NIRCam Instrument Overview

Larry Burriesci

Lockheed Martin Advanced Technology Center
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18 NIRCam Instrument Presentations

5904-01 Marcia Rieke; Overview of James Webb Space Telescope and NIRCam's Role

5904-02 Bruce Steakley; NIRCam systems engineering: the recipe

5904-03 Larry Burriesci; NIRCam instrument overview

5904-04 Lynn Huff; NIRCam Instrument optics

5904-05 Yalan Mao; NIRCam optical analysis

5904-06 Alison Nordt; Optical bench assembly for the near-infrared camera

5904-07 Steve Somerstein; NIRCam optical calibration sources

5904-08 Gopal Vasudevan; Some performance results from NIRCam's coronagraphic prototype masks

5904-09 Leigh Ann Ryder; Lens design for the Near Infrared Camera for the James Webb Space Telescope

5904-10 Paul Mammini; Cryogenic mirror mounts for use on JWST's NIRCam instrument

5904-11 Sean McCully; NIRCam filter wheels

5904-12 Charles S. Clark; NIRCam pupil imaging lens mechanism and optical design

5904-13 Liz Osborne; NIRCam thermal subsystem

5904-14 David L. Mason; NIRCam integration and test

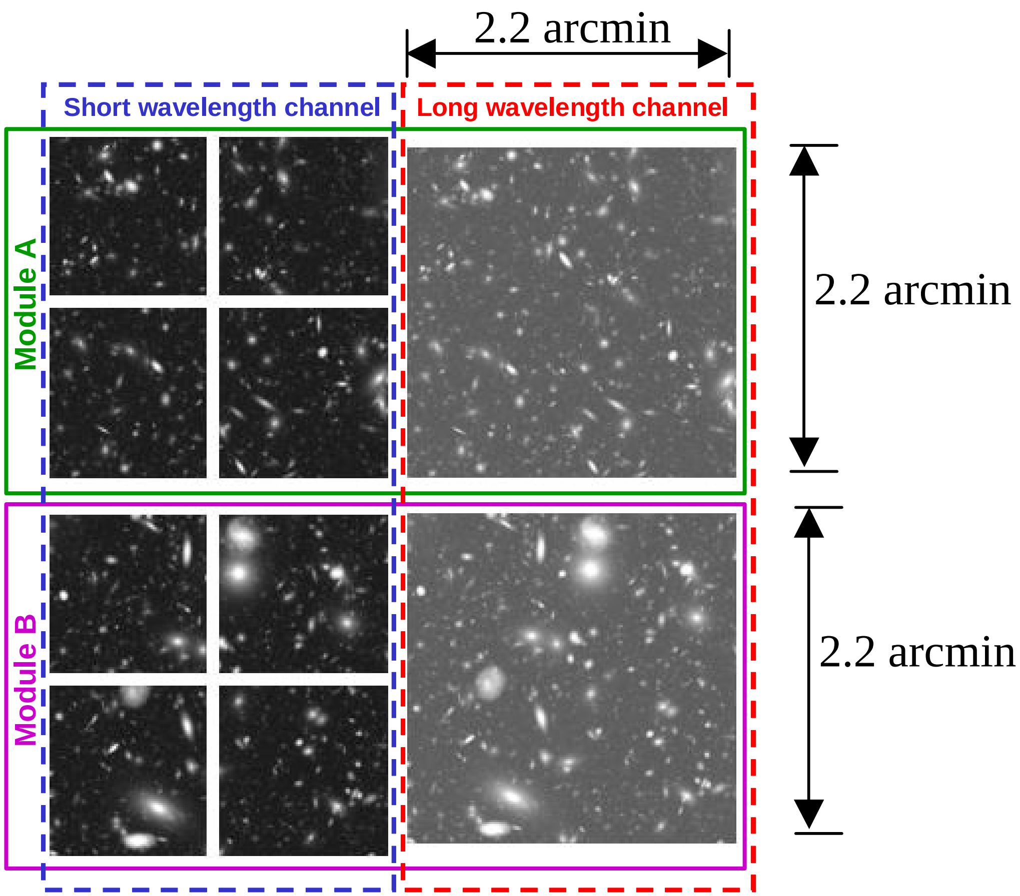
5904-24 E. Todd Kvamme; Lithium fluoride material properties as applied on the NIRCam instrument

5868-35 Edinger & Nordt; Selection of I-220H Beryllium for the NIRCam Optical Bench

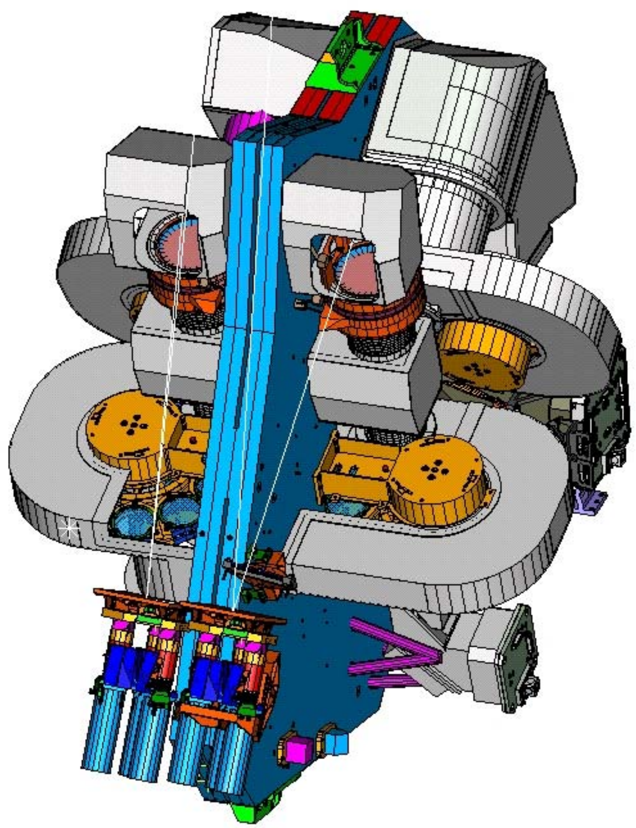
5877-29 Edinger, Mammini & Osborne; Compact, lightweight, and athermalized mirror and mount for use on JWST's NIRCam instrument

5877-33 E. Todd Kvamme; A low stress cryogenic mount for mounting of large lithium fluoride space-based optics

Two Imagers in each of two Modules

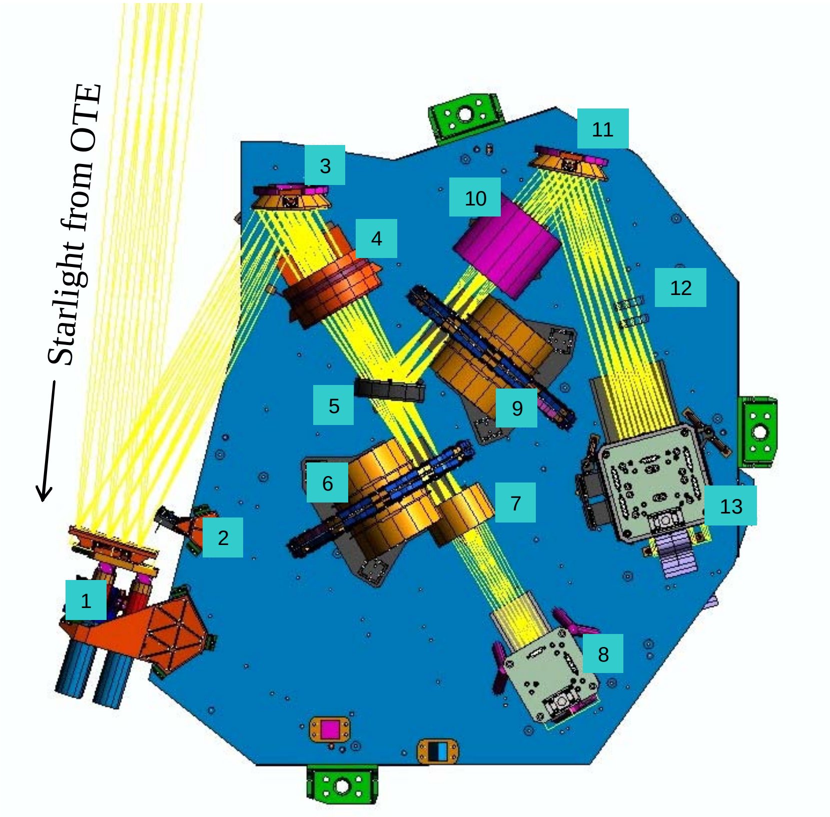


Two adjacent fields of view (2.2 arcminute)^2
Both fields in SW and LW bands



Two back-to-back imagers

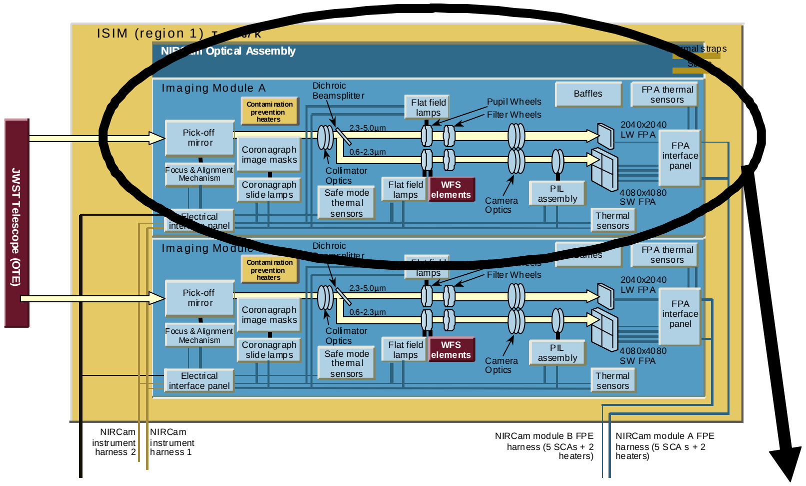
NIRCam Module-A Layout



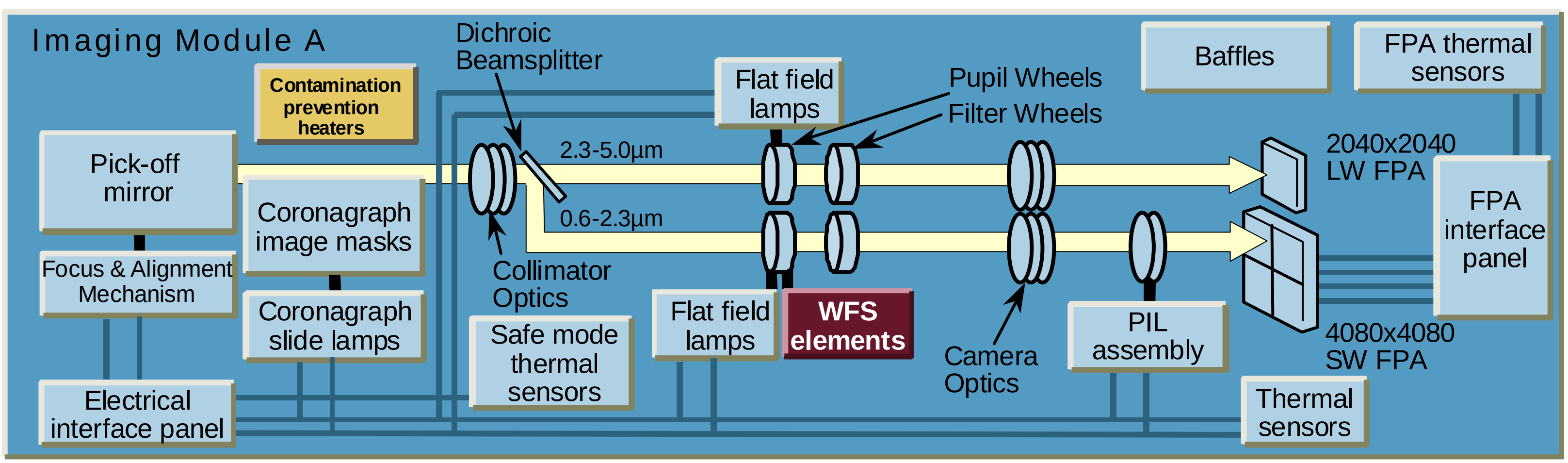
1	Pick-Off Mirror Assembly
2	Coronagraph
3	First Fold Mirror
4	Collimator Lens Group
5	Dichroic Beamsplitter
6	Long Wave Filter Wheel Assembly
7	Long Wave Camera Lens Group
8	Long Wave Focal Plane Housing
9	Short Wave Filter Wheel Assembly
10	Short Wave Camera Lens Group
11	Short Wave Fold Mirror
12	Pupil Imaging Lens
13	Short Wave Focal Plane Housing
14	ICE Interface Panel
15	FPE Interface Panel

One module images in two wave bands:
(0.6 to 2.3 microns and 2.4 to 5.0 microns)

NIRCam Hardware Block Diagram

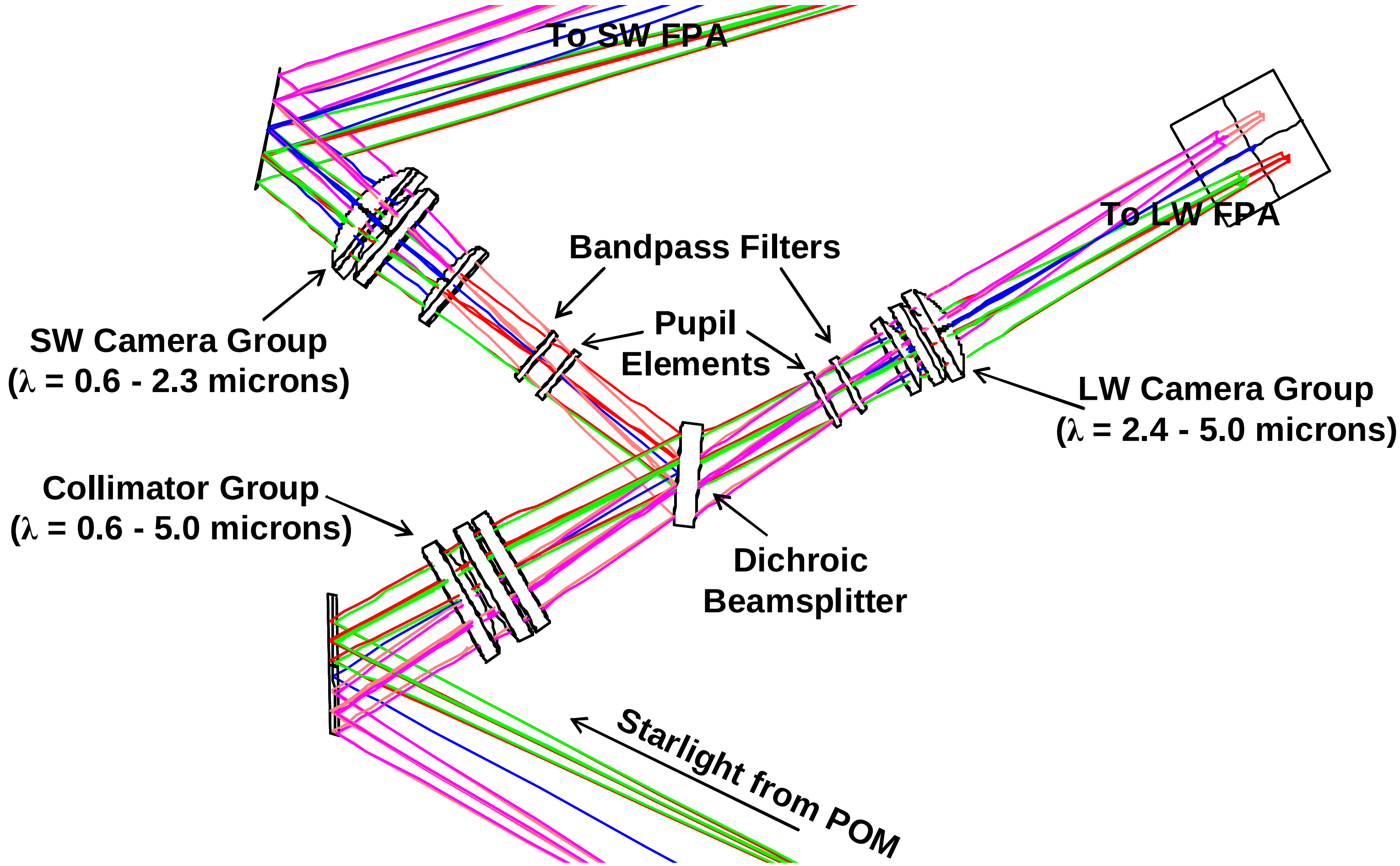


Short wave and long wave science-mode imaging as well as SW metrology* capability are included in both of the modules.



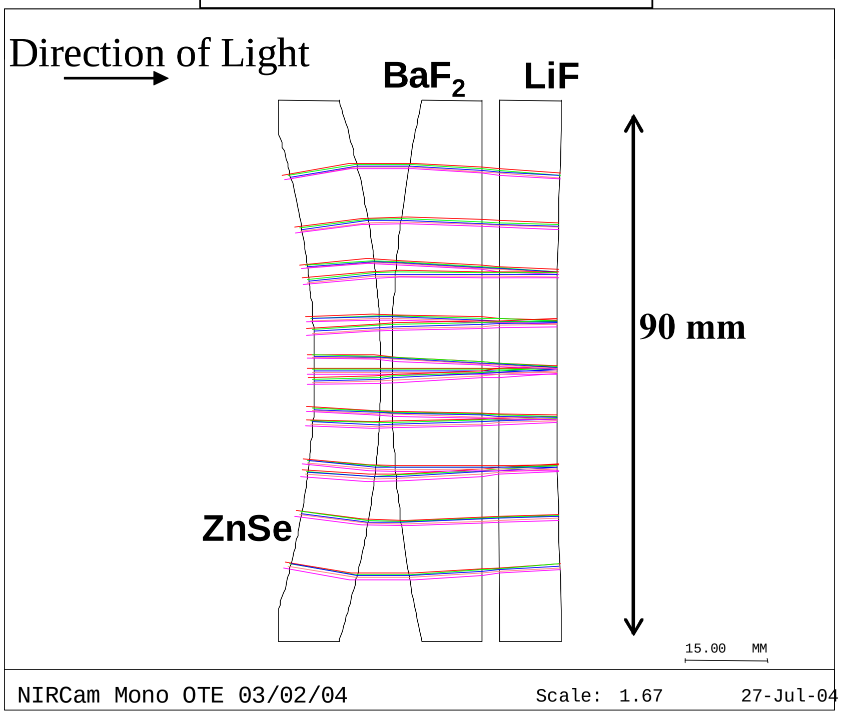
* “metrology” includes wavefront sensing and alignment of the 18 segments of the JWST primary mirror

SW and LW imaging optical paths

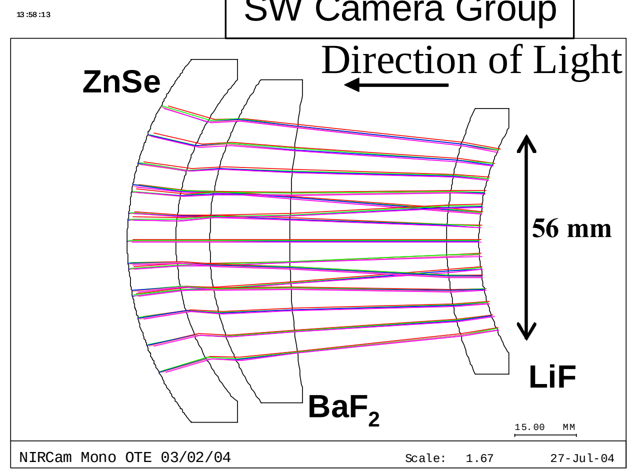


Refractive Triplets: Three Types

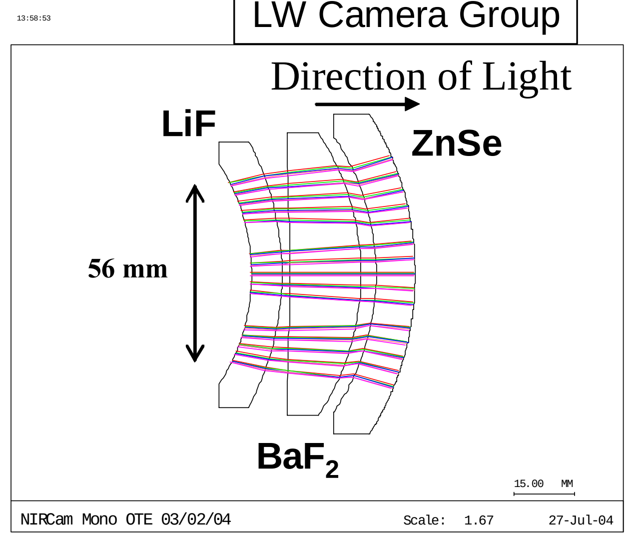
Collimator Group



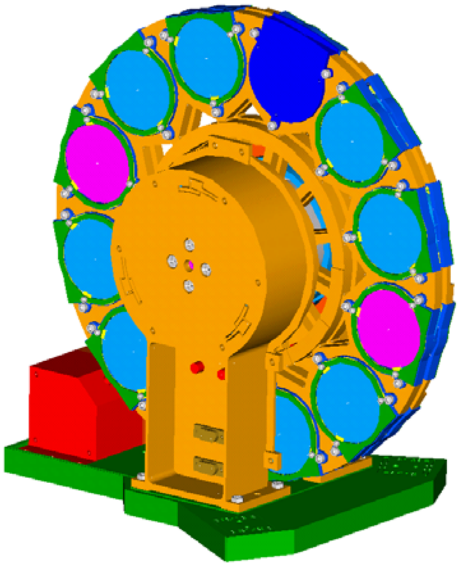
SW Camera Group



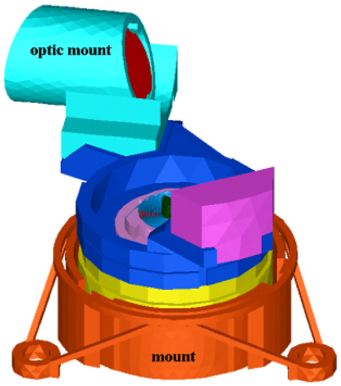
LW Camera Group



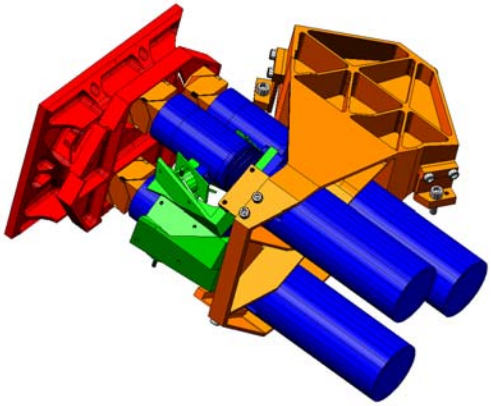
Mechanisms



Filter Wheel Assembly

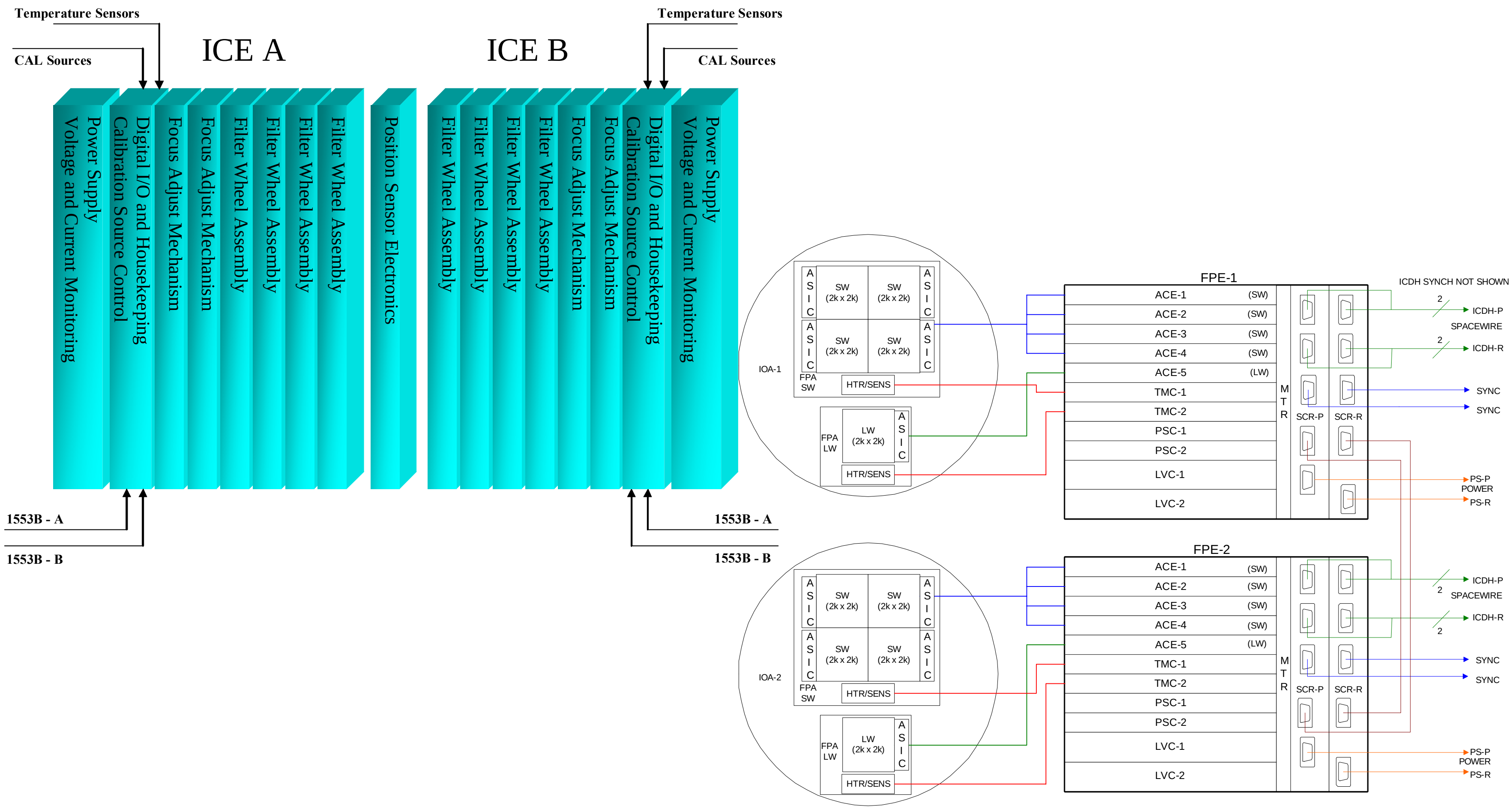


Pupil Imaging Lens Assembly



Focus and Alignment Mechanism

Instrument Control Electronics and Focal Plane Electronics



Supplemental Slides

Selection of I-220H Beryllium for NIRCam Optical Bench

Derek Edinger

Alison Nordt

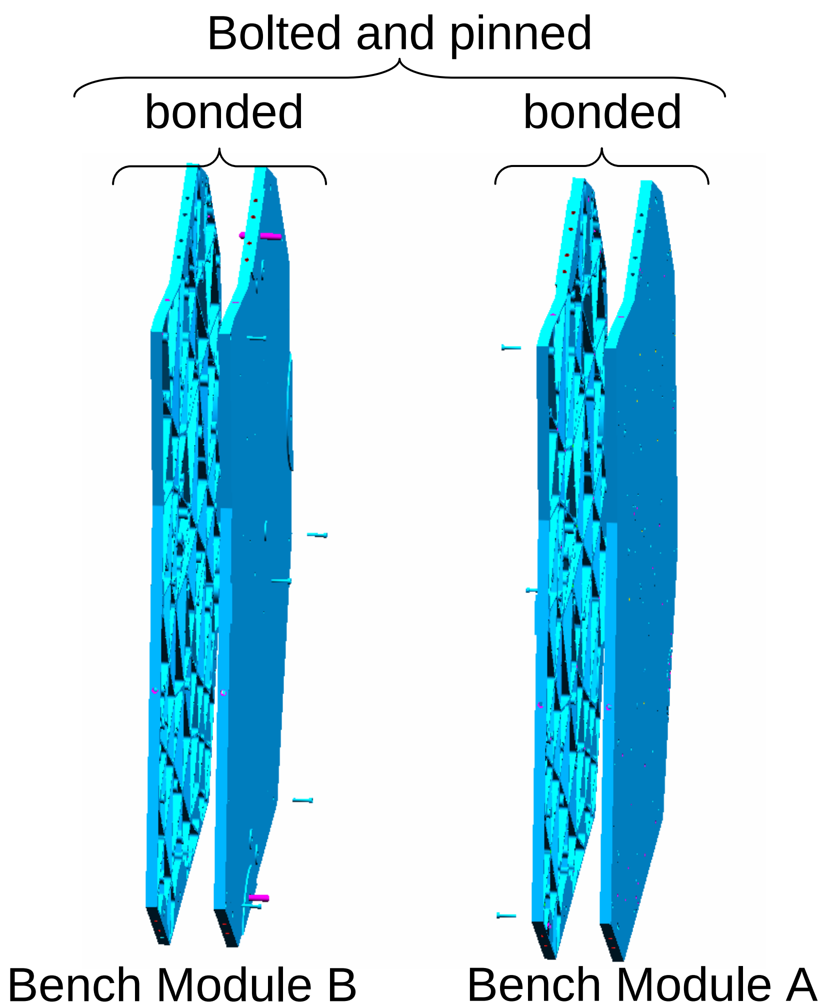
Lockheed Martin Advanced Technology Center

Outline

- Introduction
- Trade Studies
- Design Issues
- Heat Treating and Microyield Issues
- Current Status
- Conclusion

Introduction

- Driving Requirements for Optical Bench:
  - Low mass to support tight NIRCam's tight overall mass budget.
  - High stiffness to meet minimum launch frequency and minimize gravity sag distortions during optic integration and alignment.
  - Adequate strength to survive launch loads.
  - High dimensional stability to maintain optical alignments during cool down from room temperature to 35K and during operation at 35K.
  - High thermal conductivity to minimize thermal gradients during operation which cause thermal distortions.



Material Trade Study

Candidate Materials

Material	Stiffness (GPa)	Density (g/cm^3)	Specific Stiffness	Tensile Yield Strength (MPa)	Specific Strength	Fracture Toughness (MPa mm^1/2)	Thermal Conductivity at 30K (W/mK)	CTE at 30K (ppm/K)	CTE at 293K (ppm/K)	dL/L between RT and 30K (ppm)
6061 T651 Aluminum	69	2.7	25	276	102	938	41	1	23.6	-4150
AlBeMet 162H	200	2.1	95	193	92	316	210	0.2 (long) 0.7 (trans)	13.91	-2000
SiC	450	3.2	140	307	96	126	<50	0.1	4.3-4.5	-320
I-220H Beryllium	300	1.86	161	345	185	348	85.6	0.04	11.38	-1298
M55J/954-3 Graphite/Cyanate	107	1.63	65	159	98		0.82	0.04	-0.36	185
6AL-4V Titanium	112	4.43	25	827	187	1700	1.7	6.3	8.8	-2076

Beryllium performs the best against driving requirements and only material that will meet mass budget.

Beryllium Grade Trade Study

Candidate Grades

Grade	Tensile Yield Strength (MPa)	Microyield Strength (MPa)	Fracture Toughness (Mpa mm^1/2)	% Elongation	Isotropy
I-220H Grade 1	345	41	~348	1	Good
I-220H Grade 2	345	69	~348	1	Good
S-200FH	296	-	~348	3	Fair
O-30H	207	21	~348	2	Very Good
I-70H	207	21	~348	2	Good

- Only hot isostatically pressed (HIP) material considered for isotropic properties.
- Rolled sheet is efficient form for sandwich structures, but properties are anisotropic.

I-220H has highest strength and good isotropy.

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Surface Preparation Trade Study

- Three surface preparation techniques tested were:
  - Black anodized (only)
  - Black anodized and primed
  - Etched and primed
- Surface preparation tested by double lap shear (ASTM D3528):
  - S-200F substrates (shouldn't affect bond if grade isn't I-220H).
  - Bonded with Epibond 1210A/9615-10.
  - Thermal cycled 3 times from 313K to 77K (LN2). Prior experience with Epibond at Lockheed Martin shows no degradation in properties from 77K down to 4K.
  - 3 coupons (one of each surface prep) were ultimately thermal cycled to 4K (LHe) and show no visible cracks. Coupons may eventually be shear tested.

Surface Preparation Trade Study

Bond Test Results

Anodized		Anodized and Primed		Etched and Primed	
Coupon	**Strength (MPa)**	**Coupon**	**Strength (MPa)**	**Coupon**	**Strength (MPa)**
A1	27	AP1	34	EP1	34
A2	24	AP2	32	EP2	33
A3	31	AP3	33	EP3	32
A4	25	AP4	33	EP4	35
A5	24	AP5	35	EP5	31
A6	31	AP6	35	EP6	32
A7	27	AP7	34	EP7	35
Average:	27	Average:	34	Average:	33
Std. Dev:	3	Std. Dev:	1	Std. Dev:	1
B-Basis Allowable:	**18**	B-Basis Allowable:	**30**	B-Basis Allowable:	**29**

- Anodized only performed surprisingly well.
- Anodized and primed performed better than etched and primed.

Anodized and primed has best shear strength and minimizes cleaning and contamination risk.

Design Issues

- Reworkability:
  - Optical bench has large number of threaded inserts for optical components, thermal straps, harness tie downs, lift baffles, etc. which are difficult to define up front due to long lead time for beryllium and may change at a later point.
  - Due to toxicity, beryllium can't be reworked at Lockheed Martin. Material has to be returned to supplier for rework.
- Fracture Toughness:
  - Optical bench is mostly stiffness driven, but there are some high stress areas.
  - "Safe Life" fracture analysis required to ensure minimally detectable crack in high stress area won't grow large enough to fail part over all load cycles in life of part.
  - Although I-220H has a yield strength of 345 MPa, the equivalent allowable in some circumstances to meet safe life is only 95 MPa.

Heat Treating Issue

- I-220H material failed to meet Grade 2 microyield strength (aka Precision Elastic Limit) specification.
- Root causes believed to be:
  - Increase in consolidation temperature from 830C to 1000C after Gran Canary Telescope mirror failure. Higher temperature improves elongation to reduce machining risk, but degrades microyield.
  - Low iron/aluminum ratio. This is property of raw powder which is difficult to control and was at bottom of acceptable limits.
- Additional heat treatments with slower cooling rate (< 20C/hour) attempted to improve microyield. Original microyield was 61 MPa. After heat treatment there was no significant change:

X1 = 63 MPa	Z1 = 57 MPa
X2 = 64 MPa	Z2 = 63 MPa
X3 = 59 MPa	Z3 = 63 MPa

Heat Treating Issue

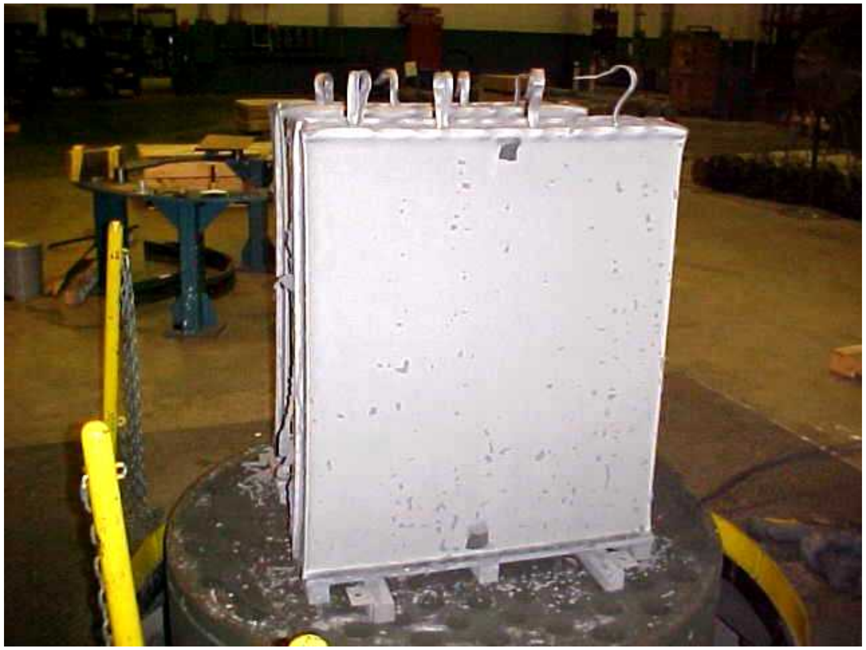
- Material also processed to simulate expected heat treatments during machining to make sure other properties are not degraded:

Property	Original Results	Results after Heat Treatment
Yield Strength, MPa (X/Z)	576/582	579/567
Ultimate Strength, MPa (X/Z)	493/495	487/483
Elongation (X/Z)	3.8%/4.0%	4.2%/3.5%
Microyield, MPa	57/64	58.6

- Material was procured to vendor specification which includes microyield. However, microyield is not an issue for an optical bench.

Current Status

- I-220H has been successfully HIPed, heat treated, and is being machined.

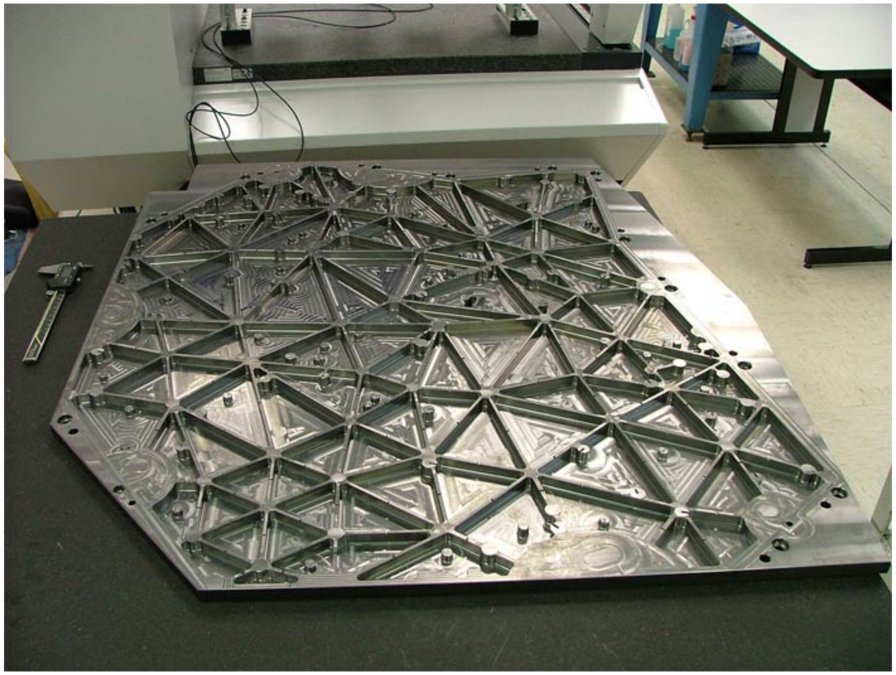


I-220H After HIP

I-220H Heat Treated and Machined to Rough Shape

Current Status

I-220H Set up for Machining



I-220H After Rough Machining

Conclusion

- I-220H beryllium chosen for the optical bench on NIRCam.
- Trade studies performed to pick the best materials and construction methods.
- Adhesively bonded, rib sandwich structure was selected.
- Adhesive and surface preparation qualified to survive launch loads and cryogenic operational temperatures.
- Minor design issues of reworkability and fracture toughness were encountered and overcome.
- Minor manufacturing issue of heat treating and micro-yield strength was dealt with.

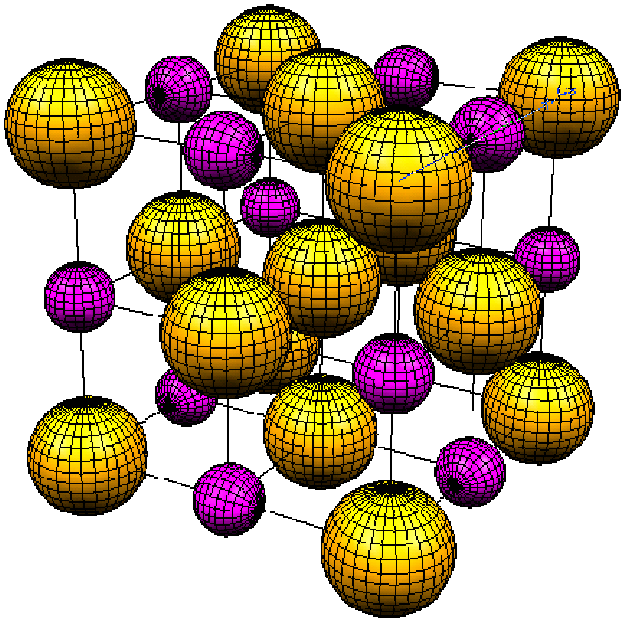
Lithium Fluoride material properties as applied on the NIRCam instrument

Todd Kvamme
Lockheed Martin Advanced Technology Center
Palo Alto, California

LiF General Overview

Lithium Fluoride:

- Crystal Structure: Cubic FCC (NaCl)
- Density: 2.64 gm/cm^3
- CTE at 300K: 37 ppm/K
- Cleavage: (100)
- Anisotropic

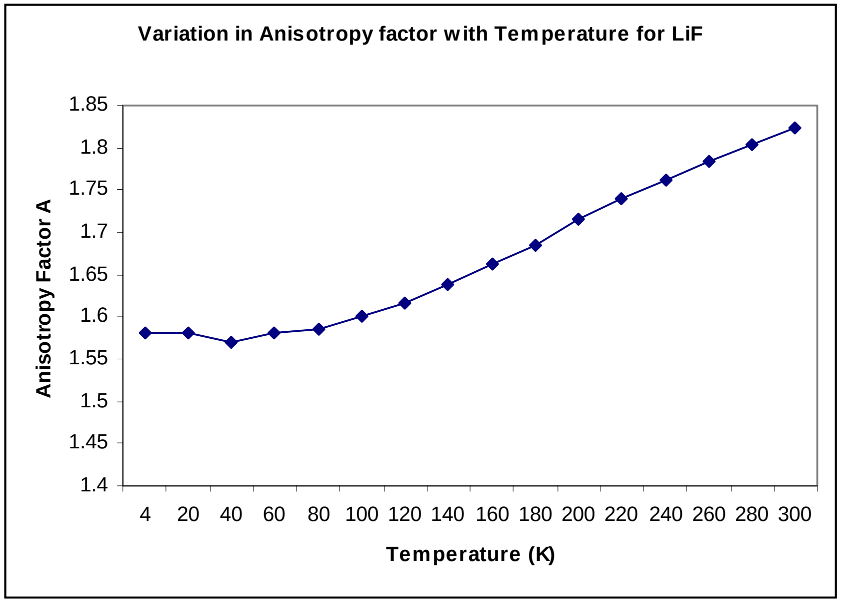


- Grown via Bridgman-Stockbarger method in vacuum (for best quality)
- A soft material in its pure state, LiF will deform plastically under relatively low load due to dislocation movement in the material
- It can be hardened by way of exposure to radiation (not an option optically due to color center generation) or doping with Mg (unknown optical effect)

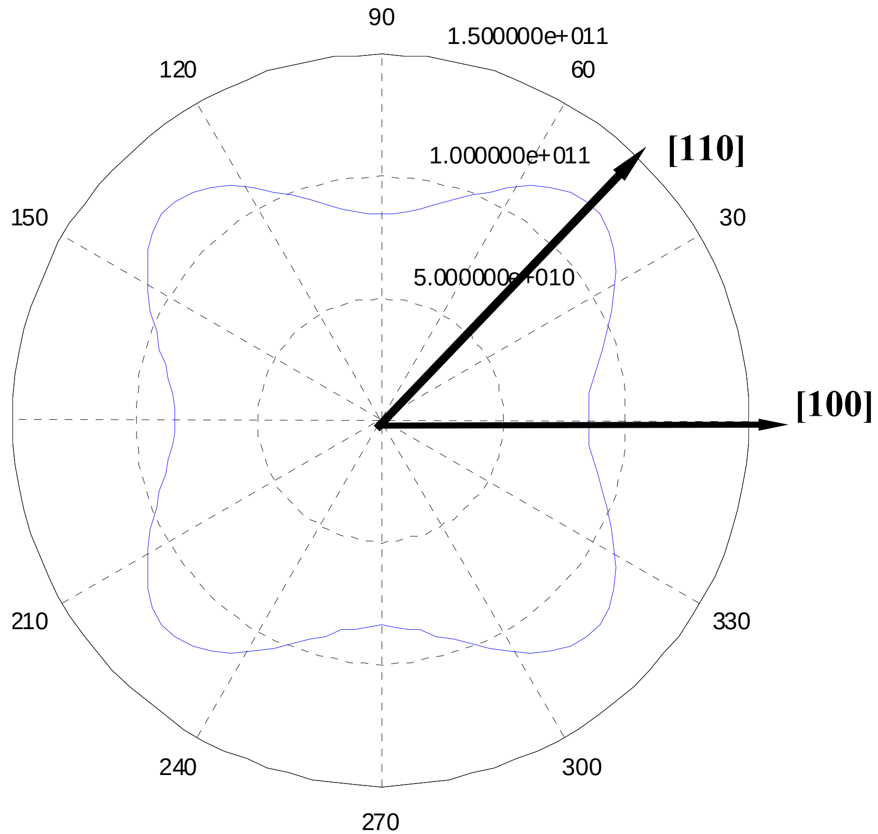
Anisotropy

- LiF is not isotropic. Several of its properties vary with crystal direction

$$A = 2c_{44}/c_{11}-c_{12}$$



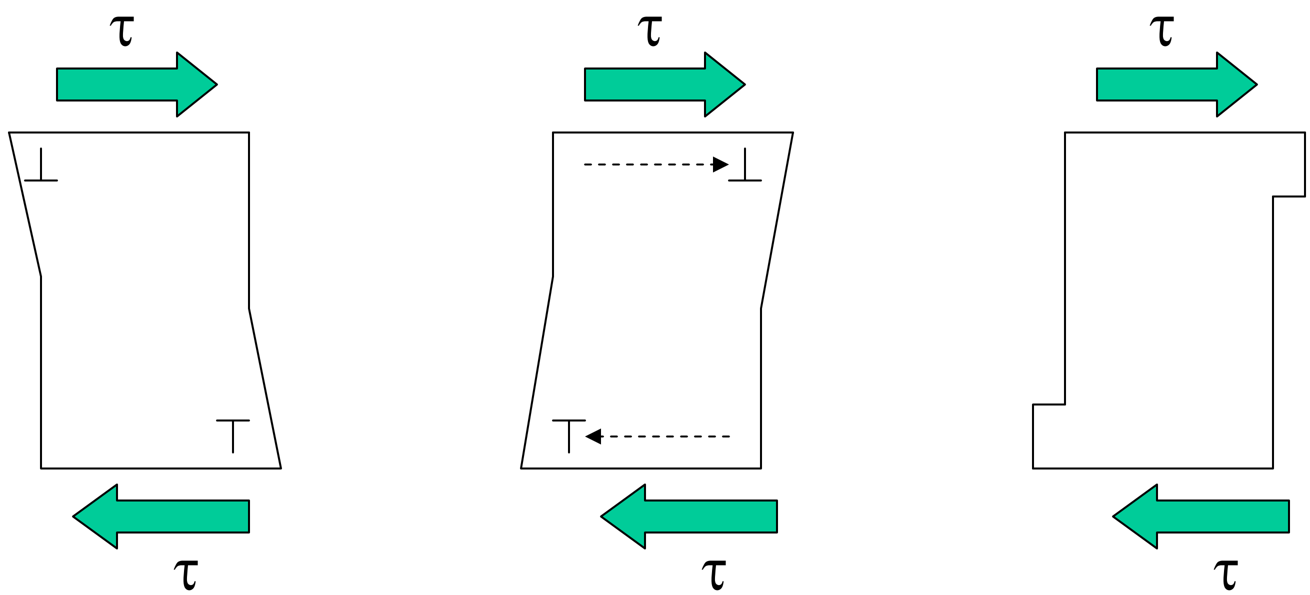
Anisotropy as a function of temperature for LiF



Variation of elastic modulus in Pa with crystallographic loading direction for LiF

Dislocations & Plasticity

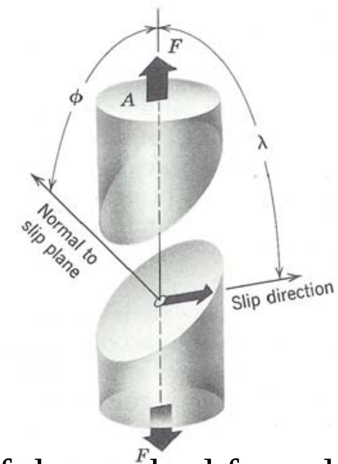
- This is a broad topic
- Crystals can behave in a brittle fashion if inter-atomic forces are strong
- If these forces are weak however, edge and screw dislocations in a material can migrate.



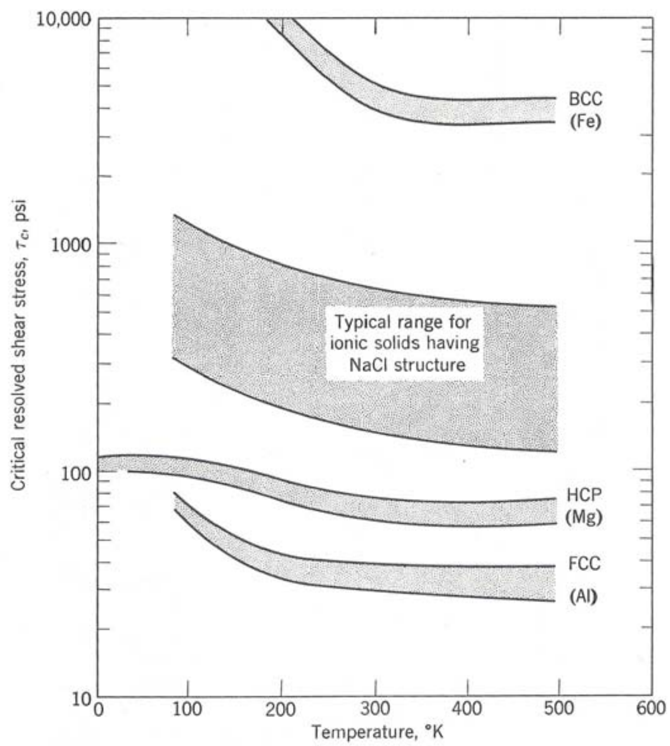
Edge dislocation motion under a shear load. Adapted from [6]

Resolved Critical Shear Stress

- Resolved shear stress given as:
  $\tau = (F \cos \lambda)/(A/\cos \phi)$



Schematic of the method for calculating resolved shear stress (from [6])



Temperature variation of critical resolved shear stress for several classes of crystalline materials (from [6]).

- Critical resolved shear stress, τ_c, defined as the stress which causes material to slip
- Values from literature suggest a τ_c of ~5MPa for LiF. We are using 2MPa max on NIRCam.
- Ultimately, τ_c will be highly dependent of processing and surface finish

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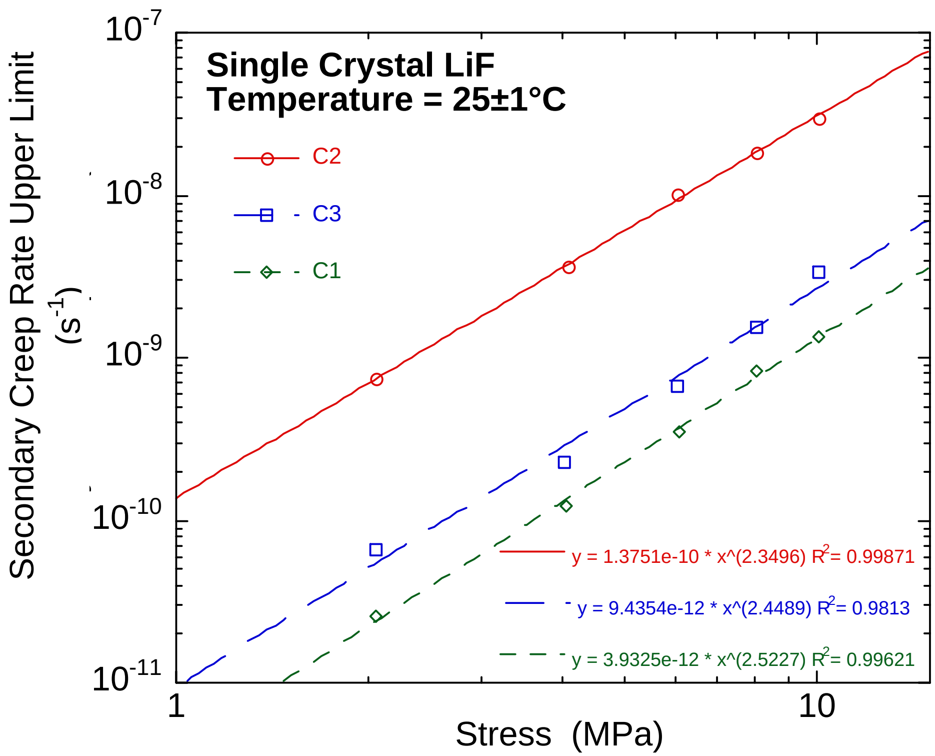
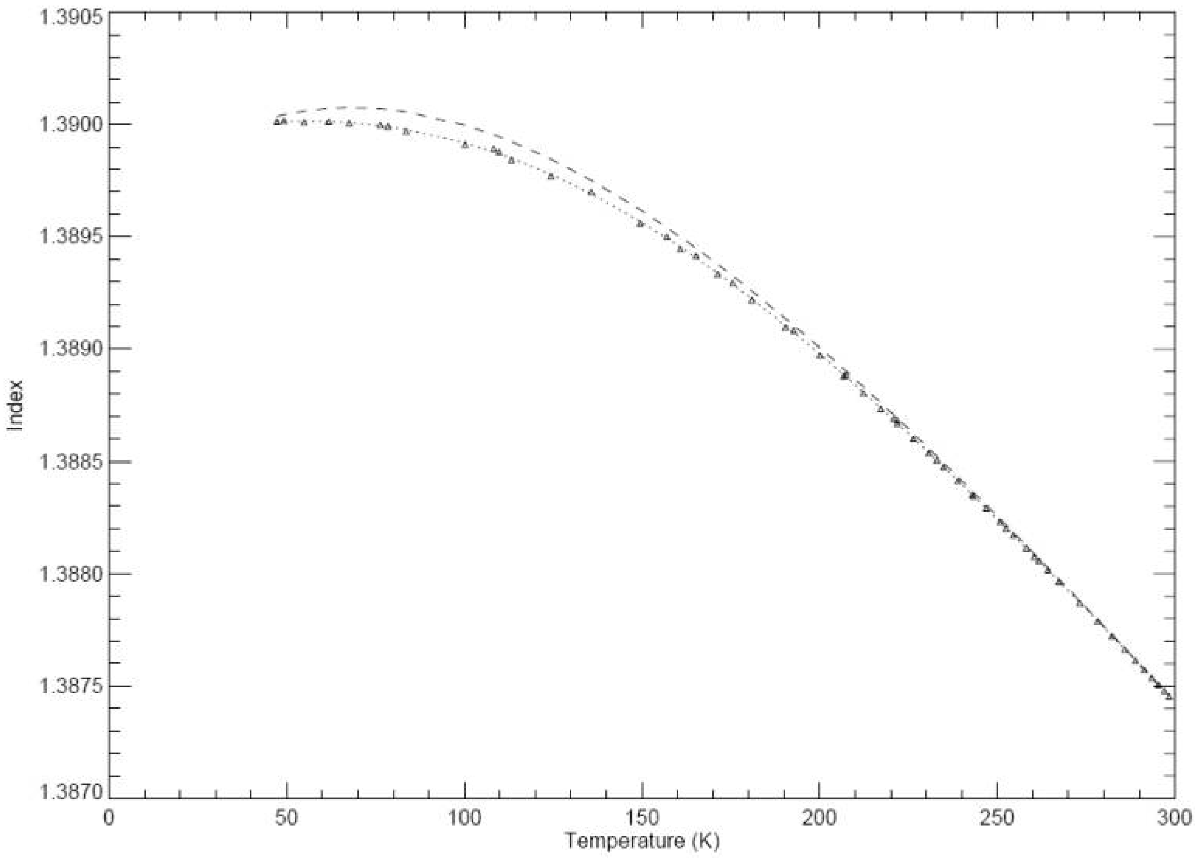
Creep

- 10mm diameter by 20mm long test specimens under constant load
- These specimens were not polished on their cylindrical radii
- Secondary creep rate is an upper limit, and was decreasing. Values are still large however.



Creep rate after six hours as a function of constant load in LiF oriented specimens. This rate was considered a conservative upper limit for the secondary creep rate

Index of Refraction



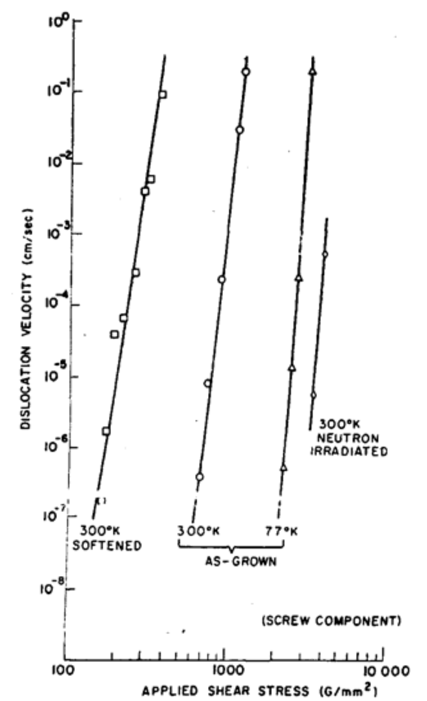
Variation of refraction index over temperature for LiF at a wavelength of 1μm (the dotted line represent the Tropf model, the solid line is measured data) from Leviton & Frye

Thermal Characteristics

- Thermal shock defined as: $R' = \dfrac{S(1-\nu)k}{\alpha E}$
- Boule processing is important and can have a large effect on material critical shear stress.

	Expansion Coefficient α E-6/K	Young's Modulus E GPa	Thermal Conductivity k W/mK	Poisson's Ratio ν	Mean Strength S Mpa	R' W/m
LiF	37.0	85	14.2	0.27	11	37
BaF2	17.0	65	7.1	0.31	27	120
CaF2 (Hot Forged)	18.9	76	10	0.28	55	276
Ge	6.1	103	59	0.28	90	6085
Sapphire	5.3	344	36	0.27	300	4324
ZnSe	7.6	70	16	0.28	50	1083
ZnS (standard)	7.0	74	19	0.29	100	2604

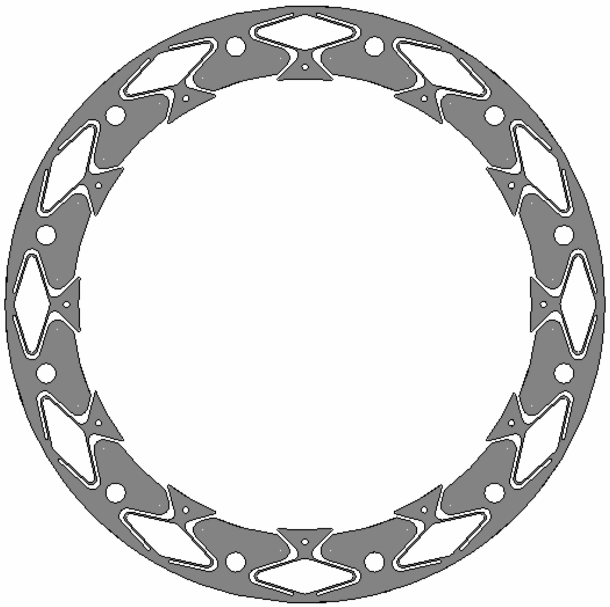
Hasselman figures of merit for thermal shock. E for LiF is in the 100 direction. [12]



Variation in critical shear stress for equivalent dislocation velocity in hard and soft LiF crystals (from [3])

Mounting

- This material demands a unique mount for space launch.
- The stresses in the material needed to be kept to a minimum (below our 2MPa limit) and accommodate centration requirements
- For more info, see paper 5877-33 “A low stress cryogenic mount for space-borne lithium fluoride optics“.



The diamond flexure lens cell design and manufactured titanium lens cell hub

Summary

- LiF is a single crystal material with non-scalar mechanical properties. It is anisotropic.
- LiF deforms plastically under load. These deformations can be macroscopic in scale.
- For mounting purposes it is important to know what the resolved stress along the slip planes of the material are.
- Material processing and finishing have a direct impact on critical shear stress.

A low stress cryogenic mount for space-borne lithium fluoride optics

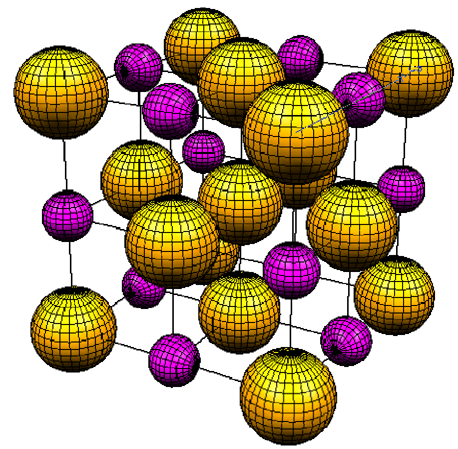
SPIE Annual Meeting
San Diego
August 4, 2005

E. Todd Kvamme
Lockheed Martin Advanced Technology Center
Palo Alto, California, USA

Lithium Fluoride General Overview (1)

Lithium Fluoride:

- Crystal Structure: Cubic FCC
- Density: 2.64 gm/cm^3
- CTE at 300K: 37 ppm/K
- Cleavage: (100)
- Anisotropic



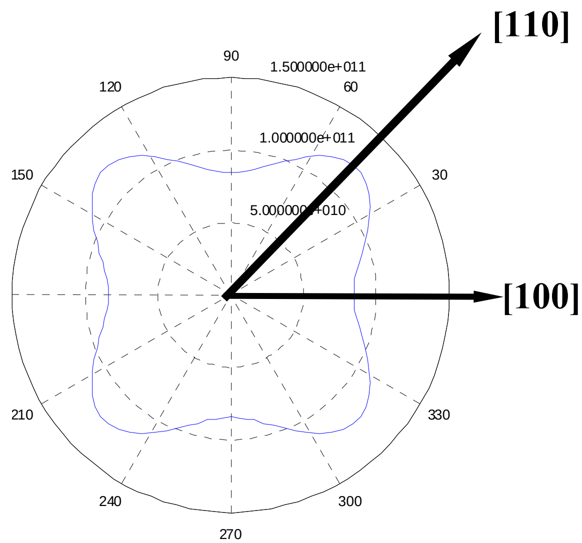
- A soft material in it's pure state, LiF will deform plastically under relatively low load due to dislocation movement in the material
- It can be hardened by way of exposure to radiation (not an option optically due to color center generation) or doping with Mg (unknown optical effect - investigating)

Lithium Fluoride General Overview (2)

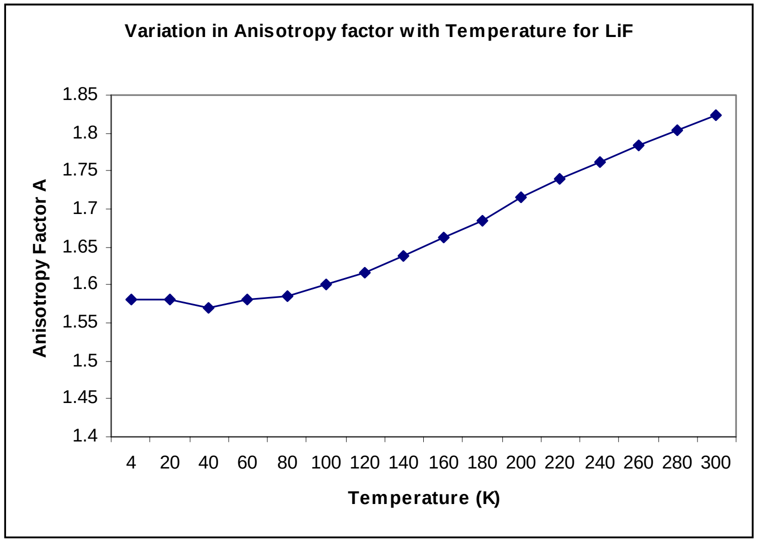
- LiF is fully defined by 3 compliance/ stiffness matrix values (c_{11}, c_{12}, c_{44} or s_{11}, s_{12}, s_{44}), but moduli and Poisson ratio will vary significantly depending on the orientation of the crystal
- LiF can be grown in air or vacuum. The material is slightly hydroscopic (0.27g/100g of H_2O).

Anisotropy Factor given by:

$$\frac{2\,c_{44}}{c_{11} - c_{12}}$$



Variation of elastic modulus in Pa with crystallographic loading direction for LiF



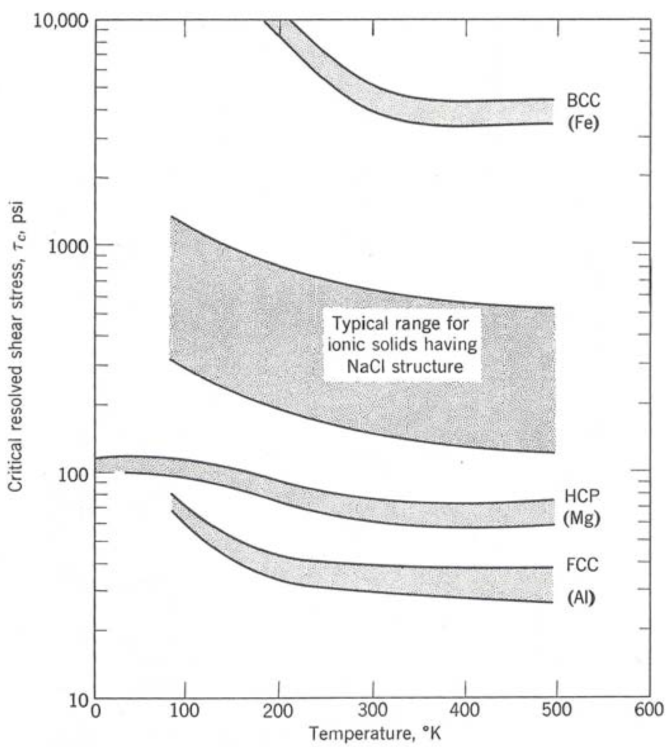
Anisotropy as a function of temperature for LiF

LiF is a tricky material to mount due to low yield stress and "plastic" behavior.

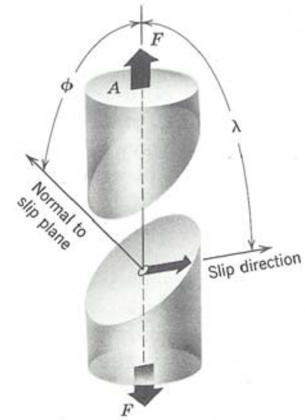
Resolved Critical Shear Stress

- Resolved shear stress given as:

  $\tau = (F\cos\lambda)/(A/\cos\phi)$



Temperature variation of critical resolved shear stress for several classes of crystalline materials (from [6]).

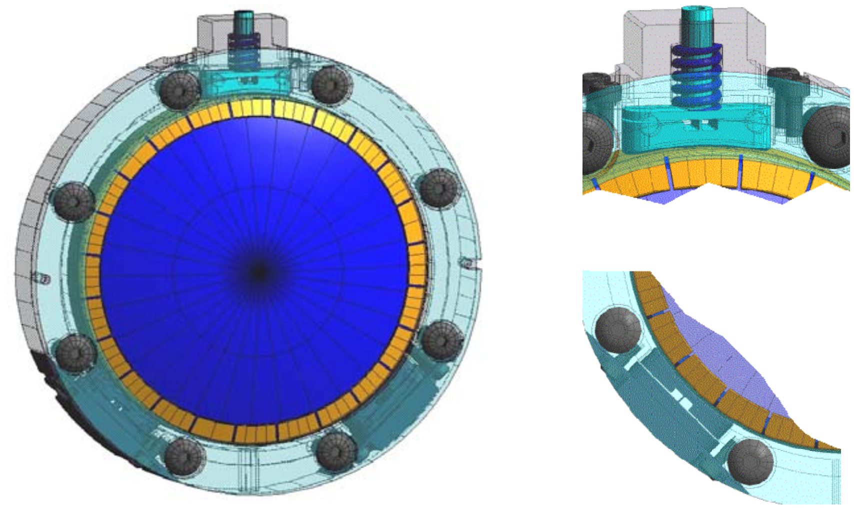


Schematic of the method for calculating resolved shear stress (from [6])

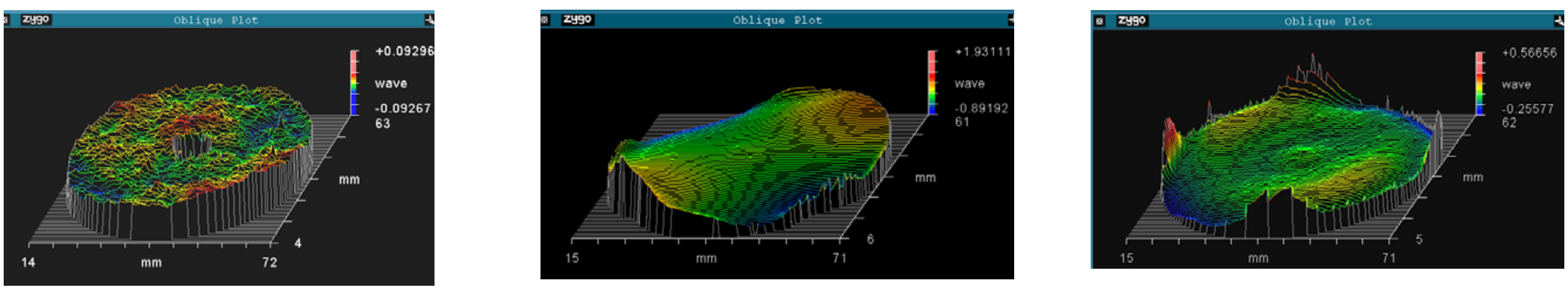
- Critical resolved shear stress, τ_c, defined as the stress which causes material to slip
- Values from literature suggest a τ_c of ~5MPa for LiF. We are using 2MPa max on NIRCam.
- Ultimately, τ_c will be highly dependent of processing and surface finish

Original Mount

- **Three point mount with 1 DOF flexures at each mounting point**
- **Axial seating accomplished with a multi-fingered flexure**



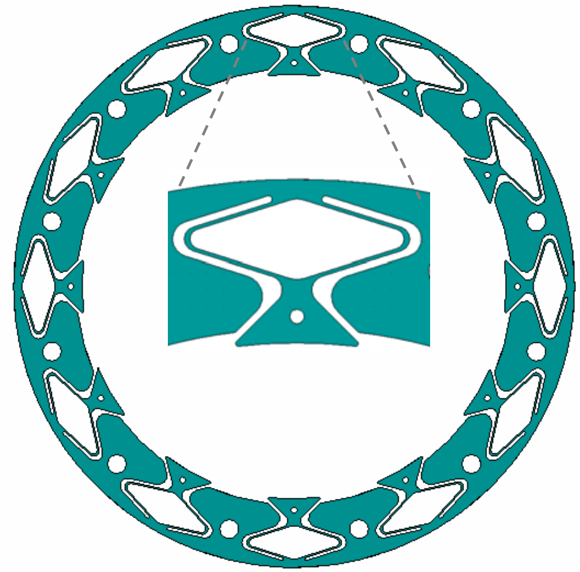
Original 3 pad flexure design at left. At right, the spring loaded plunger and flexure pad (2places)



In the left image, a ZYGO surface map of the LiF optic as received by the vendor. Total rms WFE = 0.012 waves at λ=633nm; 0.186 wave P-V. The middle image shows the optic after having been mounted, and then removed from the mount. Clearly there is already distortion evident in the optic with rms WFE = 0.073 wave; 0.822 P-V. The right image shows the optic un-mounted after vibration. Many waves of distortion (off-scale) are evident at the radial mount points

Redesigned Mount – Diamond Flexure

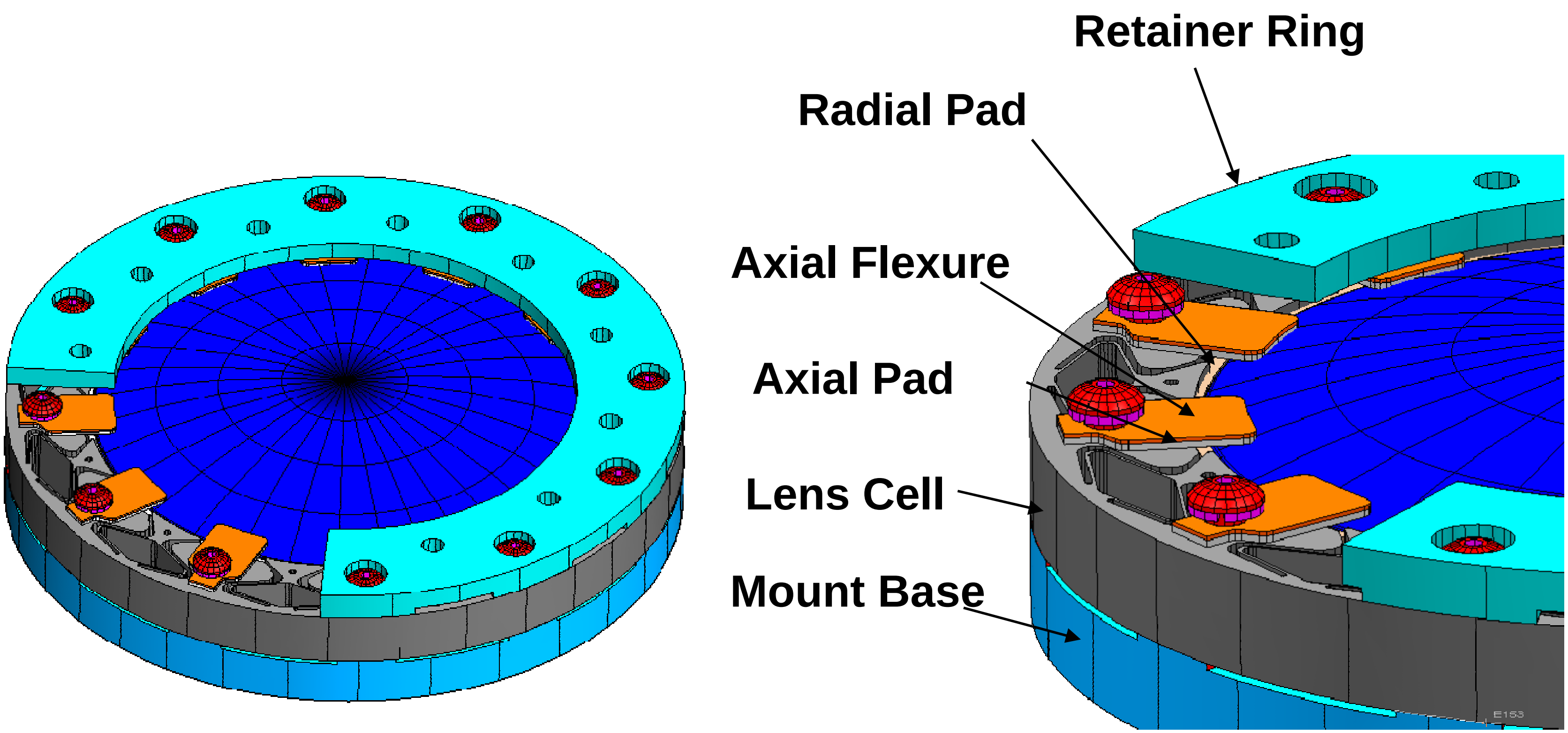
- 12 diamond shaped flexures in the radial direction
- Pad geometry altered from previous to avoid punch loads
- Compliant material (Neoflon) in between the Ti pads and the lens
- This design accommodates desire for



The diamond flexure lens cell design and manufactured titanium lens cell hub

Redesigned Mount - Assembly

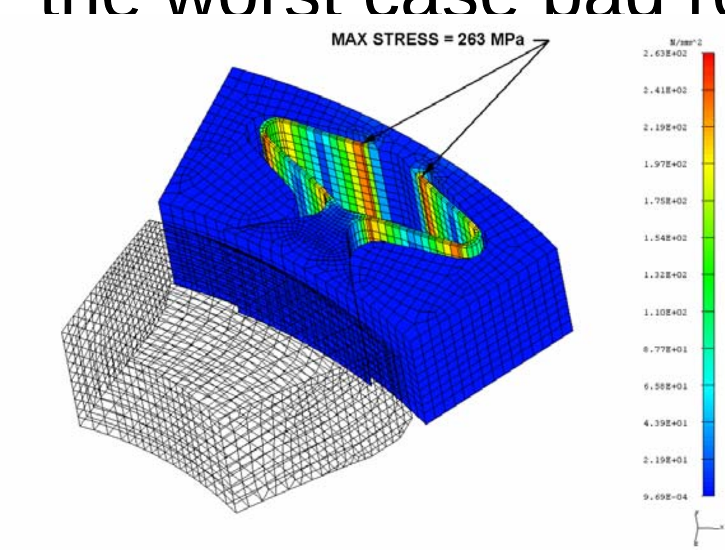
- **Axial pads are made of Ti-6Al-4V and act in 12 places**
- **Compliant material (Neoflon) between axial flexures and lens**
- **Retaining ring pre-loads the axial flexures into the lens**



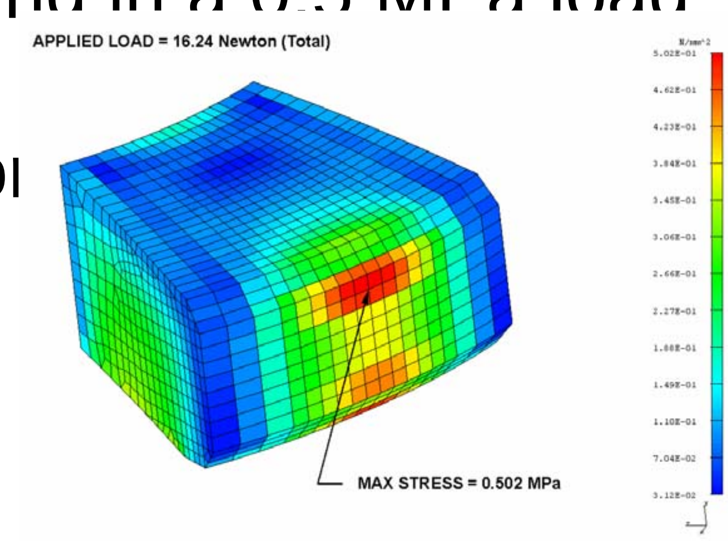
Lens cell cutaway and detail of axial and radial flexures and pads

Mechanical Analysis

- Lens mount analyzed to meet Qualification levels from the GEVS and mass acceleration curve from JWST requirements
- Worst case – 5 of 12 pads carrying load in the 54g launch environment. This gives 16.24N at the worst case pad resulting in a 0.5 MPa load
- ad fo



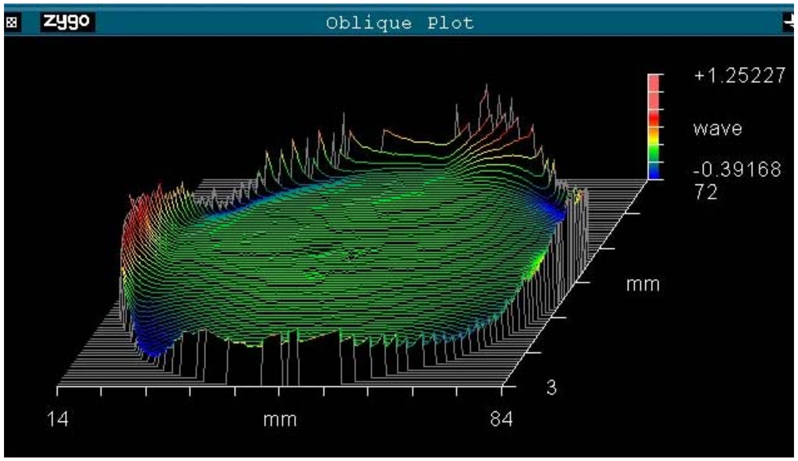
Titanium Flexure Maximum Stress due to Applied F = 16.24 Newtons

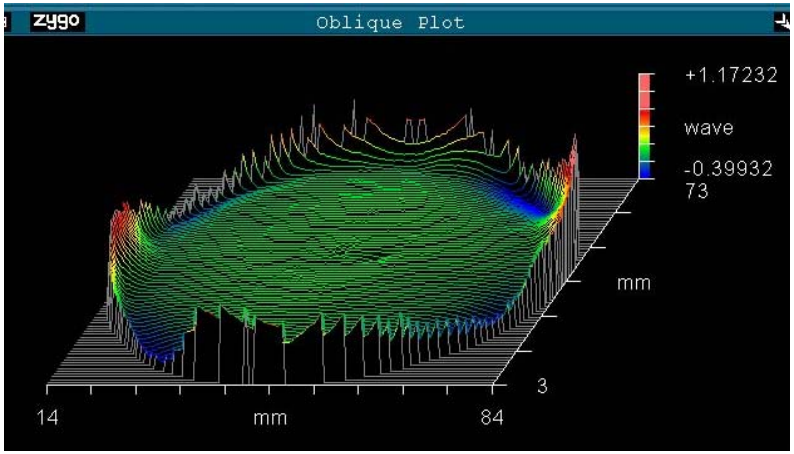


Lithium Fluoride Lens Max Stress due to Applied F = 16.24 Newtons

Vibration Testing

- **Vibe test was conducted in the mount to test for survivability.**
- **Mount shaken to GEVS qualification values**
- **Mount did not distort the optic**





Comparison of the surface maps for the LiF optic pre and post vibration in the 12 - pad diamond flexure mount. The pre-vibration plot is on the right; rms WFE was 0.128 waves, 1.644 waves P-V (λ=633nm). The post vibration plot is on the right; rms WFE value was 0.134 waves, 1.572 P-V.

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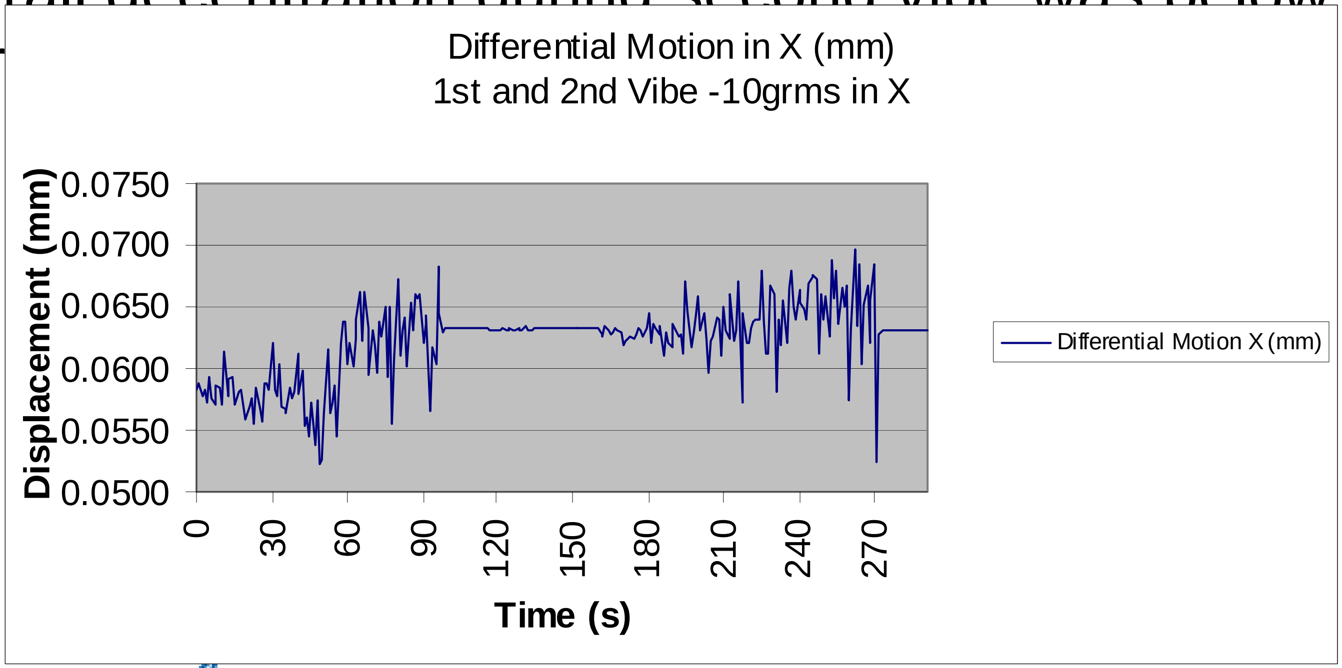
Centration Testing - Vibration

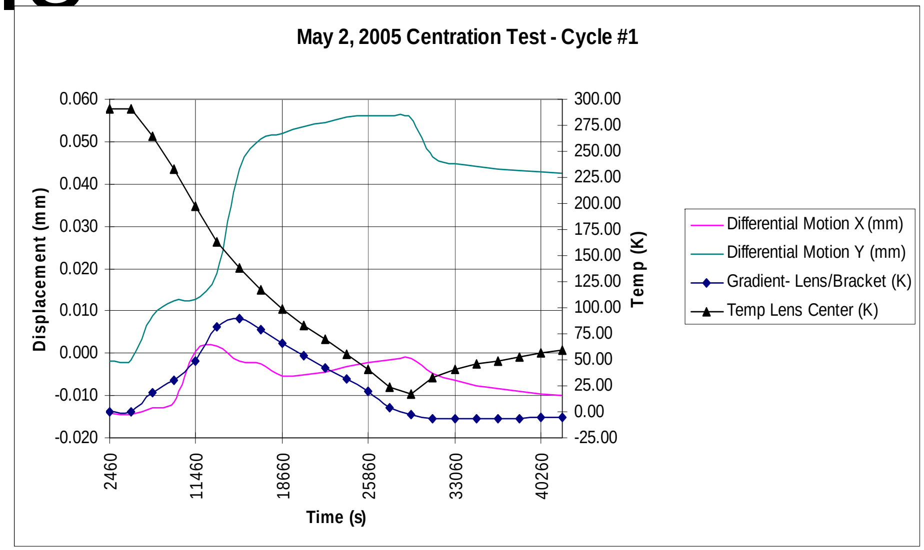
- Key requirement for the mount was centration
- Test set-up using differential KAMAN sensors was used to determine lens motion in the cell during vibe
- Dummy aluminum lens was utilized
- Vibration served to seat the optic
- Overall decentration during second vibe was below 1 micr

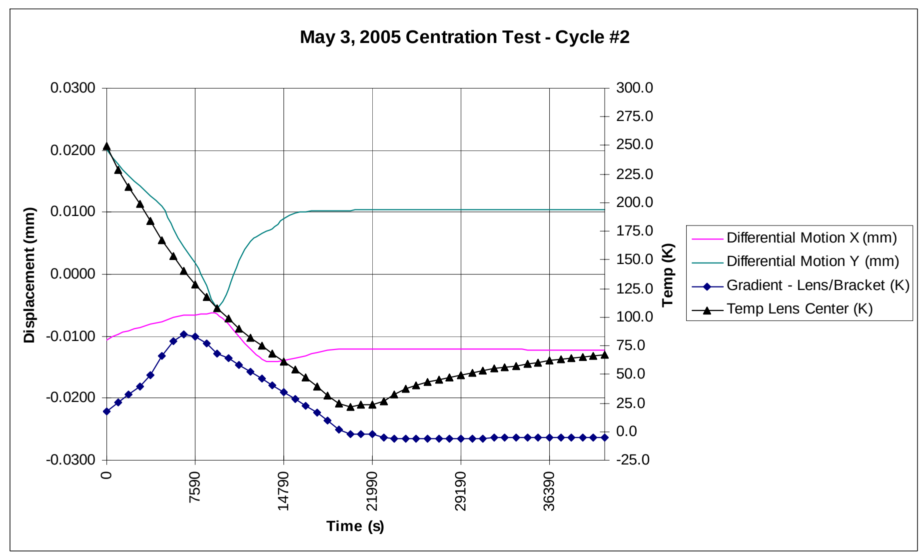


De-centration results for vibration of the dummy lens cell assembly

Centration Testing – Cryo-cycle

- **Lens was disassembled and reassembled for this test. No vibration took place prior to this testing**
- **First Cryo-cycle showed significant movement in one axis of the lens**
- **Most of the movement took place at maximum system gradient**
- **Second cycle showed less lens motion than the first**
- **Cryo-cycling had a similar effect to vibration in settling the lens into the mount**
- **Centration still looks good with second cycle de-center at ~25 microns absolute and 10 microns total**





First and Second Cryo-cycle data

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Summary

- LiF is a difficult material to mount.
- Special attention needs to be paid to crystal behavior when designing a mount for LiF.
- The 12 pad diamond flexure mount held the LiF material during a launch vibration environment without causing optical degradation.
- The 12 pad diamond flexure kept a representative lens dummy centered during vibration and cryo-cycle.

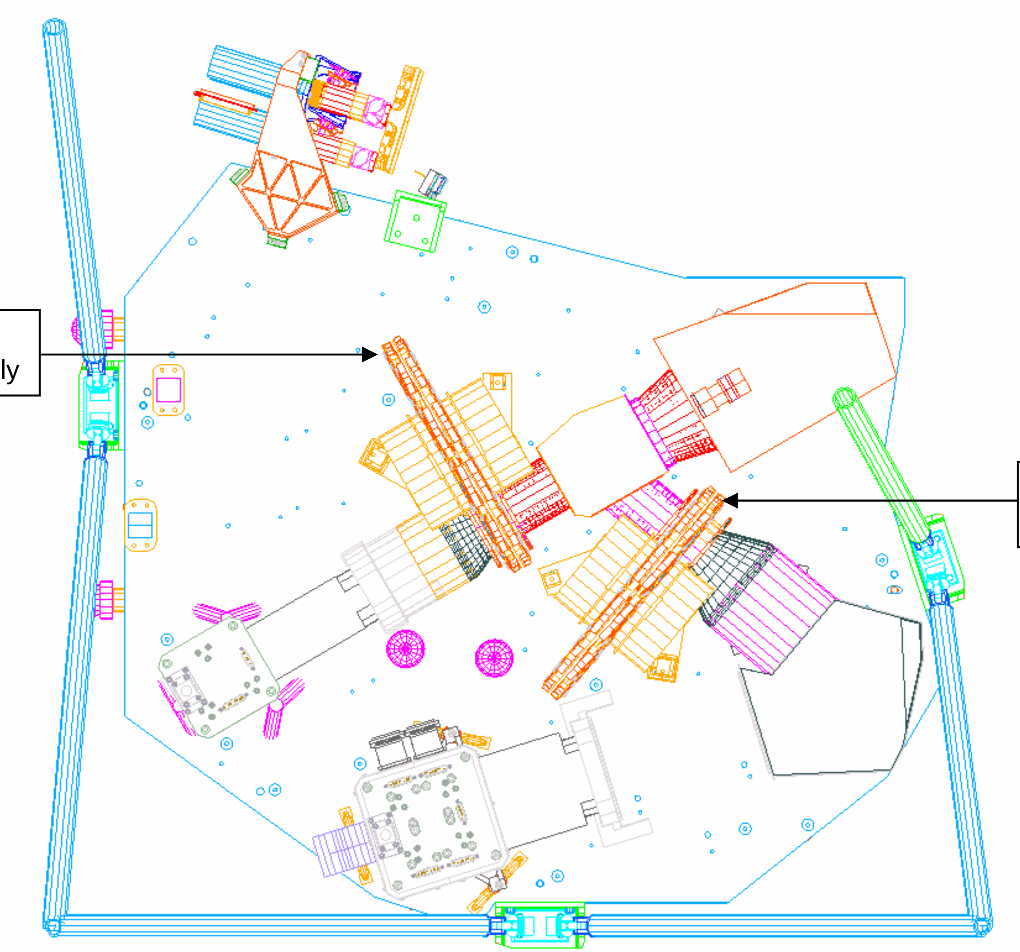
NIRCam Filter Wheel Assembly

Sean McCully

Lockheed Martin Advanced Technology Center
Palo Alto, California

Overview

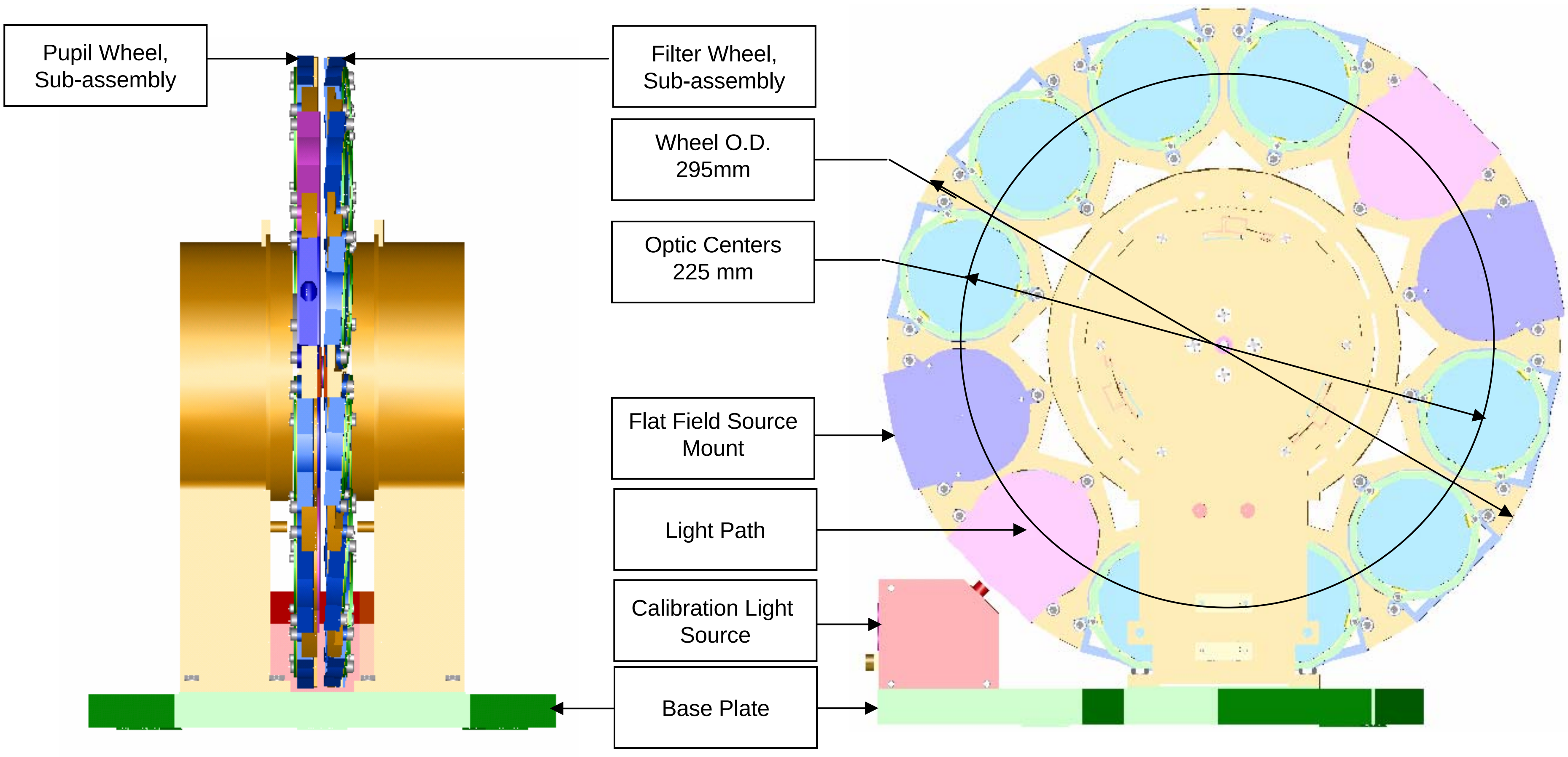
Long Wave Length Filter Wheel Assembly



Short Wave Length Filter Wheel Assembly

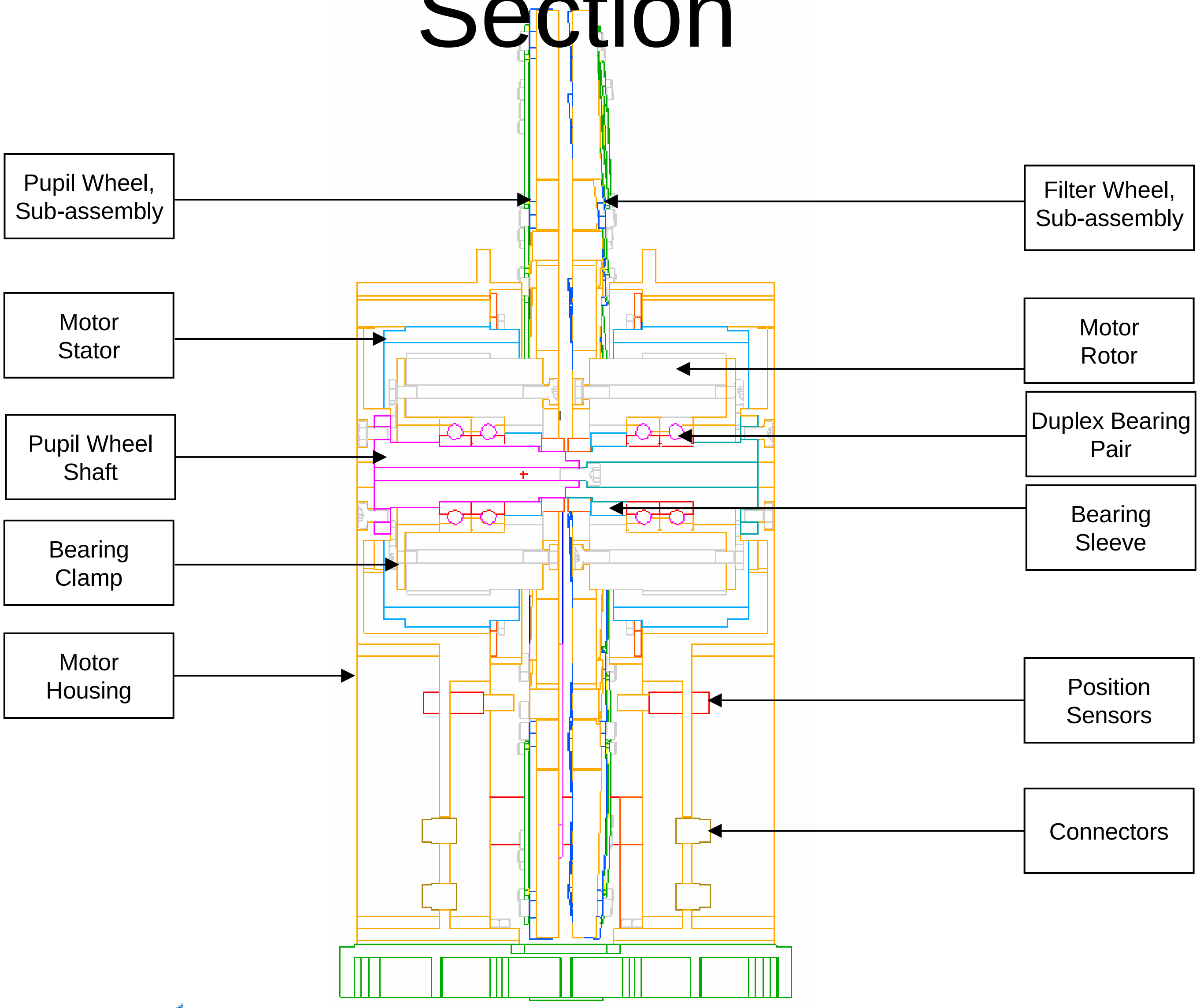
Two Optical Bench Assemblies Mounted Back to Back

Filter Wheel Assembly



Shrouds not shown for clarity

Filter Wheel Assembly Cross Section



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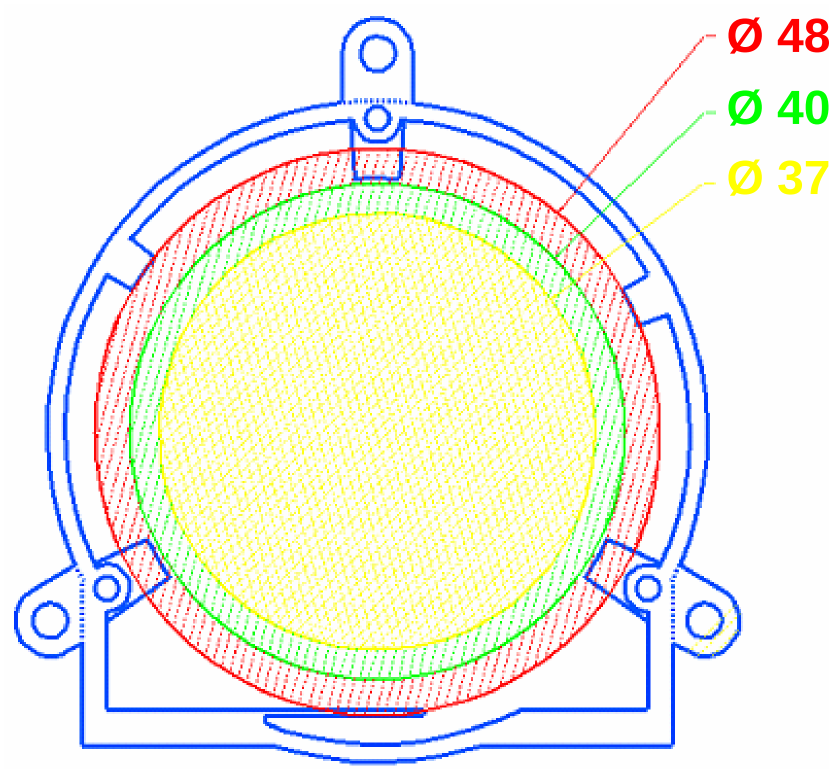
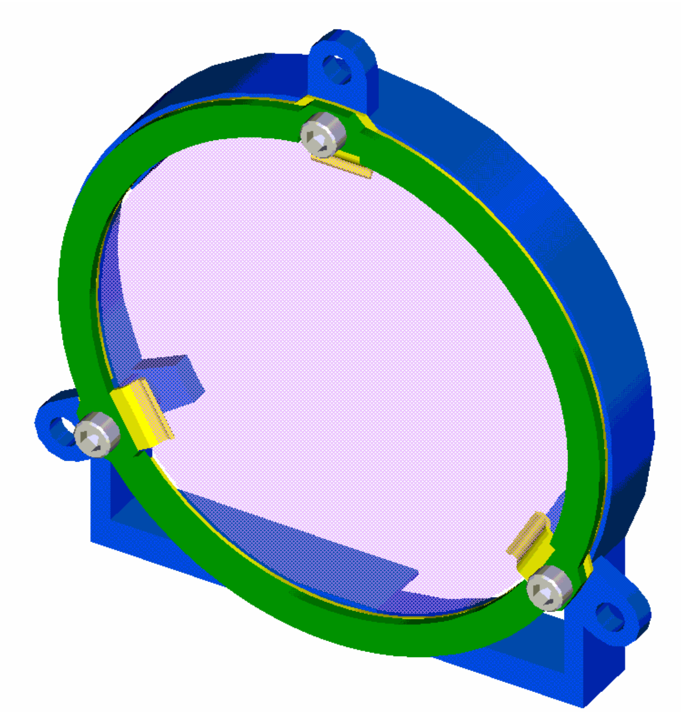
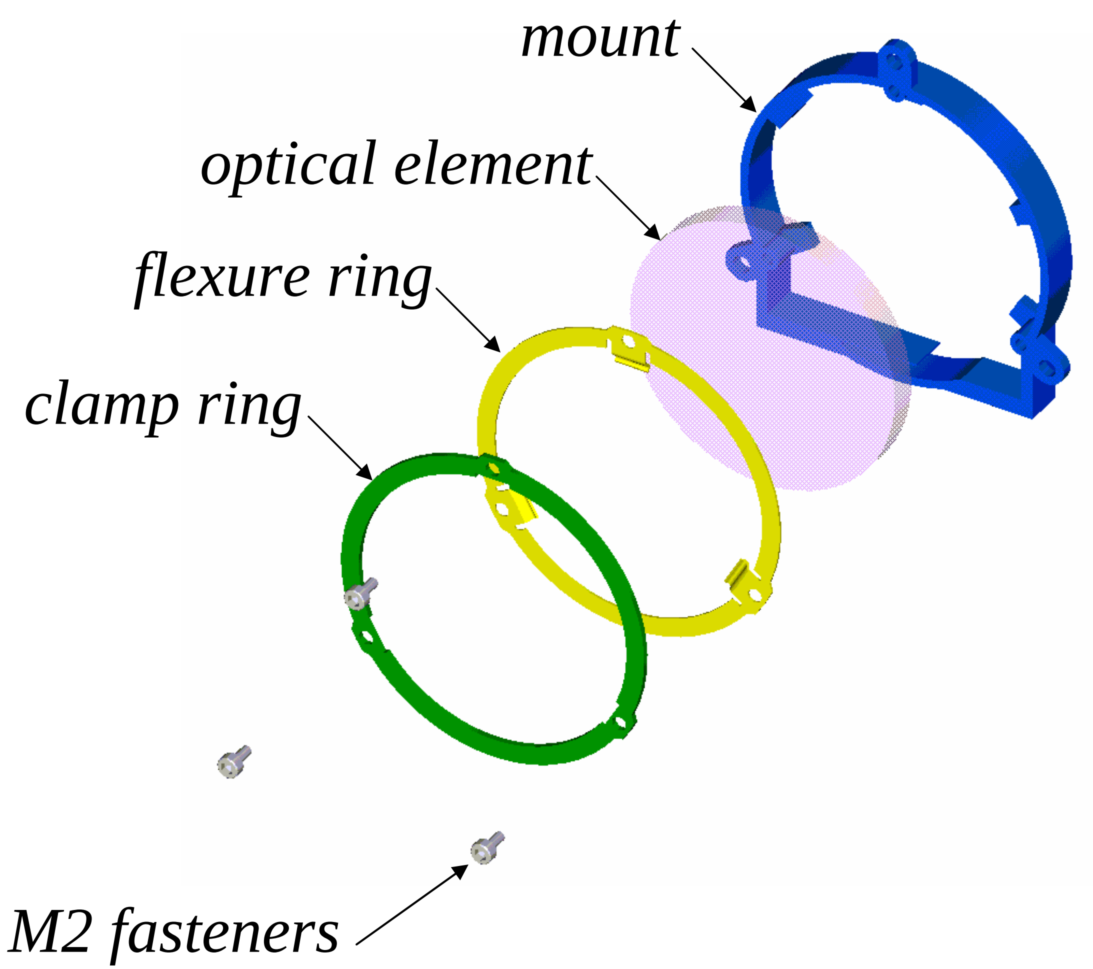
Clear Aperture Allocation

Description	Diameter	Units
Beam footprint	37	mm
Integration and Test Error Budget	3	mm
Filter Wheel Assembly Requirement	**40**	**mm**
Filter Wheel Assembly Error Budget	2	mm
Mechanical Mount	6	mm
Total Element OD	**48**	**mm**

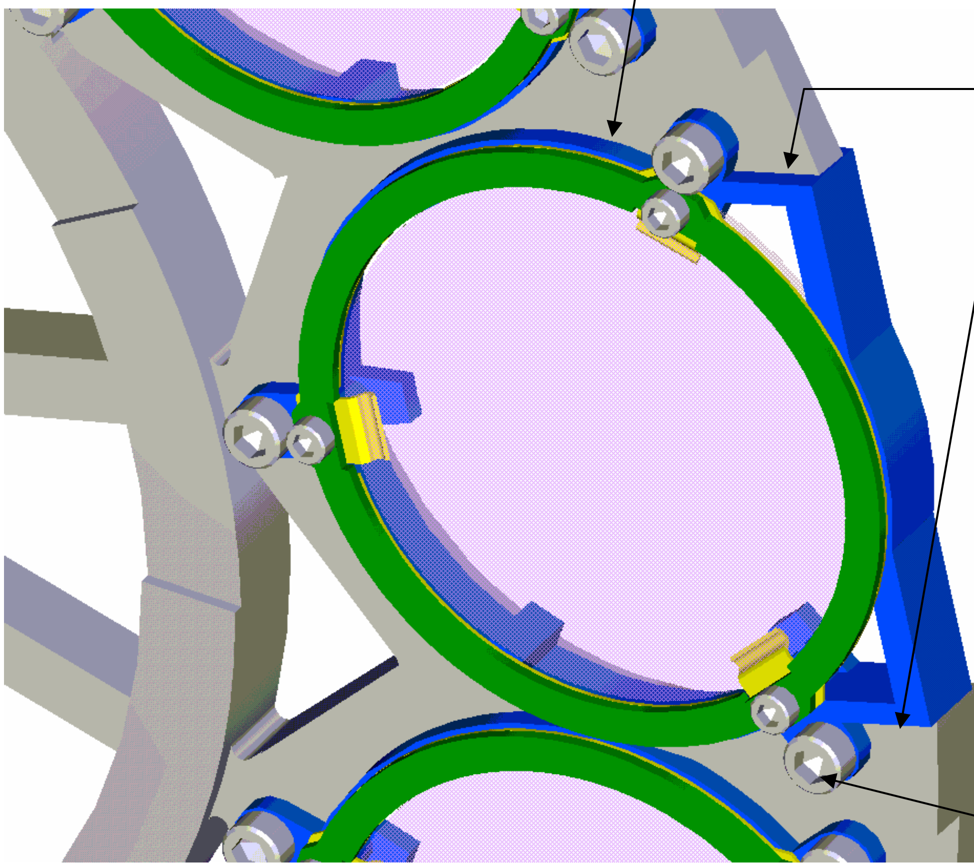


Element Mount Assembly



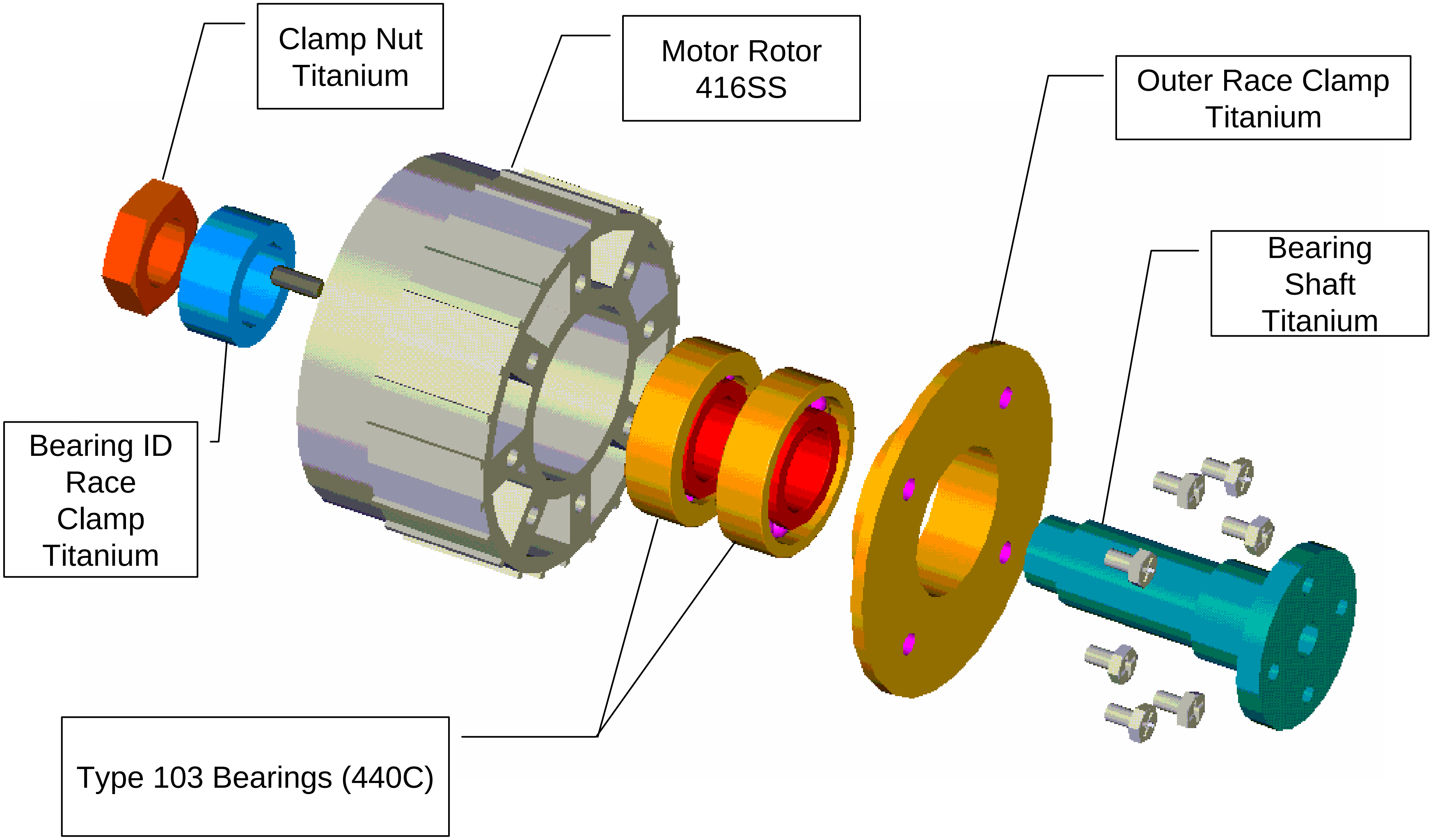


Element Mount Installation



Filter Wheel Sub-Assembly shown

FWA Bearing Assembly



NIRCam Pupil Imaging Lens mechanism and optical design

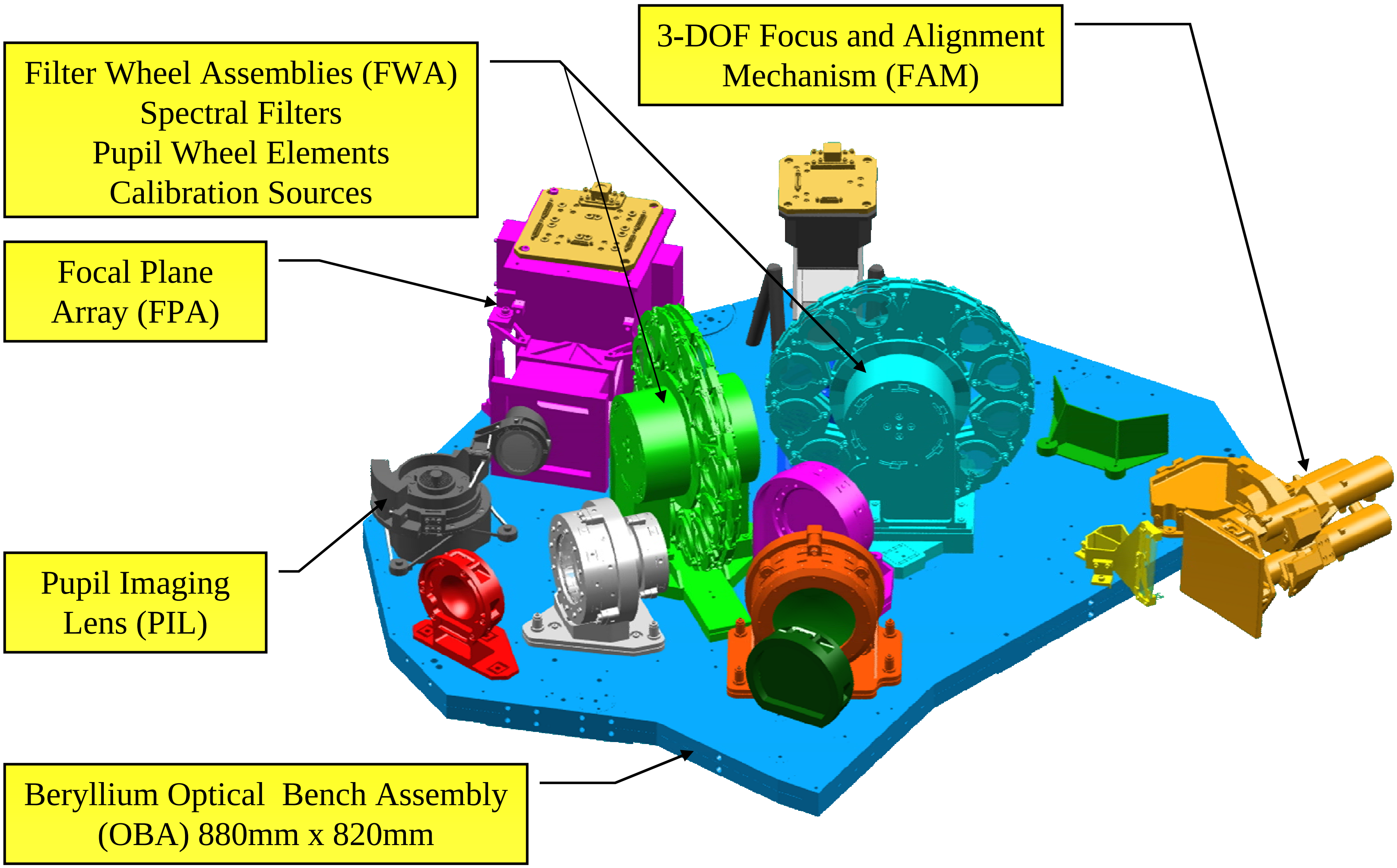
Charles S. Clark and Thomas Jamieson

Lockheed Martin Advanced Technology Center
Palo Alto, California

PIL Assembly Function

- The PIL Assembly
  - Rotates Pupil Imaging Optics into the Shortwave Beam of NIRCam Instrument
  - The image produced by the PIL will be used for:
    - Characterizing the NIRCam pupil to support phase retrieval processing
    - Characterizing the DHS to OTE image alignment
    - Alignment of the OTE exit pupil to the NIRCam pupil

Location of PIL within NIRCam



PIL Mechanism Overview

PIL Optic Housing With Alignment Adjustability Titanium

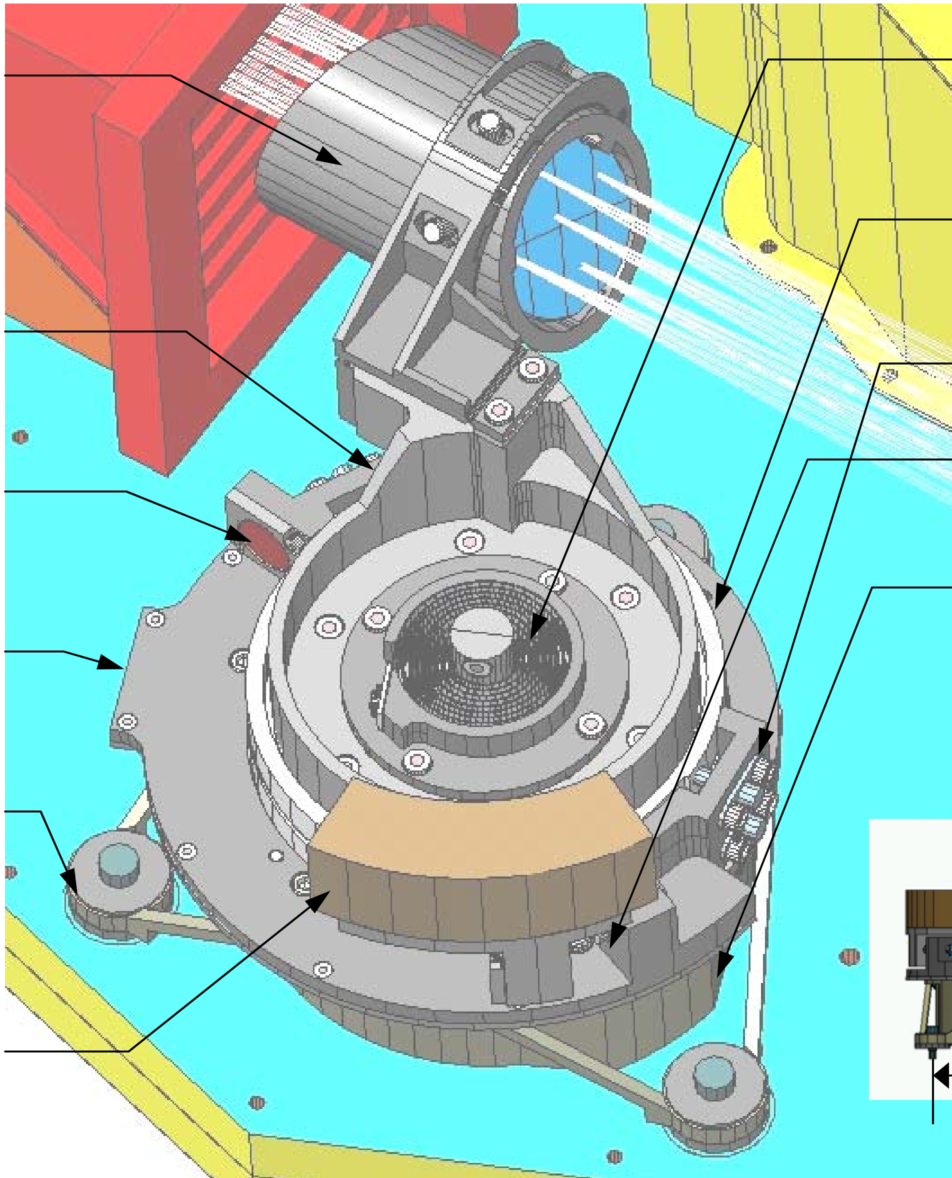
Actuator Arm Titanium

Stowage Stop Magnets

Wire Harness Retainer/Strain Relief

PIL Bipod Mounts to OBA with Locking Cams

Counter Weight Tungsten



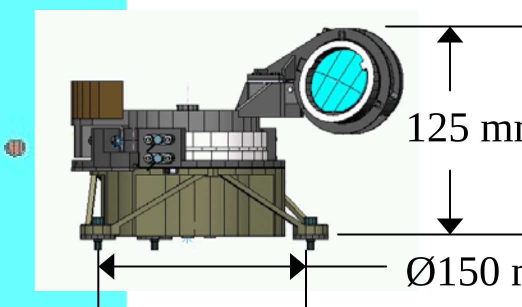
Fail-Safe Mechanism Spring Return

Position Sensor Track

Position Sensors

Rotation Hard Stop

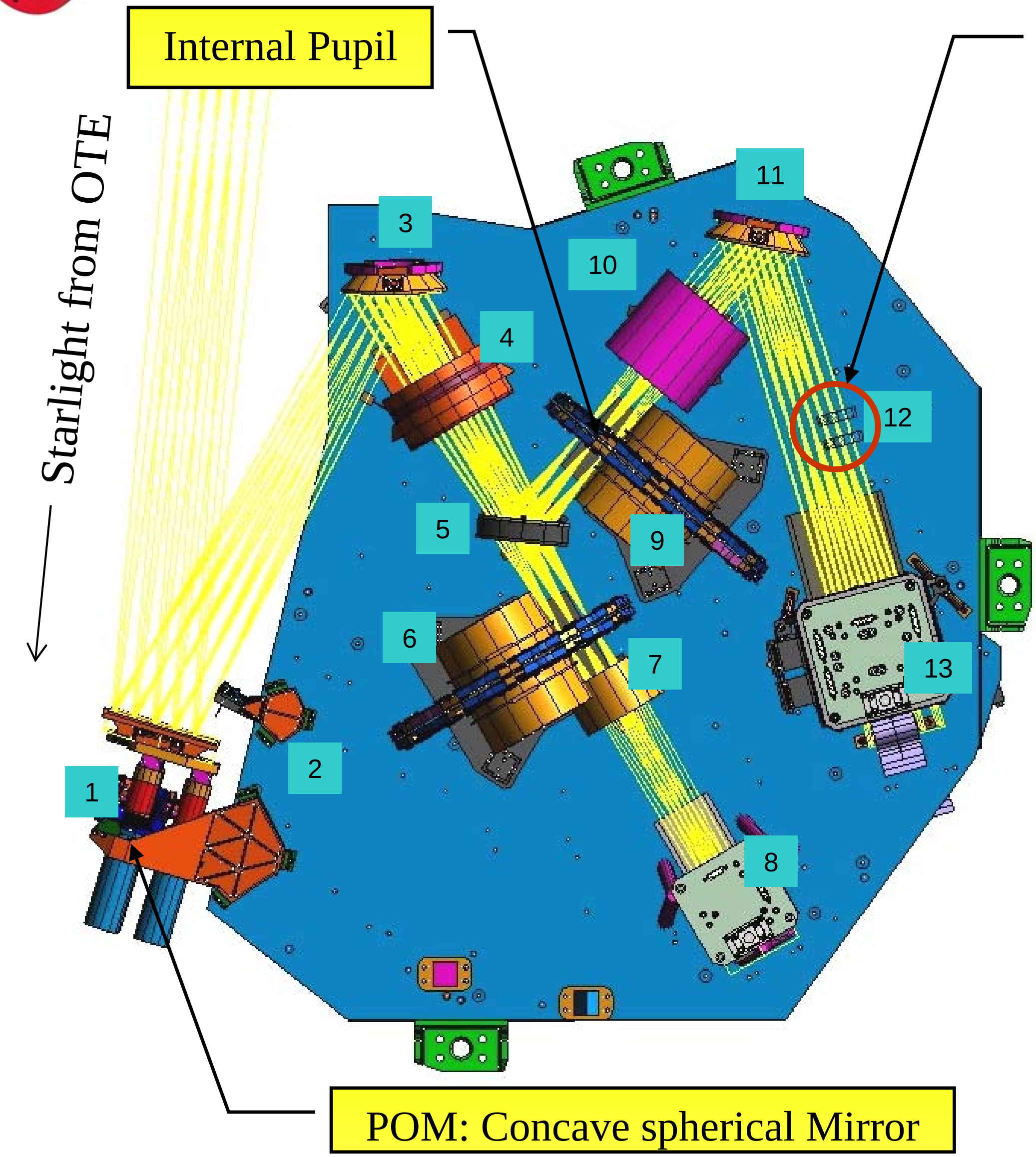
Actuator Housing Titanium Actuator: 3Phase BLDC Motor



125 mm

Ø150 mm B.C.

NIRCam Optical Layout



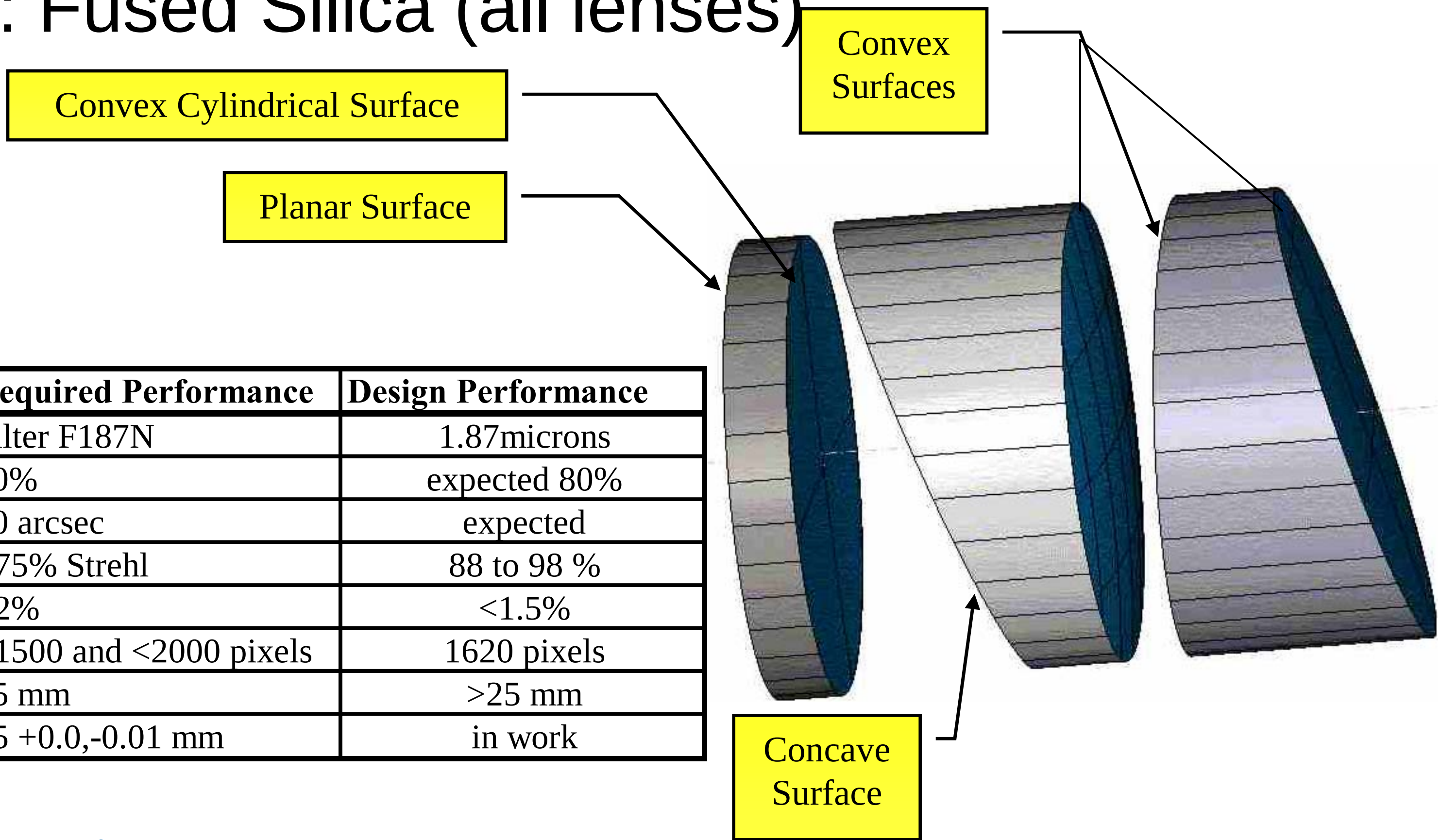
1	Pick-Off Mirror Assembly
2	Coronagraph
3	First Fold Mirror
4	Collimator Lens Group
5	Dichroic Beamsplitter
6	Long Wave Filter Wheel Assembly
7	Long Wave Camera Lens Group
8	Long Wave Focal Plane Housing
9	Short Wave Filter Wheel Assembly
10	Short Wave Camera Lens Group
11	Short Wave Fold Mirror
12	**Pupil Imaging Lens**
13	Short Wave Focal Plane Housing
14	ICE Interface Panel
15	FPE Interface Panel

PIL Design Parameters

- PIL must image the primary mirror with a single star source within 10 arc-sec half-cone of the PIL bore sight
- The lens diameter(s) to be set by the size of the unvignetted field using the PIL as aperture stop
- The PIL shall place the primary mirror image on a single-chip-array (SCA), implies a magnification of 0.0041
- PIL optics to operate over a narrow waveband only (Filter F187N)
  - No chromatic correction is required
  - PIL will use Fused Silica material
- Field of view of the PIL optics is the primary mirror segments

New PIL Baseline Design

- The three lens system with two wedged spherical lenses and the one plano cylindrical lens
- Material: Fused Silica (all lenses)



Optic Requirement	Required Performance	Design Performance
Spectral band	Filter F187N	1.87microns
Transmission	80%	expected 80%
Boresight	10 arcsec	expected
Image Quality	>75% Strehl	88 to 98 %
Distortion	<2%	<1.5%
Image Size	>1500 and <2000 pixels	1620 pixels
Clear Aperture	25 mm	>25 mm
Physical size	35 +0.0,-0.01 mm	in work

Summary

- The PIL Assembly optical requirements called for a unique optical solution
- Three lens system with two wedged spherical lenses and the one plane cylinder lens meets requirements
- The PIL Assembly team is rapidly moving forward with manufacturing the PIL optical assembly

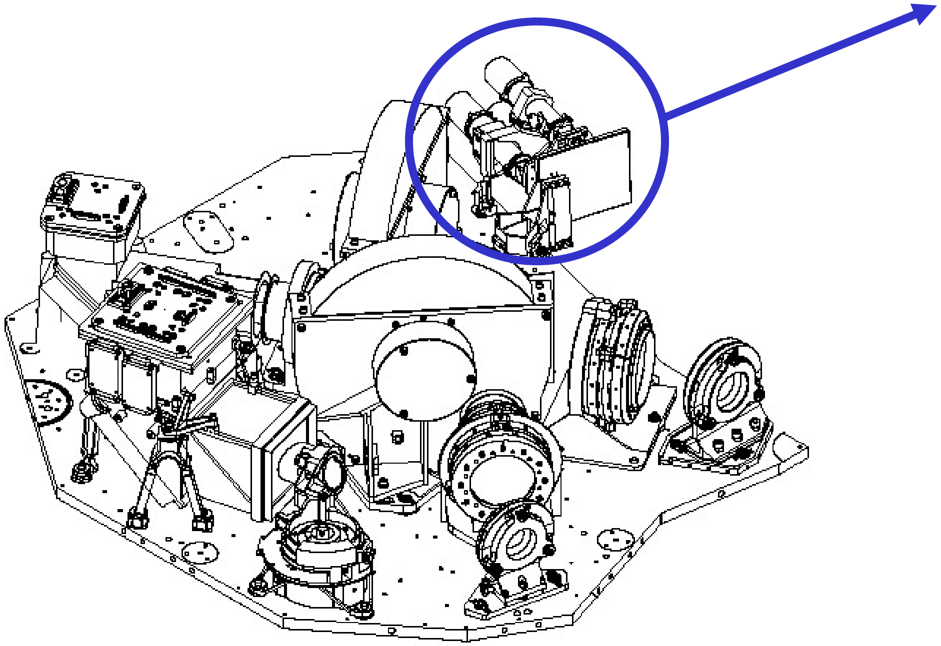
Compact, lightweight, and athermalized mirror and mount for use on JWST's NIRCam instrument

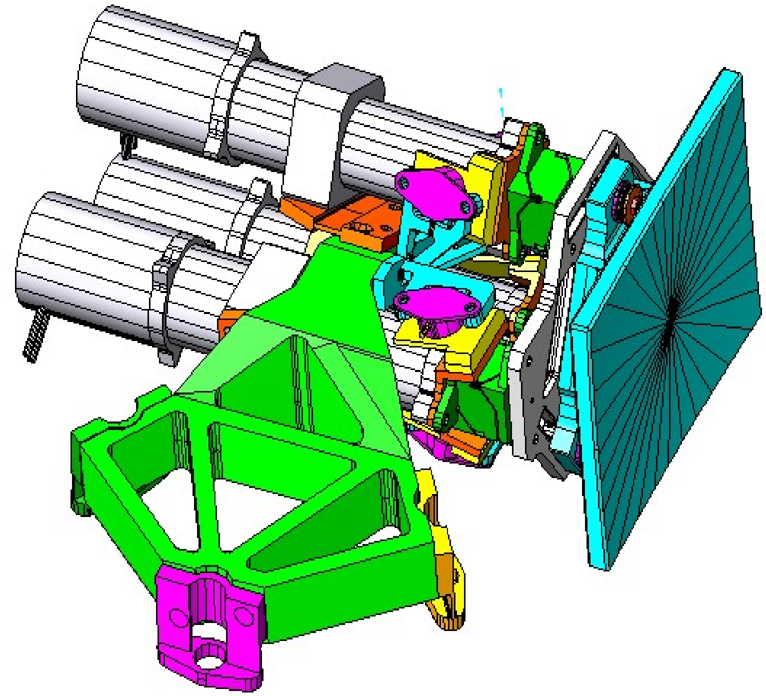
Paul Mammini

Lockheed Martin-ATC

NIRCam Module (A) & FAM

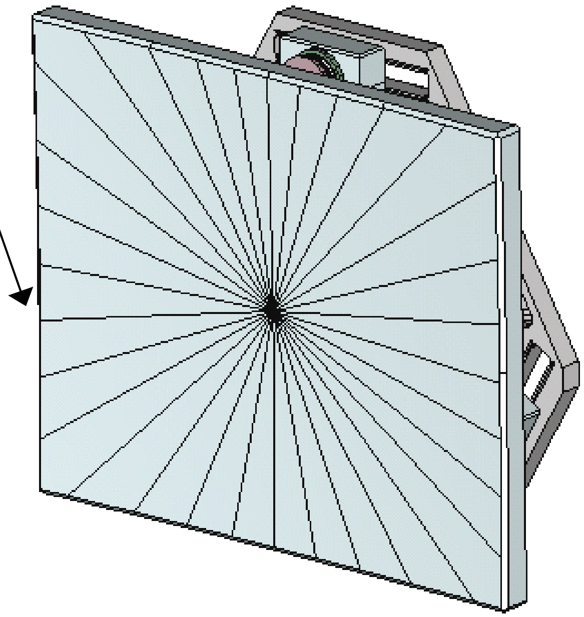
- The Pick-off Mirror (POM) is a mounted, spherically concave mirror that reflects the starlight from the JWST OTE into the rest of the NIRCam Instrument.



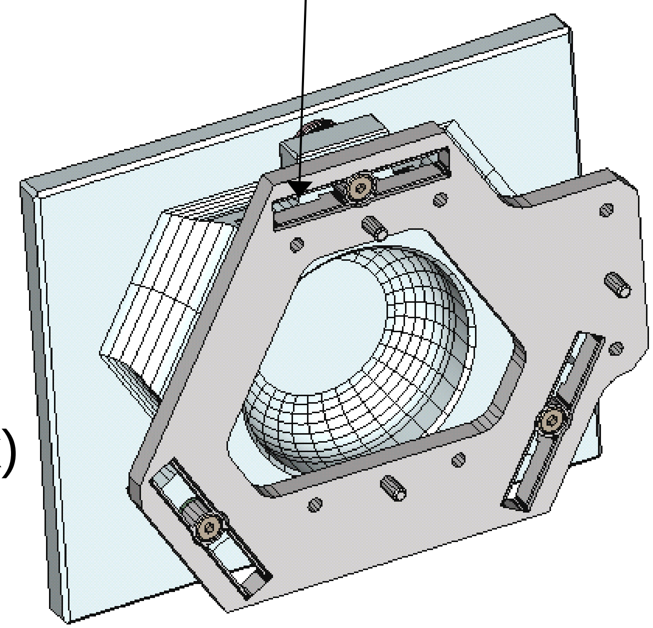


Design Overview

Fused Silica Spherical Mirror



Monolithic Titanium Plate w/ Flexures (x3)



- Nearly Athermal
- ~40% Lightweight
- Identical Mirror for Modules A & B
- Compact: 30mm thick (front surface-to-back)
- Few Components: 2 parts + fasteners, etc.
- Predictable performance via analysis

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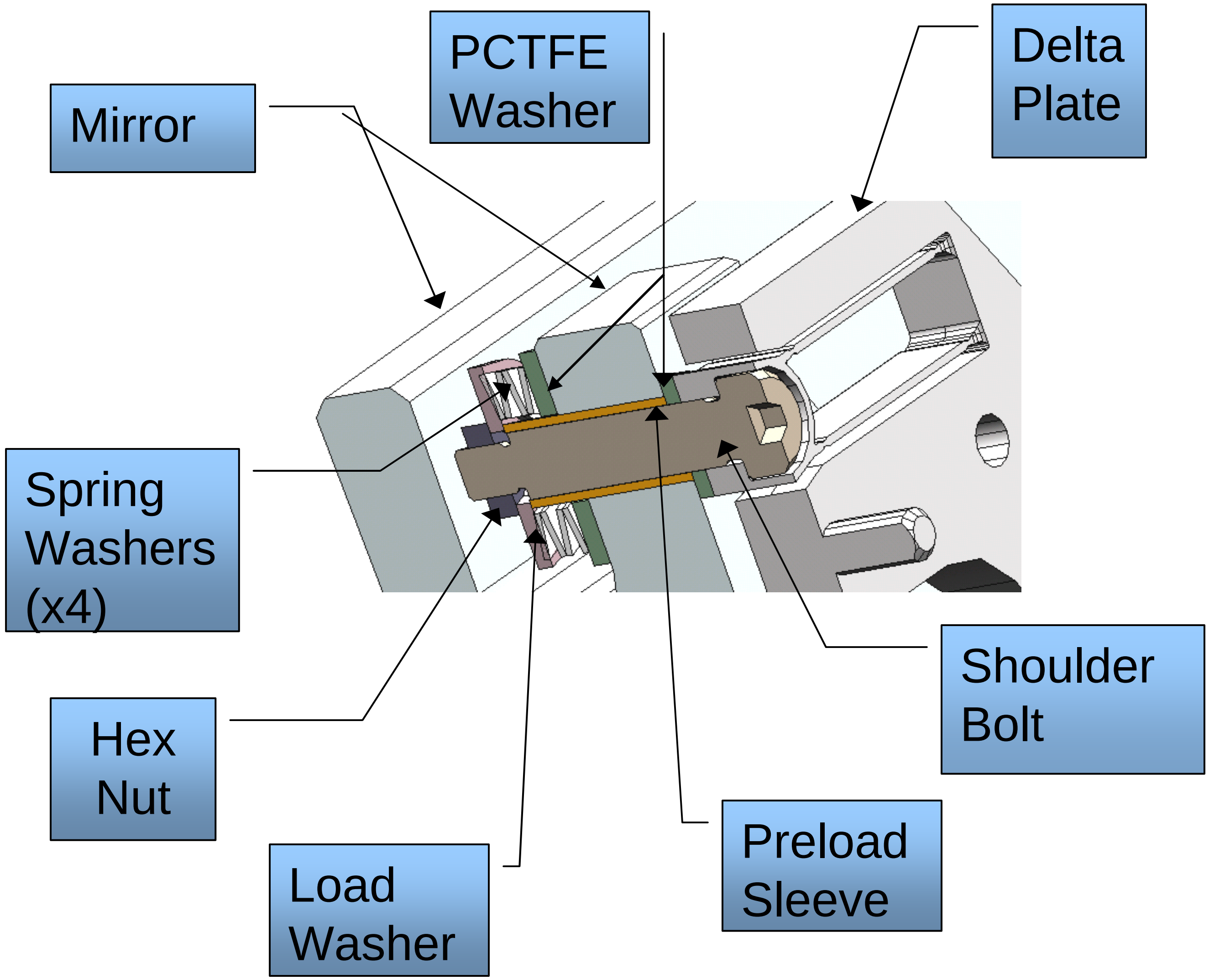
Design Overview

- Mirror-to-mount clamp assembly (3 places)



Distortion Load Cases

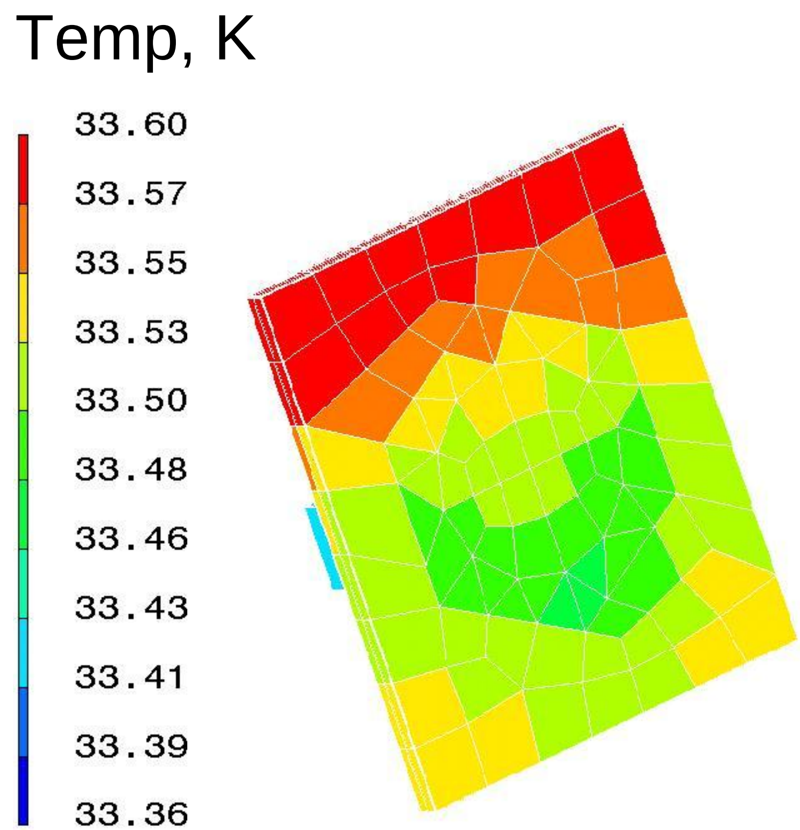
The following load cases were evaluated for their affects on the mirror surface distortion:

- **Cool Down**: Cool down from room temperature (293K) to cryo (35K), which results in 1.4 Newton flexure force.
- **1g in X:** Lateral gravity sag.
- **1g in Y:** Lateral gravity sag.
- **1g in Z:** Axial gravity sag.
- **Fastener Preload:** 68 Newton preload in fasteners attaching mirror to delta plate flexures.
- **Flexure Preload:** 127 micron enforced displacement at flexures due for assembly tolerance that results in 4.6 Newton flexure force.
- **Side Thermal Gradient:** A side-to-side operational thermal gradient of 0.25K.
- **Top Thermal Gradient:** A top-to-bottom operational thermal gradient of 0.25K.
- **FAM Load (6 cases):** FAM flexure induced distortion on delta plate when FAM is driven to 1 degree tilt with 4.0 N-m/rad FAM flexure stiffness.

Thermal Analysis

- **Objectives**
  - Determine max thermal gradients for thermal stress calculations
    - NIRCam operation
    - Rapid cool-down in test
  - Review thermal gradients from POM to bench during contamination prevention
- **Model Inputs**
  - POM integrated with FAM model for analyses
  - Front surface e=.02, back e=.7
  - Details on model cases in backup slides
- **Results**
  - Max gradient during NIRCam operation is 0.25K (shown)
  - Max gradient during rapid cooldown is 29K (not shown)
  - Since POM will not respond to bench contamination, prevention heaters are in current design

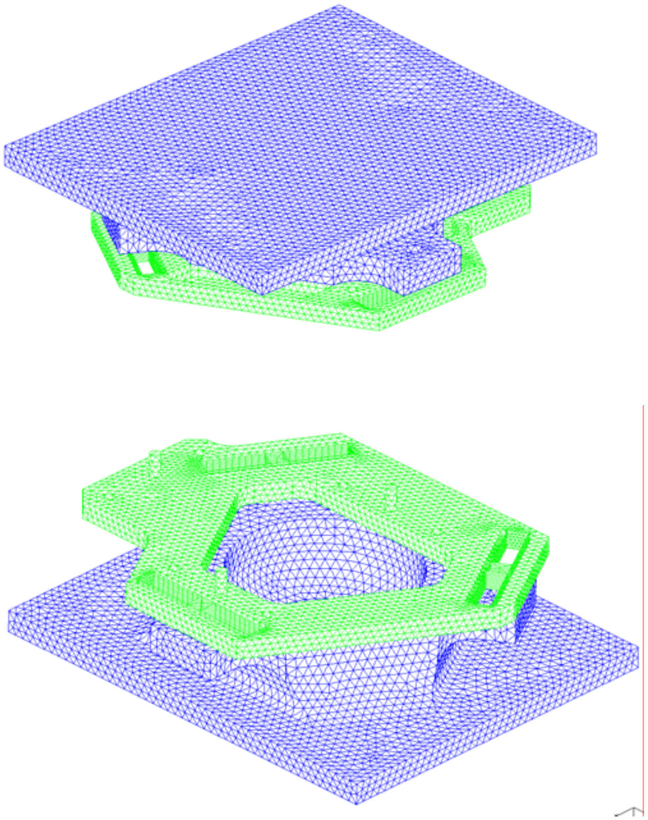
NIRCam operating



Front View

Structural Analysis

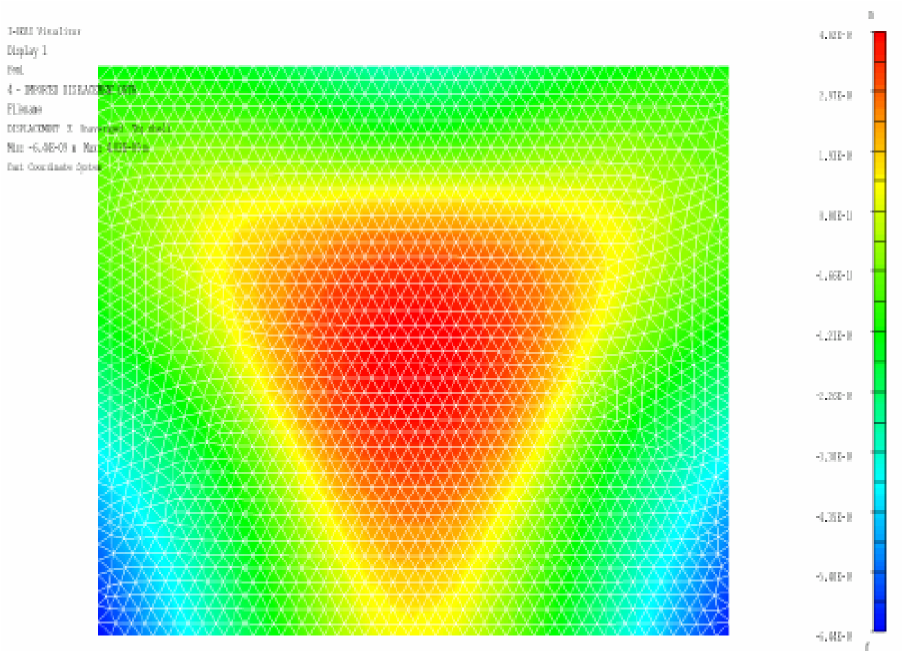
- Requirements:
  - 54g Launch Load
  - Safety Factors:
    - 3.0 Glass Ultimate
    - 10.0 Fatigue Fracture
    - 1.4 Metallic Ultimate
    - 1.25 Metallic Yield
  - > 150 Hz First Mode (Goal)
  - 39 nm RMS Surface Distortion (Mounting & Fabrication)



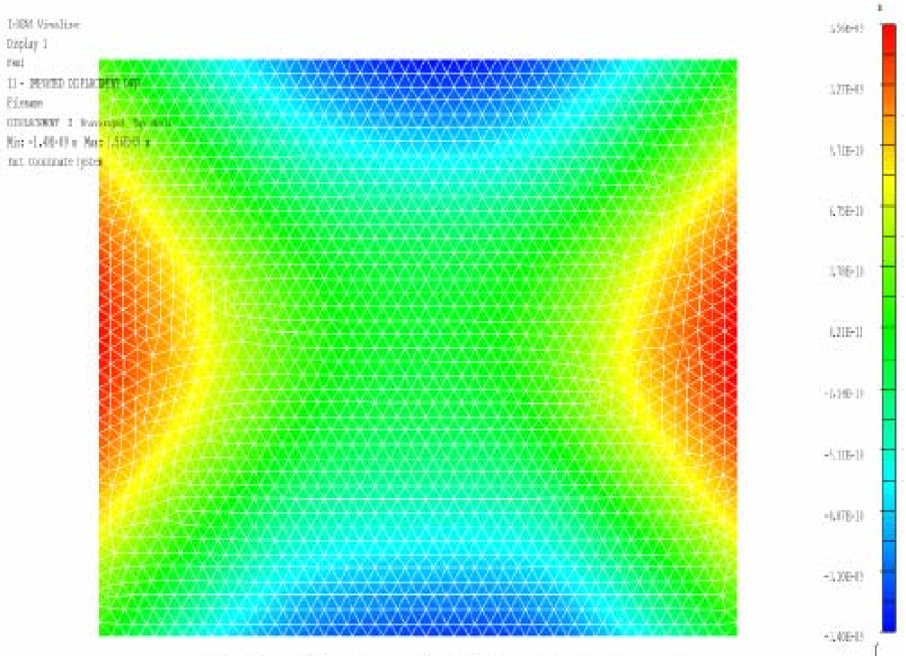
- Finite Element Model
  - Parts: second order tetrahedrons
  - Front surface of mirror: shell elements
  - Interfaces: rigid bar elements

Surface Distortion Maps

- The model was meshed in I-DEAS Master Series version 9 and exported through a translator for MSC/NASTRAN version 2001. Analysis runs and model checks were performed with NX/NASTRAN version 2.0.

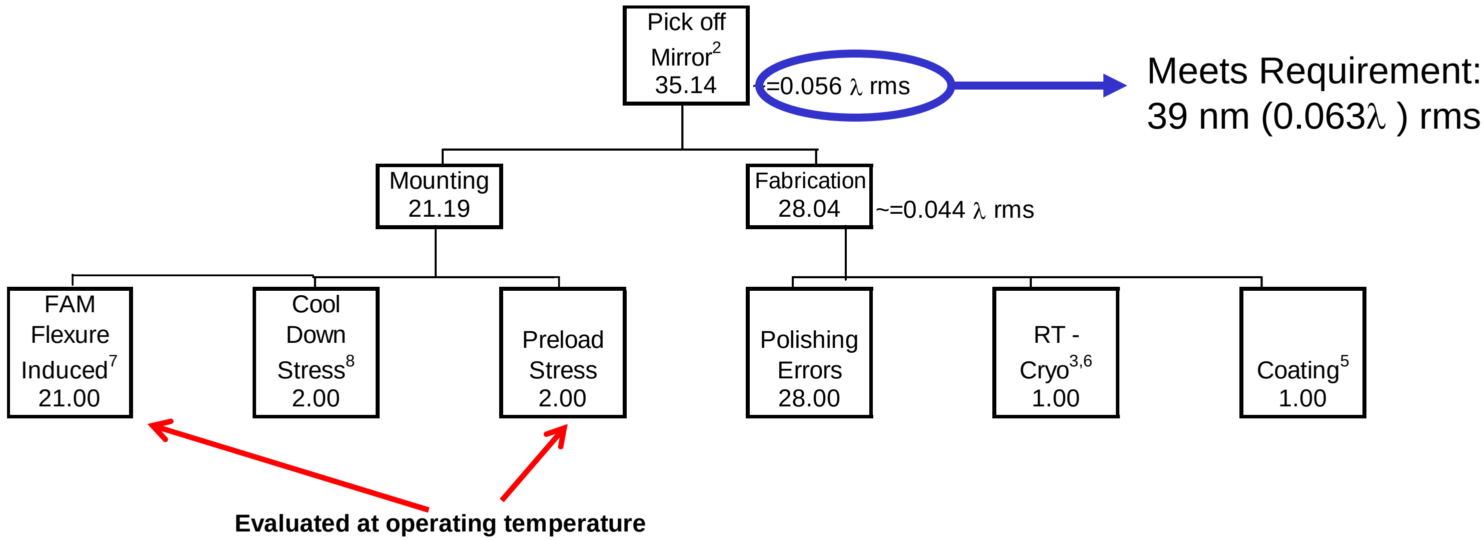


Surface Distortion – Cool Down



Surface Distortion – FAM Flexure Induced Load

Predicted Performance



1G Direction	Surface Distortion[9]
X	20
Y	16
Z	15

1st Mode Frequency: 454 Hz

1) Values are nm.
2) Includes distortion from 1G (worst case orientation). Higher symmetric gravity distortion acceptable, but distortion must not be asymmetric by 4 nm.
3) Maximum thermal gradient of 5 degrees okay across mirror surface.
4) Design residual, light scatter budget, and dynamics carried at system level.
5) Silver coating specified.
6) RT-Cryo includes effects of CTE inhomogeneity of substrate material contributing to wavefront error
7) FAM flexure induced distortion assumes articulation of 1 degree tip/tilt (which is 2x required operating range) and 4.0 N-m/rad flexure stiffness.
8) Distortion at 35K from dl/L mismatch (going from RT to Cryo) between optic and mount
9) Gravity not included in operational budget.
   Budgeted mounted (worst case) 1G mirror figure V1 down, V1 horizontal, to allow subtraction of gravity effect from NIRCam WFE calibration.
   Need to know NIRCam WFE to better than 20 nm on ground and on-orbit to prevent imprinting WFE on OTE.
   Symmetric gravity distortion acceptable, but distortion must not be asymmetric by 4 nm.

Lessons Learned & Summary

Lessons Learned

- Strive for predictable models to reduce uncertainties
  - use flexures, not bearings for small motions to rule out hysteresis/friction
  - test critical material properties at extreme temperatures/environment to minimize uncertainty
- Small changes to the FEM mesh, boundary conditions, loads, and material properties sometimes have a large effect on the outcome

Summary

- The POMA uses geometric features, flexures, materials, and careful consideration of preloading and mount points in order to perform at or better than the required level after severe launch loading and then a dramatic cool down from room temperature to 35K.
- Manufacturing considerations and a combined optical/thermal/mechanical model all contributed to a good design that meets requirements. The design of the mirror and mount are proven through correlation between the predicted performance, through analysis, and the tested performance, via the prototype.