A New Opportunity for Speckle Interferometry on the Mount Wilson 100-inch Telescope

Rick Wasson[1], Reed Estrada[2], Chris Estrada[2], Richard Harshaw[3], Jimmy Ray[4], Dave Rowe[5], Russ Genet[6], Rachel Freed[7], Pat Boyce[7 8], and Tom Meheghini[9]

1. Orange County Astronomers, Murrieta, California
2. Institute for Student Astronomical Research (InSTAR), Lancaster, California
3. Brilliant Sky Observatory, Cave Creek, Arizona
4. Arizona Sonoran Desert Observatory, Glendale, Arizona
5. PlaneWave Instruments, Rancho Dominguez, California
6. California Polytechnic State University, San Luis Obispo, California
7. Institute for Student Astronomical Research (InSTAR), San Francisco, California
8. Boyce Research Initiatives and Education Foundation (BRIEF), San Diego, California
9. Mount Wilson Institute, Pasadena, California

Abstract: Speckle interferometry observations were made by a group of students from Paso Robles High School on the Mount Wilson 100-inch Hooker Telescope - the first time that high school students have made scientifically useful observations with it. This field trip was supported by InSTAR educators and amateur speckle observers. This paper describes the "Engineering Test Run" which was conducted to check whether amateur speckle equipment could be successfully used on the large telescope, to help ensure success of the student observations. All goals of this Engineering Test were accomplished. The close binary stars STT 269AB and A 570 were observed in multiple filters. Autocorrelation and BiSpectrum Analysis astrometric and delta magnitude results are presented.

Introduction

The iconic 100" Hooker Telescope is one of the most famous and historically significant science instruments of the twentieth century, but it is not widely known that Mount Wilson Observatory has been the site of high-resolution astronomy for a full century. In 1919 J.A. Anderson built a visual interferometer for the 100" telescope, using it to measure, for the first time, the orbit of a spectroscopic binary star - the bright nearby star Capella, separation about 0.05" (Anderson, 1920 and Merrill, 1921). This landmark achievement proved that the new interferometry technique actually works on stars, making way for the famous 20-foot interferometer on the 100", with which the size of a star - Betelgeuse – was first measured (Michelson & Pease, 1921). Several other ground-breaking interferometry research projects have utilized the excellent seeing at Mount Wilson, culminating in the current CHARA array (McAlister, et al. 2005).

The 100" telescope is best known for Hubble's famous discoveries that the spiral nebulae are separate galaxies far from the Milky Way, and for initial realistic measurements of the scale and expansion of the universe. Although no longer used for deep-sky studies because of the lights of millions of people living in the cities below, Mount Wilson is still an excellent site for the study of bright objects.

The Speckle Interferometry technique, proposed and demonstrated by Antoine Labeyrie in the early 1970's and developed for binary stars by McAlister (1977), was first used by professional astronomers on the 100" in 1985. The 100-inch was closed from 1985 to 1993 but since then it has again been used for speckle observations by several professional teams (Hartkopf et al. 1997). Because the 100" mirror has no central hole, the Cassegrain focus was located high off the floor, awkward even for professional speckle observers.

In the last several years the 100" has begun a new life in astronomy public outreach. As part of that outreach, a safe, accessible location for public viewing was needed on the main floor level, to eliminate the high ladders and platforms used by past observers. A new

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Figure 1. Students got a day-time orientation tour of all the historic telescopes and history of Mount Wilson. The 100" Cassegrain relay optics is the white tube below the massive blue mirror cell. Portraits of Edwin Hubble and Mount Wilson Observatory founder George Ellery Hale look on.

system of relay optics now brings the Cassegrain focus down below the primary mirror for safe, convenient public access.

New Opportunities

Recent developments have made speckle interferometry accessible to non-professionals at Mount Wilson: (1) the 60" and 100" telescopes are open to amateur and student observers on a fee basis; (2) new sensitive high-speed cameras and free analysis software have made speckle interferometry practical and affordable for amateurs and students.

The Paso Robles School District in central California has an outstanding science field trip program, supported by generous private grants. In 2018 a group of Paso Robles High School (PRHS) students came to Mount Wilson for a history-geology-ecology-environment-astronomy field trip, viewing the sky with their own eyes through the 100" telescope.

In June 2019, a new group of eight PRHS students in the Astrometry Field Research Program, in collaboration with the Institute for Student Astronomical Research (InSTAR), completed observations, analysis and draft write-ups for two southern double stars, remotely observed with robotic 0.4-meter telescopes at Las Cumbres Observatory (Gates, et al. 2020a and Hughes, et al. 2020). These students enjoyed docent-guided tours of the mountain's environment, facilities and history, Figure 1, just like the 2018 group. But this research group came to Mount Wilson with an added goal: to observe close double stars with the 100" telescope using the Speckle Interferometry technique.

The PRHS students had no opportunity for training or experience in speckle interferometry before the field trip. Therefore, a team of amateurs and teachers were invited to mentor the students, giving them "hands-on" training in observational science. This paper supplements details that the students didn't have time to learn on the mountain or include in their accompanying paper (Gates, et al. 2020b).

The Support Team

In conjunction with InSTAR, a group of amateur speckle observers and teachers came together to support the PRHS field trip. The team proposed an "Engineering Test Run" to see whether the combination of available speckle instrumentation would work on a large telescope. Mount Wilson Executive Director Tom Meneghini graciously offered to host the team on the 100" for an evening checkout, to help ensure that speckle observations with amateur equipment never before used on such a large telescope, would be successful for the students.

The goals of the Engineering Test, conducted on June 7, 2019 were:

- Reach focus on the science camera, when mounted on the relay optics at the public focal point.
- Evaluate telescope pointing and slow-motion controls for finding and centering target stars in the very small camera field.
- Demonstrate the practicality of Drift Calibration with very long focal length.
- Develop and practice communication and coordination procedures with the Telescope Operator.
- Identify workstations and observing tasks for student involvement and participation.
- Demonstrate accurate speckle measurement of a close double star.

While Tom Meneghini operated the telescope, Reed and Chris Estrada used the fine guidance controls for finding and centering, and Rick Wasson ran the speckle camera through a laptop computer. We successfully accomplished all the goals of the Engineering Test, including demonstrating repeated calibration drifts, and measuring Separation and Position Angle of two close binary stars (i.e., separation much smaller than the "seeing disk"), in four filters.

The rest of the support team gathered a week later with the students to guide them through the speckle observations, Figures 2, 3 and 4. At the end of the evening, everyone got the bonus of looking through the great telescope, Figure 5.

Speckle Instrumentation

The camera optical train of Figure 6 consisted of a two-inch Vixen flip mirror attached to a ZWO five sta-

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tion 1¼ inch electronic filter wheel. This was attached on the straight-through port to the ZWO ASI1600 cooled monochrome science camera, on loan from Dave Rowe. A 23 mm illuminated cross hairs eyepiece was on the flip port, for a wider field to locate and center targets when a slew put the star outside the field of view of the science camera.

No Barlow was used for extra magnification; the 100"" f/11.5 relay optics and camera 3.8 μ pixels were estimated to give adequate sampling (4 to 5 pixels across the Airy disk) for initial speckle checkout. Eliminating the Barlow gave the largest field available for finding target stars (about 125 arc-sec wide), and the longest calibration drifts possible (about 8 seconds).

Several standard photometric, photographic and near-IR long-pass filters were used for the 100" observations, with the characteristics shown in Table 1. All the filters are of the modern interference type. The

Figure 2. Dave Rowe gave the students an introductory lecture on Speckle Interferometry before dark.

Figure 3. During student speckle observations, the camera view was routed to a large monitor for all to see. Science teacher and field trip leader Jon-Paul Ewing described the procedures, as the amateurs operated the camera.

Figure 4. The students got a behind-the-scenes tour of the 100" RA worm drive gear from Mount Wilson Executive Director Tom Meneghini

Figure 5. After speckling, everyone looked through the 100".

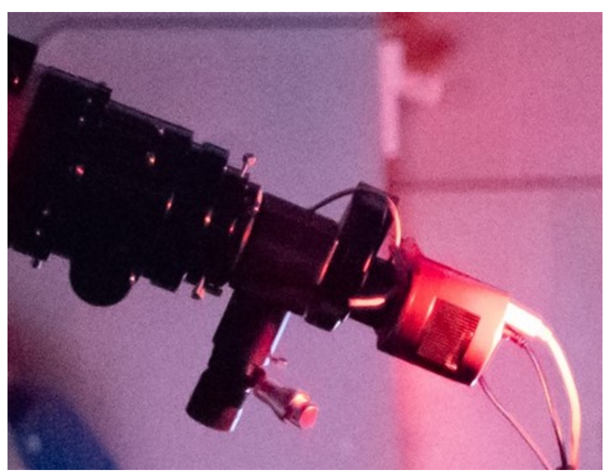

Figure 6. Speckle Optical Assembly. Left-to-Right: Focuser, Flip Mirror (1¼-inch reticle eyepiece pointing down), Filter Wheel, and ZWO ASI1600MM Pro camera. Cables control Peltier cooling, USB3.0 camera interface, and filter wheel.

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Photometric System	Manufacturer	Type	Filter	Wavelength (nm)	Width (nm)
Johnson	Astrodon	Interference	B	435	80
Johnson	Astrodon	Interference	V	542	90
LRGB	Baader	Interference	R	634	105
Sloan	Astrodon	Interference	i'_2	753	160
none	Astronomik	Interference	IR807	862	200

Table 1. Characteristics of the filters used for the Speckle Engineering Run and the Paso Robles Student Run

equivalent "Wavelength" is for the convolved characteristics: i.e., the weighted average of filter transmission times QE of the CMOS detector.

The "Width" column of Table 1 is for 50% transmission, but for the IR807 long-pass filter, the long side is determined by the CMOS Silicon detector sensitivity limit (assumed to be 1000 nm), rather than the filter transmission.

A clear (luminance) filter in the first position was used for initial target acquisition and centering. In the Engineering Run, the B, V, i' and IR807 filters were used; for the Student Run, the R filter was substituted for IR807.

Target Selection

A Target List was prepared in advance of the observations. Since the resolution of the 100" telescope, about 0.06" at 600 nm, is much better than usually available to high school students and amateur astronomers, close doubles were targeted. The WDS Catalog was searched, using the search tool WDS1.2 (Rowe, 2017), for a separation range of 0.0" to 0.5", RA near the meridian on June evenings, and declination ±20 degrees from the Mount Wilson latitude (+34 degrees). From the very large list of possible candidates, priority was given to known binaries having an estimated orbit needing more speckle observations, and doubles that may include a red dwarf.

For the Engineering run, a few stars with a separation range of 0.1"-0.4" were chosen, to evaluate the capabilities of the new speckle system. Single reference stars for deconvolution were chosen from the list of nearby SAO stars, also provided by the WDS1.2 program.

Observing Procedures

Three stations were necessary for telescope control and data acquisition:

(1) Telescope Operator (T.O.) station, from which the telescope was slewed to the target;

Figure 7. The 100" observing floor. The Telescope Operator station is located on the upper level, left of the stairs.

(2) Fine Guidance station for small movements to find and center the star, located near the telescope focus;

(3) Camera Operator station, a laptop computer on a movable table under the telescope, connected by cables to the speckle instrumentation, for control of the camera, Peltier cooler and filter wheel.

A "Target Card" was filled in with Double and Reference star information, including SAO number, which is the easiest way for the Telescope Operator to command the 100" to the target. This card was taken to the T.O. station, located up a stairway above the observing floor, shown in Figure 7. Communication between the T.O. and observers below was through a built-in, portable "Comm Box" system located near the focal point.

On request from the Camera Operator, the T.O. moved the telescope to the next target. Often the star appeared in the camera field of view (FOV), as seen in Figure 8. Sometimes the star passed slowly through and stopped just outside the FOV. If the star was not found, the telescope was moved by slow-motion controls located near the focus, while watching through the

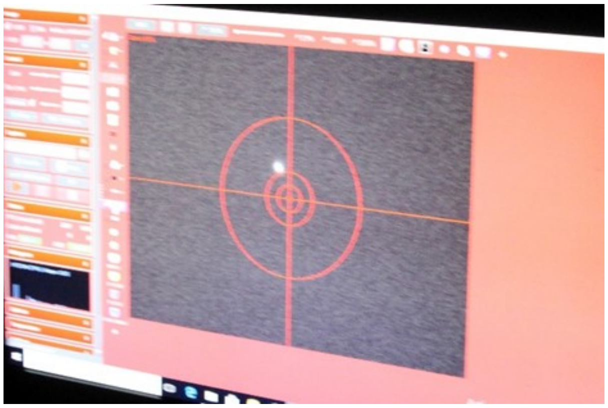

Figure 8. Example of the FireCapture display of the camera FOV, showing a star being centered.

Figure 9. Several of the authors watch the highly magnified speckle camera images as 1000 frames are automatically recorded in each of four filters.

wider-FOV eyepiece of the flip mirror.

After the target was found and centered, the focus, filter and camera settings were double-checked, and a 600x600 pixel Region of Interest (RoI) was drawn around the star. Then recording was started for a sequence of 1000 images in each of the four filters, without further intervention (Figure 9). FireCapture communicated with the filter wheel under ASCOM protocols (Denny, 2019), automatically moving the filter wheel to the next filter before each new 1000-frame sequence. The speckle images were saved as 16-bit FIT files; the camera only provides 12-bit output, but FireCapture fills the least-significant-bits with zeros to create standard FIT files.

After the first double star was recorded, the telescope was moved to its Reference star, but it was not seen in the camera or eyepiece field. After an extended but unsuccessful manual search, it was decided to move on to the next target. A series of Calibration Drifts was then done for this close double star, in case the same problem might occur again for its Reference star.

Double stars which are closer than the seeing disk may generally be used for drift calibration, because each image is used independently, and the two components have very little effect on the centroid of the seeing disk. However, a double with components wider than the seeing, particularly if they are similar in brightness, should not be used, because the centroid may shift back and forth between components in successive frames, creating unnecessary noise in the drift path.

After completing an observation, entries were made in an Observing Log, which was simply a copy of the Target List spreadsheet. Log entries included date, star, filter and Sequence number - an identifier for each sequence of frames recorded, which is automatically incremented by FireCapture. This Log acted as backup for the folder names in which the images were stored.

Although not needed in the Engineering Test, a flat screen television was attached to the laptop computer for the Student Run to allow everyone to watch the data collection. This allowed information and participation by the other student team members manually recording the sequence numbers and providing target information to the telescope operator.

Software

Before the Engineering run, a list of close double stars suitable for resolution of the 100" aperture was assembled using the “WDS1.2” program (Rowe, 2017). This utility program searches the WDS Catalog to assemble a list of all doubles within the user-input parameters; it also provides a list of all SAO Catalog stars within 3 degrees of the double, from which an appropriate Reference star can be chosen.

The “FireCapture” program (Edelmann, 2017) was used for data acquisition. It is available on his website, wonderplanets.de. This program, designed for planetary photography, features automatic telescope, camera, and filter wheel control, and flexible file naming. It can save images in several formats including FIT files, the standard image format for astronomy, required by STB.

All speckle processing and analysis made use of the “tools” in the “Speckle Tool Box” (STB) program (Harshaw, Rowe and Genet, 2017). The “Drift Calibration” tool automatically analyzes a sequence of short-exposure images, in which the star moves across the frame at the sidereal rate while the telescope RA drive is turned off. The tool uses star declination and computer time of each image, written to the FIT header by FireCapture, to calculate the average pixel scale and slope (camera rotation angle) for each drift sequence.

Speckle Autocorrelation (AC) analysis was processed in "STB1.05," using the "Make FITS Cubes," "Process FITS Cubes," and "Speckle Reduction" tools. Double star Position Angle (PA) and Separation (ρ) are the astrometry products of AC measurement.

Bispectrum Analysis (BSA) processing was done in "STB1.13" (Rowe and Genet, 2020). The goal of BSA is to reconstruct a near-diffraction-limited image of the double star, in which the PA 180-degree ambiguity, always present in AC, is removed. BSA also recovers the proportional flux of each component, so approximate delta magnitude can be extracted by aperture photometry.

If a single Reference (deconvolution) star is observed, it can be used for both AC and BSA processing, greatly improving the results by cancelling optical and atmospheric distortions which are common to both the Double and Reference star images.

Drift Calibration

Calibrations for pixel scale and camera rotation angle relative to the sky are essential for accurate astrometry. Observation of well-known double stars is a method often used for speckle instrumentation permanently mounted on an equatorial telescope. However, the Engineering and student observations were only short-term projects for observation of relatively few objects. A two-slit aperture mask, based on Young's interference principles, has been used for speckle calibration on the 100" by professionals in the past (Genet, et al. 2016). It is still available but is cumbersome and time-consuming to install and remove.

Drift calibration, commonly used with small telescopes by amateur speckle observers, is relatively easy, fast and accurate. However, to our knowledge, it has not been used before on such a large telescope of long focal length (100" f/11.5, FL~29m). We assumed it would be impractical for our small CMOS cameras, because of the extremely small FOV and short time for sidereal drift across the field. For example, the ZWO ASI290M camera FOV would be only 40 arc-sec wide, giving less than 3 seconds of drift time for a star at the celestial equator.

As part of planned automation capability for PlaneWave telescopes, Dave Rowe had already purchased a ZWO ASI1600M-Pro camera, and kindly made it available for the Mount Wilson speckle effort. The sensor of this camera is 18mmx13mm, more than 3 times larger than the 290. With this camera the 100" FOV is over 2 arc-minutes wide, yielding a drift time over 8 seconds at the equator; longer drifts occur at higher declination. Successful demonstration of the Drift Calibration technique was one of the primary goals of the Engineering run.

Fortunately, Drift Calibration worked very well, and was easier than expected on the 100". The camera's wider dimension was first roughly aligned with the E-W direction by moving a star back and forth across the FOV with the slow-motion controls. An ROI was drawn having full width (4656 pixels), but only about 400 pixels in height; this narrow ROI was necessary to minimize frame size and write time, thus increasing the number of frames recorded during each drift. About 80 frames were recorded in each drift, lasting about 9 seconds for a star at +26 degrees declination.

To prepare for each drift, the star was positioned at the eastern edge of the ROI band. A "3-2-1-stop" countdown was called over the intercom, the T.O. stopped the telescope RA drive, and the camera recording was begun. When the star reached the western edge of the field, the T.O. was requested to re-start the RA drive, and camera recording was stopped. Although it had drifted out of the FOV, the star was easy to recover by simply driving the telescope slow-motion control back to the west for the next drift; there was no declination shift that might have caused the star to miss the camera FOV.

Several drifts were completed in a few minutes so that temporary, random seeing-induced wandering of the star from the true E-W direction could be averaged. It was a great relief that the Drift Calibration technique was successful and easy to do with a telescope of such long focal length; a camera with a much smaller sensor would have made it much more difficult.

For Drift Calibration, STB calculates the centroid of the brightest star image in each frame, in the camera pixel reference system. It also reads the computer clock time for each frame, written to the FIT header during recording. The times do not need to be accurate (GPS), but only self-consistent during the brief drift. The sequence of drift centroids and times, plus the star's declination, provide all the information required for calibration of both camera angle and pixel scale. An example of the STB screen display for one Engineering drift is seen in Figure 10.

Results of all 5 drifts are shown in Figures 11 and 12. The famous Mount Wilson seeing was very good that night, as verified by the excellent agreement and small standard deviations of the 5 drifts. Generally, it is better to use the average of 10 or more drifts for calibration.

STB works only in the camera pixel row-column reference system, unaware of sky directions in advance. Therefore, actual PA must be verified or corrected by the user. STB subtracts the calibrated camera orientation angle (1.46° in our case, Figure 11) from the PA

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measured in the camera reference system.

The actual orientation of the camera was North-up and East-right, as seen in Figure 13 at left. East and West were reversed from the sky view, evident by the star drifting right-to-left in the calibration drifts. This was caused by an odd number of reflections (5) in the complete optical path: primary, secondary and tertiary mirrors in the Cassegrain configuration, plus two additional reflections in the relay optics. The secondary stars of both binaries observed in the Engineering run were expected to be in the southwest quadrant (PA 180-270). However, in the camera field, they appeared as the mirror image, in the lower left quadrant (apparent PA 90-180), and STB measured PA in that quadrant. Therefore, PA was corrected for East-West reversal using the equation

$$PA_{corrected} = 360 - PA_{STB}$$

as illustrated in Figure 13.

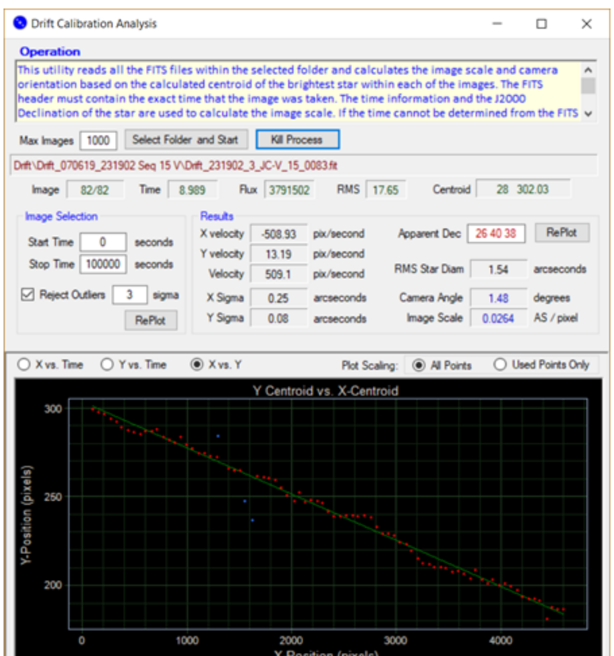

Figure 10. Screen Shot of one STB Drift Calibration sequence. Blue points are greater than 3-σ, which were not included in the linear regression.

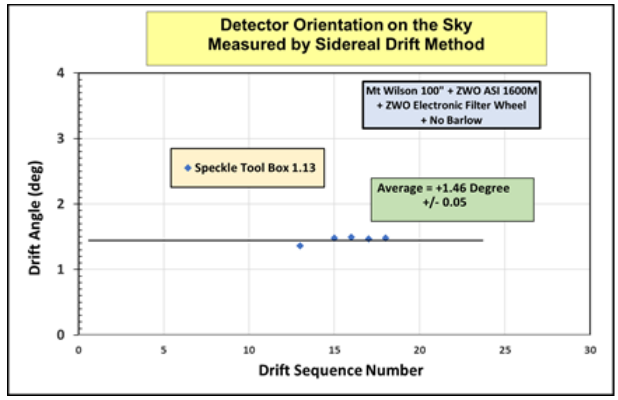

Figure 11. Drift Calibration Results for Camera Angle.

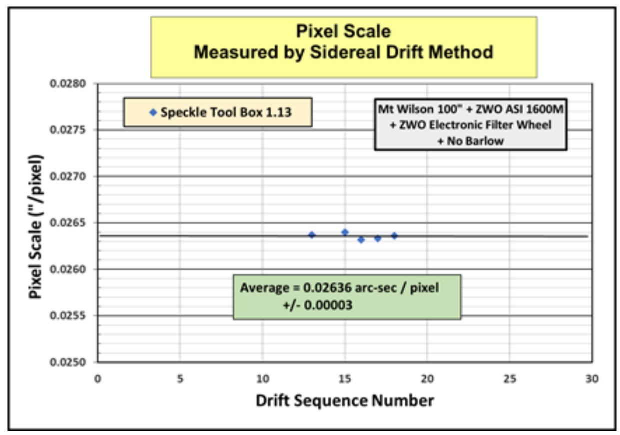

Figure 12. Drift Calibration Results for Pixel Scale.

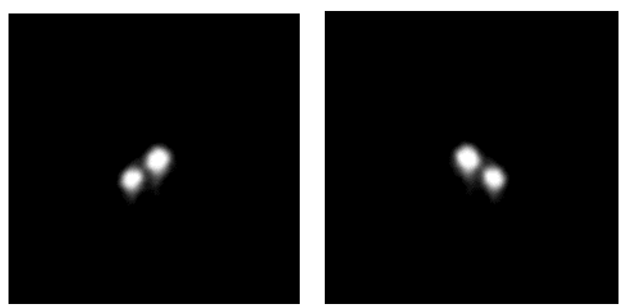

Figure 13. Binary star A570 re-constructed BSA image, in the V filter. At Left: Camera view in STB has north-up and east-right, a mirror image of the sky view, caused by an odd number of reflections in the optical train. STB measured PA_{STB} ~ 126°. At Right: Corrected PA orientation with north-up and east-left. $PA_{corrected}$ ~ 234°, consistent with the sky view and orbit ephemerides PA ~ 237°.

WDS	Discovery	Mag1	Mag2	Del V	Spectrum	Period	Grade	PA	Sep
13329+3454	STT 269AB	7.27	8.08	0.81	A6III	53	2	227	0.30
14323+2641	A 570	6.61	7.08	0.47	A6V	30	1	237	0.19

Table 2. WDS characteristics of the two double stars observed during the Engineering Test Run 7 June 2019. The columns are: WDS RA and Dec, WDS discovery designation, WDS magnitudes of primary and secondary components, WDS delta magnitude, WDS spectral type, Period (years) from WDS 6th Orbit Catalog, orbit grade, and PA and Separation ephemerides for 2019.5.

Results

Two bright double stars were observed during the Engineering Run on June 7, 2019. Their WDS characteristics are summarized in Table 2. The WDS orbit plots are shown in Figures 14 and 15.

Our new astrometric observations are presented in Table 3. Two methods of speckle data processing, both Autocorrelation (AC) and BiSpectral Analysis (BSA) as noted above, were performed for each of the four filters, giving a total of 8 measures for each star. Although the AC and BSA methods used the same original sequences of 1000 speckle frames, different processing always produces slightly different results; they were treated as independent measurements for calculation of the average and standard deviation shown at the bottom of Table 3 for each star.

Table 3 also provides BSA delta magnitudes in each filter. These ΔMag results are considerably smaller than the WDS magnitudes of Table 1, which are probably V magnitudes. This is true even for the Johnson V filter used here.

Figures 16 and 17 show AC and BSA images for the binary stars 13329+3454 STT269AB and 14323+2641 A570, respectively.

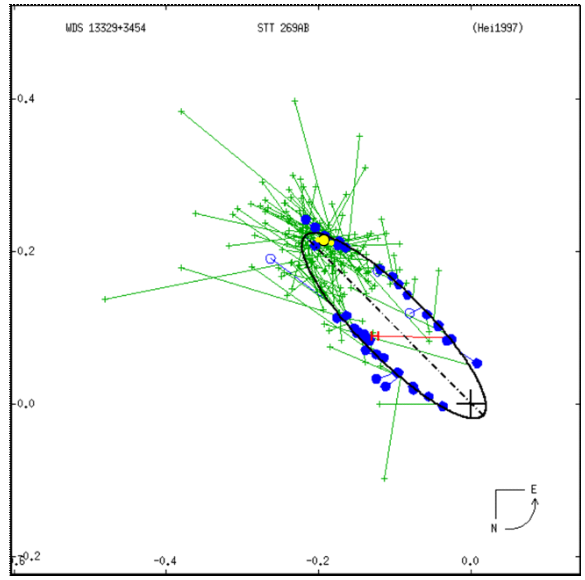

Figure 14. The WDS orbit plot of STT269AB. The larger yellow circle is the average of the new measurements from Table 3, and the two smaller yellow circles are the farthest outliers.

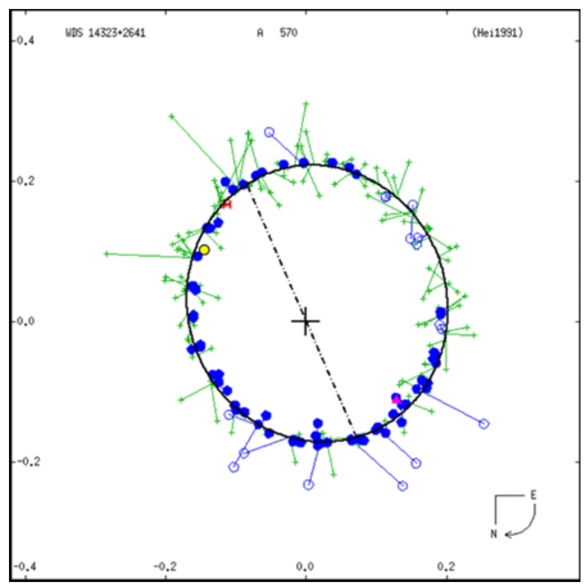

Figure 15. The WDS orbit plot of A570. The yellow circle is the average of the new measurements, and all 8 AC, BSA and filter measurements of Table 3 lie within it.

Discussion

The 100" Cassegrain focus, modified with relay optics for public access, now has a focal ratio of f/11.5, and can accommodate 2-inch or 3-inch eyepieces. Before the Engineering run, there was concern about whether the 2" speckle optical train could easily be mounted and brought to focus. However, minor movement of the tertiary mirror gave plenty of focuser travel, and there is still more tertiary travel available if needed in the future.

The famous Mount Wilson seeing was excellent on the night of the Engineering Test. Ideal weather often occurs in the Spring, when marine clouds blanket Los Angeles below, and cool, calm air flows gently over the mountain. An outside walk at midnight revealed a dark sky, bright Milky Way, no breeze, and no twinkling of the stars!

Double star targets were purposely chosen within about 20^{o} of the Mount Wilson latitude (+34^{o}) and were observed within about one hour of the meridian, to avoid extreme telescope orientation, high airmass and atmospheric dispersion; but the B filter BSA images in Figures 16 and 17 still have more distortion than at longer wavelengths.

With the very long focal length (over 29m), even the "big" sensor (17.6mm x 13.4 mm) of the ZWO ASI1600M camera gave a field of view (FOV) only about 2 arc-minutes wide. A 2-inch 55mm eyepiece having more than twice the FOV of our camera is normally used on the 100" to locate targets visually. The flip mirror has a 2" nose piece but M42 T-thread on both output ports; no adapter was available for mounting a 2-inch eyepiece. Therefore, a 1¼ inch 23mm illuminated eyepiece was used, giving a FOV only slightly larger than that of the camera. Nevertheless, the telescope pointed very well, landing the target star in the

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WDS	Discovery	Method	Filter	PA	Sep	ΔMag
13329+3454	**STT 269AB**	AC	B	220.48	0.280	
		BSA		220.95	0.286	0.20
		AC	V	222.51	0.296	
		BSA		223.04	0.295	0.09
		AC	Sloan i'	222.53	0.295	
		BSA		221.22	0.287	0.14
		AC	IR807	222.61	0.295	
		BSA		220.73	0.291	0.07
Average				**221.76**	**0.291**	
Std Dev				**1.01**	**0.006**	
14323+2641	**A 570**	AC	B	233.76	0.181	
		BSA		235.78	0.186	0.39
		AC	V	234.12	0.180	
		BSA		234.79	0.180	0.24
		AC	Sloan i'	234.02	0.179	
		BSA		233.96	0.185	0.22
		AC	IR807	234.04	0.178	
		BSA		235.44	0.181	0.15
Average				**234.49**	**0.181**	
Std Dev				**0.76**	**0.003**	

Table 3. Speckle measurements, using the Mount Wilson 100" Telescope, ZWO ASI1600M Pro CMOS camera, and interference filters, on Besselian date 2019.433. The columns are: WDS RA and Dec, WDS discovery designation, Method of speckle data analysis (Autocorrelation or BiSpectrum Analysis), filter (Table 1), Position Angle (deg), Separation (arc-sec), and BSA Delta magnitude (secondary-primary).

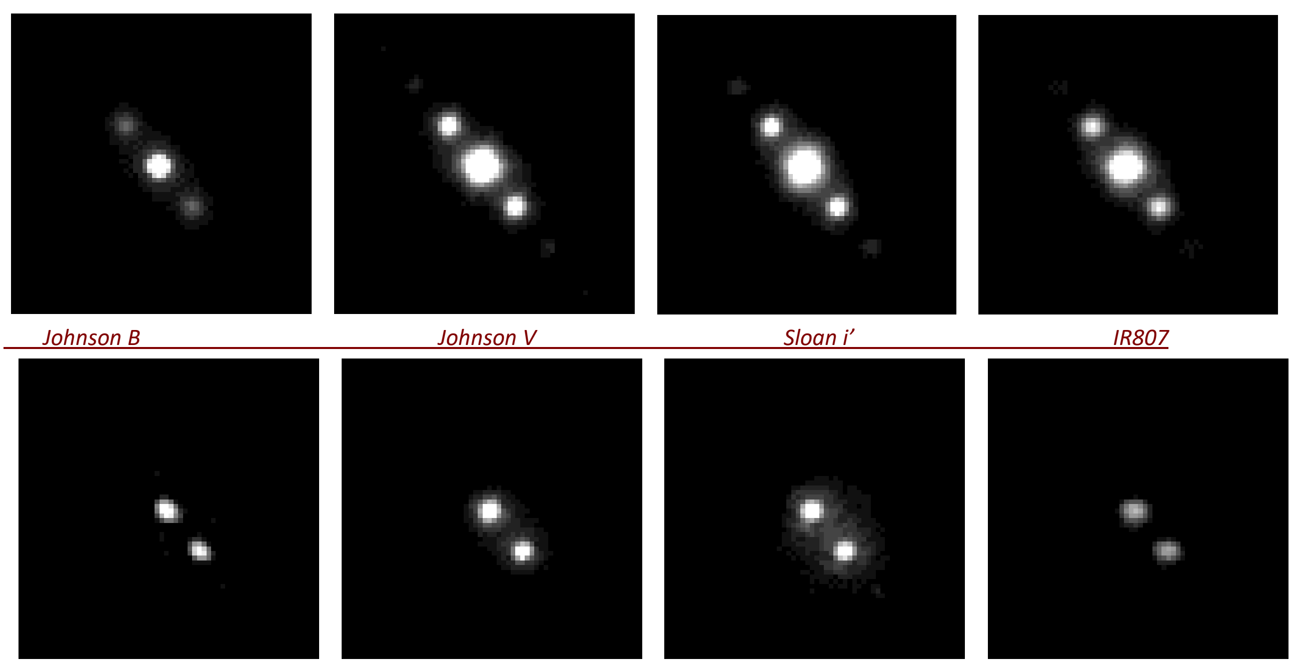

Figure 16. 13329+3454 STT269AB Autocorrelations (above) and reconstructed BSA images (below). The images are oriented North-up, East-left, as on the sky. No Reference star was observed.

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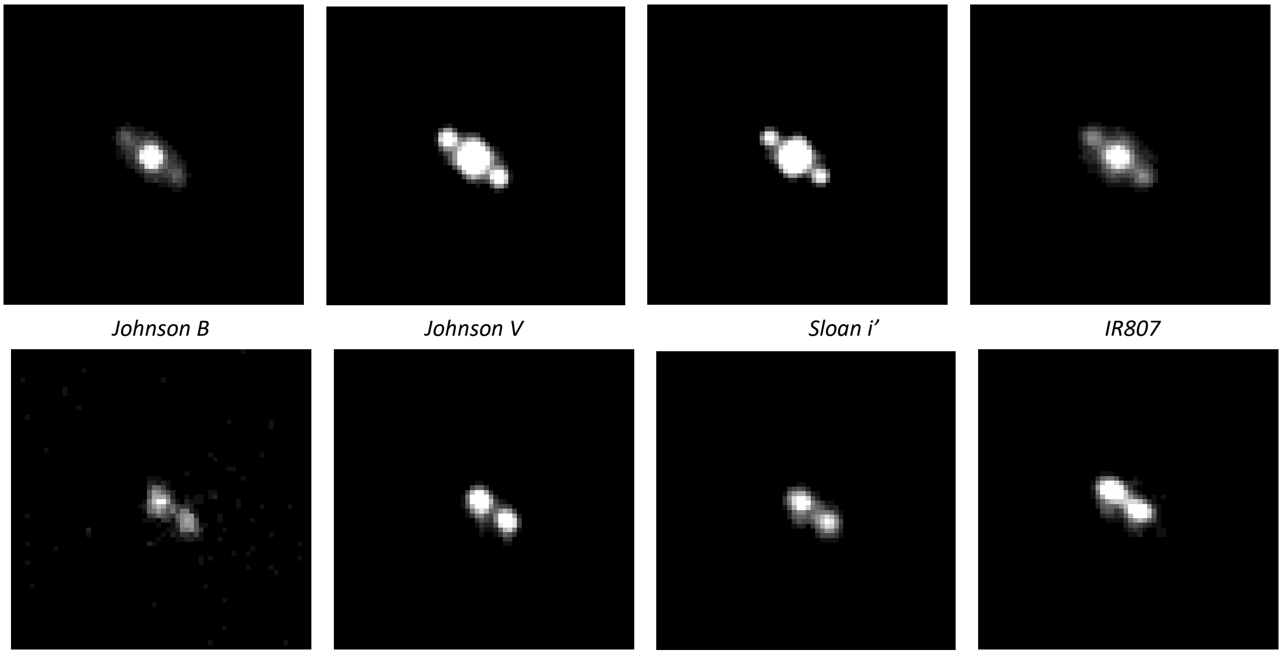

Figure 17. 14323+2641 A570 Autocorrelations (above) and reconstructed BSA images (below). The orientation is North-up, East-left, as on the sky. Reference star SAO 83321 was observed and used in both AC and BSA processing

(Continued from page 158)

camera FOV most of the time.

Centering the star on the illuminated cross hairs of the flip mirror eyepiece always placed the star near the center of the camera field, within the pre-selected ROI. Mechanical connections were all very solid, with most components coupled by standard T-threads. The 100" tracked very well, keeping the star inside the ROI for many minutes.

Before the Engineering Test, one of the greatest unknowns was whether Drift Calibration would be practical for such a small FOV. Fortunately, this technique was far easier and faster than expected, because of accurate pointing of the 100" and using the largest CMOS detector available. Full drifts of almost 10 seconds for Dec ~ 26^{o} were achieved routinely. The ROI allowed small file size, short write time and fast frame rate; more frames were recorded during each drift, to yield higher quality linear regression for each drift.

An intercom "count-down" procedure was developed to coordinate timing between the T.O. (stopping the RA drive) and Camera Operator (start recording). With a little practice, it was easy to coordinate the star position, telescope RA stop/re-start, data recording, and star recovery. The telescope declination remained solid, with no shifting north or south that might have "lost" the star after drifting out of the FOV. Pure RA slow motion westward always returned the star to the camera FOV for the next drift. Drift Calibration should be seriously considered by future speckle observers.

The ZWO electronic filter wheel was controlled by FireCapture with ASCOM protocols. Once a speckle sequence was started, the program recorded the next sequence of images, then advanced the filters and took all the sequences without further commands. In this way, multi-filter observations were made with no wasted time; this will be important for possible future "production" speckle runs.

Although the 100" theoretical resolution is less than 0.10", no added magnification was used, in order to maximize the FOV. Therefore, speckle observations of double stars closer than about 0.20" were not estimated to be practical because of moderate under-sampling (about 5 pixels across the Airy disk). However, new larger "full-frame" cameras should make higher-resolution speckle observations - all the way to the diffraction limit - possible in the future, by providing a larger FOV with similar pixel size. The ideal pixel sampling is about 7-8 pixels across the Airy disk, so a 1.5x Barlow would work well for 3.8μ pixels.

During this 4-hour Engineering Test run, only two double stars were observed, because time was spent exploring the issues discussed above. A future "production" run could observe a much higher number of stars following similar routine procedures.

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Conclusions

All the major goals of the Engineering Run were achieved. These included:

- Focus of the Speckle optical assembly was easily reached, with plenty of further adjustment capability remaining.
- Drift Calibration was successfully demonstrated with the "wide" FOV (~2') of the large format CMOS camera. Recovery of the star and repeated drifts were quick and easy to do.
- Speckle observations of two close double stars were successfully completed, including a reference star for the closer double.
- Efficient multi-filter observations were made, with virtually no wasted time between filters, using FireCapture automatic filter control through ASCOM protocols.
- Magnification of the f/11.5 modified Cassegrain focus was adequate to resolve double stars closer than 0.2". Slightly greater magnification (1.5x) should be practical for better Airy disk sampling, to approach the theoretical resolution of the 100" telescope.
- Hardware, interfaces, communication and procedures were prepared and ready for the Student observations.
- The telescope and amateur hardware were successfully used by the Student Team to make speckle observations.
- During their field trip, the students contributed their own new speckle measurements to science, while immersed in the living history of Mount Wilson Observatory, Figure 18.

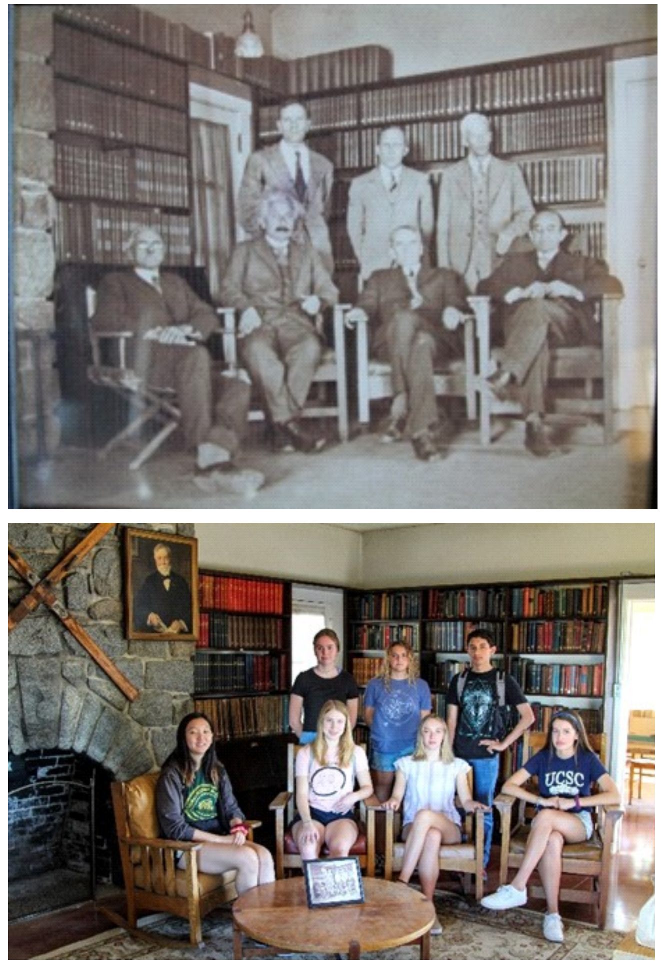

Figure 18. The PRHS students pose in the "Monastery" Library of Mount Wilson Observatory, just as some of the giants of 20th century astronomy had posed with Albert Einstein more than 88 years earlier, during his visit in January 1931.

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References

Anderson, J.A., 1920, "Application of Michelson's Interferometer Method to the Measurement of Close Double Stars." Contributions from Mount Wilson Observatory, No. 185, *ApJ*, **51**, 263-275.

Denny, R., 2019, https://ascom-standards.org

Edelmann, Torsten, 2017. FireCapture2.6. http:// firecapture.wonderplanets.de

Gates, E., Garrett, B., Corgiat, P., Ezzell, M., Ewing, J-P., Harshaw, R., 2020a, "Astrometry of WDS 13472-6235", *JDSO*, **16** (2), 148-150 (this issue).

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Gates, E., Hughes, A., McNerny, M., Rendon, R., Garrett, B., Chung, S., Corgiat, P., Ezzell, M., Ewing, J-P., 2020b, "Close Binary Speckle Interferometry on the 100-inch Hooker Telescope at Mount Wilson Observatory", *JDSO*, **16** (2), 163-168 (this issue).

Genet, R., Rowe, D., Meneghini, T., Buchheim, R., Estrada, R., Estrada, C., Boyce, P., Boyce, G., Ridgely, J., Smidth, N., Harshaw, R., and Kenney, J., 2016, "Mount Wilson 100-inch Speckle Interferometry Engineering Checkout." *JDSO*, **12**, 263-269, March 2016.

Harshaw, Richard and Rowe, David and Genet, Russell, 2017, "The Speckle Toolbox: A Powerful Data Reduction Tool for CCD Astrometry." *JDSO*, **13**, 52-67, January 1, 2017.

Hartkopf, W.I., McAlister, H.A., Mason, B.D., tenBrummelaar, T.A., Roberts, J.C. Jr., Turner, N.H., & Wilson, J.W., 1997, "ICCD Speckle Observations of Binary Stars - XVII. Measurements During 1993-1995 From the Mount Wilson 2.5-M Telescope." *AJ*, **114**, 1639.

Hughes, A., McNerney, M., Chung, S., Rendon, R., Ewing, J-P., Harshaw, R., 2020, "Astrometry of WDS 09000-4933", *JDSO*, **16** (2), 169-172 (this issue)

McAlister, H.A., 1977, "Speckle Interferometric Measurements for Binary Stars - I", *The Astrophysical Journal*, **215**, 159.

McAlister, H. A., et al, 2005, "First Results from the CHARA Array - I. An Interferometric and Spectroscopic Study of the Fast Rotator α Leonis (Regulus)", *ApJ*, **628**, 439.

Merrill, P. W., 1921, "Interferometer Observations of Double Stars", *PASP*, **33**, 209.

Michelson, A.A., & Pease, F.G., 1921, "Measurement of the Diameter of α Orionis with the Interferometer", *ApJ*, **53**, 249.

Mount Wilson Institute, 2019, https://www.mtwilson.edu

Rowe, David A. and Genet, Russell M., 2015, "User's Guide to PS3 Speckle Interferometry Reduction Program", JDSO, **11**, 266-276.

Rowe, D., 2017, "WDS1.2 Search Program." Private communication.

Rowe, D., Genet, R., 2020. "STB1.13 Bispectrum Processing," in preparation for submittal to JDSO.