Speckle Interferometry with the McMath-Pierce East Auxiliary Telescope

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Abstract Engineering runs and tests on the McMath-Pierce 0.8 meter East Auxiliary telescope successfully configured the telescope for speckle interferometry observations of close visual double stars. This paper reports the procedure and results of the speckle analysis of four double stars.

Observing Stars With a Solar Telescope

The McMath-Pierce Solar Telescope at Kitt Peak National Observatory is, at this writing, the largest solar telescope in the world. For over 50 years, it has performed outstanding service and helped astronomers gain deep insights into our own star, the Sun. Controlled by a 1960's era PDP-11 computer and run by winches and other equipment that would be viewed by many as not exactly state of the art in 2015, the telescope is a marvel of engineering and still delivers excellent performance.

Of particular interest to our team was the prospect of using the McMath-Pierce for speckle interferometry of double stars. Since time on large telescopes is difficult to secure, we believed it might be easier to obtain time on a telescope that was used primarily in the daytime. As it turned out, we were correct. The staff at the National Solar Observatory in Tucson was more than happy to let us observe at night on the McMath-Pierce. While most people would not think that stellar astronomy could be done with a solar telescope, that is not the case. For example, see LCROSS impact events (Killen et al. 2010) and Doppler imaging of binary stars (Washuettl et al. 2009).

Setting Up the Solar Telescope for Stellar Astronomy

Observing stars with a solar telescope presents challenges of its own, as we learned in an engineering run in April of 2014 (Wiley et al. 2014). Acquisition of the target is achieved by moving a heliostat. The design of the McMath-Pierce telescope dictates that three mirrors must be well-collimated (the heliostat, the main spherical mirror inside the optical tube assembly, and the tertiary mirror that deflects the light into the observing room (Figure 1)).

Not only that, but once the mirrors are in collimation, focusing adjustments must be made, as there are multiple observation ports for each of the solar telescopes in the McMath-Pierce complex, which actually consists of *three* solar telescopes—the 1.6 meter main telescope, and two 0.8 meter East and West Auxiliary telescopes.

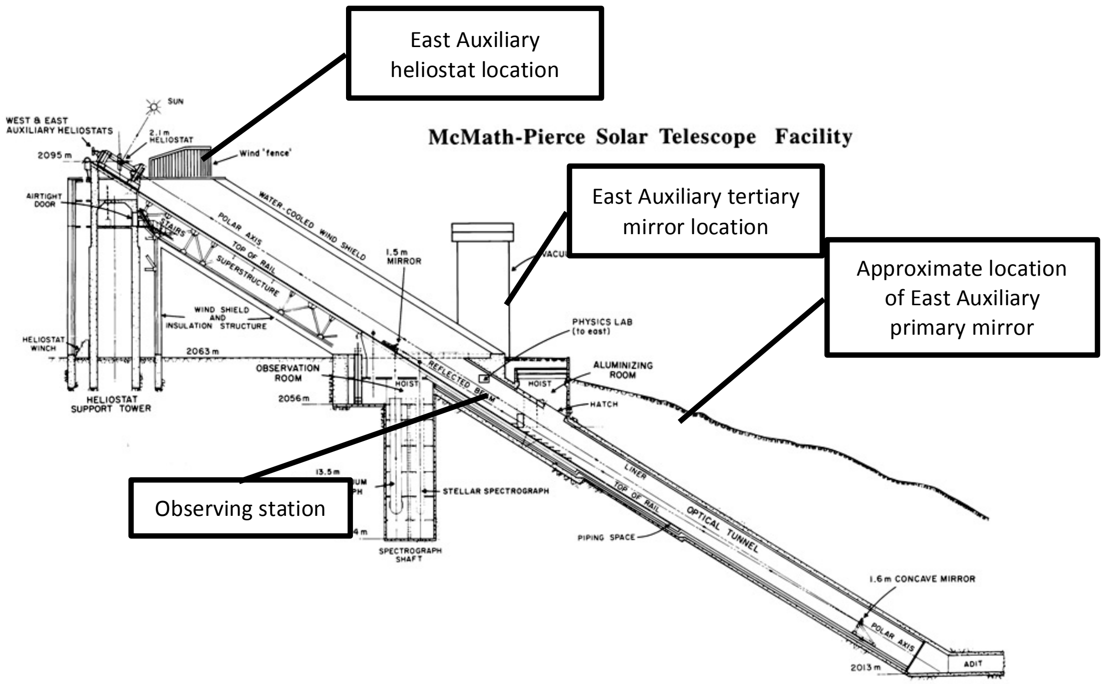


Figure 1. Layout of the McMath-Pierce Solar Telescope.

The McMath-Pierce telescopes all enjoy exceptionally long focal lengths. The main telescope is an f/54 instrument with a total focal length of 87 meters; the west auxiliary is an f/39 instrument with a focal length of 35.6 meters; and the east auxiliary (the telescope we used for our speckle work) is an f/50 instrument of 40.37m focal length. As mentioned by Wiley et al. (2014), we opted not to use the main telescope for speckle interferometry as it lacked the acquisition accuracy required by our acquisition system. However, the east auxiliary is a much more accurate telescope in terms of control (Harshaw et al. 2014) and so was chosen for our speckle observing run in May of 2014. Use of the East Auxiliary Telescope introduced a new set of problems. Since the East Auxiliary's tertiary mirror drops its light into the observing room through a port in the ceiling onto an optical table (Figure 2), we had to set up a fourth mirror, a flat diagonal, to divert the light into our optical bench, acquisition, and science cameras (Figure 3).

Figure 2 also shows the 4-inch diameter optical flat diagonal we used to divert the vertical light beam from the tertiary into our optical bench, under construction in the photo. Prior to building our optical bench, we had a great deal of other work to do. For solar observing, the target is bright enough and large enough to find easily, so determining the exact center of the light path as it impinges on the optical table is not critical. Unfortunately, this is not the case when working with starlight.

We had to first determine the exact center of the light path coming down into the observation room from the tertiary mirror. To do that, we tried centering the Sun in the telescope, but the East Auxiliary's field-of-view is approximately 45 minutes of arc, meaning the Sun had a ring of sky around it. Trying to determine the exact center of the Sun in that arrangement proved to be nearly impossible. So we decided to darken the room and point the heliostat at a clear patch of sky near the Sun but not on the Sun. With the observation room darkened, the round disc of light was easy to observe, and using foam core board and some simple geometry, we were able to pinpoint the center of the light path. Once that point was determined, we drew a small circle in permanent marker on the steel optical table.

Next, we had to collimate the telescope. At first, this posed some challenges, but Jimmy Ray, our chief optician for the observing run, proposed we make a simple pinhole camera and use it to align the four mirrors of our telescope. Figure 4 shows the team collimating with the pinhole in the darkened observation room.

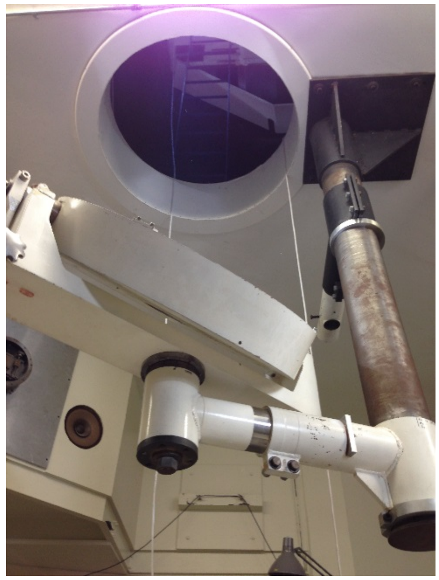


Figure 2. The East Auxiliary light feed port in the observation room ceiling

We ended up with the optical shown in Figure 3.

Figure 3. Jimmy Ray and Lori Prause work on the optical bench.

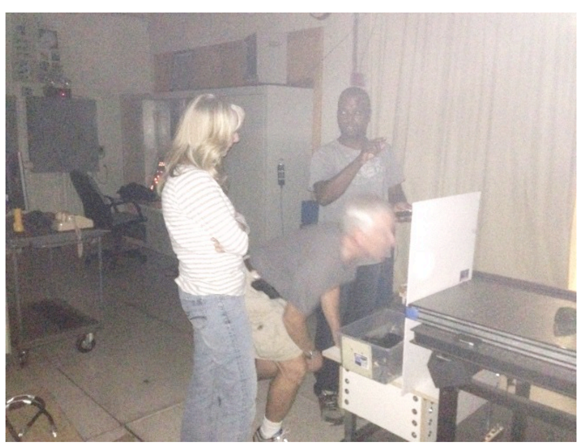


Figure 4. Prause and Ray collimate with the pinhole while telescope engineer Detrik Branston looks on.

After collimation, we brought the east auxiliary to focus, a process that only took about five minutes with the help of telescope engineer Detrik Branston. We were now collimated, focused, and ready for observing that night.

With collimation and focus accomplished, Jimmy Ray built the optical bench. We had a few hours until sunset. To build a suitable optical bench for our use, Jimmy used an assortment of lenses and a finder scope he brought along, as well as various optical bench assembly parts on hand in the vast storerooms of the McMath-Pierce, to build a suitable optical bench for our use.

Lessons Learned from Slewing Errors

After completing our collimation, focus, and construction of our optical bench, we spent our second night on the mountain obtaining images with the ZWO camera. The device worked quite well, but does produce a fair amount of background noise.

During that run, Lori Prause selected a star to observe and gave that information to David Douglass, who was our telescope operator. The east auxiliary is controlled by a desktop computer (that runs TheSky Version 4), which in turn operates the old mainframe computer that actually controls the telescope.

This became apparent when we tried to find our next target—and could not. After searching for nearly half an hour, we had to concede defeat when we realized what had happened. Unfortunately, it was impossible to find *any* star or planet we could re-sync on, so we had to shut the telescope down for the night.

It took Detrik Branston about 2 hours the next morning to recalibrate the encoders for the heliostat and reset it to its normal "park" position so it would be ready to go with accuracy the next night.

Another issue that came up on the second night of our engineering run was that TheSky speaks "J Now" positions while the control computer for the East Auxiliary telescopes speaks epoch B1950.0! This issue, as well as its solution by David Douglass, is covered in Harshaw et al. (2014).

Speckle Interferometry with an Andor Luca R Camera

Our third and final night on the mountain was a test to determine if we could obtain good speckle interferometry results using the Andor Luca R camera. This camera is an EMCCD instrument with an extremely fast shutter and very low noise.

For our observing run, we had about ten stars we wanted to observe, but encroaching weather limited us to just five. As it turned out, one of these was apparently the wrong star, as after the image was processed, it turned out to be a single star on the autocorellogram.

A set of 1,000 FITS images were obtained with the Andor camera for each star, these images being compiled into a FITS cube. As we imaged each double star, we also imaged a single star that was nearby for purposes of deconvolution. Thus we created ten FITS cubes, 9 of which were usable.

We then used Plate Solve 3.33 by David Rowe to process the FITS cubes and do the speckle analysis. Shown in Figure 5 is a typical raw image at f50 showing a classic speckle pattern (left) and the processed autocorellelogram (right).

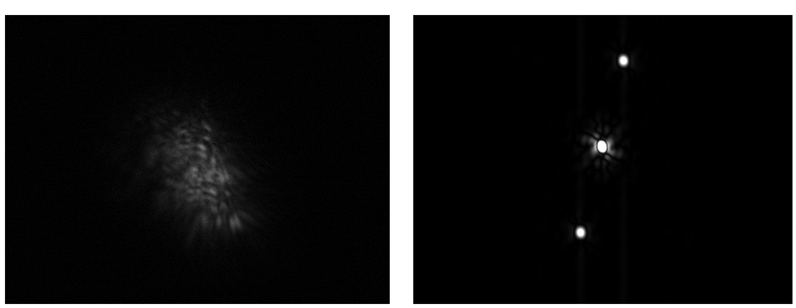


Figure 5. Raw speckle image of a double star (Wiley 2014) and the processed autocorellelogram using Plate Solve 3.

The Speckle Reduction

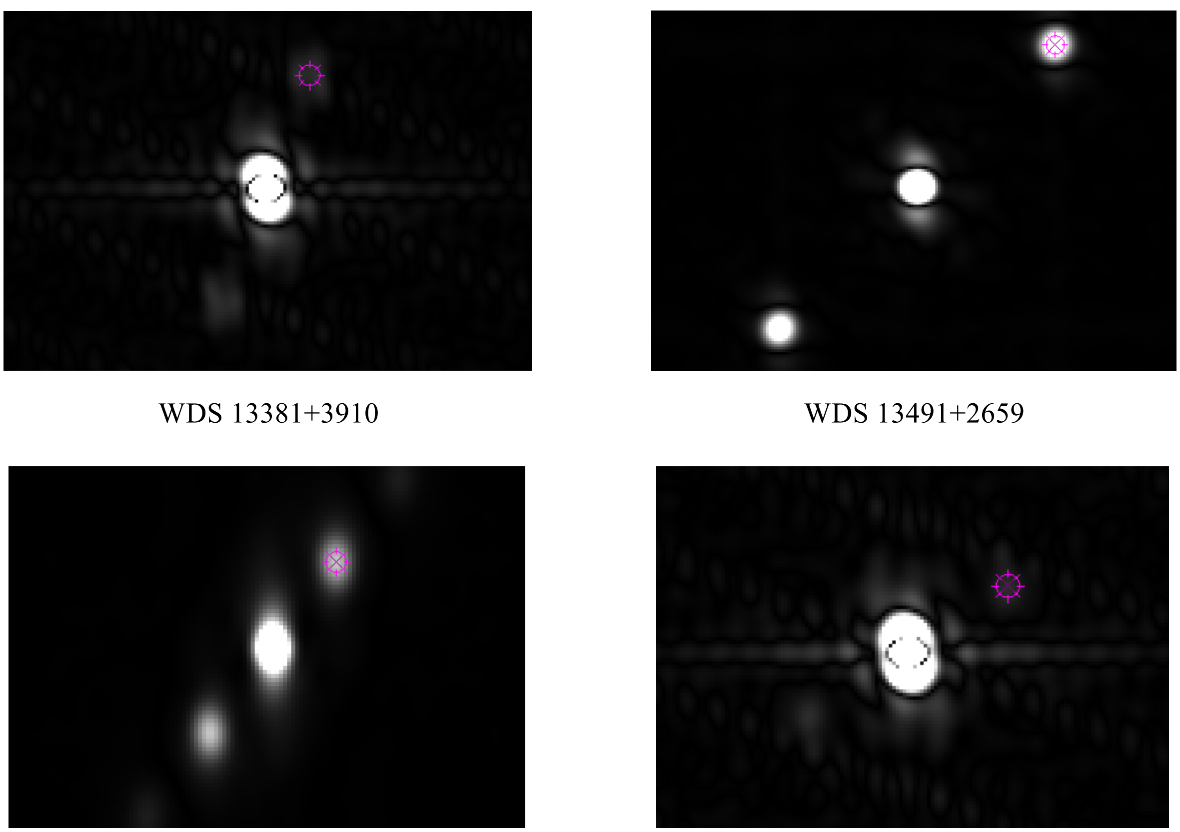
In doing reduction using Plate Solve 3.33, one needs to give the program the camera angle (the angle between true north and the camera's main axis) and the pixel scale. In mounting the camera on our optical bench, we took careful steps to be sure it was as close to vertical as possible, with the intention of having the camera angle at the meridian be zero.

However, the McMath-Pierce, being a stationery telescope that tracks stars by a heliostat, experiences field rotation. The amount of field rotation can be calculated by taking the local zenith meridian hour angle and subtracting the star's right ascension. The result must then be converted to decimal hours and divided by 24 to get what percentage of a full rotation (360°) has occurred since the star was on the zenith, then multiplying that result by 360° to get the rotation in terms of degrees.

For example, we observed WDS 13381+3910 when the zenith meridian hour angle was 16315 (16 hours, 31 minutes, 0.5 minutes, or 30 seconds). The difference between the zenith and the star's RA is 2.644167 hours. Dividing 2.644167 by 24 yields 0.1101736, which is multiplied by 360° to give the amount of rotation as 39.6625°.

For the pixel scale, we used the known focal length of the east auxiliary telescope (40.37m or 40,370mm) and the pixel scale formula: Arcseconds per pixel = (pixel size in microns / telescope focal length in mm) x 206.5 In this case, the pixel size in the Andor Luca camera is 8 microns, so we end up with 0.04087 arcseconds per pixel.

Shown below (Figure 6) are the autocorellograms Plate Solve 3.33 generated for each of our four stars. These are not the actual images of the double stars; rather they are the power spectrum distribution in a graphical format. Since a power spectrum solution is symmetric around its mean, there are companion stars on both sides of the central star (the primary).



WDS 13381+3910 WDS 13491+2659

WDS 13544+2955 WDS 16044-1222

Figure 6. Autocorellelograms for the four pairs we studied.

When we used the angle of field rotation in Plate Solve 3.33, the measured values for theta were all off by a large amount, and there was no consistency to the discrepancies. Table 1 presents the data from the first round of analysis:

Star	Rotation	Theta 1[a]	Rho 1[b]	Theta M[c]	Rho M[d]	Res Theta[e]	Res Rho[f]
13381+3910	43.3458°	158.902°	1.6239”	115.365°	1.5946”	+43.255°	+0.0293”
13491+2659	41.4125°	135.628°	2.9516”	94.399°	2.961”	+41.299°	-0.0094”
13544+2955	46.675°	121.928°	1.3735”	77.042°	1.4102”	+44.866°	-0.0367”
16044-1122	39.6625°	143.921°	1.0772”	104.275°	1.0737”	+39.646°	-0.017”

Table 1. Analysis using the field rotation values for the camera angle.

Notes:
[a]The value for theta based on recent observations and the Sixth Orbit Catalog (when available).
[b]The value for rho based on recent observations and the Sixth Orbit Catalog (when available).
[c]The measured value for theta.
[d]The measured value for rho.
[e]The residual between theta and observed theta.
[f]The residual between rho and observed rho.

The average residual for Theta M was +42.3245°. The mean residual for Rho M was -0.0033”. The standard deviations (based on four data points) was 16.2574° for Theta M and 0.0275 for Rho M.

In trying to find a reason for the high residuals between Theta 1 and Theta M, we tried several combinations and permutations—we tried using the rotation angle as a negative number (minus 43.3458° for instance), subtracting the rotation angle from 90°, adding it to 90°, and likewise for 180° and 270°. Nothing we tried produced Theta M that was even close to Theta 1 nor in any way consistent.

At this point, we decided to set all values of the camera angle at 0 in Plate Solve. Here are the results:

Star	Rotation	Theta 1[a]	Rho 1[b]	Theta M[c]	Rho M[d]	Res Theta[e]	Res Rho[f]
13381+3910	43.3458°	158.902°	1.6239”	158.711°	1.5946”	+0.191°	+0.0293”
13491+2659	41.4125°	135.628°	2.9516”	135.812°	2.961”	-0.184°	-0.0094”
13544+2955	46.675°	121.928°	1.3735”	123.717°	1.4102”	-1.789°	-0.0367”
16044-1122	39.6625°	143.921°	1.0772”	143.938°	1.0737”	-0.017°	-0.017”

Table 2. Analysis using a camera angle of 0°.

Notes:
[a]The value for theta based on recent observations and the Sixth Orbit Catalog (when available).
[b]The value for rho based on recent observations and the Sixth Orbit Catalog (when available).
[c]The measured value for theta.
[d]The measured value for rho.
[e]The residual between theta and observed theta.
[f]The residual between rho and observed rho.

The mean residual for Theta M was now -0.4965° and for Rho M it was -0.0033”. The standard deviations are -0.4965 for Theta M and 0.0275 for Rho M. It is as if there was no field rotation in this experiment, for when we assumed a camera angle of 0° *no matter when the FITS cube was generated*, the observed value for theta is in almost perfect agreement with the predicted value.

As an astronomy mentor of Harshaw once said, “We cannot always give the reason for everything!” Harshaw fully expected the field rotation angles to act as inputs for Plate Solve 3’s camera angle function, but as you can see, doing that gives wildly discordant values for Theta M.

Overall the values for rho look very good.

Conclusion

We concluded that the McMath-Pierce 0.8m east auxiliary telescope can—with the proper preparation, collimation, focus, and coordinate inputs—do high quality speckle interferometry. As far as we know, we may be the first team to ever successfully obtain speckle interferometry data using a solar telescope. Hopefully our success will inspire others to try similar experiments with solar telescopes that do not see much night use.

Acknowledgments

The authors thank the United States Naval Observatory for use of the Washington Double Star Catalog and the Sixth Orbit Catalog; the National Solar Observatory at Kitt Peak National Observatory for their support, specifically Mark Giampapa, Matt Penn, and Detrik Branston. We thank David Rowe for his many helpful suggestions. Genet thanks California Polytechnic State University Office of Research and Economic Development for support through their Extramural Funding Initiative, and the Keck Foundation for support through the Concordia University Undergraduate Education Program.

References

Harshaw, R., Ray, J., Prause, L., Douglass, D., Branston, D., & Genet, R. M. December 2014. Testing of the McMath-Pierce 0.8 meter east auxiliary telescope's acquisition and slewing accuracy. *Journal of Double Star Observations*, 10, 4a, 366-371.

Hartkopf, W. I., Mason, B. D., & Worley, C.E. 2001. *Sixth Catalog of Orbits of Visual Binary Stars*. http://www.ad.usno.navy.mil/wds/orb6/orb6.html.

Killen, R. M., Potter, A. E., Hurley, D. M., Plymate, C., & Naidu, S. 2010. Observations of the Lcross impact event from the McMath-Pierce solar telescope: sodium and dust. *41st Lunar and Planetary Science Conference*.

Washuettl, A., Strassmeier, K. G., & Weber, M. 2009. *The chromospherically active binary star EI Eridani: II. Long-term Doppler imaging.* Astron. Nachr. / AN 330, No. 4, 366 – 376 (2009) / DOI 10.1002/asna.200811136.

Wiley, E. O., Harshaw, R., Jones, G., Branston, D., Boyce, P., Rowe, D., Ridgely, J., Estrada, R., & Genet, R. M. December 2014. Close binary star speckle interferometry on the McMath-Pierce 0.8-meter solar telescope. *Journal of Double Star Observations*, 10, 4a, 372-375.