Astrometric Measurements and Proper Motion Analysis For WDS 11582 +0335 HJ 1204

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Abstract: We obtained and analyzed CCD images of the double star system WDS 11582 +0335 (HJ 1204) using the iTelescope network and a variety of specialized software. WCS coordinates were attached to each image, and the separation distance (ρ) and mean position angle (θ) were measured at ρ = 7.9" ± 0.03" and θ = 59.3º ± 0.2º. These results were compared to historical data, dating back ~200 years and we find that HJ 1204 is currently exhibiting a linearly decreasing ρ and a constant θ. This suggests that HJ 1204 could be a visual double or an edge-on binary. Follow-up spectroscopic observations should resolve the two possibilities.

Introduction

Double stars are two stars that appear close to each other when observed from Earth. Some double stars are gravitationally bound, referred to as binary stars, and some are apparent, simply aligned by chance in our line of sight. By observing double stars over time, we can track their relative proper motion, which can aid in distinguishing between gravitationally bound and apparent, or visual double star systems.

The goal of our research is to provide current astrometric measurements of separation distance (ρ) and position angle (θ) for one double star system, known by its Washington Double Star (WDS) identifier, 11582+0335 HJ 1204 and hereafter referred to as HJ 1204 (Figure 1). Cumulative data on the system will ultimately show presence or absence of observed motion - evidence which distinguishes between visual doubles and gravitationally bound systems. Binary and multi-star systems are of broader scientific interest because by analyzing their orbits stellar mass can be determined, offering insight into the life cycle and death of the star. We also learn from binary systems that the laws of gravitation apply to distant stellar and solar systems and are therefore a universal property of mass.

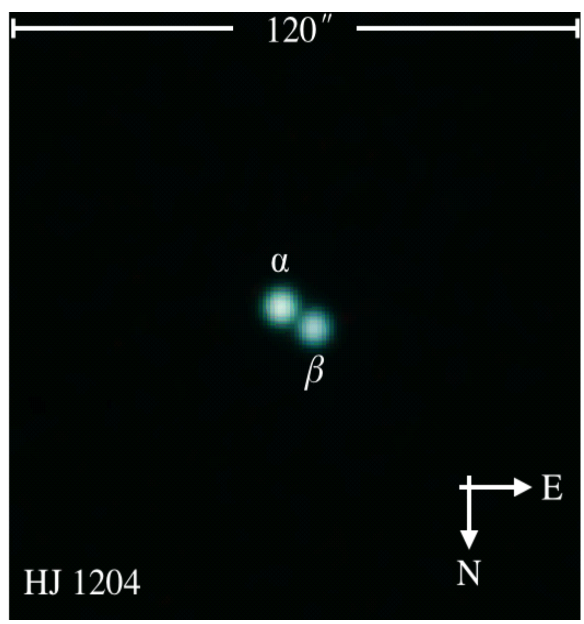

Figure 1: False color image of HJ 1204. North is down, east is right. The primary star is labeled α and the secondary star is labeled β. The image size shown is 120" x 120".

We selectively choose a double star system that fit our search parameters: right ascension and declination such that the pair are observable from approximately ~35° north latitude during the astronomical spring season, with a previously measured ρ between the primary (α) and secondary (β) stars of 7" and a magnitude dif-

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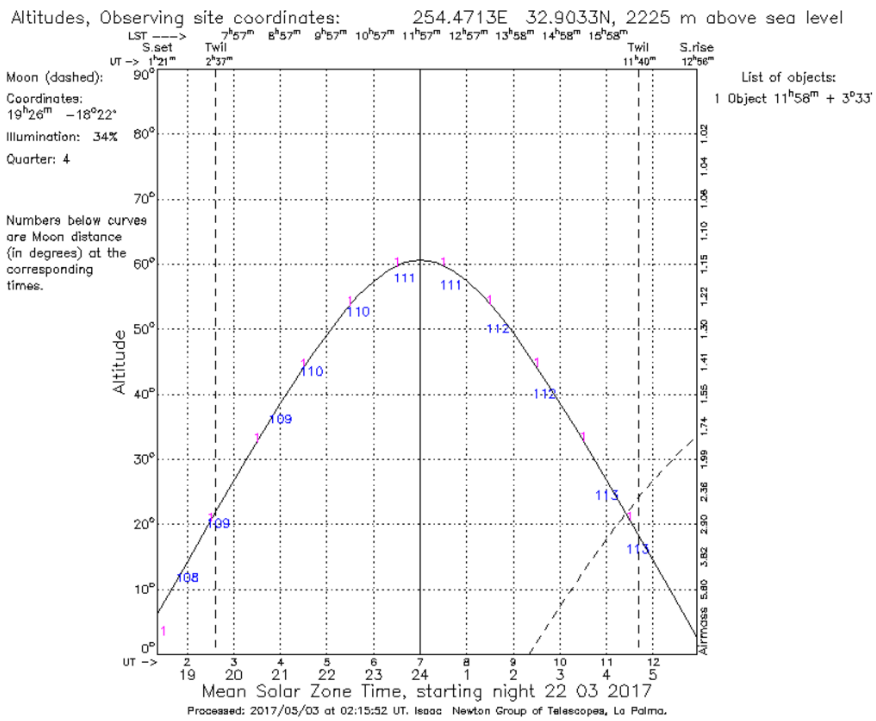

Figure 2. Graphical representation of HJ 1204's relative path through the night sky. The Object Visibility plot shows altitude above horizon (°) vs. time (hours), which was useful in determining an appropriate date and time to observe the pair. The curve indicates HJ 1204's path with numerical figures in blue representing relative distance from the Moon in degrees.

ference (Δm) between α and β of less than 1. The double star system HJ 1204 was an ideal candidate for observation, located in the Virgo constellation.

This system was first observed in 1828 by English astronomer Sir John Frederick William Herschel (1792-1871), who first recorded ρ = 15" and θ = 125°. The latter measurement is inconsistent with subsequent measurements, and Herschel's records indicate he was unsure about the orientation (Herschel, 1831). We have noted when this data point has been adjusted or omitted for the sake of consistency (see Discussion). Since 1828 there have been 13 observations, the most recent was a large sky survey in 2014 (Cvetkovic et al. 2015), with a ρ = 8" and θ = 59°, and a difference in magnitude of 0.44.

Methods and Equipment

We utilized the iTelescope network and requested images from two telescopes, T11 and T24, located in Mayhill, New Mexico and Auberry, California respectively. Both telescopes are equipped with cameras classified as CCD, or Charged Coupled Device technology (Table 3). The CCD camera has had a tremendous impact on astronomical imaging and spectroscopy since the 1980's. Deep space imaging is complicated by conditions of low light, noise, and cosmetics, however the CCD's high quantum efficiency (a ratio of the number of charge carriers collected by the solar cell to the number of incident photons) is 80-90% at peak in optical and is greatly advantageous over past observation methods (O'Connell, 2015). Figures 6 and 7 support the notion that measurements became more accurate with use of CCD. The T11 is a Planewave CDK20 equipped with a FLI ProLine PL1102M CCD and has a pixel scale of 0.81"/pixel. The T24 is a Planewave CDK24 equipped with an FLI Proline PL09000 CCD camera and has a pixel scale of 0.62"/pixel. We selected the telescopes based on geographic location, sub-arcsecond resolution, and equipment performance.

Observations were performed during times when HJ 1204 was approximately ~52° above the horizon in order to minimize atmospheric effects. Figure 2 shows the system's visibility curve for March 22, 2017 (ING, 2017). Eight images were taken on March 22, 2017 via the T11 (2 in luminance, 2 in Hα, 2 in green, and 2 in blue) and three images were taken April 24, 2017 via the T24 (1 in luminance, 1 in Hα, and 1 in blue). The flat-fielded and dark subtracted images were processed

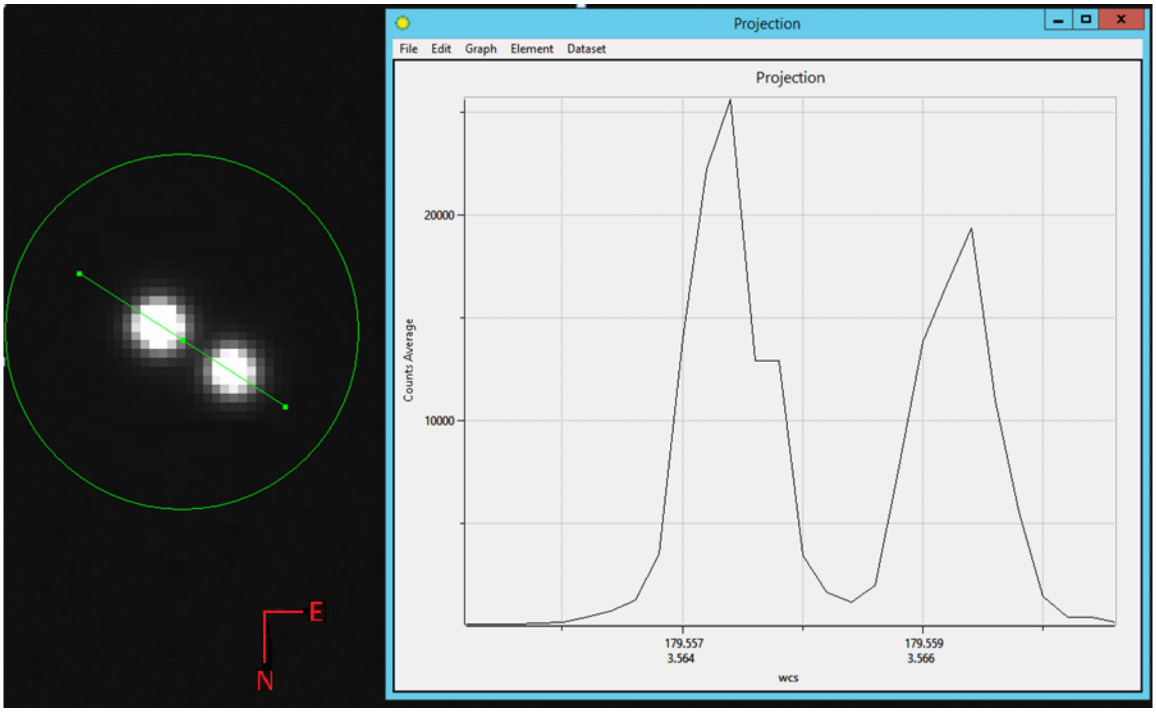

Figure 3. Quality analysis for one of eleven images taken of HJ 1204. The figure is a screenshot, using SAO Image DS9 software. The stellar image on the left is from the first set of images and shows the projection tool as a line segment that crosses the highest pixel value of each star. The graph on the right relays electron counts vs. pixel location (in WCS degree coordinates). The shape of the graph indicates a quality image, as the electron saturation for each star is less than half of the full-well limit of the T11 CCD, which is 60,000 electrons per pixel.

by the iTelescope Network's data reduction pipeline and downloaded.

In order to verify the quality of each image, we used SAO Image DS9 software's projection tool to display a graph of pixel count vs. position (Figure 3). By observing the peak count and the overall shape of the histogram, we were able to check that no saturation or unusual artifacts were present in the pixels associated with our double star system.

We used Maxim DL software to attach WCS coordinates to the image pixels. The U.S. Naval Observatory CCD Astrograph Catalog (UCAC4) was used as the WCS reference catalog for pattern recognition. Coordinates are determined by aligning known positions of stars within the image's field-of-view. A total of 867 imaged and catalog stars were used to fit WCS coordinates, with an average root-mean-square of 0.1".

To measure separation distance and position angle, each image was analyzed using Mira Pro software's point-to-point tool that connects a line between the centroids of the α and β stars (Figure 4). Mira Pro measures the centroid position by performing a Gaussian fit with a specified radius. The process is repeated several times on each image to ensure consistent results.

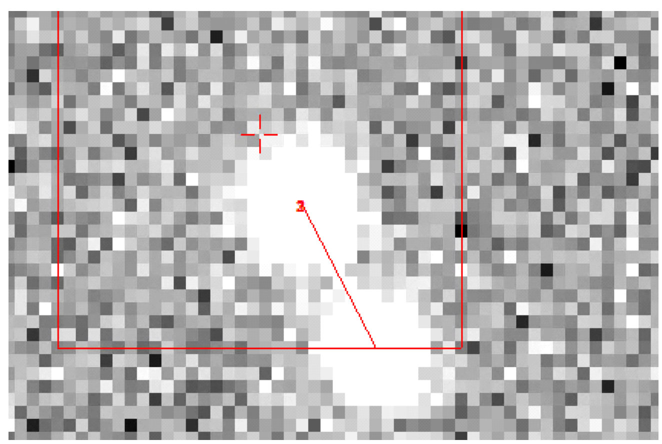

Figure 4. Astrometric analysis for one of eleven images taken of HJ 1204. This image was analyzed in Mira Pro. The red line depicts the point-to-point tool connecting the centroid of the primary to the centroid of the secondary star. Several red lines are superimposed, indicating the measured centers are consistently located to provide accurate measurements.

Results

Two sets of images were taken at separate locations, 31 days apart. The data sets are consistent with each other, indicating that the system exhibited negligi-

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Table 1. Recent data sets for observations of HJ 1204. *Position angle and separation distance are recorded for each telescope and epoch. For comparison, the most recent measurements taken in 2014 from the Rozhen Observatory in Bulgaria are listed in blue at bottom. Consistent with historical data, HJ 1204 currently exhibits a linearly decreasing ρ and a constant θ.*

Astrometric Results for HJ 1204		
T11 Telescope **(8) Images** **Filters: (2) Luminance, (2) Hα, (2) G, (2) B**		
Epoch 2017.2224	**θ(°)**	**ρ (")**
Mean	59.3	7.92
Standard Deviation	0.2	0.03
Standard Error of Mean	0.08	0.01
T24 Telescope (3) Images Filters: (1) Luminance, (1) Hα, (1) B		
Epoch 2017.3114	**θ(°)**	**ρ (")**
Mean	59.3	7.9
Standard Deviation	0.1	0.2
Standard Error of Mean	0.07	0.1
Epoch: 2014.2543 (Bulgaria)	59.3	8.01

ble movement between these two times. The results also concur with the trend exhibited by historical data.

Table 1 shows measurements from both observations along with the most recent for comparison. The average position angle calculated from the first set of images taken from the T11 telescope is 59.3º ± 0.2º, and separation of 7.9" ± 0.03" For the images obtained from the T24 telescope, we calculated a position angle of 59.3º ± 0.1º and a separation of 7.9"± 0.2" We note that we are unable to compare the statistical significance of our results with the last observation (Cvetkovic et al. 2015), since no uncertainties were reported with their measurements.

A full summary of historical astrometric data for HJ 1204 is shown along with present results in Table 2, and the method of measurement for each observation is further detailed in Table 3, with an implication that astrometric data for HJ 1204 may become more precise as a result of advanced technology.

Separation distance and position angle are plotted over time, shown in Figure 5 and Figure 6 respectively. The separation between α and β appears to be decreasing and supports a linear trend, with the two stars getting closer at a rate of 0.0375" per year.

The evolution of relative orientation between α and β features an obvious outlier of 125 degrees, recorded by Herschel in 1828. According to his remarks, Herschel was unsure about the correct orientation of north and south. Based on subsequent measurements including our own, we conclude this data point is likely an orientation error. If we adjust this record to reflect a reversed north and south, the result is 55 degrees, shown as an adjusted data point on the orbital plot (Figure 7) and the plot showing position over time (Figure 6). Once adjustments are made, α and β exhibit a position angle that has remained approximately con-

Table 2. Historical data for HJ 1204. Observer code indicates author and year of publication. The technique code (Table 3) identifies the type of technical equipment associated with each observation. Delta t in years is shown to note two significant periods of no observations following the initial observation and the 1913 observation.

Historical Data for HJ 1204					
Observation Date	**θ(°)**	**ρ (")**	**Δt (yrs)**	**Observer Code**	**Technique Code**
1828	125	15	N/A	HJ_1831	Mb
1903.3	62.2	12.042	75.3	Gau1926a	Pa
1910.34	60.4	12.009	7.04	WFC1998	Pa
1912.481	60.9	11.91	2.141	Fox1915	Ma
1913.34	61	11.76	0.859	Doo1923	Ma
2000.319	59.7	8.541	86.979	UC_2013	Eu
2000.91	59.6	8.48	0.591	TMA2003	E2
2006.315	59.4	8.32	5.405	Wly2007	C
2011.2379	59.43	8.06	4.9229	Pal2013	C
2012.3114	59.41	8.14	1.0735	Cve2015	C
2013.2843	59.32	8.05	0.9729	Cve2016	C
2014.2543	59.3	8.01	0.97	Cve2016	C
2017.2224	59.25	7.92	2.7457	N/A	C
2017.3114	59.3	7.9	N/A	N/A	C

Table 3. Expanded technique codes from those listed in Table 2.

Technique Code	**Method of Measurement**
Ma	Micrometer with Refractor
Mb	Micrometer with Reflector
Pa	Photographic technique, with astrograph
Eu	U.S. Naval Observatory CCD Astrograph Catalog (UCAC4)
E2	Two Micron All-Sky Survey (2MASS)
C	Charged Coupled Device (CCD)

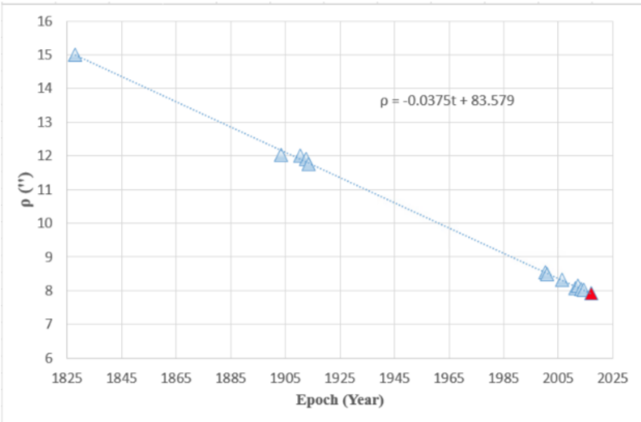

Figure 5. The graph represents the separation distance between α and β stars in arc seconds over time. Our 2017 measurement for ρ is shown as a darkened triangle at bottom right. Thirteen measurements over nearly two centuries show the distance between the stars is decreasing, and the data supports a linear trend, expressed in algebraic form. The linear fit suggests HJ 1204 is a visual double rather than gravitationally bound.

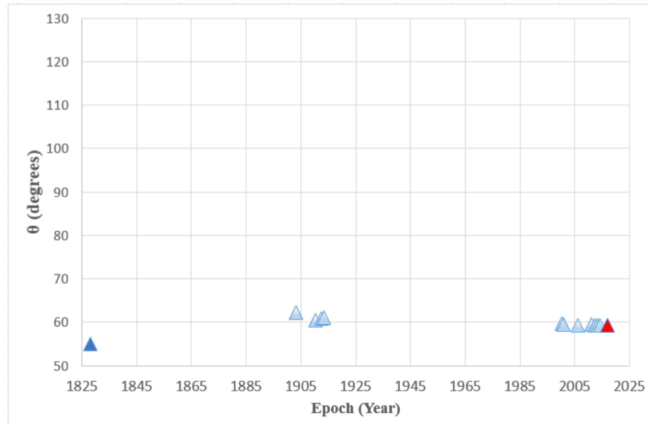

Figure 6. HJ 1204's change in position over time. Hershel's initial measurement in 1828 of 125° (darkened blue marker) at bottom left has been adjusted to reflect reversed poles. Our 2017 data points are combined at bottom right (darkened red marker). The vertical axis is degrees from north, the horizontal axis is time.

stant over the past 200 years.

The trends shown in Figure 5 and 6 are reflected in the orbital plot, with the secondary directly approaching the primary, positioned at the origin (Figure 7). The current set of data supports a linear solution for HJ 1204, where the relative proper motion will eventually cause these two stars to be completely aligned along our line of sight. If this is indeed the case, we would expect them to be aligned in ~2200 years, given the current rate at which the separation distance is decreasing. If this happens and given the right conditions, HJ 1204 might demonstrate an extremely rare and exotic strong gravitational lensing event (Einstein, 1936), producing multiple images of background star, lensed by the foreground star.

Another less likely possibility is that the primary

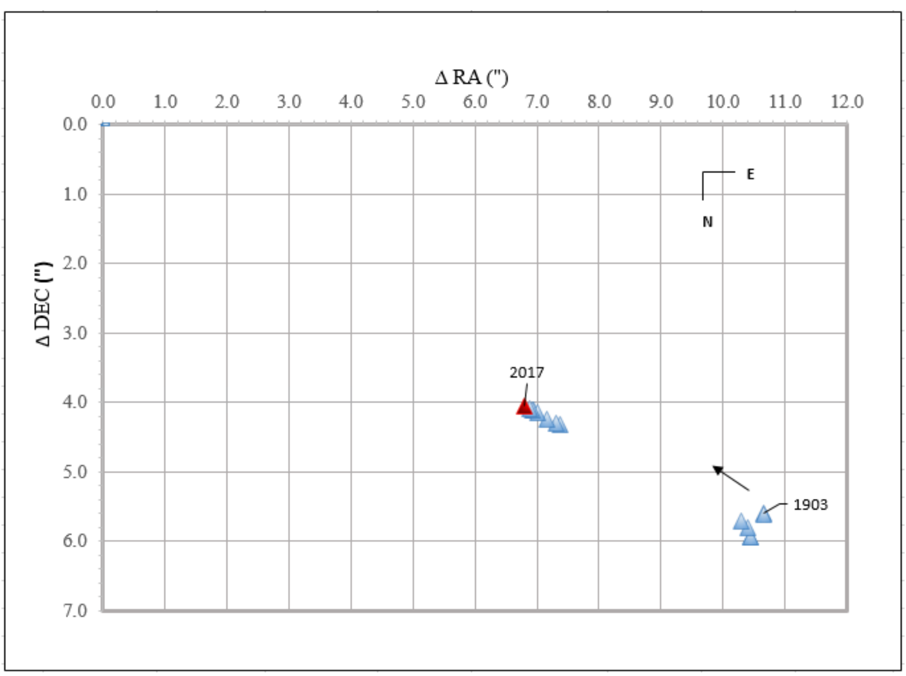

Figure 7. *The graph shows relative declination and relative right ascension with respect to the origin, where the primary star is placed. The data shows a generally linear motion where the position is changing at a constant rate, which would suggest a linear solution. Our 2017 result (Table 2) is shown as a darkened triangle. Herschel's 1828 data point is omitted for consistency.*

and secondary are physically associated and is being observed edge-on, making HJ 1204 an ideal candidate for spectroscopic observations. In addition, having spectroscopic data would also determine physical distances for both stars, which will allow observers to correctly classify whether the HJ 1204 is a physical or a visual double. If HJ 1204 is a spectroscopic binary, we would expect it to have a period in the order of thousands of years, given that the slope in Figure 5 has remained constant for ~200 years.

Conclusion

We obtained and processed CCD images to measure the separation distance and position angle for HJ 1204. Our results are consistent with historical data. Over a timespan of ~200 years, the separation distance is linearly decreasing and cumulative changes in position angle are small enough to consider it constant. The current set of results show two possibilities: HJ 1204 could be aligned by chance or it could be an edge-on binary system. Spectroscopic follow-up observations would be necessary in order to arrive at a resolution.

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