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Recent Advances in Cryogenic Optics Technology for Space Infrared Telescope and Interferometer Systems

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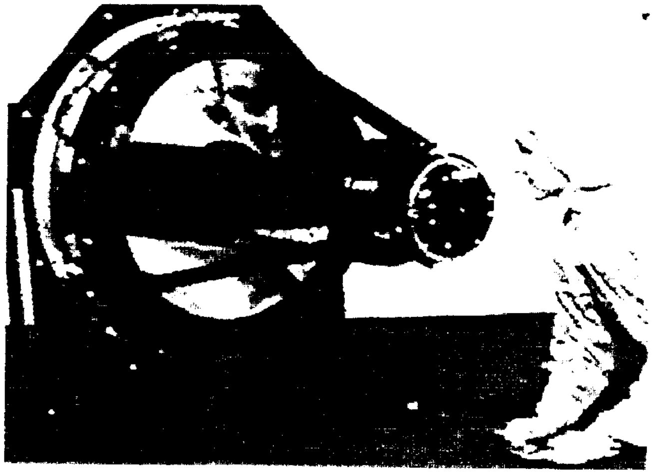
Cryogenic Space Telescopes

IRAS



1983 launch
liquid He cooled
57cm aperture
Ritchev-Chretien configuration
diffraction limited @ ≈20μm
beryllium* mirrors & structure
70kg mass
(*vacuum hot pressed material)

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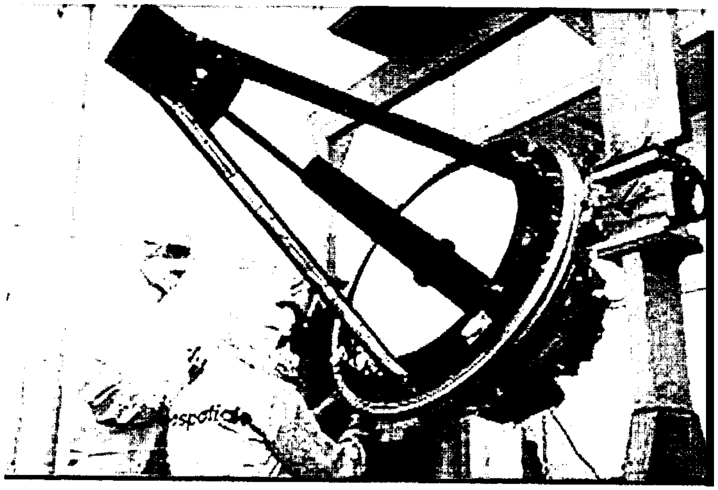
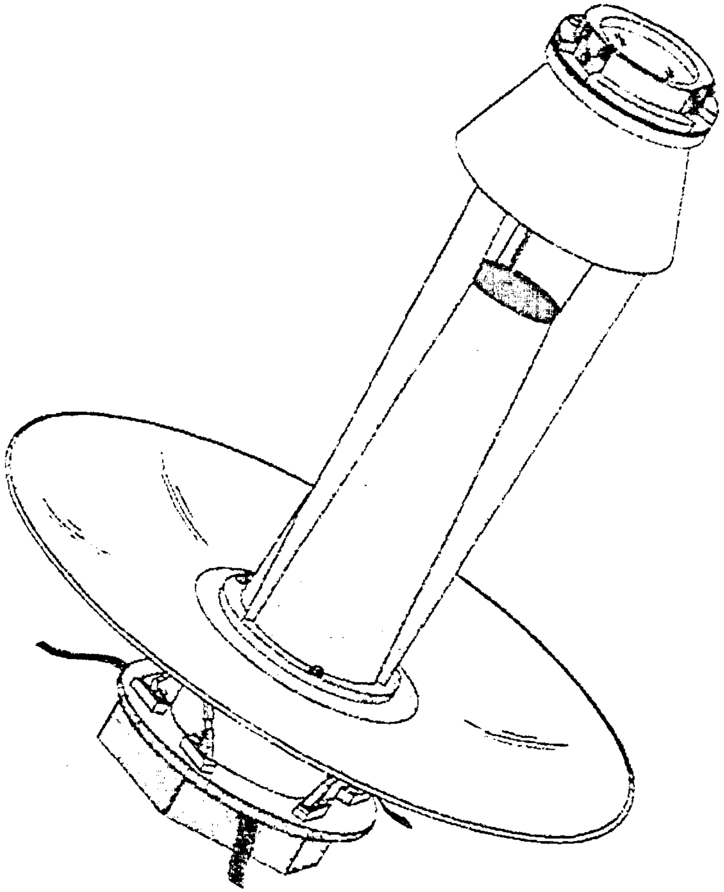


1995 launch
liquid He cooled
60cm aperture
Ritchey-Chretien configuration
diffraction limited @ 5 μm
fused silica mirrors
invar/aluminum structure
50kg mass

SIRTF Telescope



2001 launch

launched warm

- -passively cooled to <70K
- -gaseous He cooled to 5 .5K

85cm aperture

Ritchey-Chretien configuration

diffraction limited @ 6.5μm

beryllium* mirrors

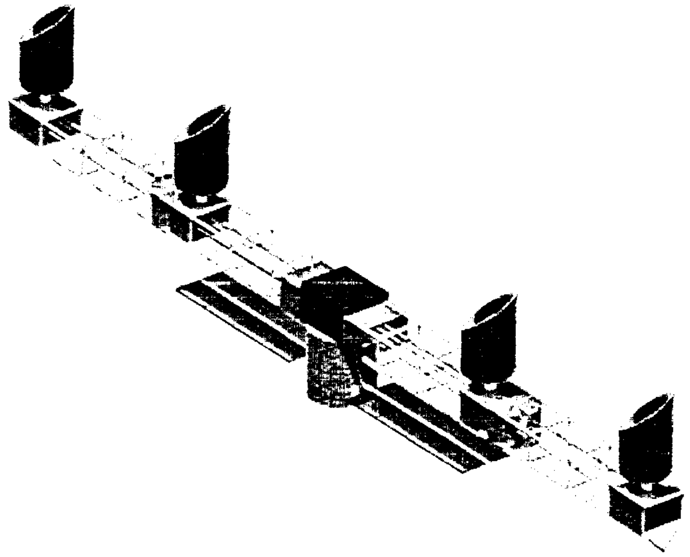
beryllium* structure

(* hot isostatic pressed material)

Ultra-1ightweight design yields 30kg mass

Cryogenic Telescopes for Space Interferometers

ExNPS Interferometer Concept



ExNPS Telescope 'Requirements'

- passive cooling to 35K
- ≈50kg mass (per telescope)
- 7-17 urn observational bandwidth
- 1.5m unobscured apertures
- diffraction limited at 2 µm
- high Strehl ratio? low scatter
- amplitude? phase and polarization matching (for nulling)

Cryogenic Space Telescopes

Design Considerations

- Cost (Manufacturability)
- Mass
- Optical design (including baffles)
- Athermalized design
- Durability (launch and on-orbit)
- Mode of cooling (passive or w/ cryogen)
- Thermal contraction, thermal mass, thermal conductivity
- Surface figure and micro-roughness
- Coating
- System testing

Candidate Materials

Mirrors

- Fused silica
- Silicon carbide
- Beryllium
- Aluminum
- Composites
- Hybrids

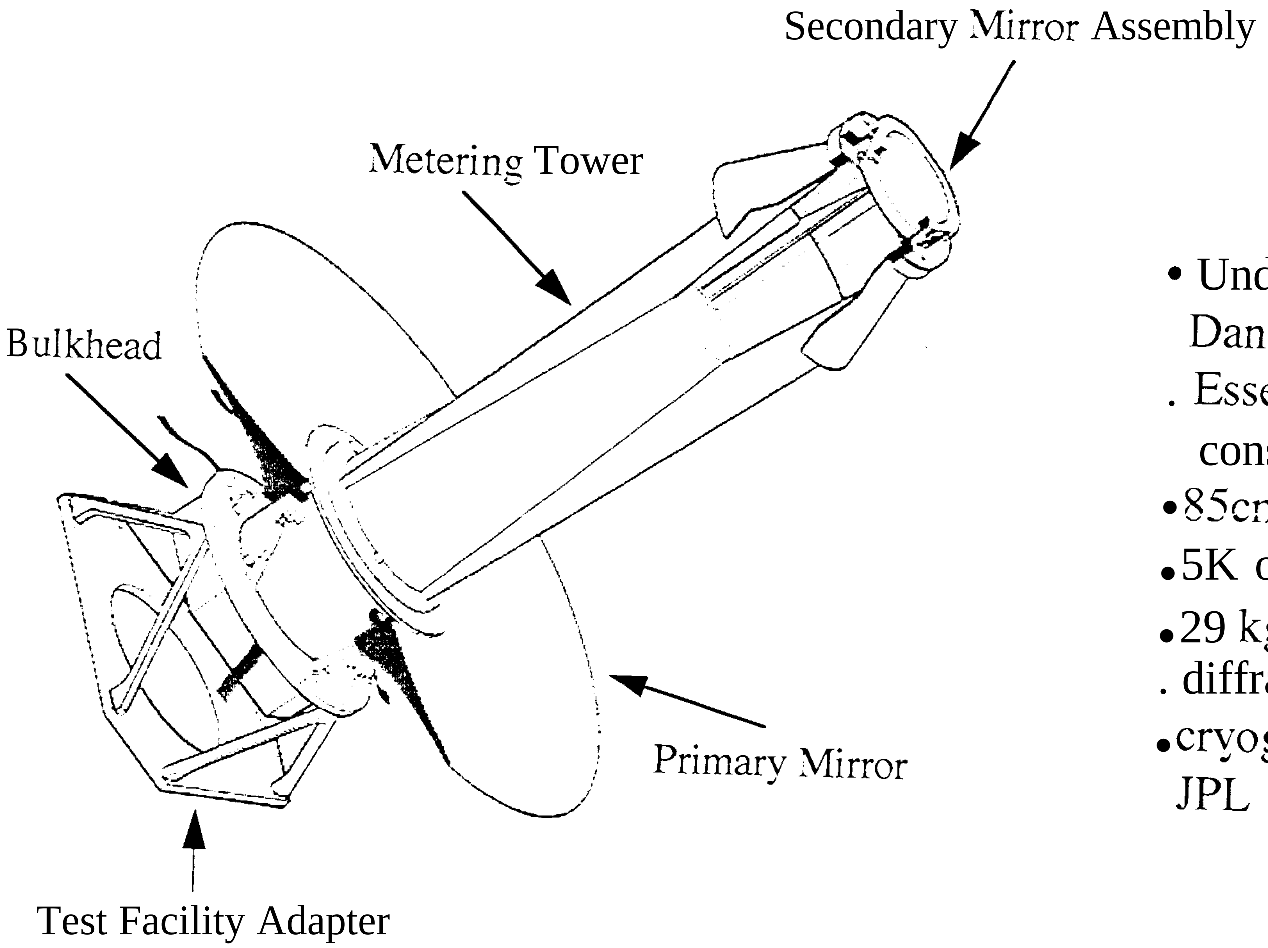
Structure

- Aluminum
- Silicon carbide
- Beryllium
- Invar
- Composites

Cryogenic Space Telescopes
Selected Mirror Materials Considerations

Fused Silica	**Silicon Carbide**	**Beryllium**	**Aluminum**	**Composites (CFRP***)**
PROS				
• Large Experience Base • Low Surface Scatter • Good Figure Quality • Good Dimensional Stability • Low Specific Heat • Good Homogeneity	• High Stiffness • Low Surface Scatter • Good Figure Quality • Good Dimensional Stability • Low Specific Heat • High Thermal Conductivity • Athermalized Systems • Near Net Shape with RB*	• Very Lightweight • High Stiffness • Good Figure Quality • High Thermal Conductivity • Easy to Mount • Athermalized Systems • Durable • Near Net Shape by HIP**	• Very Low Cost • Easy to Fabricate • High Thermal Conductivity • High Strength • Easy to Mount • Athermalized Systems • High Durability	• Low Cost • Very Low Mass • Tailorable Properties • High Stiffness • High Strength • Athermalized Systems • High Durability • Replication
CONS				
• Low Thermal Conductivity • Difficult to Mount • Difficult to Athermalize • Heavy or.... • Fragile if Lightweighted	• Immature Technology • Limited Availability • Brittle • Difficult to Mount • Heavy • Extent of Possible Light-weighting Unknown	• Low Microyield • High Thermal Contraction • Null Figuring Required • Limited Availability • Limited Size • Surface Scattering • Expensive	• Very High Thermal Contraction • Heavy • Low Stiffness	• Poor Figure Quality • High Surface Scatter • Material Variability • Anisotropic • Moisture Absorbing • Outgassing
	* Reaction Bonded	**Hot Isostatic Pressed		*** Carbon Fiber Reinforced Polymer

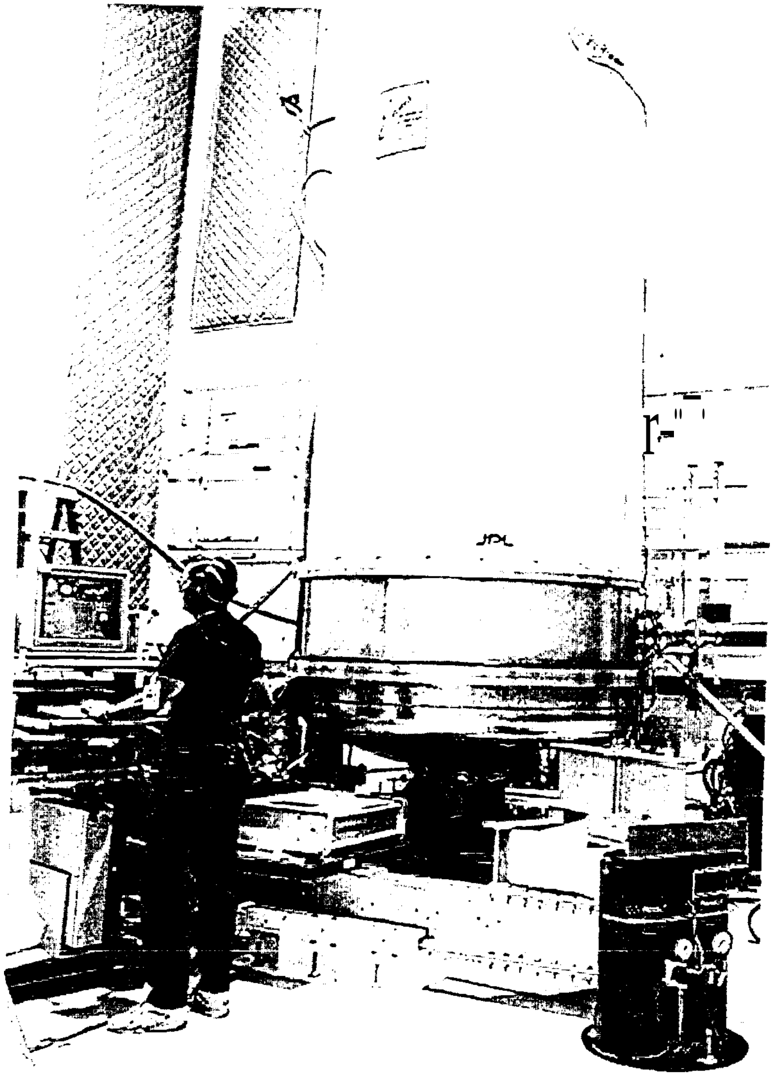
Infrared Telescope Technology Testbed

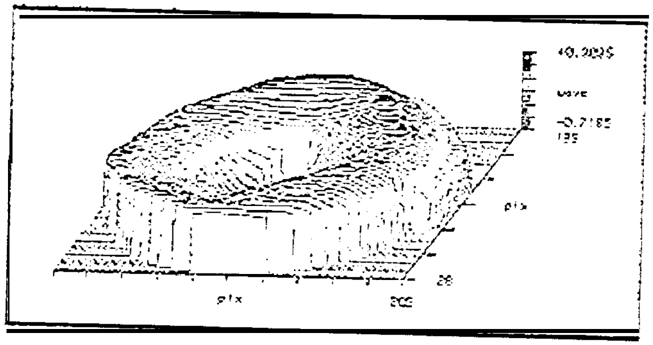


- Under development at Hughes Danbury Optical Systems
- Essentially all beryllium construction
- 85cm clear aperture
- 5K operation
- 29 kg mass
- diffraction limited at 6.5 µm
- cryogenic optical testing at JPL

Infrared Telescope Technology Testbed (ITTT) Primary Mirror Assembly

SIRTF Telescope Test Facility

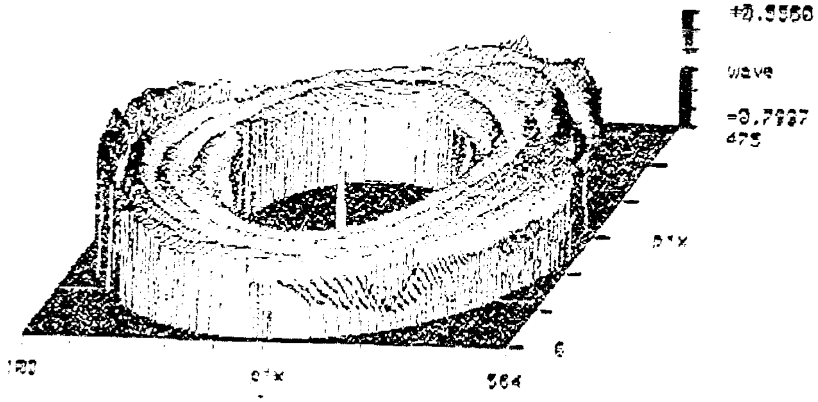




State of the Art Capability

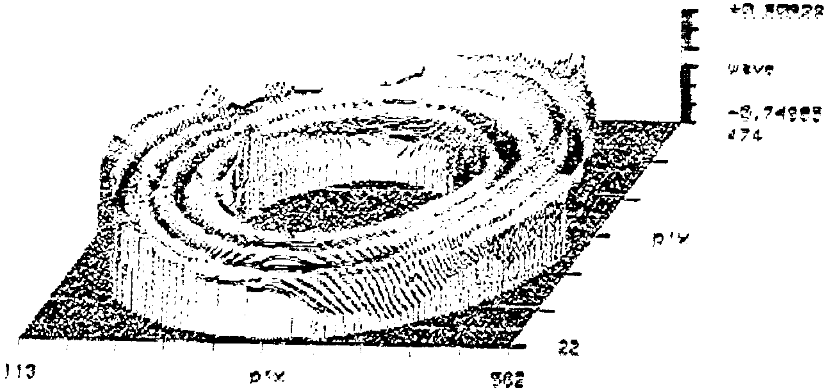
- Phase Shifting Interferometry @ .633µm
- Vertical test configuration
- Vibration isolated
- 1.4m diameter He shroud
- <5K operation

ITTT Room Temperature Interferometry



September 29, 1995

- P-V = 1.56 waves
- rms = 0.192 waves*
- dominant error: concentric zones due to form grinding



February 14.1996

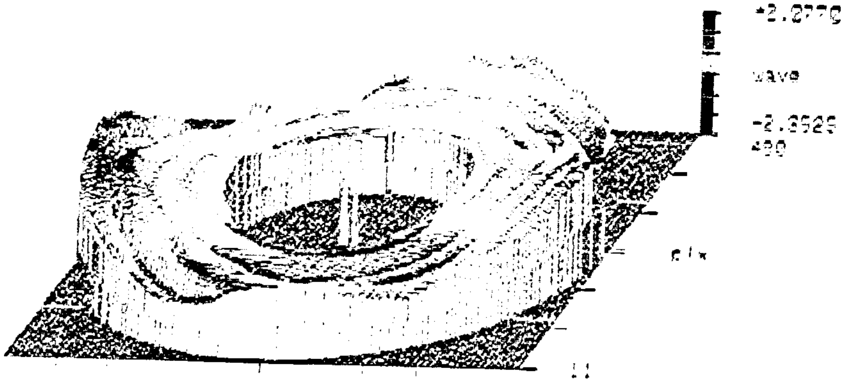
(following 5 N_2 & 3 He cycles)

- P-V = 1.35 waves
- rms = 0.194 waves*

(* surface error)

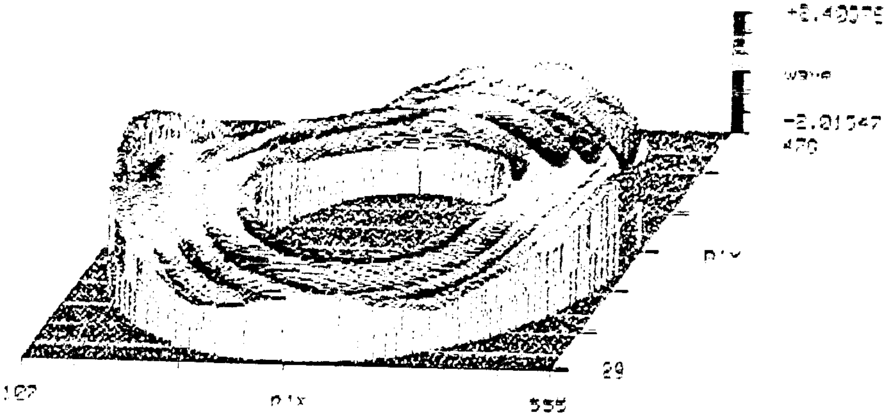
No “thermal hysteresis” observed in the Primary Mirror Assembly

ITTT 77K Interferometry



<u>October 9.1995</u>

- P-V = 4.43 waves
- rms = 0.574 waves*



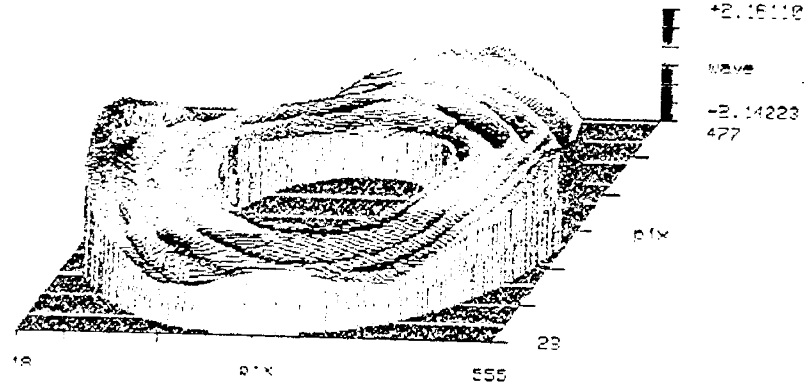
<u>February 20.1996</u>

- P-V = 4.42 waves
- rms = 0.580 waves*

(* surface error)

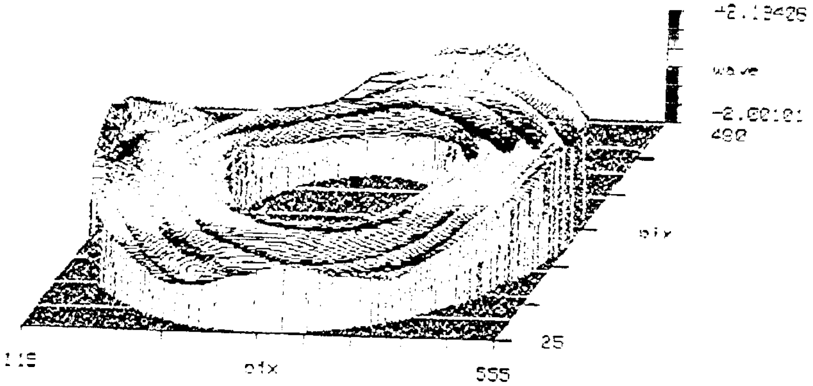
≈0.5 wave cryo-distortion observed at liquid nitrogen temperature

ITTT 5K Interferometry



February 21, 1996

- P-V = 4.30 waves
- rms = 0.581 waves*



January 30, 1996

- P-V = 4.20 waves
- rms = 0.588 waves*

surface error

Liquid helium data essentially the same as liquid nitrogen data

ITTT Primary Mirror Data Summary

Temperature (K)	RMS Surface Figure Error (waves @ 0.633µm)
295	0.2[illegible] ± 0.016
77	0.574 ± 0.02
5	0.585 ± 0.02

ITTT Current Status Summary

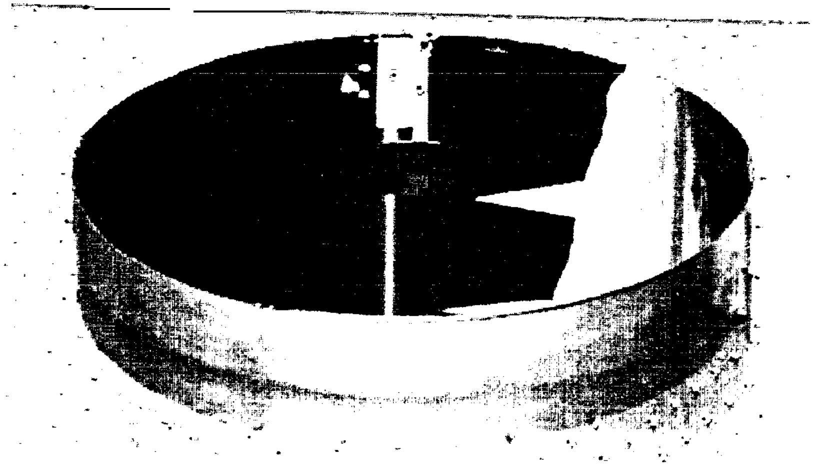
Summary to Date

- Initial primary mirror assembly (PMA) testing completed (8 cycles to 77K, 3 cycles to 5K)
- PMA disassembled, primary mirror (PM) tested alone and PMA reassembled
- Room temperature PMA and PM error dominated by concentric zones (≈0.2 waves rms surface)
- Moderate cryo-distortion observed in the PMA and PM (≈0.5 waves rms surface)
- No “thermal hysteresis” observed
- No changes observed in PMA following reassembly
- PMA has been returned to Hughes Danbury
- Secondary mirror assembly currently in optical fabrication
- Metering tower/baffles currently being machined

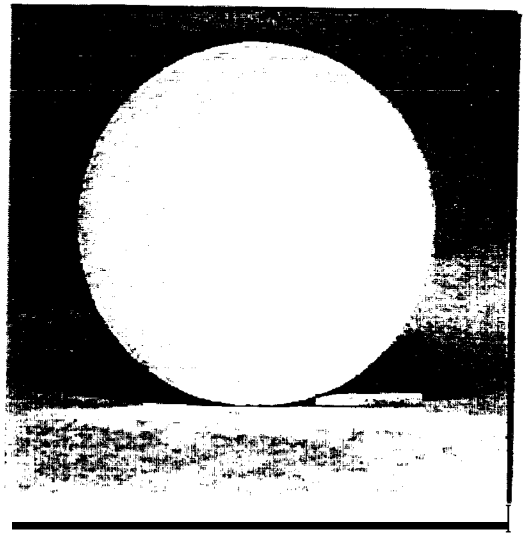
Future Plans

- Remove concentric zones from PM with computer controlled polishing (<0.1 waves rms surface)
- Null figure the PM to achieve (<0.2 waves surface at 5K)
- Complete secondary mirror assembly
- Complete metering tower/baffles
- Retest the PMA to 5K
- Perform second null figuring cycle if necessary
- Integrate, align and test ITTT to 5K (≤0.72 waves rms wfe @ 0.633µm)
- Shake ITTT to launch vehicle loads and retest

50cm Test Mirrors

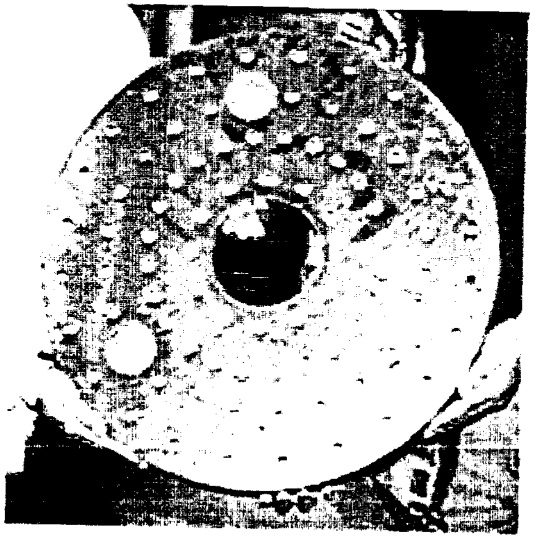


- HIP Beryllium
- Manufactured by Brush-Wellman Loral American" Beryllium, Tinsley
- Not lightweighted
- 1m focal length, sphere
- Cryo-test data (λ=0.633μm):
  - 0.071λ rms wfe @ 300K
  - 0.15λ rms wfe @ 77K
  - 0.14λ rms wfe @ 5K
- "Thermal hysteresis" = 0.004λ

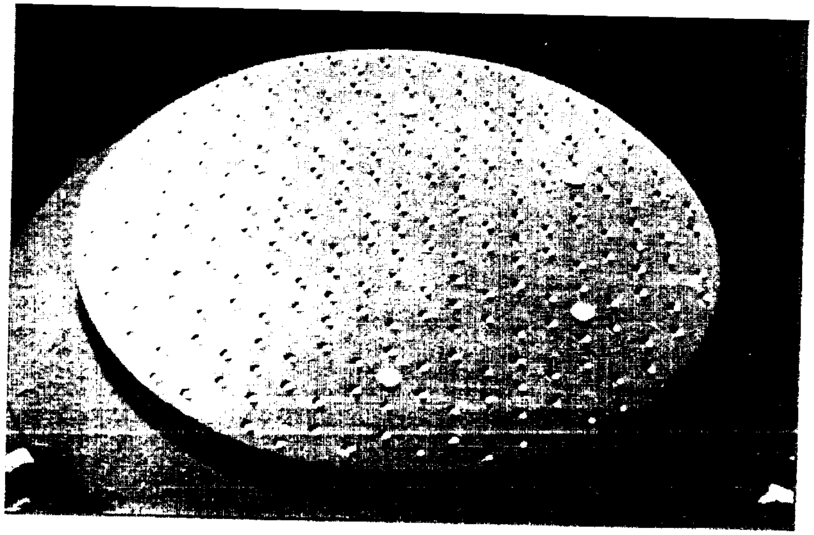


- Reaction bonded silicon carbide
- Manufactured by United Technologies, Lockheed and ITEK
- Lightweighted: closed back (5kg)
- 1m focal length, sphere
- Cryo-test data (λ= 0.633μm):
  - 0.053λ rms wfe @ 300K
  - 0.126λ rms wfe @ 5K
- "Thermal hysteresis" = 0.03λ

Lockheed-Martin/Vavilov Institute Silicon Carbide Mirrors



- 60cm diameter
- lightweighted (5kg)
- 0.024λ rms wfe @ 0.633nm
- Not intended for cryogenic use



- cryogenic autocollimation flat for testing ITTT
- 93cm diameter
- not extensively lightweighted (36kg)

Conclusions

- There is currently a significant level of activity in the development of cryogenic optics
- A number of cryogenic optics approaches are available to support space interferometry - choice depends on detailed mission requirements
- The ‘thermal hysteresis” problem with large cryogenic beryllium optics has been solved
- The state-of-the-art in large cryogenic silicon carbide optics is advancing rapidly
- The future cryogenic optics needs of the space interferometry community appear to be reasonable extensions of existing technology if ....

Issues

- Sufficient support for lightweight cryogenic optics technology development
- Clear, concise statement of requirements for nulling interferometer light collection telescopes
  - very low stray & scattered light
  - amplitude, phase and polarization matching in multiple arms of the interferometer
- Very large (5m,10m,20m), lightweight apertures will require significant technology development efforts
  - segmented mirrors
  - precision deployable structures
  - on-board alignment and control