Goodman Technologies, LLC

NEAR-ZERO CTE 3D PRINTED ROBOSIC DEPLOYABLE TRUSS CORE STRUCTURES WITH ACTIVE PRECISION ADJUSTMENT

2018 Mirror Technology Days

NASA Phase I Results

Contract #80NSSC18P2058

An ACTIVE Participant in STEM

“You have to give it away to keep it”

- NASA Needs (PCOS and COR PATR)
- Marketplace
- Path to Precision Deployable Telescope - Technical Objectives
- Performance
- TRUSSES
- HINGE STUDY
- Phase II TECHNOLOGY DEMONSTRATOR
- The Vision

OVERVIEW

- **High-contrast (10^{-10}) imaging and spectroscopy for exoplanet science is critically dependent on telescope optics and wavefront stability.**
  - Common theme for NASA 2017 Physics of the Cosmos (PCOS) and Cosmic Origins (COS) Program Annual Technology Report (PATR). Multiple Priority Tier 1-4 technology gaps.
- **Opto-mechanical system requires WFE stability on the order of 10 pm RMS per wavefront control step (~10s of minutes)**
  - Spatial frequencies that correspond to the dark-hole region of the focal plane.
- **2nd Generation structural-grade "RoboSiC-S"**
  - Degree of passive athermality required by the HaBEX, LUVOIR, eLISA, and LISA missions
  - Low areal density (4-5 kg/m^2) and the ability to perform active precision adjustment.
- **Common solution of interest: Silicon Carbide and 3D printing or additive manufacturing**

NASA NEEDS FROM THE DECADAL SURVEY

- **2017-2027> $100B will be spent for Small-Large Optical Systems**
- ***Market Opportunity:*** Provide New Worlds Technology Development Program teams and STDTs with affordable, low areal density and ultra-stable opto-mechanical structures.
- ***Potential NASA applications:*** HabEx, LUVOIR, eLisa Program, LISA, NASA balloon-borne missions, and multiple other missions.
- ***Products:*** mirrors, instruments requiring optical benches, ultra-stable opto-mechanical structures (hinges, latches, trusses, tubes, pins, flexures, whiffles, struts, etc.)
- ***New Technology Called RoboSiC™***

MASSIVE COMMERCIAL MARKET

- Demonstrate Super-Dimensionally Stable Structural Grade
  - Focus on lower end of Temperature Range for L2 and Deep Space Observation
- Perform Mechanical Engineering Design using SolidWorks and Finite Element Analysis software to evaluate JWST Primary Mirror Wing Hinges
- Phase II Plan
- Deliverables from Contract: Feasibility Coupons
  - 120-mm 3D/AM truss structures.

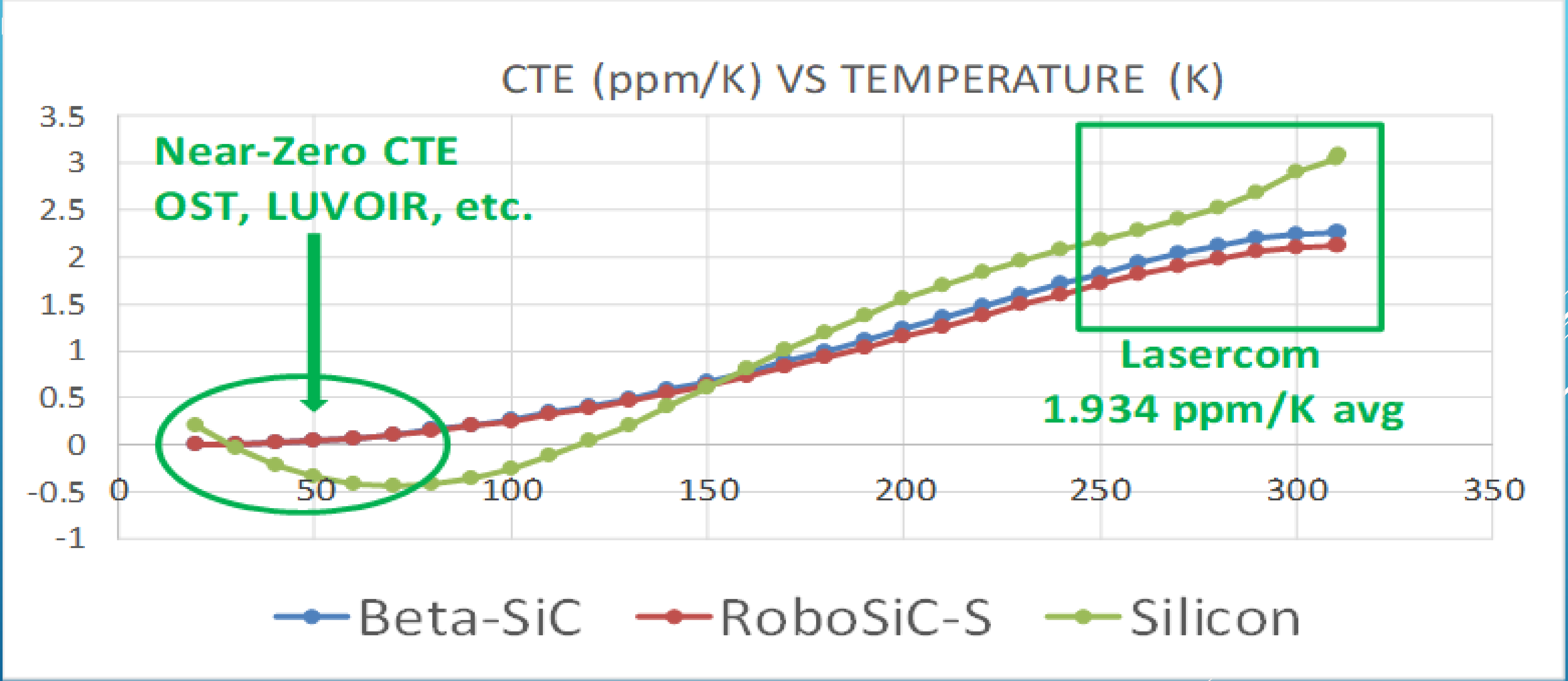
TECHNICAL OBJECTIVES

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

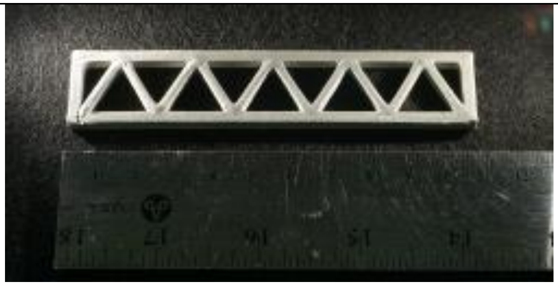
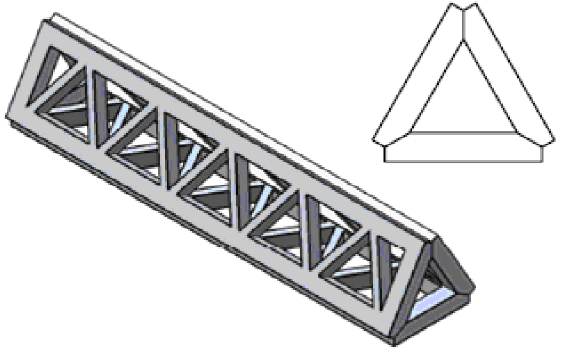
	ρ	E	E/ρ	σ_t	σ_t/ρ	α	k	C_p	D=k/ρC_p	k/α	D/α	ν
Room Temperature Property:	Density	Young's Modulus	Specific Stiffness	Tensile Strength	Specific Strength	Thermal Expansion	Thermal Conductivity	Specific Heat	Thermal Diffusivity	Steady State Stability	Transient Stability	Poisson's Ratio
Units:	kg/m^3	GPa	MPa-m^3/kg	Mpa	MPa-m^3/kg	10^{-6}/K	W/m-K	j/kg-K	10^{-6}/m^2/s	W/μm	m^2-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		

ACTUAL PATENT PENDING RoboSiC-S EVEN BETTER!

- RoboSiC-S can provide the thermal stability required for Precision Deployable Structures



"FLAT" CTE VS T IS HIGHLY DESIRABLE

Part	Description
	**Flat Truss (Warren Configuration):** ~110x20x4mm
	**Flat Truss with Cantelever (Pratt Configuration):** ~145x20x4mm
	**Sloping Parallel Chord Truss (Howe Configuration):** ~135x20x4mm
	**Truss Assembly Schematic (Warren Configuration):** ~110x15mm tall

TRUSSES

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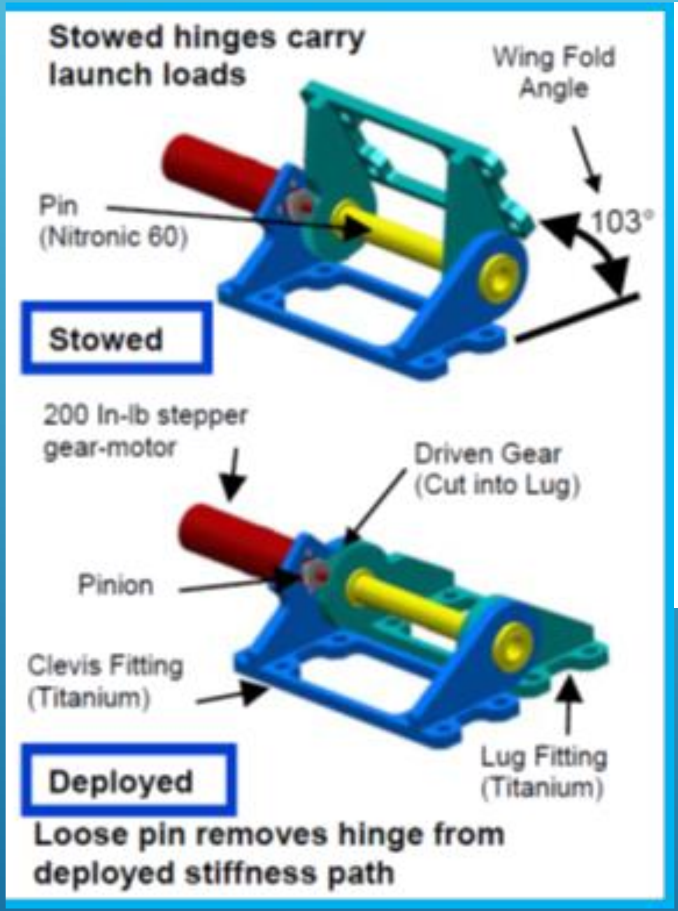
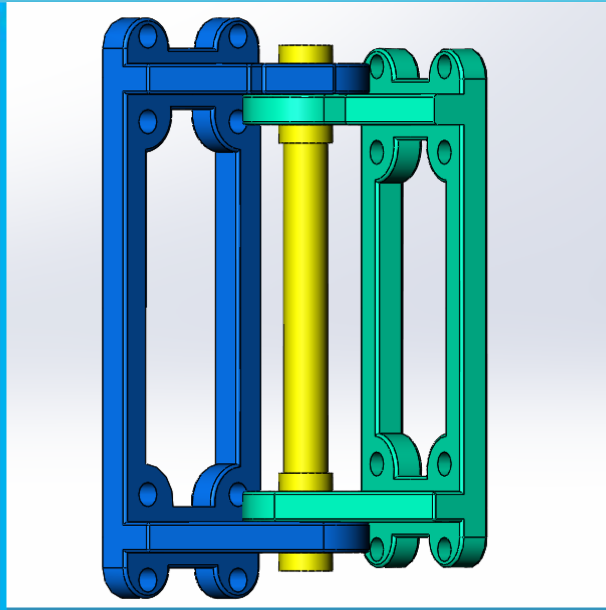
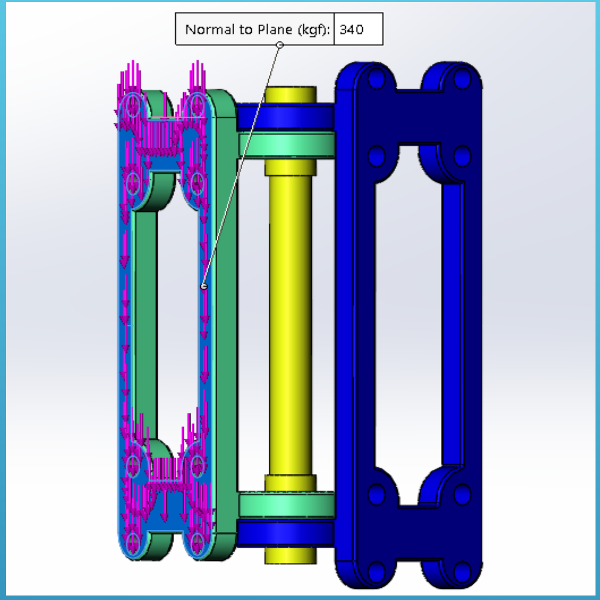
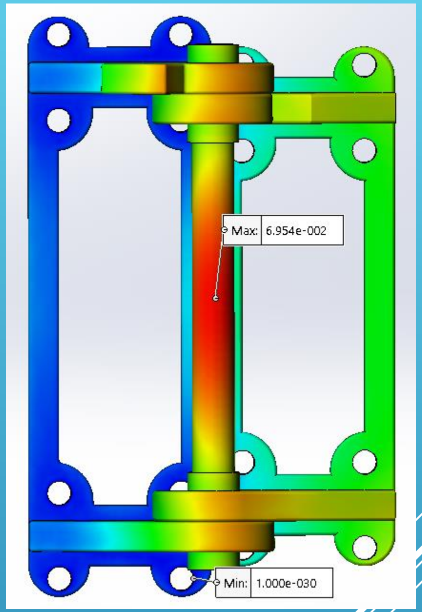
- **JWST PMBSS type wing hinge in RoboSiC-S, ~180 cases Analyzed 1) Structural loads during launch in stowed position, and (2) thermal soak to 25 K in Deployed Position**







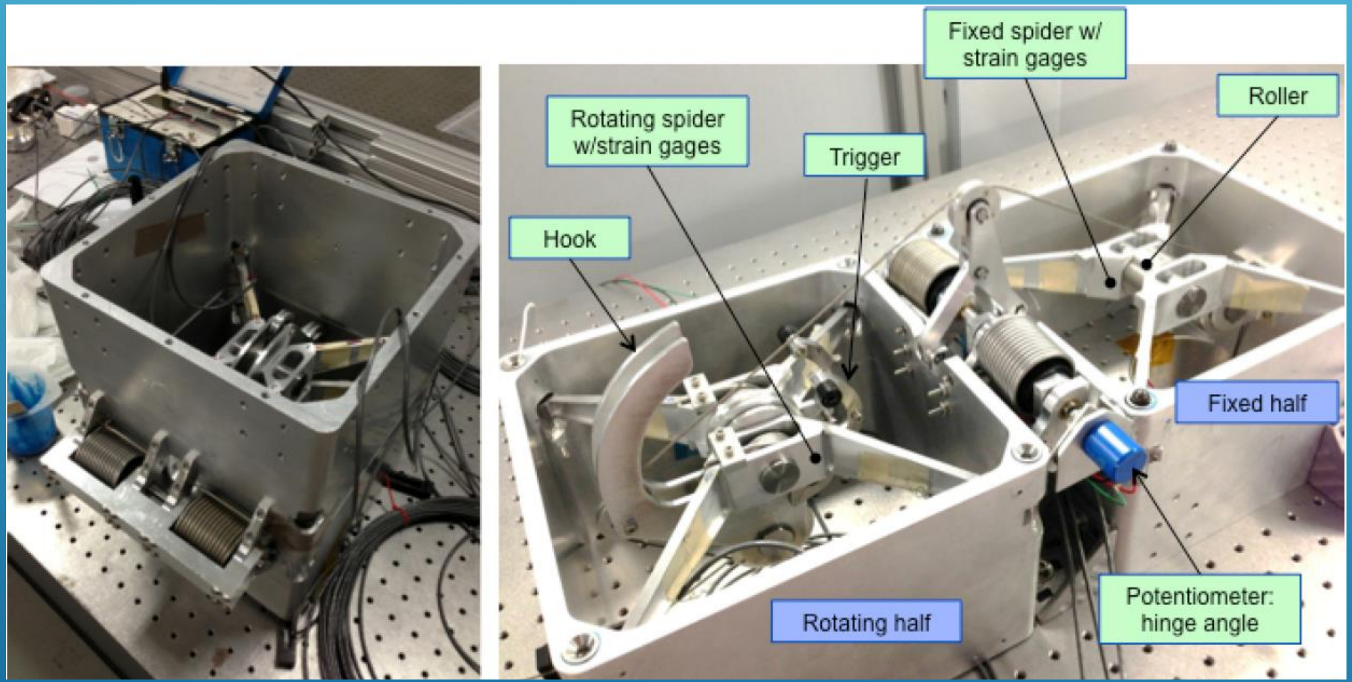


Paul Reynolds, Charlie Atkinson and Larry Gilman, **"Design and Development of the Primary and Secondary Mirror Deployment Systems for the Cryogenic JWST"**, Proc. 37th Aerospace Mechanisms Symposium, Johnson Space Center, May 19-21, 2004.

	Titanium	Nitronic 60	RoboSic Structural
Factor of Safety for Structural Loading: 2g	34	1.49×10^5	6.8×10^2
Maximum Total Displacement	5.422×10^{-1} mm	5.812×10^{-1} mm	6.954×10^{-2} mm

ROBOSIC-S HINGE STUDY

- **RoboSiC Advanced Precision Ultra-Stable Deployable (RAPUD) Technology Demonstrator would buy down the risk for at least 4 PATR Priority Technology Gaps.** By adding a boom (WARREN TRUSS) and RoboSiC large optic to RAPUD we could provide a **Ultra-Stable Deployable Optical Telescope System (US-DOTS)**.



Gregory S. Agnes, Jeff Waldman, Richard Hughes and Lee D. Peterson, **"Testing the Deployment Repeatability of a Precision Deployable Boom Prototype for the Proposed SWOT KaRIn Instrument"**, AIAA Scitech 2015, Kissimee, Florida, January 5-9, 2015.

PHASE II TECHNOLOGY DEMONSTRATOR

THE VISION