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Optomechanical Design And Fabrication Of A Snap Together Freeform TMA Telescope

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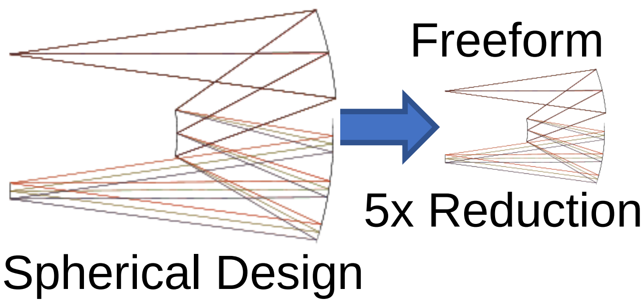
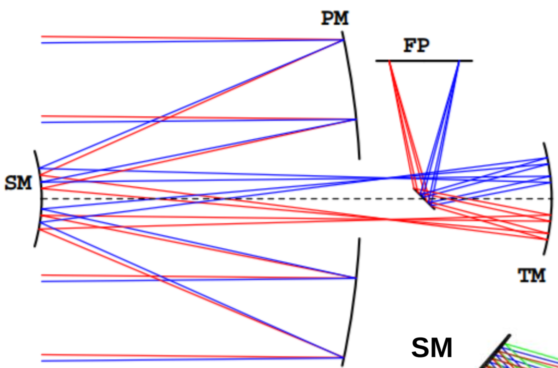
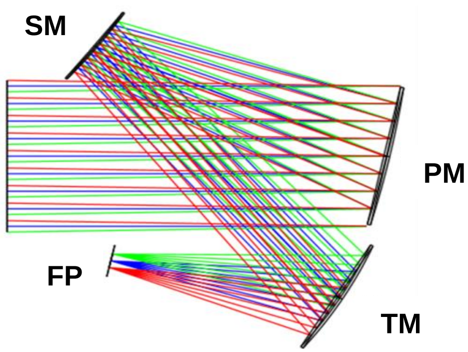
This talk will focus on the mechanical design and fabrication of a Wide Field of View (WFOV) Freeform Three Mirror Anastigmatic (TMA) Telescope



- **Freeform Optics** can allow for compact imager designs that do not sacrifice field of view or image quality (Reimers et. al.).



- **TMA** designs allow for off axis systems, with no obstruction in the FOV, compared to co-axial configurations.



  - *Coupling* ***precision manufacturing*** *with* ***precision design*** *techniques can reduce the amount of compensation required in optical systems.*

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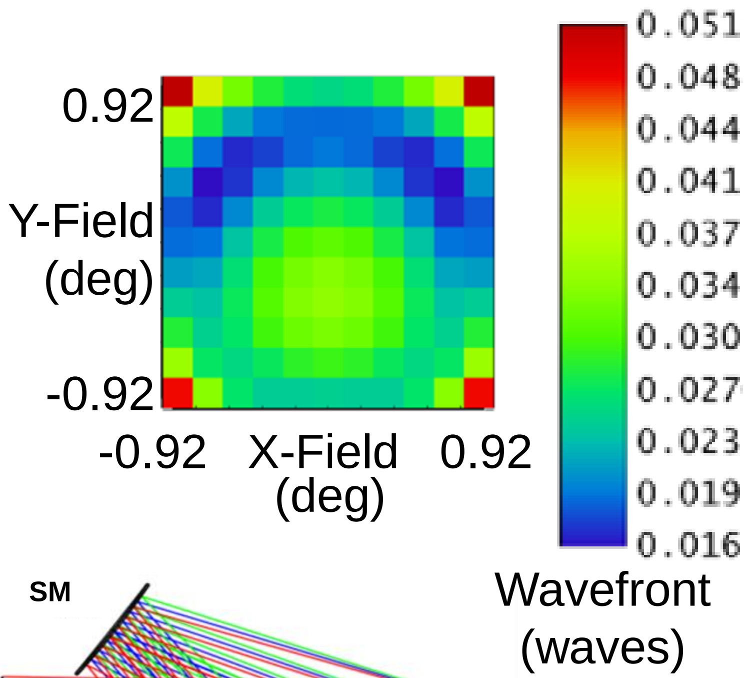
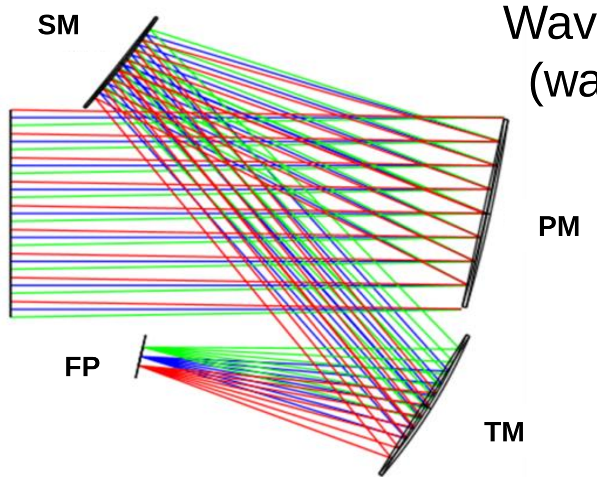
This system was designed for a 250 mm class aperture and was reduced 3x for prototyping





- The optical design was created by the University of Rochester (Schiesser et. al.)
- The prescriptions for the 3x reduction were verified by UNC Charlotte (Shultz)

Optical Specification (587 nm)	*3x Reduced Scale*
System Volume	220 mm x 257 mm x 86 mm
W.F.E	< 0.07 waves diffraction limited
E.Pupil Diameter	86 mm
Field of View	2.6°

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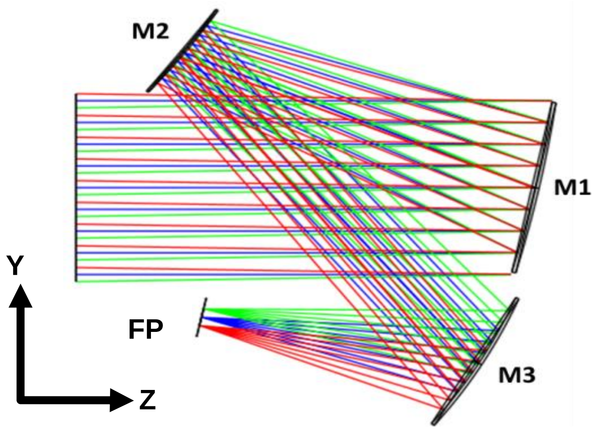
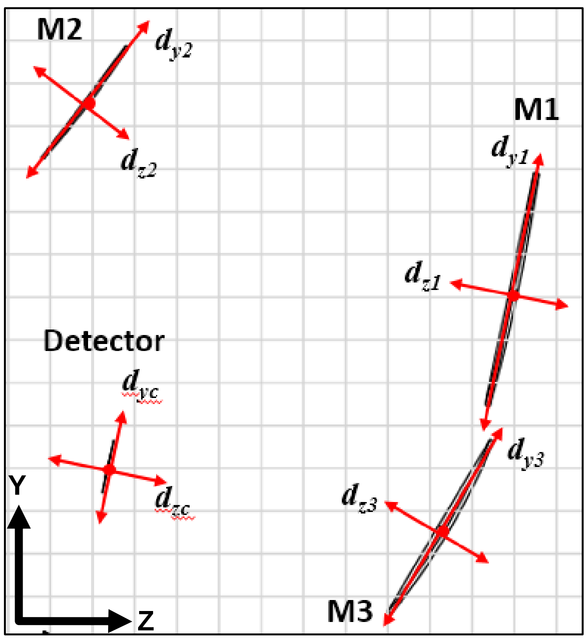
A best effort tolerance budget was developed at UNCC from prior experience with fabrication techniques





- A Monte Carlo simulation was performed at Univ. of Rochester
- The 3x scaled system would recover to diffraction limited performance with just refocus if tolerances were met

Specification per Optic Location	*Expected Uncertainty*	*Target Uncertainty*
Positioning (X-Y) (µm)	14	5
Positioning (Z) (µm)	9	3
Clocking (Rz) (µrad)	141	28
Tilt (Rx-Ry) (µrad)	86	17

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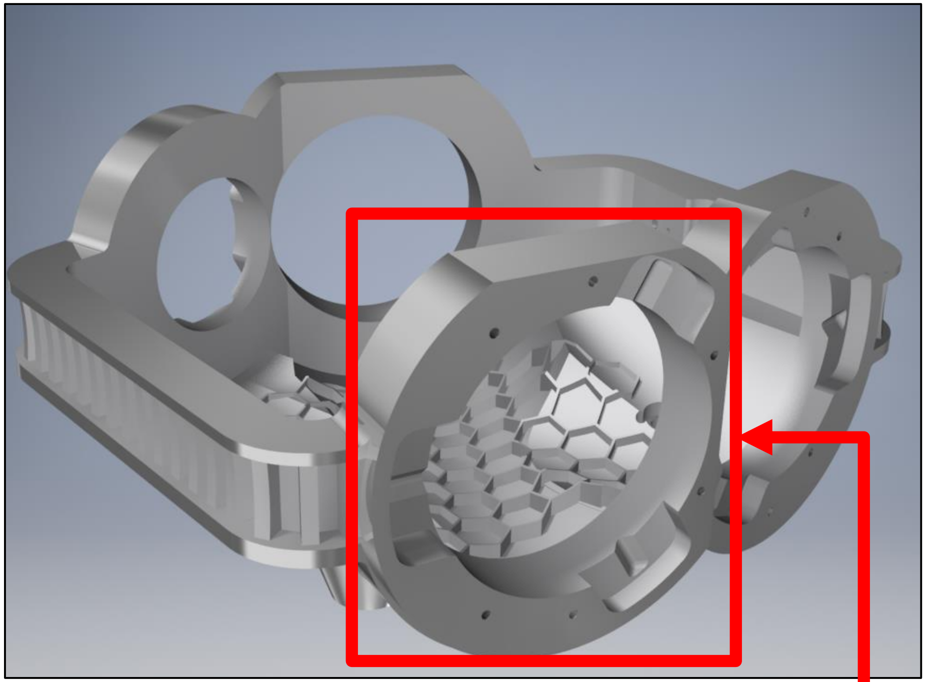
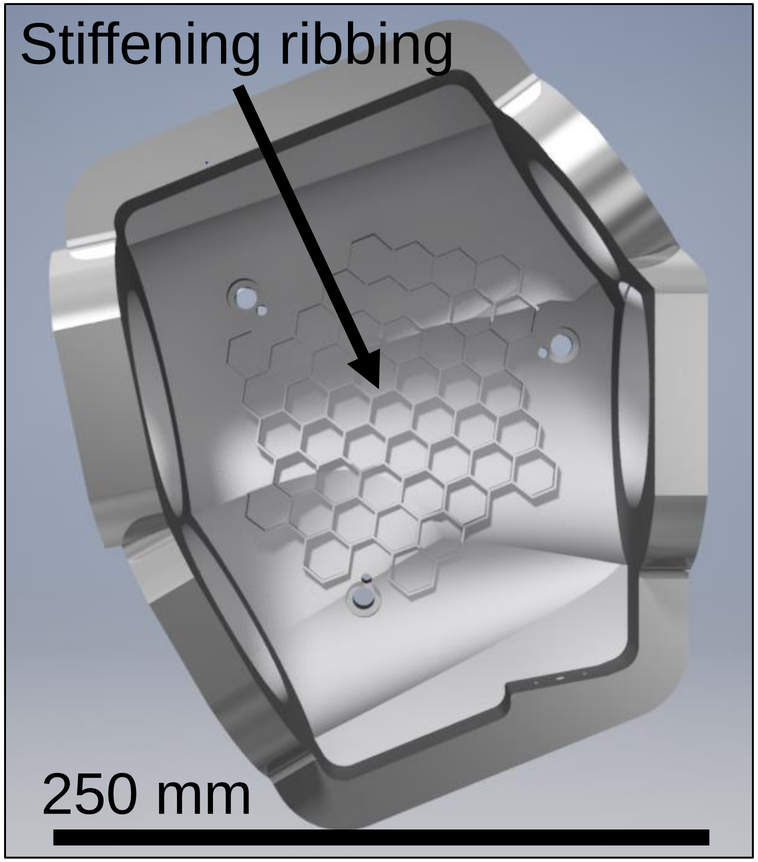
A monolithic housing, manufactured with high speed milling, was designed to reduce assembly tolerances





- FEA <10 nm deflection out of optical plane due to optic mass
- >90% stock removed: <5 kg
- Indicating gage pins located at each optical cell

Optical Cell with Kinematic V’s and asymmetric orientation tabs

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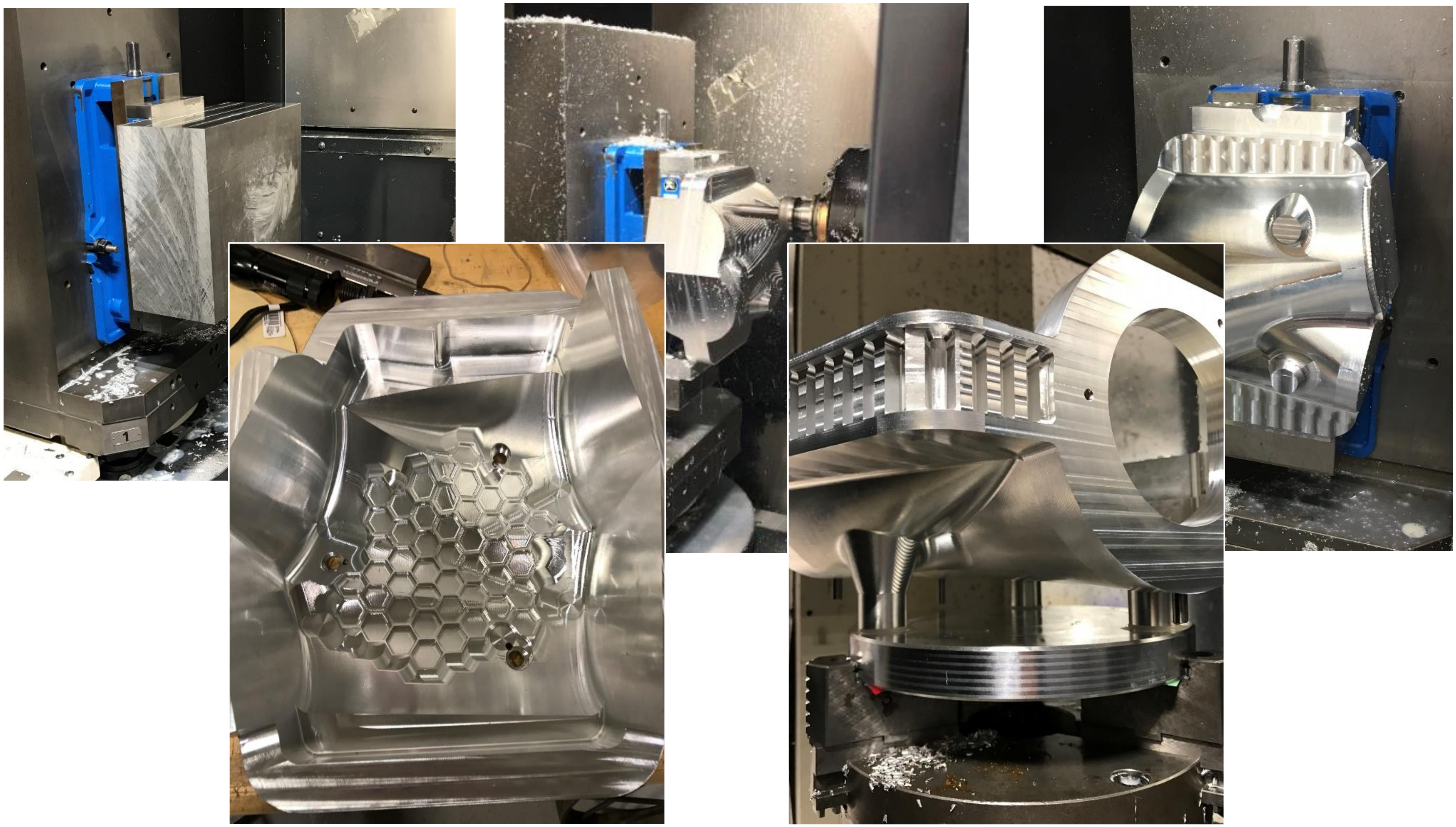
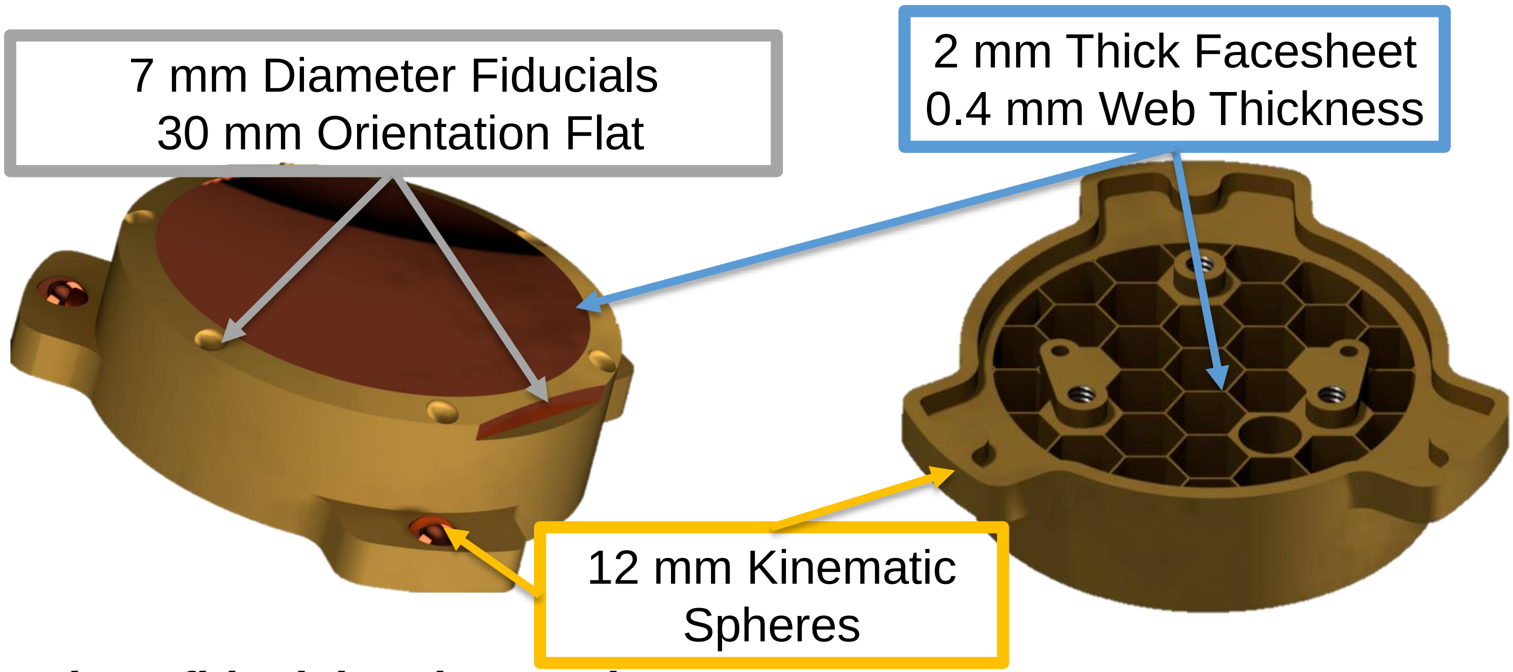


Optics were designed and fabricated with fiducials for prescription orientation, assembly metrology, and mounting features in one manufacturing setup

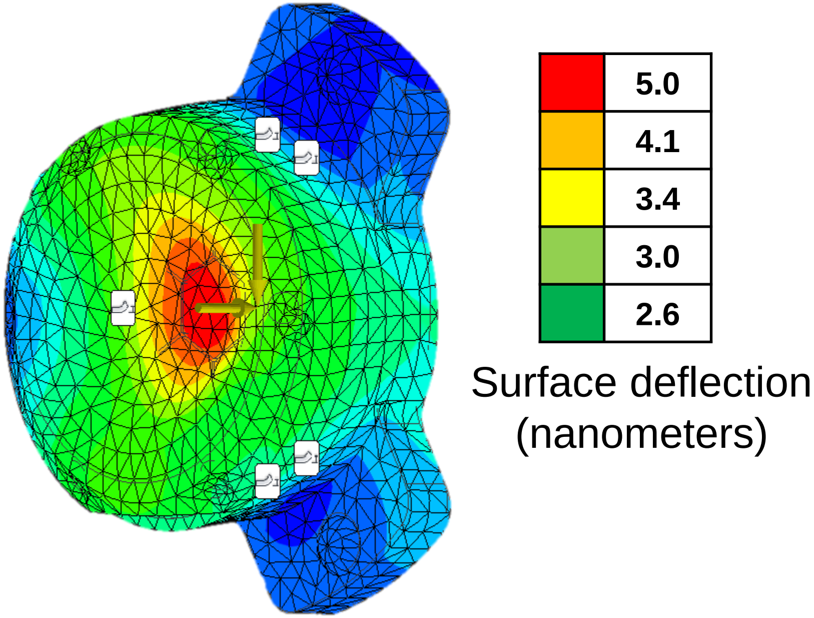


Mirror fiducial and mounting design

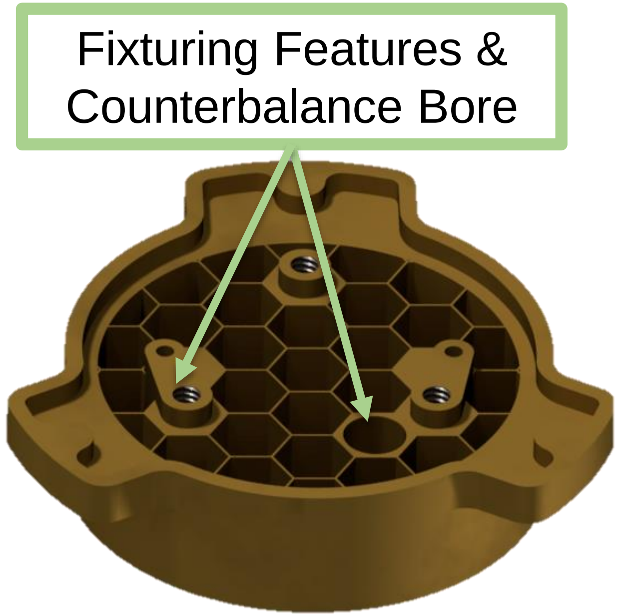
Light-weighted brass mirror design

- Optics utilize kinematic mounts (3 V-groove – 3 Sphere)
- Fiducials machined along chamfer just outside aperture

Optics were designed and fabricated with fiducials for prescription orientation, assembly metrology, and mounting features in one manufacturing setup



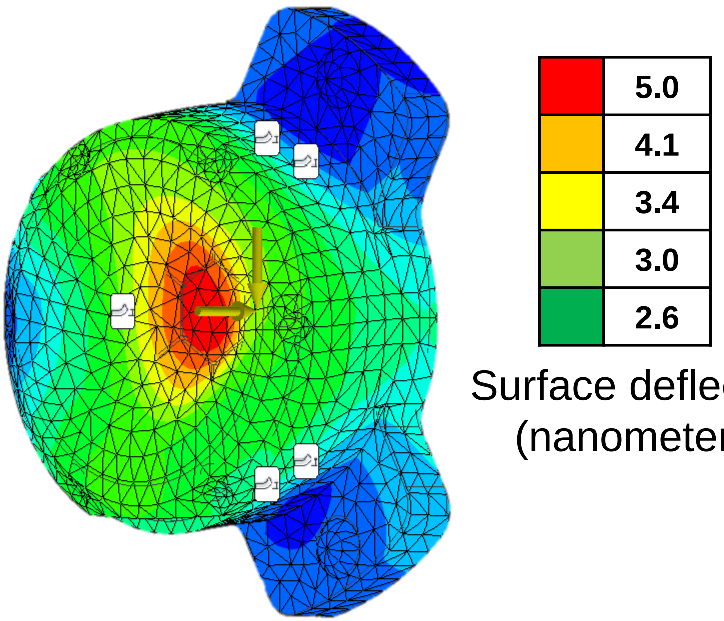
FEA of deflection due to cutting forces



Light-weighted brass mirror design

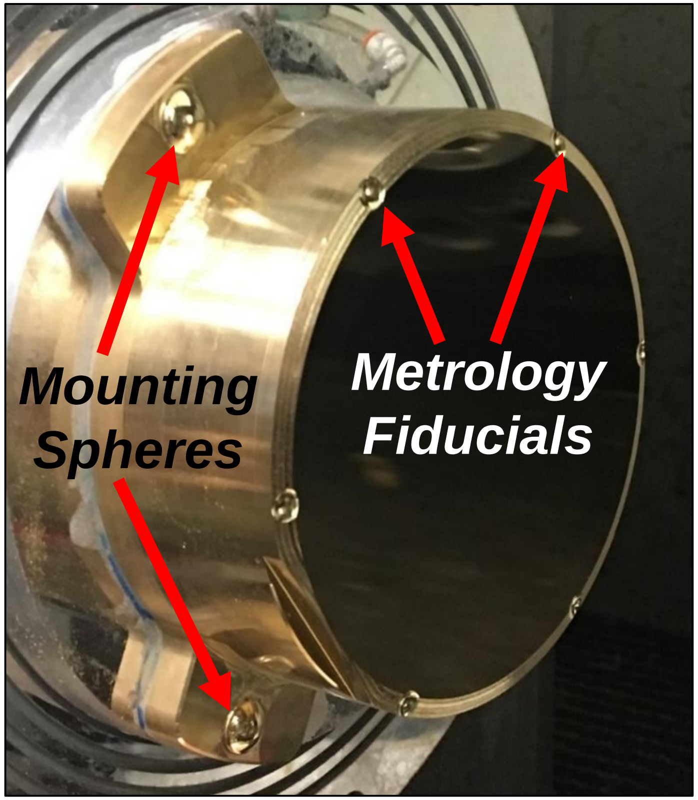
- 2 N tangential force assumed in roughing
- <0.1 N force assumed in finishing
- Face sheet and web thickness adjusted to reduce risk of print through

Optics were designed and fabricated with fiducials for prescription orientation, assembly metrology, and mounting features in one manufacturing setup



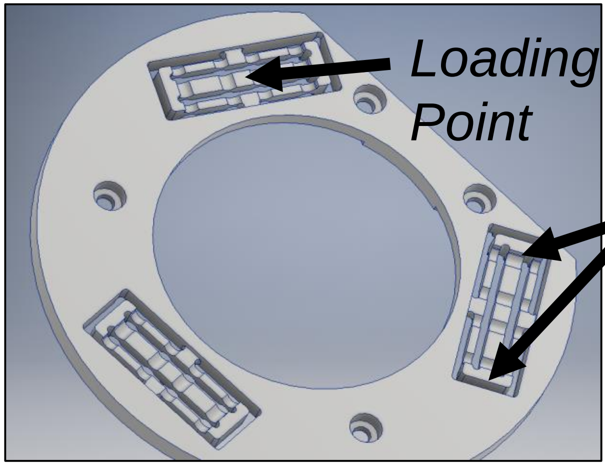
Surface deflection (nanometers)

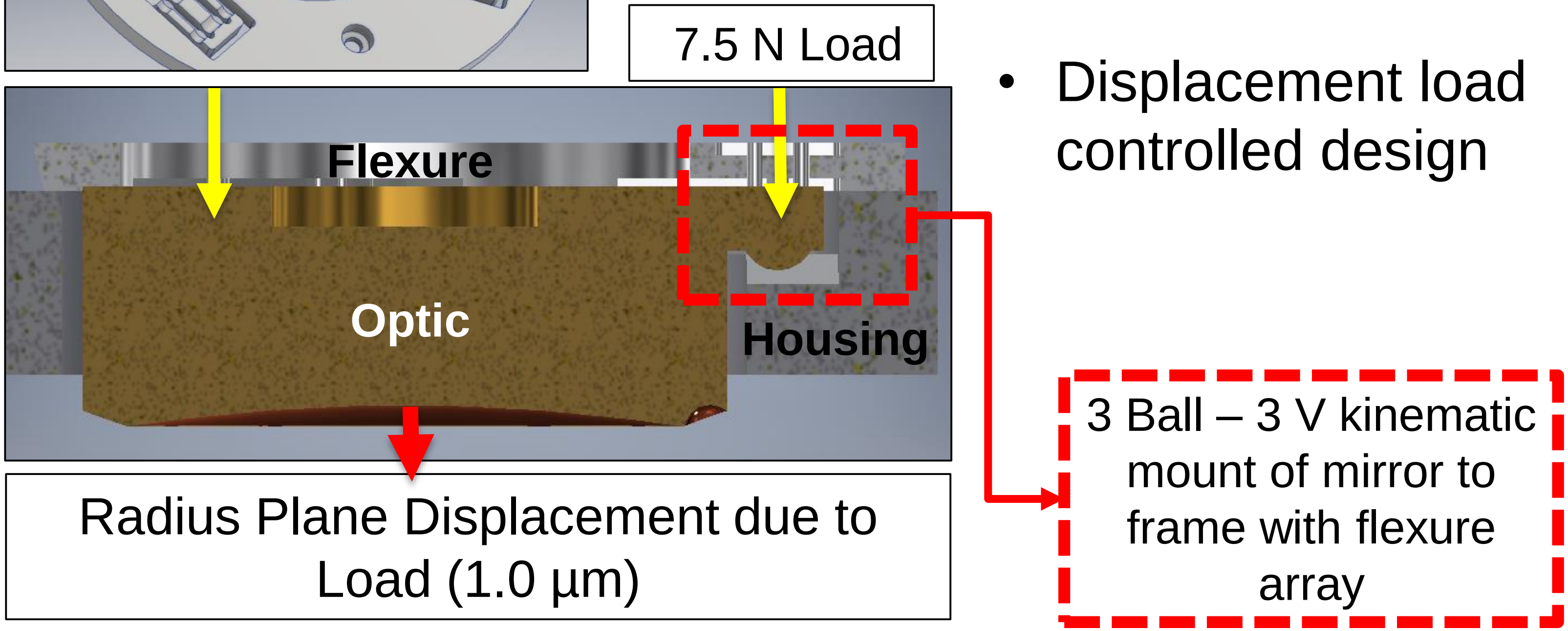
FEA of deflection due to cutting forces



- Finish pass with Slow Slide Servo diamond turning and milling spindle staged for mounting features and fiducials

The athermal kinematic arrangement, coupled with flexures as sole means of constraint increased repeatability and ease of assembly





- Flexure array bolts to housing – flexure elements provide load to the optic
- Displacement load controlled design

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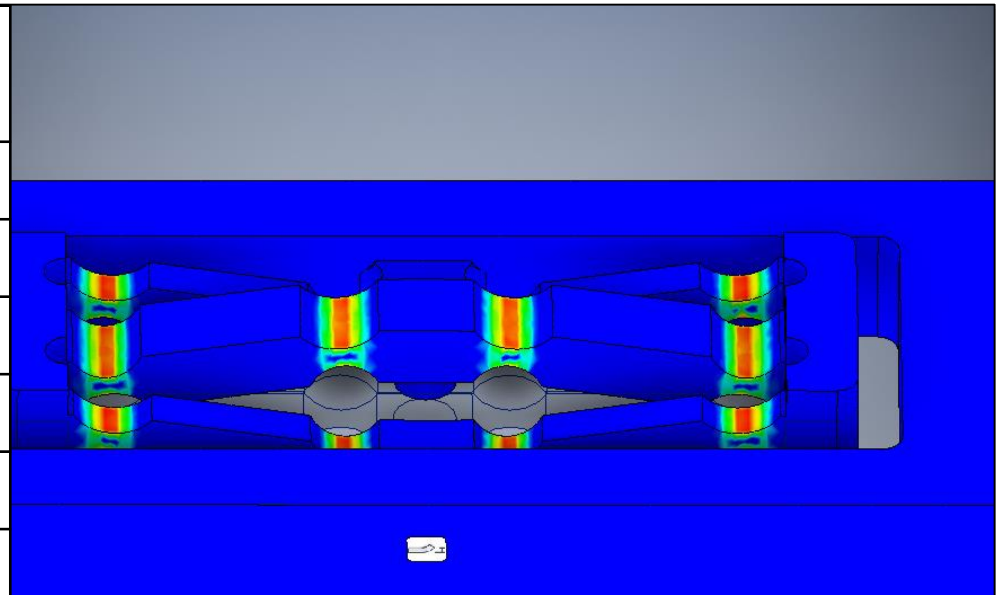
The flexures were mathematically modeled and then verified with finite element and a manufactured test part and CMM

Flexure Mathematical Results (@7.5 N Load)					
Angular Stiffness (N-mm/rad)	1878	Equivalent Stiffness (N/mm)	62.1		
Statics		Dynamics		Stress	
Θ_{max} (deg)	0.34	Natural Freq (kHz)	7.1	σ_{max} (MPa)	114.9
Displacement (µm)	121	FVT (µm)	121	Safety Factor	2.5

Stress (MPa)	
(red)	117.2
(yellow)	96.1
(light green)	74.3
(green)	47.9
(light blue)	22.6
(blue)	0.0



Finite Element Analysis of Flexure

Uncertainty in fabrication was mathematically modeled to develop an acceptable tolerance range for the elements and the effect on the kinematics

Flexure Mathematical Results (@7.5 N Load)					
Angular Stiffness (N-mm/rad)		1878	Equivalent Stiffness (N/mm)		62.1
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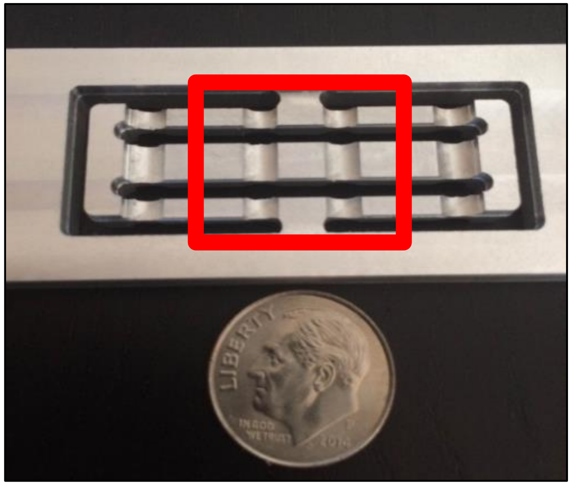
Displacement (µm)	121	FVT (µm)	121	Safety Factor	2.5

Specification	*Uncertainty*
Equivalent Stiffness (N/mm)	2.67
Stiffness Uncertainty Ratio (%)	4.31
Force (N)	0.35

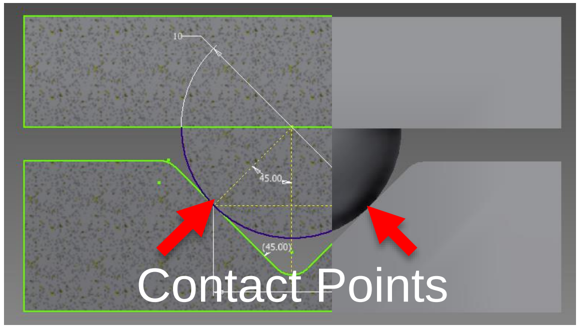


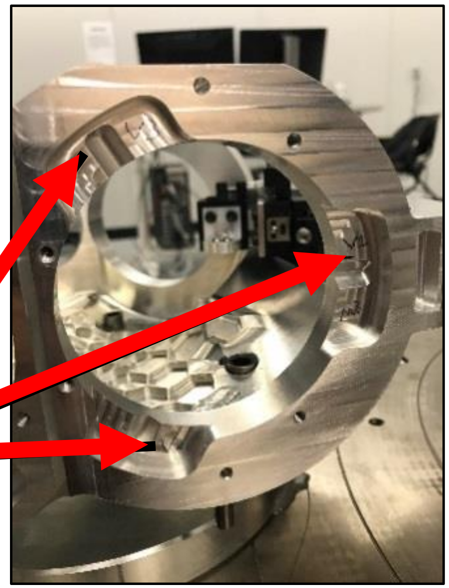
CNC Test Part

A .75 kg weight was hung from loading point and displacement was measured (118 µm +/- 6)

A 15 µm tolerance was required on the element web thickness and load cell boss

The kinematic coupling was characterized and tested for repeatability once assembled





V Grooves

Remains in the elastic region of both materials

Kinematic Contact Stress Results (@7.5 N Load/Sphere)	
Normal Forces to Groove (N)	5.3
Contact Ellipse D_{major} (µm)	160
Contact Ellipse D_{minor} (µm)	159
Max Contact Stress (MPa)	400
Max Shear Stress (MPa)	126
Safety Factor	1.2
Displacement of Z-Plane (µm)	1.0

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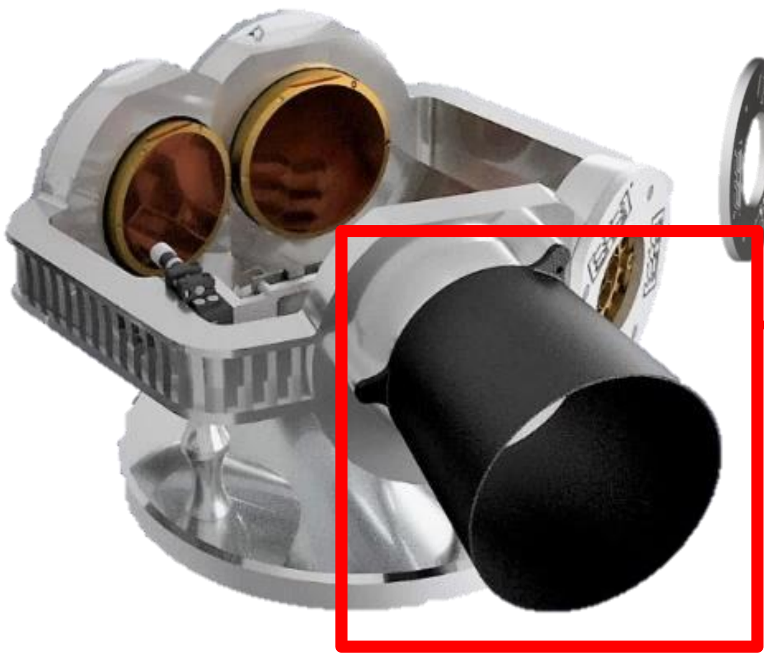
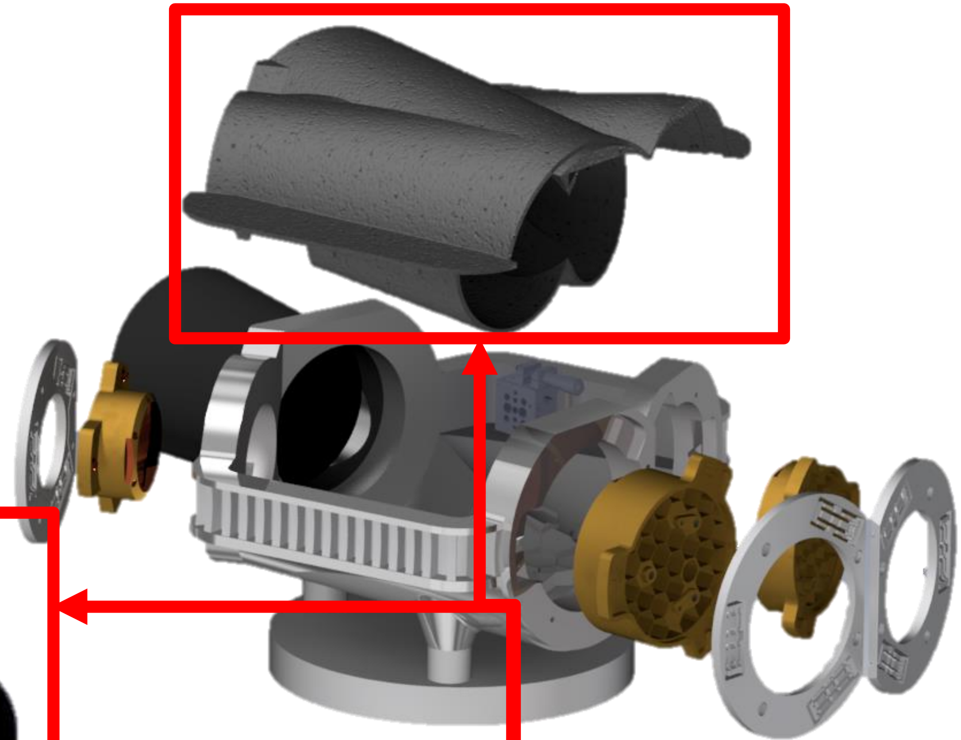
The assembly requires no special tooling, gage blocks or instructions.
It can be assembled and image in less than 10 minutes.



CAD Model Assembled

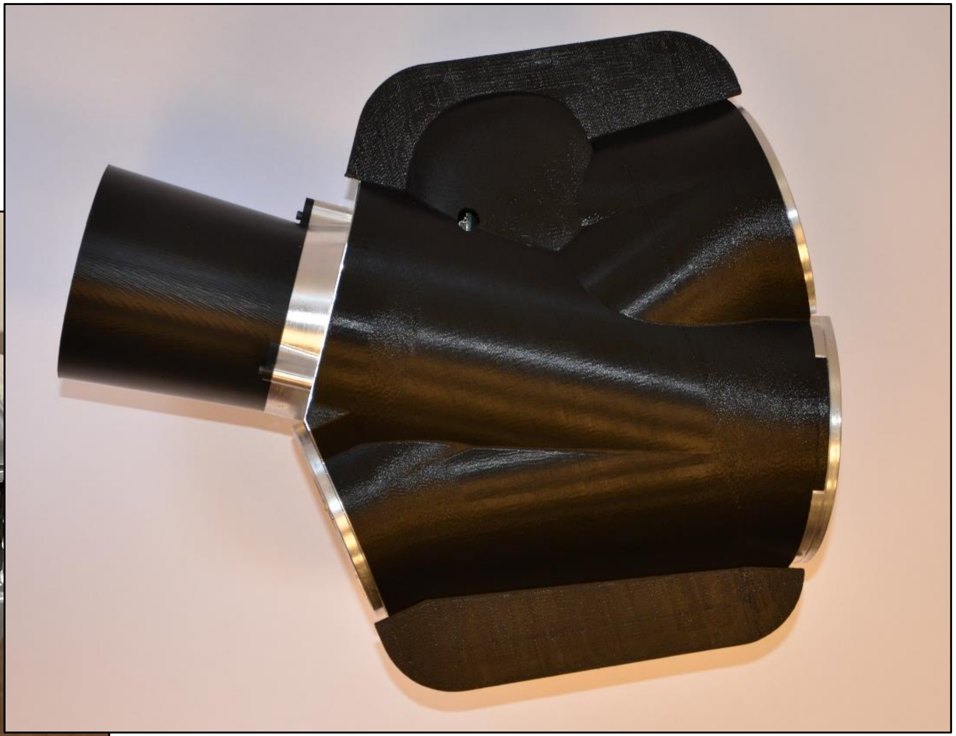


CAD Model Exploded View

Stray Light Baffling
Top Shell 3D Printed with
Nylon – Clips to Housing

The assembly requires no special tooling, gage blocks or instructions. It can be assembled and image in less than 10 minutes.

Completed System

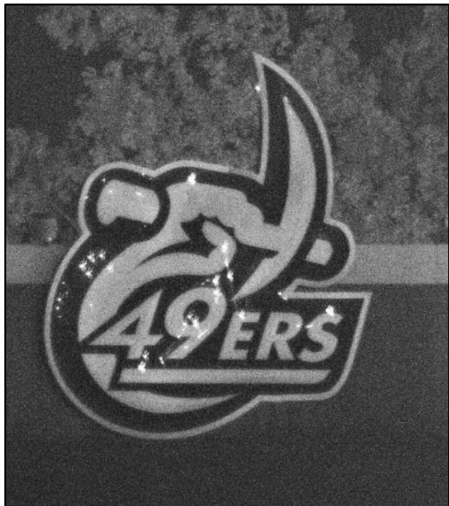


Completed System

Repeatability tests showed no significant contribution to WFE

Initial functional testing was performed with a CMOS detector, which resulted in a detector limited performance of the system

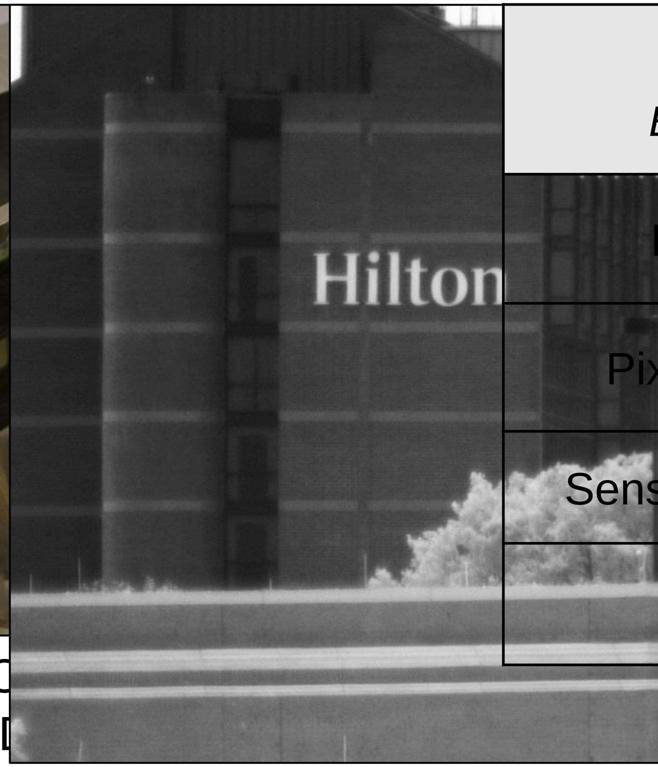
Note: Design is diffraction limited at 1000 m or greater



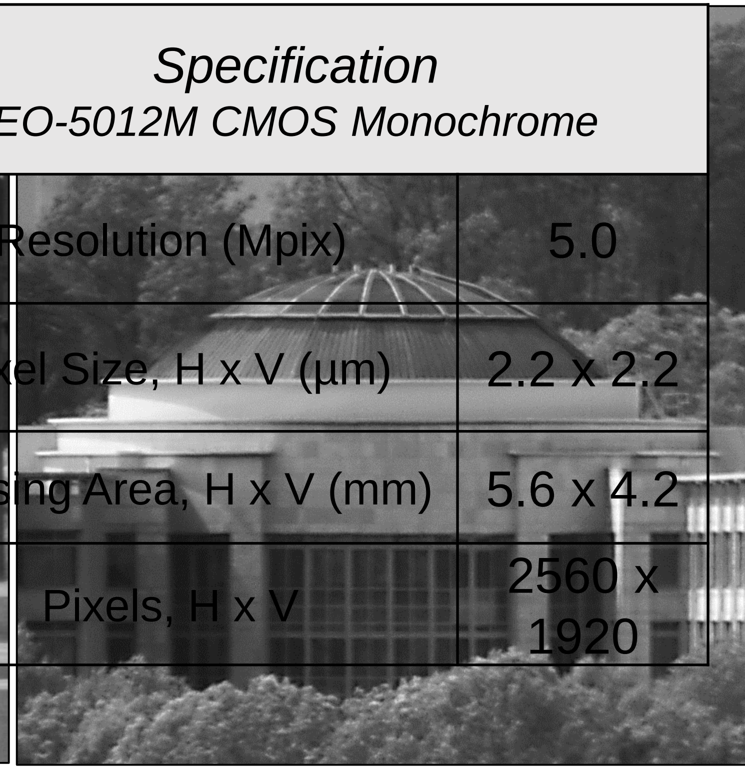
UNCC Scoreboard Logo at 250 m

EO CMO

D



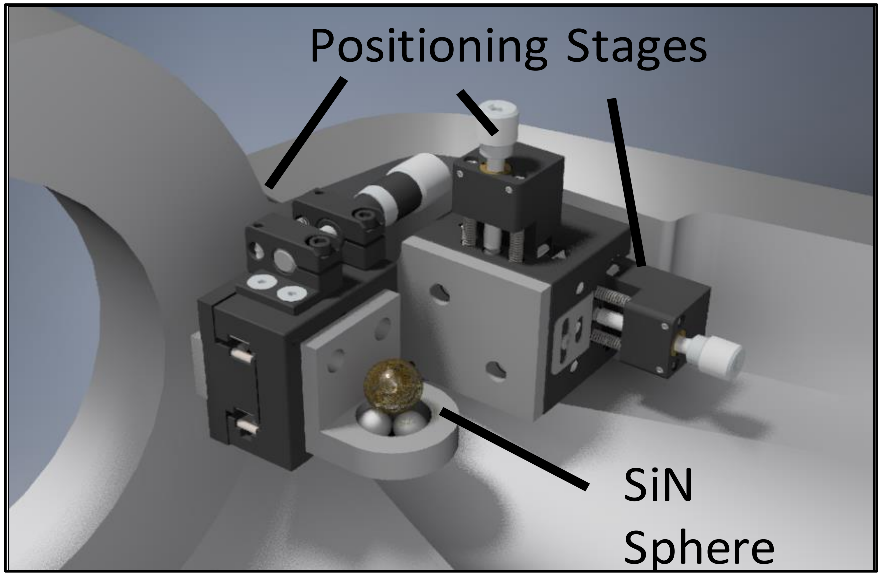
Hilton Hotel at 1.46 km



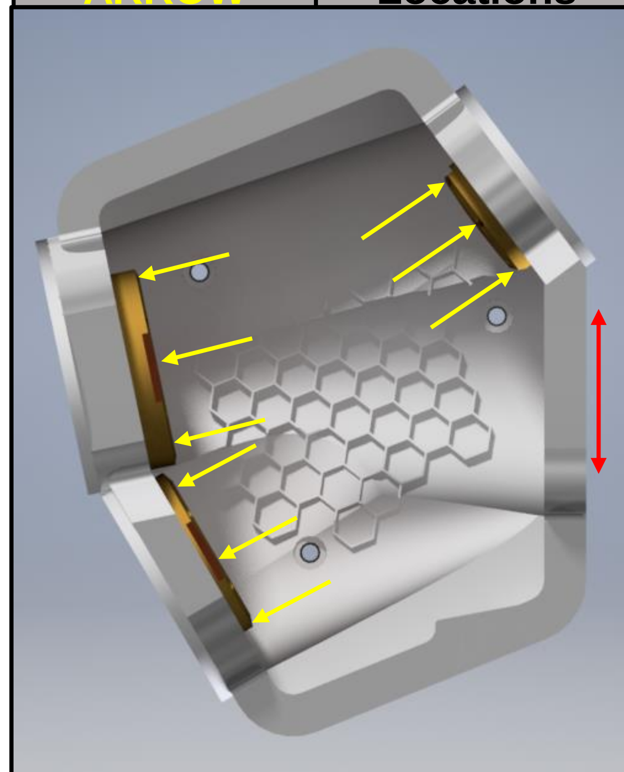
TIAA Financial Building at 2.26 km

Specification *EO-5012M CMOS Monochrome*	
Resolution (Mpix)	5.0
Pixel Size, H x V (µm)	2.2 x 2.2
Sensing Area, H x V (mm)	5.6 x 4.2
Pixels, H x V	2560 x 1920

The system is going through an optical redesign for a less sensitive TMA. The future system will be a 250 mm class with SiC freeform optics.



RED ARROW	Entrance Pupil
YELLOW ARROW	Fiducial Locations



- Random Ball Testing configuration completed (Parks et. al.)
- WFE Interferometric testing undergone at the Air Force Research Lab (AFRL)
- Testing to be done at UNCC for verification of measurements
- CMM Testing of assembly to source any error in system – tie WFE to Placement errors

Acknowledgements

- NSF I/UCRC Center for Freeform Optics (IIP-1338877 and IIP-1338898)
- Dr. Chris Evans (UNC Charlotte), Dr. Tom Suleski (UNC Charlotte), Dr. Jason Shultz (UNC Charlotte), Dr. Tom Nelson (AFRL), Dr. Peter Marasco (AFRL)
- Dr. H. Philip Stahl (NASA) for the opportunity to present my work

Thank you!
Questions/Comments?