# MEMS Deformable Mirror Development for Space-Based Exoplanet Detection

Iris AO, Inc.

**NASA Phase II SBIR: NNX11CE94P**

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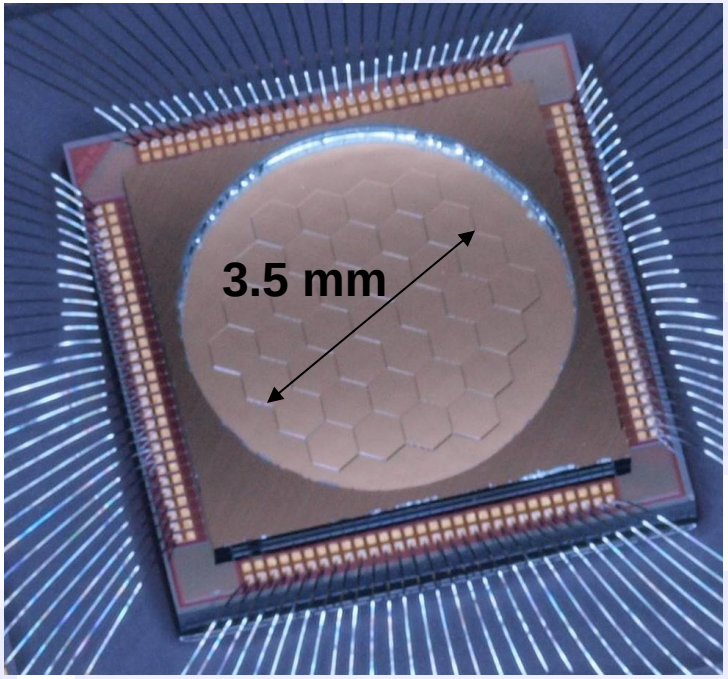
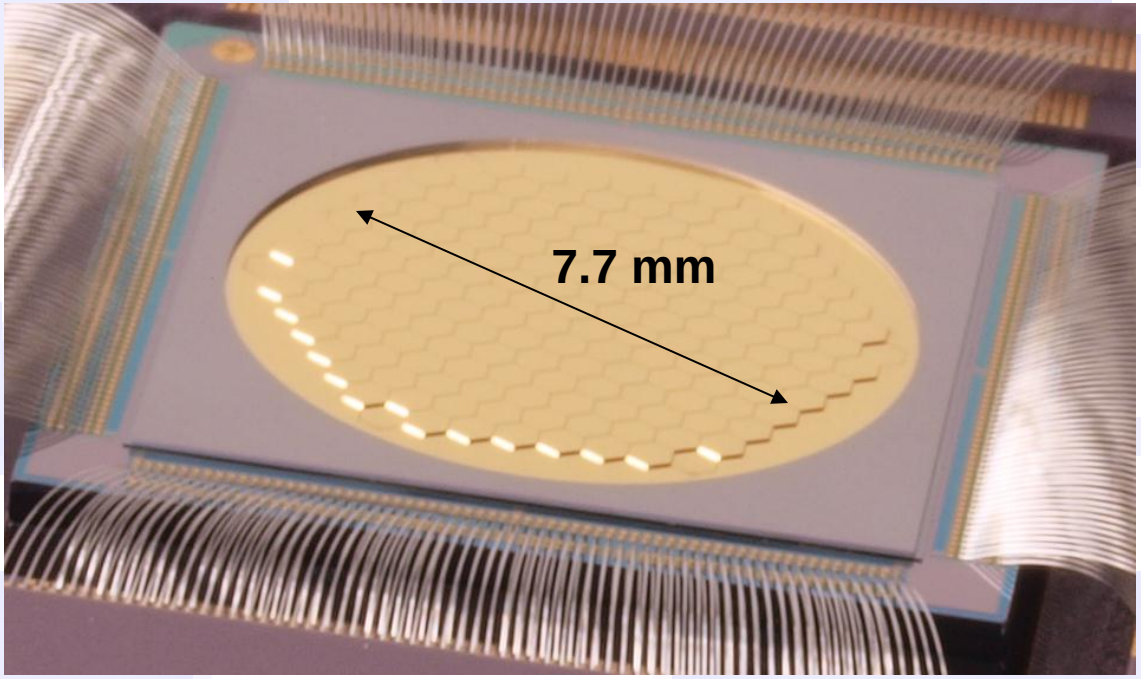
# Iris AO Segmented DM Background

# Iris AO MEMS Segmented Deformable Mirrors

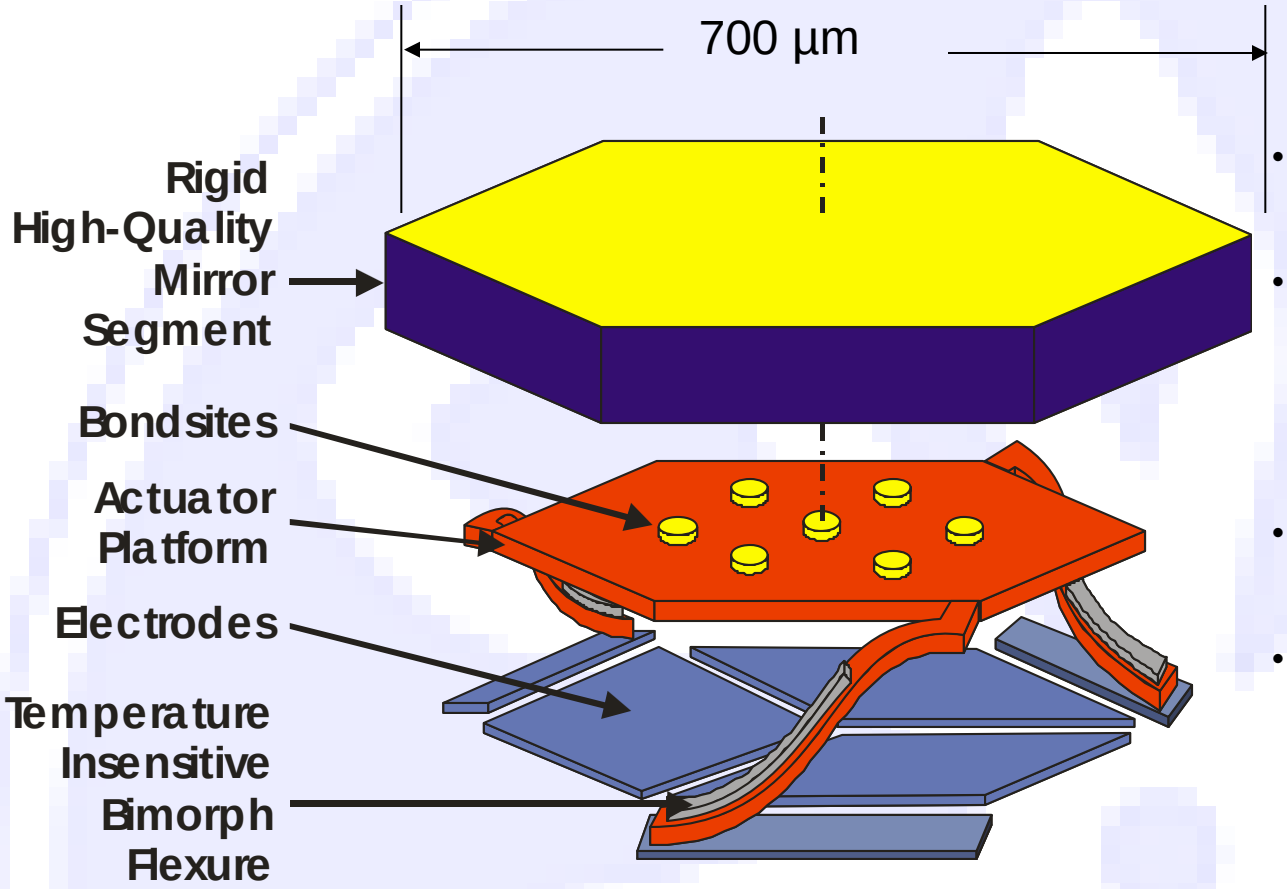



**PTT111 DM**
- 111 Actuators
- 37 PTT Segments
- 3.5 mm inscribed aperture
- Factory calibrated

**PTT489 DM**
- 489 Actuators
- 163 PTT Segments
- 7.7 mm inscribed aperture
- Factory calibrated

# Iris AO Segmented DM Background

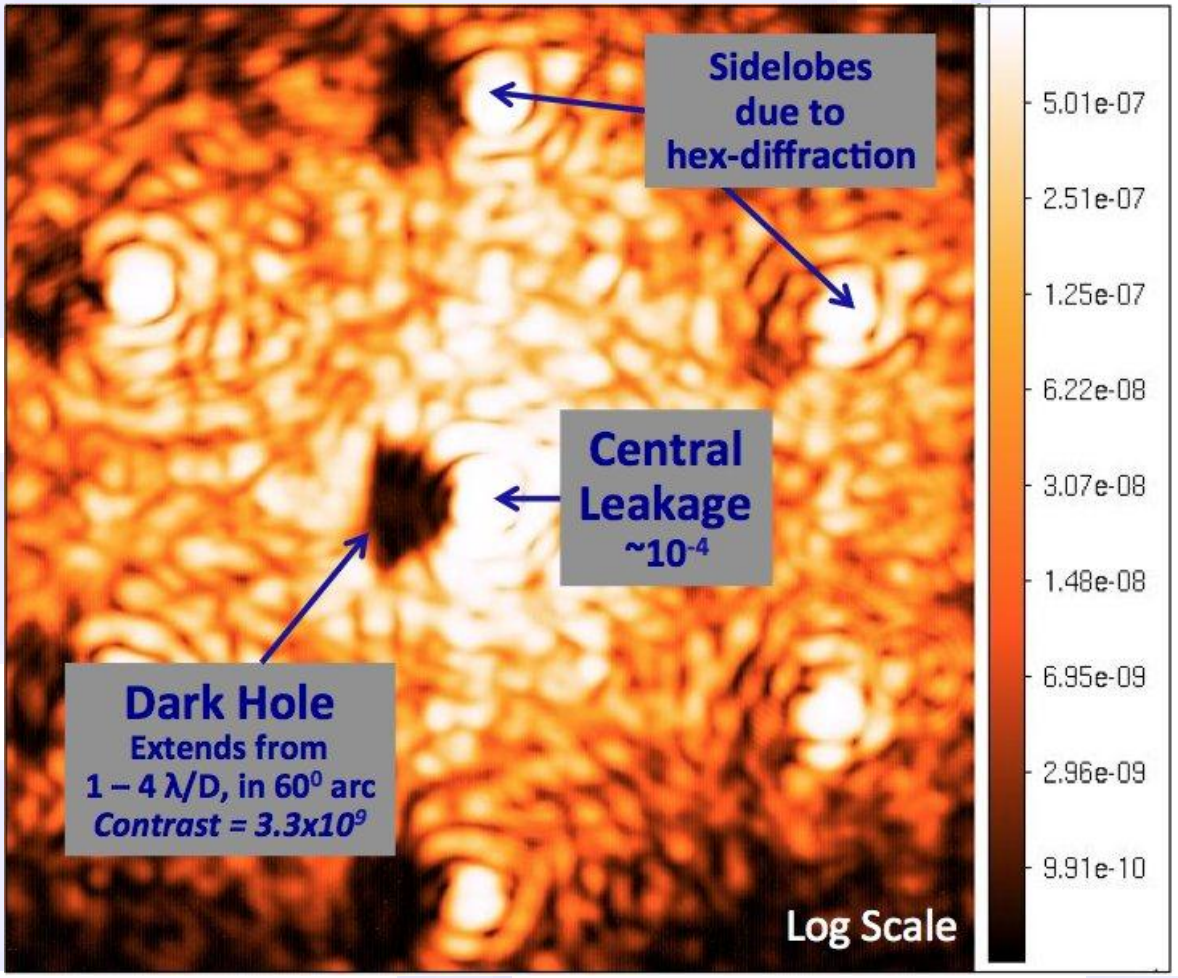


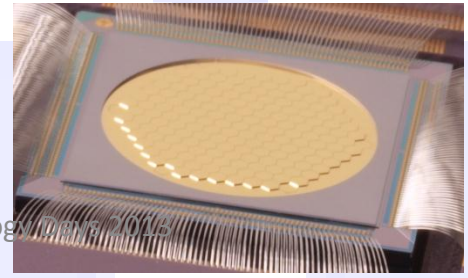

- 3 DOF: Piston/tip/tilt electrostatic actuation – no hysteresis
- Hybrid fabrication process
  - 3-poly surface micromachining
  - Single-crystal-silicon assembled mirror
- Unit cell easily tiled to create large arrays
- Hybrid technology
  - Thick mirror segments
  - Enables back-side stress-compensation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

# $10^9$ Contrast @ IWA 1 – 4 λ/D Results GSFC VNC Instrument on 06/09/12



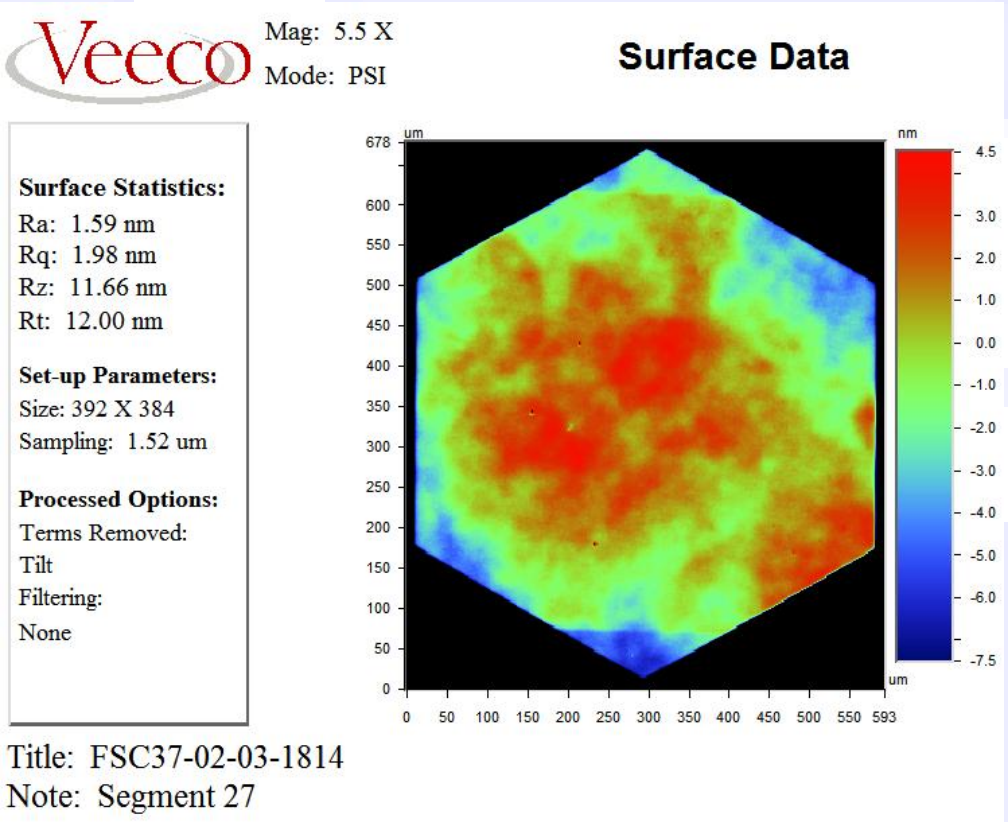
- GSFC/Visible Nulling Coronagraph
- 4 Data Collection Events (DCE)
  - 50,000 frames per DCE
  - Average last 3,800 frames
  - Closed-loop at 40 Hz / 4 Hz in vacuum tank
  - (λ,Δλ) = (633, 1.2) nm
- **>$10^9$ Contrast averaged over 1-4 λ/D, $60^0$ arc region**
- 1st Demo of segmented aperture coronagraphy
  - hex-packed segmented MEMS DM
- Meets FY10/11 TDEM milestones
- FY12/13 TDEM broaderband
  - increase spectral bandpass from Δλ= 1.2 nm to Δλ= 40 nm
- VNC investigated in 3 Astrophysics Strategic Mission Concept Studies
  - ATLAST, EPIC, DAViNCI



# Exoplanet Imaging Requirements: *VNC Technology*

- Usable Dynamic Range (Stroke): 0.5 µm
- Segment Control Resolution: 50 pm
- ~1000 Segment DM
- Segment Flatness: 1-3 nm *rms*
  - 2 nm *rms* demonstrated on best segment
- Robust to snap-in failures
  - Anti-snap-in device (ASD) technology survives 100M snap-in events

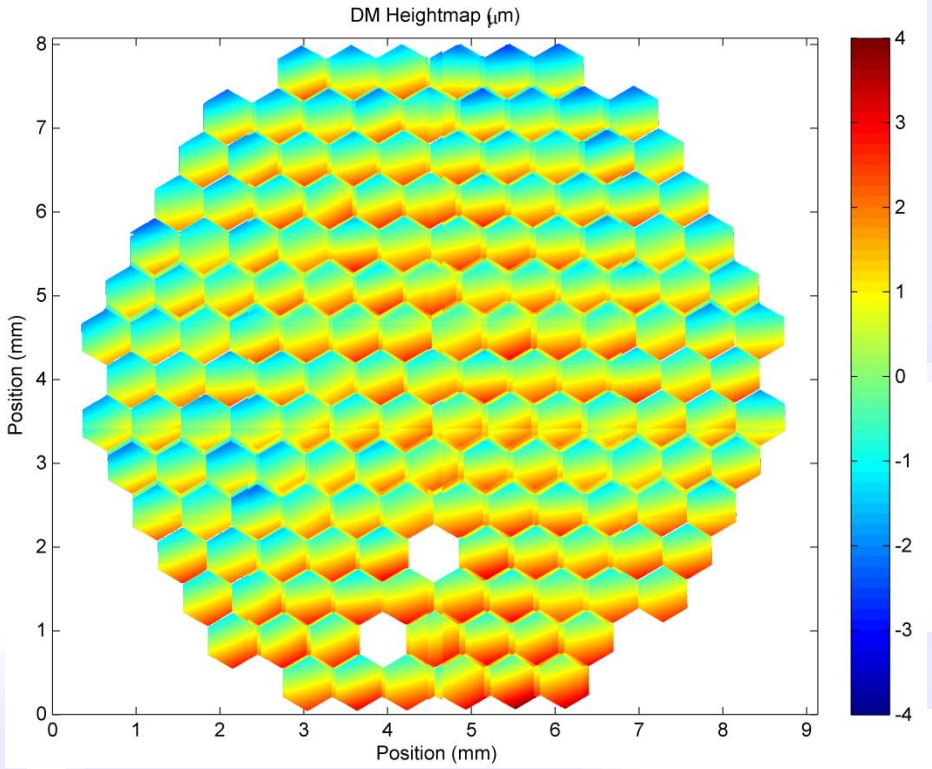


# Phase II Objectives

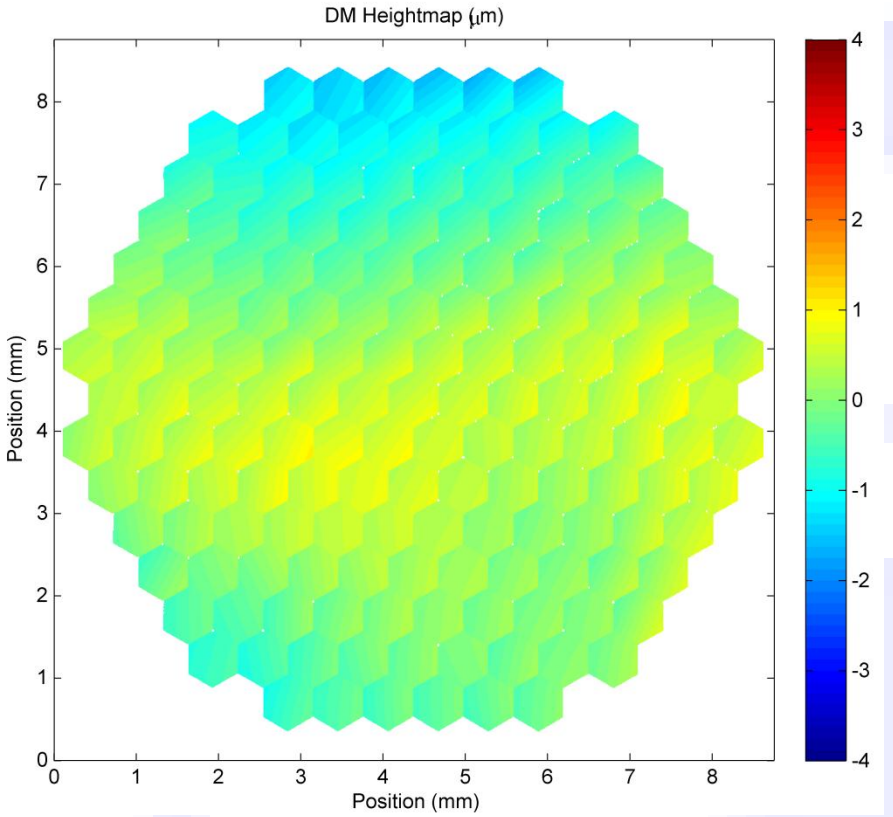
- Improve DM quality
  - Reduce chip bow
  - Increase segment position uniformity
  - Improve segment flatness for entire array
- Scale technology to 1000-actuator DM
  - Increase yield
  - Demonstrate PTT939 array
- Demonstrate pm-level positioning

# NASA Phase II Result: DM Quality Improvement

## Unpowered PTT489 DM

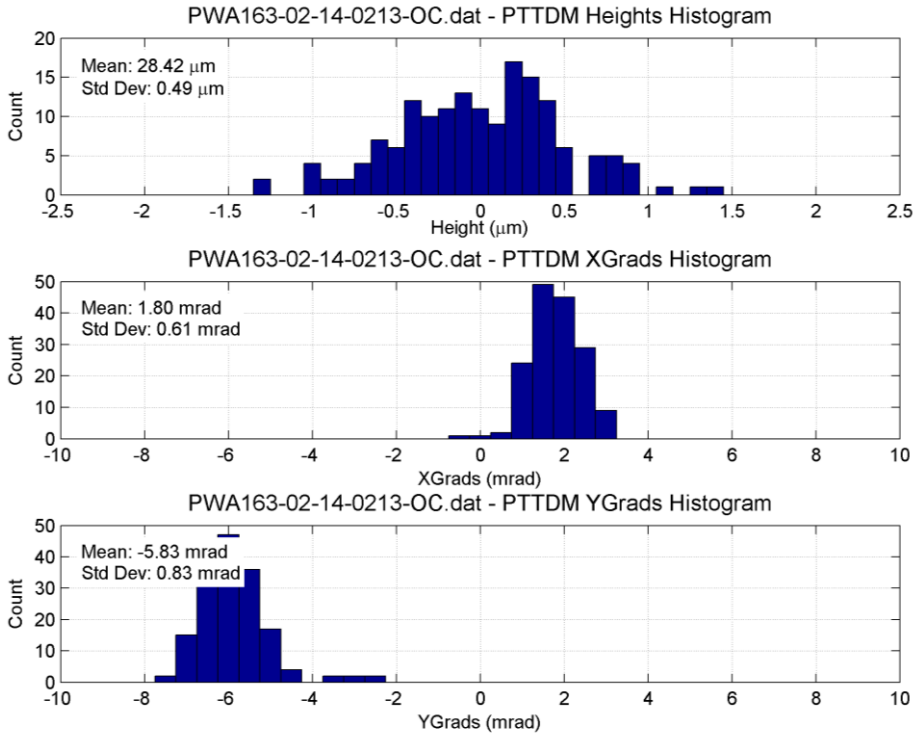


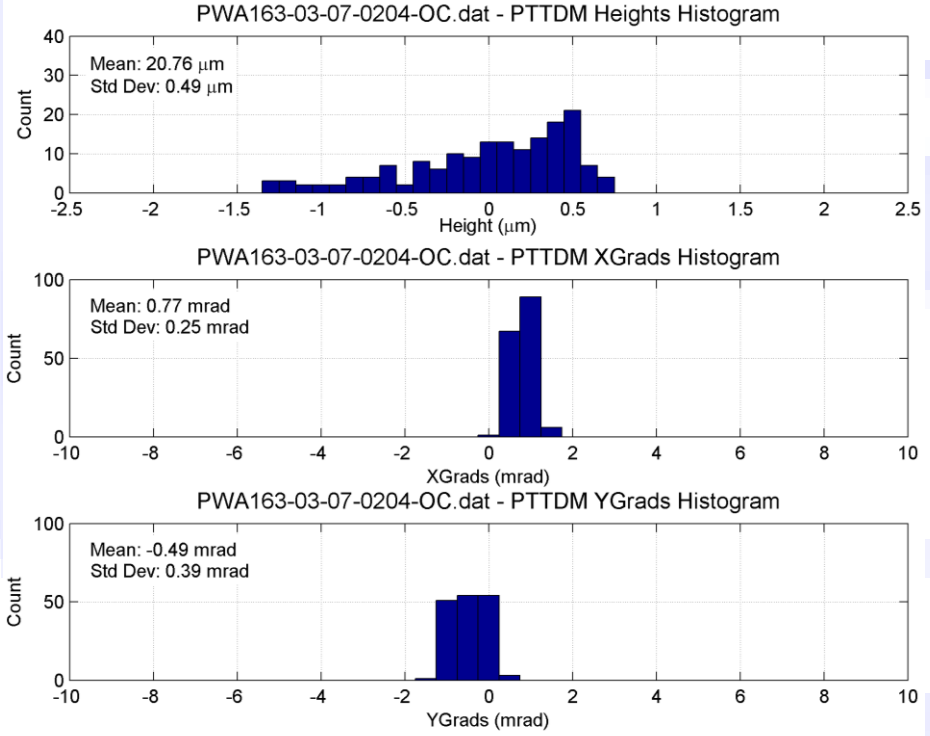

Pre Phase II




Phase II Interim Deliverable

# NASA Phase II Result: DM Quality Improvement



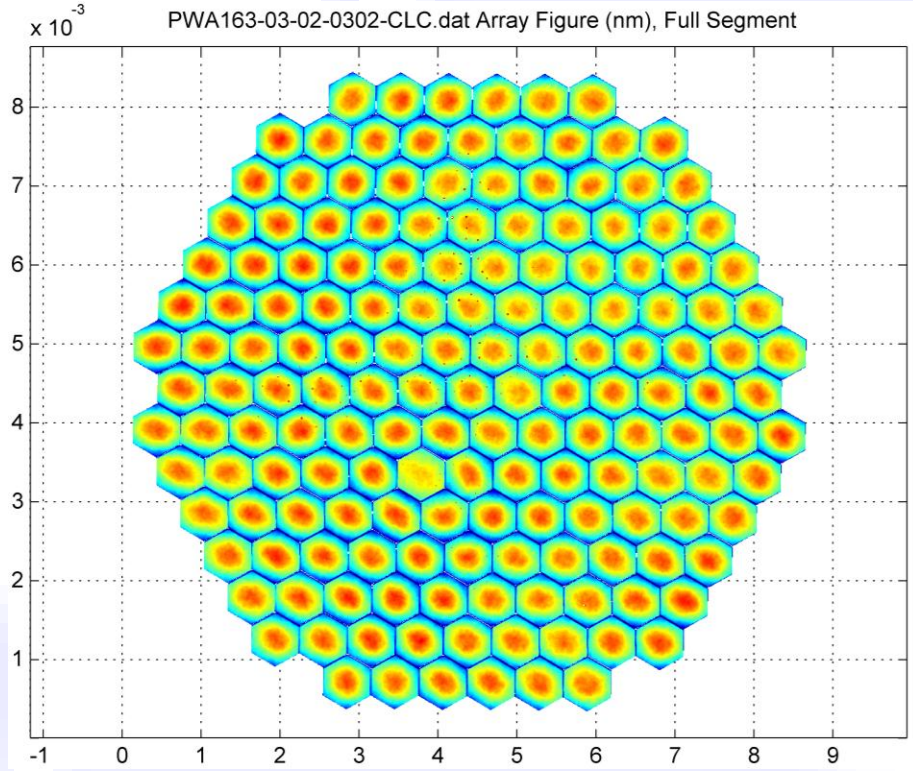



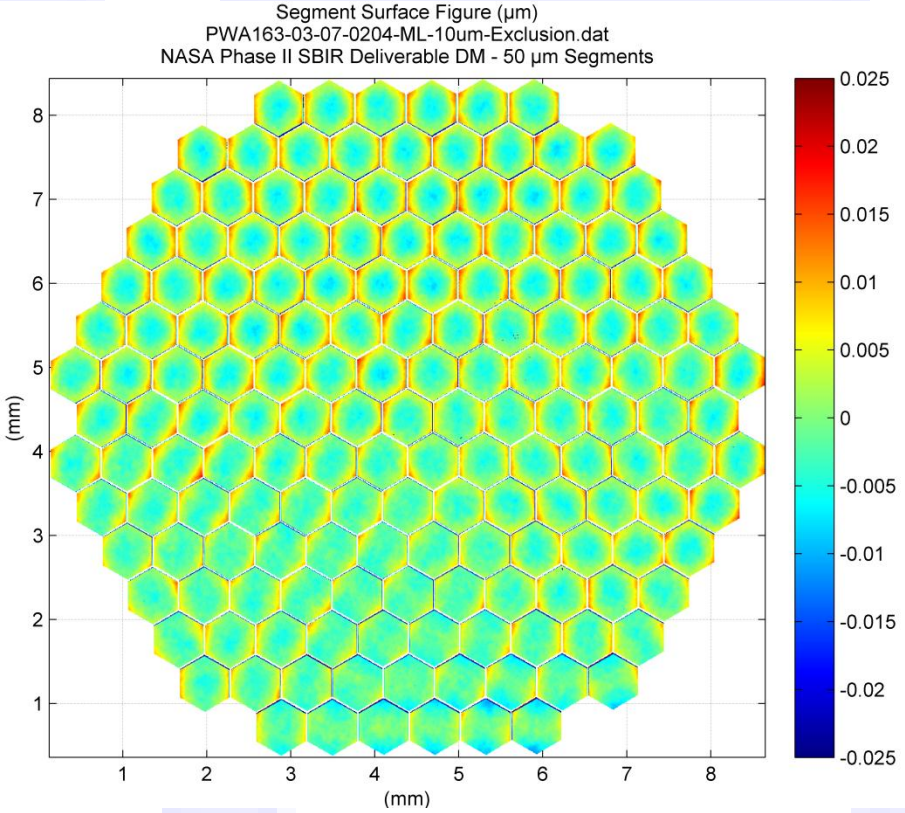

**Pre Phase II**

**Phase II Interim Deliverable**

- Further improvements expected when fabrication technology transferred to DUV photolithography system

# NASA Phase II Result: DM Quality Improvement

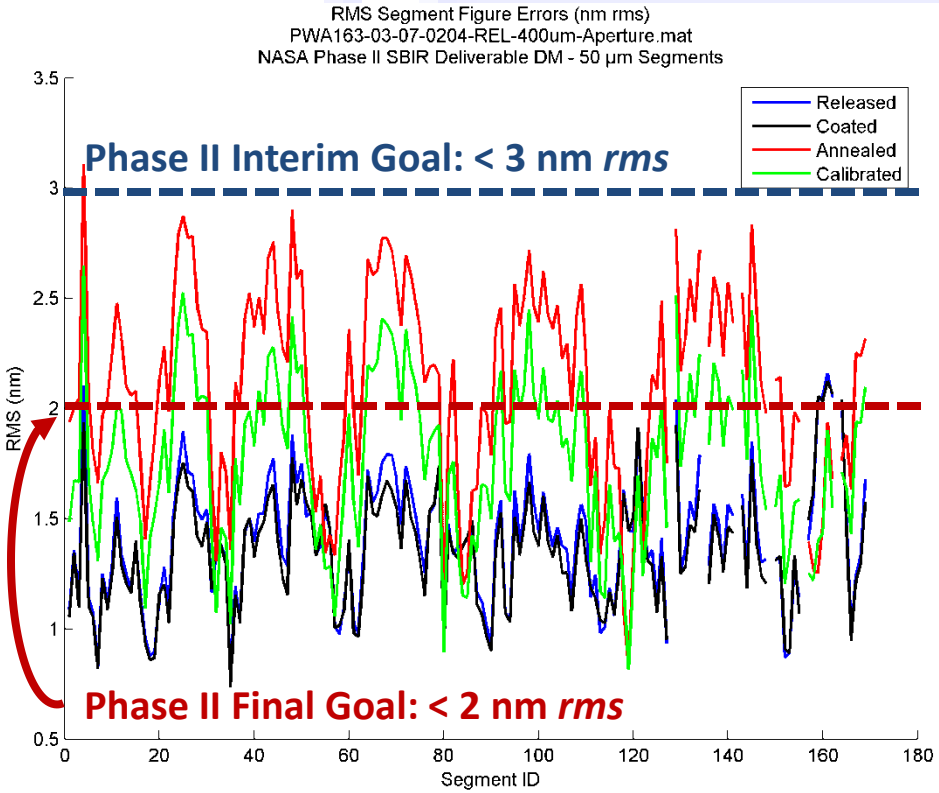


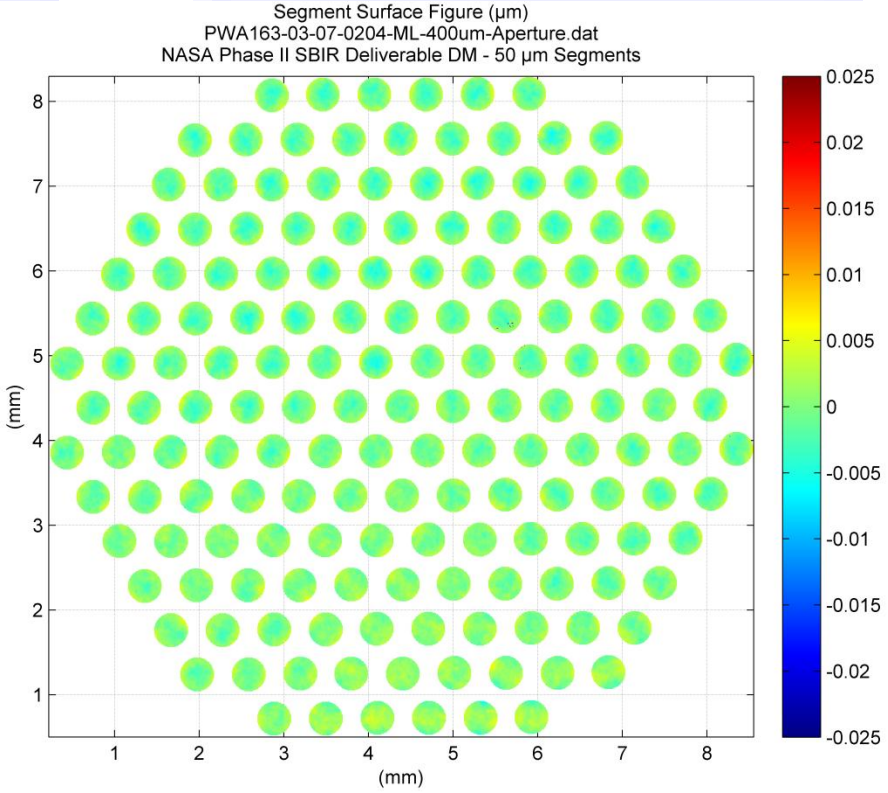




**Pre Phase II**

**Phase II Interim Deliverable**

# NASA Phase II Result: DM Quality Improvement

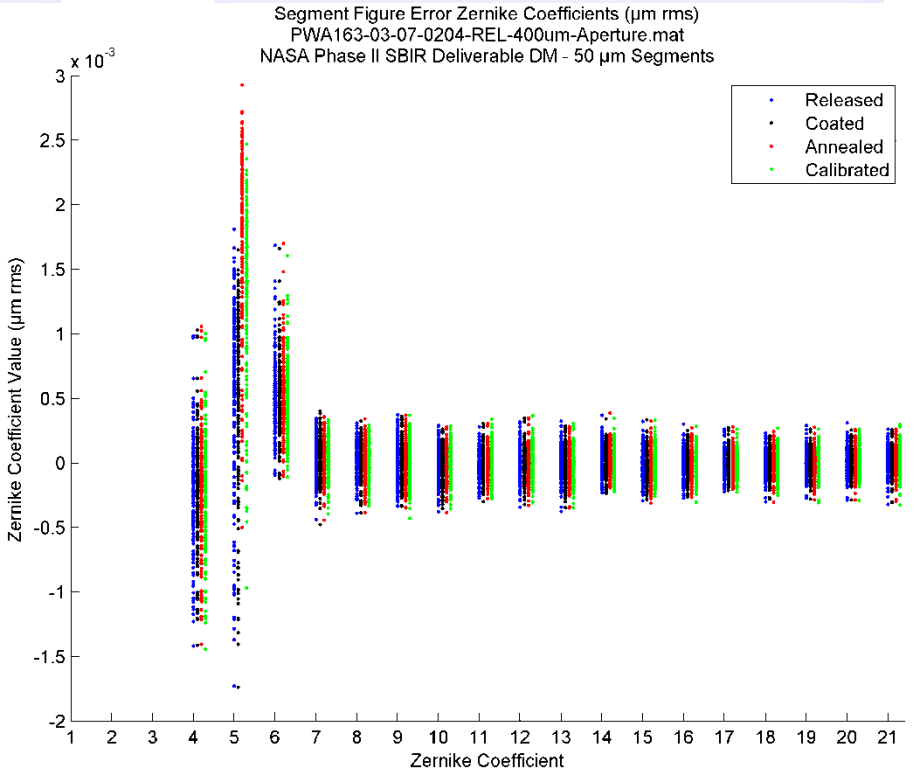



**Phase II Interim Deliverable**

# DM Segment Fitting – Zernike Coefficients

- Individual segments fit with Zernike terms
  - 400 µm circular aperture
- Fitting errors dominated by low-order terms
- Starting silicon wafers are assumed flat
- DM fabrication processes introduce low-order deformations
- Room for improvements



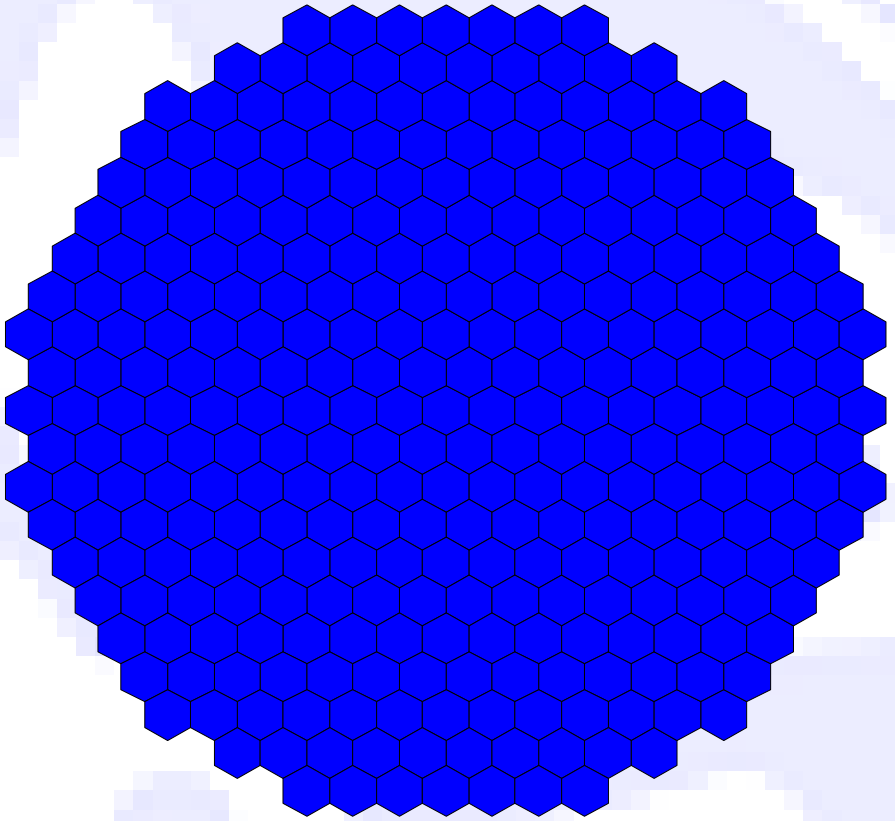
# NASA Phase II Result: Yield Increases

- Segment yield must be increased to demonstrate a fully functional PTT939 array
- Dominant electrical yield reduction identified
  - Low breakdown voltage of a passivation layer
  - Short-loop fabrication run nearly complete to test thicker passivation layer
- Dominant mechanical yield reduction identified
  - Gases generated during microstructure wet release process damage segments
  - Chemical treatments of DMs prior to release have improved yield
  - Design modification will be implemented to reduce chemical reactions

| Mirror Build | Actuator Wafer Version | Mirror Wafer Version | Mech. Segment Yield | Electrical Segment Yield | Total Segment Yield | Chip Yield |
|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 66.8% | 83.4% | 55.7% | 0.0% |
| 2 | 1 | 2 | 93.9% | 92.4% | 86.8% | 0.0% |
| 3 | 2 | 2 | 97.6% | 98.8% | 96.8% | 18.8% |
| 4 | 2 | 2 | 98.8% | 99.1% | 96.5% | 20.0% |
| 5 | 2 | 2 | TBD | TBD | TBD | TBD |

# NASA Phase II SBIR: Remaining Work

- Demonstrate PTT939 DM
  - Transition fabrication process to DUV stepper lithography system
- Demonstrate pm-level positioning resolution
  - Signal processing technique to increase effective resolution demonstrated



**PTT939 DM**
**10.85 mm aperture**
**313 PTT segments**
**939 actuators**