Goodman Technologies, LLC

ULTRA-LIGHTWEIGHT, ULTRA-STABLE ROBOSIC ADDITIVELY MANUFACTURED LASERCOM TELESCOPE

2018 Mirror Technology Days

NASA Phase I Results

Contract #80NSSC18P1995

An ACTIVE Participant in STEM
"You have to give it away to keep it"

- NASA Needs (PCOS and COR PATR)
- Marketplace
- Path to Lasercom Telescope - Technical Objectives
- Performance
- Bolts
- OAP
- Phase II Plan

OVERVIEW

- **Dimensional stability, low scatter, extreme light-weighting, and precision structures**
  - Common theme for NASA 2017 Physics of the Cosmos (PCOS) and Cosmic Origins (COR) Program Annual Technology Report (PATR). Multiple Priority Tier 1-4 technology gaps
- **NASA's Long Range Optical Communications Goals for FSOC**
  - >100 gigabit/s cislunar (Earth or lunar orbit to ground)
  - >10 gigabit/s Earth-sun L1 and L2,
  - >1 gigabit/s per AU-squared deep space
  - >100 megabit/s planetary lander to orbiter.
- **Laser communications telescopes (LCTs):**
  - 30-100 cm CA, WFE <62 nm, cumulative WFE and transmission loss < 3-dB (far field)
  - Advanced thermal/stray light design for operation while sun-pointing (3-degrees)
  - -20° C to 50° C operational range (wider range preferred)
  - Areal density <65kg/m^2.
- Common solution of interest: Silicon Carbide and 3D printing or additive manufacturing

NASA NEEDS FROM THE DECADAL SURVEY

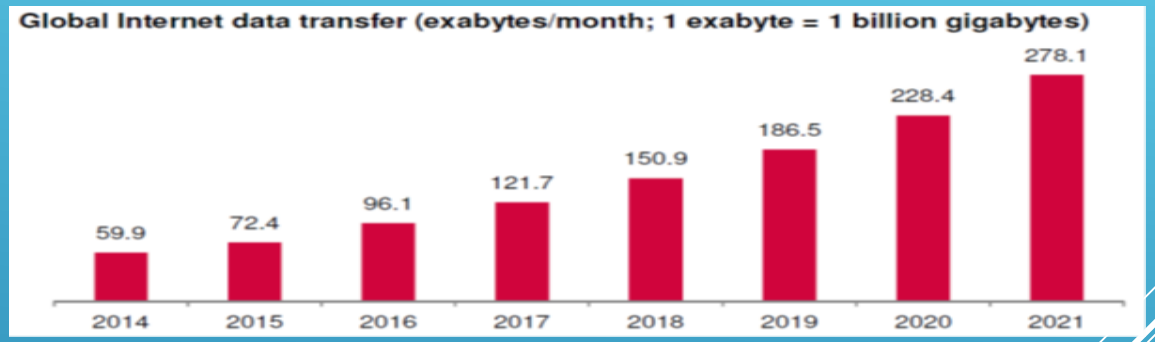
- December 31, 2017 "Internet World Stats" estimates that there are 4.2 billion global internet users

- CISCO: 24% CAGR for data transfer between 2016 and 2021
  - 278.1 exabytes by 2021

- Companies planning high-volume space satellite networks include Telesat, SpaceX, Kaskilo and Leosat

WORLD INTERNET USAGE AND POPULATION STATISTICS
DEC 31, 2017 - Update

World Regions	Population (2018 Est.)	Population % of World	Internet Users 31 Dec 2017	Penetration Rate (% Pop.)	Growth 2000-2018	Internet Users %
Africa	1,287,914,329	16.9 %	453,329,534	35.2 %	9,941 %	10.9 %
Asia	4,207,588,157	55.1 %	2,023,630,194	48.1 %	1,670 %	48.7 %
Europe	827,650,849	10.8 %	704,833,752	85.2 %	570 %	17.0 %
Latin America / Caribbean	652,047,996	8.5 %	437,001,277	67.0 %	2,318 %	10.5 %
Middle East	254,438,981	3.3 %	164,037,259	64.5 %	4,893 %	3.9 %
North America	363,844,662	4.8 %	345,660,847	95.0 %	219 %	8.3 %
Oceania / Australia	41,273,454	0.6 %	28,439,277	68.9 %	273 %	0.7 %



Company	Constellation
SpaceX	Creation of constellation in several stages: 1 stage: 1,600 satellites 2 stage: 2,825 satellites (altitude: 1,100 to 1,325 kilometres) 3 stage: 7,518 satellites (altitude: 340 kilometres) Total number of satellites: 11,943
Kaskilo	Constellation of 300 satellites (altitude: 1,100 kilometres)
Telesat	Creation of constellation in several stages: 1 stage: 117 satellites (altitude: 1,000 to 1,250 kilometres) 2 stage: 117 satellites (altitude: 1,000 to 1,250 kilometres)
Leosat	Creation of constellation in several stages: 1 stage: 78 satellites 2 stage: 30 satellites (altitude: 1,400 kilometres)

MASSIVE COMMERCIAL MARKET

- Demonstrate new RoboSiC Optical and Structural Materials
  - Minimize surface roughness and scatter for mirrors (super-polishable)
- Print general asphers (We are printing an Off-Axis Parabola)
- Demonstrate Super-Dimensionally Stable Structural Grade
  - W.R.T. BASELINE RoboSiC (100% SiC) Structural Grade is Lower Density, Higher Stiffness, Higher Strength, Lower Coefficient of Thermal Expansion and other Multi-Functionality
  - Phase II Plan
- Deliverables: *New Technology Called RoboSiC™*
  - ¼ x 80 and 1/4x 20 threaded RoboSiC bolts
  - 10-30 mm diameter printed RoboSiC OAP substrate & DD Form 250

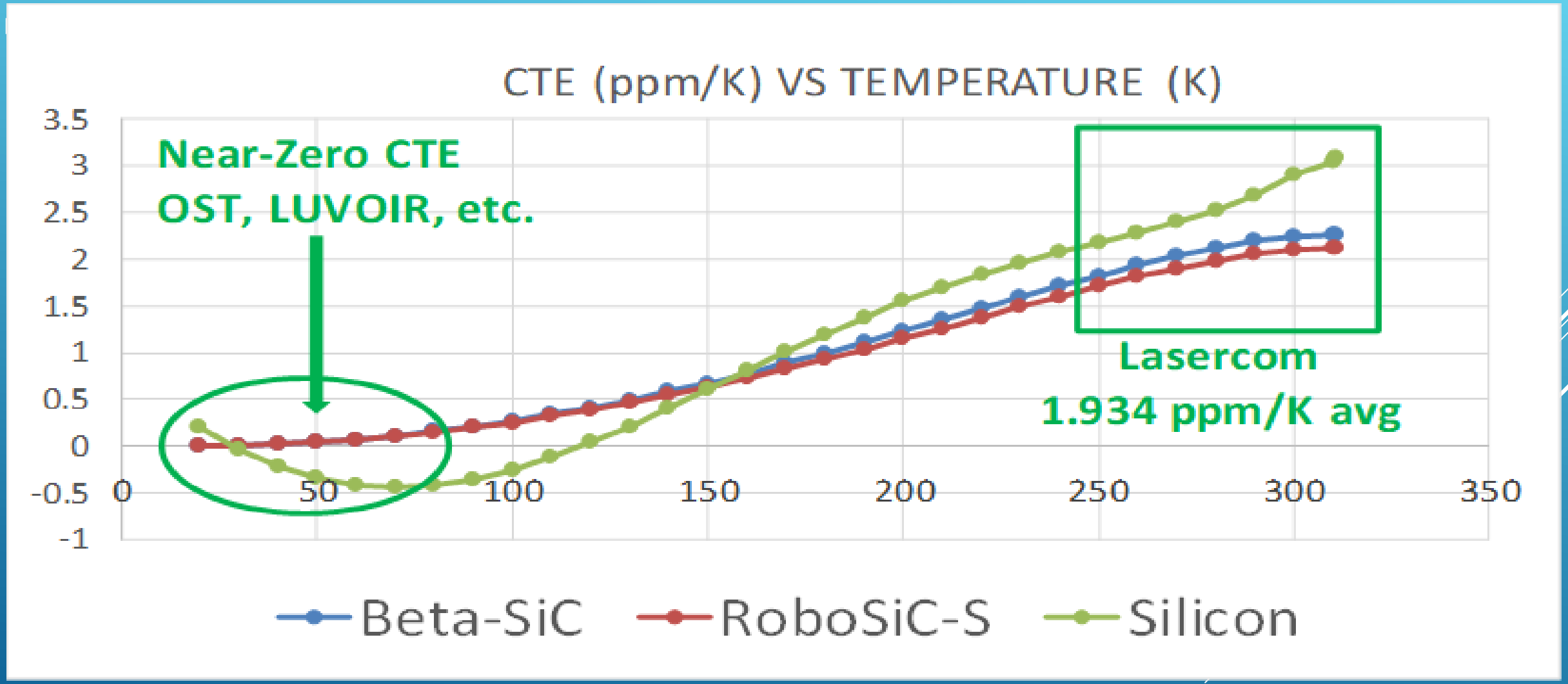
TECHNICAL OBJECTIVES

- The reason SiC works - simple linear expansion equation: $dL = L \alpha dT$, where L is the length, α is the linear CTE, and dT is the temperature gradient. $dT \rightarrow 0$ when Thermal Diffusivity is HIGH……If $dT \rightarrow 0$, then $dL \rightarrow 0$

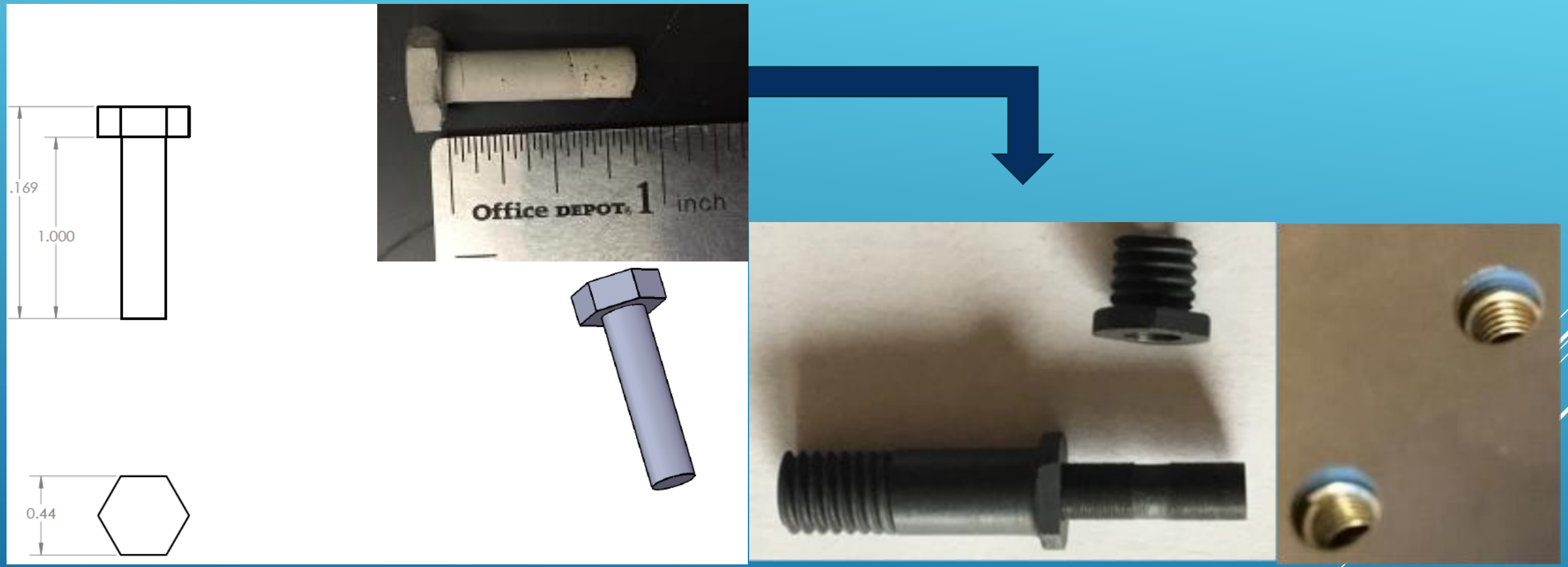
	ρ	E	E/ρ	σ_t	σ_t/ρ	α	k	C_p	$D=k/\rho C_p$	k/α	D/α	ν
Room Temperature Property:	**Density**	**Young's Modulus**	**Specific Stiffness**	**Tensile Strength**	**Specific Strength**	**Thermal Expansion**	**Thermal Conductivity**	**Specific Heat**	**Thermal Diffusivity**	**Steady State Stability**	**Transient Stability**	**Poisson's Ratio**
Units:	kg/m^3	GPa	$MPa\text{-}m^3/kg$	Mpa	$MPa\text{-}m^3/kg$	$10^{-6}/K$	W/m-K	j/kg-K	$10^{-6}/m^2/s$	W/μm	$m^2\text{-}K/s$	arbitrary
Preferred Value:	**Small**	**Large**	**Large**	**Large**	**Large**	**Small**	**Large**	**Large**	**Large**	**Large**	**Large**	
Zerodur	2530	90.3	36	variable	variable	-0.09	1.46	800	0.72	-16.22	-8.01	0.24
M55J/954-6 T300/954-6 Axial	1742	53	30			-0.125	10			-80.00		
M55J/954-6 T300/954-6 Hoop			43		Spanner Tube avg 25-125K							
Invar 36	8050	141	43	276	0.03	1	10.4	520	2.48	10.40	2.48	
Aluminum:6061	2700	68	25	276	0.10	22.5	167	900	68.72	7.42	3.05	0.33
Single Crystal Silicon	2330	130	56	120	0.05	2.5	148	750	84.69	59.20	33.88	0.24
SiC: Sintered (alpha)	3100	410	132		0.00	4.02	125	670	60.18	31.09	14.97	0.14
SiC: Reaction Bonded	2950	364	123	300	0.10	2.44	172	670	87.02	70.49	35.66	0.18
Carbon Nanotube	2100	1060	505	100000	47.62	-12	3000	750	1904.76	-250.00	-158.73	
Graphene Nanosheet	2100	1000	476	130000	61.90	-8	3000	750	1904.76	-375.00	-238.10	
RoboSiC-Optical	3210	460	143	470	0.15	2.2	380	640	184.97	172.73	84.08	0.21
RoboSiC-S-R1	3198.9	466	146	1465.3	0.46	2.058	406.2	641.1	198.07	197.38	96.24	0.21
FACTOR OF IMPROVEMENT			**4.08**	**<--**	**COMPARED TO**		**Zerodur-->**		**274.58**	**-12.17**	**-12.01**	
			4.79	**<--**					**JWST-->**	**-2.47**		

PATENT PENDING RESULTS ARE ASTONISHING

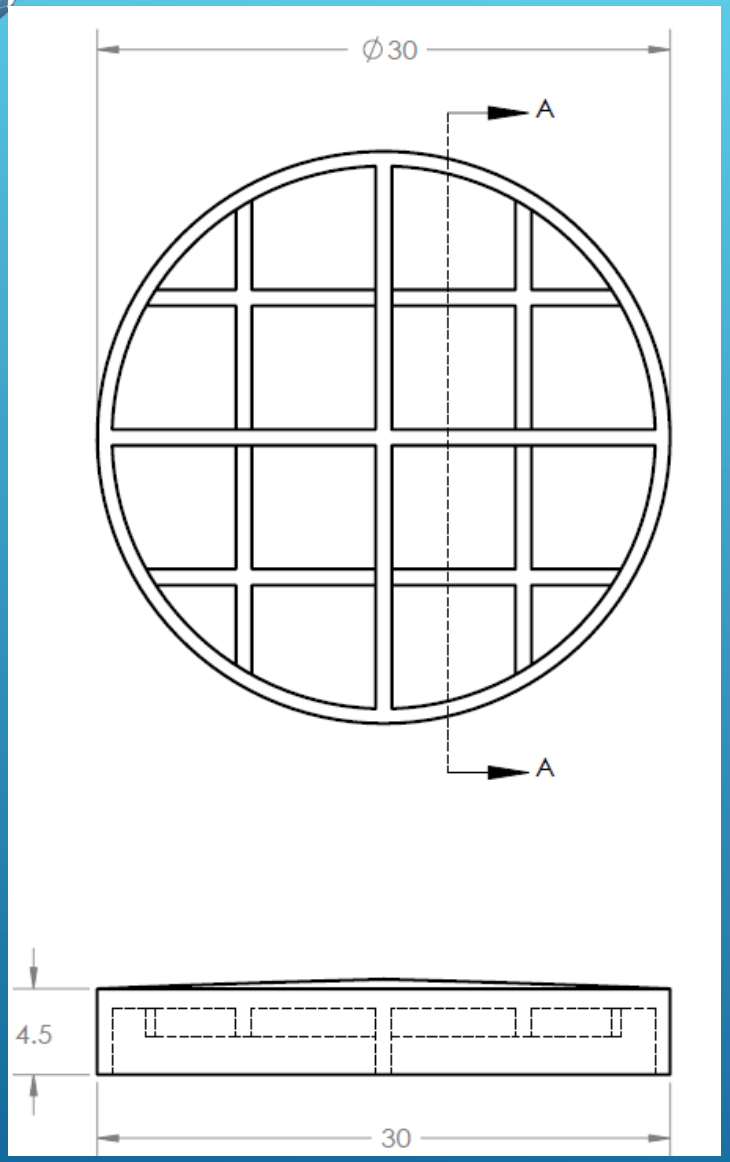
- RoboSiC-S can provide the thermal stability required for Lasercom and other mission requirements

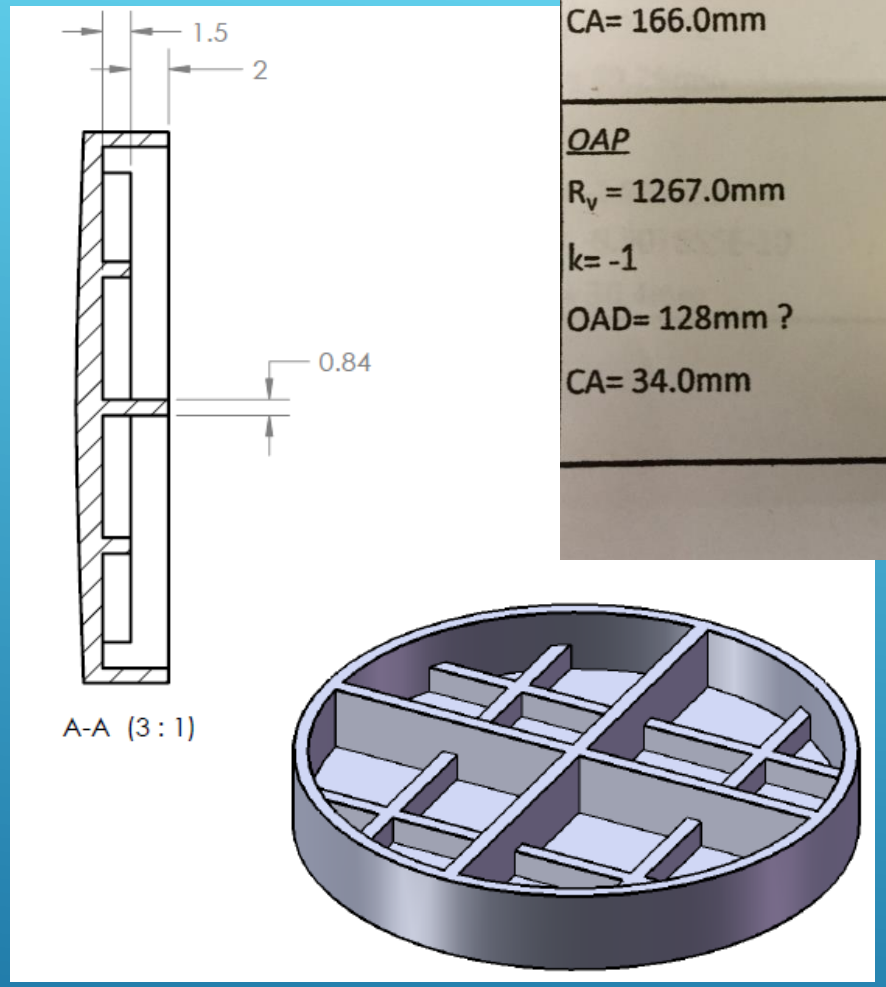


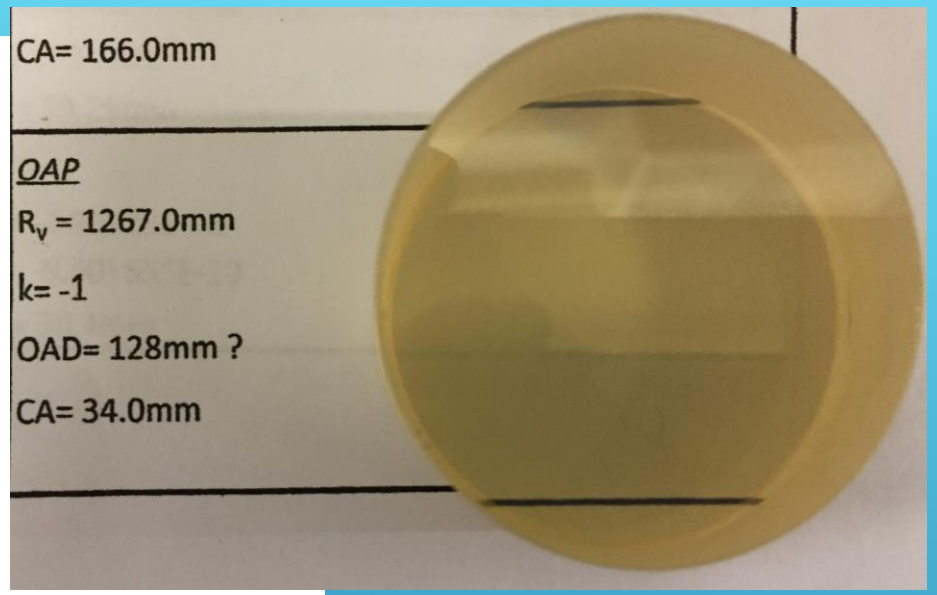
"FLAT" CTE VS T IS HIGHLY DESIRABLE



"BOLT-TOGETHER DESIGN" FOR LOW COST ASSEMBLY/ALIGNMENT

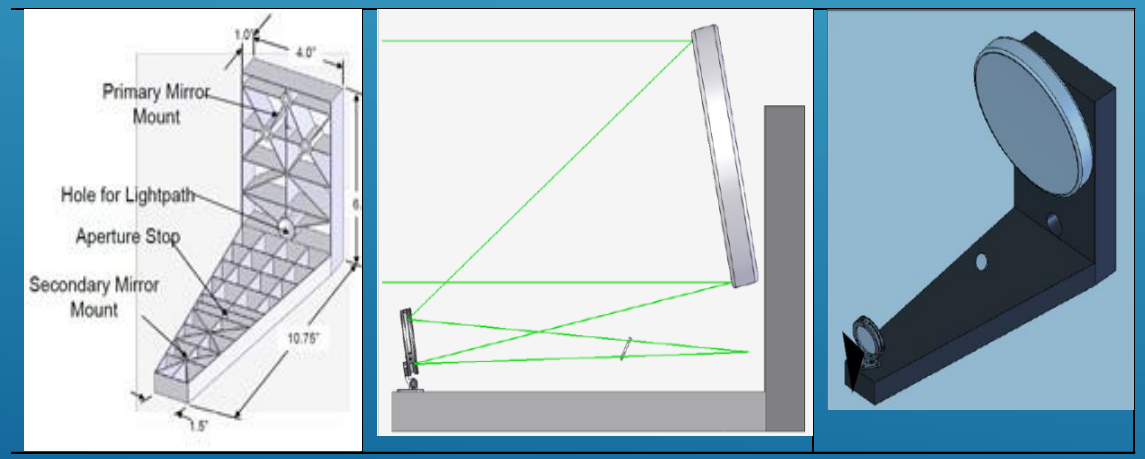


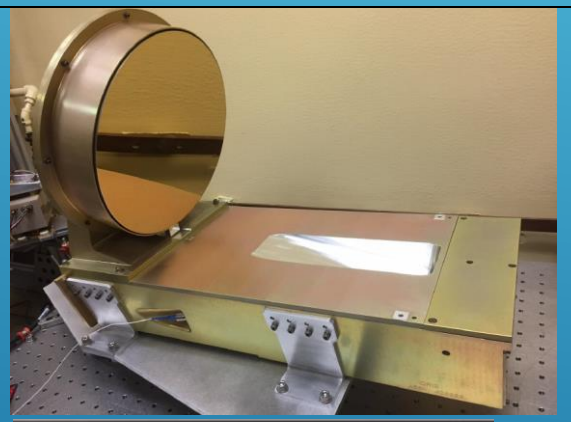


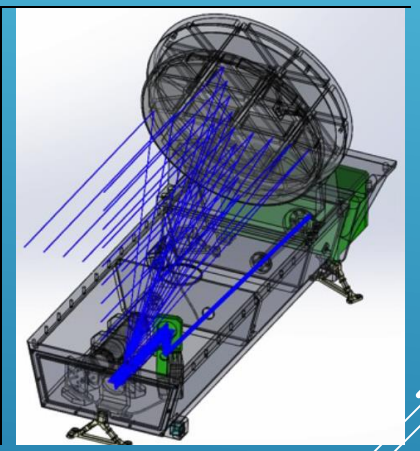


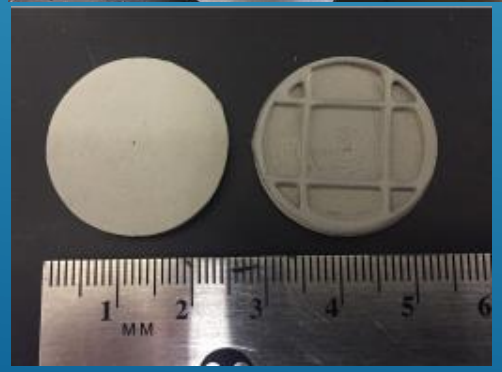
OFF-AXIS PARABOLIC DEMONSTRATOR

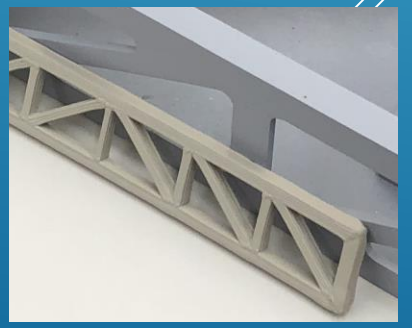
- NASA Gregorian Telescope – internal field stop for straylight control
- GT Senior Systems Engineering team: design/build lightweight & dimensionally stable telescope meets/exceeds all NASA requirements
  - PM: Dr. Andy Motes – GT Chief Technologists – wrote a book on Lasercom
  - 3D, AM and bolt-together approach for rapid, low cost assembly











PHASE II PLAN