Speckle Astrometry of WDS 03344+2428

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Abstract
From data collected at El Sauce Observatory on 2022.848, the position angle and separation of the double star WDS 03344+2428 were calculated using Speckle Tool Box. The results of calculations made by six different people were ρ=0.79" ±0.003 and θ=350.06° ±0.29. The results matched the predicted interpolated values for this date from the Sixth Orbit Ephemerides, with a difference of 1.5% for the separation and 0.2% for the angle. Given the agreement with previous data and predictions, as well as the precision of these results, STB is shown to be a useful tool in an educational setting, allowing new scientists to obtain accurate results from data taken on smaller remote robotic telescopes.

Introduction

Speckle Interferometry is a powerful technique that allows astronomers to remove the effects of atmospheric distortion on images of double stars, allowing much smaller separations to be measured than would otherwise be possible. Pioneered by Antoine Labeyrie who originally took multiple exposures on one photographic plate to "stack" images, the technique is now performed by computers (Labeyrie 1970). First, several hundred short exposures are taken to "freeze" the atmospheric distortion of each. An example of a speckle image is shown in Figure 1.

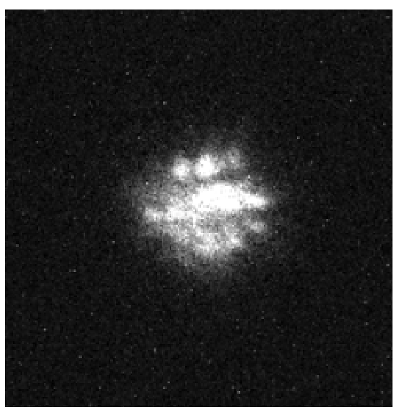

Figure 1. Single 0.03 second exposure of WDS 03344+2428

Then the images are stacked and Fourier transforms are used to remove the distortion. Speckle allows for the imaging of very tight binaries (less than 0.3″ on a 1.0 m telescope) and is particularly useful for students and new astronomers to use in conjunction with smaller and often remote robotic telescopes, yielding publishable results.

This paper provides a compilation of past observations of WDS 03344+2428 as well as adding a new observation which may help refine the plotted orbit path of the two stars in the future. It also shows the versatility of Speckle Interferometry to be used by anyone to generate publishable data.

Target and Past Observations

WDS 03344+2428, or STF 412, was chosen from a database of stars that are in both the WDS and the 6th Orbit catalog (McCudden et al. 2022). It was chosen for study because its separation is between 0.2 and 1.0 arcseconds, ideal for speckle reduction, its magnitude is less than 12 making it visible to smaller telescopes, and it is visible from the Northern Hemisphere, allowing data to be taken by the Colorado Mountain College Ball Observatory as part of the Astronomy independent study program.

WDS 03344+2428, or STF 412, has an orbital period of 522.16 years. The magnitude of the A star is 6.60 and ΔMag is 0.26. Table 1 shows selected past observations reported in the Washington Double Star Catalog.

Table 1. Table of selected past observations of WDS 03344+2428 from the WDS database (sample data from about every ten years)

Date	Position Angle, θ (degrees)	Separation, ρ (arcseconds)	Observer
1828.19	271.9	0.62	StF1837
1839.80	261.1	0.34	Ch11908
1846.98	256.4	0.4	Mad1856
1857.06	259.1	0.3	Mad1859
1865.180	243.0	0.6	Eng1882
1878.57	233.9	0.47	Sp_1888
1888.07	203.5	0.24	Sp_1909
1898.00	192.9	0.23	Hu_1898
1908.77	147.0	0.17	Bu_1913
1928.17	66.0	0.30	Fur1927
1938.13	42.3	0.32	Rab1939
1948.71	30.0	0.43	VBs1954
1958.08	22.4	0.47	B__1960b
1968.15	11.3	0.56	Baz1972
1978.087	6.2	0.54	Wor1989
1988.8045	4.	0.79	Iso1990b

Date	Position Angle, θ (degrees)	Separation, ρ (arcseconds)	Observer
1998.678	357.8	0.684	Sca2000c
2008.035	354.9	0.714	G112012
2019.076	350.8	0.766	WSI2021

Equipment and Methods

Astrometric data was obtained for WDS 03344+2428 on 2022.847 by a 1.0 m Plane Wave Instruments telescope located at 30.4705° S, 70.7649° W at the El Sauce Observatory in Chile (Hardy et al. 2023). Using Nighttime Imaging 'N' Astronomy software (NINA) the telescope took one 60 second exposure of the target star WDS 03344+2428 using a luminance filter followed by 500 0.03 second exposures with a Sloan r' filter and 300 0.03 second images of the reference star HD 18737.

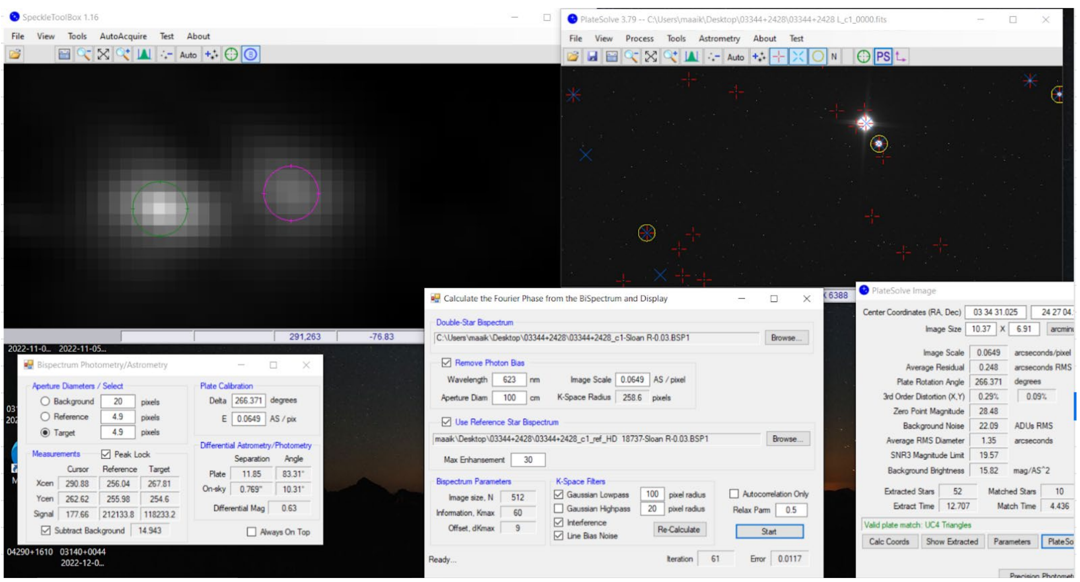

Figure 2. Screenshot of Plate Solve and Sample STB Reduction, showing settings and output values

Using Plate Solve (Harshaw et al. 2017) on the long exposure image, the image scale and plate rotation angle were found. This process also verified that the intended star was captured. See the right side of Figure 2 for the plate solution. The image scale and plate rotation angle were then used to calibrate Speckle Tool Box (STB) software.

Using STB, the two sets of short exposures were stacked into FITS cubes, then converted to BSP files. BSP files were formed in three different sizes (see Figure 3.), 512, 256, and 128 pixels to gauge the effect of image size on the image quality. The 512 by 512 pixel image was used for all data reductions.

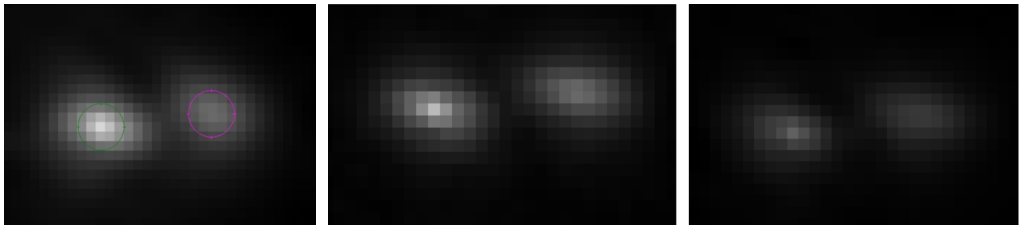

Figure 3. Comparison images with different pixel dimensions. Left to right: 512x512, 256x256, 128x128 pixels

Then, using the Bispectrum Phase Reconstruction tool (which uses Fourier transforms to deconvolute the atmospheric distortion), the angular separation of the stars, ρ, and the angle between them with respect to north, θ, were calculated four times each by six researchers and averaged. Each researcher selected the photocenter of the A and B stars. Even with the peak lock function on STB, selection was still somewhat subjective, and the results varied between researchers.

Data

The average of the 24 measurements made by 6 researchers are shown in Table 2. The air mass at the time the images were taken was 1.74.

Table 2. Average Calculated Values of ρ and θ

ρ (arc seconds)	Error	θ (degrees)	Error
0.79	0.003	350.06	0.29

The observation from Table 2. was added to the orbital plot from the Sixth Orbit Ephemerides as the open red circle in Figure 4.

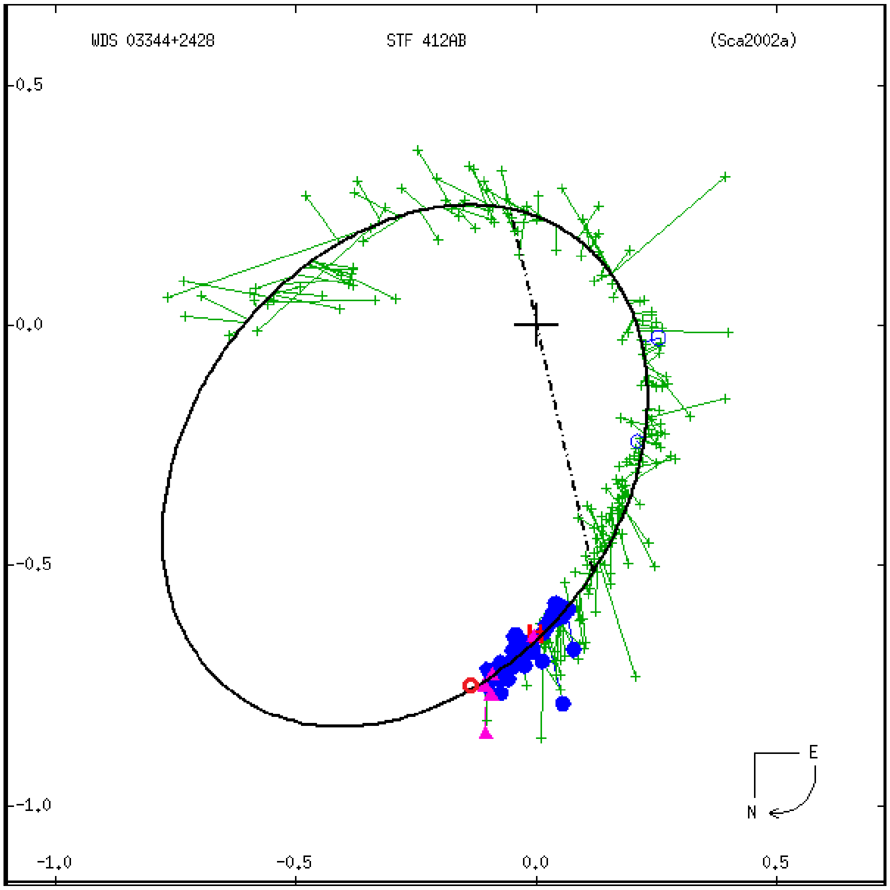

Figure 4. Orbital Plot of WDS 03344+2428 taken from the Sixth Catalog of Orbits of Visual Binary Stars (Matson et al. 2023). The blue dots are speckle data. The red circle is the new measurement.

In addition to the graphical display of the new observation in Figure 4, the observation was compared quantitatively with the prediction provided by the 6th Orbit Catalog Ephemerides in Table 3, interpolating to 2022.848.

Table 3. Predicted values from the Sixth Orbit Ephemerides

<table>
<tr><th>Year</th><th>Rho (Ephemerides)</th><th>Rho (Calculated)</th><th>Theta Ephemerides</th><th>Theta (Calculated)</th></tr>
<tr><td>2022</td><td>0.774</td><td rowspan="3">0.79</td><td>349.5</td><td rowspan="3">350.06</td></tr>
<tr><td>2022.848 (interpolated)</td><td>0.777</td><td>349.25</td></tr>
<tr><td>2023</td><td>0.778</td><td>349.2</td></tr>
</table>

Discussion

When compared with the interpolated values from the 6th Orbit Ephemerides for ρ and θ in 2023, there was a 1.5 percent difference for ρ and a 0.2 percent difference for θ. This accuracy is remarkable for data taken on a smaller telescope and reduced mainly by students new to the software.

Six different people were asked to take measurements on STB to test the subjectivity of the software. The error of 0.003 for ρ and 0.29 for θ between the measurements made by different people is also noteworthy, speaking to STB's prowess as a data taking tool.

For stars with a smaller separation, it is often helpful to create and reduce smaller BSP files from 512 by 512 to 256 by 256 or even 128 by 128 pixels. In this case, however, the separation was large and the 512 by 512 pixel images appeared good enough as can be seen in Figure 3. The smaller pixel size probably gave no advantage in this case.

Error in the measurements taken from STB is the result of the subjectivity in selecting the middle of each star. As evidenced in the error in the measurements made in STB, the program lends itself to good consistency even between multiple people taking the data. This may be in part due to the "peak lock" function, which automatically locks the crosshairs onto the brightest pixel in the surrounding area. Some researchers used this while others did not. When separated into two groups, those that used the peak lock had results closer to those of ρ but farther from those of θ from the 6th Orbit Catalog.

The highest pixel values in the single 0.03-second image (see figure 4) are around 700 ADU. This is surprisingly low given the pixel values on the 60-second image are around 65,000. The 0.03 second images may be underexposed and a longer exposure should be considered, although longer exposures can induce atmospheric smearing.

Conclusions and Potential Follow Up

Given the accuracy of measurements taken using STB, the data points of ρ and θ will be helpful in refining the orbital path of this pair of stars. As STB continues to be used in an educational setting, future measurements may help map out the orbit.

The use of PlateSolve and AstroImageJ (Collins et al. 2017) will be expanded further into the educational sector. In anticipation of these programs being used at Colorado Mountain College, a long exposure was taken of WDS 03344+2428. While PlateSolve was not able to find a solution of the image, another program, AstroImageJ provided a plate solution as seen in Figure 5.

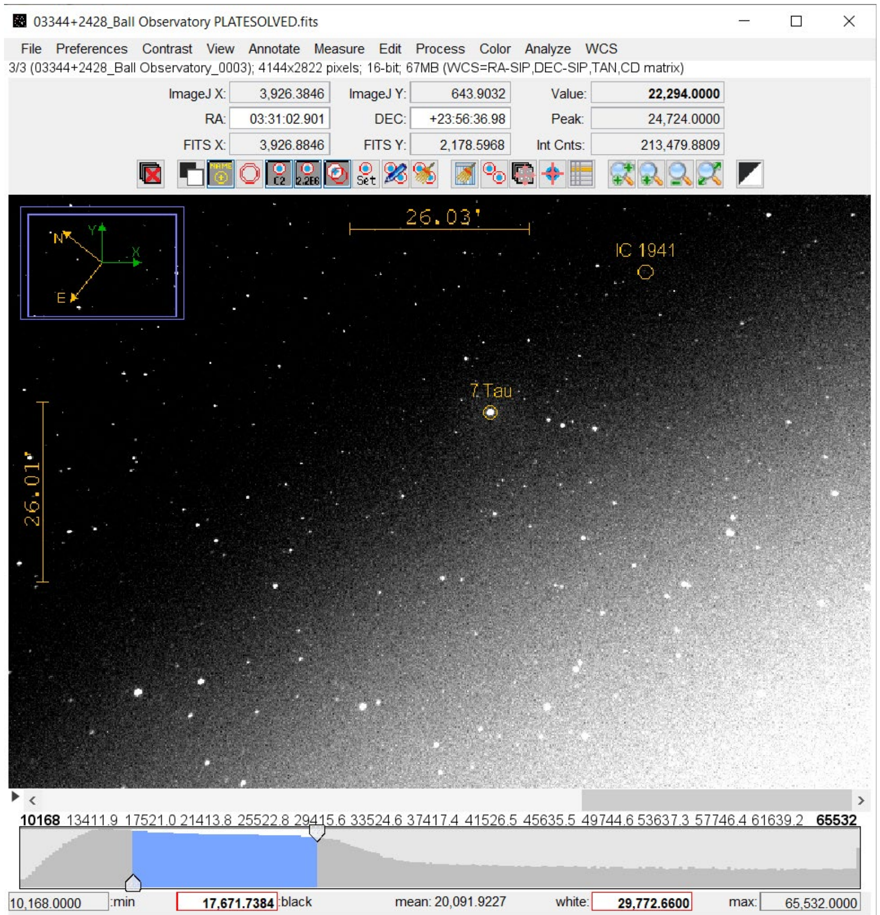

Figure 5. Plate Solved Image of WDS 03344+2428 taken from the Colorado Mountain College Ball Observatory. This 10 second image was taken on 2023.13 with a Celestron 11'' Edge telescope on a Paramount ME mount using a ZWO ASI 294MC pro camera (McCudden 2023).

In the future, when the observatory at CMC is set up to take speckle images, ρ and θ could be measured again with this smaller telescope. Comparing these values with those taken from data captured on a larger telescope will tell how flexible STB over differently sized telescopes is.

It would also be of interest to attempt to measure the separation and angle of the A and C stars using PlateSolve, as they are too far apart to appear together in a speckle image.

Acknowledgements

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