Field Test Results for Iris AO Deformable Mirrors in High Power Laser Applications

Carl Kempf

Iris AO, Inc.

www.irisao.com, 510.849.2375
carl.kempf@irisao.com, info@irisao.com

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DMs in High Power Laser Systems

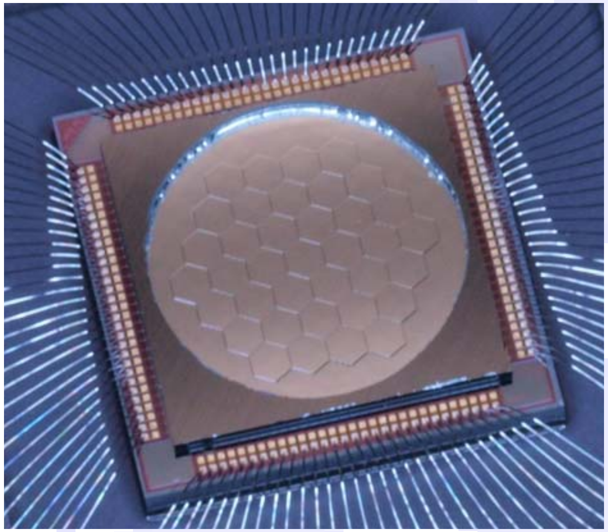
Variety of Goals

- Dynamic aberration correction
- Beam shaping
- Compensate for thermal lensing and drifts
- Broaden pulse-repetition rate operating range
- Extend laser effective lifetimes
- Simplify manufacture of lasers

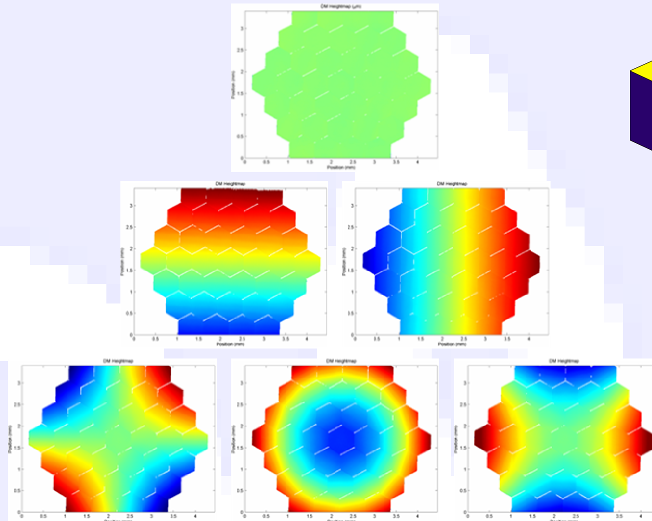
Required Enabling Technology

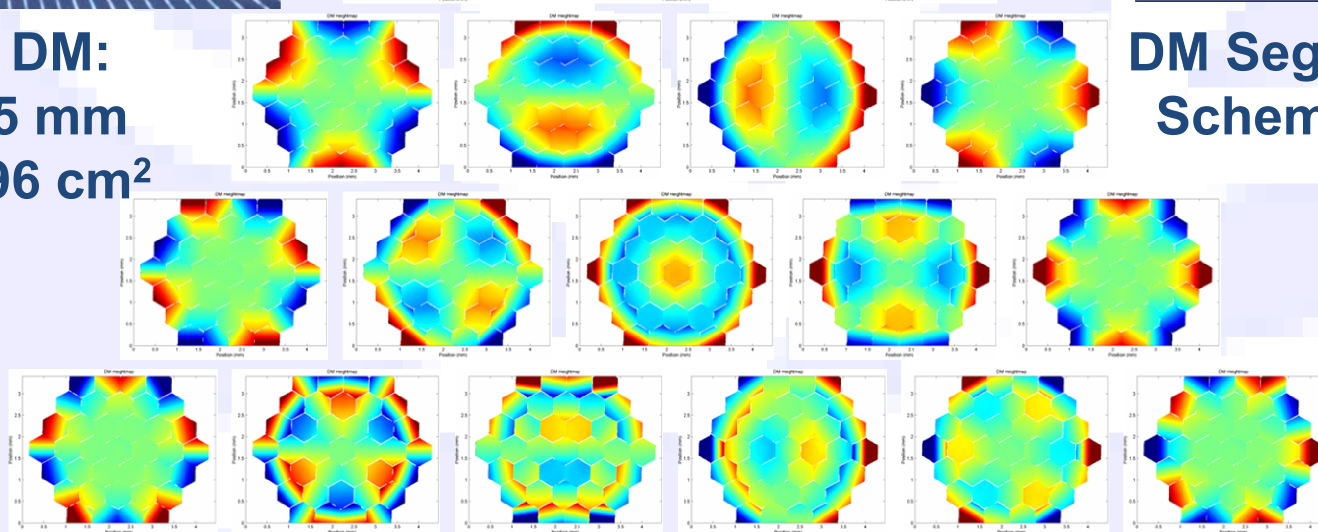
- Dielectric coatings
- Thermal management
- DM control techniques

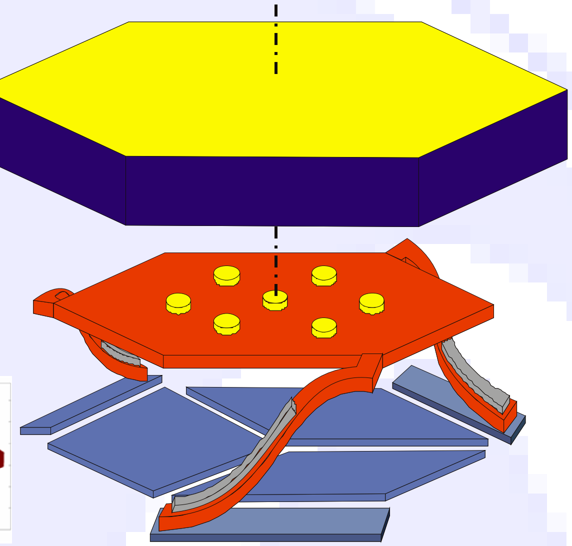
Iris AO PTT111 Deformable Mirror



PTT111 DM:
diam: 3.5 mm
area: 0.096 cm^2







DM Segment Schematic

Color Map of Mirror Shape: *Measured Open-Loop Commanded Zernike Basis Set*

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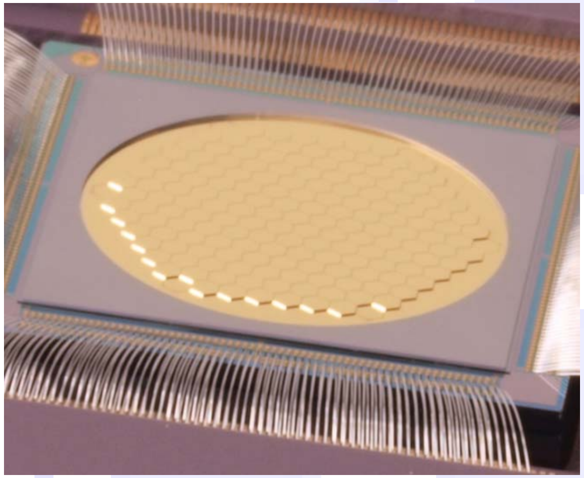
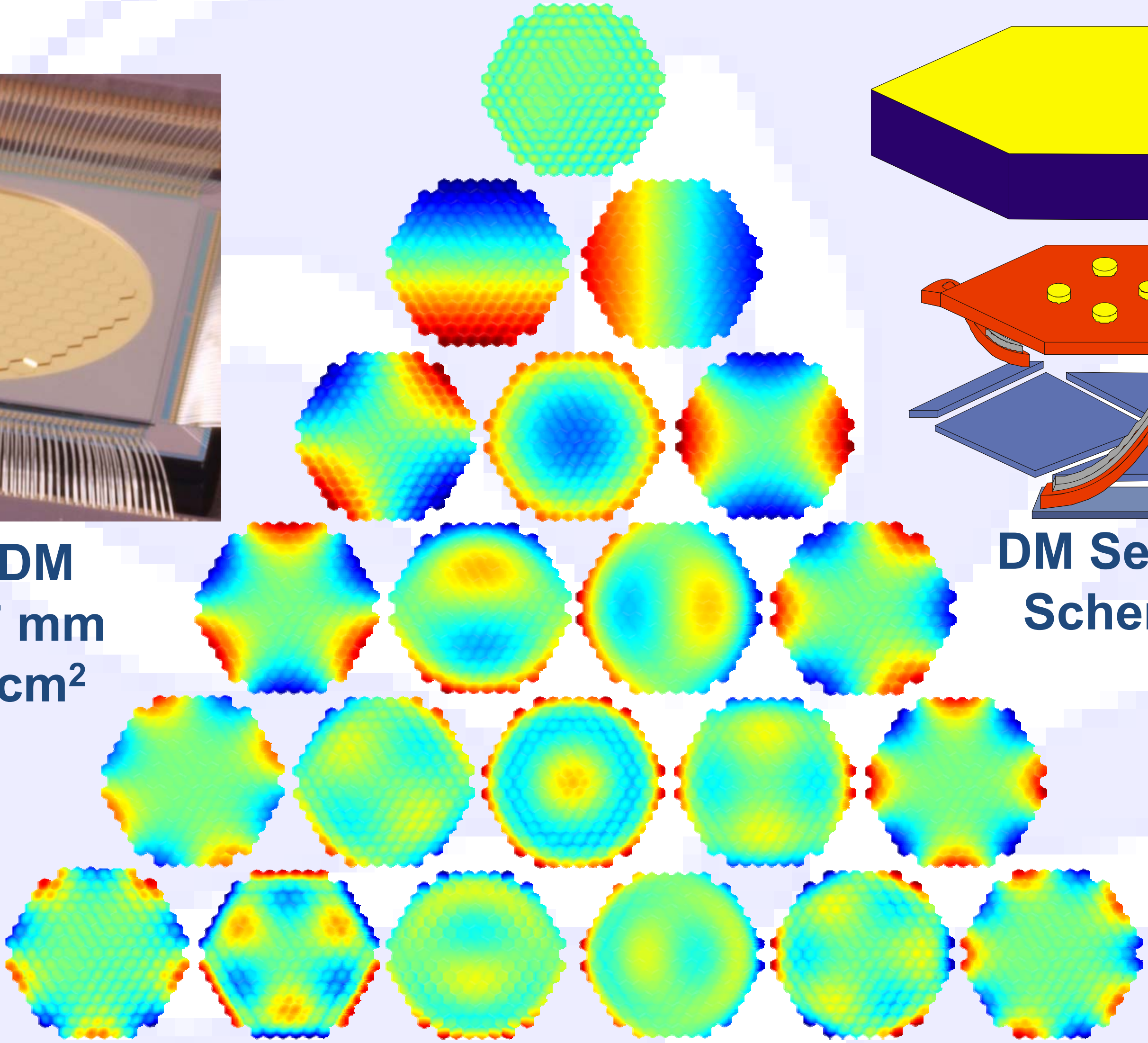
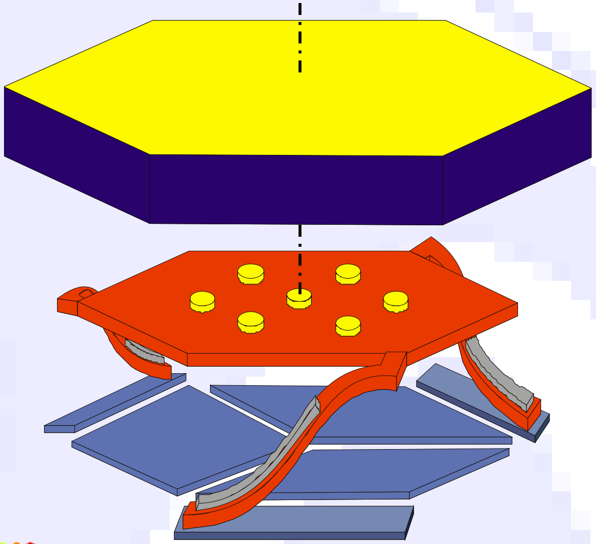
Iris AO PTT489 Deformable Mirror



PTT489 DM
diam: 7.7 mm
area: 0.47 cm²

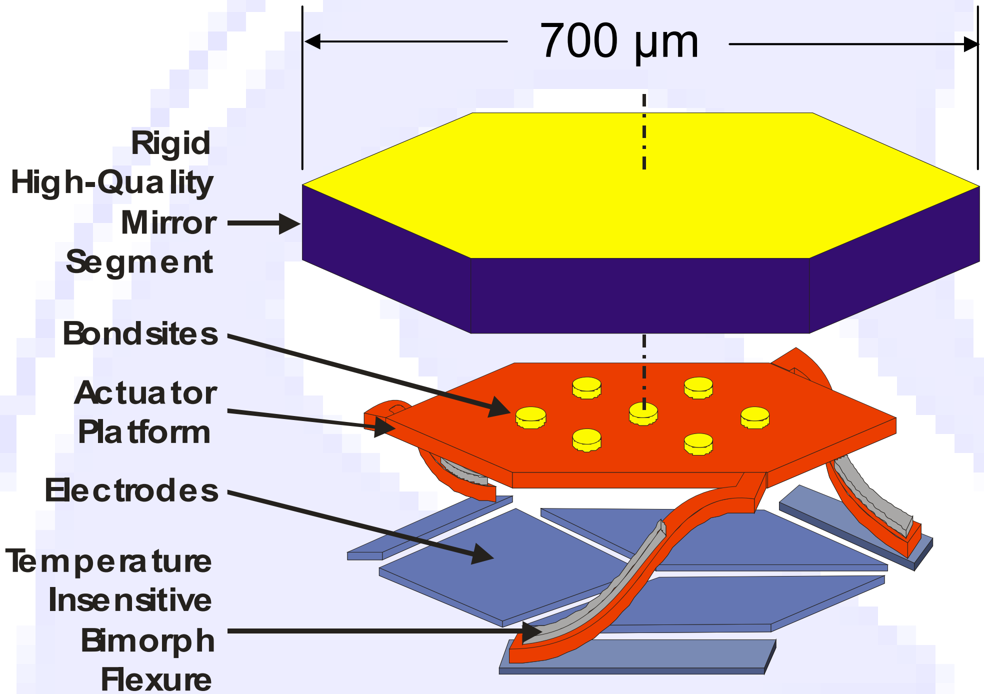




DM Segment Schematic

Color Map of Mirror Shape: ***Measured Open-Loop Commanded Zernike Basis Set***

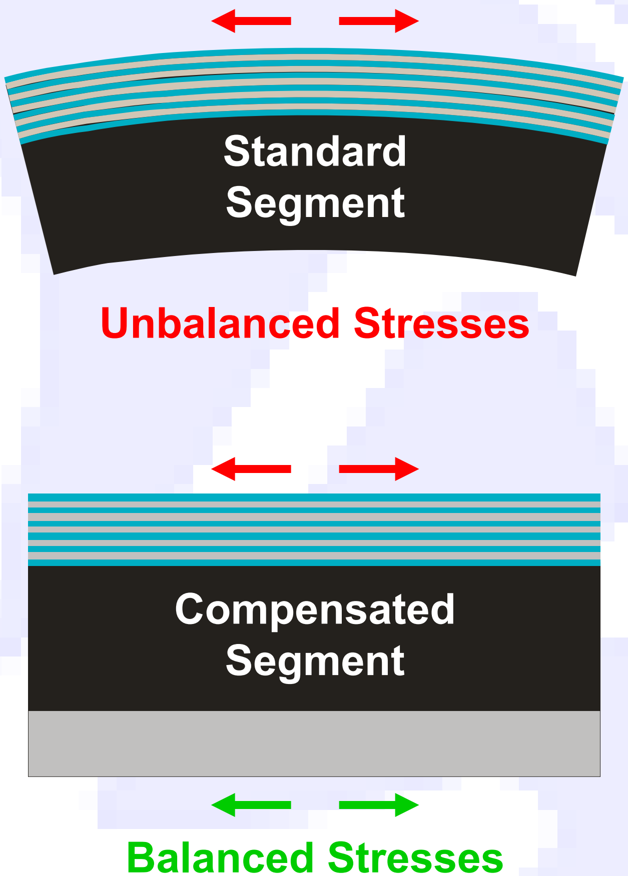
Iris AO Segmented DM



- Piston/tip/tilt (PTT) electrostatic actuation
  - no hysteresis
- Calibrated segment-by-segment
  - positioning device
  - command as an array (Zernikes)
  - command using PTT for each segment
  - saturation and bounds-checking handled automatically
  - linear within reachable space
- Hybrid fabrication process
  - 3-poly surface micromachining
  - single-crystal-silicon mirror surface
- Unit cell easily tiled to create large arrays
  - Unique hybrid technology
  - optimize for speed, stroke, etc.
  - thick mirror segments
  - ***enables dielectric coatings***

Dielectric Coatings

- Enable large power handling
  - High reflectance >99.9%
  - High damage threshold
- Iris AO unique stress-compensation approach *enables* dielectric coatings
- Thick segments resist CTE mismatches and coating stress changes
- Dielectric coatings from UV to IR possible
  - 355, 532, 589, 1064, and 1540 demonstrated
- Pulsed Laser Tests (No damage detected)
  - 355 nm: 130 MW/cm2, 2 mJ/cm2 peak fluence, 15 ps, 50 µm diameter straddling segment gap
  - 1540 nm: ~75 MW/cm2, 4.2 mJ, 7 ns, 1 mm diameter



Thermal Management

- Harsh Environment Packaging:
  - Water-cooled heatsink for substrate cooling
  - Sealed DM cover with gas purge ports
- Power Handling Projections (CW)
  - Based on tests on sub arrays at 532nm
  - 300 W/cm2 w/o heatsink
  - 2,800 W/cm2 with heatsink and 2nd generation DM

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DM Control Techniques

- Wavefront Sensor Approach
  - 1:1 segment lenslet matching
  - Multi-sampling approach for varied beam intensities
  - Modal reconstructor and controller
  - Fast sampling and correction
- Image (PSF) Based Approach
  - Iterative, so not as fast as WFS
  - Works with camera or point detector
  - Maximizes intensity-squared integrated within Airy disk
  - Mode-by-mode optimization
  - Massively oversamples for robustness against noise
  - Great for static or slow aberrations

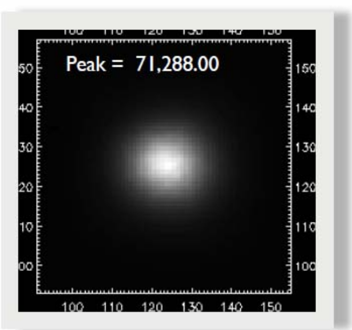
Testing Results

- LGS at Lick, Fall 2013
  - Spot sharpening based on iterative algorithm (static corrections)
  - Pick-off before launching out of dome
- Extended use (1000 hour) testing, 2014
  - Commercial customer
  - 1000 hour life testing at UV wavelengths
  - Looking for degradation in DM
  - Looking for losses in laser energy
- Other tests
  - Image sharpening/beam shaping, commercial customer

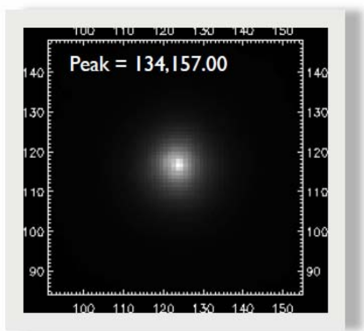
Laser Guide Star Correction

- Sodium laser-guide-star (LGS) uplink correction
- Demonstrated at Lick Observatory
  - Compensates for laser and beam train optics
  - Produces smaller and brighter LGS spot
  - Results in improved science images

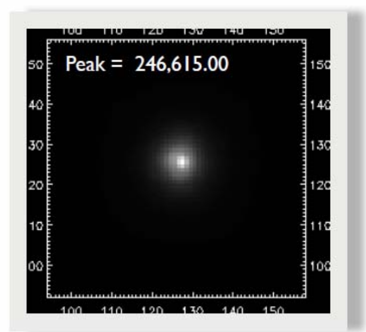
IRCAL Images of Star HIP 9507



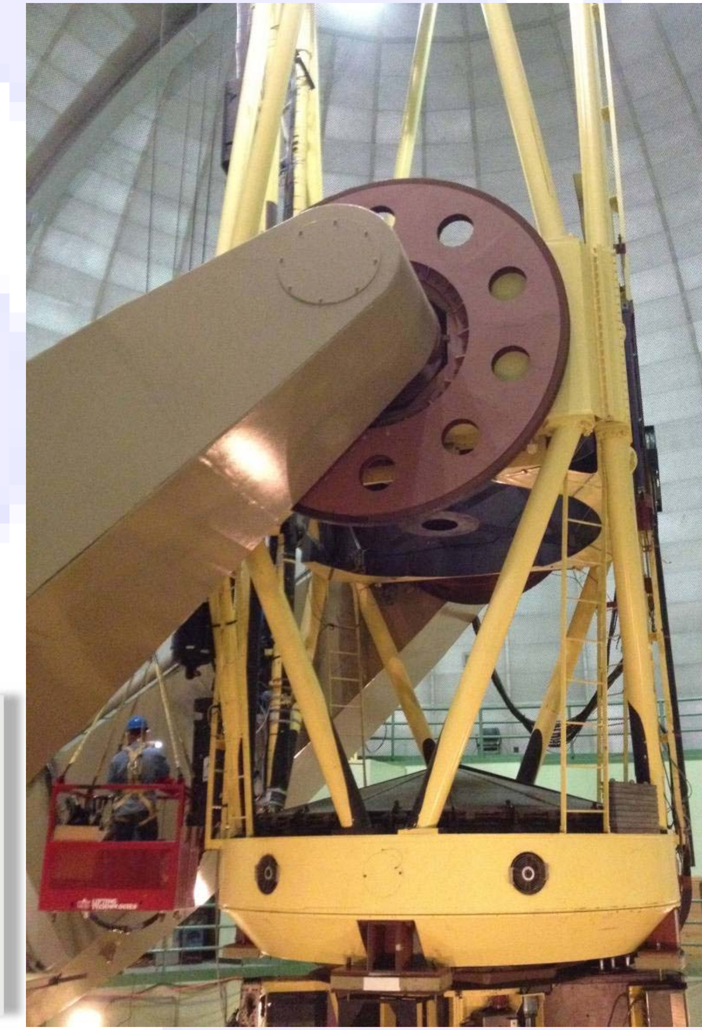
FWHM = 1.08″ +/- 0.15″
DOWNLINK AO OFF
UPLINK-AO: NA



FWHM = 0.82″ +/- 0.24″
DOWNLINK AO: ON
UPLINK-AO: OFF

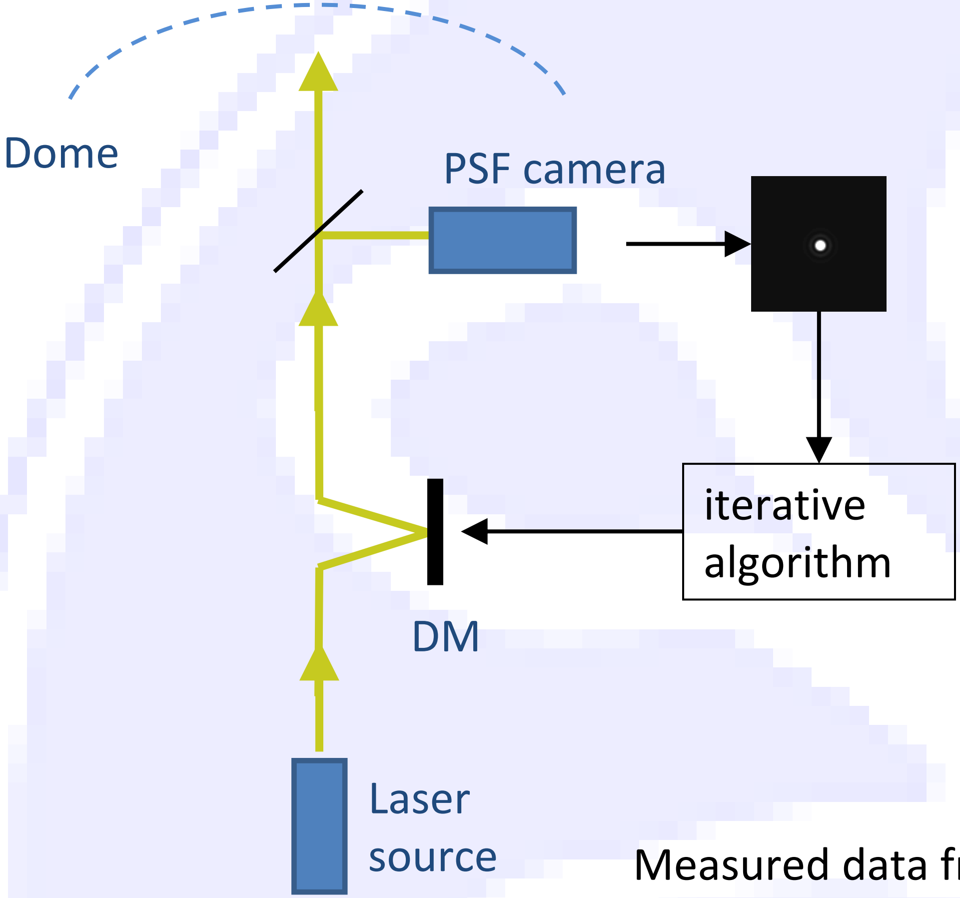


FWHM = 0.62″ +/- 0.05″
DOWNLINK AO: ON
UPLINK-AO: ON

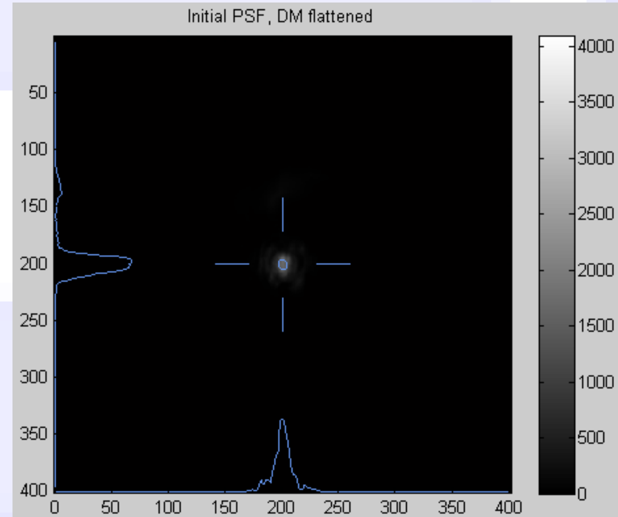


A.P. Norton *et al.*, “Laser guidestar uplink correction using a MEMS deformable mirror: on-sky test results and implications for future AO systems”, Proc. of SPIE, 9148-47

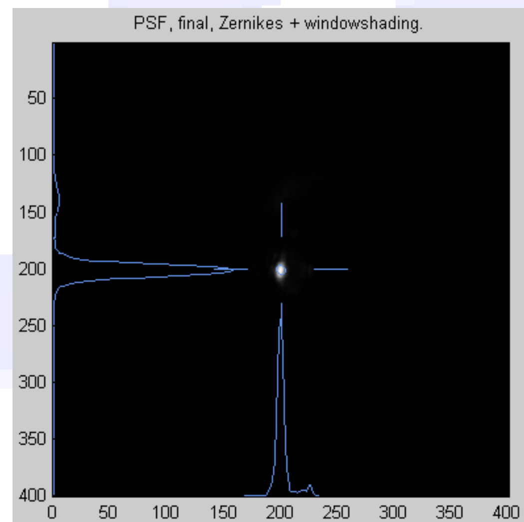
Laser Guide Star Correction



Measured data from a 589 nm sodium laser guide star correction

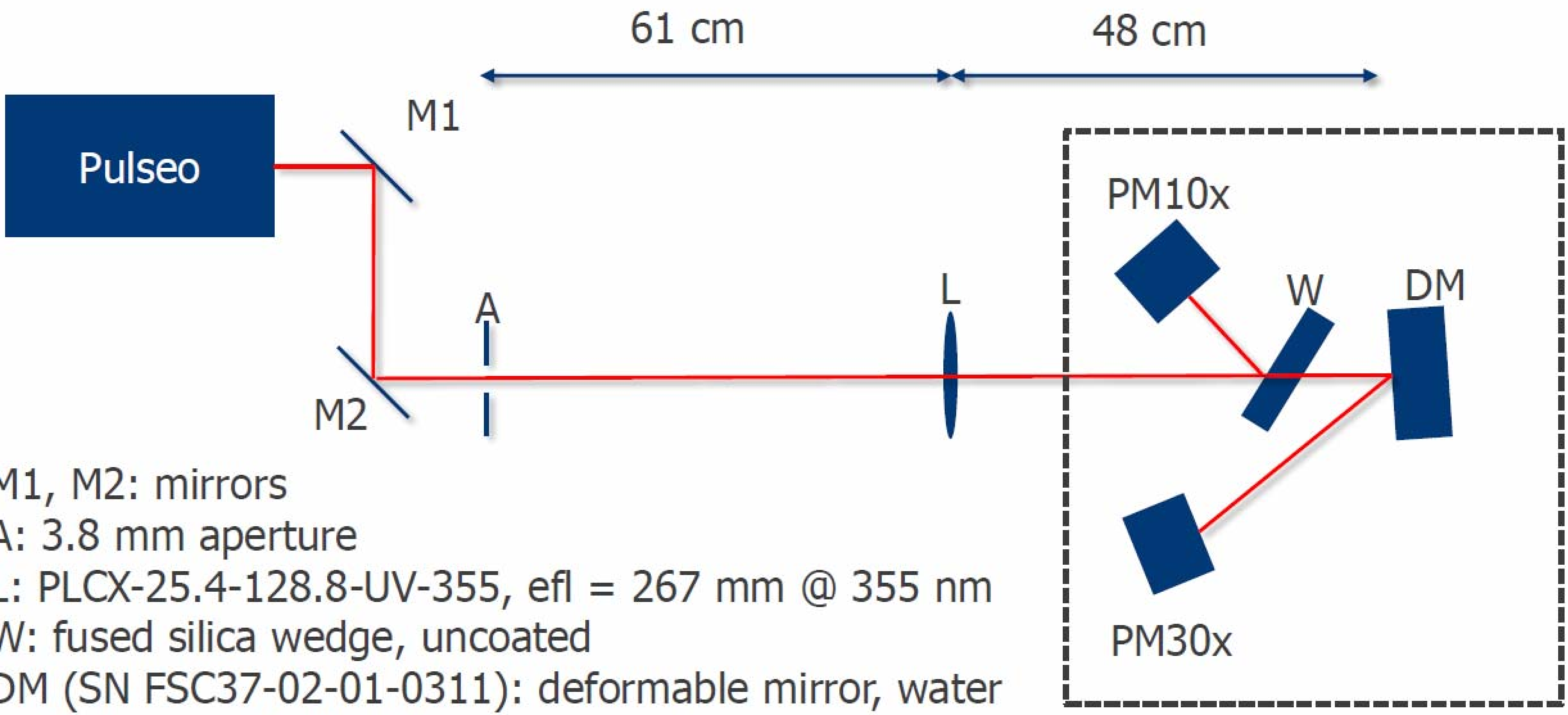


Uncorrected



Corrected

Dielectric-Coated DM: *1000 Hour Test Set Up*

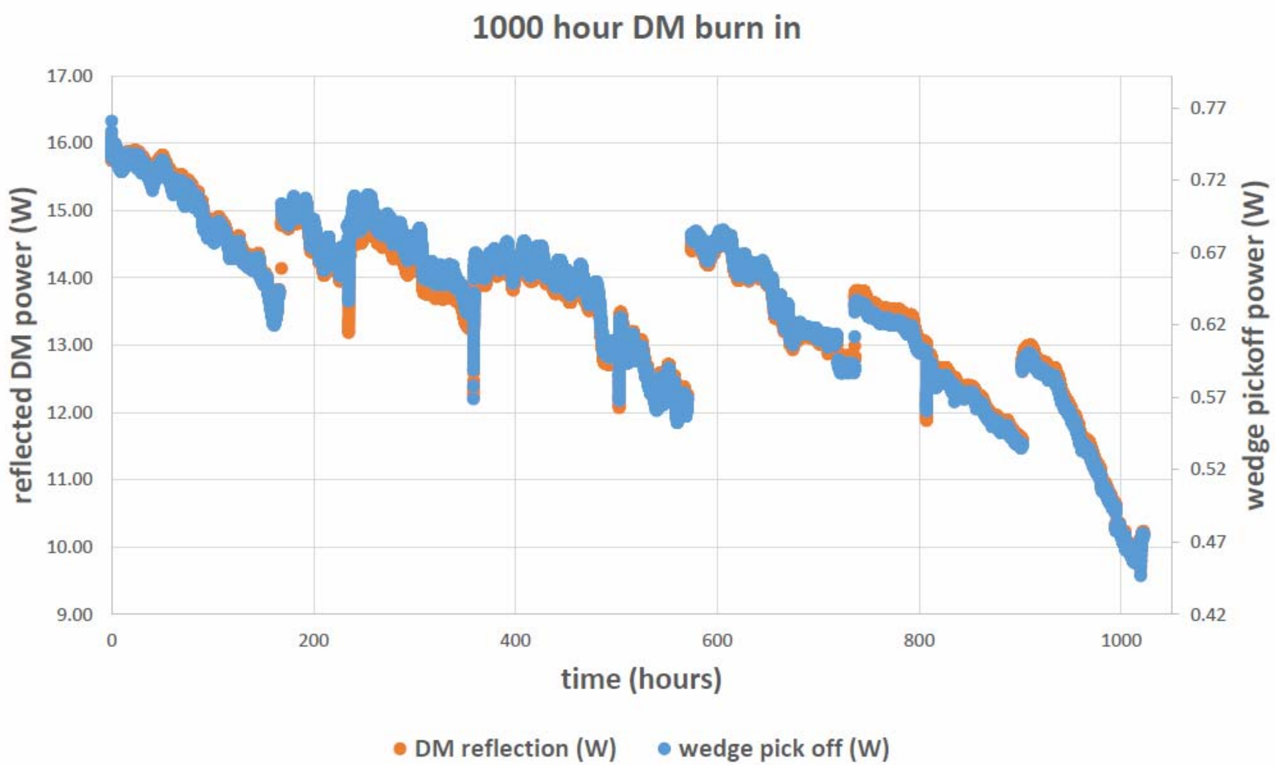


M1, M2: mirrors
A: 3.8 mm aperture
L: PLCX-25.4-128.8-UV-355, efl = 267 mm @ 355 nm
W: fused silica wedge, uncoated
DM (SN FSC37-02-01-0311): deformable mirror, water cooled, purged with UHP nitrogen, mirrors are continuously actuated at ~ 100 Hz.
Dashed line: outline of area purged with clean air).

Note: the lens re-images the 3.8 mm aperture at the DM to a 3 mm size and provides a diverging beam to have a sufficiently large beam diameter at the PM30x.

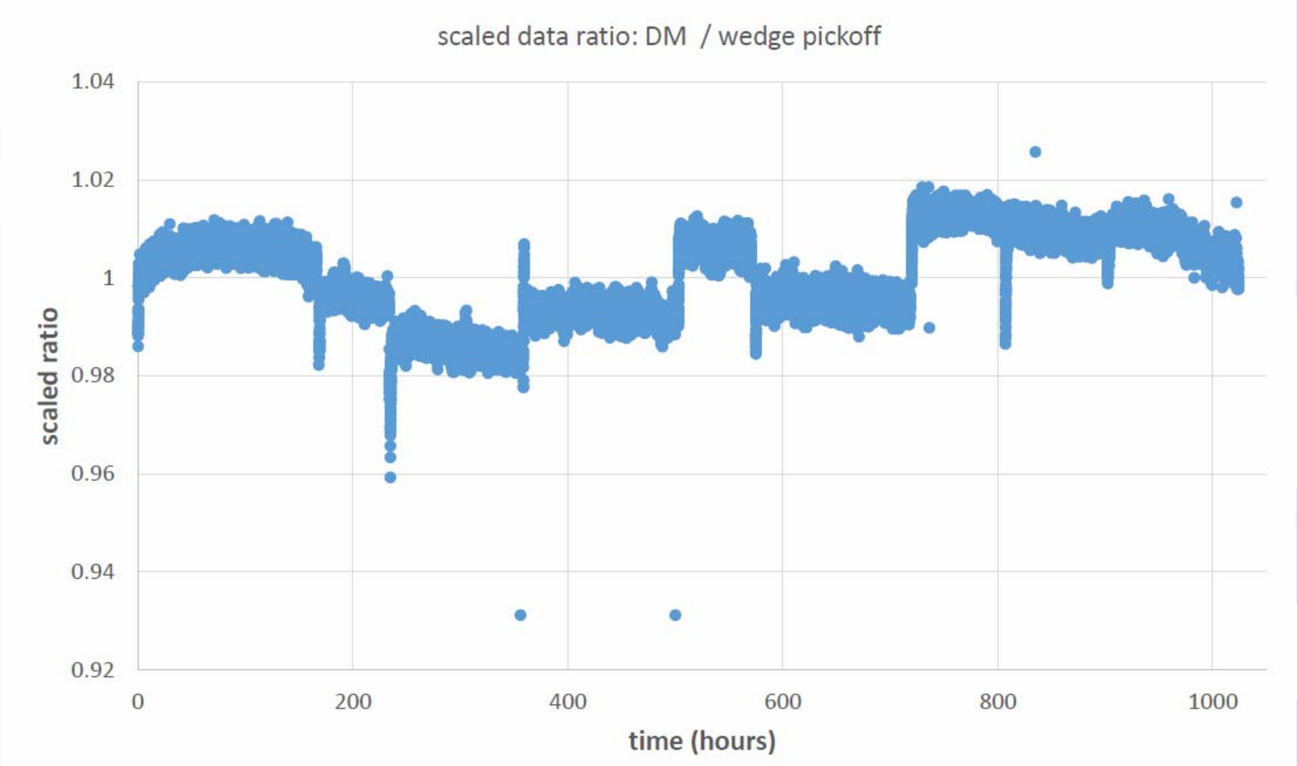
Dielectric-Coated DM: *1000 Hour Test Results*

- Customer Field Testing: 1000 hr DM burn in
- Test Goal: Determine if the DM degrades after 1000 hr exposure to UV laser
- Laser: λ=355 nm, ns-pulsed, 100 kHz rep rate, 10-17 W average power



Discontinuities are due to optics cleaning, harmonic crystal indexing and minor realignments.
Overall power decline is due to non-purged, upstream optics burning up over time.

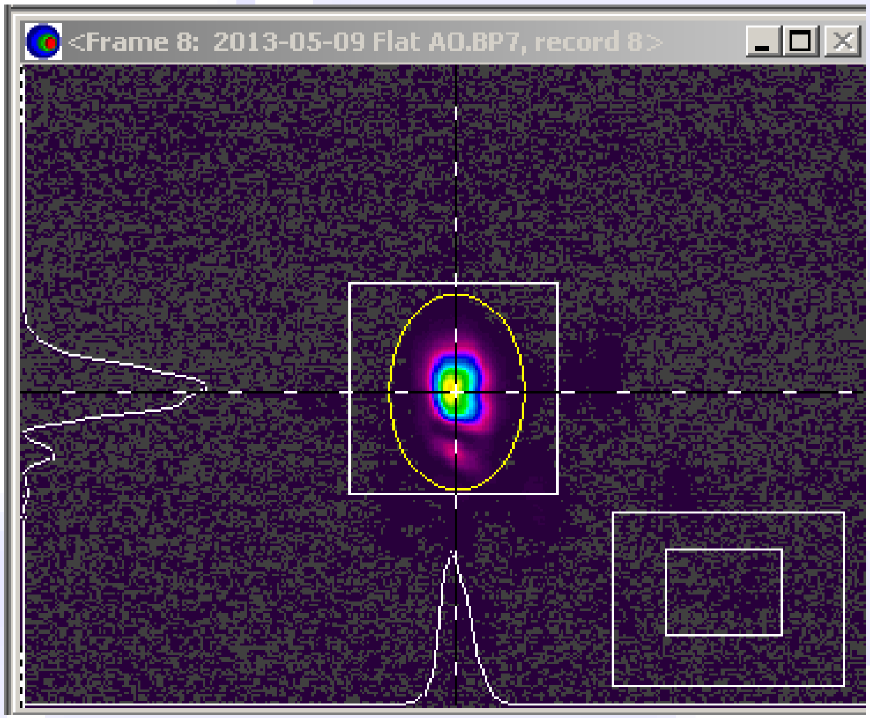
Dielectric-Coated DM: *1000 Hour Test Results*



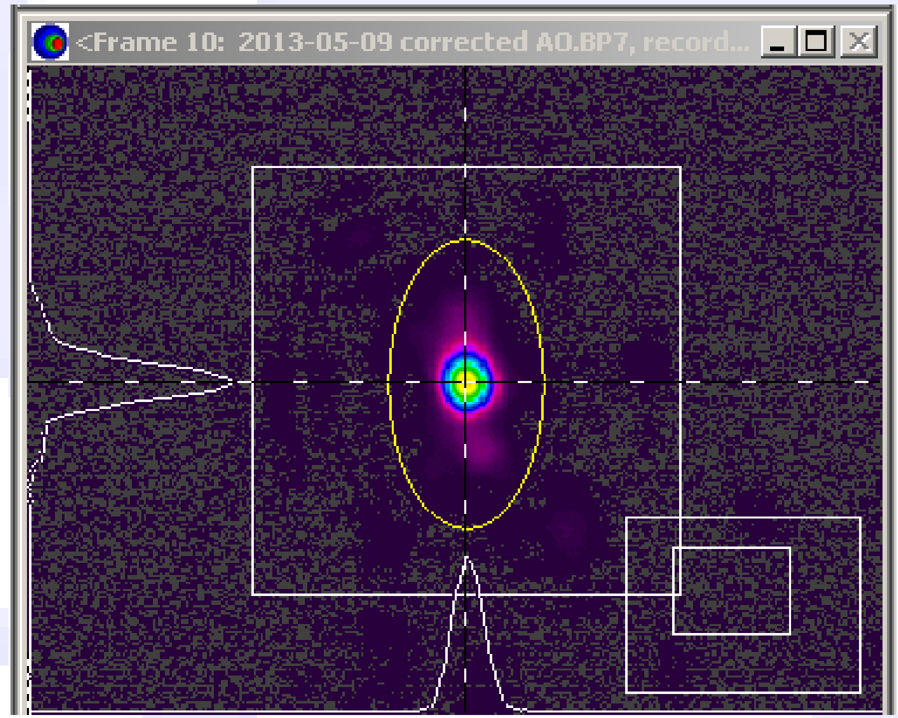
"These data are consistent with the deformable mirror experiencing no measurable degradation due to long term, high power UV exposure (100 kHz, 10-17 W on 3 mm target, < 23 ns pulse width, 355 nm), while the deformable mirror cavity is purged with UHP nitrogen, the outside of the deformable mirror is purged with clean air and the mirror is actively water cooled."

Image-Based Laser-Beam Compensation

- Commercial Application
- Measured beam profiles of an experimental 1064 nm Nd:YAG laser



Uncorrected



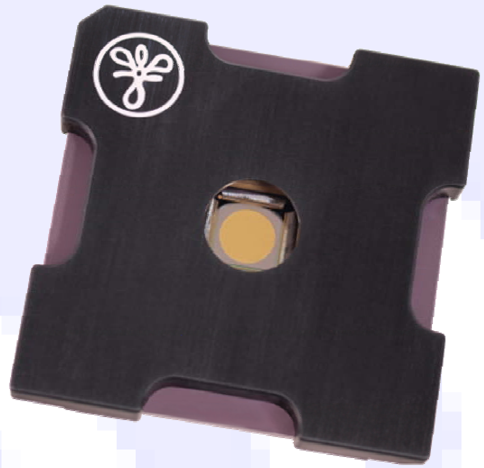
Corrected

Summary

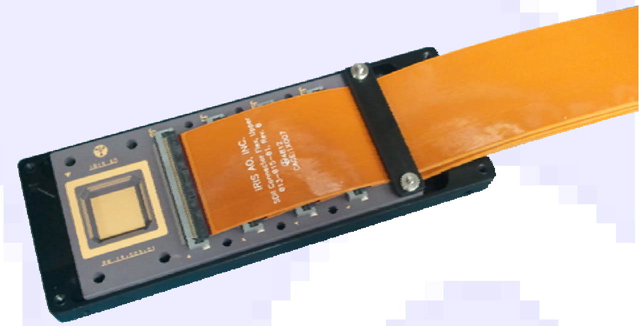
- Iris AO MEMS DMs
  - Precision open-loop control
  - Dielectric coatings for laser applications, UV to NIR
  - Packaged for laser application, cooling and purge ports
- Field testing to date
  - 589nm LGS initial testing with active correction of static errors
  - 1000 hour testing at 355nm (nominal $140 W/cm^2$) with no loss in power efficiency
  - Beam clean-up at 1064nm
- Roadmap relating to lasers
  - More testing
  - Coatings at more wavelengths
  - Advances in control, primarily beam shaping

Appendix: Packaged DMs, Drive Electronics

PTT111 DM



PTT489 DM



PTT489 DM
Compact Package

- Compact DM enclosure
- High resolution
  - 14 bit, 200 V
- Factory calibration
- Simple USB interface: 140 Hz
- High-speed interface: <165 µs latency
  - > 6 kHz synchronous mode
  - >10 kHz asynchronous mode
  - > 14 kHz pre-recorded mode
  - Frame rates of 35 kHz possible
  - $f_{-3dB} \geq 30$ kHz

Appendix – Iris AO DM Specifications

Maximum Dynamic Range (Stroke)	**5, 8 µm mechanical**
Maximum Segment Angle	**4, 7 mrad**
Mechanical Step-Response Speed	**< 200 µs (10-90%)**
Segment Positioning Resolution	**< 2 nm**
Optical Coatings	
Metal	**Protected-Silver, Gold, Protected-Aluminum**
Dielectric: *Demonstrated*	**λ = 355, 532, 589, 1064, 1540 nm**
Dielectric: *Possible*	**188-1600 nm**
Segment Flatness	
Metal Coating	**< 20 nm *rms*, <7 nm *rms* (optional)**
Dielectric Coating	**< λ/20 *rms*, < λ/40 *rms* (optional)**