First Remote Student Speckle Interferometry Double Star Observations on the InStAR Student Robotic Telescope Network

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Abstract: In this first operation of the Institute for Student Astronomical Research (InStAR) Student Robotic Telescope Network, students in Hawaii, California, and New York remotely operated the telescope at the Purple Sky Observatory in Midland, Texas. Speckle interferometry astrometric measurements were obtained for 31 close double stars with separations ranging from 1.89 to 6.15 arcseconds. The new network is briefly described, along with the remote observation instrumentation, software, procedures, and results.

Introduction

Having a dedicated robotic observatory network provides an environment where students can learn to develop and manage a modern research organization. The InStAR Student Robotic Telescope Network will complement existing observatories to provide research data for all levels of astronomers — from amateur to professional. Today's undergraduate students will become tomorrow's graduate students, and eventually professional astronomers. Providing them with a means of collecting research-grade data is an important step in this process.

Currently there are five observatories in the InStAR Student Robotic Network. The Purple Sky Observatory is the first to host this network's remote student observations, forming the basis for this paper. The Fairborn Institute Robotic Observatory, FIRO, (Genet) is just now starting to host remote student observations. The Shepherd's Lair (Gray) and Estrada Observatory (Estrada) are ready to host remote student observations, but have not done so yet, while the Plum Tree Observatory (Freed) is still coming online. Other observatories are welcome to join the network.

Speckle interferometry is an image processing technique, pioneered in the 1970's (Labeyrie, 1970) where the diffraction limit of a telescope can be reached, operating below the seeing limit of the atmosphere (Harshaw, 2017). It is therefore relatively independent of atmospheric conditions and shifts the limiting factor from atmospheric seeing to the telescope's aperture. Speckle interferometry allows stars with smaller separations to be split when compared to CCD imaging. Measuring these stars are important because doubles with smaller separations are more likely to be orbiting and to be orbiting with short periods.

Instrumentation

The Purple Sky Observatory, led by Ryan Caputo, consists of a six-inch classical Cassegrain telescope with a focal length of 1800mm (f/12) and an ASI 1600mm CMOS camera. The small 3.8 μm pixels and long focal length give a sampling of approximately 0.4″ per pixel. This instrumentation is particularly suitable for speckle interferometry because of the fine sampling relative to the 6" aperture of the telescope. Furthermore, the camera is a CMOS sensor with a high readout speed and low read noise (~1 e). The low read noise allows faint signals to be recorded in short exposures, giving CMOS chips an advantage over CCD chips even when the quantum efficiencies are similar (Genet 2016). Figure 1 shows the telescope.

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A Baader G-filter was employed to restrict the bandpass.

Figure 1: Caputo and the Purple Sky Observatory.

Target Selection

Because speckle interferometry allows diffraction limited measurements to be made, the main limitation was the six-inch aperture of Caputo's telescope. However, the full resolving power of the telescope could only have been achieved if the sampling was adequate. The airy disk at 540 nm (G-filter) is 1″, meaning there are about five pixels across the airy disk. Six to seven pixels is optimal for maximum resolution (Rowe, personal communication); therefore, the telescope was further limited by pixel scale, so higher separations were targeted. Separations 1.9″ and wider were chosen. Since the exposure time could be no greater than 40 milliseconds to avoid image smearing, the stars had to be relatively bright, so stars above magnitude 10.5 were not considered. High delta magnitude pairs, set as anything greater than two magnitudes of difference, were also not considered. Finally, only stars visible from the Purple Sky Observatory in June were chosen, corresponding to right ascensions of 11 to 22 hours and declinations north of -20°. All of these stars were chosen using a spreadsheet compiled by Richard Harshaw (2020).

Software

Dave Rowe's SpeckleToolBox was used to generate FITS cubes, process the results using Fourier transforms, and then present them as autocorrelograms for measurements (Harshaw, 2017). To calibrate the meas-

urements, we used drift calibration to determine a camera angle and pixel scale for this run of, respectively, -110.74° and 0.42866″/pixel.

The software Cartes du Ciel (Chevalley) allowed targets to be selected by HD number and commanded the mount to the selected coordinates. NINA, "Nighttime Imaging 'n' Astronomy," (Berg) allowed, among many other functions, an on-the-spot plate solve routine to determine pointing error. NINA commanded a quick exposure which it then passed off automatically to Platesolve2, written by Dave Rowe. The coordinates of the image were uploaded to the mount to update its pointing. A re-slew command was then sent manually through Cartes du Ciel to center the target.

The capture software was then opened. We initially used FireCapture (Edelmann), but found the download times to be slower than the capture rate of the camera. SharpCap (Glover) performed the same basic functions as FireCapture, and due to the more streamlined nature of SharpCap, we switched to this software in the middle of the first observing run, and we used it for the entirety of the second observing run. Figure 2 shows SharpCap being controlled by Marchetti.
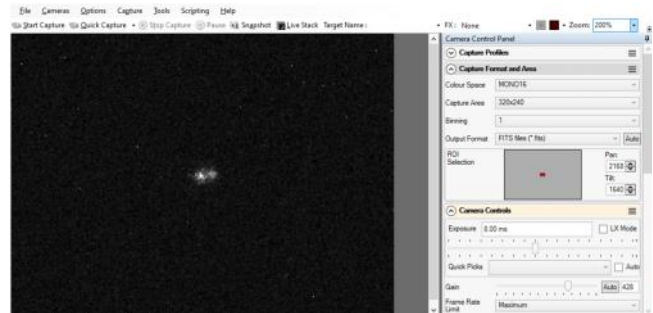

Figure 2: SharpCap imaging the double star STF 1785, 2.64″ separation (raw frame).

A problem arose when it came time to measure the stars; all five of the images that were taken using SharpCap during the first observing run had position angles that varied drastically from what the previous measurements suggested. To try and find what was causing this problem, image stacks from the short speckle exposures were made in Registax 6. Registax can perform lucky imaging which allows better images, in this case stars with lower FWHM values, to be recorded (Malsbury, 2013). When these were opened in AstroImageJ, the orientation of the stars was mirrored across the x axis, as shown in Figure 3. The problem was that SharpCap automatically produced .ser files, which we had been converting to .fits files. We found that this conversion was breaking image orientation, resulting in the discrepancy in position angle. When SharpCap's settings were adjusted to save directly

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to .fits files, the image orientation was preserved, and the problem was resolved. Aside from that, both Fire-Capture and SharpCap appear to be identical in basic functionality, and there is no distinction between data gathered by them.
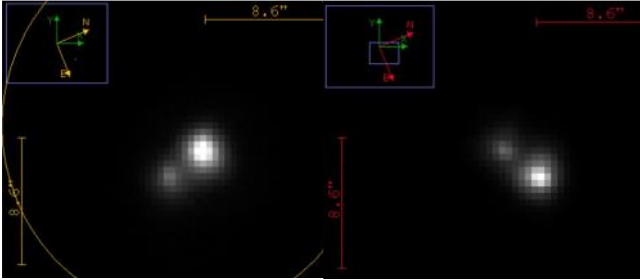

Figure 3: A five second exposure of D 22 (left) compared to the image stack of the speckle files (right), which had been convert-ed from .ser to .fits, flipping the image about the horizontal axis.

Remote Observation

Above all, the goal of the project was to conduct remote speckle observations. Students from Hawaii, California, and New York logged into the Purple Sky Observatory computer with AnyDesk, which allows multiple people to be connected to the host computer at once; they can see the screen and have mouse control. The significant difference that arises from remote operation is that the team cannot see or hear the telescope.

Not being able to interact with a telescope physical-ly — only though predetermined software and rather limited hardware — poses many potential problems. The main issue encountered was the telescope's poor pointing accuracy. Due to it not being a permanent set-up, the telescope is never polar aligned well, nor does it have a mount model. The procedure incorporated the plate solve routine to correct for the pointing error.

The speckle routine allowed a much cleaner split of the primary and secondary than traditional CCD imag-ing techniques, as is evident in Figure 4. On the left, a single eight millisecond exposure is displayed in As-troImageJ. The autocorrelogram generated by Speckle-ToolBox is displayed on the right. The bright spot in the middle is the primary, and the secondary star is one of the bright spots surrounding. One minor inconven-ience of the autocorrelogram is the secondary star is duplicated as two sidebands. Resolving this ambiguity requires at least rough knowledge of the expected posi-tion angle. All of the double stars measured here move slowly, so we can be confident the stars will have near-ly the same position angle as before, resolving the am-biguity.
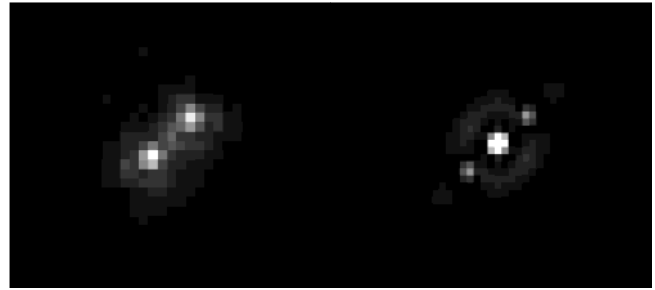

Figure 4: A raw image frame of STF 2909AB (left), and the processed speckle interferometry image from SpeckleToolBox (right).

Measurements

Measurements are given in Table 1. The systems are listed in order of right ascension. The Number of Images is the number of fits cubes measured, with each fits cube consisting of 1000 individual frames.

Sample Orbit

STF 1785 has an estimated period of 155 years. Gaia measured this pair in 2015.5, five years before our measurement. Therefore, the pair is expected to have traversed about 3% of its orbit between Gaia's meas-urement and our measurement.

The Orbit Predictions spreadsheet devised by Drummond can quantify this expectation (Drummond 2020). This spreadsheet provides the ex-pected position angle and separation for a known binary star at a given time. The spreadsheet was updated with the most recently published orbital elements for STF 1785 (Izmailov, 2019), and it predicted a position angle of 190.8o and separation of 2.749″ at the time of our measurement. Our measurement (191.3o, 2.6″) is in good agreement with this prediction, so much so that the two points are almost on top of each other as shown in Figure 5 below.
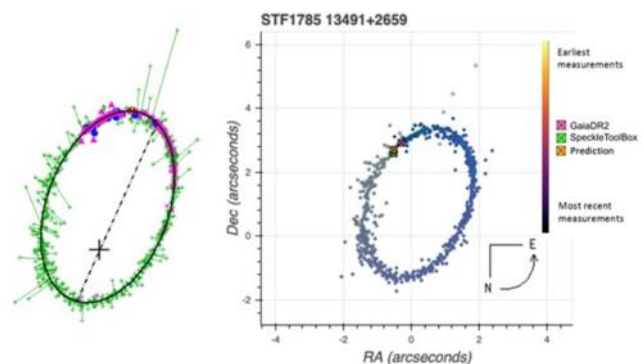

Figure 5: At left, the historical measurements of STF 1785 are plotted with our measurement and the Gaia DR2 measurement labeled. At right, the WDS orbital solution is compared.

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System	Date	Number of Images	Position Angle (°)	Standard error on Position Angle (°)	Separation (")	Standard Error of Separation (")
STF 1510	2020.43	6	328.0	0.08	5.64	0.01
STT 261	2020.43	4	337.4	0.15	2.53	0.00*
STT 266	2020.43	6	355.3	0.06	1.92	0.00*
STF1785	2020.43	4	191.3	0.06	2.64	0.00*
STF1858 AB	2020.43	5	36.8	0.11	3.10	0.01
BU 346	2020.43	5	276.7	0.19	2.80	0.01
STF1890	2020.43	6	45.8	0.61	2.56	0.02
STF1905	2020.43	6	162.6	0.33	3.00	0.02
STF1896 AB	2020.43	5	276.4	0.14	4.14	0.02
STF1950	2020.43	4	91.0	0.18	3.30	0.00*
STF1954 AB	2020.43	4	171.4	0.10	3.97	0.01
STF1985	2020.43	4	354.4	0.07	6.15	0.01
STF2213	2020.43	5	327.0	0.03	4.77	0.00*
STF2404	2020.43	4	180.2	0.04	3.61	0.00*
STF2466 AB	2020.43	5	102.4	0.07	2.50	0.01
STF2522	2020.43	4	338.2	0.24	4.55	0.01
STF2525 AB	2020.43	6	289.2	0.16	2.26	0.01
STF2545 AB	2020.43	5	326.4	0.10	3.66	0.01
STF2613 AB	2020.43	5	354.3	0.10	3.52	0.00*
HJ 1485	2020.43	4	275.6	0.11	4.72	0.01
H N 138	2020.43	4	326.7	0.05	3.27	0.00*
WEI 35 AB	2020.43	5	213.7	0.02	4.19	0.01
HJ 1537	2020.43	5	22.4	0.08	3.57	0.01
STF2742	2020.43	6	213.4	0.09	2.95	0.02
STF2749 AC	2020.43	5	176.3	0.10	3.46	0.03
STF2760 AB	2020.43	4	33.1	0.07	5.62	0.01
STT 437 AB	2020.43	5	19.6	0.04	2.54	0.00*
STF2799 AB	2020.43	6	258.1	0.07	1.89	0.00*
BU 274	2020.43	5	180.3	0.07	3.66	0.01
STF2826 AC	2020.43	5	81.4	0.14	4.0	0.02
STF2909 AB	2020.43	4	156.4	0.50	2.38	0.01

Table 1: Position angle and separation measurements of the target systems
*Stars with standard error listed as .00 have standard errors between .001 and .004

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Discussion: Benefits of Speckle Interferometry

Speckle Interferometry allows close pairs, such as those presented here, to be measured. During the observing run, one of us (Armstrong) requested standard CCD images of several of the stars in multiple filters using the Las Cumbres Observatory 16" telescopes. Even though the images were coming from observatory locations with excellent seeing, only a few of them were able to be measured because of the stars' small separations. Figure 6 shows STF 2404, a pair with a 3.6″ separation, imaged by LCO on the left and Caputo's 6" telescope on the right. Caputo's 6" telescope outperforms the 16" telescope because speckle interferometry removes the atmospheric limitation.
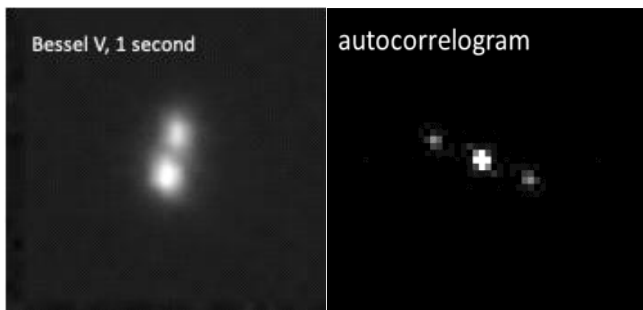
Figure 6: STF 2404: A 3.6-arcsecond separation, imaged with the LCO 16-inch telescope (left) and with Caputo's 6- inch telescope processed in SpeckleToolbox (right). Note they have different orientations due to different camera angles.

Speckle interferometry is a single-target type of observation that can only be done target by target. As such, efforts are being made to develop a network with the main science goal being speckle interferometry.

Furthermore, Gaia Data Release 2 (DR2) has revealed thousands of previously unknown double stars with similar proper motion and parallax. These targets are well situated for speckle interferometry of moderate-aperture telescopes.

Conclusion

InStAR is working to build a large-volume speckle interferometry program for double stars too close to measure via traditional long exposure imaging. The Purple Sky Observatory has performed the first remote speckle observations in the network with 31 measurements of close double stars within the range of 2-6″. Students from Hawaii, California, and New York connected to the observatory computer and controlled the telescope. The telescope operator, Ryan Caputo, was only present to supervise the telescope and the students.

Acknowledgements

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