Remote Speckle Interferometry of Undiscovered Double Stars

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Abstract: Speckle interferometry observations on stars not in the Washington Double Star Catalog were remotely gathered using the Fairborn Institute Robotic Observatory. Bispectrum astrometric measurements of 21 double star systems with separations ranging from 0.94 to 5.84 arcseconds are reported, and the instrumentation, software, procedure, and results are described.

Introduction

The Fairborn Institute Robotic Observatory (FIRO) is focusing on double star research, specifically speckle interferometry— a technique of measuring double stars developed by Labeyrie (1970).

Speckle interferometry allows stars below the seeing limit of the atmosphere to be resolved (Harshaw 2017). Short exposures, typically less than 40 milliseconds are taken of the target, which freezes the seeing and allows double stars that would otherwise blur together with Conventional long-exposure imaging to be measured. A Fourier transform is then applied to the images to generate an autocorrelogram. An autocorrelogram is not a typical image, but a Fourier transform of the power spectral density of the image. The autocorrelogram has two sidebands, only one of which is the secondary star. Bispectrum analysis is a further refinement beyond the autocorrelogram: it adds back the image phase that was lost when the complex Fourier transform of the image was squared to form the PSD. This removes the extraneous sideband, and resolves the 180^o position angle ambiguity.

For these observations, speckle interferometry was used to measure stars that had previously only been measured by Gaia and have not been studied before. As of 2018, these stars were not yet in the Washington Double Star Catalog. Along with the goal of measuring close double stars, these observations continued to push the limits of the FIRO telescope. Closer and dimmer stars were measured than in the first set of previously-reported observations (Caputo et a. 2020), with one system having a separation of 0.94″, and many systems having secondaries with magnitudes 12 or dimmer.

Target Selection

All target selection for these observations was done using the Gaia Double Star (GDS) search tool (Rowe 2018). From the 1.3 billion stars of the Gaia Data Release 2 (DR2), GDS extracted a subset of 6,820,000 double stars with separation less than 10 arcseconds. From that subset, all double stars which met specified parameters shown below, in Figure 1, were further extracted (Wasson et al. 2020).

Due to the FIRO horizon being limited by trees, target selection was restricted to declinations between +13 and 60 degrees and a within the horizon limit at time of observation. Further target constraints were magnitudes less than 13, delta magnitude less than 3, and separations less than 6″. While separation had no lower bound, the system with the closest separation meeting the other requirements was the system with GDS 1.0 ID 5676692 with previously measured separation of 0.892″. Only targets without a WDS index were selected, which means that as of 2018, when GDS was written, no measurements had yet been entered into the WDS. As bright stars are easier to observe and measure, only observing unreported stars results in many faint target systems. The targets observed here were all fairly dim, with primary magnitudes ranging from magnitude 7.7 to 9.9 and secondary magnitudes ranging from 9.5 to 13.0.

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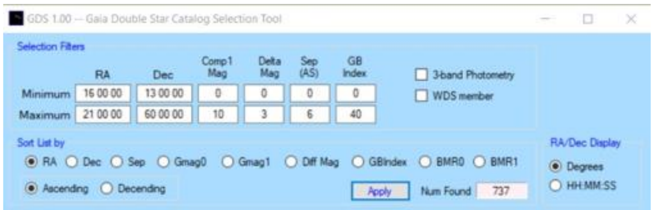

Figure 1: GDS1.0 shown with the sorting parameters used for these observations.

Instrumentation

FIRO has a C-11 telescope mounted on a custom mount designed and built by Genet and students at California Polytechnic State University. The C-11 is f/10, having a focal length of 2800mm. The ZWO ASI 1600mm camera has 3.8 µm pixels, giving a scale of approximately 0.26 ″/pixel. This sampling allows 1.0″ separation double stars to be resolved. The theoretical diffraction limit of an 11-inch telescope is 0.4 ″, however the sampling does not allow this limit to be reached. The sampling is relatively coarse for speckle, as at least four to five pixels between the centroids are needed to make confident measurements. However, the course sampling has the advantage of packing more light into each pixel, thereby increasing the SNR , meaning fainter doubles can be measured. In addition, no filter restricted the bandpass. By definition, this transmits the most light, helping to measure faint double stars. (Marchetti 2020).

Figure 2: The Fairborn Institute Robotic Observatory telescope

Procedure

For these observations the telescope was controlled remotely by Marchetti, Duan, and Nordenholz.

AnyDesk was used to log into the observatory computer and control the telescope software. SiTechZWOCam software (Gray 2020) controlled the mount and performed an autofocus routine. Nighttime Imaging 'n' Astronomy (NINA) (Berg 2020) slewed to the target system, then corrected for pointing error by doing a platesolve and resync. This platesolve routine, as well as correcting for pointing error, provided the camera angle and pixel scale of 0.1o and 0.27″ per pixel. Cartes du Ciel (Chevalley 2020) synced to the telescope's location and was then used to find and slew to a reference star. Finally, SharpCap (Glover 2020) controlled exposure time, gain, and executed the speckle image capture for both the target system and the reference.

The procedure was almost the same as described in depth in Caputo et al. (2020), one deviation being that Caputo's telescope was focused manually and these observations used SiTech's autofocus. A second difference is in the first science, four separate captures of 1000 frames were taken. Since then we learned that 500 frames was more than enough to result in a clean image, and rather than taking four separate captures, one large capture was taken. This single capture was later processed into four fits cubes using Dave Rowe's SpeckleToolBox software, described below. These slight differences didn't change the quality of measurement, but they saved time and eliminated the occasional error of forgetting to take enough captures.

For some of the fainter stars, we were uncertain if the typical 40ms exposure time would be long enough for the dim secondary to show up. As a precaution, an extra set of captures with higher exposure times were taken. The exposure times were between 100ms and 250ms, and the number of frames per fits cube was lessened from 500 to around 250. This precaution ended up being unnecessary since the stars were able to be resolved in both the normal fits cubes and the higher exposure ones. There appeared to be no substantial difference between the images, as shown below in Figure 3, so the measurements were averaged together.

SpeckleToolBox 1.14 (Rowe 2019) was used for the speckle interferometry data reduction. STB generates fits cubes and performs the Fourier analysis. Results can be presented as a power spectral density (PSD) using autocorrelation, or it can be further processed using bispectrum, which transforms the PSD back into an image, removing the sidebands. For these observations bispectrum was used, as it results in a more accurate measurement. The mechanics of autocorrelation and bispectrum are explained in depth in Marchetti et al. (2020).

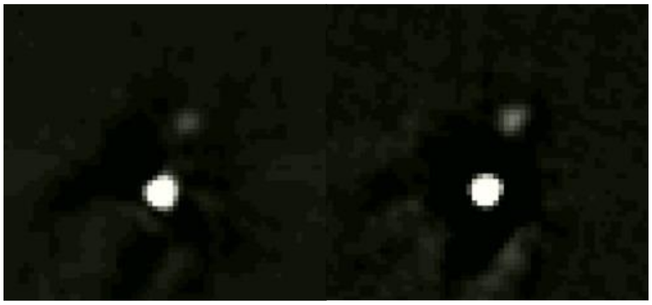

Figure 3: Bispectrum image of 18 55 04 +14 17 37 taken with 45ms exposure (left) and 150ms exposure (right).

Results

Position angle and separation measurements are given in Table 1. Systems are listed by their GDS 1.0 ID and their celestial coordinates, and are ordered by right ascension.

Two systems, 6116075, at coordinates 17 12 58 +17 12 58 and 5257587, at coordinates 18 02 45 +13 59 23 were unable to be resolved. Nothing unusual was noticed when taking images of the system, but in SpeckleToolBox they showed up as a single star, shown in Figure 4. It is unclear why this happened; based on Gaia data these should have been easy to resolve. The Gaia separations for these systems are 2.6″ and 3.6″, which are quite large considering many stars with lower separations resulted in a clean split. The two were also among the brighter of the target systems, with secondary magnitudes of 8.7 and 10.6, and both doubles had delta magnitude of less than 2.

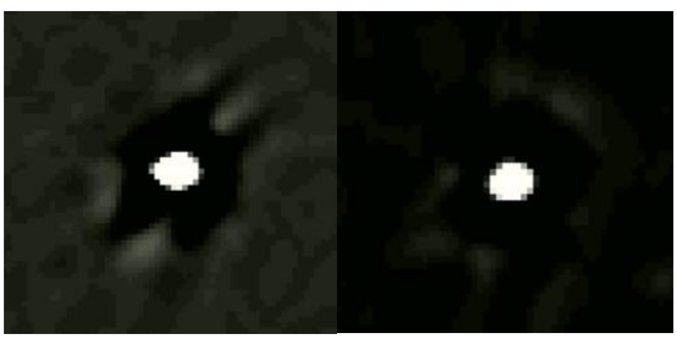

Figure 4: Bispectrum image of 17 12 58 +17 12 58 (left) and 18 02 45 +13 59 23 (right). A measurement was not possible as the images only contain a single star.

Another measurement to note is that of 18 43 45 +39 01 20. All the other measured doubles had position angles and separations in the range of their Gaia measurement. However, for 18 43 45 +39 01 20 both measurements are quite far off. Gaia predicted the pair to have a position angle of 271.2o and separation of 1.16″, which vary significantly from the measured 192.39o and 2.912″. It is unclear what is the cause of this discrepancy. Sometimes stars have noticeably moved in their orbit since a previous measurement, but it's unlikely that these stars would have moved so drastically. For the stars to have moved so far since 2018 their separation would need to be a lot smaller.

Sometimes when an image is noisy, it is possible for a bright spot of noise to be confused for the secondary, but that is again unlikely in this case, as the image shown in Figure 5 is quite clean. A remeasurement of this star and the two described above might clear up these confusions.

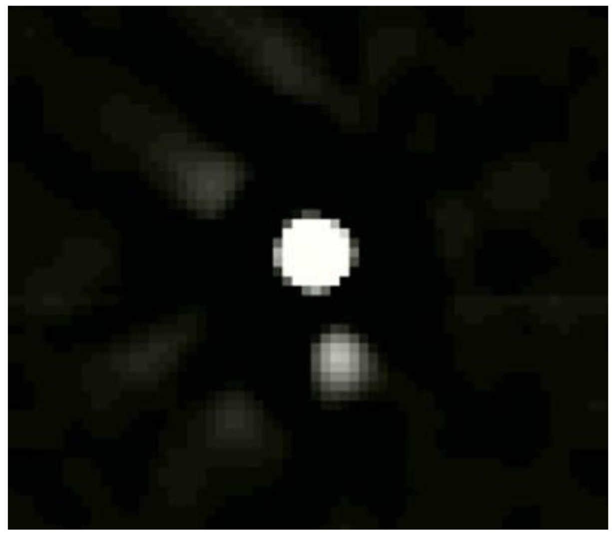

Figure 5: Bispectrum image of 18 43 45 +39 01 20. The split between stars is clean and it is apparent where the secondary star is.

Conclusion

Using the Fairborn Institute Robotic Observatory and speckle interferometry we obtained measurements on 21 double stars. These stars were not in the Washington Double Star Catalog as of 2018. As our measurement is only one data point, these stars require future observations to determine if they are actually orbiting.

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System	Date	Number of Fits Cubes	Position Angle (°)	Standard Error of Position Angle (°)	Separation (″)	Standard Error of Separation (″)
5789128 16 35 25 +36 54 45	2020.62	4	151.28	0.15	3.248	0.008
5911695 16 41 15 +43 34 53	2020.62	4	256.25	0.08	4.845	0.004
6737086 17 05 06 +27 59 48	2020.62	4	17.99	0.03	5.842	0.005
6731147 17 14 16 +25 02 51	2020.62	4	46.52	0.09	5.704	0.006
6189706 17 19 32 +58 31 45	2020.60	4	63.85	0.07	1.727	0.003
5537259 17 19 32 +26 46 38	2020.62	3	92.96	0.24	1.538	0.008
5750711 17 23 22 +35 26 15	2020.60	4	98.59	0.09	3.427	0.002
5662409 17 49 53 +31 34 00	2020.61	4	23.95	0.10	3.463	0.006
5314592 17 51 19 +16 17 41	2020.60	5	289.42	0.25	2.281	0.024
5647865 17 56 19 +30 56 38	2020.60	5	120.99	0.04	3.234	0.016
6047439 18 08 41 +50 30 59	2020.60	4	101.73	0.24	2.573	0.011
6727058 18 24 47 +22 54 26	2020.61	4	164.06	0.04	5.563	0.004
5292309 18 39 57 +15 19 55	2020.60	3	65.75	0.36	3.433	0.054
5833495 18 43 45 +39 01 20	2020.60	4	192.39	0.10	2.912	0.010
5375417 18 44 40 +18 45 35	2020.60	3	4.98	0.16	2.607	0.051
5676667 18 46 38 +32 10 03	2020.60	4	153.20	0.03	3.063	0.002
5495716 18 52 37 +24 41 49	2020.60	5	295.91	0.17	2.22	0.015
5265440 18 55 04 +14 17 37	2020.60	5	339.30	0.10	3.994	0.012
5676692 18 57 34 +32 09 21	2020.60	3	245.74	0.33	0.944	0.005
6028133 18 59 14 +49 35 26	2020.60	4	35.62	0.78	2.440	0.029
6737887 19 32 06 +28 16 00	2020.61	4	3.45	0.02	5.434	0.005

Table 1: Position angle and separation measurements of the target systems, along with date observed, number of fits cubes, and standard errors

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