Operating

General Considerations The operation of the observatory has been optimized for flexibility and convince of use. The telescope is left permanently in position covered by a Desert Storm Shield. The telescope control and CCD imaging is done from a room approximately 10 feet from the telescope where the LX-200 hand controller, focus controller and computers are located. The control room has a window that faces the telescope. To use the telescope the cover is removed and the dust cap is taken off the corrector plate. The dew shield is attached and the power is switched on . The telescope is now ready to be used. When the power to the telescope is turned off the telescope is positioned to point south on the meridian (Dec =0 and RA = local sidereal time) which insures that the telescope is aligned when the power is turned back on. In normal use the covers are removed about an hour before sunset and power is turned on to everything but the telescope. This allows the telescope to reach thermal equilibrium and the CCD to be cooled to operating temperature. At dusk flats are made and the power to the telescope is switched on. The telescope is slewed to a bright star near the zenith using the LX-200 hand controller. The star is centered on the imaging CCD and the star is synced using the hand controller. The focus is then adjusted using the JMI hand controller with its digital read out. The program "The Sky" is then activated and the telescope is linked to the program. A short mapping run is normally then made using "T-Point" (usually about 10 stars). Typically the mapped stars are within an accuracy radius of 200 arc seconds which means that in practice the target objects will be in the central region of the CCD during the night. The desired images are then taken either with active guiding for best quality or by using scripts with the program "Orchestrate" to obtain images under complete computer control. When the list is finished the telescope is slewed to Dec = 0 RA = local sidereal time, power switched off and the covers replaced. Six topics on the setup and operation of the telescope are covered in detail in the following sections:

- Collimation
- Polar Alignment
- Enhanced Pointing Accuracy
- Tracking
- Automated Imaging
- Flat Fields

Collimation

Collimation of the telescope is accomplished in two steps using the CCD camera. First a bright star (magnitude 1-3) near the zenith is centered in the imaging CCD. The star is then defocused (this corresponds to approximately a 5mm shift in the camera position) so that it fills approximately one half of the CCD. A series of rings will be observed. If the collimation is good the circles will be concentric. If the collimation is off the circles will be compressed on one side. If that is the case the tilt of the secondary must be changed to center the rings. This is done by turning one of the three adjustment screws on the secondary with an Allen wrench to move the center of the rings away from the compressed region. The star is then centered again on the imaging CCD and the process repeated until a concentric set of rings is obtained. This is essentially the procedure given in the Meade operating manual except that the CCD is used instead of an eyepiece is used. The limitation at this point is that it is difficult to determine the when the circles are concentric because of atmospheric turbulence. The collimation can be made more exact by now proceeding to a second step. The focus is reset to its normal position and a new star with a magnitude of approximately 8 is centered on the imaging CCD. It is now defocused so that it becomes a doughnut with an exposure time of 3-5 seconds. If the telescope is not collimated then one edge of the doughnut will be darker. The secondary is then adjusted to move the doughnut in a direction away from the darker region until symmetry is obtained. The use of a fainter star allows an accurate fine adjustment to be made and the longer integration time minimizes the effects of atmospheric turbulence. The telescope should be collimated with no mirrors or lenses in the optical path to obtain the best results for the telescope optics. Once properly adjusted the collimation does not appear to change over the seasons (in our case the telescope is permanently mounted but left outside covered by the Desert Storm Shield year round).

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Polar Alignment

The LX-200 is mounted on the Meade super wedge which is in turn mounted on the Meade giant tripod. The tripod is positioned on a wooden deck approximately 10 feet from the operating room. The rough polar alignment is made following the instructions in the Meade operating manual for polar alignment followed by the procedure for refined polar alignment. The ST-7 is then placed on the telescope and a modified procedure is followed for precise polar alignment. Drift alignment as described in Appendix B3 of the Meade manual is used as the final stage of Polar alignment except that the CCD is used instead of the eyepiece. An appropriate star is monitored for 10 minutes and the change in Dec position noted. The appropriate change in the wedge is then made and the process is repeated until the drift is eliminated for both RA and Dec. The final fine tuning is tedious because of the mechanical construction of the wedge but polar alignment within one minute as measured by the use of "T-Point" was obtained. Once set the polar alignment has been stable for more than a year.

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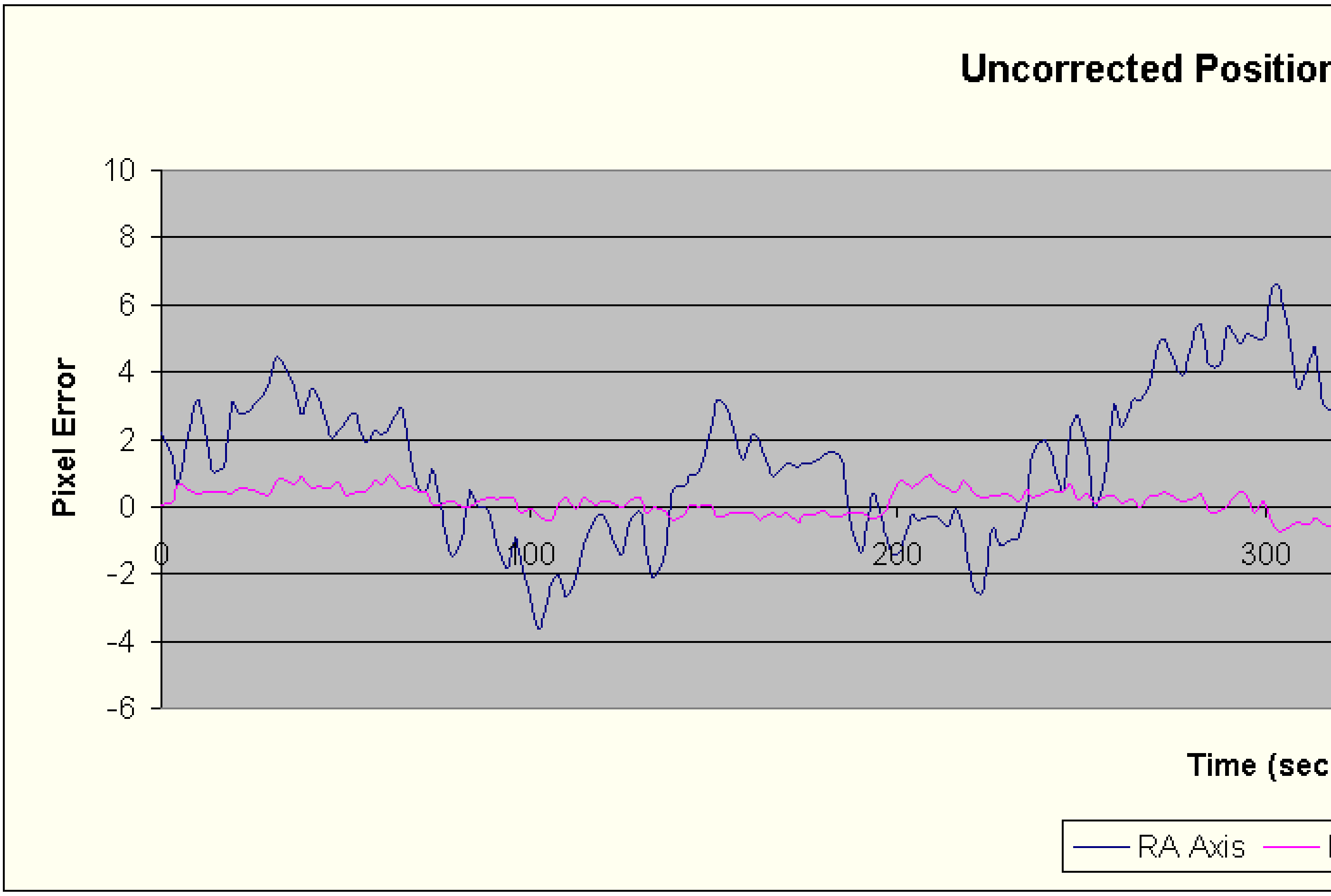
Tracking

There are three different ways to track an object,

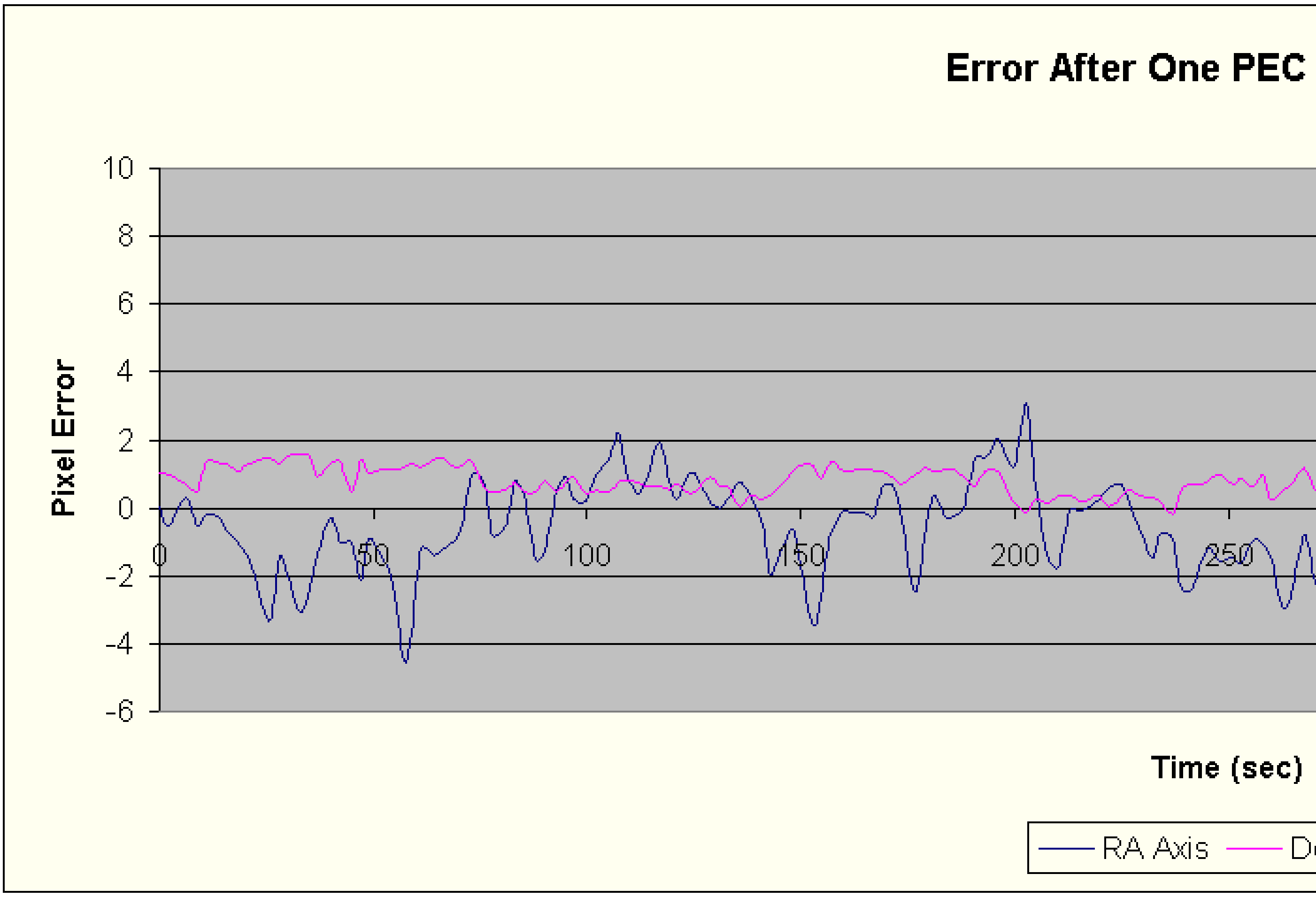
1. use the LX-200 with its built in precision error correction (PEC)
2. use the guiding CCD on the ST-7 camera or
3. use the AO-7 unit in conjunction with the tracking CCD.

The tracking results obtained can be ranked as good, better and best in that order. Using the telescope with just PEC is both easy and simple and does not require that a tracking star be positioned on the tracking CCD. Guiding with the tracking CCD produces better results in virtually all cases but a sufficiently bright star must be in the tracking CCD's field of view. Finding a sufficiently bright star is possible in most cases but the camera may have to be rotated to place it in the field of view. Images taken thru color filters particularly blue or a narrow band filter such as an H-Alpha significantly attenuate the guide star light intensity which may result in tracking times that are many seconds in length. Use of the AO-7 unit results in the best results and does not place any additional constraints on the selection of a guide star. The disadvantages are the initial cost of the unit and the additional back focus that it requires may place limitations on what can be placed in the optical path. A detailed description of the results obtained with each method is described in the there sections below.

PEC Precision Error Correction or PEC is a built in capability of the LX-200 telescope. It provides a computer controlled fine adjustment to the pointing of the telescope to remove positional errors generated by the movement of the gears in the RA drive. A total of 240 corrections can be made during the eight minute cycle of the worm that drives the RA axis. This corresponds to a potential correction every 2.4 seconds. A comprehensive description of the workings of PEC can be found at the PEC Operation page at Dr. G's site. The best way to see the effect of PEC is to look at the performance of the telescope before any error correction is implemented. This situation is shown in the graph below.



The data was taken using the "Convert Track Log" function of CCDOPS. On this graph one pixel equals 1.81 Arc Seconds for the RA axis and 1.92 Arc Seconds for the Dec axis. The telescope was polar aligned to within one arc minute (polar positional data from T-point) and data points were taken every 2.4 seconds over the eight minute cycle of the worm. The average RA error is 3.02 and the RA RMS error is 4.3. The corresponding errors in Dec position are 0.21 and 0.67. As expected the principle variation is in the RA axis where we see what appear to be two effects. First is the random variation caused by the irregularities in the gear train and second an upward drift in position caused by error in the drive rate. The drive rate error is probably due to temperature induced variations in the frequency of the crystal that controls the RA drive. In this case the error will change as the ambient temperature varies. The dec positional error shows the effect of turbulence in the atmosphere and a small amount of downward drift caused by polar positioning error. Use of PEC can eliminate much of the drive gear error and virtually all of the drift error as shown in the next chart which shows the unguided positional error after one learning cycle of PEC.

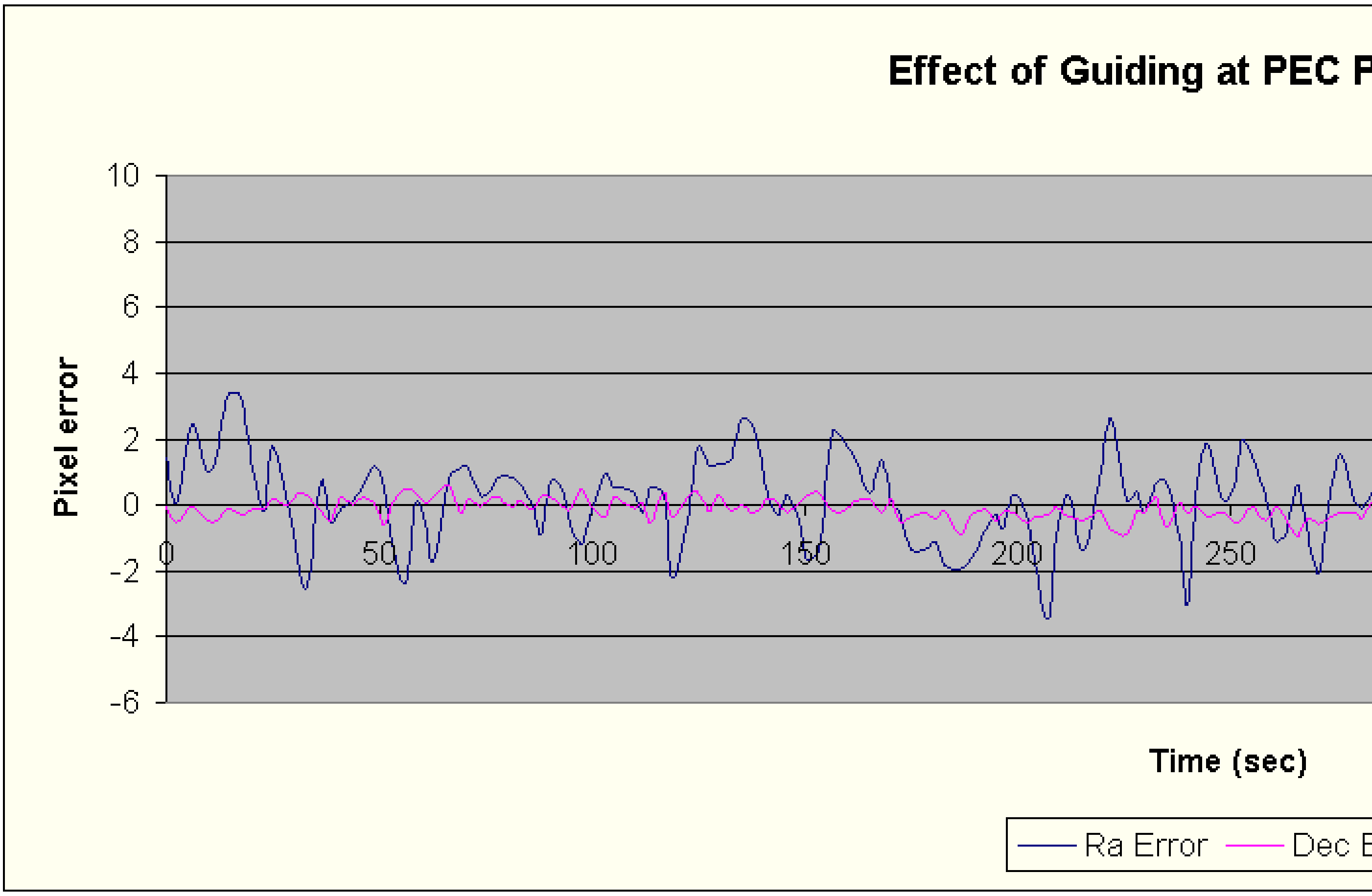


The PEC was made using the guiding feature of the ST-7 with a guide time that gave one correction every 2.4 seconds or one PEC increment. It should be noted that the aggressiveness setting of the guider has a significant impact on the quality of the PEC training. A change of one unit in this setting can have a noticeable impact on the results. In our case an aggressiveness setting of 3 produced the best results. The average RA error was reduced to -0.82 and the average RA RMS error was reduced to 1.54. A single use of PEC was able to reduce the RMS error by a factor of 2.8. The drift component is virtually eliminated and the longer period gear error is significantly reduced. However the RA error is still about twice the Dec error. Updating the PEC was found to have no significant effect on the RA RMS value. Translated into polar coordinates the use of PEC gives an RMS error of 2.8 Arc Seconds in RA. By comparison the RMS error in the DEC axis which is due to atmospheric turbulence is 1.3 Arc Seconds. The PEC training data is stored in computer memory so it can be used from one night to the next, however is the temperature is significantly different the tracking should be checked for drift in the RA axis.

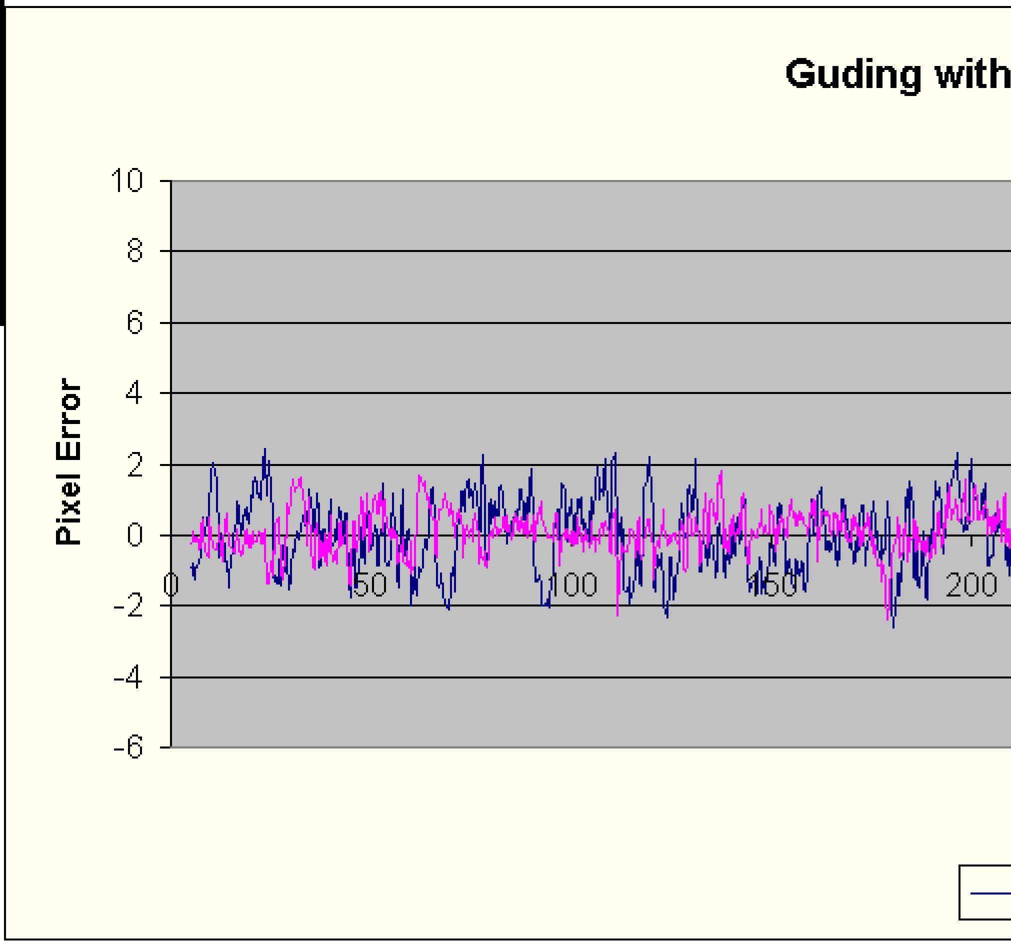
If there is significant drift in the Dec axis due to inaccuracies in polar alignment the "Dec Learn" function of the LX-200 can be used to eliminate it. This compensation will be useful for nearby regions of the sky but will have to be redone if the telescope is pointed to a different region of the sky. The correction for Dec drift is not stored when the power is shut down.

The next improvement is to see the effect of active guiding.

Guiding For the first step of this evaluation the same star that was used to make the PEC correction was used to guide the telescope at the PEC correction rate of once every 2.4 seconds. The guide star was approximately magnitude 7 and was located near the zenith.



The RMS error for the RA axis is now 1.22 slightly better than with the PEC alone and the RMS error on the Dec axis is 0.35 an improvement of almost a factor of 2. As expected there is no drift component in this case. The guide period can be decreased to improve guiding performance. This effect is shown in the next chart where the guide exposure time was decreased to 0.1 seconds. This gave a guide period of .26 second. The difference is the additional communication and processing time required for each cycle.



The RA RMS error has now been reduced to 0.88 while the Dec error is 0.56. The increased sampling has reduced the RA error by about 30%.

Adaptive Optics The AO-7 unit varies the tilt of a mirror to keep the guide star centered. The position of the telescope is not normally changed in this mode so any mechanical inaccuracies such as Dec backlash are removed. There is no "Track Log Function available for the AO-7 so the best comparison is to use the images themselves. Shown below are 5 images taken with the different techniques. The first three are 480 second exposures while the last two are 120 second exposures all of the same field. A central region approximately 130 pixels on a side has been cropped from the original images and enlarged 2X for clarity. The dynamic range of the image was adjusted to equal the intensity of the brightest star for each image. The setup and resulting seeing is listed next to each image.

This image was taken with PEC only. The seeing is 7.1 Arc Seconds in RA (x) and 5.0 in Dec (y).

This image was taken with the guide period equal to the PEC period of 2.4 seconds. the seeing conditions are now 6.7 Arc Seconds by 4.0 Arc seconds.

This image was taken with a tracking exposure time of 0.1 seconds which gave a tracking period of 0.26 seconds. The seeing conditions are now 5.6 Arc Seconds by 4.2 Arc Seconds.

This image was taken using the AO-7 with an exposure time of 0.1 seconds. The seeing is 4.1 Arc Seconds in RA and 3.6 Arc Seconds in Dec.

This image was taken at the highest correction speed that could be reached by the AO-7 when used with our computer which was 29 Hz. The seeing is now 3.5 Arc Seconds in RA and 3.4 Arc Seconds in Dec.

The use of the AO-7 at the highest correction rate has eliminated the effects of RA gear irregularities and a symmetric image has been produced. The AO-7 unit is not especially sensitive to either the aggressiveness or slew rate settings.

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