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Silicon Carbide Pointing Mirror Gimbal System (PMGS) Summary

Mirror Technology Days 2007

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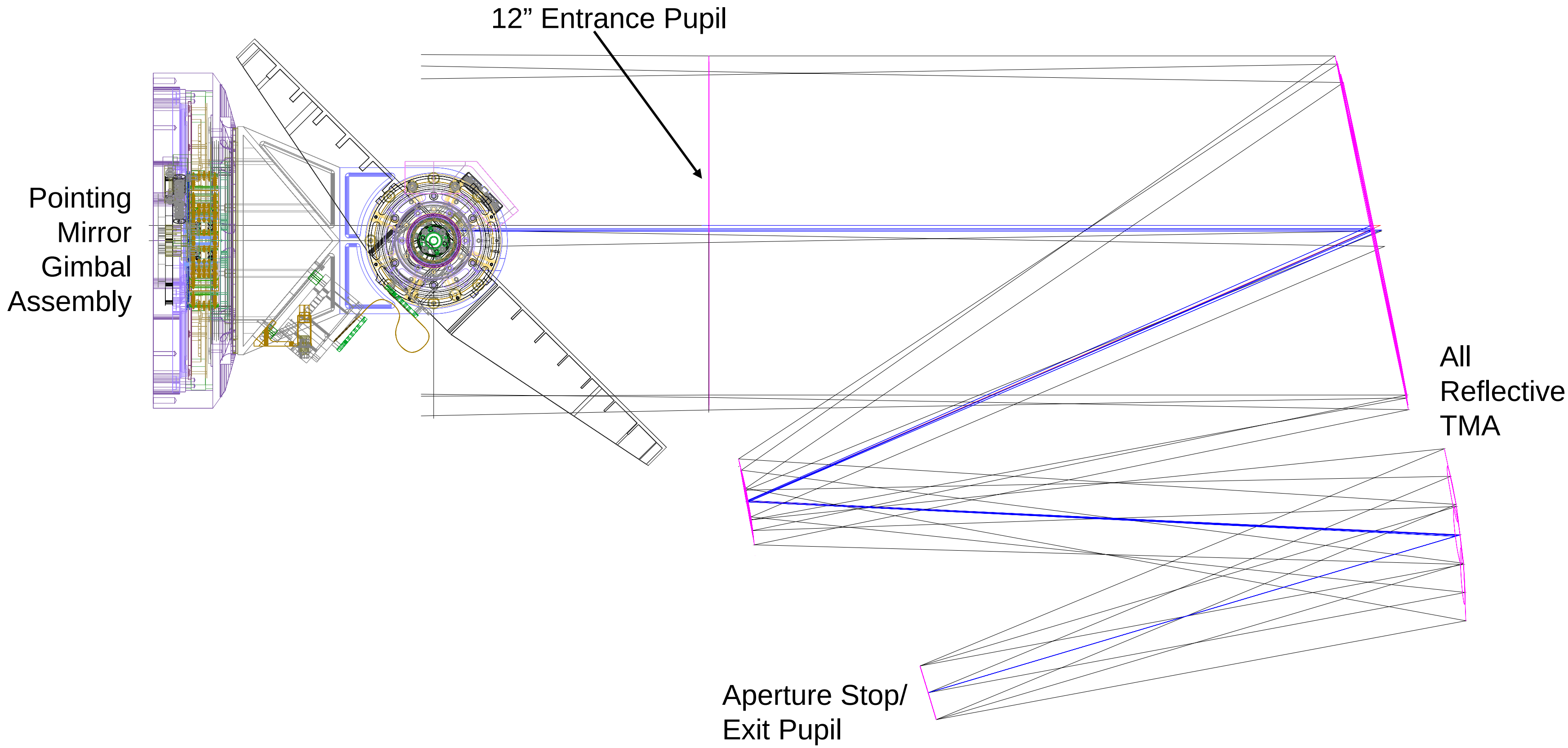
Outline

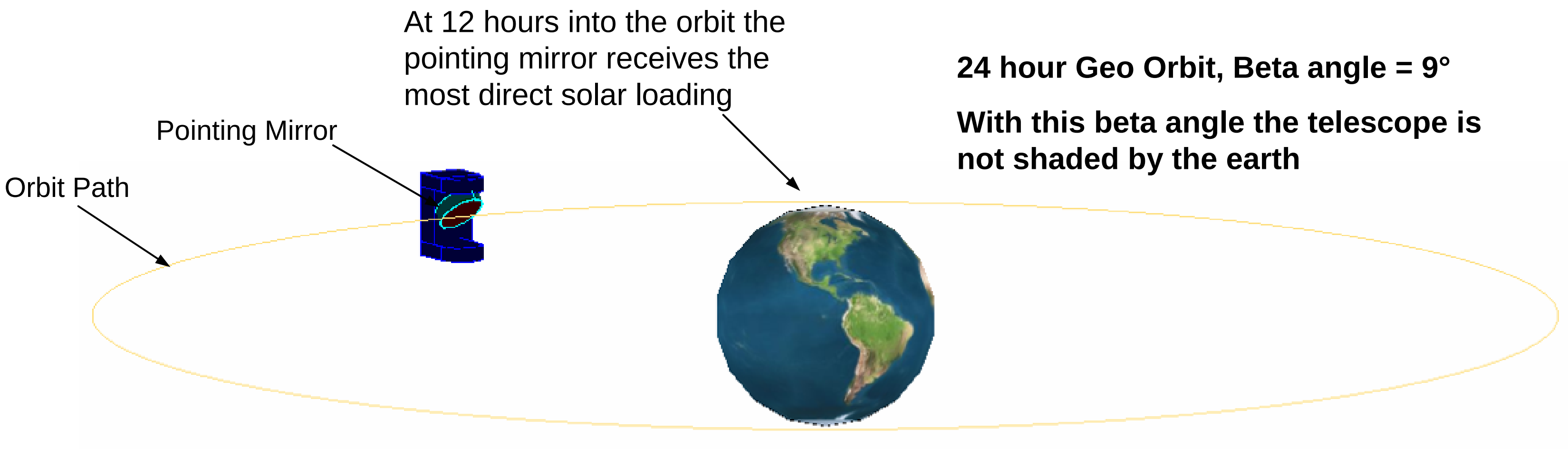
- PMGS Requirements/Objectives
- Mechanical Design
- RB SiC Scan Mirror
  - *Near-net-shape Manufacturing*
  - *Polishing Results*
  - *Thermal Test Results*
- System Level Mechanical Testing
- Closed Loop Servo Performance
- Summary

PMGS Overview



- Program Goals: Demonstrate a SiC based wide field of view pointing mirror assembly, providing line-of-sight control for a fixed, space based imaging system
  - *Three Mirror Anastigmat (2 degree FOV) selected as baseline imaging system*
  - *PMA needs to address a wide range of operational scenarios, including the possibility of direct solar loading of the pointing mirror*

SiC Allows Operation with Direct Solar Loading

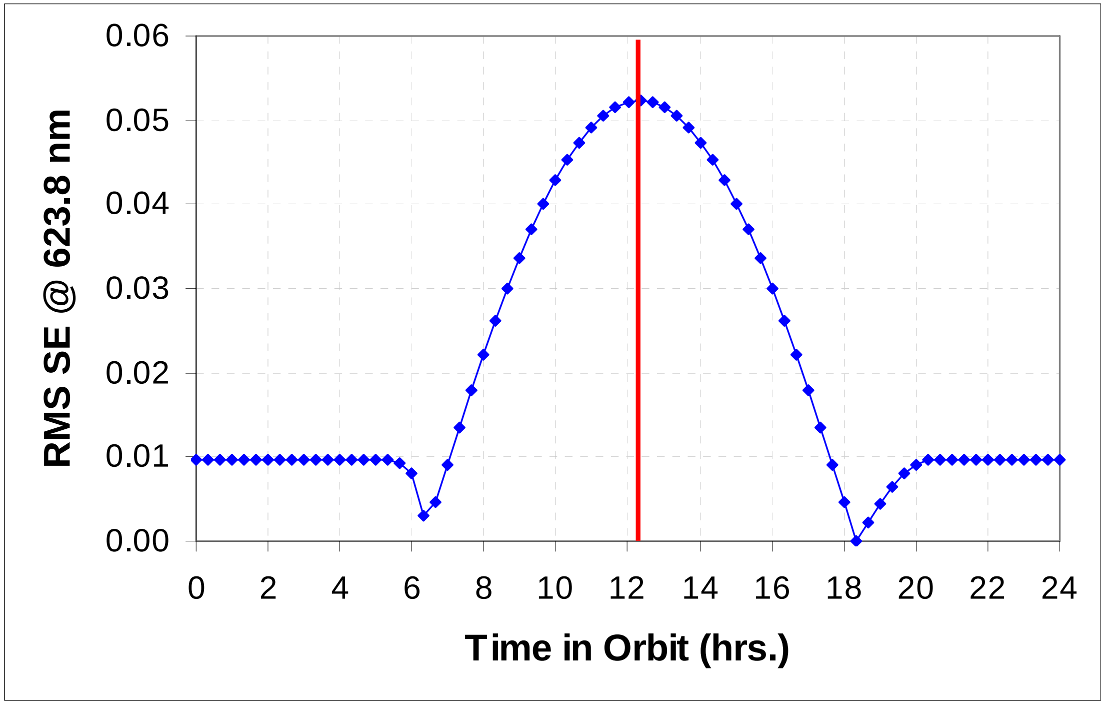


View From Sun

24 hour Geo Orbit, Beta angle = 9°

With this beta angle the telescope is not shaded by the earth

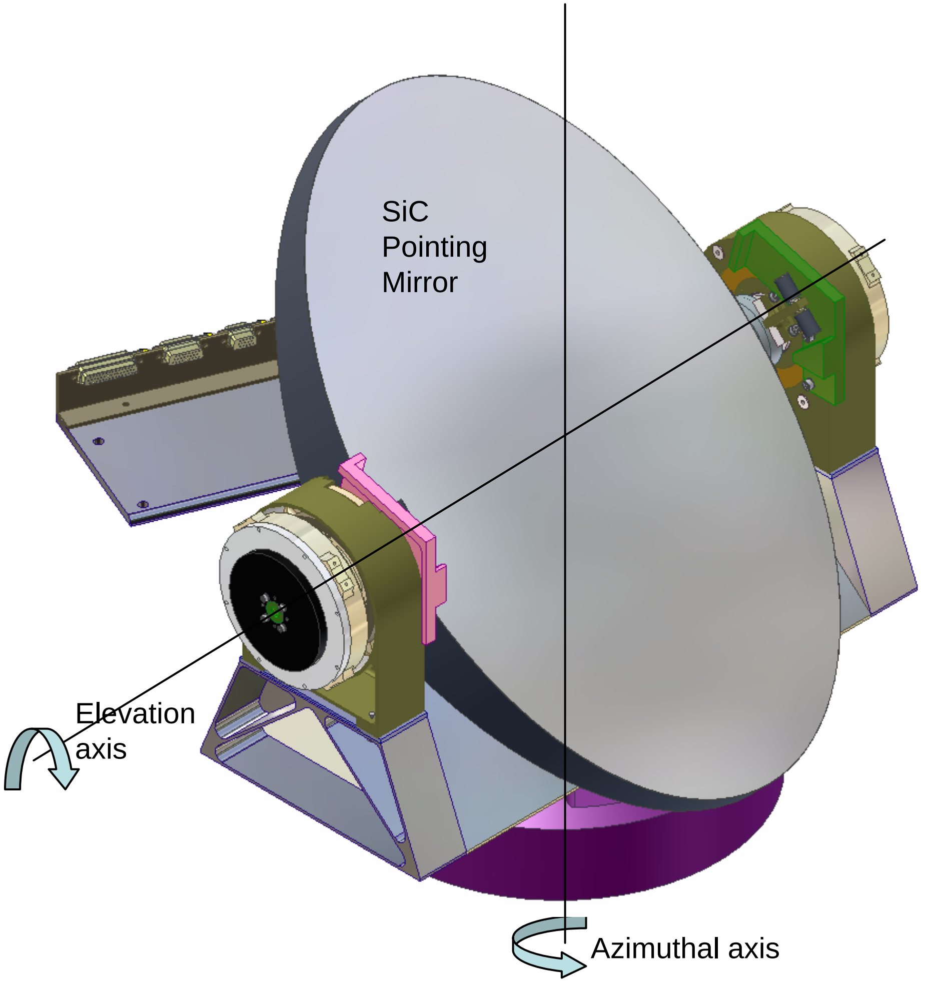
- Low CTE and high thermal conductivity of SiC allow operation with direct solar illumination
  - *Thermal model calculates mirror gradients throughout orbit*
  - *Gradients used to determine thermal-elastic distortion, converted to RMS surface error*
- At 12 Hrs into orbit peak SE from solar loading = 0.052 waves RMS (@ 633 nm)

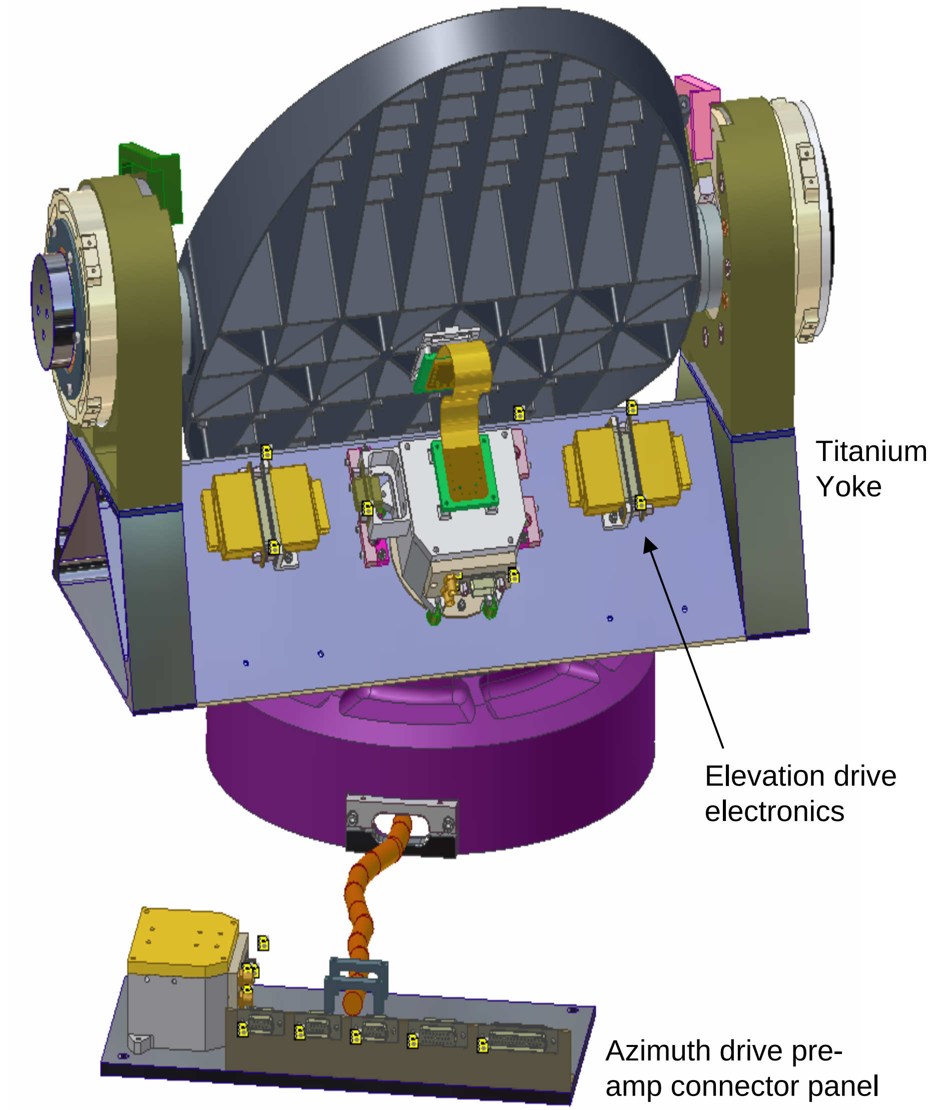


PMGS Requirements

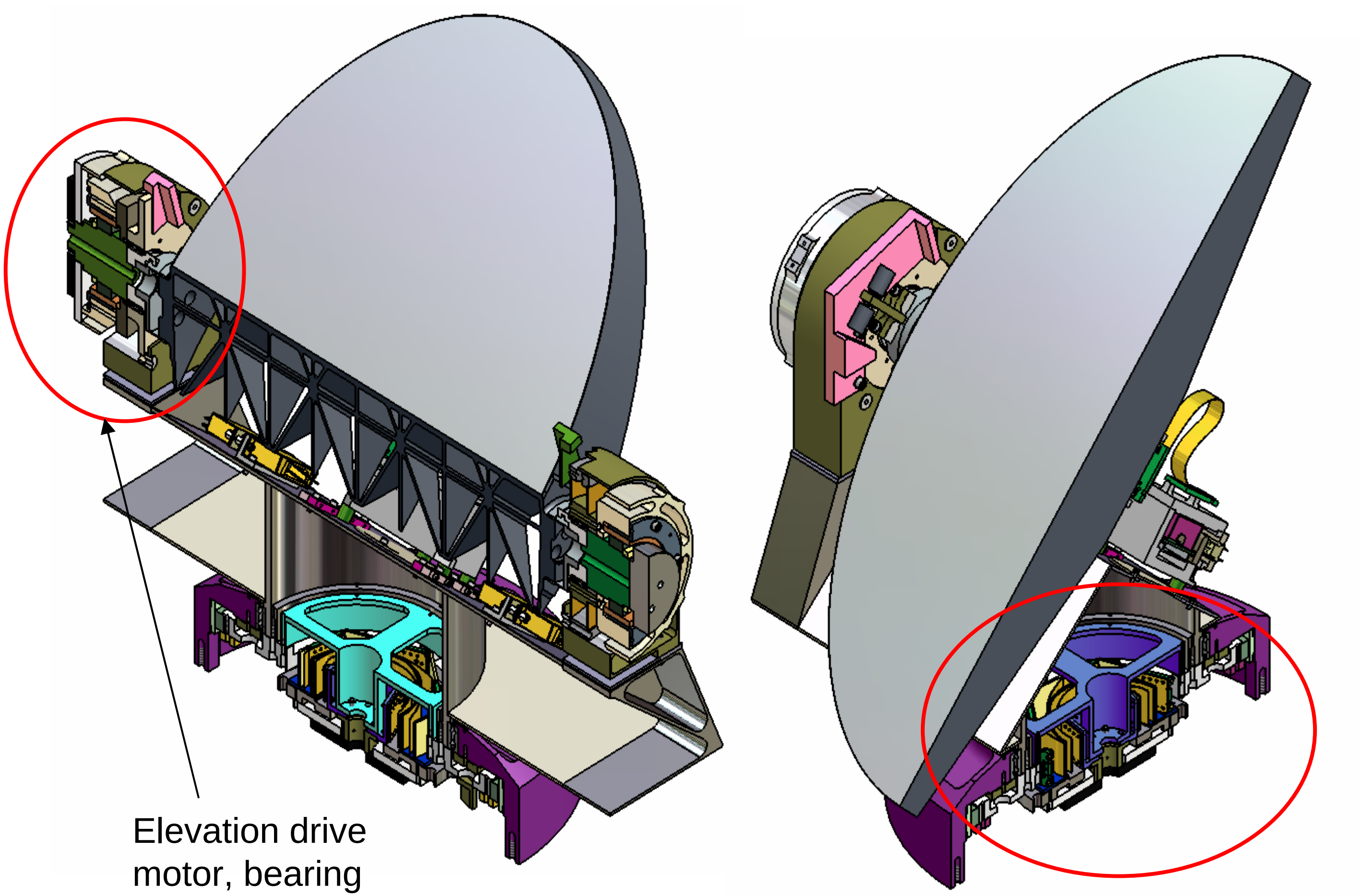
Parameter	Baseline Value	Comments
Mass	$\leq$ 23 Kgs	
Power	$\leq$ 15 Watts Ave	
Envelope	50.5 x 51.3 x 34.8 cm	
Mirror Size	35.8 x 51.4 cm oval	Includes oversizing for fabrication and alignment tolerances
Environment	Laboratory	The basic design is traceable to space flight.
Electronics Radiation Environment	Use GIFTS space flight hardware designs	Build electronics using COTS versions
Outgassing	compliant	compliant, low outgassing coatings, surface treatments and paints will be used
Command Data Rate	per axis every 10 msec	
Measurement Data Rate	per axis, every 10 msec	
Spatial Coverage	20 degree full angle cone	Full earth disk
Bandwidth	> 30 Hz	
LOS sensor resolution	3 urad/axis	
LOS Sensor NEA	5 urad/axis	
LOS sensor accuracy	50 urad/axis	
RMS Wavefront Error	$\leq$ 0.07 waves at 633 nm	Based on total system requirement of <0.12 waves RMS at 633 nm
Clear Aperture	to within 0.5” of edge	

PMGS Design


SiC
Pointing
Mirror
Elevation
axis
Azimuthal axis


Titanium
Yoke
Elevation drive
electronics
Azimuth drive pre-
amp connector panel

Assembly Section Views



Elevation drive motor, bearing and inductosyn position sensor

Azimuth drive motor, bearing and inductosyn position sensor

Custom Kaydon Bearings

Aeroflex brushless DC motors

Farrand Inductosyns

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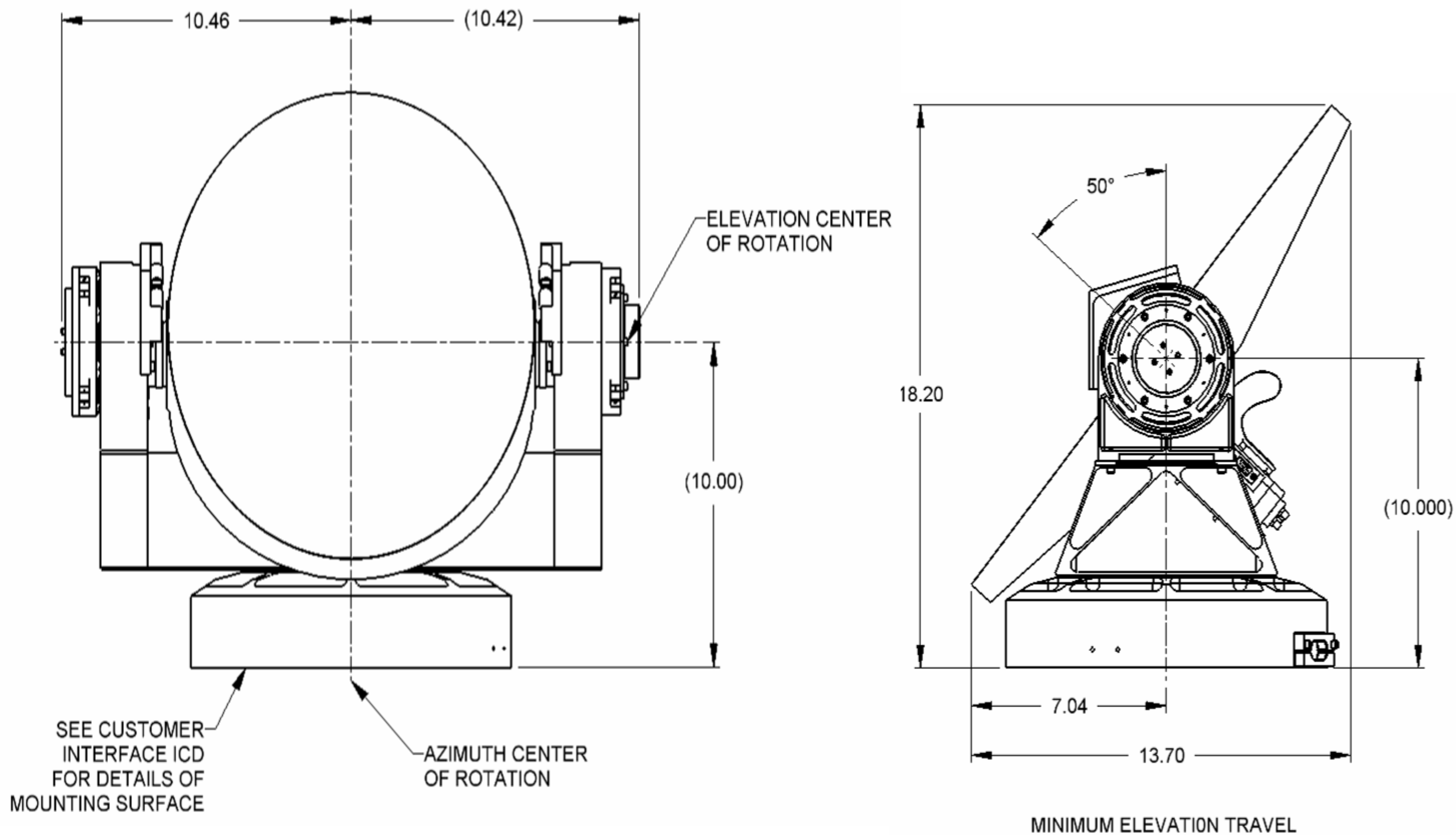
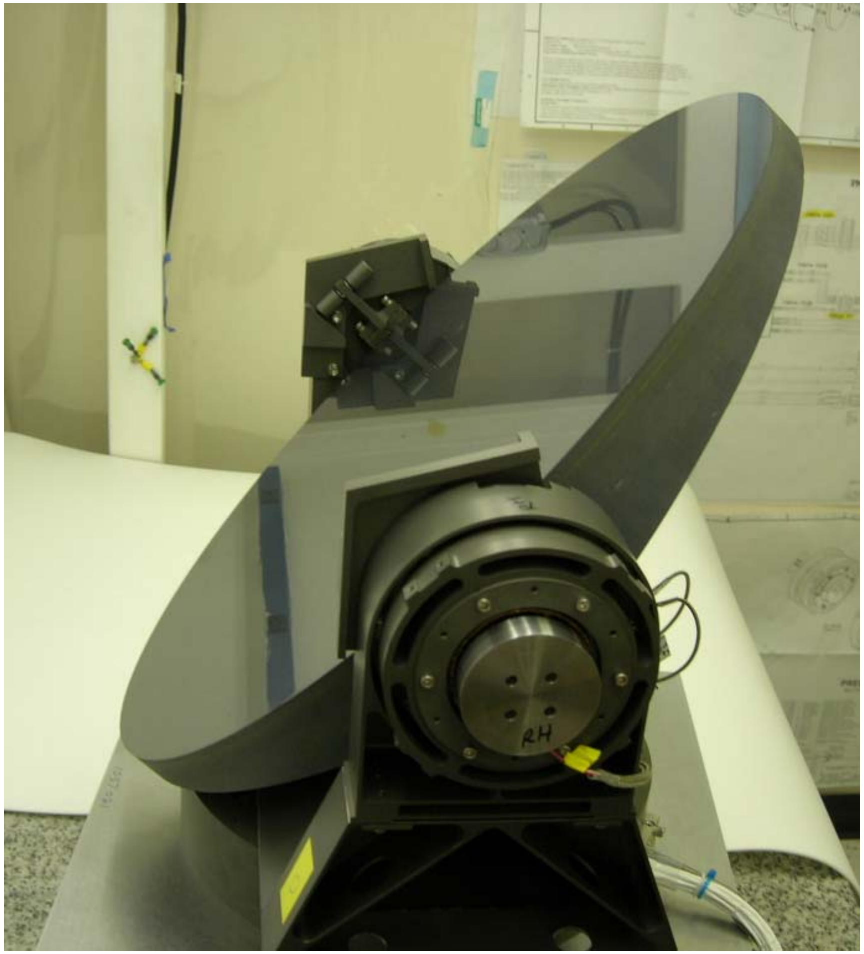
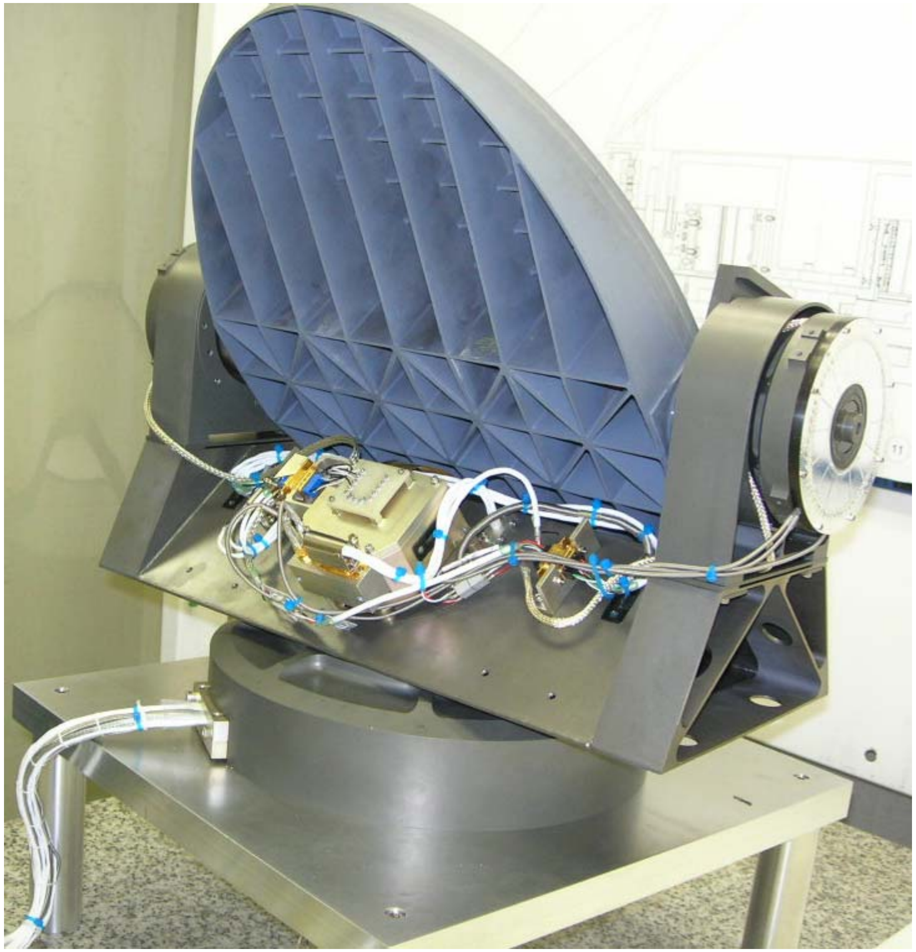
PMGS Envelope

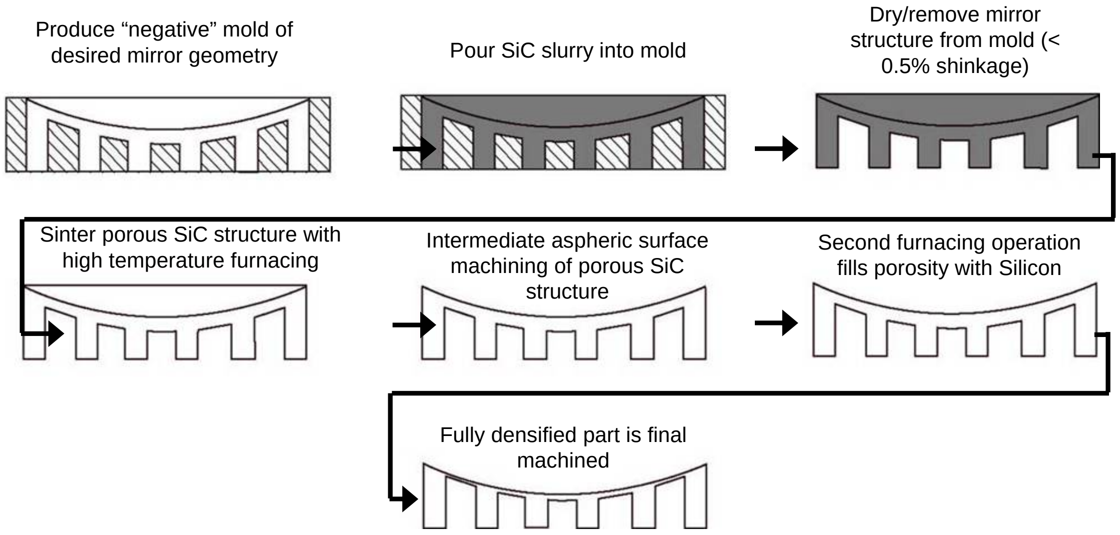


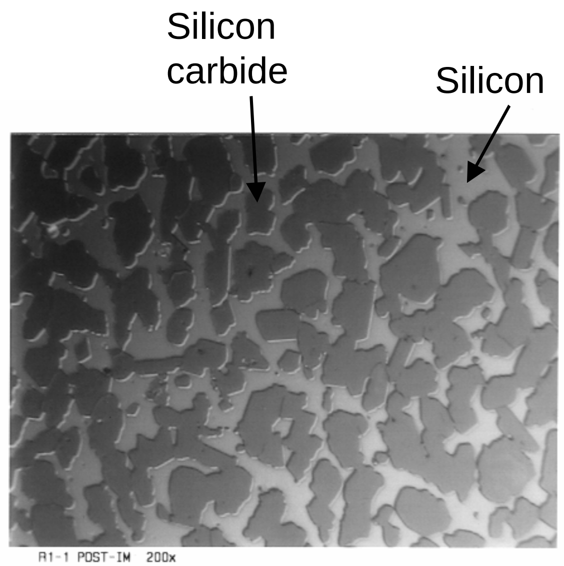
PMGS Hardware in Integration





L3-SSG RB SiC allows Low Cost Manufacturing





RB SiC Microstructure

- Slurry of SiC particles, water and defloculants are slip cast into reusable molds, allowing near-net-shape fabrication of complex features without the need for costly/time-consuming post machining
  - *0.005” – 0.010” typical as-cast tolerances*
  - *Shrinkage during processing < 0.5%*
  - *End product is fully densified with silicon and SiC regions uniformly dispersed throughout the microstructure*
  - *Components can be sinter-bonded together to form more complex structures*

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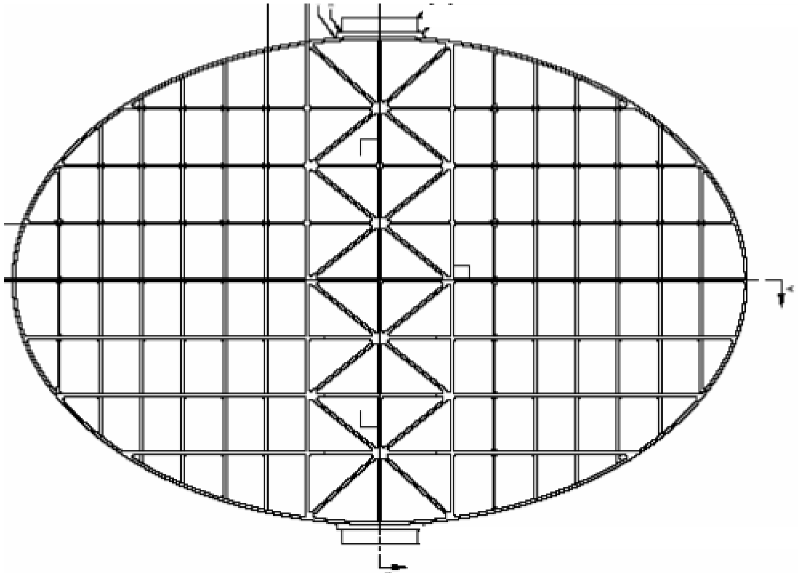
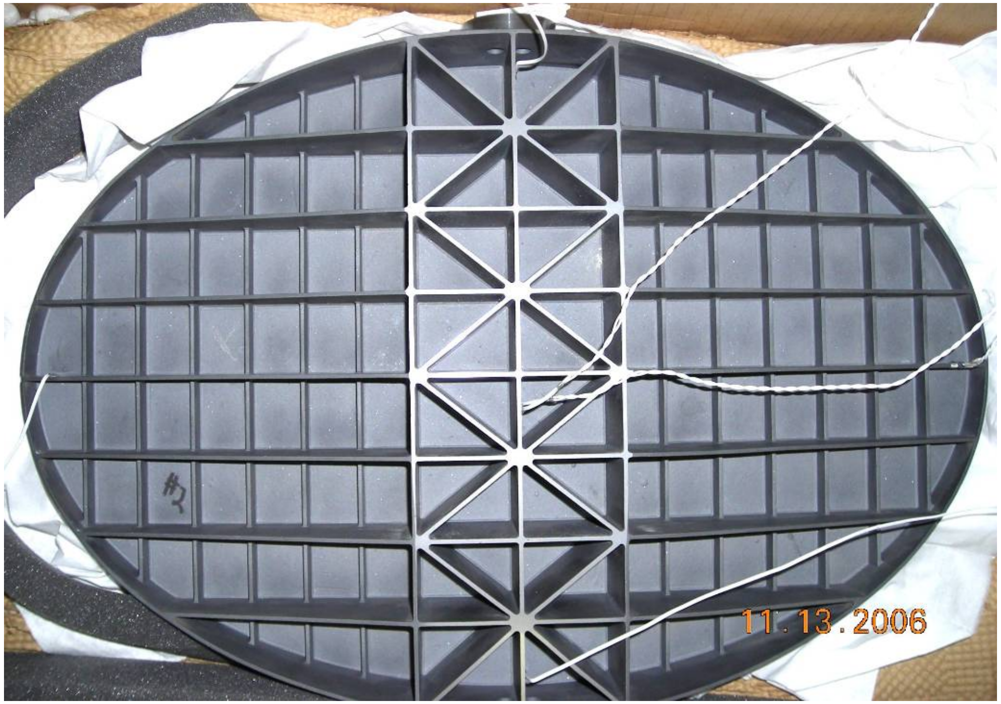
PMGS SiC Scan Mirror Details

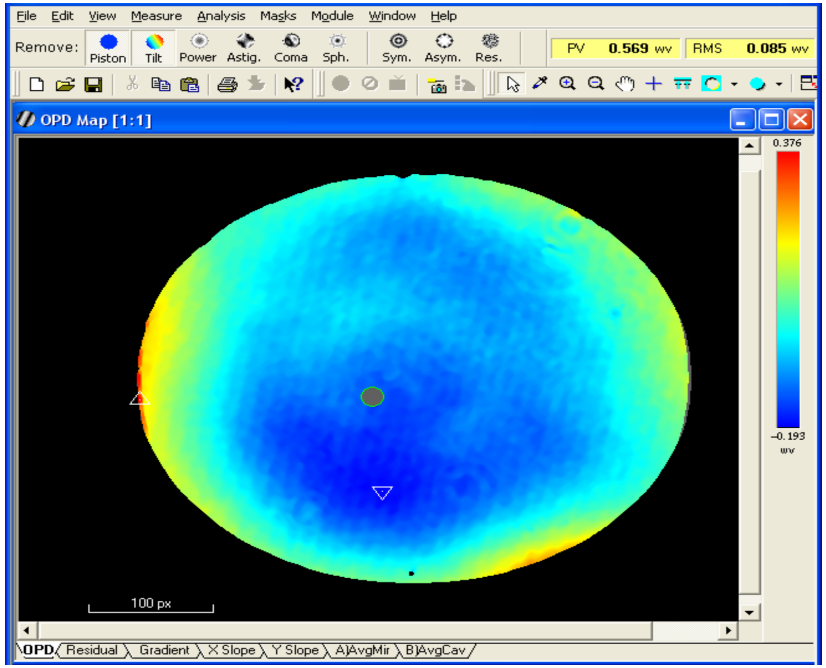


As-Cast RB SiC Mirror Substrates

- Multiple mirror substrates produced using L3-SSG's slip cast Reaction Bonded SiC
- Mirror Geometry
  - *0.125" facesheet*
  - *0.08" rib thickness (typical)*
  - *2.79" mirror depth (deepest section)*
  - *20.25" long axis*
- Mirror mass: 3.6 kgs
  - *Areal Density: 26 kg/m^2*

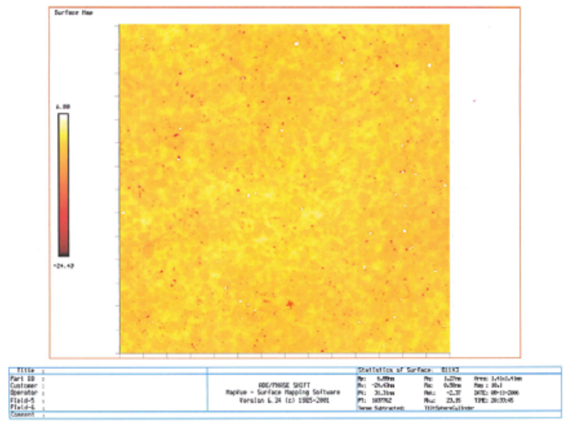
RB SiC Mirror Polishing Results





Surface Figure: 0.08 waves RMS (@ 633 nm)

- Polishing process developed to allow polishing of the two-phased RB material directly
  - *Surface Finish: 12 Angstroms RMS*
- Surface figure achieved adequate for subsequent thermal testing, validation of material stability
  - *Surface Figure: 0.08 waves RMS*



Surface Finish: 1.2 nm RMS

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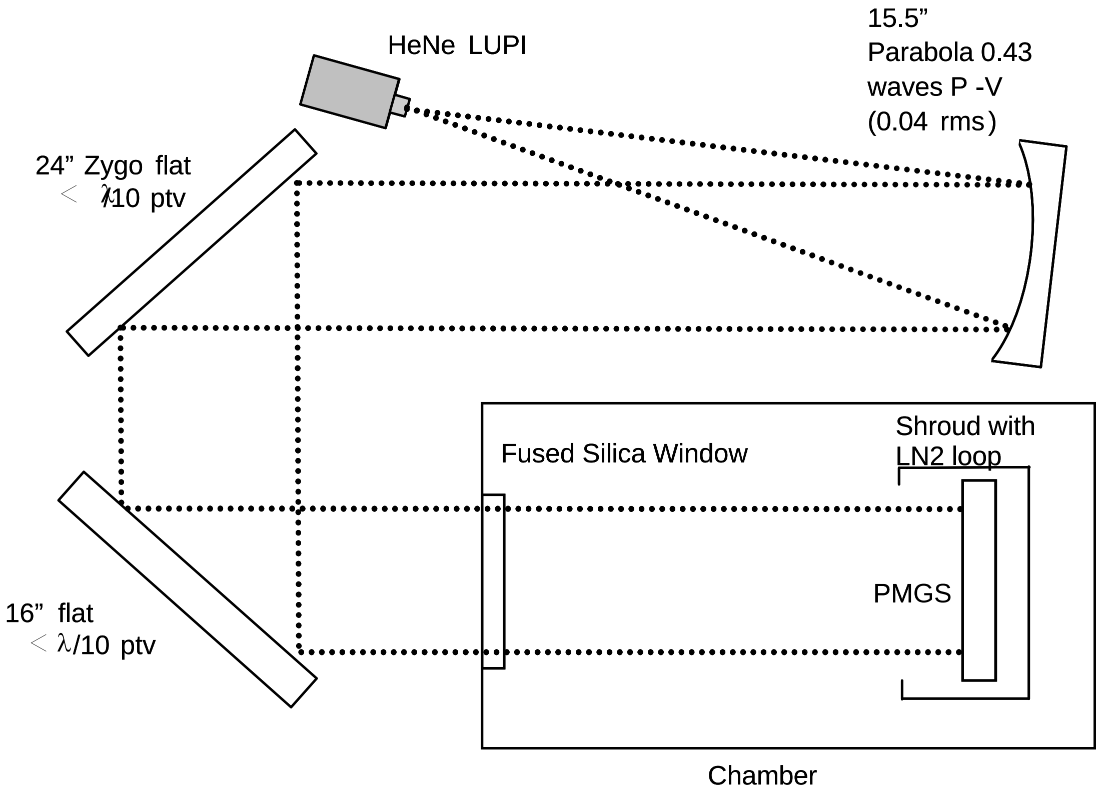
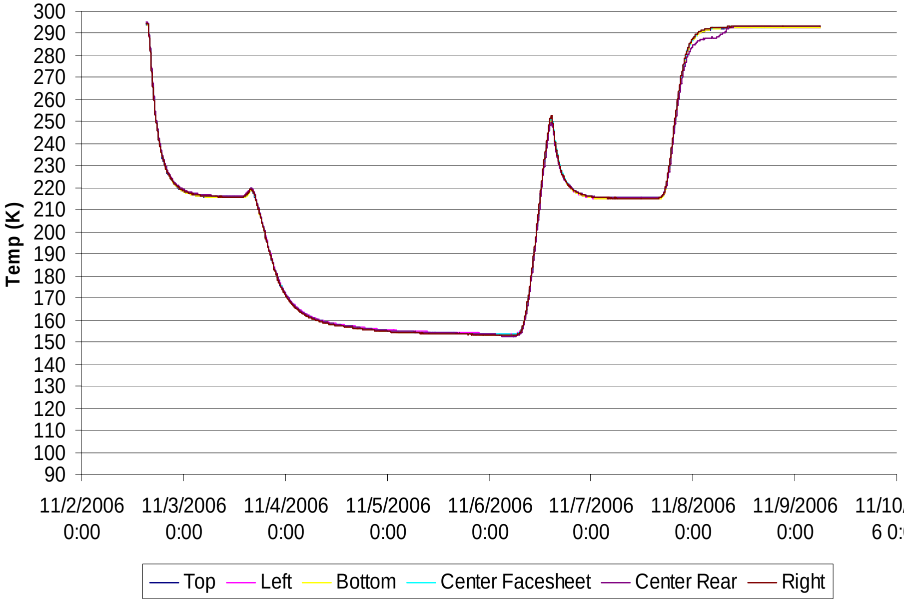
RB SiC PMGS Mirror Cold Test



- Cryogenic testing done to quantify the thermal stability of the PMGS mirror substrate
  - *Testing done over 12” x 14” elliptical sub-aperture*

RB SiC PMGS Mirror Demonstrates Excellent Thermal Stability

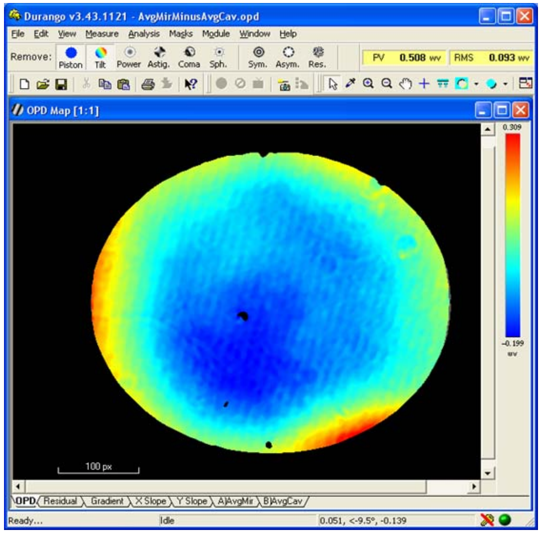


Date Temp (K)	11/1 293	11/3 220	11/6 152	11/7 215	11/8 293
Total	0.093	0.106	0.109	0.119	0.095
Power	0.108	0.133	0.137	0.147	0.118
Astig	0.029	0.046	0.061	0.041	0.032
Coma	0.020	0.029	0.033	0.037	0.016
Spherical	0.020	0.032	0.040	0.031	0.027

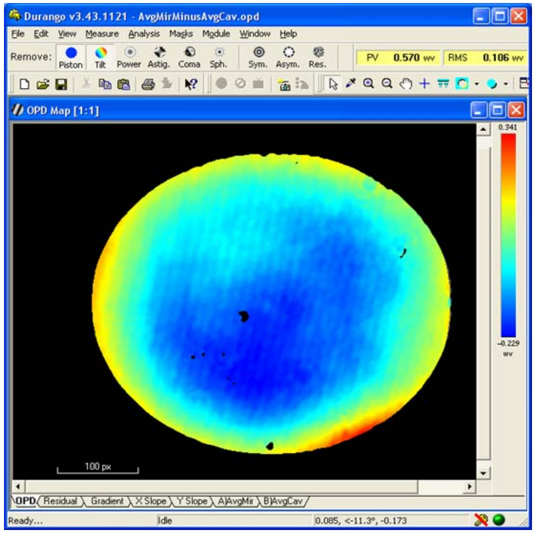
Surface errors in RMS waves (@ λ = 633 nm)

- RB SiC PMGS pointing mirror tested down to cryogenic temperatures
  - *Cycled from ambient (293K) to 152K*
  - *Temp sensors confirm good thermal stability of substrate at each surface figure measurement (< 1 degree gradient)*
  - *Mirror stability to ~ 0.02 wave RMS demonstrated, roughly consistent with test error*

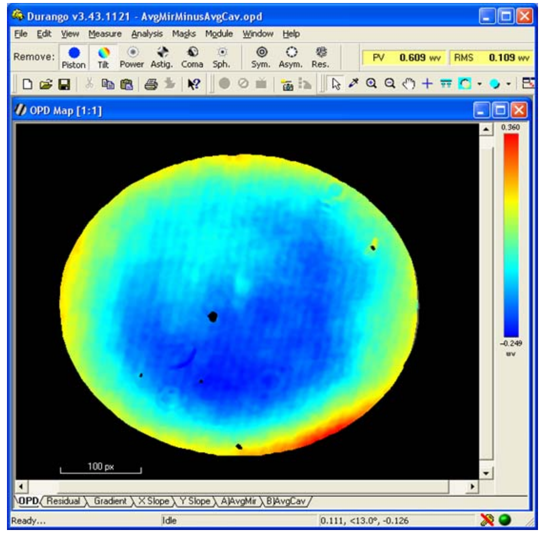
PMGS Wavefront Maps over Temperature



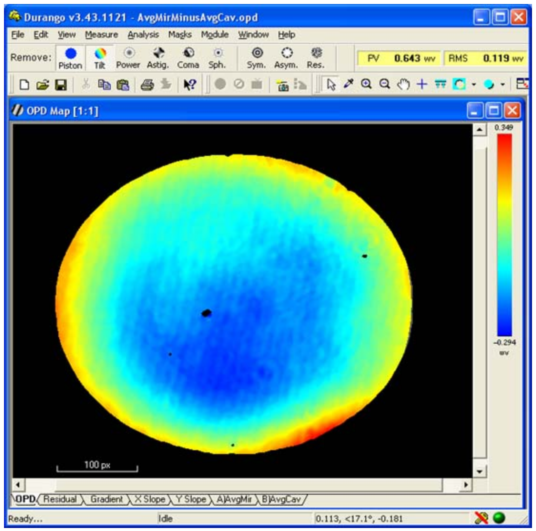
1 Nov: 293



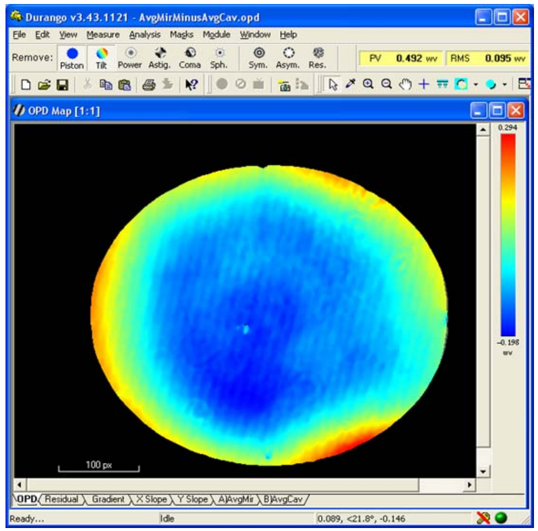
3 Nov: 220K



6 Nov: 152K



7 Nov: 215K

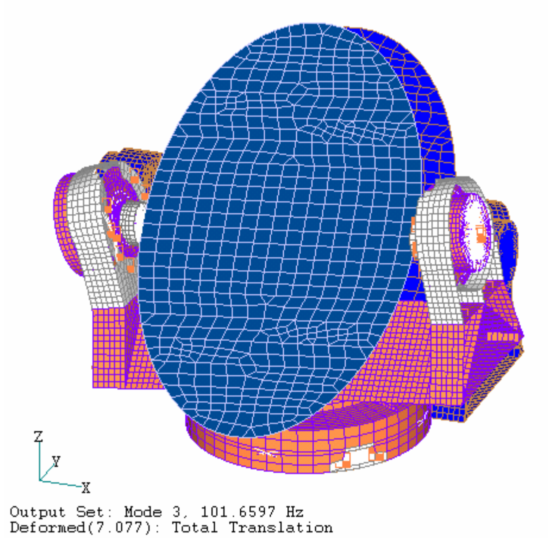


8 Nov: 293K

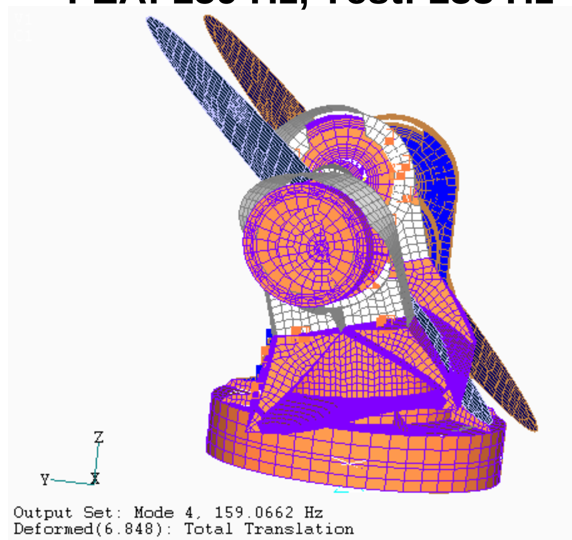
System Level Mechanical Testing

- FEA of the PMGS assembly has been confirmed by modal tap testing
- Tap test results agree well with FEA projections
  - *General agreement within 10%*
- FEA results incorporated into Matlab models in order to obtain closed loop servo modeling

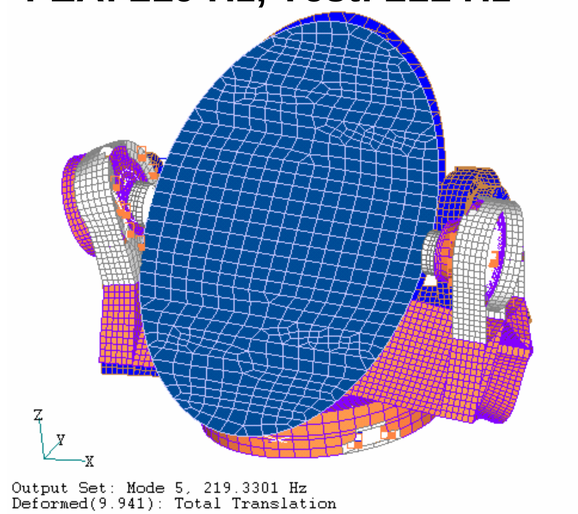
FEA: 102 Hz, Test: 93 Hz



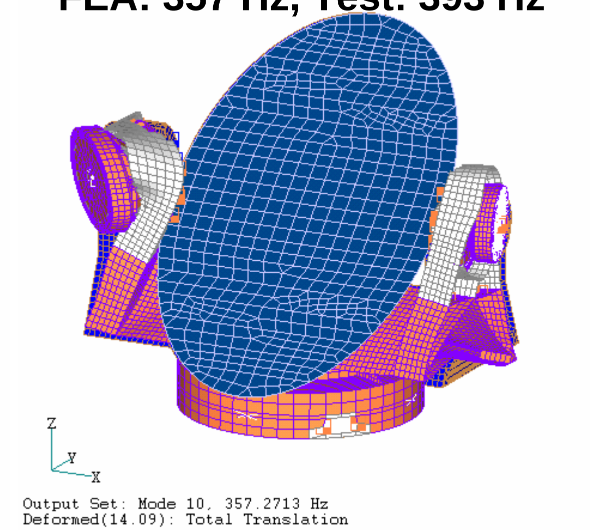
FEA: 159 Hz, Test: 138 Hz



FEA: 219 Hz, Test: 211 Hz



FEA: 357 Hz, Test: 393 Hz



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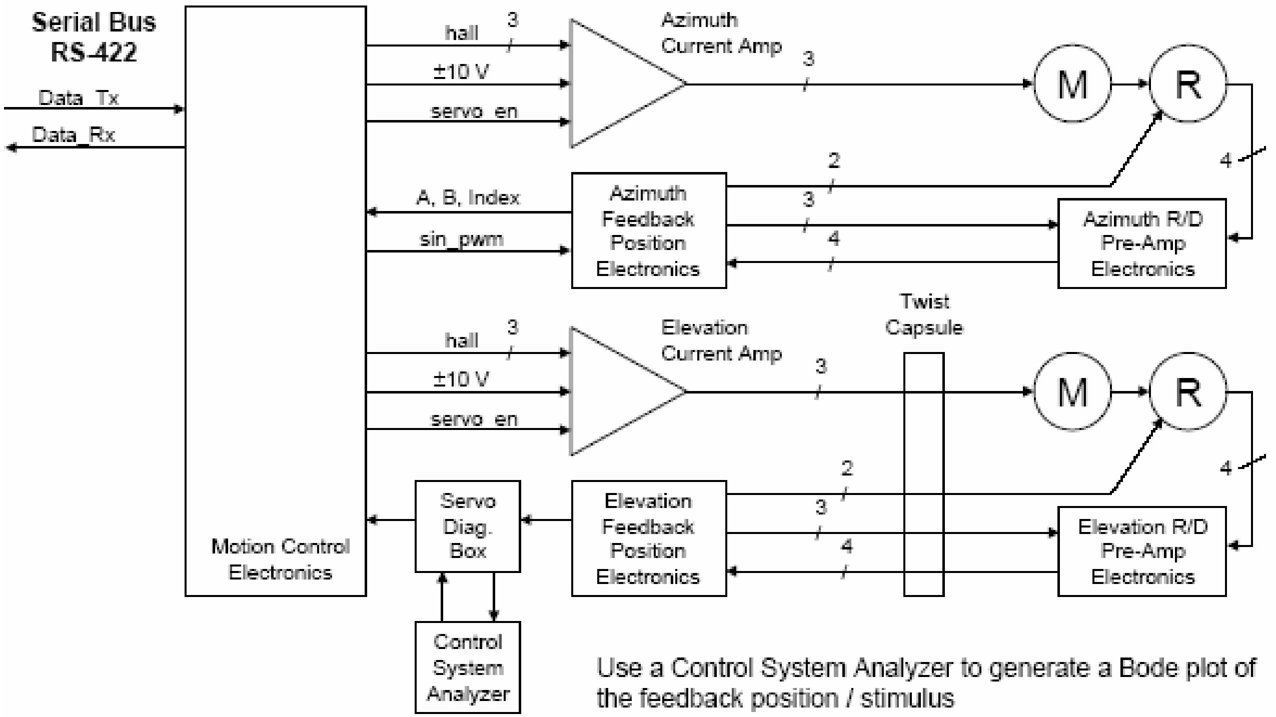
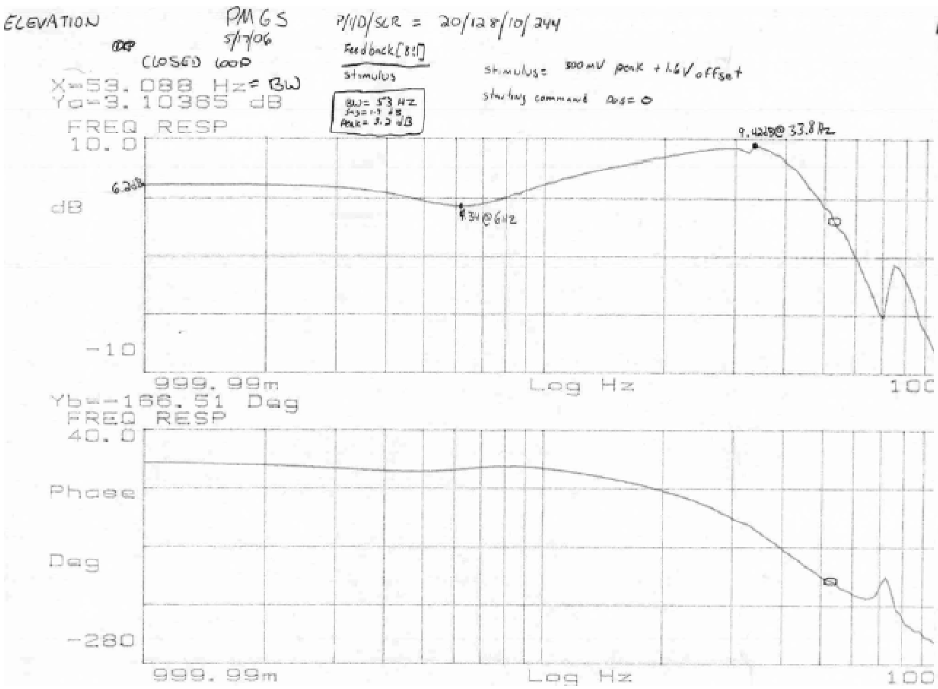
PMGS Closed Loop Servo Testing



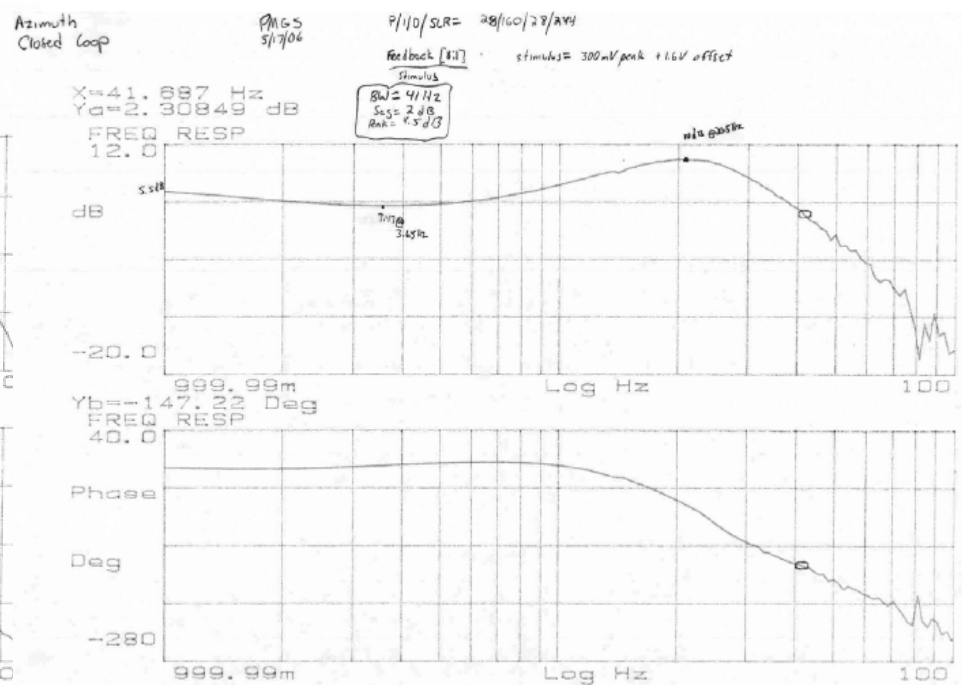
- Closed loop performance of the PMGS system measured with test schematic shown
- Control system analyzer used to generate input stimuli for each axis
- Open and closed loop responses/Bode plots collected
  - *Servo loops closed with unpolished SiC mirror substrate*
- Both axes exceed requirements with significant phase margin
  - *Azimuth: 41 Hz closed loop*
  - *Elevation: 53 Hz closed loop*

PMGS Closed Loop Servo Results



PMGS Elevation Axis Closed Loop Transfer Function, Magnitude and Phase

- Closed loop BW: 53 Hz



PMGS Azimuth Axis Closed Loop Transfer Function, Magnitude and Phase

- Closed loop BW: 41 Hz

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GIFTS Flight PMA

- PMGS components have heritage to flight GIFTS PMA developed for USU/SDL
  - *RB SiC scan flat*
    - 45 x 30 cm
    - Bare RB SiC polished mirror
  - *Beryllium yoke to maximize bandwidth*
  - *Closed loop control to > 100 Hz demonstrated*

	Azimuth	Elevation
	-----------	------------
Bandwidth, -3dB closed loop	100 Hz	107 Hz
Phase Margin, 0 dB open loop	42 deg	45 deg
Jitter, standard deviation (500 samples)	0.5 uR	0.9 uR
Repeatability after homing	1.5uR	1.5uR
Repeatability after stepping	1.5uR	1.5uR
Step & Settle, 14 mR move	560 ms	560 ms
Following error, 14 mR move	<15 uR	<15 uR

Summary

- Wide field of view, two-axis SiC gimbal pointing mirror has been demonstrated
- System leverages off of several approaches developed for the GIFTS PMA
- RB SiC allows operation under stressing thermal loads, suitable for use with direct solar loading of the pointing mirror
- System level structural modes, and servo performance has been confirmed
  - *Closed loop performance exceeds requirements of 30 Hz bandwidth*
  - *GIFTS flight system has been improved (Be yoke) to achieve 100 Hz bandwidth*
- Modified polishing process has demonstrated the ability to achieve visibile quality surface finish in the bare RB SiC material
- Thermal stability of the RB SiC material has been quantified with cryogenic testing
- Acknowledgements
  - *System work performed under AFRL contract # FA9453-04-C-0031*
    - Dr. Brett Deblonk/AFRL TPOC
  - *Team at L3-SSG-Tinsley: A. Akerstrom, D. Crompton, P. Cucchiaro, G. Deveau, S. Frey, P. Laquidara, S. Mason, M. Peters, C. Ullathorne*
  - *Polishing development and substrate testing done with L3-SSG-Tinsley IRAD*