MEMS Deformable Mirror Development for Laser Applications

Iris AO, Inc.

NSF Phase II SBIR: NNX12CA42C

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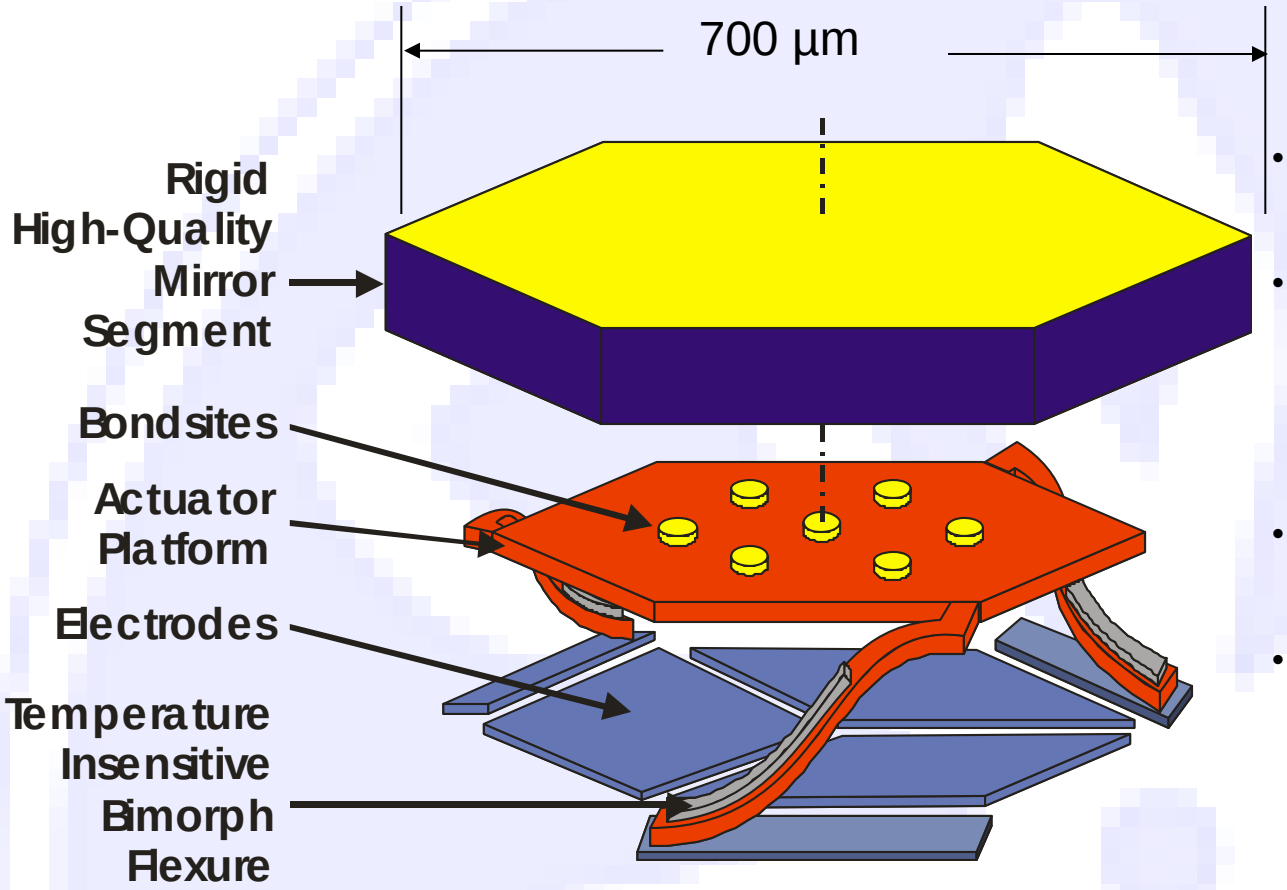
Iris AO Segmented DM Background



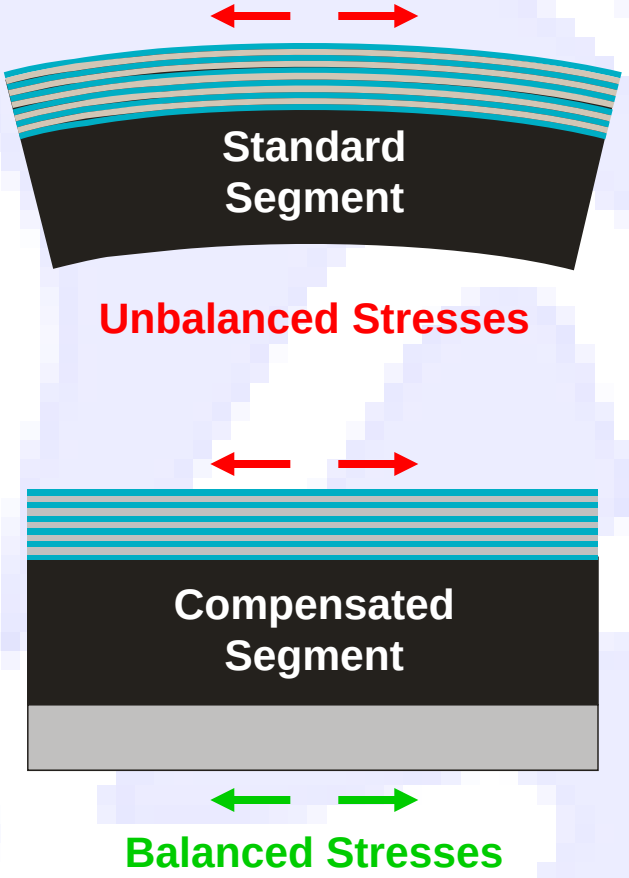
- 3 DOF: Piston/tip/tilt electrostatic actuation – no hysteresis
- Hybrid fabrication process
  - 3-poly surface micromachining
  - Single-crystal-silicon assembled mirror
- Unit cell easily tiled to create large arrays
- Hybrid technology
  - Thick mirror segments
  - Enables back-side stress-compensation coatings

Dielectric Coatings

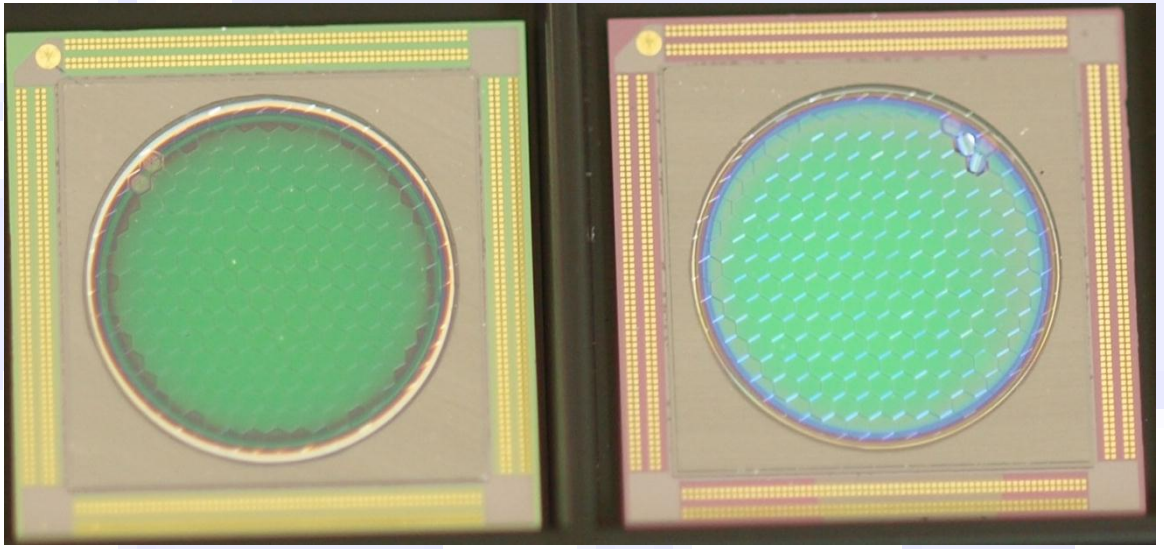
- Dielectric coatings enable large power handling
  - High reflectance >99.9%
  - High damage threshold

- Challenging for MEMS devices
  - Coating temperature: 200-400°C
  - High residual stresses
    - Up to ±300 MPa
    - Humidity dependent
      - Up to 100% change in stress levels for some coating types
  - Very thick coatings
    - 99.9% coating is ~5x λ

- Stress compensation required
- Thick segments to resist humidity and CTE mismatches



NSF Phase I SBIR: *Longer Wavelengths - 1064 µm, 1540 µm*



PTT489 DMs w/ Dielectric Coatings

- 1064 nm Coating, R=99.85%
- Coating Thickness: 5.41 µm
- As Coated Flatness
  - λ/27.7 (38.4 nm *rms*)
- Post-Processed Flatness
  - λ/93.3 *rms (*11.4 nm *rms)*

- 1540 nm Coating, R=99.85%
- Coating Thickness: 7.88 µm
- As Coated Flatness
  - λ/20.4 *rms* (75.3 nm *rms*)
- Post-Processed Flatness
  - λ/75.9 *rms* (20.3 nm *rms*)

Same compensation layer used for 1064 and 1540 nm coatings ∽ reduces fabrication costs

Phase II Objectives

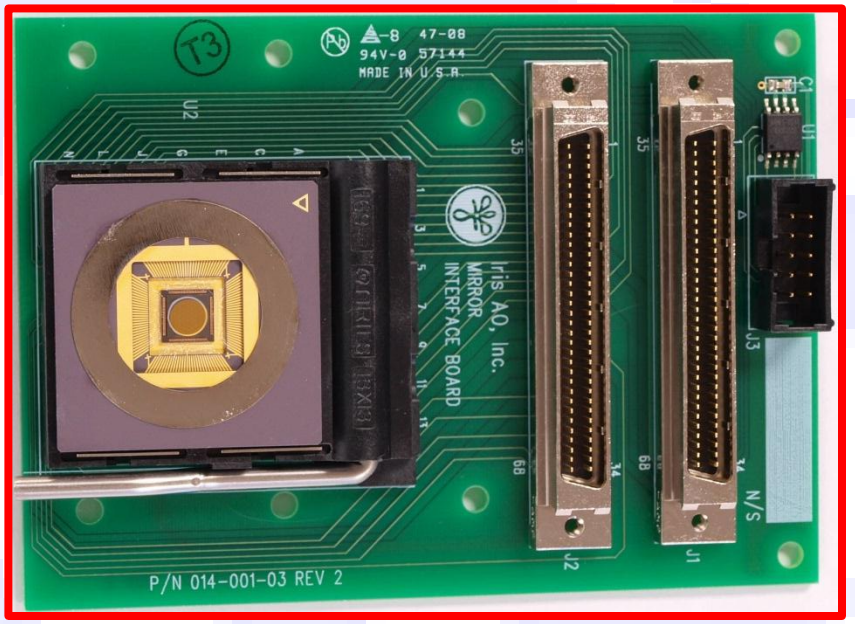
- Increase power handling: > 2kW/cm^2
  - Higher reflectance coatings: >99.9%
  - Improved fill factor
  - CTE matching
  - Heat sinking
- Improved sensing and control
  - PSF based corrections
  - Shack-Hartmann wavefront sensing for Gaussian beams
  - Beam shaping
- Laser guide star correction demonstration

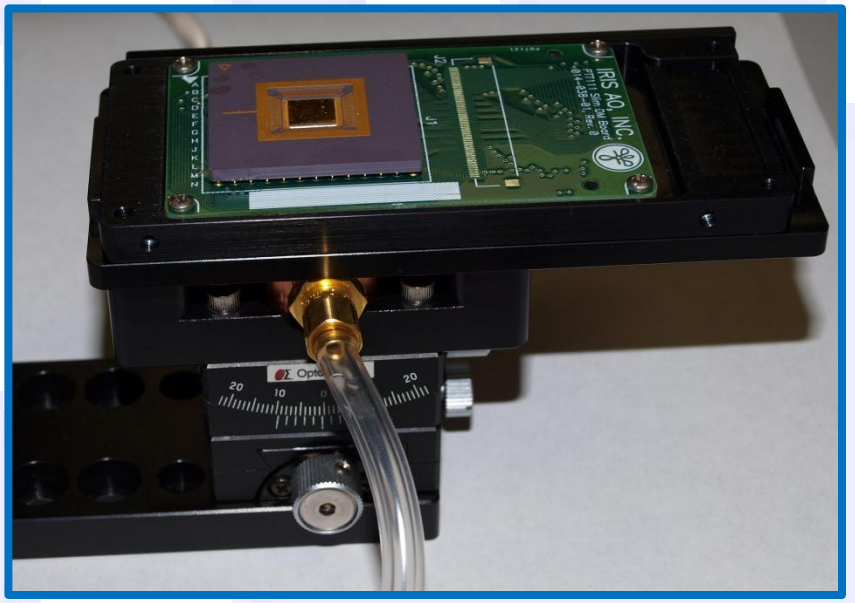
Phase II Results: Power Handling

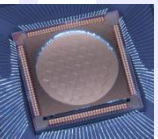
- 99.9% reflectance coating test runs
  - 355 nm
  - 589 nm
  - Characterization underway to determine compensation layers
- Mirror trench etch optimized to reduce gap size
  - Test run demonstrated gaps < 4 µm
- Mirror-wafer fabrication ~50% completed
  - CTE compensation will be included as well
- Heatsink demonstrated

Projected CW Power Handling: 532 nm

- Limit to λ/20 *rms* increase in figure error
- Existing packaging
  - 300 W/cm^2
  - Projections based on 2 W tests
- Higher power handling
  - Funded by NSF Ph. II SBIR
  - Heat sinking
  - Higher reflectance coatings
  - Reduced gaps
  - 2,800 W/cm^2
- Higher power handling possible
  - Conceivable to get to ~10kW/cm^2
- Higher power lasers required to validate projections



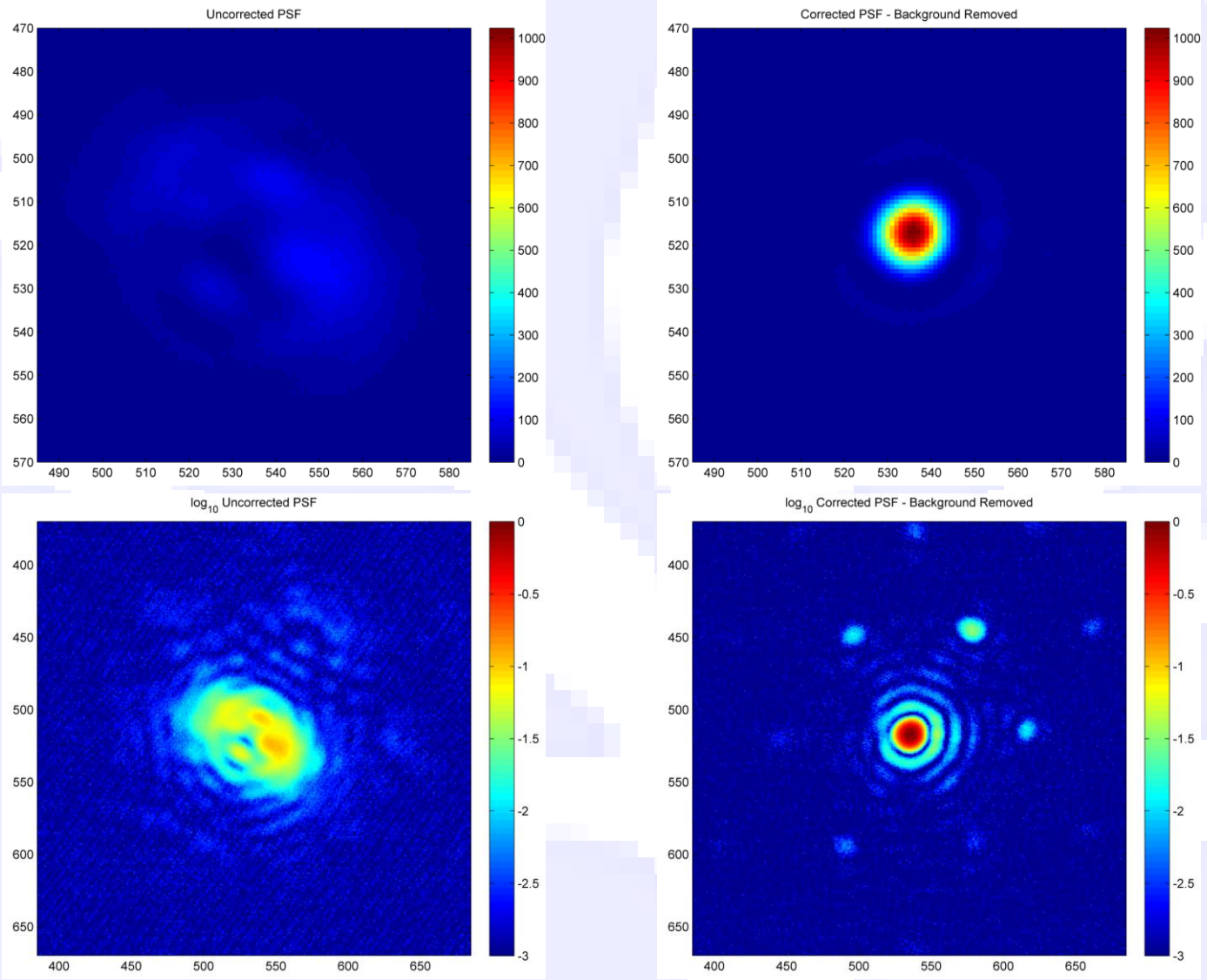




Phase II Result: PSF-Based Sensing and Control

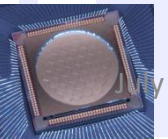
Linear Scaling

Log$_{10}$ Scaling



AO Off

AO On

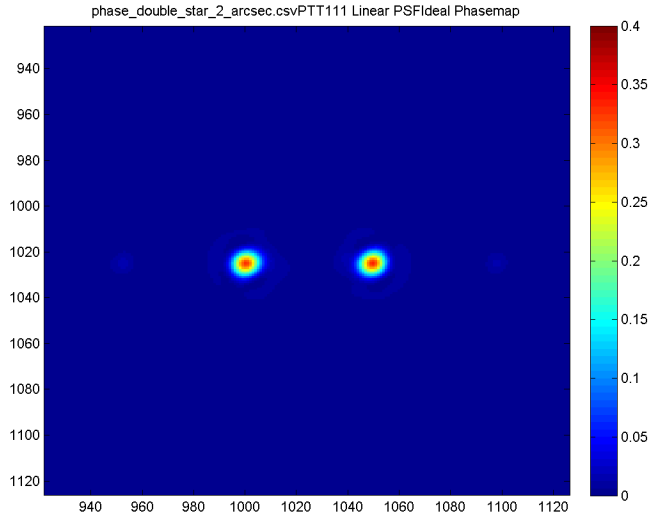


Phase II Result: SH WFS for Gaussian Beams

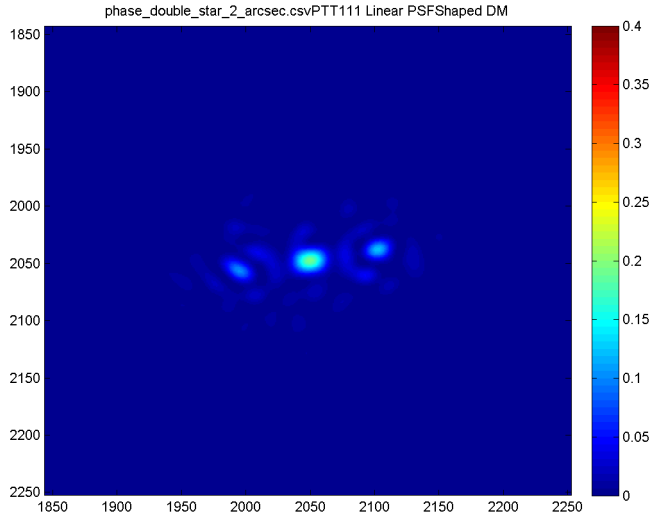
- Traditional SHWFS – top hat beams
- Lasers: Gaussian beams
  - Central spots are saturated
  - Outer spots are too dim
- Solution
  - 1: Reduce power and use central spots
    - Large WFS errors
  - 2: Multiple samples at different shutter speeds
    - Read in multiple images
    - Build composite of best samples
- System has been purchased by a laser manufacturer to demonstrate AO correction

Phase II Result: Beam Shaping

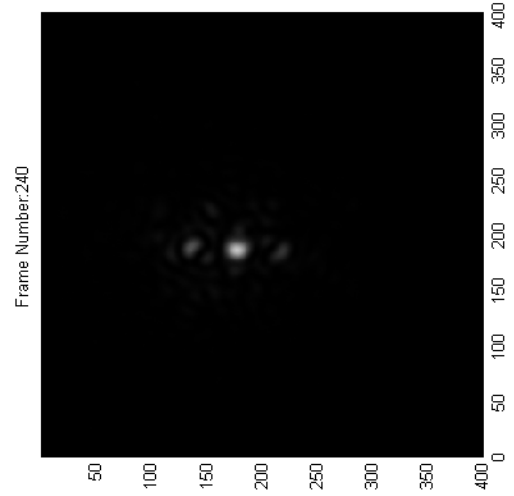
- New effort starting now
- PSF-based control effort resulted in extensive toolset
  - Matlab-based image capture and camera control testbed
  - PSF simulations
- Preliminary demonstration using Gerchberg Saxton



Ideal Simulation



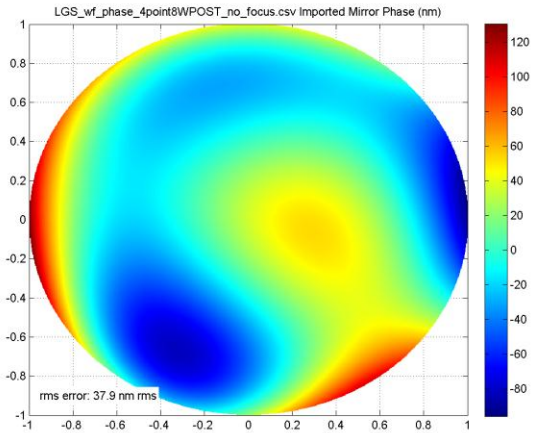
PTT111: Simulation



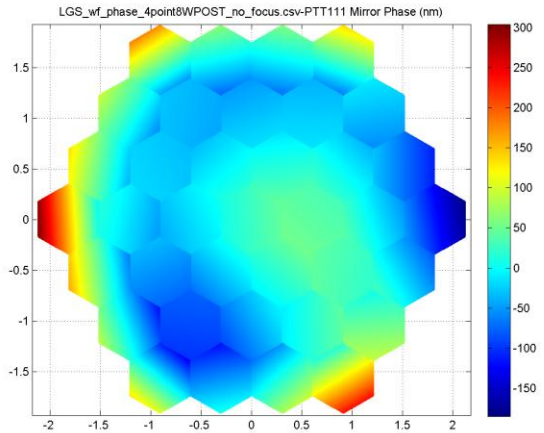
PTT111: Measured

Simulated PSF Improvement from Lick Observatory LGS Laser

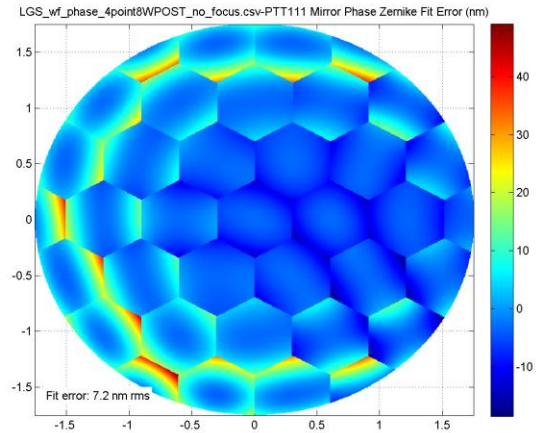
Uncompensated Wavefront



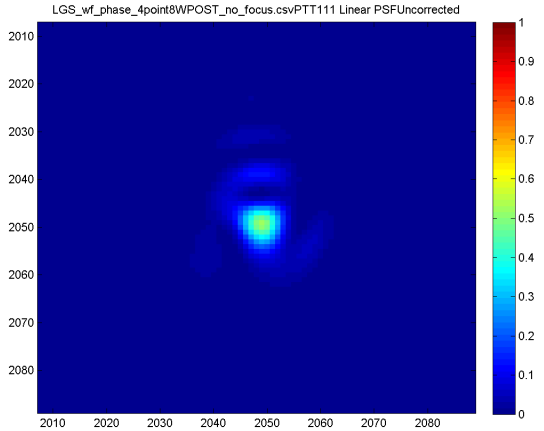
DM Correction Applied



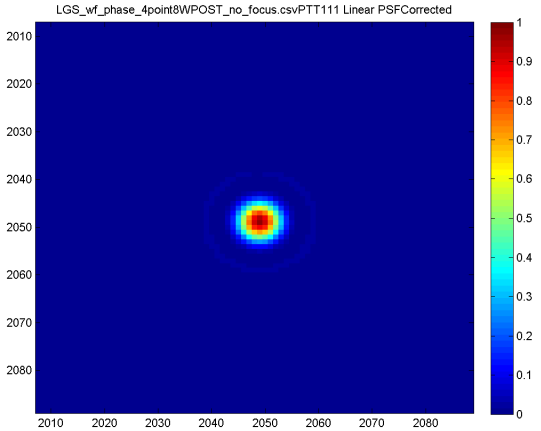
Compensated Wavefront

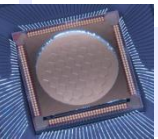


Uncompensated PSF



Compensated PSF

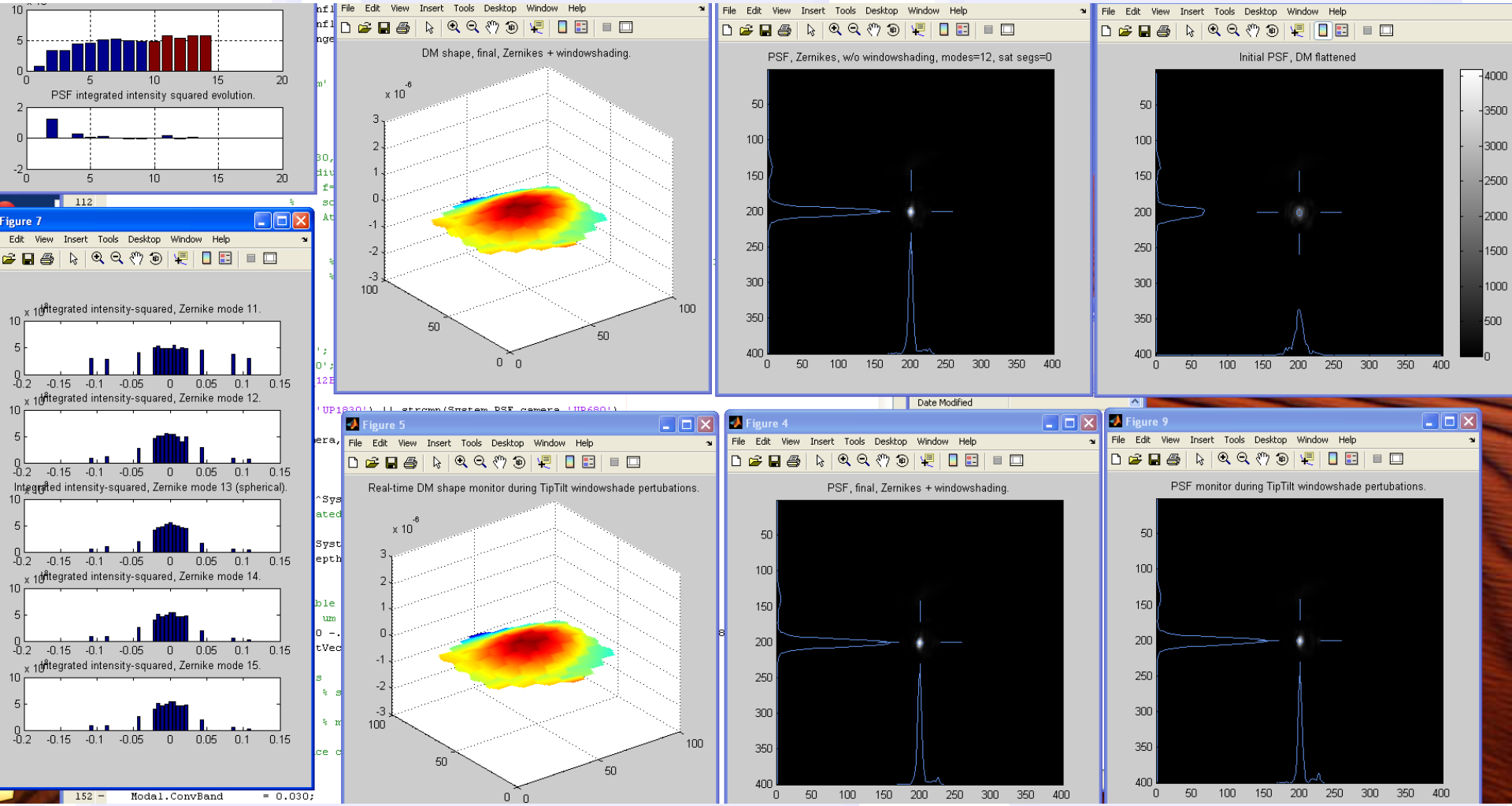




Phase II Result: LGS Uplink Correction

- Lick Observatory: Shane 120” (4m) telescope
- PSF-based DM control
- PSF camera mounted on diagnostic bench
- DM mounted on pump bench
- System remotely operated

Phase II Result: LGS Uplink Correction



Phase II Result: LGS Uplink Correction