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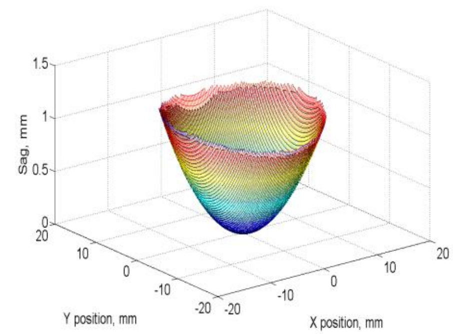

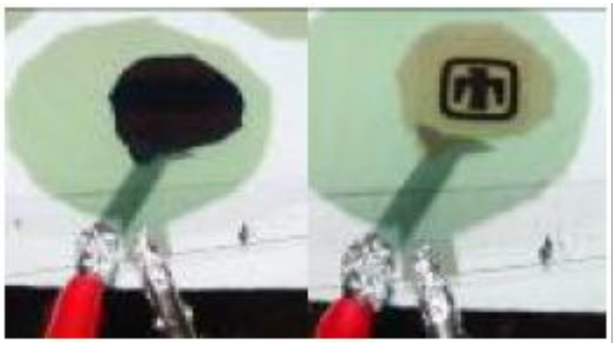

Hands-Free Zoom System for SCENICC

(Soldier Centric Imaging via Computational Cameras)

Rob Boye, PI

Mike Descour, PM

Sandia National Laboratories, Albuquerque, NM

San Diego, March 27th, 2012

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Program Overview

Goal: Design and build lightweight binoculars for soldiers with two magnifications, M=1 and M=10. Switch between states in ~100 ms.

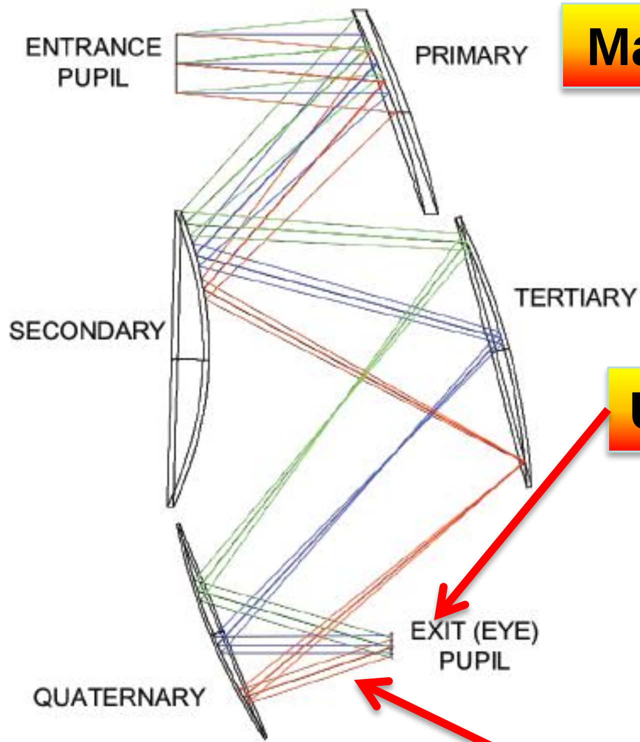
Proposed solution: A four-mirror telescope with M=10X. Electro-chromic switchable mirror on final element for hands-free-zoom.

Year One Objective: Prove out individual technologies
- Reflective optical design approach
- Slow-slide servo mirror fabrication
- Electro-chromic mirror

Outline:
- Optical design – Bill Sweatt
- Mechanical design – Aaron Ison / Ted Winrow
- Mirror fabrication – Bradley Jared
- Electro-chromic development – Graham Yelton

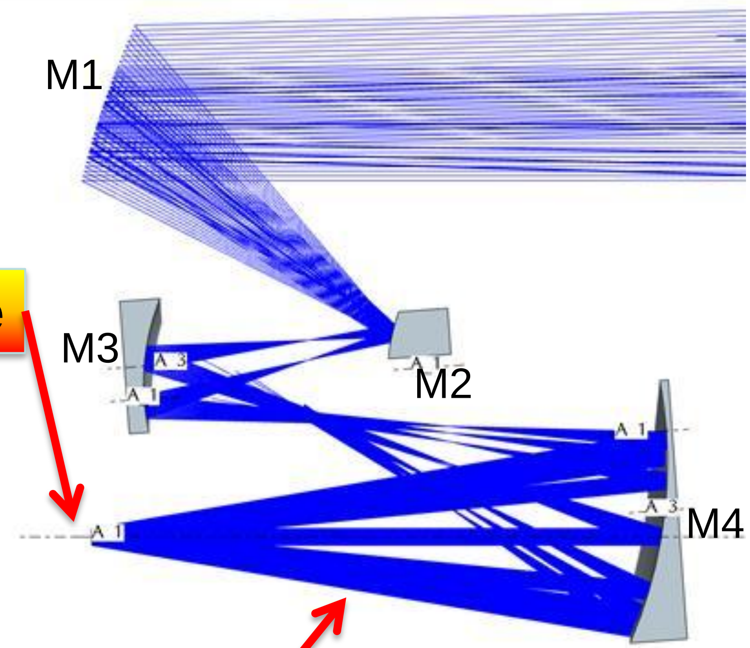
Optics - Overview

Original (Proposal) Design vs. Final
Year One Goals: Mag = 5x / FFOV = 6º (object) 30º (eye)



Ref.: Reynold S. Kebo, US Patent No. 4,804,258 (Feb. 1989).

Magnification increased from 3.5x to 6.6x

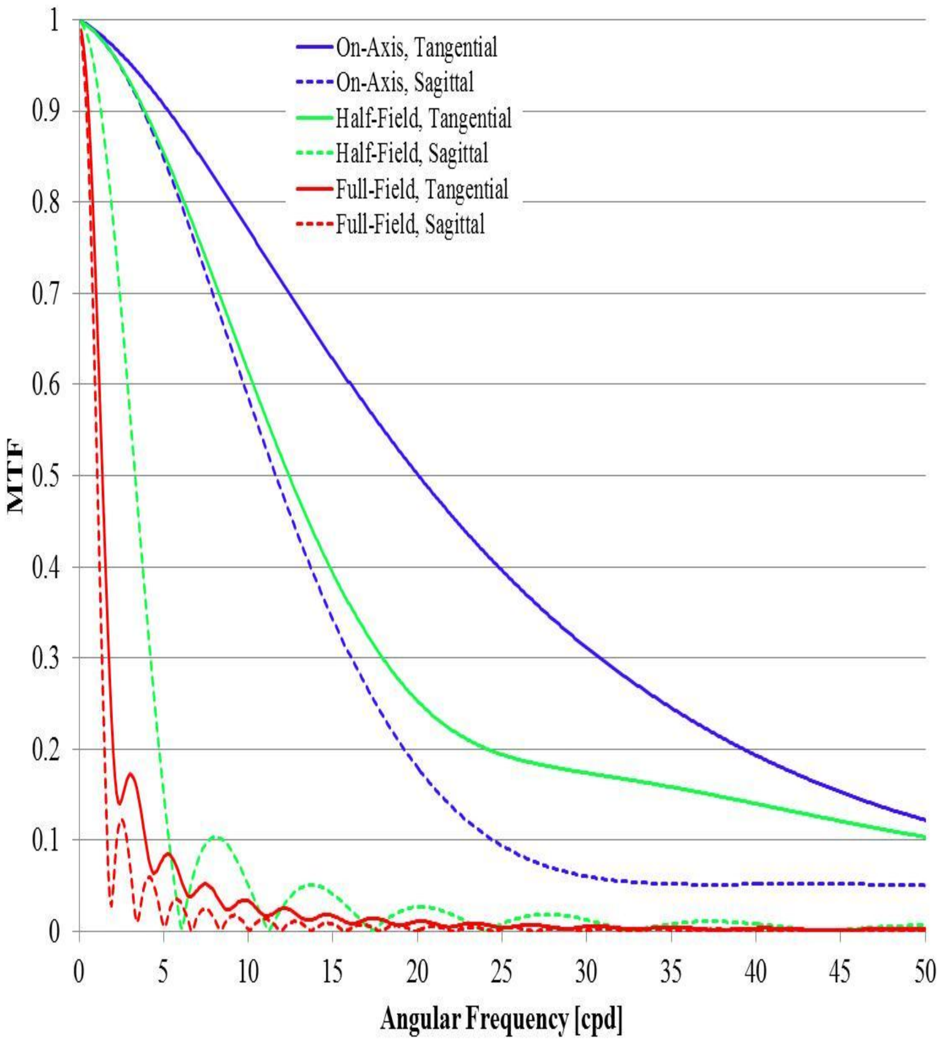


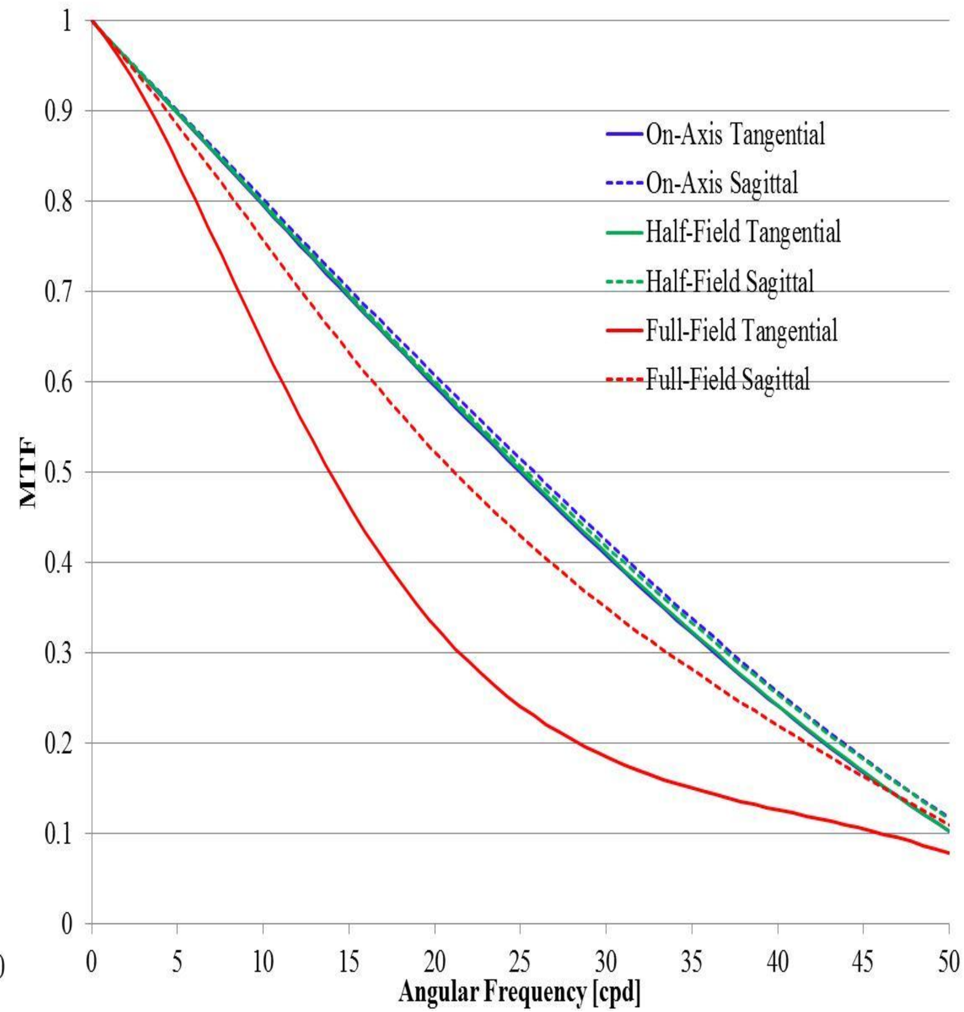
Upright image

Extended eye relief

Optics - Performance

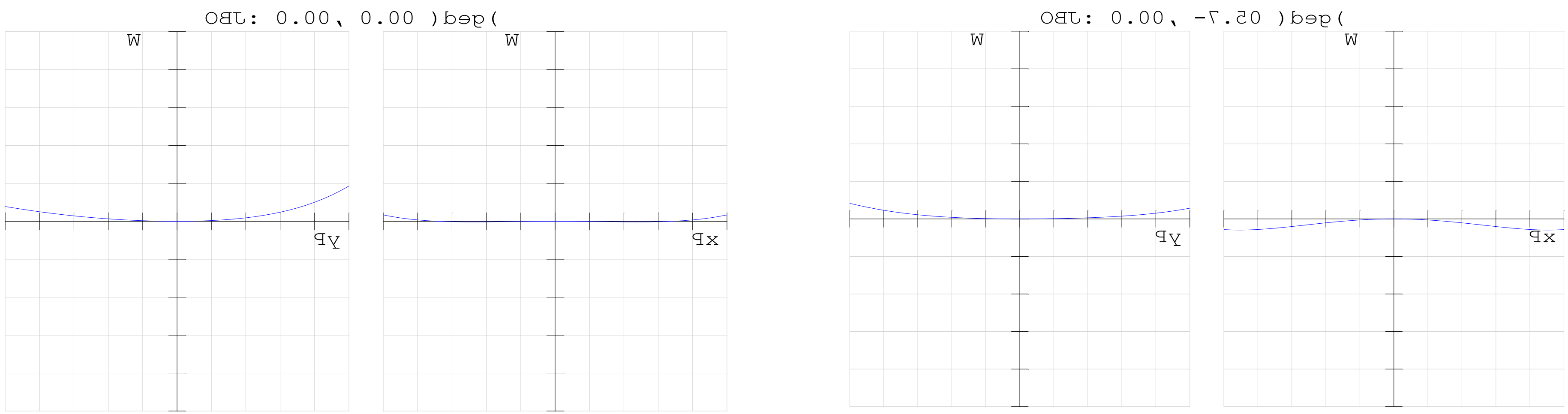
Original (Proposal) Design vs. Final



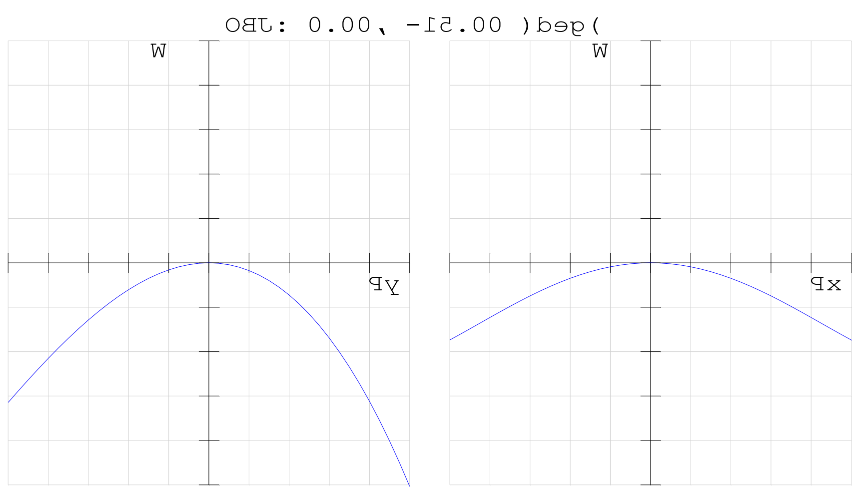


Optics - Performance

Wavefront Error – Aligned 3 mm Pupil



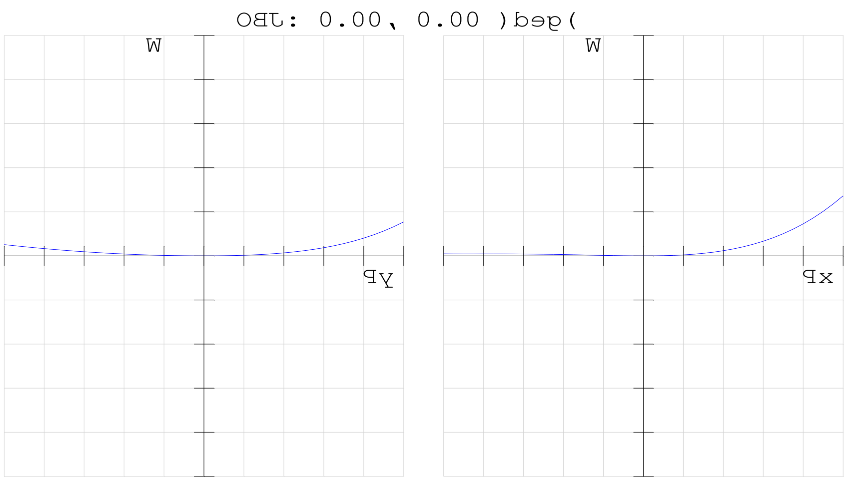
Worst case field shown

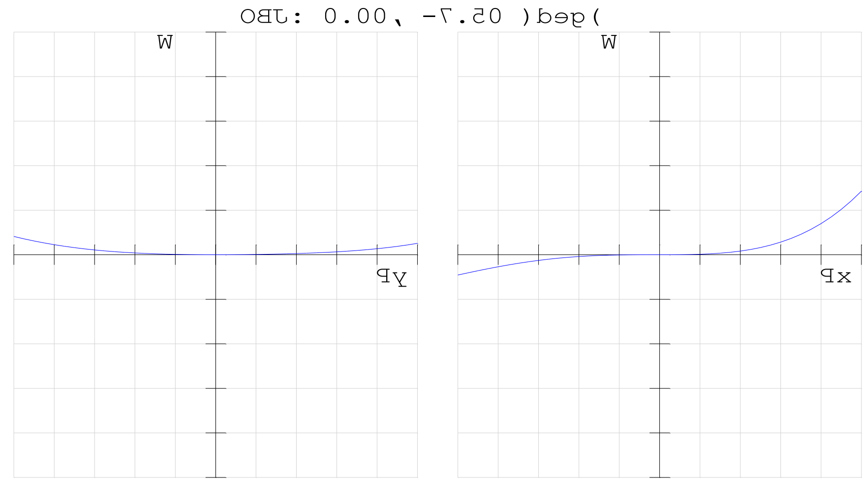


Full scale = 1 λ

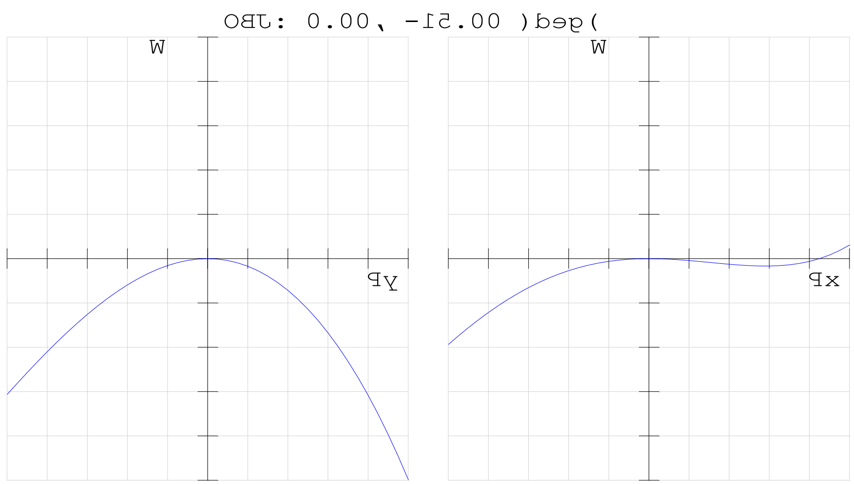
Optics - Performance

Wavefront Error – 3 mm Pupil Misaligned by 0.8 mm





Worst case field shown



Full scale = 1 λ

Optics - Performance

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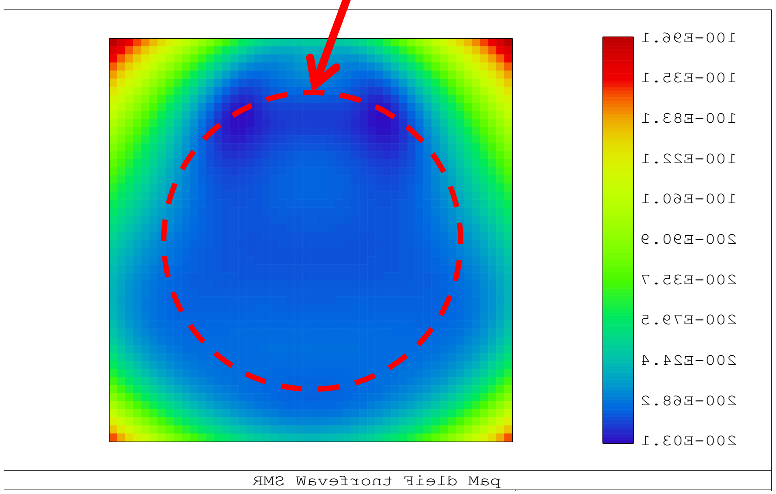
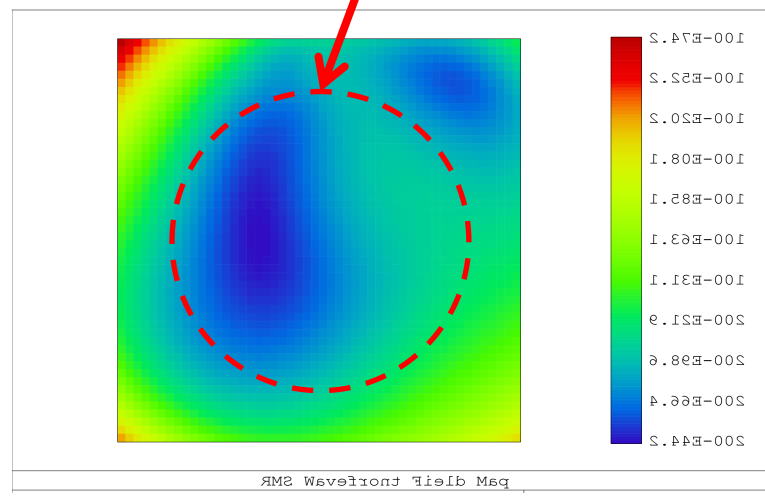
RMS Wavefront – Center of Field

Note: Center 7.5º displays ~ 0.05λ



On-axis pupil

Note: Center 7.5º displays < 0.1λ

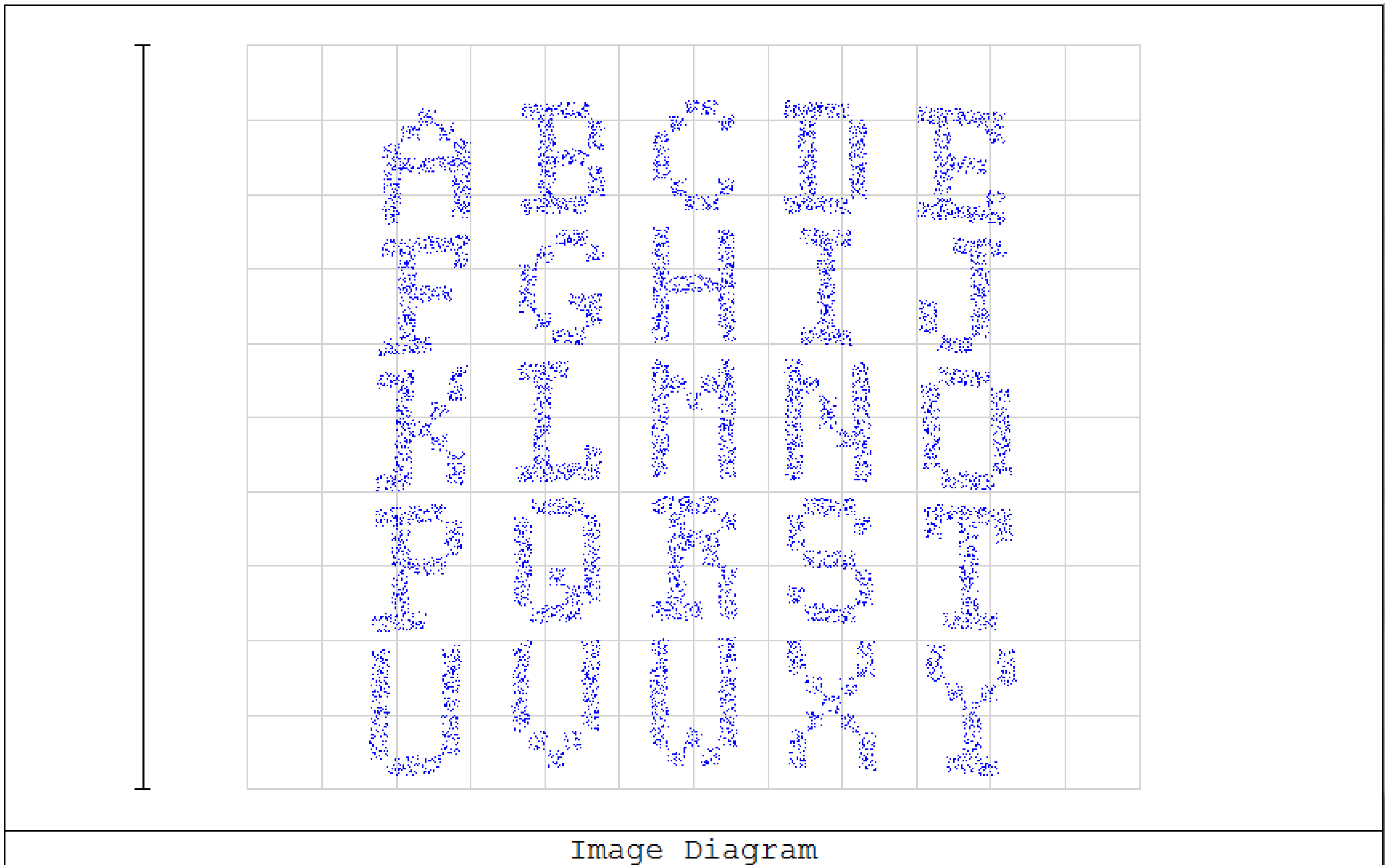


Off-axis pupil

This is the worst of the four cases

Optics - Performance

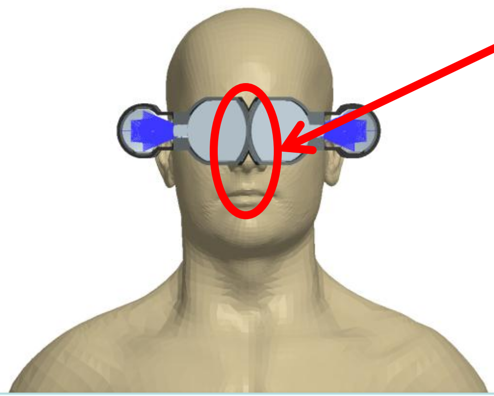
Simulated Image

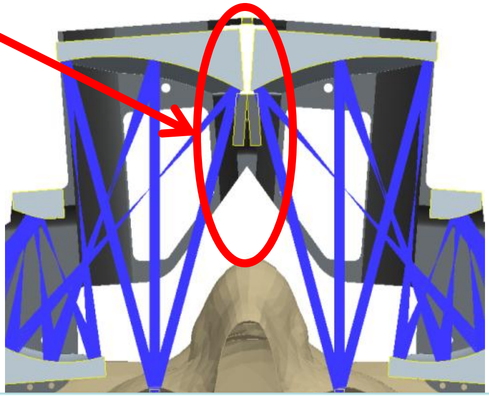


Distortion remains largest source of performance degradation

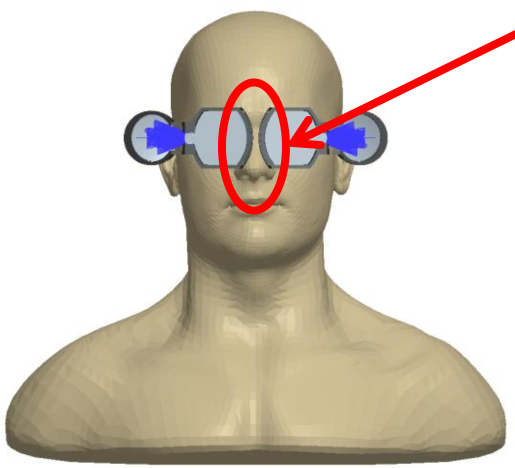
Optics – Rescaled Design

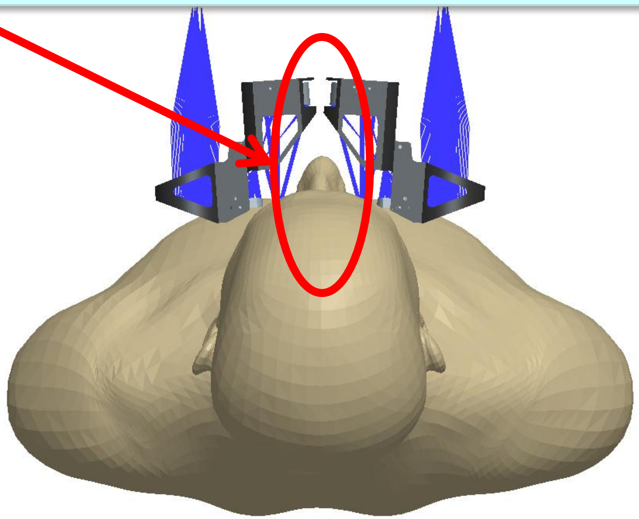
Reduced Scale
3 mm design pupil leads to mechanical interference





Reduced pupil (2.5mm vs. 3.0mm) design allows for some space between the two assemblies
(Note: Baffles, i.e. light blocker, not shown and raytrace includes paraxial lenses in front of system)





OptoMechanics - Allowable Error

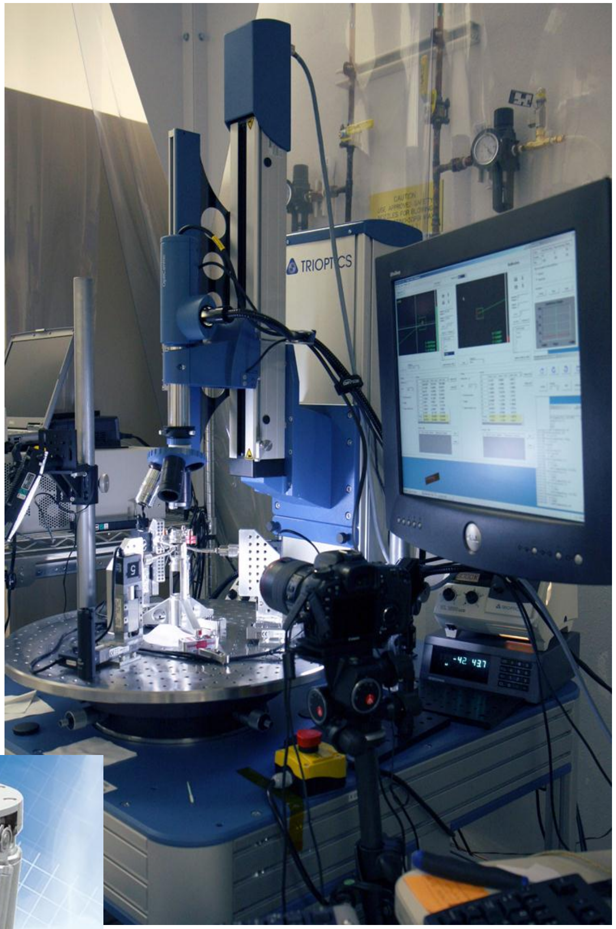
Tolerances of optical design determined alignment approach

Total Allowable Error								
	Decenter		Tip/Tilt		Piston		Clocking	
	± mm	± inch	± deg	± amin	± mm	± inch	± deg	± amin
Mirror 1 (M1)	0.05	0.0020	0.065	3.9	0.1	0.0039	0.13	7.8
Mirror 2 (M2)	0.05	0.0020	0.13	7.8	0.1	0.0039	0.26	15.6
Mirror 3 (M3)	0.05	0.0020	0.26	15.6	0.1	0.0039	0.57	34.2
Mirror 4 (M4)	0.05	0.0020	0.045	2.7	0.1	0.0039	0.18	10.8

Error sources, such as reference mirror fab and fiducial placement on M2 (as an example) reduce the respective allowable error, and define the values in the “build” error budget.

Optomechanics - Alignment Setup

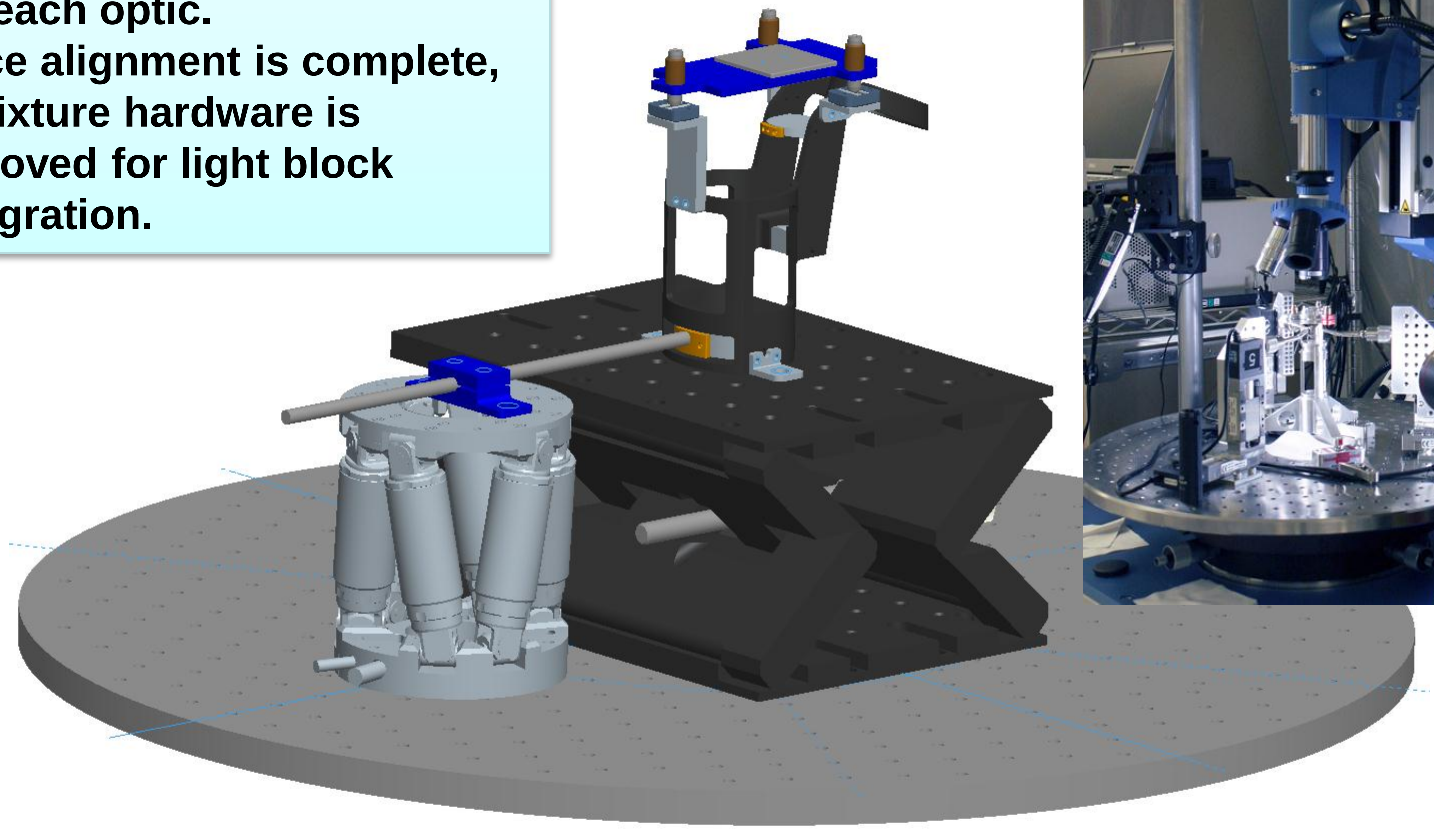
- **Basics for mirrors M2-M4**
  - Feedback Loop.
    - Hexapod provides 6 axis, micron scale movements with programmable pivot center.
    - Trioptics machine (focusing autocollimator with air bearing) for alignment feedback. (tip/tilt, decenter, despace).
  - Bonding of subcells
    - Epoxy injection through holes in the structure.
    - Radial bond pads (3x-6x)

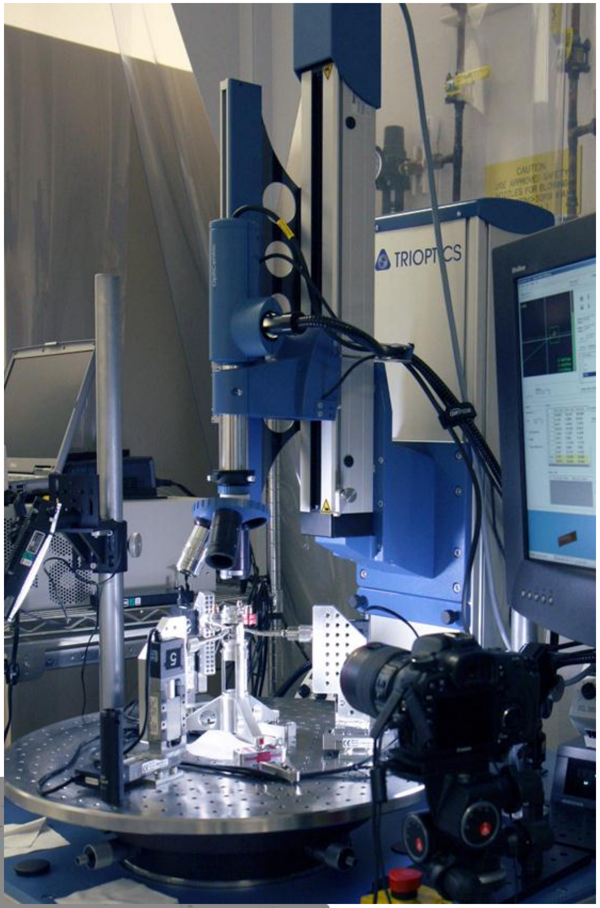


Optomechanics -Alignment Setup

- Hexapod provides 6 DOF movement for each optic.
- Kinematic reference mirror is used to define the position for each optic.
- Once alignment is complete, all fixture hardware is removed for light block integration.

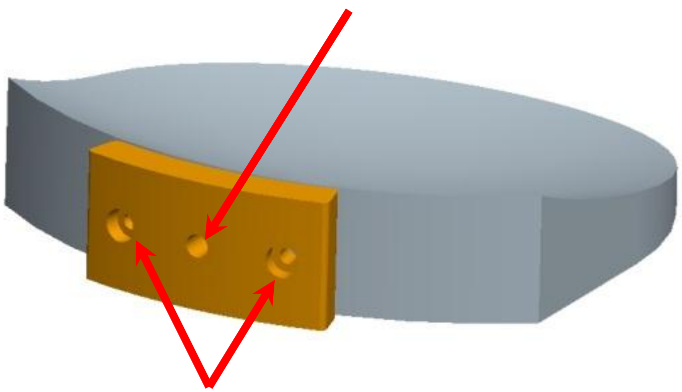
Trioptics looking down into system

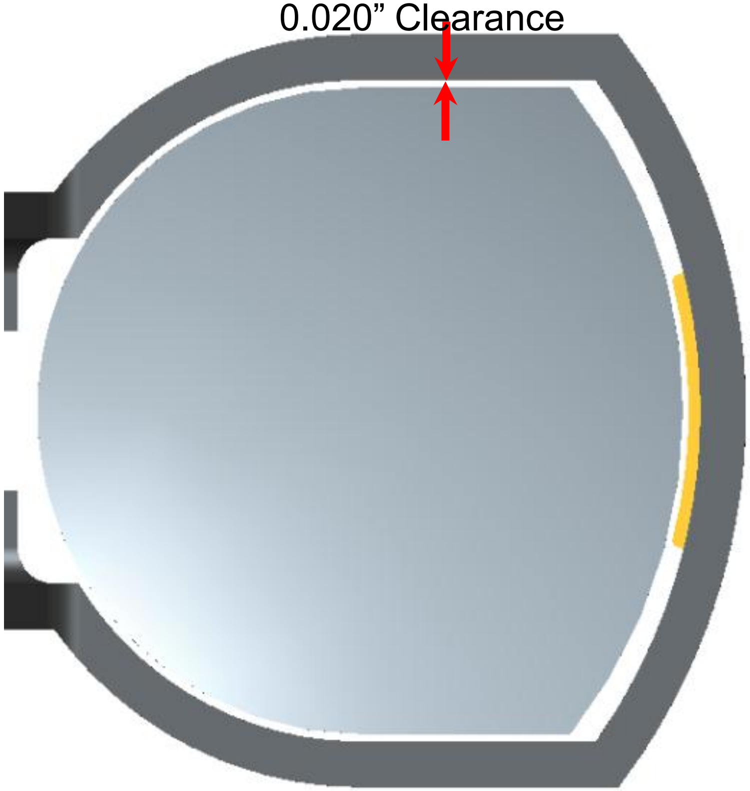




Optomechanics - Alignment Setup

- **All optics are bonded to a "subcell", which is used for manipulating the optic.**
- **Each subcell has two injection hole, and a threaded #2-56 hole, which is used for attachment to the hexapod/stinger arm.**
- **Each optic has 0.020" clearance from the structure wall.**

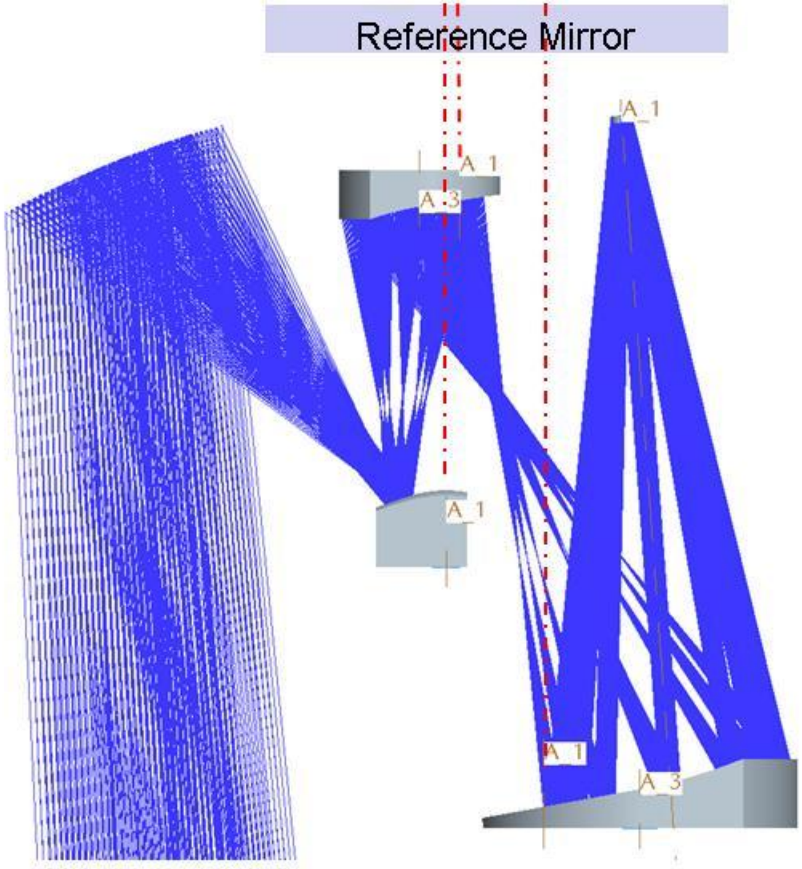




Optomechanics - Alignment Plan

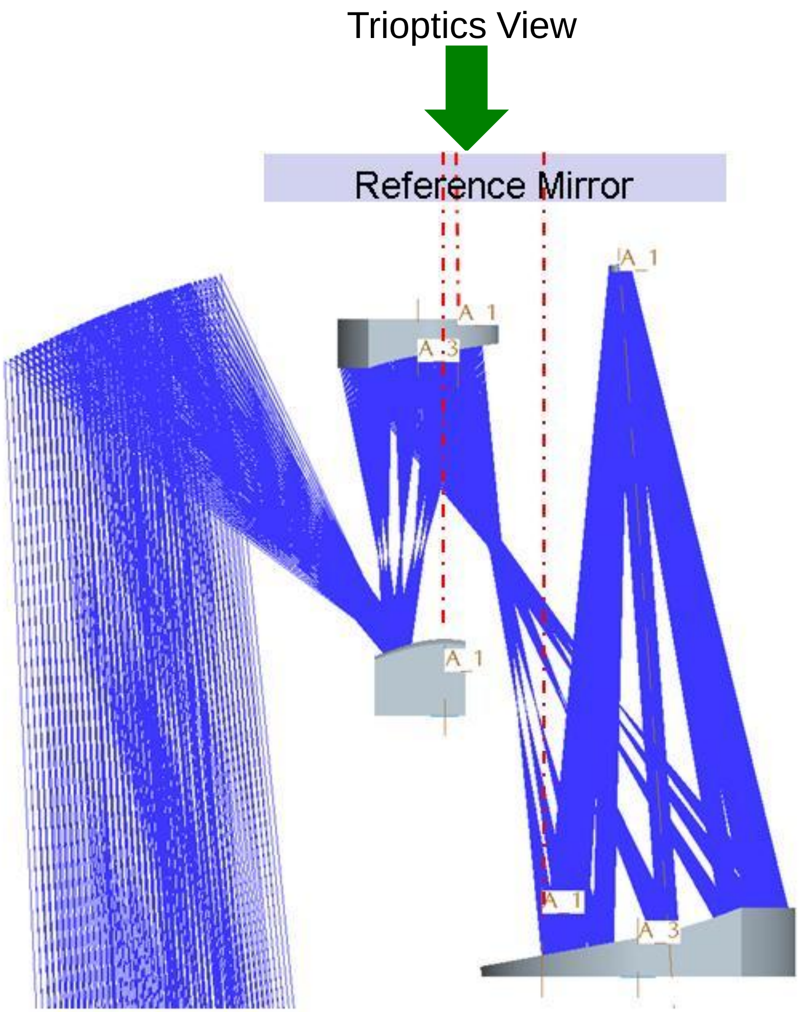
- **Prep work**
  - Create master reference mirror with fiducials at the parent axes of mirrors M2, M3, M4
  - Make M2, M3, M4 with flat backs normal to the parent axis and scribe a fiducial at the location of the parent axis (front of M2, M4, back of M3)
  - Bond all mirrors into round subcells with RTV (example shown in previous slide).
    - Shim to center
    - RTV to relieve thermal induced stresses in optics.
    - Subcell provides attachment features for the hexapod (keeps fab of the mirrors simple).

Reference mirror will be attached to main structure



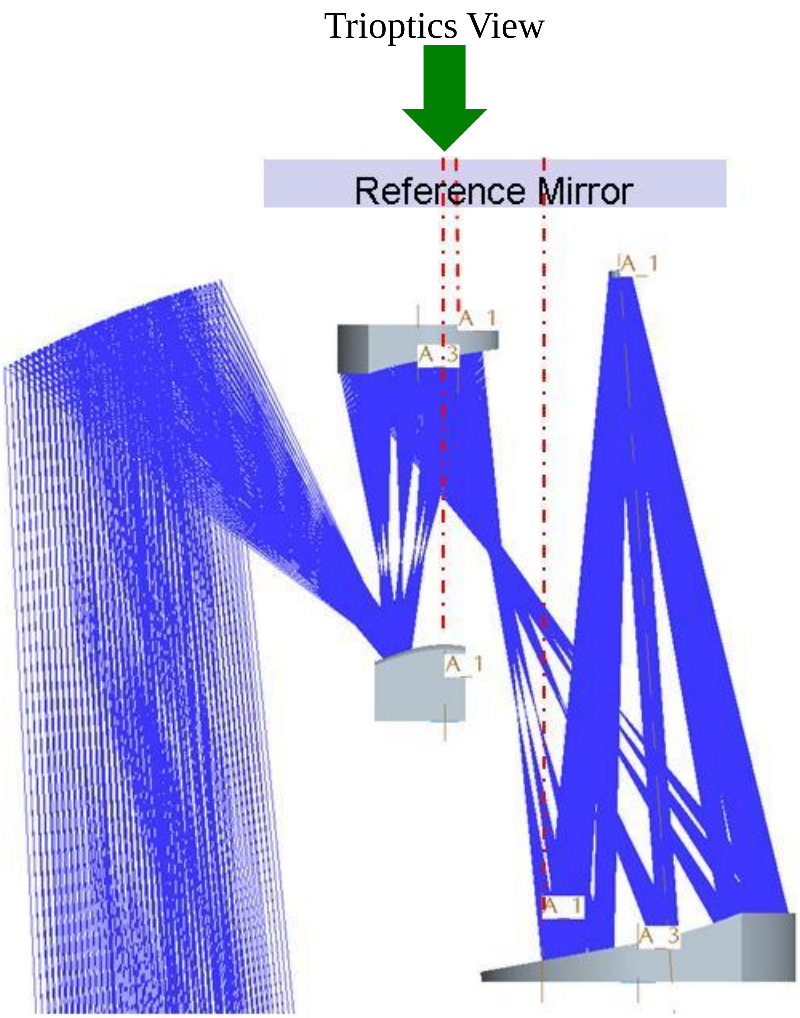
Optomechanics - Alignment Plan

- **Set Master Reference Mirror on Trioptics Machine.**
  - Mirror on kinematic removable mount to the main structure.
  - Base alignment of the Trioptics machine to the M4 fiducial, normal to the reference mirror.
- **Align and Bond M4**
  - Use Trioptics machine and hexapod to position M4 via it's parent axis fiducial and pip return to air bearing.
- **Repeat process for M2**
- **Repeat process for M3**

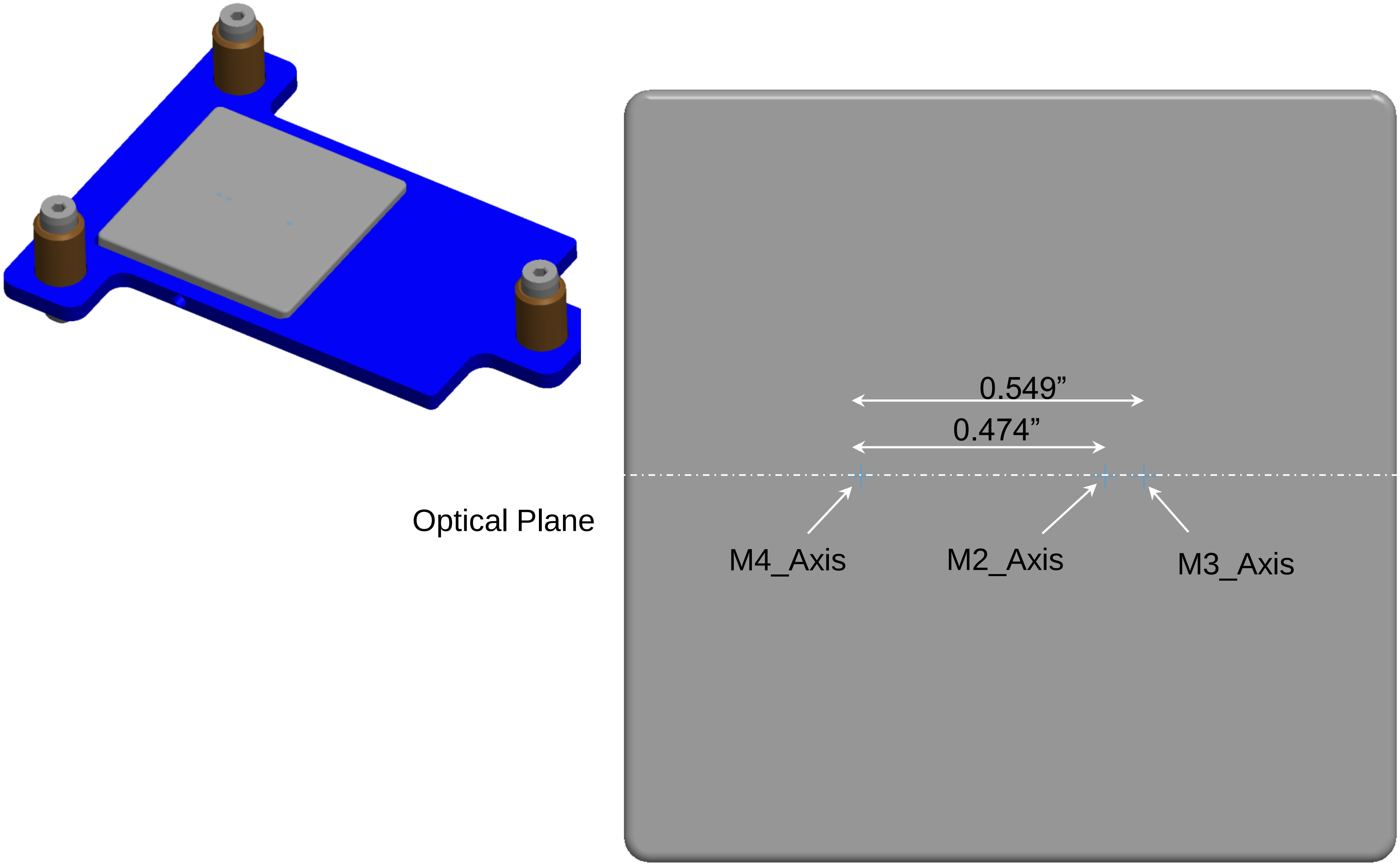


Optomechanics - Alignment Plan

- **M1 Alignment with through-system test**
  - Detector feedback at the eye position.
  - M1 mounted on hexapod for movement
  - M1 manually tweaked to provide best performance.
  - Bonded in place.
  - Detector definition and optimizing parameter TBD

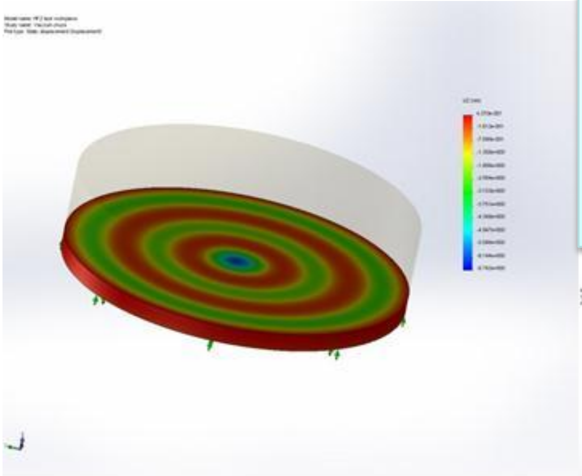


Mechanics - Reference Mirror

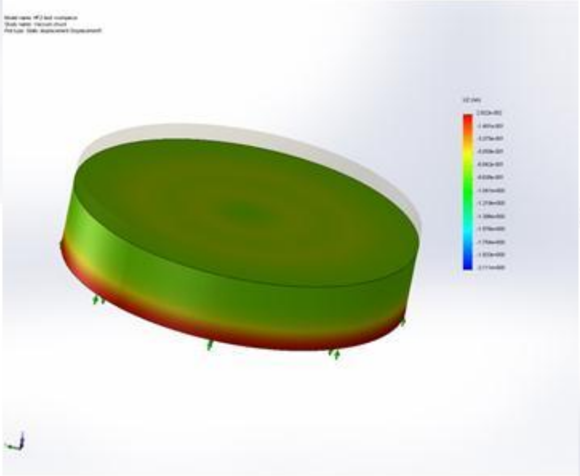


Mechanics – Mirror Thickness

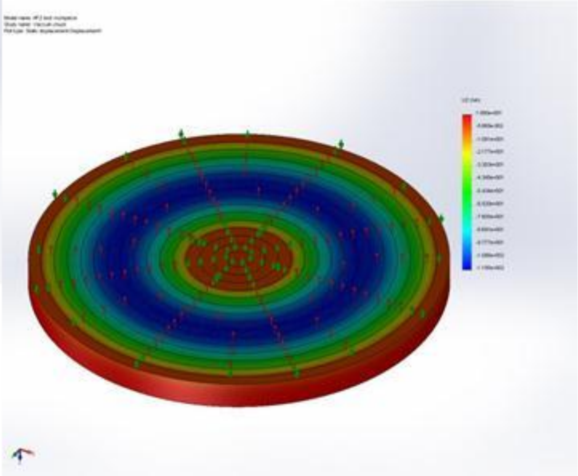
- Finite element analysis performed on deformation caused by vacuum chuck during diamond turning
- Results show that a minimum mirror thickness of 0.2” will be adequate for brass* mirrors
- Previous work on E48R has used thicknesses down to 0.05”



1” diameter, 0.05” thick
(max = 0.44 nm, min = -6.7 nm)



1” diameter, 0.2” thick
(max = 0.029 nm, min = -2.1 nm)

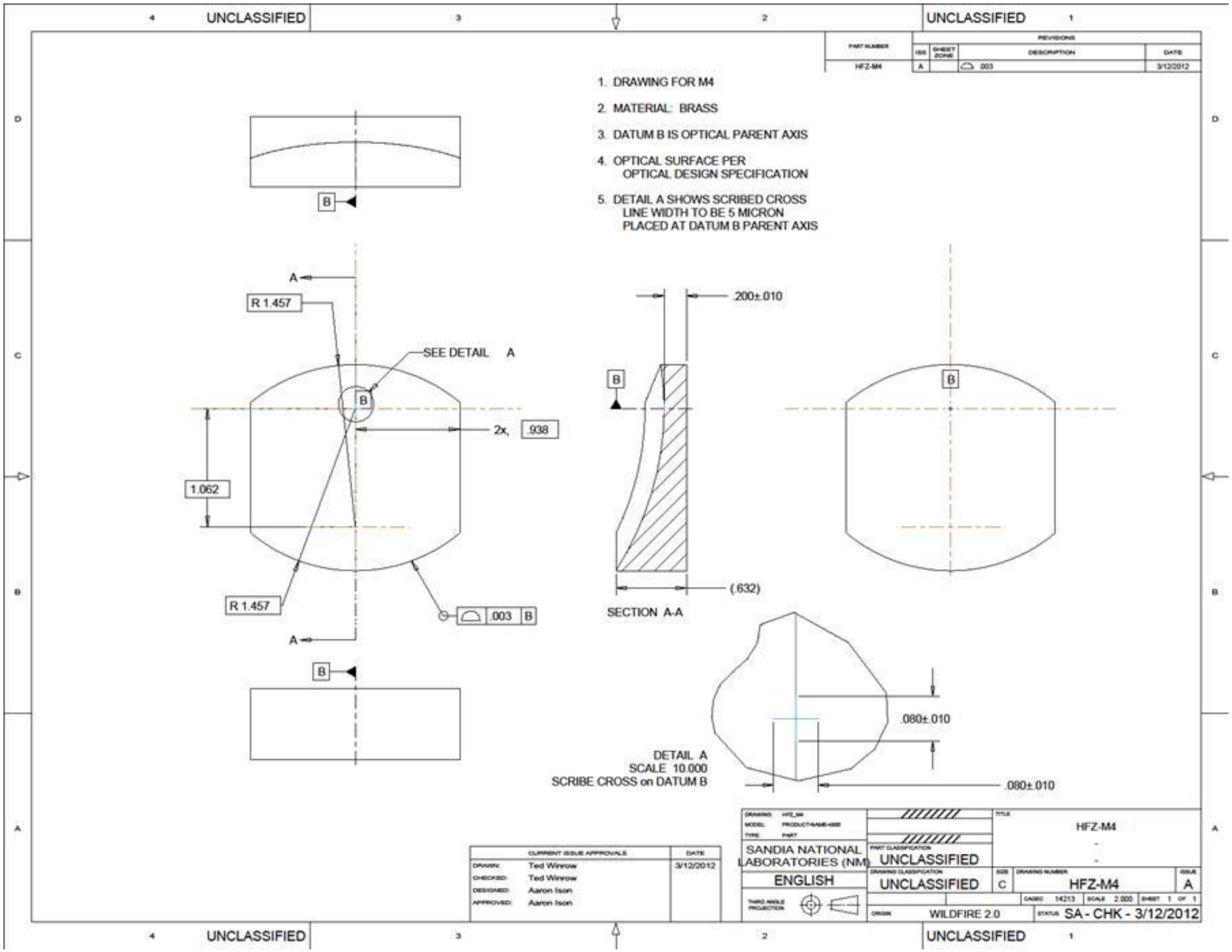


3” diameter, 0.2” thick
(max = 11 nm, min = -120 nm)

*** Material being used is Alloy 464 Naval Brass (1/2 hard state)**

Mechanics – Mirror Thickness

Mirror 4 – Sample Drawing



Mechanics - Weight Estimate

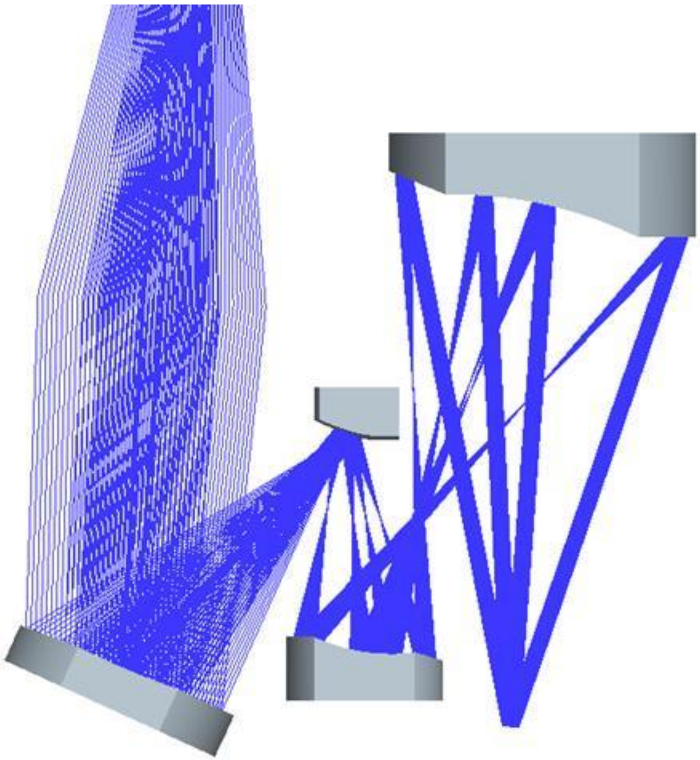
- **Reduction due to reduced pupil design - d**own to 325 grams
- **Listed weights are for brass* mirror components (density ~8.5 g/cm^3) and aluminum bonding structure**
  - Zeonex E48R density = 1.01 g/cm3 → > 8x reduction in mirror mass, i.e. 27.9 g vs. 235 g
  - Will need to find alternative to aluminum for bonding structure in second year

100 mm 3.0 Pupil

HFZ Weight Table	
	15deg FOV 100mm
	0.2" thk
Item	(g)
M4	219
M3	46.3
M2	9.98
M1	59.9
Bonding Structure	106
M4 Subcell	1.81
M3 Subcell	0.454
M2 Subcell	0.454
M1 Subcell	0.907
Light Blocker (SLA)	TBD
Total (g):	444

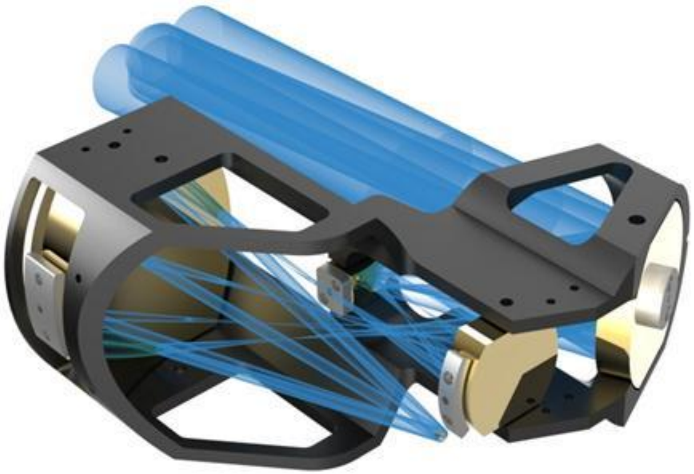
85 mm 2.5 Pupil

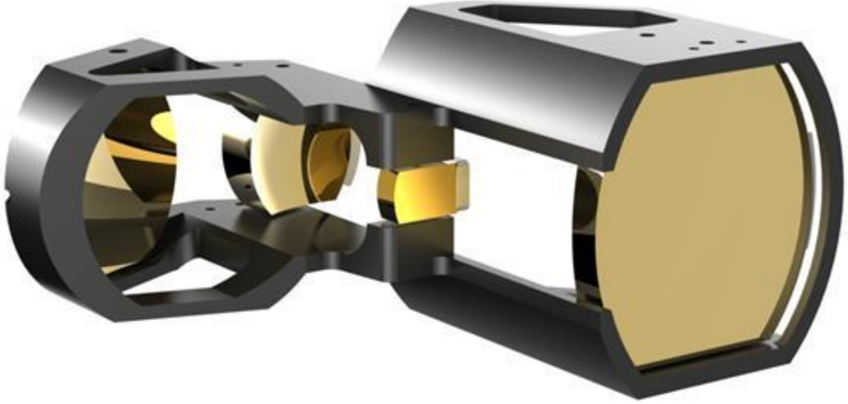
HFZ Weight Table	
	15deg FOV 85mm
	0.2" thk
Item	(g)
M4	151
M3	25.9
M2	6.80
M1	51.7
Bonding Structure	87.1
M4 Subcell	1.81
M3 Subcell	0.454
M2 Subcell	0.454
M1 Subcell	0.907
Light Blocker (SLA)	TBD
Total (g):	325

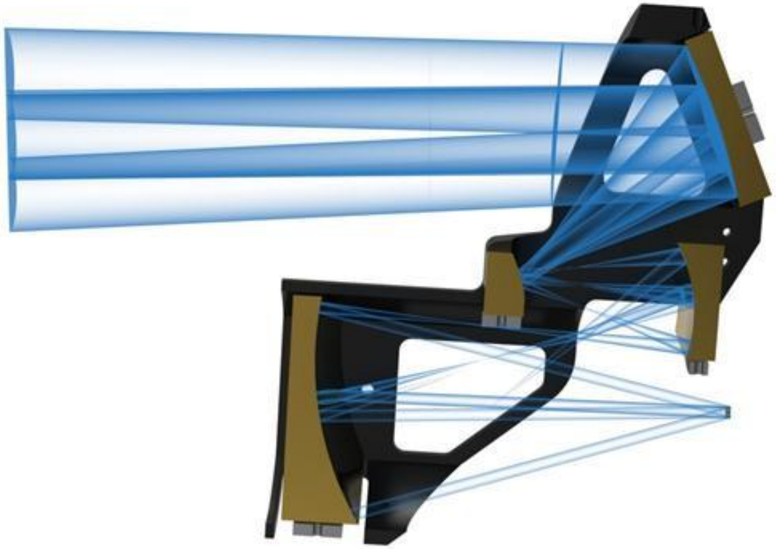


*** Material being used is Alloy 464 Naval Brass (1/2 hard state)**

Rendered Monocular Design

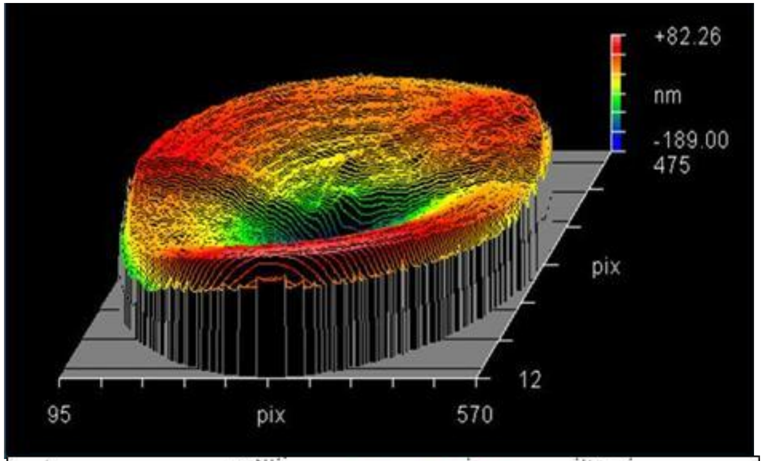


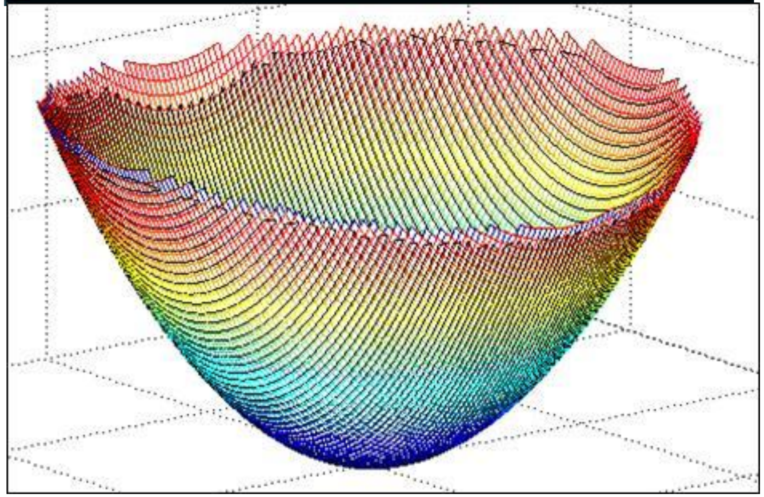




Fabrication - Overview

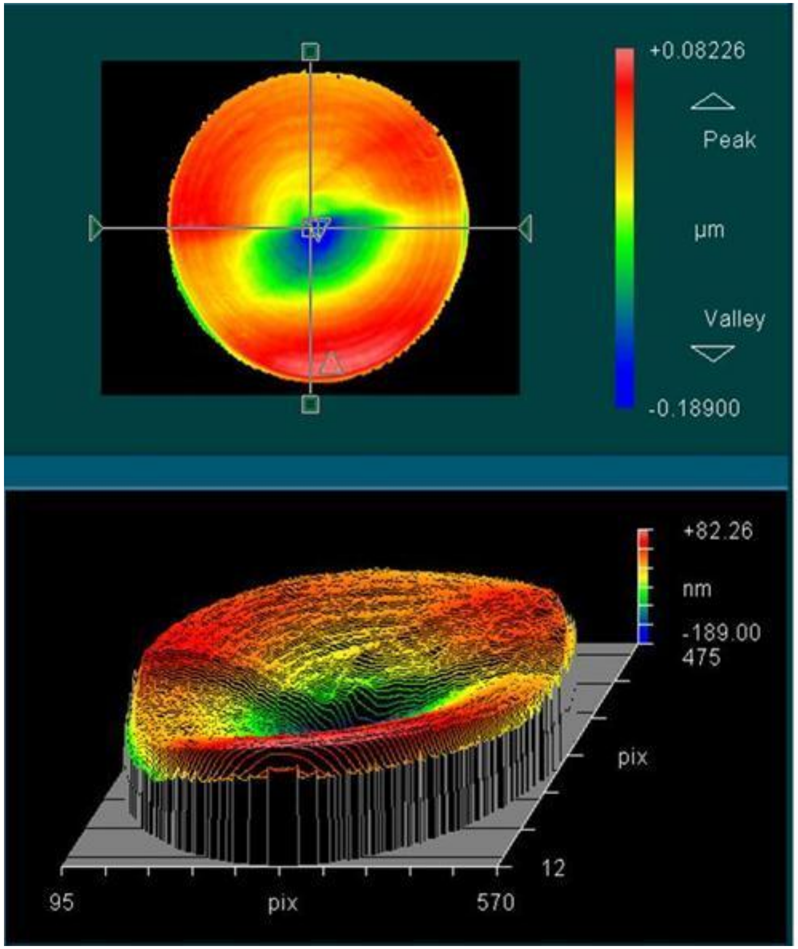
- **Test Pieces – Slow Tool Servo**
  - Tilted flat
    - 100 μm tilt across 1”
    - < 10 nm Ra surface finish
    - 0.5 μm form deviation
  - Off-axis parabola
    - Parabola defined in tilted frame
    - < 10 nm Ra surface finish
    - 1.0 μm form deviation from μ-CMM
- **Mirror Definitions Complete**
  - Optical surface machining
  - Overall part definition

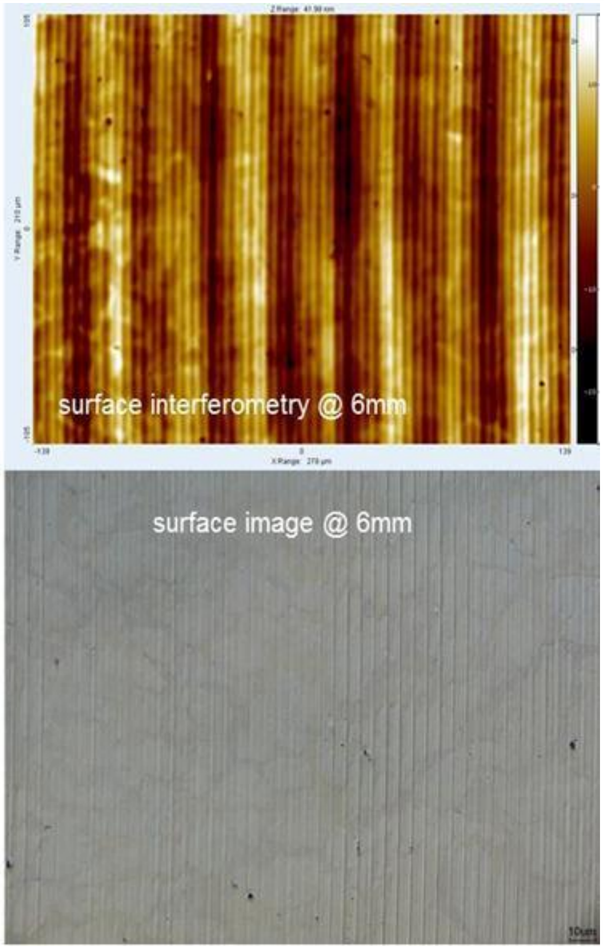




Fabrication – Tilted Flat

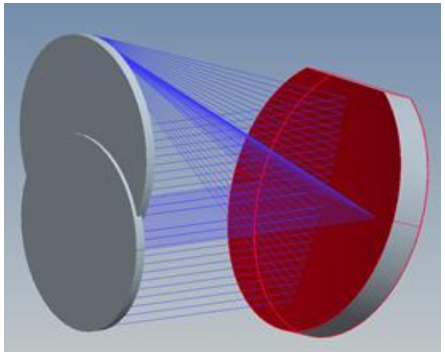
- **Tilted flat - straightforward test of slow tool servoing**
- **Departure of 100 μm - expected value in freeform mirror**

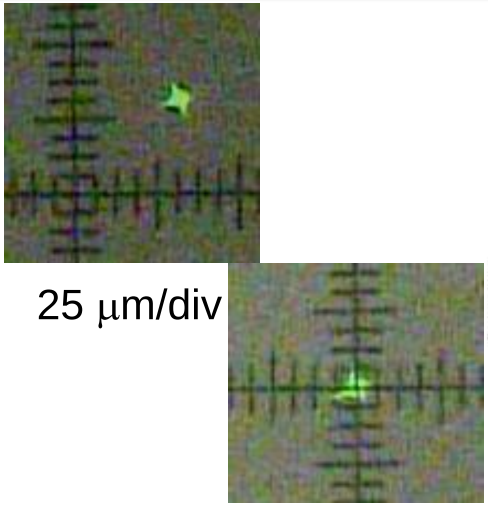




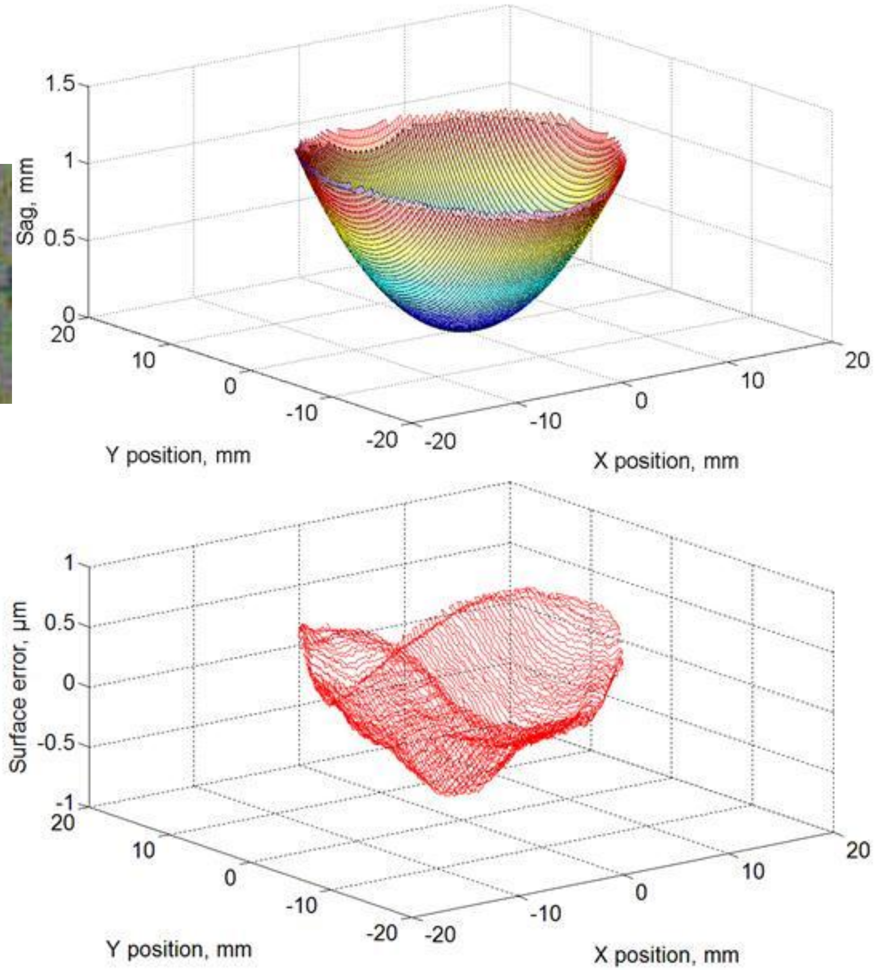
Fabrication – Off Axis Parabola

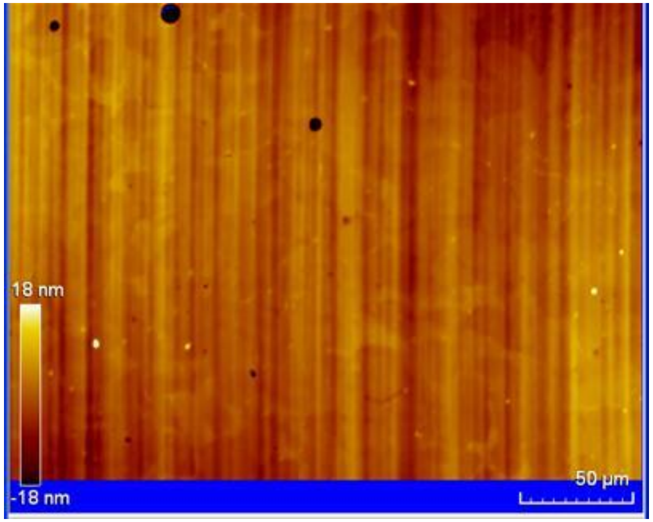
Parabola – Close analog to designed mirrors





25 μm/div





Electrochromics - Overview

"On-demand" zoom / Switching / Power / Mass → Electrochromics

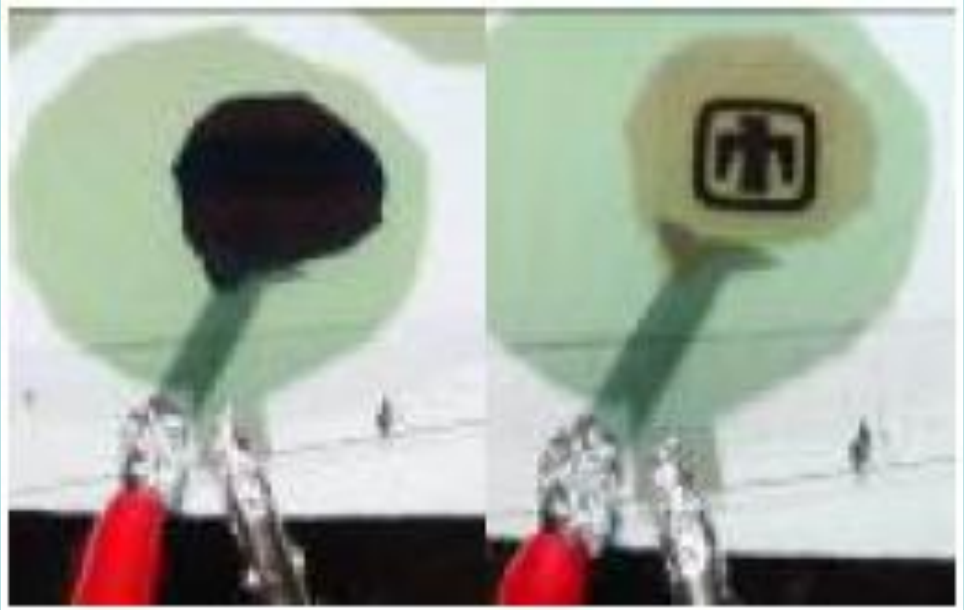
Electrochromics

Advantages

- Reversible change in absorption/reflection
- Low power consumption
- Conformal deposition

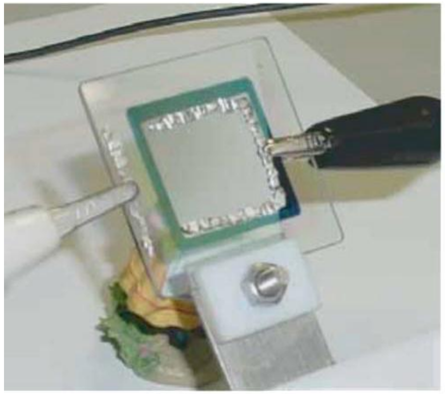
Challenges

- Slow switching speed
- Contrast (esp. reflective)
- Performance degradation

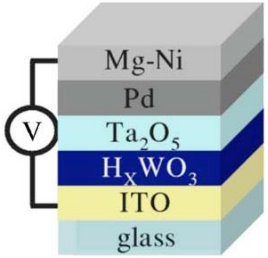


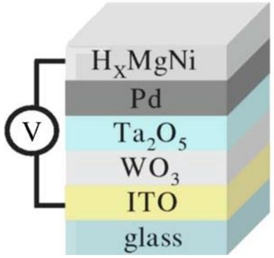
Ref.: R. Kammler, et al, "Use of Electrochromic Materials in Adaptive Optics," SPIE, **5895** (2005) pp. 5895.

Electrochromics - Baseline Design



Ref.: K. Tajima, et.al., Electrochemical and Solid State Letters, **10**(3) J52-J54 (2007).





Will add Al between Pd and Ta_2O_5 as additional diffusion barrier

REFLECTIVE MODE ELECTROCHROMIC DEVICE

Anodic reaction

Mg_2Ni (reflective state) + $4H_+$ + $4e_-$ = Mg_2NiH_4 (transparent state)

Mg (reflective state) + $2H_+$ + $2e_-$ = MgH_2 (transparent state)

Cathodic reaction

H_xWO_3 (colored state) = WO_3 (transparent state) + xH_+ + xe_-

where x is generally $0.05 < x < 0.4$.

Electrochromics - Status

- **Chamber built for off-axis deposition of dielectric layers**
- **Deposition of initial WO_3 layers done**
- **Investigating role of O_2 pressure during deposition**
- **Half-cell test setup redesigned**
  - Half-cell uses liquid electrolyte to drive electrochromic reaction with only dielectric or metal half of device
  - Original setup used gasket directly on device – led to damaged films and shorted devices
  - Updated setup uses cuvette arrangement enabling coincident electrical and optical measurement
- **Deposition of MgNi alloy beginning now**

Sandia HFZ - Conclusions

- **Optical Design Complete**
  - Pupil scaled down (3.0 → 2.5 mm) to accommodate binocular build
  - Magnification ~ 6.6x, FFOV at eye = 30º
- **Opto-Mechanical Design Complete**
  - Alignment process developed
  - Mechanical structures currently being machined
  - Mirror definitions finalized
- **Mirror Fabrication Starting**
- **Electrochromic development**
  - New chamber successfully depositing WO_3
  - Half-cell characterization of dielectric and metal halves of devices underway