SiC For Space Based and Ground-Based Astronomical Observing Applications

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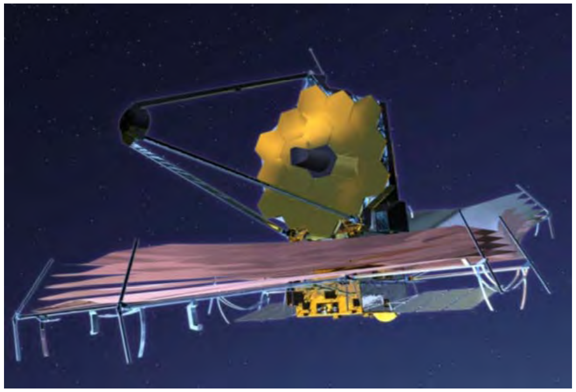
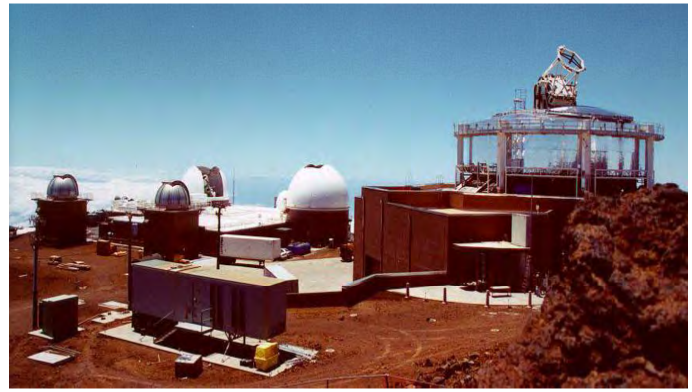
L-3 Communications Integrated Optical Systems

Tinsley Laboratories
Premier Optical Polishing

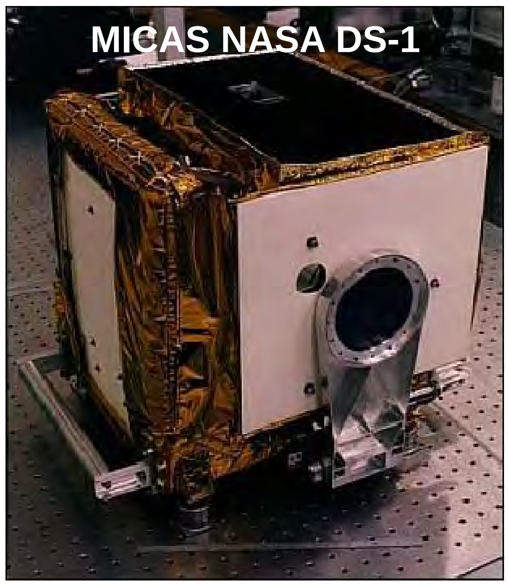


SSG
Space Flight Instruments

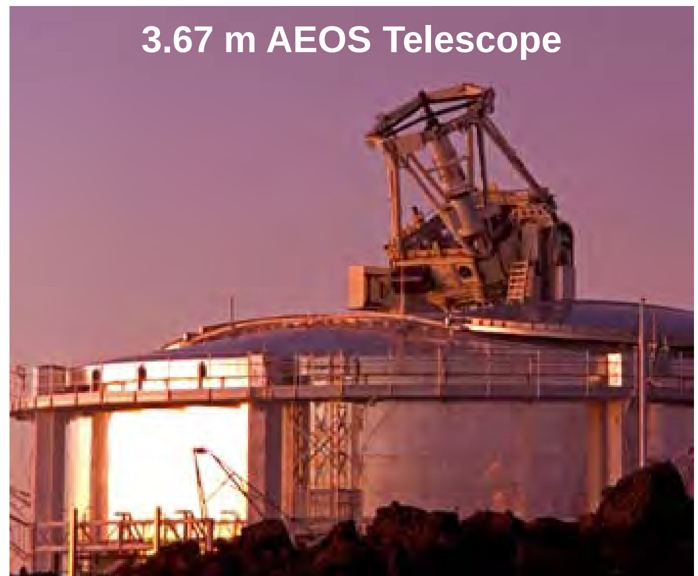
Brashear
Ground Based Observatories



JWST Mirror Polishing

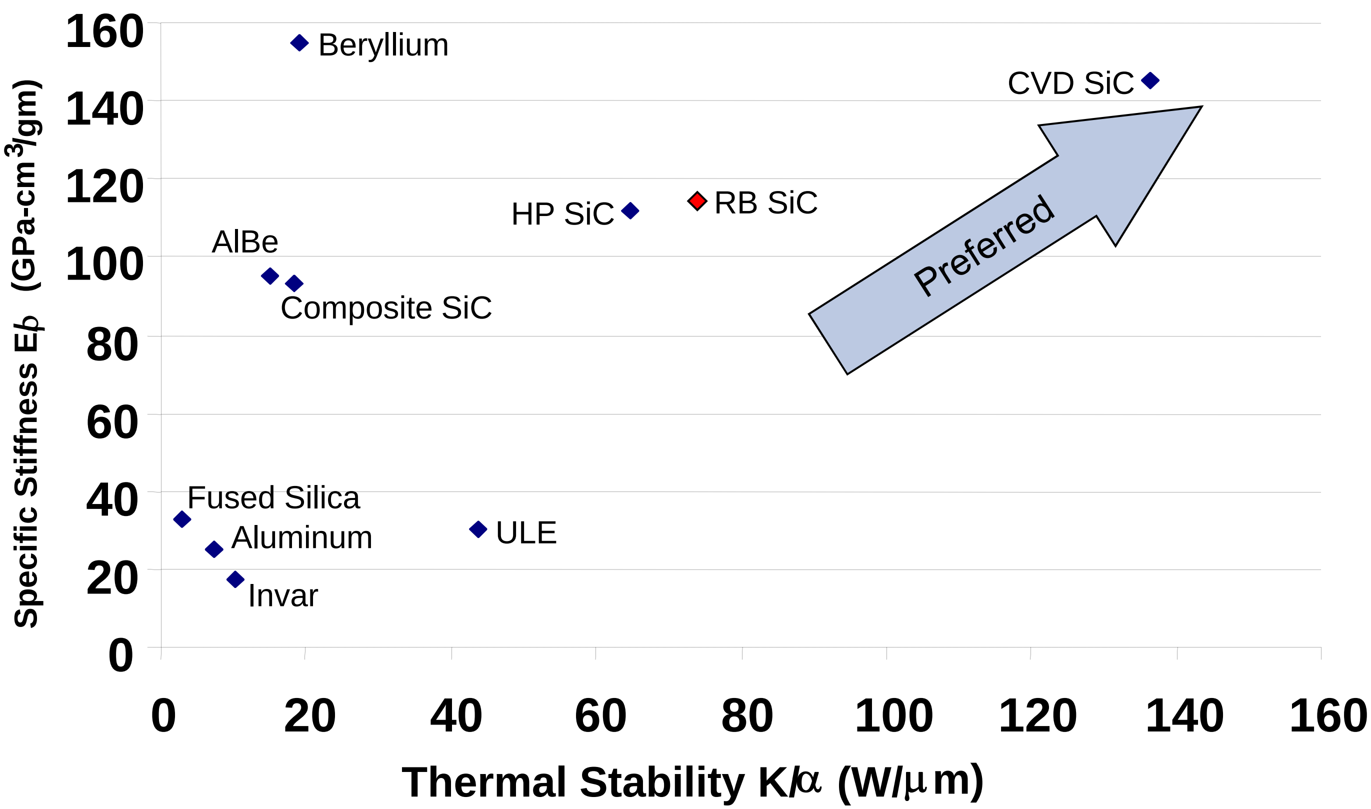


MICAS NASA DS-1



3.67 m AEOS Telescope

SiC Provides Material Properties Advantages



- Very light weight optics and systems due to high stiffness to weight ratio
- Excellent thermal stability under non-uniform thermal loading due to high conductivity and low coefficient of thermal expansion
- L-3 IOS SSG's Reaction Bonded (RB) SiC provides low cost, near-net-shape fabrication

SiC Technology Demos have led to Successful L-3 IOS SSG SiC Space Flight Hardware

MICAS
NASA Deep Space-1

HIRDLS
NASA AURA

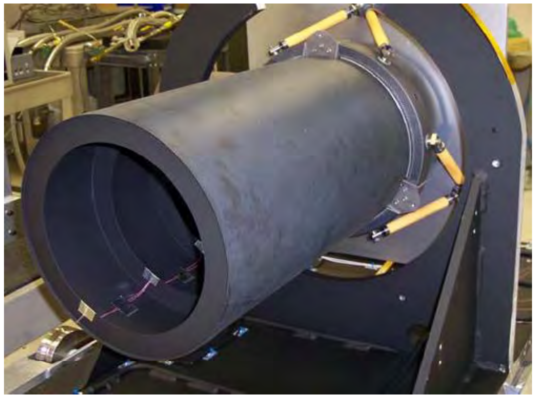
ALI NASA
Earth Observing-1

GIFTS-Afocal
NASA EO-3

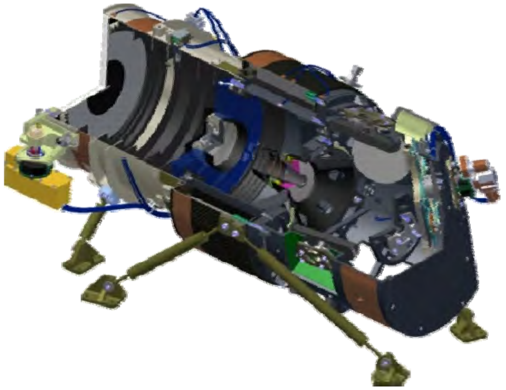
GIFTS-PMA
NASA EO-3

ABI NASA/
NOAA GOES-R

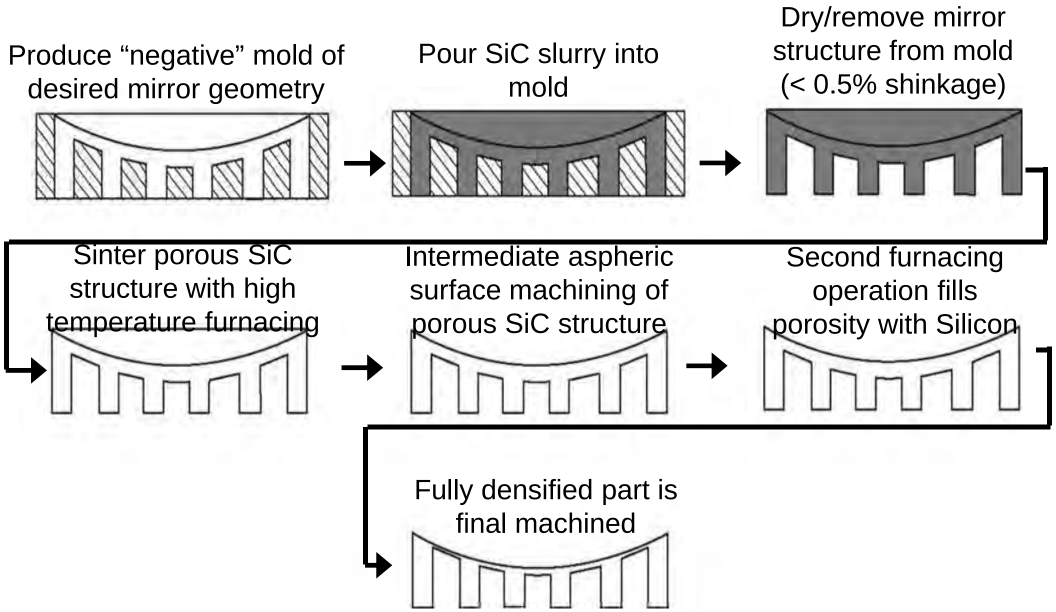
LORRI
NASA New Horizons

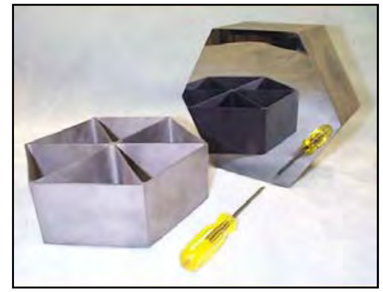


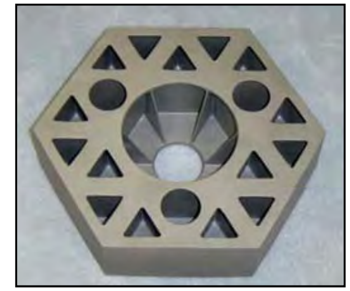
JMAPS
U.S. Naval Research Lab

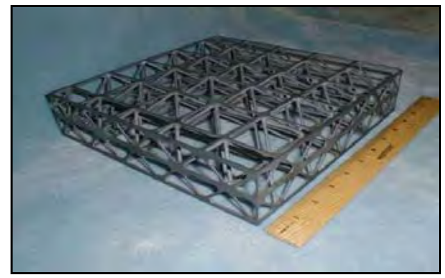


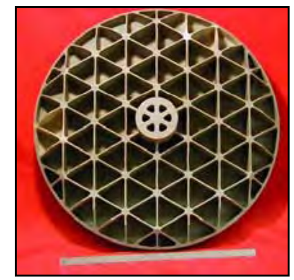
L-3 IOS SSG RB SiC allows Low Cost Manufacturing









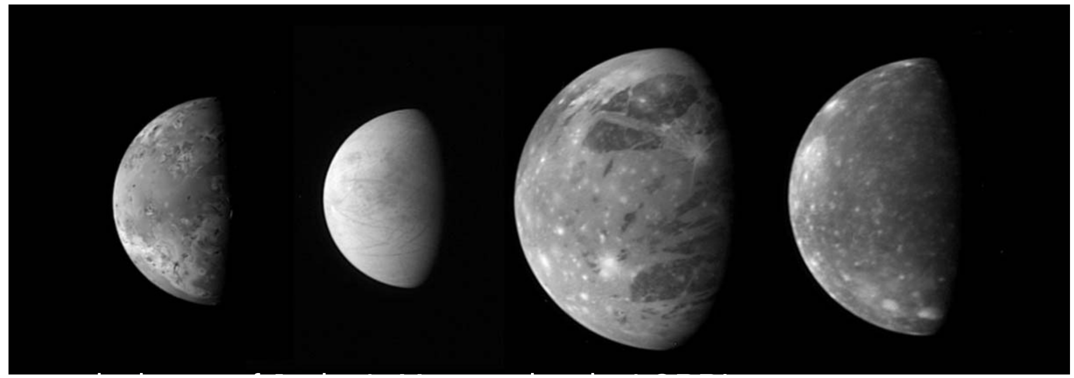


Slip-casting provides near-net-shape fabrication of complex features without the need for costly/time-consuming post machining

- 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

LORRI – Overview

- High resolution visible instrument within the New Horizons payload
- Launched 2006
- 3.2 billion km traveled
- 1000's of images to date
- Science Objectives
  - Reconnaissance imaging of Pluto-Charon and Kuiper Belt
  - Measure shape/size of Pluto-Charon
  - Data on Pluto's geology, surface morphology, collisional history, and atmosphere-surface interactions (50 m resolution)
  - Mapping of craters on Charon
  - Map orbits of objects in the Kuiper Belt
  - Provide Jupiter flyby imaging




LORRI being integrated onto the New Horizons spacecraft (courtesy APL/SWRI/NASA)

L-3 communications Integrated Optical Systems SSG

Why SiC for LORRI?

Thermal Performance

- Challenging thermal environment requires a low CTE and high Thermal Conductivity
- Environment as hot as +40 C, CCD held to -70 C, viewing cold space
- Tight thermal gradients of 1.0 C (lateral) and 2.5 C (axial)

Low Mass Requirements

- 5.6 kg mass allocation for telescope with minimum resonant frequency of 60 Hz
- No mass allowance for a focus adjust mechanism drives passively athermalized opto-mechanical design configuration

Long Term Dimensional Stability

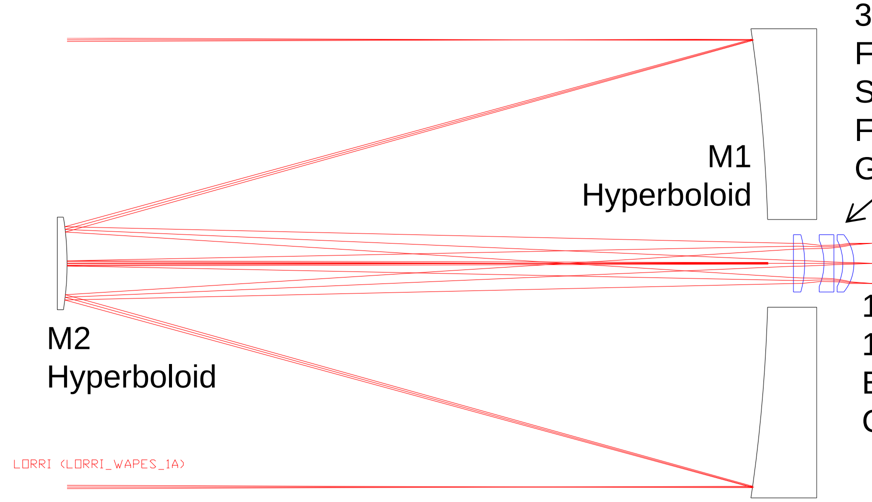
- Launch in 2006, primary imaging initiates in 2015

Low-Outgassing

- Internal cleanliness at beginning of life 250 A/2 and end of life 300 A (MIL STD 1246B)

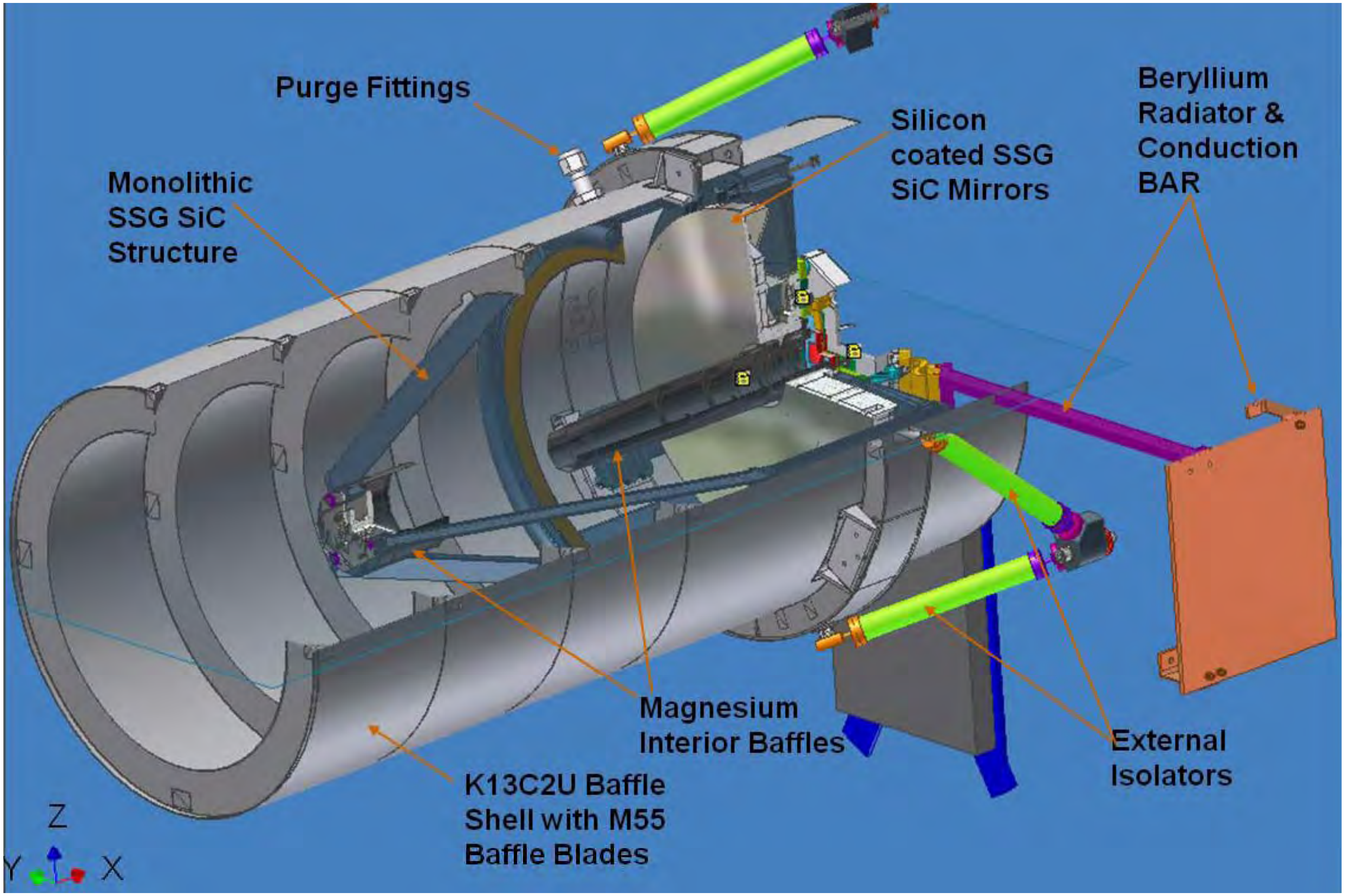
LORRI Optical Design (Field Corrected Ritchey-Chretien)

LORRI Optical Design Parameters	
Aperture	0.21 m
EFL	2.59 m
F/Number	12.6
FPA Format	13 micron pixel 1024x1024 array
FOV	0.29 x 0.29 degrees
Bandpass	680 to 920 nm
Operational Temp	170K – 230K
Launch	Atlas Launch Vehicle
Central Obscuration	< 10% by area
Mass	8.6 kg 3.0 kg for SiC telescope
Power	< 30 W
WFE	< 0.15 λ RMS @ λ= 0.63 microns test @ 130 K



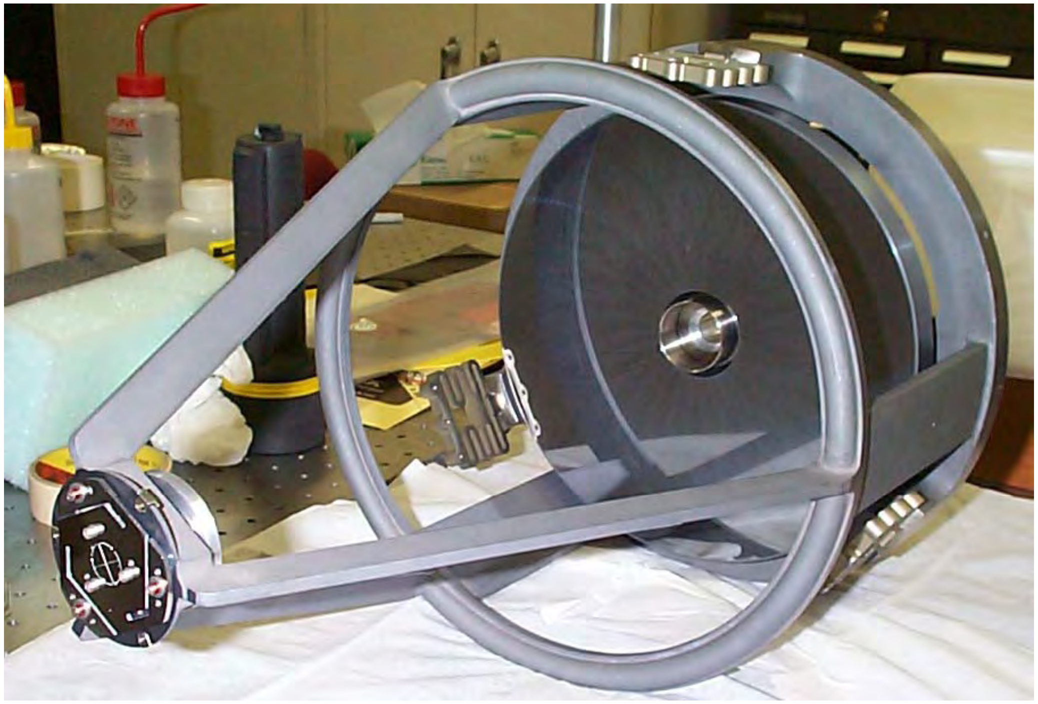
- Very light weight optics and structure due to high stiffness to weight ratio
- Excellent thermal stability under non-uniform thermal loading due to high conductivity and low coefficient of thermal expansion
- L-3 IOS SSG's Reaction Bonded (RB) SiC provides low cost, near-net-shape fabrication

LORRI Mechanical Design Overview



LORRI SiC Telescope

- Silicon Carbide telescope structure material is identical to the mirrors
  - Allows for nearly ideal metering with low CTE, high conductivity material
  - Very high stiffness and low mass design



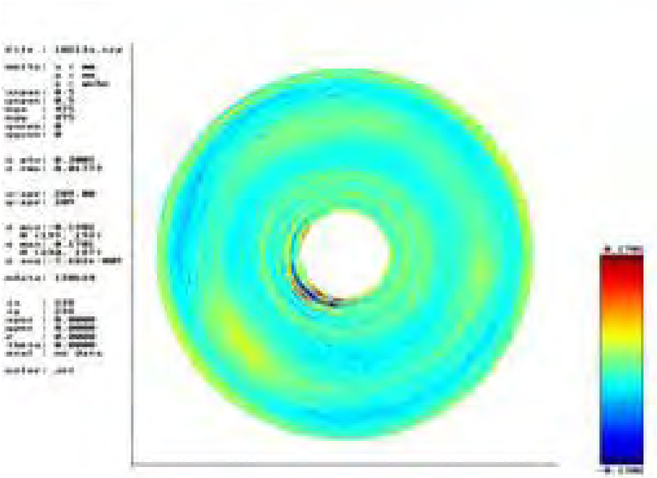
Monolithic Silicon Carbide Metering Structure

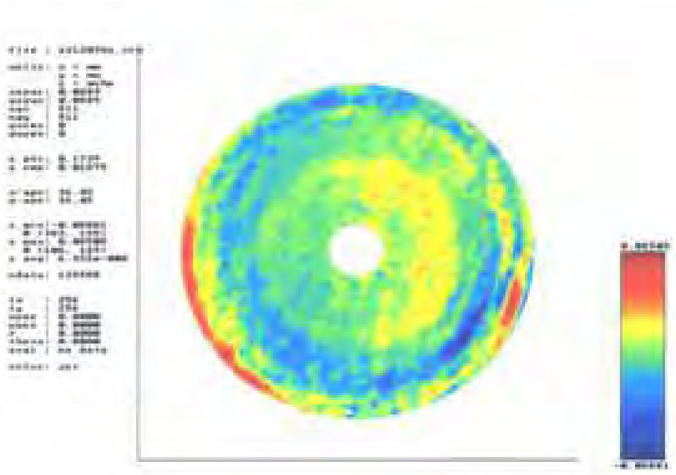
- L-3 IOS SSG RB Silicon Carbide fabrication process allows for very complex geometries
- Individual pieces are cast as simple parts, then sinter bonded together.
  - Joining material is the same as the parent material
  - Process can be repeated as many times as needed to build up monolithic structure
  - Joints are much stronger and more stable than epoxy joints
- Small Invar inserts are bonded at attachment points

LORRI SiC Aspheres Polished by L-3 IOS Tinsley

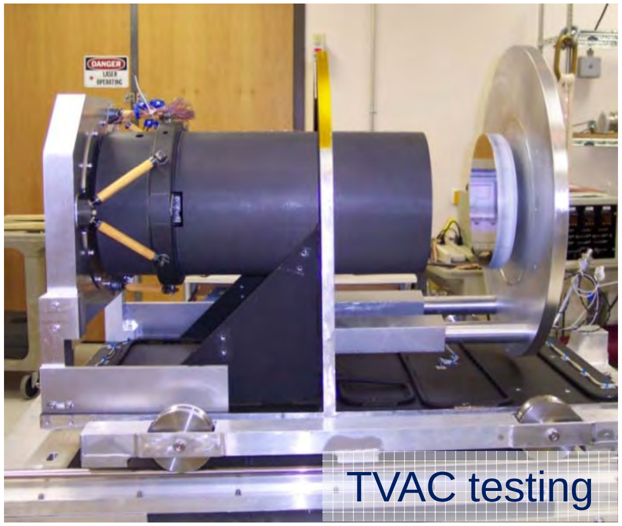
Primary Mirror
11 nm rms surface error

Secondary Mirror
12 nm rms surface error



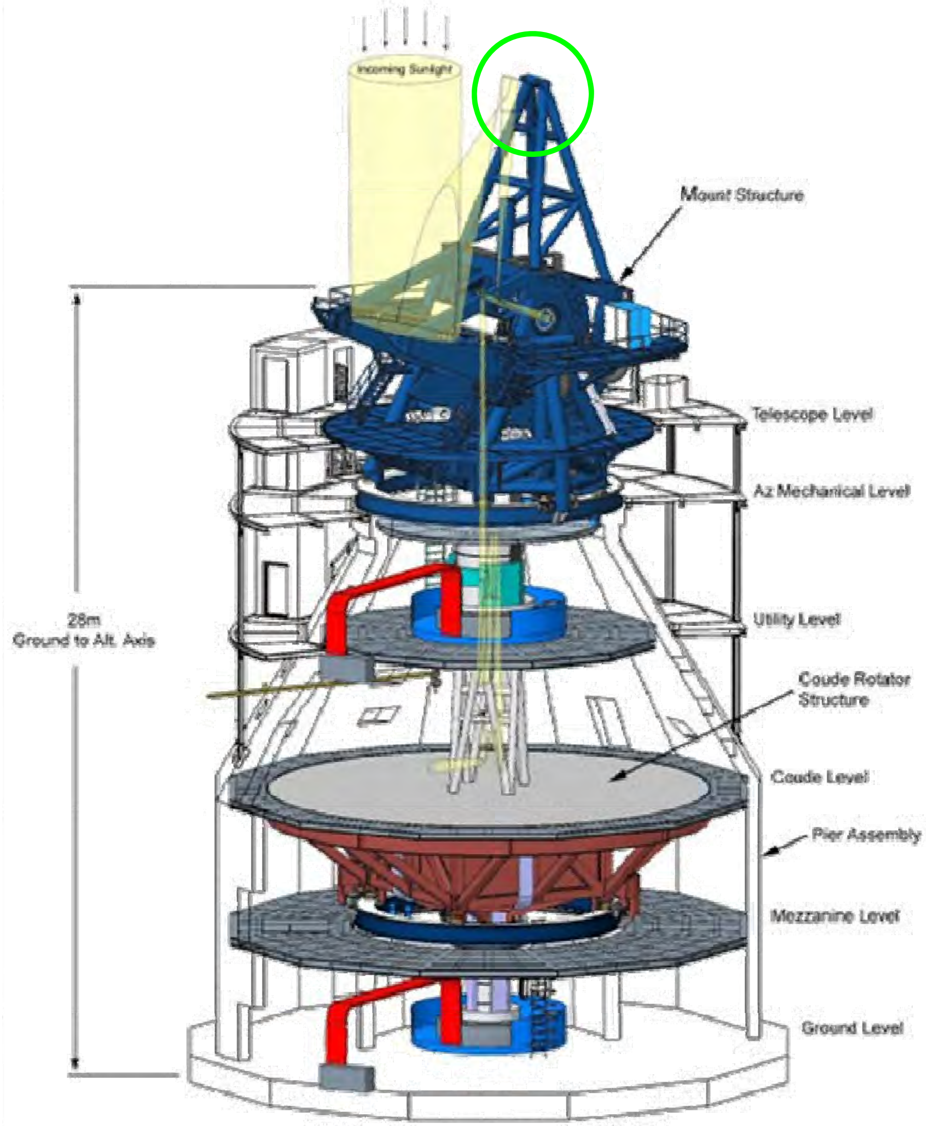


Laboratory Environmental Qualification Verified with On-Orbit Performance Characterization



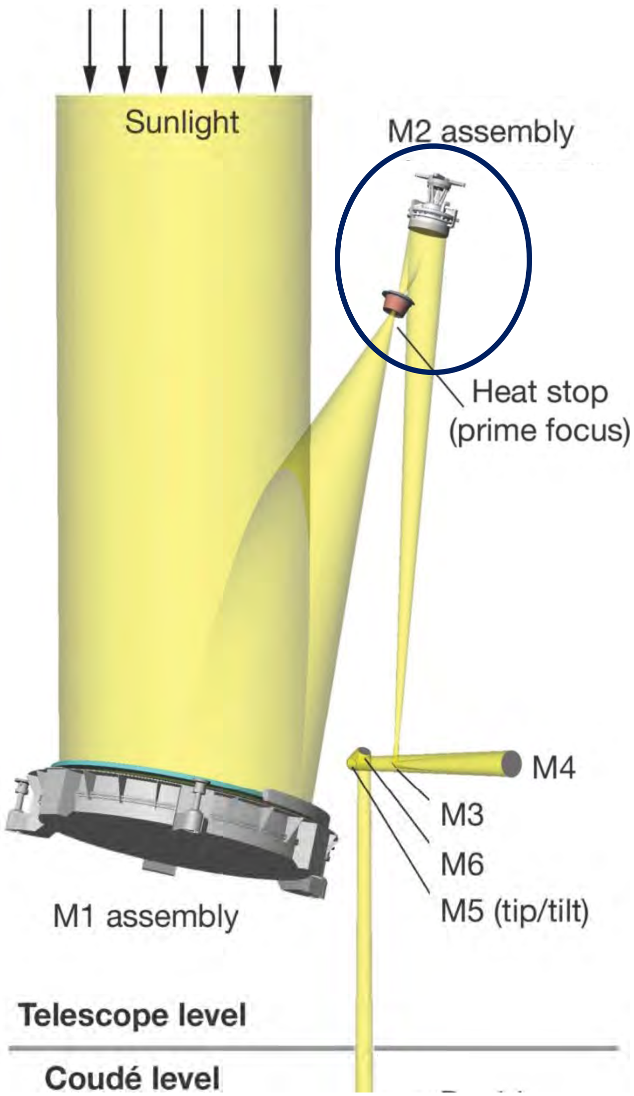
Messier 7 Star Cluster reveals stars down to 12th Magnitude confirming LORRI Signal-to-Noise Ratio, Multiple measurements demonstrate no performance degradation over 6+ years. (courtesy APL/SWRI/NASA)

SiC Benefits for Ground Observatories: Advanced Technology Solar Telescope (ATST)



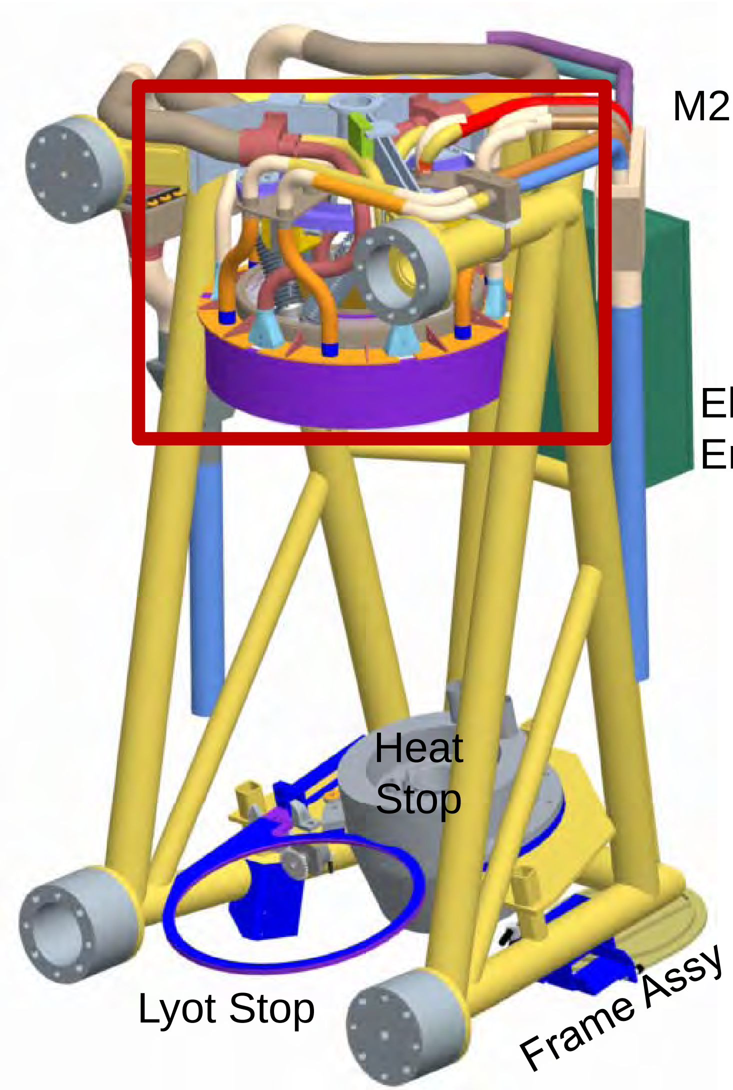
- Advanced Technology Solar Telescope (ATST) Summary:
  - 4 meter aperture solar telescope under construction on Haleakala, Maui, Hawaii
  - Explore 3-D structure of the solar magnetic field including corona at IR wavelengths and high resolution (30 milli-arc-sec) visible waveband imaging

L-3 IOS SSG SiC Being Applied to Produce ATST Secondary Mirror within TEOA



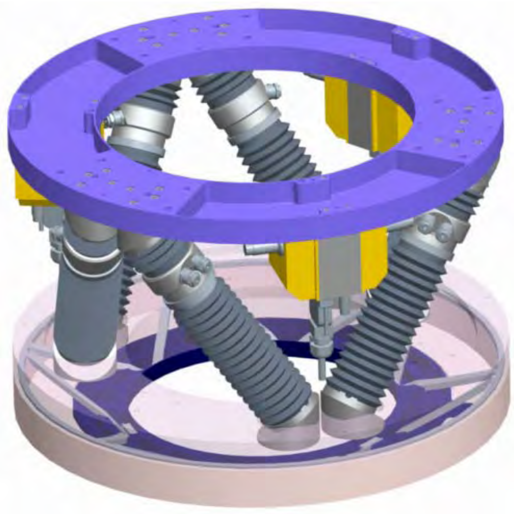
- L-3 IOS SSG RB SiC Used for M2 mirror within Top End Optical Assembly (TEOA)
  - 2.5% of the solar flux incident on M1 passes through the heat stop to M2 = 300 Watts
  - High heat load demands thermal gradients are minimized (High K) and thermal deformation is low (Low CTE)
  - Active control of M2 mirror demands low mass and high stiffness to weight ratio (High E, low r)

ATST Top End Optical Assembly (TEOA) Overview

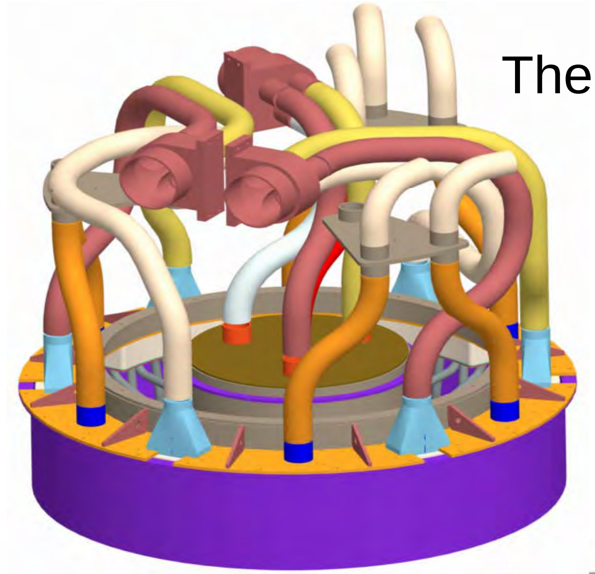


- L-3 IOS Brashear under contract for Top End Optical Assembly (TEOA)
  - M2 Assembly
    - *Spider*
    - *Positioner System*
    - *Inner and Outer Plenums*
    - *M2 Bonded Mirror Assembly*
  - Heat Stop / Shutter
  - Lyot Stop
  - Frame Assembly
  - Electronics Enclosure

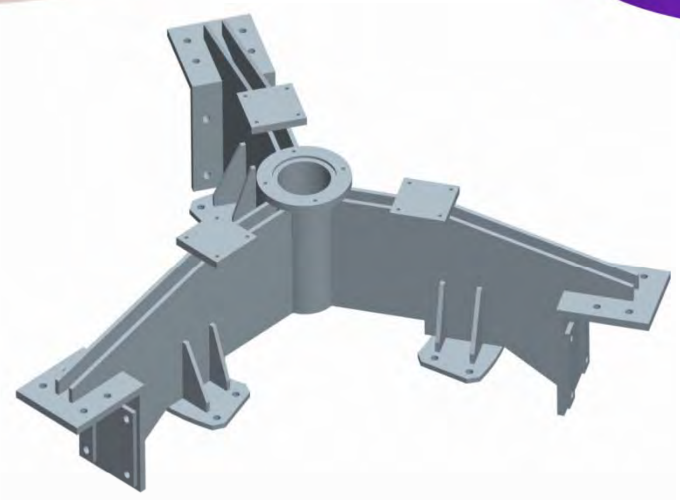
ATST Top End Optical Assembly (TEOA) Overview



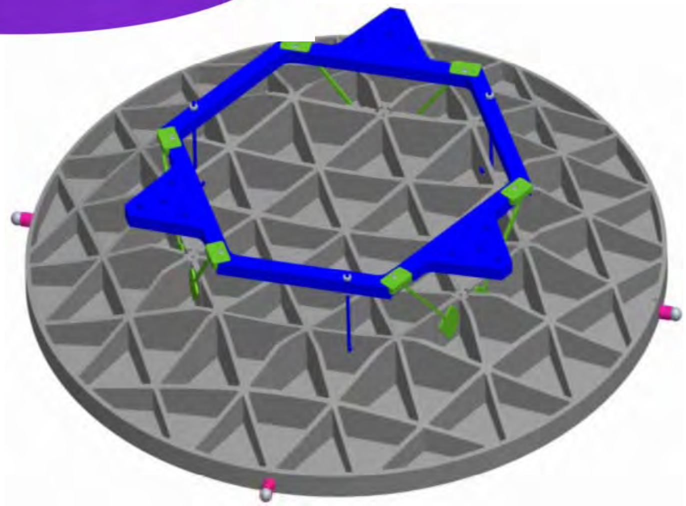
M2 Positioner



Thermal Control



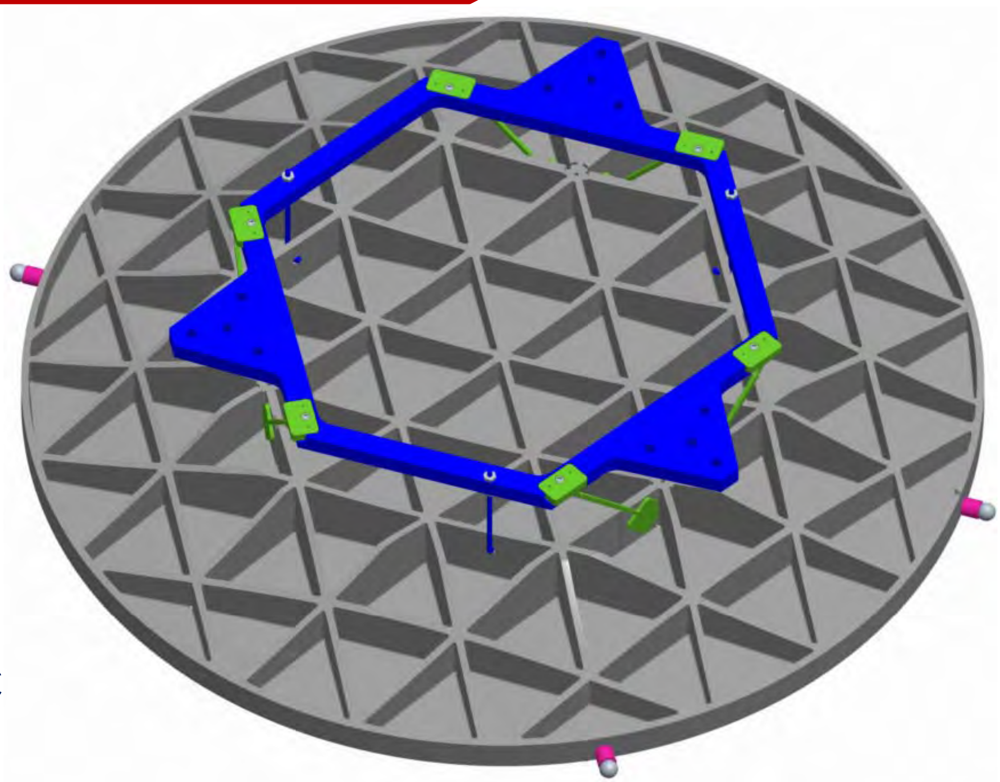
Spider Mount



SiC M2 Mirror and Mount

ATST SiC M2 Mirror Description

ATST M2 Mirror Parameters	
Aperture	0.65 m
Radius of Curvature	2.08 m
Off Axis Distance	0.59 m
Conic Constant	-0.539 (ellipse)
Weight	25 lbs (11.3 kgs)
First Free-Free Mode	728 Hz

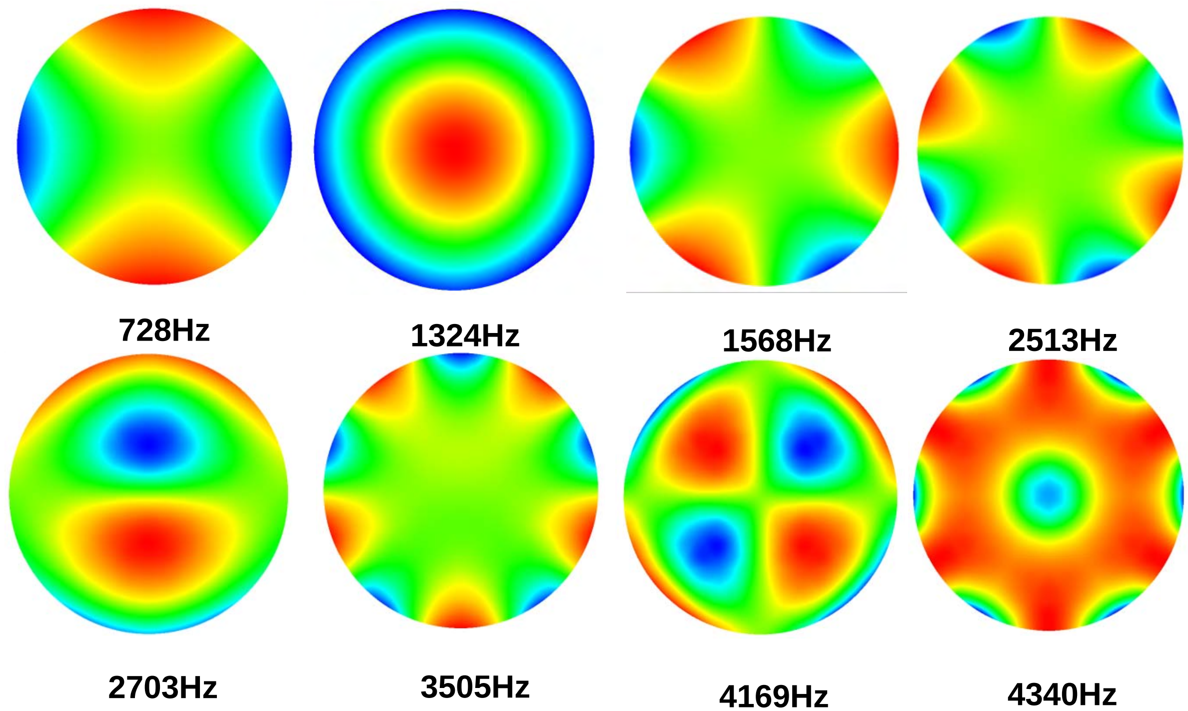


- L-3 IOS SSG Reaction Bonded SiC
- Aluminum Mounting plate
- Invar 36 epoxy mounted bipods
- Silicon Cladding for polishability
- FSS-99 Silver coating for reflectivity

- Typical Rib Thickness: 5 mm (0.2”)
- Maximum Rib Depth: 86 mm (3.4”)

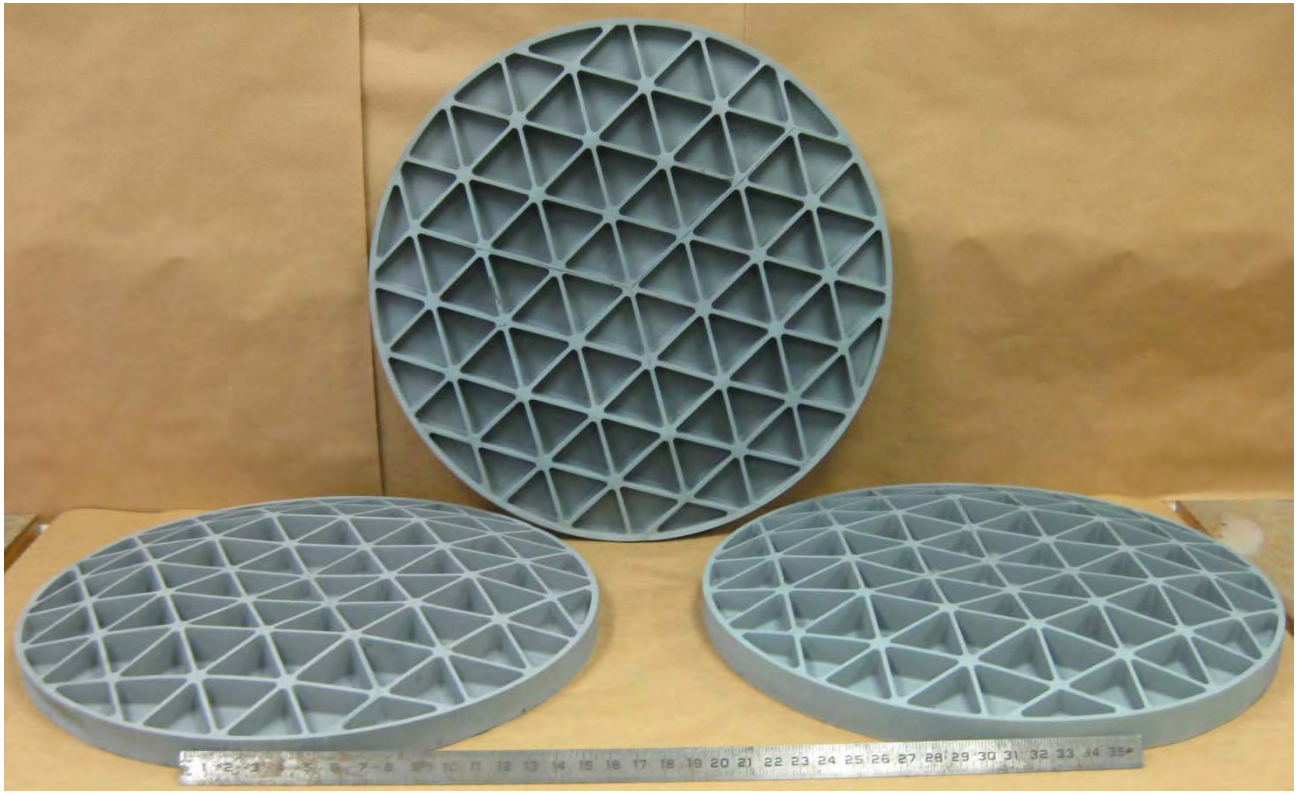
ATST SiC M2 Mirror Status

- Analysis completed
  - First free-free mode
  - Thermal soak surface error
  - Coating stress deformation
  - Gravity sag as a function of telescope zenith tilt angle
  - Surface error due to cooling jet impingement
  - Mount induced error
- Detailed design in-process
- Manufacturing planned to begin Q3 2012



M2 Substrate – Free-Free Modes

ATST SiC M2 Mirror Prototypes



- Prototypes, similar in scale to the ATST M2 mirror have been produced using L-3 IOS SSG RB SiC Slip Casting manufacturing process
- Near-net-shape fabrication produces lightweighting ribs with no post-machining

Summary

SiC Provides critical benefits for both ground and space-based optical systems

- Very lightweight optics and systems due to high stiffness to weight ratio
- Excellent thermal stability under non-uniform thermal loading due to high conductivity and low coefficient of thermal expansion
- No outgassing/moisture absorption
- L3-SSG's Reaction Bonded (RB) SiC provides low cost, near-net-shape fabrication
- L-3 SSG has extensive experience in design, analysis, manufacturing and test of SiC optics/optical-systems including over 10+ years flight heritage