Determining the Nature of WDS 20375+4233 A398 using Speckle Interferometry

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Abstract: We analyzed the star system WDS 20375+4233 (A398) using speckle interferometry to determine if the two stars are gravitationally bound. We performed the observations with the Boyce Astro Research Observatory PlaneWave CDK 17" telescope. Using Speckle Tool Box 1.16 for the analysis of the images, we found a mean position angle of 23.5° ± 0.9° and a mean separation of 1.83" ± 0.02". Based on this data and other factors, it is likely that the pair is physically bound and not a visual double, but it cannot be determined for certain.

1. Introduction

To determine the nature of a double star, we can use measurements of the position angle, radial distance, and proper motion, along with plotting the new position of the double star and historical data, looking for indicators that a pair is gravitationally associated. A confirmed binary system makes it possible to obtain accurate information on the stellar masses of the system. From there, information about the star's size, luminosity, life cycle, and chemical composition can be found.

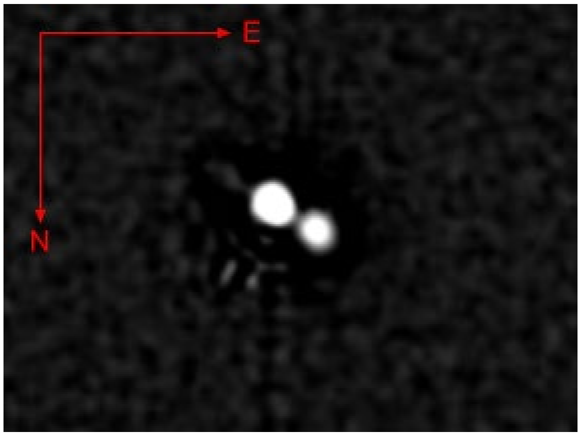


Figure 1: Image of WDS 20375+4233 (A398) after speckle analysis

In this study, we measured the position angle and separation of the double star WDS 20375+4233 (A398), Figure 1, and in combination with historical data, attempted to determine if the system is a true binary (gravitationally-associated system) or an optical double (chance alignment of two stars far apart in space). Historical data for WDS 20375+4233 (hereafter A398) was provided by the United States Naval

Observatory (USNO). The star systems were located using the Washington Double Star and SIMBAD catalogs. Further information was acquired from GAIA using database query software.

The double star was chosen due to its small angle of separation and its similar, relatively bright magnitudes of 9.57 and 10.40, respectively. Additionally, it is in an area of the sky that is visible from the observatory during October and November, when the images were to be taken. The system was also chosen because it is unknown whether or not the stars are gravitationally bound, meaning our team could be the first to determine its nature.

There have been 22 total observations of A398 since 1902, with the most recent one being in 2016 (Stelle Doppie). The position angle and separation of the double as first observed were 359° and 0.9", respectively; the position angle (theta, θ) and separation (rho, ρ) of the double as last observed in 2016 were 22° and 1.7", shown in Table 1. The two stars of A398 are less than 3 arcseconds apart, meaning they are difficult to optically separate using a CCD camera. Because of this, speckle interferometry was used, which allows close doubles to be observed to the diffraction limit without affecting the image quality (Saha 2002). The primary star of A398 is classified as an F5 spectral class, which gives it a yellow-white color (Stelle Doppie).

Table 1: Historical observations provided by WDS.

Observation Date (year)	**Position Angle (θ)**	**Separation Distance (ρ)**
1902.828	358.7°	0.89"
1902.857	358.2°	0.90"
1916.53	359.7°	0.95"
1916.58	2.8°	0.96"
1926.26	8.6°	1.04"
1934.55	10.1°	1.10"
1935.58	13.8°	0.88"
1944.84	10.6°	1.18"
1960.29	15.4°	1.50"
1962.62	15.7°	1.38"
1972.69	16.5°	1.34"
1972.809	16.2°	1.42"
1986.56	20.0°	1.60"
1989.66	16.7°	1.41"
1991.25	18.8°	1.615"
1991.71	20.7°	1.562"
1997.711	18.7°	1.64"

2000.6715	20.9°	1.66"
2003.573	20.20°	1.669"
2010.6881	20.31°	1.729"
2015.5	21.788°	1.733"
2016.0	21.86°	1.733"

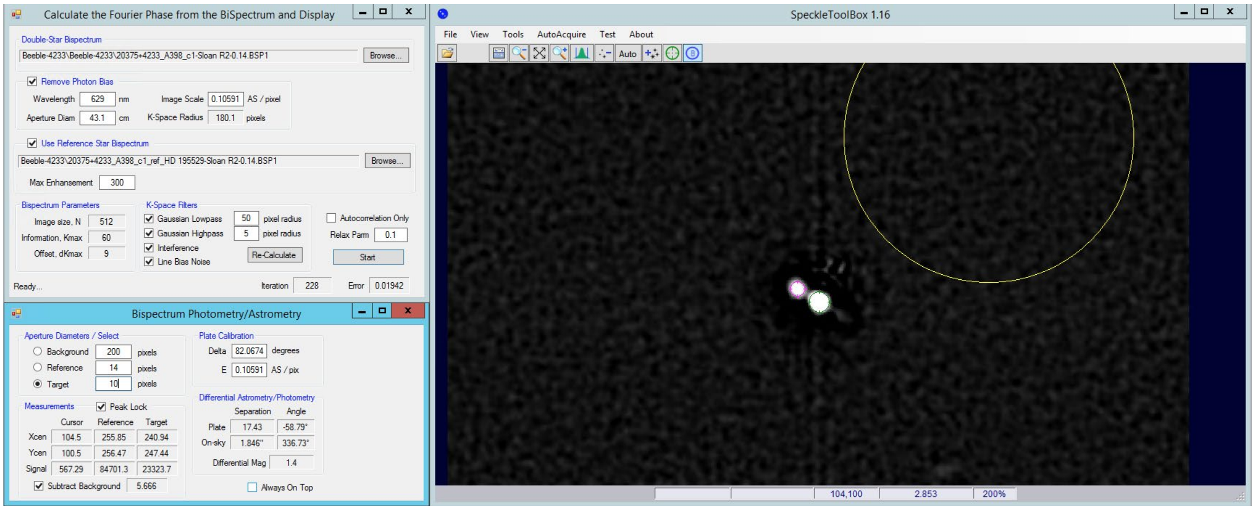
2. Equipment and Methods

All data was collected through the Boyce-Astro Research Observatory (BARO)'s PlaneWave Corrected Dall-Kirkham (CDK) 17" telescope, Figure 2, with a ZWO 1600 CMOS camera for imaging.

Figure 2: BARO's PlaneWave CDK 17".

First, we needed to calibrate the telescope to plate solve the images. To do this, we pointed the scope at a large cluster and took 16 10-second exposure images. With these, we used Dave Rowe's Plate Solve 3.80 to find the position angle and plate scale for each image and averaged them to use in Speckle Tool Box. From here, the analysis images of the double star system were acquired. Three different exposure times, 0.12s, 0.14s, and 0.16s, were used for the analysis after test runs determined which times produced suitable images, and the Sloan R2 filter was applied for all images.

The Speckle Tool Box (STB) 1.16 (Rowe) was then used to compile the images into FITS cubes and then processed with a bispectrum algorithm. Next, STB was used to perform the speckle reduction and calculate the rho and theta values for each set of images. Figure 3 shows an example of this. Finally, in a spreadsheet, the mean, standard deviation (SD), and standard error of the mean (SEM) were calculated for both and are listed in Table 3.



Double-Star Bispectrum: Beeble-4233\Beeble-4233\20375+4233_A398_c1-Sloan R2-0.14.BSP1

☑ Remove Photon Bias
Wavelength 629 nm
Image Scale 0.10591 AS / pixel
Aperture Diam 43.1 cm
K-Space Radius 180.1 pixels

☑ Use Reference Star Bispectrum: Beeble-4233\20375+4233_A398_c1_ref_HD 195529-Sloan R2-0.14.BSP1
Max Enhansement 300

Bispectrum Parameters
Image size, N 512
Information, Kmax 60
Offset, dKmax 9

K-Space Filters
☑ Gaussian Lowpass 50 pixel radius
☑ Gaussian Highpass 5 pixel radius
☑ Interference
☑ Line Bias Noise

☐ Autocorrelation Only
Relax Parm 0.1

Ready...
Iteration 228
Error 0.01942

Aperture Diameters / Select
○ Background 200 pixels
○ Reference 14 pixels
● Target 10 pixels

Plate Calibration
Delta 82.0674 degrees
E 0.10591 AS / pix

Measurements ☑ Peak Lock

	Cursor	Reference	Target
Xcen	104.5	255.85	240.94
Ycen	100.5	256.47	247.44
Signal	567.29	84701.3	23323.7

☑ Subtract Background 5.666

Differential Astrometry/Photometry

	Separation	Angle
Plate	17.43	-58.79°
On-sky	1.846"	336.73°

Differential Mag 1.4

☐ Always On Top

Figure 3: Speckle Tool Box 1.16 being used to perform the speckle reduction and find the θ and ρ.

3. Data

There were two nights of observation, with 12 sets of 500 images collected on October 29, 2022 (epoch 2022.8264), and 9 sets of 500 images on November 12, 2022 (epoch 2022.8651).

Table 2: Data collected for WDS 20375+4233 A 398 at BARO.

Date	**Epoch**	**Filter**	**Number of Measurements**
10/29/22	2022.82640	Sloan R2	12 sets of 500 images
11/12/22	2022.86511	Sloan R2	9 sets of 500 images

The results after speckle analysis are shown in Table 3. The mean position angle was 23.5° ± 0.9°, while the mean separation was 1.83" ± 0.02".

Table 3: Results, averaged for each exposure time over all observations.

	Position Angle				**Separation**		
	Mean	**Standard Deviation**	**Standard Error of the Mean**		**Mean**	**Standard Deviation**	**Standard Error of the Mean**
0.12	22.25°	0.900°	0.520°		1.822"	0.0145"	0.0084"
0.14	23.78°	0.277°	0.160°		1.834"	0.0080"	0.0046"
0.16	24.36°	1.129°	0.652°		1.829"	0.041"	0.024"

Total	23.46°	0.900°	0.300		1.828"	0.0228"	0.0076"

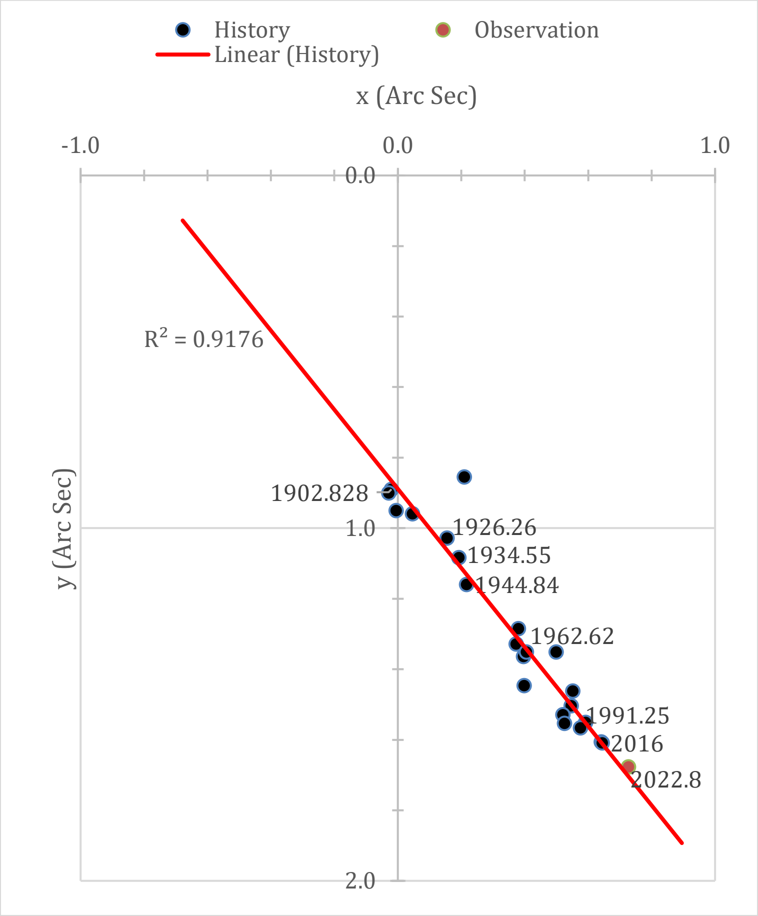


Figure 4: Plot of historical data for WDS 20375+4233 A 398 with the observation added

4. Discussion

Based on the GAIA parallax data, Table 4, for the A and B stars (10.7489 ± 0.1354 mas and 11.0332 ± 0.0215 mas, respectively) and the separation we found with our observations, (1.828 ± 0.0228 as), the apparent separation between the two stars is 170.0 ± 3.02 AU, or 2.688 x 10^{-3} ± 0.0477 x 10^{-3} light years. This was calculated using the formula

$$\frac{\rho \cdot d \cdot 2\pi}{1296000} = \frac{1.828 \cdot 19180386\,AU \cdot 2\pi}{1296000} = 170.0\,AU$$

where ρ is the separation and d is the radial distance to the A star. This is relatively close, though it only accounts for the plane of our vision, not their distance from Earth. Based on the same parallax data, there is a 2.8% chance of the stars being within 1 light year radially. Since almost every binary system has a radial separation of less than 1 light year, a much greater distance means a lower probability of the system being gravitationally bound (Harshaw 2018). This was calculated through a distance and probability calculator spreadsheet provided by Bob Buchheim and Pat Boyce using the error on the radial distance. Based on the mean data from GAIA, there would be a radial distance of 7.81 light years.

Table 4: GAIA Parallax data for the two stars

	A Star	B Star
Parallax (mas)	10.7489	11.0332
Standard Error (mas)	0.1354	0.0215

As shown in Figure 4, the historical data follows a definitive trend that is continued by the observation. This, along with the very similar proper motions of the two stars as indicated by Figure 5 and Table 5, would suggest that the stars are gravitationally bound. The Harshaw proper motion statistic, which is calculated by dividing the difference of the two proper motion vectors by their sum, is 0.015625. The proper motion statistic value ranges from 0 to 1, with smaller numbers indicating higher probabilities of the system being binary (Harshaw 2018).

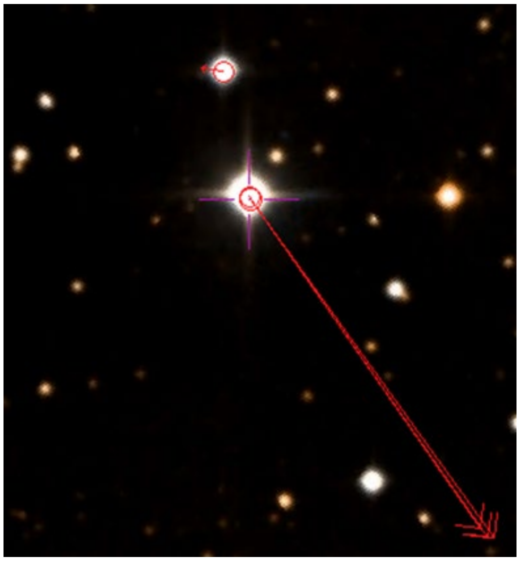


Figure 5: Aladin v11.0 image of the proper motion

Table 5: Proper motion of the two stars.

	Right Ascension (mas/yr)	Declination (mas/yr)
Primary Star	-110.7	-154.1
Secondary Star	-105.4	-151.0

Conclusion

Based on the small apparent separation and similar proper motions for the system, there is a reasonable chance that A398 is a gravitationally-bound system. The greatest indicator that it is visual is the radial distance, which is most likely larger than normal for a binary. Additionally, the trend of the historical data is very linear. This could be a portion of an orbit, though it could also simply be the stars moving away from each other. In Richard Harshaw's Excel spreadsheet created for his October 2018 paper to calculate the probability of a system being a binary, there is a 77 percent chance for A398, which merits a "maybe" classification (Harshaw 2018). There is a very low Harshaw proper motion statistic value of 0.015625, indicating they are moving together, but there is still a visible divergence between the vectors. With all of these factors combined, the system is quite possibly gravitationally associated, though it is not certain. Some indicators lean toward binary, while others lean toward visual, so the data is not conclusive.

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