CCD Astrometric Measurements and Historical Data Summary of Double Stars WDS 05548-2527 and WDS 00177+2630

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Abstract: We report CCD astrometric measurements of the double star system WDS 00548-2527 (B 92AB) and WDS 00177+2630 (BUP 5AB) using the iTelescope network. A position angle of 309.7° ± 0.03° and an angular separation of 7.33" ± 0.004" was determined for B 92AB. A position angle of 200.7° ± 0.007° and angular separation of 77.53" ± 0.02" was determined for BUP 5AB. Based on our new measurements and historic data on the systems we see no clear evidence that either system is binary.

Introduction

Astrometry is a branch of astronomy that measures a celestial body's position in the sky and its movement. Through astrometry, we can track the movement of the secondary star relative to the primary star of a double star system by recording its position angle (theta), measured in degrees from the celestial north, and angular separation (rho) between the two stars in arcseconds. By fixing the position of the primary star, the secondary star's movement can be tracked based on the pair's relative position angle and angular separation over time. The linear separation between binary pairs determines the time needed to complete one orbit by the secondary star (third Kepler's law). Binary components in a pair with a large separation may exhibit a linear motion with respect to each other over a long period of time. In this case even if the stars are true binaries, we may not see the signature of elliptical orbits in a few hundred years of observing. Small separation between binary components may quickly yield curvature in the motion of the secondary component confirming their binary nature. Optical pairs can display a linear/flat trend or random motion over extended time. Additionally, a double star's properties, such as common proper motion, parallax, and spectral type, can be inspected to further investigate its binary or optical identity.

We selected two double star systems with unknown status: WDS 00548-2527 (B 92AB) and WDS 00177+2630 (BUP 5AB). The pairs meet the following criteria per the Washington Double Star (WDS) Catalog, accessible through Stelle Doppie: (a) observable during the fall in the northern and southern hemisphere by having a right ascension between 00 and 06 hours, (b) a magnitude difference (Δm) of 6 or less, (c) and an angular separation of 6" or more. We then (1) measured position angle and angular separation for each selected pair by the analysis of CCD images provided by the iTelescope network, and (2) investigated the double star's binary or optical properties by examining its historical data provided by The United States Naval Observatory (USNO), the WDS catalog, and SIMBAD, an astronomical database.

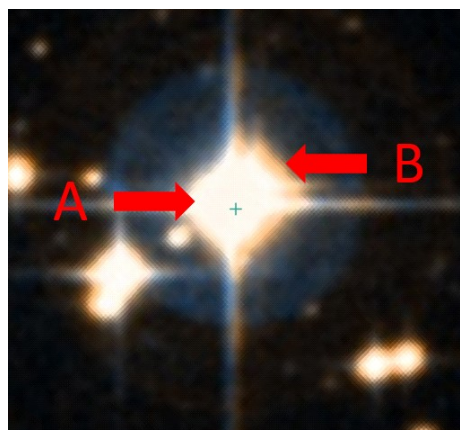

Figure 1. SIMBAD's optical image of B 92AB.

Historical Measurements of B 92AB				
Epoch	Position Angle (deg)	Angular Separation (arcseconds)	Source	Measurement Type
1911.01	314.1°	7.88"	WFC1998	Pa - Photographic with an astrograph
1926.00	310.2°	7.30"	B__1928b	Ma - Micrometer with refractor
1965.44	310.0°	7.10"	Knp1996a	Ma - Micrometer with refractor
1965.67	309.8°	7.28"	B__1968	Ma - Micrometer with refractor
1999.02	309.2°	7.38"	TMA2003	E2 - 2MASS Survey
1999.14	309.2°	7.32"	UC_2013b	EU - UCAC Catalog

Table 1. Historic measurements and data available on B 92AB; measurements are courtesy of the WDS catalog.

B 92AB Historical Background

B 92AB, Figure 1, found in Lepus, was discovered by Willem Hendrik van den Bos, a Dutch-South African astronomer, using a micrometer and a 0.7-meter refracting telescope in 1926. However, there was an earlier observation in 1911 not noted until 1998 by the Washington Fundamental Catalog (Wycoff, Mason, Urban 2006). Van den Bos recorded a position angle of 309.8° and angular separation of 7.28". The most recent observation was by USNO CCD Astrograph Catalog (UCAC) in 1999 and recorded a position angle of 309.2° and an angular separation of 7.32". There are currently seven observations of B 92AB in the WDS and it has been 18 years since its last observation. The historic observations for B 92AB are summarized in Table 1 (Mason, Hartkopf 2015).

B 92AB's A component is a star similar to our Sun, with a spectral class G1/2V and a magnitude of 8.67, and its B component has magnitude of 11.20 (Mason, Hartkopf 2015). Gaia DR2 reported the A component to have a proper motion of [-98.428 -33.771] and a parallax 15.1665 (±0.0353) milli-arcseconds (Gaia 2018b). For the B component Gaia DR2 reported a proper motion of [-96.864 -23.442] and a parallax 16.0971 (±0.1873) milli-arcseconds (Gaia 2018b). The small angular separation of 7.3" may appear challenging to image, Figure 1, however its 2.53 difference in magnitude grants leverage to the resolution capabilities of the iTelescope network.

BUP 5AB Historical Background

BUP 5AB, Figure 2, located in Andromeda, was discovered by Sherburne Wesley Burnham, an American astronomer, using a micrometer and a 1-meter refractor telescope of the Yerkes observatory in 1910. There was an earlier observation in 1895; however, it was not noted until 1998 by the Washington Fundamental Catalogue (Wycoff, Mason, Urban 2006). Burnham recorded a position angle of 199.7° and angular separation of 80.2" for BUP 5AB. The most recent observation was by USNO CCD Astrograph Catalog (UCAC) in 1999 and recorded a position angle of 200.5° and an angular separation of 77.90". There are currently seven observations of BUP 5AB in the WDS and it has been 16 years since its last observation. We summarize the historic observations for BUP 5AB in Table 2 (Mason, Hartkopf 2015).

BUP 5AB's A component has magnitude of 10.52 and was reported from Gaia DR2 to have a proper motion of [+40.024 -10.851] and a parallax 3.2695 (±0.0570) milli-arcseconds (Gaia 2018b). The B component has a 12.27 magnitude and was reported from Gaia DR2 to have a proper motion of [+33.598 +16.084] and a parallax 4.5776 (±0.0557) milli-arcseconds (Gaia 2018b). Having an 77.9" angular separation and 1.75 delta magnitude makes it a good candidate to observe without challenge to the iTelescope network. Different proper motions and parallaxes suggest an optical system.

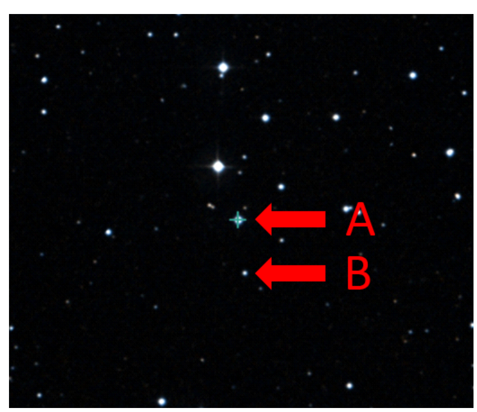

Figure 2. SIMBAD's optical image of BUP 5AB.

Historical Measurements of BUP 5AB				
Epoch	Position Angle (deg)	Angular Separation (arcseconds)	Source	Measurement Type
1895.76	199.2°	80.49"	WFC1998	Pa - Photographic with an astrograph
1897.77	199.6°	79.83"	WFC1998	Pa - Photographic with an astrograph
1907.78	199.6°	80.41"	WFC1998	Pa - Photographic with an astrograph
1910.56	199.7°	80.02"	Bu_1913	Ma - Micrometer with refractor
1991.47	200.5°	78.34"	TYC2002	Ht - Tycho
1997.80	200.5°	78.08"	TYC2003	E2 - 2MASS Survey
2001.58	200.5°	77.90"	UC_2013b	EU - UCAC Catalog

Table 2. Historic measurements and data available on BUP 5AB; measurements are courtesy of the WDS catalog.

Equipment

B 92AB images were acquired by Telescope T32, Figure 3, located in Siding Springs, Australia at an elevation of 1,122 meters. The CCD camera for T32 is a FLI Proline 16803 with a resolution of 0.63" per pixel housing an array 4096 by 4096 with a FOV of 43.2 by 43.2 arcminutes. The CCD camera is mounted on a Planewave 17" Corrected Dall-Kirkham (CDK) with a focal length of 2,912 mm, an aperture of 431 mm, and a focal ratio of f/6.8.

BUP 5AB images were acquired by Telescope T11, Figure 4, located in Mayhill, New Mexico at an elevation of 2,225 meters. The CCD camera for T11 is a FLI Proline PL1102M with a resolution of 0.81" per pixel housing an array 4008 by 2672 with a FOV of 36.2 by 54.3 arcminutes. The CCD camera is mounted on a Planewave 20" CDK with a focal length of 2,280 mm, an aperture of 510 mm, and a focal ratio of f/4.5. All images were saved as FITS files.

Figure 3. T32 17" PlaneWave f/6.8 CDK Astrograph with FLI Proline 16803 CCD in Siding Springs, Australia.

Methods and Procedures

Through the iTelescope network, we requested images of B 92AB and BUP 5AB at various exposure times and filters. The images B 92AB were observed at an exposure times of 60 seconds and 90 seconds with the Blue, OIII, and Hydrogen-alpha filters, and 90 seconds for the Ionized Sulfur filters. The images of BUP 5AB were captured at an exposure length of 45 seconds and 90 seconds with two filters: Luminance and Red.

The FITS files were individually uploaded to Astrometry.net for an astrometric calibration. The Right Ascension and Declination coordinates were calculated for the stars in the FITS images by comparing them to catalog images. Right Ascension and Declination grid of the image creates World Coordinate System (WCS) and was saved in the FITS file header. The down-

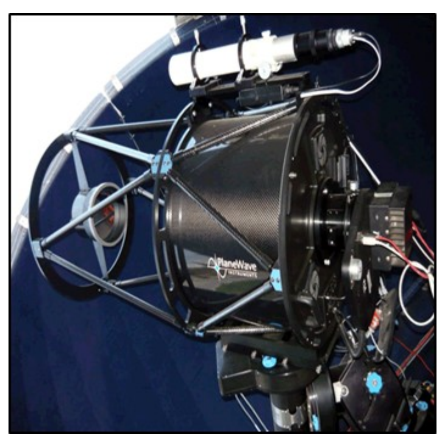

Figure 4. T11 20“ PlaneWave f/4.58 CDK Astrograph with FLI Proline PL1102M CCD Mayhill, New Mexico.

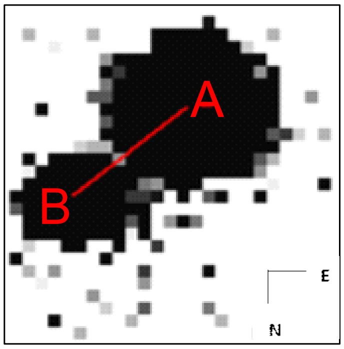

Figure 5. B 92AB under Hydrogen Alpha Filter-60 seconds. Image was processed in Mira Pro x64.

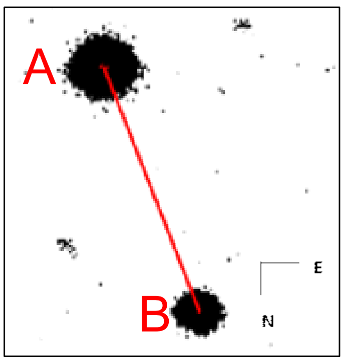

Figure 6. BUP 5AB under Luminance Filter-45 seconds. Image was processed in Mira Pro x64

loadable calibrated images were transferred to Mira Pro x64, an image processing software developed by Mirametrics, Inc.

Each image was processed in Mira Pro x64 (Mira) to calculate position angle and angular separation. The WDS catalog and SIMBAD were referenced to verify the A and B component's location on the calibrated images. Mira's Vertical Transfer Function and Vertical Palette granted better star visibility. With Mira's Distance and Angle tool, a line was drawn to connect the primary and secondary star's centroid and astrometric measurements were generated.

Results

Nine images of B 92AB were acquired on November 22, 2017, Table 3, and a sample image (Hydrogen Alpha filter with 60 second exposure) is provided in Figure 5. Four images of BUP 5AB were acquired on November 11, 2017 by T11, Table 4. A sample image (Luminance filter with 45 second exposure) of BUP 5AB is provided in Figure 6. Mira measurement of position angle and angular separation for each exposure and filter were exported to Microsoft Excel. Excel was used to calculate the mean, standard deviation, and

WDS 00548-2527 (B 92AB) Astrometry		
Telescope T32	Epochs 2017.89	
Filter Type-Exposure Time (seconds)	**Position Angle (degrees)**	**Angular Separation (arcseconds)**
Red-60s	309.58°	7.362"
Red-90s	309.65°	7.33"
OIII-60s	309.91°	7.31"
OIII-90s	310.11°	7.24"
Hydrogen Alpha-60s	309.08°	7.32"
Hydrogen Alpha-90s	310.00°	7.33"
Blue-60s	309.87°	7.32"
Blue-90s	309.76°	7.35"
SII-90s	309.66°	7.37"
Mean	**309.7°**	**7.33"**
Std. Deviation	**0.3**	**0.04"**
SEM	**0.03**	**0.004"**

Table 3. Position angle, angular separation and uncertainties for B 92AB.

WDS 05548-2527 (BUP 5AB) Astrometry		
Telescope T11	Epochs 2017.87	
Filter Type-Exposure Time (seconds)	**Position Angle (deg)**	**Angular Separation (arcsec)**
Luminance-45s	200.69°	77.47"
Luminance-90s	200.68°	77.52"
Red-45s	200.75°	77.53"
Red-90s	200.72°	77.62"
Mean	**200.7°**	**77.53"**
Std. Deviation	**0.03**	**0.06"**
SEM	**0.007°**	**0.02"**

Table 4. Position angle, angular separation, and uncertainties for BUP 5AB.

standard error of mean for position angle and angular separation. The results are summarized for B 92AB in Table 3, and BUP 5AB in Table 4.

To determine if the pair's components had similar proper motion, we generated a Richard Harshaw (Harshaw 2014) rating, a classification system for common proper motion pairs (CPMs), by dividing the difference in the vectors by the sum of the vectors. The

Harshaw Rating for B 92AB				
WDS	COMP	PM Ra (mas)	PM Dec (mas)	Rating %
05548 -2527	A	-98.428 ± 0.038	-33.771 ± .051	0.05128
	B	-96.864 ± 0.198	-23.442 ± .272	

Table 5. Proper motion of B 92AB Components; measurements are courtesy of Gaia DR2.

Harshaw Rating for BUP 5AB				
WDS	COMP	PM Ra (mas)	PM Dec (mas)	Rating %
00177 +2630	A	+40.024 ± 0.061	-10.851 ± 0.062	0.351773
	B	+33.598 ± 0.062	+16.084 ± .061	

Table 6. Proper motion of BUP 5AB Components; measurements are courtesy of Gaia DR2.

rating value range from 0 for CPMs and 1 for optical pairs. In the interest of obtaining accurate data with cited sources, the proper motion values for B 92AB, Table 5, and BUP 5AB, Table 6, were obtained from Gaia DR2 rather than the WDS catalog.

Discussion

Is B 92AB a physical pair?

Historic trends for the angular separation, Figure 7, range from 7.1" to 8". In 1999, the 2MASS Survey in 1999 reported a 7.38" separation and UCAC reported a 7.32" separation (Mason, Hartkopf 2015) and our measurement is at 7.33" of separation. Within the limits of our camera resolution, these data agree indicating constant separation between components and not much motion, not just the last twenty years but possibly from the very first measurement in 1911.

Position angle vs. time, Figure 7 bottom panel, shows somewhat random behavior. The largest position angle is reported in the first measurement (1911) to be around 314 degrees and in the following measurement (1926) measured 310 degrees consistent with our measurements. Most historical observations of this pair were performed using a micrometer, which has lower precision than our current measurement or the 1999 measurements (2 MASS Survey and UCAC Catalog). Both 2MASS Survey and UCAC report the same measurements for the position angle of 309.2°, very close to our measurement is 309.7°. With the first historic observational point excluded, we would get flat line fit, indicating no change in position angle in the last hundred years.

The orbital plot for the B 92 AB system is shown in Figure 8. In the top panel B 92 A is fixed in the origin (0,0) position, and motion of the B component is shown by blue dots. As expected, based on position and angular separation vs time plots, not much motion is apparent. Most points cluster in the same spot, with first his-

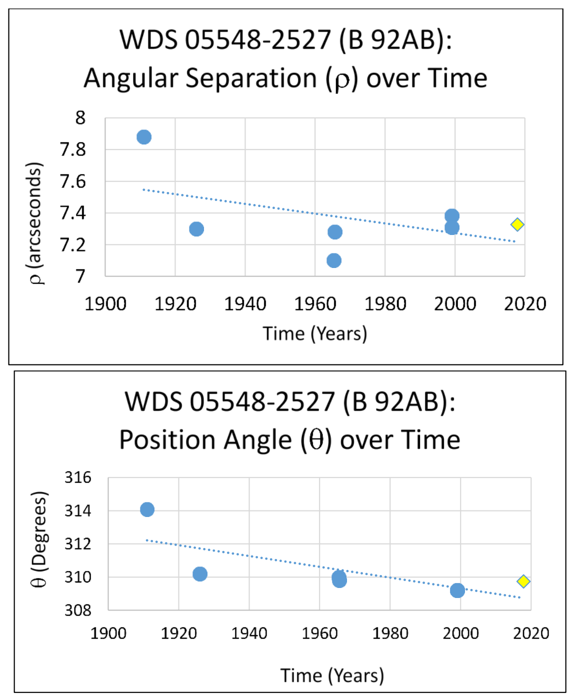

Figure 7. Angular separation versus time (top) and position angle versus time of B 92AB. The yellow diamond symbol represents our measurement.

toric point slightly offset. In the bottom panel of Figure 8, we zoom into the motion of the secondary component and each historic point is labeled. The trend displays somewhat random movement over time.

By analyzing B 92A's A parallax (15.1665 milli-arcseconds) and its error (±0.0353), we calculated its minimum distance (214.45 light years), mid-point distance (214.95 light years), and maximum distance (215.45 light years) from our Sun. We analyzed component B's parallax (16.0971 milli-arcseconds) and its error (±0.1873) and calculated a minimum distance (200.19 light years), mid-point distance (202.52 light years), and maximum distance (204.91 light years) from our Sun. Even at three standard deviations from the mean measurements, the two stars would be almost four light years apart. A 0.051 Harshaw rating per Table 5, a value closer to 0 than 1 is suggestive of a common proper motion pair. A large separation suggests that they may be a physical pair traveling in the same direction in space, Table 5.

Is BUP 5AB a physical pair?

Using historical data and our new measurements, position angle and separation of the A and B components are plotted as a function of time, Figure 9. The data indicate clear trend in the decrease in the separation, Figure 9 top, and increase in position angle, Figure 9 top, since 1907.

In Figure 10 we show the orbital plot for the BUP 5AB system. In the top panel, A is fixed in the origin (0,0) position, and motion of the B component is shown by blue dots. This image doesn't reveal a long stretch of the secondary star's path relative to the primary star. Most data points are clustered close together. In the bottom panel of Figure 10, we zoom more into the motion of the secondary component, where we label each historic data point. The secondary star appears to be moving from southeast to northwest direction. Data points fluctuate around the line that connects first and last position and this may be attributed to the measurement errors. Overall the secondary star appears to be moving along the straight line with respect to the primary which is consistent with both long term binary and/or physically unrelated systems.

By analyzing BUP 5A's parallax (3.2695 milli-arcseconds) and its error (±0.057), we calculated its minimum distance (980.01 light years), mid-point distance (997.09 light years), and maximum distance (1014.79 light years) from our Sun. We analyzed component B's parallax (4.5776 milli-arcseconds) and its error (±0.0557) and calculated a minimum distance (703.60 light years), mid-point distance (712.16 light years), and maximum distance (720.94 light years) from our Sun.

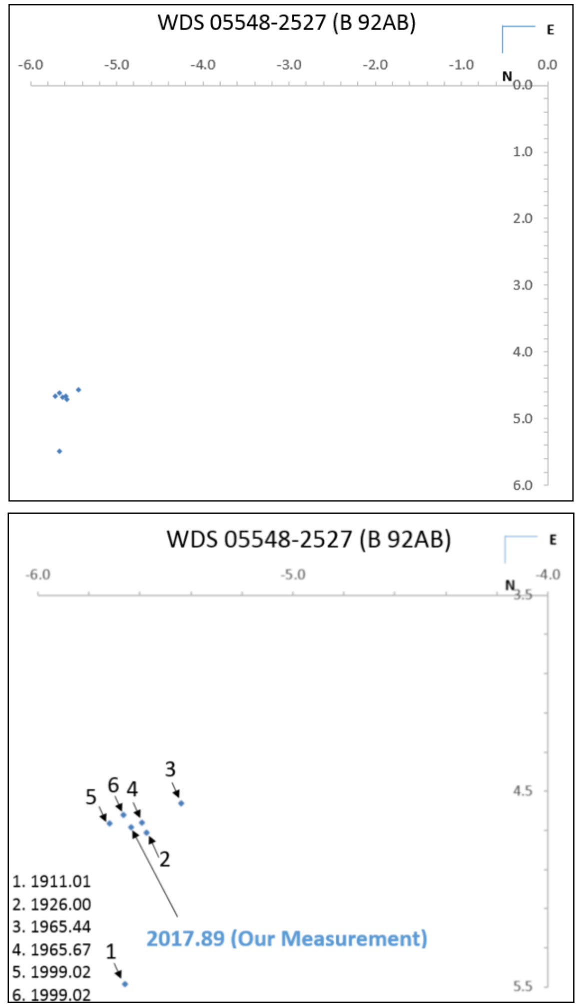

Figure 8. XY plot of the historical and new astrometric data of B 92AB with B 92A at (0,0) (top). The difference between these two panels is the level of zoom applied. In the bottom panel B 92A is not present, but details of B 92B motion are more obvious.

A Harshaw rating of 0.352, a value settled between 0 and 1, is suggestive of not being a common proper motion pair, Table 6. Our astrometric data in combination with historical data, its Harshaw rating and very wide distance between components essentially eliminates the possibility that these are a physical pair.

Conclusion

B 92AB's separation and position angle did not change much in the last hundred years. In our astrometric data we see no indication of the gravitationally bound orbit of the secondary star B around the primary star A. However, with similar parallaxes and proper motion, they may be physical with orbital motion not observable in a few hundred years but possibly tens of

CCD Astrometric Measurements and Historical Data Summary of Double Stars WDS 05548-2527 ...

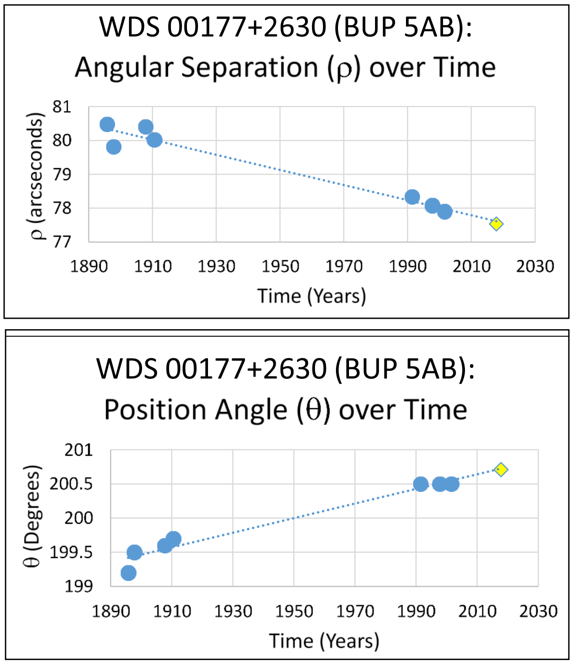

Figure 9. Angular separation vs time (top) and position angle versus time of BUP 5AB. The diamond symbol represents our measurement (bottom).

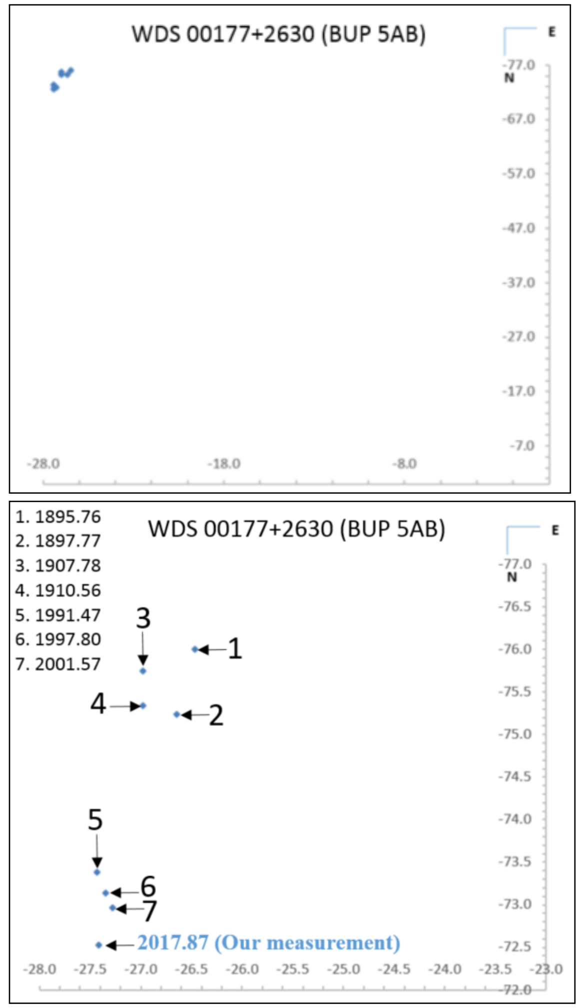

Figure 10. XY plot of the historical and new astrometric data of BUP 5AB with BUP 5A at (0,0) (top). The difference between the two panels is the level of zoom applied. In the bottom panel BUP 5A is not present, but details of BUP 5B motion is more obvious.

thousands of years from present day. Therefore, additional observational methods are encouraged to reveal the target's true nature.

BUP 5AB's 2017 measurements are close to its most recent WDS values from 2001 and combined with the historic data we see some consistent trends in change of position angle and separation. Common proper motion values are not suggestive of traveling in the same direction. This and parallax data from Gaia suggest these have no physical relationship.

Acknowledgements

We thank Brian Mason from USNO for helping the Fall 2017 semester research teams and past teams obtain the historical data of our elected double star systems. Additionally, we thank Pat and Grady Boyce of the Boyce Research Initiative and Education Foundation (B.R.I.E.F) for their instructional support and financial donation that allowed us access to the iTelescope network and the software tools on the BARC server. This research has made use of the Washington Double Star catalog maintained by the USNO, Aladin Sky Atlas software developed at CDS, Strasbourg Observatory, France, and the SIMBAD database operated by CDS, Strasbourg Observatory, France. 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 made use of data provided by Stelle Doppie and Astrometry.net.

References

Gaia Collaboration, 2016, "The Gaia misson", *Astronomy & Astrophysics*, **595**, A1.

Gaia Collaboration, 2018b, "Gaia Data Release 2: Summary of the contents and survey properties", *A & A*, **616**, A1.

Genet, R., Johnson, J., Buchheim, R., and Harshaw, R, 2016, *Small Telescope Astronomical Research Handbook*. Ed. Collins, D.

Harshaw, R., 2014, "Another Statistical Tool for Evaluating Binary Stars", *Journal for Double Star Observations*,**10** (1), 32-51.

Mason, B. and Hartkopf, W., 2015, The Washington Double Star Catalog, Astrometry Department, U.S. Naval Observatory.

Skrutskie, M.F., et al., 2006, "The Two Micron All Sky Survey (2MASS)", *The Astronomical Journal*, **131**, 1163-1183. http://adsabs.harvard.edu/abs/2006AJ....131.1163S

Wycoff, G.L., Mason, B.D., and Urban S. E., 2006, "Data Mining for Double Stars in Astrometric Catalogs", *The Astronomical Journal*, **132**, 50-60. http://adsabs.harvard.edu/abs/2006AJ....132...50W

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