Thermal Stability of a 4 meter Primary Reflector for the Scanning Microwave Limb Sounder (SMLS)

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Overview

- SMLS measur
  concepts
- Design and an
- Reflector fabric
  - Demonstra
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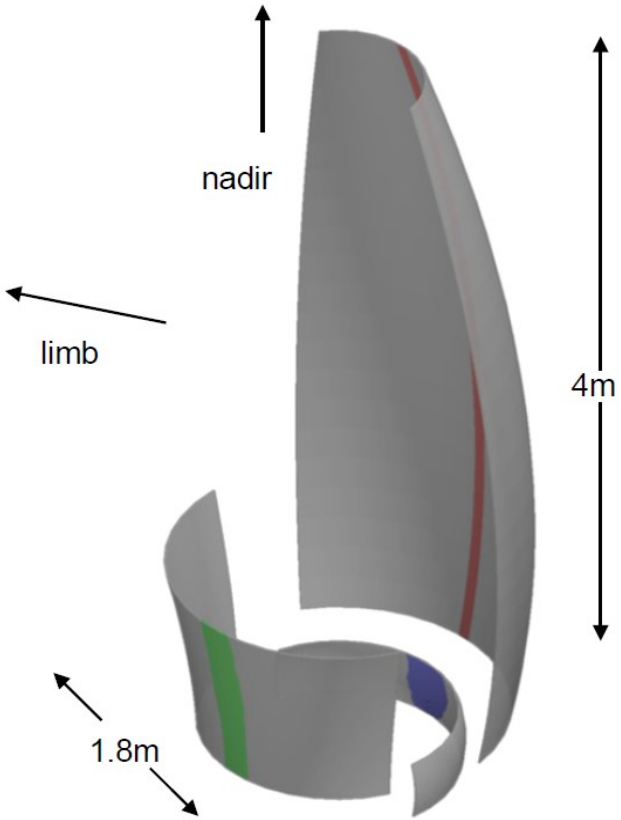
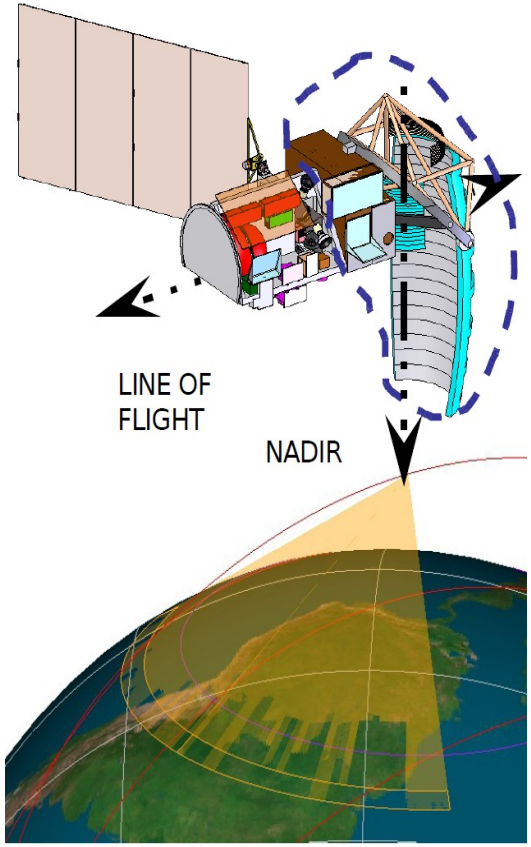
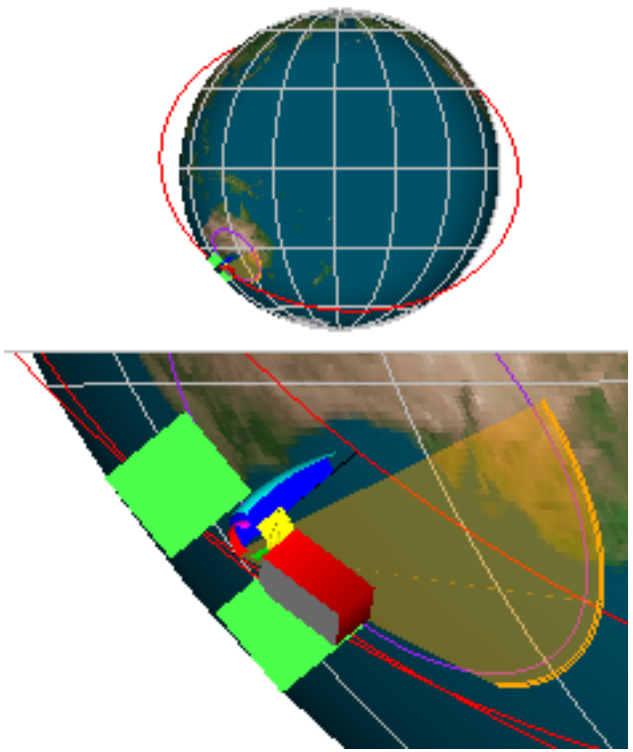
  - Breadboar
    current pro
- Summary and





Limbsounding Science Requirements and Orbit

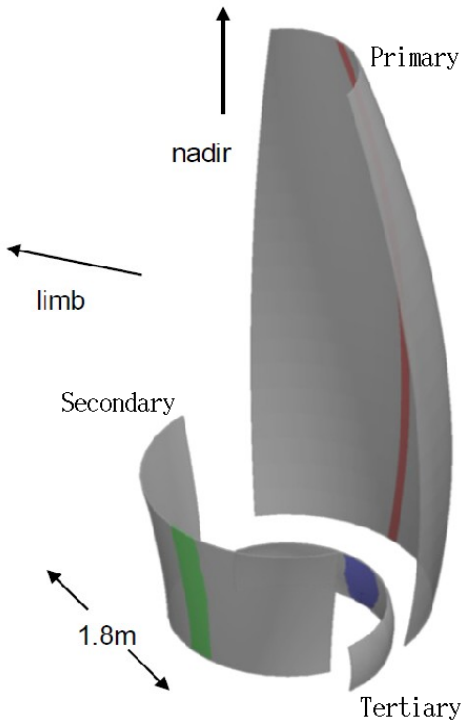
- SMLS observes thermal emission from Earth's atmospheric limb.
  - Parameters/Species measured include pressure/temperature, geopotential height, cloud ice, H_2O, O_3, ClO, HCL, N_2O, HNO_3, SO_2, CO, HOCl, BrO, and many other trace gases in the stratosphere and upper troposphere.
  - Frequency bands cover 180–280 GHz and 620–680 GHz (heterodyne radiometers in mm/sub-mm wavelength regimes)
- SMLS was identified in the 2007 NRC Decadal Survey for a Global Atmospheric Composition Mission (GACM)
- Coverage and resolution will be greatly improved over previous MLS instruments (UARS 1991–7, Aura MLS 2004–present)
- Understanding in-orbit antenna thermal performance is key to success of SMLS.



SMLS antenna viewed from Sun in 830 km, 52° inclination GACM orbit at time of worst-case solar heat load

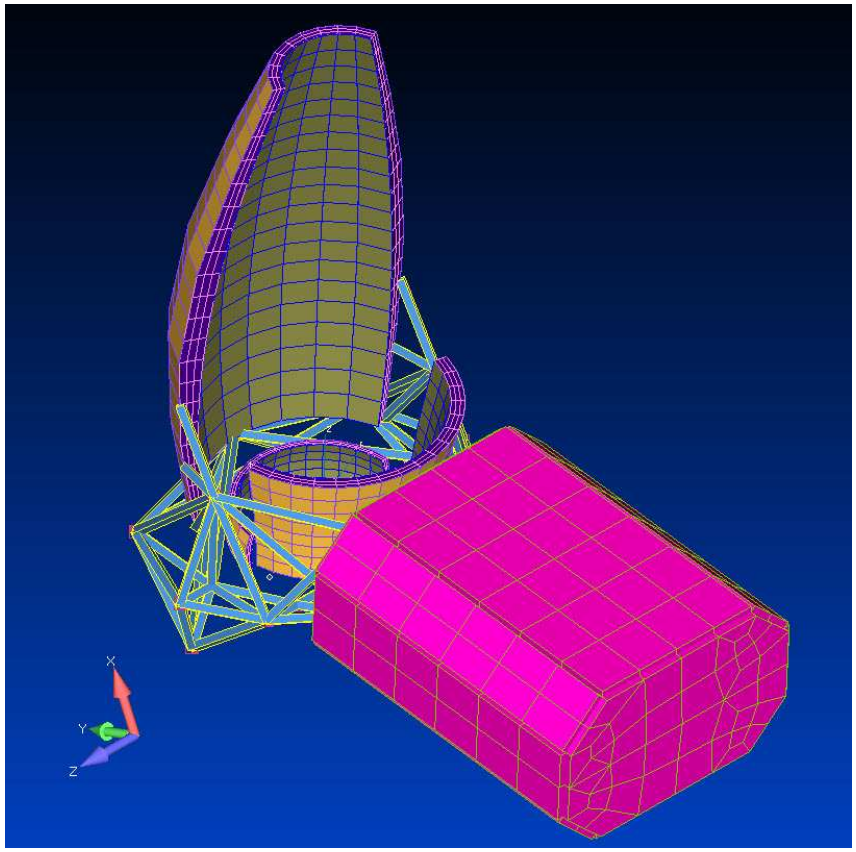
SMLS antenna concept

- The toric Cassegrain antenna designed for SMLS provides azimuth-independent scanning over a $\pm 65^\circ$ swath of a conical scan from the 830km GACM orbit. ([Cofield *et al.*, Proc.SPIE **4849**, 2002])
  - Primary, Secondary and Tertiary surfaces are generated by rotating conic sections about a common toric axis in the nadir direction.
  - Proper choice of the conic foci and the toric axis transforms a feed pattern with circular symmetry into a very narrow vertical illumination of the Primary.
  - The resulting footprint is diffraction limited in the limb vertical direction and $\sim 20\times$ broader, independent of azimuth, in the horizontal.
  - A small ($\sim$ 10 cm diameter) mirror scans the beam over the antenna, while a slower $\sim 2^\circ$ nod of the entire antenna provides the vertical scan.

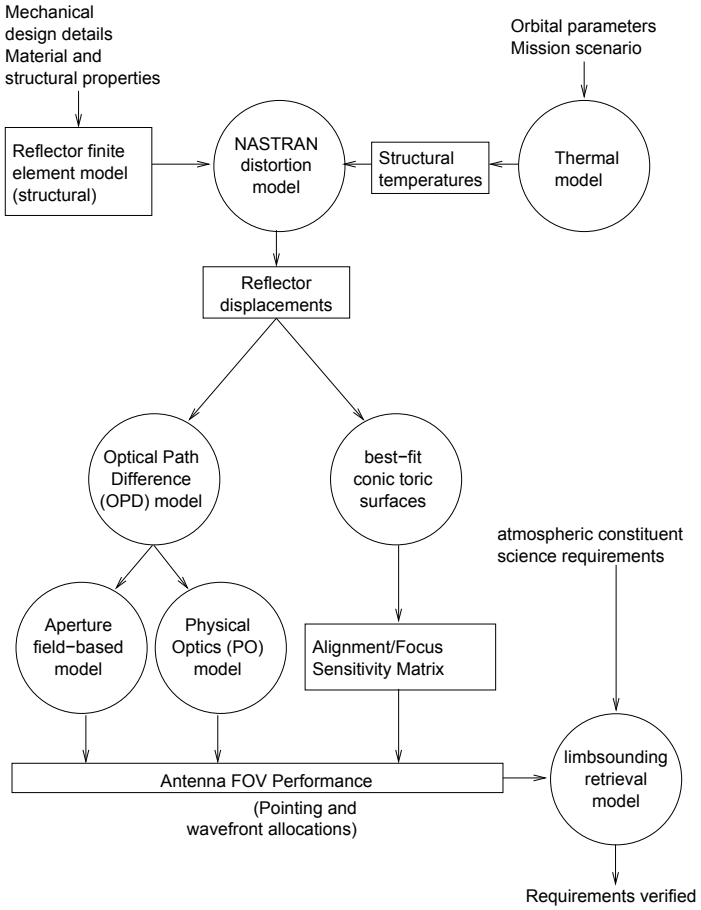


Footprints of the +10° azimuth pixel on SMLS Primary, Secondary and Tertiary reflectors

SMLS finite element models



(a)



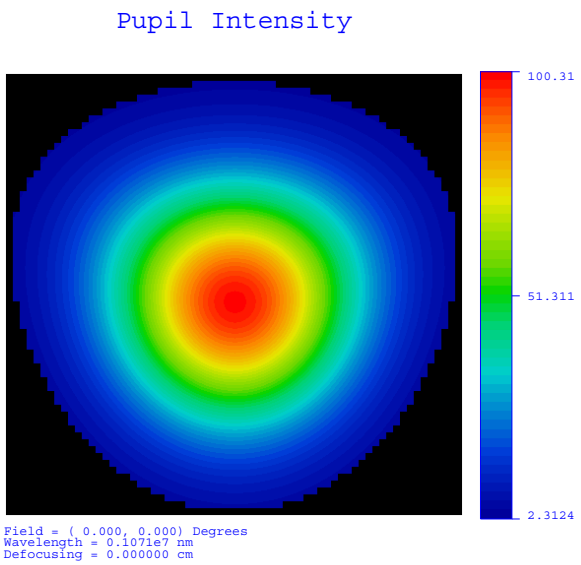
(b)

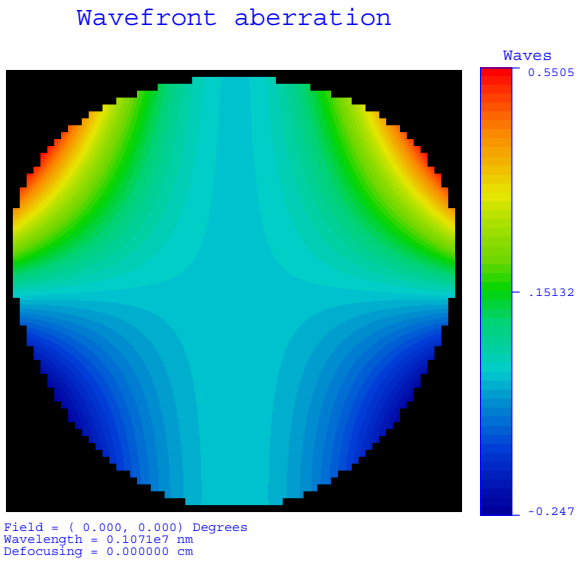
- Primary material properties from reflector fab.
  - Aluminum secondary, tertiary, truss for breadboard
- surface treatments as on Aura MLS
- Notional spacecraft bus (“sunshade”)

- **I-deas** environment hosts mechanical, thermal models
- Ray-trace and physical optics models from UARS, Aura MLS heritage
- Atmospheric retrievals from Aura MLS heritage

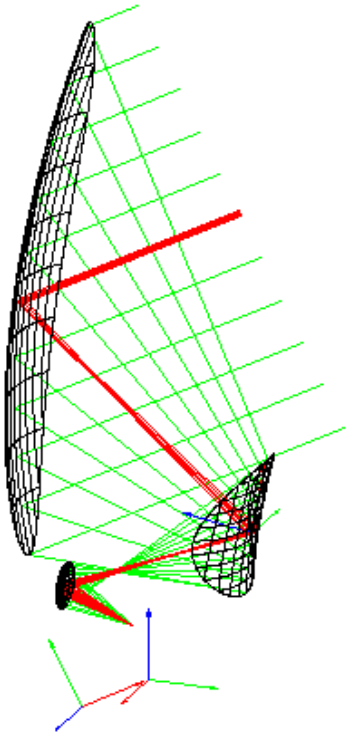
Exit pupil maps for undistorted receive mode

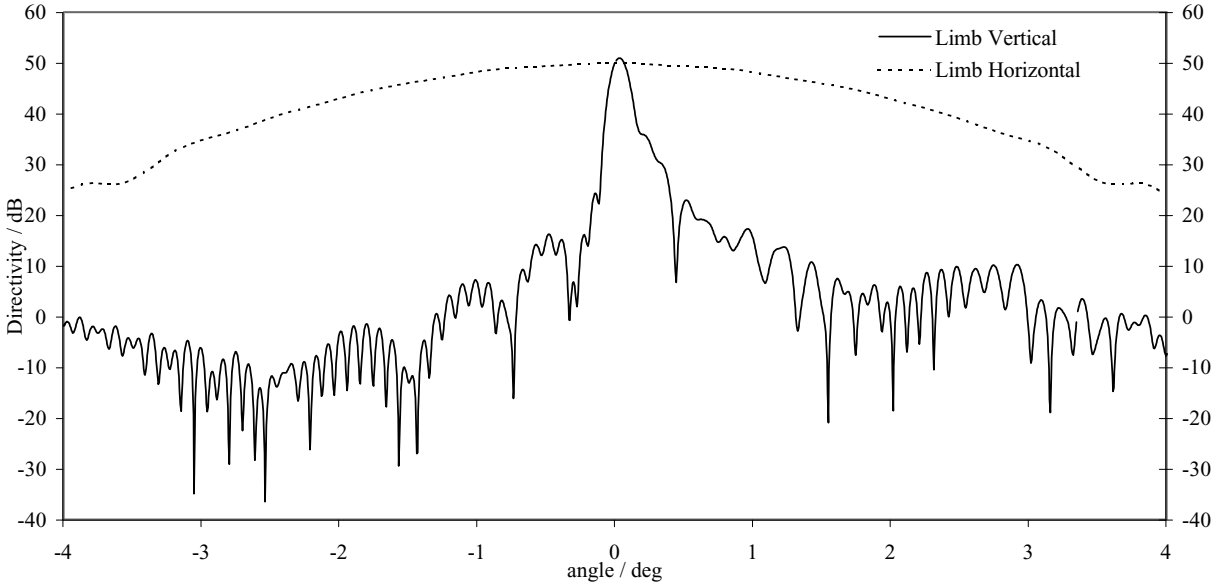
- Gaussian illumination
  - -20 dB edge taper
  - 280 GHz (atmospheric retrievals most sensitive to beam performance)
- Cumbersome surface models in Code V suggested alternative optical models
  - Optical Path Difference ($\mathrm{OPD} = 2\hat{n} \cdot \vec{\delta} \cos\theta_i$) model best for quick evaluation of surface distortion effect
  - Physical Optics formulation most accurate for electrically small antennas; easiest to model feed horns, other mm-wave components
  - Transmit mode easier to combine with atmospheric retrieval model.





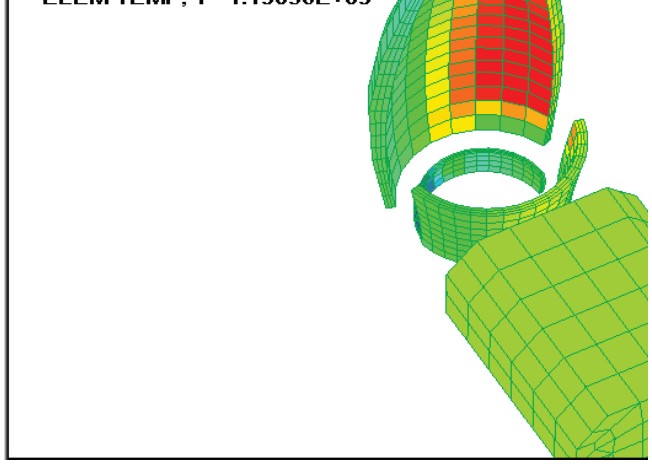
SMLS physical optics model





- principal ray fans: 1:1 → 20:1 beam
- surface currents integrated over more than pixel footprint for pattern accuracy

- Far-field pattern angular scale from 2002 design
- sidelobe asymmetry results from wavefront errors at edge of azimuth pixel
  - same shape for all pixels except near edge
  - characterized before launch for atmospheric retrievals
  - additional effect of thermal distortions from models and breadboard measurements.



Thermal model: A
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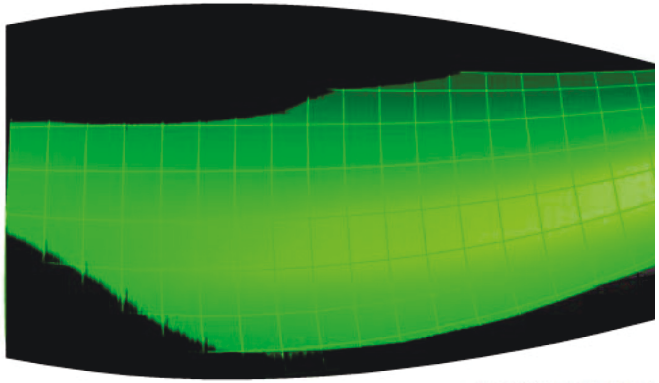
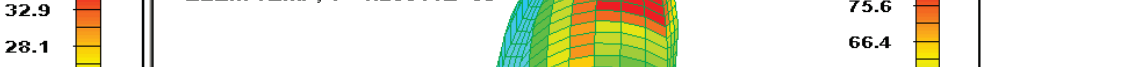
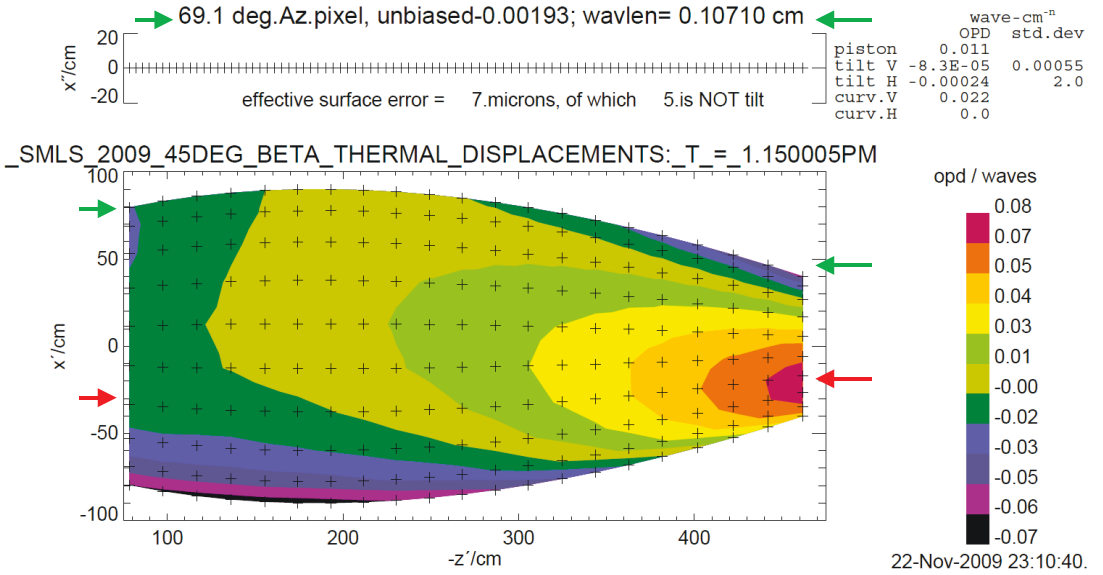
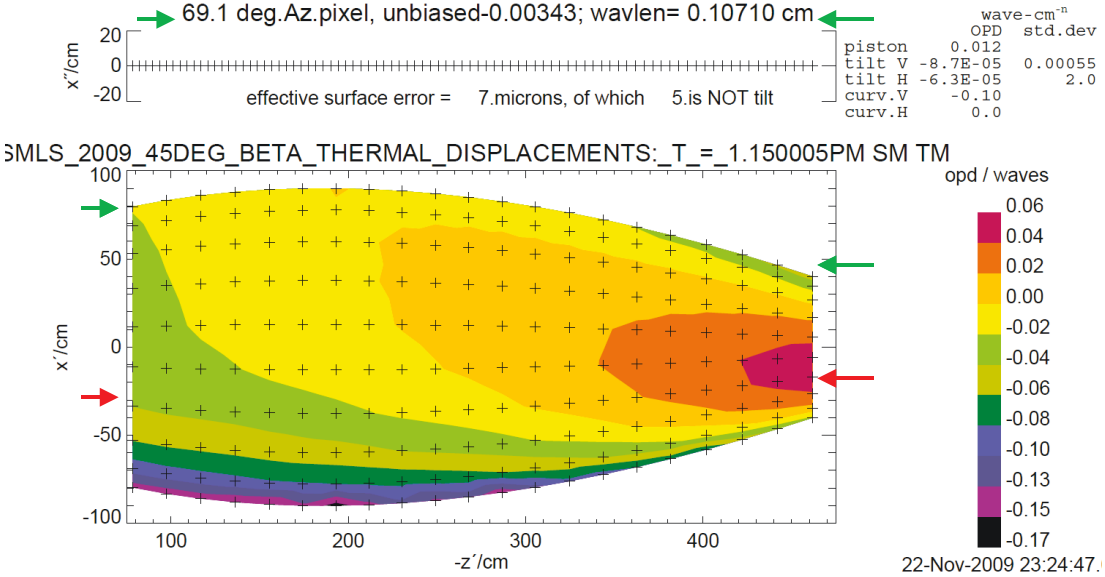


deformations exaggerated 5000×

Primary refle
Optical F







OPD: Primary alone (above); entire antenna (below)

Demon

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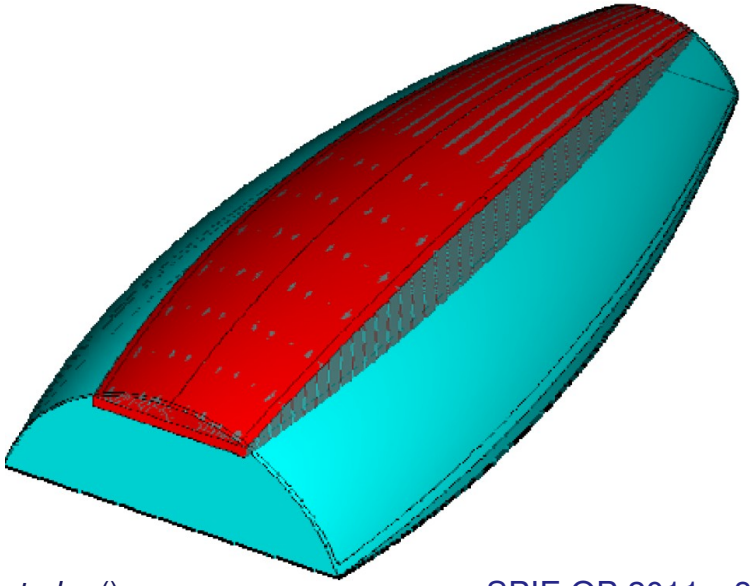
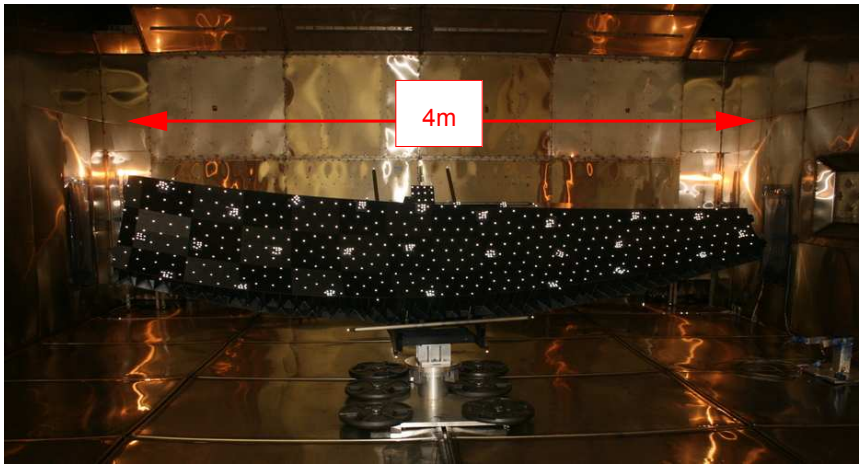
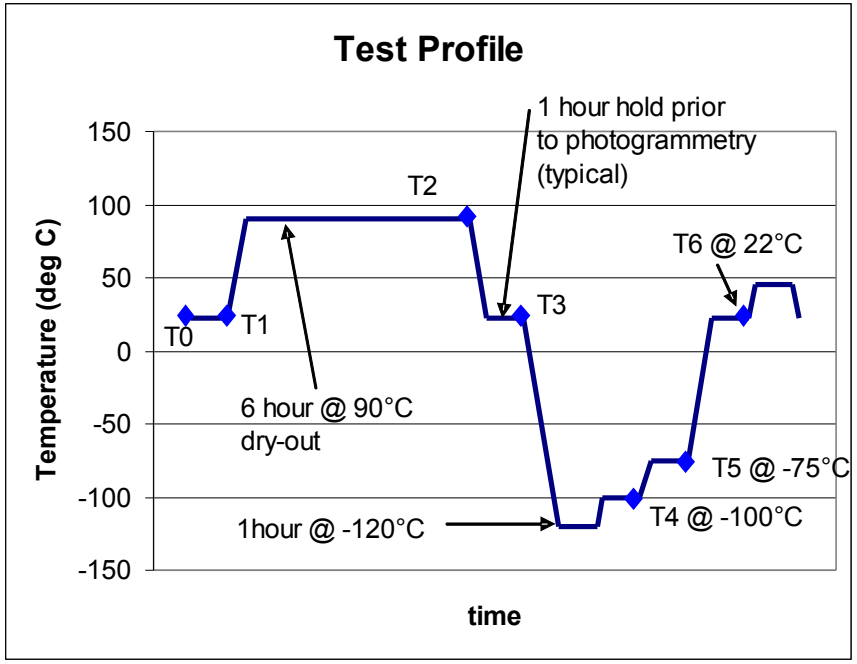


Thermal soak test of demonstration reflector

- Tests in air at Wyle Lab.s chamber, 2009; funded by Earth Science Technology Office (ESTO)
- 362 photogrammetry targets at rib/face-sheet junctions
- Soak ΔT exceeds orbit prediction by $\sim 7\times$; infer effective measurement accuracy $\sim 2\mu$m
- maintained $\sim 38\mu$m rms from best-fit-toric through test,
  - figure changes appear in toric coefficients
- Current work refines initial order-of-magnitude correlation with FEM

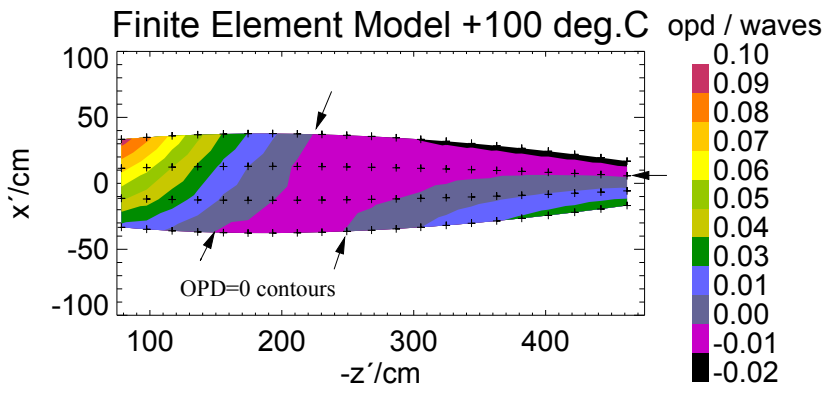




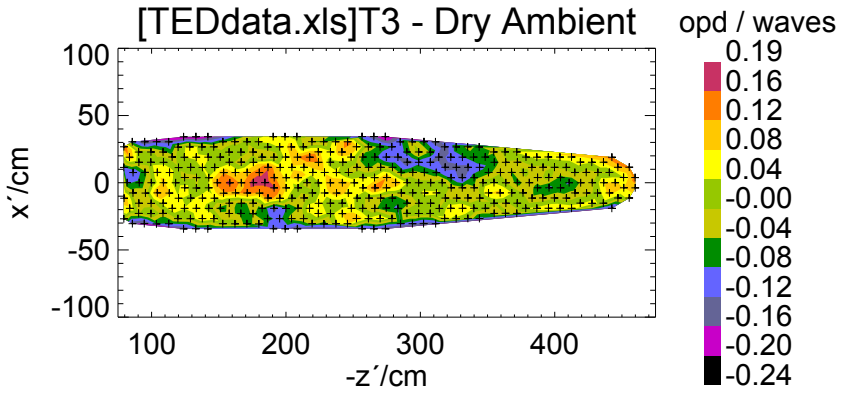
Thermal soak test correlation with FEM

OPD maps of demonstration reflector in thermal soak test configuration:

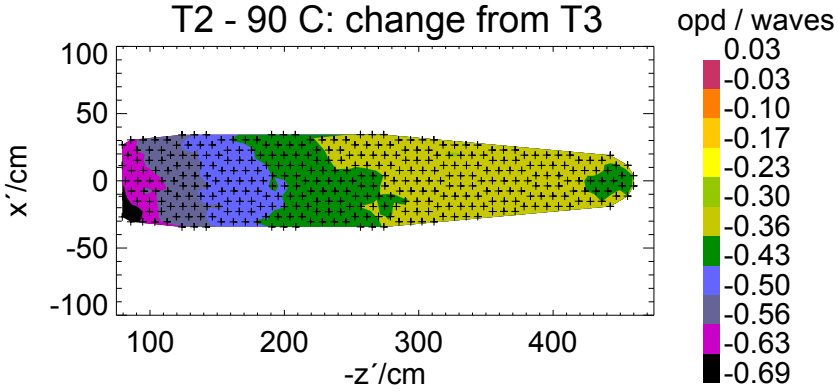
prediction



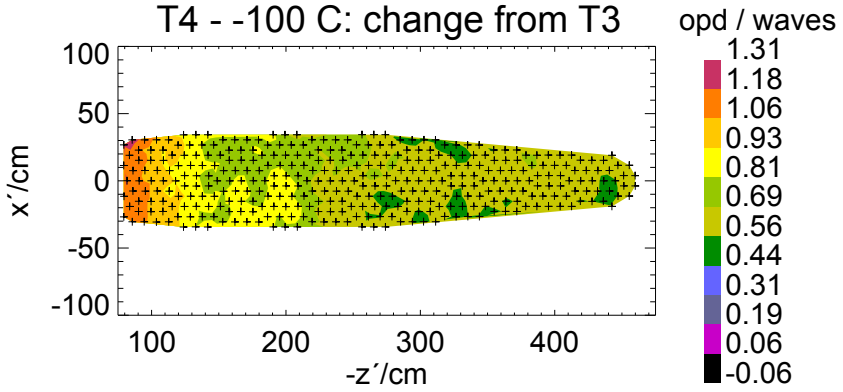
measurement



Hot case



-100° C - ambient

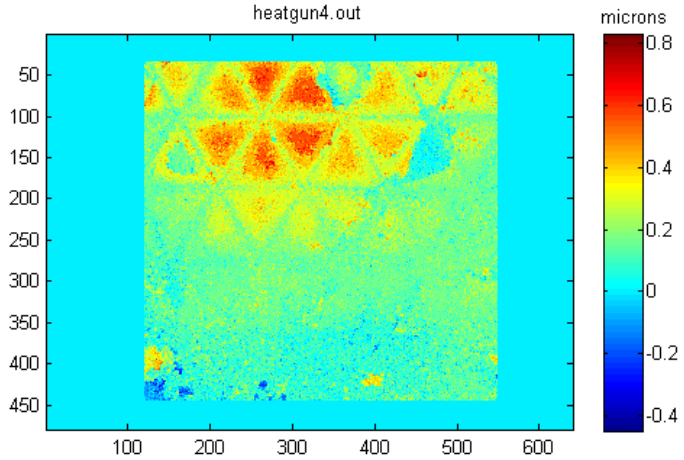


Correlation analysis: adjust model material properties to match measured OPD changes

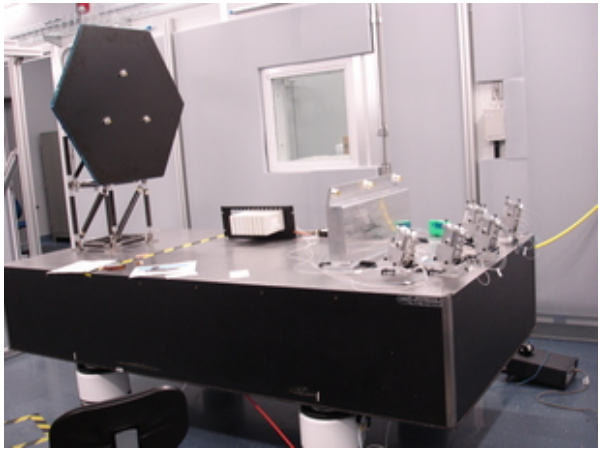
Breadboard Reflector Fabrication Plans

- Through a contract with Vanguard Space Technologies, we are pursuing a 1.8 $\times$ 4 meter composite Primary with better surface accuracy than the SBIR demonstration reflector and thermal properties meeting SMLS FOV performance requirements in the expected GACM environment.
  - Preliminary quotes have identified vendors for the large mold, machining to a 680 GHz surface and μm-level surface verification on a state-of-the-art Coordinate Measuring Machine (CMM).
  - Contingencies involve an alignment/assembly truss, re-machining the SBIR mold, and making the full-width primary in 3 petals.
  - Through SBIRs, Vanguard continues to study replication errors (*e.g.* "spring-back" after the reflector face skin is cured on and then released from the mold). In the case of Aura MLS, with a 3 μm rms mold, such errors resulted in a 5.5 μm rms reflector.
  - The current schedule calls for a preliminary design at the end of year 1, fabrication beginning in year 2, and delivery early in year 3.

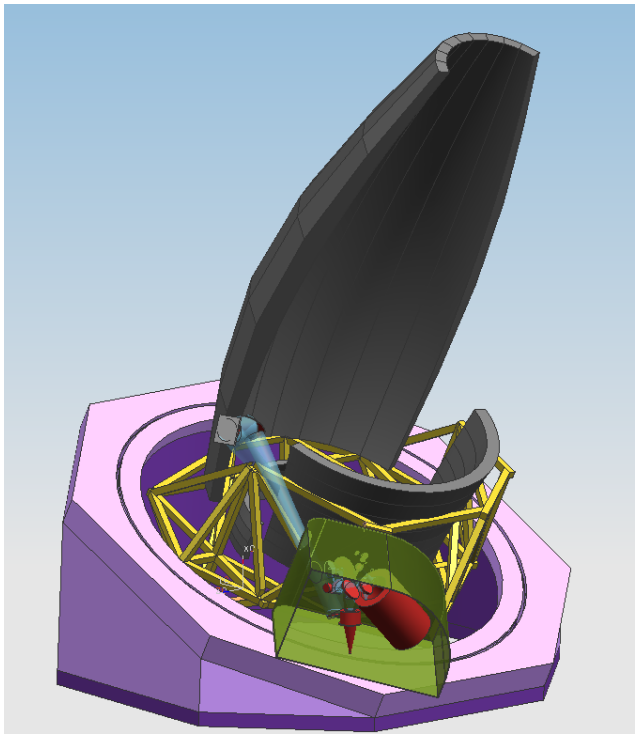
Metrology techniques for SMLS breadboard antenna



- *Speckle interferometry* measures relative displacement over entire aperture



- *Laser Ranging interferometry* sensor measures absolute position at selected peripheral points.



- Integrate primary with breadboard antenna *ca.* 2013
- Fabricate truss, remaining optics from Aluminum
- Use dewar, receivers from a prior NASA program
- Measure beam patterns on a near field range

Summary, Further Work and Acknowledgements

- Conceptual design meets GACM science requirements with composite primary reflector as on Aura MLS.
- Thermal deformation effects are understood from math models and 2009 soak test.
- Current research continues SMLS development:
  - Thermal Gradient tests; develop using SBIR reflector
  - Breadboard antenna: repeat thermal and add RF pattern tests
  - Adapt MLS retrieval algorithms; combine with measured/modeled beam patterns to verify science requirements met
- Research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the National Aeronautics and Space Administration.
- This work was supported by the NASA ESTO Instrument Incubator Programs IIP-07, IIP-10 and NASA Small Business Innovative Research (SBIR) program.