Astrometric Measurement and Analysis of Celestial Motion for Double Star WDS 10494+5517

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Abstract: Our team observed and analyzed the double star system WDS 10494+5517 (HJ 2545) through the Las Cumbres Observatory (LCO) telescope network. We used the astrometric software SAOImage DS9 to measure new data for changes in mean position angle and mean separation distance. Our calculations revealed a new value of 25.9" ± 0.3" for the mean separation distance (rho) and a value of 114.2° ± 0.8° for mean separation angle (theta). Based on a consistent proper motion trend, very little retrograde motion or arcing, and a Harshaw value of 0.988, it is likely that HJ 2545 is an optical double.

Introduction

The objective of this research is to observe and analyze double star systems to determine whether the stars are physically bound or just visually associated. If a star is physically bound, the mass can be calculated for the stars in the set through determination of an orbit. Optical double stars are defined to be two stars that, due to forced perspective from the Earth, seem to be within close proximity of each other, yet do not have a gravitational connection. Other doubles are physically or gravitationally bound; these stars are referred to as binary stars. Throughout this paper, the term double star will be used as the gravitational nature of HJ 2545 is uncertain.

A common method for classifying double stars is to compare the position and orientation of the two stars against previous observations. By taking historical data and the double star's current position angle (theta / θ), and separation distance (rho / ρ), an observer can visualize relative motion of the pair.

Our team observed WDS 10494 + 5517 (hereafter referred to as HJ 2545), Figure 1. Initial observations were performed by English astronomer and polymath Sir John William Herschel (1831). Herschel documented many double stars, including HJ 2545, continuing the groundwork laid by his father William Herschel.

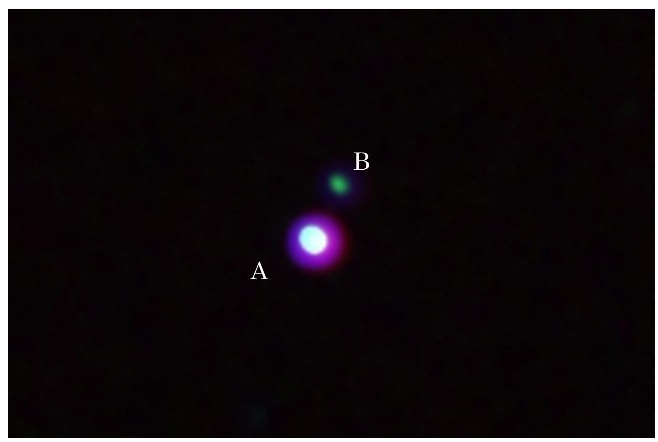

Figure 1. False color image of HJ2545 generated on DS9.

This system was selected due to a number of factors. Since our measurement window was in the spring, the Right Ascension (RA) must fall between 08-16 hours. Other criterion included the difference in magnitude between the primary and the secondary stars. Having magnitudes that are close means that similar exposure times can be used for both stars. The magnitude difference for HJ 2545 was 2.77 (Sordiglioni, 2018), which was low enough for good image quality. In addition, we chose apparent magnitudes with values less than 12 to make data collection easier.

After filtering the list of candidate stars down using this process, HJ 2545 was selected based on a number of additional criteria including: at least ten historical measurements, a change in ρ greater than 5" or a

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Table 1. Position angle and separation distance measurements for HJ 2545 10494+5517. Position angle is measured in degrees and separation distance in arcseconds.

Epoch	Position Angle	Separation Distance
1831.11	116.3	15
1902.27	111.11	18.96
1910.22	113.2	20.52
1914.25	113	20.345
1917.28	114.2	21.188
1926.20	114.1	20.403
1991.44	113.8	24.608
1999.88	114.7	25.04
2003.143	113.9	25.097
2007.303	114.4	25.01
2010.183	114.8	25.42
2010.5	115	25.42

change in θ greater than 25°, a long observation period, the most recent observation greater than 5+ years, an uncertain double star nature (physical or optical), and no publication history. HJ 2545 is visible in the Northern Hemisphere in the constellation Ursa Major which was interesting for our group since we can view this pair using a set of binoculars from home.

A summary of the historical measurements is outlined in Table 1 (Mason, 2018), demonstrating the separation distance has changed substantially since first observation. Table 1 also shows an annual rho increase of approximately 58 milliarcseconds per year from first to most recent measurement.

Equipment, Observations, and Data Analysis

Equipment

Data was collected by the Las Cumbres Observatory (LCO) telescope network, a global system of telescopes. The LCO telescopes provided were 0.4-meter modified Meade with SBIG STL-6303 CCD camera, which uses 2 x 2 binning to provide a resolution of 1.14 "/pixel. The telescopes have a field of view of 29.2 x 19.5 arcminutes. Available filters include Sloan u', g', r', i', z', Johnson-Cousins B, V, and Pan-STARRS w. The first data set was collected from the Teide Observatory (telescope code kb88) in Tenerife, Spain. The second data set was collected by the McDonald Observatory (telescope code kb80) in Texas, USA.

Observations

Two sets of images were taken with exposure times ranging from one to five seconds based on filter type, which resulted in non-saturated pictures. The first set of data included eleven images. Due to poor image quality from unfocused telescopes, we analyzed nine of the eleven images: three images taken with the luminance filter, two with the green, three with the red, and one with the infrared filter. The second data set included eight images. Due to poor image quality, only five images were analyzed from this set: two images in the luminance filter, one in the green, and two in the red filter.

Analysis Procedures

Two sets of images were provided to the research team with initial processing already performed. The data was reduced using the Our Solar Siblings Pipeline (Fitzgerald, 2018). This process attached WCS coordinates, removed 'hot' pixels, image artifacts, and flat fielded the images. The image quality was subsequently assessed through visual observation.

Using image analysis software SAOImage DS9 (DS9), the team measured separation distance (ρ) and separation angle (θ) for fourteen data points. Each data point was independently measured by two team members, and the results were averaged. Measurements were taken by placing circles around each star enabling the auto centroid feature to find the star's center. The auto centroid feature works by using pixel values as a weighting tool taking the weighted average of all pixel values within a specific user defined radius and measuring the center point from this average. Multiple iterations of best fit were calculated by the program, and the best option was provided as the actual separation distance and angle. The ruler feature provided the separation angle and distance in degrees and arcseconds respectively.

We averaged the collected data to produce our mean values for reporting purposes. For the first data set (Epoch 2018.22), the average position angle was measured to be 114.1° ± 0.8° and a separation distance of 25.9" ± 0.3". For the second set (Epoch 2018.26), the average position angle was measured to be 114.3° ± 0.7° and a separation distance of 25.8" ± 0.3". Both observations were within a few weeks and are within one standard deviation showing statistical consistency. Due to the close time proximity and the fact that both measures were within a standard deviation, we took the average of all points together to provide a single reported value of 25.9" ± 0.3" for separation distance and 114.2° ± 0.8° for separation angle. The epoch of the second set was used for reporting purposes. This can be observed in Table 2.

Discussion

Comparing the set of newly acquired points with the historical data provided by the WDS catalog showed results consistent with an optical double system. The separation distance, Figure 2, continued to increase linearly with a linear model correlation of 0.986; this suggests that during the historical observation window, that a linear model is a near perfect fit. It

Table 2. Position angle (θ) and separation distance (ρ) measurements for HJ 2545.

Epoch	# of Images	Mean Separation Angle (θ, deg)	Std. Dev.	Mean Separation Distance(ρ a.s.)	Std Dev.
2018.6	14	114.2	0.8	25.9	0.3
2010.5	Last Measurement	115	0	25.42	0

is also possible that this is within statistical tolerances, however since these are unknown for previous measurements, it cannot be stated certainly. The 1917 data point is the most out of line with the linear increase model. More would have to be known about the conditions of measurement to state if this was due to sampling errors or whether this is indicative of something else.

Observing the separation angle, Figure 3 shows only minor variation. It appears that as the stars separate linearly, and despite a slight oscillation around 114° this does not resemble an arc. The coefficient of determination of the separation angle vs. time is 0.01, which indicates that the linear regression line does not fit the data for angular measurements. Converting raw measurements into a Cartesian plane, Figure 4, shows a more apparent linear path of separation with all values appearing in quadrant I and moving up and right from the primary star. The regression analysis shows a model correlation of 0.921 which suggests that a linear separation model is a good fit for the data. Since this pair of stars is either linearly separating, or has an extremely long period, less frequent astrometry is necessary for continued monitoring of this double star system. A good time to take an additional point would be the 200th anniversary of discovery (2031). Our model would predict that the separation distance should be approximately 26.7".

Additional analyses were performed to determine the characteristics of the primary and secondary stars. First, the minimum possible straight-line distance was calculated using parallax data on the primary star from SIMBAD. This parallax number was 11.6621 with an error of 0.0514. This number was converted to light years, giving a minimum possible distance from Earth to the A star of 278.31 light years. Since the minimum straight line distance would occur if the stars were perpendicular relative to radial distance from Earth, the distance could be calculated using the minimum distance of A*tan(ρ) where ρ is converted to radians and A is the primary star minimum radial distance. This minimum possible straight-line value between the two stars was 0.03 light years. With the assumption that they are physically associated, parallax data would yield approximately equal radial distances for the primary and the secondary star.

The second analysis performed was a vector comparison of proper motions to determine a Harshaw value. The proper motions for the primary and secondary star were acquired from SIMBAD and the vector difference was divided by the vector sum. It has been shown (Harshaw, 2014) that stars with a value close to 0 tend to be physical pairs where stars with a value close to 1 are more likely to be optical doubles. Our values were approximately 0.988 which suggests that it is likely that this pair is an optical pair.

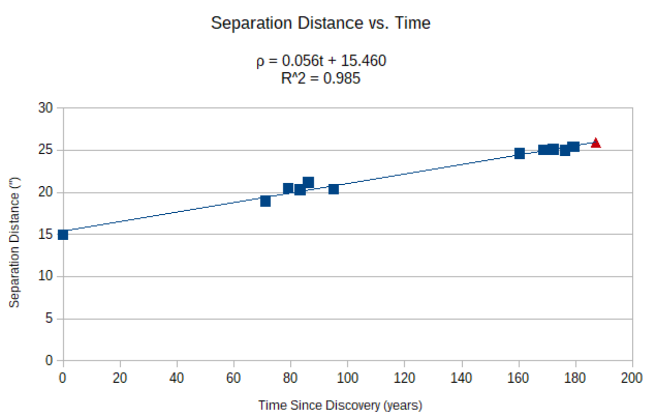

Figure 2. Graph of separation distance in arcsecond and epoch for HJ 2545, including historical data and new measurements. The red triangle is the new measurement. The separation distance has increased over time.

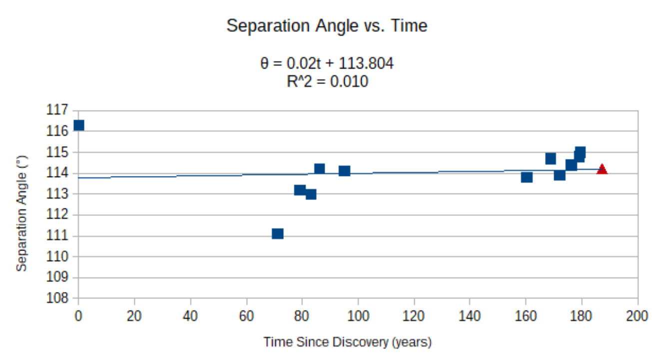

Figure 3. Graph of position angle in degrees and epoch for HJ 2545, including historical data and new measurements. The red triangle is the new data point. The separation angle measurements are relatively the same, which suggests that the star system is an optical pair.

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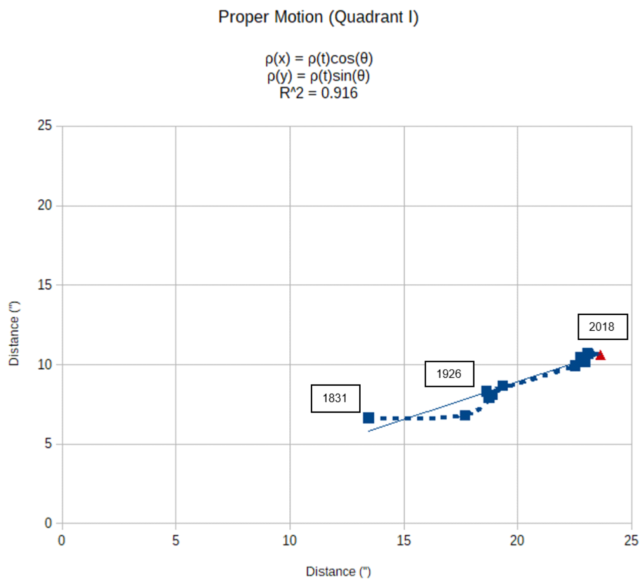

Figure 4. Plot of HJ 2545 movement relative to the primary, placed at the origin. The red triangle is the new data point. The data suggests that the star pairs are separating linearly over time.

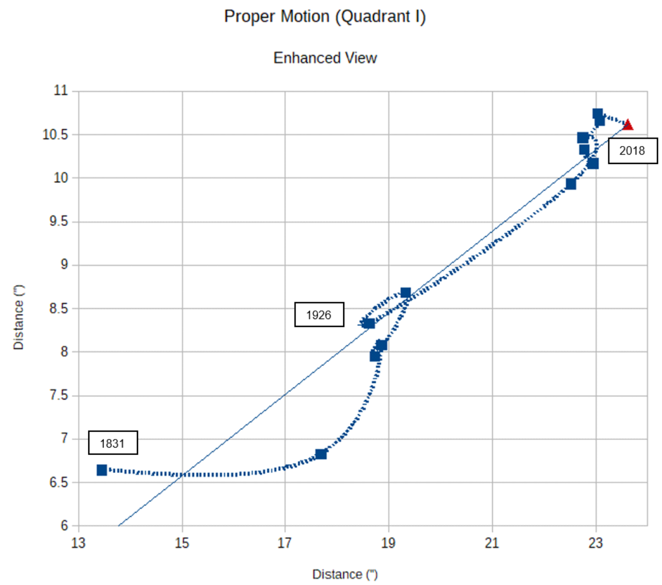

Figure 5. An enhanced plot of HJ 2545 movement relative to the primary, placed at (0,0) which is not pictured in enhanced view. The red triangle is the new data point. This plot shows the subtle amounts of retrograde motion in the data, but still shows the stars separating linearly over time.

Conclusion

The data analysis suggests that the primary and secondary stars of the HJ 2545 double star system are linearly separating. The new data obtained during the course of this research supported the trend of linear separation. Further parallax data should be taken on the B component star to verify minimum possible straight-line distance between primary and secondary components. Due to a strong regression analysis value from a linear model, a non-elliptical change in theta, and a Harshaw value close to one, it is likely that HJ 2545 is comprised of an optical primary and secondary star pair.

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