Lightweight cryostable mirrors
David Content - NASA GSFC

Goal: Cost effective, lightweight, cryostable mirrors

- Specific goal: Achieve cost effective, lightweight solution that allows "fabricate & align warm, use cold" approach
- Significant savings in weight, cost, and I&T time
- Goal is not only primary mirrors but subsequent telescope mirrors and instrument optics also

Team:

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Outline

- Overview
  - Materials summary
  - Product development flow
- Aluminum lightweight optics development
  - Al foamcore mirrors
  - Al superpolishing
  - Al Offner relay demonstration system status & plans
- Silicon lightweight optics development
  - Si Offner relay demonstration system
  - Schafer Si Foamcore mirror development (initial funding through MSFC SBIR/S. Montgomery)
  - McCarter Single crystal Si (SCS) mirror development

Lightweight mirror materials properties

	Table 1: lightweight materials properties									
	Property	units	desired value	Al 6061	Si	ULE	Zerodur	Be I-70 H	SiC [CVD b]
Basic properties	density, r	kg/m^3	small	2700	2330	2210	2530	1850	3210
	Young's Modulus, E	GPa	high	68	131	67	91	287	465
	CTE, a	1.E-6/K	low	22.5	2.6	0.03	0.05	11.3	2.4
	Thermal conductivity, k	W/m.K	high	167	148	1.31	1.64	216	198
	Thermal Diffusivity, D	1.E-6m^2/s	high	69	94.3	0.78	0.77	57.2	84.2
	Ability to be diamond turned		high	high	high	low	low	low	low
	Difficulty of polishing		low	medium	low	low	low	high	high
Figures of merit	Self Deflection, r/E		low	3.97	1.78	3.3	3.3	0.64	0.69
	Steady state Thermal, a/k	um/W	low	0.135	0.018	0.023	0.030	0.052	0.012
	Transient thermal, a/D	sec/m^2.K	low	0.326	0.028	0.038	0.065	0.198	0.029
	Cost of finished optic			$	$	$$	$$	$$$	$$$

Product Development flow

- Funding sources:
  - Space-based technology program (crosscutting/ULSSO)
  - NGST technology funding
  - COVIR project (ESSP)
  - co-funding for lightweight Al benches through phase II SBIR w/ Nu-Cast & Proto-Engineering
- Products/near term deliverables
  - COVIR flight Al foamcore scan mirror
  - 2 Offner relay systems for NGST Instrument technology program
    - 1st Offner - Aluminum
      - solid, with heavy bench
      - foamcore, with lightweight bench
    - 2nd Offner - Silicon mirrors and C/SiC mounts
      - current funding only covers component testing on mounted mirrors
- Far term plan
  - infuse ~0.5m optics into Explorer missions and NGST instrument
  - use future technology funding to demonstrate aperture scaling to ~1m and up

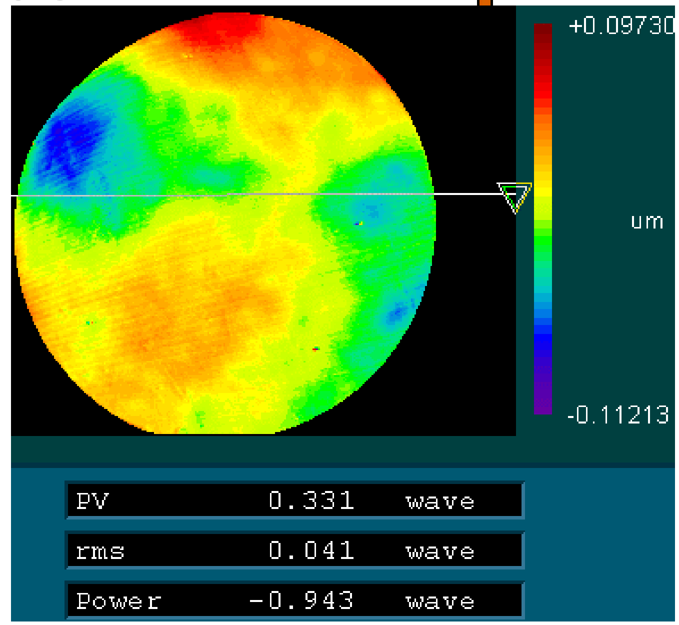
Aluminum foamcore CETDP/ULSSO task - new in FY00

Product Objectives

- Demonstrate potential of Al & other foam-core materials for rapid fabrication, inexpensive cryo-stable optics & structures. Key is exclusive use of materials useful for both structures and optics to **avoid CTE mismatches**
- Demonstrate cryo stability on flats and spheres, and design 0.5 meter telescope by end of FY2000
- Assemble & cryo-test 0.5 meter telescope by end of FY2002; demonstrate improvement & scaling in all metrics (cryo stability, weight [kg/m^2], cost [\$/m^2], & lead time).

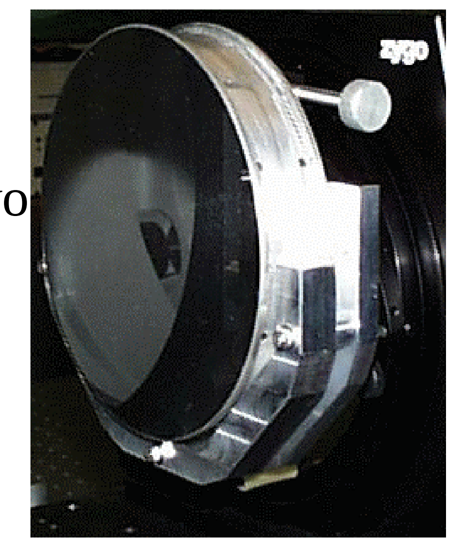
Status

- Fabricated, diamond turned and cryo tested 15 cm flats, to 18 kg/m^2, superpolished
- Cryo-stability appears to be < 0.1 l rms
- Test is limited by induced thermal gradients, to which Al (w/ large CTE) is very sensitive
  - 3 Al mirrors and 1 Si mirror tested
  - Gradients of this size are not present in most applications
  - 544 helping w/ thermal shutter for dewar



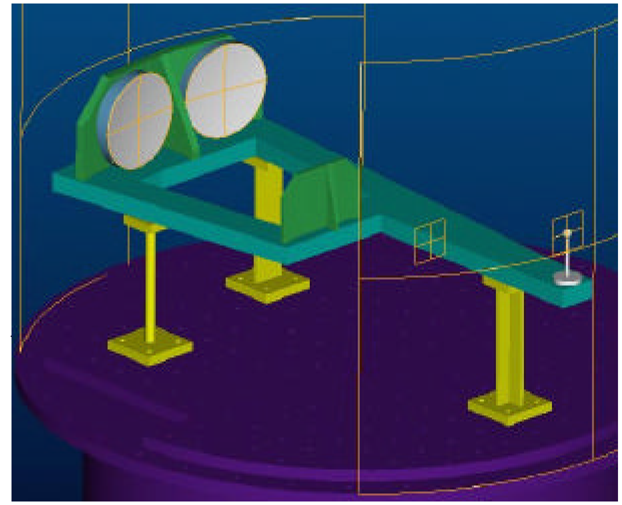
Thermal deformation (300->100K) of foamcore mirror, power removed

Foamcore mirror in cryo test mount



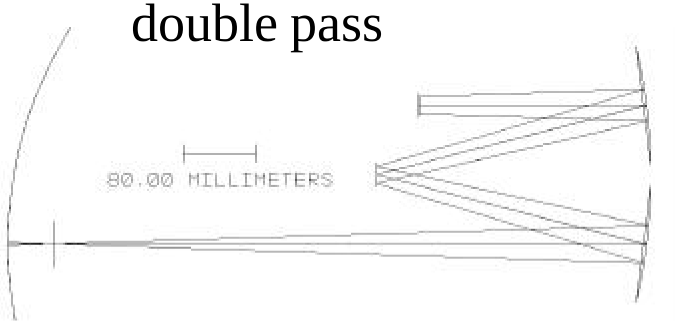
Aluminum Offner Relay

- Goal is a demonstration of ability to 'fab & align warm, use cold'
- All spherical optics [2-5 inches]
  - 5 inch foamcore spheres for M1 & M3
  - Initial test uses single field point in double pass to test cold wavefront
  - System is usable for micromirror array testing later (warm or cold)
- Mount and bench design underway now (Swales task)

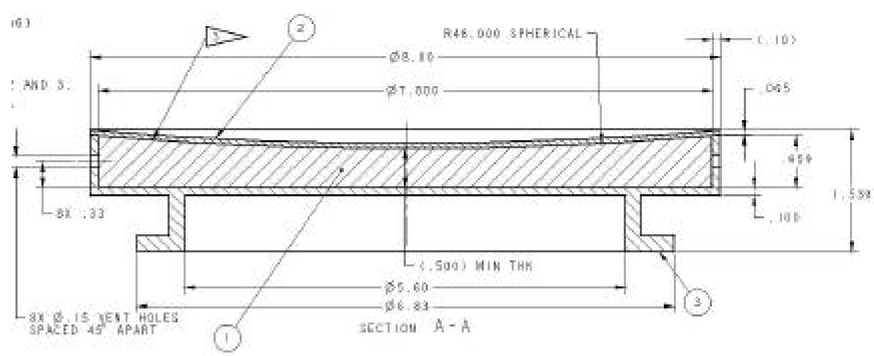


View of Offner bench and optics in IRAC test dewar

Offner Relay layout, using 1 field point, double pass



Drawing for 8" foamcore blank, ready to mount [~24 kg/m^2]

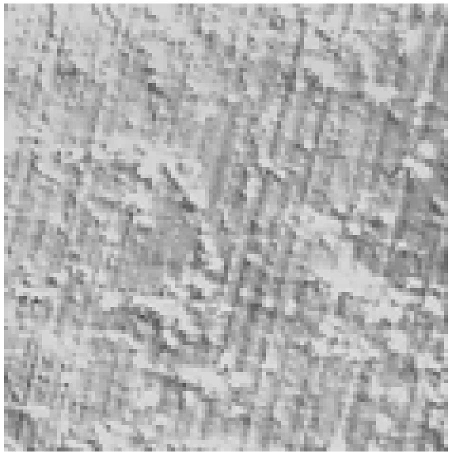


Aluminum Superpolishing

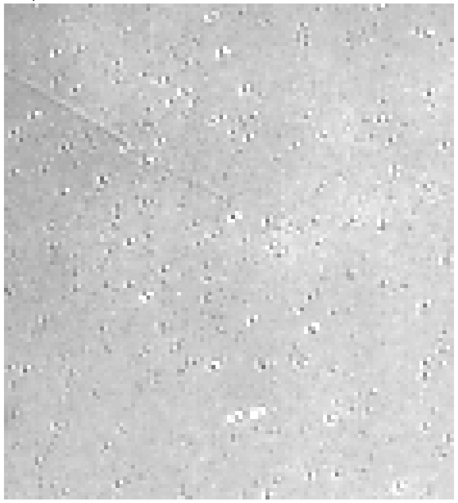
- Patent applied for in FY99, pursuing licensing now (Technology Opportunity Workshop held 11/15/00)
- FY00 DDF demonstrated superpolishing on aspheres:
  - f/8 and f/3 on axis, 15 cm parabolas (solid Al) polished to 0.8 nm rms

Micrographs of Al superpolishing (40x)

Before polishing: DTM marks and pits visible



After polishing: DTM marks gone, but pits still visible



Silicon lightweight mirrors

- The opto-mechanical advantages of Si are clear in the materials table
- Si is also highly polishable and has many processes already developed by the semiconductor and lithography industries
- Two basic varieties are under development by this team
  - 1) foamcore (Ultramet and Schafer)
  - 2) Single crystal silicon (SCS) lightweight mirrors
    - 2a) McCarter process (described below)
    - 2b) Vince Bly Fy2001 DDF proposal (just funded)

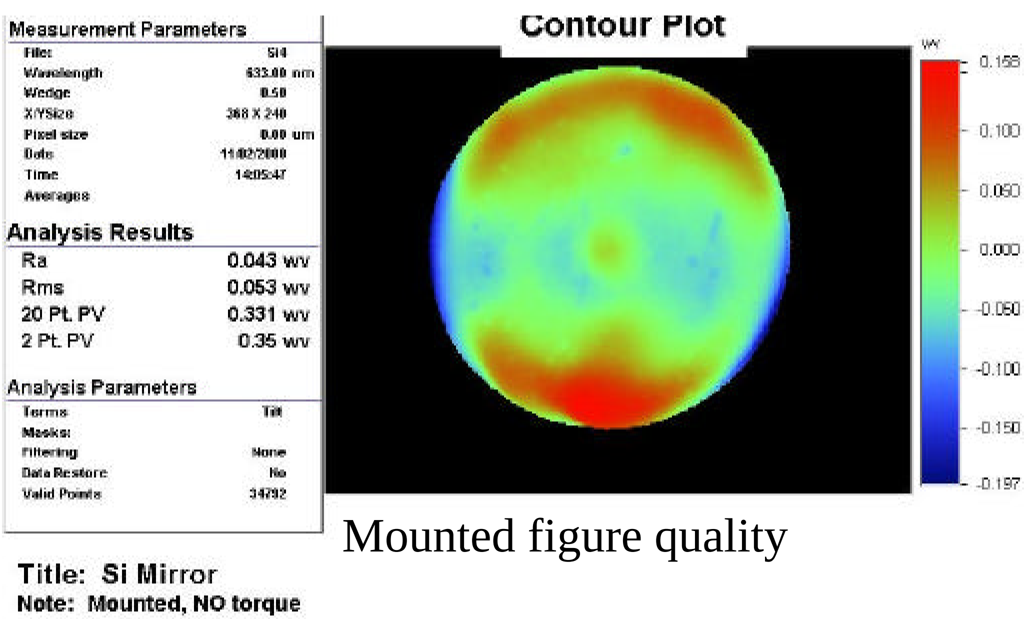
Schafer Si foamcore, Mounted in CTE matched C/SiC mount

Si Offner mounts and M2 mirrors

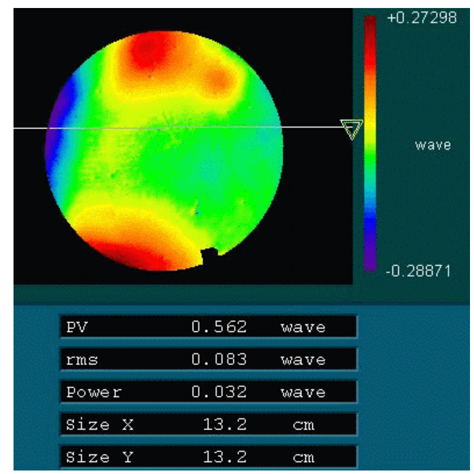
Schafer Silicon Flat Demo Optic in Thermally Matched C/SiC Mount

- First mode of silicon lightweight mirror predicted to be 4418 Hz
- C/SiC optical mount custom designed by Schafer

Design Parameter	Specification	Achieved
Material	Silicon Foam Core	Silicon Foam Core
Diameter	15 cm	15 cm
Side Walls	Open or Closed-Out with Vent Holes	Vented
Weight (Areal Density)	≤277 grams (≤15 kg/m^2)	273 grams (≤15 kg/m^2)
Microroughness	≤3.0 nm rms	1.5-2.0
Figure Quality (at room temperature and 77 K)	≤50 nm rms	33.5 nm rms

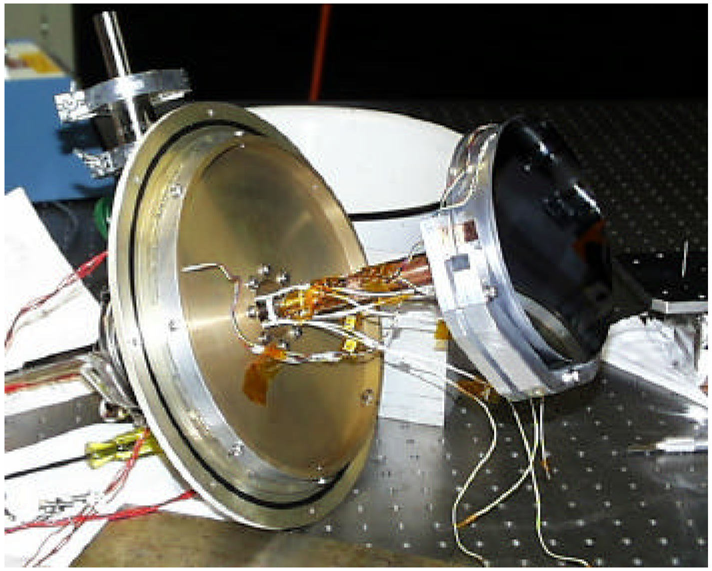


Mounted figure quality

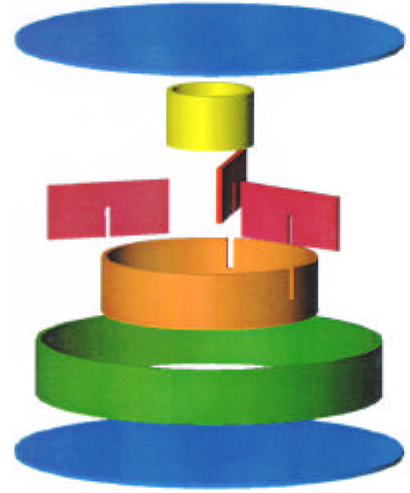


Unmounted cryo-figure stability

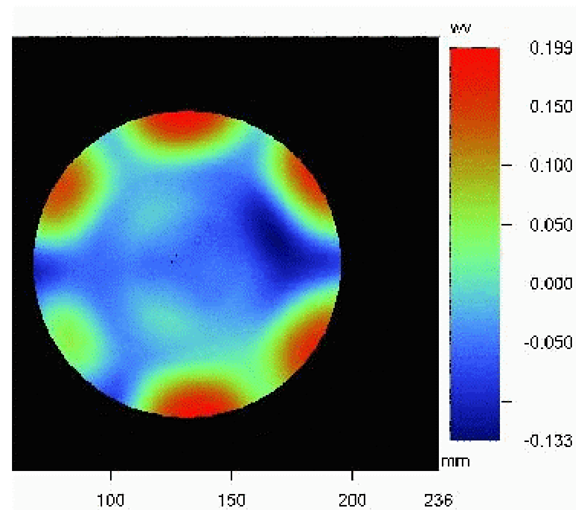
McCarter SCS flat, Mounted for cryo figure testing



McCarter SCS flat, exploded view



McCarter SCS Offner sphere; 18 kg/m^2; superpolished to 0.5 nm rms



McCarter SCS Offner sphere: 0.067 l rms ambient wavefront (but substructure prints through)

Summary

- Several approaches to lightweight mirrors are showing promise
  – lightweight, cryostable to 0.1λ rms
- CTE compatible structures are mature and available
    - Al for Al foamcore mirrors
    - C/SiC for Si mirrors
- The Si mirrors may apply to the need for precision lightweight optics for UV/optical applications