Speckle Interferometric Observation of WDS 14564+8503

Stephen White[1], Paige Benson[1], Sepehr Ardebilianfard[1], Gezal Bahmani[1], Alexander Beltzer-Sweeney[1], Irena Stojimirovic[1], Richard Harshaw [2], Grady Boyce[3], Pat Boyce[3]

1. San Diego Mesa College – San Diego, CA
2. Brilliant Sky Observatory – Cave Creek, AZ
3. Boyce Research Initiatives and Educational Foundation

Abstract: Speckle interferometric observations of the tertiary system WDS 14564+8503 were made in order to measure the position angle (theta) and separation (rho) of the AB component, and were found to be 291.516° ±0.098º and 3.433" ±0.010", respectively. The measurements showed a continuation of the linear motion trend, but were inconclusive in confirming whether or not the AB component is gravitationally bound.

Introduction

The main objectives of this research were to make astrometric measurements of the tertiary star system WDS 14564+8503 WFC 157 AB (hereinafter WFC 157), utilizing speckle interferometry to resolve the small distances between the primary and secondary stars, to calculate the position angle (theta) and separation (rho), contribute data to the Washington Double Star Catalog (WDS), and attempt to confirm whether or not WFC 157, Figure 1, is a gravitationally bound binary system.

The WDS was utilized to find a candidate for this research. WFC 157 fit the criterion necessary for observation with a right ascension of 14h:56m:21.57s, a delta magnitude of 0.4, and a last estimated rho of 3.5". This system was originally chosen by our team in order to make a measurement of the BC component utilizing CCD astrometry, however it was found that we could not discern the separation of the AB component necessary to make reliable measurements. The inability of CCD images to resolve small distances forced us to shift our attention to measuring the AB component instead utilizing speckle interferometry.

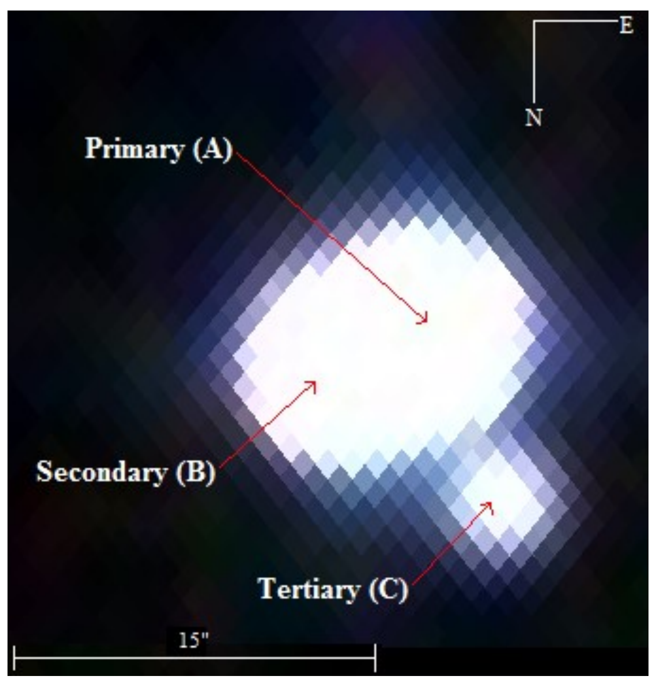

Figure 1. *Color image of WFC 157. Atlas Image obtained as part of the Two Micron All Sky Survey (2MASS).*

Ebersberger and Weigelt (1979, p. 24-27) described speckle interferometry as the process of taking short-exposure images, using a high-speed camera, in order to achieve a resolution much closer to the theoretical resolution of a telescope despite the turbulent atmosphere. The images must be taken at sub-40 millisecond exposure lengths in order "freeze" the atmosphere. The light from each star in the binary system passes through nearly the same part of the atmosphere, in turn creating two almost identical speckle patterns.

Speckle Interferometric Observation of WDS 14564+8503

Table 1. Historical Data for WFC 157

Epoch	θ (°)	θ Error (°)	ρ (")	ρ Error (")
1899.41	296.9	-	3.327	-
1899.41	285.5	-	3.352	-
1969.272	190.12	.033	3.503	0.017
1970.247	290.58	0.58	3.503	0.023
1972.171	291.218	0.324	3.377	0.041
1974.312	290.79	0.480	3.399	0.031
1975.24	291.023	0.243	3.418	0.026
1978.302	291.203	0.133	3.347	0.033
1991.73	291.3	-	3.56	-
1999.29	289	-	2.7	-
2002.404	292.3	-	3.41	-
2004.14	291	0.1	3.448	0.008
2013.4	291.1	-	3.48	-

Historical Observations

Historical reports, obtained from the United States Naval Observatory (USNO), show that WFC 157 has had a total of 13 observations between 1899.41 and 2013.4. The AB component was originally discovered by Frank Schlesinger and Ida Barney in 1899, and was subsequently entered into the Washington Fundamental Catalog. WFC 157 was not observed again until epoch 1969.272, over 70 years after its initial discovery, but was observed five times over the following 10 years. In epoch 1991.73, the European Space Agency (ESA) Hipparcos satellite made a measurement of WFC 157 that was included in the Hipparcos Tycho Catalog along with over a million other stars (Hipparcos Tycho Catalog). Table 1 shows all of the known historical measurements obtained from the USNO Historical Report.

Figure 2. Celestron C11 telescope. (Image by Richard Harshaw)

Observations, Equipment, and Analysis

A total of 12 observations were made of WFC 157 by Richard Harshaw at the Brilliant Sky Observatory in Cave Creek, Arizona on April 23, 2017, epoch 2017.311. The first two observations were made at 350 gain and a 275 millisecond exposure, but these images were not utilized for the speckle reduction process because of the longer exposure length. The other 10 observations were made at 550 gain and a 35.5 millisecond exposure, all of which were used. Each observation run lasted roughly 35 seconds, and captured 1000 images during this time.

The telescope utilized for this observation was a Celestron C-11 Schmidt-Cassegrain type 279 mm telescope, Figure 2, with a focal length of 2800 mm and a resolving power of 0.41". The telescope is mounted on a GGEM-DX mount controlled by TheSky 6 software, and is atop an adjustable PierTech pier (R. Harshaw, personal communication, May 17, 2017).

Coupled with the telescope is a high speed ZWO ASI290MM monochrome CMOS camera, Figure 3, controlled by FireCapture software, and capable of taking the short exposures required for speckle interferometry observations. Also attached to the camera is a Johnson-Cousins "R" filter, used to reduce atmospheric attenuation, and a 2x Barlow lens used to double the

Figure 3. *ZWO ASI290MM monochrome CMOS camera, 2x Barlow lens, and Johnson-Cousins "R" filter. (Image by Richard Harshaw).*

Speckle Interferometric Observation of WDS 14564+8503

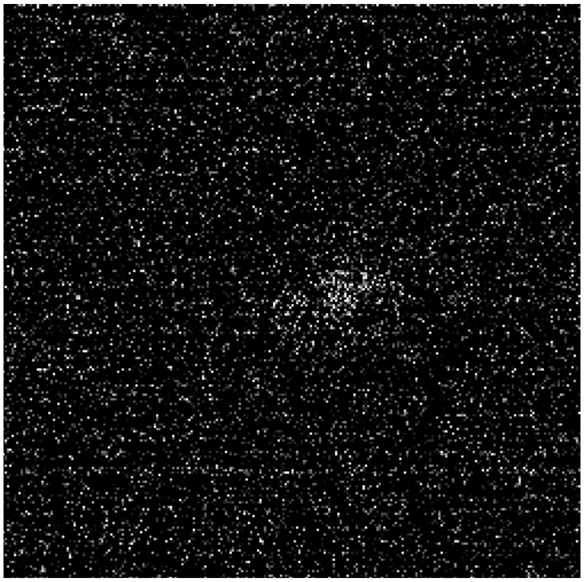

Figure 4. Unprocessed speckle interferogram.

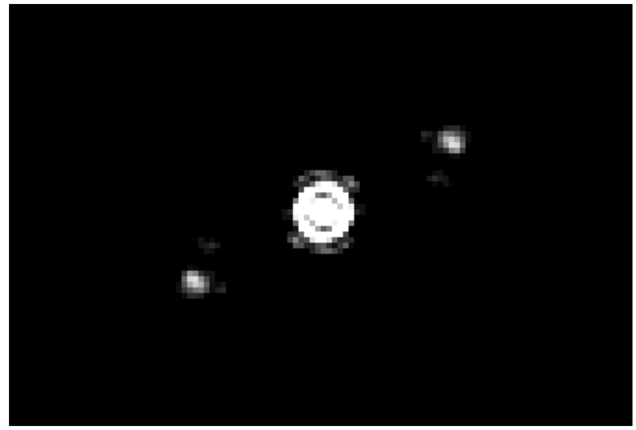

Figure 5. Autocorellogram of WFC 157 AB after speckle reduction.

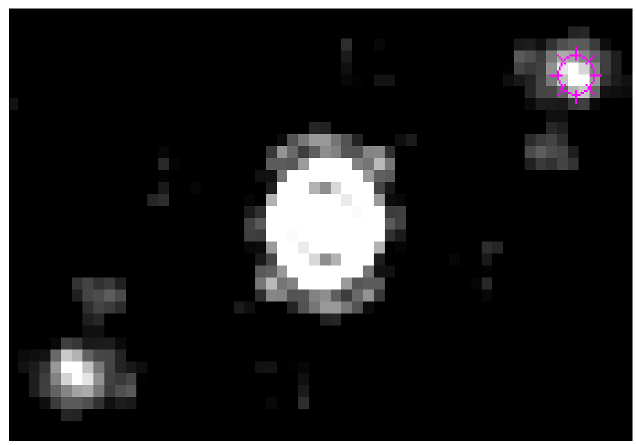

Figure 6. Auto detection of the autocorellogram centroid

magnification (R. Harshaw, personal communication, May 17, 2017).

The images captured by Harshaw, called speckle interferograms, contain many small interferences, or "speckles," Figure 4. The 1000 images from each observation were then imported into The Speckle Toolbox (STB) (Harshaw, 2017, p. 52) in order to bind them into a single file, called a FITS cube.

Once in FITS cube format, the files were put through pre-processing, which consists of the program computing the power spectrum of each individual image, and is done in order to speed up the reduction process. After processing, all of the individual frames are averaged and then the FITS cube file is labeled with a _PSD suffix. These processed PSD files, along with a deconvolution PSD file, were then analyzed using the speckle reduction tool. The result of the reduction process, known as an autocorellogram, Figure 5, is a graphical representation of the total power spectrum of the file (Harshaw, 2017, p. 53).

Ebersberger and Weigelt describe the pre-processing and reduction as follows:

> *"High resolution information is extracted from speckle interferograms by averaging the modulus square of the Fourier transforms of all recorded speckle interferograms. This procedure, and the compensation of the speckle interferometry transfer function, yield the power spectrum of the object...The outcome is the autocorrelation of the object, with a resolution limited only by diffraction, not anymore by the turbulent atmosphere."* (1979, p. 24)

After each of the PSD files were put through the speckle reduction process, the background noise and brightness of the autocorellogram was then adjusted using the levels and dimmer tools. Doing this allowed us to differentiate the background noise from the centroid of the stars, yielding a more accurate measurement if manual detection was necessary instead of auto detection, Figure 6.

Finally, the astrometry tool was used in STB in order to make the separation distance and position angle measurements. Each autocorellogram was measured using a 10, 11, and 12 object aperture diameter, and the best fit for each individual measurement was utilized.

Results

From the images analyzed, a mean position angle of 291.516° ±0.098° and a mean separation of 3.433" ±0.10" was calculated. These results show an increase of 0.416° in mean position angle and an increase of

Speckle Interferometric Observation of WDS 14564+8503

Table 2. Results of Speckle Interferometric Observations.

Observation Number	Theta	Rho
1	291.022	3.3438
2	290.519	3.4635
3	290.929	3.2774
4	290.153	3.391
5	291.217	3.4435
6	291.293	3.4239
7	293.317	3.4976
8	292.333	3.3548
9	291.823	3.5033
10	292.552	3.6358
SD (σ)	0.98	0.1
Mean	291.516	3.433
SDofM (σ/√N)	0.098	0.01

0.047" mean separation distance when compared with the most recent observation in epoch 2013.4. Table 2 shows the results of all 10 of our measurements along with the mean, standard deviation, and the standard deviation of the mean.

Discussion

By combining our data with the previous measurements, we were able to generate the following three plots:

1. Historical plot, Figure 7.
2. Theta as a function of time, Figure 8.
3. Rho as a function of time, Figure 9.

From the data available to us, it is clear to see that there has not been much, if any, change over the 118 years this binary pair has been observed. While WFC 157 was denoted as a physical system in the WDS based on the relative proper motion values, it is uncertain at this time whether or not the two are gravitationally bound to each other. What we can conclude at this time, is that the system is a common proper motion pair, and likely had similar origins.

As can be seen in Figure 7, the change in declination and right ascension of the secondary star in relation to the primary has stayed mostly constant. While we would like to use this information to show that the system is non-gravitationally bound, we are unable to because of the lack of parallax data on the system.

Figure 8 and Figure 9 show a very similar trend of inactivity to that of Figure 7, as can be seen by the linear fit lines in both the theta and rho measurements, respectively. WFC 157 is shown to have an average de-

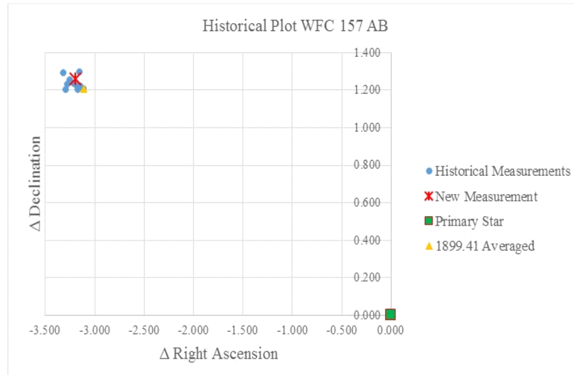

Figure 7. Changes in declination and right ascension for WFC 157. This plot models an orbit with the primary star artificially centered at the origin (red square). The blue circles represent historical measurements while the red asterisk represents our newest measurement. The yellow triangle, as indicated, is the average of the two available measurements from the same observation in 1899.41. Please note: the measurement from 1999.29 was disregarded as an observational error.

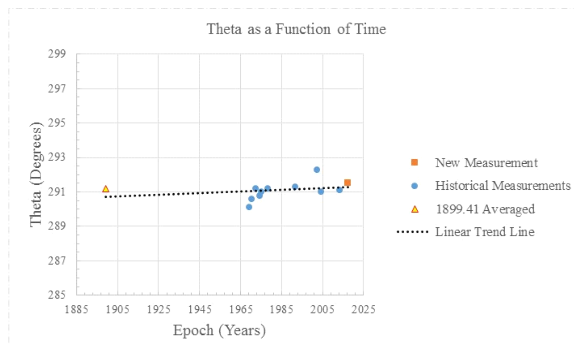

Figure 8. Change in theta over time. The blue circles represent the historical measurements while the red square represents our new measurement. The yellow triangle, as indicated, is the average of the two available measurements from the same observation in 1899.41. Please note: the measurement from 1999.29 was disregarded as an observational error.

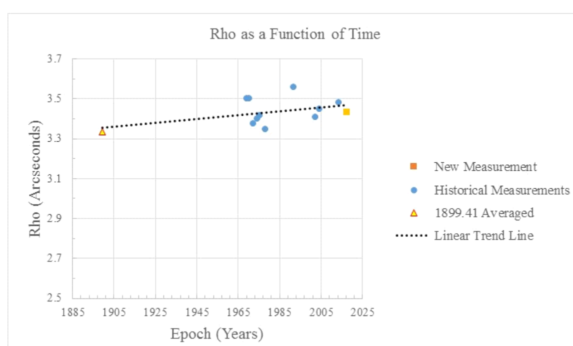

Figure 9. Change in rho over time. The blue circles represent the historical measurements while the red square represents our new measurement. The yellow triangle, as indicated, is the average of the two available measurements from the same observation in 1899.41. Please note: the measurement from 1999.29 was disregarded as an observational error.

parture from the linear fit line throughout the history of its measurements of only 1.5°, Figure 8, and 0.2", Figure 9, if the measurements in 1899.41 are averaged and if the measurement in 1999.29 is disregarded as an outlier.

Conclusion

On epoch 2017.311, 10,000 images were captured by Richard Harshaw at the Brilliant Sky Observatory, in Cave Creek, Arizona, in order to make speckle interferometric observations of binary star system WFC 157. The Speckle Toolbox was utilized in order to bind each 1000 image run into a single FITS cube. After a speckle reduction process, The Speckle Tool Box was then used in order to make measurements of the position angle and separation distance. Combined with the historic data dating back to epoch 1899.41, our data did not show any obvious signs of orbital motion, and we were therefore unable to confirm whether or not this system is gravitationally bound. However, a continuation of a linear motion trend was confirmed. We were able to conclude that WFC 157 is a common proper motion pair, and that the two components likely had a similar origin.

Acknowledgements

The authors wish to thank the Boyce Research Initiatives and Education Foundation (B.R.I.E.F.), without which this research would not have been possible, and David Rowe for his advice and the use of The Speckle Toolbox software. Also, they would like to thank Brian Mason from the United States Naval Observatory (USNO) for supplying the historical data which was used throughout this research. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

References

Ebersberger, J., and G. Weigelt., 1979, “Speckle Interferometry and Speckle Holography with the 1.5m and 3.6m ESO Telescopes”, *ESO Messenger,* **18**, 24-27.

Harshaw, Richard, 2017, "The Speckle Toolbox: A Powerful Data Reduction Tool for CCD Astrometry", *Journal of Double Star Observations,* **13**(1), 52-67.

"Hipparcos Tycho Catalogue", Harvard-Smithsonian Center for Astrophysics, n.d. Web. 17 May 2017.

“USNO”, USNO Double Star Data for WDS 14564 +8503. Web. 20 Feb. 2017