Astrometric Analysis of Binary Star WDS 07508-1854

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Abstract: We present new measurements of the position angle and separation of double star system WDS 07508-1854 taken with the Las Cumbres Observatory global telescope network in March 2021. We report a position angle of 191.91° and a separation of 5.60″. The new observations were combined with historical data for the source to glimpse the evolution of separation and position angle of the pair over time. Our results confirm that the system is binary in nature, but the determination of orbital solutions require further observations.

1 Introduction

Astrometric observations of binary star systems provide the data necessary to directly determine the masses of stars, information that is essential to fully understand their structure and evolution. Data for stellar positions and orientation of their orbits, combined with precise radial velocity or distance measurements, allow for the determination of the individual masses of the binary components. In addition, measurements taken over time can be combined to constrain the physical orbits of the primary and secondary components of the system. In this paper, we report new measurements of the position angle and separation of binary system WDS 07508-1854 to help constrain orbital parameters of the binary pair.

2 Target Selection and Observations

Dave Rowe's Gaia Double Star Selection Tool (GDS) (Rowe 2020) was used to search the Washington Double Star Catalog (WDS) (Mason et al. 2019) for candidate target systems observable by the Las Cumbres Observatory global telescope network (LCOGT) (Brown et al. 2013) that met the criteria presented in Table 1. Potential targets were limited to those with a right ascension (α) and declination (δ) that were observable from the LCOGT in March 2021. In addition, we required that the separation (ρ) of the primary (A) and secondary (B) components be within the range of 5″ - 10″ to be resolved by the LCOGT 0.4-m telescopes while also fitting within the field of view. To further narrow the list of potential target sources, we required that the components each have visual magnitudes (m) between 11 and 9 to eliminate brighter sources that may have been recently observed by smaller telescopes. Furthermore, the magnitude difference (Δm) between the two stars was limited to be less than 3 to ensure the fainter, secondary component would not be shielded by the primary.

Table 1: Target Selection Criteria

α (J2000)	4^h – 17^h
δ (J2000)	-80°– +80°
m	9 – 11
Δm	0 – 3
ρ	5″ – 10″

The GDS search results satisfying our target selection criteria were sorted for sources that had not been observed within 6 years and had few previous observations. The Stelle Doppie Double Star Database (Sordiglioni 2020) was used to narrow our candidate list to only double stars that are known to be physical binaries, as indicated by previous observations and similar proper motions (μ) of the two individual components, and have position angles (θ) and separations (ρ) that have shown change since discovery.

We chose to observe double star WDS 07508-1854. Also named DAW29, this system was discovered by Argentine astronomer Bernahard Hildebrande Dawson in 1915. Stelle Doppie astrometric data for this binary system are shown in Table 2. We note that Stelle Doppie indicated that this binary is not visible outside of the infrared bands. However, a search

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for this target in SIMBAD (Wegner et al. 2000) and Aladin (Bonnarel et al. 2000) revealed observations for which both stars were seen in visual bands, which was confirmed by our observations of this system. We found this source to be particularly interesting since there have been few observations, and none since 2015.

Observations of WDS 07508-1854 were carried out on 11 March 2021 with the Cerro Tololo Inter-American Observatory 0.4-m telescope of the LCOGT. Ten exposures of 1.5 seconds each were taken through the clear filter of the SBIG STL6303 camera mounted on the telescope.

Table 2: Properties of WDS 07508-1854

α (J2000)	$07^h\ 50^m\ 50.52^s$
δ (J2000)	-18° 54′ 34.2″
Constellation	Puppis
m_A	9.17
m_B	9.56
$\mu_A\ (\alpha)$	-0.012″ yr^{-1}
$\mu_B\ (\alpha)$	-0.014″ yr^{-1}
$\mu_A\ (\delta)$	+0.004″ yr^{-1}
$\mu_B\ (\delta)$	+0.005″ yr^{-1}
$\Delta\rho$ (1915 – 2015)	1.2″
$\Delta\theta$ (1915 – 2015)	5°
Spectral type	A9V

3 Analysis and Results

Initial data calibration and reduction was performed by the LCOGT pipeline (Fitzgerald 2018). Astrometric analysis of the data was performed using the AstroImageJ image analysis software (Collins et al. 2017). The aperture photometery tool was used to measure the separation, position angle, and difference in magnitude between the primary and secondary components. The object aperature and the inner and outer sky annulus radii were 4, 20 and 25 pixels, respectively. The Howell centroid method (Howell 2006) was used for centering the point-spread function (PSF) for each star during measurement. A sample measurement of separation and position angle for observation 4 is shown in Figure 1. Results of measurements for each of the 10 individual observations are shown in Table 3 with the average, standard deviation, and standard error for each quantity. We find that the average separation between the primary and secondary components of the system is 5.60″ and the average position angle is 191.91°.

Table 3: Measurements of Separation and Position Angle

Observation	ρ (″)	θ (°)
1	5.60	192.12
2	5.55	192.02
3	5.56	192.45
4	5.61	191.87
5	5.67	191.74
6	5.64	191.80
7	5.57	191.73
8	5.59	192.26
9	5.61	191.21
10	5.57	191.95
average	5.60	191.91
standard deviation	0.04	0.34
standard error of mean	0.01	0.11

AstroImageJ was also used to create median, average intensity, and sum image stacks. Measurements within each of these stacks yielded a separation of 5.59″ and a position angle of 192.00°, in close agreement with the average values calculated from the 10 individual images.

4 Discussion

Historical data for double star WDS 07508-1854 were requested from the U.S. Naval Observatory to be combined with the results of this work. The list of prior observations containing information about both separation and position angle are given in Table 4 to the precision reported by each author, with the results of this work added.

Table 4: Historical Data

Observation Date	ρ (")	θ (°)	Reference
1915.05	4.38	187.3	Urban et al. 1998
1916.05	4.6	184	Fender 1929
1917.05	4.831	181	Urban et al. 1998
1917.81	5.66	190.4	Dawson 1918
1965.69	5.55	190.8	Knipe 1966
1983.95	5.81	190.5	Miret & Tobal 2007
1991.79	5.67	191	Fabricius et al. 2002
1999.10	5.59	192.1	2Mass Catalog
1999.90	5.66	191.5	Hartkopf et al. 2013
2004.23	5.93	191.1	Arnold 2005
2007.24	5.56	191.4	Mason et al. 2008
2010.26	5.62	191.6	Mason et al. 2011
2010.50	5.43	190.1	Cutri et al. 2012
2015.50	5.62324	191.802	El-Badry & Rix 2018
2021.19	5.60	191.91	present work

Based upon the measurements from the first and most recent observations, the separation and position angle of the two

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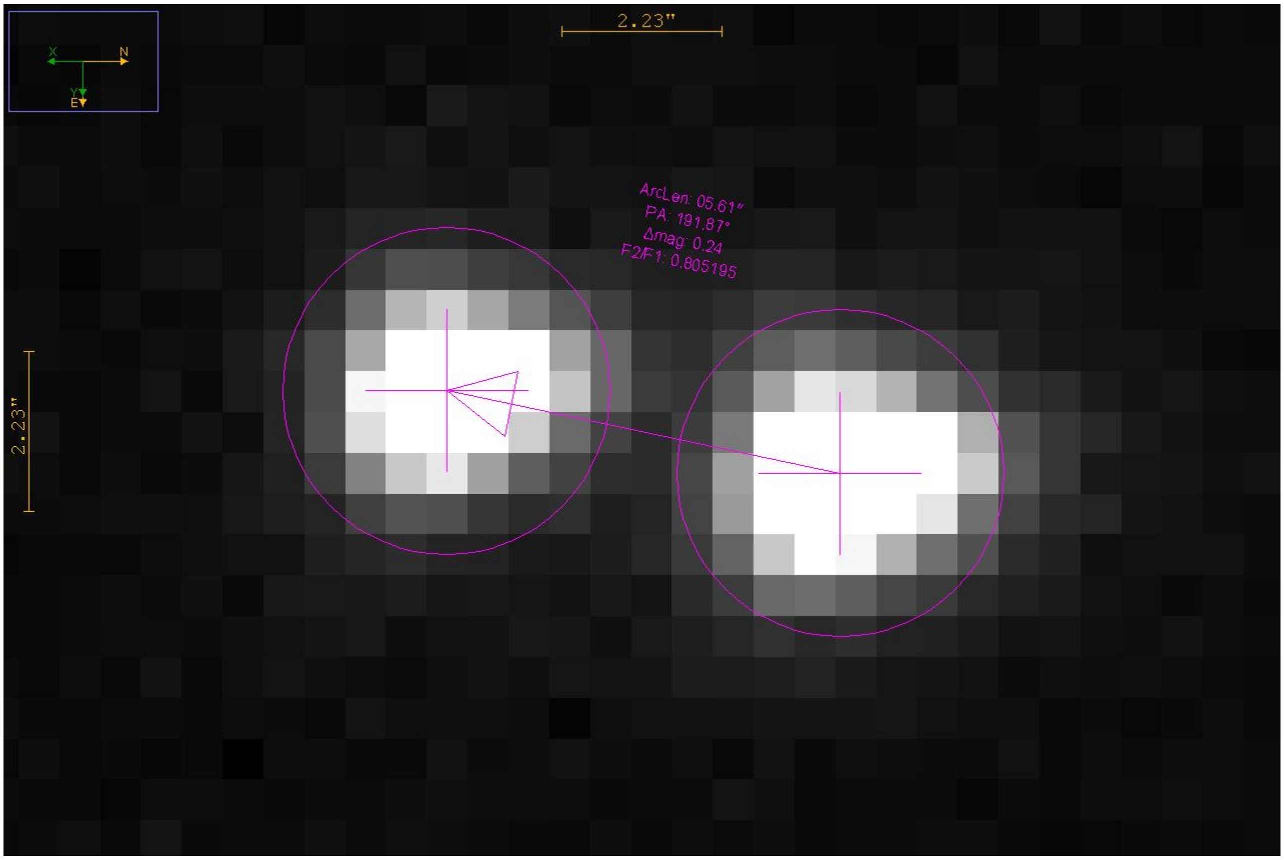

Figure 1: Measurement of separation and position angle using the Aperture Photometry Tool in AstroImageJ for observation 4. The separation and position angle were determined to be 5.61″ and 191.87°, respectively.

components changed by 1.22″ and 4.61°, respectively in the approximately 106 years since discovery. While the rate of change of these measurements over time depends upon the instantaneous separation of the stars and are not constant, a first-order approximation of the change reveals that both separation and position angle can be expected to change by a few hundredths of their respective units per year. The historical data generally follows this expectation, with the exception of the first three observations. One can see that the change in both properties of the system changed significantly in the one-year time period between each of these observations. The change in relative stellar positions between 1917.05 and 1917.81 is particularly surprising, as $\Delta\rho \sim 17\%$ and $\Delta\theta \sim 5\%$ in a fraction of a year. It is also interesting that each of the first three observations are recorded as being observed on the same day in each of three consecutive years. While these three data points are relatively consistent with one another, the combination of the observation date and the variation of those measurements as compared to more recent data suggests that they may not accurately describe the true nature of the double star. Given the accuracy and precision of modern measurement methods compared to those in the early 20$^{\text{th}}$ century, it is also reasonable for these measurements to be omitted from our discussion. However, it is also interesting to note that the observations indicating the largest change in relative stellar positions in time corresponds with the smallest measurements of separation. To conserve angular momentum in the system, the orbital speed of the two components must increase as the separation between them decreases. In addition, the change in orbital speed depends upon the ellipticity of the orbit, with stars in more eccentric orbits experiencing a larger change in orbital speeds throughout a period. Therefore, it is possible that the orbits of the stars are highly elliptical and the earliest observations were taken when the stars were relatively close together and moving much quicker than in more recent observations. We therefore present the collective data in two ways in this section: including all previous observations and eliminating the first three observations to highlight the more modern data.

The separation and position angle as a function of time are shown in Figures 2 and 3, respectively. It can clearly be seen in the top panel of each image that the first three observations do not follow the trend of the rest of the data, supporting the decision of the authors to exclude them from the discussion. While there is a large variance in measurements over time, the separation appears to be decreasing with time while the position angle is increasing.

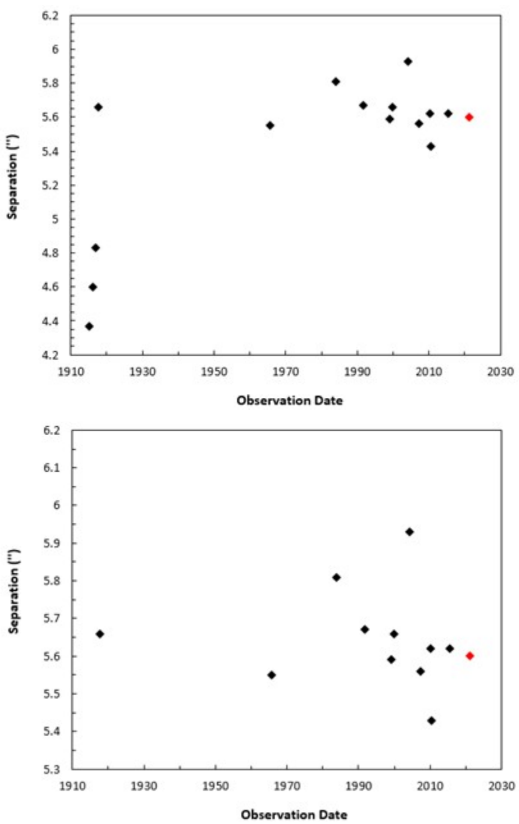

Figure 2: Angular separation of the primary and secondary components as a function of time showing all historical data (top) and omitting the first three observations (bottom).

The Plot Tool 3.19 (Harshaw 2020) was used to create a plot of the orbit of the secondary companion (B) relative to the primary component (A) of the double star system (Figure 4). The astrometric observations of separation and position angle shown in Table 4 were converted from polar to Cartesian coordinates and plotted with the primary component at the origin. As could be clearly seen in Figures 2 and 3, the first three observations are not consistent with the rest of the data and have therefore been removed in the bottom panel of Figure 4. With position angles ranging from 183°– 192°, the secondary component is found to the southwest of the primary star. Close inspection of the orbital positions and labeled observation dates in Figure 4 reveals no clear motion of the secondary star with time. Due to the large variance in position and the small number of observations taken over a narrow time period, an orbital solution could not be determined for the system.

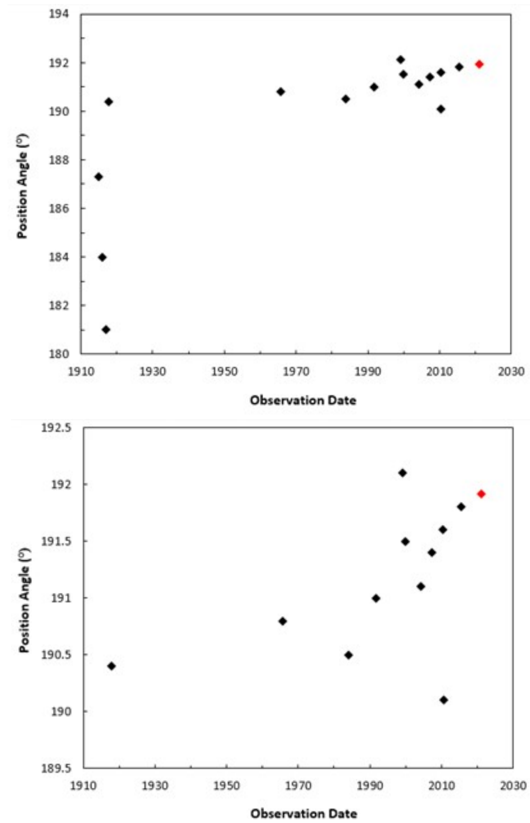

Figure 3: Position angle as a function of time showing all historical data (top) and omitting the first three observations (bottom).

Though historical data and our separation and position angle measurements could not yield specific orbital parameters, these measurements, in combination with Gaia Data release 3 (Gaia Collaboration 2020) proper motion and photometric data, can provide constraining information on whether the double star system is a true physical binary system. Table 5 shows the Gaia parallax measurements for each binary component and the corresponding distance and separation results. These parameters are in close agreement for each component. When combined with the similar proper motion measurements for the two stars (See Table 2), we conclude that the system is indeed a physically bound system.

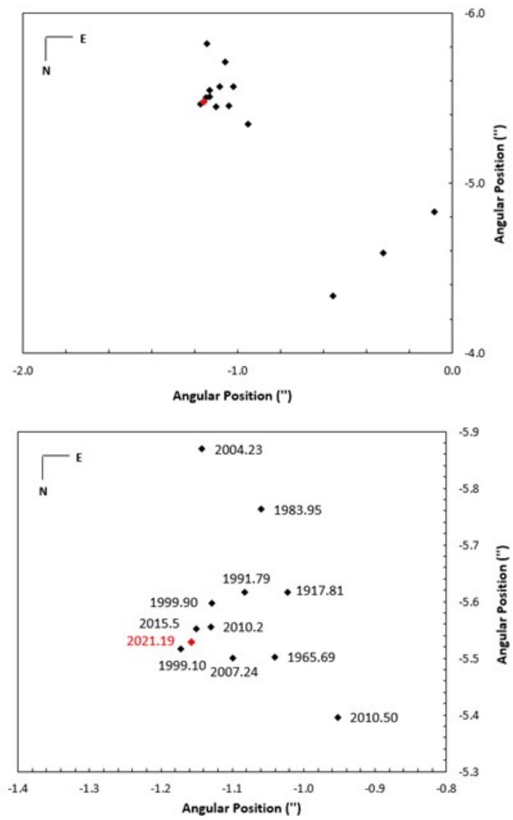

Figure 4: Angular position of secondary companion star, B, in reference to the primary star, A, which is located at the origin (off screen, bottom right). Historical data is represented by black symbols and the result of the current work is shown in red. The top panel includes all historical data since the discovery of the system. The first three observations are omitted in the bottom panel and the scale changed accordingly.

Table 5: Binary Constraints

	Primary, A	Secondary, B
Parallax	5.13 mas	5.14 mas
Parallax Error	0.02 mas	0.01 mas
Distance	195 pc	181 pc
Separation	1096 AU	1093 AU

Physical parameters of the double star system can be determined using Gaia photometric data and parallax measurements in combination with our results for separation and position angle. The luminosity of each star in the system can be determined via the distance modulus using Gaia G-band apparent magnitudes, extinction estimates, and distances. We find luminosities of the primary and secondary components to be $L_A = 17.1\ L_\odot$ and $L_B = 12.8\ L_\odot$. As these stars are Sun-like main sequence stars, the mass-luminosity relationship reveals masses of $M_A = 2.25\ M_\odot$ and $M_B = 2.08\ M_\odot$. These individual masses, used in combination with our measured stellar separation and Kepler's third law of planetary motion, gives an orbital period of 26,800 years for the system. It is important to note that the true separation of the stars, needed in Kepler's third law, will be larger than the observed value if the inclination i of the orbit is greater than $0°$. As the inclination of the orbit is unknown, we applied a correction factor for inclination equal to the average value of $\cos^3 i$, $\langle\cos^3 i\rangle = 0.424$, to our observed separation prior to calculation of the period (Carroll & Ostlie 2007).

It is worth noting that the GDS reports an estimated period of 20,800 years for this system based upon measurements from the Gaia Data Release 2 (Gaia Collaboration 2016, 2018). However, the GDS calculation did not include extinction or a correction for inclination angle. Using the methods of the GDS in combination with our measured separation and position angle, we find an orbital period of 20,300 years for the system, in close agreement with the value reported by GDS using earlier measurements.

Given our extinction- and inclination-corrected period estimate of approximately 26,800 years, it is not surprising that an orbital solution for the system could not be calculated from discrete observations over 106 years. The determination of orbital parameters will require additional observations into the future.

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References

2MASS Point Src Cat. 2003 all-sky release. http://pegasus.phast.umass.edu/

Arnold, D. 2005. Double Star Observer 11, 3.

Bonnarel, F. et al. 2000. The ALADIN interactive sky atlas. A reference tool for identification of astronomical sources. Astronomy and Astrophysics Supplement 143, 33.

Brown, T. M. et al. 2013. Las Cumbres Observatory Global Telescope Network. Publications of the Astronomical Society of the Pacific 125, 931, 1031.

Carroll, B.W. & Ostlie, D.A. 2007. *An Introduction to Modern Astrophysics*, Second Ed. San Francisco, CA: Pearson Education Inc.

Collins, K. A. et al. 2017. AstroImageJ: Image Processing and Photometric Extraction for Ultra-Precise Astronomical Light Curves. Astronomical Journal 153, 77.

Cutri, R.M., Wright, E.L., Conrow, T., et al. 2012. VizieR Online Data Catalog II/311.

Dawson, B. H. 1918. Publicaciones del Observatorio Astronomico 4, Pt 1.

El-Badry, K. & Rix, H. W. 2018. Monthly Notices of the Royal Astronomical Society 480, 4885.

Fabricius, C., Hog, E., Makarov, V. V., Mason, B. D., Wycoff, G. L., & Urban, S. E. 2002. Astronomy & Astrophysics 384, 180.

Fender, F. G. 1929. Astronomische Nachrichten, 235, 24.

Fitzgerald, M. 2018. The Our Solar Siblings Pipeline: Tackling the data issues of the scaling problem for robotic telescope based astronomy education projects. Robotic Telescopes, Student Research and Education Proceedings 10.32374/rtsre.2017.033.

Gaia Collaboration. 2016. Astronomy & Astrophysics 595, A1.

Gaia Collaboration. 2018. Astronomy & Astrophysics 616, A1.

Gaia Collaboration. 2020. arXiv e-prints 2012.01533.

Harshaw, R. 2020. Journal of Double Star Observations, 16, 386.

Hartkopf, W.I., Mason, B.D., Finch, C.T., Zacharias, N., Wycoff, G.L., & Hsu, D. 2013. Astronomical Journal 146, 76H.

Howell, S. B. 2006. *Handbook of CCD Astronomy*. Cambridge, UK: Cambridge University Press.

Knipe, G. F. G. 1966. Republic Observatory Johannesburg Circular 125, 99.

Mason, B.D., Hartkopf, W.I., & Wycoff, G.L. 2008. Astronomical Journal 136, 2223.

Mason, B.D., Hartkopf, W.I., & Wycoff, G.L. 2011. Astronomical Journal 142, 46.

Mason, B. D., Wycoff, G.L., and Hartkopf, W.I. 2019. VizieR Online Data Catalog: The Washington Visual Double Star Catalog. VizieR Online Data Catalog. http://as.usno.navy.mil/proj/WDS/

Miret, X. & Tobal, T. 2007. Webb Soc., Double Star Circ. 16.

Rowe, D. 2020. Gaia Double Star Catalog. GDS 1.02.

Sordiglioni, G. 2020. Stelle Doppie Double Star Database 2.7.1. https://www.stelledoppie.it

Urban, S.E., Corbin, T. E., Wycoff, G. L., Martin, J. C., Jackson, E. S., Zacharias, M. I., & Hall, D. M. 1998. Astronomical Journal 115, 1212.

Wegner et al. 2000. The SIMBAD Astronomical Database. Astronomy and Astrophysics Supplement 143, 9.