Close Binary Speckle Interferometry on the 100-inch Hooker Telescope at Mount Wilson Observatory

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Abstract: This research team conducted astrometric measurements of the close binary stars COU 1757 and HU 1268. Using Speckle Interferometry on the historic Mount Wilson 100-inch telescope, the calculated position angle for COU 1757 was found to be 111.65°, with a separation of 0.169 arc seconds. For HU 1268, the position angle was calculated to be 338.45° and the separation was found to be 0.376 arc seconds. Drift calibrations and Bispectrum Analysis were used to extract position angle and separations from the data for a complete analysis. Through the analysis of these double stars, subsequent data points were added to the cumulative historic observations of these star systems.

Introduction

A team comprised of eight students from Paso Robles High School (PRHS) conducted research at the Mount Wilson Observatory on the 100-inch telescope with the support of a small group of amateur astronomers. The team of researchers were able to congregate and establish observations through the PRHS Field Studies Collaborative: Astrometry Research Seminar to observe double stars using speckle interferometry. The purpose of this seminar was to allow the students to experience scientific research while also giving them an introduction into the field of astronomy and teaching them about the history of Mount Wilson.

On June 11, 2019 (JD 2458646), two stars were observed: COU 1757 and HU 1268. These stars were chosen based on certain parameters: the resolution of the 100", the limited observations conducted on both stars, and the conditions of the viewing night. For each star observed, a reference star was chosen to accurately process the speckle images. The reference stars were chosen based on how similar in magnitude and spectral class they were to the observed star, as well as their proximity to the target.

WDS 14260+4213 (COU 1757) was discovered in 1978 and has a total of 23 observations; COU 1757 was most recently observed in 2012. The star is in the spectral class G5, with the magnitude of the primary star being 9.6 and the secondary star's magnitude being 9.97. The separation of the system is 0.18" and the position angle is 120°, based on the Grade 3 WDS orbit with a period of 50 years. The reference star chosen was SAO 45083, also in the spectral class G5. SAO 45083 has a magnitude of 8.71 and its distance in relation to the target star is 0.9°.

Figure 1: Students inside the 100" dome selecting reference stars on the observation night

WDS 14295+3612 (HU 1268) is in the spectral class F5. It was first discovered in 1905 and was most

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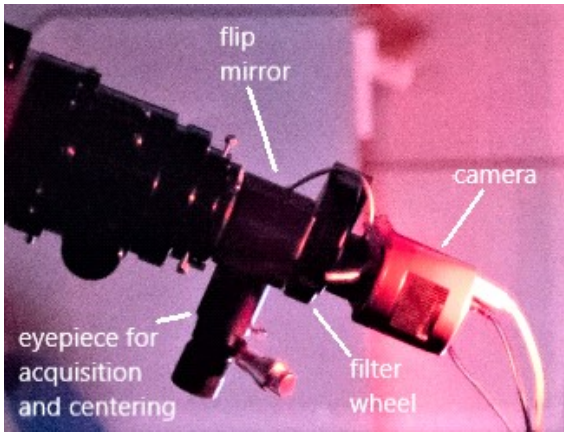

Figure 2: The speckle optical assembly used for the observations; for more details access the paper written by the team who tested the set up a week prior (Wasson et al. 2020)

Figure 3: View of the night sky through the 100" dome as seen on the night of the observations, showing thin cirrus clouds.

recently observed in 2009. HU 1268 has a total of 18 observations. The magnitude of the primary star is 9.77 and the magnitude of the secondary star is 9.9. This star has a separation of 0.33 arc seconds and a position angle of 332°. SAO 64192 was chosen for the reference star, with a magnitude of 9.1 and a spectral class G1III. The distance of SAO 64192 in relation to the target star is 0.3°.

Equipment and Procedures

The images used to gather data in this study were collected on the 100-inch Hooker telescope at the Mount Wilson Observatory in California. At this location, the team acquired 1,000 images in each of the following filters: Johnson B, Johnson V (Visual), SLOAN i (near infrared), and Baader R (CCD LRGB series). The exposures and gains of each of the images were continuously adjusted to optimize the filter being used through the data acquisition program FireCapture (Edelmann, 2019). The camera, loaned by Dave Rowe, had a large CMOS sensor to get a large field of view: approximately 2 arc-minutes wide. This equipment was necessary to ease the process of finding each star and for the Drift Calibration. To find reference stars, Dave Rowe's search tool WDS1.0 (Rowe, 2017) was used. In order to do this, the target stars were input into the tool, which then found nearby, available reference stars from the SAO catalogue. The team then selected the best reference star for each target star using the spectral classification and the magnitude.

The student team used the same speckle optical setup, shown in Figure 2, and followed protocols tested one week earlier on the 100-inch telescope (Wasson et al, 2020). Unfortunately, high, thin cirrus clouds covered the sky all evening (Figure 3). However, since this was the only night reserved for the group on the 100-inch telescope, they attempted speckle observations anyway, and could easily see the stars in the camera field through the clouds.

Drift Calibration Analysis

The image collection was done using the 100" telescope on Mt. Wilson, with a narrow region of interest strip (rather than full-frame images) to get a faster image rate and more images. With a faster image rate and more images, the data points for the drift calibration are more precise and accurate. With the drift calibration, astrometric measurements of the observations were properly corrected for camera misalignment and image scale.

During the drift calibration process, the team conducted 10 drifts in order to calibrate the camera position angle and pixel scale of the images. The average of all the angles is 2.181° with a standard deviation of 0.098, and a pixel scale of 0.02659 arc-sec/pixel with a standard deviation of 0.00005. The very consistent drift results are shown in Figures 4 and 5.

Speckle Autocorrelation Analysis

Speckle Tool Box 1.05 (STB 1.05) (Harshaw, Rowe, and Genet, 2017) was used for speckle processing to get the Autocorrelation of each double star observed. First, the program was used to make a FITS cube from all 1000 images captured. A FITS cube was made for each of the four filters for both the observed double star and reference star images. Each image was cropped to 128x128 pixels around the star before saving them as a FITS cube. The cubes were then processed (average of the Fourier Transform of each image) to produce Power Spectral Density (PSD) files. Once each cube had been processed, the Speckle Re-

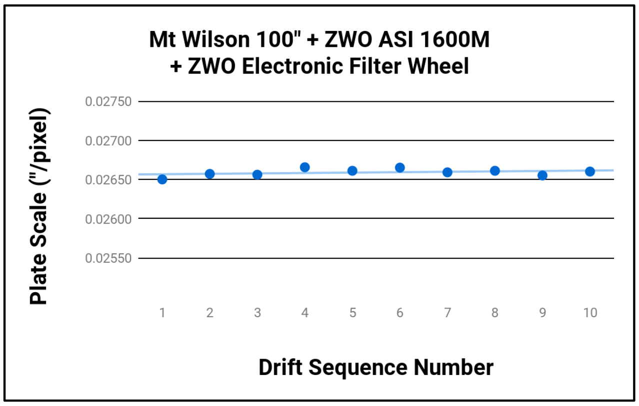

Figure 4: Drift Calibration results for pixel scale.

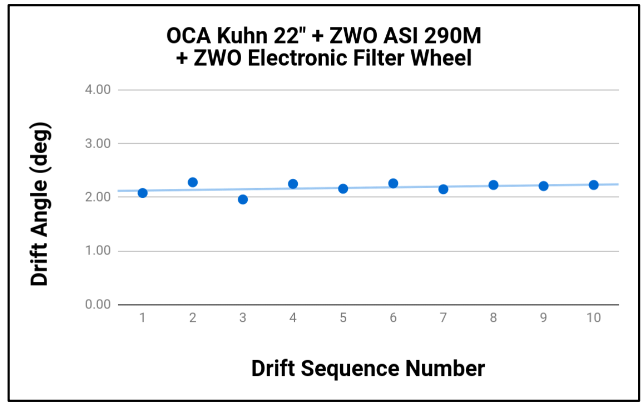

Figure 5: Drift Calibration results for camera angle on the sky.

duction tool found in STB 1.05 used the PSD files to display the Autocorrelation of the double star for each filter. These Autocorrelations were then measured using the program, and the data collected was transferred to an Excel file. This process was done for both COU 1757 and HU 1268.

Bispectrum Analysis

Along with the FITS cubes created in STB 1.05, Speckle Tool Box 1.13 (STB 1.13) (Rowe and Genet, 2020) was used for the Bispectrum Analysis (BSA) of the images. The FITS cubes for both the double star and reference star had to be reprocessed so that they were BSA files. After they were all processed, these files were run through the Bispectrum Phase Reconstruction tool in STB 1.13 to produce images of the double star. These images were then measured in the Bispectrum Phase Reconstruction tool and the data found were saved in the same excel file as the data collected in the Autocorrelation process. Again, this process was done for both COU 1757 and HU 1268. Examples of the BSA reconstructed images in the Johnson V filter are shown in Figure 6. They are very clear, even though the 1000 original speckle images were taken through high, thin clouds.

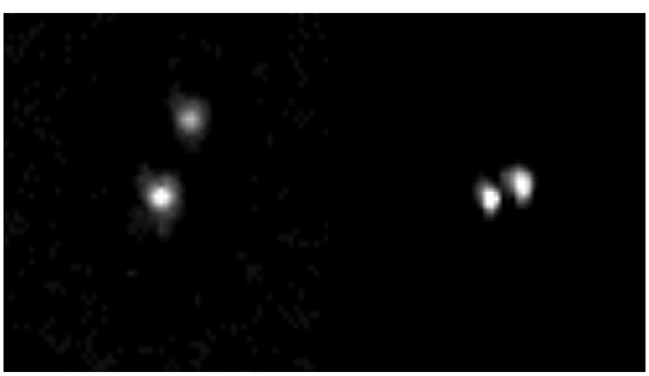

Figure 6: Bispectrum Analysis (BSA) Re-constructed images (V filter) of HU 1268 (left) and COU 1757 (Right). These images are oriented north-up and east-left, as on the sky, and are 64x64 pixels (1.70x1.70 arc-sec) in size.

Results

The observations that lead to the analysis of the images occurred on June 11, 2019, 2019.444 (JD 2458646), and the analysis of the images occurred on June 12, 2019 in the Mt. Wilson Library. The measurements for both stars were taken using Speckle Interferometry. For COU 1757, the position angle was determined to be 111.65° and the separation was found to be 0.169 arc seconds; the data for COU 1757 is shown in Table 1. The position angle and separation for HU 1268 are 338.45° and 0.376 arc seconds, respectively; these values are found in Table 2.

Due to the unusual optical train (shown in Figure 7) used to make the eyepiece accessible for public viewing, five reflections reversed East and West in the camera view from the normal sky view. Since this same setup was used for the camera, this caused an East-West reversal in the images collected. Therefore, we correct-

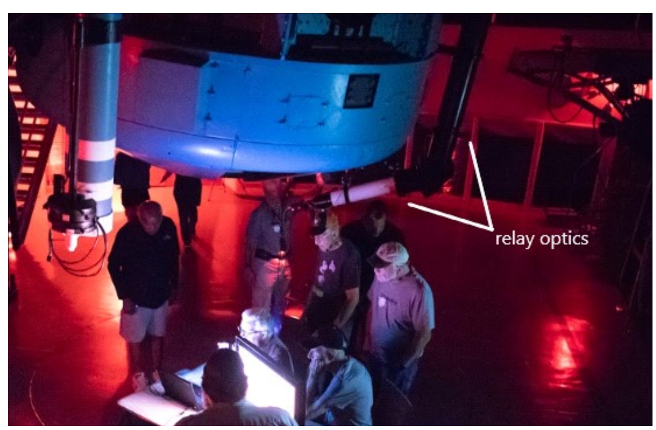

Figure 7: The relay optics on Mt. Wilson's 100" hooker telescope that brings the focus to the public viewing platform

	Autocorrelation (AC)		Bispectrum Analysis (BSA)	
Filter	**Position Angle (deg)**	**Separation (as)**	**Position Angle (deg)**	**Separation (as)**
Johnson B	108.70	0.167	113.67	0.180
Johnson V (Visual)	110.74	0.166	114.40	0.167
SLOAN i (Near infrared)	110.60	0.166	114.46	0.169
Baader R (CCD LRGB series)	110.73	0.166	109.88	0.165
Mean	110.19	0.166	113.10	0.170
Standard Deviation	1.00	0.000	2.18	0.007
Standard Error of Mean	0.50	0.000	1.09	0.003
Averages of all Filters for AC and BSA	**Position Angle (deg)**		**Separation (as)**	
Mean	111.65		0.169	
Standard Deviation	2.21		0.005	
Standard of Error of Mean	0.78		0.002	

Table 1: Separation and Position Angle for COU 1757 using Autocorrelation and Bispectrum Analysis. Measurements made on JD2458646

	Autocorrelation (AC)		Bispectrum Analysis (BSA)	
Filter	**Position Angle (deg)**	**Separation (AS)**	**Position Angle (deg)**	**Separation (AS)**
Johnson B	338.53	0.373	335.34	0.367
Johnson V (Visual)	338.62	0.374	340.28	0.391
SLOAN i (Near infrared)	338.89	0.375	338.54	0.370
Baader R (CCD LRGB series)	339.03	0.377	338.40	0.377
Mean	338.77	0.375	338.14	0.376
Standard Deviation	0.23	0.002	2.05	0.011
Standard of Error of Mean	0.12	0.001	1.03	0.005
Averages of all Filters for AC and BSA	**Position Angle (deg)**		**Separation (AS)**	
Mean	338.45		0.376	
Standard Deviation	1.39		0.007	
Standard of Error of Mean	0.49		0.003	

Table 2: Separation and Position Angle for HU 1268 using Autocorrelation and Bispectrum Analysis Measurements made on JD2458646

ed the East-West reversal using the equation PA = 360 - PA (from STB).

Figures 8 and 9 represent the calculated WDS orbit of each star with this team's new data added to it. The average of the team's data is represented by the red circles.

Discussion

The purpose of the speckle observations was to add data and further the knowledge of the existing orbits of these doubles. Both of the doubles, COU 1757 and HU 1268, are physical binary star systems. As seen in Figure 8 above, the data acquired during this seminar fol-

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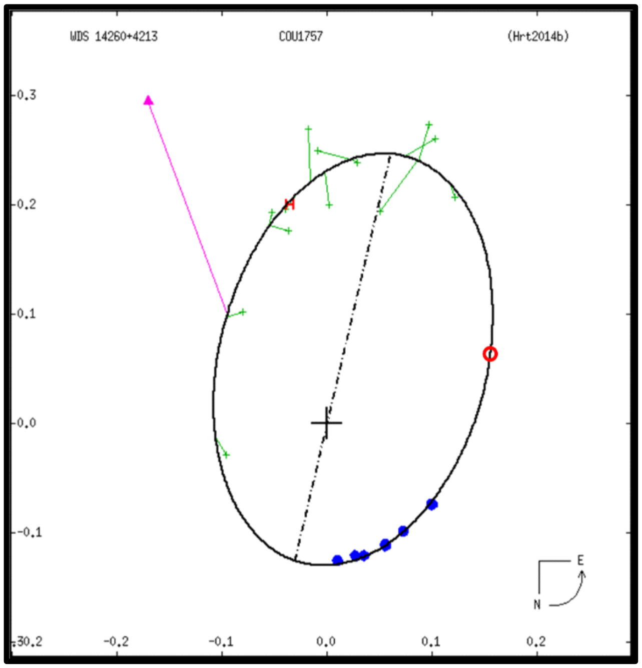

Figure 8: COU 1757 Plotted Orbit, with the new observation indicated by the red circle.

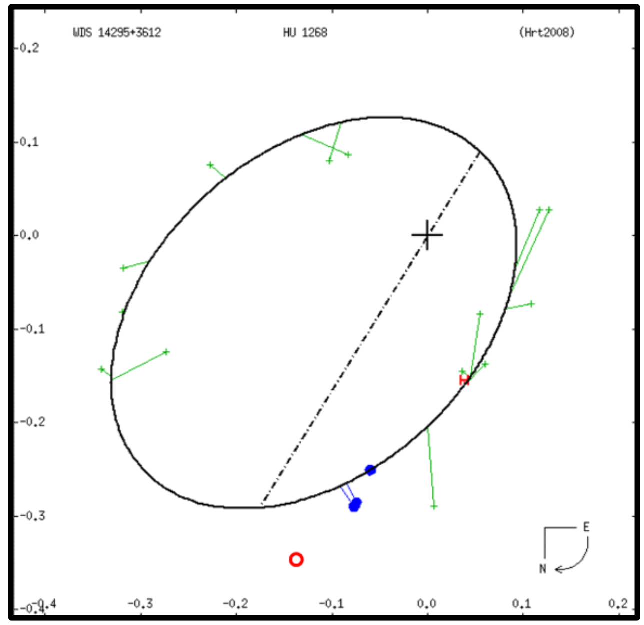

Figure 9: HU 1268 Plotted Orbit, with the new observation indicated by the red circle.

lows the calculated orbit of COU 1757. However, our point appears before where the point was predicted to be (measured 0.169" at 111.65°, predicted 0.18" at 120°). This could mean that the orbital period of COU 1757 is shorter than what was previously calculated.

Based on our observations shown in Figure 9, the orbit for HU 1268 may need to be recalculated, as our data point and those prior to it appear to drift away from the current orbital path.

While going through the drift calibration process and collecting the images, the biggest issue that came up was the consistent thin cirrus cloud cover. The cloudy weather caused the images to be of a poorer quality than desired, especially in the case of the images taken with the Johnson B filter. Fortunately, the images were still usable and we were able to acquire data from them.

Conclusion

The objective of this research was to make speckle observations of the close binary stars COU 1757 and HU 1268 to add to the double star research database. By taking a thousand images at different exposures, gains, and filters (Johnson B, Johnson V (Visual), SLOAN I (near-Infrared), Baader R (CCD LRGB series) and using Speckle ToolBox 1.05 and Speckle ToolBox 1.13, the students gathered enough data to produce successful astrometry and images of each star chosen.

Throughout the seminar, the team had very few difficulties. The biggest problem was the cloud cover mentioned earlier in this paper. Another issue that came up was the students' lack of experience in the field of astronomy; this made it difficult to get everyone on the same page during both the observation and analysis portions of the seminar, causing the whole operation to take longer than expected. In order to avoid this confusion in the future, further preparation may be necessary.

Despite these issues, the team was still able to work together to collect quality data; the drift calibration, autocorrelation, and bispectrum analysis were all successful. Along with the success of the observational part of this seminar, every student involved was able to contribute in some way to the scientific research held at Mount Wilson, allowing each of them to engage in the learning experience. With this in mind, this Field Studies Collaborative was an overall success.

Acknowledgements

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This research has made use of the Washington Double Star Catalog and the 6th Orbit Catalog maintained at the U.S. Naval Observatory.

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