Measurements of the Position Angle and Separation of Two Pairs in WDS 21406+5419 ES 35, an 11-Fold System

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Abstract

New measurements were made for three stars within the 11-fold star system WDS 21406+5419 ES 35. Specifically, we analyzed the AC and the plausibility of a BC pair. By looking at the historical data, new measurements, and graphs of both pairs, we were able to find evidence for the AC pair being a common proper motion double and believe the BC pair is likely not a physical double.

1. Introduction

WDS 21406+5419, Figure 1, is an 11-fold system with a variable primary star possibly consisting of some physical double stars. The size of the system provided a unique prospect for observation. In our images we were able to observe most stars in the system with our eyes. We could make out very faint marking that we assumed were the stars in the system by looking at previous images, but the contrast of our specific images was not large enough for AstroImageJ to analyze all of them. AstroImageJ was able to detect and measure the A, B, and C stars only. The AB pair was first observed in 1900 by British astronomer Rev. T.E. Espin. It was observed 11 times until 2014 and found to not be a physical double as indicated in the WDS catalog. The AC pair was first observed in 1898 by S.E. Urban and T.E. Corbin, and it was observed 18 times until 2014. The nature of the AC pair is uncertain. Most of this paper will be analyzing the AC pair.

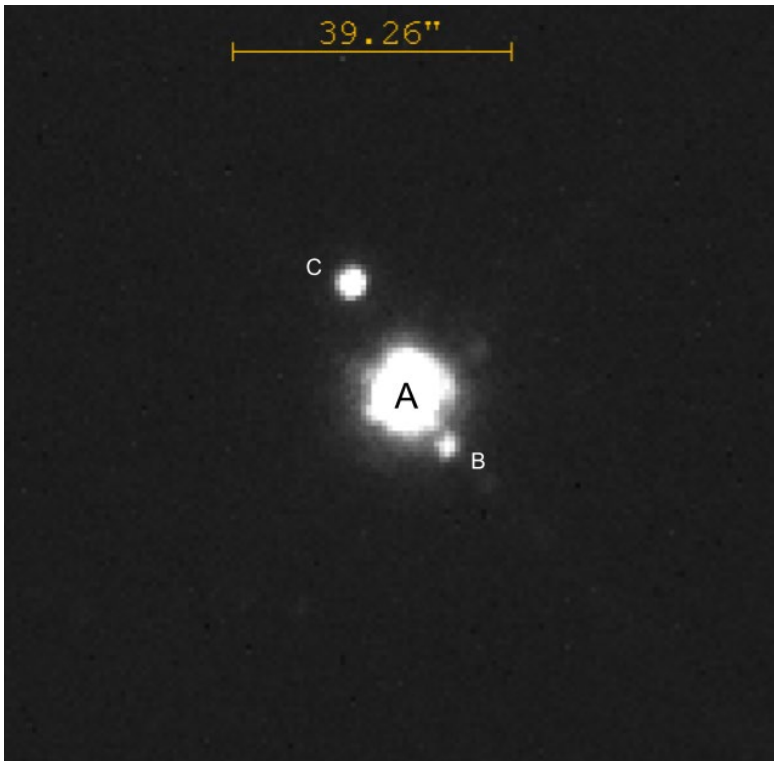

Figure 1: Image of the A, B, and C stars of the WDS 21406+5419 star system from AstroImageJ

2. Equipment and Methods

We took ten images of the star system each with one second of exposure time on 2023.7356 using the Pan-STARRS w filter. We originally tried six and two second exposure times, but the primary star was overexposed. All the images were taken at the Haleakala Observatory through the Las Cumbres Observatory's global network of telescopes. We used a 0.4-meter telescope that has a QHY600 camera system with an FOV of 1.9 x 1.2 arcmin and a pixel size of 0.73 arcsecs. The images were calibrated using the LCO's automatic BANZAI pipeline. Measurements of the separation and position angle were made using AstroImageJ (Collins 2017). After the measurements were made, we calculated the average and standard deviation values. We also requested the historical data of the system from Dr. Rachel Matson at the U.S. Naval Observatory. Finally, we plotted the historical data and our measurements using Richard Harshaw's *Plot Tool* (Harshaw 2022).

3. Data

Tables 1-3 show data for the AC pair. Table 1 shows our ten measurements, Table 2 shows summary statistics, and Table 3 shows the historical data. Tables 4-6 show data for the AB pair. Table 4 shows our ten measurements, Table 5 shows summary statistics, and Table 6 shows the historical data. Table 7 shows the data for all three stars from the Gaia DR3 release (Gaia Collaboration 2023j).

Table 1. WDS 21406+5419 ES 35 AC measurements.

Position Angle (°)	Separation (″)
17.8	17.76
17.7	17.69
17.6	17.61
17.7	17.70
17.8	17.79
17.7	17.69
17.6	17.63
17.7	17.73
17.7	17.66
17.8	17.77

Table 2. Average, standard deviation, and error values of WDS 21406+5419 ES 35 AC.

	Position Angle (°)	Separation (″)
Average	27.5	17.70
Standard Deviation	0.16	0.054
Standard Error of the Mean	0.048	0.016

Table 3. WDS 21406+5419 ES 35 AC Historical Data.

Year	Position Angle (°)	Separation (″)
1898.64	28.6	19.137
1900.16	29.3	18.64
1902.77	28.1	18.083
1903.75	28.2	18.47
1929.66	27.8	17.873
1956.73	27.6	18.128
1962.63	27.3	18.01
1962.72	28.2	18.21
1987.686	28.48	18.32
1991.49	27.8	18.28
1996.728*	28.8	21.3
1996.73*	29.4	21.3
2003.528	27.8	18.227
2006.605	26.9	18.15
2007.607*	29.1	21.23
2009.991	29.29	18.34

2013.63	27.83	18.163
2014.65	27.73	18.203

Rows with asterisks (*) indicate outliers.

Table 4. WDS 21406+5419 ES 35 AB measurements.

Position Angle (°)	Separation (″)
217.2	8.76
218.2	8.82
217.8	8.63
218.8	8.70
218.7	8.66
219.4	8.95
217.8	8.88
219.7	8.40
218.7	8.68
217.6	8.84

Table 5. Average, standard deviation, and error values of WDS 21406+5419 ES 35 AB.

	Position Angle (°)	Separation (″)
Average	218.4	8.73
Standard Deviation	0.81	0.16
Standard Error of the Mean	0.25	0.049

Table 6. WDS 21406+5419 ES 35 AB Historical Data.

Year	Position Angle (°)	Separation (″)
1900.16	223.7	11.1
1902.77	216.8	11.235
1929.66	224	9.958
1956.73	219.9	10.087
1962.63	222.9	9.09
1962.72	220	9.5
1987.686	220.33	9.15
1996.728	219.5	11
1996.73	219.6	10.5
2009.991	217.81	9.99
2014.6	219.37	8.602

Table 7. Gaia proper motion and parallax data for WDS 21406+5419 ES 35 A, B, and C stars.

	A	B	C
PM RA (″/yr)	-9.863	3.543	-10.041
PM Dec (″/yr)	-10.522	2.52200	-10.012
Parallax (mas)	1.8144	1.18820	1.7417

4. Discussion

For all pairs we evaluated, we used the *Plot Tool* created by Richard Harshaw to generate graphs for the historical motion with the inclusion of our measurement, denoted by the red + on all graphs.

AC Pair

After creating the graphs, we noticed three outliers from the dates 2007.607, 1996.728, and 1996.73, marked by asterisks in Table 3. It was interesting that these three observations were all about 3 arcseconds away from the rest of the observations. These measurements were taken by different observers, which rules out the possibility of systematic error. Regardless, we decided to remove these points and update our graphs to reflect such to assess if a better timeline of the motion could be established. Figure 2 displays the AC pair motion before the removal, and Figure 3 displays the AC pair motion after the removal. As shown in the new graph, this did not result in a different conclusion. When looking at the Gaia data in Table 7, the proper motions of stars A and C are similar, suggesting that they are a part of a moving group. Also, the parallax values are close. The graph, however, does not contribute to a definitive conclusion, even with the outliers omitted, because of possible atmospheric interference and general uncertainty in the measurements. The largest contributor to this uncertainty of the graph is the fact that there has been less than 1” of motion in the past 125 years. Because of this, we cannot rely heavily on the graph to make definitive conclusions. Despite this, based on the proper motions and parallax values of these stars, there is evidence for the two stars being a moving pair, i.e. a common proper motion double. Future measurements that are more accurate could result in a more definitive conclusion.

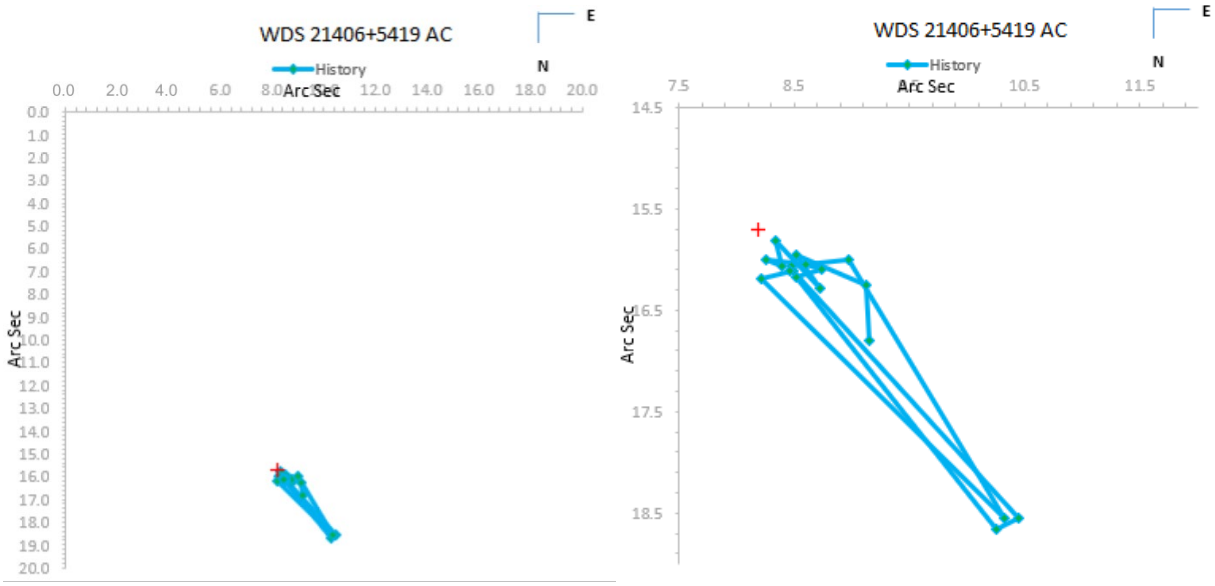

Figure 2: Graphs of historical motion of the AC Pair; Left: origin included; Right: zoomed in.

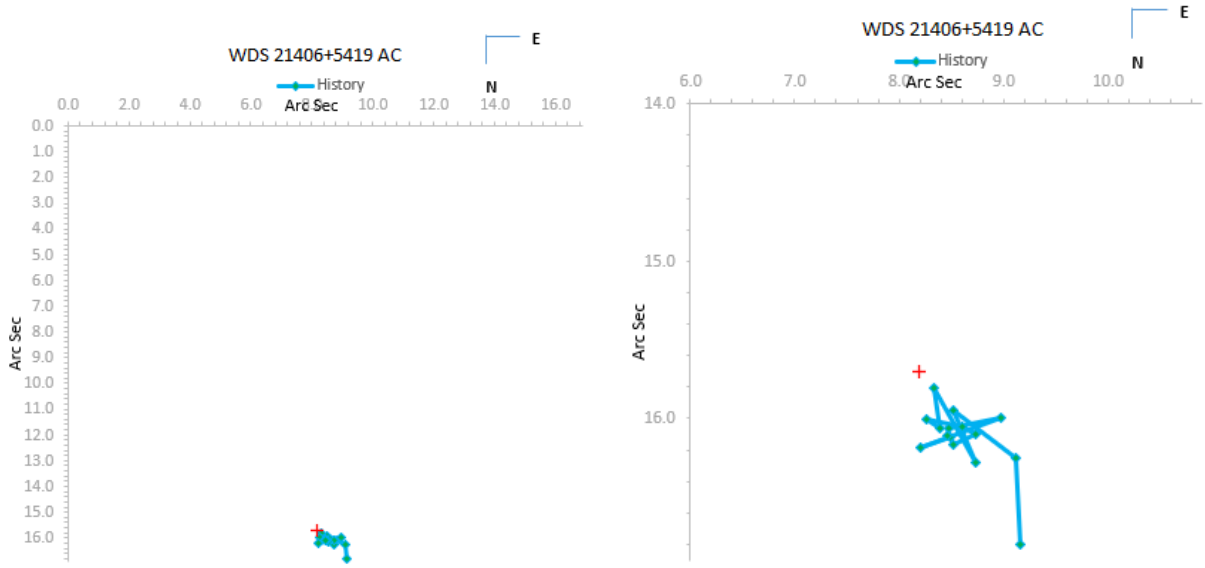

Figure 3: Graphs of historical motion of the AC Pair with omission of outlying points; Left: origin included; Right: zoomed in.

BC Pair

Since we recorded measurements about the B star and the AB pair is already observed to not be a physical double, we decided to analyze the motion of the B star relative to the C star in order to explore their relationship. To do this, we consulted each star's historical data and removed the entries that do not exist in both star's historical data. Then, in a new spreadsheet, we converted each stars' angle and separation relative to the A star into Cartesian coordinates. Then we transformed the coordinates so that C is the new primary star. We used the new coordinates of B to plot the motion of the B star against the C star. The result of this is shown in Figure 4.

Unfortunately, the graph does not provide any significant information. At a glance, there does seem to be a slight curve in the graph that could possibly suggest the orbiting of the B star around the C star. After further investigation, however, the curve does not move in a single direction over time, meaning this curve could be attributed to inaccuracies in measurements or atmospheric interference. Additionally, the proper motions and parallax values of the stars do not align. Based on these observations, there is no clear evidence that points towards a definite relationship between the B and C stars.

Table 8. Historical data and new measurements of WDS 21406+5419 ES 35 BC pair, transformed to use C as the primary star.

Year	Position Angle (°)	Separation (″)
1900.16	214.6655371	29.52062094
1902.77	211.432092	29.23815833
1929.66	213.5821946	27.57590895
1956.73	211.9911004	28.06584159
1962.63	212.5183896	26.87654407
1962.72	212.2395422	27.57775241
1987.686	212.4208371	27.33964359
1996.728	212.4394956	32.17362828

1996.73	212.7638671	31.68865247
2009.991	212.2922885	28.25853888
2014.6	211.4591248	26.68459637
2023.74	211.0901618	26.33022498

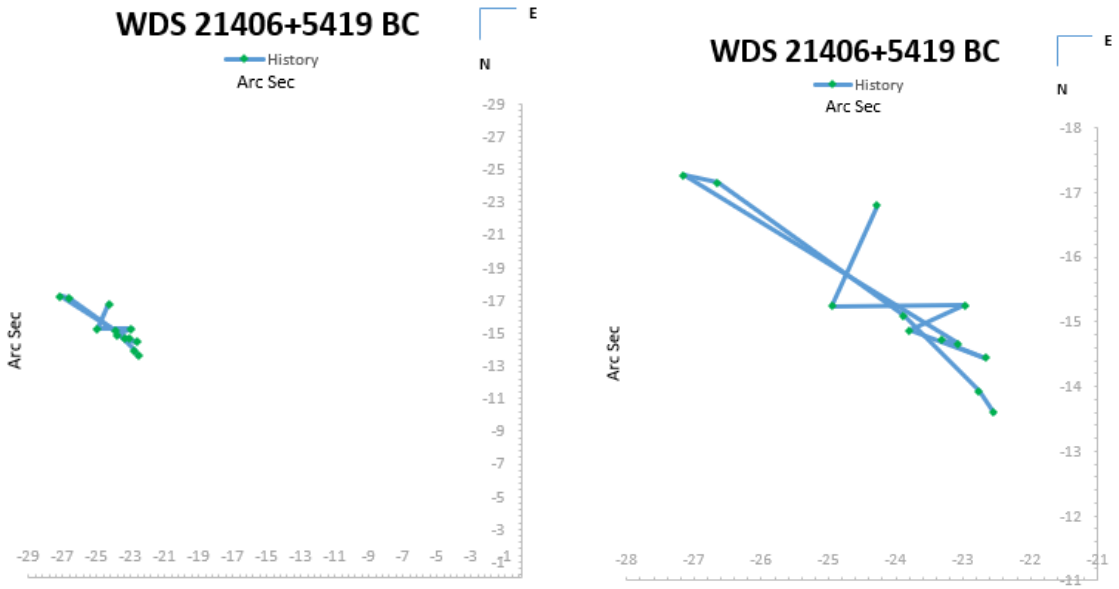

Figure 4: Graphs of historical motion of the BC Pair; Left: origin included; Right: zoomed in

5. Conclusions

After our analysis of the AC pair of the 11-fold system WDS 21406+5419, including the removal of outlying points, we were able to find evidence for A and C being a common proper motion double. The parallax difference between A and C is only 0.0727 mas and the difference between the PM RA and PM Dec values is only 0.51 ″/yr. However, additional research is necessary to further confirm the relationship of the AC pair. The AB pair was found to be non-physical in prior analyses by others. After our analysis of the BC pair, we were not able to establish a clear relationship between the B and C stars, due to the nature of the graph, the significant difference in the proper motions of both stars, and the difference in parallax values. Based on this information, the BC pair is likely not a physical double.

Acknowledgements

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