

# Characterization of a Bimorph Deformable Mirror in a Closed Loop Adaptive Optics System for Vision Science Purposes



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Wave front correcting adaptive optics is a giant leap in optical resolving technology. The deformable mirror (DM) wave front corrector, which is the key component in an AO system, is also the most expensive part. Thanks to recent technology outbreaks, though, low cost DMs are now available on the market. I have tested the capability of one of them, the AOptix bimorph DM, originally developed for high bandwidth laser communications. Past research has shown that the bimorph deformable mirror is excellent at correcting low order aberrations, but so far, studies have only been done on open loop systems and not performed on closed loop. For the purpose of characterization I introduced aberrations into an AO system that is to be used for vision science applications. Aberrations were physically introduced by trial lenses at the entrance pupil of the system for low order aberrations or artificially. Higher ordered aberrations were generated through MATLAB and entered into the system in the form of residual wave front error, that the AO controller needs to minimize as good as possible in an iterative process, in order to get a flat wave front at the output of the system. By correcting for this residual wave front error the DM, progressively after each loop, is taking the complementary shape of the wave front and reflecting a considerably more flat wave front (Phase Conjugation). We measured how well the DM is compensating for this residual error by estimating the variance in the centroid displacements onto the Hartmann-Shack wave front sensor before and after AO correction. If results follow expectations, higher performance AO systems utilizing two cascaded DMs will soon come into use. One mirror of the system will be the bimorph, and the second one, most likely a MEMS, will specifically correct higher order aberrations.

## My Project

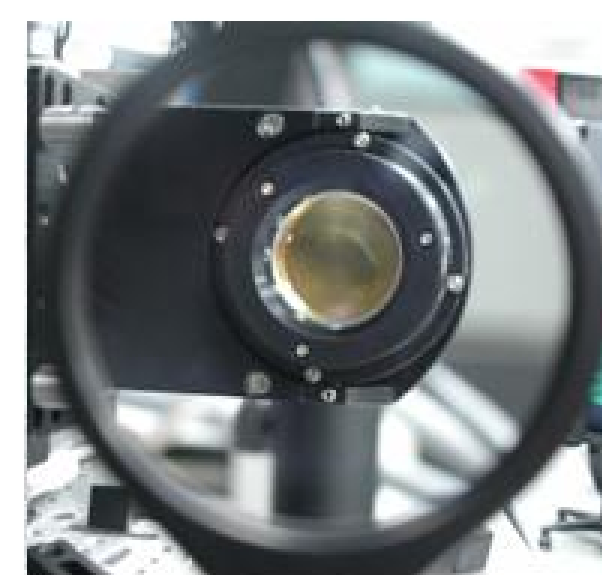
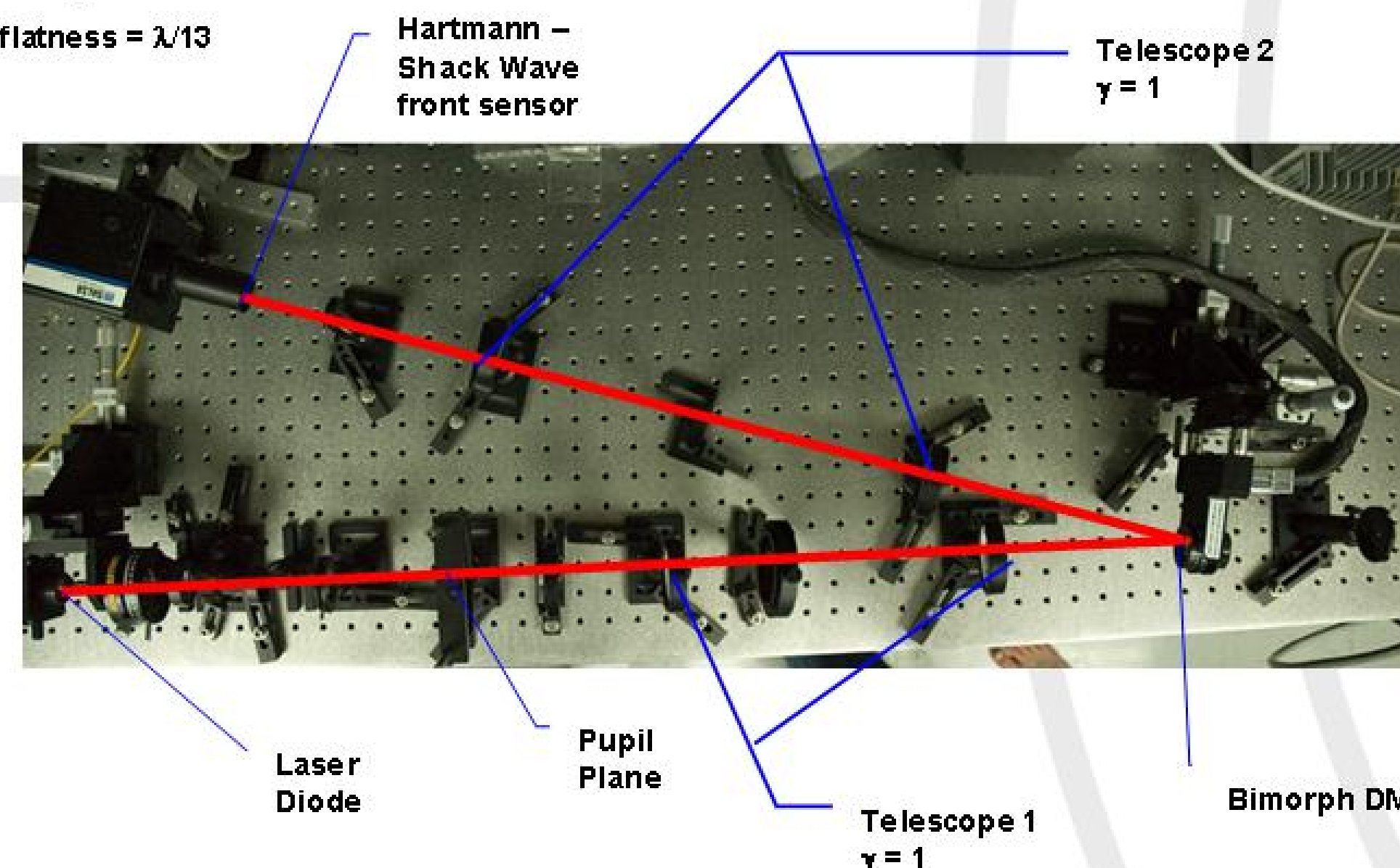
Was to help characterize a mirror for use in a next generation Adaptive Optics imaging system. On this project I:

- Helped with the layout, alignment and collimation of the system
- Wrote several programs in MATLAB and Python to help create high ordered aberrations for the system
- Took data on the mirror.

## Imaging Setup

### System Information

total  $\gamma = 1.00$   
flatness =  $\lambda/13$



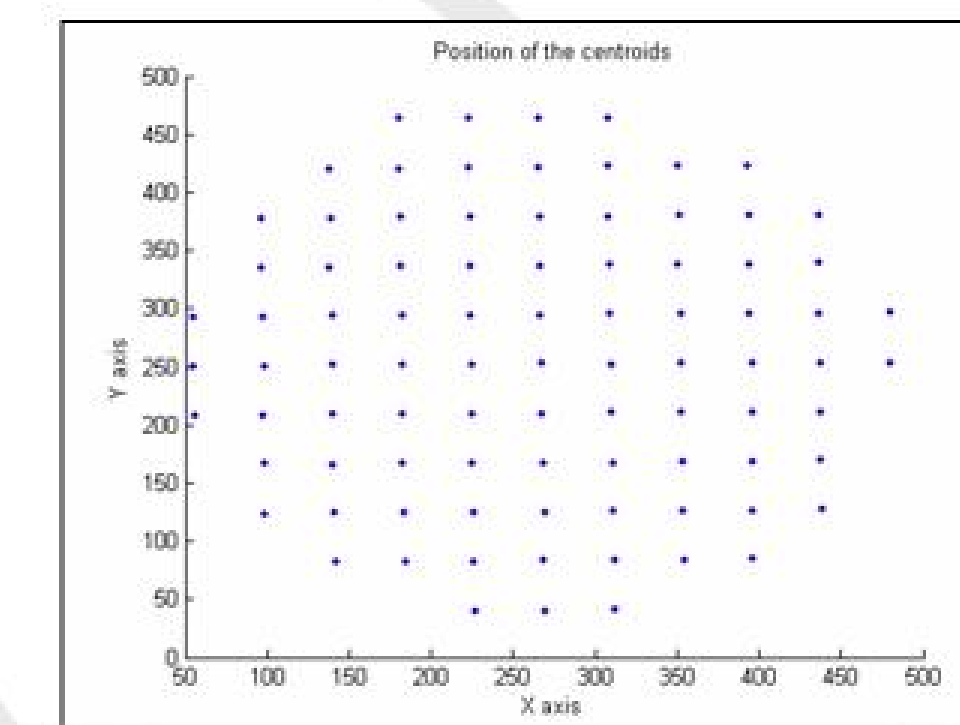
The AOptix bimorph deformable mirror

## Use of Aberrations in the System

- Lower ordered aberrations
  - Introduced using trial lenses.
  - Cylinder and Sphere
- Higher ordered aberrations
  - Trial lenses cannot be used
  - Generated in MATLAB
- All aberrations were 0- +/- 2.0 diopters

## High Ordered Aberrations

• Start with a file of reference positions



• Reads the value of each reference Centroid id from a matrix of partial derivatives for the particular Zernike mode, and calculates the slope in x and y

$$\{S_{x1}..S_{xn}, S_{y1}..S_{yn}\} = A \cdot \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}$$

Solution Vector (Slope)

Matrix of partial derivatives for all used Zernike modes

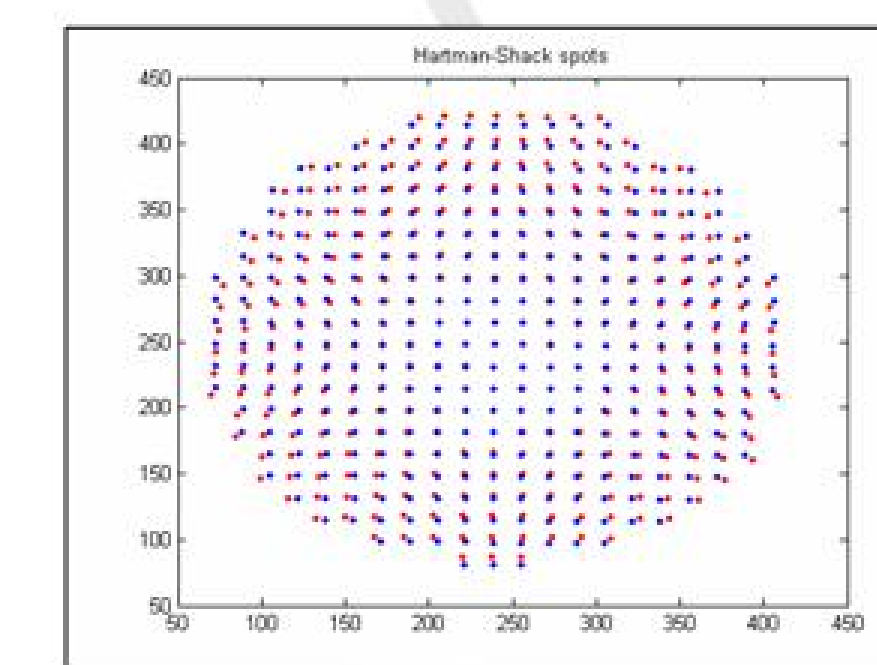
Vector of normalized Zernike coefficients

$$\alpha_{ij} = \left[ \frac{\partial(x, y)}{\partial x} \right] = \frac{2\pi}{\lambda f} \Delta x_{ij}$$

$$\beta_{ij} = \left[ \frac{\partial(x, y)}{\partial y} \right] = \frac{2\pi}{\lambda f} \Delta y_{ij}$$

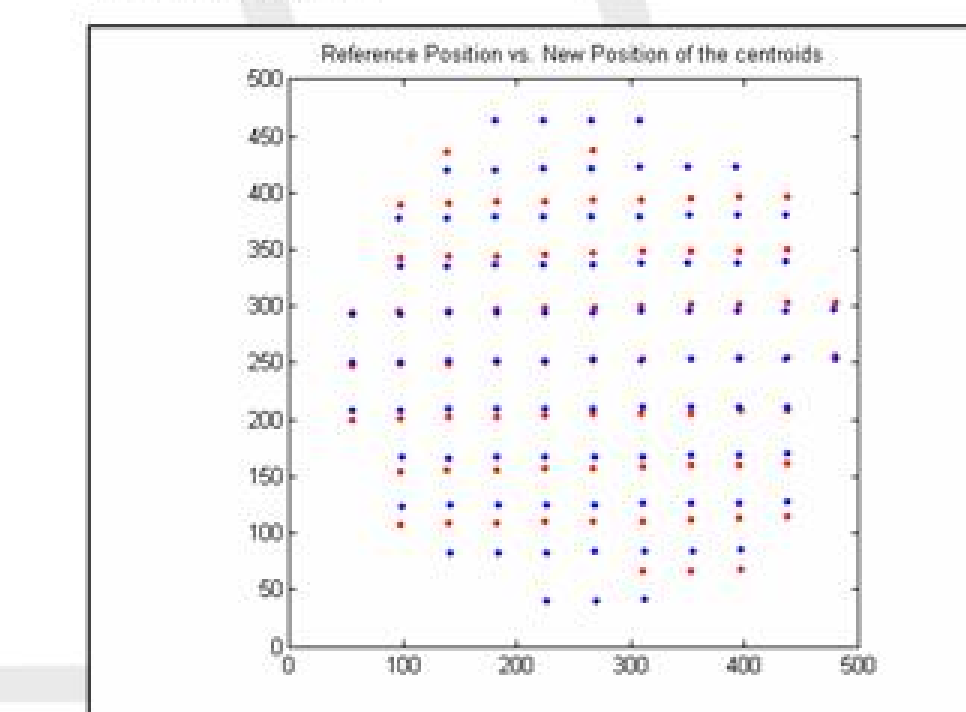
• The slope is directly proportional to the displacement

• The displacement is added to the reference position and logged

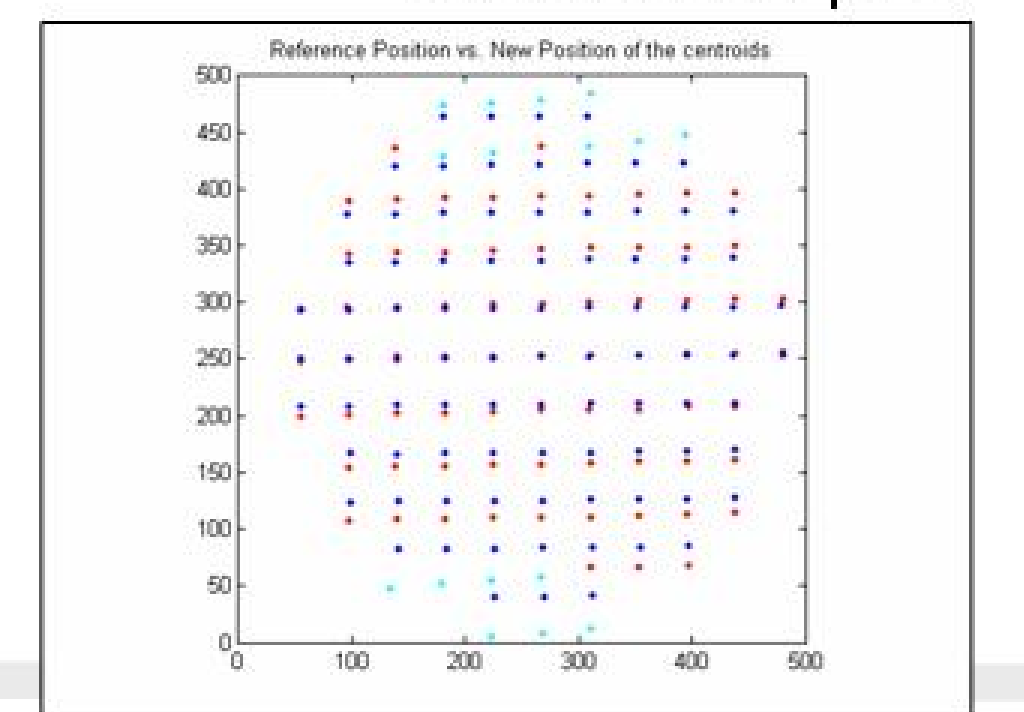


## Data Issues

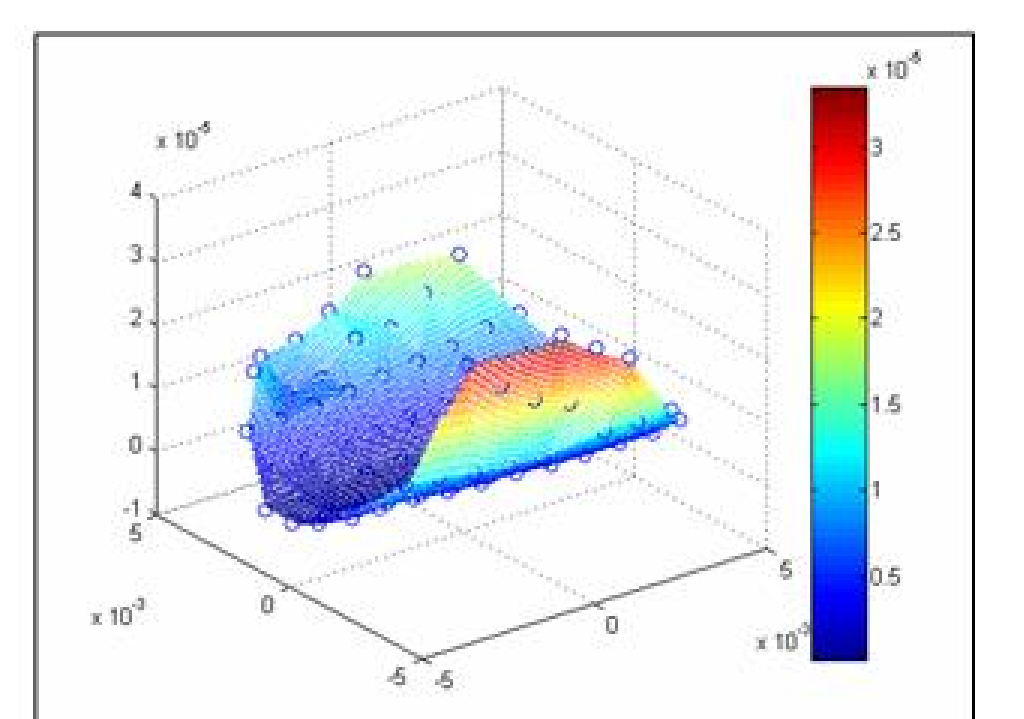
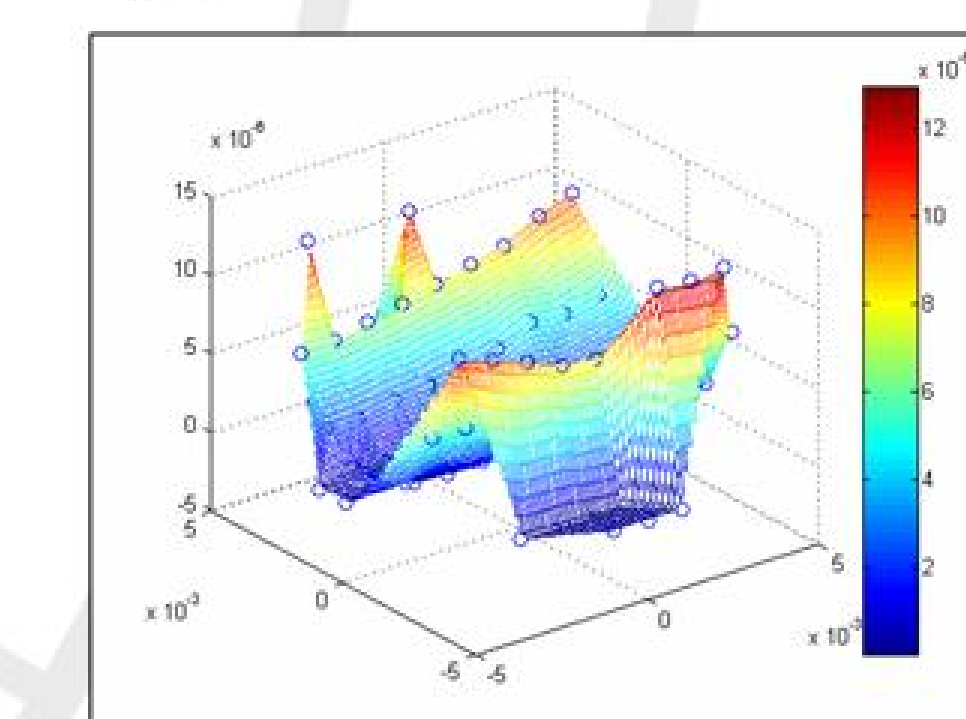
When aberrations are too strong with the trial lenses the centroids spread beyond their sub-aperture and the wave front sensor cannot 'see' them.



Thanks to MATLAB, we developed an extrapolation algorithm which can "correct" for these discontinuities in the reconstructed wave front, by estimating the missing centroid positions in the wave front sensor plane.



This phenomenon produces some artifacts in the wave front reconstruction and can be problematic for the analysis of the data



## Results

As of the end of my internship (5 August 2005) data and analysis was still being conducted. So far:

1. The more we increased the Zernike coefficient value, the larger the aberration is (or initial variance of the centroid displacements): it is totally normal and logical! Along with this we observed a symmetry for positive and negative aberration compensation.
2. After a certain Zernike coefficient value (different for each order) the system can no longer compensate for the aberration, and can no longer correct for the whole aberration. If we continue to increase the aberration, we notice that the amount of wave front correction stays constant. This corresponds to the maximum capacity for the aberration correction of the system for the specified mode. This value is different for each Zernike mode and decreases as you go into higher Zernike modes. Once again, normal. This particular mirror is noted for its ability to correct low ordered aberrations well

A complete analysis of the mirror will be presented at the Optics East SPIE conference in October 2005.

## -.75D Cylinder aberration being corrected

