A deployable 4 Meter 180 to 680 GHz antenna for the Scanning Microwave Limb Sounder

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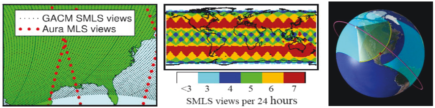
Overview

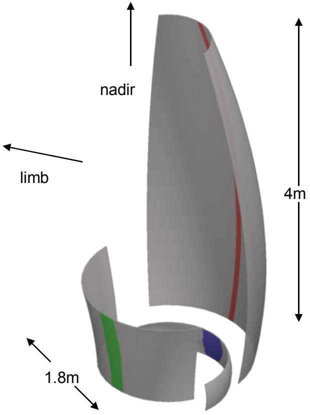
- SMLS antenna concept for the Global Atmospheric Composition Mission (GACM)
- Instrument Incubator Program (IIP-10) April 2011 – March 2014 has 4 Major Tasks:
  - Develop requirements from simulated geophysical retrievals and verify they will be met using math models of engineering performance and measured FOV patterns.
  - Fabricate a full-width primary reflector with improved surface accuracy, based on experience from a previous Small Business Innovative Research (SBIR) program, in which a 1/3-width demonstration reflector was built and tested with ESTO support.
  - Test both SBIR and full-width reflectors under flight-like thermal gradients in JPL's Advanced Large Precision Structures (ALPS) facility.
  - Assemble a breadboard antenna and measure beam patterns in a Near Field Range.

SMLS measurement concept

- The toric Cassegrain antenna designed for SMLS provides azimuth-independent scanning over a ±65° swath of a conical scan from the 830km GACM orbit.
  - 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 ~20x broader, independent of azimuth, in the horizontal.
  - A small (~10cm diameter) mirror scans the beam over the antenna, while a slower ~2° nod of the entire antenna provides the vertical scan.



SMLS coverage: (LEFT) compared to Aura MLS for part of 1 orbit; (CENTER) Temporal coverage; (RIGHT) azimuthal scan



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

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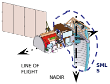
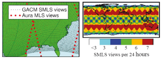
PI: Richard Cofield / JPL

Objectives:

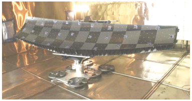
- Demonstrate fabrication and performance of the azimuth- and elevation-scanning antenna for the Scanning Microwave Limb Sounder (SMLS) on the Global Atmospheric Composition Mission (GACM).
  - Fabricate a Graphite Fiber Reinforced Composite (GFRC) panel using a recently delivered SBIR mold.
  - Verify reflector performance in flight-like thermal environments using JPL's Large Aperture facility.
  - Demonstrate GACM requirements are met by SMLS antenna design.
  - Verify antenna performance using SMLS breadboard components.



(a) SMLS Concept



(b) SMLS vs. Aura coverage



(c) 4-m x 1/3 width breadboard Primary reflector from Phase II SBIR

Approach:

- Refurbish existing (SBIR) mold and fabricate full width composite Primary Reflector.
- Design and fabricate remaining antenna reflectors, scan mechanism, and structure.
- Develop Thermal/Mechanical/Optical and retrieval math models.
- Test Reflector to verify thermal stability; test antenna performance on Near Field Range.

Co-Is/Partners:

- Paul Stek, Nathaniel Livesey, Bill Read, Greg Agnes, Mark Thomson; JPL
- Eldon Kasl; DR Technologies

Key Milestones:

1. Model deformations effect on beam patterns	10/11
2. Thermal-test SBIR Primary (JPL ALPS facility)	2/12
3. Simulate geophysical retrievals with model patterns	4/12
4. Build antenna structure, partial secondary and tertiary reflectors, and scan mechanisms	2/13
5. Refurbish mold and Fabricate Primary meeting GACM/SMLS requirements	8/13
6. Integrate antenna with demonstration dewar (2007 IIP) and Full-Width Primary; thermal-test in ALPS	١١/١٣
7. Measure beam patterns on Near Field Range	2/14
8. Final Report	4/14

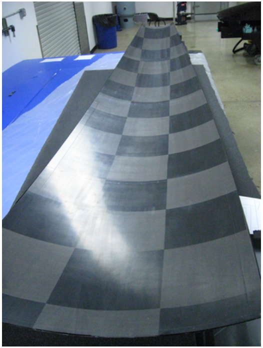
TRL_{in} = 3 $TRL_{current}$ = 3

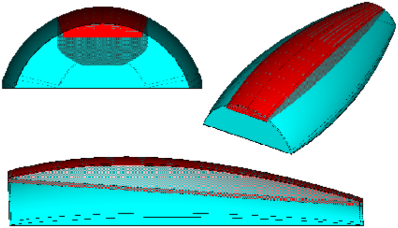
ESTO Earth Science Technology Office

4/08/2011

Full (IIP)- and 1/3 (SBIR)-width Primary Reflectors

- SBIR budget constrained costs:
  - Reduced aperture (mold drawn below)
    - Full SMLS aperture (blue)
    - 1/3 width for SBIR (red)
  - Coarse grain (CS grade) graphite mold
    - 0.0016 inch rms achieved; GACM 680 GHz will require 0.0005 inch
- GACM Primary needs truss or mold extensions for full width, plus the improved accuracy.
- Vanguard to select truss or new mold in IIP year 1

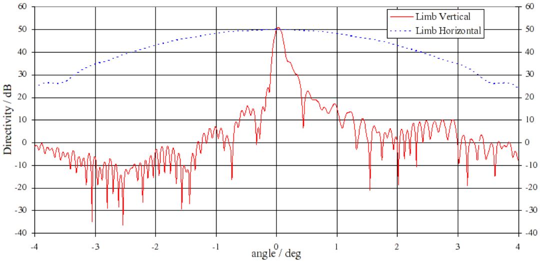




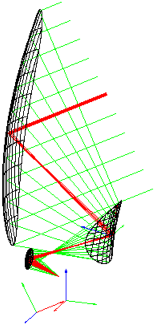
Full-Width Primary Reflector Subcontract

- Through a large contract with Vanguard Space Technologies (formerly DR Technologies), we will obtain 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.* "springback" 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.
- RFP to Vanguard in June 2011

Beam patterns and retrieval simulations

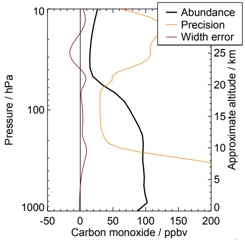


Angle axis labeled for f=60GHz; previous SMLS design

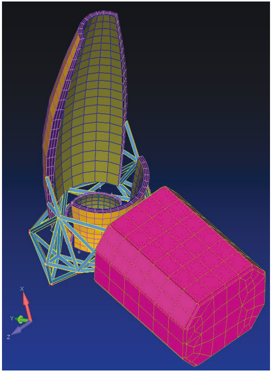


GRASP model, GACM SMLS ray fans

- Update physical-optics calculation of beam patterns (left), for reflector geometry matching the GACM orbit (top right).
- Simulate geophysical retrievals for profiles at multiple azimuths.
- Include FOV changes due to modeled and measured thermal distortions; find systematic error sensitivities (as at bottom right, for 10% error in measured FOV width).
- Correlate with breadboard antenna patterns measured on Near Field Range in year 3; show requirements compliance.

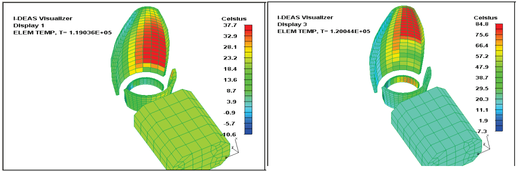


GACM SMLS predicted orbital thermal deformations

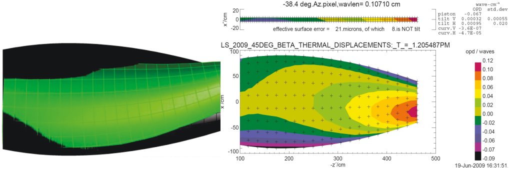


JPL I-deas finite element model

- Updated Thermal, Mechanical and Optical models from a 2006 study
    - Lowered orbit from MEO (1500km) to LEO (830km)



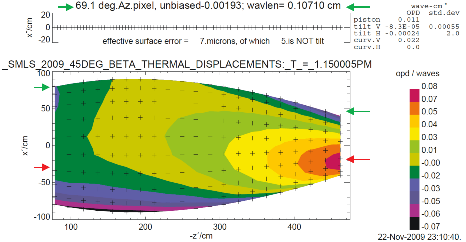
Thermal model: Antenna reflector and spacecraft bus temperatures at 2 times in β = 45° orbit.

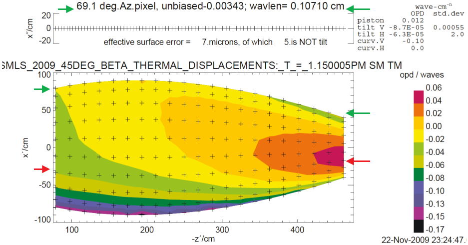


Primary reflector: Deformations (left,5000x) and Optical Path Differences (OPDs, right)

- Models were also extended to include Secondary and Tertiary reflectors, and support structure.

Thermal distortion of all antenna optics

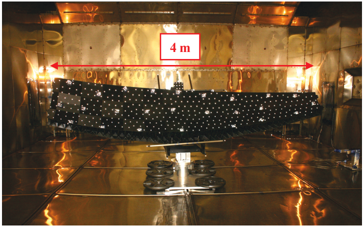




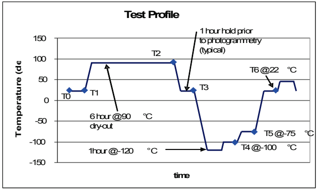
- Secondary and Tertiary Reflector deformations contribute significantly to optical performance (though less than Primary).
  - Rms OPDs suggest contribution is in pixel pointing more than in beam shape.
  - Current model (based on Aura MLS) uses only translations of each node; given the narrow Primary footprints, more accurate horizontal pointing and beam width can be gotten using slope data already in the deformations file.
  - Further study underway (IIP yr.1).

→ -23° Azimuth pixel ¬					
reflectors			**Optical Path Difference**	**/ waves**	
included			**min**	**max**	**rms**
PM	SM	TM	-0.0405	0.0534	0.0242
PM			-0.0107	0.0740	0.0223
	SM		-0.0125	0.0011	0.0035
		TM	-0.0216	-0.0130	0.0019

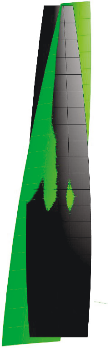
Thermal soak test of SBIR Primary Reflector



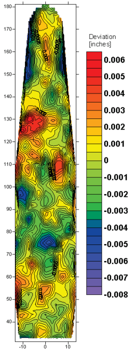
Reflector in Wyle Labs chamber;
photogrammetry targets illuminated



Soak ΔT exceeds orbit prediction by ~7x; infer effective measurement accuracy <~2 μm



JPL model ΔT=100°C
prediction shown 5000x

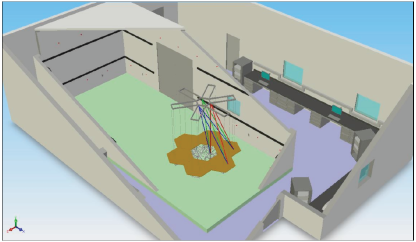


-100°C soak T4:
0.0011 inch rms
from best-fit toric

•cold soak maps compared: FEM prediction vs. photogrammetry measurement

•Refinement of initial order-of-magnitude correlation with FEM is underway in IIP

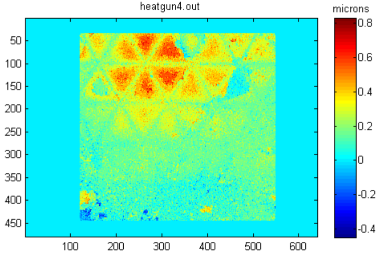
Thermal gradient testing in ALPS facility



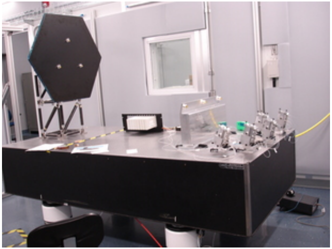
The JPL Advanced Large Precision Structures Laboratory (ALPS) features a thermally stable and isolated 3 x 5 x 10 m test enclosure within a class 100K clean room(left). Localized heaters will be applied to simulate orbital heat loads on the SMLS antenna, according to the math models and results of the 2009 SBIR thermal soak tests. ALPS also provides gravity compensation fixtures, shown on the right with an 8-m deployable L-band SAR, and available for SMLS if needed.

ALPS metrology capabilities

The ALPS facility provides two metrology techniques capable of measuring sub-micron surface displacements, as needed to characterize SMLS performance at 680 GHz.

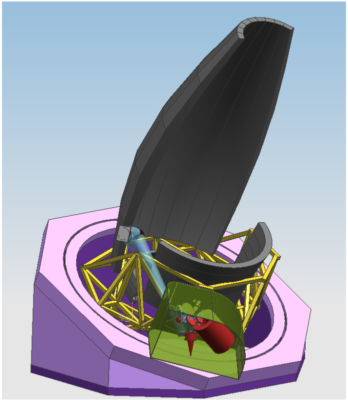


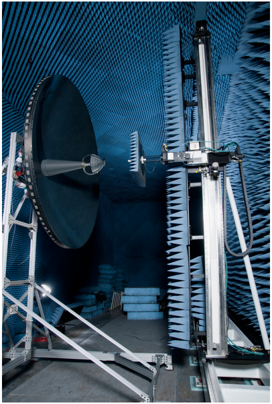
Speckle interferometry measures relative displacement over the entire aperture; this example was a 16” test panel for the phase I SBIR.



Measure absolute position at selected points across the antenna from *Laser Ranging interferometry* sensors (in ALPS from visible light projects)

RF test on a Near Field Range





- Integrate breadboard antenna in 2nd and 3rd years.
  - Combine full-width composite Primary with Secondary and Tertiary, likely Aluminum. Repeat selected ALPS thermal gradient tests.
  - More optics couple antenna to dewar and receivers from the 2007 SMLS IIP.
- Measure patterns on a Near Field Range (NFR) at JPL in 3rd year.
  - NSI has quoted upgrades for MLS scanner or $30' \times 15'$ JPL mesa range (above).

Acknowledgements

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- This work was supported by the NASA ESTO Instrument Incubator Programs IIP-07, IIP-10 and NASA Small Business Innovative Research (SBIR) program.

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