CCD Astrometric Measurements of WDS 00420-5547 MLO 1

Camerin Kith[1], Jake Wilson[2], Sam Agro[2], Sarah Toms[3], Bella Andreski[4], Emily Torrance[5], Kalée Tock[6]

1. Falls Church High School, Falls Church, Virginia
2. Severn School, Severna Park, Maryland
3. Indian Springs School, Indian Springs, Alabama
4. Beach Middle School, Chelsea, Michigan
5. Chelsea High School, Chelsea, Michigan
6. Stanford Online High School, Stanford, California

Abstract: The position angle and separation of WDS 00420-5547 MLO 1 has been measured and noted in 20 publications since Robert Lewis Ellery's initial observation in 1877. This system was observed using the R-COP robotic telescope in Australia, which is part of the Skynet Robotic Telescope Network. Their small separation made it difficult to resolve the two stars, except for the lowest-exposure-time images (5 seconds and 10 seconds) using a small measuring aperture (3-4 pixel aperture radius). AstroImageJ software was used to reduce the data and contribute a new measurement: position angle 165° ± 0.63 (1± SEM) and separation ρ= 6.0 arc sec ± 0.12 (1 ± SEM) on 2017.093 (Besselian date). The observation was plotted along with the past observations using the Desmos plotting tool, which allows the date to be displayed next to each position of the secondary. Despite the fact that these stars are a Common Proper Motion pair, the data and plot do not currently support classification of this system as one that is gravitationally bound.

Introduction

If the period and semimajor axis length of a binary star system can be determined, the sum of the masses of its constituent stars can be computed. In turn, knowledge of the star masses helps to pin down the mass-luminosity relationship for stars in general. Because the interdependence between a star's mass and its luminosity is such a useful and important relationship for astronomy, double stars merit careful study for evidence of any physical relationship. Hoping to find such a relationship, we perused the Washington Double Star Catalogue for likely candidates. Several possibilities were observed using telescopes in the Skynet Robotic Telescope Network (https://skynet.unc.edu/) , and WDS 00420-5547 MLO 1 was chosen for study.

Target Selection

The CCD telescopes that make up the Skynet Robotic Telescope Network cannot simultaneously resolve double stars that are closer than 5" together in the sky or that are more than 3 magnitude units different in brightness. These constraints provided some initial filters for our selection of a star system to observe. Since stars that are closer together are more likely to be gravitationally bound, it was desirable to find a target without an existing orbital or linear solution whose last measured separation was as near as possible to 5". Because having a substantial number of previous observations increases the likelihood of revealing an arc in the motion of the secondary star relative to the primary (if one exists), the search was further narrowed to systems that had at least 20 previous measures on record. To allow adequate time for movement to occur since the last measurement was made, the requirement was added that the most recent observation of the system be at least a few years in the past.

Finally, it was desirable to select a system that had been observed over a long period of time. A 5" separation in the sky as seen from Earth translates to a relatively large separation and orbital period for stars that are any substantial distance away. For example, if a binary star system with a separation of 5" is 40 parsecs from Earth, then the stars are separated by at least 5" * 40 parsecs = 200 AU, and more if there is a radial component to the distance between them. By Kepler's third law, such a large separation would imply a correspondingly long orbital period for the stars, so it would take a record of observations stretching far into the past to discern any significant relative movement. Double star astrometry has been going on since the late 1700's, so the selection filter was set to find systems that had been observed prior to 1850.

The Stelledoppie database (on the web at http://stelledoppie.goaction.it/index2.php) is a search engine that facilitates searching on criteria such as those named above. The database was used to select several double star systems. Image requests for several systems were made to Skynet, since vagaries of weather and the queue at different telescopes give rise to uncertainty in the time it takes for images to be returned. In some cases, the limits of the constraints were tested. For example, WDS 16397-5700 was observed using the Prompt 1 telescope in Chile despite the fact that the stars in the system were only 3.3" apart. The AstroImageJ software was unable to find separate centroids for the two stars, which appeared together as one bright, oblong blur on the image. Another system, WDS 05143+6949, had a 5.1" separation but was nevertheless unable to be resolved, possibly due to the difference in star magnitudes (primary 7.52, secondary 9.06). It seems that the smaller the separation of the stars, the smaller their difference in magnitude must be to be able to resolve them separately for CCD images.

Two of the observation requests were returned and able to be resolved using AstroImageJ. These were WDS 10489-4126 and WDS 00420-5547. The system WDS 00420-5547 was chosen as the subject of further study. WDS 00420-5547 is a Southern hemisphere double star whose position in the sky is highlighted in the Astrometry.net plate solution results page shown in Figure 1.

The Stelledoppie data for this system are shown in Figure 2.

The Washington Double Star Catalog lists a more recent observation for this star system, implying that Stelledoppie is updated less frequently than the Washington Double Star Catalog. The WDS listing is shown in Figure 3. The date of last observation is listed as 2015 according to the Washington Double Star Catalog.

Discovery of WDS 00420-5547

The discoverer of this system was Robert Ellery, who initially observed the stars from the Melbourne Observatory in January of 1877. His image is shown in Figure 4. His observation was first published in the 1927 Double Star Catalogue. Unfortunately, his notes on the weather and conditions on the evening of his first observation are no longer kept by the Royal Victorian Society.

Robert Lewis John Ellery was born into a family with a doctor, so he was taught medical science for the beginning years of his life. He was well educated from a young age, in hopes that he would qualify for medical jobs. However, when some family friends at Greenwich Observatory noticed his interest in astronomy, they brought him to the observatory to use the equipment. Soon after, at the age of 26, he became the head of a new observatory. This new observatory was in Williamstown. The Victorian government had made this new observatory and filled it with only three astronomi-

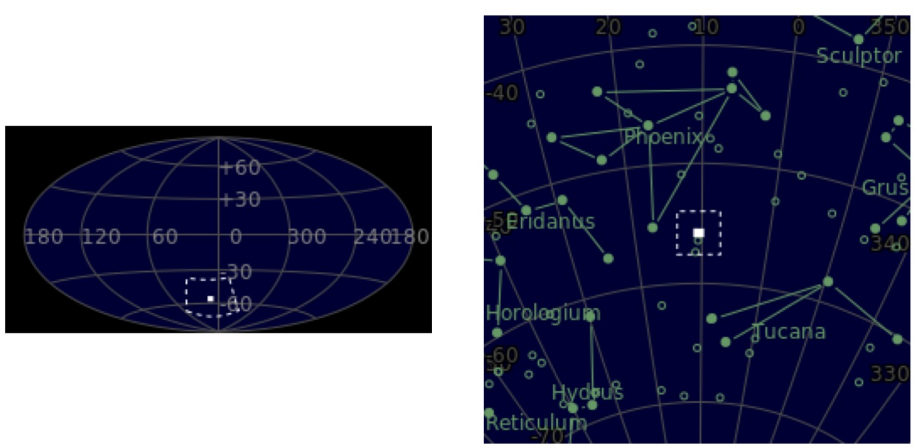

Figure 1: Position of 00420-5547 MLO 1 in the southern hemisphere sky as shown by the Astrometry.net plate solution (http://nova.astrometry.net).

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00420-5547 MLO 1

00H 41M 59.78S -55◆ 46' 55.4" P.A. 161 SEP 6.3 MAG 8.03,8.96 SP F7III/IV DIST. 89.69 PC (292.57 L.Y.)

Coord 2000	00420-5547	**Discov num**	MLO 1	**Comp**		**Coord arcsec 2000**	00 41 59.78 -55 46 55.4
Date first	1877	**Date last**	1999	**Obs**	20		
Pa first	159	**Pa last**	161	**P.A. Now (θ)**	161°		
Sep first	7.1	**Sep last**	6.3	**Sep. Now (ρ)**	6.3"		
Mag pri	8.03	**Mag sec**	8.96	**delta mag (ΔM)**	0.93	**Spectral class**	F7III/IV (yellow-white)
Pri motion ra	-043	**Sec motion ra**	-042				
Pri motion dec	-026	**Sec motion dec**	-031				
Notes							

rPM=0.1 (< 0.3, Physical double)

OTHER CATALOGS AND DESIGNATIONS

Constellation	Phoenix	**SAO**	232154	**HIP**	3290	**Tycho2**	8469-00242-1
HD	4001	**CP**	CP-56 132	**Distance**	89.69	**Distance ly**	292.57
last precise pa	161.1	**last precise sep**	6.3				

Figure 2. Stelledoppie results page for the double star 00420-5547, retrieved March 2017.

ad.usno.navy.mil/wds/Webtextfiles/wdsnewframe.html 00420-5547

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    WDS    Discovr Comp  EPOCH      #  THETA      RHO    Magnitudes Spectral  Prop Mot   2nd PM   DM Desig Note      Precise
Identifier              Frst Last     Fst Lst First  Last  Pri    Sec  Type      RA" DEC"  RA" DEC"                  Coordinate

00420-5547MLO   1       1877 2015   21 159 167   7.1   6.6  8.03  8.96 F7III/IV  -043-026 -042-031 -56  132        004159.78-554655.4
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Figure 3. WDS 00420-5547 as listed at http://ad.usno.navy.mil/wds/Webtextfiles/wdsnewframe.html.

cal devices. However, after a year Ellery obtained two new astronomical devices and a few meteorological ones. Between 1853 to 1895, he continued to be an astronomer. All of his life, he was a great leader in his community. So, naturally, he became president of the Royal Victorian Society in 1866 until 1885. Ellery continued to make many achievements throughout the rest of his life, which included involving himself in the Australian Antarctic Exploration Committees. Even after retirement, he continued working at an observatory until the day he died. He passed away in 1908.

The Melbourne Observatory was founded in Melbourne, Victoria, Australia in 1862. Its purpose was to record all astronomical observations made by the colony and keep track of the time system. The observatory's main telescope was known as the "Great Melbourne Telescope" in 1869 because it was the largest steerable telescope in the world at that time. This allowed the city to begin mapping out the stars. The observatory became known for its part in the project to better understand the relationship of the Earth and sun, known as the Transit of Venus. Slowly, as the observatory was needed less by the city, it became the government's observatory. Later on, some of the observatory's equipment was removed, but some of it remains today.

Figure 4: Robert Lewis Ellery, first observer of WDS 00420-5547.

The 1927 Double Star Catalogue was a collection of double stars kept in two separate books. These were published to the public so new observations could be shown to other astronomers. This catalog is currently kept in the care of the US Naval Observatory as part of the Washington Double Star Catalogue.

Unfortunately, the observation conditions on the night of Ellery's observation of WDS 00420-5547 were not recorded, so the name of the telescope that was used for this first momentous observation is unknown. However, the telescope that was most likely used was the "Great Melbourne Telescope." This telescope was a steerable telescope used to map the skies and track nebulae. It is shown in Figure 5.

Proper Motion

The USNO CCD Astrograph Catalog, 4th reduction (UCAC4) lists the proper motions (PM's) for WDS 00420-5547. In right ascension and declination, the primary has PM (-042.5, -025.7) milliarcseconds/year (mas/year) and the secondary has PM (-041.7, -031.2) mas/year. Even though the movement takes place on the celestial sphere, the star motions are sufficiently small that we can treat their proper motions as two-dimensional vectors. The longer of the two PM vectors is that of the secondary star, which has length

$$\sqrt{(-41.7)^2 + (-31.2)^2} = 52.1 \text{ mas/yr.}$$

The difference in the PM vectors for the two stars is -41.7 - (-42.5) = 0.8 mas/yr for right ascension and -31.2 - (-25.7) = -5.5 mas/year for declination. Taking the length of this difference vector, we have

$$\sqrt{(0.8)^2 + (-5.5)^2} = 5.6 \text{ mas/yr.}$$

If we divide the scalar length of the difference vector by the length of the longer of the two PM vectors, we obtain a ratio of 0.1. This small ratio indicates that the two stars in this system have Common Proper Motion (CPM). Binary stars usually have CPM, but CPM does not in itself indicate a gravitational relationship. If the stars are at the same distance from Earth, CPM could signify that they share a common origin, even if they are too widely separated to be gravitationally bound.

Past Observations

Table 1 summarizes the historical observations of WDS 00420-5547.

There are some peculiarities in the past observations. For example, the two different observations made almost simultaneously in 1892.74 imply that either the secondary star moved about 2° in a very short amount of time, or there was an error of about that magnitude in the position angle measurement. The "Pa" designation in the technique code column for these observation signifies that they were made photographically, with an astrograph.

Figure 5: The "Great Melbourne Telescope".

RCOP Telescope Images of WDS 00420-5547 MLO 1

WDS 00420-5547 MLO 1 was imaged on Feb 3, 2017 (Besselian date 2017.093). Because the target was low in the southern sky on that evening, it was necessary to reduce Skynet's default requirement for minimum target elevation from 30° to 25° above the horizon. One 30-second exposure, one 10-second exposure, two 5-second exposures, and one 1-second exposure were requested. For the 30- and 10-second exposures, AstroImageJ could not distinguish the star centroids because they were blurred together. However, for the 5- and 1- second exposures, the centroids were found by the software using a small aperture radius. To improve the accuracy of the observation, further image requests were made using the smaller exposure times. However, by then the target had slipped even lower on the horizon, as depicted in Figure 6, and the images were not returned from Skynet. Therefore, only the three images (two 5-second exposures and one 1-second exposure) obtained on Feb 3 were used for purposes of this analysis.

The aforementioned observations were made remotely using the 0.4m RCOP telescope at the Perth Observatory in Australia. Like the other telescopes in the Skynet network, the RCOP telescope was originally designed to observe gamma-ray bursts (GRB's).

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Table 1 Summarizes of Historical Observations of WDS 00420-5547.

Date	Position Angle (°)	Separation (arc seconds)	Aperture of Telescope (m)	Number of Observa-tions (Averaged)	Reference Code	Technique Code
1887	159.3	7.06	0.1	1	Ell1927A	Ma
1887.8	170.2	7.66	0.1	1	Skf2013b	T
1886.87	163.4	7.22	0.2	1	Pol1887	Ma
1887.81	164	5.78	0.3	2	Pol1887	Ma
1892.74	155.0	4.542	0.3	1	WFC1998	Pa
1892.74	157.1	4.6	0.3	1	SyO1927A	Pa
1899.91	164.7	6.6	0.3	3	Slr1910	Ma
1909.8	161.3	6.669	0.2	4	WFD1928d	T
1913.62	163.2	6.59	0.4	3	Daw1918a	Ma
1924.61	163.2	6.34	0.2	2	Vou1926	Ma
1932.29	162.7	5.88	0.4	4	Wal1934	Ma
1946	162.1	7.114	0.2	4	WFD1959	T
1953.24	162.04	6.3	0.6	1	Lem1958	Po
1960.85	162.3	6.34	0.7	2	B__1961a	Ma
1986.842	161.1	5.91	0.4	4	Sca1989	Ma
1991.25	161.2	6.315	0.3	1	HIP1997a	Hh
1991.58	161.9	6.261	0.3	1	TYC2000b	Ht
1991.661	161.3	6.09	0.3	3	War2000a	Ma
1991.802	161.24	6.31	0.9	6	Cuy1999	C
1998.616	161.4	6.405	0.2	3	UC_2013b	Eu
1999.8	161.1	6.3	1.3	1	TMA2003	E2
2015	167.2	6.591	0.7	1	Dam2016g	Hg

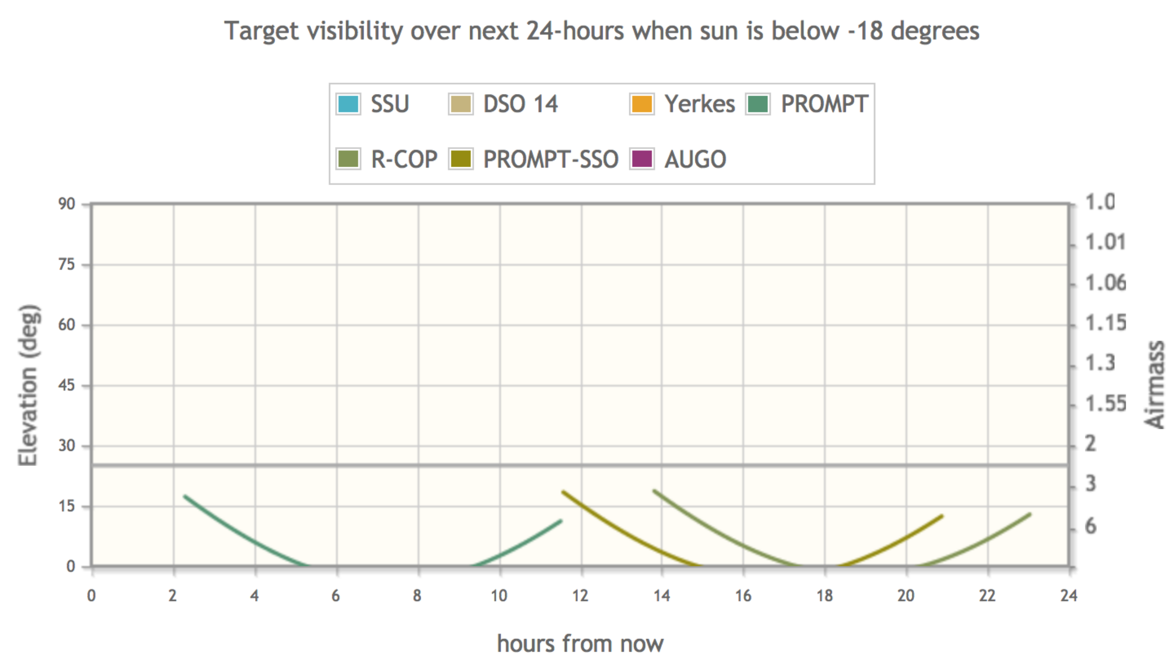

Figure 6: WDS 00420-5547 visibility on Skynet on March 24, 2017.

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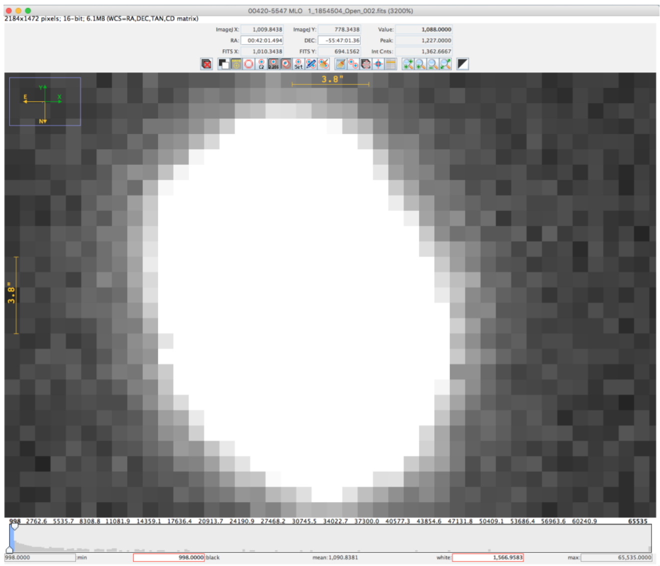

Figure 7: WDS 00420-5547 as viewed at maximum resolution in AstroImageJ.

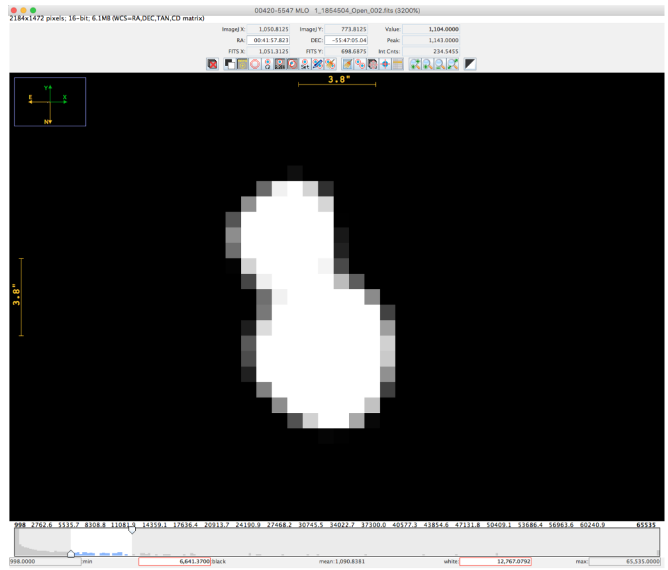

Figure 8: WDS 00420-5547 after contrast adjustment in AstroImageJ.

(Continued from page 141)

GRB's are mysterious, distant, and ephemeral bursts of radiation thought to accompany either the death throes of supermassive stars or the merging of binary neutron stars in the early universe. However, because the observable aftermath of a GRB lasts only for a few minutes, Skynet telescopes are typically available for use by astronomers and students about 90% of the time.

Position Angle and Separation Measurements in AstroImageJ

Once the image files were returned on Skynet, they were opened in AstroImageJ (AIJ), which plate-solved the image using Astrometry.net. A separate plate solution was done directly on Astrometry.net so that the image properties could be viewed and checked outside of AIJ.

When the image was enlarged in AstroImageJ, the double star was initially an oblong blur of light, as shown in Figure 7.

However, after changing the contrast at the bottom of the image window, the two separate stars were visible. Figure 8 shows the image following contrast adjustment. Note that the sliders on the histogram at the bottom of the image have been moved from their previous positions in Figure 7.

As might be anticipated from the proximity of the stars, finding the star centroids presented a challenge. AIJ computes a centroid for each star within the circle centered on the user's click whose radius in pixels is given by the aperture setting on the software. The software found the centroid of the primary star without any problem, but because light from the primary bled into

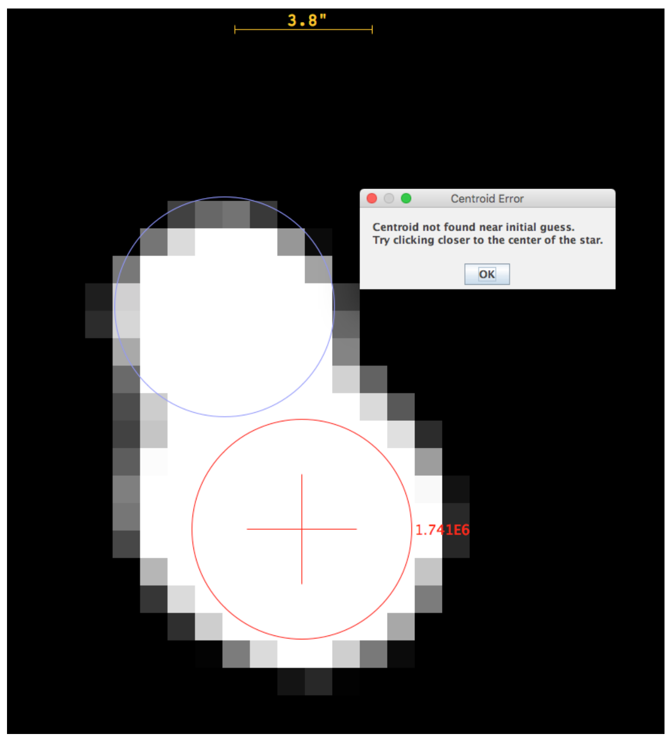

Figure 9: Although AIJ found the primary star centroid (in red) it was unable to find the secondary star centroid within the 4-pixel radius blue circle because of light from the primary bleeding into the circle at bottom right.

the secondary, the secondary star centroid could not be computed unless the aperture radius was very small: either 4 pixels or, in some cases, 3 pixels. In Figure 9, the blue circle represents the 4-pixel radius aperture

CCD Astrometric Measurements of WDS 00420-5547 MLO 1

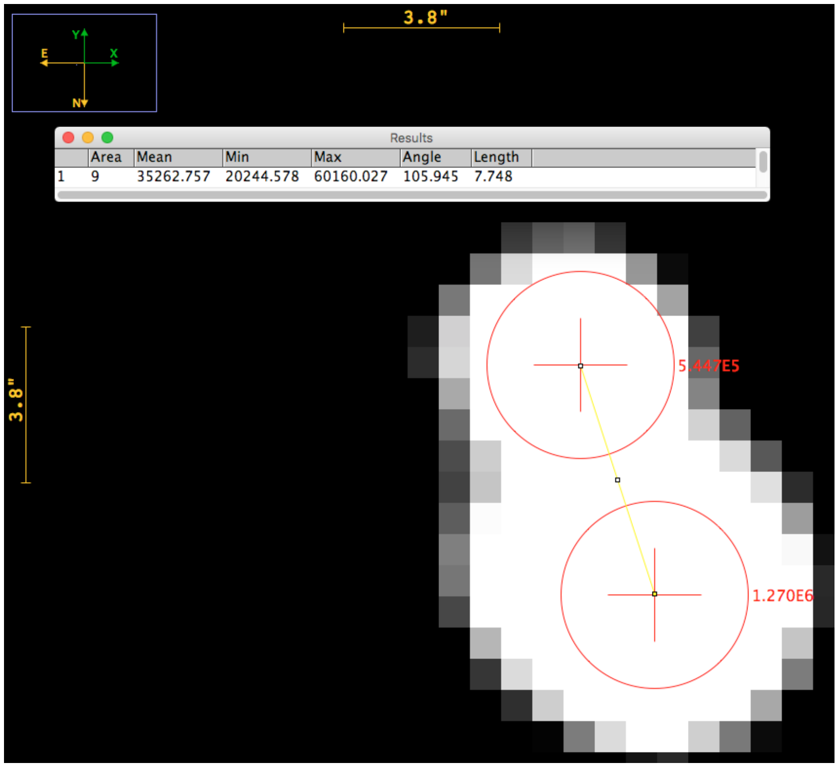

Figure 10: Measurement of 00420-5547 MLO 1 in AIJ with a 3-pixel aperture radius, showing the angle calculated by the software and the length of the centroid-centroid distance in pixels.

within which the software was attempting to compute a centroid for the secondary star. Since it was unable to find the centroid, the 3-pixel aperture setting had to be used for the secondary star in this image.

According to Astrometry.net, “up” in the image is 180° East of North, which corresponds to the compass rose at upper left of Figure 10. However, as is evident from the degree measure of 105.9° in Figure 10, AIJ measures the angle between the two star centroids counterclockwise from the x-axis, which corresponds to West going through South. For double star astronomy, the position angle by convention is taken as the angle from North going through East, as shown in Figure 11. Therefore, to obtain the correct position angle, we subtract the angle measured by the software from 270°. In this case, the position angle obtained from the image shown in Figure 10 below is 270° - 105.9° = 164.1°.

To find the separation of the stars, it is necessary to multiply the separation value in pixels that is measured by the software by the pixel scale from the image .fits header. According to the AIJ user manual, the World Coordinate System headers are added to the image .fits header when it is plate-solved. AIJ uses Astrometry.net to do the plate solution. Since the pixel scale for the image shown in Figure 10 is 0.76 arcseconds / pixel, the separation value for the stars as computed for by AIJ for this image is 5.9 arcseconds. Note that since these measurements were made, the AIJ software has been updated to compensate for the image orientation and plate scale automatically. Now, it can output the position angle relative to Celestial North and the separation in arcseconds directly.

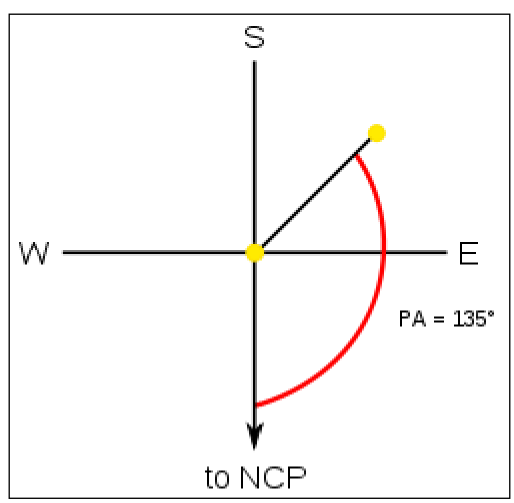

Figure 11: Wikipedia definition of position angle for double star astronomy from ***[https://commons.wikimedia.org/wiki/File:Position_angle.svg.](https://commons.wikimedia.org/wiki/File:Position_angle.svg)***

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Table 2. Measurements of 00420-5547 from AstroImageJ.

Researcher	Image Number	Exposure Time (seconds)	AIJ Aperture radius (pixels)	Position Angle (°)	Separation (arcseconds)
Kalée	1	5	4	166	6.2
Jake	1	5	4	166	6.2
Kalée	2	5	3	164.1	5.8
Jake	2	5	3	164.1	5.8
Kalée	3	10	4	166.0	6.1
Average	--	--	--	165	6.03

The three images for which measurements could be made were analyzed independently by two different researchers, for separation and position angle. The table of measurements is shown in Table 2. Given the variability in the numbers obtained, it would be misleading to report the position angle to higher precision than the nearest degree, or to report the separation to higher precision than the first decimal place. Although the results were the same between researchers, they did vary from one image to the next.

The average of our measured position angles was 165° and the average separation was 6". Using the Desmos plotting tool (https://www.desmos.com/), these measurements were plotted together with the historical observations in Figure 12 below. The standard error of the mean was 0.63° for position angle and 0.12" for separation.

The plot in Figure 12 was constructed from the double star data on past observations for WDS 00420-5547. The year of the observation is colored only to help it stand out from the other observation years on the plot.

Evidence of an arc would indicate that the secondary star is in orbit around the primary star. However, past observations in the graph above do not show that an arc is being formed over time. Instead, the points on the graph jump around from year to year. Older data points are generally more scattered throughout the quadrant while the more recent data points appear to clump together. This may be explained by greater

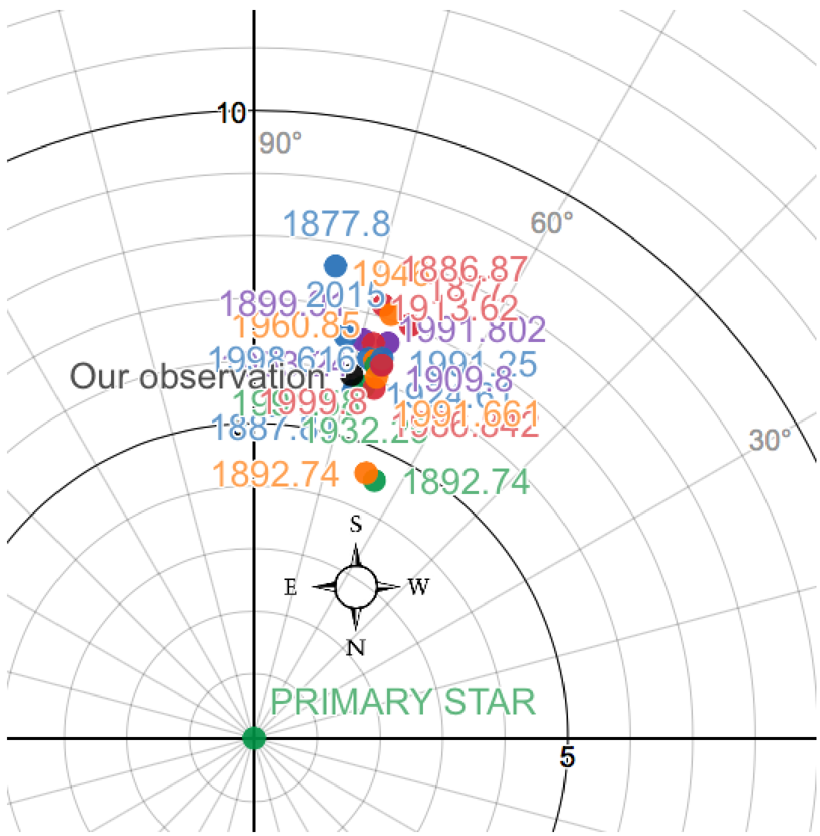

Figure 12: Historical observations of WDS 00420-5547 together with the current observation.

measurement error in the older observations, which is expected given the more rudimentary equipment that was available.

Conclusion

The 166° position angle and 6″ separation measured for 00420-5547 MLO 1 are within the variability of past observations of this system. From the plot in Figure 12, the position of the secondary relative to the primary exhibits a fair amount of scatter. The stars in this system are a Common Proper Motion pair, and therefore they are likely to have been born in the same stellar nursery. However, based on both our measurements and those of the past, we cannot conclude that 00420-5547 MLO 1 is physical at this time. If the stars are gravitationally bound, it may take centuries or even millennia for an arc to emerge.

Acknowledgements

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