of WDS 06425-2314 BU 195AC.

Epoch	θ	ρ	Primary Magnitude	Secondary Magnitude	Δmag
1999.824	178.9°	34.83"	7.15	12.71	5.56

3. Data

Tables 5-6 are measurements from the two image sets (the tables corresponding to their respective images) gathered from AIJ. We used these measurements to gather the mean, standard deviation, and the standard error of the mean for the θ, ρ, and Δmag (in the respective filter), Tables 7-8. Figure 2 is an image of the WDS 06425-2314 BU 195 star system from the second image set (i.e., the images with the C component). Figures 3-4 are graphs of the historical observations.

Table 5. WDS 06425-2314 BU 195AB Data Table.

Number of Measurements	Date of Measurement	Filter	θ (in degrees)	ρ (in arcseconds)	Δmag
1	2021.8378	SLOAN i	215.1	5.83	2.715369
2	2021.8378	SLOAN i	214.4	5.87	2.70293
3	2021.8378	SLOAN i	215.4	5.86	2.75793
4	2021.8378	SLOAN i	216.1	5.76	2.772893
5	2021.8378	SLOAN i	215.7	5.86	2.738401
6	2021.8378	SLOAN i	216.2	5.72	2.728511
7	2021.8378	SLOAN r	214.8	5.95	2.796431
8	2021.8378	SLOAN r	215.5	5.85	2.817249
9	2021.8378	SLOAN r	216.4	5.85	3.055622
10	2021.8378	SLOAN r	215.5	5.79	2.863203
11	2021.8378	SLOAN r	215.4	5.77	2.773866
12	2021.8378	SLOAN r	215.6	5.81	2.857179

Table 6. WDS 06425-2314 BU 195AC Data Table.

Number of Measurements	Date of Measurement	Filter	θ (in degrees)	ρ (in arcseconds)	Δmag
1	2021.8925	SLOAN g	179.1	34.72	4.667875
2	2021.8925	SLOAN g	179.0	34.62	4.712198
3	2021.8925	SLOAN i	178.8	34.67	3.972648
4	2021.8925	SLOAN i	178.8	34.64	3.974698
5	2021.8925	SLOAN i	178.9	34.66	4.066036
6	2021.8925	SLOAN i	178.9	34.58	4.064998
7	2021.8925	SLOAN r	177.9	34.42	3.273194
8	2021.8925	SLOAN r	178.8	34.07	3.214303
9	2021.8925	SLOAN r	178.4	34.35	3.109352
10	2021.8925	SLOAN r	178.0	34.25	3.093489
11	2021.8925	SLOAN r	178.7	34.37	4.17041
12	2021.8925	SLOAN r	178.7	34.48	4.215761
13	2021.8925	SLOAN r	178.8	34.54	4.089775
14	2021.8925	SLOAN r	178.9	34.48	4.056723

Table 7. WDS 06425-2314 BU 195AB Measurement Results.

Telescope, Images, Filters	Average Results	θ (degrees)	ρ (arcseconds)	Δmag SLOAN r	Δmag SLOAN i
LCO (0.4m; SBIG STL 6303), 12, SLOAN r, i	Mean	215.5	5.827	2.861	2.736
	Standard Deviation	0.571	0.061	0.102	0.026
	Std. error of mean	0.165	0.018	0.041	0.011

Table 8. WDS 06425-2314 BU 195AC Measurement Results.

Telescope, Images, Filters	Average Results	θ (degrees)	ρ (arcseconds)	Δmag SLOAN r	Δmag SLOAN i	Δmag SLOAN g
LCO (0.4m; SBIG STL 6303), 14, SLOAN r, i, g	Mean	178.693	34.489	3.653	4.020	4.690
	Standard Deviation	0.354	0.183	0.519	0.053	0.031
	Std. error of mean	0.095	0.049	0.183	0.027	0.022

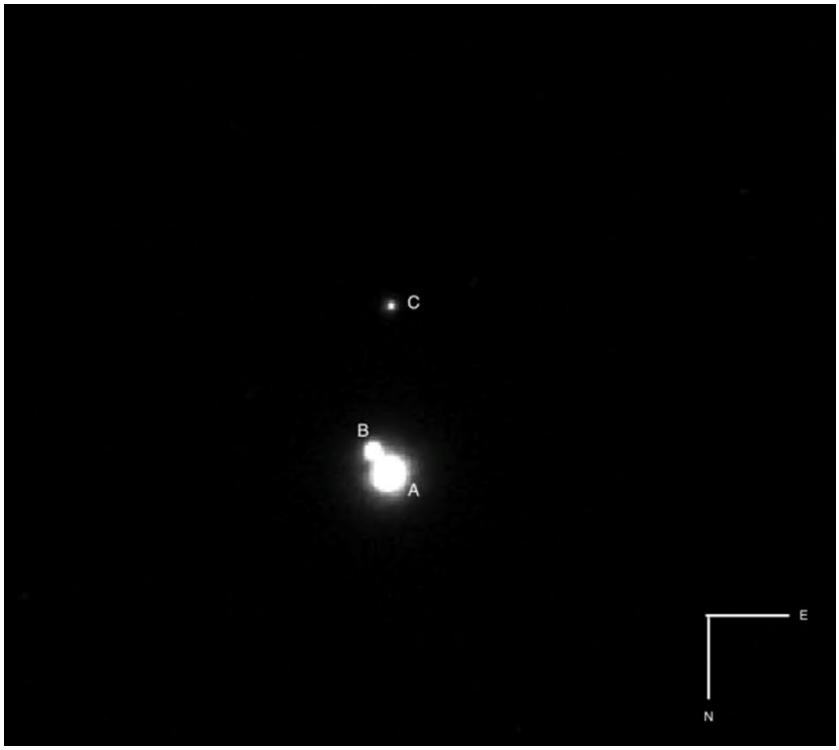

Figure 2: Image of the WDS 06425-2314 BU 195 star system

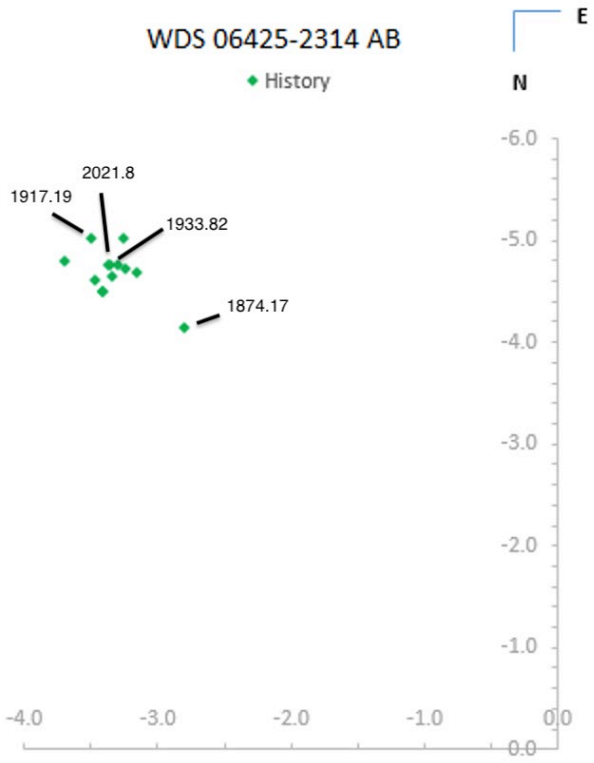

Figure 3: Historical Graph of AB Pair

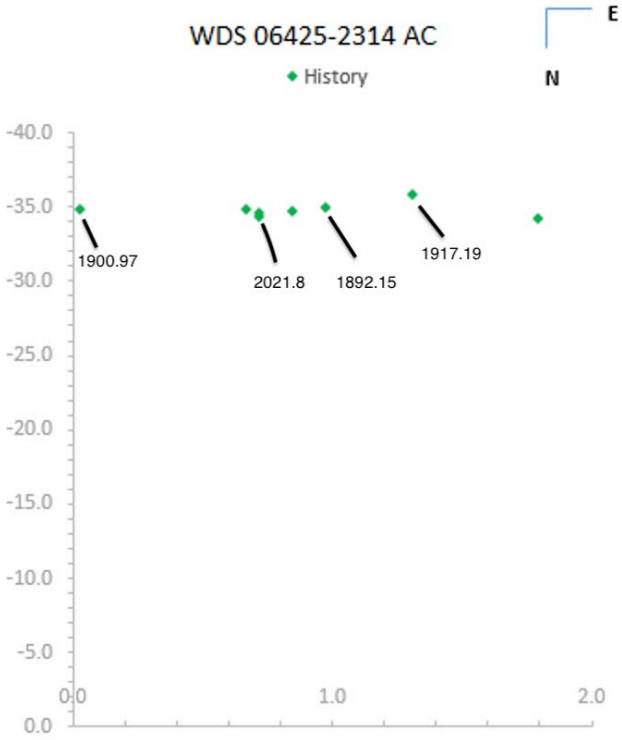

Figure 4: Historical Graph of AC Pair

4. Discussion

The graphs of the historical observations, Fig. 3-4, for both BU 195AB and BU 195AC show no clear pattern nor trend. Our calculation of the current closest distance (sometimes referred to as the "apparent separation") between BU 195AB and BU 195AC resulted in 2447 and 14534 Astronomical Units (AU) respectively. Separation was computed using parallax values of A, B, and C, Table 9, from GAIA (2020), and our ρ measurements, Tables 7-8. We determined these results via the small angle tangent. To be a candidate for a binary star, the two components need to be within at least 63241 AU of each other (Reipurth 2012). This calculation is only considering the observed angular separation along the line of sight, which means that BU 195AB and BU 195AC could be binary, not considering other factors (e.g. proper motion).

One method to determining whether or not a double star is binary or optical is to calculate the probability of a double star being binary in the radial direction via the parallax measurements (Harshaw 2018). The parallax measurements were obtained from GAIA (2020), Table 9, which were used to calculate the binary probability in the radial direction. The binary probability in the radial direction calculation and the parallax measurements (with the error bars) of BU 195AB and BU 195AC are shown in Table 9. The calculation (i.e., probability) result for both double stars show that the BU 195AB and BU 195AC (0.5% and 0%, respectively) are unlikely to be gravitationally bound in the radial direction, and likely to be optical doubles, which falls in line with the differences in parallax (measured in milliarcseconds).

Table 9. Radial Separation Distance and Probability.

Primary (A) Star Parallax (mas)	Secondary (B) Star Parallax (mas)	Secondary (C) Star Parallax (mas)	BU 195AB Binary Probability in the Radial Direction (%)	BU 195AC Binary Probability in the Radial Direction (%)
2.38 ± 0.046	2.47 ± 0.021	1.24 ± 0.012	0.5	0

Another method of evaluation is the Harshaw Proper Motion Statistic (Harshaw 2014), where the closer the outcome is to 0, the more likely the double star is to be binary, and the closer to 1, the more likely to be optical (on the proper motion factor alone). Table 10 used data from GAIA (2020) for the proper motion values. The Harshaw proper motion statistic outcome for BU 195AB and BU 195AC are 0.03 and 0.19, respectively, Table 10. Figure 5 shows the proper motion vectors of stars A, B, and C, which comes from the ALADIN interactive sky atlas (Bonnarel 2000). An indicator of a double star being binary is if the two components have identical, or very nearly identical, proper motions (Harshaw 2018). With this, we can say that BU 195AC is likely to be optical due to the large difference in the proper motion values shown in Table 10, which also aligns with the difference in proper motion vectors between A and C shown in Fig. 5. For BU 195AB, the proper motion values, Table 10, also have a large difference (differences between the RA and DEC proper motion values, 0.254 mas/yr and 0.459 mas/yr, respectively), indicating that this double star is also likely to be optical, based upon this factor alone.

Table 10. Harshaw Proper Motion Statistic (Harshaw 2014) and Proper Motion Values of the BU 195 system.

Primary (A) Star Proper Motion (mas/yr)	Secondary (B) Star Proper Motion (mas/yr)	Secondary (C) Star Proper Motion (mas/yr)	BU 195AB Proper Motion Statistic	BU 195AC Proper Motion Statistic
RA: -4.632 ± 0.031 DEC: 6.208 ± 0.041	RA: -4.886 ± 0.015 DEC: 5.749 ± 0.019	RA: -5.737 ± 0.008 DEC: 9.576 ± 0.011	0.03	0.19

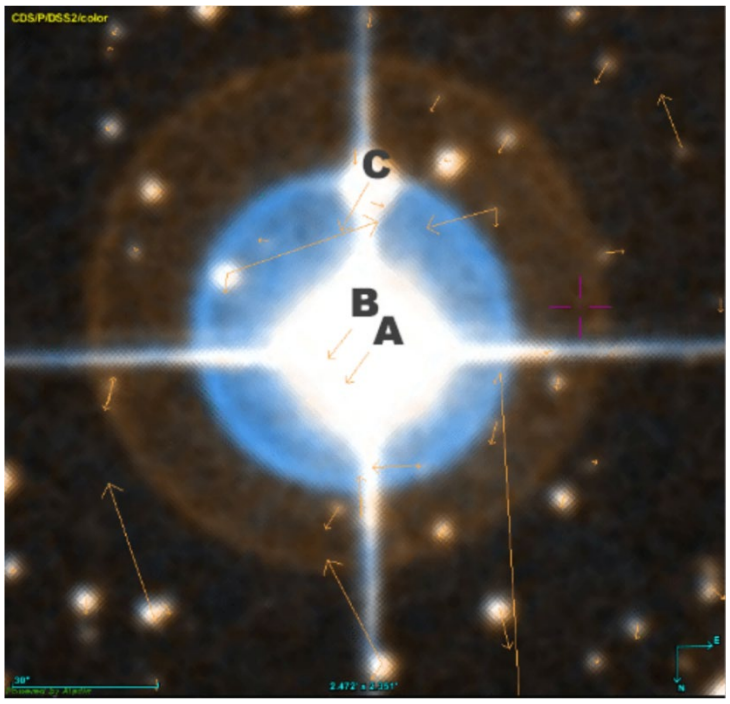

Figure 5: Aladin 10 Image with Proper Motion vectors of the BU 195 triple star system

5. Conclusion

Our team added to historical measurements of the BU 195 triple star, providing updated separation, position angle, and magnitude values for the AB and AC pairs. Additionally, by analyzing the parallaxes, proper motions, distances, and prior observations of the three stars, we have determined that the BU 195AC and BU 195AB pairs are likely to be optical doubles.

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This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory.

This work makes use of observations from the Las Cumbres Observatory global telescope network SBIG STL6303 camera on the LCOGT 0.4m telescope at Cerro Tololo Observatory.

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

Bonnarel, F. et al. (2000) The ALADIN interactive sky atlas. A reference tool for identification of astronomical sources. Astronomy and Astrophysics Supplement, v.143, p.33-40

Brown, T.M. et al. (2013) Las Cumbres Observatory Global Network. Publications of the Astronomical Society of the Pacific, v.125, i.931, p.1031-1055

Fitzgerald, M.T. (2018) The Our Solar Siblings Pipeline: Tackling the data issues of the scaling problem for robotic telescope based astronomy education projects. Robotic Telescopes, Student Research and Education Proceedings, v.1, no.1.

Gaia Collaboration, et al. (2020) Gaia Early Data Release 3: Summary of the contents and survey properties. A&A 616, pp. A1

Harshaw, R. (2014) Another Statistical Tool for Evaluating Binary Stars. Journal of Double Star Observations, v.10, no.1, p.32-51.

Harshaw, R. (2018) Gaia DR2 and the Washington Double Star Catalog: A Tale of Two Databases. Journal of Double Star Observations, v14, p.735-736.

Mason, B., (2018) "The Washington Double Star Catalog", Astrometry Department, U.S. Naval Observatory. http://ad.usno.navy.mil/wds/Webtextfiles/wdsnewframe2.html

Reipurth, B., Mikkola, S. (2012) Formation of the widest binary stars from dynamical unfolding of triple systems. Nature, v.492, p.221–224.

Wenger, M. et al. (2000) The SIMBAD astronomical database. The CDS reference database for astronomical objects. Astronomy and Astrophysics Supplement, v.143, p.9-22.

Stelle Doppie (2018) 06425-2314 BU 195AB. https://www.stelledoppie.it/index2.php?iddoppia=27607