Foreword

I received an email in late spring 2012 from Russ Genet. Russ had become interested in speckle interferometry as an outgrowth of his many years of teaching astronomical research by way of at-the-eyepiece measurements of double stars. He had just acquired a Luca-S emCCD camera and needed a telescope to try it on. The email described the camera and the observing program and asked if I knew of "a telescope in the 0.5 to 2 meter range" that could be used to make speckle observations. Russ knew that I had an operational PlaneWave Instruments CDK20 at my observatory deep in the Mojave desert. It has an aperture of 20" which satisfied his lower cutoff limit. I was also aware that Russ knew far more than I did about the availability of telescopes in this size range. Clearly, he was on a fishing expedition.

I took a brief look into speckle interferometry and, like Russ, became fascinated with the subject. A long sequence of short exposure images is taken of an object, most often a double star, and the collection is processed in the Fourier domain, where the average power spectrum is computed. The power spectrum retains all of the high-spatial-frequency information available from the full aperture of the telescope, and upon taking the inverse Fourier transform, one finds the sub-arcsecond double star sparkling within the symmetric sidelobes of the autocorrellelogram, defiantly disobeying our well-known seeing-limited aphorism. Of course, I was hooked.

So, Russ and I began planning an observing run at Pinto Valley Observatory (PVO) for mid-November. PVO is a small facility with a cabin, a bunkhouse, and an observatory. It is completely off-grid, with energy from solar panels and water from a well. It had old batteries that no longer held a complete charge. The 20" corrected Dall-Kirkham telescope and its German Equatorial mount were original prototypes. The telescope worked well but the mount was a bit cranky. The RA gear had 50 arcseconds of periodic error that repeated 15 times per rotation.

Speckle interferometry sounds simple: Center a double star on a high-speed, low-noise camera. Take a thousand 20-millisecond images. Process the subsequent "FITS cube" using free software. However, in order to take advantage of the resolution that one can achieve with the technique, the full-resolution diffraction disk must be oversampled by a factor of 5 to 10 times. In practice, this means stacking Barlows before the camera until the effective focal ratio of the telescope is something around f/50 and the field of view is less than an arcminute. The old mount with its large backlash and periodic error was not going
to work.

I called my old friend Dan Gray, the man behind Sidereal Technology, and he said that he would be delighted to come down from Portland and volunteered to put high resolution on-axis encoders on the mount. Dan and I had worked together for many years on direct-drive motors and on-axis encoders, and Dan's new controller was capable of using measurements from encoders mounted directly on the axis, thus bypassing the problems in the gear train. This would solve the problem of finding the double stars, or so we thought.

Russ asked if he could bring an assistant and I said that was fine. On the Saturday night of a star party in the desert, I have always make cedar-planked salmon on the Baja-grill, and in order to size the chunk of salmon, about a week before the run I asked Russ if he was bringing a student. Yes, he said. In fact, he said, he had invited 8 students and expected all of them to join us. Russ is very enthusiastic and sometimes, in his excitement, he forgets the usual courtesies. Anyway, the cabin and its infrastructure can't support such a large group, and so, after threatening to cancel the run, Russ grudgingly capitulated into bringing only one student, Joe Richards, a brilliant and hardworking young man with a love of telescopes, astronomy, and image processing.
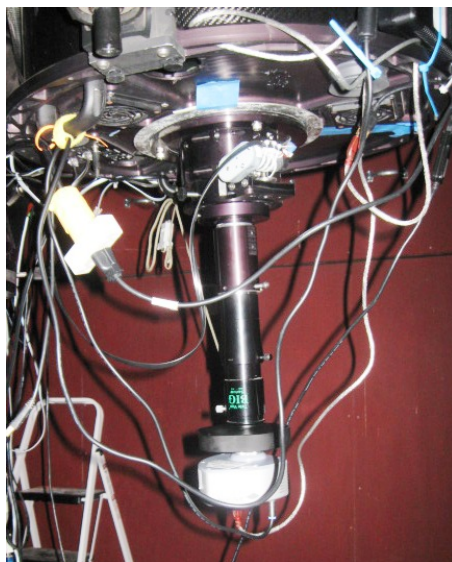
A stack of Barlows was used to increase the focal ratio of the telescope from its native f/6.8 to approximately f/50. The stack was followed by a filter wheel and the Andor Luca-S camera. As this image demonstrates, careful planning for cables and wire is a must on modern equipment.

A day before the run, Dan arrived with a new controller, encoder readheads, and encoder tape. The idea was to fasten the readheads to a mount that was not designed for readheads, and to mount the tape on the aluminum housing of the GEM that was not machined to the accuracy needed to hold the tape. As it turns out, the high-resolution tape encoder technology requires rather exacting placement of the readhead with respect to the tape, including tip, tilt, yaw, and spacing.

Dan had machined the mounting brackets for the readheads from photographs of the mount that we had taken six months earlier, and they worked remarkably well considering the circumstances. Dan tweaked the brackets with a hand file in order to get the readheads aligned properly, and mounted the tape in an ingenious way that eliminated the problem of differential thermal expansion between the aluminum housing and the stainless steel encoder tape. Only one problem remained. The distance between the tape and the readhead changed as the mount was rotated about the RA axis because the outside of the housing had a few thousandths of an inch of runout. Nobody cares about the accuracy of the *outside* of a housing, right?

Dan asked for Scotch Tape. We were out of luck in the cabin so I drove to the nearest neighbor and borrowed a roll, all the while thinking that this is crazy. Dan then spent the next eight hours applying and removing the sticky tape, filing the brackets, and tweaking the position of the readheads while observing the behavior of the encoders as the axes were rotated. I would have given up in an hour, realizing the problem was hopeless, especially without an indicator. Hopeless? Not! In the end, after a long day of seemingly Sisyphean persistence, Dan got both encoders to work flawlessly. Good thing.

My friend Jonah Hare had spent the previous day upgrading and checking software and hardware on the telescope, and installing and testing a wireless network between the cabin and observatory, a run of about 100 meters. For the first time at PVO we had full control of the telescope, camera, and mount without being in the observatory. November evenings get cold in the high desert, and it was a joy to operate the equipment from the cabin where a hot fire in the stove kept us all warm.

Dan installing high-resolution on-axis encoders on the Pinto Valley Observatory's telescope mount.
In the end it took hand files and Scotch tape to get them to work.

Russ and Joe arrived Friday evening and we installed the long Barlow stack and the camera. The practical problems were quickly apparent. The very small field of view made it impossible to find a star to focus the system, and the out of focus images made it impossible to find a star. Anyone that's tried it will immediately know what I'm talking about. The solution was to remove the science camera and put the main imaging camera back on, do a full mount model using Sitech and PointXP, then swap the main camera for the science camera and start hunting for a bright star. With luck and persistence, a star was found to focus with, an offset initialization was performed, and we were off and running…

…until we tried to find the first target double. Nothing. The field of view was indeed very small. The Barlow stack was flexible and the telescope had other un-modeled errors, all of which conspired to lower the chances of finding the target to something close to zero. We all sat around the small kitchen table staring at the laptop, trying various unsuccessful search strategies by hand, and arguing a bit about the best course of action. Finally, Dan took his laptop and sat in the chair by the fire and wrote a square spiral search in VB Script. In a couple of hours he had it working. After a normal, but unsuccessful, GoTo, the search script was started and the real-time image from the science camera was watched very carefully. When the target was detected by eye, the Stop Search button was clicked. Because the search space was so large, the search speed needed to be quite high, and the target would fly by and was often outside of the field of view by the time the operator hit the Stop button. So Dan wrote a routine that allowed the square spiral search to be played slowly backwards, and the target would gently drift back into view.

Late that evening we acquired our fist FITS cube of a known double. Russ opened the data in Florent Losse's REDUC software and processed it. I still remember the moment vividly. It was magic. A double star having a separation much less than the seeing limit was fully resolved in the autocorrellelogram. In fact, as someone said at the time, "You could drive a truck through it". In the end, it all worked and we went to bed.

The next night was mostly about logistics and data recording. As simple as it sounds, there's a lot to it. A massive spreadsheet was created to record all the camera settings, the object designations, the time of observation, the reference star information, and the dozen other things that might be needed in the future when details have been forgotten. Dan, Jonah, and I left it to Russ and Joe to work out.

Dan, Dave, Joe, and Russ passionately discussing the problems and potential solutions for finding the science targets. The telescope and science camera were being controlled via a wireless network and remote desktop software from the warmth and comfort of the cabin.
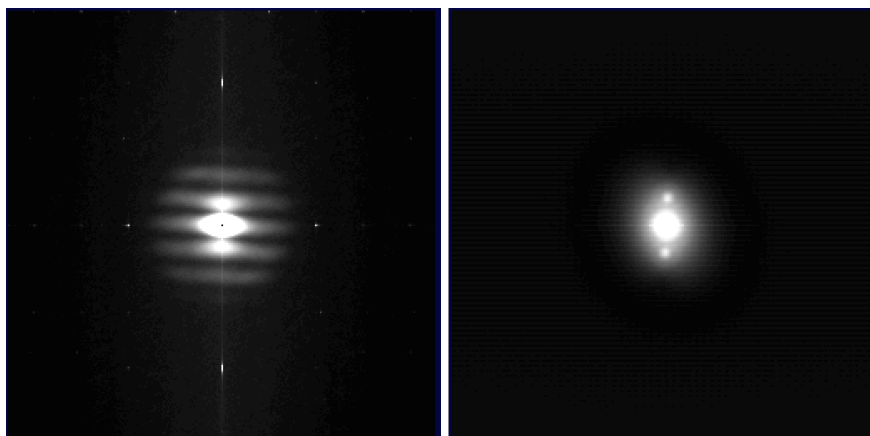
One of the first double star reductions from Pinto Valley Observatory. It was pure magic. The image on the left is the averaged power spectrum showing fringes from the double. The image on the right is the Fourier transform of the power spectrum, known as the autocorrellelogram. The sidebands clearly show that the object is double. In speckle interferometry the autocorrelation will always have two sidebands. There are techniques, including bispectrum analysis, that can be used to create a true image.

The third and final night was the science run. Even with only five people, the cabin, observatory, and bunkhouse require a surprising amount of electrical energy over the course of four days. It's easy to forget to turn off lights; and laptops, cameras, fans, and mount consume lots of energy over the long days and longer nights. The electric coffee percolator, toaster, and 240 Volt water pump are also demanding loads. For 11 year old batteries, it was too much. On the evening of the science run, I noticed the batteries were a bit on the low side and I warned the team that under no circumstances should the batteries be allowed to drop below 23.8 Volts, the point at which battery life is harmed. Dan and I went to bed early while Russ and Joe recorded FITS cubes, measurements for entries on the long spreadsheet list of science doubles. Due to the quirky design of the cabin, to get to the voltmeter that measures the battery voltage one must go through the bedroom where I was sleeping. I remember Russ sneaking through the room several times in the middle of the night. In the end, the batteries failed a little after midnight.

Joe, Dan, Dave, and Russ at Pinto Valley Observatory in the Mojave desert; CDK20 in the background.

In spite of the difficulties, Russ and Joe acquired useful FITS cubes for 42 double stars that evening, and many of the subsequent reductions yielded improved orbits for the gravitationally bound binaries. Two of the observations even led to the discovery of two new triple stars. But the real value of that long weekend in November was the confidence gained by that small group on a modest budget, who realized that they could materially add to the scientifically important field of double star observations using the techniques of speckle imaging. Russ and I went on to have a total of three observing runs at Pinto Valley Observatory. Each run had its own difficulties and each set of difficulties in turn causes advancements. Russ greatly improved the instrumentation from run to run, and I wrote speckle reduction code that overcame interference in the camera and allowed semi-automatic processing of large data sets. These improvements were very important to much larger runs on much larger telescopes, as you will hear about in subsequent chapters. Enjoy the adventure.

David Rowe / August 2015