Astrometric Analysis of WDS 20418-0430 and WDS 06367-2237

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Abstract: Double star WDS 20418-0430 and triple star WDS 06367-2237 were observed using the Las Cumbres Observatory to perform new measurements of the angular separation and position angle of these two systems. The average angular separation and position angle of WDS 20418-0430 was found to be 9.36″ and 219.57°, respectively. These measurements, in combination with parallax and proper motion data from Gaia DR2, suggest that the stars are not physically related. The average angular separation and position angle of the three stellar pairs of WDS 06367-2237 were found to be 8.98″ and 336.16° for AB, 37.45″ and 224.39° for BC, and 35.13″ and 238.20° for AC. The AB pair are found to not be physically related. While the sample of observations is small for the AC and BC pairs, data suggest that the AC pair is not physically related, confirming the current Stelle Doppie classification. However, the BC pair requires further observation to determine the nature of the stars.

1 Introduction

Although double stars are thought to be common, the physical nature of many systems has yet to be determined. In this paper, we present recent observations and analysis of astrometric measurements of position angle and separation for systems WDS 20418-0430 and WDS 06367-2237. Criteria used for the selection of our target sources and our observations are presented in Section 2. We present the analysis of both sources and a discussion of the results in Sections 3 and 4, respectively.

2 Source Selection and Observations

The Gaia Double Star Selection Tool (GDS) (Rowe, 2020) was used to identify stars from the Washington Double Star Catalog (Mason et al., 2001) suitable for observation in Fall 2021 by the Las Cumbres Observatory global telescope network (LCOGT) (Brown, 2013). Selection criteria for the GDS are shown in Table 1. The magnitudes of the primary and secondary components of candidate systems was limited to 7 - 11 to allow the stars to be easily imaged by the 0.4-m telescopes of the LCOGT while excluding sources that are readily studied using smaller telescopes. In addition, the magnitude difference between the stars was required to be less than 3 such that the brighter primary star did not obscure the presence of the dimmer companion. We also required that the angular separation of the stars be greater than 5″ to match the resolution of the instrument. As changes in angular separation and position angle over time are of interest for the determination of the physical nature of double star systems, we required candidate systems to have not been observed within the last 5 years and have relative positions that have noticeably changed over time as reported by the Stelle Doppie Double Star Database. (Sordiglioni, 2020).

Table 1: Target Selection Parameters

RA Range	4^h - 17^h
DEC Range	-80° to +80°
Primary/Secondary Magnitude Range	7 - 11
Difference in Magnitude	0 - 3
Angular Separation	5″ - 10″

Two target sources were chosen from the list of suitable candidates generated by the GDS: WDS 20418-0430 and WDS 06367-2237. Double star WDS 20418-0430 (HJ 921), located in Aquarius, was discovered in 1827 by John Herschel and was last observed in 2016. Stelle Doppie data for this system are shown in Table 2. The physical nature of this double star has not been determined from previous observations.

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Table 2: Properties of WDS 20418-0430

RA	20^h 41^m 47.11^s
DEC	-04° 29′ 37.0″
Constellation	Aquarius
Discovery Date	1827
Position angle as of 2016	220°
Separation as of 2016	9.4″
Primary Magnitude	9.47
Secondary Magnitude	9.71

Target source WDS 06367-2237 (H 2 60 AB and HJ 3876 AC) is a triple star system located in the Canis Major constellation. The primary (A) and secondary (B) stars were the first to be discovered in this triple star system in 1835. The pair has only been observed 17 times, with the last observation occurring in 1999. According to Stelle Doppie, the nature of this pair is still uncertain. WDS 06367-2237 AC was later found in 1903, and the last recorded observation occurred in 1999 for a total of 3 observations. According to Stelle Doppie, the nature of this pair is not physical. There is no information available in the Double Star Database on the relationship between BC of the system. This source is particularly interesting due to the lack of information about the BC component of the system and the uncertain nature of the AB components. Stelle Doppie data for this system is shown in Table 3.

Table 3: Properties of WDS 06367-2237

RA	06^h 36^m 41.07^s
DEC	-22° 36′ 53.1″
Constellation	Canis Major
Discovery Date	AB 1827 and AC 1903
Position angle as of 1999	335° for AB and 238° for AC
Separation as of 1999	8.7″ for AB and 35.7″ for AC
Primary Magnitude	6.39
Secondary Magnitude	9.31
Tertiary Magnitude	10.30

The 0.4-m telescopes of the LCOGT and the attached SBIG STL6303 cameras were used to observe both target sources. Fifteen exposures of 1.5 seconds each were taken of WDS 20418-0430 on 15 September 2021 (2021.71) at the Cerro Tololo Inter-American Observatory. The Siding Spring Observatory recorded 15 exposures of 0.5 seconds each of WDS 06367-2237 on 17 November 2021 (2021.88).

3 Analysis and Results

Data calibration was performed by the LCOGT pipeline (Fitzgerald, 2018) before analysis in AstroImageJ (Collins et al., 2017). The aperture photometry tool was used to measure the angular separation and position angle for each pair of stars in the systems. The Howell centroid method (Howell, 2006) was used to center the point-spread function of each star to ensure consistency in aperture placement for each measurement. Details about the analysis and results of each target source can be found in Subsections 3.1 and 3.2

3.1 WDS 20418-0430

The aperture photometry tool in AstroImageJ was used to measure the angular separation (ρ) and position angle (θ) of the two stellar components in each of the 15 exposures. A sample measurement for WDS 20418-0430 is shown in Figure 1. The brighter A component of the system is at the lower left of the image, and the fainter B component is to the southwest.

Measurements for each of the 15 exposures are shown in Table 4 along with the average, standard deviation, and standard error of each quantity. We find the average separation and position angle of the component stars to be 9.36″ and 219.57°, respectively.

Table 4: WDS 20418-0430 Measurements

Image	Separation (″)	Position Angle (°)
1	9.37	219.82
2	9.39	219.74
3	9.35	219.81
4	9.34	219.77
5	9.37	219.63
6	9.42	219.32
7	9.38	219.22
8	9.35	219.20
9	9.32	219.59
10	9.28	219.72
11	9.34	219.36
12	9.34	219.62
13	9.46	219.40
14	9.38	219.75
15	9.38	219.59
Average	9.36	219.57
Standard Deviation	0.04	0.2
Standard Error	0.01	0.05

3.2 WDS 06367-2237

Separations and position angles for each stellar pair (AB, BC, and AC) in WDS 06367-2237 were measured using AstroImageJ. A sample image and measurement for each of the three pairs is shown in Figure 2. The bright, primary component (A) is nearest the top of the image with the secondary (B)

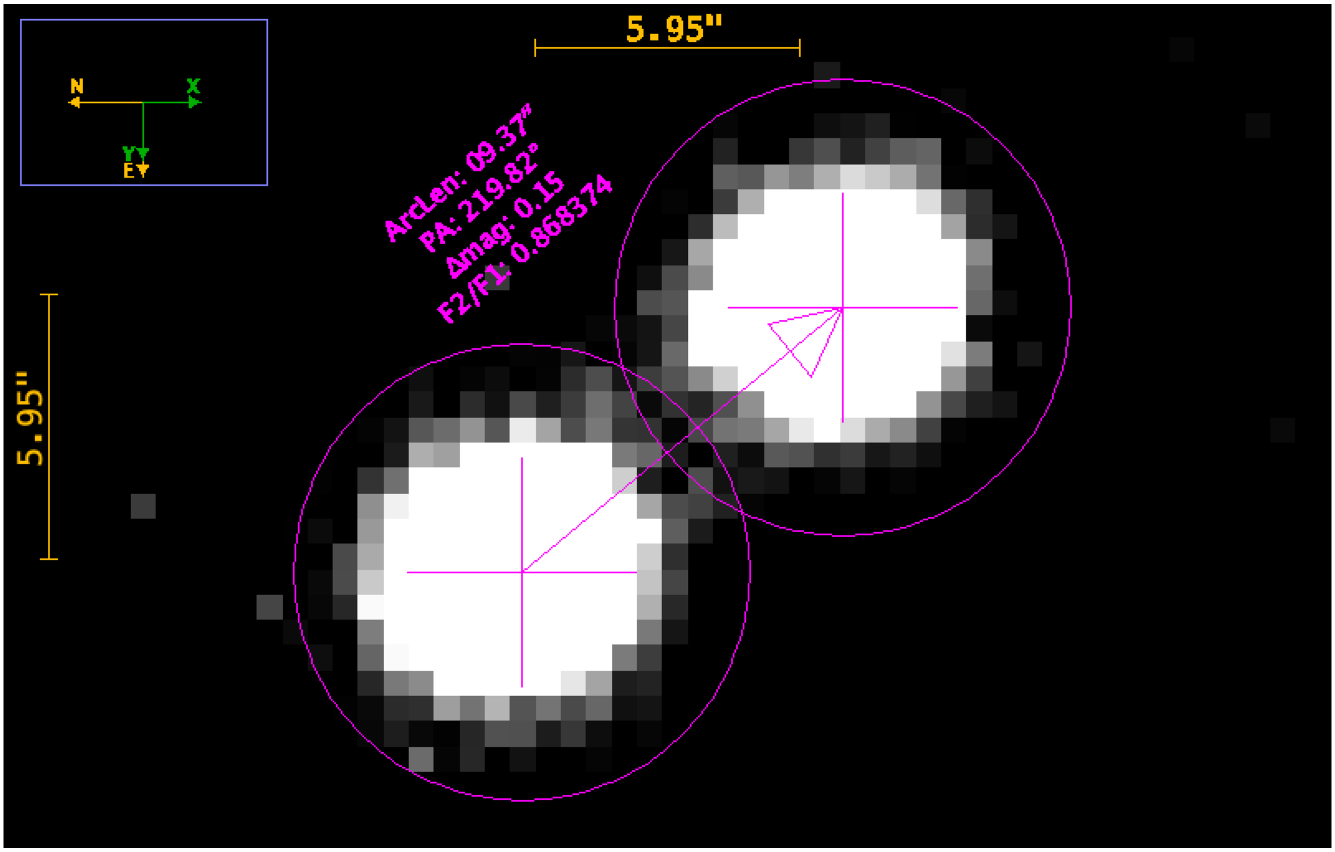

Figure 1: Exposure 1 of WDS 20418-0430. The stellar components have a separation of 9.37″ and a position angle of 219.82°.

component nearby to the northwest. The faint tertiary component (C) is more distant and located to the southwest of the primary component. Measurements of separation and position angle for all 15 exposures, as well as average values (Avg), standard deviation (STD), and standard error (STE), can be found in Table 5. We find the AB components to be separated by 8.98″ with the secondary component at a position angle of 336.16° relative to the primary. The separation and position angle of the BC components are 37.45″ and 224.39″, respectively. The AC components have a separation of 35.13″ and have a position angle of 238.20°.

Table 5: WDS 06367-2237 Measurements

Image	AB		BC		AC	
	ρ (″)	θ (°)	ρ (″)	θ (°)	ρ (″)	θ (°)
1	8.97	335.87	37.53	224.37	35.25	238.06
2	9.04	335.87	37.39	224.20	35.08	238.05
3	9.05	336.10	37.47	224.36	35.12	238.20
4	9.01	335.99	37.28	224.42	34.99	238.27
5	9.04	335.99	37.43	224.40	35.11	238.26
6	9.04	336.32	37.46	224.39	35.10	238.22
7	9.09	336.34	37.53	224.48	35.17	238.36
8	8.86	336.33	37.52	224.52	35.20	238.03
9	9.01	336.12	37.43	224.38	35.10	238.17
10	8.66	336.04	37.20	224.18	35.06	238.53
11	9.03	336.72	37.49	224.70	35.12	238.48
12	9.03	336.29	37.38	224.24	35.00	238.08
13	8.82	336.32	37.53	224.50	35.22	237.95
14	9.04	335.87	37.65	224.26	35.33	238.02
15	9.05	336.30	37.48	224.45	35.13	238.28
Avg	8.98	336.16	37.45	224.39	35.13	238.20
STD	0.16	0.24	0.11	0.14	0.09	0.20
STE	0.03	0.06	0.03	0.04	0.02	0.04

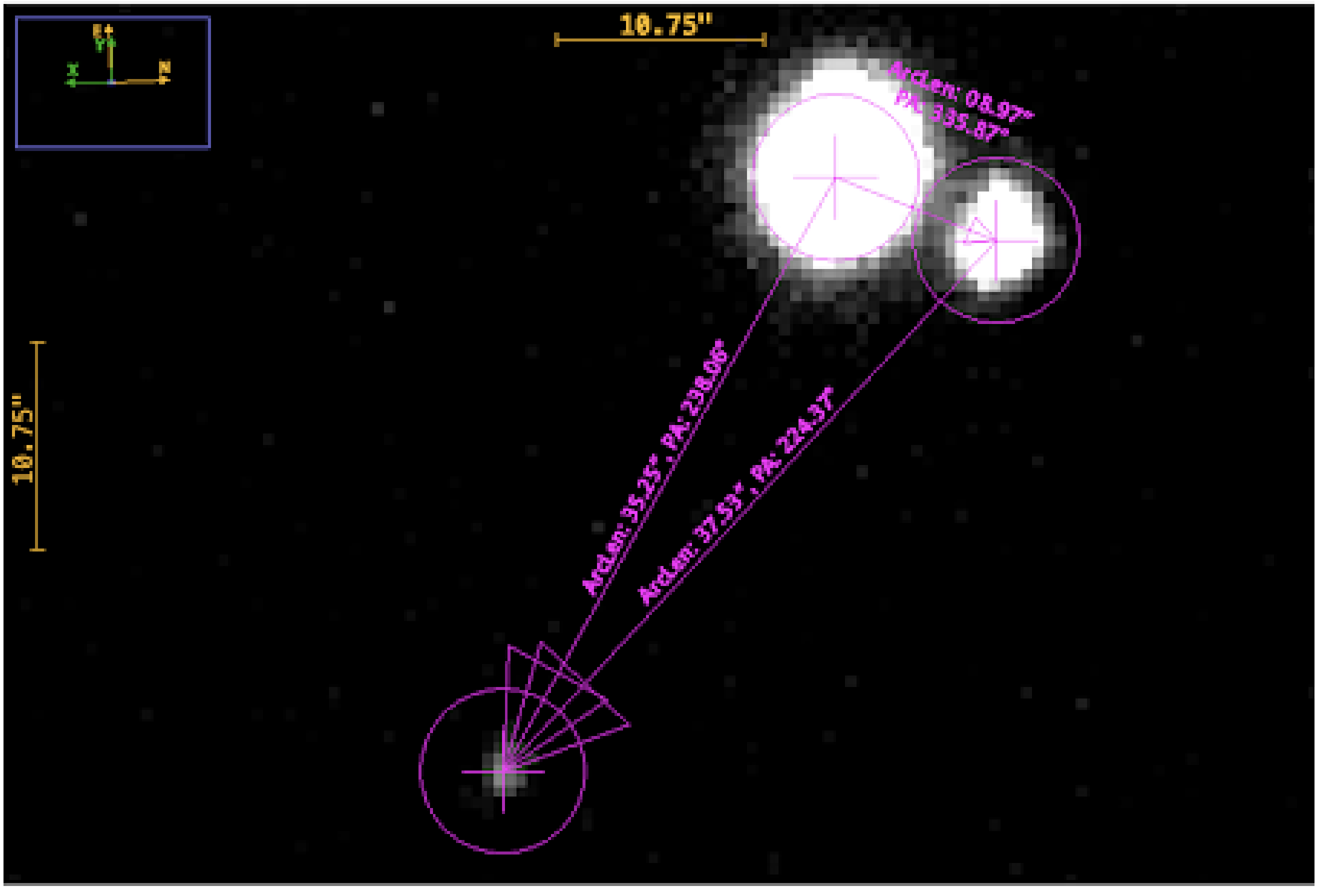

Figure 2: Sample image and measurement of the AB, BC, and AC stellar pairs in WDS 06367-2237.

4 Discussion

Historical data for both systems were requested from the US Naval Observatory to be combined with the results of this work. The change in separation and position angle over time was then analyzed to determine the likelihood of the stars in each system being physically related and binary in nature. A discussion of the results for each stellar system can be found here.

4.1 WDS 20418-0430

Historical data for WDS 20418-0430 were combined with the results of the present work to search for trends in the separation and position angle as a function of time. The average separation of the two stars in this system is shown in Figure 3, with historical data shown in black and the results of the present study in green. The new measurement is in close agreement with other recent measurements of separation. It can also be seen that the data prior to 1980 show a large discrepancy in the separation of the two stars. With expected periods of several centuries for binary systems, this variance in separation angle is likely due to uncertainty in the data and accuracy of measurement rather than any physical properties of the system. A similar variance can be seen in data prior to 1980 for the position angle of the stars. We have therefore chosen to exclude data prior to 1980 from our discussion of the system. Therefore, the results presented in this work are based on the most recent 13 measurements of the system.

To further investigate the nature of WDS 20418-0430, the Plot Tool of Harshaw (2020) was used to visualize the motion of the secondary component relative to the first and to analyze separations and position angles. Figure 4 shows the motion of the secondary companion B relative to the primary component A, with each data point representing an independent measurement of position angle and separation. Historical data is shown in black and the new measurement in green. No clear trend can be seen to suggest relative orbits of the stars.

Gaia Data Release 2 (DR2) (Gaia Collaboration, 2018)

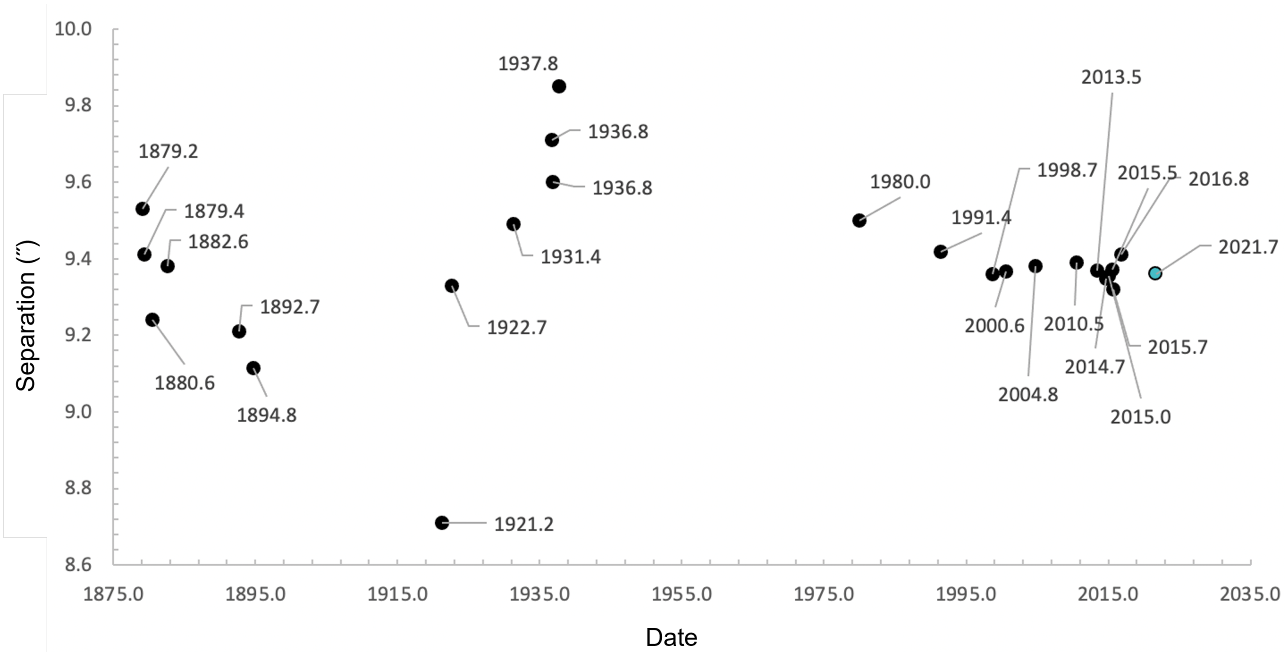

Figure 3: Average separation of the stars in WDS 20418-0430 as a function of time. Historical data is shown in black and the result of this work is shown in green.

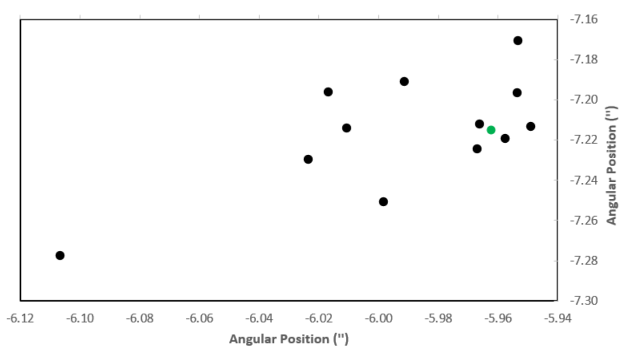

Figure 4: Motion of the secondary star of WDS 20418-0430 relative to the primary. Historical data is shown in black and the results of the current study in green.

and Early Data Release 3 (EDR3) (Gaia Collaboration, 2021) measurements of parallax and proper motion were used in combination with the observed separation and position angle data to learn more about the physical nature of the stars. We found that the values reported by DR2 and EDR3 were not in agreement for this source. Gaia measurements for both data releases are shown in Table 6. Note that the the parallax measurements for the primary component differ by 2.4605 mas, which is far greater than the reported uncertainty in either value. In addition, the proper motion in right ascension for the primary star differs by 1.847 mas yr^{-1}, which is also much greater than the uncertainty for either data release. The other measurements are similar between the two data releases.

Table 6: Gaia DR2 and EDR3 Values for WDS 20418-0430

		DR2	EDR3
Parallax (mas)	A	3.2170	5.6775
	B	4.8251	4.8124
Parallax error (mas)	A	0.4702	0.5814
	B	0.0584	0.0548
PM RA (mas yr^{-1})	A	-39.470	-37.623
	B	-38.510	-38.517
PM RA error	A	0.823	0.663
	B	0.098	0.062
PM DEC (mas yr^{-1})	A	-32.081	-31.805
	B	-32.039	-32.101
PM DEC error	A	0.696	0.488
	B	0.058	0.041
Gmag	A	9.30	9.31
	B	9.47	9.47

To determine which parallax and proper motions are more accurate, the Plot Tool was used to examine the expected relative motion due to the Gaia proper motion vectors and the observed relative motions between 1980 and the date of the most recent data (2021.71). As seen in Table 7, the observed relative motions on the sky are more similar to the expected motion using the proper motion (PM) data from DR2. We therefore conclude that the parallax and proper motion measurements from Gaia EDR3 are in error.

Table 7: WDS 20418-0430 Measured and Expected Relative Motions

	Relative motion in ρ ($''$)	Relative motion in θ ($^\circ$)
Measured value on the sky	0.16	66.59
Expected from DR2 PM	0.04	87.49
Expected from EDR3 PM	0.04	251.68

The Gaia DR2 parallax data were used in combination with measured separations and position angles to determine the distance to the system and the separation between the stars. The primary and secondary stars are located at distances of 311 pc and 207 pc, respectively. This difference in stellar distance suggests that the stars are not physically related.

The authors also note the presence of a double star southeast of WDS 20418-0430 at (α, δ) = (20^h 43^m 0.5.095^s, -4° 41$'$ 25.70$''$). Figure 5 shows the position of these stars (circled in blue) relative to WDS 20418-0430 (circled in white). These stars are present in Gaia DR2 and have parallaxes that suggest they are too far apart to be physically related. However, we were not able to find record of these stars in the WDS Catalog. The average separation and position angle of the stars were found to be 7.29$''$ and 187.25°, respectively.

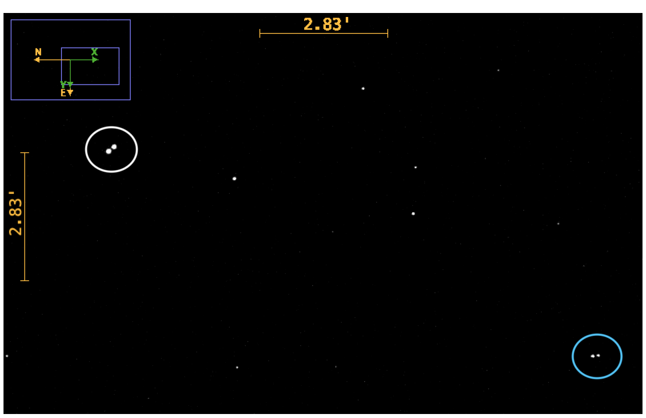

Figure 5: Observed optical double (blue circle) near WDS 20418-0430 (white circle) not appearing in the WDS Catalog.

4.2 WDS 06367-2237

New observations of WDS 06367-2237 were combined with historical data to learn about the physical nature of the system. The recorded separation and position angle of the AB pair for dates earlier than 1878 were much different from the more recent observations, likely due to measurement accuracy. They were therefore omitted from our sample. After excluding these observations, the AB pair of the triple system had 14 previous records of separation and position angle, and the AC pair had 3 recorded observations. Separation and position angle data for the BC pair were not included in the historical data. Triangulation was used to determine the BC relative locations for historical observations that included both AB and AC measurements that were taken on the same date. This yielded 3 historical measurements for the BC pair, shown in Table 8.

Table 8: Historical Relative Positions of WDS 06367-2237 BC

Date	ρ (arcsec)	θ (°)
1903	37.64	280.63
1999.05	37.72	267.96
1999.83	37.79	265.78

The Plot Tool was used to visualize the relative position of the fainter star in each pair relative to the brighter star. Figures 6, 7, and 8 show these positions for AB, AC, and BC, respectively. In each figure, the brighter component is located at the origin and the relative position of the fainter companion for each observation date is shown. Historical data is shown in black, and the results of this work are in green.

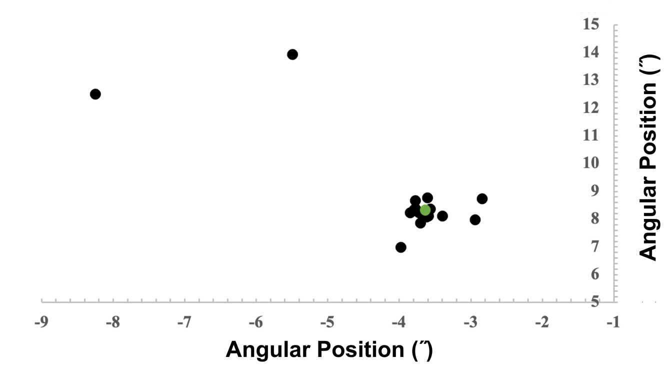

Figure 6: Position of star B relative to star A in WDS 06367-2237. Each point represents an independent observation in time. Historical data are represented by black dots and the new measurement is shown in green.

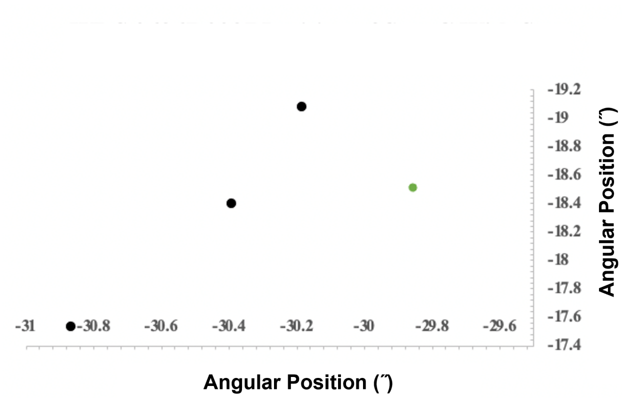

Figure 7: Position of star C relative to star A in WDS 06367-2237. Each point represents an independent observation in time. Historical data are represented by black dots and the new measurement is shown in green.

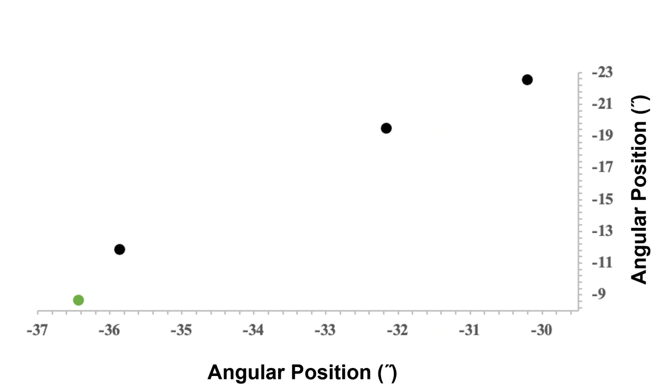

Figure 8: Position of star C relative to star B in WDS 06367-2237. Each point represents an independent observation in time. Historical data are represented by black dots and the new measurement is shown in green.

There is no clear trend in the position of star B relative to A. The Gaia EDR3 parallaxes for these stars are similar, placing the A and B components at distances of 303 pc and 295 pc, respectively. However, combining these distances with relative positions yields a separation of nearly 2700 AU, larger than would be expected for a gravitationally bound binary pair. Therefore, we conclude that the AB pair is not physically related.

Unfortunately, Gaia data was found to not contain information about the C component of the WDS 06367-2237 system. Therefore, a similar analysis of distance and separation cannot be done for the AC or BC pairs. Stelle Doppie reports that the stars in AC are not physically related. Since there are, including the new measurement, only 4 observations of this pair, the sample is quite small. However, there does not appear to be a trend in the relative position of the stars with time. Since no historical data was available for the BC pair, no information about it can be found in Stelle Doppie. Our bootstrapped values for position angle and separation from the historical data and the new observation provide only 4 measurements of relative position for these stars. Although the sample is small, there does appear to be an interesting trend in the relative positions of the stars, as seen in Figure 8. However, additional measurements as well as accurate parallax and proper motion data are required to determine the nature of the pair.

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