Measurement of the Position Angle and Separation of HJ 1924

Umar Ahmed Badami[1, 2], Kalée Tock[1, 2], Steve Carpenter[1, 3], Kurt Kruger[1, 3], Rachel Freed[1, 4], and Russell M. Genet[1, 5,]

1. Cuesta College, San Luis Obispo, California
2. Stanford Online High School, Stanford, California
3. Piner High School, Santa Rosa, California
4. Sonoma State University, Sonoma, California
5. California Polytechnic State University, San Luis Obispo, California

Abstract: The position angle and separation of the binary HJ 1924 have been measured and noted in 10 publications since John Herschel's initial observation in 1828. Measurement techniques have improved in both precision and accuracy since that time. Although Herschel's initial measurement was slightly different, the position angle and separation of these stars have remained relatively constant for the past 122 years. The system was observed using the Skynet Robotic Telescope Network. AstroImageJ software was used to contribute a new data point. Our measurement of 8.12" ± 0.0127 (1 ± SEM), 225.1° ± 0.0298 (1 ± SEM),was in agreement with the 10 most recent published measurements, but not the initial one, implying that Herschel's measurement may have been inaccurate. While these stars appear to exhibit similar proper motion, and may therefore share a common origin, they are unlikely to be gravitationally bound.

Introduction

Understanding the evolution and astrophysical properties of stars depends on knowing the masses of the stars in question. The orbits of binary stars can be used to determine stellar masses if the distance to the pair is known, thereby helping to determine the relationship between stellar mass and luminosity, and making possible an estimation of the masses of single stars based on their luminosities. Using the Skynet collection of ground-based telescopes, observations were made in order to contribute data for potential future analysis of the motion of one double star.

One challenge in the study of double stars is being able to distinguish between mere optical doubles, which simply appear to be next to each other from our line of sight, and pairs that are actually physically associated with each other. In the latter category there are common proper motion (CPM) stars, which are moving in generally the same direction at the same rate because they may have been born together out of a single molecular cloud, and true binary stars with a common center of gravity around which they orbit. Observations of double stars can help determine which are truly gravitationally bound versus systems that simply have common proper motion, often indicating a common origin.

This research was conducted as a part of Cuesta College's Astronomy Research Seminar, which provides high school and undergraduate students opportunities to fully participate in the scientific process. A major goal of the seminar is to engage students in real science, with the premise that this kind of early exposure will motivate students who might not otherwise consider studying science, to pursue STEM careers.

Due to the team's disparate physical locations, meetings of this research group occurred wholly online, with no in-person meetings of the full team.

Target Selection

The team used Stelle Doppie, a website (http://stelledoppie.goaction.it/) that allows the user to find double star systems that fit certain parameter requirements such as angular separation, constellation, and delta magnitude . A search was made via Stelle Doppie to find double star systems in the constellation Cepheus, since Cepheus is high in the sky in the northern

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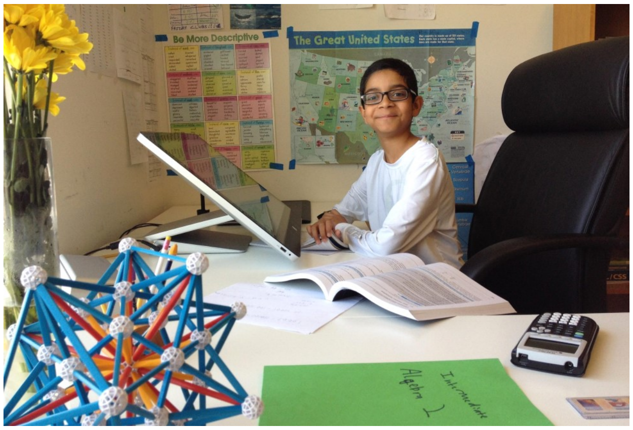


Figure 1: Umar Ahmed Badami, seminar team member and student at Stanford Online High School.

hemisphere during fall evenings. The search was limited to stars that had a delta magnitude less than 3.0, an angular separation between 5" and 30", and a name containing “Cep”. The former two parameters were chosen as such so that the Skynet telescopes could resolve both stars in the same image. Seven systems were found that met our criteria, and we narrowed it down to one: HJ 1924 (WDS 00005+6713). The search result for this double star from Stelle Doppie is shown in Figure 2.

Stelle Doppie is an online search engine developed by Gianluca Sordiglioni, an amateur astronomer who lives in Milan, Italy, shown in Figure 3. He enjoys observing double stars, so he needed a resource that would help him to find stars to observe. This was the original inspiration for his creation of Stelle Doppie, which means “double stars” in Italian.

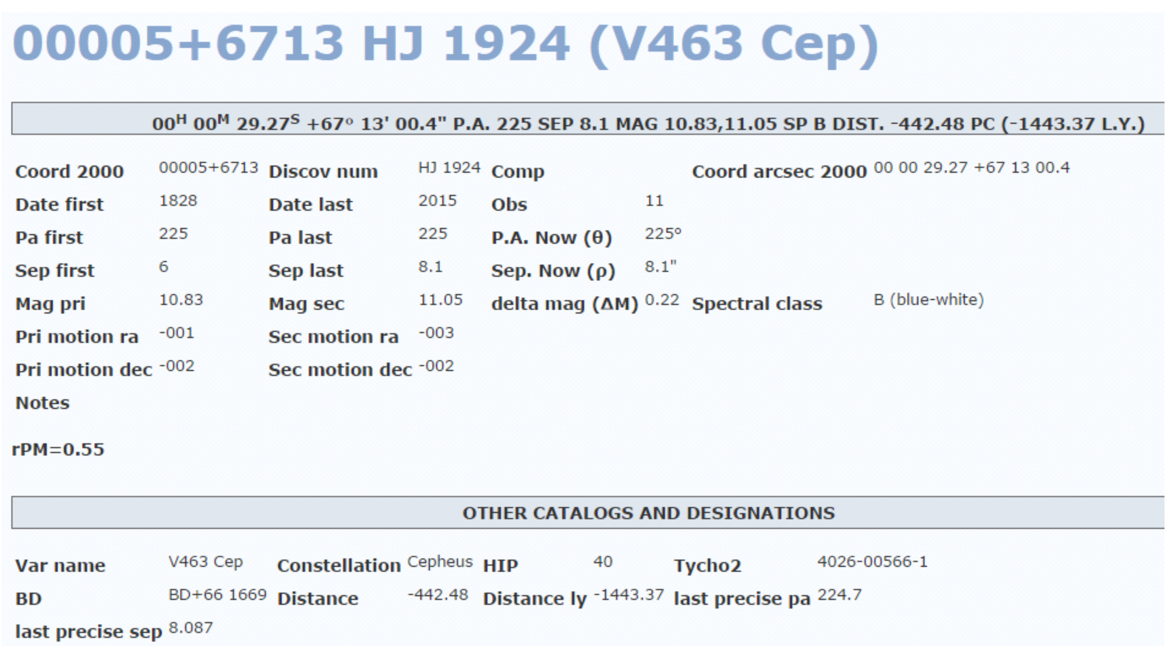
Discovery of HJ 1924

The first observer and discoverer of HJ 1924 was Sir John Herschel (see Figure 7). He observed the system with a 20-foot focal length telescope in 1828 (see Figure 4) and published his results, along with the measurements of 1,235 other double star pairs, in the *Memoirs of the Astronomical Society of London* (Figures 5 and 6).

After Sir John’s observations, additional observations were made in 1894, 1895, 1908, and 1913. The Hipparcos space telescope observed the system in 1991, and the Two-Mass Survey observed it in 1998. The most recent observer was Richard Harshaw (see Figure 7), who observed the system as part of a larger study in 2015. When Harshaw’s measurement was made on November 10th, 2015, the position angle was measured at 224.761° and the angular separation of the pair was measured at 8.087" (see Table 6).

Observation Method

The team used three different telescopes in the Skynet Robotic Telescope Network (https://skynet.unc.edu/). This network consists of telescopes at more than 10 different sites around the globe and was initially created to do optical follow-up imaging of gamma ray bursts. Most of the telescopes are now also



00005+6713 HJ 1924 (V463 Cep)

00^H 00^M 29.27^S +67° 13' 00.4" P.A. 225 SEP 8.1 MAG 10.83,11.05 SP B DIST. -442.48 PC (-1443.37 L.Y.)

Coord 2000	00005+6713	Discov num	HJ 1924	Comp		Coord arcsec 2000	00 00 29.27 +67 13 00.4
Date first	1828	Date last	2015	Obs	11		
Pa first	225	Pa last	225	P.A. Now (θ)	225°		
Sep first	6	Sep last	8.1	Sep. Now (ρ)	8.1"		
Mag pri	10.83	Mag sec	11.05	delta mag (ΔM)	0.22	Spectral class	B (blue-white)
Pri motion ra	-001	Sec motion ra	-003				
Pri motion dec	-002	Sec motion dec	-002				
Notes							

rPM=0.55

OTHER CATALOGS AND DESIGNATIONS

Var name	V463 Cep	Constellation	Cepheus	HIP	40	Tycho2	4026-00566-1
BD	BD+66 1669	Distance	-442.48	Distance ly	-1443.37	last precise pa	224.7
last precise sep	8.087						

***Figure 2**. Stelle Doppie results page for the Double Star WDS 00005+6713/ HJ1924.*

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Figure 3: Gianluca Sordiglioni, creator and maintainer of Stelle Doppie, in his basement workroom.

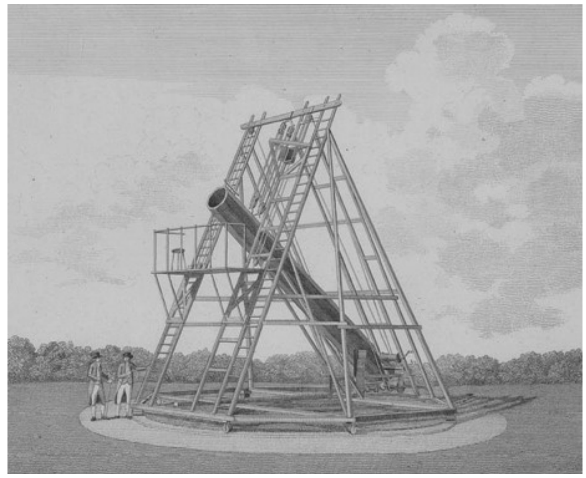
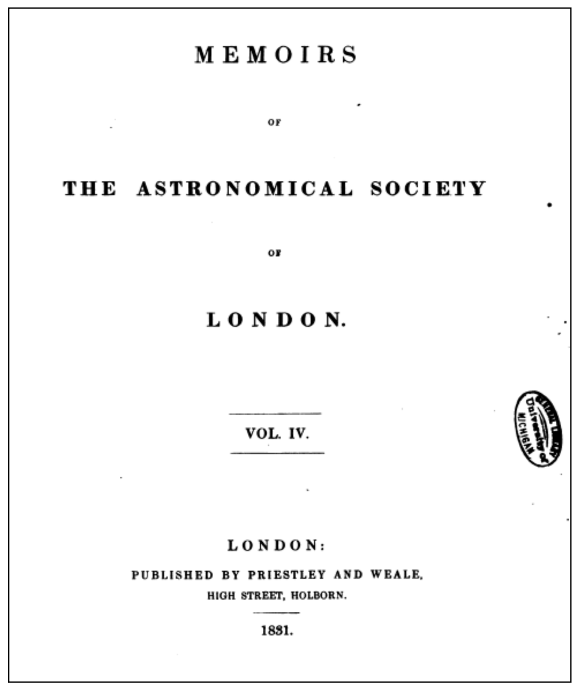


Figure 4: Sir John Herschel's 20-foot telescope at Slough.



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HIGH STREET, HOLBORN.

1831.

Figure 5: Cover of the Memoirs of the Astronomical Society of London where Herschel published his observations of 1236 double stars in 1828 and 1829.

available for other research and education endeavors. Several image requests were made, each having 5 exposure times (10, 20, 30, 40, and 50 seconds). The telescopes used were the 14-inch Athabasca University Robotic Telescope (Athabasca, 2017) in Athabasca, Alberta, Canada (aperture 37 cm, focal length 200cm, f-ratio f/5, designation AURT-14), the historic 40″ refractor telescope at Yerkes Observatory in Williams Bay, WI (aperture 40 inches, focal length 744 inches, f-ratio f/18.6, designation Yerkes-41), and the 14" telescope at Dark Sky Observatory (Smith, 2009) in Boone, NC (aperture 14 inches, focal length 154 inches, f-ratio f/11, designation DSO-14). Some of the returned images were not used because the stars were elongated or saturated in the image. Table 1 summarizes the images used in this analysis. Figure 8 gives shows sample images of the pair.

Astrometry using AstroImageJ

AstroImageJ (AIJ) is a software tool based on ImageJ, the open-source image analysis software from the National Institutes of Health (https://imagej.nih.gov/ij/). Karen Collins of Vanderbilt University has developed a set of robust astronomical image analysis tools as additions to the existing basic program (Collins et al, 2016). AstroImageJ has been widely used both for education and research. The vast majority of the analyses carried out using AIJ have been aimed at reducing photometric

No. h.	Æ. 1830.	N.P.D. 1830.	Position.	Dist.	Magnitudes.	Remarks.	Sweep.	Reference.
1924	51 50,3	23 43 50	224·6	6	11 = 11	Pos. mean of 225·2, 224·0.	223	

Figure 6: John Herschel's original data on HJ 1924 (page 378).

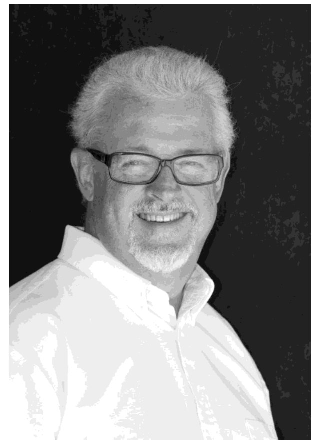

Figure 7: John Herschel and Richard Harshaw, first and most recent observers of HJ 1924.

observations. While the software already included tools for binary star astrometry, additional features to make astrometric analysis more explicit were added by Karen Collins upon request during the course of this analysis. The new tools were easy to use, and their remarkable consistency suggests that AIJ is a robust tool for binary star research.

Each image was first plate solved using a pull-down menu connecting AIJ to astrometry.net, which has the result of also writing the World Coordinate System headers into the image .fits header. The AIJ plugin has a measurement tool which automatically determines the centroid of each star. Both separation and position angle were measured using AIJ by locating the centroids and dragging the mouse between them. This separation is converted to arcseconds using the image plate scale from the FITS header.

Results

The images from the Dark Sky Observatory, when enlarged, showed the stars to be elongated and therefore these images were omitted from the analysis. The longest exposures (50 seconds) from the Yerkes telescope were saturated within the measurement area; therefore those data were also omitted. The remaining images were independently analyzed in AstroImageJ by two different researchers, who made measurements of the separation and position angle for each of 5 exposure times (10, 20, 30, 40, and 50 seconds) on each telescope, using a photometry aperture of 8 pixels. From the astrometry.net plate solution, the image pixel scale was approximately 0.5"/pixel for AURT and approximately 0.6"/pixel for Yerkes. The exact pixel scale values, which varied by image, were used in the analysis. There was very little variability in AIJ measurements

Table 1: Skynet images used in the analysis of HJ 1924. [1] 50s exposure saturated [2] stars elongated

Telescope	Skynet ID	Date Image Taken	Julian Date	Number of Images
AURT-14	1674730	Nov 10, 2016	2457703	5
AURT-14	1674731	Nov 10, 2016	2457703	5
AURT-14	1674732	Nov 10, 2016	2457703	5
AURT-14	1646217	Sep 20, 2016	2457652	5
AURT-14	1674708	Nov 10, 2016	2457703	5
Yerkes-41	1706169	Nov 6, 2016	2457699	4 [1]
Yerkes-41	1706171	Nov 6, 2016	2457699	4 [1]
Yerkes-41	1706172	Nov 6, 2016	2457699	4 [1]
DSO-14	1706170	Nov 6, 2016	2457699	0 [2]
DSO-14	1706173	Nov 6, 2016	2457699	0 [2]
DSO-14	1706174	Nov 6, 2016	2457699	0 [2]

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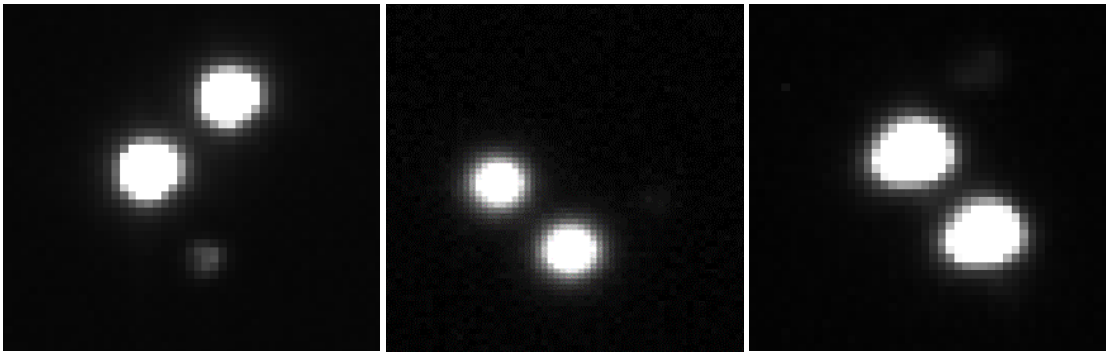

Figure 8. Sample images from the Yerkes 41" telescope, the 14" AURT telescope, and 14" Dark Sky Observatory telescope.

between researchers: only 3 of the 37 images showed any difference at all in position angle and/or separation, and where variability existed, it was a maximum of 0.06" separation and 0.4° PA (Yerkes 20s exposure). This inconsistency did not affect our results to a significant extent; however, this unexpected discrepancy is worth looking into.

The AstroImageJ measurements are shown in Tables 2 and 3, with a comparison to previous measurements.

Using an unpaired t-test, the separation measurement was not statistically significant between the AURT and Yerkes telescopes. The difference in the position angle measurement *was* statistically significant but the difference was small: between 0.078 and 0.32" for the AURT minus Yerkes measurement with a 95% confidence interval.

Exposure time did not have a statistically significant effect on the values obtained for position angle. For the separation values, there was a statistically significant difference between the 10 second and 30 second images from Yerkes as well as between the 30 second and 40 second images from Yerkes, but otherwise the exposure time did not affect the value of the separation measurement. Tables 4 and 5 summarize these measurements.

Discussion

As indicated by the historical data in Table 6, the differences in position angle and separation over many years of observations are small, with the only outlier being John Herschel's original separation measurement. This is shown graphically in Figure 10. Without Herschel's measurement, the standard deviation of the previous measurements shrinks by more than a factor of 5.

It is possible that John Herschel's original separation measurement was less accurate than the subsequent

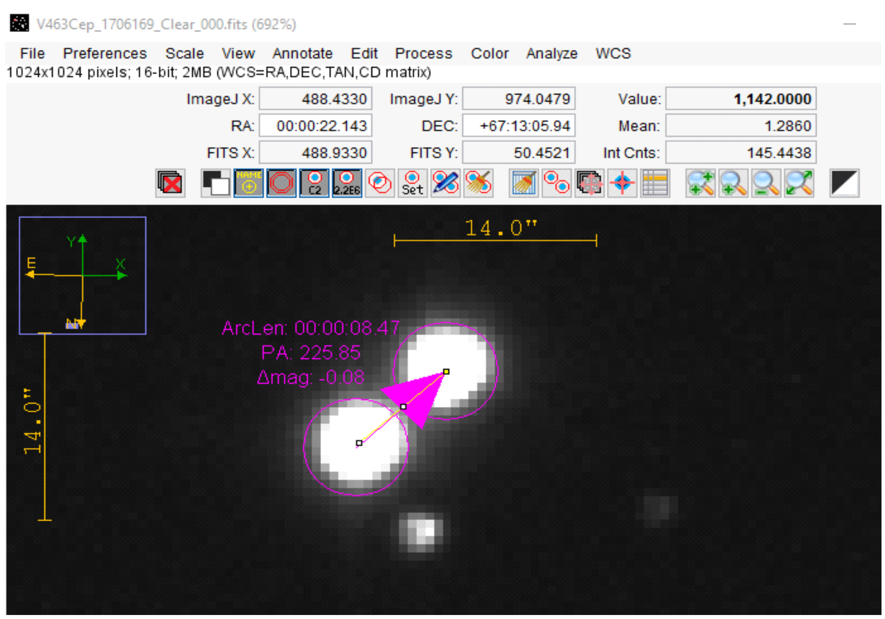

Figure 9. Centroid determination of HJ 1924 using AstroImageJ software.

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Table 2: Separation (arcseconds) of the double star HJ 1924 using different telescopes compared to the average separation of the historical measurements.

Separation Values (arcseconds)					
	14-inch AURT	41-inch Yerkes	Combined	Historical Measurements w/o Herschel's	Historical Measurements w/ Herschel's
Average	8.12	8.12	8.12	8.2	8.0
Standard Deviation	0.082	0.070	0.077	0.08	0.67
Sample Size	25	12	37	10	11
SEM (Standard error of the mean)	0.0164	0.0203	0.0127	0.03	0.20

Table 3: Position angles (degrees) of the double star HJ 1924 using different telescopes compared to the average of the historical measurements.

Position Angle Values (degrees)				
	14-inch AURT	**41-inch Yerkes**	**Combined**	**Historical Measurements**
Average	225.1	224.9	225.1	224.8
Standard Deviation	0.147	0.214	0.181	0.70
Sample Size	25	12	37	11
SEM	0.0294	0.0618	0.0298	0.21

measurements. The seeing disk associated with ground -based images of stars can be smeared out into a seeing disc with a 1" radius. Herschel may have been indicating a high uncertainty in his measurement by reporting the separation to only one significant figure.

Although the distance to the primary is known to be 442pc, the distance to the secondary is not listed in the SIMBAD astronomical database at the time of this writing (SIMBAD, 2017). If the stars in this system are at nearly the same distance, then regardless of whether they are gravitationally bound, it is likely that they formed at nearly the same time from the same nebula. If this is the case, then the stars are "physically related" because they were born in the same stellar nursery. Harshaw explains the the classification of double stars based on their proper motion as follows:

The proper motion of a star can be depicted as a vector. When the resultant of the two vectors is divided by the largest vector, the result will either be zero (or very near it) if the proper motions are identical, somewhere between 20% and 60% of the resultant of the vectors, or over 60% of the resultant. Pairs in the first category are classed as Common Proper Motion pairs, or CPM (Harshaw, R., 2016).

Harshaw calculated the ratio of the vectors for HJ 1924 as 55%, putting it into the Similar Proper Motion category (Harshaw, R., personal communication). We repeated Harshaw's calculation using more recent data from the UCAC5 catalog (USNO, 2017), which lists the proper motions in milliarcseconds per year as

and

The updated relative proper motion ratio is 41.7%,

$$PM_{primary} = (-2.5, -1.1)$$

confirming his classification of this system as a Similar

$$PM_{secondary} = (-1.8, -2.0).$$

Proper Motion pair.

Conclusions

The Stelle Doppie website provides a valuable means of finding double stars suitable for observation by ground-based telescopes. The telescopes in the Skynet network can be used to collect double star images, though it is important to examine the returned images carefully by eye to avoid including distorted images in the analysis. The free AstroImageJ software is a useful tool for double star astrometry.

It seems unlikely that HJ 1924 is a gravitationally bound binary. The measurements made here support a lack of significant change in separation or position an-

(Text continues on page 188)

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Table 4: Position angle (degrees) of the double star HJ 1924 using different exposure times.

Position Angle Values for Different Exposure Times (degrees)									
	14-inch **AURT**					41-inch **Yerkes**			
	10 sec	**20 sec**	**30 sec**	**40 sec**	**50 sec**	**10 sec**	**20 sec**	**30 sec**	**40 sec**
Average	225.1	225.1	225.1	225.1	225.1	225.1	224.7	224.9	225.0
Standard Deviation	0.131	0.086	0.257	0.164	0.044	0.263	0.262	0.092	0.141
SEM	0.0586	0.0384	0.1151	0.0733	0.0199	0.1517	0.1515	0.0532	0.0813

Table 5: Separation (arcseconds) of the double star HJ 1924 using different exposure times.

Separation Angle Values for Different Exposure Times (degrees)									
	14-inch **AURT**					41-inch **Yerkes**			
	10 sec	**20 sec**	**30 sec**	**40 sec**	**50 sec**	**10 sec**	**20 sec**	**30 sec**	**40 sec**
Average	8.14	8.11	8.10	8.13	8.10	8.16	8.07	8.16	8.08
Standard Deviation	0.047	0.106	0.100	0.078	0.099	0.012	0.121	0.031	0.006
SEM	0.0211	0.0475	0.0448	0.0347	0.0442	0.0067	0.0700	0.0176	0.0033

Table 6: Past observations of double star HJ 1924, courtesy of the US Naval Observatory, with our current observations from the Yerkes (Our obs 2) and AURT (Our obs 1, 3) telescopes.

Date	Position Angle (Degrees)	Separation (arcseconds)	Aperture of Telescope (m)	Number of Nights of Observations (Averaged)	Ref	Ob
1828	224.6	6	0.5	1	Herschel, 1831	Mb
1894.85	225.4	8.121	0.3	1	Urban et. al., 1998	Pa
1895.72	223	8.355	0.3	1	Urban et. al, 1998	Pa
1908.93	224.9	8.1	0.4	4	Van Biesbroeck, 1914	Ma
1913.78	224.4	8.26	0.5	2	Doolittle, 1923	Ma
1991.25	224.9	8.198	0.3	1	Hipparcos Catalogue, 1997.	Hh
1991.67	225.8	8.188	0.3	1	Hog et. al,., 2000	Ht
1999.79	224.9	8.25	1.3	1	2MASS, 2003	E2
2003.727	225	8.19	0.2	6	Hartkopf et. al., 2013	Eu
2010.884	225.1	8.2	0.7	2	Mason et. al, 2011	Cu
2015.858	224.761	8.087	0.3	1	Harshaw, 2016	C
2016.720	225.3	7.97	0.36	1	Our obs 1	C
2016.848	224.9	8.10	1.0	1	Our obs 2	C
2016.859	225.0	8.16	.36	1	Our obs 3	C

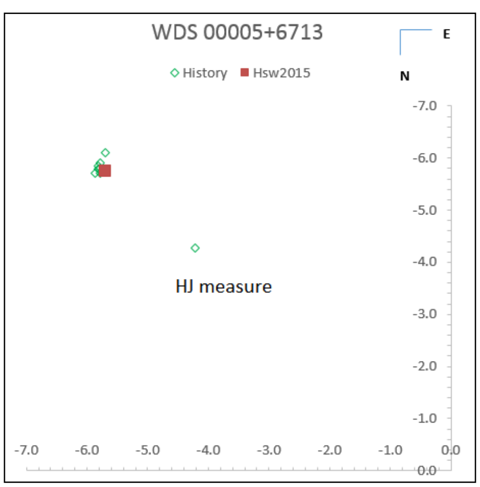

Figure10. Historic measurements of WDS 00005+6713.

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(Continued from page 186)

gle over the past 122 years. This corroborates the recent suggestion by Richard Harshaw that the two stars are a Similar Proper Motion Pair.

Acknowledgements

This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory, the Skynet Robotic Telescope Network, the Stelle Doppie catalogue maintained by Gianluca Sordiglioni, the SIMBAD database operated at CDS, Strasbourg, France, and AstroImageJ software written by Karen Collins and John Kielkopf at the University of Louisville which was updated for double star astrometry by Karen Collins.

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The research team for this paper consists of Umar Ahmed Badami and Kalée Tock, a student and instructor, respectively, at Stanford Online High School, Rachel Freed, an Instructional Technology Consultant and Specialist from Sonoma, CA, Steve Carpenter and Kurt Kruger, instructors at Piner High School in Santa Rosa, and Russell Genet, an instructor at Cuesta College.