Close Binary Star Speckle Interferometry on the McMath-Pierce 0.8-Meter Solar Telescope

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Abstract Observations were made in April 2014 to assess the utility of the 0.8-meter solar telescope at the McMath-Pierce Solar Observatory at Kitt Peak National Observatory for performing speckle interferometry observations of close binary stars. Several configurations using science cameras, acquisition cameras, eyepieces, and flip mirrors were evaluated. Speckle images were obtained and recommendations for further improvement of the acquisition system are presented.

Introduction

From 10-16 April 2014, a group of observers met at Kitt Peak National Observatory to collect measurements on double stars with an emphasis on short arc binaries. Part of the observing plan was to evaluate the use of the National Solar Observatory McMath-Pierce Telescope facility (Figure 1) for speckle imaging. Herein we report on initial results using the 0.8 meter East Auxiliary telescope.


Figure 1. The McMath-Pierce Solar Telescope at Moon rise.

The National Solar Observatory at Kitt Peak consists of three telescopes: a main 1.6-meter telescope and two 0.8-meter auxiliaries. Each telescope consists of a heliostat (M1) that reflects light to a spherical primary mirror (M2), and then to a tertiary flat (M3) that projects the light path down into the observing room (Figure 2).
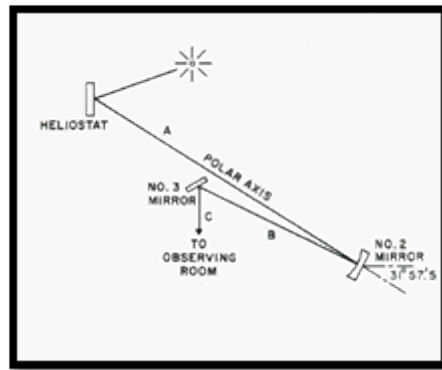
Figure 2. Optical configuration of the McMath-Pierce Solar Telescope.
(Source: *www.nsokp.nso.edu/mcmp-inst*)

The East Auxiliary telescope consists of a 0.91-meter heliostat, a 1.07-meter spherical primary and a 0.61-meter secondary, the overall system having an effective aperture of 0.81-meters. The focal length is 40.4 meters with a focal ratio of f/50. A spherical mirror of this size and f-ratio is limited by diffraction and not spherical aberration. Light from the telescope's tertiary mirror is directed to an optical bench equipped with a flat (M4) that projects the light horizontally along an optical bench on which image acquisition and capture apparatus can be mounted (Figure 3).
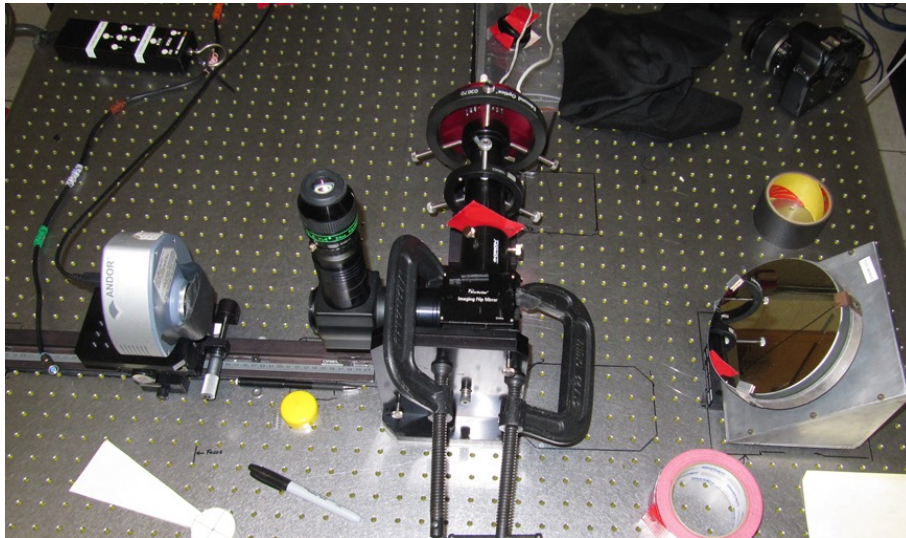
Figure 3. The optical bench "open" set-up and Andor Luca S camera.

The 0.8m East auxiliary telescope has an off-axis optical design (very slight) and has two main constraints: (1) it is alt-azimuth with no correction for field rotation, and (2) pointing is limited to mid-declination (<+40°) due to foreshortening of images by the heliostat. Nevertheless, there are a great number of doubles that can be imaged within these constraints. It is controlled by TheSky® IV software.

Methods and Materials

Several image acquisition configurations were tested on the optical bench. Each consisted of three components: the science camera for imaging the double, an eyepiece to provide a wide-field image, and an acquisition camera with an intermediate field-of-view (FOV) to center the target before switching to the small-format chip of the science camera.

As the FOV of each science camera was approximately 12 arc seconds by 12 arc seconds, acquisition was a major consideration in configuration of the apparatus. Three different science cameras were tested: a Flea3 (Point Grey), a DMK618AU (Image Source), and a Luca S (Andor). Several different optical table configurations were tested, consisting of two basic types:

(1) An "open system" consisting of two flip mirrors mounted on a rigid stand directing light to a science camera and an acquisition camera. One flip mirror was used to direct light to the eyepiece, the other to the acquisition camera. Both cameras could be moved in X, Y, and Z axes. This setup (Fig. 3) was necessary for mounting the Andor Luca S camera, which was too heavy to mount directly to a flip mirror. This arrangement was also used with the Flea3 as the science camera.

(2) A "closed system" consisting of a smaller science camera (IS DMK21) coupled directly to the flip mirror, with the entire assembly mounted on an X/Y platform to facilitate collimation and centering the star on the science camera CCD (Figure 4).


Figure 4. The "closed" set-up with Pat Boyce and Richard Harshaw.

Acquisition

We found that the 0.8 meter telescope had a fast slew rate and good pointing, placing the target with sufficient accuracy that a bright pair could be seen using a white card above the diagonal. However, placing the target into the acquisition camera was difficult due to two factors. 1) The acquisition optics and camera were not precisely aligned with the optical axis of the telescope. 2) The FOV of the acquisition camera was not large enough to acquire the target after a slew. As a temporary solution, we "walked" the target image to a point where it could be visualized by the acquisition camera (open set-up) or eyepiece (closed set-up) and then positioned the image on the science camera chip.

Speckle Results

Using manual acquisition, speckle images were successfully obtained on two nights with both the "open" and "closed" configurations. Figure 5 shows a typical image and the autocorrelation of WDS 12417-0127STF1670AB (Porrima), demonstrating that the 0.8-meter auxiliary telescope is quite capable of being used to image binary star systems. Furthermore, this particular pair was imaged with the inexpensive Image Source DMK21618 camera. The autocorrelation resulted from 1,000 frames taken with 15 ms exposure. The plate scale is 0.028 pixels/arcsecond based on a separation of 2.161 arc seconds, calculated using ephemeris data from the Sixth Catalog of Orbits of Visual Binary Stars (Hartkopf et al. 2001).
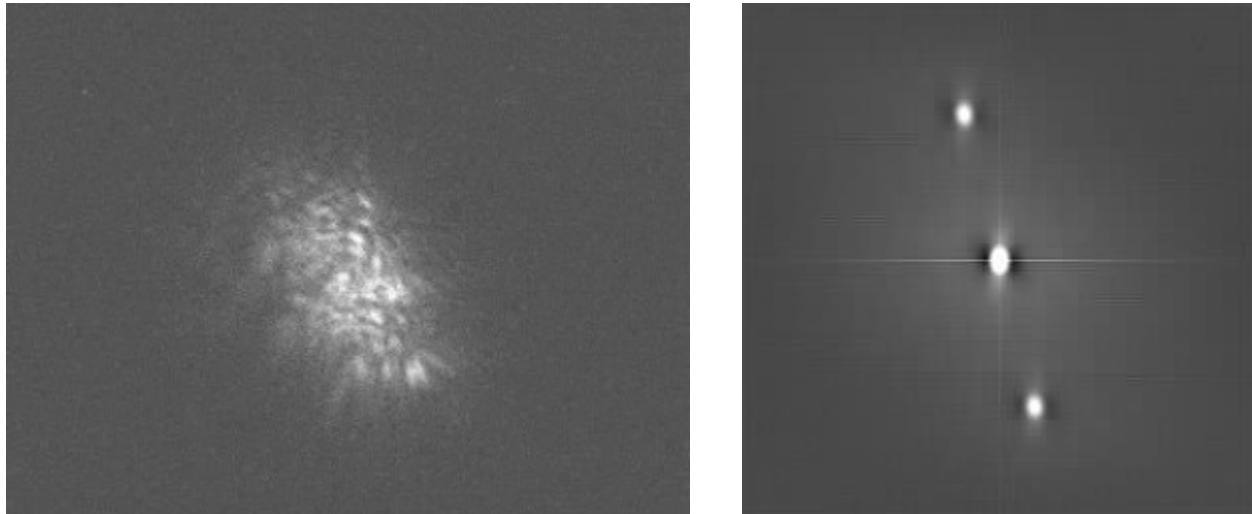
Figure 5. Speckle image (left) and autocorrelation (right) of STF1670AB (Porrima) from the
IS DMK21618 camera and "closed" set-up.

Future Directions

We have successfully demonstrated that the 0.8-meter McMath-Pierce auxiliary telescope can be used to perform speckle imaging of bright binaries. Further work is needed to develop a more robust acquisition system and to achieve better collimation between the telescope optical path and the capture apparatus, permitting us to quickly acquire and image faint doubles.

The improvements are:

(1) Use a focal reducer in front of the acquisition camera to increase its FOV. This will allow the acquisition of faint doubles in the presence of large telescope pointing errors.
(2) Provide for collimation mechanics between the acquisition system and the science camera. This will allow quick in-situ alignment of the apparatus.
(3) Initialize the pointing model to the optical axis of the apparatus.

If these improvements are insufficient to reliably acquire faint doubles, a small telescope with camera (possibly a DSLR) could be placed in the McMath-Pierce telescope shaft near M3, directly above the observing room ceiling. The small telescope's camera would be positioned just outside the optical path of the McMath-Pierce telescope, not obscuring the light path. This acquisition camera would capture light directly from the heliostat, thus forming a wide field of view that would be used with a plate-solver to determine the pointing angle of the heliostat with sub-arcsecond accuracy. The pointing direction of the telescope would then be determined through simple vector geometry, allowing accurate closed-loop pointing in order to position target stars in the field of view of the science camera.

Conclusion

The 0.8-meter McMath-Pierce East auxiliary telescope has the potential to be a very capable speckle interferometry instrument. Once acquisition problems are resolved, the telescope should allow an experienced team to efficiently capture speckle interferometry data on double stars.

References

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.