

1) Abstract

Exoplanets, planets orbiting stars other than our sun, are of great interest to astronomers, especially those planets that reside in the habitable “Goldilocks” zones which have the potential to harbor life. The SAINT team is demonstrating technology intended for suppressing starlight to search for and measure exoplanet orbits and atmospheres using direct imaging. The Segmented Aperture Interferometric Nulling Testbed low order wavefront sensor (LOWFS) provides alignment feedback for controlling the system's primary mirror segments, which focus the telescope beam for fine pointing stabilization prior to being relayed to the Visible Nulling Coronagraph (VNC). The 7 mirrors of the segmented primary (M1) are mounted on piezoelectric transducers (PZT) to control tip, tilt, and piston. Response of the PZT-mounted mirrors is measured initially to characterize the movement of the mirrors when the PZT is subject to a voltage change. Data is recorded by manually varying the independent control axis voltage signals of the PZTs for each mirror, individually. Tip/tilt actuation of each segment introduces point spread function (PSF) motion observed by the LOWFS. The centroids of these PSFs are calculated and used to measure pixel per control voltage response. This response measurement is performed as a first step in the control code being developed to automatically align the segmented M1.

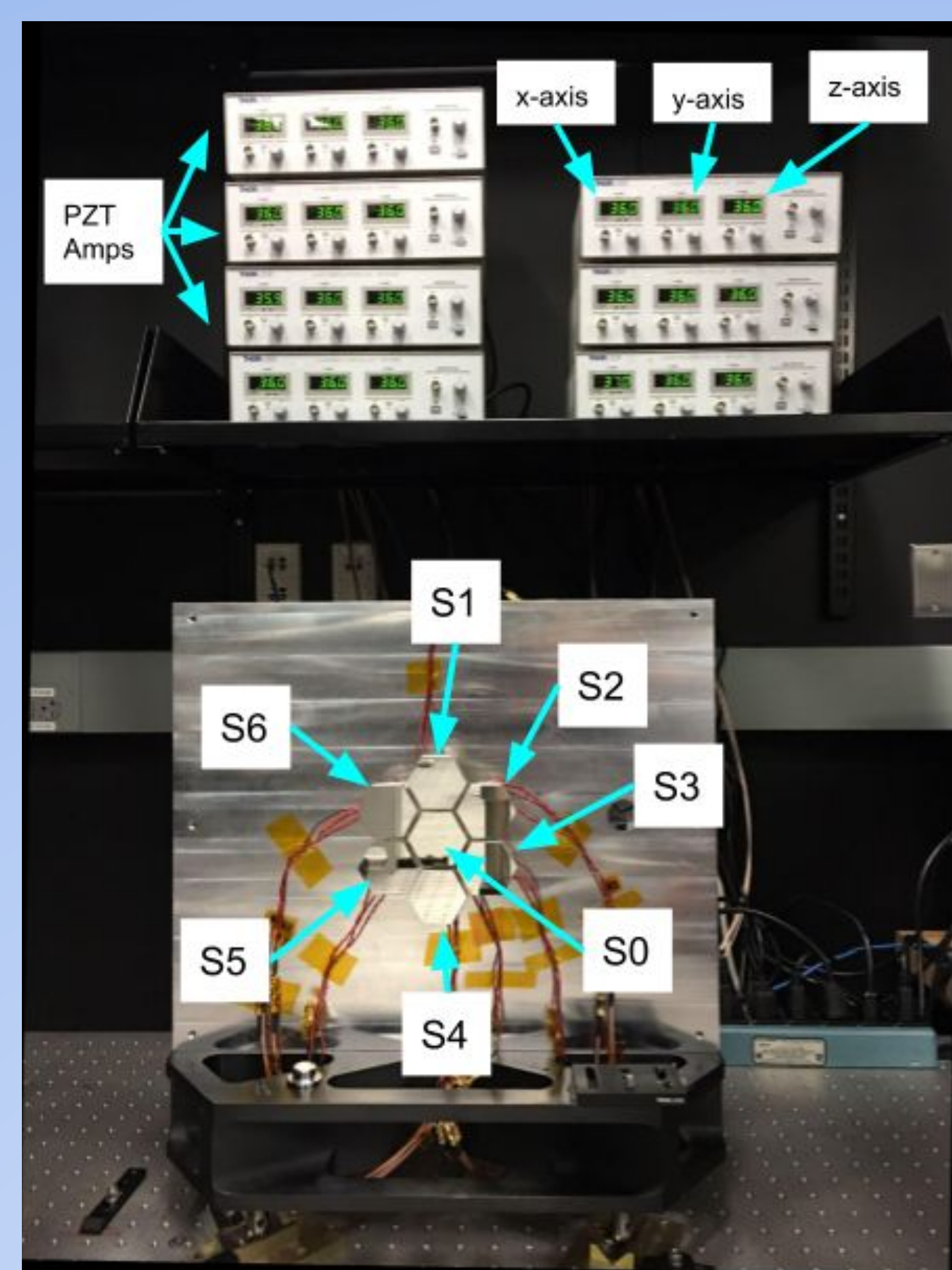


Figure 2. S0-S6 make up all the mirror segments that constitute the telescope M1. The amplifiers are used to control the x, y, and z voltage signals of the Thorlabs PZT mounts for each segment. The x and y signals are used to control tip and tilt while a combination of all three signals are used to control piston phase.

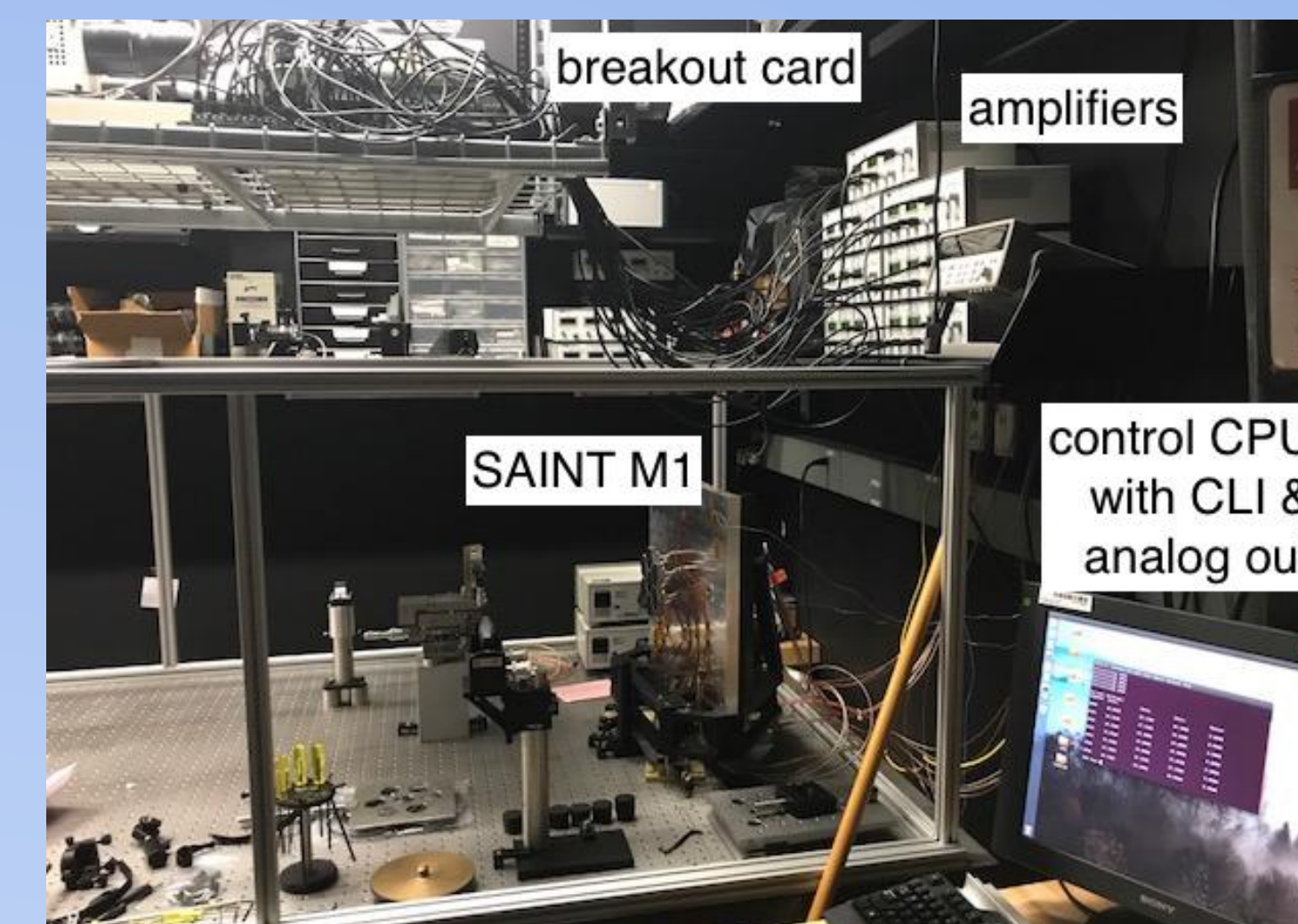


Figure 3. The amplifiers and LOWFS are controlled from a desktop Linux machine running C++ code. The Zyla LOWFS uses a Bitflow Karbon-CL frame grabber controlled using the Andor Software Development Kit (SDK). The amplifiers are connected to a UEI PowerDAQ breakout card.

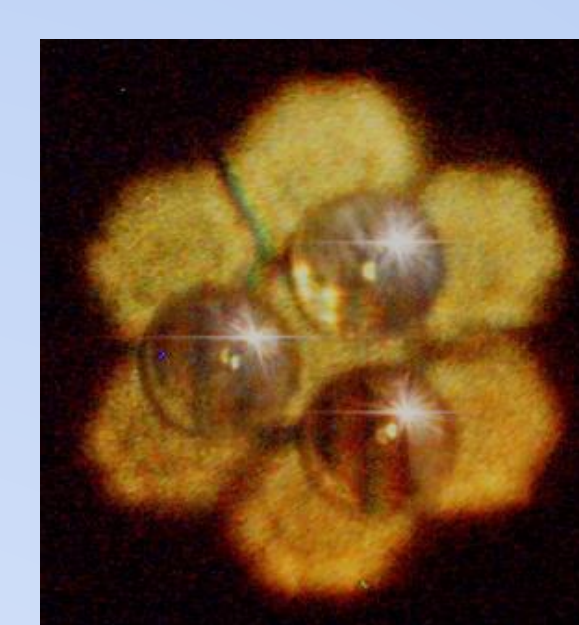


Figure 4. This image shows the incoming, unfiltered beam on the LOWFS. There are three lenses on the LOWFS arranged in an equilateral triangle formation. Each lens intersects three vertices of three segments. This creates three PSFs per lens. S0 is visible in all three lenses and remains static during the alignment process described to the right. This gives a common PSF to which the remaining segments can be aligned. The goal is to align each group of three PSFs in each lens.

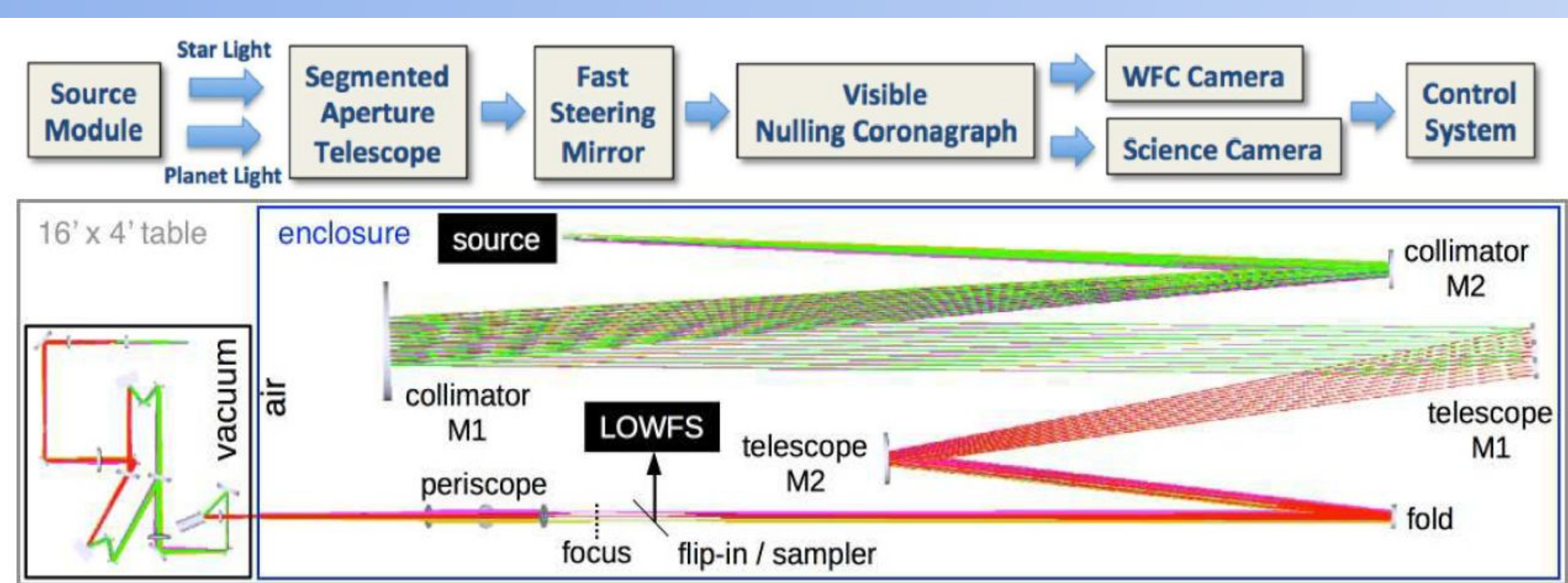


Figure 1. Optical Layout and block diagram of SAINT. Telescope M1 is the segmented mirror with the 7 segments that must be properly aligned and phased. The Low-Order Wavefront Sensor (LOWFS) is an Andor Zyla camera.

3) Coarse Alignment of M1

Coarse alignment of segmented M1 is necessary to ensure that the PZTs can make a voltage correction that is within their specified range of around ± 35 V. This is achieved using 100 thread per inch set screws to adjust tip, tilt, and piston while the PSF is monitored with a Pixelink camera.

PSFs for S1-6 are aligned individually with S0. Pistoning can then be adjusted until the strongest interference pattern is attained. This coarse alignment should only need to be done once unless creep or voltage drift becomes significant enough to limit amplifier range.



Figure 10. Pixelink image showing S6 properly aligned with S0. Strong interference bands indicate proper alignment.

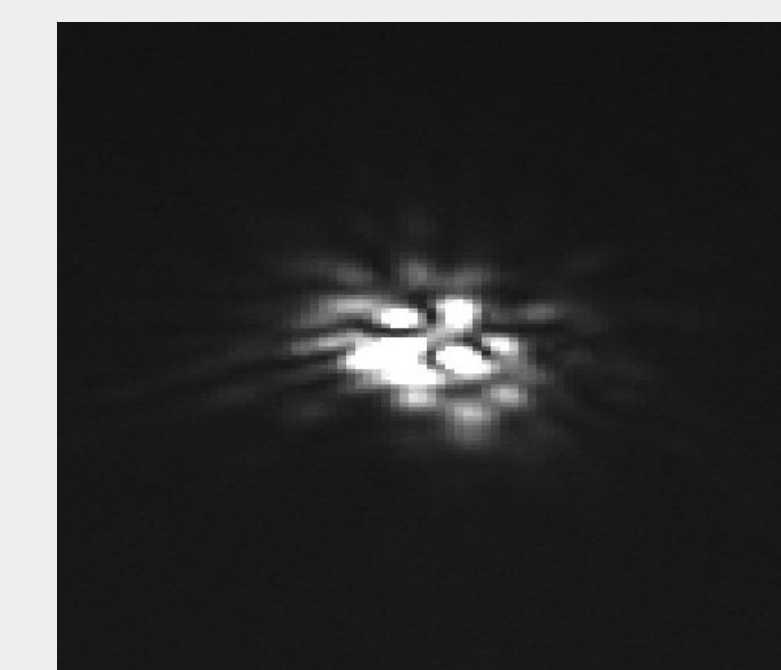


Figure 11. Resultant image of best alignment of all segments achieved by hand and eye.

2) Measured PZT to Pixel Deflection Motion Response

In order for the mirror alignment program to work properly, the behavior of each of the 21 PZTs in response to an input voltage must be characterized. In other words, how many pixels on the LOWFS does the focused PSF move per volt (pixel/volt)? A Matlab script was written that takes data from the LOWFS at varying x and y signal voltages, independently, in the form of .fits files. The code locates the centroids of each of the 3 shown PSFs in each image and compares it to the following images as the voltage changes. The end result produces figures like the ones shown below:

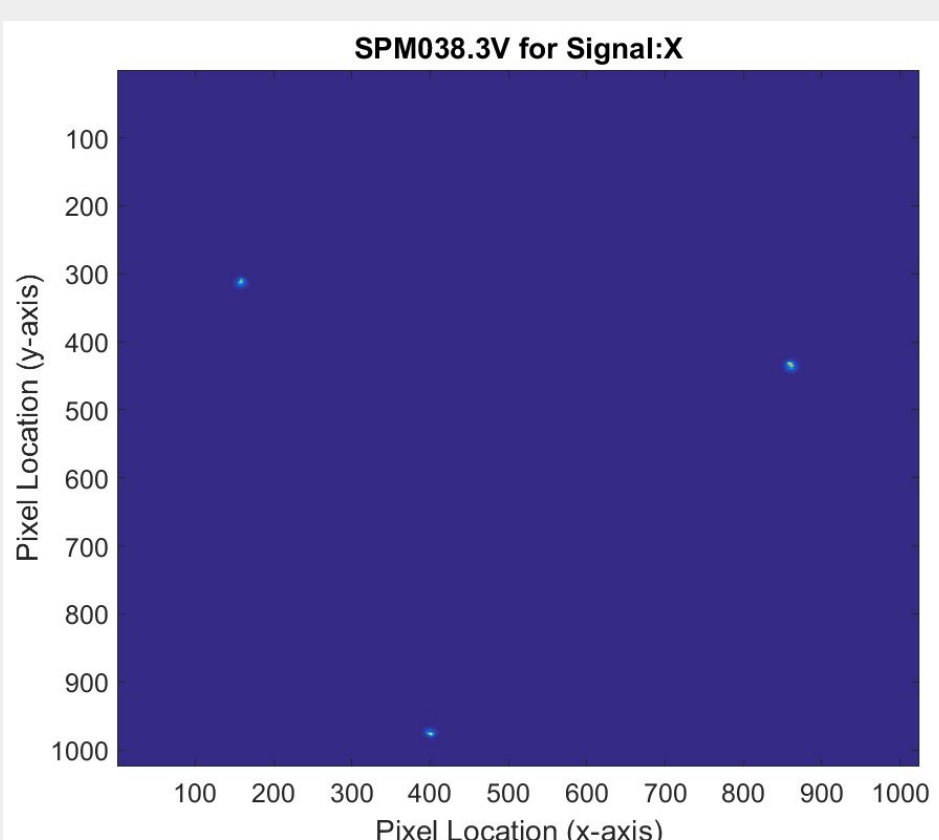


Figure 5. The three PSFs generated by only S0. Data was also taken at 40.3 V, 42.3 V, 44.3 V, and 47.3 V. The data is filtered such that everything except the PSFs are equal to zero. This is necessary for locating centroids.

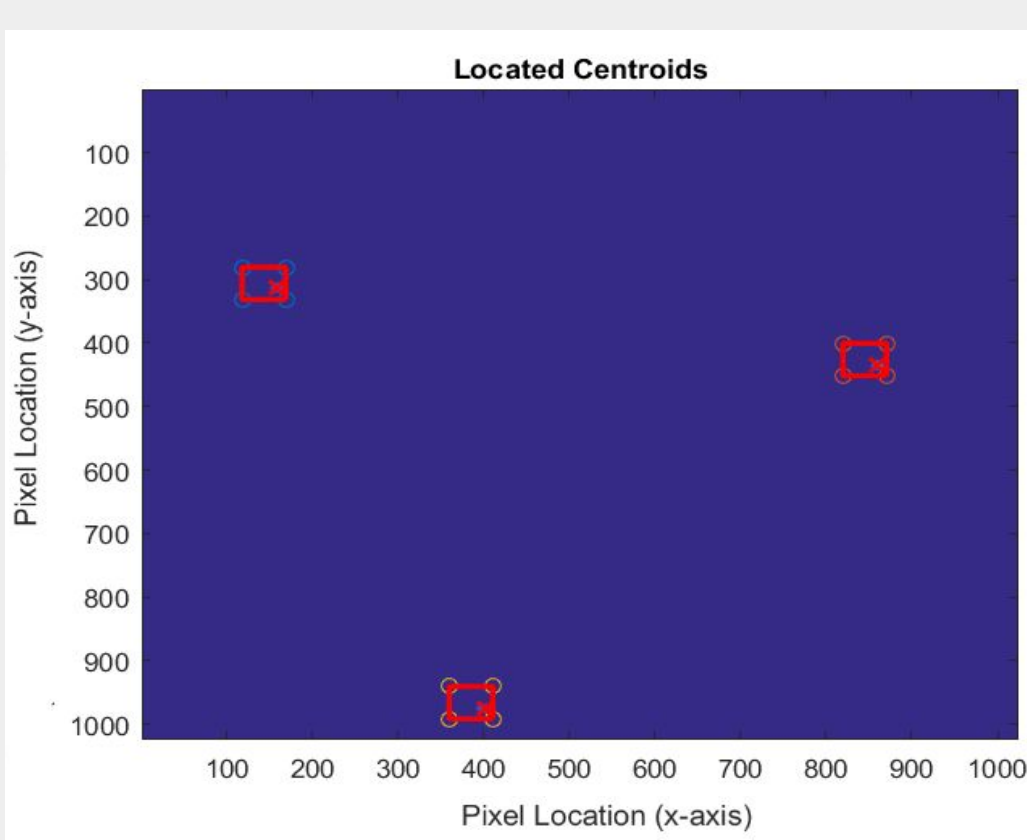


Figure 6. The centroids were found by having a window (represented by the red square) sweep through the image, starting at the top left and moving down a row once reaching the last column. Once the window completely enclosed and located an object, the centroid of that window could be found and related back to the position in the overall image.

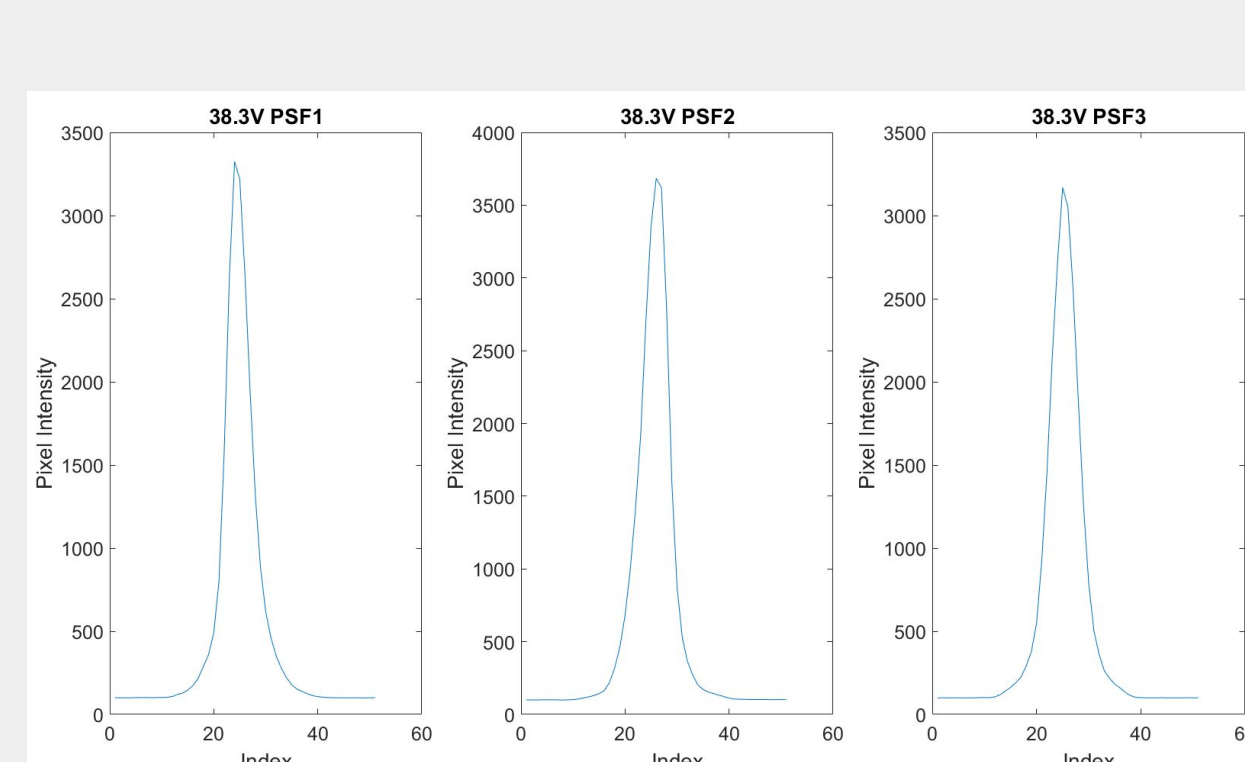


Figure 7. The pixel intensity across each PSF is plotted above.

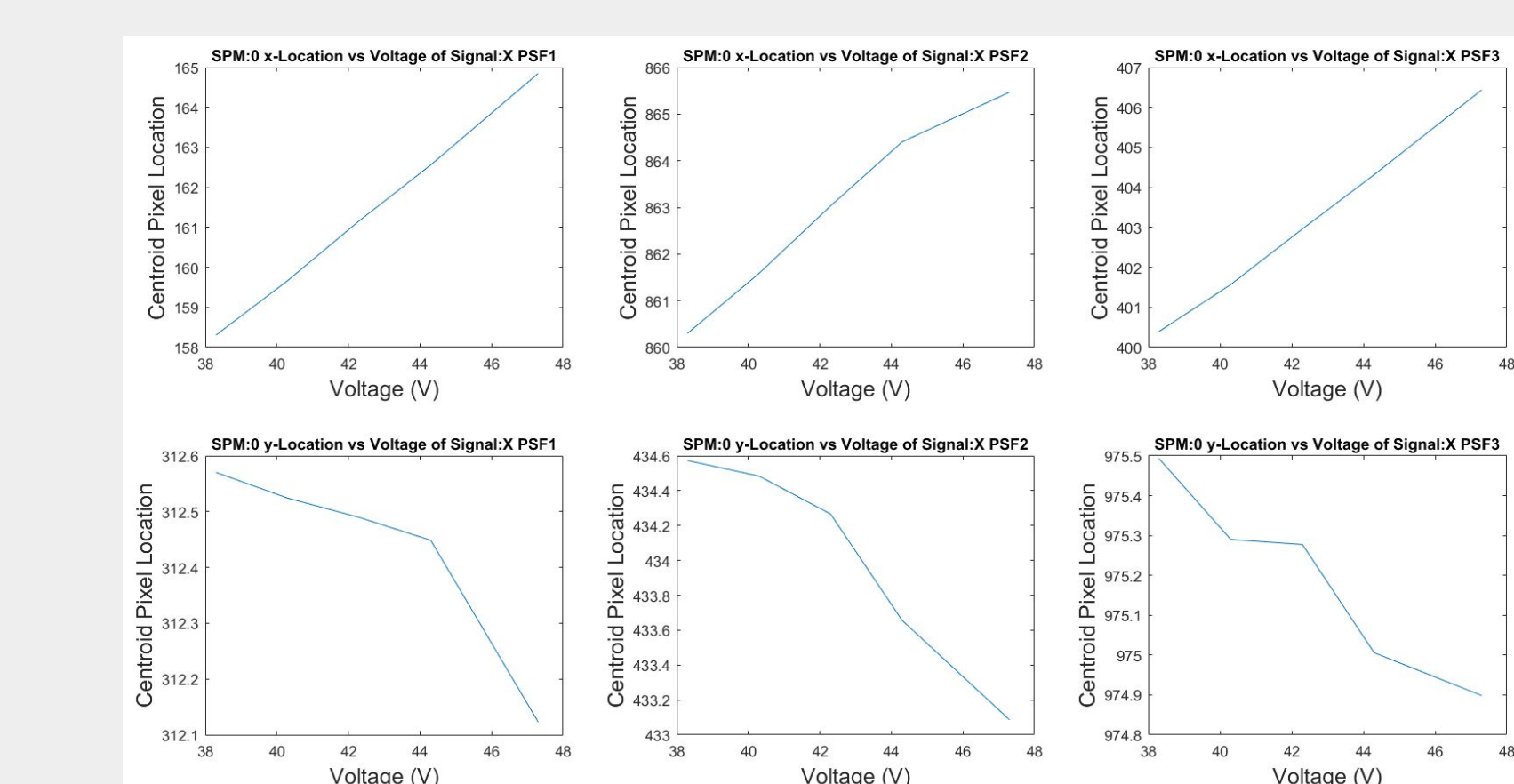


Figure 8. The movement of each PSF is then plotted to show how each changes in the x and y directions. Take note that the y-axes are not the same in the top and bottom charts. There is much less movement in the y-direction when only the x voltage signal is varied. The x movement is also very linear which shows that there is a constant pixel/volt (slope) value.

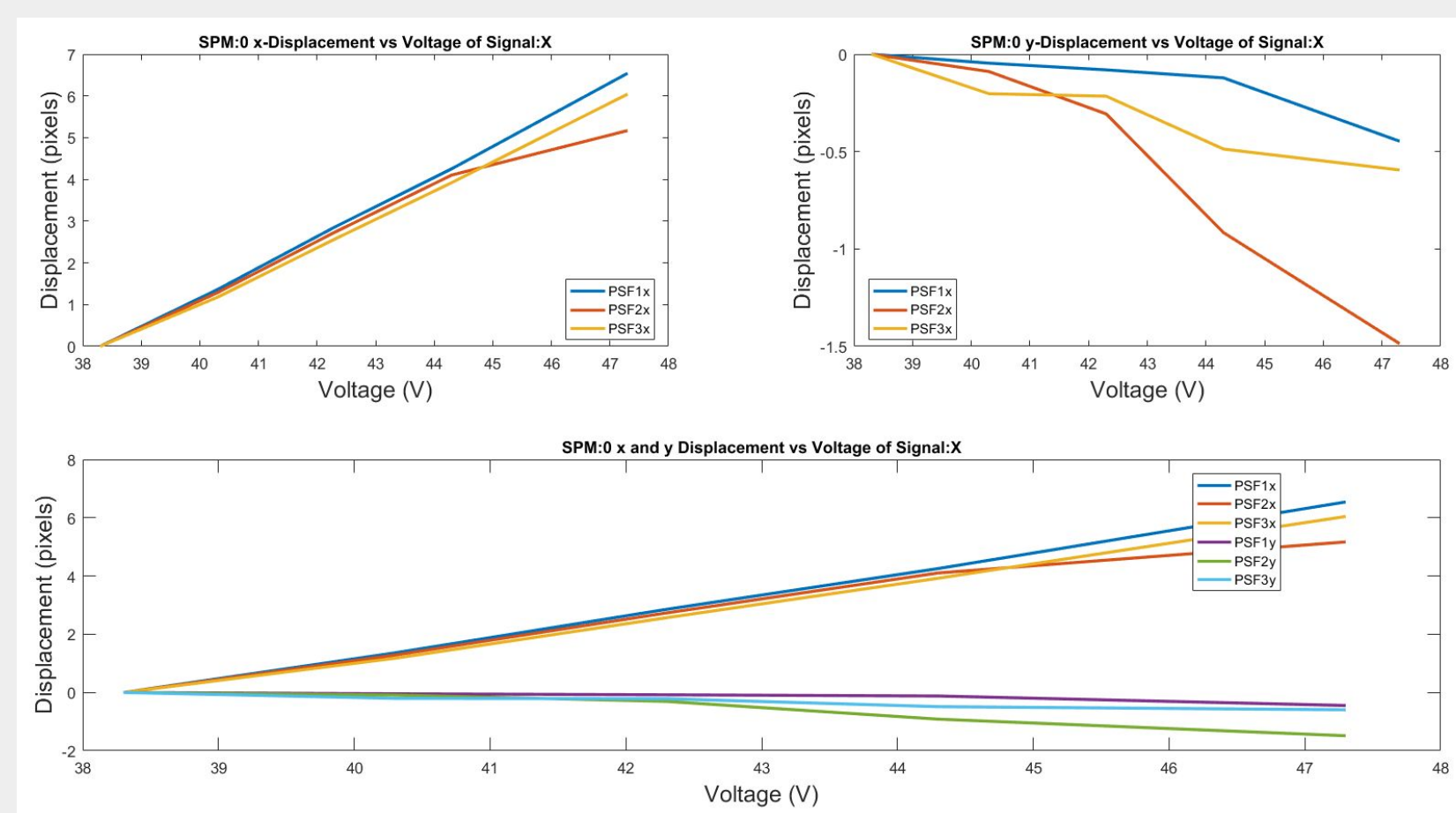


Figure 9. This figure shows a comparison of the change in position of the centroids of the three PSFs when subjected to only a change in the x voltage signal. All PSFs move linearly except for PSF2 which is suspected to have gone outside the range of its respective lens. Also notice that the centroid translation is not entirely in the x-direction even though only the x signal of the PZT is altered. A slight y variation needs to be considered when aligning the mirrors.

5) Results and Future Work

Code has been successfully developed to characterize the pixel per volt behavior of the segmented M1 and PZTs. This information can then be used in the mirror alignment code, which currently only works with simulated data that will be modified to work for a real experiment. Future work remains to be done to install all necessary software and drivers onto a single Linux machine so that the LOWFS and PowerDAQ can be accessed simultaneously by the same C++ program. The code is also being developed to account for phasing of the mirror segments which steps in piston to maximize PSF Strehl as measured by pixel intensity.

The current code is designed to run once at the beginning of an experiment and repeated as necessary at a frequency anticipated to be on the order of tens of minutes, but yet to be well-determined. These minor corrections will most likely need to be made in response to temperature changes and voltage drift. Plans have been formulated for a future experiment that would add electromechanical sensors to maintain an alignment solution.

6) Acknowledgements

Special thanks to the VNC/SAINT team: Teresa Sheets, Keith Jahoda, Andrew Lea, Jenna Marcus, and Matthew Cosby. I would also like to thank the Education Office and CRESST II.

4) Segmented Mirror Alignment Code

Alignment code was first developed in Matlab due to its superior graphing and plotting capabilities over C++. After completion, the Matlab code was then translated to C++ because all VNC/SAINT control code is C/C++. In the figures below, a single pixel was used to represent the centroid of each of the PSFs for S0-6. To the left, Figure 4 describes how the lenses are aligned with the mirror segments. This code can be easily adapted to work with real data once the Zyla and PowerDAQ are integrated into the same computer system. The following images outline the process the code takes to align the mirrors:

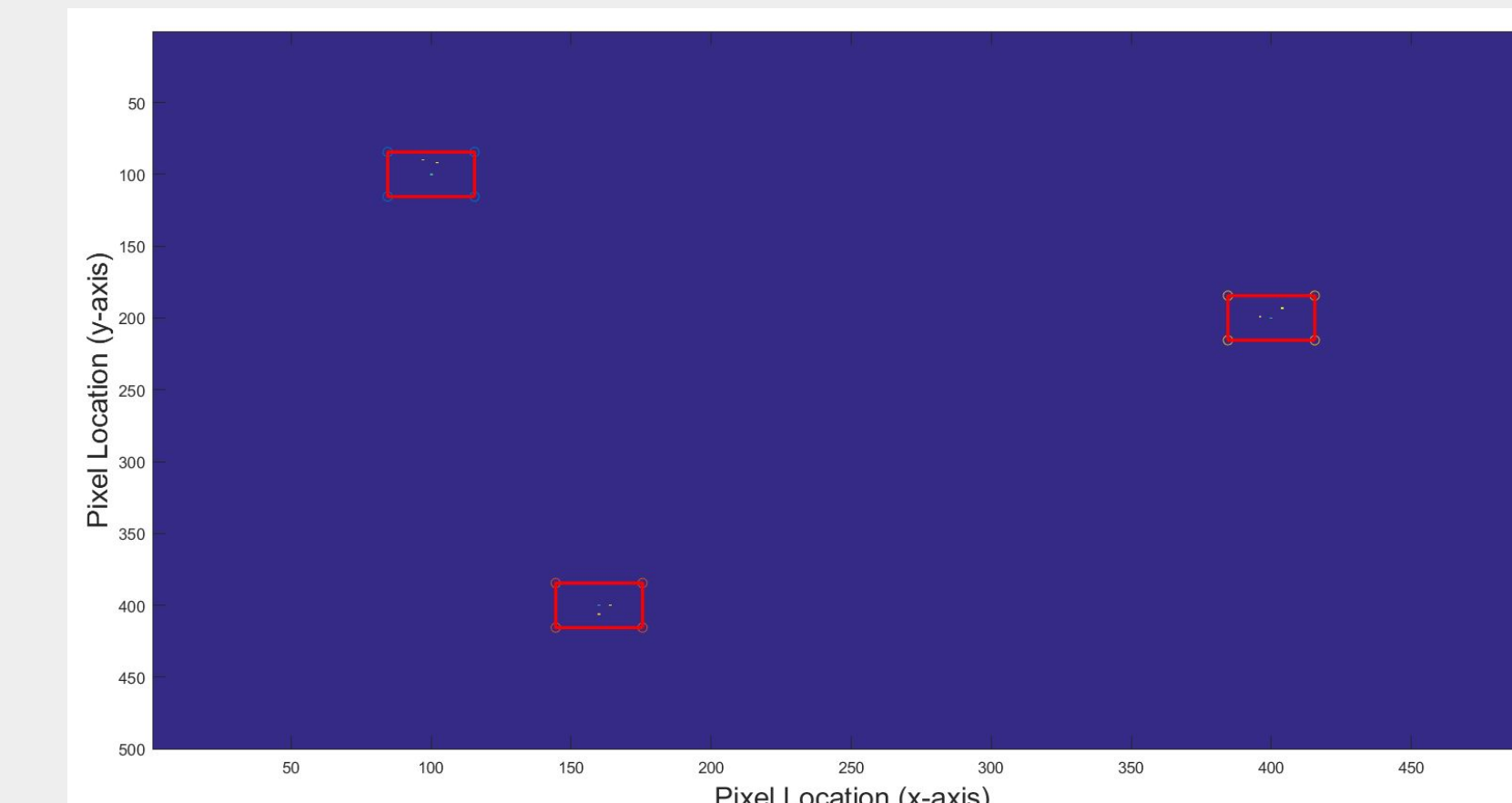


Figure 12. The red boxes around the simulated PSFs represent the field of views. Anything outside of these areas are off of the lenses represented in the image on the left.

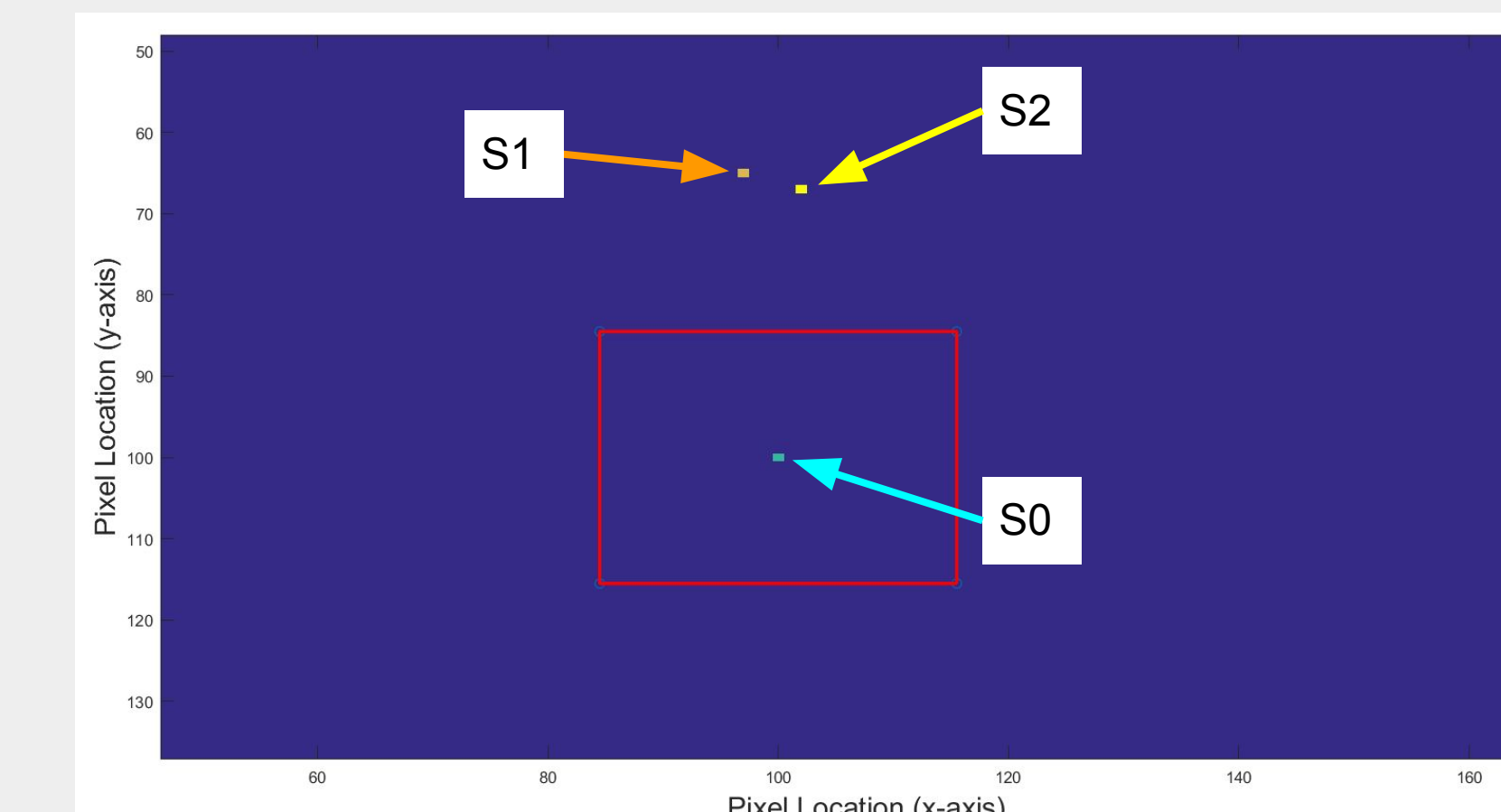


Figure 13. Zooming to a single field of view for clarity. The PSFs for S1-6 are moved outside the field of view of the LOWFS leaving only the three S0 PSFs in their respective windows. Centroids are then calculated. Now the goal positions for S1-6 are set.

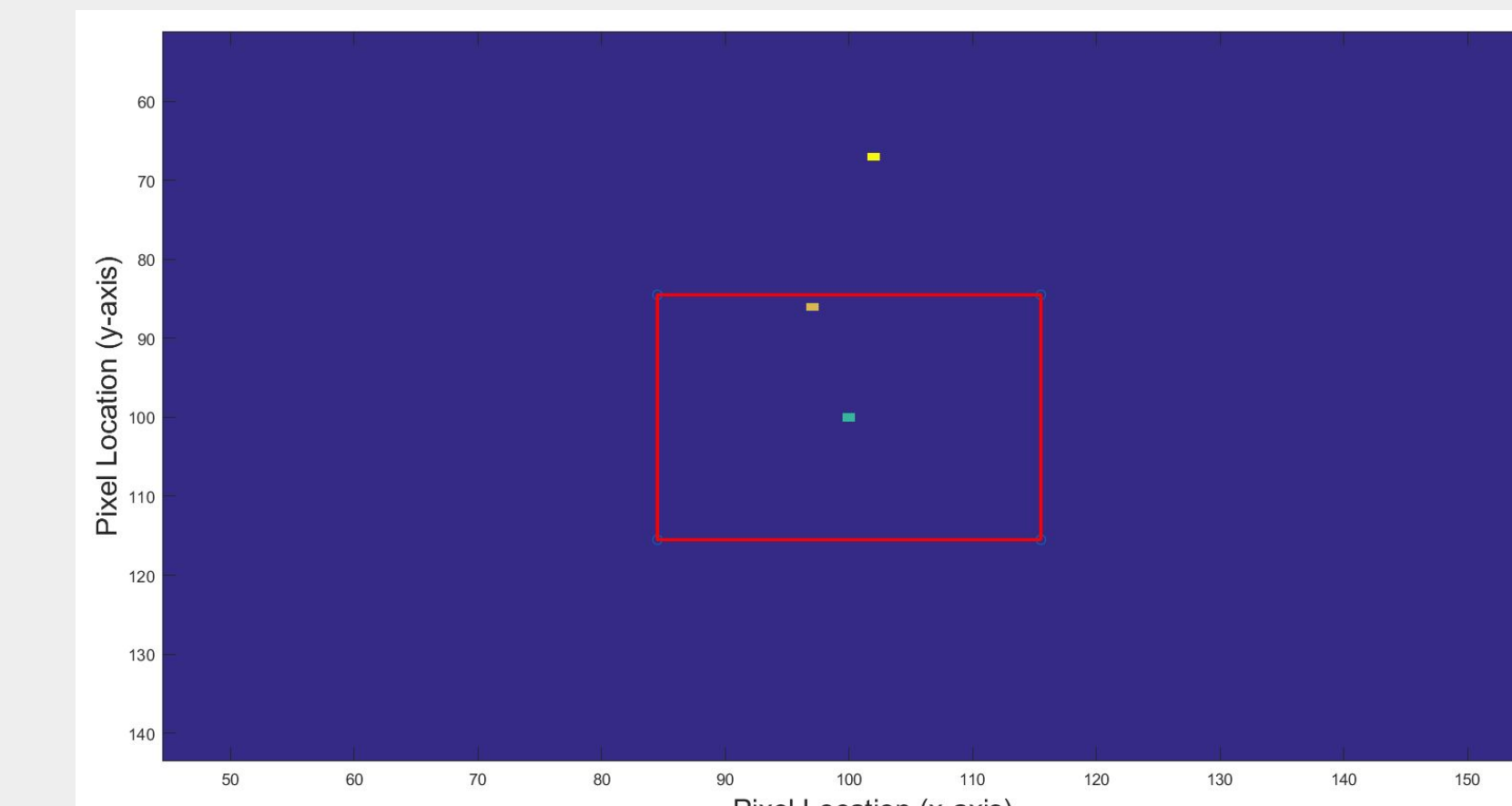


Figure 14. The PSFs for S1, S3, and S5 are gradually lowered until completely within the field of view. Once inside, the centroids and distances to S0 are calculated. A correction voltage is applied that aligns the two PSFs in each window.

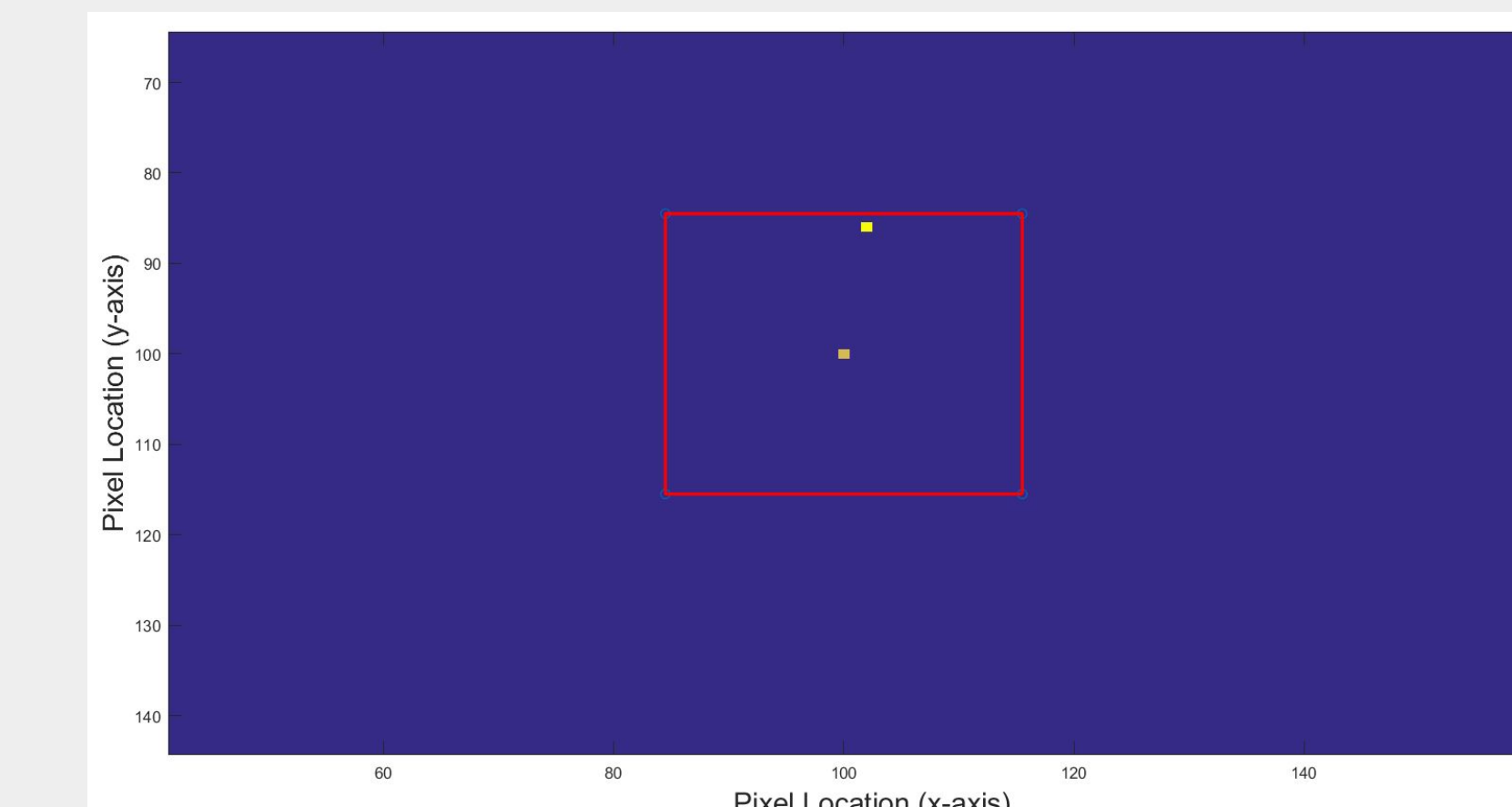


Figure 15. An identical process occurs for the PSFs for S2, S4, and S6. Move into window, calculate centroids and distances, make alignment correction.

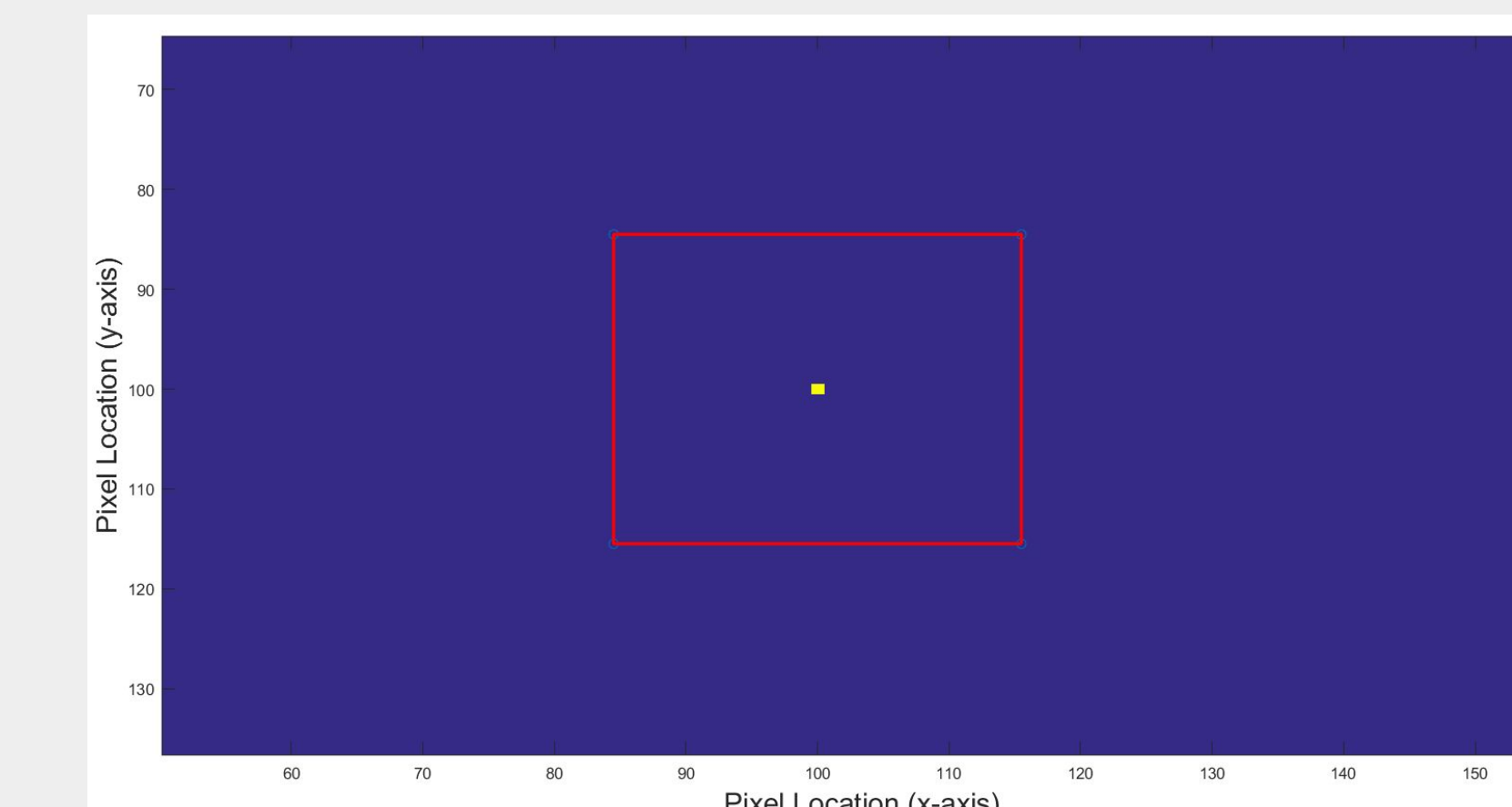


Figure 16. The final result is a properly aligned mirror with three sets of stacked PSFs. It should be noted that this code only aligns the mirrors in the x and y direction. Phasing (i.e. pistoning) still needs to be accounted for in the final experiment.