communications

SSG-Tinsley

Development of EUV Quality SiC Optics
NASA Phase 2 SBIR

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Mirror Technology Days, September 19, 2006

- Program Title: “High Quality, Low Scatter, SiC Optics Suitable for Space-Based UV and EUV Applications.” NASA Phase 2 SBIR
- Contract Number: NNG04CA15C
- NASA Technical Monitor: David Content, Ph.D. (GSFC)
- Program Objectives
  - *Develop manufacturing process for EUV quality, lightweight SiC aspheric optics*
  - *Demonstrate process through the design, modeling and fabrication of flight-like Secondary Mirror for delivery to NASA Goddard*

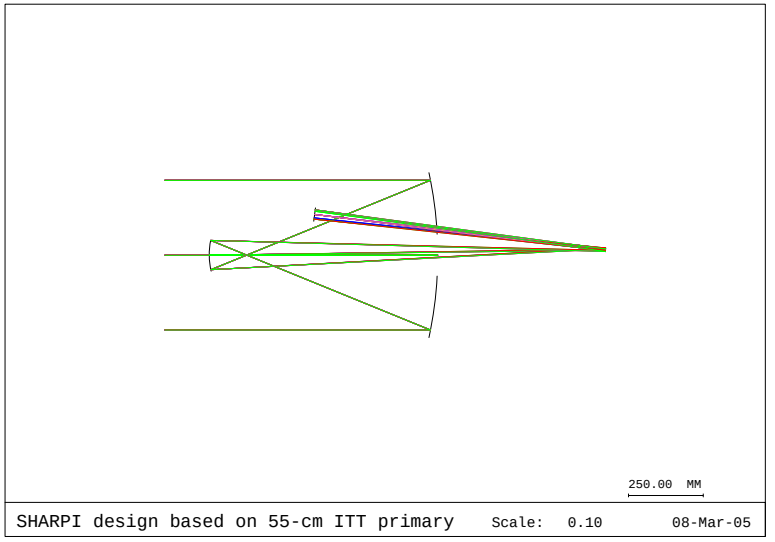
Program Overview

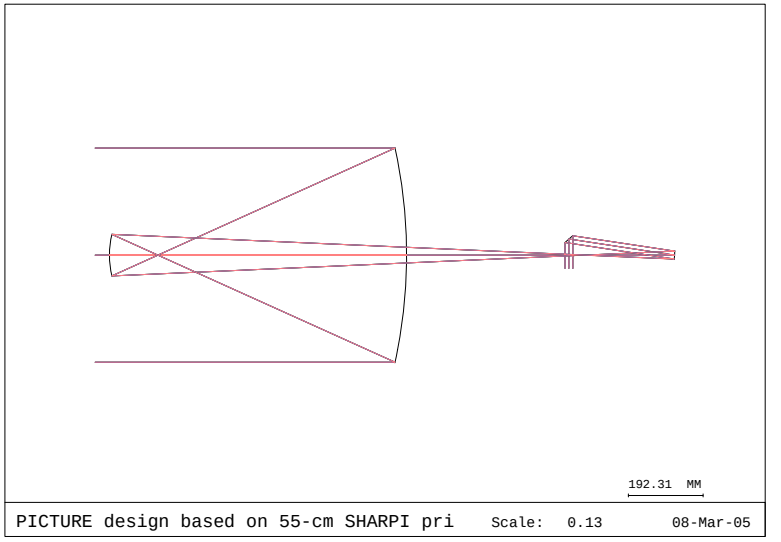
- Process development of superpolishing techniques to achieve EUV quality in Si cladding
- Design and modeling of Secondary mirror
  - *Thermal loading (gradient and soak)*
  - *Effects of cladding (bi-material)*
  - *Mounting errors*
  - *Launch Load*
  - *Gravity*
  - *Stiffness*

- Delivered hardware-Secondary Mirror for PICTURE/SHARPI missions
  - *100 mm aperture lightweighted SSG 55A SiC substrate*
  - *Amorphous Silicon cladding*
  - *Invar mounting foot*
  - *Operational SE requirements < 5 nm RMS met*
  - *As fabricated surface error results*
    - 3.1 nm RMS (>10 mm)
    - 1.3 nm RMS (1 mm< spatial frequency<10 mm)
    - 0.38 nm RMS (0.001 mm < spatial frequency < 1 mm)

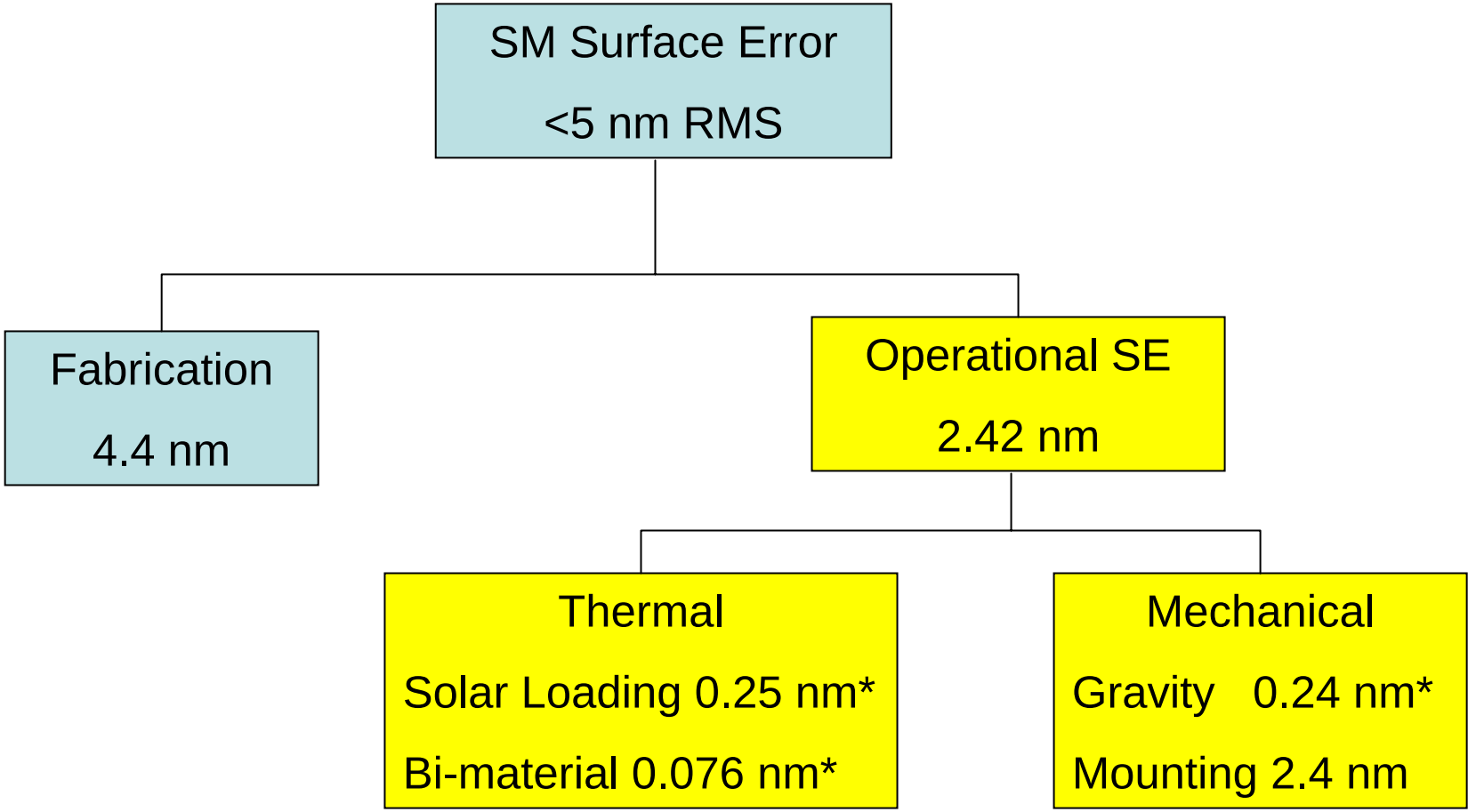
Mirror Design

- Substrate
  - *SSG 55A SiC*
  - *Amorphous Si cladding on facesheet*
  - *Physical diameter: 4.8” (122 mm)*
  - *Facesheet thickness: 0.10” (2.5 mm)*
  - *Rib and rim thickness: 0.10” (2.5 mm)*
  - *Mass:0.457lbs. (Areal density of 17.7 kg/m2)*
  - *Invar Mounting Foot*
- Optical surface characteristics of Secondary Mirror
  - *Clear aperture: 3.864”*
  - *Conic Constant: -0.663290*
  - *Base radius: 8.93030”*
  - *Off-axis distance: 0.060”*





Error Budget



All surface error values presented are RMS

***Focus term removed**

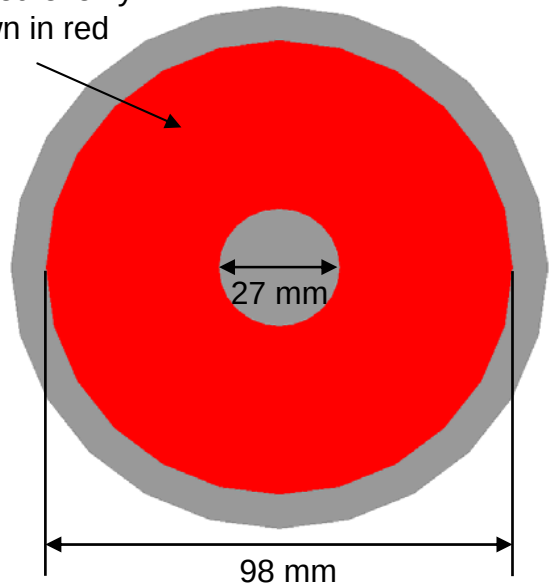
Yellow indicates derived from modeling and analysis

Modeling Results

Modeled Condition	Contribution to Surface Error	Comments
Solar Loading		
1.86 watts	0.25 nm	Focus removed, error is 94% focus
Bi-material Effect		
Si (10 microns)	0.076nm	Focus removed, 94% focus
Gravity Error	0.24 nm	
Mounting Errors		
0.0002" normal to mounting	2.4 nm	No focus term
Launch Load (20g's RMS)	N/A	Max. stress in mounting foot = 783 psi (60 G's)
First Mode	N/A	1751 Hz, fixed at three mounting points
RSS'd Surface Error	2.43	nm

SM Thermal Model and Heat Load

Heat load applied evenly over area shown in red



The mirror face is loaded with 1.86 watts of solar radiation. This load is distributed over a "doughnut shape" area on the mirror face

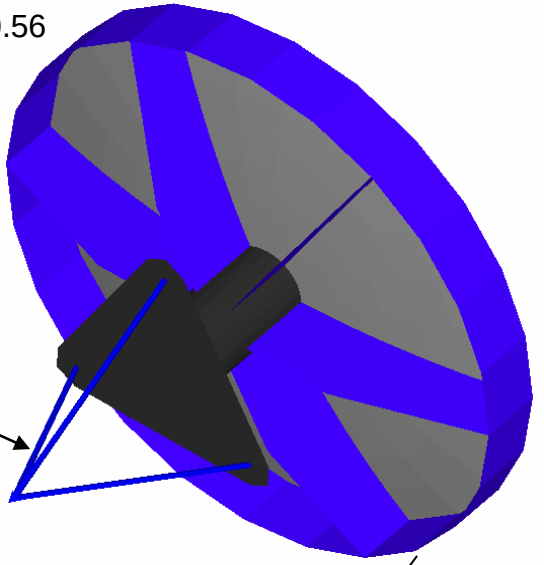
8 % of the energy is absorbed

Emissivity of Ribs and Mirror Back= 0.56

Emissivity of Mirror Face = 0.02

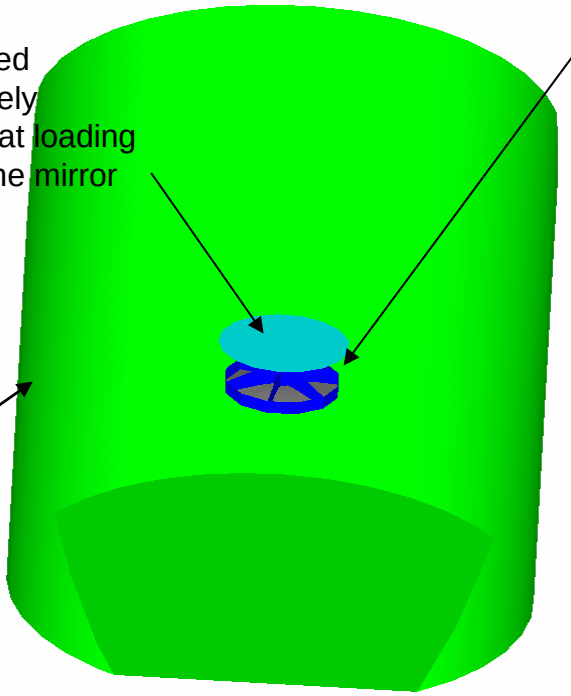
Three conductors represent the bolted joint conductance to a boundary held at 20 °C

Conductance = 0.4 W/°C



A simple insulated reflector effectively prevents any heat loading on the back of the mirror

Mirror radiates to a black body housing at 20 °C



Critical Mirror Dimensions	inches
Face Thk.	0.1
Ribs Thk.	0.1
Rim Thk.	0.1

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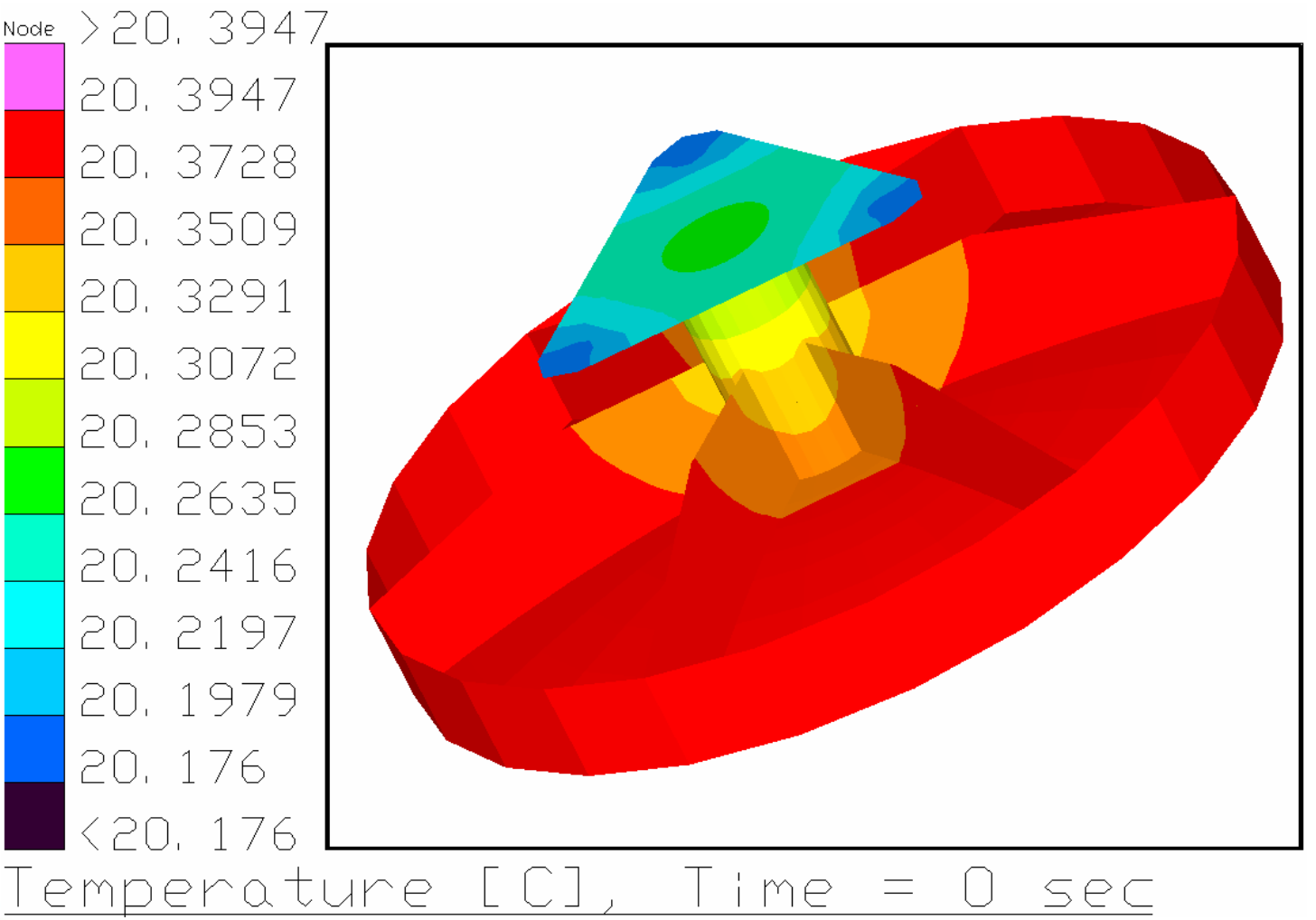
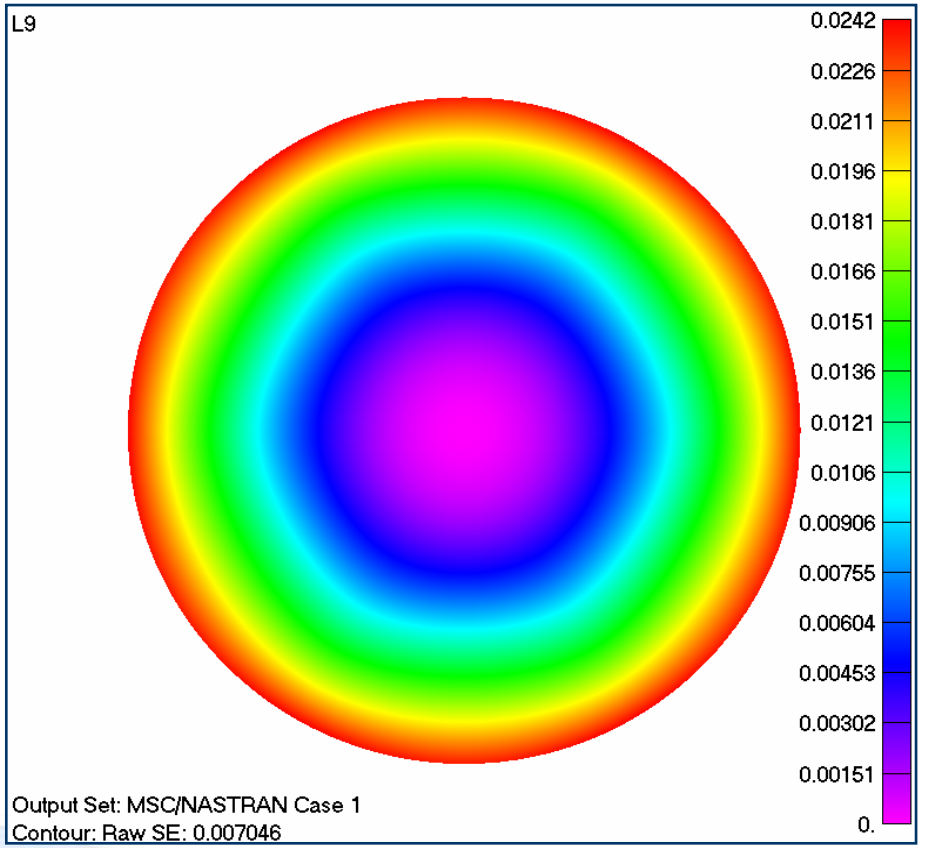
Thermal Model Results

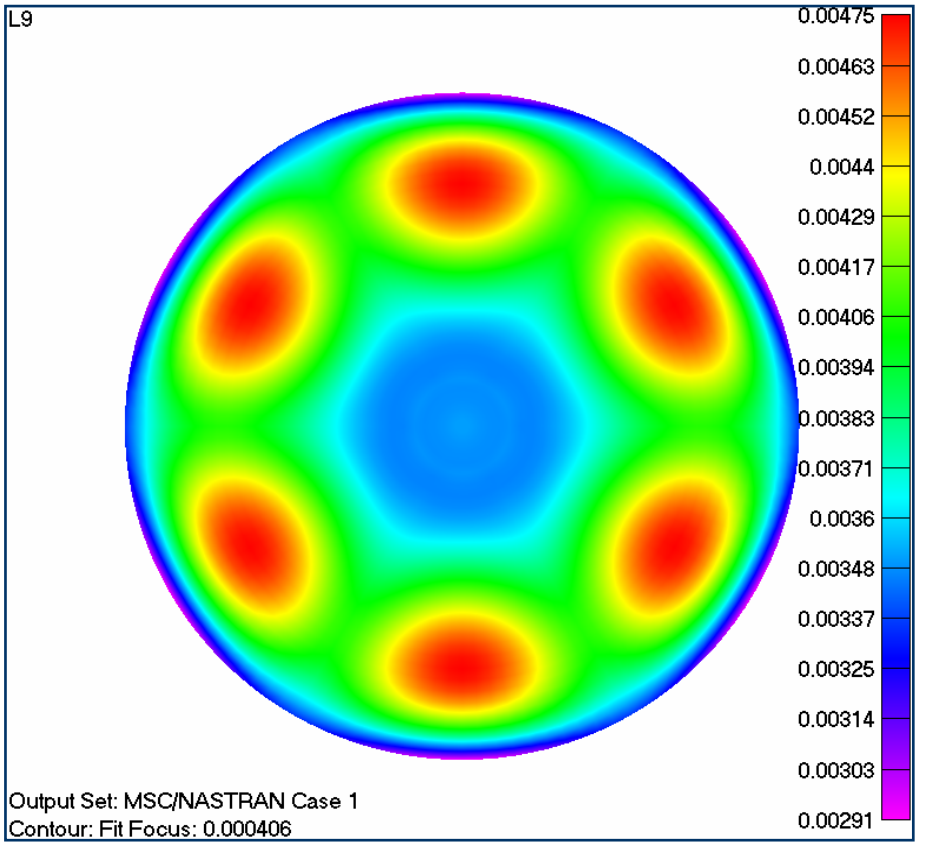
The maximum mirror gradient = 0.219 °C



Thermally Induced Surface Error

- The RMS Surface Error = 0.0070 waves at 632.8 nm (4.43 nm)
- With Focus Removed the RMS Surface Error = 0.0004 waves at 632.8 nm (0.25 nm)
- The Error is 94 % Focus





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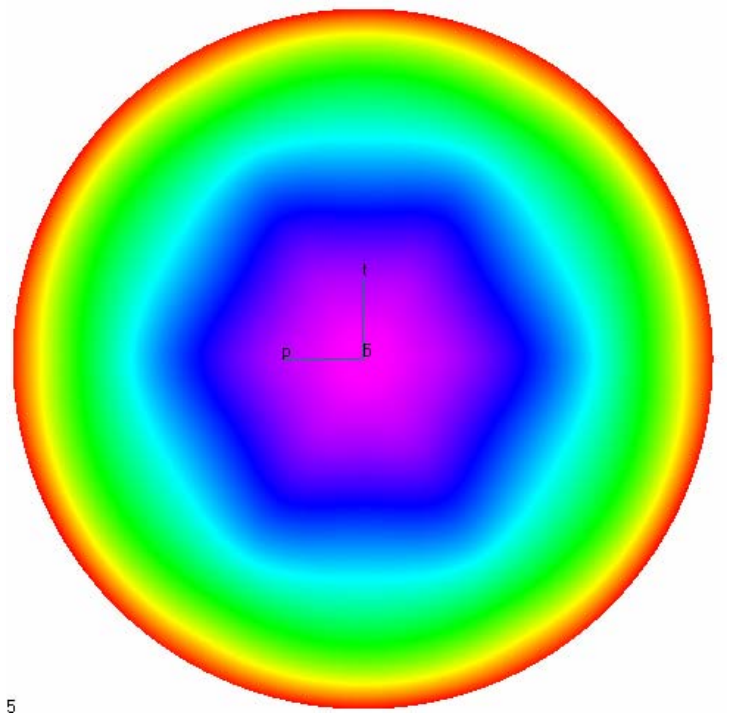
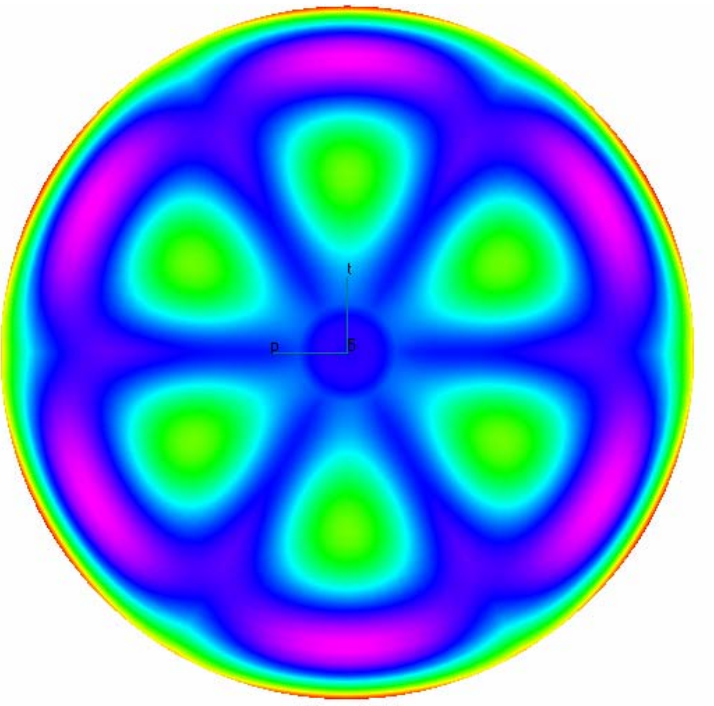
Temperature Soak (Bi-Material Effect)

- Nominal 10 micron amorphous Si cladding on facesheet
- The RMS Surface Error = 0.00195 λ (1.23 nm) at 632.8 nm for Si coating
- With Focus Removed the RMS Surface Error = 0.00012 λ (0.076nm) for Si coating
- The Error is 94 % Focus



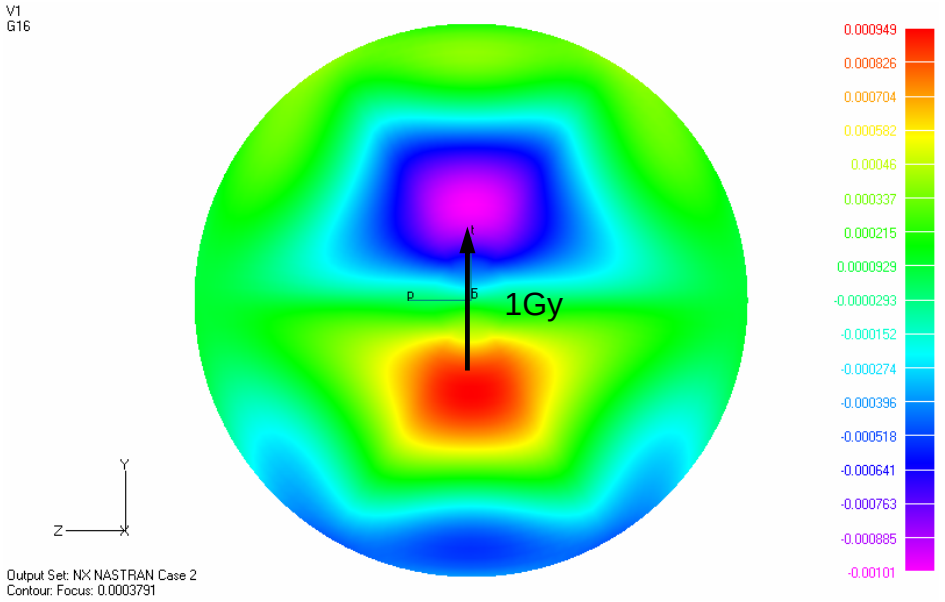
RAW SE



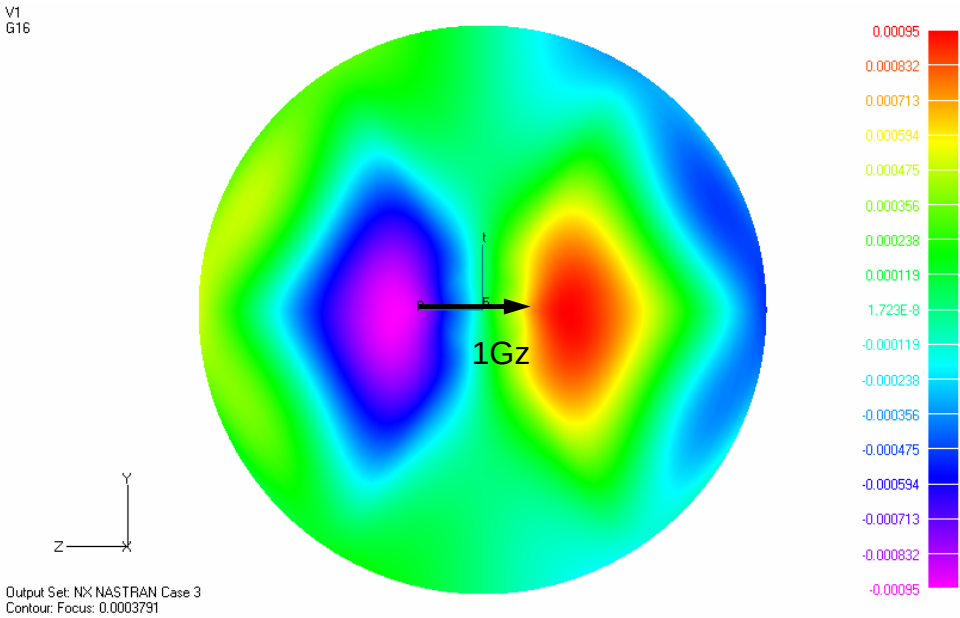
Focus Removed

Gravity Errors

- **RMS Surface Error = 0.24 nm RMS for both y and z orientations**
- **With Focus Removed**



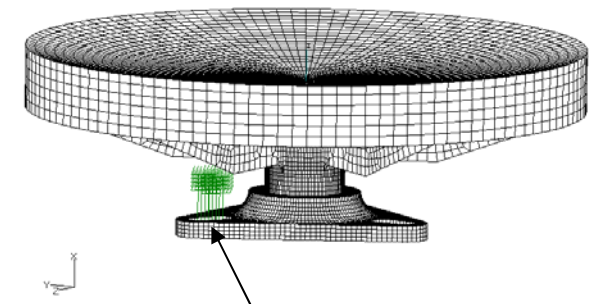
0.000379 λ rms (0.24nm)

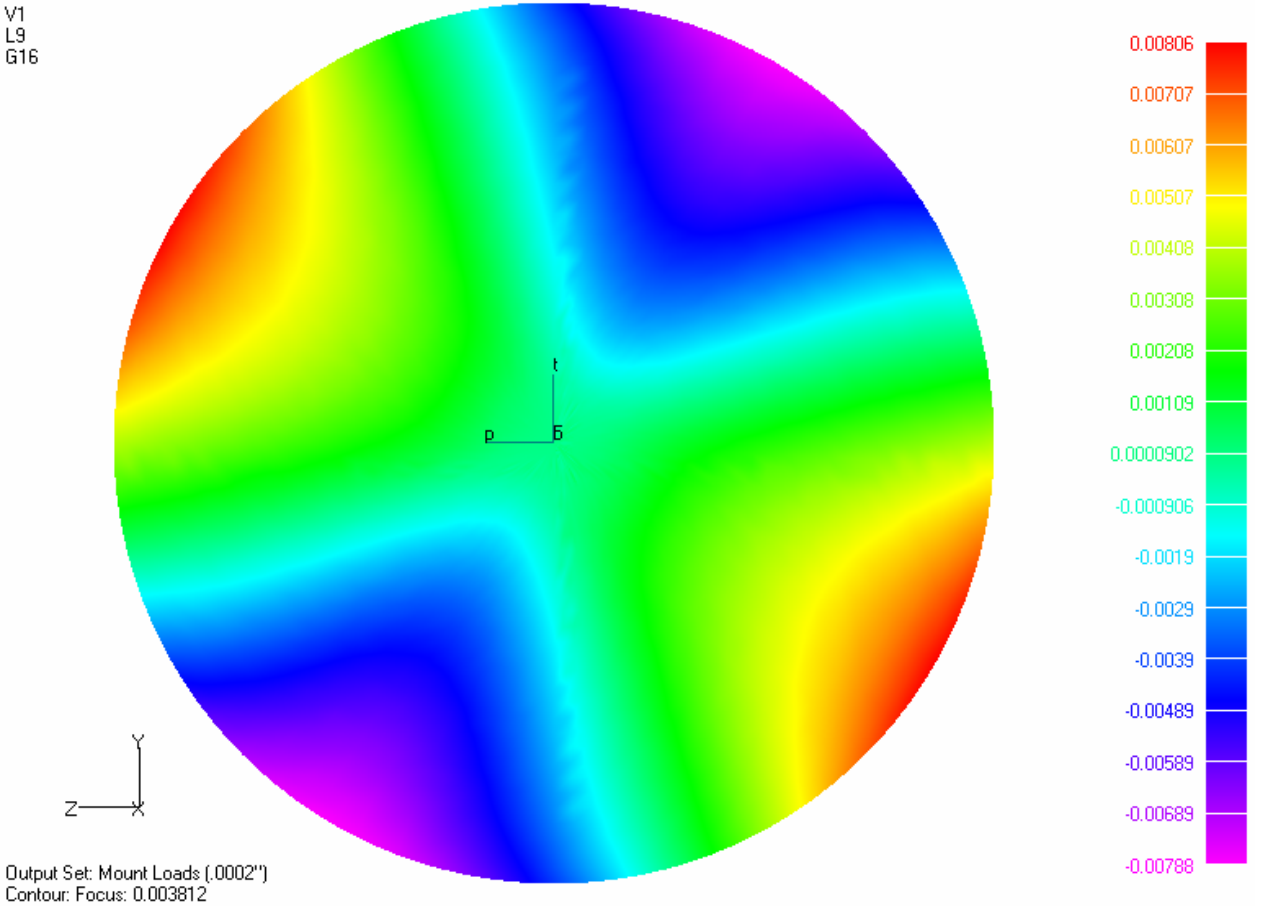


0.000379 λ rms (0.24nm)

Assembly Mounting Error

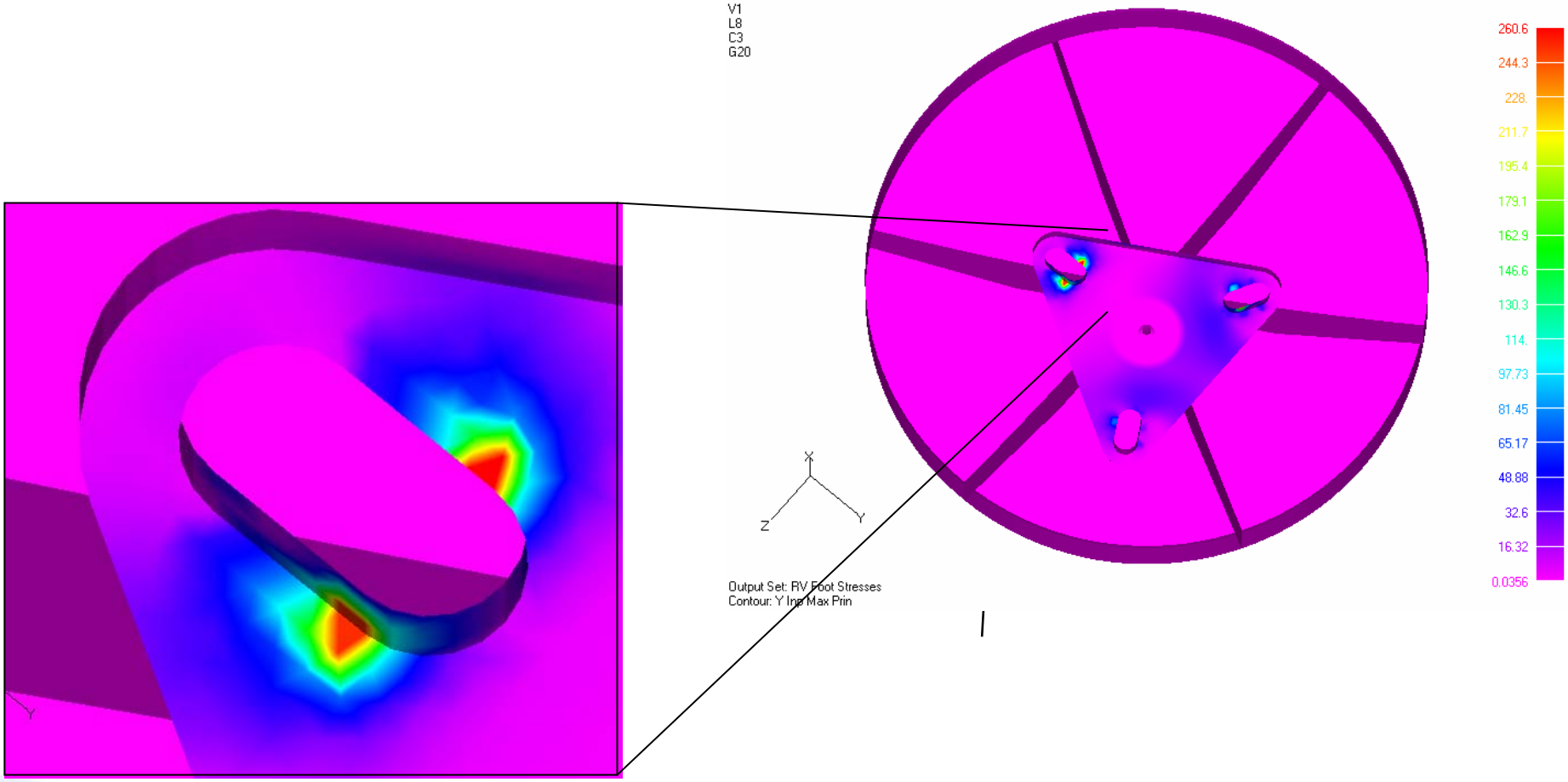
- The RMS Surface Error = 0.00381 λ at 632.8 nm (2.4 nm)
- With Focus Removed the RMS Surface Error = 0.00381 λ (2.4nm)
- The Error is 0 % Focus





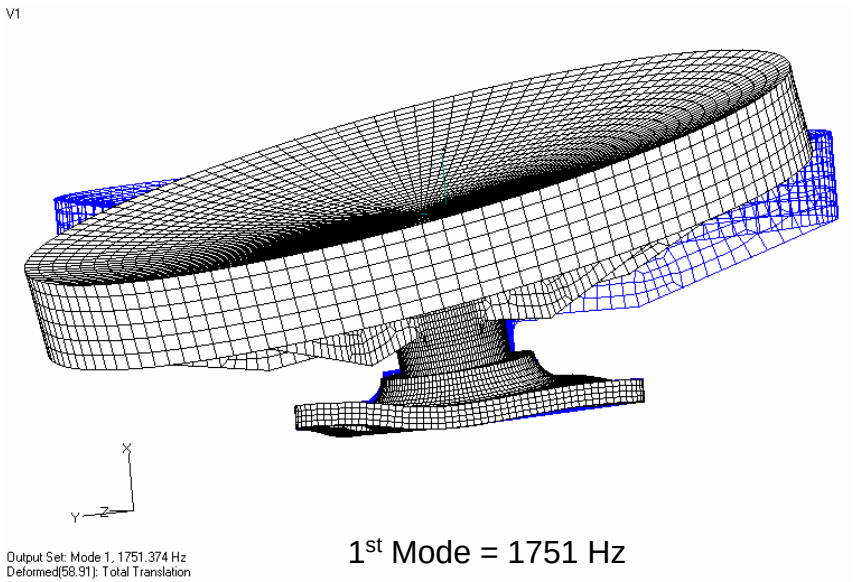
Launch Stress

- The RMS G's = 20
- Max. tension stress in mounting foot = 783 psi (60 G's)



Modes & Frequencies

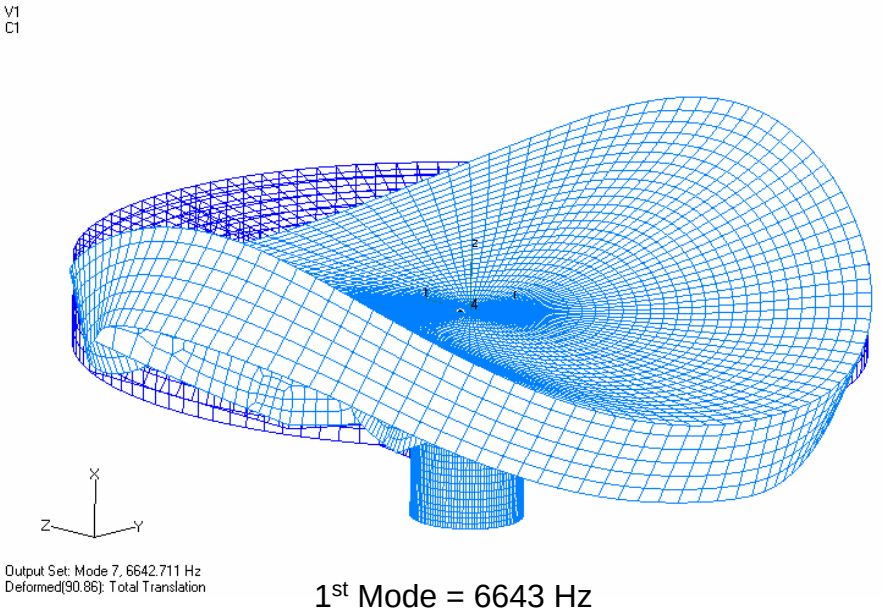
- **Assumed fixed boundary condition at three mounting points**



1st Mode = 1751 Hz

Mode	Frequency (Hz)	Comment
1	1751	Bending of mounting foot
2	1752	Bending of mounting foot
3	1771	Torsional about post
4	5001	Extensional at post

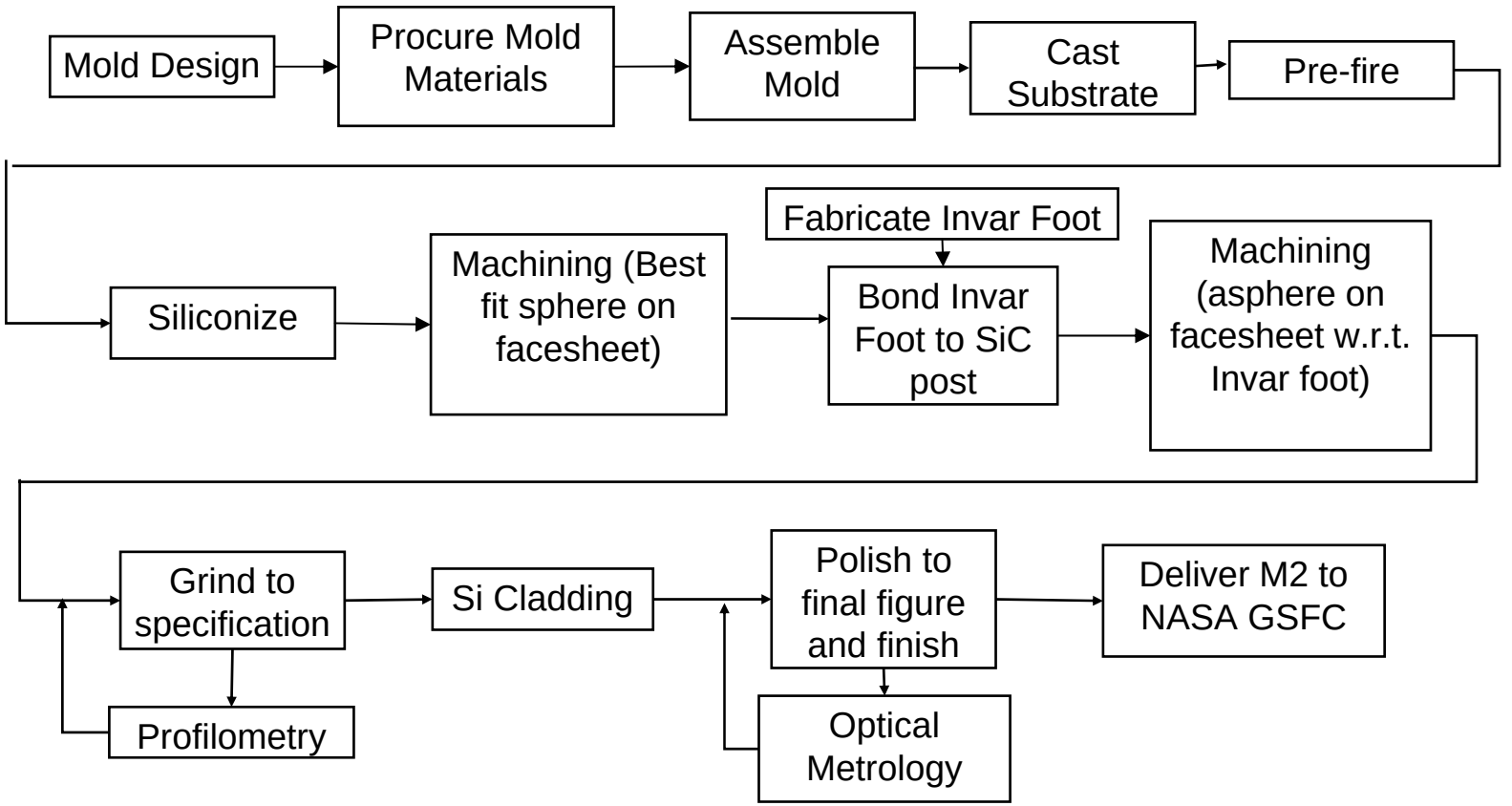
- **Assumed free-free boundary condition**



1st Mode = 6643 Hz

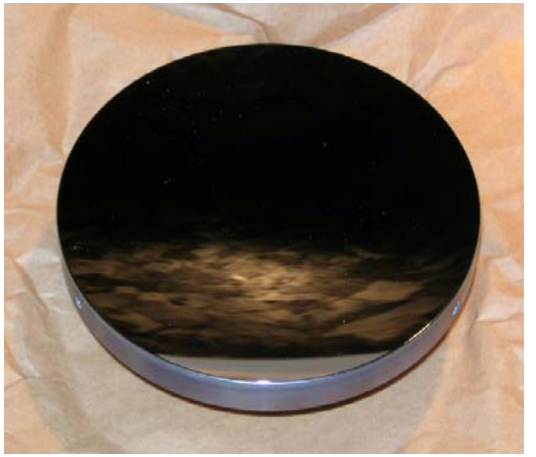
Mode	Frequency (Hz)	Comment
1	6643	Bending of mirror surface
2	6643	Bending of mirror surface
3	10101	Bending of mirror surface
4	12090	Extensional at post

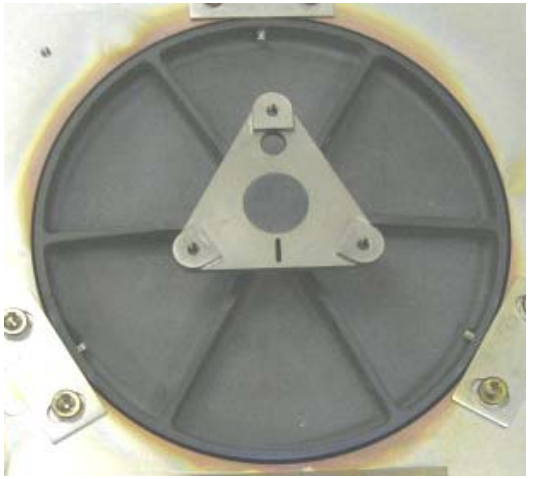
Fabrication Overview



UV/EUV Quality SiC Asphere

- High Precision Secondary Mirror Fabricated and Delivered to NASA GSFC
  - 100 mm CA Off-axis ellipsoid
  - UV quality surface error (3 nm RMS goal)
  - Solar loading over clear aperture (1.82 watts)
  - To be integrated into telescopes for two upcoming NASA experiments (sounding rocket platform)
    - PICTURE visible
    - SHARPI UV coronographic mission
- Surface Error Results
  - 3.1 nm RMS (> 10 mm)
  - 1.3 nm RMS (1 mm to 10 mm)
  - 0.38 nm RMS (0.001mm to 1mm)

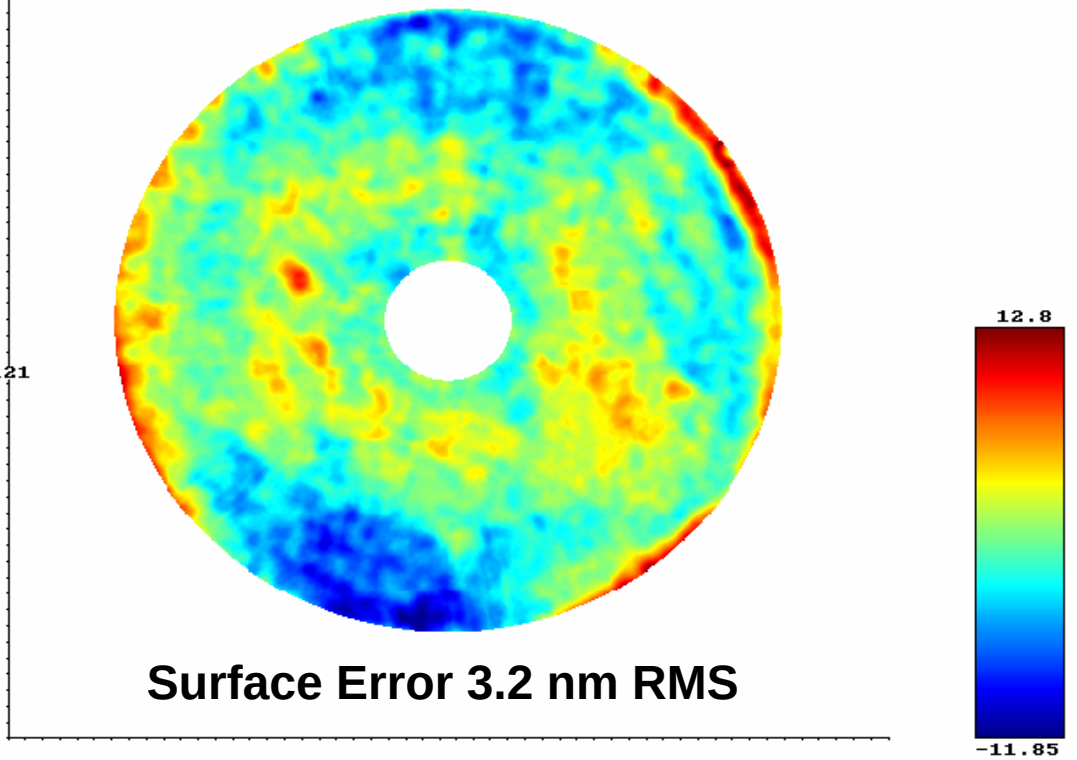




Secondary Mirror Metrology Results

```
file : 0322.ca

units: x = mm
       y = mm
       z = nm
xspac: 0.254
yspac: 0.254
ngx  : 511
ngy  : 511
gxcen: 0
gycen: 0

z ptv: 24.65
z rms: 3.232

x-apr: 98.04
y-apr: 97.79

z min:-11.85
  @ (229, 76)
z max: 12.8
  @ (372, 106)
z avg:-0.2896

npnts: 112889/261121

ix   : 256
iy   : 256
xpos : 0.0000
ypos : 0.0000
r    : 0.0000
theta: 0.0000
zval : no data

color: jet
```

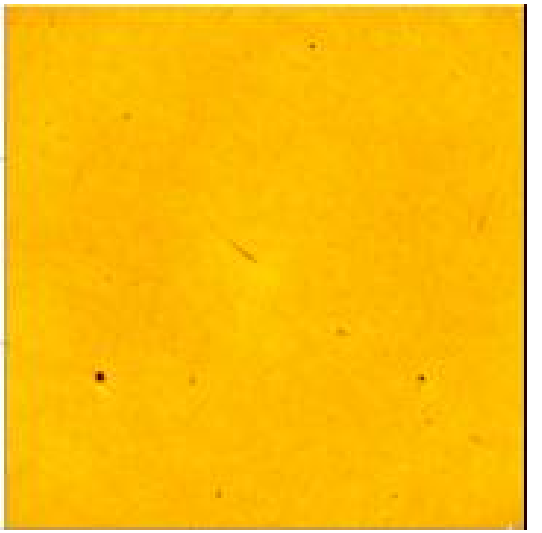
Clear Aperture Interferogram



Surface Error 3.2 nm RMS

- Unfiltered Interferogram
- Central shadow from obscuration masked from interferogram
- Clear Aperture of 3.864”

Micro-roughness



0.24 nm RMS

- 50x Objective
- 1.0 Magnification
- .28 x .28 mm

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EUV M-2 Measurement Summary

Figure of Merit	Actual	Comments
Figure υ > 10mm	3.1nm rms	ACCEPTED BY GSFC
Figure 10 > υ > 1 mm	1.3 nm rms	ACCEPTED BY GSFC
Figure 1 > υ > 0.001 mm	0.38 nm rms	ACCEPTED BY GSFC
Optical Axis Centration ± 0.005”	0.002” *	ACCEPTED BY GSFC
Surface Quality 60/40 MIL PRF 13830	60/40	ACCEPTED BY GSFC
Base Radius 8.93030 +/- .020”	8.92988 +/- 0.0003” **	ACCEPTED BY GSFC
Conic Constant -0.663290 (no tolerance)	-0.663304 +/- 0.00001	REFERENCE
F1 125.014 mm (no tolerance)	125.008 +/- 0.004 mm	REFERENCE
F2 1222.313 mm (no tolerance)	1222.313 +/- 0.002 mm ***	REFERENCE

*** Optical axis centration was measured with respect to the best fit diameter**
**** Based on estimated accuracy of profilometer radius fit**
***** Based on estimated accuracy of DMI spacing**

Summary

- Manufacturing process developed for lightweight SiC EUV aspheric optics
- Delivered demonstration mirror to NASA Goddard for use in PICTURE and SHARPI missions.
  - *SHARPI/PICTURE Secondary Mirror*
    - SSG 55A SiC
    - Thin amorphous Si cladding on facesheet
    - Designed for thermal load of 1.82 W on facesheet
    - Designed for 20g launch conditions
    - Measured Surface Error
      - 3.1 nm RMS (> 10 mm spatial frequencies)
      - 1.3 nm RMS (1 mm < spatial frequency < 10 mm)
      - 0.38 nm RMS (0.001 mm < spatial frequency < 1 mm)
    - Operational SE (RSS of fabricated mirror and model results) = 3.9 nm RMS
- Mirror represents highest precision Si clad SiC aspheric optic fabricated to date
- 3 nm RMS surface error achieved on lightweighted optic

Acknowledgements

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Andrea Jordan, Jay Daniel