# SSG Space Based Silicon Carbide Optical Systems

# SSG Precision Optronics (SSGPO) Profile

Aerospace Engineering, Optical Fab & integration/Test

System Manufacturing Facility

Tinsley Laboratory

SiC Foundry

- 24 year old company specializing in major optical/ mechanical and precision beam/motion control systems
  - National Asset, Major NASA Science, Advanced Technology Demos, tactical & commercial
  - Over 35 space & aircraft flight systems; many FFP
  - Over 50 Phase 2 SBIR grants - key technology enabler
  - >180 employees
- Commercial production supplier of precision optical/ scanner product for 3D metrology markets
- >10 tactical ATD programs;

- World class technical & management staff
- Fully integrated computer design tools & major optical/LOS & vacuum test facilities
- >120,000 sq. ft. in 4 modern locations
- Team member with most US Aerospace instrument primes & Government Labs
- ISO 9001 Certified

**SSGPO's Growth Based on Unique Technologies, Solid Reputation & Successful Track Record Solving Tough Engineering Problems**

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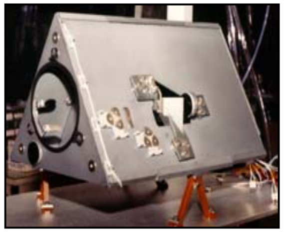
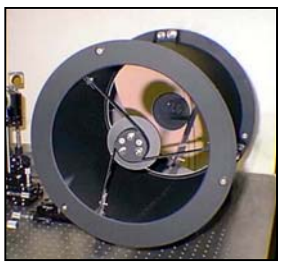
# SSG Fabricates Precision Opto-Mechanical Instruments in ALL Candidate Materials

## SiC



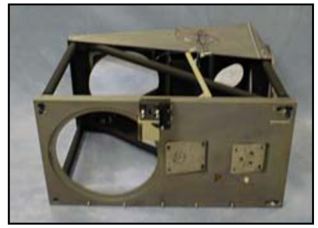
NMP-DS1 MICAS

NMP/EO-1



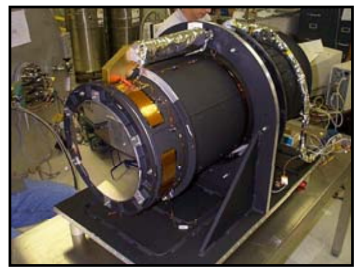
Laser Comm

## Be



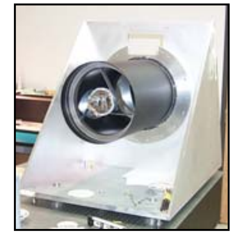
SBIRS-Lo/LADS Afocal

HIRDLS

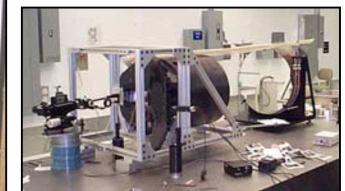


IR Telescope

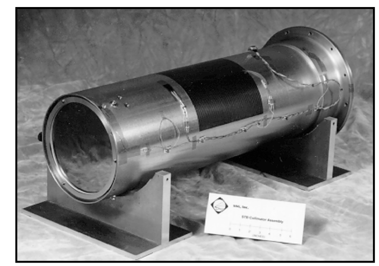
## Glass/GrCy



TRIANA

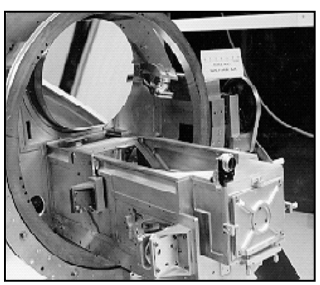


Orbview 3 Telescope

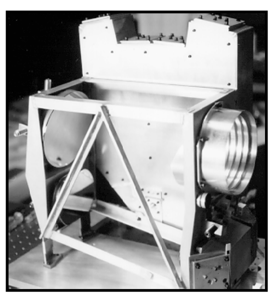


Cryo Refractor

## Al (w & wo Ni)

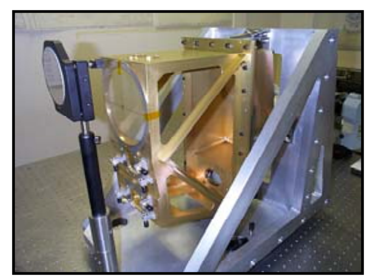


SPIRIT III MSX

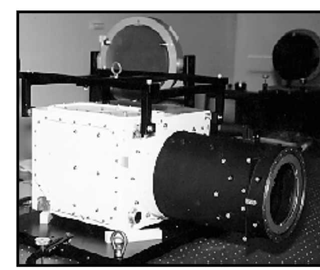


HSI/Lewis

KOMPSAT



Hyperion



SBV/MSX

Extensive experience designing, fabricating & testing with numerous materials allows us to take a systems approach on material selection, applying the right materials on an application by application basis

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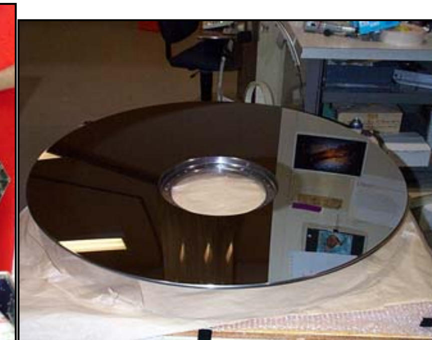
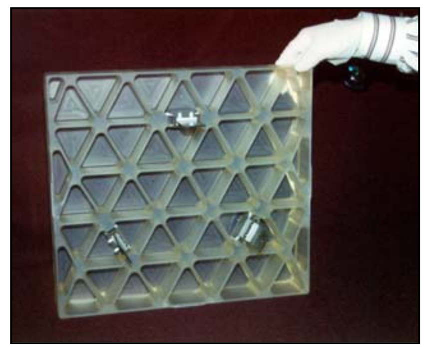
# SSG/Tinsley Recognized as a Premier Optical Manufacturing Resource

- SSG/Tinsley Laboratories recognized state-of-the-art aspheric optical manufacturing resource
  - Surface figures better than 5 nm pk-valley
  - Computer Controlled Optical Surfacing used to produce state-of-the-art optics in a fast, deterministic fashion

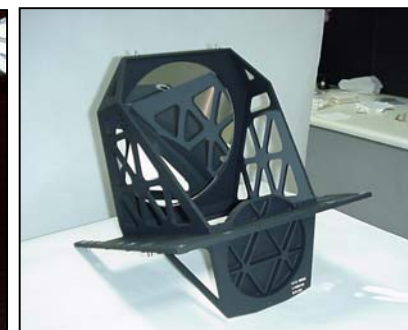
AMSD



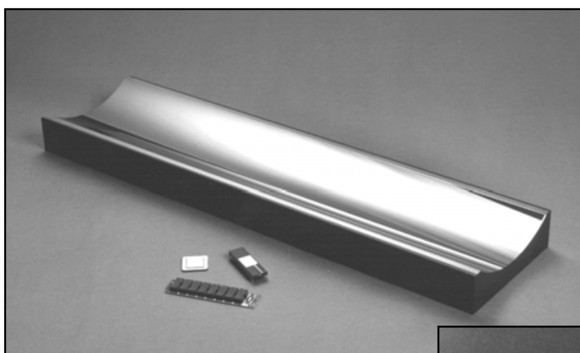
SIRTF



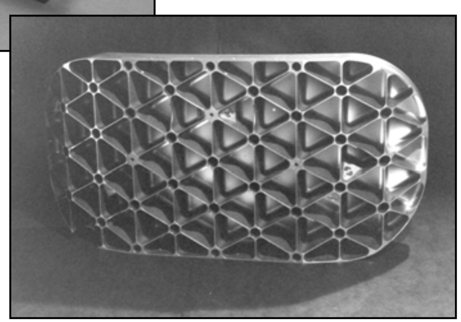
FUSE



Collimator



SiC X-Ray Toroidal Mirror



Lightweighted Beryllium Mirror

Subscale Be Mirror Demonstrator
(0.5m Precursor to AMSD/NGST)

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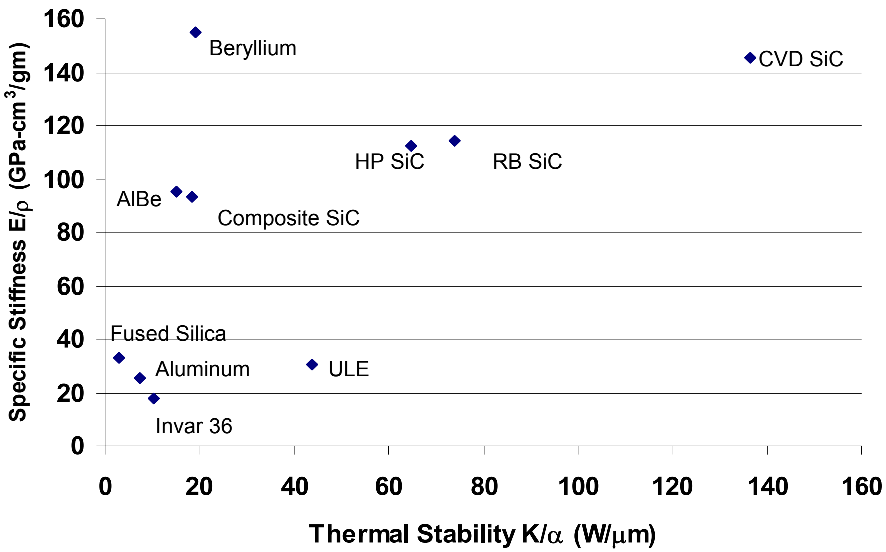
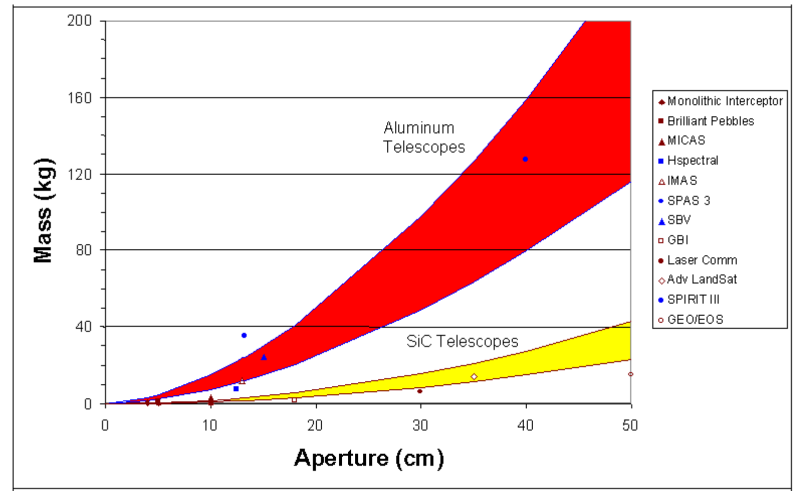
# Why Silicon Carbide for Space-based Optical Systems?




<u>SiC Offers:</u>

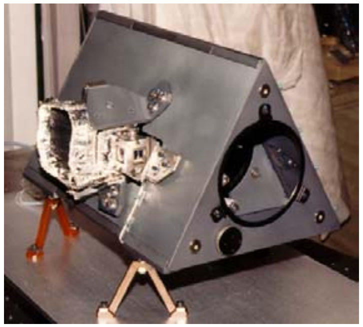
- Lightweight features of Be
- Cryogenic optical performance of glass to visible/UV wavelengths
- Superior thermal stability to cryo temperatures (8x)
- Cost advantages of Al - lower potential production costs
- Fast delivery schedule due to inexpensive commercial processes

<u>Issues:</u>

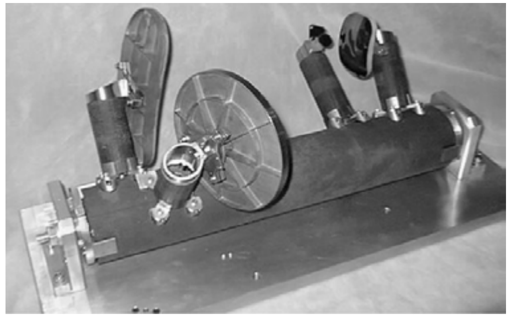
- Brittleness
- Attachments
- Scaling to larger sizes, esp. structures

SiC only solution for very lightweight visible quality telescopes
(2.5 to 3X lighter than glass)
SSG has hardware demonstrated solutions to mitigate SiC issues

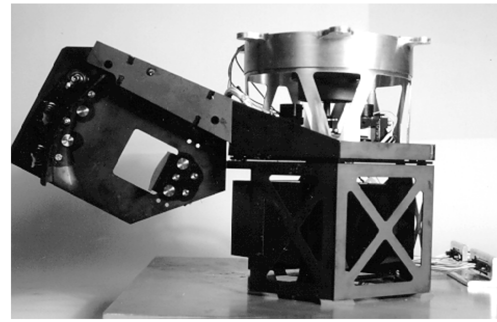
# SSG Is Industry Leader in SiC Telescope Systems



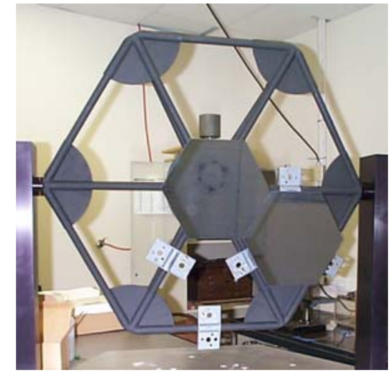
NMP DS-1/MICAS



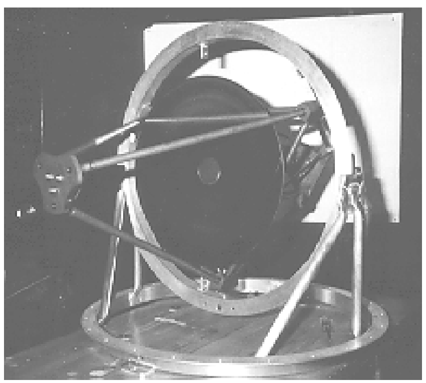
IMAS/NPOESS



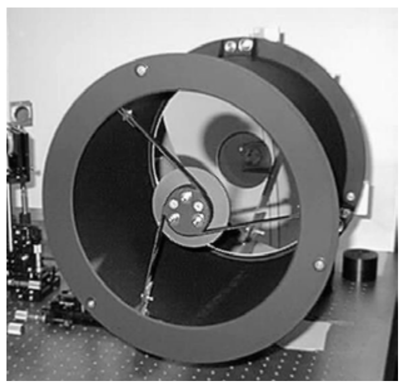
BP



Phased Array



0.5m GEO



LaserComm

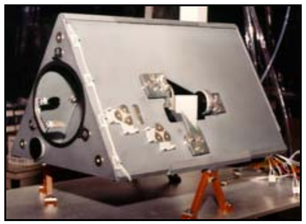
NMP EO-1/ALI

GBI

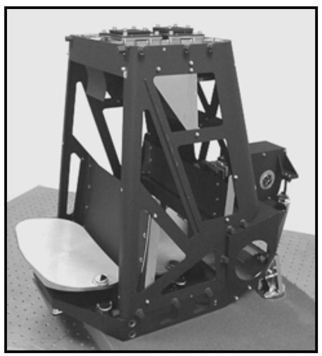
- SSG has extensive experience designing, manufacturing, integrating, aligning and testing SiC optical systems and opto-mechanical systems
- Numerous SBIR systems and technology demonstrations
- Two SiC flight systems

# SSG is Leading Supplier of SiC Systems and Components

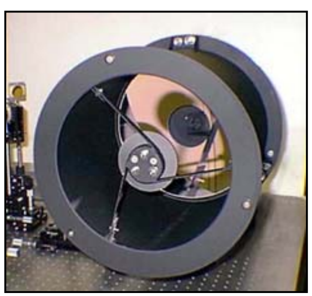
### *Optical Systems*



NASA DS-1 MICAS

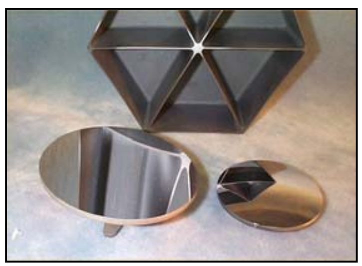


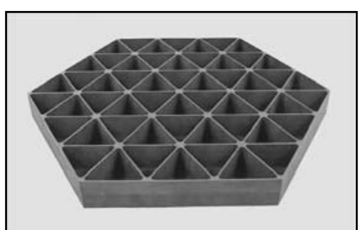
NASA EO-1 ALI



Lasercom Transceiver

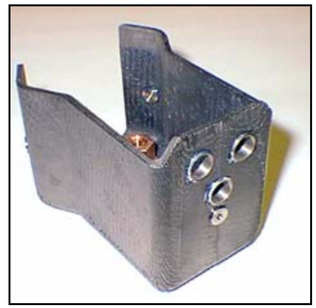
### *Mirrors*





Aspheres and flats, light weight & thermally stable

### *Structures*

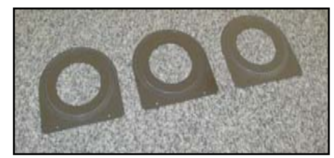


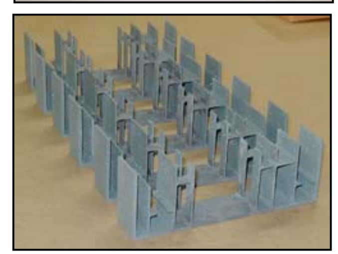
flight composite SiC components

Optical benches in RB and composite SiC

### *Components*

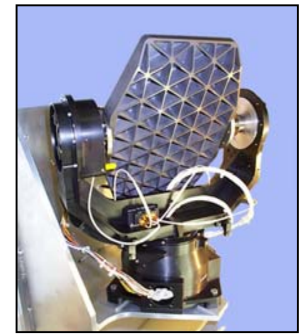
Optical mounts



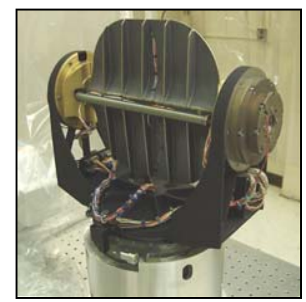


Lithography Components

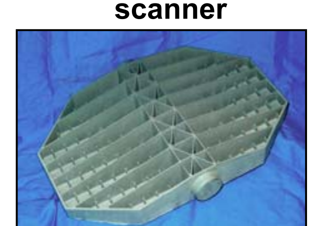
### *Scan Mirrors*



2-axis aircraft scan/stabilization



NASA's HIRDLS scanner



GIFTS scan mirror

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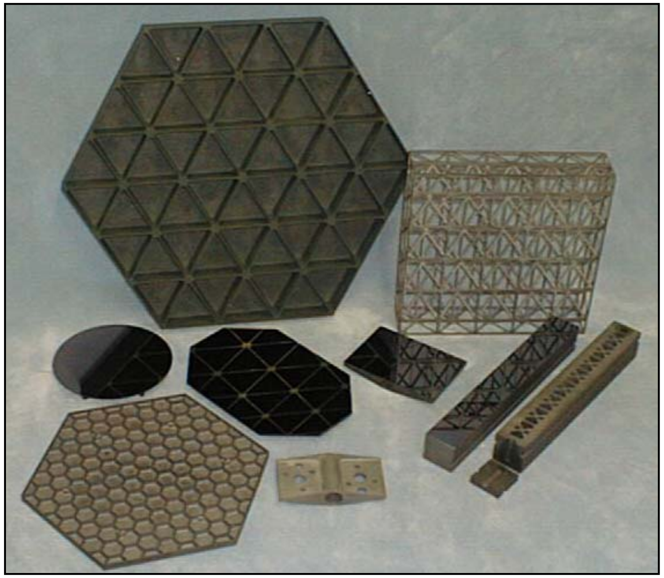
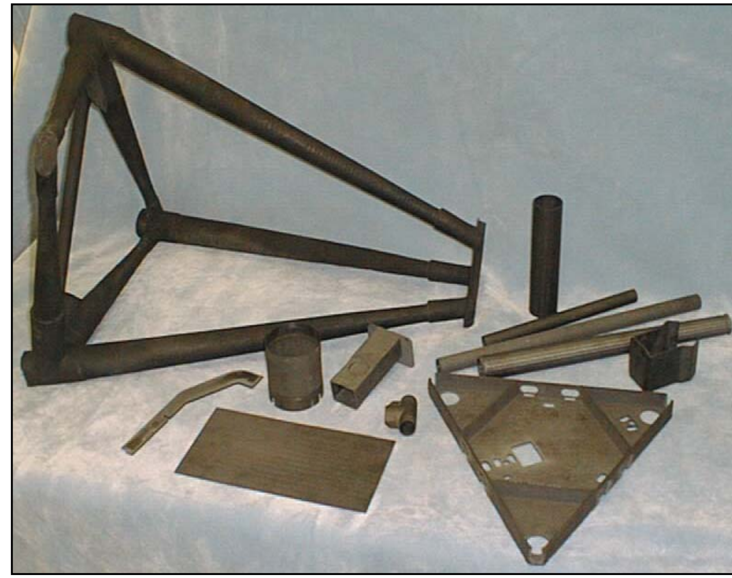
# SiC - Materials Selection





Reaction Bonded (RB) SiC

- Suitable for optical surfaces
  - High specific stiffness (~80% the specific stiffness of Be; 2x better than carbon/GrEp)
  - Excellent thermal conductivity (4x better than carbon/GrEp)
  - Excellent polishability to optical tolerances

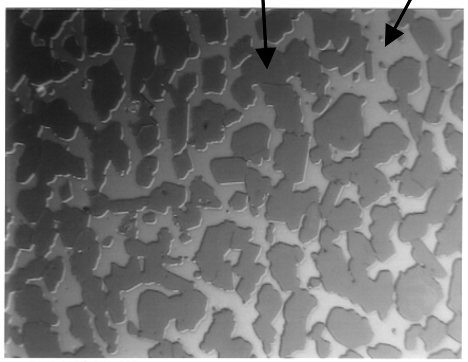
Fiber Reinforced Composite SiC

- Optimized for structural applications
  - Excellent fracture toughness or damping (2x better than carbon/GrEp; 20x better than Be)
  - Both SiC materials can be combined to exploit the advantages of each
  - Both have no problems with anisotropic material properties of CME

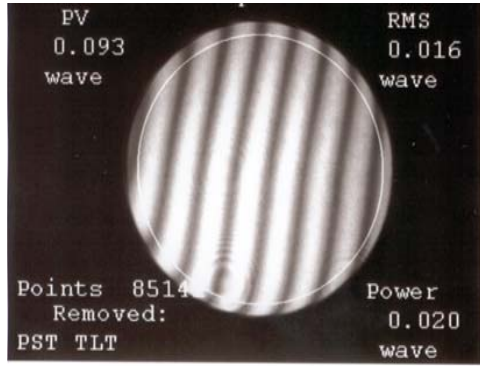
Several Proprietary forms of SiC developed to address the specific needs of high precision optics/structures

# Optical Properties – RB Silicon Carbide

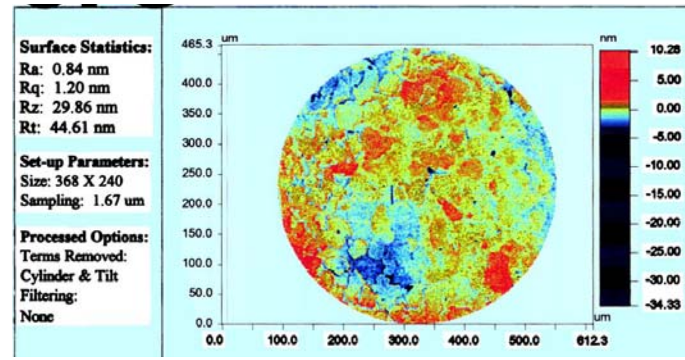
Silicon carbide
Silicon




RB SiC Microstructure

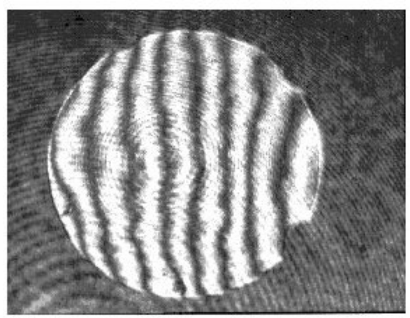


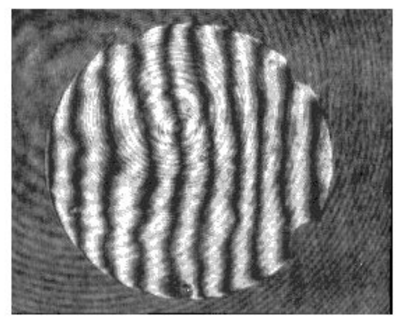

Excellent Polishability
(< 0.1 waves pk-valley @ 0.6 um)




Excellent Surface Finish
(< 13 Angstroms RMS)

T = 135 K
Pk-valley WFE = 0.53 λ
RMS WFE = 0.08 λ



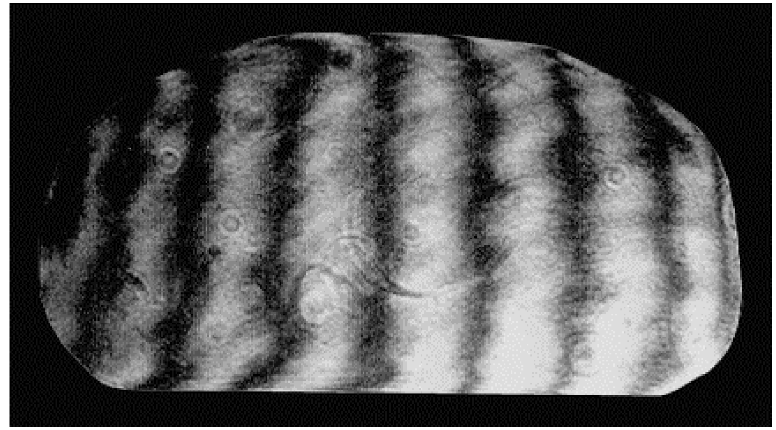


T = 295 K
Pk-valley WFE = 0.47 λ
RMS WFE = 0.08 λ

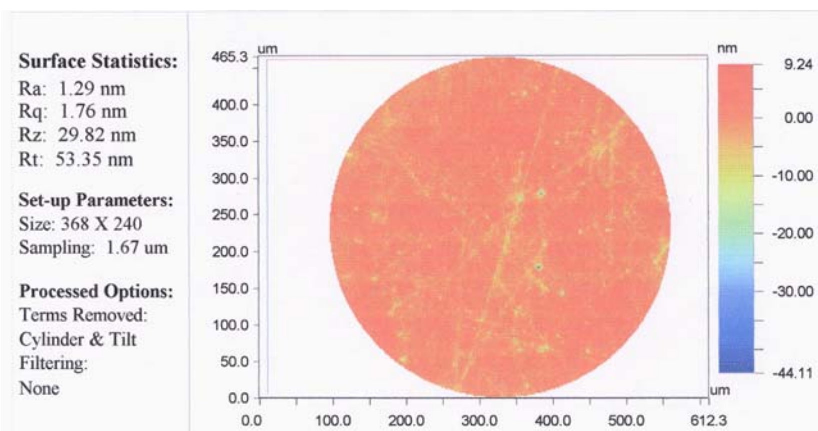
Excellent stability down to cryogenic temperatures

- RB SiC demonstrated to have excellent optical properties
  - Surface figure, finish and cryogenic stability demonstrated at the component and the system level

# Optical Properties – Silicon coated Silicon Carbide



Excellent Polishability
(< 0.25 waves pk-valley @ 0.6 um)




Excellent Surface Finish (< 18 Angstroms RMS)

- Silicon cladding somewhat compromises the surface finish achievable with the aspheric optics
- Silicon cladding has no negative effect on surface figure achievable
- Thermal stability depends on the thickness of the silicon cladding and the stiffness of the SiC mirror substrate

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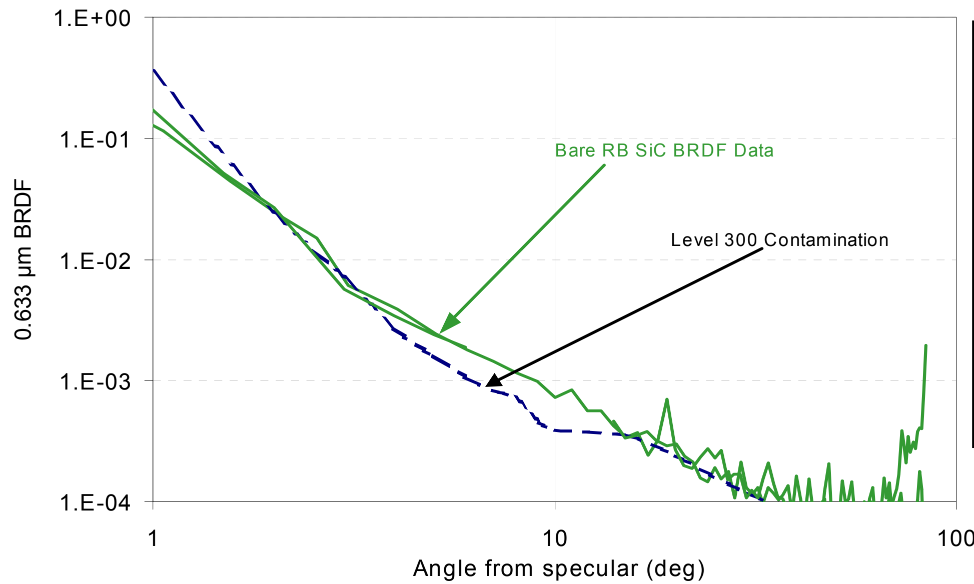
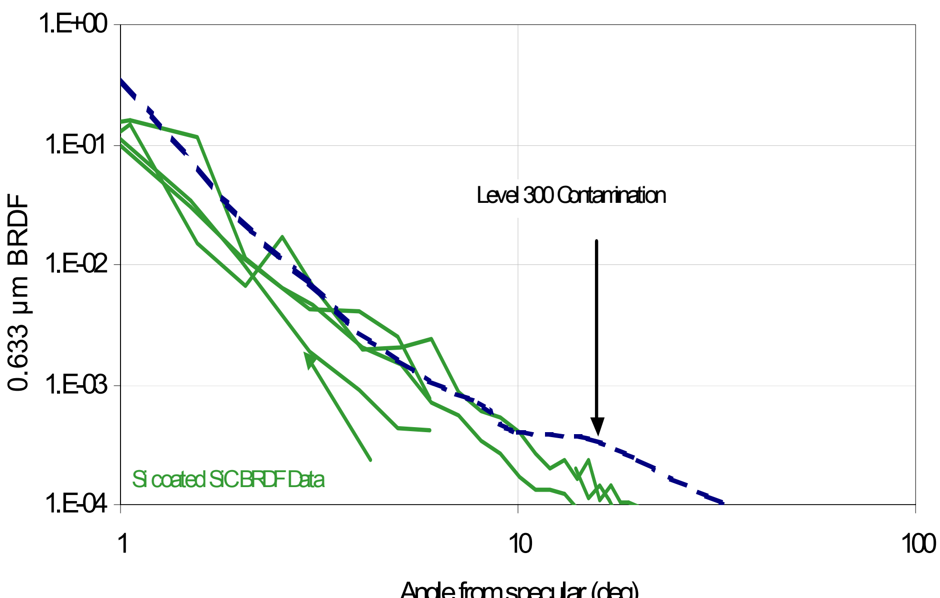
# Stray Light Characteristics of SiC




## Component BRDF Performance

- SSG has done extensive work to optimize the SiC manufacturing polishing process to ensure optimal stray light performance of SiC optics
- Component BRDF demonstrated to be consistent with level 300 contamination

# CVD SiC Coated RB SiC Optics

Talystep at Naval Air Warfare Center
China Lake, California 93555

August 2, 2000

Stylus: ETI-13, 0.8 μm radius; 1 mg loading

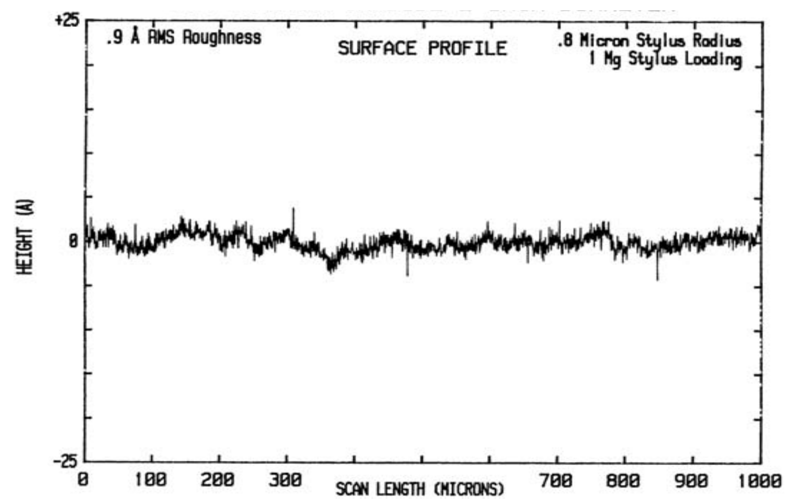
Profile lengths: 1000 μm (1 mm); 31 μm/sec stylus speed; 2658 Data Points; Gain 8
100 μm; 3.1 μm/sec stylus speed; 2658 Data Points; Gain 9

Data stored on Dell Computer at C:\taly\tdata\

20.3°C; 60 % RH; 0.49 Å rms instrument noise

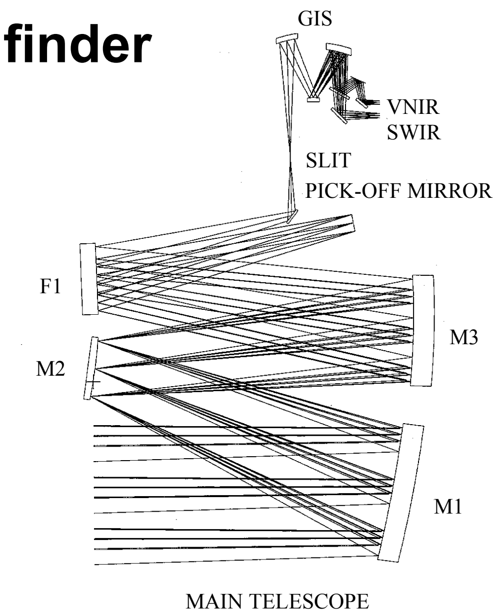
| 1000 μm profile length | | 100 μm profile length | |
|---|---|---|---|
| SSG_1 | 1.01 Å rms; 8.00 Å PV | SSG_2 | 0.83 Å rms; 7.4 Å PV |
| SSG_3 | 1.73 Å rms; 9.40 Å PV | SSG_4 | 0.82 Å rms; 5.4 Å PV |
| SSG_5 | 0.92 Å rms; 8.00 Å PV | SSG_6 | 0.72 Å rms; 5.0 Å PV |
| SSG_7 | 1.14 Å rms; 9.00 Å PV | SSG_8 | 0.78 Å rms; 7.7 Å PV |
| **Average** | **1.20 ± 0.26 Å rms** | **Average** | **0.79 ± 0.04 Å rms** |
| | **8.60 ± 0.60 Å PV** | | **6.40 ± 1.2 Å PV** |

Multiple Pieces demonstrated with Surface Finishes ranging from 0.7 – 1.4 Angstroms RMS

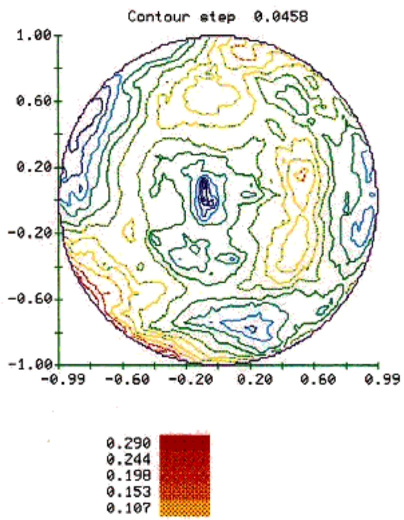


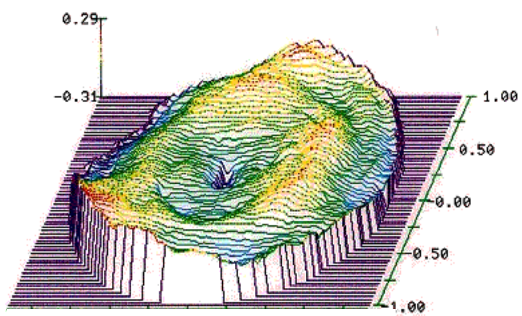

- Work has been done in CVD SiC coating RB SiC optics in order to improve surface finish capabilities

# NMP EO-1
# Advanced Landsat Pathfinder

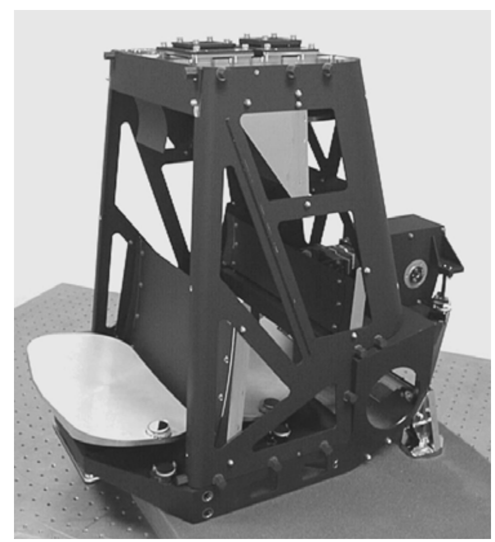



Description
- 12.5 cm aperture; 45 cm mirrors
- 15 degree FOV VIS/IR imager partially populated with multicolor FPA modules
- SiC/Si telescope mirrors with invar structure
- Temperature range 0 deg ±50 deg C
- Structural pallet/enclosure/kinematic mounts
- In-flight calibration
- Weight: 40 kg.
- Delta launch



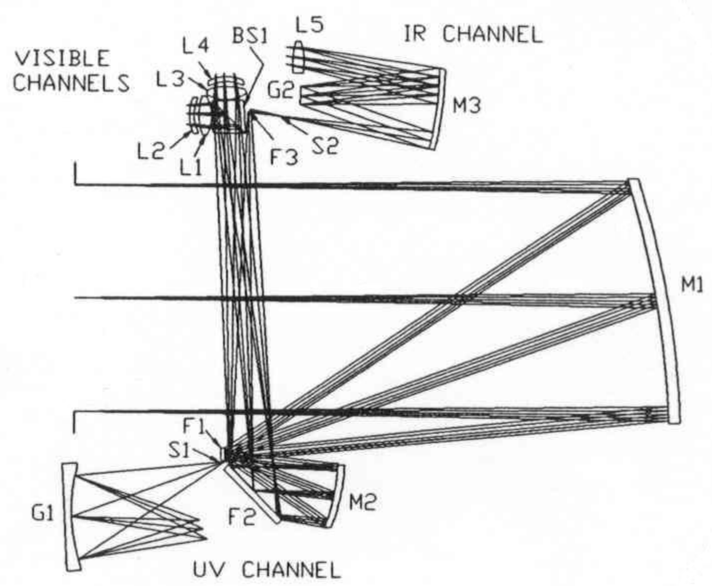




**On-axis Field Point**
**.596λ P-V .083λ RMS**



**NMP Earth Orbiter 1st Mission is co-flying with LandSat 7 demonstrating SiC based technology**

# NMP DS-1
# Miniature Infrared Camera and Spectrometer (MICAS)




| Temperature | System Wavefront Error (Pk-Valley) | System Wavefront Error (RMS) |
|---|---|---|
| 293 K | 0.70 λ | 0.13 λ |
| 136 K | 0.79 λ | 0.16 λ |

Results of the MICAS Thermal Vacuum Testing (@λ = 0.633 μm)

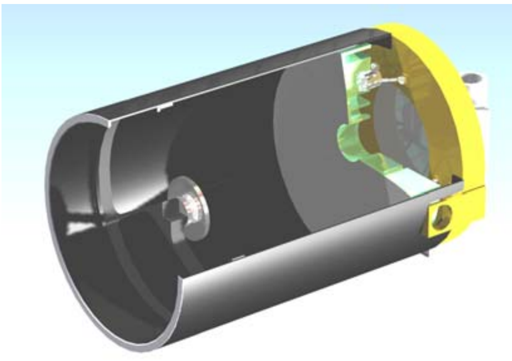
Description
- 10 cm aperture;
- All SiC instrument
- Two visible imaging channels, IR spectrometer, and UV spectrometer combined
- System demonstrated excellent thermal stability down to cryogenic temperatures
- Weight: 2.8 kg.

**NMP DS-1 Mission successfully completed, MICAS used for primary science data collection and navigation**

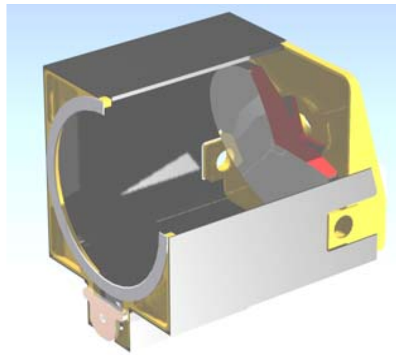
# LaserCOMM & GEO Applications

## Telescope Concepts

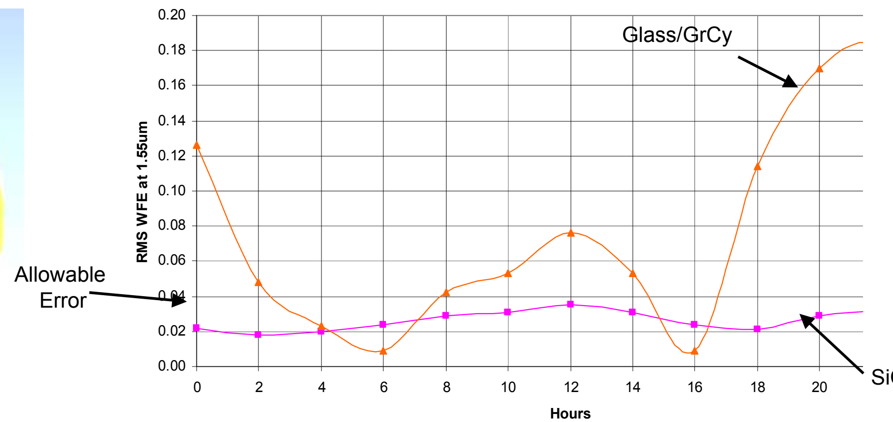
On Axis



Off Axis



## Direct Solar Loading on Telescope



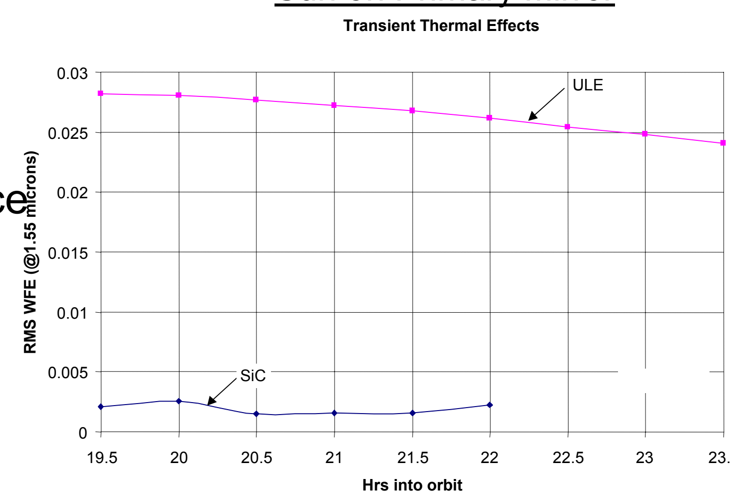

## Applications

- GEO remote sensing
- LaserCOMM crosslinks for GEO & LEO

## Telescope Problem

- Sun in aperture causing solar induced performance degradation & system outages

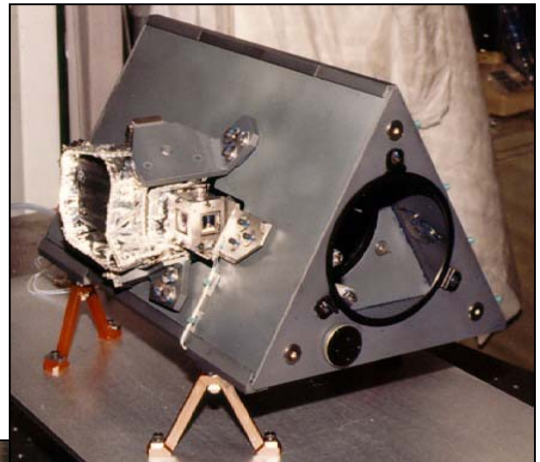
## Sun on Primary Mirror

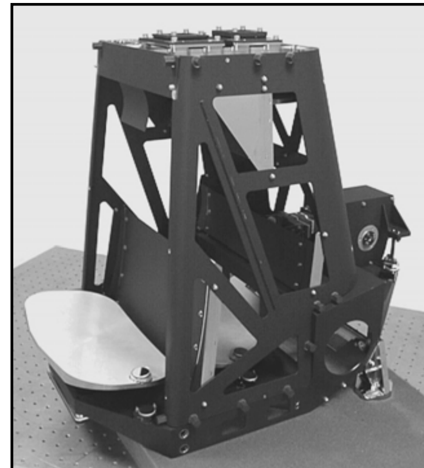



**SiC Telescope Can Maintain Visible Quality Performance with DIRECT Solar Loading; Only Possible Material Solution**

# SiC Demonstrated as a Critical Technology within NASA's New Millennium Flight Program

SiC MICAS instrument developed by SSG (NASA DS-1)

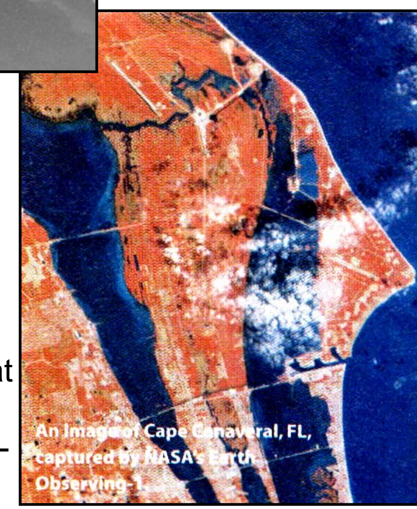




SiC ALI instrument developed by SSG (NASA EO-1)

Patricia Beauchamp of JPL holding the MICAS Instrumentation. The 1970s Voyager Instruments can be seen in the background

Advanced LandSat Imaging data obtained from ALI-EO-1 instrument




- SiC is one of several critical technologies required for a dramatic change in space based EO Instrumentation
- The MICAS instrument weights <7 kgs but performs all of the same functions as the voyager instruments, which weighed >100 kgs, while providing improved sensitivity