An Astrometric Measurement and Analysis of Celestial Motion for WDS 11006-1819

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Abstract: Our team studied the history of the star system WDS 11006-1819 aiming to construct patterns in determining this system's double star nature. In doing so, we've taken images of the system and performed astrometric measurements. Our calculations yield new measurements for its position angle being 267.8° and separation distance of 63.05". After analyzing the trends in separation angles and distances, irregularity in historical motions of the stars, and the large straight-line distance between the two given by their parallax data, we suggest that WDS 11006-1819 may be an optical binary.

Introduction

The goal of this research is to observe and analyze the position angle (θ) and separation distance (ρ) of WDS 11006-1819 to analyze if this system may be an optical double or a binary star system. Optical double stars are defined as stars that appear close in proximity when viewed from earth, whereas true binary star systems orbit around a shared center of mass. The position angle, theta (θ), is the angle between the stars relative to one another, measured counterclockwise from the celestial north. The separation, rho (ρ), is the arc distance between the stars. With knowledge of a double star's orbital pattern, it is possible to gain accurate measurements of their stellar masses and other aspects of the star's components. Once the stellar masses are known, more information about the star's size, brightness, lifespan, and chemical make-up can be determined.

WDS 11006-1819 (hereafter referred to as HJ 1181) is a double star system that can be seen in the southern hemisphere during late winter and early spring. The star was initially observed by Sir John William Herschel, a great English astronomer and mathematician. This double star system was selected because it met the parameters of our research. Since our team's observation window was in spring, we were limited to a Right Ascension (RA) range between 08 - 16 hours. To retain good image quality, star systems with a difference magnitude greater than 3 or a separation distance less than 5 arcseconds were eliminated. Additionally, the star system was chosen because the most recent observation was over 9 years ago. It had more than 15 previous observations, and its gravitational connection seems to be uncertain making it an interesting subject to study.

The United States Naval Observatory (USNO) provided historical measurement data for HJ 1181. The primary component of HJ 1181 (Referred to as R Crt in the SIMBAD catalog) is classified as a red giant M7/8III star. GAIA data provided an effective temperature (Teff) of 3295 K. Red giant is a phase in a star's life cycle when the hydrogen in its core has ceased to be the main method of fusion. As a result, helium is now the primary contributor to the star's fusion process. Its outer shell has expanded tremendously in diameter and thus its photospheric temperature begins to cool. Due to the increase in size, the star's luminosity also increased in brightness. Red giants are known to be very large stars of high luminosity and low surface temperature (COSMOS 2019). The second component of HJ 1181 (Referred to as HD 95383 in SIMBAD) is a blue main sequence star with a temperature of 7059 K. Compared to R Crt, HD 95383 is a much younger star. 90% of the stars in the universe, including our very own Sun, are main sequence stars. They fuse hydrogen atoms to form helium atoms in their cores.

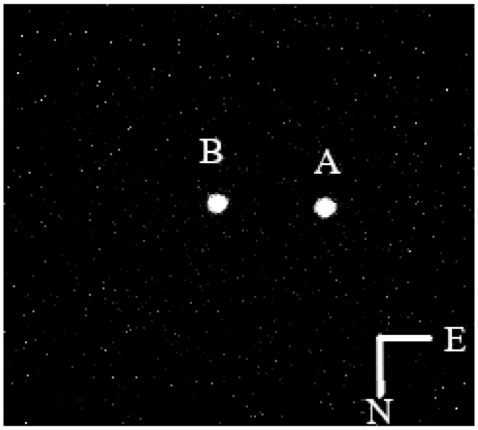

*Figure 2: HJ 1181 using Bessel B filter with 8 seconds exposure time, A is the primary star (R*Crt) and B is the secondary (HD 95383) (Image shown in AstroImageJ).*

Methods and Materials

Equipment

Data was collected by the Las Cumbres Observatory (LCO), a worldwide network of telescopes. Images were taken on April 17, 2019 (2019.294 in Besselian epoch) using a 0.4 m telescope with an SBIG-6303 CCD camera located at the South African Astronomical Observatory (SAAO) in Sutherland, South Africa. It sits on a hilltop at an altitude of 1,798 m above sea level, near the Karoo village of Sutherland.

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Four images were captured using the Bessel B filter with exposure times of 8 and 9 seconds. Another four were collected using the Bessel V filter with exposure times of 5 and 6 seconds. Both sets of images had an air mass of 1.03. Filters were determined by examining each star's effective temperature, provided by SIMBAD, and how it peaks at certain wavelength on the black body diagram and relating it to the star's power output. Trying to avoid oversaturation in our images, we picked these as the most suitable filters and exposure times.

Each image has undergone photometric calibration through OSS (Our Solar Siblings) Pipeline, provided by Michael Fitzgerald (Fitzgerald 2018). Image calibration flattens the images, removes bias, noise, hot pixels, cosmic rays, etc. World Coordinate System (WCS) has also been processed for each of our images. Figure 1 shows one of our images captured by the LCO.

Measurements

The calibrated images were exported to AstroImageJ (AIJ) software for plate solving. This process was necessary to properly orient the image in the sky with their correct Right Ascension (RA) and Declination (Dec) identified by Henry-Draper catalog which are linked to SIMBAD. Though our images already had the WCS from the OSS Pipeline, plate solving was done manually to get the needed measurements, such as differential magnitudes (ΔM), which are not available without WCS calibration via Astrometry.net. The separation angle (θ) and separation distance (ρ) were also measured. Each team member individually measured 8 images, 16 data points collectively. Calculations were subsequently performed to determine the statistical error in our measurements of arc length and position angle, as well as the new RA and Dec of the star system HJ 1181.

Measurements were taken from the center of our primary to secondary star, yielding theta (degrees) and rho (arcseconds) measurements, differential magnitude (measured by AIJ), as well as RA and Dec. Once all measurements were completed, the data was exported to an excel spreadsheet for record keeping and analysis. The team calculated the statistical error of our newfound measurements by finding the mean, standard deviation, and the standard deviation of the mean. The same process was performed for the new RA and Dec measurements and the differential magnitudes of the two stars. These data can be seen in the Results section.

Resources

Gaia, Aladin 10 software, the Washington Double Star Catalog (WDS), and Stelle Doppie were instrumental in providing information that contributes in the construction of our data set. Data for radial velocity for HJ 1181 were collected from Gaia via Aladin 10. "Gaia is an ESA cornerstone mission mapping the point sources on the sky to a magnitude limit of 20.7. Positions are variable due to proper motions which are fundamental elements of the catalogue" (CDS 2019). WDS provided by the USNO outlined basic information for HJ 1181 such as the epoch, number of observations, first and last measurements for theta (θ) and rho (ρ), magnitudes, spectral types, proper motions, and the precise coordinates of the subjects. Supplemental data was collected from Brian Mason of the USNO regarding our target star system which provided more up-to-date information (Mason 2018).

Aladin 10 provided visualization of the Gaia data for HJ 1181's proper motions, Figure 2, which show both A and B stars are moving southwest. The Harshaw

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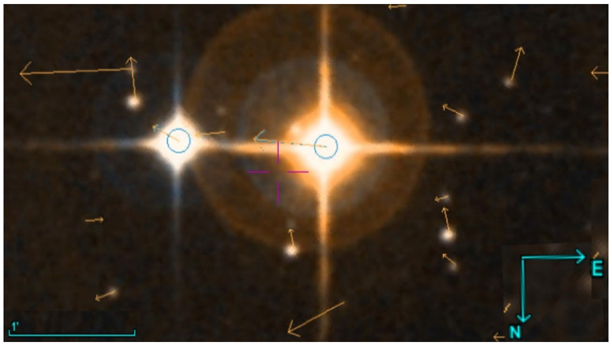

Figure 2. Star system WDS 11006-1819 with their proper motion provided by GAIA data taken from Aladin 10.

Method was applied to help determine whether the system is an orbital pair or an optical pair, scoring a rating of 46%. The ratings range from 0% ~ 99%, orbital pairs showed small "ratings" nearing towards 0.0, while optical pairs showed high values approaching 100.0 (Harshaw 2014).

Results

The following results are the average of the group members' independent measurements. Table 1 is the list of HJ 1181's position angle and separation distance, provided by Brian Mason, throughout the years, including our own measurements highlighted on the bottom. Table 2 shows theta and rho measurements along with the standard deviation and the standard deviation of the mean. Table 3 shows the mean measurements of A and B stars' RA and Dec. The statistical error for HJ 1181 system's newly measured RA and Dec are almost negligible. Table 4 shows the parallax data for both components of HJ 1181 (GAIA Database 2019). Table 5 shows the differential magnitudes between our primary and secondary star in B and V filter acquired using AIJ software.

Discussion

There are a total of 22 measurements in the WDS historical record for HJ 1181, plotted on Figures 3 & 4. The initial analysis shows no apparent patterns in the B star's motion. The system's first measurement in 1828 appears to be an outlier as all other measurements of HD 95383 lie close together between 65 and 63 arcseconds away from the A star, Figure 3. Figure 4 is an inset outlining the dispersion of the measurements. Due

Epoch	Observer	PA (deg)	Separation (as)
1828	HJ_1831	270.0	75.00
1866.36	Knt1877	268.5	65.99
1895.7	WFD1908b	267.3	64.95
1907.89	Bu_1913	268.2	65.26
1911.26	Wz_1923	268.0	65.00
1915.12	Gau1926a	267.8	65.21
1915.12	WFC1998	268.1	65.48
1915.12	Poc1916	267.8	65.21
1916.17	Bha1916	267.4	65.36
1916.17	WFC1998	268.1	64.85
1916.17	WFC1998	267.7	65.85
1916.26	Gau1926a	267.4	65.42
1918.21	Frk1918	269.0	65.04
1925.25	Fox1946	268.1	64.96
1933.20	WFC1940a	267.8	64.75
1969.46	WFC1992	267.9	64.09
1985.44	WFC1994	268.2	63.48
1991.61	TYC2000b	267.9	63.61
1997.38	UC_2013b	267.7	65.10
1999.38	UC_2013b	267.6	63.45
2000	UC_2013b	267.7	63.49
2007	Arn2007c	268.3	63.20
2019.29	Team's Data	267.8	63.05

Table 1. Historical measurements showing the position angle and the separation distance dated back to when it was first observed up to its most recent observation.

	PA (deg)	Sep (as)
Mean	267.78	63.05
Std. Dev.	±0.05	±0.09
Std. Dev. of the Mean	±0.02	±0.03

Table 2. Mean measurements and statistical error of the HJ 1181 system's position angle and arclength measured using AIJ.

	A Star's RA (hh:mm:ss)	A Star's DEC (dd:mm:ss)	B Star's RA (dd:mm:ss)	B Star's DEC (dd:mm:ss)
Mean	11:00:32.4	-18:19:30.0	11:00:28.8	-18:19:33.6

Table 3. Mean measurements of RA and Dec of A and B Stars.

	A Star's RA (hh:mm:ss)	A Star's DEC (dd:mm:ss)	B Star's RA (dd:mm:ss)	B Star's DEC (dd:mm:ss)
Mean	11:00:32.4	-18:19:30.0	11:00:28.8	-18:19:33.6

Table 3. Mean measurements of RA and Dec of A and B Stars.

Results	Parsecs			Light Years		
	Min Distance	Mid Point	Max Distance	Min Distance	Mid Point	Max Distance
Star A	225.25	236.29	248.48	734.32	770.32	810.04
Star B	344.72	351.10	357.72	1123.79	1144.58	1166.16

Table 4. Parallax data and Straight-Line distance provided by SIMBAD and calculated using Harshaw's Parallax Calculator

Filter	Mean	Standard Deviation	Standard Deviation of the Mean
B	0.217	±0.008	±0.004
V	1.757	±0.009	±0.005

Table 5. Differential Magnitudes between A and B stars in Bessel B and V filters.

to the scatter of the measurements, a discernable pattern cannot be used to suggest the gravitational nature of HJ 1181.

In the paper "Another Statistical Tool for Evaluating Binary Stars," Richard Harshaw proposed another way of determining whether a double star is a binary by examining the proper motion of the given pair (Harshaw 2014). Using this method, our double star had a rating of 46% which provides no clarity in determining whether HJ 1181 system is an optical pair or an orbital pair. This leaves us to look for other ways in determining the nature of HJ 1181.

Further analysis of the parallax data from SIMBAD, seen in Table 4, of each star was performed to find the minimum radial distance between the two stars of 374.6 light years. We know that the straight-line distance between to two stars cannot be smaller than the radial distance because of the laws of trigonometry. Thus, the straight-line distance between the two stars must be greater than 374.6 light years. In a paper published by

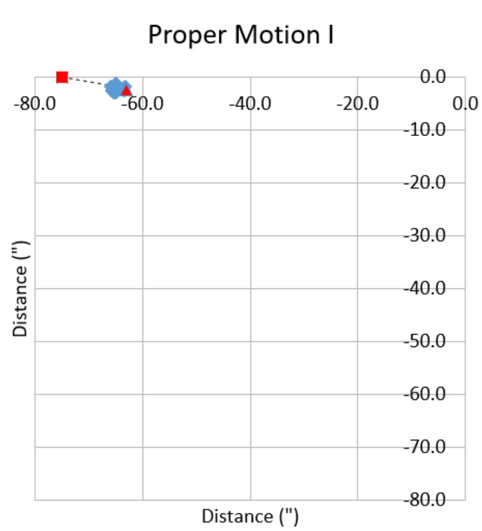

Figure 3: Plot of B star's movement relative to A star on the origin. The red triangle is the new data point. The red square is the first data point taken in 1828.

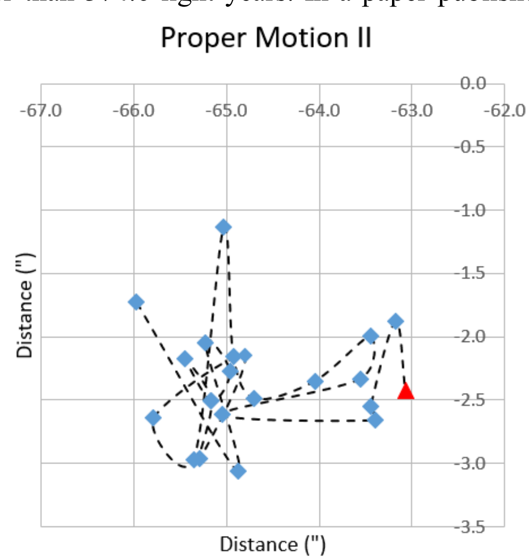

Figure 4: Plot of B star movement relative to the A star on the origin excluding the first observation that was taken in 1828. The red triangle is the new data point.

the University of Hawaii Institute of Astronomy, it is shown that the greatest straight-line distance between binary stars is one light year (Good, et al. 2018) which is two orders of magnitude smaller than the smallest possible distance between the two components of HJ 1181.

Conclusion

Though the two stars share a similar common proper motion, the movements of the B star relative to the A star cannot be used to suggest an orbit, but instead shows possible characteristics of a Common Proper Motion (CPM) pair. However, the nature of HJ 1181 can be definitively determined. Statistically, different parallax for star components suggest they are non-physical pair. The parallax data from A and B stars indicate that the two are most probably not gravitationally bound because of the great distance between them.

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